Environmental Assessment: European ATM Network Fuel Inefficiency Study

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Foreword

The European Commission adopted the reform of the Single European Sky (SES) on 22 September 2020. EUROCONTROL has independently produced this report to respond to the publication of the European Commission’s reform package.

The analysis contained in this report carried out by EUROCONTROL addresses the extent of the benefit pool of CO₂ emissions from fuel inefficiency in the European Air Traffic Management network.

The implementation of proposed measures in the reform of the Single European Sky, as well as the full collaboration of all aviation stakeholders, will determine to what extent the benefits will be realised.
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1 Executive Summary

On the 22\textsuperscript{nd} September 2020, the European Commission proposed to upgrade the Single European Sky (SES) regulatory framework in order to take into account the objectives of the Green Deal and to modernise the management of European airspace, establishing – among others - more sustainable and efficient flightpaths. Commissioner for Transport, Adina Vălean, declared that the amended SES proposal could reduce air transport emissions by up to 10%. Pending the outcomes of the deliberations at the Council and Parliament levels on the proposed amendment, this study has been generated to address the extent of the benefit pool of CO\textsubscript{2} emissions from fuel inefficiency in the European ATM network.

While a high-level ambition of a 10% reduction in CO\textsubscript{2} emissions has remained stable over the years, there have previously been a number of approaches and baselines used to determine the potential fuel efficiency gains from operational ATM improvements.

Previous work has mainly focused on individual flight phases and time or distance based indicators (as operational proxies for flight efficiency) which were subsequently converted into fuel burn or CO\textsubscript{2} emissions\textsuperscript{1}. While such a flight phase based approach is useful and provides valuable insights to improve operational performance, it does not easily allow to make a holistic assessment of the potential fuel/CO\textsubscript{2} savings for the entire flight trajectory. Furthermore, a distance-based approach may not always represent the optimum profile (lowest fuel/CO\textsubscript{2}) due to factors such as wind.

In contrast to this previous work, the top down approach taken in this report focuses directly on fuel burn from take-off to landing. Using the EUROCONTROL Network Manager’s enhanced tactical flow management system (ETFMS) fuel consumption data, this study assesses the potential benefit pool of CO\textsubscript{2} emissions from fuel inefficiencies in the European ATM network.

Depending on the reference used for the calculation\textsuperscript{2}, the new excess fuel burn indicator suggests an average fuel inefficiency of between 8.6\% to 11.2\% from take-off to landing on flights within the EUROCONTROL Network Manager area in 2019. In some extreme cases for example the airport pair Dusseldorf – Zurich, the average excess fuel burn was greater than 20\% in 2019.

The analyses in this report highlight the multiple factors and drivers that may contribute to fuel inefficiency in the ATM system. Achieving a reduction of up to 10\% requires different tools, policy measures and the full collaboration of the various involved aviation stakeholders.

Analysing 2020 data with the new indicator shows that on average, a fuel efficiency improvement of 5\% was measured (from 8.6\% in 2019 to 3.5\% in 2020\textsuperscript{3}) which also demonstrates the network efficiency improvements that may be achieved in low traffic periods by eliminating a huge number of airspace restrictions. There are multiple factors that influence flight inefficiency. These include, inter alia, route network constraints, availability of airspace, and airspace users’ choices, for example due to significantly different unit rates between states. Due to the complexity of these interrelated factors, the top down approach in this report does not quantify the identified fuel inefficiencies to the underlying causes and hence possible measures proposed in the SES recast.

Nevertheless, the main drivers of the fuel inefficiencies are described in concrete examples. Each driver is supported by data analysis and demonstrates the need for collaboration in the roles and

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\textsuperscript{1} Note that fuel burn and CO\textsubscript{2} is used interchangeable in the report.

\textsuperscript{2} The level of fuel inefficiency computed with the new excess fuel burn indicator is based on a comparison of the actual fuel burn to the 5\textsuperscript{th} percentile (XFB5) or 10\textsuperscript{th} percentile (XFB10) on each airport pair/ aircraft type combination.

\textsuperscript{3} The excess fuel burn (XFB10) falls from just over 9\% in Q1/20 to around 2.5\% at the height of the pandemic, increasing to around 4.5\% in July and drops back to 3.5\% (December 2020).
responsibilities of each operational stakeholder: from ANSPs to airlines, including airports and the EUROCONTROL Network Manager.

It also emphasizes the importance to accelerate the re-organisation of the European airspace and the deployment of new technologies, including SESAR solutions, to provide a more resilient and scalable network. Further optimisation of surface operations and broadening the implementation of Airport collaborative decision-making (A-CDM) should provide additional fuel savings to those shown in this report.

This first top-down analysis is the reference point for future complementary studies on influencing factors - especially when these extra studies require data or tools that are not currently available.

Although aviation has impacts on climate change through both its carbon dioxide (CO₂) emissions and non- CO₂ effects and whilst aviation noise is a concern for communities, this study is limited to conventional jet fuel burn and CO₂ emissions.
2 Introduction

2.1 Background

The emission reduction target of the Single European Sky (SES), quoted at between 6-10% per flight, has origins in the SES High-Level Goals defined by Commissioner Barrot in 2005. These figures are quoted in the 2020 amended SES proposal [1], and its accompanying Staff Working Document (SWD/2020/187 final) [2], which was adopted by the European Commission on 22nd September 2020.

"Today, the European Commission is proposing an upgrade of the Single European Sky regulatory framework which comes on the heels of the European Green Deal. The objective is to modernise the management of European airspace and to establish more sustainable and efficient flightpaths. This can reduce up to 10% of air transport emissions.

The proposal comes as the sharp drop in air traffic caused by the coronavirus pandemic calls for greater resilience of our air traffic management, by making it easier to adapt traffic capacities to demand." [3]

The European ATM Master Plan Edition 2020 [4] has set a Performance Ambition on gate-to-gate CO₂ emissions per flight of 5 to 10% for 2035 as compared to its 2012 baseline 4. This maintains the high-level ambition for fuel burn and CO₂ emissions – formulated in the 2015 edition - for the ATM Master Plan implementation.

<table>
<thead>
<tr>
<th>Operational efficiency</th>
<th>Gate-to-gate fuel burn per flight, kg/fly</th>
<th>5280 kg</th>
<th>4780-5030 kg</th>
<th>200-500 kg</th>
<th>5-10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Additional gate-to-gate flight time per flight, min/fly</td>
<td>8.2 min</td>
<td>3.7-4.1 min</td>
<td>4.1-4.5 min</td>
<td>50-50%</td>
<td></td>
</tr>
<tr>
<td>Gaseous oxides to gate flight time per flight, min/fly</td>
<td>(111 min)</td>
<td>(111 min)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 2-1: Performance ambitions for 2035 – ATM Master Plan

While a high-level ambition of a 10% reduction in CO₂ emissions has remained stable over the years, there have previously been a number of approaches and baselines used to determine the potential fuel efficiency gains from operational ATM improvements.

Previous work has mainly focused on individual flight phases and time or distance based indicators (as operational proxies for flight efficiency) which were subsequently converted into fuel burn or CO₂ emissions. While such a flight phase based approach is useful and provides valuable insights to improve operational performance, it does not easily allow to make a holistic assessment of the potential fuel/CO₂ savings for the entire flight trajectory. Furthermore, a distance-based approach may not always represent the optimum profile (lowest fuel/CO₂) due to factors such as wind. Additional inefficiencies could be identified by the use of indicators that concentrate directly on fuel burn (CO₂ emissions) as opposed to the operational proxies.

In contrast to the approach of estimating the ATM performance benefit pool in previous studies, other points should be taken into consideration such as the impact on fuel / CO₂ performance following the introduction of novel concepts (for instance, electric taxi/taxi bot) into the ATM system. Such concepts may eliminate pools of emissions that previously were accepted as the norm which could actually result in a larger efficiency benefit pool than what is currently the case. The European Green Deal puts digitalisation and the decarbonisation of transport at the very heart of EU aviation policy.

