

**EUROCONTROL**  
Experimental Centre

Sylvie CHESNEAU  
Ian FULLER  
Jean-Claude HUSTACHE

**ATM FLIGHT EFFICIENCY AND  
ITS IMPACT ON THE  
ENVIRONMENT**

**2002 Study**

**EEC/ENV/2003/001**



## **ATM Flight Efficiency and its Impact on the environment**

### **2002 Study**

Sylvie CHESNEAU (TRANSICIEL), Jean-Claude HUSTACHE (STERIA), Ian FULLER

Society, Economics and Environmental Studies Business Area  
EUROCONTROL Experimental Centre

EEC/ENV/2003/001

© European Organisation for the Safety of Air Navigation EUROCONTROL July 2003

This document is published by EUROCONTROL in the interest of the exchange of information. It may be copied in whole or in part providing that the copyright notice and disclaimer are included.

The information contained in this document may not be modified without prior written permission from EUROCONTROL.

EUROCONTROL makes no warranty, either implied or express, for the information contained in this document, neither does it assume any legal liability or responsibility for the accuracy, completeness or usefulness of this information.

## REPORT DOCUMENTATION PAGE

<b>Reference:</b> EEC/ENV/2003/001		<b>Security Classification:</b> Unclassified				
<b>Originator:</b>  Society, Economics and Environmental Studies Business Area		<b>Originator (Corporate Author) Name/Location:</b>  EUROCONTROL Experimental Centre Centre de Bois des Bordes B.P.15 91222 BRETIGNY SUR ORGE CEDEX France Telephone: +33 1 69 88 75 00				
<b>Sponsor:</b>  EUROCONTROL PRU		<b>Sponsor (Contract Authority) Name/Location:</b>  EUROCONTROL Agency Rue de la Fusée, 96 B -1130 BRUXELLES Telephone: +32 2 729 90 11				
<b>TITLE:</b> ATM Flight Efficiency and its Impact on the environment - 2002 Study						
<b>Authors :</b> Sylvie CHESNEAU, Ian FULLER, Jean-Claude HUSTACHE	<b>Date</b>  July 2003	<b>Pages</b>  60	<b>Figures</b>  34	<b>Tables</b>  16	<b>Appendix</b>  4	<b>References</b>  16
<b>EATMP Task Specification</b> -	Project  ENV-KPI		Task No. Sponsor  -		Period  September 2002 to June 2003	
<b>Distribution Statement:</b> (a) Controlled by: EUROCONTROL Project Manager (b) Special Limitations: None (c) Copy to NTIS: YES / NO						
<b>Descriptors (keywords):</b> Env-KPI, KPI, Emissions, Performance Indicator, Emissions Study 2001, Route Efficiency, Total Fuel burn, Flight Efficiency.						
<b>Abstract:</b>  This Environmental Key Performance Indicators (Env-KPI) 2002 study evaluated air traffic control route efficiency and total fuel burn from the environmental and economic aspects for traffic in the ECAC area. The data for the study used surveillance data and flight plan data from the CFMU. The fuel burn was modelled using the Eurocontrol Experimental Centre's (EEC) Advanced Emission Model version 3 (AEM3). The report includes an initial study of the feasibility of applying performance indicators to a TMA environment.						



## EXECUTIVE SUMMARY

The European Air Traffic Management (ATM) system is subject to regular changes in order to satisfy the differing needs of its users in terms of safety, capacity, and economy. However, route network optimisation criteria do not always sufficiently include environmental impact.

Because of these constraints of the ATM system, flights are forced to fly longer and further than is theoretically possible. The extra delays and distances flown increase the airlines operating costs. The extra fuel burnt has a direct impact on the environment.

The planned routes of civil flights are verified and approved by Air Traffic Control (ATC), but the real route flown may be quite different from the planned one. A flight may be allowed to take a direct route, or obliged to take a longer route due to weather, dense traffic, military zones, and so on. These tactical ATC changes have an environmental impact; fuel burn on the upper atmosphere and, in the vicinity of airports, both fuel burn and noise.

The "Flight Efficiency and Impact on Environment" project has been set up to develop indicators that can be used to measure the impact of the ATM system on the environment. These indicators measure the efficiency of the actual routes and profiles flown in terms of distance, flight duration, fuel burn and costs to airlines and environment. They are used by the EUROCONTROL Performance Review Commission for its annual performance review report of air traffic management in Europe.

This report describes the "2002 study" which used the indicators to analyse the environmental and economic impact for a sample of domestic and Intra-European flights within the ECAC area.

We consider the impact of the extra distance flown as isolated events. We do not address the trade-off made by airlines between ground delays and in-flight delays.

The present report is the continuation of an activity that started in 2000. At that time, the flight efficiency study was limited to selected flights in the Maastricht upper area control centre. In 2001 the study covered a wider area of Europe - Austria, Benelux, Italy, and UK.

The 2002 study of flight efficiency indicators are presented in this report. The geographic area has further been increased both geographically and in time to cover Benelux, Denmark, France, Germany, Ireland and UK. The data for the study were derived from the Enhanced Traffic Flow Management System (ETFMS) of the Central Flow Management Unit (CFMU).

The 2002 study split the analysis to provide results for en-route and Terminal Manoeuvring Area (TMA).

According to the ATFM summary 2002 published by CFMU [Ref 4] there were on average 22567 flights per day in the EUROCONTROL boundaries (31 member states), corresponding to a daily average of distance of approximately 17,240,000km (31,000 flying hours per day)

The Route Efficiency, Duration and Total Fuel burn indicators were calculated on a sample of data comprising 10 days of 24 hours traffic in July and September 2002, averaging 27000 flights per day of which an average of 4000 were used for study (16%).

The analyses focus on domestic and Intra-European flights, i.e. flights starting and terminating within the geographic area covered by sample data. Flights that departed to or arrived from airports outside that area, as well as over-flights are not included. From approximately 27000 flights per day in the EUROCONTROL area, the study could make use of approximately 4000 flights per day.

This study shows that, based on the data sample used, the intra-European and domestic European flights fly distances up to 9% more than would be the case if the aircraft could follow direct routes between the departure to destination airports. The extra distance flown has a direct on the environment through increase fuel consumption.

The Route Efficiency results with the 2002 data sample indicate that real routes are on average 8.9% longer than the corresponding "Direct routes".

Duration, Fuel Burn and emission for each flight were analysed by the Advanced Emission Model (AEM) tool. Results show that real traffic consumes 9.6 % more fuel than the corresponding traffic flying direct trajectories. The Landing and Take-Off cycle (LTO) was not included in these calculations, as it is impossible for most aircraft in this phase of flight to go directly between the airport and the limit of the TMA. The approach procedure can be simplified, but not removed completely.

To complement the study on the issue of landing and take-off phases additional investigations were made for a Terminal Manoeuvring Area (TMA) scenario. The applicability of distance, noise and fuel consumption indicators for the LTO phases are discussed. The study relies on simulated data generated by the Total Airspace and Airport Modeller (TAAM). Indicators were measured by comparing "real" procedures with "most direct" procedures. However, focussing on a single TMA, the results are difficult to generalise. The ultimate purpose of applying indicators to a TMA would be to identify possible trade-offs between procedures to mitigate noise and fuel consumption. A future study should include a wider selection of airports.

Finally, an economic evaluation of the en-route flight efficiency indicators is presented, measuring the costs of flight efficiency in the European route network. Two categories of costs (internal and external) have been estimated. Internal costs of flight efficiency are defined as the amount of airline direct operating costs that could be avoided under the hypothesis of direct trajectories. External costs of flight efficiency are estimated to be the cost reduction of climate change impacts that could be obtained with direct trajectories. The latter cost estimation should be considered as a first approximate attempt to give a monetary value to negative externalities associated with flight inefficiencies. Considering the limited scientific understanding of some emissions (oxides of nitrogen, formation of condensation trails) and the economic debates on the valuation methods, the values we obtain should be considered as an order of magnitude which aim is to put flight efficiency performance in relative perspective among the other two main key performance areas which are ATM delay and capacity costs. These preliminary results indicate that the potential savings (the average of high and low bound hypotheses) which could be achieved if optimum profiles were feasible, compared to actual flight profiles reach € 1,764 million for airlines 'internal costs', and € 327 million for environmental "external" costs, which in total represent respectively 113% and 43 % of the annual European air traffic management delay and capacity costs.

The environmental indicators for ATM flight efficiency cannot be measured in isolation. There has been much previous work in the field of flexible use of airspace and direct routes, mainly in the context of en-route capacity. Future studies in the context of Flight Efficiency must take into account these aspects including safety, ATC system capacity, economic and noise restrictions

<b>1</b>	<b>INTRODUCTION</b> .....	<b>1</b>
1.1	Objectives .....	1
<b>2</b>	<b>EN-ROUTE STUDY</b> .....	<b>3</b>
2.1	<b>Methodology</b> .....	<b>3</b>
2.1.1	Basic principles.....	3
2.1.2	The indicators.....	3
2.1.3	Selection and Filtering Criteria .....	4
2.2	<b>Data Collection</b> .....	<b>4</b>
2.2.1	Data sources .....	4
2.2.2	Data sample Validation .....	8
2.3	<b>Data Processing</b> .....	<b>11</b>
2.3.1	4D Direct Route Profile Creation .....	11
2.3.2	CFMU Flight Plan Processing .....	13
2.3.3	CPR Processing .....	13
2.4	<b>Environmental evaluation</b> .....	<b>14</b>
2.4.1	Route Efficiency.....	14
2.4.2	Duration.....	15
2.4.3	Total Fuel Burn.....	16
2.4.4	Conclusions - Environmental evaluation.....	17
2.5	<b>Economic evaluation</b> .....	<b>18</b>
2.5.1	Adjustment of the calculated indicators (Route Efficiency & Total Fuel Burn).....	18
2.5.2	Cost to Airlines .....	20
2.5.3	Issues in evaluation environmental costs .....	23
2.5.4	Costing environmental effects of flight efficiency .....	26
2.5.5	Conclusion – Economic Study.....	29
<b>3</b>	<b>TMA STUDY</b> .....	<b>31</b>
3.1	<b>Overview</b> .....	<b>31</b>
3.2	<b>Measurement of the Environmental Performance Indicators</b> .....	<b>32</b>
3.3	<b>Traffic Sample</b> .....	<b>33</b>
3.4	<b>Procedure</b> .....	<b>33</b>
3.4.1	Configurations .....	34
3.4.2	TAAM processing .....	35
3.5	<b>Profile Analysis</b> .....	<b>35</b>
3.6	<b>Results</b> .....	<b>36</b>
3.7	<b>Noise contours</b> .....	<b>37</b>
3.7.1	Arrivals .....	37
3.7.2	Departures .....	37
3.8	<b>Noise contour results</b> .....	<b>38</b>
3.9	<b>Fuel Burn</b> .....	<b>38</b>
3.10	<b>Comparison of complete flight to TMA portion (Runway up to FL75)</b> .....	<b>40</b>
3.11	<b>Conclusions – TMA study</b> .....	<b>41</b>
<b>4</b>	<b>CONCLUSIONS</b> .....	<b>43</b>
<b>5</b>	<b>ACKNOWLEDGEMENTS</b> .....	<b>45</b>
<b>6</b>	<b>REFERENCES</b> .....	<b>47</b>
<b>7</b>	<b>GLOSSARY</b> .....	<b>49</b>
<b>ANNEXE 1</b>	<b>CPR CLASSIFICATION</b> .....	<b>51</b>
-	CPR samples classification.....	51

**ANNEXE 2 TOOLS USED IN THE STUDY ..... 53**

- AMOC ..... 53
- AEM 53
- ArcView ..... 54
- TAAM ..... 55
- STBEC ..... 55
- INM 55
- ENHANCE ..... 55

**ANNEXE 3 DATA INVENTORY ..... 56**

**ANNEXE 4 DETAILED RESULTS..... 58**

## LIST OF FIGURES

Figure 1: The two contexts of the study .....	1
Figure 2: 2001 Radar Geographical coverage – left: ‘as recorded’, right: ‘prepared’.....	6
Figure 3: Flights with Last Filed Flight Plan for the 5 <sup>th</sup> July .....	6
Figure 4: Example CPR coverage used in the 2002 study.....	7
Figure 5: Flight range distribution.....	9
Figure 6: Data processing scheme .....	11
Figure 7: Example of CPR profile with its corresponding 4D direct Profile, against duration (seconds).....	12
Figure 8: AEM "Complete all flight profiles" option.....	12
Figure 9: Trajectory Profile classification schematic .....	13
Figure 10: Efficiency of the actual route flown .....	14
Figure 11: Average of Route Efficiency Diagram.....	15
Figure 12: Average of % Duration for 10 days recorded as function of the direct distance corresponding .....	16
Figure 13: Average of Total Fuel Burn for 10 recording days.....	17
Figure 14: Route Efficiency & Duration & Total Fuel Burn Tendencies .....	17
Figure 15: Radiative forcing.....	25
Figure 16: Application of Environmental Efficiency Indicators to TMA.....	31
Figure 17: Ground Track and Profile – a typical Real vs Direct Departure .....	32
Figure 18: TMA study ground Tracks – config C19 .....	33
Figure 19: Direct configuration - Ground Tracks.....	34
Figure 20: Alternative Direct Scenario - arrivals .....	34
Figure 21: Example of Arrival Profile.....	35
Figure 22: Flight Efficiency in a TMA – an example for Departure and Arrivals .....	36
Figure 23: TMA Study - Noise Arrival Direct config D1) .....	37
Figure 24: Arrival Noise contours - C19 overlaid on D1 .....	37
Figure 25: Departure Noise contours - C19 overlaid on D1 .....	37
Figure 26: Mean Duration Difference (Real-Direct) as function of Engine Type .....	39
Figure 27: Mean Fuel Burn Difference (Real-Direct) TMA sample .....	39
Figure 28: Number of CPR Flights kept for the study, function of the direct distance corresponding .....	51
Figure 29: AEM3 flight profile for emission calculation .....	53
Figure 30: AEM3 method to create the Landing Take-Off phases .....	54
Figure 31: ArcView screen shot of the new module of track visualisation.....	54
Figure 32: Number of CPR complete Profile flights per distance flown .....	57
Figure 33: Percentage of Duration as a function of direct distance .....	58
Figure 34: %Fuel (CPR/Direct) as a function of the direct distance.....	58

## LIST OF TABLES

Table 1: Comparison of different data sources .....	5
Table 2: Description of the studied sample: comparison of MTOW .....	9
Table 3 :Description of the studied sample: comparison of engine types.....	10
Table 4: Most common aircraft in the studied sample .....	10
Table 5: Estimation of the average inefficiency for flight duration (% difference between radar and direct trajectories) .....	19
Table 6: Estimation of the average inefficiency for fuel burn .....	20
Table 7: Direct operating costs of carriers operating in Europe .....	21
Table 8: Extra cost to airline of flight inefficiency (potential savings) .....	22
Table 9: Final energy consumption share by mode of transport (EU15) .....	24
Table 10: Radiative forcing impacts relative to CO2 .....	27
Table 11: Values of emissions resulting from their relative impacts.....	27
Table 12: Share of external cost in transport (EU17, 1995).....	28
Table 13: Estimated external costs of flight inefficiencies.....	29
Table 14: Average Route Efficiency for TMA flights .....	36
Table 15: INM Noise contour surface areas.....	38
Table 16: Flight inventory -Environmental Efficiency Indicators 2002 study.....	56

# 1 Introduction

Improving the efficiency of the European Air Traffic Management system could not only reduce air traffic congestion and delays but also reduce fuel costs and the impact on the environment. Improvements to route efficiency would have a direct impact on the environment through reduced fuel consumption and emissions. Efficiency must also be balanced against high level of safety, cost-effectiveness and reliability.

The 2002 'Flight Efficiency and Impact on Environment' study was conducted by the Society Environment and Economy (SEE) business Area of Eurocontrol Experimental Centre (EEC) and sponsored by the Eurocontrol Performance Review Unit (PRU).

Previous studies in the context of the project were based on the Route Efficiency and Total Fuel burn indicators [Ref 1].

## 1.1 Objectives

This report describes the results of the 2002 study for Flight Efficiency and Impact on the environment. The objectives of the study were:

- Calculate performance indicators that measure the Flight extension of the European Air Traffic Management system.
- Compare the results with previous studies to assess the evolution of the indicators
- Assess the impact on environmental impact of flight extension.
- Assess the economic impact for the environment and general air traffic.
- Improve the quality and quantity of data used compared to previous studies.

The 2002 study was based on three performance indicators with data collected in July and September 2002:

- Route Efficiency compared the distance flown along the real ground track with the distance along the reference ground track (Chapter 2.4.1)
- Flight Duration compared the duration between real and reference profiles (Chapter 3.4.2).
- Total Fuel Burn, based on the 4D profiles, compared the fuel consumption between the real and reference profiles (Chapter 2.4.3).

The indicators were applied to two contexts (see Figure 1):

- En-route traffic for flights starting and ending within the European Civil Aviation Council (ECAC) area.
- Investigation of how the indicators could be used in an airport Terminal Manoeuvring Area (TMA).

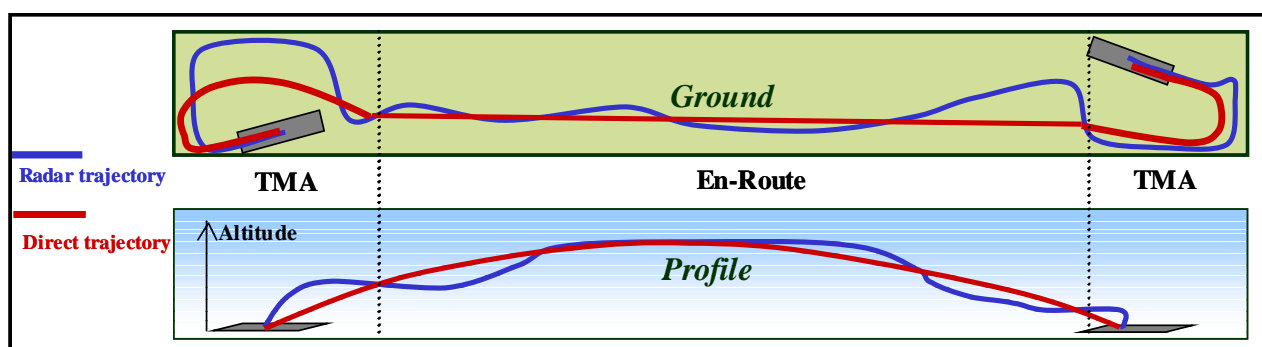


Figure 1: The two contexts of the study

Intentionally blank

### 2.1 Methodology

This section describes the flight efficiency indicators and the methodology used to analyse them.

The method used for this study differed from the method used in the 2001 in the way that the vertical profile was calculated. In the 2001 study there were no constraints on the vertical profile imposed so that AMOC was free to choose the vertical profile as a function of flight duration.

#### 2.1.1 Basic principles

The flight efficiency indicators are intended to measure how closely the actual, or eventually the planned, 4D path flown by an aircraft approaches the optimum 4D trajectory for route flown.

Generally, the indicators are applicable to civil aviation for commercial flights. Military and General Aviation flights are included if they have flight plans and the necessary elements of the flight history – target position and identity during the complete flight.

##### 2.1.1.1 Direct Route

The indicators are referred to the Direct Route, also called direct distance and ground track, between the initial and final geographic position of a flight.

The Direct Route is defined as the great circle distance between the initial and final points. The points may be the airport reference points of the departure and destination airports, in which case no account is taken of the runway configurations or departure and arrival routes.

For this study the initial and final points were first and last positions provided from surveillance data.

##### 2.1.1.2 Optimum Profile

The optimum profile is the vertical path flown that is best suited to the type of aircraft for the route to be flown. The vertical profile is a function of aircraft type and distance flown. The distance flown equates to take-off weight and hence a direct effect on emissions and noise.

#### 2.1.2 The indicators

##### 2.1.2.1 Route Efficiency

The Route Efficiency indicator measures the ground route extension of the actual ground route flown. The indicator is in fact an intermediate indicator that considers only the ground track and does not take account the vertical component. It is calculated as a percentage of the direct route for each flight:

$$\% \text{ Route Efficiency} = \frac{\text{Actual Ground Distance flown} - \text{Direct Route}}{\text{Direct Route}}$$

##### 2.1.2.2 Duration Difference

The Duration indicator is equivalent to the Route Efficiency expressed as time delay. Actual Flight Duration and Direct Duration begin at Off-Block time and end at On-Block time.

The indicator represents the percentage difference in duration between the actual flight duration and duration if the flight followed a direct ground track between the Airport Reference Points of the departure and destination airports. The formula is shown below:

$$\% \text{ Duration Difference} = \frac{\text{Actual Flight Duration} - \text{Direct Duration}}{\text{Direct Duration}}$$

### 2.1.2.3 Total Fuel Burn

Total Fuel Burn indicator represents the amount of fuel burnt during a flight compared to the fuel burnt if the aircraft flew directly from the departure to the destination at the most optimum altitude. The indicator is calculated using the same ground tracks used in the Route Efficiency indicator together with the vertical flight history and simulated optimal vertical profile. The formula is shown below. It is necessary to know the type of aircraft in order to calculate this indicator.

The results are presented as percentages relative to the direct trajectory.

$$\% \text{ Total Fuel Burn} = \frac{\text{Radar FuelBurn} - \text{Direct FuelBurn}}{\text{Direct FuelBurn}}$$

### 2.1.3 Selection and Filtering Criteria.

The indicators are calculated using complete flight histories. That means the aircraft's position and identity is known from the start of take-off to landing. The scope of this study was for flight departure and destination airports within the ECAC area, i.e. domestic and Inter-European flights. Intercontinental flights were not included.

In practice the surveillance data will probably not give a complete history of each flight. Coverage limitations, data availability and problems of correlation with flight plans make it necessary to apply some selection and filtering the recorded target position data.

