Enhanced Flight Efficiency Indicators

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Enhanced Flight Efficiency Indicators
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Abstract:
This report presents the result of a study to explore ways of progressing towards ‘enhanced’ Air Traffic Management (ATM) flight efficiency indicators. The indicators will allow the performance of the environment related efficiency of the ATM system to be monitored and to generate meaningful environmental impact assessments through continuous monitoring over the whole EUROPEAN airspace.
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<th>Full Form</th>
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<tbody>
<tr>
<td>ACC</td>
<td>Air Control Centre</td>
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<tr>
<td>AEM</td>
<td>Advanced Emission Model</td>
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<td>AMOC</td>
<td>ATFM Modelling Capability</td>
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<td>ANCAT</td>
<td>Abatement of Nuisance Caused by Air Transport (ECAC working group)</td>
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<td>ANS</td>
<td>Air Navigation Services</td>
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<td>ANSP</td>
<td>Air Navigation Service Provider</td>
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<td>ATC</td>
<td>Air Traffic Control</td>
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<td>ATFM</td>
<td>Air Traffic Flow Management</td>
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<td>ATM</td>
<td>Air Traffic Management</td>
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<td>BADA</td>
<td>Base of Aircraft Data (Aircraft Performance Database)</td>
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<td>CBA</td>
<td>Cost Benefit Analysis</td>
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<td>CDA</td>
<td>Continuous Descent Approach</td>
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<td>CFMU</td>
<td>Central Flow Management Unit</td>
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<td>CNS</td>
<td>Communications, Navigation, Surveillance</td>
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<td>CPR</td>
<td>Correlated Position Report</td>
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<td>CRCO</td>
<td>Central Route Charges Office</td>
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<td>EBA</td>
<td>Environmental Benefit Analysis</td>
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<tr>
<td>ECAC</td>
<td>European Civil Aviation Conference</td>
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<td>EEC</td>
<td>EUROCONTROL Experimental Centre</td>
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<td>ETFMS</td>
<td>Enhanced Tactical Flow Monitoring System</td>
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<td>EU</td>
<td>European Union</td>
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<td>FAA</td>
<td>Federal Aviation Administration</td>
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<td>FL</td>
<td>Flight Level</td>
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<td>FRA</td>
<td>Free Route Airspace</td>
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<tr>
<td>ICAO</td>
<td>International Civil Aviation Organisation</td>
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<td>IFPS</td>
<td>Integrated Flight Plan Processing System</td>
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<td>KPI</td>
<td>Key Performance Indicators</td>
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<tr>
<td>LTO</td>
<td>Landing and Take-off (Cycle)</td>
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<td>MTOW</td>
<td>Maximum Take-off Weight</td>
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<td>NAS</td>
<td>National Airspace System</td>
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<tr>
<td>NM</td>
<td>Nautical miles (1000NM=1852metres)</td>
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<tr>
<td>PRC</td>
<td>Performance Review Commission</td>
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<td>TMA</td>
<td>Terminal Manoeuvring Area</td>
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1 Introduction

This report presents the result of a study to explore ways of progressing towards ‘enhanced’ Air Traffic Management (ATM) flight efficiency indicators. The indicators will allow the performance of the environment related efficiency of the ATM system to be monitored and to generate meaningful environmental impact assessments through continuous monitoring over the whole EUROPEAN airspace.

The study was conducted by ISA Software for the EUROCONTROL Experimental Centre, in the context of the ‘Flight Efficiency and its Impact on the Environment’ (ENV-KPI) project. The project focuses on developing indicators that could be used to measure the impact of the ATM system on the environment.

The 2004 research activities in this domain were divided into two complementary studies. The first one was described in a note [Ref1] that presented the Flight Efficiency 2003 study global results. The 2003 study advanced the work on indicators established for the Performance Review Unit [PRR6] and addressed feasibility aspects surrounding practical implementation. It also suggested transitory research elements introduced in this report.

The second research activity is the subject of this report.

1.1 Objectives

Flight efficiency progress can be achieved through various means: better aircraft (reducing drag); better engines (better thrust); better fuel quality (or even alternative fuels in the future); and better ATM network design and utilisation (shortest routes, flexible use of airspace, etc.). As aircraft, engine and fuel future enhancements are long run sources of efficiency and environmental improvements, ATM is the only source where short term gains could be expected. Therefore, the ATM flight efficiency and its impact on the environment have to be measured and monitored on a regular basis to allow for understanding the drivers of ATM flight efficiency and measuring the accomplished progress.

The fundamental aim of this work is to identify ways to measure how well the ATM system is able to respond to user demand and allow aircraft to fly the most environmentally efficient trajectory. Ways towards the definition of “enhanced indicators” should be driven by the overall objective that they should allow to identify the root causes of flight efficiency, and therefore could be used to steer and to monitor the ATM system design and possibly Air Navigation Service Providers (ANSPs) performance. The indicators must identify the tight interrelation between fuel-burn, environment and economics, airline and ATM, whilst taking account that safety is the topmost priority.

“Enhanced indicators” should then be driven by the overall objective to become metrics that can be used on a regular basis by the EUROCONTROL agency to steer and to monitor ANSPs environmental performance. Ultimately, the indicators should be transferable into cost metrics, allowing them to be integrated in trade-off assessments together with other performance metrics, as, for example, the ones already used by the Performance Review Commission.

In addition, the indicators should provide metrics able to assess and to benchmark the performance of future ATM system organisation in terms of environmental effectiveness.
These indicators focus on the regional (national and European level) and local (within a TMA) aspect of flight efficiency. The work discussed may be useful to ANCAT in their work towards "enhancing the awareness of possible environmental problems at the level of states and Director’s General”

1.2 Scope

This document adopts deliberately, in its first chapters, the widest possible scope. The aim is to cover all aspects of flight efficiency, as experienced by the air transport actors, and to review existing debates and practices outside of Europe.

As progressing through the steps of this study, the focus becomes more and more microscopic. Some city pairs are used as case study to test new indicators and to identify real constraints and behaviours.

1.3 Methodology

The methodology used to conduct investigations on ‘enhanced flight efficiency indicators’ is a combination of a top down approach (defining different actors viewpoint, and worldwide practices around flight efficiency) with a bottom up approach (looking at particular origin destination pairs, real trajectories, testing indicators and looking at local constraints). It also relies on ideas, recommendations, and particular needs expressed within the EUROCONTROL agency, through a working group composed of the Environmental Domain, the Performance Review Unit, the CFMU, the Airspace Design Unit, and the Experimental centre.
2 Current state of flight efficiency perception

This section starts with a brief overview of flight efficiency and environment perception form different actors around ATM (airlines, airports, air navigation service providers, and passengers). The applications of related indicators by both European and US ATM organisations are then reviewed before proposing a synthesis on existing flight efficiency and environmental indicators.

2.1 Flight efficiency concept and definitions

Flight efficiency is a generic term that can refer to different concepts and definitions. Each actor involved in air transportation activities has its own perception of flight efficiency, but none of them, except may be Air Navigation Service Providers (ANSPs), do consider flight efficiency with a global viewpoint. As flight efficiency performance has a direct impact on possible environmental achievements, flight efficiency and environment are treated together throughout this report.

2.1.1 The airline's viewpoint

Recently, air carrier business strategies have been developed around hub and spoke operations, yield management, cost reduction, and pursuit of growth [Ref. 2]. As a consequence, an efficient flight is assumed to be a flight increasing load factor, and yield while reducing costs. ATC has no impact on revenue elements but plays a significant role on the cost side. Thus, for airlines, ATM flight efficiency could be summarised by a minimisation of total operating costs.

Airlines operating cost drivers are mainly a function of fuel burn and time, where fuel burn is itself a function of wind, speed, altitude, aircraft weight, and vertical profiles. On the other hand, time is a function of distance, speed, ATFM constraints, and value of operating costs varying with flight time.

Thus, achieving a detailed definition of airline flight efficiency involves a number of parameters, linked by complex relations. However, these can be summarized into a relatively simple indicator, well know under the name of ‘cost index’ [Ref. 3]. The cost index is the ratio between the airline value for time and price of fuel. Then, a particularity of the airline flight efficiency definition is that, all else being equal, a change in fuel price will impact quite significantly the shape of the most efficient 4D trajectory.

Environment is not taken into account as such, and while some airline drivers do contribute to good environmental practice (yield management and load factors allowing a better fuel efficiency per workload unit transported), others, like hub and spoke practice, do increase emissions and noise [Ref. 4]. Finally the cost minimisation objective is ambiguous, as on the one hand it will lead to minimise fuel consumption and related emissions, but on the other hand, it will stimulate demand growth, partially cancelling out efficiency per unit transported.

Apart from the specific flight efficiency / environment relationship, an increasing number of airlines do monitor their environmental effectiveness, and do communicate about it. This is a rather positive element, showing that the link between airline operational performance and its
impact on the environment is measured and reported to the public. An example of such reporting is provided in appendix 1.

2.1.2 The ATM viewpoint

ATM impacts on the environment have only recently be formally included as such into ATM policies and strategies. The basis for Eurocontrol environmental policy were adopted by its Member States in April 2001, see [Ref. 5] for more information. The main strategy axis cover a wide range of ambitious activities. They are listed below:

- “Contributing to progressive improvements to aviation’s environmental performance on an ECAC-wide basis;
- Promoting and implementing (MUAC) the use of new ATM concepts, procedures and systems that, while enhancing safety, capacity and flight efficiencies, will bring environmental benefits, including improved environmental assessment methodologies and inventories;
- Encouraging more effective air traffic operations at airports that also serve to reduce or limit the ATM-related impact of noise and gaseous emissions in the airport vicinity;
- Developing and implementing enhanced ATFM tools and practices to shorten flight times, optimise flight profiles and reduce airborne holding, thereby improving aviation’s environmental performance;
- Analysing the impacts of introducing environmental charges or modulation of existing charges and implementing, as required, such arrangements into the route charges system;
- Taking into account the consequences of, inter alia, ICAO, ECAC and EU activities on environmental issues related to ATM; and
- Contributing to more efficient ATM in order to help achieve global solutions and targets to minimise aircraft emissions, which have been agreed in international conferences and appropriate bodies, such as the Kyoto Protocol and ICAO.”

Air Navigation Services, as service providers, have to make airline’s objective their own objective, while having to achieve their first priority, safety, and to optimise a number of complex tradeoffs. So far, an equivalent to the ‘airline cost index’ metric for determining ANSP’s flight efficiency does not exist.

ANSPs responsibility in flight efficiency occurs at least at three deferent levels: network design, air traffic flow management, and tactical control manoeuvres.

On the first issue, network design, the constituents of ANSPs flight efficiency are basically to provide a set of alternative routes between airport pairs being, as short as possible, consistent with airlines known preferred choices, and allowing sufficient capacity to meet demand. Thus, ANSPs flight efficiency approach is, at the network design stage, a mixture of individual preferences (allow individual flights to fly short or preferred routes), and collective preferences (network capacity meeting demand, and overall, meeting safety standards). As for airlines, environment as such is not taken into account in network design, although this might become possible when appropriate tools are validated.