4 2012 is the first year of the 1st Reference Period of the SES Performance and Charging regime.
The conflicting messages provided by industry stakeholders do not help the exercise of quantifying the potential performance improvement of the aviation industry while there is a need to clearly explain the potential efficiency benefits available with detailed explanations and concrete examples.

2.2 Report objective

This report has been generated to address the extent of the benefit pool of CO₂ emissions from fuel inefficiency in the European ATM network using a new operational excess fuel burn indicator. It uses 2019 as a baseline. This report complements and augments the ad-hoc report called “Environmental Efficiency in the European Aviation Network up to and including 2019” [5] that fed the Staff Working Document (SWD) for the amended proposal on SES [2].

2.3 The bigger picture – aviation efficiency in the CO₂ context

Based on the figures of the European Environment Agency (EEA), aviation accounted for approximately 3.8% of total EU28 greenhouse gas (GHG) emissions (4.5% of CO₂ emissions) in 2017 [6]. Although this share appears to be comparatively small, aviation is one of the fastest growing sources of GHG emissions in Europe.

With the relative share of fuel cost in airline operational costs increasing, there has historically been a strong focus on increasing fuel efficiency. Hence the pressure to reduce fuel burn is not new but gained additional momentum through the environmental focus.

Essentially there are four pillars to reduce CO₂ emissions from aviation: (1) Aircraft technology (airframes and engines), (2) Sustainable aviation fuels, (3) Market based measures and offsets, and (4) Improved infrastructure and operations (operational efficiency).

**Aircraft technology:** Although aircraft manufacturers find it increasingly difficult to deliver efficiency gains from design and engine improvements, the efficiency improvements over the past years are remarkable. According to the manufacturers, the latest generation of aircraft (e.g. A350, B787) burn about 15-20% less fuel than the aircraft they replace. Overall, fuel burn per 100 passenger kilometres fell by 24% between 2005 and 2017 [7].

In September 2020, Airbus revealed three concepts for the world’s first zero-emission commercial aircraft which could enter service by 2035 [8].

However, in view of an aircraft lifespan of 20-30 years, the aforementioned efficiency gains through fleet replacements will however take time to fully filter through the entire aircraft fleet.

**Sustainable aviation fuels (SAF):** In order to reduce the net carbon content, the aviation industry is preparing for an energy transition away from fossil fuels towards Sustainable Aviation Fuels (SAF). SAF production at a level and price allowing widespread adoption by airlines will be a game-changer in terms of aviation’s CO₂ emissions (if based on renewable sources). SAFs are expected to play a major role in
the industry meeting its environmental goals. Biofuels and electrofuels provide the necessary energy density and can power existing aircraft with only minor modifications to engines and existing infrastructure.

**Market based measures (MBM):** MBM refer to financial settlements to reduce the climate impact of aviation beyond operational, technical and SAF improvements. MBMs include emissions trading (cap on aggregate emissions e.g. ETS), levies (e.g. taxes, excise duties, charges), and emissions offsetting (compensating for emissions from aviation through reductions in other sectors e.g. CORSIA).

**Improved operational efficiency:** There is a close link between inefficiencies in the four dimensional trajectory (operational efficiency) and associated fuel burn and emissions (environmental impact). For every tonne of fuel (kerosene) saved, an equivalent amount of 3.15t of CO$_2$ is avoided.

Operational efficiency is the result of numerous interactions between airlines, airport operators and ATM, from the planning and scheduling phase up to the day of operation. In this context it is important to point out that (1) operational inefficiencies cannot be reduced to zero (safety requirements, operational trade-offs, etc.) and (2) that improvement requires a joint effort from all stakeholders.

To increase capacity and flight efficiency, ATM deploys a number of projects and initiatives aimed at improving operational efficiency, including performance based navigation (PBN), free route airspace (FRA), Flexible Use of Airspace (FUA), continuous climb and descent operations (CCO/CDO), and other SESAR solutions. These initiatives are supported by a communications, navigation and surveillance (CNS) infrastructure which can be seen as the foundation of aviation operational performance.

ATM also collaborates with partners to improve ground movement efficiency and taxiing procedures with projects such as Airport Collaborative Decision Making (A-CDM). All these technologies and procedures enable aircraft to fly safer and optimised routes, which reduce aircraft emissions.

Additional efficiency gains are expected to come from the further digitalisation in ATM, together with the automation of the industry (especially as drones proliferate) which will enable the better use of data-driven technologies.

### 3 Previous work

There were a number of approaches and baselines used to determine potential efficiency gains from operational ATM improvements over the past years.

Previous work has mainly focused on individual flight phases and time or distance based performance indicators (as operational proxies for flight efficiency) which were subsequently converted into fuel burn. While this flight phase-focused approach is useful and provides valuable insights to improve operational performance, it does not easily allow to make a holistic assessment of the total available benefit pool for operational improvements for the entire flight trajectory.

Before presenting a possible new approach based directly on a fuel burn indicator, the following section provides a brief overview of previous (time and distance based) work to assess the level of operational inefficiencies in various phases of flight, as presented in the Performance Review Report 2019 [9] by the EUROCONTROL Performance Review Commission (PRC).

Figure 3-1 provides an overview of the various gate-to-gate phases, the respective performance indicators, and an indication of the supporting ATM related projects/enablers. A more detailed explanation of some of the previous work on indicators by flight phase is provided in Annex 1.
The “benefit pool” of emissions for which ANS has an influence is estimated for each phase of flight based on a comparison of actual flight trajectories with theoretical reference trajectories\(^5\) \cite{9}. It is important to highlight that ANS cannot eliminate all inefficiencies, as it must manage constraints such as separation minima, runway throughput, adverse weather, military activity, avoidance of ‘Danger Areas’ and interdependencies etc. The “benefit pool” cannot and should not be reduced to zero, and therefore constitutes a total estimated upper bound of possible savings from the individual flight phases. Based on the flight phase-focused approach, the latest estimate\(^6\) of the “benefit pool” that ATM can influence is approximately 6.3% of the total gate-to-gate fuel burn in the ECAC area\(^7\).

Figure 3-2 provides a breakdown of estimated gate-to-gate excess CO\(_2\) emissions as a percentage of

\(^5\) The theoretical reference trajectory is characterised by: zero additional taxi-out time, no level-off during climb (full fuel CCO), no sub-optimal cruise level, en-route actual distance equal to great circle distance (ISA conditions), no level-off during descent (full fuel CDO), no additional time in the Arrival Sequencing and Metering Area (ASMA), zero additional taxi-in time. The EUROCONTROL area average is slightly lower than the sum of the individual flight phases as some of the inefficiencies take place outside of the EUROCONTROL area.

\(^6\) The calculation is the current best estimate and is being continuously refined and improved to reflect new or additional data as it becomes available.

\(^7\) Only the share of the trajectories in the European Civil Aviation Conference (ECAC) area are considered.
emissions from unimpeded gate-to-gate trajectories in the ECAC area [2],[9].

It is important to point out that the percentage is an ECAC average. The average gate to gate inefficiency masks notable differences in performance at city pair or airline level across the network. On short haul flights operating on airport pairs with complex terminal manoeuvring areas (TMA), the inefficiency can exceed 25% in some cases. Therefore, inefficiencies for individual flights, airport pairs or airlines can be notably different from system-wide averages.

4 New fuel burn indicator

4.1 Introduction

The EUROCONTROL Network Manager uses a number of indicators to monitor network performance. It has developed an excess fuel burn indicator to monitor flight fuel efficiency and to support operational performance improvement. The new indicator highlights operational flows with higher than average fuel burn with respect to a reference. It is the basis for further investigations into why such high fuel burn exists. For example, are network operational restrictions affecting route choices? The indicator is not included in sections 1 and 2 of Annex I to Regulation (EU) 2019/317.

This section outlines the source data, scope and calculation method of the excess fuel burn indicator. It presents the main findings from different perspectives and some operational examples of why excess fuel burn exists. The final section notes how excess fuel burn has changed in 2020 and discusses lessons for the future.

