PRC TECHNICAL NOTE

VERTICAL FLIGHT EFFICIENCY

Technical note prepared by the EUROCONTROL Performance Review Unit (PRU) and commissioned by the Performance Review Commission (PRC)

April 2021

Background

This Technical Note, commissioned by the Performance Review Commission (PRC) has been prepared by the EUROCONTROL Performance Review Unit (PRU).

The PRC was established in 1998 by the Permanent Commission of EUROCONTROL, in accordance with the ECAC Institutional Strategy (1997). One objective of this strategy is "to introduce a strong, transparent and independent performance review and target setting system to facilitate more effective management of the European ATM system, encourage mutual accountability for system performance…"

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Summary

This Technical Note has been produced by the EUROCONTROL Performance Review Commission (PRC), The PRC was created in 1998 to provide independent advice to the EUROCONTROL Permanent Commission on all aspects of ATM performance in Europe.

This Technical Note, which is an update to a PRC Technical Note published in 2008, concludes that Vertical flight efficiency has been quite stable over the past few years but the COVID pandemic has had its impact on VFE as well. The report highlights the results in 2020 and the change with respect to 2019. In addition, the results during the COVID period are highlighted.

Overall, vertical flight efficiency during descent has improved while it has remained quite the same for climbs.

In the en-route phase, vertical flight efficiency has improved for most airport pairs. Also, the most inefficient airport pairs in 2019 have seen an improvement in 2020. However, the inefficiency on these airport pairs stayed pretty high.

Keywords

EUROCONTROL Performance Review Commission, ATM Performance , Vertical Flight Efficiency, Data Processing, Performance Review

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1 INTRODUCTION

1.1 General

For some years, stakeholder interest in the field of the vertical aspect of flight efficiency has been increasing substantially, complementary to the horizontal aspect. The PRC first addressed Vertical flight (in)efficiency in 2008 with the publication of a PRC Technical Note estimating the impact of ATM on vertical flight efficiency (Performance Review Commission, 2008). Since 2015, the PRC and its supporting unit the Performance Review Unit (PRU) has been continuing this work by developing and testing possible performance indicators for vertical flight efficiency.

Vertical flight efficiency during the climb, descent and en-route phases of flight are continuously monitored and the results are published on a regular basis on ansperformance.eu. In addition, reports for specific airports and airport pairs can be requested on this website.

1.2 Purpose of the document

This PRC Technical Note updates the PRC Technical Note published in 2008. It gives an overview of the latest observations regarding vertical flight efficiency during the climb, descent and en-route phases of flight.

1.3 Scope

This Technical Note analyses vertical flight efficiency during the climb and descent phases of flight departing from or arriving at airports in the ECAC area during 2019-2020.

The results for en-route vertical flight efficiency are presented for airport pairs within the ECAC area for 2020.

1.4 Acronyms and terminology

Table 1: Acronyms and terminology

Term	Definition
ACC	Area Control Centre
CCO	Continuous Climb Operations
CDO	Continuous Descent Operations
CPF	Profile based on correlated positions reports
FTFM	Last filed flight plan
NM	EUROCONTROL Network Manager
PBN	Performance Based Navigation
PRU	Performance Review Unit
RAD	Route Availability Document
SESAR	Single European Sky ATM Research
SID	Standard Instrument Departure
STAR	Standard Instrument Arrival

2 DATA SOURCES

For the purposes of this Technical Note, the PRU used data available in the EUROCONTROL PRISME database, which provides a continuous feed of trajectory data.
For the climb and descent metrics, the PRU used CPF data (i.e. profile based on correlated positions reports) based on radar data and FTFM data (last filed flight plan) for the en-route metrics.

2.1 Data coverage

2.1.1 Number of flights

The CPF data used by the PRU originates directly from the Network Manager and is an aggregation of the radar data submitted by the different States. The pre-processing of the data determines which flight data are fit for purpose. This includes checks for a minimum number of data points in every trajectory and filters to exclude circular flights (flights with the same departure and arrival airport), diverted flights and flights with erroneous trajectory data like vertical and horizontal glitches. For all the flights for which data were available in 2019 and 2020, 88.1% of the NM flight profiles were analysed by the PRU, ranging from 33.0 to 100.0%, depending on the airport.
The PRU analysis showed that the CPF data did not contain information for a large number of flights operated at Turkish airports, because Turkey does not provide radar data. Thus, a significant amount of trajectory data is missing in the climb and descent phases for flights to/from Turkish airports.
Table 2 shows the amount of flights available in the NM data and the amount and share of flights fit for purpose (flights for which sufficient and reliable trajectory data are available) during 2019 and 2020. A more extensive list is available in Appendix A.

Table 2: Number of flights available and fit for use (2019-2020)

Airport	Available flights	Flights fit for use	Share of flights fit for purpose
EHAM	372235	370314	99.5%
EDDF	363049	360412	99.3%
LFPG	362565	360324	99.4%
EGLL	341305	339520	99.5%
LEMD	295758	293543	99.3%
EDDM	279140	277405	99.4%
LTFM	255035	24340	9.5%
LEBL	233400	232134	99.5%
LIRF	206469	205653	99.6%
LOWW	194821	194007	99.6%
LSZH	187098	185453	99.1%
ENGM	187015	186079	99.5%
EGKK	182572	180932	99.1%
EKCH	180733	179990	99.6%
LTFJ	176287	37429	21.2%
LGAV	164613	163109	99.1%
LIMC	163291	162244	99.4%
EIDW	162371	161517	99.5%

EBBR	160167	159070	99.3%
ESSA	159441	158608	99.5%
LPPT	154967	153107	98.8%
LFPO	153024	151950	99.3%
EDDL	152113	150509	98.9%
LEPA	146762	146151	99.6%
EGSS	141867	140092	98.7%
EPWA	136904	135858	99.2%
EGCC	134695	133548	99.1%
EFHK	133597	130895	98.0%
LTAI	133323	4646	3.5%
LSGG	128842	127872	99.2%

The FTFM data used in the en-route methodology is available for all flights. Since only one point per flight is needed and a statistical method is used, all the data needed for the calculations is available.

2.1.2 Geographical coverage

The geographic area analysed covers almost all EUROCONTROL Member States.
Figure 1 and Figure 2 show the position data available on respectively 01/05/2015 and 01/05/2020. It is clear that there is a better coverage over and around the Warszawa, Nicosia, Casablanca and Tel-Aviv FIRs since 2015. As earlier stated, Turkey has not provided radar data. This results in the low amounts of flights being analysed as mentioned before. Nevertheless, there are flights to/from Turkey that are being analysed because some radar data is available from neighbouring States.