On the second issue, air traffic flow management, the main idea is that ground delays are, overall, more efficient than airborne delays. However, the dynamics of slot allocation, the
quality of information exchange, and the fact that ATFM regulations are relative to specific sectors, may lead to inefficiencies for some particular actors (gate occupancy for the airport, airlines preferring to trade a longest route against to ground delay, etc.). From the environmental viewpoint, however, ATFM measures grounding aircraft instead of imposing airborne speed restrictions, flight level capping, rerouting, etc. may be seen as a real positive contribution, limiting pollution at the source.

On the third issue, tactical control manoeuvres, ATC plays an active role. The controller will deliver instructions to the pilots, and flight time as well as fuel consumption are impacted by these manoeuvres. For example, when two flights have converging trajectories, three options are available to the controller to maintain a safe separation between aircraft:

- Vectoring consists in asking one or both flight to change heading.
- Speed control is made through acceleration and or speed reduction of flights.
- Vertical manoeuvring allows the safe separation by altitude deviation of one or both aircraft.

Adopting one of the three solutions will naturally depend on the configuration of the conflict, on the sector’s shape, and the time left to give instructions and having them executed in the appropriate time frame. In the US, [Ref. 6] it seems that vectoring is the most commonly used solution, as in Europe there is not a single ‘most common’ procedure, and en-route conflicts are mainly resolved by vectoring or vertical separation, depending on the time left for action (vertical separation requiring less monitoring time from the controller). Clearly, the main drivers in ATC traffic and conflict resolution procedures are related to managing each situation in real time. The flight efficiency / environmental performance are consequences of those procedures.

### 2.1.3 The airport’s viewpoint

The airport implication into flight efficiency is rather limited. However, its own operational constraint, its policy regarding environmental matters and its degree of coordination with terminal control areas may impact flight efficiency, at least in the first and last flight segments. More than anywhere else, flight efficiency from airport viewpoint is a question of tradeoffs between noise and emissions, and concentration versus dispersion issues. Environment is often taken into consideration but mainly focusing on noise issues at the price of emissions.

For some of the major European airports, environment is not a new field of interest. Environmental concerns are increasingly becoming an important cause of capacity constraints. Environmental best practice and collaboration with all stakeholders, including airport neighbourhood is thus a key element to allow for further development of airport activities. In a study commissioned by Eurocontrol [Ref. 7] a conceptual model for airport environmental capacity was developed. It includes 8 domains of potential airport capacity issue:

- Noise
- Third party risk
- Local air quality
- Global emissions / climate
- Solid waste
2.1.4 The passenger's viewpoint

From the passenger viewpoint, flight efficiency is not perceived as such, but only its symptoms can be seen. Thus, through consumer choice, passengers will certainly reveal preferences for shorter flights and cheap tickets. But overall one can assume passengers objectives have negligible impact on flight efficiency. Presented differently, one could say they are already internalised in airline objectives.

Passengers are also citizens. As local and global environmental issues are increasingly publicised by the media, even non-perceived environmental effects become known to the citizens. Depending on individual interest and knowledge of environmental matters, one can assume that, all else being equal, there is an overall preference for less noise and less emissions from aviation. However, it is most probable that these environmental preferences are without consequence when transport choices are taken, direct economic considerations being included first.

2.1.5 Synthesis

Finally, flight efficiency and environment performance perceived by the main actors of ATM domains appear to be non homogenous concepts, sometimes referring to individual choices, and other times to global system optimisation.

From all view points, flight efficiency is always a concept embedded into trade-offs (efficiency versus capacity, fuel cost versus time cost; noise versus emissions).

The convergence / divergence of actors interests may be summarized as follow:

- Convergence of interest is facilitated by low traffic density, high fuel cost, good land use planning at airport.
- Divergence of interest is facilitated by high traffic density, low fuel cost, high noise significance around airports.

Another conclusion appearing from this rapid review is that environmental efficiency, closely linked to flight efficiency is seldom considered as such, and when included, is taken as a second order parameter. More investigations of flight efficiency and ATM environment perception, policies and strategies would be interesting to further understand the factors underlying convergence and divergence of interest. Interviews among selected ANS providers, airlines and airport, could bring a significant added value to gather information and case studies highlighting real situations and behaviours.
2.2 ATM applications – review of existing studies

The notion of flight efficiency applied to air traffic management has been used for many years. In the early 80’s already, alternative TMA organisations testing sequencing options, were benchmarked against fuel consumption.

This section is based on a literature review around the concepts of flight efficiency, route structure, network design, free flight, etc. The main domains of application are presented and illustrated by existing studies, trying meanwhile to provide a wide perspective covering both European and non-European experiences.

2.2.1 En-route network design

Flow separation, organised in function of headings and altitude, and in function of traffic density at crossroads of Europe, is the main constraint in route organisation. Actually, if there were no safety concern, air routes would even not exist. Given this essential aim and constraint, authorities in charge of designing air routes, do evaluate alternative solutions according to airspace users objectives.

The first objective refers to the pursuit of growth, and a good air route system is therefore an organisation providing sufficient capacity to meet airspace users demand through days and years. Second and third objectives being considered are to achieve the shortest possible distance between 2 airports, and to propose users a set of alternatives corresponding to their preferences, as observed from past requests.

Fuel consumption and related emissions are consequences of the three main drivers cited above, but are not taken into account as such in air route design.

When considering the optimisation of air route distance, the EUROCONTROL airspace unit is using a model called SAAM\(^1\). SAAM is an integrated system allowing an assessment of traffic flow organisation, route network and airspace optimisation. The following quotations are extracted from the EUROCONTROL web pages dedicated to SAAM.

“Users can create/change/design both air traffic route networks and airspace volumes. At any time full 4D trajectories can be generated (based on traffic demand, route network, aircraft performance) and intersected with airspace volumes. By default, SAAM will choose the best trajectory option (shortest path and optimal profile performance), but operational rules can be applied such as flight level constraints (arrival, departure, cruising) and/or reserved or restricted route network segments.

In order to help optimise airspace structures, the user can request the traffic demand be optimally and automatically distributed on the structure at the lowest cost, whilst respecting operational rules, thus revealing structural weaknesses of airspace areas. This function makes use of advanced linear programming techniques, embedded in the SOP model and developed in the Eurocontrol AMN Unit.

SIDs and STARs can be portrayed for different cases, possibly with terrain data to help understand and improve TMA organisation.”

\(^1\) [http://www.eurocontrol.int/asm-nav/saam.html]
When addressing ATM route design efficiency, an important issue is how to separate TMA from en-route flight segments. Actually, within TMA, operational constraints are much present, and the definition of an optimum trajectory cannot be the same during the en-route segment as during departure and approach flight segments.

To deal with this issue when evaluating the flight efficiency of a given route, SAAM offers the possibility to use standard departure and approach procedures specific to each airport. It starts from ground and goes until the nearest en-route point. It is between these start and end en-route points that the flight distance is used for the optimisation process.

2.2.2 Pure creation of new route

A dense and complex network of routes already exists in Europe. Flight efficiency and, a fortiori, environmental performance are used as optimisation factors leading to marginal but still significant cost saving. However, at other places, a pure creation of new route can have a much wider impact. Actually, the recent experience (tests started in 1998) of opening of polar routes [Ref. 8] shows that route network efficiency goes beyond marginal fuel savings and has consequences on airlines market demand, operations organisation, passengers benefits, and ANSPs revenues.

With the end of the Cold War, Russian and Chinese airspace became available to international commercial air traffic. Thus, using modern long range aircraft (6000-9000 miles) flying between Asia and North America became possible without stopover. A feasibility study conducted in 2001 on 33 airport pairs showed that these more direct routes are both feasible and attractive for all stakeholders. This study evaluated:

- Changes in passengers demand resulting from the opening of these new routes
- Minimum flight time function of wind, based on historical meteorological data
- 3 scenarios of these new route utilisation by airlines (100% - 75% - 50%)
- A stepped introduction of operational concepts relying on future technical enhancements (CNS / ATM technologies, satellite navigation facilities, automatic dependence surveillance, etc.).

An economic evaluation of costs and benefits to Russian and Canadian ANSPs was performed. It showed that:

- Over 10 years revenues generated to Canadian ANSP are estimated between 9 and 24 millions € compared to an investment cost of 5 millions € over the same period.

- Over 10 years revenues generated to Russian ANSP are estimated between 54 and 107 millions € for routes 1 and 2; and 131 to 261 millions € for routes 3 and 4. The related investment cost is 37 millions € over the same period.

- Passengers benefits are cheaper flight tickets between a given airport pair, and faster flights.

2 Figures were converted from initial Canadian dollars, (respectively 13,33, and 7) using the OECD exchange rate for 2001 (1 USD = 1.548 CAD = 1.117 EUR)
3 Figures were converted from initial US dollars, (respectively 48, 96, 117, 234, and 33) using the OECD exchange rate for 2001.
- Airlines benefits are reduced operating costs via less fuel consumption, and less maintenance costs. Time saving and stopover saving play also a significant role in airlines reduction cost.

Examples below show for some airport pairs the time and cost saving allowed by the implementation of polar routes:\(^4\):

- Atlanta - Séoul 124 minutes 32 000 €
- Boston - Hong Kong 138 minutes 24 000 €
- Los Angeles - Bangkok 142 minutes 24 000 €
- New York - Singapour 209 minutes 32 000 €
- Vancouver - Beijing 108 minutes 24 000 €
- Vancouver - Hong Kong 125 minutes 24 000 €

As far as we know, environmental effects of polar routes were not evaluated in the feasibility study. As far as CO\(_2\) emissions are concerned, one can deduce with confidence that a net CO\(_2\) benefit proportional to fuel saving was achieved. The case of other global warming sources is less obvious. Actually, it is possible that the formation of condensation trails is more frequent on polar routes than other routes, because contrails are formed in areas of very cold and very moist air. For the global warming indirect effects of NO\(_x\), the balance is neither straightforward as the effects are a function of emissions altitude relative to the troposphere.

### 2.2.3 Terminal airspace

As for en-route flight efficiency, TMA flight efficiency is principally determined by safety concerns. Investigations of flight efficiency in the terminal area are not new. In the early 80’s, as traffic grew, major airports had to find solutions to absorb delays due to runway slot availability. Alternatives were benchmarked principally against their fuel consumption performance.

A EUROCONTROL study conducted by Benoit and Swierstra in 1983 [Ref. 9] quantified the benefits of introducing alternative control methods in TMAs. The main objective was to identify procedures allowing to absorb ATC delays and to reduce the amount of fuel burnt.

Examples were computed for Brussels and London TMAs. Its showed that applying cruise/descent speed control was more efficient than any of the current 1983 practices (diversion at cruise level, holding at cruise level, path stretching at low altitude) to absorb delays due to runway slot availability. The authors identified the measured efficiency was sensitive to the following influencing factors: traffic density, traffic configuration, local policies, level of automation, type of co-ordination between en-route and approach.