The various tools used for the processing are described in Annexe 2 on page 53.

## 4

## 2.2 Data Collection

A high priority for the 2002 study was the quality and quantity of data used to calculate the indicators. The 2001 study was based on radar data recorded via the Air Traffic Control Radar Tracker And Server (ARTAS) systems in United Kingdom and at EEC Surveillance Integrated Test bed (SurvITE), in Brétigny/Orge (France).

The 2002 study was based on a sample of data from the European Traffic Flow Management System (ETFMS) complemented by airspace parameters and Flight Plan information from CFMU.

The constraints of the different data sources that we have taken into account are:

- Technical availability
- Restriction classification
- Duration and time-of-day
- Geographical coverage completeness (4D Profile)
- Operational influences
- Data precision

### 2.2.1 Data sources

The quantity of data for the study was improved over the 2001 study in terms of duration and geographic coverage. Prior to commencing the data collection, a review of the different available data sources was carried out.

The review took into account the following factors:

- The geographic extent of the available data
- Reliability and accuracy of the target position reports and target identification.
- Temporal precision of target position.
- Duration of available data – number of days and hours of traffic
- Cost of data collection.
- Legal and political restrictions for the use of the data.

- The practical aspects of managing and storing the huge amounts of data involved.

One of the requirements for the 2002 study was to obtain as many complete flights as possible within the ECAC area. Complete flights meant that the flight history (aircraft position) was recorded from the departure airport to the arrival airport. Intercontinental flights and transit flights were not required for this study.

Several sources of flight data were examined as potential candidates for the 2002 study. Their characteristics are presented below.

**Table 1: Comparison of different data sources**

Source	Advantages	Disadvantages	Remarks
ARTAS track data	Used for 2001 study. Good position reliability and accuracy and availability.	Geographical coverage of ARTAS system is linked to local ATC system A-posteriori correlation with flight plan data is problematic.	
ETFMS CPR data	Good geographical and vertical coverage of Ireland, UK, France, Benelux, Germany, Denmark.	Incomplete coverage of ECAC area for the 2002 study. Update rate for some sectors was 8 minutes.	System was being introduced in 2002.
CFMU Flight Plan – Last Filed	Complete coverage of traffic in ECAC.	No coverage of real route taken by flight. Prevision.	
Flight Data Recorder (FDR)	Complete state vector for a flight. Recorded by every flight.	Very limited.	Not given
First System Activation (FSA) message	Good ECAC coverage.	Approximation of time and few plots per tracks.	
Actual CFMU Flight Plan	Good coverage, and accuracy	Has never been used and tested in EEC.	Not given

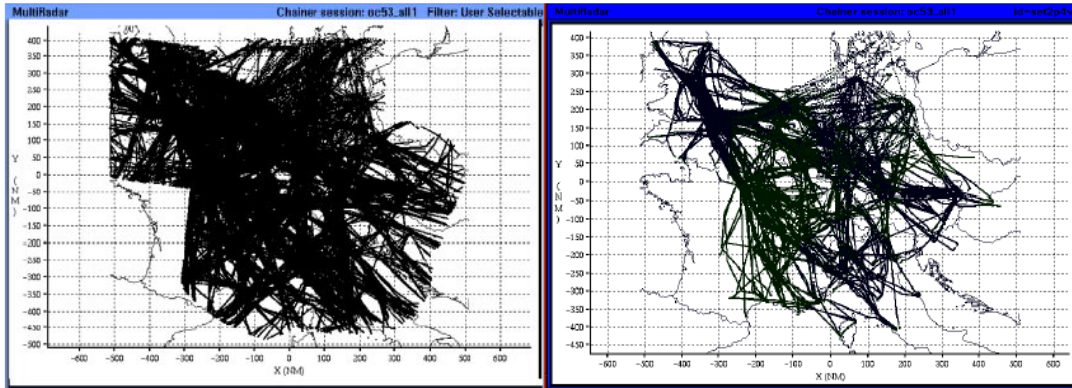
ETFMS CPR data were chosen for the reasons describe below.

#### 2.2.1.1 ATC SuRveillance Tracker And Server (ARTAS) data

ARTAS data were used in the 2001 study. Although the 2001 geographical coverage from the ARTAS data gave good coverage of the core European area and that in turn was better than the 2000 study coverage, the a-posteriori correlation of radar data with Flight Plan data was difficult, resulting in large proportion of unused data.

In the 2001 study, the radar data used for the study were ARTAS tracks provided by NATS-UK and the SurvITE project at EEC. The SurvITE ARTAS tracks were generated from radar data provided by Austrocontrol Austria, STNA-4 Toulouse France, ENAV Padua ACC Italy, Maastricht UAC and Skyguide Geneva.

The difficulties encountered with correlating the radar and flight plan data in the 2001 study led to some inaccuracies in the direct route calculations.

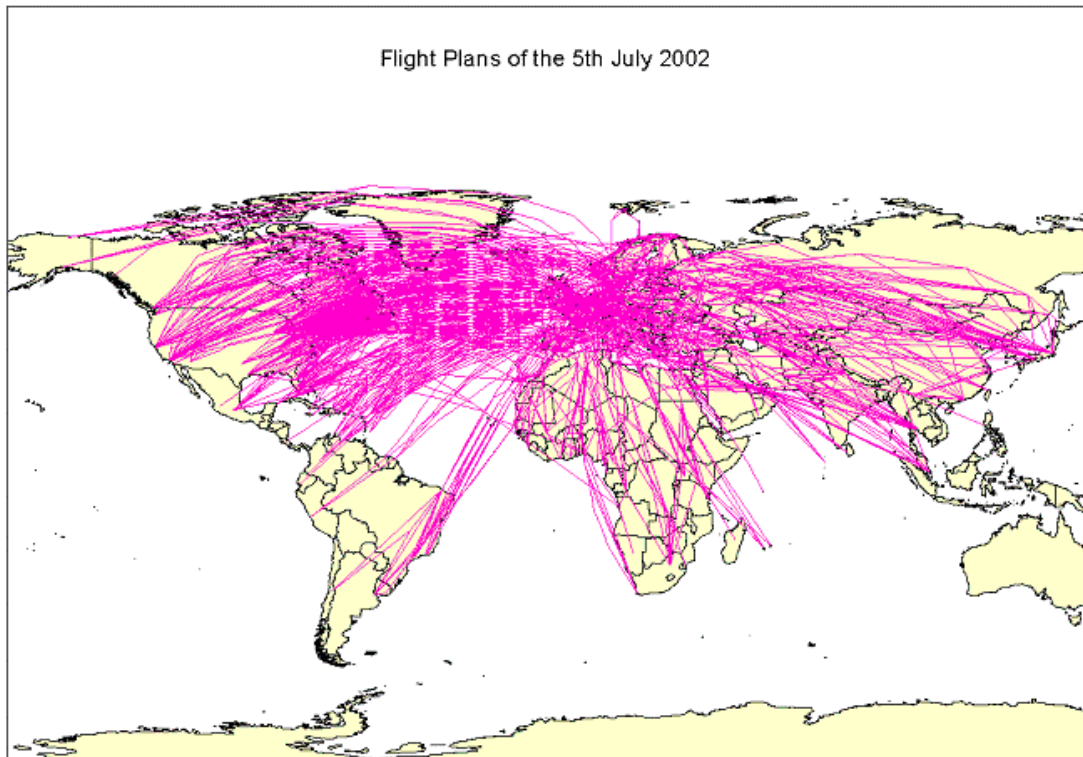


**Figure 2: 2001 Radar Geographical coverage – left: ‘as recorded’, right: ‘prepared’**

### 2.2.1.2 CFMU Last Filed Flight Plan

The recordings of CFMU Flight Plans were in blocks of 24 hours. The recordings comprised the Last Filed flight plans that gave the planned itinerary of each flight validated by the CFMU and the scheduled time of departure. The ground track and vertical profile followed by the flight does not always adhere to the last filed flight plan for tactical and operational reasons. Although the modifications to the flight plan implemented during the flight were not available, the Last Filed Flight Plan gives a representative picture of ECAC-wide daily traffic. Because of the wide coverage and availability of long recording durations (24 hours) the Flight Plans were chosen for the economic study, see paragraph 2.5.

6



**Figure 3: Flight s with Last Filed Flight Plan for the 5<sup>th</sup> July**

### 2.2.1.3 Flight Data Recorder data (FDR)

FDR data is recorded for each flight (black box recording). Since FDR data can provide very detailed information about flight history – position and aircraft configuration – it is very useful to be able to obtain these data when making detailed studies. However, FDR data have two major restrictions: availability and quantity.

FDR data are the property of the operating airlines, some of which are sensitive about how the data are used and distributed for research projects. Companies tend to be unwilling to release FDR data for fear of disclosing operating techniques to bodies outside the company and, in some countries, for fear of incrimination.

FDR data are extremely detailed and the quantity of data would be unmanageable for all flights in the ECAC area for a period of 24 hours.

### 2.2.1.4 First System Activation message (FSA)

FSA is a message sent before an aircraft enters a given control area. The message contains an approximated entry time for the flight.

Two problems were clearly identified before testing the data:

- The frequency of plots in a track is around 10 to 15 minutes, which is too long in our study, the plane could change its way in such a time period.
- the non-accuracy of data is quite important, because it is just based on prediction and not on radar information.

### 2.2.1.5 Correlated Position Report CPR

The European Traffic Flow Management System (ETFMS) provides Correlated Position Reports (CPR). CPR data are derived from processed radar track data that are provided by the Air Navigation Service Providers (ANSP) in the States participating in ETFMS.

At the time of the data collection the ETFMS system was undergoing integration trials. Eventually the system will provide ECAC-wide coverage of the 4D flight histories. The first CPR files (radar data) were generated in January 2002.

The ETFMS CPR data was selected for the study as it offered improved geographical coverage and more consistent correlation of position data with the flight plans compared to the 2001 study 0.

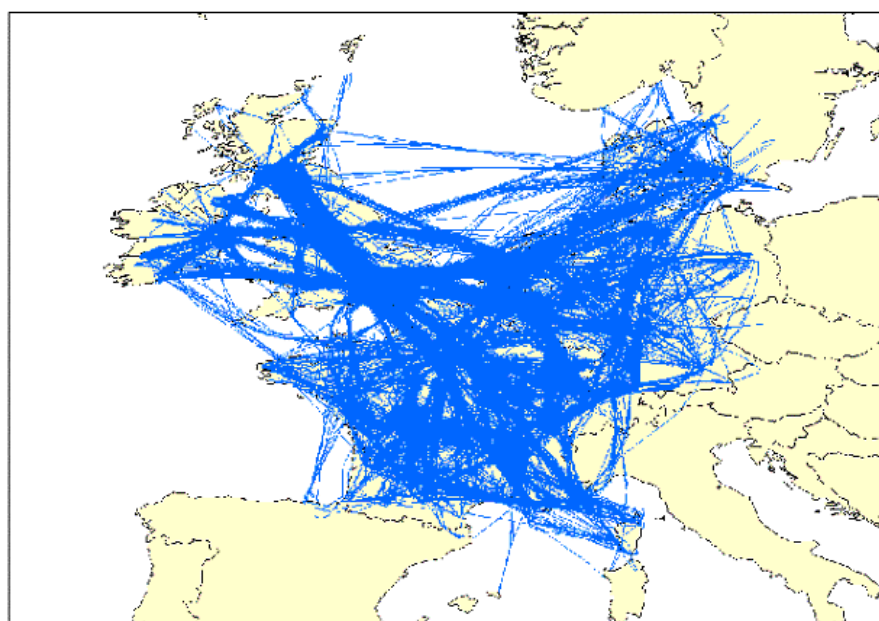


Figure 4: Example CPR coverage used in the 2002 study

The CPR data were obtained by special agreement with the ETFMS team at CFMU. The data sample for the 2002 study comprised 10 days of recordings: 3 days in July 2002 and one week in September 2002. The Network Capacity and Demand Management (NCD) team at EEC carried out initial data formatting and verification. Annexe 1 contains an overview of the collected data with summary of the classification of the samples before and after each process.

The ETFMS will eventually cover the whole CFMU responsibility area. However, not all data suppliers were on-line at the time of the recordings resulting a limited geographical coverage of the European core area and extending to Ireland and Denmark. Figure 4 shows an example for one day of radar tracks that were studied under this limited scope. Despite the limited geographical coverage each recording was 24 hours duration so provided a comprehensive record of the flights on those days.

Thus the 2002 study had larger sample sizes, so that, after processing and filtering, we were left with approximately 14% of all ECAC flights for efficiency analyses, see data inventory in Annexe 3.

CFMU Flight Plan Data were necessary to check the consistency of the CPR data, and also to generate Direct 4D Profile, see chapter 2.3.

#### 2.2.1.6 *Actual Flight Plan*

Updated with the CPR information and/or First System Activation messages. Since these updates are made 'on-line', Actual Flight Plans have the same availability restrictions as Actual Flight Plan data are based on CFMU Flight Plans that have been correlated and CPR data.

### 2.2.2 Data sample Validation

Because of the analysis criteria applied in the study, only 14% of the total CFMU Last Filed Flight Plan traffic (Annexe 3 -Table 16 row A) was used for the flight efficiency measurements. After classification and filtering, the flights used in the study were reduced in time, space and aircraft types. For example, there were fewer long haul aircraft types in the measured sample because inter-continental and transit flights were not included. Annexe 3 gives details of the each recording and the data at each stage of the processing.

Figure 5 shows the distribution of flight range for the 'Total traffic' traffic' (Annexe 3 -Table 16 row A) and Reduced sample (used for measurement - Annexe 3 -Table 16 row F) with respect to the distance flown within the ECAC area. The flight range is the distance between departure and destination airports. The 'Total Traffic' includes complete and partial flight histories, i.e. flights histories that are truncated geographically or temporally. The recorded samples do not contain flights longer than 1,700 kilometres because of the geographical restriction. Short flights thus occupy a more important share than in the total CFMU traffic.

Flight range distribution

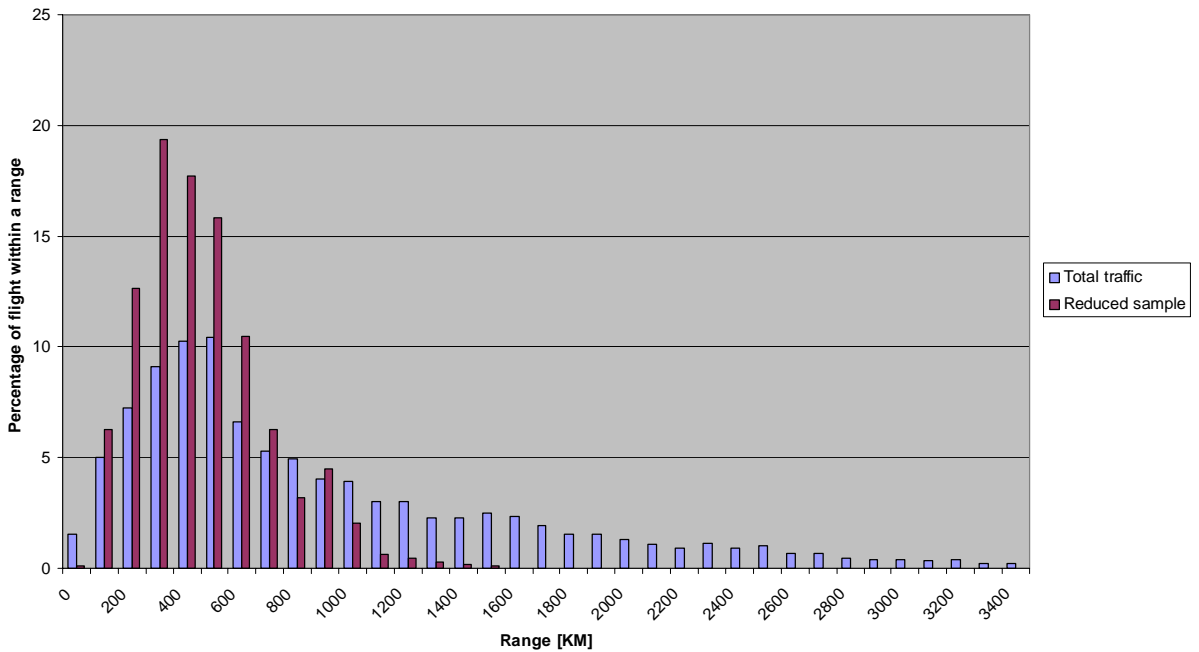


Figure 5: Flight range distribution

To retain compatibility with the Env-KPI 2001 study, only flights with direct distance between 200km and 1100km were used in the 2002 study for Route efficiency, Duration and Fuel Burn.

Table 2 and Table 3 show a description of the traffic in terms of weight and engine types. The tables compare the proportion of aircraft / engine types for the total ECAC traffic (without filtering) with the proportion of aircraft / engine types in the samples used for computing the Flight Efficiency study.

Table 2: Description of the studied sample: comparison of MTOW

Range of the maximum take-off weight(Kilogram)		Flights in the ECAC area within range limits		Flights in study sample within range limit <sup>b</sup>	
		Total Number of flights over 10 days	%	Total Number of flights over 10 days	%
1	25,000	89,911	33,3%	16,907	43,9%
25,001	50,000	23,048	8,5%	2,486	6,5%
50,001	100,000	113,356	41,9%	17,530	45,5%
100,101	150,000	9,390	3,5%	597	1,6%
150,001	200,000	12,656	4,7%	697	1,8%
200,001	250,000	4,791	1,8%	85	0,2%
250,001	300,000	8,755	3,2%	71	0,2%
300,001	350,000	304	0,1%	1	0,0%
350,001	400,000	8,007	3,0%	133	0,3%
Total		270,218		38,507	

<sup>a</sup> Flights for which the link aircraft type – maximum take-off weight could be made: 98% of the total traffic.

<sup>b</sup> Flights for which the link aircraft type – maximum take-off weight could be made: 88% of the ENV KPI sample.

The studied sample was selected from the recorded sample. Table 2 summarizes the results. The studied samples overvalue smaller aircraft (below 25 tonnes) and aircraft between 50 and 100 tonnes. All other aircraft categories are undervalued, especially for MTOW exceeding 200 tonnes.

The engine type comparison (Table 3) shows that the studied samples are more representative of the whole European area than was the case in the MTOW comparison. The low share of piston aircraft is well represented, whereas turbo-propellers are slightly over represented, balancing the lower share of jets.

**Table 3 :Description of the studied sample: comparison of engine types**

Engine Type	Number of flights in the whole traffic <sup>a</sup>		Number of flights in the studied sample <sup>b</sup>	
		%		%
5 July 2002				
Jet	11,731	69%	2,649	65%
Piston	452	3%	130	3%
Turbo prop.	4,881	29%	1,304	32%
Total	17,064		4,083	
25 September 2002				
Jet	11,102	64%	2,461	63%
Piston	563	3%	102	3%
Turbo prop.	5,626	33%	1,318	34%
Total	17,291		3,881	

Flights for which the link aircraft type – engine type could be made (% of the corresponding sample): <sup>a</sup> 66%; <sup>b</sup> 73%; <sup>c</sup> 67%; <sup>d</sup> 75%

**Table 4: Most common aircraft in the studied sample**

Aircraft name	Engine type	Number of flights during the 10 days in the studied samples	%
Boeing 737-300	Jet 2 engines	3,408	8%
Embraer 145	Jet 2 engines	3,064	7%
Airbus A320	Jet 2 engines	3,059	7%
Canadair Regional Jet	Jet 2 engines	2,449	6%
Airbus A319	Jet 2 engines	2,305	5%
British Aerospace 146	Jet 4 engines	1,981	5%
Boeing 737-500	Jet 2 engines	1,978	4%
Fokker 100	Jet 2 engines	1,610	4%
Boeing 737-200	Jet 2 engines	1,501	3%
Airbus A321	Jet 2 engines	1,427	3%
Aerospatiale/Alenia ATR 42-300	Turbo Prop 2 engines	1,371	3%

Table 4 is based on aircraft that represent at least 3 % of the studied traffic. All together, these 11 aircraft types constitute 55% of the samples, and the Boeing 737 (200-300 and 500) alone accounts for a proportion of 15 %.

## 2.3 Data Processing

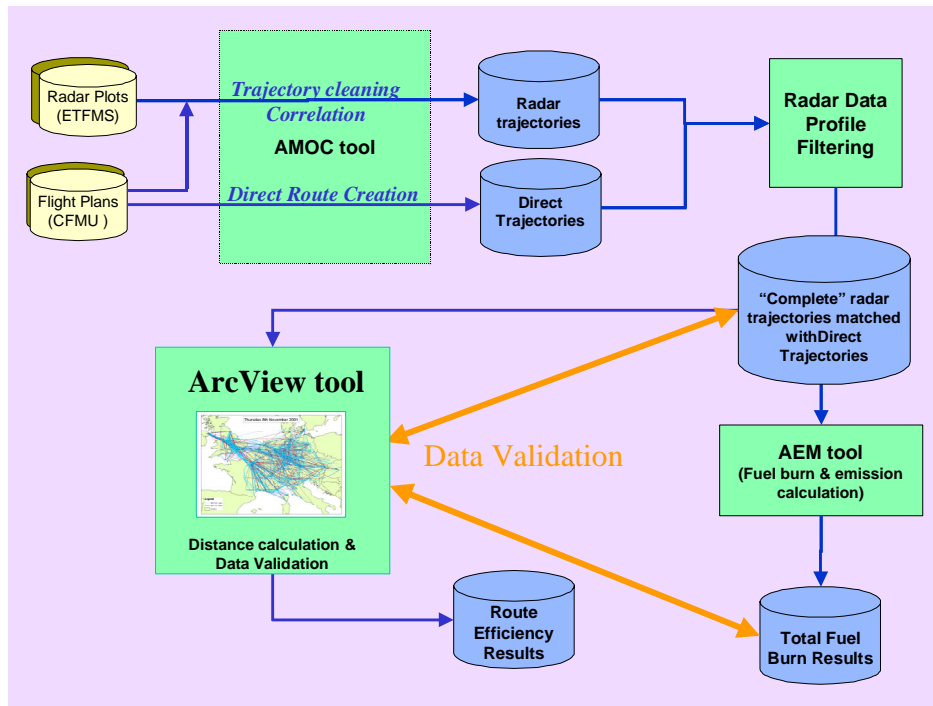


Figure 6: Data processing scheme

Apart from the necessary data processing to transform the recorded data into the formats required by the analysis tools (AMOC, AEM, ENHANCE, etc...) the data preparation process was important to ensure consistency and coherency between the three sets of flight information used in the study (CPR, Flight Plan and Direct).