4.2 The sources

EUROCONTROL has three approaches to estimate flight fuel burn.

1) For macro studies, e.g. airspace architecture, it uses an average fuel burn per nautical mile estimate. Combined with route length savings, it gives the benefits of future airspace changes.

2) For environmental monitoring, it uses individual flight length and applies a fuel burn model depending on the aircraft type.

3) For operational monitoring and route evaluation, it has ETFMS data on fuel consumption.

This study uses ETFMS fuel burn data for the actual route flown. ETFMS uses a meteorological flight profile combined with aircraft performance data (from the BADA database) to calculate flight fuel burn. The calculation uses mainly aircraft speed, altitude changes, meteo (winds) and horizontal deviations. Its primary use is to provide key criteria for route choices in the context of rerouting tools. The fuel prediction corresponds to the en-route phase of the flight, excluding the fuel burn during take-off and taxi (in/out). As flight plan data evolves, ETFMS updates fuel burn estimates. The indicator uses the actual route flown fuel burn for each flight.

Annex 2 provides more information on the ETFMS fuel burn calculation.

EUROCONTROL validated the ETFMS fuel burn data with other internal calculations and selected airline fuel-burn data. Annex 2 explains the validation exercise and concludes that ETFMS fuel burn data is a good source for the purposes of this study.

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8 ETFMS is the EUROCONTROL Network Manager’s enhanced tactical flow management system.

9 ANSPs send regular aircraft position reports to NM and the flight profile is updated in real time.
The best fuel burn data comes from the aircraft Flight Management System. Unfortunately, this data is unavailable to EUROCONTROL in a single source. EUROCONTROL plans to engage with both aircraft operators and aircraft manufacturers to establish a fuel burn data validation approach.

### 4.3 Scope of study

The study focusses on flights that take-off and land within the Member States of the EUR region forming the scope of application management of the ATM network functions ((EU) 2019/123) – hereafter the study uses the term Intra NM. This represents around 77% of 2019 traffic, most of which operated in the 0500-2000 period of the day (see Figure 4-1).

#### Figure 4-1: Average hourly traffic (2019)

The fuel burn of long-haul flights is relatively large compared to Intra NM flights. Figure 4-2 shows that nine percent of flights in European airspace had route length over 3,000 km and they accounted for 54% of the 2019 fuel burn.

#### Figure 4-2: Cumulative distribution of departure traffic and fuelburn (2019)

The prevalence of long-haul flight in fuel burn is clear in Figure 4-3. Despite being less than 20% of flights in the 0500-2100 period, long-haul flights represent around two thirds of total fuel burn.
The international flight fuel burn is variable. ETFMS has accurate route data up to the border of European airspace since NM receives surveillance data from member states. Beyond the border, ETFMS relies on the flight plan route and, therefore, fuel burn estimates are less precise for long-haul flights.

In addition, the many long-haul route options seriously affect the fuel burn level. For example, there were over 1,200 B777 flights from London Heathrow to Singapore in the eighteen months period to September 2020. Their fuel burn ranged from 85 tonnes to 125 tonnes. Including such flights would skew the fuel burn analysis of NM area flights.

The study excludes international arrivals / departure and overflights.

EUROCONTROL is working on capturing new ETFMS fuel data that will be available in April 2021. The new data will show international flights’ fuel burn in European airspace. It will also provide a basis for understanding where fuel burn excess is prevalent – terminal area, climb, cruise and descent. Data will be available after summer 2021 for further analysis.

4.4 The metric

Current regulatory metrics such as KEP and KEA\(^\text{10}\) use a standard distance reference, the Great Circle Route, to provide a benchmark. Unfortunately, there is no reference for fuel burn. The study, therefore, uses the 10th percentile fuel-burn observation (Ref10) of each airport pair / aircraft type combination – there were 440,000 such combinations in 2019.\(^\text{11}\) In effect, 90% of flights for a combination burnt more fuel than the reference; 10% of flights burnt the equivalent or less fuel.

This “reference” approach is not as robust as the Great Circle approach since the selected reference may still be fuel inefficient; or could be fuel efficient under favourable operating conditions, e.g. tailwinds. However, it is the best approach in the short term. EUROCONTROL plans to engage with aircraft manufacturers to assess fuel optimal profiles as a basis of future references.

The excess fuel burn for an airport pair / aircraft type combination is the total fuel burn for flights in the combination divided by total fuel burn if all flights had achieved the reference fuel burn. The Intra NM excess fuel burn is the aggregation of all combinations within the scope. As a reminder, the fuel burn is for the “wheels up – wheels down” portion of the flight. The report used the reference XFB10 for this excess fuel burn.

\(^{10}\) Horizontal route extension indicators based on last filed flight plan (KEP) and actual route (KEA).

\(^{11}\) The study ALSO uses the 5th percentile reference (Ref5) to assess excess fuel burn (XFB5).
Annex 3 provides more detail on the metric. The metric highlights those airport pairs where relatively high fuel burn is prevalent (see section 4.5.) The goal is to understand which conditions cause such excess and how to address the excess where possible.

### 4.5 Findings

#### 4.5.1 Headlines

The excess fuel burn 2019 for Intra NM flights is 8.6% (XFB10). It is 11.2% using a 5\textsuperscript{th} percentile reference (XFB5). The excess fuel burn 2019 for Intra EU\textsuperscript{12} flights is 8.9% (XFB10). The excess fuel burn is consistent across the geographical areas (NM and SES).

#### 4.5.2 Time perspective

Figure 4-4 shows there is a consistent excess fuel burn (XFB10) over 2019. The excess is higher in summer (around 9%) and lower in winter (around 8%). The weeks 10-11 and weeks 50-51 periods also show higher excess fuel burn. These were periods of ATC industrial action when flights flew extended routes to avoid network restrictions.

![Figure 4-4: Intra-NM actual vs XFB10 fuel burn (2019)](image)

Annex 4 shows that excess fuel burn is consistent over days of the week and hour of the day.

#### 4.5.3 Distance perspective

Figure 4-5 shows that excess fuel burn, in relative percentage terms, is higher for the shorter distance flights and reduces as flight distance increases\textsuperscript{13}. Annex 4 confirms this point. The Domestic flow has the highest excess fuel burn (11.1%) of the three main network flows.

\textsuperscript{12} Internal flights between SES states 2019: EU, Norway, Switzerland and UK.

\textsuperscript{13} There were some 1,000 flights over 5,000 km in 2019 with 8.1% XFB10
4.5.4 Airlines

The top 25 aircraft operators represent over 60% of 2019 Intra NM traffic – see Figure 4-6.

Most of the aircraft operators have excess fuel burn of between 8%-11% - see Figure 4-7. Two are well above 11% and four are a little below 8%. There appears to be scope for working with individual aircraft operators to reduce fuel burn. In practice, the potential to reduce fuel burn will depend on the prevailing operating conditions and practices – discussed in next section.
4.5.5 Aircraft categories

Three aircraft categories performed 94% of Intra NM flights in 2019. Figure 4-8 shows narrow body aircraft performed the majority of flights in the Intra NM area (average 16,214 daily flights in 2019)\textsuperscript{14}.

Figure 4-8: Intra-NM average fuel burn per flight by aircraft category – traffic (2019)

Figure 4-9 shows narrow body aircraft burnt on average 4,176 kg of fuel, with excess fuel burn at 8.7% (XFB10). The large turbo-prop aircraft represent around 2,500 daily flights and have 11.1% excess fuel burn. This in line with the “domestic” category. Turbo props perform many short, domestic flights.

Figure 4-9: Intra-NM average fuel burn per flight by aircraft category - savings (2019)

\textsuperscript{14} Wide body aircraft operated 1.6% of 2019 flights in Intra NM and are not shown here.
4.6 Aircraft Operator business and operational considerations

It is important to understand some of the reasons why excess fuel burn exists.