Possibilities of time adjustment are subject to two factors: the operational speed range, and the distance over which speed control can be performed. Within these two constraints, the study demonstrated that 15% to 34% fuel saving were achievable when applying speed control instead of holding at high altitude (for an ATC delay of 5 minutes). The results were

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\(^4\) Figures were converted from initial Canadian dollars, (respectively 44000, 33000, 33000, 44000, 33000, 33000) using the OECD exchange rate for 2001.
obtained using a sample of 4 different aircraft (F28, B737, DC10, B747) for flight length between 100NM and 200NM.

Four reference procedures were considered to perform a comparative assessment of fuel consumption efficiency:

- Actual transit procedure (as observed from radar data)
- Minimum fuel consumption procedure (each aircraft considered alone in the system): This is an ideal case impossible to implement but showing the potential savings. It allowed 30% fuel burn reduction for Heathrow and 20% reduction for Brussels.
- Pilots preferred procedure, function of time cost and fuel cost. Because of the time component in the airline cost function, fuel efficiency is not as good as in minimum fuel scenario, but the transit time is shorter than in this latest scenario. This reference allows for 20% and 10% fuel burn reduction at Heathrow and Brussels respectively.
- Minimum consumption under ATC constraints. In this scenario, observed arrival times are respected to account for a realistic time slot utilisation. Speed is adjusted accordingly. These latest case allowed for 20-25% and 10% fuel saving at Heathrow and Brussels respectively.

On the methodological viewpoint, all of these references are still valid. However, the context has significantly changed over 20 years. Traffic at most European airports is regulated by CFMU, and runway capacity shortage can be integrated in the flight management at the departure, and not only through speed control in the last hundreds nautical miles. Besides, levels of traffic have considerably increased, as well as the population density living around airports. As a result, the focus is more now on noise mitigation procedure than on fuel burn reductions.

In Europe, it is considered that noise impacts in the vicinity of airports will increasingly become a constraint for further capacity development. “Any ATM procedure that helps to minimise aircraft noise or emissions will help our industry to serve society’s growing mobility needs and also help to alleviate the adverse impact on local communities”

One of possible ATM procedure allowing to meet both noise and emissions reduction objective is called Continuous Descent Approach (CDA). Efficiency indicators for CDA are not available yet. Trials assessing its benefits should be implemented during the year 2004. The UK National Air Traffic Services, and the Netherlands’ National Aerospace Laboratory will support EUROCONTROL in this process.

At this point it is worth recalling that reductions in noise impact are not always commensurate with reductions in emissions and a trade-off is necessary to mitigate both aspects.

2.2.4 Free route and free flight assessment

Free route and free flight assessment studies are typical cases where global flight efficiency indicators and environmental indicators can be used. Experiences are available from Europe and US projects. Both are summarised hereafter. However, due to important differences in

the way air traffic is controlled, all metrics can’t be transposed, or would lose relevance if they were transposed.

Free route airspace cost benefit analysis

Free Route Airspace (FRA) in Europe is planned to be introduced in parts of Belgium, Denmark, Finland, Germany, Luxembourg, the Netherlands, Norway and Sweden. The implementation is planned for 2006, and only airspace above flight level 335 is concerned. A cost benefit analysis of the project was conducted in 2002 [Ref. 10].

FRA refers to a concept where, for a predefined airspace block, airspace users would be free to fill in their flight plan independently of existing route structures. Only entry and exit points in the airspace are constrained by existing waypoints. In this context, the great circle distance between entry and exit points becomes a realistic benchmark, although subject to wind conditions. However, deviation from the great circle route would indicate that further benefits are achievable, which makes the great circle distance a ‘conservative’ benchmark.

FRA benefits were quantified by comparing historical IFPS routes to Great Circle distances. The outcome is a net benefit around 30 million Euros per year, after corrections. Results were “adjusted” (benefits diminished by 24%) to take into account several factors, among which the fact that direct routes (not captured by IFPS data) might already be given to pilot on ad hoc basis (impacts on benefits: minus 5%).

Free route airspace environmental assessment

The business area "Environmental Studies" of the EUROCONTROL Experimental Centre performed a complementary analysis [Ref. 11] focusing on environmental aspects of the Free Route Airspace project. Flight shortening and more efficient flight profiles allowed by FRA were converted into ‘global warming’ benefits via the quantification of CO₂, NOₓ and H₂O.

The study concluded that, within the FRA airspace block, the alleviation of route network constraints would allow for a reduction in transit time up to 2.8%. It was identified that FRA would also allow for a reduction in fuel consumption (and therefore in emissions strictly proportional to fuel, such as CO₂ and H₂O) up to 2%. Benefits for NOₓ emissions were slightly lower, estimated at 1.6%.

Mediterranean Free Flight - Environmental Benefit Analysis

The Mediterranean free flight project [Ref. 12] includes a vast area above the Mediterranean sea, including parts of the following ACCs: Athens, Barcelona, Brindisa, Macedonia, Malta, Marseille, Nicosia, Roma, Tirana. The environmental benefit assessment was conducted on 4 large Italian sectors which were representative of the MFF area. Within this studied area, current fixed route structures were compared with traffic direct from entry to exit of the studied sectors, only avoiding active military zones. It thus corresponds to pseudo great circle routes used as a proxy for optimum airline routes. In addition to route shortening, MFF simulations took into account various scenarios of implementation of future concepts, such as: Airborne Traffic Situational Awareness, ASAS Spacing Procedure, and ASAS Crossing Procedure. Results indicate that fuel savings could be achieved in the order of magnitudes of 1%.
FAA Free Flight Phase 1 studies

With the purpose to monitor proactively the National Airspace System (NAS) performance with regard to future systems, FAA produced a set of metrics [Ref. 13 and Ref. 14] for specific performance areas (safety, user access, delay / efficiency, predictability, flexibility, and system productivity).

In order to be able to include any performance area into trade-off assessment, the FAA is performing an economic valuation of expected benefits from future capabilities. This is done in cooperation with NAS users and is principally based on aircraft direct operating costs, as well as on passengers value for time.

In addition, FAA is also producing environmental impact assessment of future NAS organisation, via quantification of impacts on principal aviation emissions (NO\textsubscript{x}, HC, CO, CO\textsubscript{2}, SO\textsubscript{2}).

As far as delay / efficiency is concerned FAA recognises that for users “schedule integrity seems to be the highest concern” and thus that “fuel optimisation is important but not at the expense of missing connections”.

Performance metrics relative to the FAA Delay / efficiency fold are the following:

- Average en-route time and distance flown (on-time departures)
- Average en-route air distance flown (on-time departures)
- Average fuel usage
- Percentage of time spent at or near desired altitude for city pairs
- Number of restrictions eliminated
- Aggregate degrees turned

The following belong to TMA category:

- Mean flight time from 200 NM range ring to meter fix
- Mean arrival delay
- Mean fuel usage from 200 NM range ring to meter fix
- Variability of fuel usage from 200 NM range ring to meter fix

For flexibility:

- Average en-route time and distance flown (late departures)
- Average en-route air distance flown (late departures)

2.2.5 ATC simulations result assessment

Major ATC changes, like new sector design, route modification, new operational procedures, new controller tools and interfaces, etc. are subject to simulations (either fast or real time, or both) prior to implementation. With the aim to evaluate performance metrics usable in a standard way for both fast and real time simulations, EUROCONTROL developed the INTEGRA ATM system metrics [Ref. 15]. These cover safety, capacity and efficiency.
In the efficiency domain, the metric focus on the efficiency of trajectories flown in a given portion of airspace (it does not assess the whole flight trajectory from departure to arrival airports).

The INTEGRA Efficiency metric is actually a total factor productivity index. The measured ATM output is the number of hours flown in a given airspace portion. The inputs required to calculate the number of hours are fuel, maintenance, labour and capital. When costs are mapped into the input factors list, the INTEGRA efficiency metric allows to compare alternative ATC organizations / procedures in terms of the time-cost ratio.

2.2.6 Global performance assessment

The five flight efficiency application domains described above (en-route network design, pure creation of new route, terminal airspace organisation, free route / free flight assessment, and ATC simulation assessment) all make use of flight efficiency and environmental assessment i) in the context of a specific ATM project, and ii) on a limited portion of airspace.

Actually there are very few studies for which the first aim is to evaluate and monitor the performance of a global or regional (European or US) existing system. The literature review in the field of ATM flight efficiency is abundant when new ATM organisations / procedures in some sectors or ACCs have to be justified with regards to airspace users.

Two projects were found to seek to investigate global ATM indicators using large sets of traffic. These are the Eurocontrol ‘Flight efficiency and its impact on the Environment project’, and the FAA Free Flight studies focusing on the National Airspace System (NAS) flight efficiency [Ref 6].

Eurocontrol flight efficiency methodology and indicators were already described in dedicated reports [Ref. 1], and only a brief summary of key elements is provided here, to ease the comparison with FAA approach. The flight efficiency indicators are used to measure how closely the actual, or eventually the planned, 4D path flown by an aircraft approaches the optimum 4D trajectory between the departure airport and the destination airport. To support this principle two sets of data are needed: The actual trajectory flown by the aircraft, and the optimum trajectory the aircraft could have flown, or the pilot/operator would have chosen to fly, if no air traffic control and environmental constraints existed.

- Actual trajectories are best captured by real radar tracks than by any other available air traffic statistic.
- Optimum trajectories are assumed to be, for the horizontal part, the great circle distance, and, for the vertical part, a profile based on aircraft performance. The cruise altitude would ideally be limited only by aircraft performance.

Then, the two references are used for comparison in terms of distance, duration, and fuel consumption. Because of the use of real radar trajectories, the studied sample is however reduced between 5% and 15%, depending on flight definition that was used.

Defining the flight segment upon which to compute efficiency is actually a key assumption. The Eurocontrol flight efficiency studies are using flight levels boundaries within which

6 Total Factor Productivity is “the ratio of some outputs to some inputs, where the outputs measure what an organisation produces, and the inputs represent the different economical costs that are involved to get the considered outputs”. [Ref. 15]
metrics are evaluated. Different scenarios were tested, using either FL75 or FL30 as the limits. When using the lower bound, it is clear that resulting indicators almost completely include both en-route and TMA airspace route extension. As a conclusion, potential saving estimated in the Eurocontrol flight efficiency study are an optimum optimorum\(^7\), only partially achievable in the real world.

The FAA study [Ref. 6] presents many common points with what was done at Eurocontrol. The following list points to these commonalities and also identifies some key differences. It will help identifying most adequate options to investigate how existing Eurocontrol flight efficiency indicators could be enhanced in future.