The tools used for data preparation are described briefly in Annexe 2.

Many CPR flights could not be correlated to Flight plans due to missing information in the recordings. The missing information was mainly due to incomplete coverage of the ECAC area – only some of the ECAC states were ‘on-line’ when the recordings were made.

### 2.3.1 4D Direct Route Profile Creation

The direct routes/profiles were calculated using ATFM MOdelling Capability (AMOC) together with the BADA aircraft performance database. The direct profiles were constrained to the maximum flight level of the associated CPR flight. The Maximum CPR flight level was taken to force the profile generator to avoid using a default ‘theoretical’ maximum flight level. The choice was also influenced by the lack of a reliable optimum vertical profile generator. This restriction was imposed to allow valid comparisons to be made between the CPR and Direct profiles in terms of fuel burn. Fuel burn is a function of cruise Flight Level, Climb and Descent rates.

The direct route follows the great circle, considering that it is the best approximation, as it is the shortest distance between two points on the earth’s surface.

For the distance intervals studied (200-1100 kilometres) no meteorological effect were considered. It should be noted that for long-haul flights (Intercontinental) the optimum route is not necessarily the great circle route, for example winds at high altitudes affect transatlantic routes.

The arrival time was recalculated by AMOC.

The following diagram shows an example of a calculated direct profile corresponding to the CPR profile with the Direct maximum Flight Level limited to the CPR maximum Flight Level.

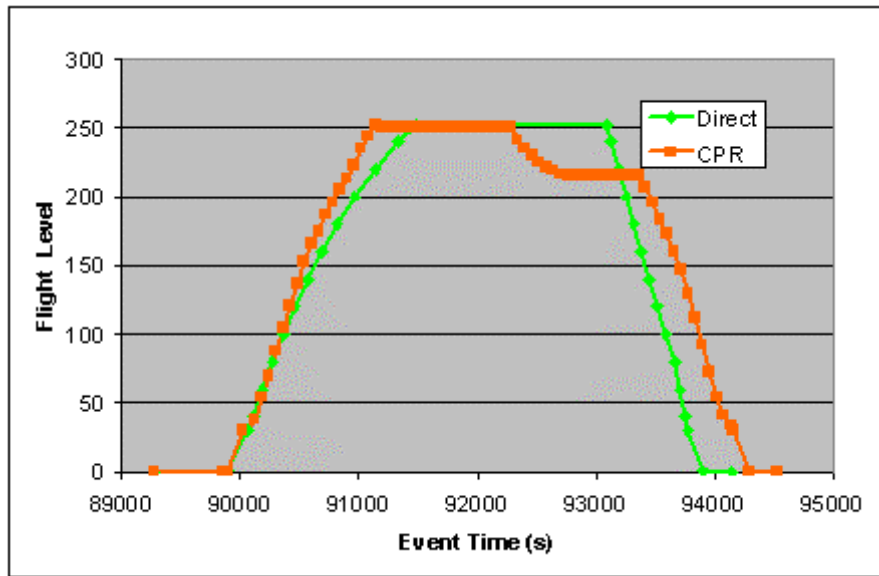


Figure 7: Example of CPR profile with its corresponding 4D direct Profile, against duration (seconds)

When the 4D profiles were generated by AEM <sup>1</sup> input data below FL 30 were ignored. AEM inserted standard LTO phases for each flight according to the type of aircraft. If the first or last plots of the CPR data were greater than FL30, the vertical profile was interpolated between the LTO cut-off point (FL30) and the first/last plot. This technique was used to improve the homogeneity between the CPR and the Direct Tracks, caused by irregular coverage of the CPR data between departure and destination airports.

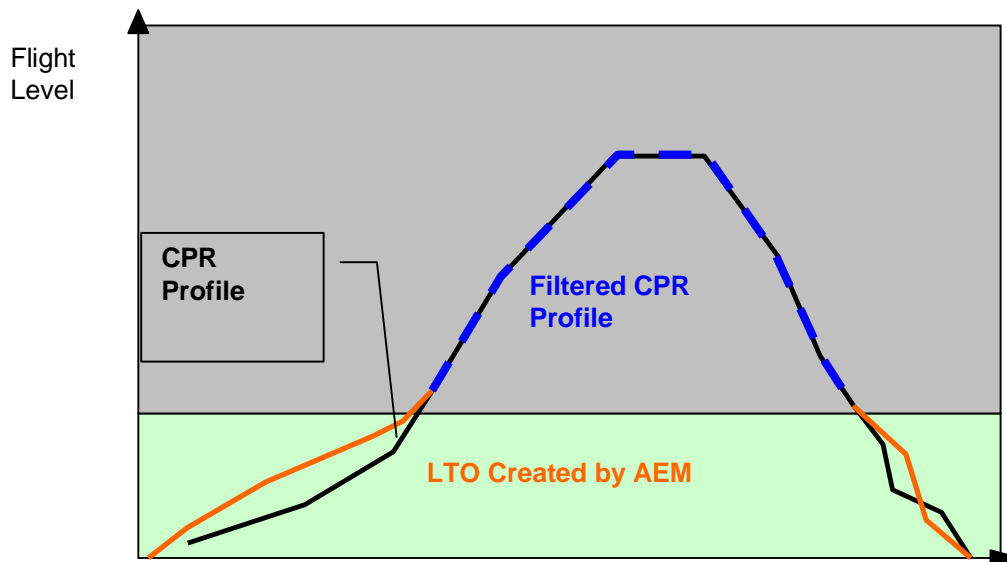


Figure 8: AEM "Complete all flight profiles" option

<sup>1</sup> Using the AEM "Complete All Flight Profile Option".

### 2.3.2 CFMU Flight Plan Processing

The CFMU Flight Plan files were processed and completed by AMOC. Some flight estimated tracks were incomplete (usually missing waypoint information) which made it necessary to extrapolate trajectories. Care was taken to ensure consistency of information before such trajectories were used in the analysis.

### 2.3.3 CPR Processing

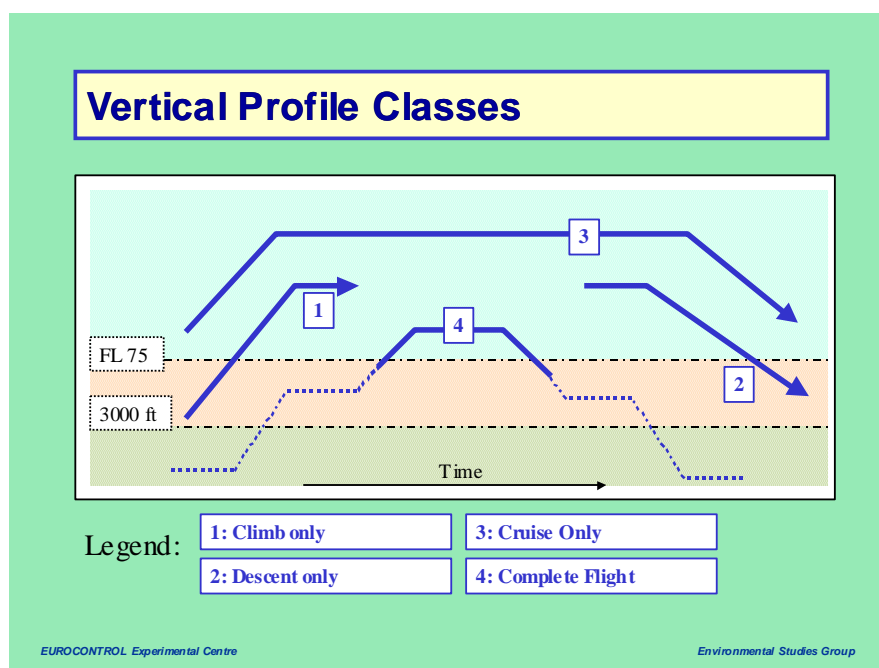
The CPR flights were correlated and filtered first by AMOC.

The original CPR files from ETFMS contain geographical plots with a callsign as identifier, which is not unique. The correlation has revealed some flights with an insufficient number of plots, some plots without any Flight Plan. Also, inside some flights the wrong plots were taken off.

At the end of this first processing, a large set of tracks was kept.

A second filtering process had to be done to keep only 'complete' profiles that met the following criteria:

- First CPR plot is less than FL75
- Last CPR plot is less than FL75
- CPR Flight duration is longer than 15 minutes,
- Flight comprises the 3 phases: Climb, Cruise and Descent



**Figure 9: Trajectory Profile classification schematic**

Flight Level 75 was chosen as an arbitrary boundary between LTO and en-route flight segments. FL75 to retain the maximum number of flights that had 'complete' profile histories, i.e. CPR data at the start and end of each flight was available below FL75 and the maximum Flight Level of each flight was above FL75. FL75 was also used for the 2002 study to maintain consistency with the 2001 study.

The other selection criteria were also consistent with the selection criteria used in the 2001 study.

## 2.4 Environmental evaluation

### 2.4.1 Route Efficiency

The Route Efficiency indicator measures the route extension of the actual route flown in the horizontal projection. It is calculated as a percentage of the direct distance for each flight:

$$\% \text{ Distance Difference} = \frac{\text{Actual Distance flown} - \text{Direct Distance}}{\text{Direct Distance}}$$

- Different parameters influence the measure route efficiency:
- ATC route structure, for example: military zones.
- ATC separation of traffic.
- Special authorisation for shortcuts, or deviation allowed to the airline.
- Meteorological phenomena that cause deviation from planned route.
- TMA route extension, if the radar track contains the airport procedure.

For the distance intervals studied (200-1100 kilometres), the optimal distance chosen was the great circle distance, see paragraph 2.3.1.

The method for calculation the direct route was the same as used for the 2001 study.

The low number of flights in the sample with a direct distance > 1100km was due to the geographic extent of the recorded data.

**NB:** Flights where the CPR distance exceeded the direct distance by more than 30% were removed from calculation. This allowed easier comparison with the 2001 study, as we already considered those extreme differences due to erroneous computation.

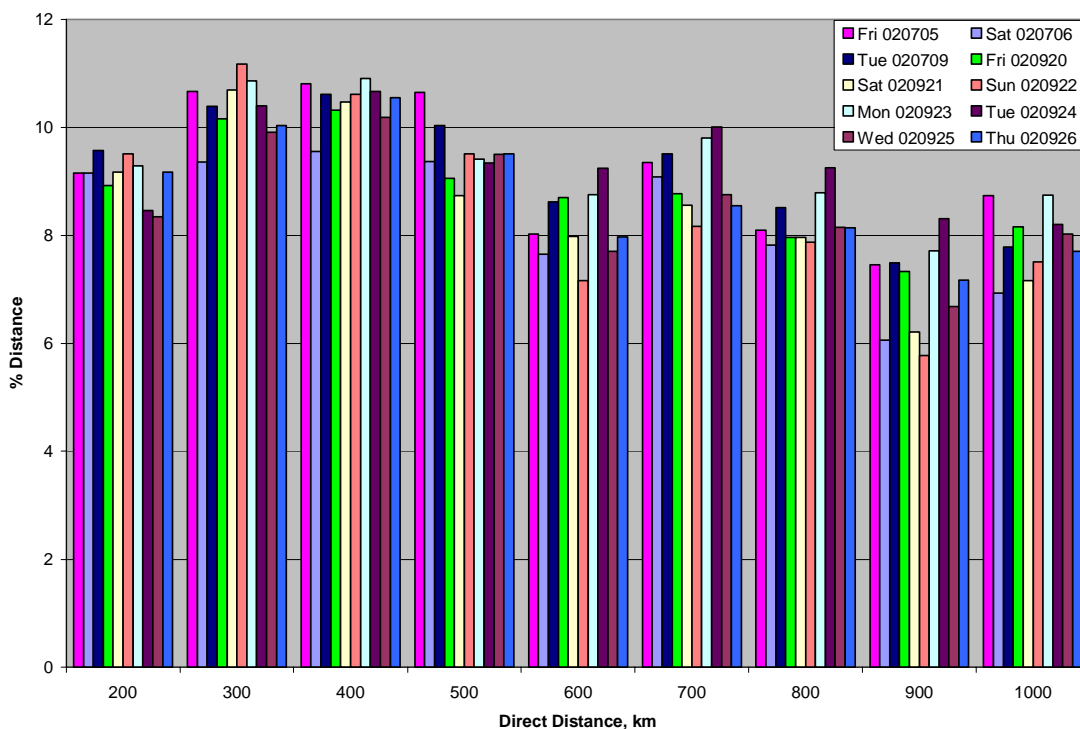


Figure 10: Efficiency of the actual route flown

For the 10 days recorded, the Route Efficiency is on average 8.9% for flights between 200-1100 kilometres.

Results for each day are presented in Figure 10, showing the percentage distance in function of the direct length corresponding. The ten days have a common slight decreasing trend, with a minimum for the 900-1000 kilometres interval, which is revealed in the average histogram of. Weekend days have a lower Route Efficiency, which can be due to:

- reduction of air traffic, implying lower ATC constraints
- reduction of the military zones impacts

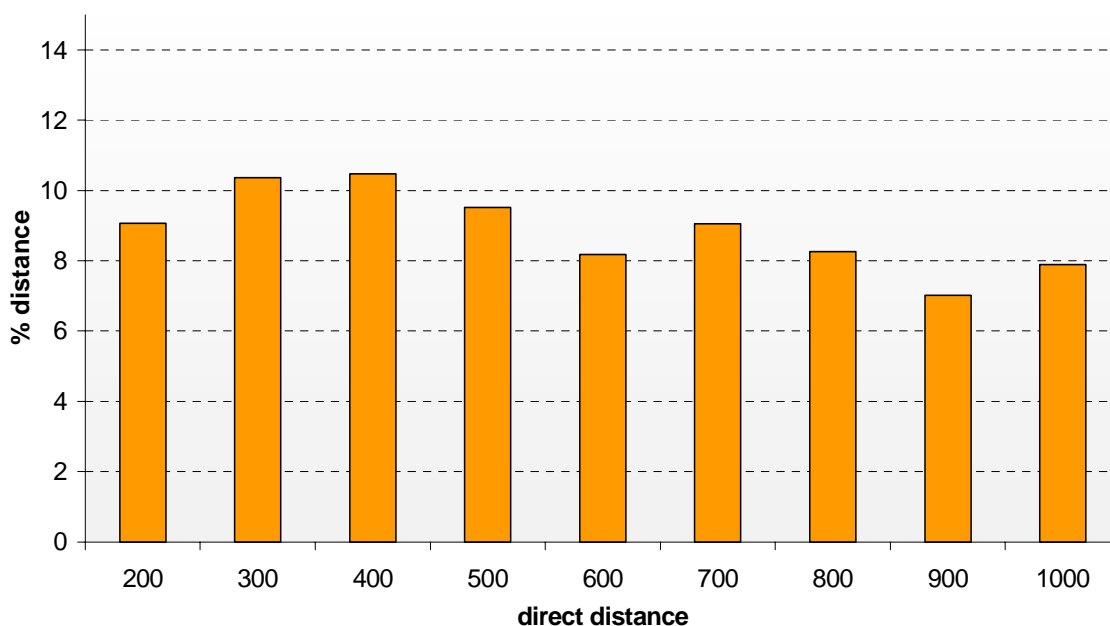


Figure 11: Average of Route Efficiency Diagram

## 2.4.2 Duration

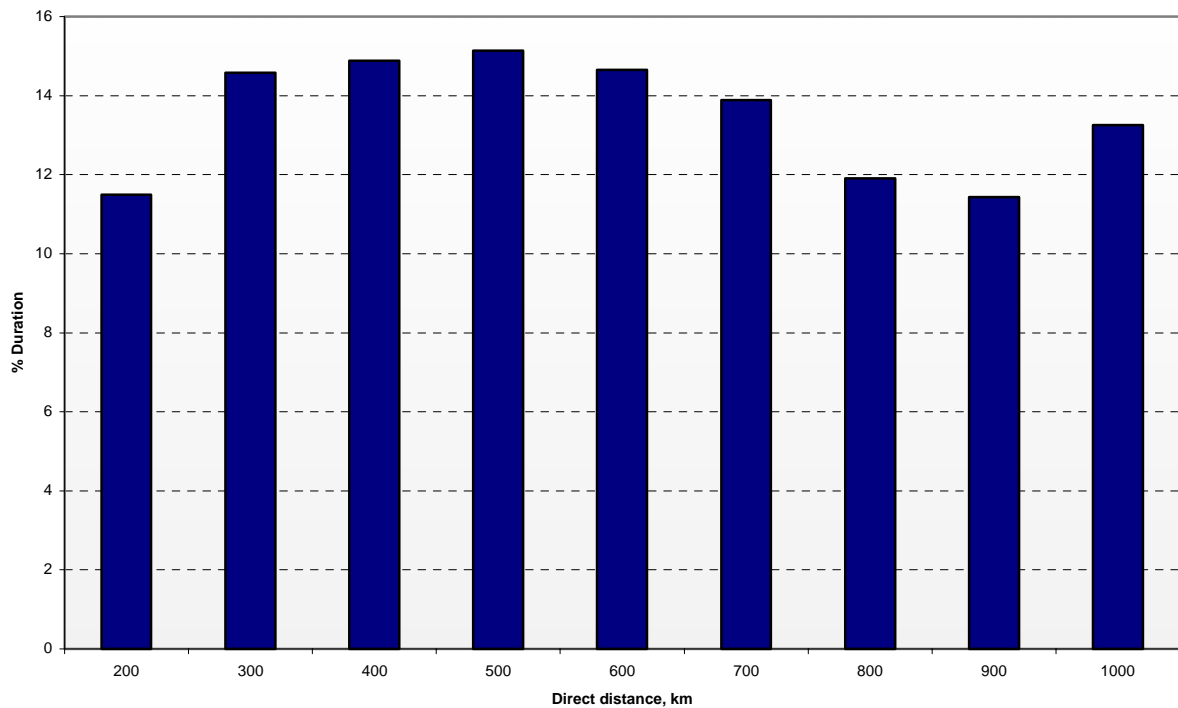
Duration was obtain subtracting begin time to end time of each flight.

The results are presented as percentages relative to the direct trajectory.

Actual Flight Duration and Direct Duration begin at Off-Block time and end at On-Block time.

$$\% \text{ Duration Difference} = \frac{\text{Actual Flight Duration} - \text{Direct Duration}}{\text{DirectDuration}}$$

Duration results include information on both ground track and vertical component of the flight history. The duration indicator represented in Figure 12 has the same global trend than the Route Efficiency indicator presented before. The average for the ten days recording of the percentage duration is 13.5 %, which is more than the Route Efficiency percentage (8.9%). Duration takes into account both horizontal and vertical efficiencies, whereas Route Efficiency indicator only considers horizontal ground tracks. Finding a higher percentage for Duration is then logical. However, the comparison is limited because radar tracks were not completed for the Route Efficiency study whereas Duration and Total Fuel Burn were calculated on completed flights.



**Figure 12: Average of % Duration for 10 days recorded as function of the direct distance corresponding**

### 2.4.3 Total Fuel Burn

Total Fuel Burn indicator is calculated using both ground track and vertical component of the flight history. The type of aircraft was also significant.

The results are presented as percentages relative to the direct trajectory.

ActualFlightTotalFuelBurn and DirectTotalFuelBurn started at the Off-Block phase and ended after the On-Block phase.

$$\% \text{ Fuel Difference} = \frac{\text{RadarFuel Burn} - \text{DirectFuel Burn}}{\text{Direct Fuel Burn}}$$

Total Fuel Burn indicator follows the global trend (Figure 16) with a minimum for the direct distance interval of 900-1000 kilometres. The average of Total Fuel Burn for the ten days recorded is 9.6 % for the direct distance interval 200-1100 kilometres.

The fuel consumption calculation is based on the duration linked to the BADA performance table.