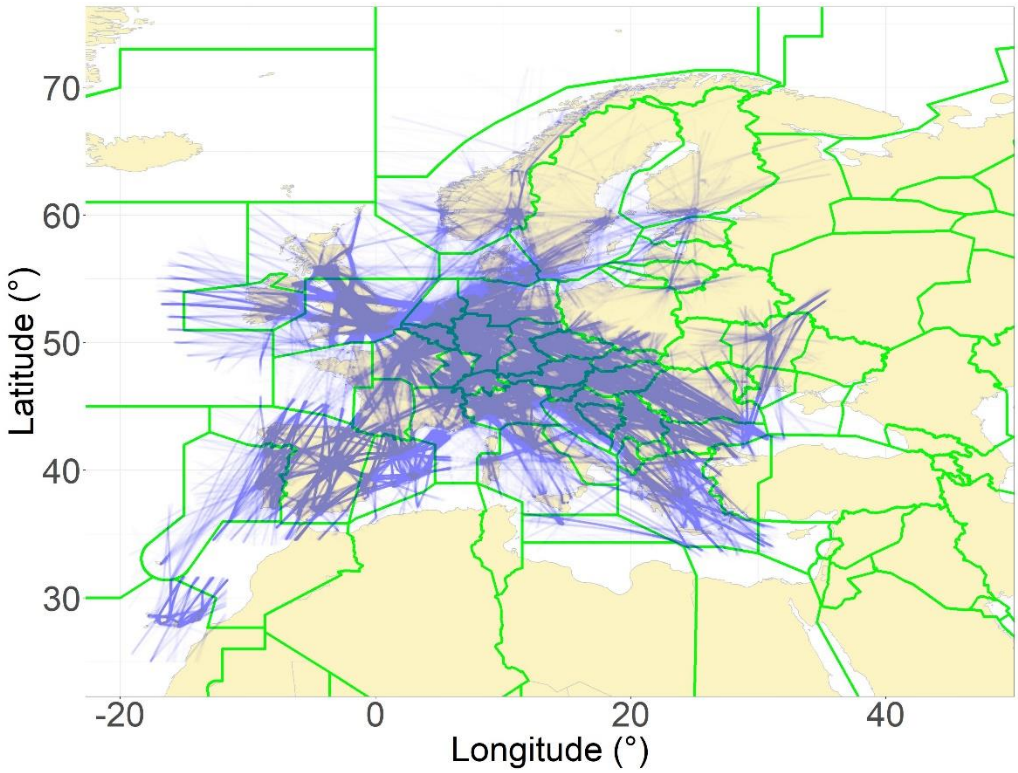

Figure 1: Data coverage on 01/05/2015

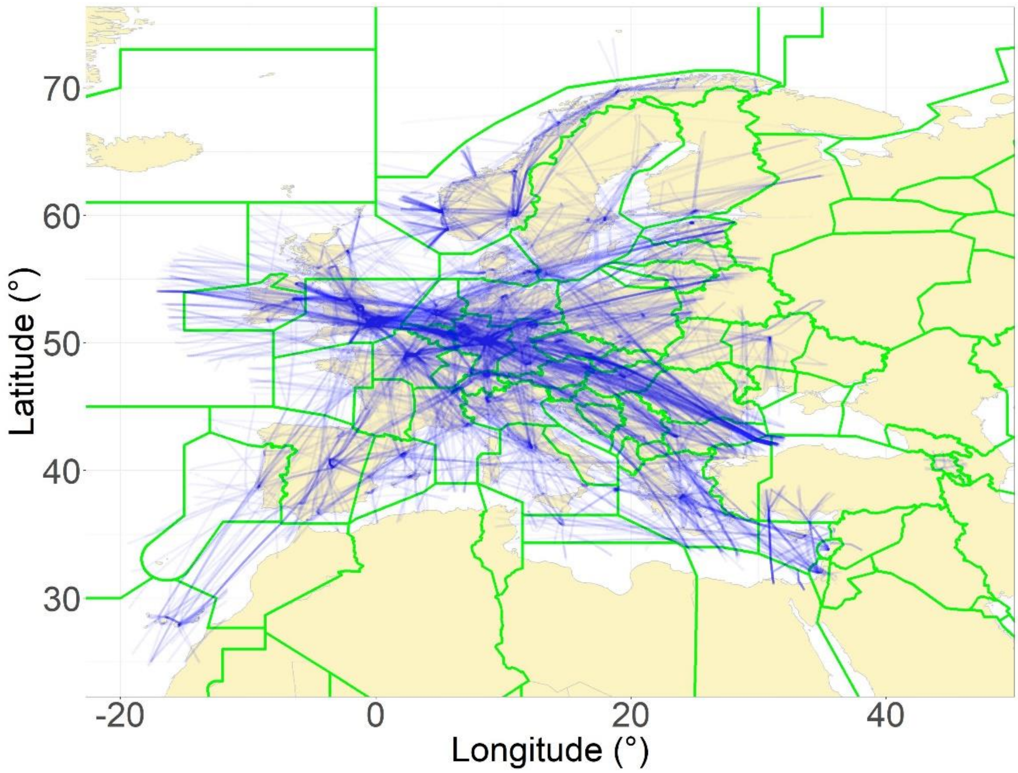

Figure 2: Data coverage on 01/05/2020

2.2 Data quality

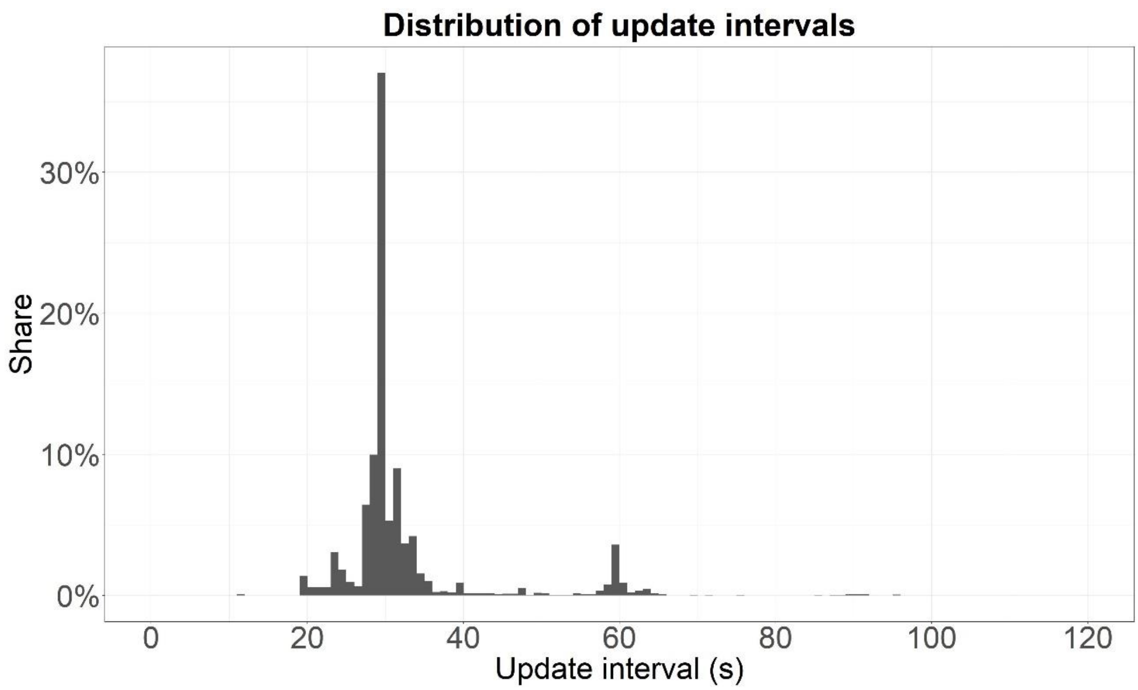

Figure 3: Distribution of update intervals for PRU data

Figure 3 shows one high peak and one lower peak at update intervals of respectively 30 and 60 seconds. This is due to the legal requirement for States to provide surveillance data based on 30 seconds reporting interval. The small peak at 60 seconds is a result of data points missing, creating an interval of around 60 seconds between two data points.

As previously examined and described in (Performance Review Unit, EUROCONTROL, 2017), the update interval has an impact on the results. In general, the lower the update interval, the more accurate level flight can be detected. The results presented in (Performance Review Unit, EUROCONTROL, 2017) also indicate that more level flight can be detected when the update interval is lower.

3 VERTICAL FLIGHT EFFICIENCY DURING CLIMB AND DESCENT

3.1 Methodology

The methodology for vertical flight efficiency during climb and descent is explained in detail in (Performance Review Unit, EUROCONTROL, 2017). Level flight is measured within a radius of 200 NM around an airport and the main assumption is that level flight is inefficient. The methodology doesn't take into account non-optimal positions of the Top of Climb/Descent, e.g. when the Top of Descent is too late, there are no level segments but the descent path is too steep which is another form of inefficiency.

A trajectory part between two points on that trajectory is considered as level when the trajectory stays within a fictional window as can be seen in Figure 4.

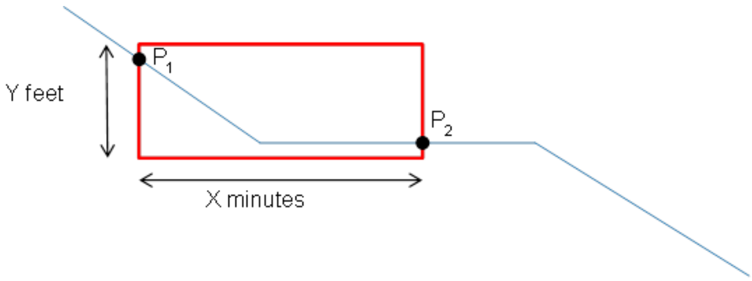

Figure 4: Rolling window for level segment detection

This window has temporal and altitude dimensions related to a specific vertical velocity that is considered to be the limit between level flight and climb/descent. This limit has also been under discussion in the CCO/CDO Task Force, whose purpose was to propose a harmonised methodology to assess vertical flight efficiency during climb and descent. The Task Force followed the recommendation of the PRC and PRU to use 300 feet per minute as a limit for the vertical velocity. Consequently, the dimensions of the window have to adhere to the following relationship:

$$\frac{Y}{X} = 300\ feet\ per\ minute$$

E.g. when a temporal size of 10 seconds is used, the window is 50 feet high. In this case the altitude information of the climb or descent trajectory is considered at every interval of 10 seconds. However, since trajectory data are a discrete representation of the actual trajectories, the necessary altitude information is not available for every required time instance. Because of this and whenever required, a linear interpolation is done to obtain the information needed for the analysis.

3.2 Results

3.2.1 Time in level flight

3.2.1.1 Full climb and descent

Figure 5 presents the average time flown level per flight during descent for the top 30 airports in 2020. The amount of time recorded in level flight in the descent phase has decreased significantly due to the low amount of traffic. Nevertheless, the values for the Paris airports stayed quite high.

Figure 6 shows the amount of time recorded in level flight in the climb phase, which has almost not changed. The values have always been very low so there is much less room for improvement in the climb phase. Nevertheless, a reduction of 40 seconds (50 seconds for the COVID period) is seen for flights departing from Zurich. Skyguide was contacted and provided feedback regarding this observation. Every SID for the two main departure runways (28 and 16, which are used about 80% of the time) crosses a STAR. This resulted in a lot of flights with level flight in order to deconflict crossing traffic. Due to the lower amount of traffic in the COVID period, less crossings were happening, so more continuous climbs could be achieved.

In addition, many en-route sectors could be collapsed to one single sector due to the low amount of traffic. Probably less level flight is needed at sector boundaries, partially because there is more time for coordination during handovers to neighbouring sectors.
Figure 5 and Figure 6 also present the values for the COVID period (01/03/2020-31/12/2020). For most airports, the values are a bit lower in this period. This is expected since a lower number of flights usually results in a lower amount of possible conflicts. Levelling off an aircraft is one method for deconfliction so less level flight is indeed expected with the lower amount of flights.
Overall, the average time flown level is around 6 times higher during the descent than during the climb, both for the full year and the COVID period.
The numerical results can be found in Appendix B.1 for the descent and in Appendix B.2 for the climb.

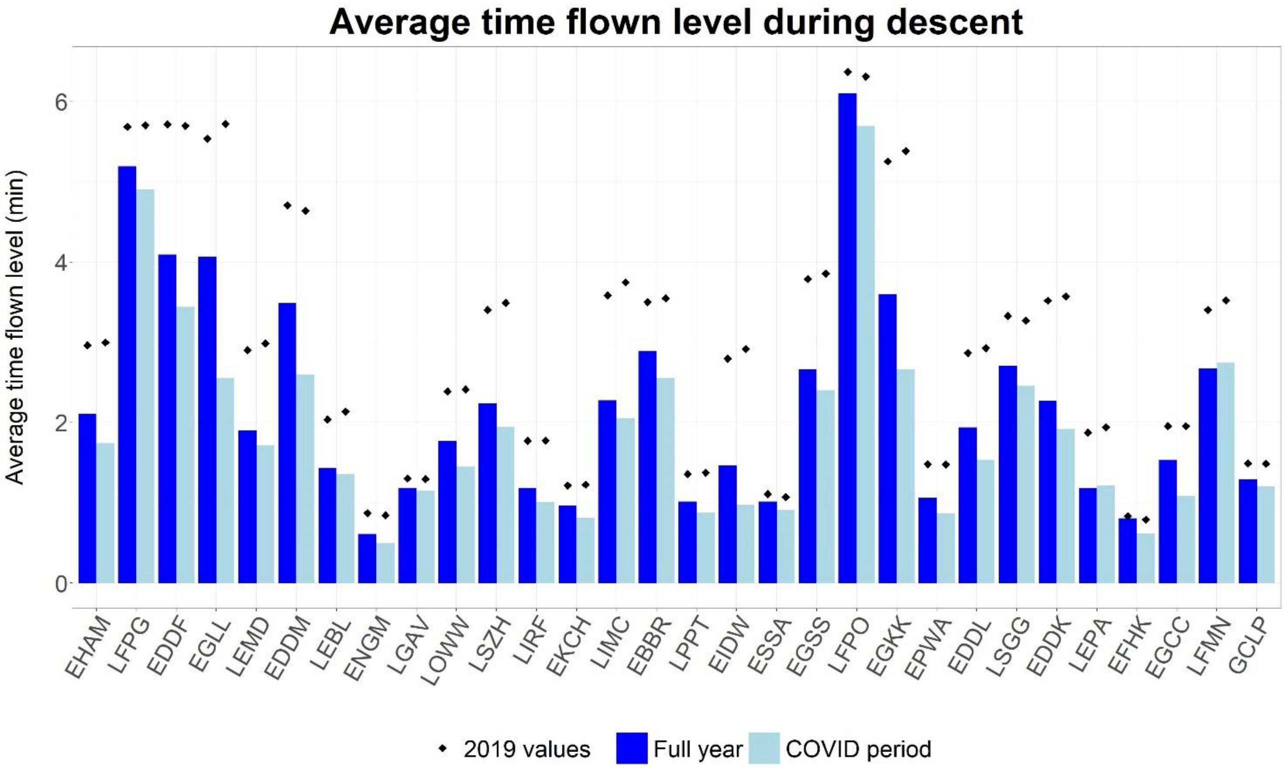

Figure 5: Average time flown level per flight during descent

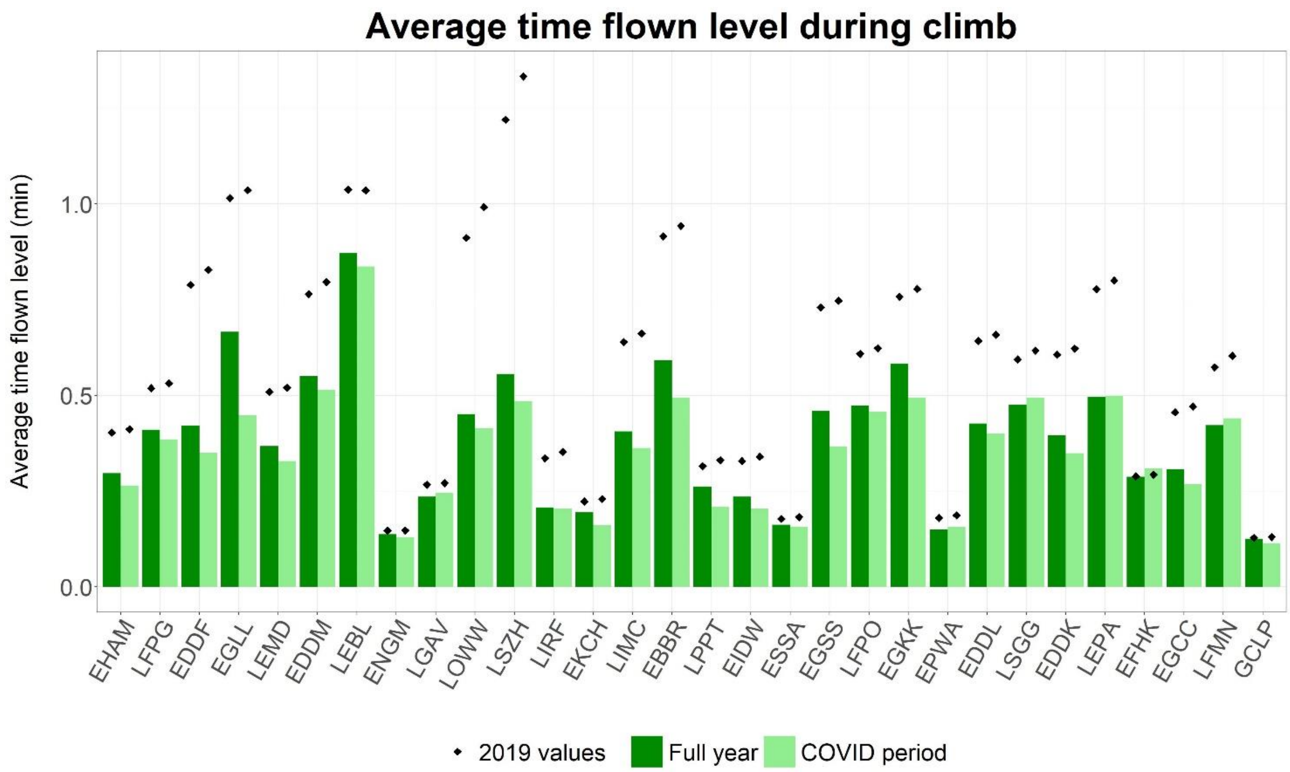

Figure 6: Average time flown level per flight during climb

3.2.1.2 Descent below FL075 and climb until FL105 (noise impact)

Climbs and descents at lower altitudes have an environmental impact on noise and on fuel consumption. For descents, the altitude from which SESAR estimates that the principal environmental impact upon the ground relates to noise is 7,000 feet while for climbs SESAR estimates that noise is the principal environmental impact until 10,000 feet (CANSO; ACI;, 2015).