- The aim is comparable: “to determine the maximum possible benefits if all flights were optimised”.
- The definition of flight efficiency and metrics proposed are the same as well: “we broadly define en-route inefficiency as distance, flight time or fuel burn in en-route airspace in excess of that which would occur if each sampled flight were the only one in the system”.
- The five categories of flight inefficiency identified for the US National Airspace System are not all relevant to the European situation. The first two (terminal congestion and delays related to en-route sector capacity limitations) correspond to specific US situations that are rarely observed in Europe. The last three categories (conflict avoidance; routing around severe weather; and static inefficiency) are however common sources for inefficiency for both organisation.
- A common point of the two studies, is that progress did not allow yet to attribute a share to each of the identified explanatory factors.
- FAA based the flight efficiency study on 16 days traffic in March 2002 (intra US) observation. This is similar the number of days used on the European side, and besides corresponds to the same reference month.
- A differentiation element: obviously the quantity of data available allowed a much wider geographical coverage in the US than in Europe.
- The wider coverage allowed to make an analysis by ACC, which was not feasible in the European study. FAA results show that flight efficiency is linked with traffic load in ACCs. The average excess distance per flight steadily increase as the traffic load in the centre increase form 0 to 20% of its maximum capacity. Then at average capacity utilisation (30% to 70%), flight efficiency trend is stable. At higher capacity utilisation, as the centre becomes congested, flight inefficiencies increase again because of TMA and en-route delays, and conflicts resolution as well.
- As the way air traffic is controlled differ significantly between US and Europe (Miles in trails in the US, CFMU regulations in Europe) it is not evident at all that the same efficiency - capacity utilisation relation could be observed in Europe.
- As in Europe, the separation between TMA and En-route is a complex issue to deal with: “any choice of a boundary between terminal and en-route airspace is somewhat arbitrary”. The way FAA addresses this issue is however quite different from the

\(^7\) Best of the best, refers in economics to a situation where several local optimal solutions existed, but there is only one achieving the global optimum.
solution adopted in Eurocontrol flight efficiency studies. Instead of setting the studied flight segment using altitude cut off point, FAA uses a 50 NM ring around airport depart and arrival points.

- Then FAA compares, just like Eurocontrol does, actual trajectories (radar data) with great circle distance between the reference points. However, duration and fuel are not addressed in the FAA paper which limit the investigation to horizontal efficiency only, and is thus less relevant to environment.

- The wider traffic coverage apparently allows for enough consistency between ground to ground and 50NM ring indicators. In the Eurocontrol studies, it was noticed that the radar data availability did allow to capture only 5% of CFMU traffic at FL30 (almost ground).

- Between start and end points, actual distance flown are compared to great circle distanced (as illustrated in Figure 2 and Figure 3)

- Results from FAA study showed actual distances were on average per flight 28.5 NM longer than great circle distance (approximately 7% flight extension) between ground to ground reference points. When the selected reference is the flight segment between 50 NM rings, the flight extension is only around 2.5%. This allows FAA to conclude that around 70% of flight inefficiencies occur within the 50NM rings, and are thus mainly attributable to terminal manoeuvres.

- FAA goes then one step further and concludes that between 6% and 16% of distances flown in excess to great circle distance (between 50NM rings) cannot be avoided because it corresponds to conflict avoidance manoeuvres. This actually reduced the flight inefficiency in the range of 2.1% to 2.4% extra distances.

- Potential benefits for direct flights were converted into monetary terms and compared with other studies (not reviewed here) by MITRE, Delta Airlines, NASA Ames, and Segull Technology. Quoted values often converge around 700 millions $.

Other studies and projects were identified to support global performance assessment of flight efficiency and environment but could not be reviewed in the scope of our study. They are mentioned hereafter for completeness:

- AERO model “The measures that can be analyzed with the help of AERO vary from operational and technical measures to economic measures. For example: operational measures such as flying at lower altitudes, following other routes, flying according to other procedures of ascending and descending, flying at lower speeds, etc. But also the improvement of air traffic control, flying more direct routes, and the reduction of holdings. “

- AERO2K8: Allows a robust calculation of real fuel and emissions at the world scale versus those from assumed flight-levels and great-circle distances.

As a conclusion, the literature / project review in the field of ATM flight efficiency and environment allowed the identification of many interesting approaches. Two sources are particularly relevant to the construction of “enhanced flight efficiency and environmental

http://www.eurocontrol.fr/_centre/Projects/projects/300.htm
indicators”: the EUROCONTROL SAAM tool, and the FAA approach to route efficiency assessment. Further work following from this report would benefit by being based on the EUROCONTROL/FAA approaches to initiate feasibility tests of enhanced indicators.

2.3 Synthesis

What can be learned from existing studies?

- Firstly, all actors hold a share of responsibility in flight efficiency and environmental impacts of ATM. However, ANSPs and international ATM organisations have a key position. They have, as guarantors of safety, the enforcement power to make flight follow a particular trajectory. Then, they hold a responsibility in both network design and in the network utilisation.

- Secondly, when all put together, there is a large set of existing metrics relevant to some or all flight efficiency aspects. There is however no evidence that the usage of these metrics can’t be improved.

- Thirdly, there is a gap as far as global performance reviewing and monitoring are concerned, both for flight efficiency and environment.

- Fourthly, FAA flight efficiency indicators that were reviewed earlier provide an interesting source for testing enhancements.

Table 1 presents the list of indicators that were used or that can be deduced from the reviewed literature and projects:

<table>
<thead>
<tr>
<th>Indicator Name / Efficiency element</th>
<th>Purpose</th>
<th>Users</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity / distance ratio</td>
<td>Combines two elements of airlines requirements: capacity allowing for the development of their activities and short distance to minimise trip cost. The higher the better</td>
<td>SAAM</td>
</tr>
<tr>
<td>Stopover avoidance</td>
<td>New airspace availability might allow to avoid stopover when combined with the utilisation of long range aircraft. Number of stopovers resulting from airline hub and spoke operations are not ATM related. However, as it impacts the whole air transport environmental efficiency, it could be a metric to monitor.</td>
<td>Organisations involved in Polar route assessments</td>
</tr>
<tr>
<td>Flight duration</td>
<td>Captures both airlines and passengers expectations.</td>
<td>Many…</td>
</tr>
<tr>
<td>Speed</td>
<td>Closely link to duration but easier to handle looking at particular flight because speed a flight parameter and can be more easily connected with other flight parameters (climb descent rates, altitude, aircraft weight, fuel consumption).</td>
<td>Many, but rather focusing on small scale studies than global performance assessment.</td>
</tr>
<tr>
<td>Metric</td>
<td>Description</td>
<td>Users</td>
</tr>
<tr>
<td>------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-------------------------</td>
</tr>
<tr>
<td>Trip cost (fuel + other DOC)</td>
<td>Captures both airlines and passengers expectations.</td>
<td>CBA</td>
</tr>
<tr>
<td>Fuel burn / Emissions proportional to fuel burn: CO₂, SO₂, H₂O</td>
<td>Captures both environmental impacts and part of airline cost drivers.</td>
<td>Eurocontrol EBA + FAA</td>
</tr>
<tr>
<td>Emissions not proportional to fuel burn: NOₓ, HC, CO</td>
<td>Captures environmental impacts that are not in any other efficiency metrics.</td>
<td>EBA</td>
</tr>
<tr>
<td>Flight distance</td>
<td>Easier to measure than duration, and strictly separate the horizontal component of flight efficiency.</td>
<td>Many</td>
</tr>
<tr>
<td>Percentage of time spent at or near desired altitude for city pairs</td>
<td>Clearly separate the vertical part of efficiency</td>
<td>FAA</td>
</tr>
<tr>
<td>Number of restrictions eliminated</td>
<td>Measures ATC flexibility</td>
<td>FAA</td>
</tr>
<tr>
<td>Aggregate degrees turned</td>
<td>Maintaining speed in turn requires more thrust, and thus more fuel. Indicates the “smoothness” of the horizontal trajectory and would immediately highlight cases of holding stacks.</td>
<td>FAA</td>
</tr>
<tr>
<td>Total factor productivity index: Flight duration per support cost to perform the flight</td>
<td>Captures the tradeoffs between the ability of a system to expedite the transit of a flight at the minimum cost.</td>
<td>INTEGRA</td>
</tr>
<tr>
<td>Extra distance from GCD relative to traffic load (or capacity utilisation)</td>
<td>Assess the impact of traffic density on flight extension.</td>
<td>FAA</td>
</tr>
<tr>
<td>Cost (in distance) due to conflict avoidance manoeuvre</td>
<td>Allows to assess an incompressible flight inefficiency. Even if all flights were on direct routes, there would still be some conflict avoidance manoeuvres, thus leading to extra distance flown.</td>
<td>FAA</td>
</tr>
<tr>
<td>Number of manoeuvres</td>
<td>Captures the number of altitude, heading, and speed change, each weighted by its relative impact on fuel consumption.</td>
<td>Not reviewed in this report. See footnote 9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Route reference / Trajectory reference</th>
<th>Purpose</th>
<th>Users</th>
</tr>
</thead>
<tbody>
<tr>
<td>IFPS</td>
<td>Proxy for actual trajectories</td>
<td>CBA</td>
</tr>
<tr>
<td>CFMU Model 3</td>
<td>Proxy for actual trajectories</td>
<td>Possible source for future EEC study</td>
</tr>
<tr>
<td>Great circle distance</td>
<td>Supposed optimum trajectory for short flight, or long flight if no wind</td>
<td>Many…</td>
</tr>
<tr>
<td>Actual aircraft trajectory (radar track)</td>
<td>Measure what happened in the reality</td>
<td>Eurocontrol, FAA</td>
</tr>
<tr>
<td>Ground to ground basis</td>
<td>Capture the efficiency over the whole flight</td>
<td>FAA</td>
</tr>
<tr>
<td>FL 30 to FL30 basis</td>
<td>Ground to ground alternative allowing to keep a significant traffic sample when working with radar tracks</td>
<td>EEC</td>
</tr>
<tr>
<td>FL 75 to FL75 basis</td>
<td>Compromise allowing to work on a larger flight sample without completely excluding</td>
<td>EEC</td>
</tr>
</tbody>
</table>

9 [http://www.asc.nasa.gov/aatt/wspdfs/Mullikin.pdf](http://www.asc.nasa.gov/aatt/wspdfs/Mullikin.pdf)
In the limited scope of this study, it was not possible to perform feasibility tests for all of these indicators. Therefore, a choice had to be made.

- First, in terms of reference to use, most interesting results are expected with the 50 NM ring limits. The advantage, compared to existing EEC indicators, are: to provide an insight on the share of flight inefficiency occurring in en-route segments only, and, it would also allow to highlight some US / Europe initial comparison of flight inefficiencies.

- Second, we propose to investigate here the % time spend at or close to optimum altitude. This would be a complementary indicator, as, until now, there are no indicators clearly separating horizontal from vertical efficiency.

To provide continuity from the previous report description of flight efficiency per city pair, it was chosen to base the new feasibility tests on three city pairs, all with direct distance greater than 200km.

- One city pair for North-South flux, representative for group 333.
- One city pair for North-South flux, representative for group 133.
- One city pair for East-West flux, representative for group 331.
3 Feasibility tests

3.1 Horizontal efficiency

3.1.1 Flight segment references

Three references are used in flight efficiency related studies and tools. Fixed altitude references, fixed distance references, and airport SID/STAR references. Table 2 presents the main attributes of each of them.