Aircraft operators aim to minimise their direct operating costs, which include fuel costs, flying time costs and route charges. This often means that flights may operate over longer distances and burn more fuel in order to save money although there are airport-pairs where no such route charge advantage exists. However, aircraft operators may still fly longer for other operational considerations, such as avoidance of active military airspace or ATFM regulated airspace. They may also fly at sub-optimal flight levels, and burn more fuel, to avoid flying longer, more (route charge) expensive routes.

For example, the map in Figure 4-10 shows a September 2019 flight from Warsaw (EPWA) to Rome (LIRF).

The shortest constrained route available (green) is arguably better - 15 nautical miles shorter and 115 kg less fuel – than the flight-planned route (red). However, the FPL route was 109€ cheaper and actually flown. There are many examples where longer routes are cheaper than shorter ones. These tend to be long routes with a significant unit rate difference between states.

Annex 5 uses three airport examples to show how excess fuel burn occurs, particularly with aircraft operator focus on route charges. Other airspace and operational reasons exist as to why a fuel-efficient flight is not always possible. Such reasons include: holding / missed approaches; avoiding restricted areas to arrive on time; sub-optimal flight level or speed.

4.7 Fuel efficiency in an improved operating environment

Given the extraordinary “pandemic” circumstances, there were very few network restrictions during 2020 summer and arrival punctuality was high. Aircraft operators were able to file more direct routes. They also filed and flew at more fuel-efficient flight levels. Given traffic levels at 50% of 2019 levels, network conditions were relatively simple (non-complex) compared to previous years.

Figure 4-11 shows the excess fuel burn indicator (XFB10) for 2020. The excess falls from just over 9% in Q1/20 to around 2.5% at the height of the pandemic – few flights and few restrictions. As traffic recovers, the excess fuel burn increases to around 4.5% in July. It drops to around 3.5% in November as traffic reduces again. The trend shows that in a low-traffic / low-restriction environment, aircraft operators are using routes that consume around 5% less fuel than in 2019 (8.6% versus 3.5%).

This provides the first indication of the potential benefit of a non-complex airspace with few restrictions.
Figure 4-12 shows that fuel burn for most airport pair / aircraft type combinations has reduced (positive change) in 2020 (July-August comparison).

Some combinations have increased fuel burn but these tend to be on the shorter routes (<500 nautical miles).

The fuel burn improvement in the July-August period is around 6% compared to the same period in 2019. Annex 6 provides examples of the improved flight profiles and fuel consumption on specific routes.

4.8 Observations

The study shows that comparing actual fuel burn to a reference fuel burn provides a useful metric – the excess fuel burn. The average Intra NM excess fuel burn is between 8.6% and 11.2% depending on the chosen reference.

Excess fuel burn values remain consistent regardless of the day of the week or hour of the day. It is also higher on shorter airport pairs and reduces as the distance between airport pairs grows. Two of the three biggest traffic flows have higher than average excess fuel burn, particularly the domestic flow.

Several top 25 aircraft operators have higher than average excess fuel burn. There is scope, therefore, to work with them to improve fuel efficiency.

Within the current scope, Narrow body aircraft operate the most in the Intra NM area and drive the excess fuel burn indicator.

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15 The study excludes out-of-area flights; it will include wide bodied aircraft excess fuel burn in future work when data is available.
5 Conclusions

Previous estimations of flight inefficiency have mainly focused on using time or distance based indicators (operational proxies for flight efficiency) to measure the inefficiency of individual flight phases and which were subsequently converted into fuel burn. This report has introduced a new approach, directly based on fuel burn for the “wheels up – wheels down” portion of the trajectory in order to better assess the potential benefit pool that can be addressed by ATM.

Taking the 10th percentile as a reference, comparing the range of fuel burn recorded for each airport pair / aircraft type combination within the EUROCONTROL Network Manager geographical “internal” area (XFB10), the study shows that in 2019, the average excess fuel burnt was 8.6%. If the reference had been the 5th percentile, hence a more efficient reference, the average excess fuel burnt would have increased up to 11.2%.

Based on an indicator relating directly to fuel consumption and emissions, this approach suggests that ATM can influence roughly 10% of aviation’s emissions in Europe which is above earlier estimates (6% average ANS-related gate-to-gate fuel burn inefficiency as compared to the unimpeded trajectory). It is important to highlight that not all ATM inefficiencies can be eliminated, and a certain flexibility in the system us required to manage constraints such as separation minima, runway throughput, adverse weather, avoidance of ‘Danger Areas’, interdependencies etc. The “benefit pool” therefore constitutes an estimated upper bound of possible savings in the respective flight phases.

The analyses in this report highlight the multiple factors and drivers that may contribute to ATM fuel inefficiency. Achieving a reduction of up to 10% requires different tools, policy measures and the full collaboration of the various involved stakeholders. From Air Navigation Service providers (ANSPs) to Airlines, including the airports, the EUROCONTROL Network Manager or the Computerised Flight Plan Service Providers (CFSPs), they all have a shared responsibility to collaborate and contribute to reducing inefficiencies as much as possible. For context, as Europe’s airspace emptied amid the Covid-19 pandemic, the XFB10 indicator for 2020 illustrates the network efficiency improvements that can be achieved in low traffic periods by eliminating a huge number of RAD restrictions16, hence facilitating optimised use of the existing route network and free route airspace, and the huge coordination efforts by the EUROCONTROL Network Manager and its partners. In 2020, aircraft operators have been flying trajectories that consumed around 5% less fuel than in 2019 (8.6% versus 3.5%).

Accelerating the re-organisation of the European airspace and the deployment of the SES reform to eventually enable seamless, flexible and scalable provision of services, as well as optimising taxiing operations and implementing Airport collaborative decision-making (A-CDM) would come in addition to the 5% savings shown in 2020. This gives credit that ATM’s short to mid-term contribution to decarbonising aviation could influence up to 10% in a post-COVID world. Realising the fuel burn reductions available from this benefit pool will require the implementation of SES2+ as well as the cooperation and collaboration of all actors of the aviation value chain.

In addition to ATM impacts upon fuel (in)efficiency, this report also demonstrates the impact of airlines decision-making upon fuel inefficiency. The filed flight plan may not reflect the most fuel optimal flight plan, for various legitimate reasons such as changes to cost index, the speed, the fuel / flight planning policy, the CFSP software etc. and these can provide additional contributions to fuel inefficiency in the network. These factors are not directly related to ATM performance but they have an impact on the

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16 The Route Availability Document (RAD) restrictions is a flight planning document that is used by ANSPs to maximise capacity and reduce complexity by defining restrictions that prevent disruption to the organised system of major traffic flows through the congested areas with due regard to aircraft operators requirements.
average fuel consumption for a city-pair per aircraft type and emphasise the need to further develop the collaboration with the airspace users to get the full potential of fuel optimisation.

To conclude, this first study focuses on flights that take-off and land within the EUROCONTROL Network Manager area. Knowing that long haul flights contribute to more than two thirds of total fuel burn attributable to the NM area, these flights should be included in the scope of this new fuel indicator for determining the CO₂ reduction of enhanced ATM measures that could be achieved within the ATM network. In addition, breaking down the CO₂ emission reduction potential per phase of flight could help to prioritize the deployment of operational improvements in those areas where the emission reduction potential is the highest. This quantification of the fuel inefficiency per phase of flight e.g. TMA, ACC etc. is planned for a future report, after summer 2021, together with a consolidation of the fuel reference trajectory (Ref10 or Ref5) in collaboration with industry and airspace users.
6 ANNEX 1 – Previous work

This Annex provides a brief overview of previous time and distance based work to assess the level of operational inefficiencies in various phases of flight, as presented in the Performance Review Report (PRR) 2019 [9] by the EUROCONTROL Performance Review Commission (PRC).

En-route flight efficiency

En-route flight efficiency has a horizontal (distance) and vertical (altitude) component.

Horizontal en-route flight efficiency

Horizontal en-route flight efficiency measures the length of flight trajectories as additional distance with respect to the corresponding “achieved” distance, which for the vast majority of flights corresponds to the Great Circle Distance (GCD) between the airports (when the airports are located outside the reference area, the border of the reference area is taken instead). The methodology is fully consistent with the SES Performance Scheme [10].