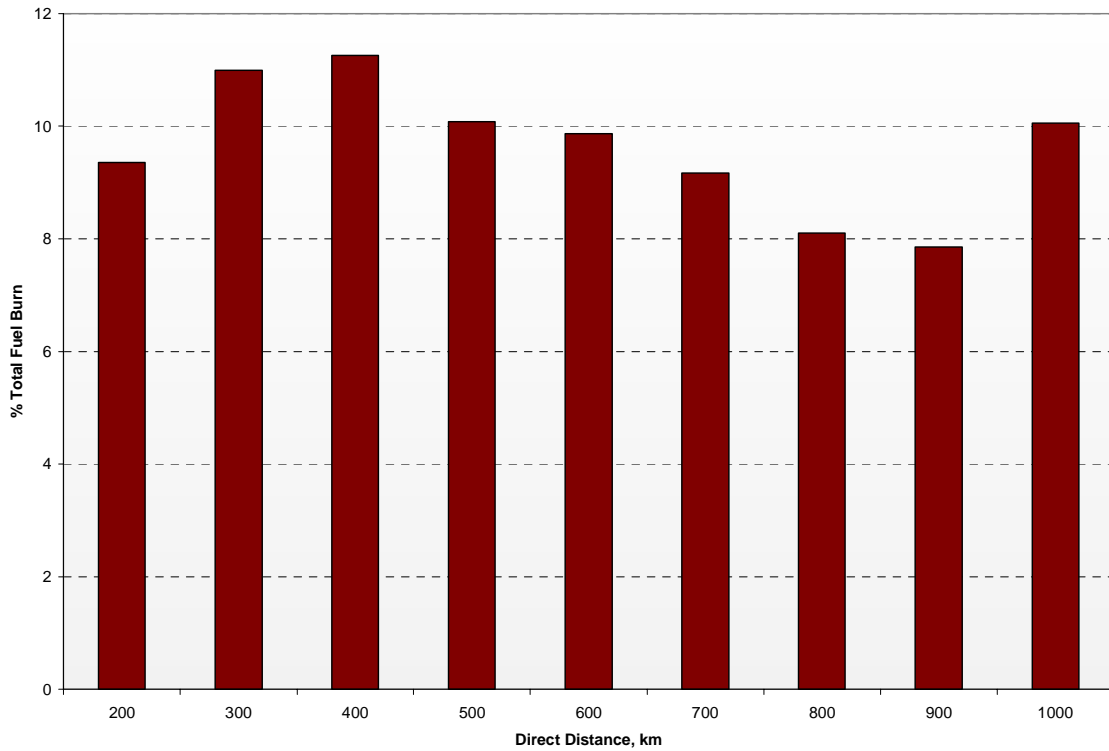


Figure 13: Average of Total Fuel Burn for 10 recording days

#### 2.4.4 Conclusions - Environmental evaluation

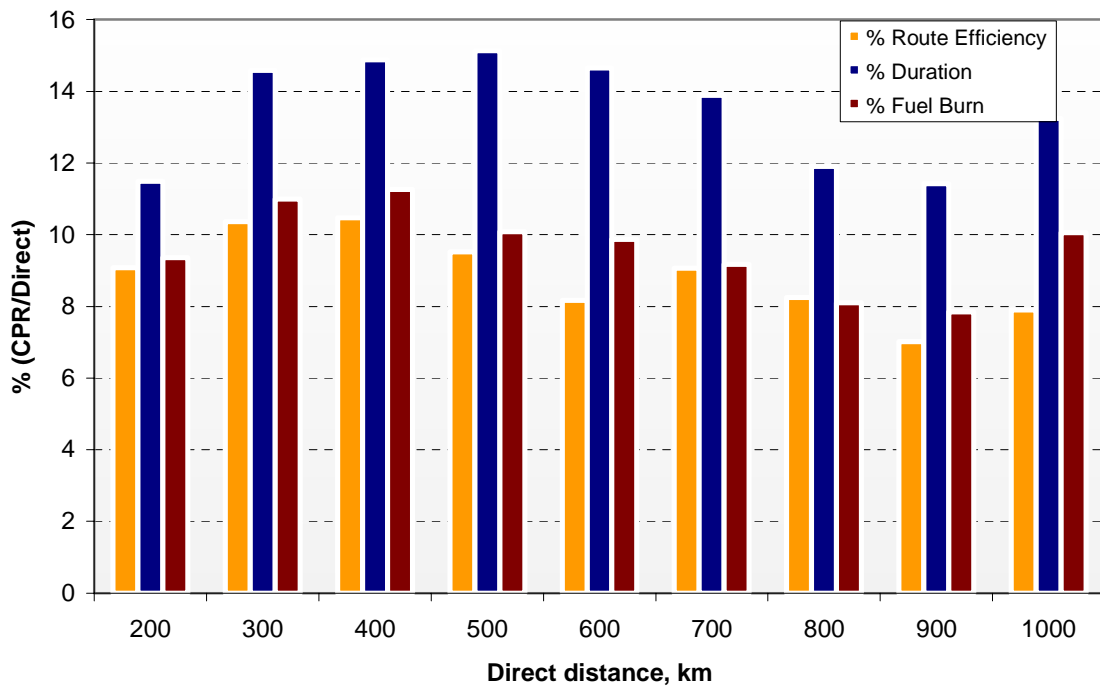


Figure 14: Route Efficiency & Duration & Total Fuel Burn Tendencies

The environmental study was based on a sample of intra-European and domestic flights spread over ten days in 2002 in the core of the ECAC area. Figure 14 shows that all three indicators: Route Efficiency, Duration and Total Fuel Burn have a comparable distribution in terms of direct route. The average values of the indicators were Route Efficiency = 8.9%, Duration efficiency = 13.5% and Total Fuel Burn = 9.6%.

## 2.5 Economic evaluation

This part of the report attempts to give a global evaluation, in monetary terms, of the flight efficiency for the EUROCONTROL air traffic in 2002. The scope is then wider than in was studied in the Environmental Evaluation. In this study a number of adjustments and additional assumptions were necessary to compute a weighted average of flight efficiency.

As far as costs are concerned, a distinction between 'internal' and 'external' is proposed. Internal costs of flight efficiency are defined as the amount of airline costs that could be avoided in the hypothesis of direct trajectories. External costs of flight efficiency are estimated to be the cost reduction of climate change impacts that could be obtained with direct trajectories. The latter cost estimation should be considered as a first approximate attempt to give a monetary value to negative externalities associated with flight inefficiencies. Considering the limited scientific understanding of some emissions (oxides of nitrogen, formation of condensation trails) and the economic debates on the valuation methods, the values we obtain should be considered as an order of magnitude which aim is to put flight efficiency performance in relative perspective among the other two main key performance areas which are ATM delay and capacity costs.

This chapter is organised as follows. Section 2.5.1 describes the traffic sample that is used for the scope of the study and how representative it is in respect of the whole European traffic. This leads us to compute adjusted efficiency indicators that allow assessing an average inefficiency for the whole European traffic with further confidence. Section 2.5.2 presents the "internal" costs estimation. These costs to airlines are estimated using ranges of possible values for the unit cost of an extra hour flown. The measure of external (negative) effects and their valuation are discussed in Section 2.5.3 proposes a range of probable values for environmental costs.

### 2.5.1 Adjustment of the calculated indicators (Route Efficiency & Total Fuel Burn)

As explained earlier in paragraph 2.3.3, the studied traffic was reduced in time, in space, and in flight types. The result of these successive filters is that only 14% of the total traffic has been considered for the flight efficiency analysis. A number of adjustments will then be necessary if we want to increase the degree of confidence when applying inefficiency coefficients to the whole European annual traffic.

As the flight efficiency of long-haul flights has not been assessed in the Environmental Study (chapter 2.4), one will have to consider different assumptions, according to the flight length, distributed onto three intervals.

- 200-1100 km range: use of flight efficiency results, presented in the previous chapters.
- 1100-1700 km range: use of the linear trend observed for the 200-1100 km range.
- 1,700-3,600 km range: two hypothesis are considered:
  - In a low bound hypothesis, 0% inefficiency is assumed. This is justified by the fact that the longer the range, the higher the probability that route extension is a deliberate choice of the airline (either to avoid a congested area, or to benefit from favourable winds that decrease the flight cost). This limitation also exists for shorter ranges, but we believe that on long ranges it could be predominant.
  - In a high bound hypothesis, the linear trend computed from the validated results will be used. This is simply derived from statistical observation, and leads to a progressive decline toward 0% inefficiency as the range increases.

The computed inefficiencies (or assumed for the longest ranges) will then be weighted by the actual duration, or fuel burn (depending on the indicator considered) in the total traffic within each range. Table 5 and Table 6 show how the weighted average has been computed for flight duration and fuel burn inefficiencies.

**Table 5: Estimation of the average inefficiency for flight duration (% difference between radar and direct trajectories)**

Range		All flight plans duration (seconds) (sum of 10 days)	Duration inefficiency (radar - direct) / direct	Extra duration % Low bound	Extra duration % High bound
0	100	2 968 455	na	na	na
100	200	19 883 004	na	na	na
200	300	38 276 890	11%	0,11	0,11
300	400	59 200 384	14%	0,14	0,14
400	500	78 470 453	14%	0,14	0,14
500	600	88 570 566	15%	0,15	0,15
600	700	64 196 258	15%	0,15	0,15
700	800	57 030 856	14%	0,14	0,14
800	900	57 116 820	12%	0,12	0,12
900	1000	50 731 271	11%	0,11	0,11
1000	1100	51 765 973	13%	0,13	0,13
1100	1200	43 070 928	9%	0,12	0,12
1200	1300	45 678 257	10%	0,11	0,11
1300	1400	37 679 412	11%	0,11	0,11
1400	1500	39 837 852	10%	0,11	0,11
1500	1600	46 145 305	8%	0,10	0,10
1600	1700	44 314 962	9%	0,10	0,10
1700	1800	39 240 781	na	0	0,09
1800	1900	32 815 965	na	0	0,09
1900	2000	34 739 954	na	0	0,09
2000	2100	29 506 811	na	0	0,08
2100	2200	26 557 744	na	0	0,08
2200	2300	22 829 059	na	0	0,07
2300	2400	30 318 082	na	0	0,07
2400	2500	24 444 929	na	0	0,07
2500	2600	28 643 819	na	0	0,06
2600	2700	19 474 802	na	0	0,06
2700	2800	21 410 645	na	0	0,05
2800	2900	14 024 587	na	0	0,05
2900	3000	12 277 159	na	0	0,05
3000	3100	12 775 515	na	0	0,04
3100	3200	12 022 954	na	0	0,04
3200	3300	14 188 220	na	0	0,03
3300	3400	8 002 841	na	0	0,03
3400	3500	7 703 082	na	0	0,03
Weighed average inefficiency				8,5%	10,7%

**Table 6: Estimation of the average inefficiency for fuel burn  
(% difference between radar and direct trajectories)**

Range		All flight plans fuel burn (kg) (sum of 10 days)	Fuel burn inefficiency (cpr-dir)/dir (env kpi)	Extra fuel burn % Low bound	Extra fuel burn % High bound
0	100	464 927	na	na	na
100	200	4 348 111	na	na	na
200	300	13 596 721	0,10	0,10	0,10
300	400	25 779 320	0,11	0,11	0,11
400	500	39 910 364	0,11	0,11	0,11
500	600	52 404 618	0,10	0,10	0,10
600	700	36 553 731	0,10	0,10	0,10
700	800	35 325 360	0,09	0,09	0,09
800	900	40 778 121	0,08	0,08	0,08
900	1000	37 167 530	0,08	0,08	0,08
1000	1100	49 381 845	0,10	0,10	0,10
1100	1200	34 656 784	0,06	0,08	0,08
1200	1300	42 109 826	0,07	0,08	0,08
1300	1400	36 014 782	0,09	0,07	0,07
1400	1500	36 182 674	0,10	0,07	0,07
1500	1600	43 373 109	0,07	0,07	0,07
1600	1700	44 727 140	0,06	0,06	0,06
1700	1800	40 252 076	na	0	0,06
1800	1900	31 412 810	na	0	0,06
1900	2000	34 476 439	na	0	0,05
2000	2100	36 111 603	na	0	0,05
2100	2200	27 889 623	na	0	0,05
2200	2300	25 752 802	na	0	0,04
2300	2400	35 788 652	na	0	0,04
2400	2500	29 094 066	na	0	0,04
2500	2600	32 350 118	na	0	0,03
2600	2700	21 514 091	na	0	0,03
2700	2800	24 820 902	na	0	0,03
2800	2900	18 979 743	na	0	0,02
2900	3000	14 424 716	na	0	0,02
3000	3100	17 016 428	na	0	0,02
3100	3200	17 361 724	na	0	0,01
3200	3300	22 437 765	na	0	0,01
3300	3400	11 488 893	na	0	0,01
3400	3500	12 284 709	na	0	0,01
Weighed average inefficiency				4,7%	6,4%

## 2.5.2 Cost to Airlines

### 2.5.2.1 Selection of the appropriate criteria for quantifying the flight inefficiency

As far as the (internal) costs to airlines are concerned, two indicators are available: extra distance flown, and extra flight duration. Both have an impact on the quantity of fuel burn, which is a major cost driver for airline operations. However, taken alone, extra fuel burn is not sufficient to capture the full cost of flight efficiency to airline operators. Indeed, other operating costs (such as maintenance costs, which vary according to the aircraft time utilisation) will also be increased as a result of the flight efficiency.

Therefore, distance or duration indicators have to complement extra fuel expenses. They present the advantage of being general explanatory variables, affecting almost all the direct operating costs. While both are linked by the average aircraft speed, it is important to notice that duration is an indicator containing more information. Indeed, inefficient climb profiles and cruise levels actually affect the speed, and thus the duration, without affecting at all the distance flown. Therefore, we considered duration as the basis for valuing the extra costs (other than fuel costs) due to flight inefficiency on airlines. Notice that duration is also a unit in which the costs from International Air Transport Association (IATA) are available.

According to the Central Flow Management Unit (CFMU), there was in 2002, 11,330,124 hours controlled within the EUROCONTROL boundaries (31 member states). This duration is computed from updated flight plans, and should thus be very close to actual flight durations. Then, in the following of the study, it will assumed that flight efficiency indicators based on radar trajectories are applicable to this overall value of 11,330,124 hours.

### 2.5.2.2 Flight operating costs

To date, the most reliable source for airlines direct operating cost is IATA. The IATA Airlines Economics Task Force has defined in 1995 the costs elements to be included in cost benefit analysis as far as additional flight time in the air is concerned. The figures have been last updated in 2000, and confirmed by IATA in 2002. The costs published for valuing an additional hour of flight time are computed from a large database ensuring a good representation of the real traffic flying in Europe. 24 European carriers participated to the data provision, allowing to cover operating costs of 77 different aircraft types, over 5.6 millions of block hours operation.

**Table 7: Direct operating costs of carriers operating in Europe**

	Cost per additional hour of flight time	IATA recommendation for valuing airborne delays	Minimum values for costing route extension (low bound assumption)
Flight Deck crew	€ 496	✓	
Fuel and Oil	€ 686	✓	✓
Flight Equipment Insurance	€ 10	✓	
Maintenance & Overhaul	€ 713	✓	✓
Flight Equipment Depreciation	€ 438		
Rentals	€ 474	✓	
Airport Charges	€ 381		
Air Navigation Charges	€ 339		
Total cost per hour	€ 3,539	€ 2,380	€ 1,399
Total cost per minute	€ 54	€ 40	€ 23

Source: IATA Airline Economics Task Force

According to a study lead by the University of Westminster (2002), the average fuel cost per hour can be estimated at €1,021 per hour. This is derived from an average fuel flow of 3.3 tonnes per hour and an average price of fuel of €310 per tonne. This value will be used as the upper bound for our fuel cost estimate, and the IATA estimate (€686 per hour) will be used as the lower bound.

In the context of flight efficiency, the question of keeping, in addition to fuel costs, all cost items used for delay valuation can be debated. Contrary to airborne delays, flight duration according to the planned route is known in advance. It is not sure whether airlines could make significant savings in flight deck crew, flight equipment insurance, and rentals if the ATM network was more efficient. Actually, we have chosen to build the low bound hypothesis by keeping only maintenance costs in addition to fuel costs. Flight deck crew, flight equipment insurance, maintenance, and rentals will be used for the upper bound hypothesis.

In addition to these direct operating costs, one could raise the question of adding a value for time for the passengers. Indeed, in an optimum network, each passenger could save on average about 7 minutes<sup>2</sup>.

However, and contrary to the approach adopted when costing delays, it is not so obvious that a cost for the passenger should be added. When passengers make their decision to fly, they will consider the flight duration only when another mode of transport can offer a reasonable alternative. In this case, the passenger's trade-off between value for time and ticket prices is made according to the scheduled time, and thus the flight duration (at its current state of efficiency) is known in advance, and internalised in the passenger's choice. From the passenger viewpoint, the time "lost" because of the flight efficiency is then a loss of surplus rather than a cost. Moreover, it is likely that with only 7 minutes potential saving, the inter-modal shift from other modes to air would be very low. As a conclusion, we will not include any costs relative to the passengers' value of time.

For the purpose of this study, it is proposed to adopt a value per minute ranging from € 12 and € 28 for costing extra flight duration, and a value ranging from €11 and €17 for extra fuel consumption. (We need to separate both, as the 2002 Study results are different for duration and for fuel efficiency).

Then, the total cost to airlines in Europe for flying in the actual network instead of in a theoretical first best optimum network is computed in

**Table 8: Extra cost to airline of flight inefficiency (potential savings)**

Hours computed from flight plans for the EUROCONTROL area (2002, source CFMU)	H1	H2	H3	H4
11,330,124	Low quantity & Low price	Low quantity & high price	High quantity & low price	High quantity & high price
Estimated 'actual' hours flown (difference Flight Plan / actual = 0 %)	11,330,124	11,330,124	11,330,124	11,330,124
Extra hours flown to use for fuel expenses difference actual / direct	510,923	510,923	681,344	681,344
Extra hours flown to use for other expenses difference actual / direct	884,162	884,162	1,094,346	1,094,346
Hourly cost per hour flown for fuel min from IATA, max from UoW [Ref 8]	686	1,021	686	1,021
Hourly cost per hour flown for other operating cost (Min includes only maintenance, max includes the costs used by IATA for valuing airborne delays)	713	1,693	713	1,693
<b>Airline yearly annual "theoretical extra cost estimation" due to difference CPR-Direct (Million Euro)</b>	<b>981</b>	<b>2,018</b>	<b>1,248</b>	<b>2,548</b>

This puts the airline yearly annual "theoretical extra cost estimation" due to difference Real-Direct (), in the same order of magnitude as ATFM delay cost. Indeed, the estimation of Air Traffic Flow Management (ATFM) delay cost is between € 1600-2100 Million, for the 2002 year.

As a conclusion, one has to keep in mind that the high level of costs estimated here hides different sources of inefficiencies. All flights on direct routes and optimum flight profiles is a first best optimum, which is not realistically reachable. Measured inefficiencies between actual trajectories and optimum ones are the result of successive trade-offs, such as route design coping with the flow structure, the

<sup>2</sup> With an annual number of movement around 8.4 millions in Europe, if 1 million hours (see Table 8) could be saved, it means that each flight, and thus each passenger could save (1,000,000/8,400,000x60) 7 minutes per trip.

existence of military areas, position of navigation aids, current technologies, procedures and safety standards. Besides, part of the deviations may be a deliberate choice of the airline to avoid congested areas or to benefit from favourable winds. Thus, these costs cannot be fully avoided, but the interest of having measured them is to show that any improvement in flight efficiency, even of low magnitude can potentially bring a good return on investment.

### 2.5.3 Issues in evaluation environmental costs

#### 2.5.3.1 Aviation and environment

ICAO has undertaken a number of actions under the Committee on Aviation Environmental Protection (CAEP). Its activities aim at catalysing efforts and improvements both for aircraft noise and aircraft engine emissions (ICAO Journal, 2001). On the latter point, their work program includes the enhancement of engine certification standards, the promotion of the best operational practices, and even study the use of market-based measures that would be appropriate to aviation. Besides, it is at ICAO's request that the Intergovernmental Panel on Climate Change (IPCC) published the Special Report on Aviation and the Global Atmosphere. This document is, according to ICAO "the most comprehensive assessment so far concerning aviation's contribution to global atmospheric problems". We will see in chapter 2.5.4.1 how useful that work can be when aiming at costing the relative shares of different emissions.

At a general level, the external effects that are attributed to any transport activity can be split into three categories (Schipper, 2001, [Ref 5]):

- First, externalities that directly depend on the level of activity, i.e. for air transport, noise, local and global air pollution, congestion, etc.
- Secondly, the indirect impacts of the activity with upstream and downstream processes, such as, for aviation, kerosene production, use of pollutant products in the aircraft construction and maintenance, etc.
- Thirdly, the effects linked to the presence of ground infrastructure on land utilisation, fauna and flora deterioration, etc.

The scope of our study is restricted to the first category of externalities, and within this category, only global environmental effects are considered. This is justified by the fact that flight efficiency indicators concern principally en-route ATM services provision. Then, only carbon dioxide (CO<sub>2</sub>), oxides of nitrogen (NO<sub>x</sub>), and water vapour (H<sub>2</sub>O), which are the emissions identified as the main contributors to the greenhouse effect, will be quantified and valued (as far as possible considering the level of uncertainty there can be in this domain).

According to Eurostat (2001) the share of aviation contribution in the total CO<sub>2</sub> emissions in Europe (EU15) is low, with only 3.7% in 1998. However, the share of aviation in the final energy consumption has increased in the past years (Table 9) and several factors suggest that this share will increase in the following years, due to i) a growth rate that is forecast to be higher than in the other industries, and ii) a slowdown in the fuel efficiency progress that allowed in the past a decrease in emissions per unit transported. Olsthoorn (2001) [Ref 6] developed a statistical model based on fuel prices and GDP to explain the level of jet-fuel consumption. According to his work, the emissions directly linked to the quantity of fuel burn by aviation may be multiplied by a factor ranging from 3 to 6 between 1995 and 2050. This result is consistent with other studies based on completely different methodologies.

**Table 9: Final energy consumption share by mode of transport (EU15)**

Transport mode	Energy consumption share (%)		
	1988	1993	1998
Air	2.9	3.3	3.9
Road	22.3	24.7	24.9
Rail	0.8	0.8	0.8

Source: Eurostat (2001)

To date, no single solution has been identified as efficient enough to curb this trend, and then, any potential source of improvement has to be studied with interest. Clearly, the ATM system has a role to play as a contributor to more effective flight efficiency (more direct routes and more efficient flight profiles). In the following paragraph we will try to quantify in terms of environmental costs, the current level of flight “inefficiencies”.

#### 2.5.3.2 *Scientific uncertainties*

What can we really measure? Fuel burn? Emissions of gas? Impact on environment? Quantities of aviation fuel burn are well known, at least at the global level, as they can be deduced from fuel sales. Quantities of emissions can be either easily derived from fuel burn, or subject to many factors, like altitudes, meteorological conditions, etc. Impacts of these emissions on environment are subject to more or less impassioned debates, and for sure are still under many scientific uncertainties. The exercise of costing environmental impacts such as climate change is therefore, and already at the stage of estimating quantities (not even prices), a difficult step, having inevitably to cope with a number of uncertainties and compromises.