Table 2: Flight segment references

<table>
<thead>
<tr>
<th>Reference</th>
<th>Options</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed altitude references</td>
<td>- Ground to ground</td>
<td>FL 30 and FL 75 limits were used and compared in EEC flight efficiency studies. The lower the altitude the more portions of TMA inefficiency are captured, however tests performed did not allow to confirm FL30 references were generating higher inefficiencies. Fuel indicator was stable and distance and durations were on the contrary closer to optimum. Current radar data availability restricted the scope a flight that could be included in the studies (14% with FL75 and 5% with FL30). With FL limits, flight distance is dependent on vertical profile. For the same city pair, fast climbing aircraft will have longer distances computed. (even the great circle distance).</td>
</tr>
<tr>
<td></td>
<td>- FL 30 to FL 30</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- FL 75 to FL 75</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Any other altitude</td>
<td></td>
</tr>
<tr>
<td>Fixed distance references</td>
<td>- Airport to airport</td>
<td>The airport to airport case is the same as the ground to ground reference. In absence of precise radar data information, a linear interpolation between the airport and the last known radar data is applied. In the present study, flight sample being composed of flight with radar plots down to FL30, the linear interpolation is close to reality. The ring reference (here 50NM) is an arbitrary choice, as any other distance would be, as there is no harmonised definition for TMA horizontal (neither of vertical) limits. The risk by defining very large circles is that available flights for efficiency assessment are reduced. With 50NM limits flights must be at least 100NM which remains acceptable. However, flights of 110NM are included and are only assessed on 10NM, which on individual cases would easily lead to extreme inefficiency results. A positive attribute compared to flight level reference is that the reference is entirely horizontal and does not depend on aircraft climbing descending capabilities.</td>
</tr>
<tr>
<td></td>
<td>- 50NM radius ring - 50 NM radius ring</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Any other radius ring</td>
<td></td>
</tr>
<tr>
<td>SID &amp; STAR limits</td>
<td>Different at each airport</td>
<td>Used by SAAM, not evaluated in the scope of this report.</td>
</tr>
</tbody>
</table>
3.1.2 Comparison of references

For allowing direct comparison, only flights available with the FL30 filter (same days and same flights as in [Ref. 1], i.e. one week in March 2003 and one week in June 2003) were used, and both “actual” and direct trajectories remained constant. Just the start and end point used to compute flight distances were shifted. Table 3 provides the list of references used for the comparison.
<table>
<thead>
<tr>
<th>REF #1</th>
<th>Flight radar trajectories from FL30 to FL30</th>
<th>Same as previous report</th>
</tr>
</thead>
<tbody>
<tr>
<td>REF #2</td>
<td>Great circle distance between FL30 and FL30</td>
<td>Same as previous report</td>
</tr>
<tr>
<td>REF #3</td>
<td>Flight radar trajectories outside 50NM rings</td>
<td>Exit and entry points out and in of the 50NM ring are determined by linear interpolation between the two radar plots (last in first out, and last out first in).</td>
</tr>
<tr>
<td>REF #4</td>
<td>Great circle distance between exit point and entry point of the 50NM rings</td>
<td>Same as REF #3</td>
</tr>
<tr>
<td>REF #5</td>
<td>Flight radar trajectories ground to ground</td>
<td>Total inefficiency (TMA + En-route)</td>
</tr>
<tr>
<td>REF #6</td>
<td>Great circle distance between ground to ground</td>
<td>Optimum optimorum (great distance absolutely not realistic in TMA)</td>
</tr>
</tbody>
</table>

From this list of references, 4 indicators of horizontal inefficiency can be derived:

- Comparison of Ref #1 and #2 provides an homogeneous definition of flight segment comprising the entire en-route phase and almost the entire approach phase. It is the indicator produced in the Flight Efficiency 2003 study [Ref. 1]
- Comparison of Ref #3 and #4 isolates flight segments that are purely en-route segments. Using a fixed distance for start and end point instead of fixed altitude allows for more stability of the direct distance.
- Comparison of Ref #5 and #6 allows for an approximation of the whole flight inefficiency.
- Comparing extra distances between Ref #3 and #5, with whole flight extra distance, the share of inefficiency occurring inside 50 NM rings (thus mostly attributable to terminal control areas) can be derived.

The last three bullet point allow a consistent comparison with flight efficiency measurement that were done for the US airspace [Ref. 6].
3.1.3 Application to city pairs

As FL30 results were already discussed in [Ref. 1], the focus will be on indicators using either ground to ground or 50 NM ring references. However, as a number of issues were noted when comparing FL30 with ground to ground results, further information is provided in appendix 3. The selected city pairs are for testing purpose only. It is neither a benchmarking of these city pair inefficiencies, neither an illustration of good/bad European ANS providers. Results should not be interpreted in any other ways than research towards new indicators.

Case 1

![Figure 4: Case 1 actual trajectories outside 50NM rings](image)

<table>
<thead>
<tr>
<th>References</th>
<th>North – South</th>
<th>South - North</th>
<th>Both ways</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airport to airport inefficiency</td>
<td>11.8%</td>
<td>8.9%</td>
<td>9.8%</td>
</tr>
<tr>
<td>Average extra distance per flight [KM]</td>
<td>89</td>
<td>67</td>
<td>156</td>
</tr>
<tr>
<td>Outside 50NM rings – Mean</td>
<td>4.15%</td>
<td>2.6%</td>
<td>3.1%</td>
</tr>
<tr>
<td>Outside 50NM rings – Min</td>
<td>0.95%</td>
<td>&lt; 0.01%</td>
<td></td>
</tr>
<tr>
<td>Outside 50NM rings – Max</td>
<td>33.52%</td>
<td>35.59%</td>
<td></td>
</tr>
<tr>
<td>Average extra distance per flight [KM] outside 50NM rings</td>
<td>24</td>
<td>15</td>
<td>39</td>
</tr>
</tbody>
</table>
Comparison of airport to airport indicator with indicator outside 50 NM rings

This comparison allows to isolate flight segments that are 100% en-route segment (i.e. outside 50 NM rings), from legs that are a mixture of TMA and low airspace, where there are incompressible flight extensions.

Results show that for an overall flight extension of almost 10%, only 3% remain when only segments outside 50NM are kept.

The inefficiency repartition between inside and outside segments of 50 NM rings is around 75% inside and 25% outside which is close to FAA inefficiency repartition published in [Ref. 6] (71% inside the 50NM rings, 29% outside).

Comparison of ways

Three flows / routes can be observed:

- One is used for the North-South flows and another for South-North flows. Both look similar in terms of inefficiency, with a slightly higher inefficiency in the North-South direction. However the number of flights available in this direction is about the half of the number of available flights in the other direction. The confidence is then slightly lower.

- The third flow actually corresponds to an exceptional event. All flights avoiding the French airspace occurred the same day (19th June 2003). During this day, only early morning and evenings flights were able to use the "normal" routes. All other flights experienced high distance inefficiencies. This can be explained by two factors. Firstly, the 19th of June was a day of inter-professional manifestation against French governmental projects. Almost all the French public sectors followed this movement. Secondly, this day of social manifestation occurred during the week of Paris Le Bourget air show, during which ATC operations in the Paris area have to cope with further constraints and is then more sensitive to exceptional events.

Therefore, looking at the frequency table below, even when exceptional events are removed, the distance inefficiency of the en-route segments can be assessed at 3%.

![Distribution of inefficiency](image)

**Figure 5: Case 1 inefficiency distribution**
Analysis of diverted flights

Diverted flights experienced an extra flight duration of 20 minutes on average, which for the aircraft types in operation represents an average extra cost around 315 € per flight. Table 5 shows the detailed figures for all diverted flights. It should be noted that the extra cost computed here is not the extra cost compared to a theoretical optimum situation (as it was the case in Ref. 1), but the extra cost compared to what flights normally experience when there are no exceptional events (i.e. around 3% inefficiency).

Table 5: Tactical costs of route extension

<table>
<thead>
<tr>
<th></th>
<th>Nominal cost per minute [€] [Ref 1]</th>
<th>Average time [min] between 50NM rings (normal conditions)</th>
<th>Flight duration [min] 50NM-50NM for this flight</th>
<th>Extra time between 50NM rings [min]</th>
<th>Extra cost between 50NM rings [€]</th>
</tr>
</thead>
<tbody>
<tr>
<td>B763</td>
<td>23</td>
<td>40</td>
<td>66</td>
<td>25</td>
<td>565</td>
</tr>
<tr>
<td>A319</td>
<td>11</td>
<td>40</td>
<td>65</td>
<td>25</td>
<td>277</td>
</tr>
<tr>
<td>A319</td>
<td>11</td>
<td>40</td>
<td>64</td>
<td>24</td>
<td>265</td>
</tr>
<tr>
<td>B763</td>
<td>23</td>
<td>40</td>
<td>64</td>
<td>23</td>
<td>527</td>
</tr>
<tr>
<td>A320</td>
<td>12</td>
<td>40</td>
<td>60</td>
<td>19</td>
<td>232</td>
</tr>
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<td>54</td>
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</tr>
<tr>
<td>A320</td>
<td>12</td>
<td>42</td>
<td>50</td>
<td>8</td>
<td>94</td>
</tr>
<tr>
<td>B763</td>
<td>23</td>
<td>42</td>
<td>60</td>
<td>19</td>
<td>416</td>
</tr>
</tbody>
</table>

In addition to these extra costs, which include extra fuel burn and other operating costs like maintenance, diverted flight were, to a variable extend, obliged to fly in airspace zones where en-route charges are higher than in France. The precise extra cost is not computed (it would require detailed investigation of entry and exit point in each CRCO zone). Unit rates for concerned countries are indicated in Table 6 to illustrate that the impact could be quite significant.

Table 6: CRCO unit rates

<table>
<thead>
<tr>
<th>Country</th>
<th>June 2003 unit rates in € (source CRCO) (cost for 100 KM flown with a 50 tonnes aircraft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium - Luxembourg</td>
<td>95.23</td>
</tr>
<tr>
<td>Germany</td>
<td>92.51</td>
</tr>
<tr>
<td>France</td>
<td>62.19</td>
</tr>
<tr>
<td>Switzerland</td>
<td>97.39</td>
</tr>
</tbody>
</table>
Case 2:

Figure 6: Case 2 actual trajectories outside 50NM rings

Table 7: Case 2 horizontal efficiency indicators

<table>
<thead>
<tr>
<th>References</th>
<th>North - South</th>
<th>South - North</th>
<th>Both ways</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airport to airport inefficiency</td>
<td>14.8%</td>
<td>7.1%</td>
<td>9.4%</td>
</tr>
<tr>
<td>Average extra distance per flight [KM]</td>
<td>99</td>
<td>48</td>
<td>147</td>
</tr>
<tr>
<td>Outside 50NM rings – Mean</td>
<td>2.2%</td>
<td>1.1%</td>
<td>1.5%</td>
</tr>
<tr>
<td>Outside 50NM rings – Min</td>
<td>1%</td>
<td>&lt; 0.01%</td>
<td></td>
</tr>
<tr>
<td>Outside 50NM rings – Max</td>
<td>3%</td>
<td>23.5%</td>
<td></td>
</tr>
<tr>
<td>Average extra distance per flight [KM] outside 50NM rings</td>
<td>12</td>
<td>6</td>
<td>18</td>
</tr>
</tbody>
</table>

Comparison of airport to airport indicator with indicator outside 50 NM rings

Distance inefficiency measured from ground to ground is 9.4% instead of the 6.9% measured from FL30 to FL30. The difference is within the range of possible values shown in appendix 3. It is interesting to note that, compared with the London Geneva pair, the level of inefficiency is similar when airport to airport reference are used whereas which was not the case when the FL30 to FL30 reference were used.