It is acknowledged that the distance-based flight efficiency indicator only serves as a proxy for fuel efficiency as the most fuel efficient trajectory depends on wind. However, even the wind-optimal route might not necessarily correspond to the choice of the airspace users because they might use different measures based on total costs (time, route charges, etc.). Despite this limitation, the indicator has the advantage that the reference (GCD distance between two points) is stable and therefore enables a consistent and stable monitoring over time.

Horizontal en-route flight efficiency is affected by a large number of factors including:

- route structure, which creates specific flows but forces the trajectory on a specific path (this includes the obligation to file through specific points in free routes airspaces)
- availability of airspace (including use of civil/military structures and permanent airspace closures)
- flight planning capabilities (use of software, information available when flight plan is filed)
- airspace user preferences (time, fuel, route charges, avoid capacity bottlenecks)
- tactical ATC routings; and,
- special events such as severe weather, ATC strikes

Some of these factors translate into restrictions in the flight planning, while others lead to modification of the flight plan into the actual trajectory flown.

Flight plans are produced in accordance to the known constraints at time of filing. The actual trajectory (and its length) will therefore be different from the one planned because of occurrence of events which were unforeseen or unplannable, because of modifications of the constraints already known and because of ATC actions. Some of the modifications might lead to a lengthening of the trajectory, while others will lead to a shortening of it.

The horizontal en-route flight efficiency indicator is computed for three different trajectories: (1) the actual flown trajectory, (2) the planned trajectory according to the flight plan and (3) the shortest constrained route provided by the NM. It is expressed as a ratio of distances and is therefore an average additional distance flown within a given airspace vs achieved distance in this airspace (share of origin-destination great circle distance attributed to this airspace).

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The SCRs are the shortest trajectories which could be filed by a flight, taking into consideration the restrictions in the Route Availability Document (RAD) and conditional routes (CDRs) availability.
The shortest constrained route (SCR) reflects the effect of the constraints imposed by ANSPs (route structure, airspace availability, etc.) on flight planning. It is not influenced by weather conditions or specific airline considerations, and it sets the limits within which the airlines can optimise.

The filed flight plan takes into consideration not only those constraints, but also other factors which are linked to airlines’ preferences (including cost considerations and trade-offs). The filed flight plan must always be at least as long as, if not longer than, the SCR.

Finally, the actual flown trajectory is based on the flight plan but is influenced by unforeseen or unplannable factors at the time of filing, including weather and tactical ATC routings. Some of these modifications might lead to a lengthening of the trajectory, while others will lead to a shortening of it.

Figure A 1 from PRR 2019 [9] shows that the average horizontal en-route flight efficiency at EUROCONTROL level remained relatively constant over the past five years with a slight deterioration in 2019.

As pointed out in previous Performance Review Reports (PRRs), there is a significant gap between the efficiency of the filed flight plans (95.6%) and the actual flown trajectories (97.2%). The shortest constrained routes (95.9%) are only slightly more efficient than the filed ones. This means that the flight planning processes of airspace users don’t add much inefficiencies to the ones created by the imposed constraints.

The flown trajectories are notably shorter than the ones airspace users file. They are also notably shorter than the ones they could have filed given the existing constraints in the network (shortest const. route).

Figure A 2: Daily horizontal en-route flight efficiency and ATFM en-route delays (2019)
**Flight efficiency and capacity:** In order to better understand the EUROCONTROL wide high level annual average, Figure A 2 from PRR 2019 [9] provides a breakdown of the horizontal en-route flight efficiency (actual trajectories) by day and en-route ATFM delay in 2019. Each dot represents a day in 2019. Horizontal flight efficiency is clearly worse in summer. The analysis suggests that the lack of capacity and the resulting ATFM constraints have a notable negative effect on flight efficiency. Days with high en-route ATFM delays tend to have notably lower flight efficiency.

**Flight efficiency and Free Route Airspace (FRA):** There is a close link between flight efficiency and FRA implementation at various levels and times in a large part of EUROCONTROL airspace.

According to the European ATM Master Plan [6] and supported by Commission implementing regulation (EU) No 716/2014 [11], Free Route Airspace on a H24 basis should be implemented above flight level 305 throughout the entire EUROCONTROL area by 2022.

En-route flight efficiency is comparatively low in the core area where traffic density is highest and where Free Route Airspace (FRA) is not yet fully implemented (see Figure A 3).

![Free Route Airspace Implementation - End 2019](image)

**Figure A 3: Implementation status of Free Route Airspace (FRA) – End 2019**

FRA is expected to be one of the main contributors towards improving horizontal en-route flight efficiency as it provides airspace users with more choices to optimise their flight plans.

In view of the high traffic volume, expected savings in terms of fuel burn and CO₂ emissions following the FRA implementation in the entire core area are high.

Nonetheless it is important to point out that the overall benefits that can be expected vary by airspace and depend, inter alia, on traffic volume and growth, complexity and other factors. It should also be noted that whilst FRA can provide efficiency improvements there are still further inefficiencies that may remain. For example, flight planning will be undertaken based on existing airspace entry / exit points which may not be optimised for all routes, military airspace activity may prevent the flying of an optimised trajectory whilst airline flight planning systems may not be optimised to enable the optimal FRA flight plan to be calculated. The full benefits of FRA will come from the inter-FAB and cross border implementation of FRA.
The analysis of horizontal en-route flight efficiency from PRR 2019 [9] in Figure A 4 shows the level of flight efficiency in actual trajectories (x-axis) and filed flight plans (y-axis) by State in 2019.

States in which FRA is fully or partly implemented are shown as a red dot. The benefits are clearly visible. On average, States where FRA has been implemented show a 0.5% higher flight efficiency compared to the other states. The European Aviation Environment Report (2019) estimated that the proportion of flight time flown in Free Route Airspace in Europe during 2017 was 20% compared to 8.5% in 2014.

Moreover, it can be seen that the gap between the flight plan efficiency and the efficiency in actual flown trajectories (vertical distance between a dot and the diagonal arrow) is narrower than for the other States. Actual operations closer to plan improves the level of predictability for all players involved with a positive impact on capacity and resource utilisation. The gap is clearly more prominent in those States where FRA has not been fully implemented all day.

**Vertical en-route flight efficiency**

Because of the distinct nature of the different phases of flight, specific methodologies were developed for the analysis of vertical flight efficiency during climb and descent on the one hand (see next section) and for the analysis of en-route vertical flight efficiency on the other hand.

Based on the assumption that flights on airport pairs with similar Great Circle Distance (GCD) should be able to reach similar cruising altitudes, the methodology compares the maximum filed flight levels of flights on a specific airport pair and flights on reference airport pairs with a similar GCD and without RAD (Route Availability Document) constraints.

The EUROCONTROL Performance Review Commission (PRC) has been using its methodologies [12] to assess vertical en-route flight efficiency [13]. The methodology does currently not allow to quantify the total amount of vertical en-route inefficiencies (VFI) in the EUROCONTROL area nor does it identify all underlying reasons for the observed inefficiencies.
Instead, it provides an initial understanding of the level of vertical flight inefficiencies on specific airport pairs in order to evaluate some cases in more detail. It should be noted that there might be good reasons for certain vertical restrictions (safety, capacity) and the results should therefore be interpreted in this context.

The analysis from PRR 2019 [9] in Figure A 5 shows the number of airport pairs and flights that are impacted by a level capping constraints detailed in the Route Availability Document (RAD).

There is a considerably higher number of altitude constrained flights since spring 2018. Since then, this number stayed quite stable, even though the number of RAD constraints decreased again in the beginning of 2019.

The analysis shows a notable increase in vertically RAD constrained airport pairs which appears to be the result of the measures implemented by the 4ACC initiative in 2018 and the eNM initiatives in 2019. Following the dramatic traffic reduction as a result of the COVID-19 pandemic, ANSPs started to lift a number of RAD restrictions which consequently resulted in a decrease of the number of RAD constrained airport pairs in 2020.