The IPCC special report on aviation (IPCC, 1999) [Ref 7] focuses on impact using the concept of radiative forcing<sup>3</sup>. This notion of radiative forcing, and the work that has been done under the aegis of IPCC is very useful for costing different pollutants, as it provides a common denominator.

<sup>3</sup> “Radiative forcing is a measure of the importance of a potential climate change mechanism. It expresses the perturbation or change to the energy balance of the Earth-atmosphere system in watts per square metre (Wm<sup>-2</sup>). Positive values of radiative forcing imply a net warming, while negative values imply cooling.” IPCC report.

## Radiative Forcing from Aircraft in 1992

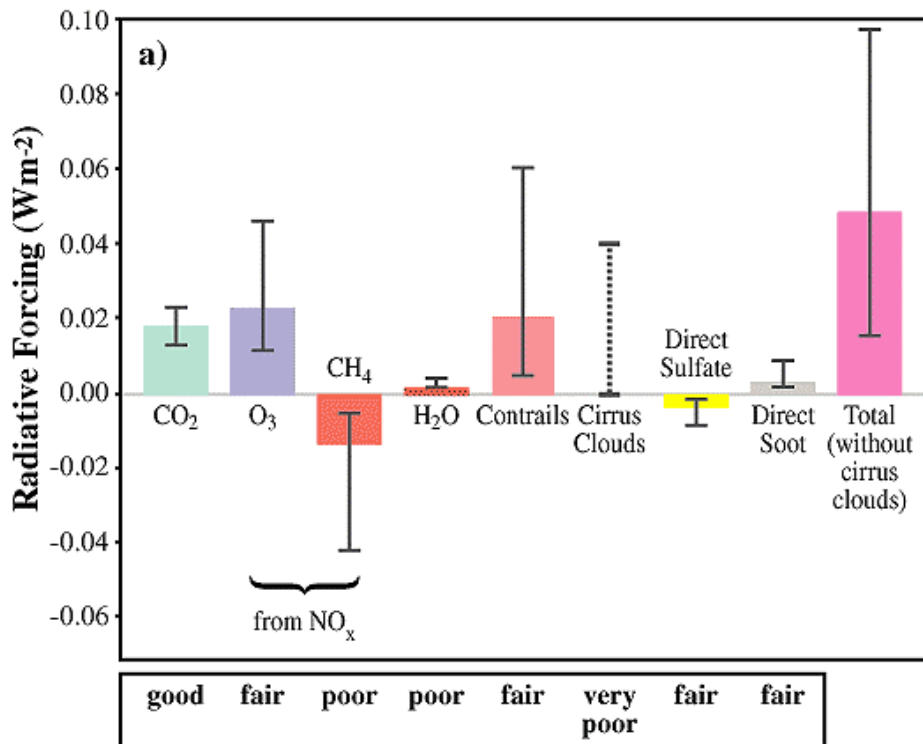


Figure 15: Radiative forcing

“The evaluations below the graph (“good”, “fair”, “poor”, “very poor”) are a relative appraisal associated with each component and indicates the level of scientific understanding” Source: IPCC (1999). In the figure the bars are two third uncertainties line. It means that there is 67% probability that the true value is between the limits of the lines. We see as a consequence that uncertainties relative to the global effect of NO<sub>x</sub> are high, and when applying the error margin, it is possible that the net effect becomes almost negligible.

Among the pollutants that are considered in this study, CO<sub>2</sub> is the easiest to handle. Its level is a constant rate of fuel consumption. Whatever the conditions, each kilogram of fuel burn generates 3.149 kilograms of CO<sub>2</sub>. However, given the long residence time of CO<sub>2</sub> in the atmosphere, around 100 years, it is not straightforward to cost CO<sub>2</sub> impact for the economists. Debates on the discount rate to be used (reflecting at one extreme the preference for the present and at the other extreme the right for future generations to live in a “clean” environment) generate very wide ranges of cost estimates for CO<sub>2</sub>.

The second pollutant under consideration is nitrogen oxide (NO<sub>x</sub>), which effects are more complex to assess. Actually, NO<sub>x</sub> is not a greenhouse gas as such, but its presence in the atmosphere leads to i) an increase in atmospheric ozone when released at altitudes around the tropopause<sup>4</sup>, ii) a decrease in atmospheric ozone when released at higher altitudes, and iii) a decrease in methane (CH<sub>4</sub>) concentration, which is a greenhouse gas. However, the opposite indirect effects of NO<sub>x</sub> emissions on ozone and methane do not compensate, and on average, the net result is likely to contribute to warming the atmosphere (Figure 15). The range of uncertainty is such that one should stay very cautious in the interpretation of results that can be derived from NO<sub>x</sub> estimates.

<sup>4</sup> The tropopause is the limit between troposphere and stratosphere, varying in function of the geographical locations, and roughly situated around 10 kilometres altitude, which corresponds to the subsonic jet aircraft cruise level.

The third emission that can be valued is water vapour, which is, as CO<sub>2</sub>, directly proportional to fuel burn. Each kilogram of fuel consumed generates 1.23 kilogram of H<sub>2</sub>O. Water vapour is a greenhouse gas, but as its Residence Time in the atmosphere is short, most of it is evacuated in the form of rain within one or two weeks. A small part of water vapour emissions, which are released in the lower stratosphere, can however have a more significant impact.

Additionally the formation of condensation trails (contrails) could be interesting to include, as they may have an impact on climate change. According to the IPCC, the best estimates of contrail impacts are similar to those of CO<sub>2</sub>. However, the formation of contrails is subject to particular atmospheric conditions, and only occurs in a small fraction of time. The range of uncertainty for contrails impact is such that it is preferable not to include it in our valuation exercise.

In conclusion, we will propose in this study a valuation of CO<sub>2</sub>, NO<sub>x</sub> and H<sub>2</sub>O impacts, keeping in mind that NO<sub>x</sub> values are still uncertain and easily debatable, and that an additional cost could be probably added if contrails were proven to be a significant driver of climate change.

### 2.5.3.3 Economic evaluation

Putting a monetary value on air transport environmental effects is a complex exercise, subject to many controversies, and which raises multidisciplinary issues: technological, social, political and economical. To be useful, monetary valuation should not seek to attribute a 'true' price, but should rather propose ranges of possible values, and in any case the values should be interpreted with caution (Perl, 1997,[Ref 11]). Economic methods for valuing externalities are organised around several approaches (Nicolas, 1998, [Ref 9] ; Wardman, 2002, [Ref 10]) among which damage costs and potential costs are relevant to the valuation of collective choices. We provide a brief description of these two approaches, as they are most relevant to our work.

Damage costs of air pollution require building an initial link between the level of emissions and the relative impacts (emission of greenhouse gases – impact on radiative forcing – impact on climate – impact on human activities and health). The valuation of damage costs takes into account the cost of protection measures already in place, and also the costs generated by losses of added value (for example, loss of agricultural productivity, or loss of human productivity).

Potential costs rely on a quite different pricing methodology, one which seeks to compute the prices that would have to be introduced in order to reach a determined pollution target. On the one hand it can cover avoidance costs such as the cost of implementing alternative technologies that would allow pollution target to be reached. On the other hand, it can be driven by political definition of objectives (like under the Kyoto Protocol) where economic valuation comes *a posteriori* in the form of level of tax, or level of price on a fictive pollution market that has to be implemented in order to reach the political target.

## 2.5.4 Costing environmental effects of flight efficiency

### 2.5.4.1 Cost references for aviation emissions

Perl, Patterson, and Perez, (1997 & 2001) have calculated costs of aviation emissions at Lyon Satolas Airport. Their methodology relies on an inventory of the emissions at the airport, computed from the ICAO LTO emissions values applied to the real traffic mix at Lyon-Satolas airport. The unit costs are taken from different studies, among which:

- Pearce (1994) based on direct estimation of damages conducted in the UK: €17 per tonne CO<sub>2</sub>.
- Crozet (1994) based on minimal damage costs direct estimation in France: €32 per tonne CO<sub>2</sub>.
- Crozet (1994) based on potential avoidance costs, costs that would meet sustainability targets: €38 per tonne CO<sub>2</sub>.
- For NO<sub>x</sub> ten references are used (Kageson, 1994; Pearce, 1994; Schultz, 1994; Crozet, 1994; Hanson, 1996; Mauch and Rothengatter cited in IWW-INFRAS, 1995). Perl, Patterson

and Perez conclude from these studies that a realistic range for valuing NO<sub>x</sub> lies between €1,300 and €6,018 per tonne.

Therefore, this paper provides a valuable reference for our exercise of costing external effects of aviation. However, it differs from our objectives in the sense that en-route emissions are not directly comparable to airport emissions, due to differences in the effects to consider.

In a recent report by Dings et al. (2002) [Ref 13] on “External Cost of Aviation”, a synthesis on the cost evaluation for CO<sub>2</sub> is performed (a dozen of references are used). It is shown that both damage and prevention costs for CO<sub>2</sub> give similar ranges, from few Euros to around €100 per tonnes. Eliminating extreme values, the authors suggest to use an average of €30, with a range of €10 - 50 to consider uncertainties. It is interesting to note that this value of €30 is very close to the costs used by Perl, Patterson and Perez in their study applied to Lyon Satolas Airport. This convergence of values provides further confidence.

In a second stage, Dings et al. propose a methodology (based on IPCC simulation results on relative radiative forcing of each emission) to derive a cost for NO<sub>x</sub> and H<sub>2</sub>O emissions. It consists in computing the ratio of relative emissions on relative impacts. Table 10 shows that 1 kilogram of NO<sub>x</sub> emitted in the atmosphere has the same impact as 132 kilogram of CO<sub>2</sub>, and that 1 kilogram of H<sub>2</sub>O has the same impact as 0.28 kilogram of CO<sub>2</sub>.

**Table 10: Radiative forcing impacts relative to CO<sub>2</sub>**

1992 situation	Fuel consumption	CO <sub>2</sub>	H <sub>2</sub> O	NO <sub>x</sub>
1992 emissions (‘NASA-1992’ scenario, in Million tonnes)	160,3	506	202	1,92
Radiative forcing (W/m <sup>2</sup> )		0,018	0,002	0,009
Globally averaged radiative forcing per kg emission, relative to 1 kg of CO <sub>2</sub> emission		1	0.28	132

Source: IPCC cited in Dings et al. (2002)

As the three emissions can now be expressed with respect to each other in terms of environmental impacts, one can easily translate values found for CO<sub>2</sub> to H<sub>2</sub>O and NO<sub>x</sub>. Table 11 shows the ranges and average values that can be computed from the relative impacts.

**Table 11: Values of emissions resulting from their relative impacts**

	Low	Medium	High
CO <sub>2</sub> (€ per tonne)	10	30	50
H <sub>2</sub> O (€ per tonne)	2,8	8,4	14
NO <sub>x</sub> (€ per tonne)	1320	3960	6600

Again, these results are consistent with the values used by Perl et al. (1997) [Ref 11], despite a different approach to compute the costs. For NO<sub>x</sub> Perl et al. used as a low bound (scenario rural context combined with minimal values) €1,300 per tonne, and as a high bound (scenario urban context combined with potential values) €6,018 per tonne.

The INFRAS/IWW study (Maibach, 2000) [Ref 12] is also widely used as reference in the area of transport externalities. It covers a wide range of externalities, accidents, congestion, noise, pollution, etc. and applies to all modes of transport (road, air, rail, and waterborne transport). It estimates for 1995 that total external cost of transport activities (excluding congestion) in the EU17 area reaches 530 billion Euros (7.8% of the GDP). Table 12 shows how this amount spreads over the different categories for all modes together, and for aviation separately.

**Table 12: Share of external cost in transport (EU17, 1995)**

Type of effects	Share of total cost (all modes)	Share of total cost (Aviation)
Accidents	29%	1%
Noise	7%	8%
Air pollution	25%	3%
Climate change	23%	74%
Nature and landscape	3%	4%
Separation in urban areas	1%	0%
Space scarcity in urban areas	1%	0%
Additional costs from up- and downstream processes	11%	10%
Congestion (not taken into account for %)		

Source: INFRAS/IWW, 2000

These costs are not equally distributed among the different modes. If road occupies by far the first rank, with 92%, aviation comes second with 6%, i.e. three times more than rail. These costs have then been translated to cost per passenger-kilometre transported and have been used to support inter-modal comparisons on specific corridors. As far as global emissions released by aviation over Europe is concerned, the study estimates that aviation (passenger transportation only) contribution to climate change can be priced at (530 x 6% x 74%) €23.5 billion. This estimation is not precisely documented, CO<sub>2</sub> is valued at €135, but it is not said whether this high value is a deliberate choice to indirectly include NO<sub>x</sub>, H<sub>2</sub>O, formation of contrails and cirrus clouds, etc. Therefore it will not be easily comparable with our results.

As a conclusion, and considering the several sources of uncertainty, we propose to use the values shown in Table 11 corresponding to the work of Dings et al. (2002) [Ref 13] on “External Cost of Aviation”.

#### 2.5.4.2 *Extra emissions and extra environmental costs*

Using the same distinction between high and low assumptions both for quantities and for unit costs, estimated environmental costs relative to flight inefficiency are shown in Table 13. Again, these results do not pretend to be the “true” environmental cost. They should be considered with caution, especially as far as NO<sub>x</sub> costs are concerned, as the ratio between fuel consumption and NO<sub>x</sub> emission that is used in Table 13 (0.012) comes from simulation results cited in the IPCC report and are only valid for a static view. In reality, as explained in subsection 2.5.3.2, NO<sub>x</sub> emissions are not a constant rate of fuel consumption.

The average fuel flow that is used to estimate the annual fuel consumption from aviation over Europe is based on the University of Westminster study (2002) [Ref 8]. It considers fuel flow in cruise for different families of aircraft, and their respective share in the total traffic fleet. The fuel flow computed in the flight efficiency study is slightly lower, which is logically explained by the presence of a higher share of light aircraft, as shown in Table 2. The annual fuel consumption we estimate is slightly lower but still consistent with Eurostat (2001) publication (38 millions tonnes of fuel).

**Table 13: Estimated external costs of flight inefficiencies**

	Low quantity & low price	Low quantity & high price	High quantity & low price	High quantity & high price
Estimated actual hours flown (difference FP / actual = 0%)	11,330,124	11,330,124	11,330,124	11,330,124
Estimated actual fuel consumption (average fuel flow=3.292 tonnes per hour)	37,298,360	37,298,360	37,298,360	37,298,360
Estimated actual CO2 emissions (3.149 tonnes per tonne of fuel)	117,452,536	117,452,536	117,452,536	117,452,536
Estimated actual H2O emissions (1.230 tonnes per tonne of fuel)	45,876,983	45,876,983	45,876,983	45,876,983
Estimated actual NOx emissions (0.012 tonne per tonne of fuel)	447,580	447,580	447,580	447,580
CO2 (estimated extra emissions)	5,296,425	5,296,425	7,063,076	7,063,076
H2O (estimated extra emissions)	2,068,785	2,068,785	2,758,839	2,758,839
NOX (estimated extra emissions)	20,183	20,183	26,916	26,916
Cost per tonne CO2	10	50	10	50
Cost per tonne H2O	2.8	14	2.8	14
Cost per tonne NOx	1320	6600	1320	6600
<b>Extra cost of pollution (million Euro)</b>	<b>85</b>	<b>427</b>	<b>114</b>	<b>569</b>

The range of magnitude obtained for environmental cost (factor 7) is logically much higher than the one obtained for airline costs (factor 3). However, it can be observed that the estimated environmental costs are lower than the airlines costs. Even the highest bound of environmental costs does not exceed the lowest bound of airline costs. Here, one has to keep in mind that the formation of contrails has not been valued because of a too high level of uncertainty, but the likely level suggested by IPCC, see Figure 15, would indicate a cost as high as for CO<sub>2</sub>. This element would change significantly the picture.

### 2.5.5 Conclusion – Economic Study

This chapter has presented a tentative of monetary evaluation of flight inefficiencies in Europe. Using indicators comparing the actual trajectories to theoretical optimum trajectories for intra European flights, we have first adapted these results for applying them to the whole European traffic. Then, we have presented both direct theoretical savings for airlines and the related environmental costs. It appears that, compared to a “first best” optimum, costs to airlines lie between 981 and 2548 million Euros. An additional cost for impacts on climate change could be added for an amount between 85 and 569 million Euros.

Of course, there is much progress still to be made, both in the way flight inefficiency percentage and costs are computed, but despite the existing uncertainties, and the multitude of sources that could justify or explain our results, the estimated costs are still very high (almost comparable with delay costs). It clearly stresses the fact that ATM has a responsibility as far as environmental efficiency, and aviation sustainability are concerned.

Intentionally left blank

### 3.1 Overview

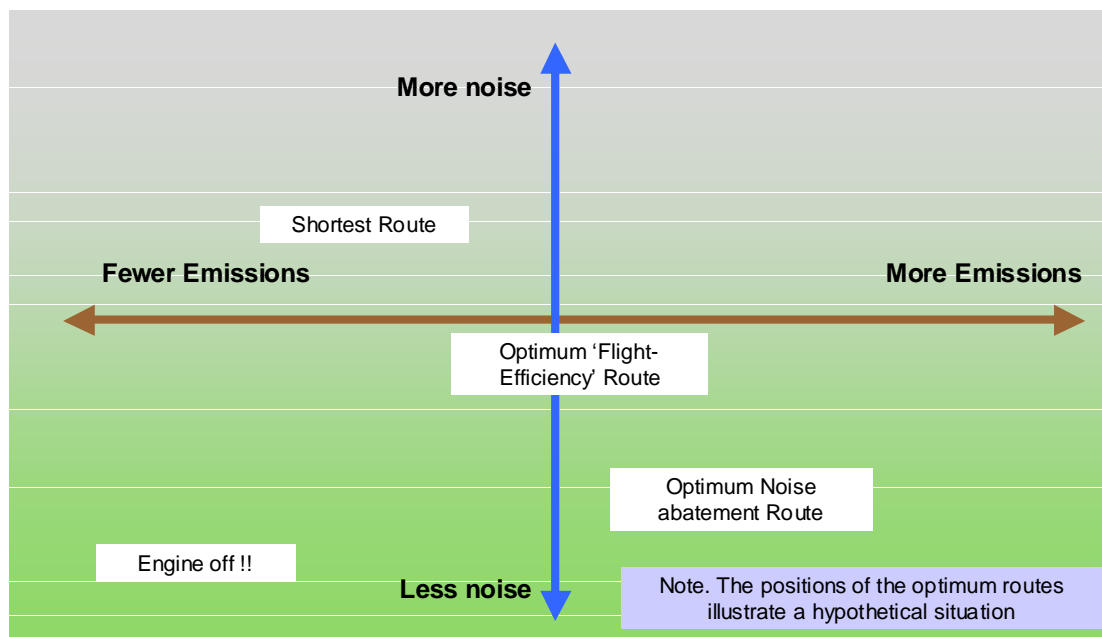
The Environmental Efficiency Indicators TMA study investigated the application of Route Efficiency, Fuel Burn and Noise in a TMA (Terminal Manoeuvring Area) environment.

The objectives of the study were to investigate if Environmental Performance Indicators could be used to determine the trade-off between emissions and noise from aircraft traffic movements in a TMA environment. The study focused in particular on the methods that could be used in a TMA to measure the indicators.

Aircraft noise and emissions from departures and arrivals are believed to have a major environmental impact of near airports. A better understanding of the scale of this impact of emissions close to airports is being studied as part of the Local Air Quality project at EEC [Ref 2]. However, the impact at the TMA scale is less well understood. Noise studies often focus on higher levels (> 55dB LAeq<sup>5</sup>) for reasons of technical reliability and legal comparison with population databases. Again, these are limited in many cases to 3000ft above airfield – essentially in final approach and initial climb phases of flight. Other contributing effects such as ground operations due to engine run-ups and taxiing have not been studied as they are outside the context of Air Traffic Control.

For these reasons the study focused on airborne operations in the TMA.

The application of environmental indicators to the TMA is based on the hypothesis that there should be an optimum 'compromise' ground track and vertical profile to mitigate noise and fuel burn for departures or arrivals at a given airport. The optimum route and vertical profile can be used as a reference in comparisons with real routes and profiles. The concept is illustrated in the diagram below.



**Figure 16: Application of Environmental Efficiency Indicators to TMA**

This study was concerned with the mechanics of how to measure the KPIs in the TMA environment.

TMA operations are normally based on a network of SIDs and STARS, RNAV routes using reporting points and navigation beacons. Noise Abatement procedures are often imposed that designate special fixed routes and profiles designed to help mitigate noise impact in a TMA. However, the real air traffic operations in TMA are dynamic. Whilst the published SIDs, STARS, Noise abatement procedures are adhered to as much as possible, the real routes and profiles vary due to a number of factors such as:- traffic density, weather, aircraft operating capabilities, aircraft operator preferences and controller workload.

<sup>5</sup> LAeq is The Energy Averaging noise level. The formal definition of LAeq is "when a noise varies over time, the Leq is the equivalent continuous sound which would contain the same sound energy as the time varying sound". LAeq is a type of average, where noisy events have a significant influence. LAeq is the designated unit for measuring airport noise in the European Community and is used for assessing Occupational Noise.

### 3.2 Measurement of the Environmental Performance Indicators

The Route Efficiency indicators are defined such that positions at the start and end of each flight in the reference data set must coincide with the start and end of the corresponding flight in the measured data set. In the en-route context, the departure and destination airports are used. However, in the TMA context only the situation is more complex – particularly in the choice of airborne start/end points. For the TMA study the airborne several start and end points scenarios were considered and shown below:

Reference	Departures	Arrivals
<b>Ground point</b>	Start of take-of run	End of landing run.
<b>Airborne point –1</b>	End: exit point from TMA	Start: entry point to TMA
<b>Airborne point –2</b>	End : Height threshold	Start: Height threshold
<b>Airborne point –3</b>	End: Top of Climb	Start: Top of Descent
<b>Airborne point –4</b>	End: FIR limits	Start: FIR limit

The TMA entry and exit points need to be coherent between the direct and real trajectories to reduce the errors in comparing the differences in ground track and profile.