Results show that for an overall flight extension of almost 10%, 1.5% remains when only segments outside 50NM are kept. Considering the average extra distance flown, it corresponds to 88% of inefficiency occurring inside the 50 NM rings, and 12% outside. Although the overall inefficiency (airport to airport) was very similar for case 1, the relative
repartition of inefficiencies is quite different. For case 2, TMA and low airspace efficiencies look relatively more constrained than for case 1.

**Comparison of ways**

As for case 1, there is one way where en-route efficiency is better than the other. However, flight extensions outside 50NM are only a few extra kilometres, therefore, when one way is twice more efficient (in percentage), it should not be misinterpreted, as, in reality, there are just a few kilometres flown, which could easily be obtained when there is even a very tiny avoidance manoeuvre executed at 900 km/h.

Apart from the two main flows observed, there is just one flight experiencing a long deviation (about 23% extra distance flown outside the 50 NM rings). This event occurred the 19th June 2003, which was the day during which exceptional trajectories where observed for case 1 as well. However, for case 2, is it surprising to see that all flight but one were able to use the “normal” route. This exceptional trajectory remains thus unexplained, although it is probably an internal airline trade-off minimizing the risk of important delays with a longer flight duration.

![Distribution of inefficiency](image)

**Figure 7: Case 2 inefficiency distribution**
Case 3

Figure 8: Case 3 actual trajectories outside 50NM rings

<table>
<thead>
<tr>
<th>References</th>
<th>West - East</th>
<th>East - West</th>
<th>Both ways</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airport to airport inefficiency</td>
<td>14.8%</td>
<td>21.2%</td>
<td>19.3%</td>
</tr>
<tr>
<td>Average extra distance per flight [KM]</td>
<td>148</td>
<td>212</td>
<td>360</td>
</tr>
<tr>
<td>Outside 50NM rings – Mean</td>
<td>12.4%</td>
<td>11.8%</td>
<td>12.0%</td>
</tr>
<tr>
<td>Outside 50NM rings – Min</td>
<td>7.0%</td>
<td>6%</td>
<td></td>
</tr>
<tr>
<td>Outside 50NM rings – Max</td>
<td>21%</td>
<td>14.7%</td>
<td></td>
</tr>
<tr>
<td>Average extra distance per flight [KM] outside 50NM rings</td>
<td>114</td>
<td>116</td>
<td>230</td>
</tr>
</tbody>
</table>

Comparison of airport to airport indicator with indicator outside 50 NM rings

Case 3 was selected for its high observed inefficiencies combined with relatively long distance and low traffic, which should normally be two factors in favour of efficiency. Actually, whatever the indicator used, distance inefficiencies remain very high. Whereas for the two other studied city pairs there was a big drop between airport to airport results and outside 50NM results, here inefficiencies remains around 12%.

The visualisation of the flows allows to see a relatively homogeneous level of inefficiency across the 10 days of traffic (1 March week and 1 June week). These long extra distances
experienced in en-route flight phases seem thus to be of a structural nature rather than explainable by exceptional events.

Comparison of ways

The repartition of inefficiencies inside/outside 50NM rings has a different pattern as what shown previously. On average, 64% of extra distances (only) occur inside the 50 NM rings, and up to 36% occur outside the rings. Actually, this average situation hides an even more interesting case: West – East flux are 77%-23% (ie close to what is observed for other city pairs), and East – West flux are 55%-45%.

Extra distance flown inside the rings are 2.8 time longer for flights going to the West than for flights going to the East:

- for flights going East direction, extra distance inside the rings= 148-114 = 34 KM
- for flights going West direction, extra distance inside the rings= 212-116 = 96 KM

As a conclusion, two sources of inefficiencies could be investigated for case 3. First, en-route permanent airspace restrictions obliging flights to use indirect routes even during en-route phase. Second the presence of airspace restrictions on the English East coast.

Cost of en-route inefficiencies (outside 50NM rings)

The cost of en-route inefficiencies in case 3 corresponds to the hypothetic (but still realistic) case where all flights could fly outside 50NM rings with the same levels of inefficiencies as what was observed case 1 and 2 (ie around 2.5% extra distance on average). Compared to the costs computation for case 1 the situation is quite different:

- The case 1 corresponds to an exceptional event, thus tactical costs only where used, whereas for case 3, the situation is likely to reproduce every day of the year. Therefore, strategic costs were considered as well.
- For case 3, aircraft are smaller, and the number of daily operation is less than for case 1. However, the daily repetition builds up a potentially high accumulation of extra costs.

Taking into account the 3 aircraft types operating on this route, and the potential saving for each individual flight, the average cost saving that could be obtained if inefficiencies were reduced to 2.5% outside the 50 NM ring is:

- 60 € per flight when only tactical costs are included
- 200 € per flight when strategic costs are considered

Provided that:

- the CPR trajectories used to assess the indicators are representative for the average inefficiencies, and
- the number of flights on this route is representative of average daily for the year,

---

10 See Ref. 1 for more information about the cost model used.
then, around 3,000 flights per year do spend an extra amount of 60€ to 200€, which represents an annual loss of 180,000 to 600,000 Euros.

![Distribution of inefficiency (outside the 50NM rings)](image)

**Figure 9: Case 3 inefficiency distribution**

**Conclusions on airport pair indicators**

- Using the ground to ground distance indicators, although the real flight trajectory between ground and first / last radar position might be an issue, provides further stability in the indicators. The advantage is that the direct distance from ground to ground is the same for all flights (which is not the case when cutting trajectories in altitude). Therefore, there is no bias in the indicator results due to direct distance variations.

- Ground references, as well as fixed distance rings, allow more transparency (and especially much easier visualisation of trajectories) in the data analysis.

- The 50NM radius could possibly be reduced. However, the analysis conducted on the three airport pairs proves that interesting results can be obtained. This is true for initiating the inefficiency sources investigation, and also for differentiating between airport pairs (and possibly for benchmarking purpose).

- In the possible future context of daily monitoring of flight efficiency, the information provided by extra distance flown between airport, and outside 50NM rings could constitute a valuable output. Structural inefficiencies as well as exceptional cases can be measured.

- When the same simple and transparent indicators can be reproduced for all (or the main) airport pairs in Europe, trend monitoring, and benchmarking will become possible. Both elements are factors able to steer the performance of ANS providers.

- Finally, as the FAA already used the same indicators for evaluating the benefits of future ATM projects, interesting lessons could be learned from comparisons between US and Europe, and a better understanding of flight efficiency drivers could result from this process.
3.2 Vertical efficiency

3.2.1 Issues in the selection of vertical references

For a given flight distance, the optimum vertical trajectory should be the trajectory minimizing the fuel consumption, and especially for airlines and passengers, allowing to meet the arrival slot. Thus, flight duration, speed, climb and descent rates, as well as cruising altitudes do impact the optimum vertical profile.

As flight times differ for every airport pair, and as optimum cruise levels and optimum climbing/descending profiles are specific to aircraft, the definition of an optimum flight trajectory is more complex than for horizontal efficiency. Actually the literature review didn’t allow to find much elements helping in the definition of what a good vertical flight efficiency indicator would be. Feasibility tests shown hereafter are, as a consequence, much more exploratory compared to horizontal indicators. They were mainly inspired from the indicator called "% time spend at optimum flight level" in a FAA report [Ref. 14].

Two options are possible to progress in the definition of an “optimum” reference of vertical profiles. Only the second option is tested in this report.

- First, using a tool such as AEM (relying on BADA fuel flows figures), vertical profiles that would respect both the real horizontal flight path, and the aircraft arrival time could be generated. Computing such an indicator for all flights would allow to compute the impact of the vertical profile on fuel consumption (both horizontal route and arrival time remaining constant). The indicator would allow both to benchmark airport pairs against each other, and to study the variability of vertical flight efficiency within an airport pair.

- Secondly simpler indicators could be obtained by comparing the range of cruise FL occupancy, and the time spend in cruise, or the % time spent in cruise. These indicators are directly computable from CPR data, or could even be assessed from CFMU Model 3 flight plans.

There are a number of issues when analysing flight level utilisation. Actually, the final metric of interest (cost, or fuel consumption) depends on the distance separating the airport pairs, the aircraft type, and the vertical profile. A good cruise flight level is a necessary condition to have an efficient vertical profile, but it is, taken alone, insufficient to explain performance differences. For example, if the optimum profile is to reach FL380 during x minutes, it might be worth to reach it x/2 minutes and then to fly x/2 minutes at 290, than to fly x at 290. So the % time spent at the max FL is interesting, but all other are also important [Ref 16].

Data analysis was conducted on the 3 studied airport pairs, and unfortunately, there was no correlation when linking maximum flight level, or flight level weighted by time with fuel consumption or fuel consumption per minute. In any case, there are a number of influencing parameters that are not measured but do influence the fuel consumption. The best results were obtained with a statistical approach testing a multiple regression model explaining the total fuel consumption with flight duration, maximum flight level, and % time spent at maximum flight levels. All variables were statistically relevant, but following this approach
3.2.2 Proposed indicator

Assuming that all aircraft in the sample are allowed to fly at the highest observed cruise levels (for a given airport pair), and that it would be cost efficient to do so, the proposed indicator is:

The percentage time spent at or higher than the:

- 1st highest observed flight level (minus 1,100 feet to account for the flow organisation into separated layers of 1,000 feet)
- 2nd highest observed flight level (minus 1,100 feet to account for the flow organisation into separated layers of 1,000 feet)
- 3rd highest observed flight level (minus 1,100 feet to account for the flow organisation into separated layers of 1,000 feet)

The three highest levels are considered in order to avoid situations where only one (or a very few) flight is exceptionally able to fly very high, which would generate a very low indicator for the airport pair when using only the 1st highest FL.

The 3 thresholds are airport pair specific and depend on observations. However, they are not aircraft specific because it is assumed that aircraft types used on a given route are homogeneous.

The percentage time spent is considered because it captures not only the number of aircraft that were able to reach high altitudes, but also the time spent at this altitude. As climbing high consumes more fuel, the benefits of climbing can be obtained only when the time spend at high altitude is significant [Ref 16].

The formula is:

\[
\frac{\text{Sum of cruise flight leg durations that occur higher than the threshold for all flights}}{\text{Sum of complete flight duration for all flights}}
\]

Another indicator could be computed under the same logic, but is hardly testable on only three airport pairs. It would consist, instead of using FL thresholds specific to airport pairs, in defining the thresholds in function of the observed flight level for all airport pairs having similar direct distances.