It is clear from Figure 7 and Figure 8 that the amount of level flight that occurs in those parts of the vertical profile where noise is the principal environmental impact, is much larger in the descent phase than in the climb phase. The actual noise levels depend upon aircraft thrust which is much higher during the climb than during descent so there is no linear relationship between the amount of level flight and the noise impact.

The reduction in level flight during the descent for the COVID period is slightly less pronounced than for the full profiles and for most airports, the values remained quite stable.

Most airports have almost no level flight below 10,000 feet in the climb, except for London Heathrow, London Stansted, Paris Orly and London Gatwick airport. However, the values for these airports are still very low.

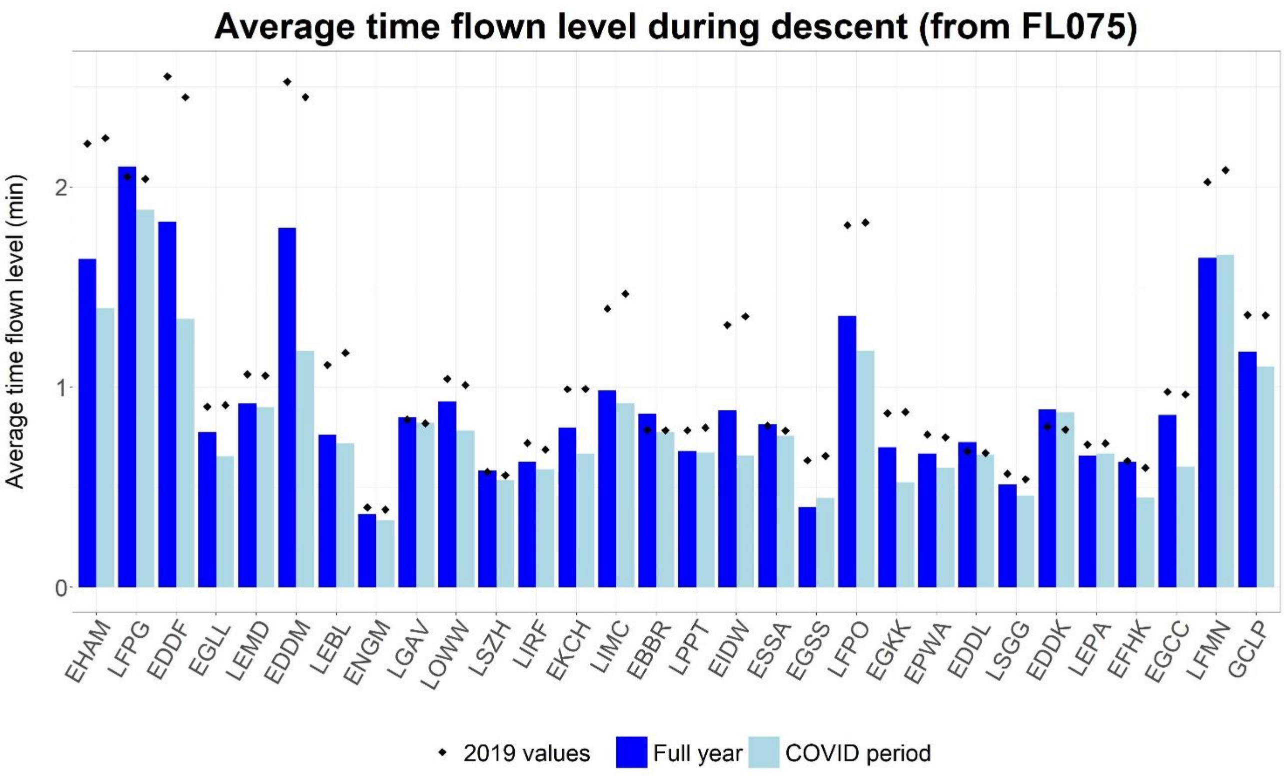

Figure 7: Average time flown level per flight during descent below FL075 (noise impact)

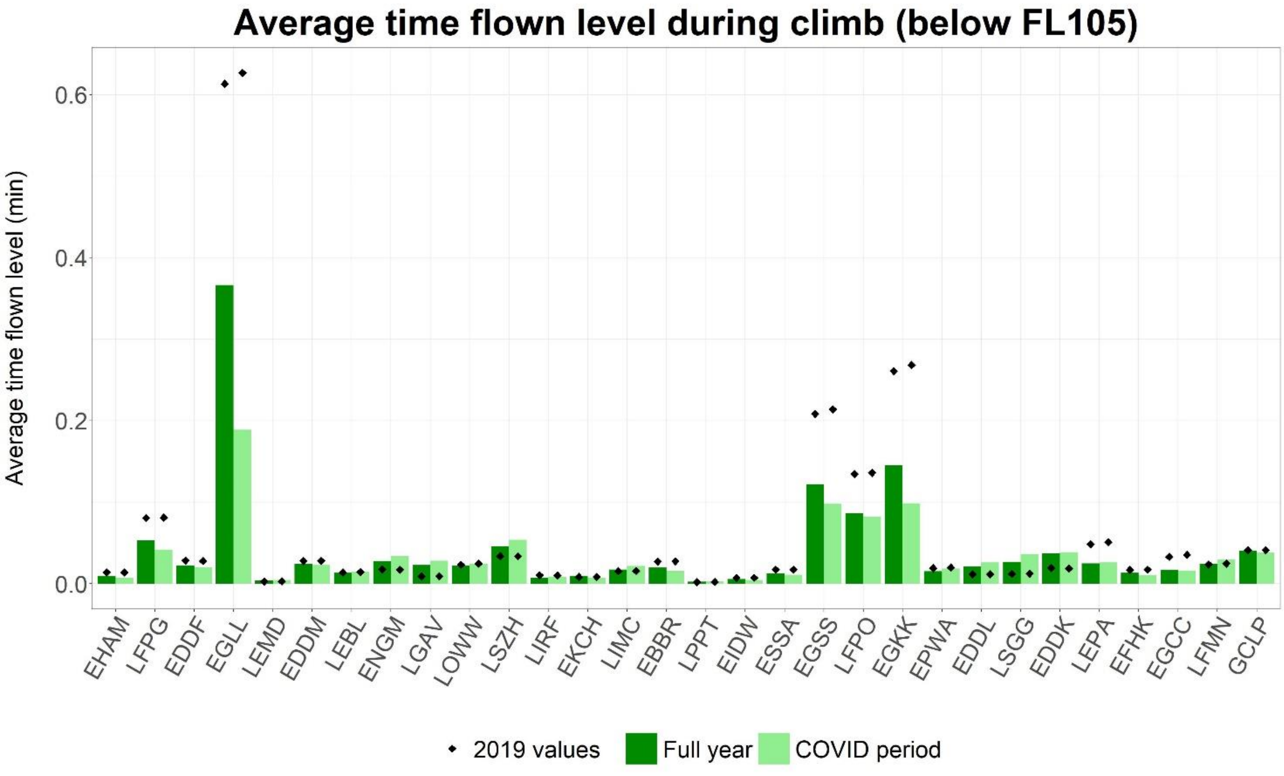

Figure 8: Average time flown level per flight during climb below FL105 (noise impact)

3.2.2 Median CDO/CCO altitude

Not only the duration of level flight but also the altitude of the level flight is an important aspect for vertical flight efficiency during climb and descent. To address this aspect, the median CDO/CCO altitude is considered which is calculated by taking the altitude of the lowest level segment for each flight. This information is then aggregated by taking the median value over all considered flights per airport. In other words, the metric indicates the altitude from/up to which at least 50% of the flights perform a continuous descent/climb.

Figure 9 and Figure 10 respectively show the median CDO and CCO altitudes. The figures show that continuous descents until the runway start at much lower altitudes than continuous climbs, probably due to specific arrival procedures and the general trend to give priority to climbing traffic when arrivals and departures have to be deconflicted.

A number of airports saw a (significant) increase of the median CDO altitudes, probably due to the low amount of traffic. The median CCO altitudes remained stable.

In most cases, the values for the COVID period are very similar to the full year values. This indicates that the number of flights has a lower influence on the median CDO/CCO altitudes than on the average time flown level.