A height threshold (height above airfield) was considered as a criterion. However, this was not used because the differences in profile between the real and direct lead to large differences in ground track start/end points, thus making the Route Efficiency measurements invalid.

The diagram in Figure 17 illustrates the potential difference between a direct route and SID departure. The end points are illustrated to emphasise the differences between using ground position and height as a End point criterion for the measurement of Route Efficiency and Fuel Burn.

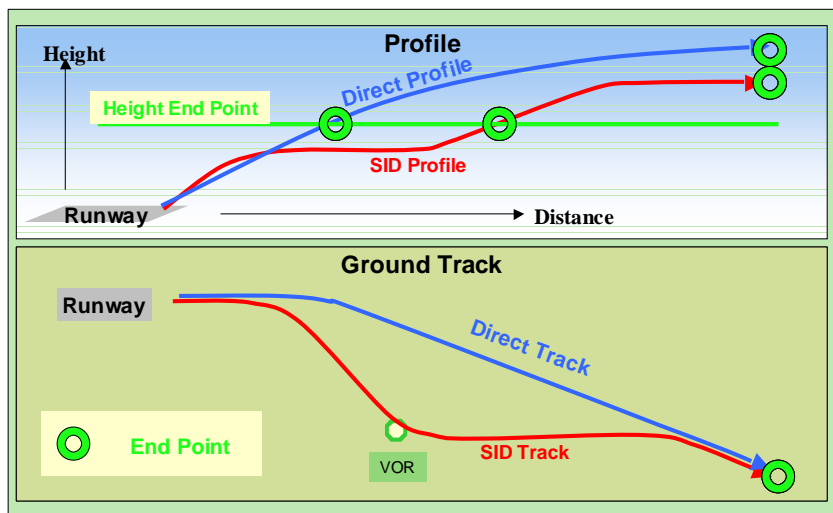


Figure 17: Ground Track and Profile – a typical Real vs Direct Departure

The Top-of-climb Top-of-descent scenario was not used for similar reasons to the TMA entry/exit points. The Airborne points can be displaced in both ground position and vertical profile leading to errors in calculating route efficiency and fuel burn.

The FIR limit scenario was used for this study. The Exit and Entry points were chosen to correspond to waypoints that were nearest to the boundaries of the Flight Information Region (FIR) and which were on the routes of flights in the C19 configuration. The points were selected outside the TMA to ensure that flights ended in cruise phase for the outbound flights and started in cruise for inbound

flights. Flights to airports within the FIR were included wherever possible and retained their complete profile (climb and descent).

The reference of the TMA study was the hypothetical case of an airport with a normal day's traffic where each flight was free arrive or depart without any third party constraints, such as ATC, weather effects, separation restrictions (wake vortex) and environmental restrictions. In other words, each flight was flown at the optimum performance of the aircraft between the start and end point.

### 3.3 Traffic Sample

This study was based on simulated flight histories generated using TAAM (Total Airspace and Airport Modeller) simulator. The traffic sample was selected from one of the configurations studied as part of an extensive simulation of a European TMA [Ref 3].

The selected traffic sample offered an interesting configuration of arrival traffic, the majority of which is from the South and West of the airport. Figure 18 shows the ground tracks of the reference sample C19.

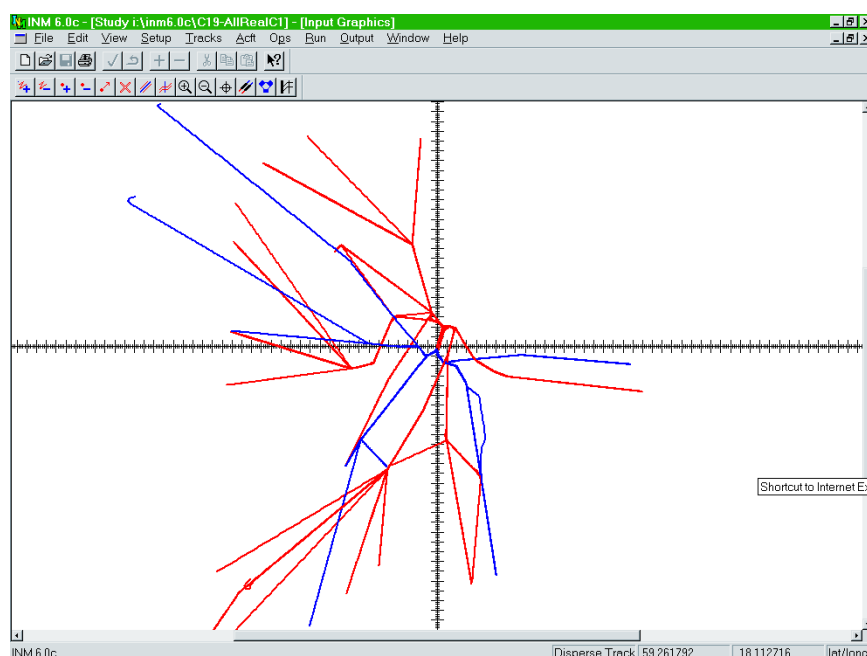


Figure 18: TMA study ground Tracks – config C19

Considerable effort was made to ensure a coherent traffic sample between the Direct and Real configurations. The actual sample used for this study was over weighted in arrivals. Out of the original 768 flights in the TAAM simulation 377 satisfied the selection criteria for consistency between direct and real flights (278 arrivals and 99 departures). The sample was chosen to speed up processing time.

A tolerance of 5% was allowed on the difference in position between start and end of the real track compared to the direct track.

### 3.4 Procedure

The study compared 'real' traffic that were subject to the normal Air Traffic restrictions of a TMA and the Direct configuration where the only constraints were runway in use and the aircraft performance.

In practice, the direct configurations required some constraints using waypoints to ensure correct operation of the TAAM simulator. No other criteria were used to constrain the flights, such as SID, STAR, noise abatement procedures, ATC sector loads, runway capacity.

For the fuel burn, the natural aircraft performance in the direct configuration is used as the basis of comparison against the real profile with the knowledge that the actual start/end Flight Levels are likely to be different.

### 3.4.1 Configurations

Two configurations were used – the Direct reference configuration (D1) and the ‘real’ configuration (C19) .

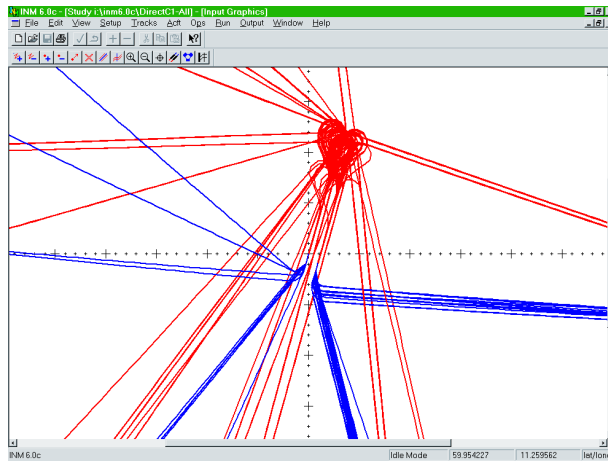


Figure 19: Direct configuration - Ground Tracks

The D1 configuration emulated as close as possible free flight between ground end points and airborne end points. In Figure 19 the arrival tracks are shown in red and the departures in blue. The flights were constrained in TAAM by just two waypoints situated at 12.5NM on the extended centre lines from the runway thresholds. The vertical profiles of arrival flights were, for the most part, continuous descent from cruise to touchdown with no level section to intercept the Instrument Landing System (ILS). The departure flights climbed straight to cruising altitude.

The configurations used in the study are summarized in the table below:

Label	Type	Traffic Remarks	Parameters
C19	Real		
D1	Direct	Arrivals were direct to intercept Arrival waypoints	Sequencing : OFF Sector Capacity : OFF

In the D1 configuration the Arrival traffic was approximately at 4000 to 5000 feet over the waypoints. Aircraft performance dictated how TAAM behaved when turning onto final approach. The arrivals from the south in configuration D1 were ‘as flown’ by TAAM and could be considered as ‘unrealistic’ from a pilots point of view but were intended to demonstrate the concept of a shortest route within the context of this experiment. In practice, realistic direct routes would be more complex and therefore a source of dispersion in the results as illustrated in Figure 20.

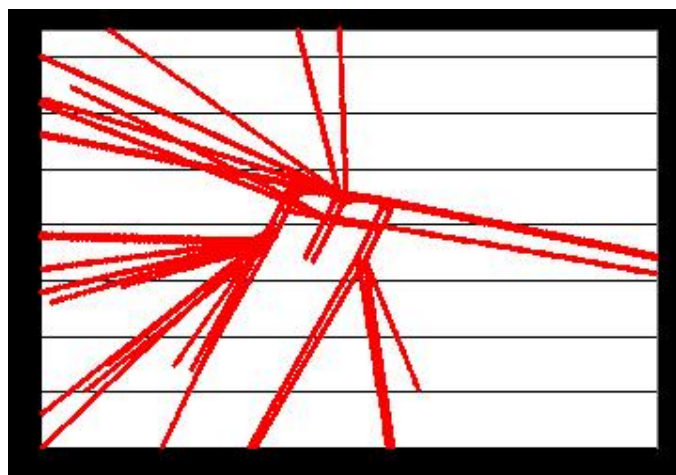


Figure 20: Alternative Direct Scenario - arrivals

### 3.4.2 TAAM processing

The Direct D1 scenario was split into Arrivals and Departures for processing by TAAM to avoid the possibility of arrival traffic conflicting with departure traffic.

The real scenario C19 was run with both departures and arrivals to simulate normal operations.

### 3.5 Profile Analysis

The profile analysis formed part of the data preparation phase to validate the vertical profiles of the direct and real configurations. In the real traffic configuration each flight should follow the flight plan. In the direct traffic configurations each flight should follow a vertical profile according to the aircraft performance.

In the direct configurations the TAAM generated profiles were nearly all of the type 'Continuous Descent Approach'.

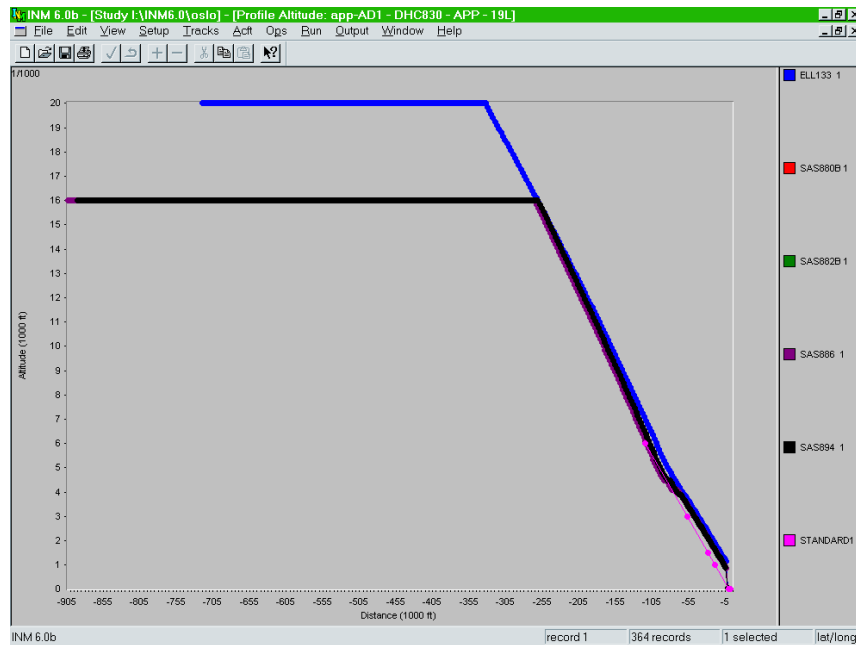


Figure 21: Example of Arrival Profile

### 3.6 Results

In addition to the global indicators reported in this report the Flight Efficiency Indicators may be classified in terms of parameters more relevant to the TMA that incorporate aircraft performance. In this report we have expressed the results as a function of Aircraft type (Engine Type) and Direct Route Distance.

The Route efficiency was calculated using the STBec tool.

$$\text{Route Efficiency} = \frac{\text{Actual Route distance} - \text{Direct Route distance}}{\text{Direct Route distance}}$$

The results are shown as function of direct distance flown.

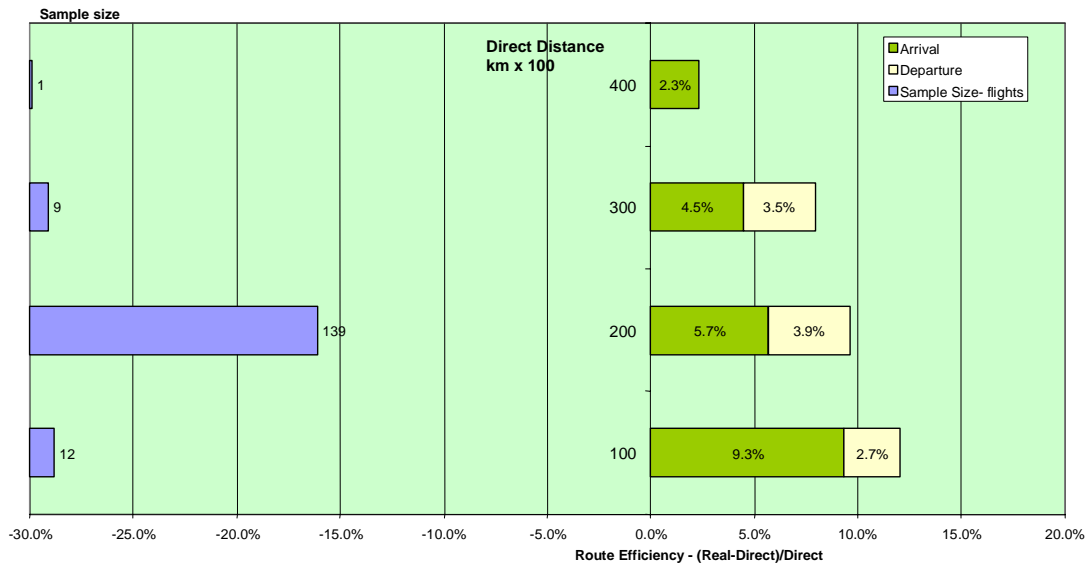


Figure 22: Flight Efficiency in a TMA – an example for Departure and Arrivals

Table 14: Average Route Efficiency for TMA flights

Average of Distance Direct Distance (km)	Operation		
	Arrival	Departure	Total
100	9.3%	2.7%	4.7%
200	5.7%	3.9%	5.4%
300	4.5%	3.5%	4.3%
400	2.3%	0%	2.3%
Total	5.9%	3.3%	5.2%

### 3.7 Noise contours

The noise contours were calculated using the European Harmonised Noise Contour modelling Environment (ENHANCE) and INM (Intgrated Noise Model) tools. The noise index was the Average Equivalent Noise Level (LAeq) calculated over 6 hours.

The samples used for the noise calculations were a subset based on 221 flights representing a 6 hour period of traffic – 60 departures and 161 arrivals.

The departures and arrivals were processed separately in TAAM to allow easier comparison of the real and direct configurations.

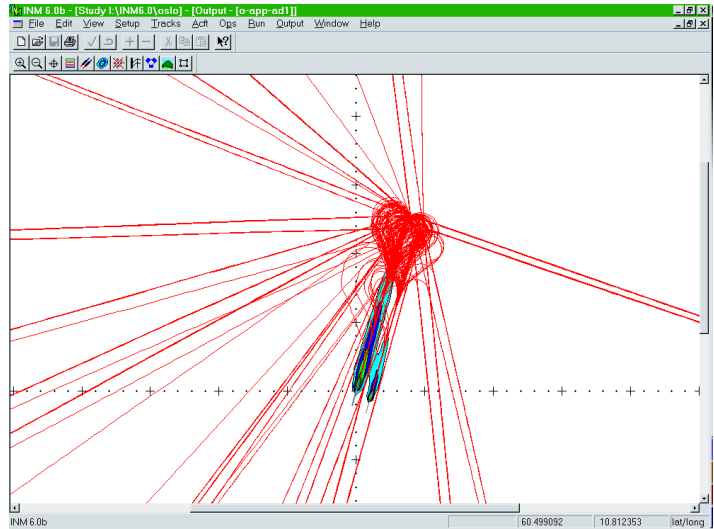


Figure 23: TMA Study - Noise Arrival Direct config D1)

#### 3.7.1 Arrivals

Figure 23 shows the Noise contours for the arrivals in configuration D1.

The measurable contours were shown to close to the approach path.

Figure 24 shows the LAeq 6 hour noise contours for the real arrival traffic (C19-filled colours) overlaid on the contours for the Direct departure traffic (D1 - unfilled colours)

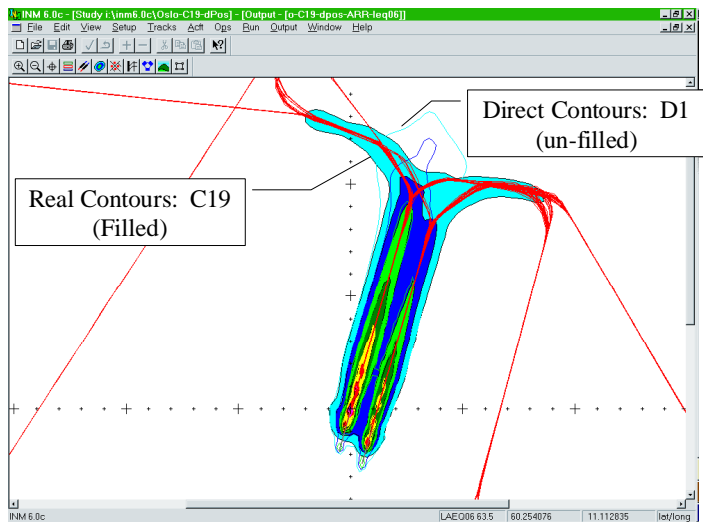


Figure 24: Arrival Noise contours - C19 overlaid on D1

#### 3.7.2 Departures

Figure 25 shows the LAeq 6 hour noise contours for the real departure traffic (C19- filled colours) overlaid on the contours for the Direct departure traffic (D1 - unfilled colours)

The use of Standard Departure routes was active for the Real configuration.

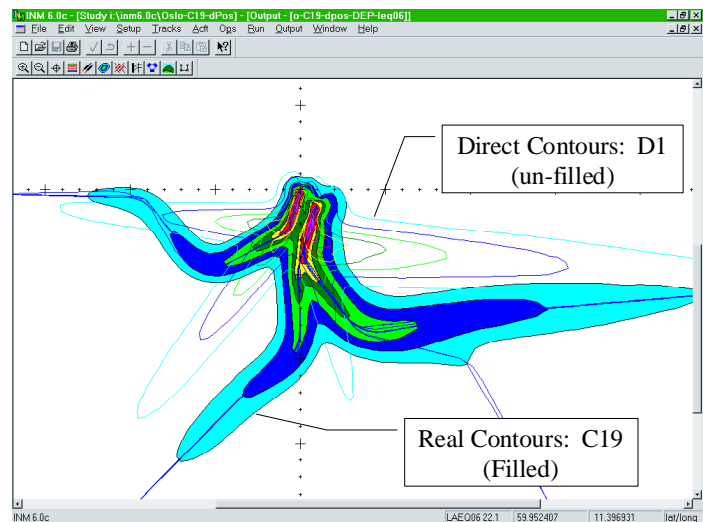


Figure 25: Departure Noise contours - C19 overlaid on D1

### 3.8 Noise contour results

The results are given for the comparison between the real and direct configurations (C19 and D1) for the 6 hour period. The contour surface areas (km<sup>2</sup>) are given in below. The direct configuration D1 showed a larger contour surface than the real configuration C19. The increase in noise impact of the direct configuration is explained in terms of profile and ground track. In this example the direct configuration showed a significantly higher noise footprint than the normal 'real' situation. However, no general conclusions can be extrapolated from this example to TMAs with real traffic.

**Table 15: INM Noise contour surface areas**

	<b>C19</b>	<b>D1</b>		<b>C19</b>	<b>D1</b>
Nflights	58	58	Nflights	164	164
LEVEL (dB)	SQ.KM	SQ.KM	LEVEL (dB)	SQ.KM	SQ.KM
40.0	508.832	522.917	40.0	150.165	151.134
45.0	234.657	232.106	45.0	83.382	94.174
50.0	101.577	106.315	50.0	41.865	43.688
55.0	45.700	50.529	55.0	18.135	18.040
60.0	21.206	24.430	60.0	7.347	7.419
65.0	10.150	12.151	65.0	2.052	2.076
70.0	3.906	4.986	70.0	0.523	0.547
75.0	0.950	1.351	75.0	0.068	0.086
80.0	0.169	0.206			
<b>Departures – LAeq 6 hours</b>			<b>Arrivals– LAeq 6 hours</b>		

The noise footprints may be used to determine the impact on residents in the vicinity of the airport in conjunction with a population census database. The nature and scope of this study meant that population impact results would be irrelevant since the sample was simulated. . Also the cost of obtaining relevant census databases would have been prohibitive. The calculation of population impact is highly dependent on an accurate population database together with careful correlation of the database with noise contours at each airport studied.

### 3.9 Fuel Burn

The Sourdine-II Thrust Based Emission Calculator (STBEC) tool was used to calculate the fuel burn for the traffic samples D1 and C19. The calculator uses radar profile data (ground track and profile data) to calculate the fuel and emissions per flight and engine fit.

The fuel burn was calculated as a function of flight duration. The results are given as percentage of the difference in flight duration between the real C19 and direct D1 configurations.

The results are given for indication of the potential use of the environmental efficiency indicators. No direct conclusions can be drawn.