For example, let’s consider the 2nd highest FL as reference for 2 airport pairs (A and B) with direct distances between 800-900 kilometre and where:

- Airport pair A ‘second highest observed flight level’ is FL360, and 20% of flight duration is higher than FL360.
- Airport pair B ‘second highest observed flight level” is FL300 and 25% of flight duration is higher than FL300.
The indicator computed from specific FL would be 20% for A and 25% for B. It would be interpreted as a superior performance of B. However, if a second maximum FL is chosen (360) the indicator of B could potentially fall to 0%.

Therefore, the second indicator, applying FL360 as a threshold for both A and B, would indicate the superiority of A.

Finally the two indicators could be used as complement. One indicating the level of ‘absolute performance’, and the other, the level of performance “relative to actual operating constraints”.

3.2.3 Application to city pairs

Case 1:

Flight level utilisation is organised by flows. Flights to the North can fly FL320, FL340, FL360, FL380, etc. whereas flights to the South can fly FL290, FL310, FL330, etc.

Longest flights are observed to occupy higher flight levels with smaller spread, whereas for short or average flight duration there is a wide spread of flight level utilisation.

Naturally, optimum flight levels are not the same for all aircraft, and the observed range does not tell much on the efficiency. BADA information is thus provided in Table 9. Minimum, median and maximum observed cruise flight level per aircraft type are given together with the corresponding fuel consumption. If minimum cruise FL vary widely, the median and maximum values are more homogeneous. This indicates that the sample of flights studied have a reasonable degree of homogeneity regarding their cruise altitude abilities and performance.
Table 9: Fuel flows at observed flight levels

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A319</td>
<td>290</td>
<td>43.8</td>
<td>310</td>
<td>41.7</td>
<td>370</td>
<td>36.0</td>
</tr>
<tr>
<td>A320</td>
<td>290</td>
<td>47.0</td>
<td>360</td>
<td>39.3</td>
<td>380</td>
<td>37.7</td>
</tr>
<tr>
<td>A321</td>
<td>340</td>
<td>46.9</td>
<td>360</td>
<td>45.5</td>
<td>380</td>
<td>44.0</td>
</tr>
<tr>
<td>B734</td>
<td>360</td>
<td>41.3</td>
<td>360</td>
<td>40.7</td>
<td>360</td>
<td>40.7</td>
</tr>
<tr>
<td>B737</td>
<td>360</td>
<td>38.0</td>
<td>360</td>
<td>38.0</td>
<td>360</td>
<td>38.0</td>
</tr>
<tr>
<td>B752</td>
<td>300</td>
<td>64.8</td>
<td>360</td>
<td>59.8</td>
<td>380</td>
<td>58.7</td>
</tr>
<tr>
<td>B763</td>
<td>360</td>
<td>83.9</td>
<td>360</td>
<td>83.9</td>
<td>400</td>
<td>80.3</td>
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<td>B772</td>
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<td>360</td>
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<td>108.0</td>
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<tr>
<td>All</td>
<td>290</td>
<td>108.0</td>
<td>360</td>
<td>108.0</td>
<td>400</td>
<td>108.0</td>
</tr>
</tbody>
</table>

BADA values show that cruising at low altitudes could significantly impact the flight cost. For an A319, every minute at FL290 instead of FL370 (which is a realistic range of operating conditions) costs 7.8 kilogram fuel to the airline. For an average value of 0.3 €/kg jet fuel, it represents a maximum (putting the extra cost of climbing at zero) cost of 2.34 €/min. This value is rather low compared to the cost of en-route delays. It indicates that all else equal, it would be more efficient to save one minute by allowing shortest route than to allow maximum flight level utilisation. However, this is a preliminary interpretation that might be invalidated by specific conditions, such as, for example, favourable wind condition at higher altitudes, allowing to save both time and fuel.

Figure 11: Vertical profiles per aircraft type (case 1, North-South flux)
Figure 12: Vertical profiles per aircraft type (case 1, South-North flux)

Table 10: Case 1 % time above reference FL

<table>
<thead>
<tr>
<th>Cruise FL</th>
<th>1(^{st}) highest cruise FL</th>
<th>2(^{nd}) highest cruise FL</th>
<th>3(^{rd}) highest cruise FL</th>
</tr>
</thead>
<tbody>
<tr>
<td>% flight duration</td>
<td>0.2%</td>
<td>6.4%</td>
<td>17.1%</td>
</tr>
</tbody>
</table>

Case 2:

Figure 13: Case 2 cruise level observations
Flight level utilisation is organised by flow direction. Flights to the South can fly FL290, FL310, FL330, … whereas flights to the North can fly FL280 and FL300. Although the horizontal efficiency of flights from case 2 was better, on average, than for case 1 (using the 50NM ring references), the vertical profiles seem more constrained. This is especially true for ‘case 2’ flights going to the North, that are most of the time caped at FL280. However, as all flights these days were not studied, but only a reduced sample for which radar data was accurate enough, a word of caution is necessary. It might be that other flights do actually use higher flight levels.

The initial interpretation that can be done is that: there is no evidence that flights with longer durations can fly higher altitudes, and flight levels are, for the distance flown, relatively low.

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>source BADA</td>
<td>Nominal Fuel Flow [kg/min]</td>
<td>source BADA</td>
<td></td>
<td>source BADA</td>
</tr>
<tr>
<td>A319</td>
<td>280</td>
<td>44.0</td>
<td>280</td>
<td>44.0</td>
<td>300</td>
<td>42.8</td>
</tr>
<tr>
<td>A320</td>
<td>250</td>
<td>47.6</td>
<td>280</td>
<td>47.2</td>
<td>390</td>
<td>37.1</td>
</tr>
<tr>
<td>A321</td>
<td>330</td>
<td>47.7</td>
<td>330</td>
<td>47.7</td>
<td>330</td>
<td>47.7</td>
</tr>
<tr>
<td>B737</td>
<td>290</td>
<td>41.3</td>
<td>310</td>
<td>41.0</td>
<td>330</td>
<td>40.3</td>
</tr>
<tr>
<td>All</td>
<td>250</td>
<td>280</td>
<td>280</td>
<td>280</td>
<td>390</td>
<td>390</td>
</tr>
</tbody>
</table>

Figure 14: Vertical profiles per aircraft type (case 2, North-South flux)
Figure 15: Vertical profiles per aircraft type (case 2, South-North flux)

Table 11: Case 2 % time above reference FL

<table>
<thead>
<tr>
<th>Cruise FL</th>
<th>1\textsuperscript{st} highest cruise FL</th>
<th>2\textsuperscript{nd} highest cruise FL</th>
<th>3\textsuperscript{rd} highest cruise FL</th>
</tr>
</thead>
<tbody>
<tr>
<td>% flight duration</td>
<td>0.4%</td>
<td>5.0%</td>
<td>7.0%</td>
</tr>
</tbody>
</table>

Case 3:

Figure 16: Case 3 cruise level observations
The same observation as for the two previous city pairs can be done. Flows are organised by directions. Compared with other airport pairs, flights fly much higher.

Table 12: Fuel flow at observed cruise levels

<table>
<thead>
<tr>
<th></th>
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<tr>
<td></td>
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</tr>
<tr>
<td>B736</td>
<td>240</td>
<td>39.9</td>
<td>360</td>
<td>35.6</td>
<td>410</td>
<td>32.4</td>
</tr>
<tr>
<td>CRJ2</td>
<td>320</td>
<td>18.6</td>
<td>400</td>
<td>14.7</td>
<td>410</td>
<td>14.1</td>
</tr>
<tr>
<td>All</td>
<td>240</td>
<td>360</td>
<td></td>
<td></td>
<td>410</td>
<td></td>
</tr>
</tbody>
</table>

Figure 17: Vertical profiles per aircraft type (case 3, East-West flux)
Mainly two aircraft types are used in ‘case 3’. Maximum cruise flight levels are higher for the B737-600 than for the CRJ2, and the altitude difference corresponds to each aircraft characteristics.

It is interesting to note that ‘case 3’ was less efficient than case 1 and 2 when using horizontal indicators. The situation becomes more balanced when the vertical indicators are used. Indeed, the percentage of flight duration above the 3rd highest cruise flight level reaches 27%, when the same indicator was only respectively 17% and 7% for case 1 and 2.

However, we note that the westbound traffic prematurely descends to FL270 for periods of several minutes, followed by further intermediate level sections during approach. In an optimum direct case, the cruise would intercept with a continuous descent profile.

The city pair serves to highlight possible compromises in route design. Especially the westbound traffic which is subject to a large route extension. The reason for the extension is not relevant here. The purpose is that the efficiency indicator should be capable of detecting and highlighting such cases from an automatic analysis.
4 Conclusion

This report focused on enhanced flight efficiency indicators and associated methodology issues. The city pairs used in the report are solely for illustration and testing the indicator methods.

4.1 Proposed indicators

For the horizontal efficiency indicator, the choice is between a system of fixed reference points or variable reference points.

The fixed references would be either at specified distance from departure/arrival airports or specific Flight Levels (FL30 is suggested) for departure and arrival for each runway. The variable reference points would essentially replicate the current method of using the start end radar points to calculate the direct route. In either case there are compromises.

It was noticed during the data analysis that fixed distance references, combined with the utilisation of ring references (to isolate en-route portions) were easier to handle and to understand. Transparency, and easy reproducibility are major advantages for the future acceptance of key performance indicators.

Tests performed on selected airports pairs argue in favour of using the ground to ground and 50NM rings on a wide basis to regularly monitor the horizontal efficiency of all the main European routes.

For the vertical efficiency measurement, indicators that focus solely on the ATM aspects of flight efficiency are needed. Two approaches were identified.

A global assessment of fuel burn differences between the actual and the most fuel efficient vertical profile would be the best approach provided this comparison could be done with horizontal trajectory and arrival time kept constants, in order to clearly isolate the vertical contribution. However, from the data available to date, such as without access to the airline operating procedures or Flight Management Systems, it is difficult to determine exactly the optimum FL for minimum fuel consumption for each flight based solely on historical data. Flight Plans may have been 'massaged' before entry and during the flow management process.

To overcome these limitations we suggest a method of using a 'maximum' flight level derived from the most used FL for all routes for a given direct distance. This allows absolute and relative indicators to be used. Some tests were performed in the scope of this study to allow a first analysis independent of fuel modelling tools. The proposed indicator is the percentage flight duration above a given cruise flight level (the maximum FL derived from most used FL). Although the indicator has intrinsically some value, it is recommended to further test its acceptability by future users before implementation.
4.2 Learning from specific cases

Although focusing on a limited number of flights and only three airport pairs, interesting attributes of ATM operations could be identified. The tests proved the ability of rather simple indicators to:

- Identify and cost exceptional ATM events, obliging for large route extensions
- Identify the order of magnitude of pure en-route flight inefficiency under “normal” conditions
- Identify route extension and extra costs due to structural inefficiencies, or permanent airspace restrictions.
- Point to large differences in the flight level accessibility for city pairs of similar direct distances.