It should be noted that current initiatives are underway for newer metrics that should be able to quantify the fuel burn inefficiencies of vertical flight inefficiency in the en-route phase for both individual flights and the network level.

**Continuous climb/descent operations (CCO/CDO)**

Reducing intermediate level-offs and diversions during climb and descent can save substantial amounts of fuel and CO₂ and also reduce noise levels in the vicinity of airports. The lower the level segment, the higher the additional fuel consumption.

Vertical flight efficiency during climb and descent is calculated by using a methodology developed by the PRC [14]. The methodology has been used for a number of case studies which were discussed with experts during the PRC’s Vertical Flight Efficiency Workshop in November 2018.
The methodology was further enhanced by the work of the European CCO / CDO Task Force who brought together a set of European stakeholders and used their experiences and the existing metrics used by them to agree on a harmonised definition of CCO / CDO and a harmonised set of metrics and parameters for measurement. The agreed metric was ‘average time in level flight’, an operational proxy for flight inefficiency and this was a big change from other indicators which focused on a binary definition of CCO / CDO (i.e. Y/N). This was because the binary metric was not able to demonstrate operational performance improvements and it did not distinguish between a small inefficiency to maintain separation between aircraft, and a long inefficiency at high fuel flow levels due to inefficient procedures.

The methodology calculates the rate of climb or descent (vertical velocity) between every pair of consecutive data points. If the rate of climb or descent between two data points is smaller than or equal to a chosen vertical velocity, that part of the trajectory is considered as level flight. A segment of the trajectory is considered as level flight when its rate of climb or descent is lower than or equal to 300 feet per minute. Level segments shorter than 20 seconds are not considered.

Doing this for the whole climb or descent trajectory, the time flown level can be calculated.

The resulting indicators measures the average time flown level per flight within a 200NM radius around airports for arrivals and a 300NM radius around airports for departures.

On average, the time flown level during descent is around five times higher than the time flown level during climb.

As shown in PRR 2019 [9], at the top 30 airports in terms of traffic in the EUROCONTROL area, average time flown level in 2020 was 3.2 minutes per arrival compared to 0.6 minutes per climb out.

The European CCO / CDO Task Force carried out the first ECAC wide CCO and CDO benefit study in 2018. This study concluded that the benefit pool from optimising CCO and CDO profiles in 2017 was up to 350,000 tonnes of fuel, which is equivalent to 1.1 million tonnes of CO₂ emissions per year. However, it should be noted that the ability to fly 100% CCO or CDO may not be possible for a number of reasons such as safety (i.e. time or distance separation), weather or capacity.
7 ANNEX 2 – ETFMS fuel burn data validation

ETFMS fuel burn method

The Enhanced tactical flow management system (ETFMS) provides enhanced tactical data to all operational stakeholders [15]. The ETFMS flight fuel burn calculation uses two key elements:

- a flight profile; and
- aircraft performance and fuel consumption data.

Flight profile

ETFMS generates a flight profile that is a list of points with, where appropriate, the name of the route leaving the point, the point identifier, the estimated time over and the flight level and the point name. It uses real-time flight data updates, wind speed and wind direction in the calculation of the flight profiles to improve the accuracy.

NM receives forecast MET data every six hours. This is used, for example, to factor tail winds into shorter flight time and vice versa.

ETFMS uses the planned flight profile for fuel burn calculation. Once a flight is airborne, ETFMS uses correlated position report (CPR) information to adapt the flight profile to an “actual”, e.g. if a flight is diverted, the flight profile will show the new destination aerodrome.

Fuel consumption is calculated on this “meteo” profile – planned or actual.

Aircraft performance and fuel consumption data

ETFMS calculates fuel burn as a function of flight time and not flight distance. It makes assumptions for flight time using factors such as drag and phase of flight (time in climb / time in cruise).

It applies (BADA) aircraft type fuel burn rates for the time duration in the different flight phases.

ETFMS supports network operations and uses fuel data to compare two alternative routes. The primary interest is relative, not absolute, fuel consumption values. ETFMS often does not have aircraft take-off weight since weight is optional in the FPL. It lacks engine characteristics information so engine efficiency is assumed.

Nevertheless, EUROCONTROL NM believes the flight fuel burn data is accurate for the purposes of this study.

Comparison with EUROCONTROL environment model

The EUROCONTROL Aviation Sustainability unit maintains the FEIS environment model. ETFMS fuel data was compared with the FEIS model.

Table A 1 shows February 2020 (winter) and July 2020 (Summer) fuel burn:

- ETFMS data shows fuel burn for wheels up to wheels down.
- FEIS data is gate-to-gate fuel burn.

<table>
<thead>
<tr>
<th>Month</th>
<th>Traffic</th>
<th>ETFMS Time minutes</th>
<th>FEIS Time minutes</th>
<th>ETFMS Fuel tonnes</th>
<th>FEIS Fuel tonnes</th>
<th>Diff %</th>
</tr>
</thead>
<tbody>
<tr>
<td>February 2020</td>
<td>568,203</td>
<td>58,268,248</td>
<td>58,260,031</td>
<td>2,124,924</td>
<td>2,355,918</td>
<td>9.8</td>
</tr>
<tr>
<td>July 2020</td>
<td>349,814</td>
<td>32,076,933</td>
<td>32,072,298</td>
<td>1,074,523</td>
<td>1,215,522</td>
<td>11.6</td>
</tr>
</tbody>
</table>

Table A 1: Comparison of ETFMS data and FEIS data
There are negligible differences between flight time and route length.

February 2020 ETFMS fuel burn is, on average, 9.8% lower than FEIS.

July 2020 ETFMS fuel burn is, on average, 11.6% lower than FEIS.

The PRC analysis reported in Chapter 3 indicates that wheel-up / wheels down fuel burn represents around 90% of total flight fuel burn.

The ETFMS and FEIS fuel burn data compare favourably.

**Comparison with airline data**

In 2019, EUROCONTROL compared the ETFMS fuel burn data to four European airlines’ fuel burn data.

**Observations:**

- Shorter routes present higher differences to ETFMS data. The terminal-airspace fuel burn explains the difference, which has a high weight on short sectors. Fuel burn is harder to estimate on short routes.
- For routes of over 400 nautical miles or more than 1 hour of flight time the percentage difference to ETFMS seems to be more stable.
- A321 fuel is a good match to ETFMS on all three airlines with this aircraft type.
- Long-haul flights in ETFMS are the best predicted models (lower % difference to airline data). The portion of en-route on these flights is much higher than in short-haul flights. However, the absolute differences (kg of fuel burn) fuel might be substantially higher.

**Conclusions**

- The fleet and the routes operated by an airline play an important role on the differences to ETFMS fuel data. For flights within Europe operated by models of the A320 and B737 families, the airlines analysed burn 10% more fuel than the ETFMS predictions for the en-route part of the flight.
- On long-haul routes, the ETFMS prediction could be considered a good reference due to the similarity of the figures provided by the airlines.
- ETFMS fuel burn data is more robust when used in analysis of average fuel consumptions (grouped on city pairs, distance range, aircraft type, etc). It provides reasonable insight into the relative fuel burn of flights.
8 ANNEX 3 – The fuel burn reference method

Definition

The excess fuel burn for an airport pair / aircraft type combination is:
Total actual fuel burn / total reference fuel burn.

The Reference fuel burn is either the 5th percentile or 10th percentile of all fuel burn observations for a specific airport pair / aircraft type combination.

The actual fuel burn is that measured by ETFMS for the actual route flown.

There were 8.5 million flights in the Intra NM area in 2019. Circular and maintenance flights are excluded from the analysis. Flights from/to unidentified airports are also excluded.

In 2019, there were over 440,000 different airport-pair / aircraft type combinations. Over 405,000 of these combinations had fewer than 20 flights.
Figure A 7 shows that 90% of 2019 traffic flew on airport-pair / aircraft type combinations with 20 or more flights.

For those airport-pair / aircraft type combinations with fewer than 20 flights, the average fuel burn value was used to create the reference fuel burn. In effect, these combinations have limited influence on the metric.