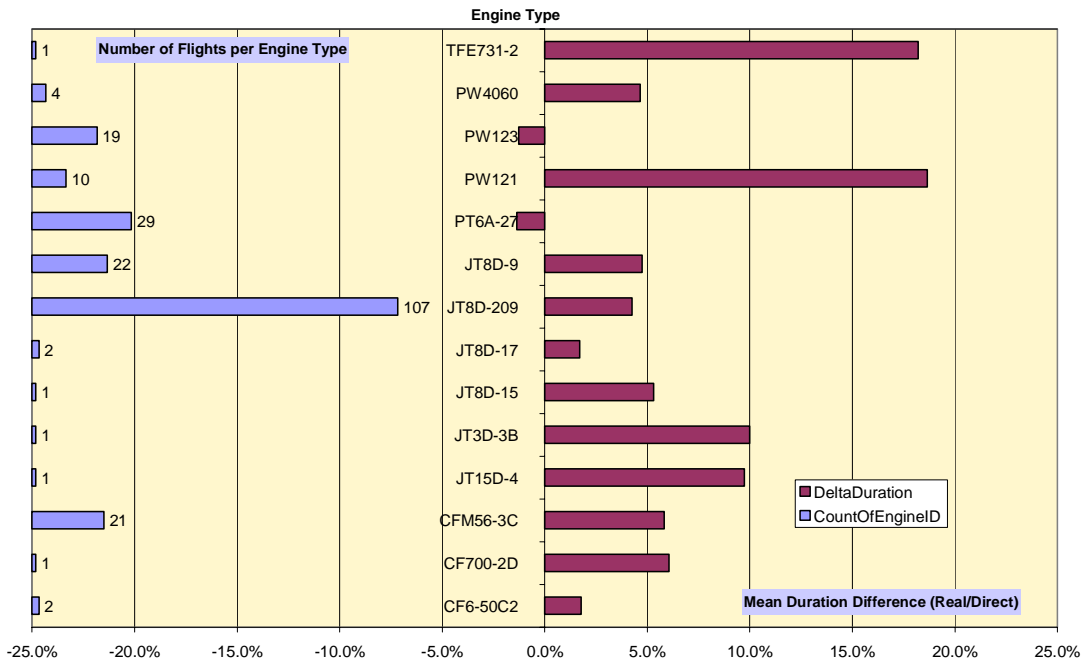


Figure 26: Mean Duration Difference (Real-Direct) as function of Engine Type

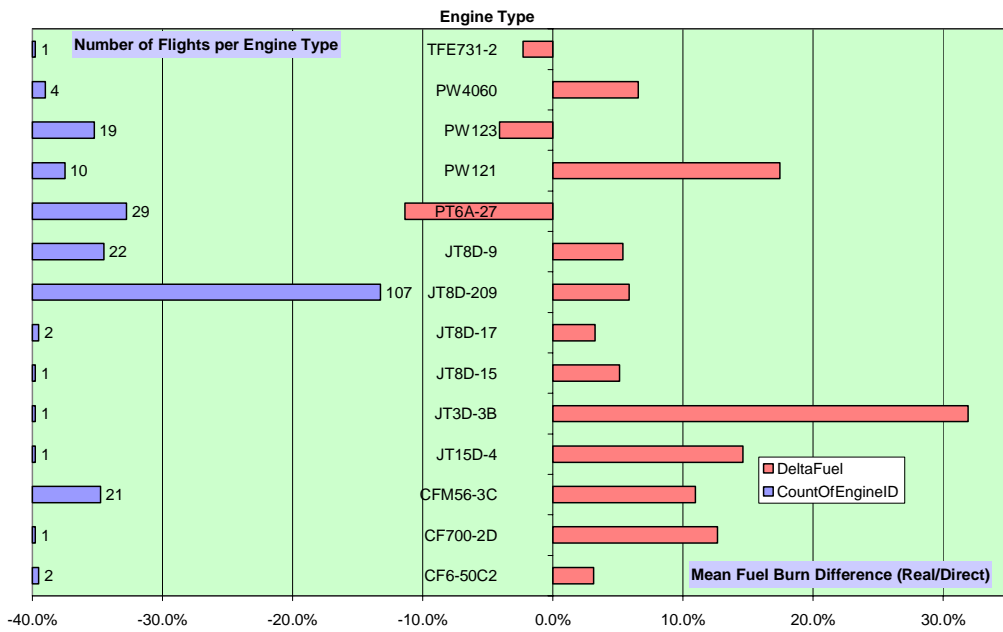


Figure 27: Mean Fuel Burn Difference (Real-Direct) TMA sample

### 3.10 Comparison of complete flight to TMA portion (Runway up to FL75)

The study highlighted several data characteristics that should be addressed before proceeding with further studies.

The results are given for a subset of 221 flights from the C19 (real) and D1 (Direct) data sets where the aircraft type and engine type corresponded to those defined in the INM database. This was done to avoid problems with misrepresentation of engine characteristics caused by the use of aircraft equivalents in INM that are based on equivalent noise, but not necessarily equivalent fuel burn characteristics.

The tables below show how the differences in ground track distances, flight duration and fuel burn for the whole flight (as simulated by TAAM) and the portion of the flights from ground level (Runway) up to Flight Level 75.

Flight Level 75 was chosen as an arbitrary boundary between TMA and en-route flight segments. FL75 also served as criteria to select 'complete' flights – the surveillance data at the start and end of each flight must be below FL75 and the maximum FL of each flight must be above FL75. FL75 was used for the 2002 study to maintain consistency with the 2001 study.

It is suggested that FL100 or higher may be more suitable cut off points for future studies to be consistent with operational sector limits.

The results for the ALL flights show that there is an apparent inconsistency between the distance (ground track) flown, the total duration of the flight and the fuel consumed. These inconsistencies are evident in the tables below. The Distance (Route efficiency) is as expected.

The difference in ground track shows approximately 5% increase, whereas the duration shows – 0.08%.

The use of Flight Level as a boundary criterion introduces some constraints in the analysis. The ground track end points (for departures) and start points (for arrivals) can be considerably far apart making the Route Efficiency and Fuel Burn measurements invalid. The basis of these two indicators is the direct route/profile between geographical start and end points. The effect on using flight level can be seen in the tables below.

Future studies should consider the use of more sophisticated techniques such as 'Top-Of-Climb' or 'Top-Of-Descent'. Reliable detection of these events was outside the scope of this analysis.

	Total Distance ground track (km)			Total Duration (sec)			Total Fuel (kg)		
	C19	D1	%	C19	D1	%diff	C19	D1	%diff
ALL	52225	49655	5.18%	54241373	54284558	-0.08%	19800235	19385097	2.1%
ARR	39434	37287	5.76%	41197958	41230143	-0.08%	11999863	11564685	3.8%
DEP	12790	12368	3.42%	13043415	13054415	-0.08%	7800371	7820412	-0.3%

All flights

	Total Distance (km)			Total Duration (sec)			Total Fuel (kg)		
	C19	D1	%diff	C19	D1	%diff	C19	D1	%diff
ALL	7624	7602	0.30%	3834276	3834000	0.01%	1051836	1060415	-0.8%
ARR	6272	6270	0.04%	3493321	3491047	0.07%	868571	873837	-0.6%
DEP	1352	1332	1.50%	340955	342953	-0.58%	183265	186578	-1.8%

TMA – runway to FL75

	Total Distance (km)			Total Duration (sec)			Total Fuel (kg)		
	C19	D1	%diff	C19	D1	%diff	C19	D1	%diff
ALL	10020	10119	-0.98%	5501373	5502483	-0.02%	1338421	1356198	-1.3%
ARR	8163	8292	-1.56%	4881294	4879737	0.03%	1051201	1065155	-1.3%
DEP	1857	1827	1.63%	620079	622746	-0.43%	287220	291043	-1.3%

TMA – runway to FL100

Whereas the Route Efficiency results generally indicate that the direct routes are shorter than the real routes, the same trend is not always true for duration and fuel.

### 3.11 Conclusions – TMA study

The TMA study investigated the application of Environmental Efficiency Indicators in a TMA environment.

At first sight, one reason why such indicators might be used is to compare TMAs for environmental effectiveness. However, each TMA is unique. Indeed each configuration of a TMA is unique, e.g. each time the wind changes and the operational runway configuration changes. Thus, a set of indicators that allow TMA to be compared seems not to be feasible.

Another use of the indicators – more realistically could be used as tools for comparing variations in route structure to a baseline.

Constraints such as start and end point need to be considered. The results of this study have been tentatively presented in terms of global figures for all traffic in the TMA and classified as a function operation type and engine type.

The results of this study suggest that fuel burn results could not be presented as one global figure for the traffic in a TMA since the results are dependent on not only route structure but aircraft type and engine fit.

Before the indicators can be calculated very selective processing of flights is necessary to ensure consistency of results. Successful comparison is also highly dependant on consistent choice of start and end points for outbound and inbound flights. The criteria used in this study meant that less than 50 % of flights were suitable for analysis using simulated data.

Whilst the TAAM simulator can fulfil the role of trajectory generator, careful control is necessary to ensure the consistent traffic samples can be retrieved for the KPI analysis.

This study used purely synthetic data simulated by TAAM. Further experimentation is necessary to investigate the impact of real data. This experimental work should investigate alternative means of generating the direct trajectory.

Assuming that the selection criteria yield a sufficient traffic sample then Environmental Efficiency Indicators can be calculated. However, further work is necessary to determine the optimum configurations that could mitigate both emissions and noise impact of TMA operations.

Future studies may include factors relevant to the immediate vicinity of the airport.

Intentionally left blank

## 4 Conclusions

The 'Flight Efficiency and its Impact on the Environment' 2002 study measured the environmental impact and economic costs of part of the air traffic route network in Europe. The indicators, Route efficiency, Duration and Total Fuel Burn were studied for En-route and Terminal Manoeuvring Area (TMA) contexts.

The En-route study was based on radar data, whereas the TMA study served as an experiment based on simulated data. In addition, an economic study also was performed in order to evaluate the costs of flight efficiency in terms duration and fuel consumed.

The data collected since year 2000 for the studies have in fact enabled access to a larger sample size which facilitate better estimation of the whole European air traffic. For instance, it can be shown that the average daily radar sample collected in 2002 represents approximately 15% of the daily European domestic and Inter-European traffic.

The findings of the en-route study are as follow: the en route portion of analysed flights within Europe travel 8.9 % further in distance, last 13.5 % longer in time, and consume 9.6 % more fuel than the direct trajectories.

This findings confirms the result of last year's study 2001 which showed that Route Efficiency for direct routes was between 8 and 12 % less than the real route. This year Route Efficiency indicator was between 7-10.5 %. The difference in the studies can be explained by the treatment of radar data, the data accuracy, data geographical reach, and the analysis software tool used for the findings. It should be noted that the results of the study 2000 were not conclusive given that the direct route was not chosen as a reference. It had compared the real route to the flight plan route instead of the direct route. No assumption on the real European air traffic can be made, as the samples have no consistency.

The findings of economic study shows a potential monetary saving to airlines between 981 to 2,500 million €, and a potential cost for impacts on climate change for an amount between 85 and 569 million €.

There is much progress still to be made, both in the way flight inefficiency percentage and costs are computed, but despite the existing uncertainties, and the multitude of sources that could justify or explain our results, the estimated costs are still very high (almost comparable with delay costs). It clearly stresses the fact that ATM has a responsibility as far as environmental efficiency, and aviation sustainability are concerned.

The findings of the TMA study fuel burn results could not be presented as a global figure for traffic since the results are dependent on aircraft type and engine fit as well as route structure. The study used purely synthetic data simulated by TAAM. Therefore, further analysis is needed to investigate the impact of real data. The new experimental work should study the alternative means of generating the direct trajectories, and also different airports.

### **Future work**

- Compare the results with previous studies to assess the evolution of the indicators
- In the TMA context, investigate the impact of SID/STAR, ATC sector load Optimum performance.
- The environmental indicators for ATM flight efficiency cannot be measured in isolation. There has been much previous work in the field of flexible use of airspace and direct routes, mainly in the context of en-route capacity. Future studies in the context of Flight Efficiency must take into account these aspects including safety, ATC system capacity, economic and noise restrictions
- Future work for the economic study will consist in improvements around three axes. First, a better definition of the "optimum cost" from airline's viewpoint (using survey results, or simulation of optima relative the "cost index", ie the ratio between value for time and cost of fuel). Second, a finer segmentation of airline costs, taking into account aircraft type and the flight phase of the inefficiency occurrence. Third, a further investigation of environmental cost, and in particular of cirrus clouds.

Intentionally blank.

## 5 Acknowledgements

---

The authors wish to thank the following for their assistance with this study:

- Eurocontrol Performance Review Unit, Brussels
- CFMU – Engineering department, Brussels
- EEC PFE Business Area AMOC team

Intentionally blank.

## 6 References

- [Ref 1] Environmental Key Performance Indicators - 2001 Study, Sylvie CHESNEAU, Ian FULLER, EEC/ENV/2002/002.
- [Ref 2] LOCAL AIR QUALITY STUDIES ProJECT, Project Management Plan, Edition 1.1. *Ted Elliff, Env\_ALAQS*.
- [Ref 3] TAAM Simulation of OSLO TMA (NORSIM–MBS–OSLO). Vergne, Henriksen, Johannessen. July 2002. EEC Report 372. <http://www.eurocontrol.fr/public/reports/eecreports/2002/372.htm>.
- [Ref 4] Central Flow Management Unit ATFM Summary Report 2002, CFMU, Issue 1.2 February 2003.
- [Ref 5] Schipper, Y., Rietveld, P., Nijkamp, P., 2001. Environmental externalities in air transport markets, *Journal of Air Transport Management*, Vol. 7, Issue 3, Pages 169-179.
- [Ref 6] Olthoorn, X., 2001. Carbon dioxide emissions from international aviation : 1950-2050. *Journal of Air Transport Management*, Vol 7, Pages 87-93.
- [Ref 7] Intergovernmental Panel on Climate change, 1999. *Aviation and the global atmosphere*. Cambridge University Press.
- [Ref 8] University of Westminster, 2002. Evaluating the true cost to airlines of one minute of airborne or ground delay. Final Report. *Transport Studies*, University of Westminster, London.
- [Ref 9] Nicolas, J.P., 1998. Le coût des nuisances des transports: méthodes d'évaluation et usage des résultats obtenus. Document de travail, laboratoire d'économie des transports, Lyon
- [Ref 10] Wardman, M. et al., 2002. Review of Research Relevant to Rail Competition for Short Haul Air Routes. EEC/ENV/2002/003
- [Ref 11] Perl, A., Patterson, J., Perez, M., 1997. Pricing aircraft emissions at Lyon-Satolas airport, *Transportation Research Part D*, Vol. 2, Issue 2, Pages 89-105.
- [Ref 12] Maibach, M., 2000. External Costs of Transport: Accident, Environmental and Congestion Costs in Western Europe, IWW/ INFRAS
- [Ref 13] Dings, J.M.W. et al., 2002. External Costs of Aviation, CE Delft.
- [Ref 14] Williams, V., Noland, R.B., Toumi, R., 2002. Reducing the climate change impacts of aviation by restricting cruise altitudes, *Transportation Research Part D*, Vol 7, Issue 6, Pages 451-464.

Intentionally blank.

## 7 Glossary

AEM	Advanced Emission Model
AMOC	ATFM Modelling Capability
ATC	Air Traffic Control
ATFM	Air Traffic Flow Management
ATM	Air Traffic Management
ATS	Air Traffic Service
BADA	Base of Aircraft Data / Aircraft Performance Database
CFMU	Central Flow Unit Management
CNS	Communications, Navigation, Surveillance
COSAAC	Common Simulator to Assess ATMF Concepts
CPR	Correlated Position Report
EATMP	European Air Traffic Management Plan
ECAC	European Civil Aviation Conference
EEC	Eurocontrol Experimental Centre
ENAV	Ente Nazionale Assistenza al Volo
ENHANCE	EuropeAN HARmonised Noise Contour modelling Environment
ETFMS	Enhanced Tactical Flow Monitoring System
EUROSTAT	Statistical Office of the European Communities
FAA	Federal Aviation Administration of the USA
FAP	Future ATM Profile
FIR	Flight Information Region
FL	Flight Level
FMS	Flight Management System
FP	Flight Plan
GIS	Geographical Information System
IATA	International Air Transport Association
ILS	Instrument Landing System
INM	Integrated Noise Model
IPCC	Intergovernmental Panel on Climate Change
KPI	Key Performance Indicators
LTO	Landing Take-Off Cycle
MADAP	Maastricht Automatic Data Processing and Display System
MAS-UAC	Maastricht Upper Area Control Centre
NATS-UK	National Air Traffic Services, United Kingdom
NDB	Non-Directional Beacon
OAG	Official Airline Guide
PKT	Passenger Kilometre, Number of passengers carried multiplied by the great distance flown (1 PKT=1 passenger carried over 1 km))
PRC	Performance Review Commission
PRU	Performance Review Unit
RKT	Revenue Passenger Kilometre, Number of seats multiplied by the distance flown in km for every individual flight.
RPK	Revenue Passenger Kilometre
SASS-C	Surveillance Analysis Support System for ATC Centres
SID	Standard Instrument Departure

STAR	STandard Arrival Route
STBEC	Sourdine-II Thrust Based Emission Calculator
STNA	Service Technique de Navigation Aérienne
SurvITE	EEC Surveillance Integrated TEstbed
TAAM	Terminal Airspace and Airport Movement
TACT	Tactical Computer System
TMA	Terminal Manoeuvring Area
TOL	Take-Off and Landing

## - CPR samples classification

Note: Number of flights = Number of CPR flights correlated with direct flights

The above diagram shows the distribution of the number of CPR flights studied, those that are correlated to Direct flights. Clearly, the number of flights that are longer than 1100km or shorter than 100km are too few to be statistically representative. Consequently these intervals are not represented in the KPI results.

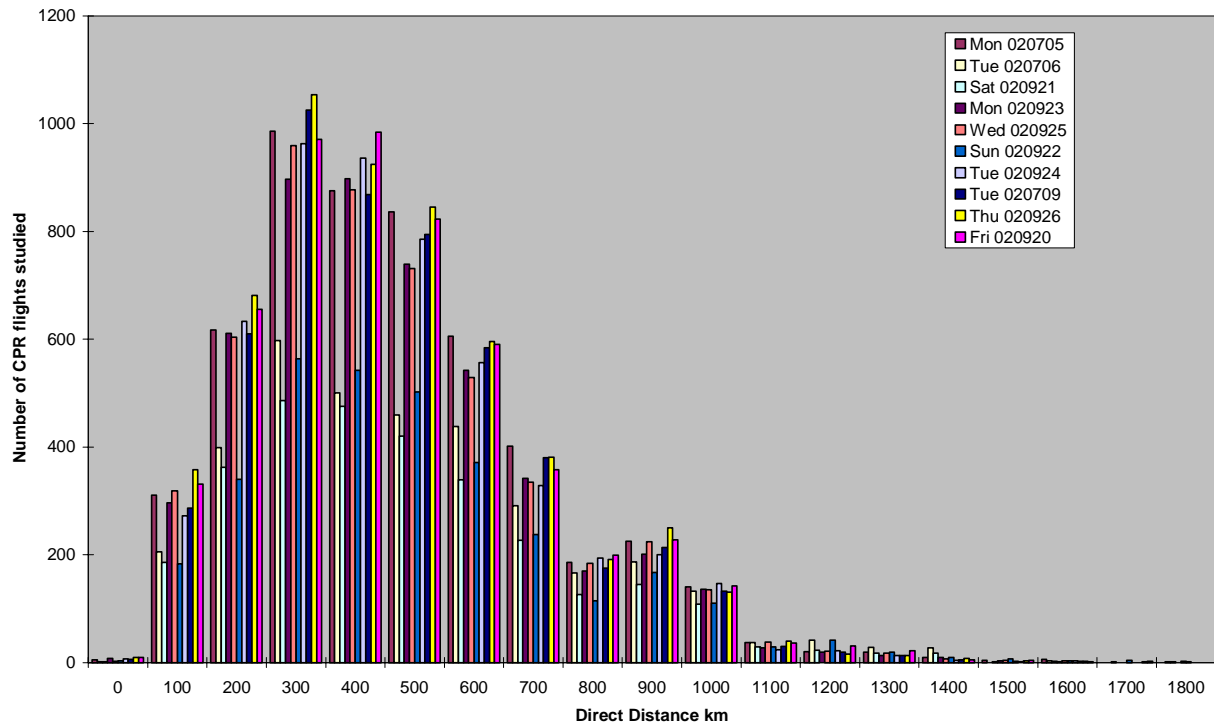


Figure 28: Number of CPR Flights kept for the study, function of the direct distance corresponding.

Intentionally blank

## Annexe 2 Tools used in the Study

### - AMOC

AMOC is an integrated ATFM simulator developed by the NCD (Network Capacity and Demand management) business area of Eurocontrol Experimental Centre.

As the ATFM Simulator for the Future ATM Profile (FAP) project, this tool allows to identify and evaluate future capacity problems, to translate them in terms of delays, and to test various potential solutions.

A new version of AMOC has been developed in order to integrate ATFM models and data from the CFMU, such as Flight Plans, CPR and Environment files corresponding. AMOC facilitates the simulation process, the traffic preparation, and statistical calculation.

AMOC have been used in this study, to transform and filter the CPR files received from the CFMU to obtain clean tracks in our own format. For this purpose, AMOC uses ALL\_FT files, which contains the Flight Plan information, and also the ENV files containing information about airports and waypoints. It also uses those files to generate all the trajectories with flight plans that are studied in the economical part (Chapter 2.5.4).

AMOC has another useful option: it creates direct 4D profiles, associated to each track of the ALL\_FT file (Flight Plan file). It takes the departure and destination airports, and the aircraft type, with its performance table associated (CFMU or BADA, depending on the option chosen), and generates a direct profile, in a predefined format, recalculating the arrival time.