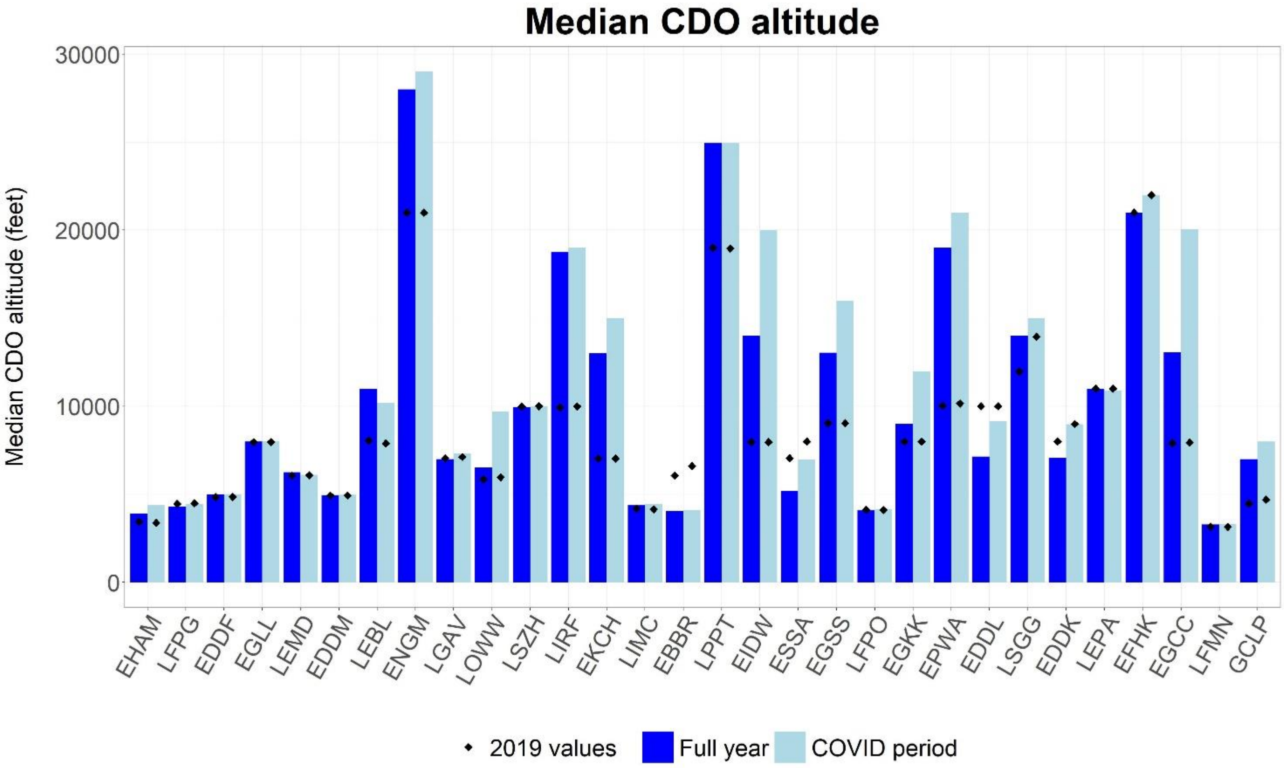

Figure 9: Median CDO altitude

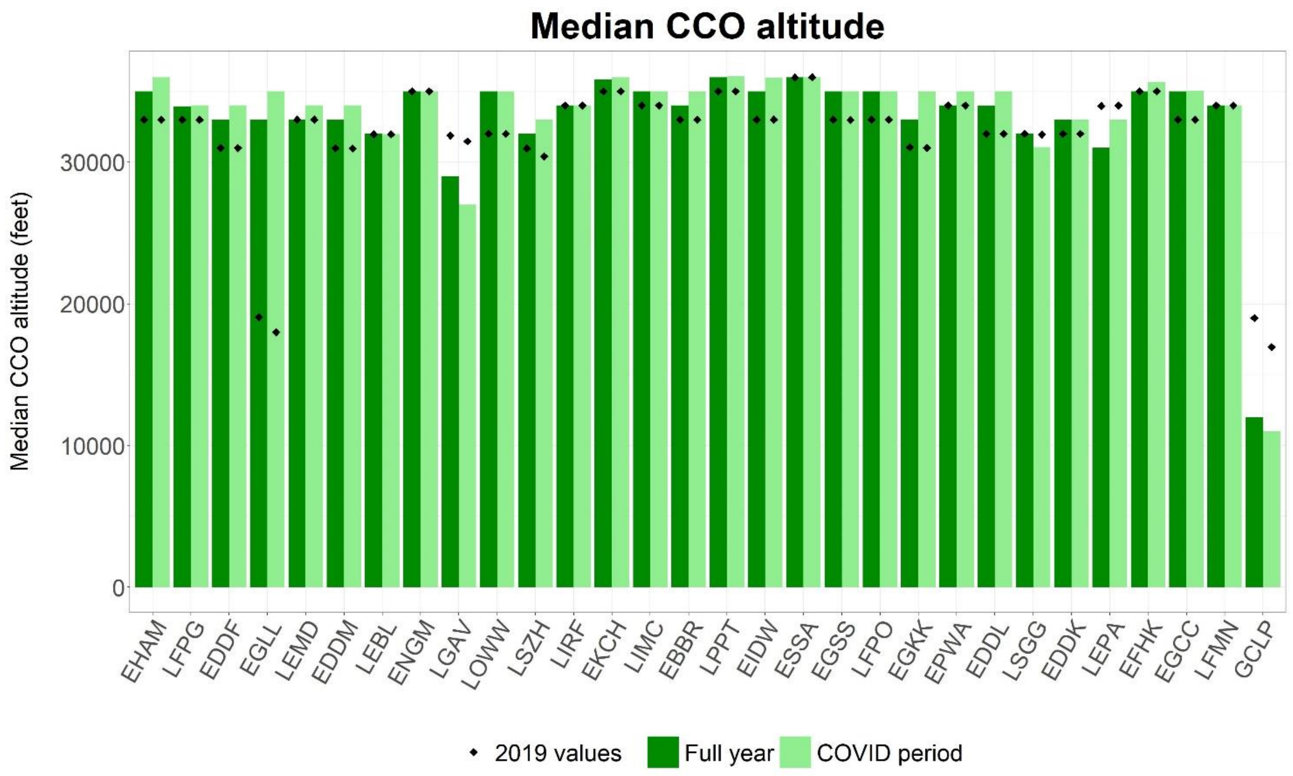

Figure 10: Median CCO altitude

3.2.3 Share of unimpeded flights

Flights without any level segments according to the methodology (minimum 20 seconds long, within the analysis radius…) are defined as unimpeded flights (CDO or CCO flights). Figure 11 and Figure 12 respectively show the shares of unimpeded flights recorded during the descent and climb phases. In general, the percentage of unimpeded flights recorded in the descent phase is lower than during the climb.

In almost every case, the share of CDO/CCO flights has increased, which is in line with the observation of the reduced amount of level flight detected (see 3.2.1).

CDO flights: despite the low traffic numbers in 2020, there are still a number of airports for which the share of CDO flights is very low: Paris Charles de Gaulle, Frankfurt, Munich and Paris Orly. For Paris Charles de Gaulle, there is almost no improvement while the share of CDO flights has even decreased for Paris Orly.

CCO flights: the share of CCO flights has remained quite stable, except for the London airports and Zurich. For the London airports, this is because the departing flights don't have to stay below the normal stack positions since no or hardly any arriving aircraft had to use the stacks due to the low traffic numbers. The improvement for Zurich can be linked to the reduction of the average time flown level during climb as discussed in 3.2.1.1.

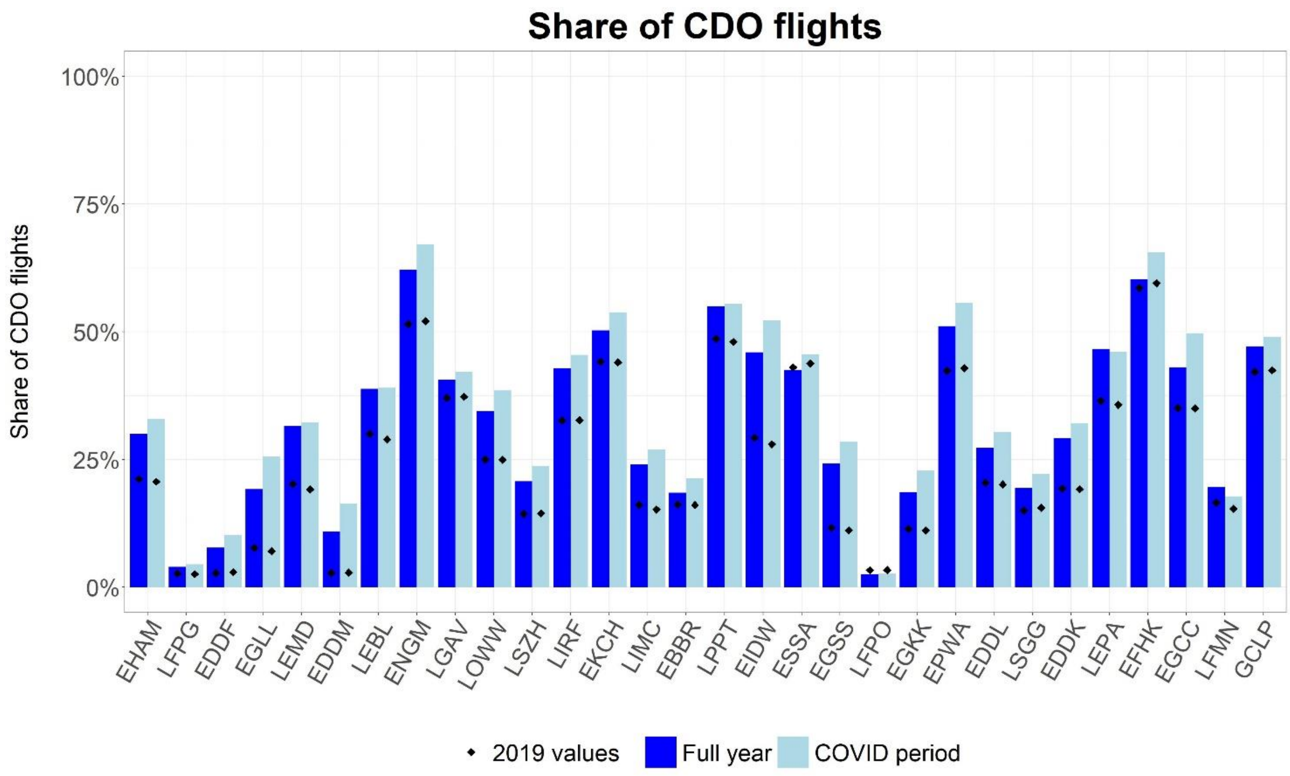

Figure 11: Percentage of CDO flights

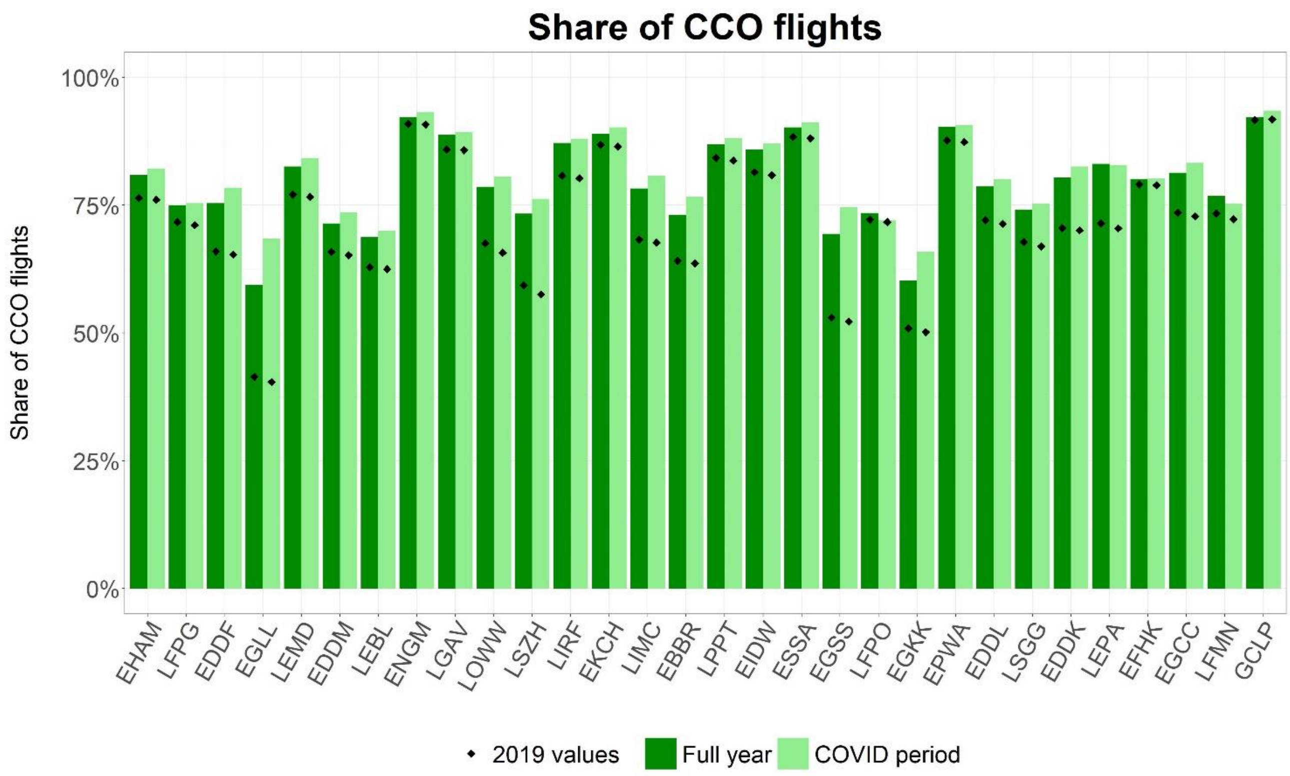

Figure 12: Percentage of CCO flights

3.2.4 Median CDO/CCO altitudes versus average time flown level

Figure 13 presents the median CDO and CCO altitudes versus the average time flown level per flight for the top 30 airports in 2020. The beginnings and ends of the arrows indicate the values for 2019 and 2020. The more to the top left of the figure, the better the vertical flight efficiency.