Metric example

There were 3,867 flights on the Dusseldorf to Zurich route in 2019; there were 1,595 Airbus A320 flights so the 5th and 10th percentile for this combination would be the 80th and 160th flights respectively when ranking fuel burn for this combination from the lowest to the highest.

EFTMS data for the Dusseldorf to Zurich / Airbus A320 combination shows:
The 80th lowest fuel burn in 2019 on this combination was 1,607 kg - 5th percentile fuel burn.
The 160th lowest fuel burn in 2019 on this combination was 1,656 kg - 10th percentile fuel burn.

Table A 2 shows the lowest and highest fuel burn observations for the Dusseldorf to Zurich / Airbus A320 flights - there is a wide variance of fuel burn difference from the Reference (Ref10).

<table>
<thead>
<tr>
<th>Fuel burn</th>
<th>Value</th>
<th>Ref 10</th>
<th>Delta</th>
<th>%difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lowest</td>
<td>1449</td>
<td>1656</td>
<td>-207 kg</td>
<td>-12.5%</td>
</tr>
<tr>
<td>Highest</td>
<td>3879</td>
<td>1656</td>
<td>2223 kg</td>
<td>+134%</td>
</tr>
</tbody>
</table>

Table A 2: Dusseldorf to Zurich (2019, A320)

All the fuel burn differences for all airport pair / aircraft type combinations are calculated and aggregated to provide a percentage difference from the reference. They can be aggregated in different perspectives.

For example, on the airport pair Dusseldorf to Zurich (for all aircraft types) there is an excess (actual v reference) fuel burn of 20.5% - based on the 10th percentile reference.

<table>
<thead>
<tr>
<th>Fuel burn</th>
<th>Traffic</th>
<th>Av route length (NM)</th>
<th>Actual fuel</th>
<th>Reference fuel</th>
<th>%difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>EDDL-LSZH</td>
<td>3867</td>
<td>279</td>
<td>7,588 tonnes</td>
<td>6,300 tonnes</td>
<td>20.5%</td>
</tr>
</tbody>
</table>

Table A 3: Dusseldorf to Zurich (2019, All aircraft types)
9  ANNEX 4 – Excess fuel burn perspectives

Figure A 8 shows that excess fuel burn is highest during the main daily operations period: 0500-2100 where it remains consistent between approximately 8 and 9% before falling to a low of just over 6% overnight.

On average there is between 10-20% more fuel burn at weekends compared to weekdays – see Figure A 9. However, excess fuel burn for all days of the week remains relatively stable at between 8% to 9%.
The EUROCONTROL Network Manager has defined traffic flows for monitoring network performance. Figure A 10 shows that the majority of daily flights (average Intra NM flights) fly on three specific flow categories: the south-west axis, south-east axis and domestic. The average fuel burn per flight on the flows are 4.3, 4.0 and 1.6 tonnes respectively.

Figure A 10: Intra-NM average fuel burn per flight by flows – traffic (2019)

Figure A 11 shows that the domestic flow has the lowest average fuel burn but also the highest average excess fuel burn – 11.1%

The other two main flows are at or below the Intra NM average excess fuel burn (8.6%).

Figure A 11: Intra-NM average fuel burn per flight by flows -savings (2019)
10 ANNEX 5 – Three examples of high excess fuel burn airport pairs

Table A 4 shows three airport pairs with high excess fuel burn in 2019.

<table>
<thead>
<tr>
<th>Airport Pair</th>
<th>Traffic</th>
<th>Av route length (NM)</th>
<th>Actual fuel</th>
<th>Fuel REF10%</th>
<th>Excess fuel %</th>
</tr>
</thead>
<tbody>
<tr>
<td>EDDL-LSZH</td>
<td>3,867</td>
<td>279</td>
<td>7,588,883</td>
<td>6,298,207</td>
<td>20.5%</td>
</tr>
<tr>
<td>EHAM-LIMC</td>
<td>3,759</td>
<td>503</td>
<td>14,320,362</td>
<td>12,760,694</td>
<td>12.2%</td>
</tr>
<tr>
<td>LFPO-LPPT</td>
<td>4,119</td>
<td>839</td>
<td>22,163,083</td>
<td>20,268,457</td>
<td>9.3%</td>
</tr>
</tbody>
</table>

The analysis is for Airbus A320s on these routes.

Table A 4: Three examples of high excess fuel burn airport pairs

EXAMPLE 1

Dusseldorf – Zurich route – short flight of around 45 minutes

Excess fuel burn in 2019 – 20.5%

1595 A320 flights in 2019

Figure A 12 shows that 77% of A320 flights on this route paid en-route charges of between 316€-325€, the lowest band. In fact, 98% paid 345€ or less.

![Figure A 12: Dusseldorf (EDLL) – Zurich (LSZH) – flights per route charge category (2019)](image)

The A320 reference fuel burn (Ref10) is 1,656 kg and that flight paid 319€ en-route charges.

It would appear that a flight could fly both economically and fuel efficiently under certain conditions on the route.

However, most of the 1227 flights that paid 316€-325€ burnt fuel in excess of the reference – see Figure A 13.
Three flights had almost the same flight distance, route charges but significantly more fuel burn compared to the reference flight (Flight 1).

Of the four flights, two flew through inactive military zones, Flight 4 avoided military airspace as the area was active, the reference flight also avoided the military zone.

<table>
<thead>
<tr>
<th>ACFT_ID</th>
<th>DATE/TIME</th>
<th>RTE LENGTH</th>
<th>FUEL BURN</th>
<th>RTE CHARGES</th>
<th>FLYTIME</th>
<th>FL REACHED</th>
</tr>
</thead>
<tbody>
<tr>
<td>FLIGHT 1</td>
<td>Mar-2019 AM</td>
<td>276</td>
<td>1656</td>
<td>319</td>
<td>44</td>
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</tr>
<tr>
<td>FLIGHT 2</td>
<td>May-2019 AM</td>
<td>280</td>
<td>3277</td>
<td>319</td>
<td>70</td>
<td>FL230</td>
</tr>
<tr>
<td>FLIGHT 3</td>
<td>Jun-2019 PM</td>
<td>275</td>
<td>2897</td>
<td>330</td>
<td>61</td>
<td>FL230</td>
</tr>
<tr>
<td>FLIGHT 4</td>
<td>Jun-2019 AM</td>
<td>280</td>
<td>2838</td>
<td>320</td>
<td>59</td>
<td>FL230</td>
</tr>
</tbody>
</table>

Table A 5: Dusseldorf (EDLL) – Zurich (LSZH) - Examples (2019, A320)
As well as extra flight time, a primary reason for the excess fuel burn is the difference in flight levels reached. The three high fuel burn flights reached FL230. The reference flight flew at FL290 and for fewer minutes.

The AO focus here is on keeping route charges down. It would appear that en-route RAD restrictions increase the fuel burn on the “lower charge” flights. Without the restriction, a relatively economic and fuel efficient flight would be possible.
EXAMPLE 2

Amsterdam – Milan route – flight of around 70 minutes

Excess fuel burn in 2019 – 12.2%

991 A320 flights in 2019

Figure A 16 shows that 80% of A320 flights paid en-route charges of between 664€-683€.

Figure A 16: Amsterdam (EHAM) - Milan (LIMC) – flights per route charge category (2019)

The A320 fuel burn reference is 2,661 kg and that flight paid 708€ en-route charges.

The fuel-efficient route is more expensive.

Figure A 17 shows that most of the 795 flights that paid 664€-683€ burnt fuel in excess of the reference.

Figure A 17: Amsterdam (EHAM) - Milan (LIMC) – fuel burn for 664-683€ category (2019)
The AO focus here is likely to be on keeping route charges down and not on fuel efficiency. The route charge system may influence the route choice for EHAM-LIMC.

Three flights had similar flight distance, lower route charges but more fuel burn compared to the reference flight.