### - AEM

The Advanced Emission Model version 3(AEM3) is a stand-alone modelling system that uses flight-profile information to calculate fuel burn and emissions.

The input information is the type of aircraft, the departure time, departure and arrival airports and characteristics of plots representing the flight trajectory. AEM3 calculates the fuel consumption for each phase of flight.

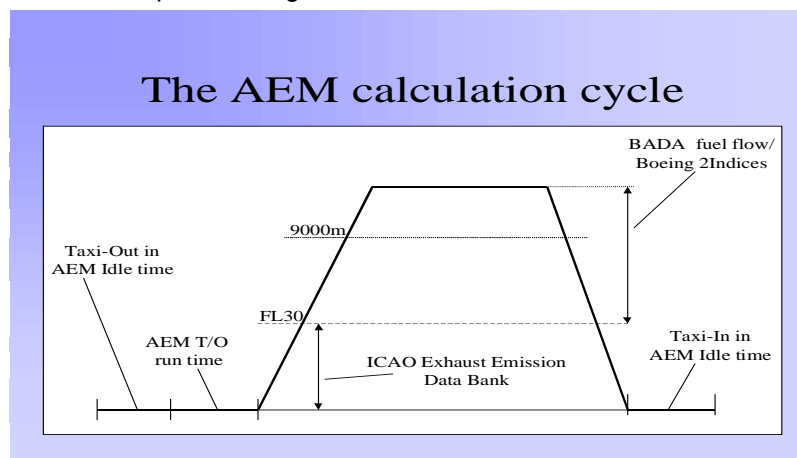
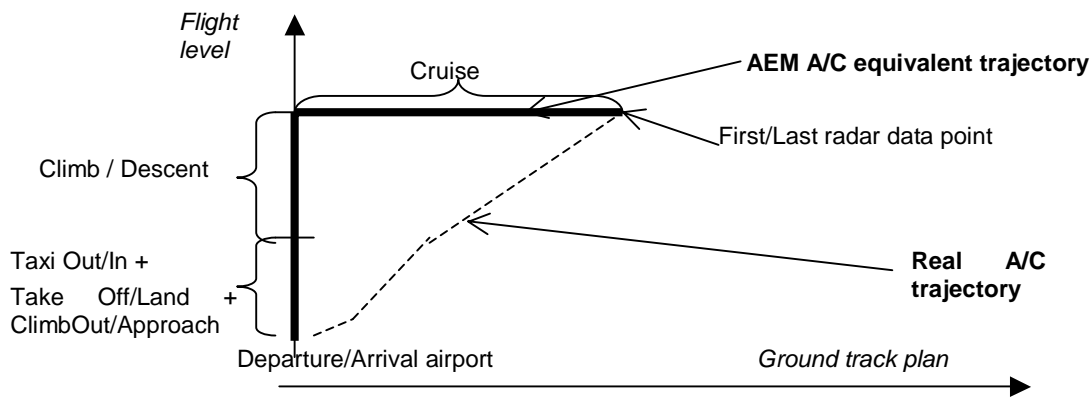


Figure 29: AEM3 flight profile for emission calculation

For flight phases above 3000 feet, AEM3 uses BADA aircraft performances to calculate fuel consumption and the Boeing 2 method to calculate the emissions, see Figure 29.

It must be noted that AEM3 has an option to exclude target position data below 3000 feet altitude and recalculate the Landing and Take-Off (LTO) phases of flight from standard data. The recalculation of the LTO data is based on the ICAO exhaust emission databank and AEM built-in taxi times see Figure 30.

The LTO option permits calculation of standard LTO phases for a given aircraft when actual LTO position and profile data are not available. This option was very useful in this study since the radar tracks did not have complete coverage for the ground track and vertical profile, even though we had filtered the data for 'complete' profiles starting and ending below FL75. AEM was also used to recreate the LTO for the 4D direct trajectories under the same altitude (3000ft), in order to make a relevant comparison with the radar trajectories results. The results using this method were more consistent.



**Figure 30: AEM3 method to create the Landing Take-Off phases**

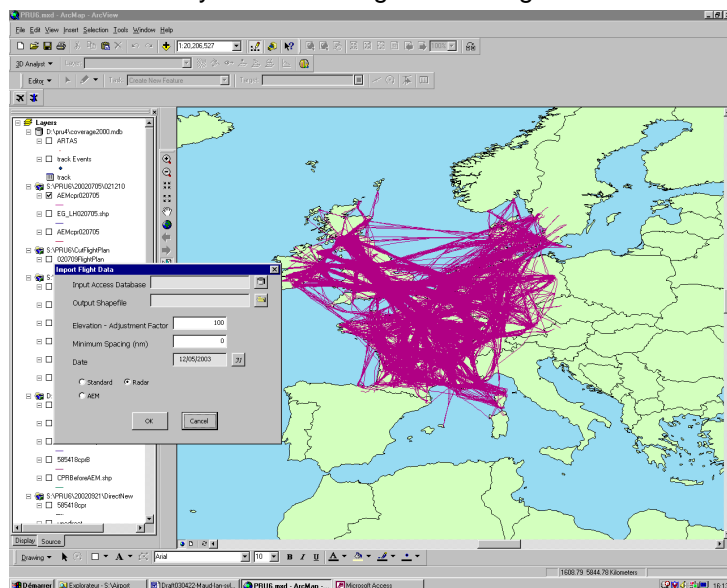
The duration was calculated by AEM, which recalculated the departure and arrival times according to the first and last radar plots as a function of aircraft performance. Duration was obtained for each segment of a track.

The same CPR “complete profiles” tracks as those used for the Route Efficiency indicator were processed using the Advanced Emission Model (AEM, see Annexe -) to compute Duration, Total Fuel Burn and emissions results.

#### - ArcView

The ArcGIS system produced by ESRI Company is an integrated Geographic Information System (GIS) that represents geography and provides all necessary tools for creating and working with geographical data. ArcGIS is composed by ArcView, ArcEditor, and ArcInfo. In this study, we have only used the ArcView 8.1 application which provides comprehensive mapping and analysis tools along with simple editing and geo-processing tools. ArcView 8.1 can also be customised using the industry standard Visual Basic for Applications (VBA). A specific module has been developed in VBA to visualise airplane tracks, the input are the geographical plots with their track unique identifier, it links plots corresponding to a same track together to obtain a polyline permitting a better visualisation and the calculation of track length, for the Route Efficiency indicator.

CPR tracks were imported into ArcView (ESRI), track lengths were calculated using a ‘great circle distance’ method developed at EEC. The direct length between the first and last plots of each CPR track was calculated by ArcView using the same ‘great circle’ method.



**Figure 31: ArcView screen shot of the new module of track visualisation**

- **TAAM**

The Total Airspace and Airport Modeller (TAAM) is a simulation model for decision support, planning, design and analysis.

TAAM is the only fast time gate-to-gate simulator of airspace and airport operations commercially available. It is being sold by the Australian Preston Group. It can simulate traffic at a very detailed level from the gate of one airport to the gate of another airport.

- **STBEC**

The Sourdine Thrust Based Emission Calculator (STBEC) is an application, developed in Microsoft Access, that was designed to be used to calculate aircraft emissions (specifically: fuel burn; Hydrocarbons (HC); Carbon Monoxide (CO); Oxides of Nitrogen (NO<sub>x</sub>); Sulphur Dioxide (SO<sub>2</sub>); Carbon Dioxide (CO<sub>2</sub>); Water and Benzene) for different arrival and departure profiles. STBEC uses INM profile data as input (see Import INM Profile Text Data below) and the International Civil Aviation Organization (ICAO) Engine Exhaust Emissions Data Bank to quantify emission levels.

- **INM**

The Integrated Noise Model (INM) is an aircraft noise contouring tool developed by the US Federal Aviation Administration.

To calculate noise contours INM needs successive values of five basic parameters specifying "how" the aircraft fly: (x, y) ground position, height, speed and thrust. INM usually takes the (x, y) values from nominal ground tracks. All the aircraft of a given studied fleet mix are assumed to follow these nominal tracks, with possibly a ground Gaussian (symmetric) dispersion around the backbone tracks to integrate more realism. Values for height, speed and thrust along the ground tracks are usually taken from the INM standard database (standard flight profiles pre-defined as a function of aircraft types).

- **ENHANCE**

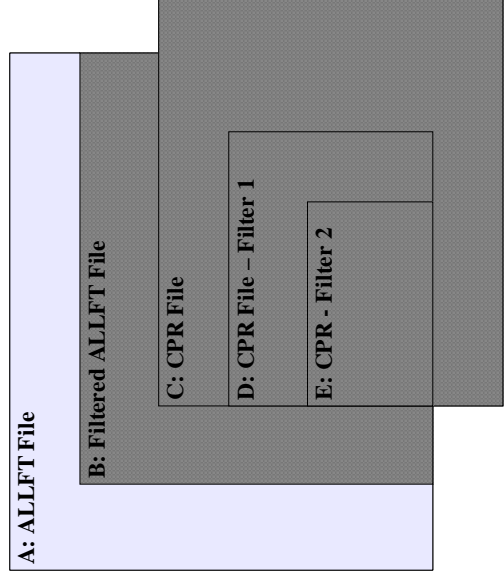
The European HArmonised Noise Contour modelling Environment (ENHANCE) is a tool that aims at improving the quality of the input data used by a noise model such as INM. It allows direct and easy importation into INM of full 4-D trajectories (3-D position + speed) taken from radar or ATC/ATM simulator data, each flight being modelled individually. In particular, through this approach, it is possible to better account for the "real" dispersion of trajectories resulting from a given procedure under operational conditions. Since thrust is not generally provided by simulators (or in radar data), one key feature of ENHANCE is to calculate it (in a "reverse-engineering" way) for each flight/trajectory.

Table 16: Flight inventory -Environmental Efficiency Indicators 2002 study

Date	Friday 5 July 2002	Saturday 6 July 2002	Tuesday 9 July 2002	Friday 9 Sept 2002	Saturday 21 Sept 2002	Sunday 22 Sept 2002	Monday 23 Sept 2002	Tuesday 24 Sept 2002	Wednesday 25 Sept 2002	Thursday 26 Sept 2002	Total
A Flights in ALLFT File	29644	23948	28018	30435	23538	24359	28777	28876	29278	29914	276787
B Filtered Flight Plan	27903	22514	26162	28477	22111	22988	25697	27015	27467	27982	258316
C Number of CPR tracks received	18622	15432	17512	18585	13148	13431	17362	17702	18084	18450	168328
D Number of CPR tracks after first filtering (AMOC)	17960	14773	16864	17916	12546	12851	16753	17044	17363	17731	161801
E Number of CPR tracks analysed (complete profile after second filtering)	4645	2996	4504	4633	2558	2785	4387	4479	4294	4792	40073
F % of CPR flights used out of the Number of Flight Plan	17	13	17	16	12	12	17	17	16	17	16

Explanation of Table 16

- A: The number of Last Filed Flight Plans without filtering in the ALL\_FT File, received from the CFMU.
- B: The number of Last Filed Flight Plans (A) after processing by AMOC to remove flights that do have complete flight data, e.g. unknown destination airport.
- C: The number of Radar flights before filtering in the CPR file received from the ETFMS.
- D: The number of Radar flights (C) after processing by AMOC to remove flights without corresponding Last Filed Flight Plans (B) and after removing outlier radar messages in position and time.
- E: The number of radar flights after the final selection and filtering. Only the flights meeting the following criteria are used for analysis:
  - First radar plot is less than FL75
  - Last radar plot is less than FL75
  - Radar Flight duration is longer than 15 minutes,
  - Flight comprises the 3 phases: Climb, Cruise and Descent
  - Radar Flight history in consistent with the direct 4D profile, see 2.3.1 on page 11.
- F: F = E/B \*100



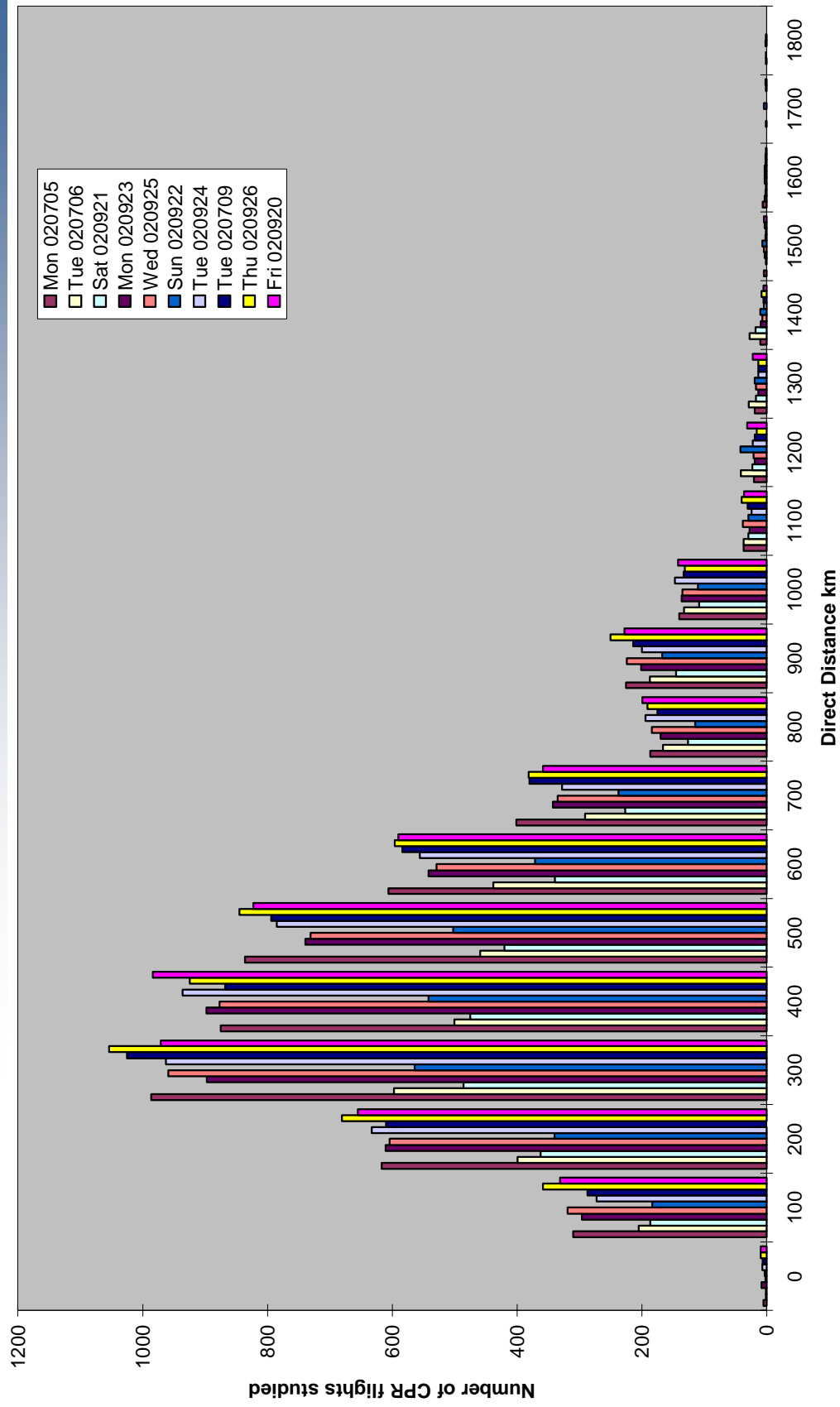


Figure 32: Number of CPR complete Profile flights per distance flown

## Annexe 4 Detailed results

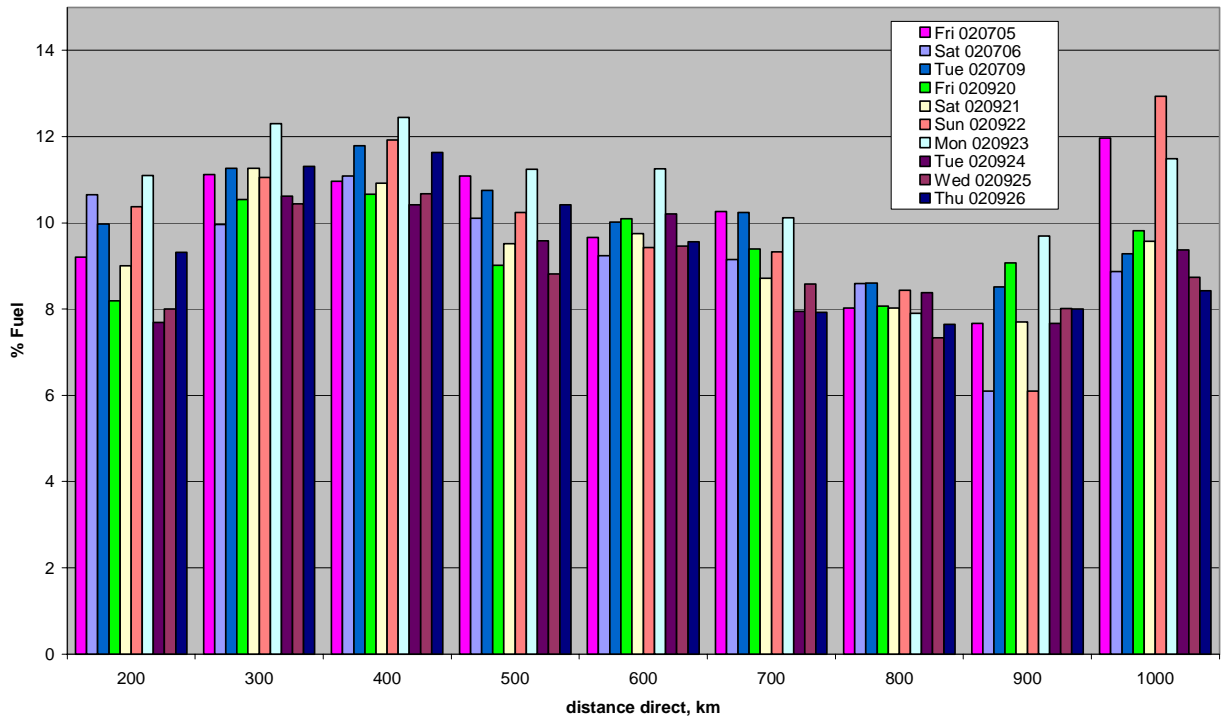


Figure 33: Percentage of Duration as a function of direct distance

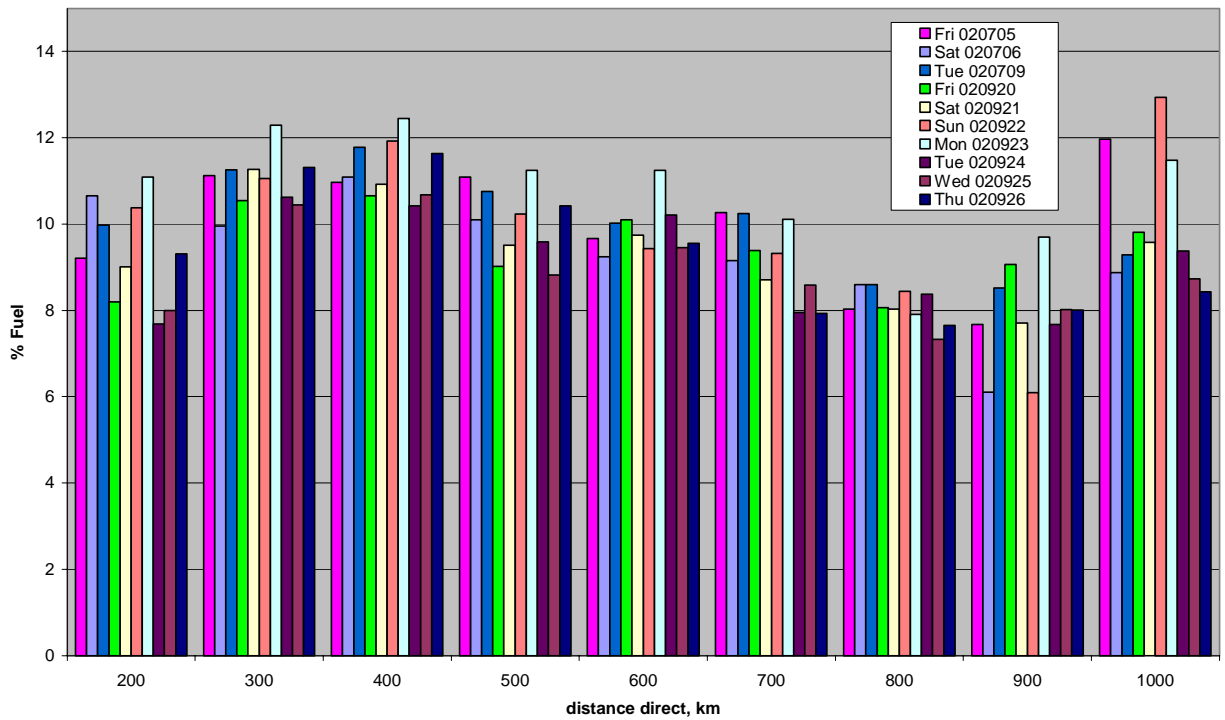


Figure 34: %Fuel (CPR/Direct) as a function of the direct distance

Intentionally blank.



For more information about the  
EEC Environmental Studies Business Area  
please contact:

Ted Elliff  
Society, Economics and Environmental Studies Business Area Manager,  
EUROCONTROL Experimental Centre  
BP15, Centre de Bois des Bordes  
91222 BRETIGNY SUR ORGE CEDEX  
France

Tel: +33 1 69 88 73 36  
Fax: +33 1 69 88 72 11  
E-Mail: Ted.Elliff@eurocontrol.int

or visit

[http://www.eurocontrol.fr/\\_centre/Projects/SEE.htm](http://www.eurocontrol.fr/_centre/Projects/SEE.htm)