This figure clearly reflects the overall reduction in 2020 in average time flown level during the descent, except for the Paris airports, and for some airports also an improvement of the median CDO altitudes. It is apparent that two groups of airports can be seen:

- Airports for which the improvements are mainly constituted by a reduction of the average time flown level. These airports generally had an average time flown level of more 2 minutes in 2019.
- Airports for which the improvements are mainly constituted by an increase of the median CDO altitudes and a slight improvement of the average time flown level. These airports already had relatively low amounts of average time flown level in 2019.

Overall, it can be assumed that with a significant decrease of the number of flights, airports with high traffic numbers in normal circumstances will adhere to the procedures in place (which might include level segments). Airports with lower traffic numbers in normal circumstances might also have the possibility to adjust the procedures, affecting the median CDO altitudes in a positive way.
There are no significant changes in the climb results, except for London Heathrow and Gran Canaria. London Heathrow has a much higher median CCO altitude because the departing flights don't have to stay below the normal stack positions since no or hardly any aircraft have to stay in the stacks due to the low traffic numbers. The median CCO altitude for Gran Canaria is lower than in 2019 because the relative share of flights to nearby airports is higher in 2020. Flights for which no level flight has been detected, have the cruising altitude as their CCO altitude. The flights to nearby airports don't go as high as longer flights so even if they don't have a level segment during the climb, they have a low CCO altitude. This results in a lower median CCO altitude in 2020 than in 2019 but with no reduction of efficiency.

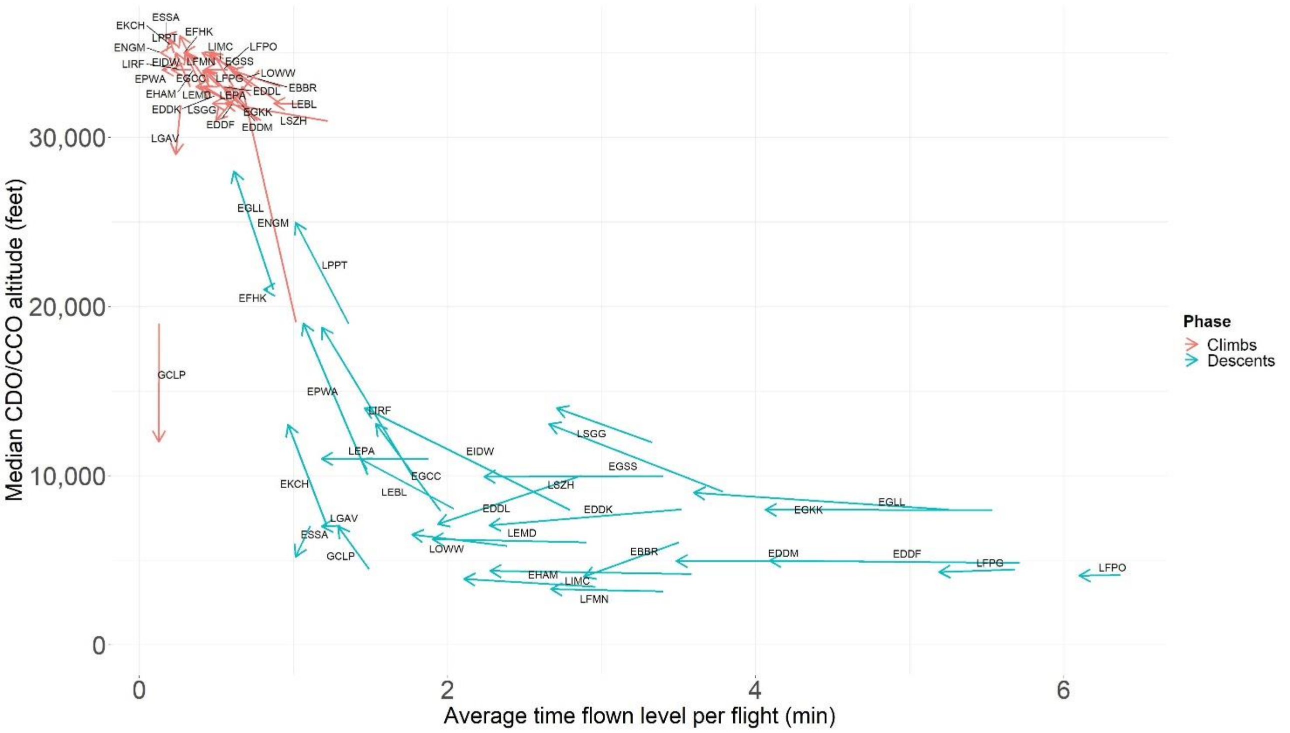

Figure 13: Median CDO/CCO altitudes vs. average time flown level (2020 vs. 2019)

3.2.5 Potential fuel benefit pool

The impact of a level segment in terms of additional fuel used depends on the duration and the altitude at which the level segment happens. Both of these aspects are reflected individually in the previous metrics but a calculation of the additional fuel used gives an idea of the potential fuel benefit pool.

The calculation is made by assuming that the detected level segments would have taken place at cruising altitude. Then, the difference in fuel burn between the level segments at their actual altitudes and at the cruising altitudes is calculated.
The potential fuel benefit pool is not reflecting the amount of fuel that can be saved by optimising the vertical profiles during climb and descent. It is rather an estimation of what amount of fuel would be saved when all flights could perform continuous descent and climbs, which is not realistic.
The calculation depends on the availability of the aircraft type in the BADA database so the calculation could not be made for all level segments.
For all examined airports, the additional fuel burn during 2020 is estimated to be 5.0 million kg during the climb and 53.7 million kg during the descent. So, the benefit pool during descent is in the order of magnitude of 10 times larger than during the climb. For the top 30 airports, 2.9 million kg of additional fuel is estimated during the climb (57% of the total) and 35.7 million kg during the descent (66% of the total). The individual contributions of the top 30 airports is shown in Figure 14.
Overall, the average additional fuel consumed per flight during the descent is 13.7 kg while this is only 1.3 kg during the climb. This is in line with the higher amount of level flight during the descent and the lower median CDO altitudes. For the top 30 airports, the average additional fuel consumed per flight during climb and descent is respectively 21.8 kg and 1.7 kg per flight, which is (slightly) higher than the overall average for all airports. Figure 15 presents the average additional fuel consumed per flight for the top 30 airports.
0 contains the numerical results regarding the fuel benefit pool for the top 100 airports.

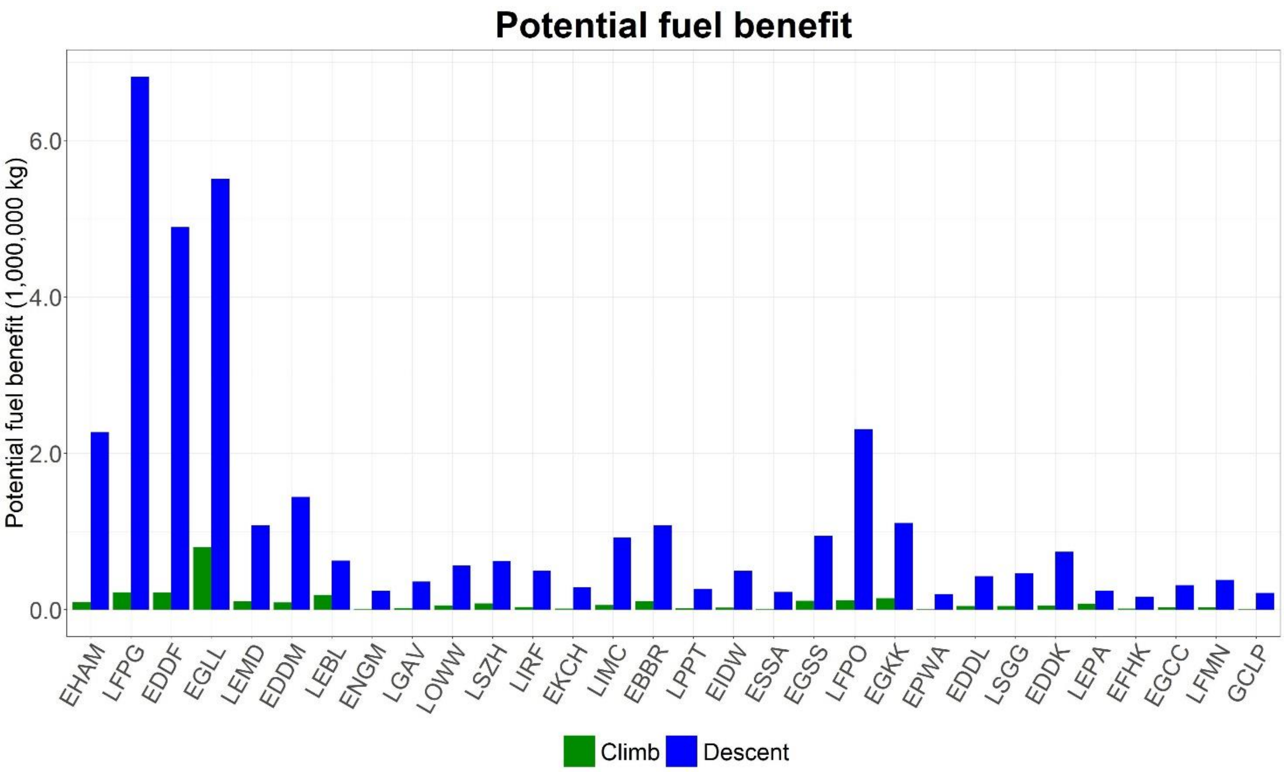

Figure 14: Potential fuel benefit for the top 20 airports (2020)

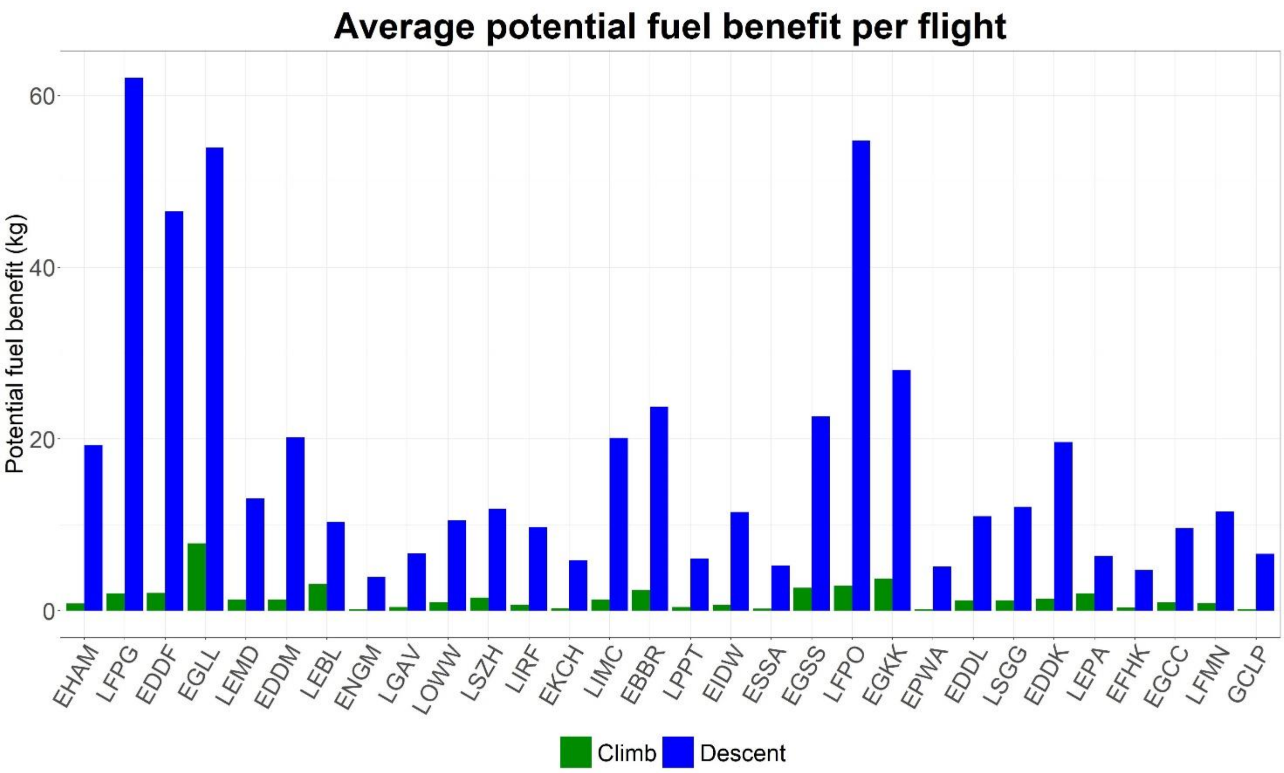

Figure 15: Average potential fuel benefit per flight for the top 20 airports (2020)

3.3 Paris airports

As mentioned before, the results for the Paris airports do not follow the general tendency of improvements. The lateral trajectories for flights arriving at Paris Charles de Gaulle in April 2020 are shown in Figure 16. The level segments are highlighted in red. A lot of level flight is detected in the vicinity of the airport, with clear hotspots in the arrival procedures.
Figure 17, Figure 18 and Figure 19 provide the monthly values for the CDO/CCO metrics during 2020. There is a decrease in April for the average time flown level during the descent but all other metrics remained stable, especially compared to the changes for other major airports.