<table>
<thead>
<tr>
<th>ACFT_ID</th>
<th>DATE/TIME</th>
<th>RTE LENGTH</th>
<th>FUEL BURN</th>
<th>RTE CHARGES</th>
<th>FLYTIME</th>
<th>FL REACHED</th>
</tr>
</thead>
<tbody>
<tr>
<td>FLIGHT 1</td>
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<td>501</td>
<td>2661</td>
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<td>73</td>
<td>FL370</td>
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<tr>
<td>FLIGHT 2</td>
<td>Oct-2019 AM</td>
<td>507</td>
<td>3654</td>
<td>681</td>
<td>84</td>
<td>FL310</td>
</tr>
<tr>
<td>FLIGHT 3</td>
<td>Aug-2019 AM</td>
<td>510</td>
<td>3627</td>
<td>699</td>
<td>89</td>
<td>FL350</td>
</tr>
<tr>
<td>FLIGHT 4</td>
<td>Nov-2019 AM</td>
<td>498</td>
<td>3543</td>
<td>683</td>
<td>98</td>
<td>FL360</td>
</tr>
</tbody>
</table>

Table A 6: Amsterdam (EHAM) - Milan (LIMC) - Examples (2019, A320)

All the flights avoided military airspace at some point.

The lower fuel burn of the reference flight is likely due to the higher cruise level (FL370) it had for most of the flight length.

Figure A 18:– Map of Amsterdam (EHAM) - Milan (LIMC) example (horizontal)
EXAMPLE 3

Paris Orly – Lisbon route – flight of around 120 minutes

Excess fuel burn in 2019 – 9.3%

1109 A320 flights in 2019

Figure A 19 shows 63% of A320 flights paid en-route charges of between 859€-878€, the lowest band. Also, 30% paid over 939€.

Figure A 19: Paris Orly (LFPO) - Lisbon (LPPT) – flights per route charge category (2019)

The A320 reference fuel burn is 4,522 kg and that flight paid 1035€ en-route charges. The fuel-efficient flight is more expensive.

Most of the 702 flights that paid 859€-878€ burnt fuel in excess of the reference – see Figure A 20.

Figure A 20: Paris Orly (LFPO) - Lisbon (LPPT) – fuel burn for 859-878€ category (2019)

The AO focus here is likely to be on keeping route charges down and not on fuel efficiency. The route charge system may influence the route choice for Orly-Lisbon.
<table>
<thead>
<tr>
<th>FLIGHT</th>
<th>DATE / TIME</th>
<th>RTE LENGTH</th>
<th>FUEL BURN</th>
<th>RTE CHARGES</th>
<th>FLYTIME</th>
<th>FL REACHED</th>
</tr>
</thead>
<tbody>
<tr>
<td>FLIGHT 1</td>
<td>Jan-2019 PM</td>
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<td>4522</td>
<td>1035</td>
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<td>FL370</td>
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<tr>
<td>FLIGHT 2</td>
<td>Dec-2019 AM</td>
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<td>5750</td>
<td>945</td>
<td>160</td>
<td>FL390</td>
</tr>
<tr>
<td>FLIGHT 3</td>
<td>Oct-2019 PM</td>
<td>853</td>
<td>5819</td>
<td>945</td>
<td>153</td>
<td>FL370</td>
</tr>
<tr>
<td>FLIGHT 4</td>
<td>Aug-2019 PM</td>
<td>865</td>
<td>5938</td>
<td>943</td>
<td>157</td>
<td>FL370</td>
</tr>
</tbody>
</table>

Table A 7: Paris Orly (LFPO) - Lisbon (LPPT) - Examples (2019, A320)

Three flights had similar flight distance, lower route charges but more fuel burn compared to the reference flight (Flight 1).

The lower fuel burn of the reference flight is likely due to a route choice that prioritised favourable, en-route, meteorological conditions – note the shorter flight time.

Figure A 21:– Map of Paris Orly (LFPO) - Lisbon (LPPT) example (horizontal)
11 ANNEX 6 – Airport pair improved fuel burn 2020 v 2019

Figure A 22 shows the airport pairs with the most improved values in excess fuel burn for the year-to-date period. It is these that drive the 5 percentage point improvement in the excess fuel burn indicator (8.6% to 3.5%). Many are short distance airport pairs. Several factors together could explain the improved values. The four examples below show routes where flight profile changes can be clearly seen.

**Figure A 22:**– improved fuel burn airport pairs (YTD 2020 v 2019)\(^{18}\)

**LCLK-EGLL**

There has been a 10% fuel saving (for type A321NEO) on the Larnaca (LCLK) to London Heathrow (EGLL) route in the July-August period. This is around 1,100kg per flight.

Typically, flights appear to be taking advantage of available direct routes (SEFRA) and are able to use higher flight levels. See examples in Figure A 23.

<table>
<thead>
<tr>
<th>FLIGHT</th>
<th>DATE / TIME</th>
<th>RTE LENGTH</th>
<th>FUEL BURN</th>
<th>RTE CHARGES</th>
<th>FLYTIME</th>
<th>FL REACHED</th>
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</thead>
<tbody>
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<td>FLIGHT B</td>
<td>Aug-2020 AM</td>
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<td>8.902</td>
<td>1989</td>
<td>270</td>
<td>FL380</td>
</tr>
<tr>
<td>FLIGHT C</td>
<td>Aug-2020 PM</td>
<td>1829</td>
<td>8.850</td>
<td>1989</td>
<td>277</td>
<td>FL380</td>
</tr>
</tbody>
</table>

---

\(^{18}\) YTD- year to date: January-October.
There has been a 16% fuel saving (for type B737-800) on the Cologne (EDDK) to Madrid (LEMD) route in the July-August period. This is around 950kg per flight. Typically, flights appear to be taking advantage of available direct routes and are able to use higher flight levels. See examples in Figure A 24.

<table>
<thead>
<tr>
<th>FLIGHT</th>
<th>DATE / TIME</th>
<th>RTE LENGTH</th>
<th>FUEL BURN</th>
<th>RTE CHARGES</th>
<th>FLYTIME</th>
<th>FL REACHED</th>
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<tbody>
<tr>
<td>FLIGHT A</td>
<td>Aug-2019 PM</td>
<td>863</td>
<td>6.145</td>
<td>1087</td>
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<tr>
<td>FLIGHT B</td>
<td>Jul-2020 PM</td>
<td>804</td>
<td>4.582</td>
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</table>
EGKK-LHBP

There has been a 13% fuel saving (for type A319NEO) on the London Gatwick (EGKK) to Budapest (LHBP) route in the July-August period. This is around 650kg per flight.

Typically, flights appear to be taking advantage of higher flight levels. See examples in Figure A 25.

<table>
<thead>
<tr>
<th>FLIGHT</th>
<th>DATE / TIME</th>
<th>RTE LENGTH</th>
<th>FUEL BURN</th>
<th>RTE CHARGES</th>
<th>FLYTIME</th>
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<tbody>
<tr>
<td>FLIGHT A</td>
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<td>FLIGHT B</td>
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<td>3.826</td>
<td>1218</td>
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</tbody>
</table>

Figure A 25: Map of London Gatwick (EGKK) to Budapest (LHBP) example (vertical)

EDDH-EDDS

There has been a 9% fuel saving (for type A320) on the Stuttgart (EDDS) to Hamburg (EDDH) route in the July-August period. This is around 210kg per flight.

Typically, flights appear to be taking advantage of higher flight levels. See examples in Figure A 26.

<table>
<thead>
<tr>
<th>FLIGHT</th>
<th>DATE / TIME</th>
<th>RTE LENGTH</th>
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<tr>
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<td>62</td>
<td>FL230</td>
</tr>
<tr>
<td>FLIGHT A</td>
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<td>FLIGHT B</td>
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<tr>
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<td>FLIGHT D</td>
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<td>FL370</td>
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<tr>
<td>FLIGHT E</td>
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<td>1.503</td>
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<td>FL370</td>
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</tbody>
</table>
Figure A 26: Map of Stuttgart (EDDS) to Hamburg (EDDH) example (vertical)
12 References