As far as horizontal efficiency is concerned, preliminary comparisons with US en-route flight efficiency showed consistent results. More interesting comparisons should become available when the horizontal efficiency for Europe can be assessed for the whole intra European traffic.

4.3 Recommendations and way forward

The main outcome of this study is that it is feasible and desirable to assess the horizontal flight efficiency using the proposed indicators. With the purpose of generating automatic and regular monitoring of this indicator, the following actions should be envisaged:

Firstly, an analysis and evaluation of air traffic routing tools that could be used in support of automated assessments should be conducted. Such tools would have to automatically generate direct route profiles, most often used routes, shortest existing routes according to constraint of the day, etc.

Secondly, radar data availability and quality remaining the main constraint, an assessment of CFMU Model 3 should be done. It should indicate its potential to represent a good proxy for real flight trajectories.

Thirdly, the automatic computation of flight efficiency indicators should be tested on a wide intra-European scale in order to validate the methodology and its full potential use, before being proposed as robust and ready to implement indicators.
References


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Appendix 1: Cathay Pacific Fuel & Energy Management

The following information was quoted from Cathay pacific environmental pages:
http://www.cathaypacific.com/au/aboutus/community/0,,,00.html

“Fuel & Energy Management

The purchase of airline fuel is the second largest operating expense of Cathay Pacific, second only to staff costs. The environmental impacts of aviation fuel burn are a global concern. Cathay Pacific, like other airlines, acknowledges its responsibility to reduce these impacts as far as possible through efforts including:

- The maintenance of a young and therefore fuel-efficient fleet. The average age of our passenger fleet is 7.35 years, well below the average commercial fleet age of 11 years. The plans for the acquisition of 5 new aircraft by the end of 2003 and another new delivery in early 2004 will bring our total fleet to 86 aircraft and further reduce the average aircraft age;

- Extensive operational training of our cockpit crew, for effective take-off, cruising and landing, to minimize fuel consumption, whilst meeting the needs of airports, air traffic control and residents;

- Ensuring optimal flight readiness through thorough engine and mainframe maintenance;

- Active weight control through the integration of weight issues into design and purchasing of in-flight and catering equipment and other fixed cabin furnishings; and

- Active participation in the detailed planning and promotion of Airspace Redesign and Air Traffic Control Procedure Redesign to enhance operational efficiency; both to reduce aircraft flight times and therefore emissions and to mitigate the impact of aircraft noise on the community.

The fuel efficiency figures for 1998 until 2002 are shown below. Fleet replacement practices, together with determined efforts by the Flight Operations has led to a fuel efficiency improvement during this time of over 12%, as indicated below.

<table>
<thead>
<tr>
<th>YEAR</th>
<th>FUEL EFFICIENCY (g/RTK)</th>
<th>% IMPROVEMENT SINCE 1998</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>309</td>
<td>-</td>
</tr>
<tr>
<td>1999</td>
<td>295</td>
<td>4.6%</td>
</tr>
<tr>
<td>2000</td>
<td>284</td>
<td>8.2%</td>
</tr>
<tr>
<td>2001</td>
<td>298</td>
<td>3.5%</td>
</tr>
<tr>
<td>2002</td>
<td>271</td>
<td>12.2%</td>
</tr>
</tbody>
</table>

Energy management is also high on the agenda in the management of Cathay facilities. From the very earliest design stages, energy conservation was a key issue in the
construction, operation and maintenance of Cathay Pacific City at Chek Lap Kok. Some of the more significant energy management features are listed below;

- A computerised building management system to centrally control air-conditioning, lighting, and lifts;
- The elimination of solar glare and reduction of solar gain through the use of double glazed windows and sensor controlled window shades;
- The use of variable air volume control and seawater cooling systems, which alone have reduced potential energy consumption by 30%;
- The use of sensors, electronic ballast, and double parabolic reflectors in high-efficiency lighting tubes.

Further to this, more energy saving features are currently being investigated, including the use of light sensors and motion detectors, allowing more flexibility for unoccupied office areas. “
### Appendix 2: Boeing Estimate of Direct Savings to Airlines

**Boeing Estimate of Direct Savings to Airlines**

<table>
<thead>
<tr>
<th>Benefit category</th>
<th>How achieved</th>
<th>Metric</th>
<th>2020 vision target</th>
<th>Annual benefit in U.S. could range between</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flight path efficiency</td>
<td>Ascent to cruise Wind-optimized routes Continuous descent</td>
<td>Time saved per flight due to flight path efficiency</td>
<td>4-8 minutes per flight</td>
<td>$1.5-3B</td>
</tr>
<tr>
<td>Delay reduction (Capacity)</td>
<td>Precision procedural control RTSP spacing Integrated services New runways</td>
<td>Delay reduction percentage</td>
<td>25-50%</td>
<td>$2-4B</td>
</tr>
<tr>
<td>Airplane utilization</td>
<td>Reduce VMC delay Increase flight path efficiency Reduce block pad</td>
<td>Block time saved per flight</td>
<td>~10 minutes per flight</td>
<td>$.5-1B</td>
</tr>
<tr>
<td>Total annual savings</td>
<td></td>
<td></td>
<td></td>
<td>$4-8B</td>
</tr>
</tbody>
</table>

Appendix 3: Flight efficiency indicator sensitivity to flight references

Comparison of distances, in kilometres, between different references:

<table>
<thead>
<tr>
<th></th>
<th>AP-AP Direct</th>
<th>FL30-FL30 Direct</th>
<th>Direct difference</th>
<th>AP-AP CPR</th>
<th>FL-FL CPR</th>
<th>CPR Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>London - Geneva</td>
<td>753</td>
<td>730</td>
<td>23</td>
<td>827</td>
<td>844</td>
<td>-17</td>
</tr>
<tr>
<td>Nice - Paris</td>
<td>674</td>
<td>650</td>
<td>24</td>
<td>737</td>
<td>695</td>
<td>42</td>
</tr>
<tr>
<td>Birmingham - Copenhagen</td>
<td>1000</td>
<td>982</td>
<td>18</td>
<td>1192</td>
<td>1194</td>
<td>-2</td>
</tr>
</tbody>
</table>

Direct distances using FL30 cut off point can theoretically be longer or shorter than than the airport to airport direct distance. We see however that for the three airport pairs considered here, direct distance are always shorter by 18 to 24 KM. (This consistent with case one presented below).

CPR distances using FL30 should however be always shorter than airport to airport distance. Thus, only the Nice-Paris airport pair results seem fully logical. CPR distances computed especially for London-Geneva, and also for Birmingham-Copenhagen in the FL30 references are longer than the CPR distance from airport to airport. This should normally not happen.

Under the assumptions that
1. there is no inefficiency between FL30 and ground
2. the average distance between take off and FL30 if 8 KM and the average distance from FL30 to landing is 22 KM (Total distance of 30 Km). Sensitivity testing to done using two extreme cases (20 KM and 40 KM)

Depending on runway configurations, there are two extreme cases:

1. FL30 points are reach along the direct path, and diminish this direct path

   ![Diagram 1]

2. FL30 points are reach along the direct path, and increase this direct path

   ![Diagram 2]
In both cases, the distance inefficiency indicator airport to airport is defined as:
\[
\frac{(CPR_{AP} - DIR_{AP})}{DIR_{AP}}
\]

**In case 1, computing the FL30 to FL30 indicator, flight efficiency is:**
\[
\frac{[(CPR_{AP} - 30) - (DIR_{AP} - 30)]}{(DIR_{AP} - 30)}
\]

At the numerator, the 30 KM cancel each other, so that the numerator is the same.
At the denominator, the direct distance is diminished by the distance flown below FL30 (ie 30KM on average).
As a conclusion, in case 1, the inefficiency indicator computed between FL30 points can be higher than the indicator from airport to airport. The longer the distance below FL30, the higher the impact will be, and the longer the direct distance, the lower the impact will be. On average, the difference between inefficiency measured with FL30 point or ground point should be very low. Numerical values are provides for studied airport pair in the table below.

**In case 2, computing the FL30 to FL30 indicator, flight efficiency is:**
\[
\frac{[(CPR_{AP} - 30) - (DIR_{AP} + 30)]}{(DIR_{AP} + 30)}
\]

At the numerator, the 30 KM add each others, which reduces the extra distance flown by twice the distance flown below FL30.
At the denominator, the direct distance is increased by the distance flown below FL30 (ie 30 KM on average).
Both effects go in the same direction: the reduction of the observed inefficiency expressed in percentage.
As the distance below FL30 affects twice the numerator, the impact on the extra distance can be very important. Actually, when the extra distance flown does not exceed 60 KM, the inefficiency indicator becomes zero.

<table>
<thead>
<tr>
<th></th>
<th>London</th>
<th>Geneva</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct distance [KM]</td>
<td>753</td>
<td>9.8%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inefficiency airport to airport</td>
<td></td>
<td></td>
<td>74</td>
<td></td>
</tr>
<tr>
<td>Extra distance flown [KM]</td>
<td></td>
<td></td>
<td>827</td>
<td></td>
</tr>
<tr>
<td>Assumed distance flown below FL30 [KM]</td>
<td>30</td>
<td>20</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>Inefficiency FL30 to FL30 case 1</td>
<td>10.2%</td>
<td>10.1%</td>
<td>10.4%</td>
<td></td>
</tr>
<tr>
<td>Inefficiency FL30 to FL30 case 2</td>
<td>1.8%</td>
<td>4.4%</td>
<td>0.0%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Paris - Nice</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------------</td>
<td>--------------</td>
<td>-----</td>
<td>-----</td>
<td></td>
</tr>
<tr>
<td>Direct distance [KM]</td>
<td>674</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inefficiency airport to airport</td>
<td>9.4%</td>
<td></td>
<td>9.4%</td>
<td></td>
</tr>
<tr>
<td>Extra distance flown [KM]</td>
<td>63</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CPR distance [KM]</td>
<td>737</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Assumed distance flown below FL30 [KM]</td>
<td>30</td>
<td>20</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>Inefficiency FL30 to FL30 case 1</td>
<td>9.9%</td>
<td>9.7%</td>
<td>10.0%</td>
<td></td>
</tr>
<tr>
<td>Inefficiency FL30 to FL30 case 2</td>
<td>0.5%</td>
<td>3.4%</td>
<td>0.0%</td>
<td></td>
</tr>
</tbody>
</table>

|                  | Birmingham - Copenhagen |     |     |
| Direct distance [KM] | 1,000       |     |     |
| Inefficiency airport to airport | 19.3%       |     |     |
| Extra distance flown [KM] | 193         |     |     |
| CPR distance [KM]    | 1,193        |     |     |
| Assumed distance flown below FL30 [KM] | 30 | 20 | 40 |
| Inefficiency FL30 to FL30 case 1 | 19.9% | 19.7% | 20.1% |
| Inefficiency FL30 to FL30 case 2 | 12.9% | 15.0% | 10.8% |
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