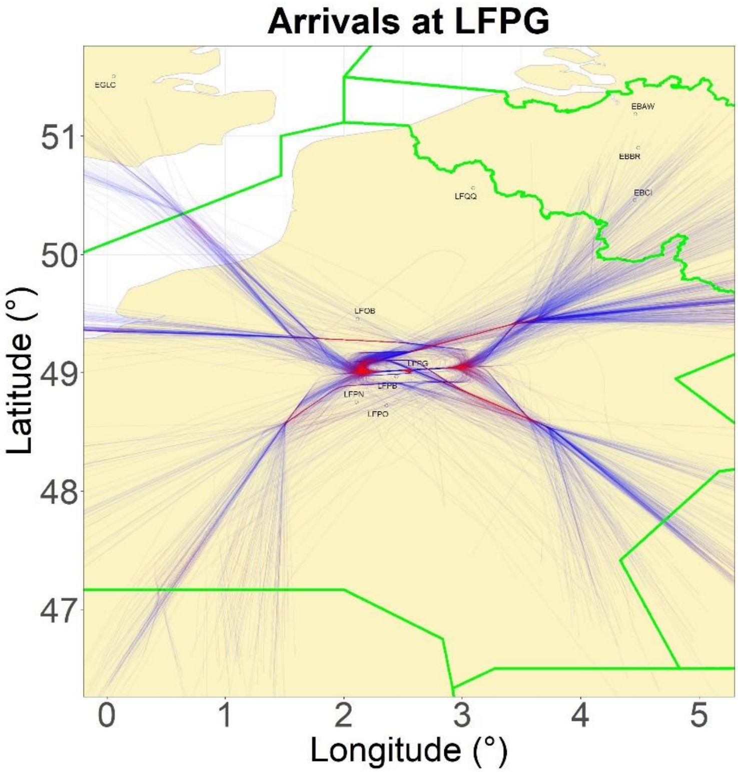

Figure 16: Trajectories with level segments highlighted in red (April 2020)

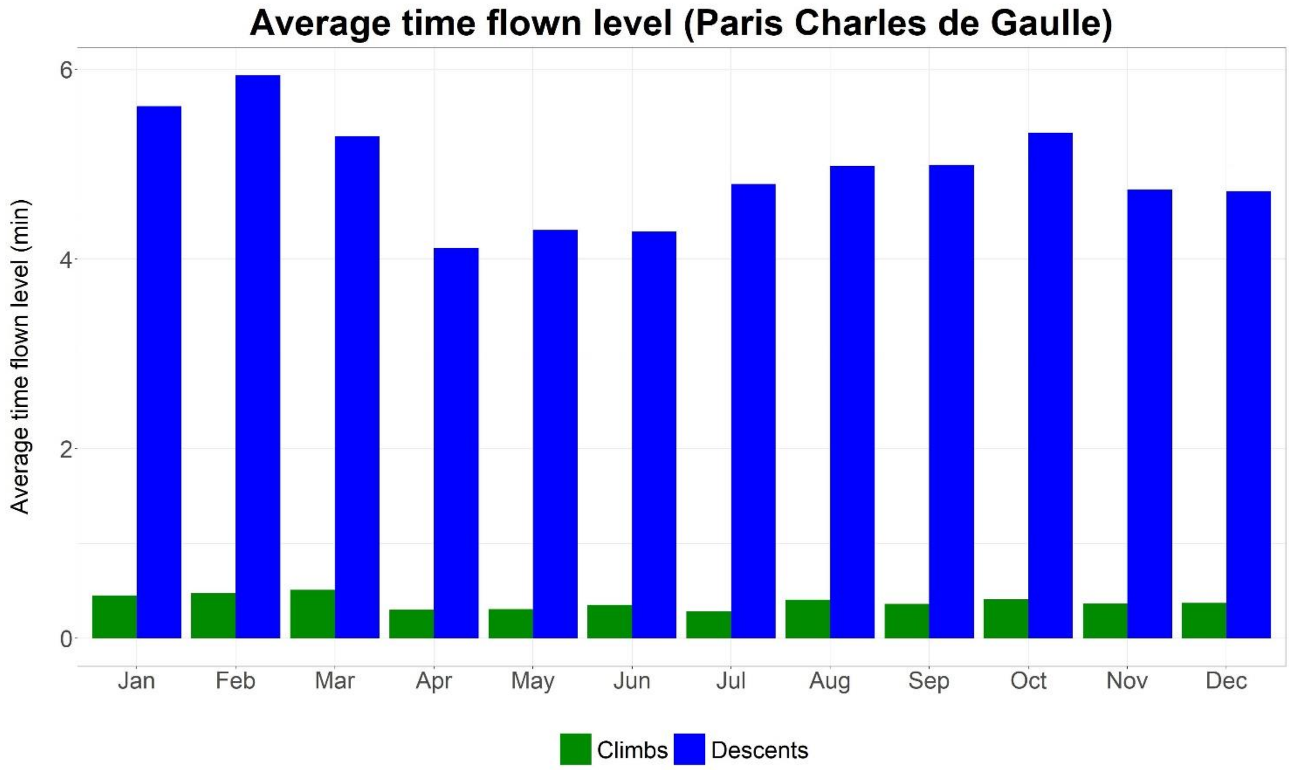

Figure 17: Monthly values of average time flown level (LFPG - 2020)

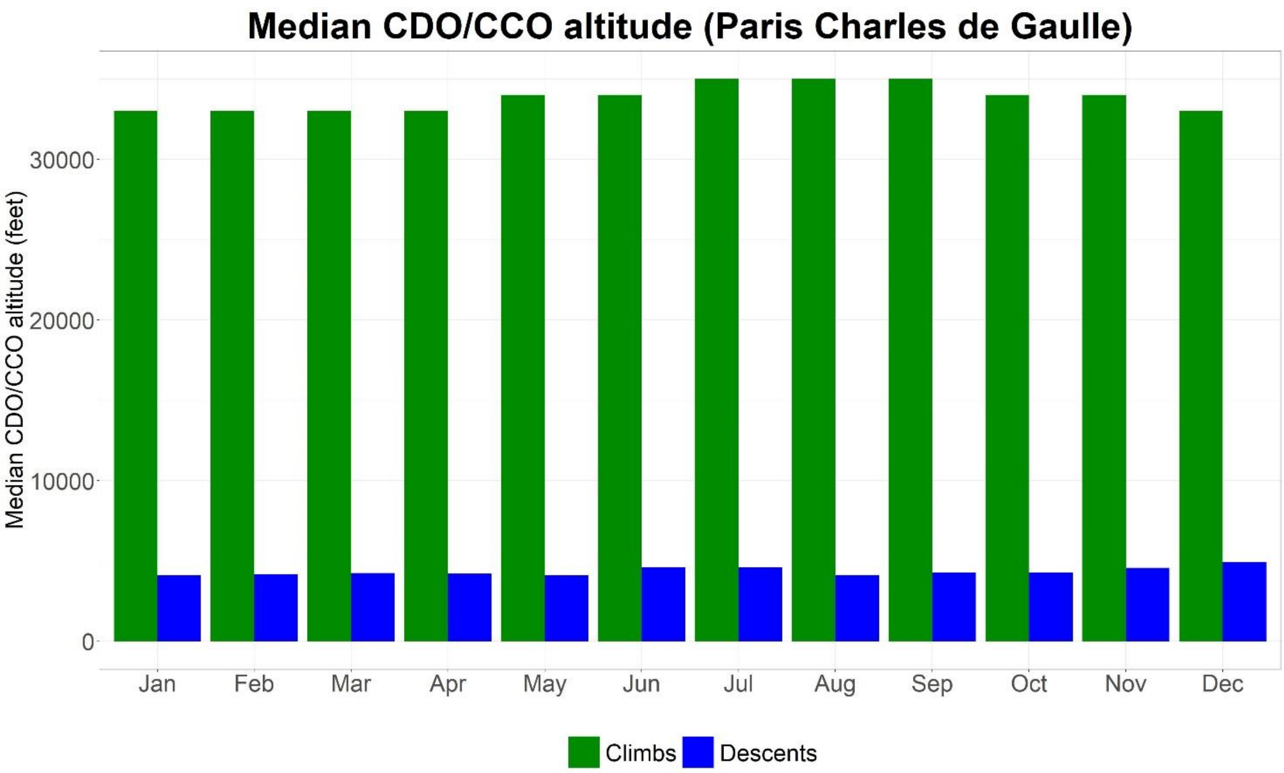

Figure 18: Monthly values of median CDO/CCO altitudes (LFPG - 2020)

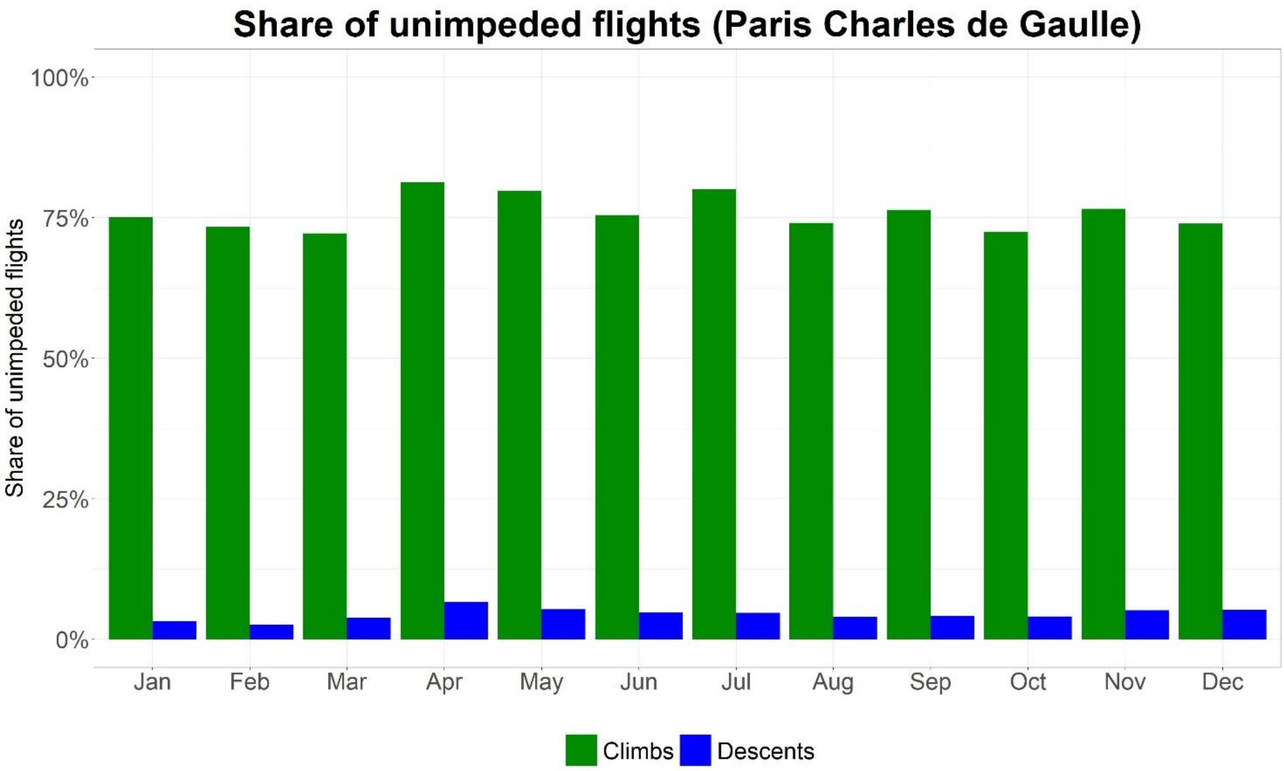

Figure 19: Monthly values of share of CDO/CCO flights (LFPG - 2020)

Air France and DSNA have been contacted regarding these observations and have provided feedback.
Air France's view on the observations is the following:
"In the Paris TMA and generally within France, there are issues with the old ATC system (CAUTRA FDPS). Most of the airspace design and subsequent Letters of Agreement are hardcoded in the ATC system. Due to its

implementation, this system is not adaptable without important developments or safety issues. Since the arrival procedures into the Paris airports contain level flight by default, these level segments are not easily removed or adapted. This is the reason why a lot of level flight is detected for the Paris airport despite the low traffic numbers.
DSNA is planning to implement the 4-Flight system together with CoFlight FDPS in the next years, which should allow more dynamicity. After this implementation, DSNA will be able to work on the airspace design (Free Route Airspace and TMA connections).
Air France in collaboration with DSNA is trying some temporary procedures to improve the situation by:

- *Adapting Letters of Agreement in certain circumstances for specific flights (requiring a lot of manual interactions and coordination between ATCOs), and*
- *PBN trials in Paris Charles de Gaulle* (ATC Network, 2021).

Those initiatives lead to some significant improvements on the specific flights with later Tops of Descent and more efficient 3D trajectories (less level flight). Unfortunately, it is not widely extended and it doesn't appear on the big picture shown in the overall results".

DSNA provided the following feedback:
"The Paris air traffic system was put into service in 2002 in order to meet the dual need for safety and capacity in the context of the operation of simultaneous double or triple parallel approaches depending on the configuration on the Paris Charles de Gaulle double runways and Le Bourget airport.
This system meets the needs of strategic separations of traffic flows, arrivals and departures of 7 airports: Paris-Charles de Gaulle, Paris-Orly, Paris-Le Bourget, Vélizy-Villacoublay, Toussus-Le Noble, Pontoise and Beauvais, representing an air traffic of approximately one million flights per year in 'normal' periods. Contrary to the Air France statement, there is nothing to do with our ATM technical systems CAUTRA or 4Flight.
Specific to the Paris region, the level of traffic to and from Paris-Le Bourget remained at a high level of approximately 70% of the normal amount of traffic. The interdependence with the trajectories of Paris Charles de Gaulle leads to less possibility of optimisation.
The COVID crisis has led to the establishment of strict sanitary measures for physical distancing for controllers in the control centres. Despite the decline in traffic, this had the following consequences:

- *A reduction in the number of open positions,*
- *A gradual decrease in the level of training of controllers, and*
- *A need for stricter compliance with published procedures, LOAs and operational manuals.*

It has been noted as well that aircrews tend to use manual control to maintain a sufficient level of training, despite their low number of flights. Therefore, the possibilities offered by ATC, as described below, for optimising flight path to crews are not fully utilised.
However, two operations has been launched in October 2020 to improve the environmental performance of incoming flights.
One is to improve vertical profiles of incoming flights in the TMA by increasing the transfer altitudes between the ACC and the APP (Approach sectors). These provisions, giving satisfaction, are intended to be permanently implemented. They are also evaluated by Paris Orly's approach control centres together with Paris ACC. A first evaluation by Air France leads to a 15% decrease in consumption between the Top of Descent and the runway threshold.
The other is the implementation of PBN to ILS procedures, in order to generalise the execution of 7/7 continuous descents, with an objective of putting it into service at the end of 2023, on all Paris Charles de Gaulle runways. An assessment has begun and to date nearly 1,000 flights have flown this new procedure. Expected future gains are 70% less overflown people and a substantial fuel consumption gain".

4 EN-ROUTE VERTICAL FLIGHT EFFICIENCY

4.1 Methodology

The methodology used to analyse en-route vertical flight efficiency is described in (Performance Review Unit, EUROCONTROL, 2016). Essentially, the maximum filed altitudes for a specific airport pair under investigation is compared to the maximum filed altitudes at similar airport pairs that have no RAD constraints. When the altitudes for the examined airport pair are lower than the altitudes for the reference airport pairs, it is assumed that there is an inefficiency. Figure 20 shows an example of distributions of maximum altitudes for an examined airport pair (blue bars) and reference airport pairs (red bars). In this example, it can be seen that there are no flights that have filed higher than FL350 on the examined airport pair while there are flights that have filed higher in the reference distribution. This might be an indication that there is an altitude restriction for the flights on the examined airport pair (probably at FL355 or FL365). The methodology assumes that the flights would normally have filed higher so there is an inefficiency.

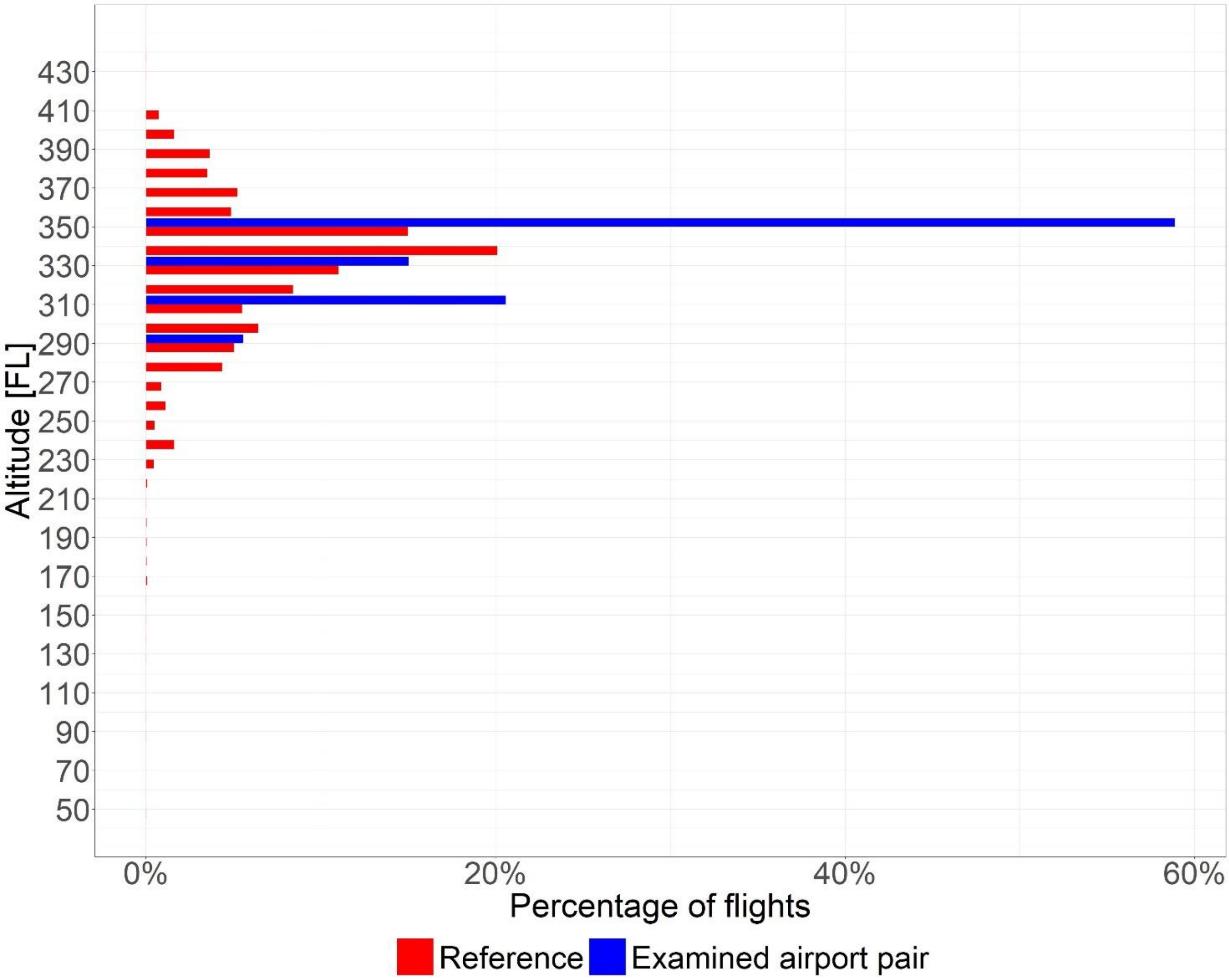

Figure 20: Example of distributions of maximum altitudes

4.2 Results

4.2.1 RAD constraints

The results highlight inefficiencies but the causes are not always easy to pinpoint. RAD constraints, airline choices, flight planning strategies and errors are a few of the most common causes for the identified inefficiencies.
In many cases, vertical RAD constraints can be identified to be the cause of a vertical inefficiency. Despite the observed vertical inefficiency, it is important to note that RAD constraints are used and needed to deal with capacity constraints.

Figure 21: Number of constrained airport pairs and flights

Figure 21 shows the number of airport pairs and flights that experience a RAD constraint since AIRAC cycle 1505. The number of constrained flights and airport pairs has seen a significant increase in the summer of 2018 due to the extra measures taken in order to deal with the foreseen capacity shortages. Since then, the amount of impacted flights has stayed relatively stable until the huge reduction of flights due to the COVID crisis.
The number of impacted airport pairs decreased before the summer of 2019 while the amount of impacted flights stayed quite stable, which indicates that a high number of airport pairs with low traffic numbers were (unintentionally/unnecessarily) impacted during 2018. The number of impacted airport pairs stayed quite stable until the end of 2020 but almost 300 vertical RAD constraints were lifted during 2020 because of the low traffic numbers.
Figure 22 presents the altitudes of the vertical RAD constraints during AIRAC cycle 1907. Most constraints are seen at or above FL245 with a large share of the constraints at FL245. This altitude is the common division between lower and upper airspace so the intention of these RAD constraints is probably to keep flights on the related airport pairs out of the upper airspace sectors. Indeed, in some cases, flights would enter the upper airspace for only a short period of time, which results in a relatively greater workload for the controller with respect to the flight time spent in the sector.

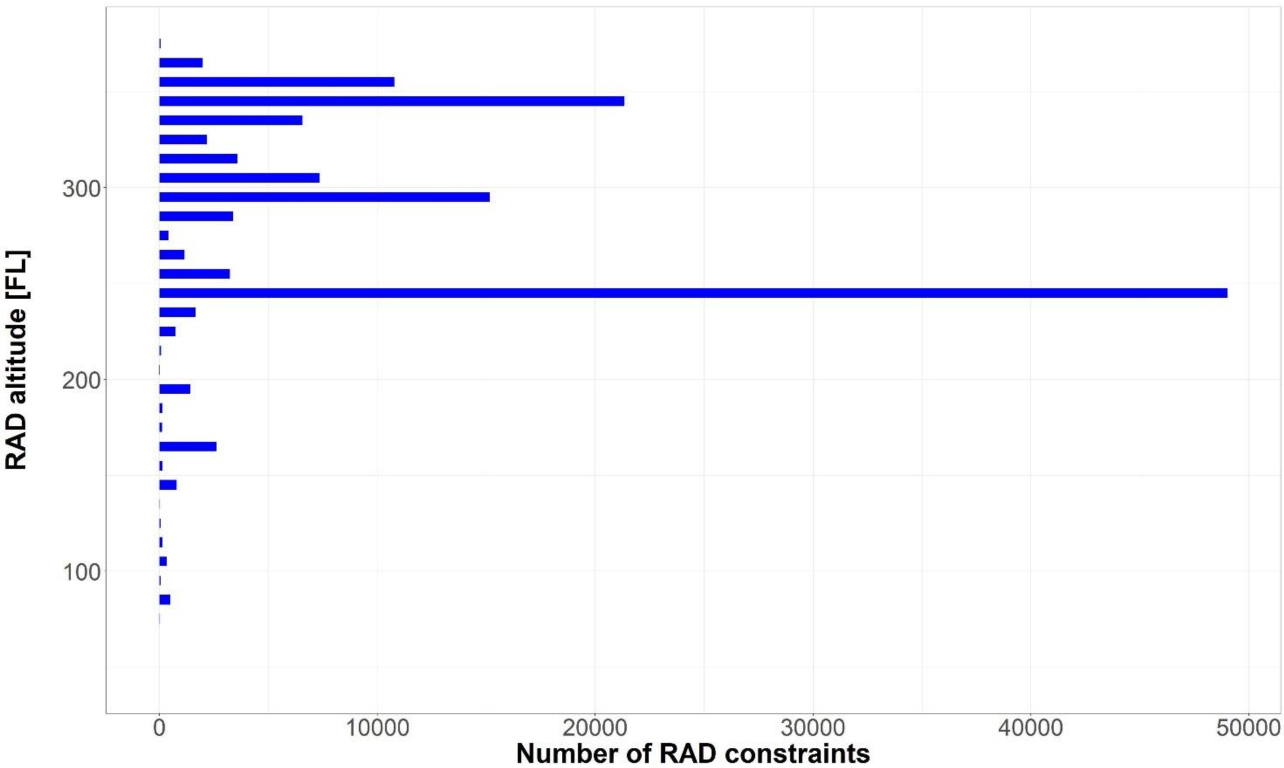

Figure 22: Altitude constraints of the impacted airport pairs

Figure 23 shows the great circle distances of the airport pairs that are impacted by a RAD constraint during AIRAC cycle 1907. The majority of these airport pairs is less than 500 NM apart. This means mainly flights with a relatively short cruise phase are impacted by a vertical RAD constraint. Nevertheless, there are a number of airport pairs with a large great circle distance (up to 1625 NM) that have a RAD constraint. A RAD constraint is applicable over the full flight so flights on these airport pairs cannot file higher than the RAD altitude during the whole flight. This might result in a high amount of inefficiency and, depending on the reason for the RAD constraint, the RAD might not be the appropriate tool to deal with the flights on the relevant airport pairs.

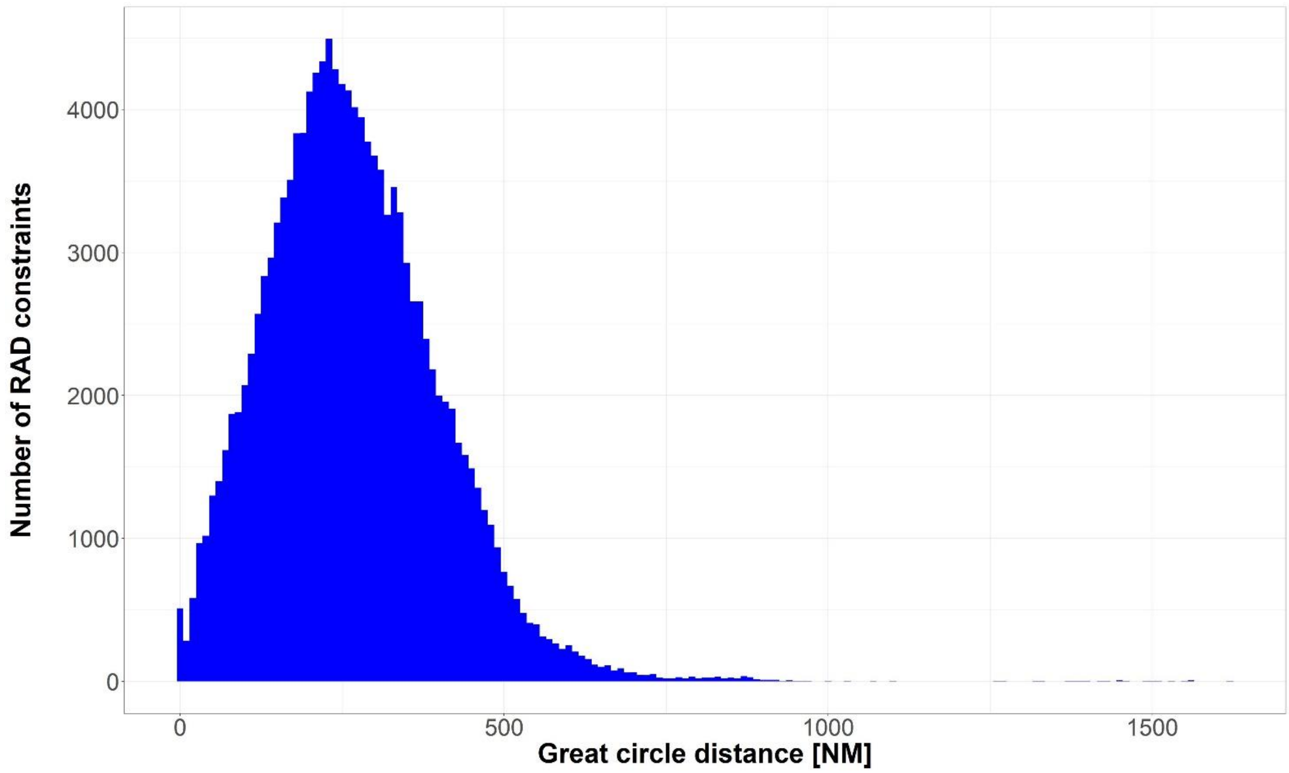

Figure 23: Great circle distances of airport pairs affected by RAD constraints

4.2.2 Total en-route vertical flight inefficiency

The number of flights influences the total en-route vertical flight inefficiency (VFI). This means higher amounts of inefficiency are seen during the summer periods and very low amounts since March 2020 (Figure 24).

The numerical results per airport pair can be found in Appendix B.4.

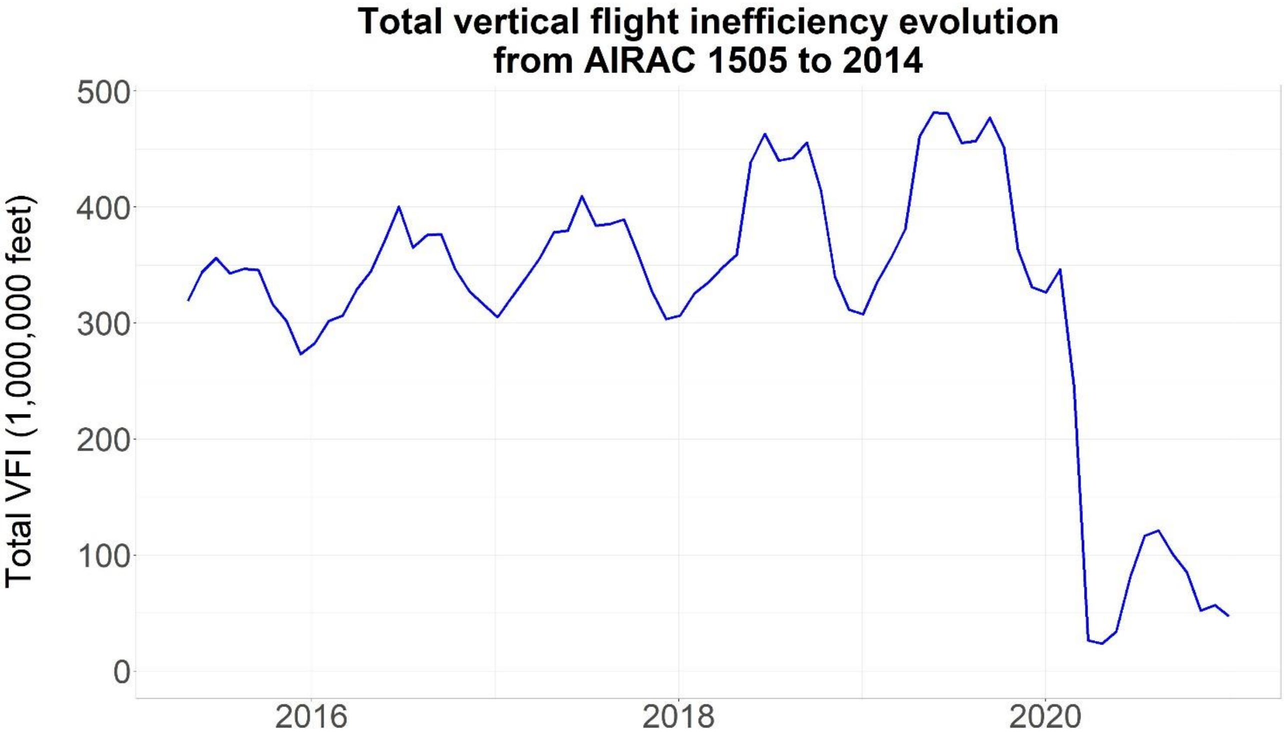

Figure 24: Evolution of total en-route vertical flight inefficiency

Figure 25 and Figure 26 highlight the difference in total en-route vertical flight inefficiency between respectively AIRAC cycles 1907 and 2007. The colour scale is the same on both figures so it is clear that a lot less inefficiency is present during AIRAC cycle 2007. Additionally, it is observed that some airport pairs still have a relatively significant amount of inefficiency despite the low traffic numbers.

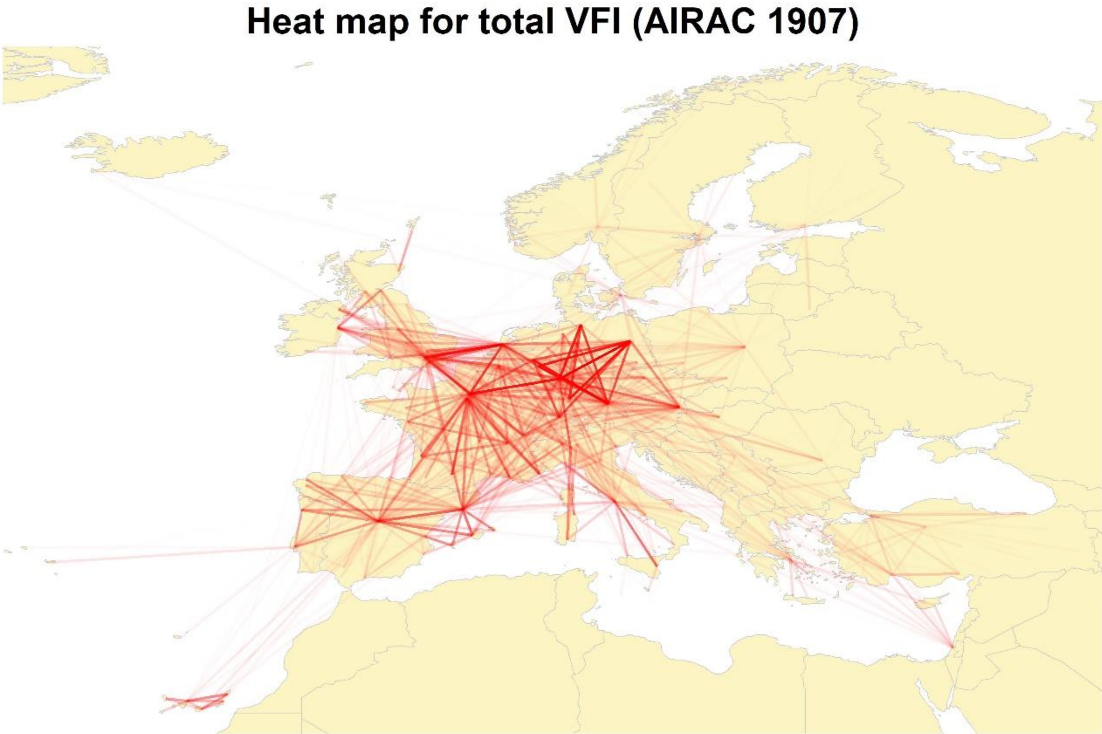

Figure 25: Heat map for total VFI during AIRAC cycle 1907

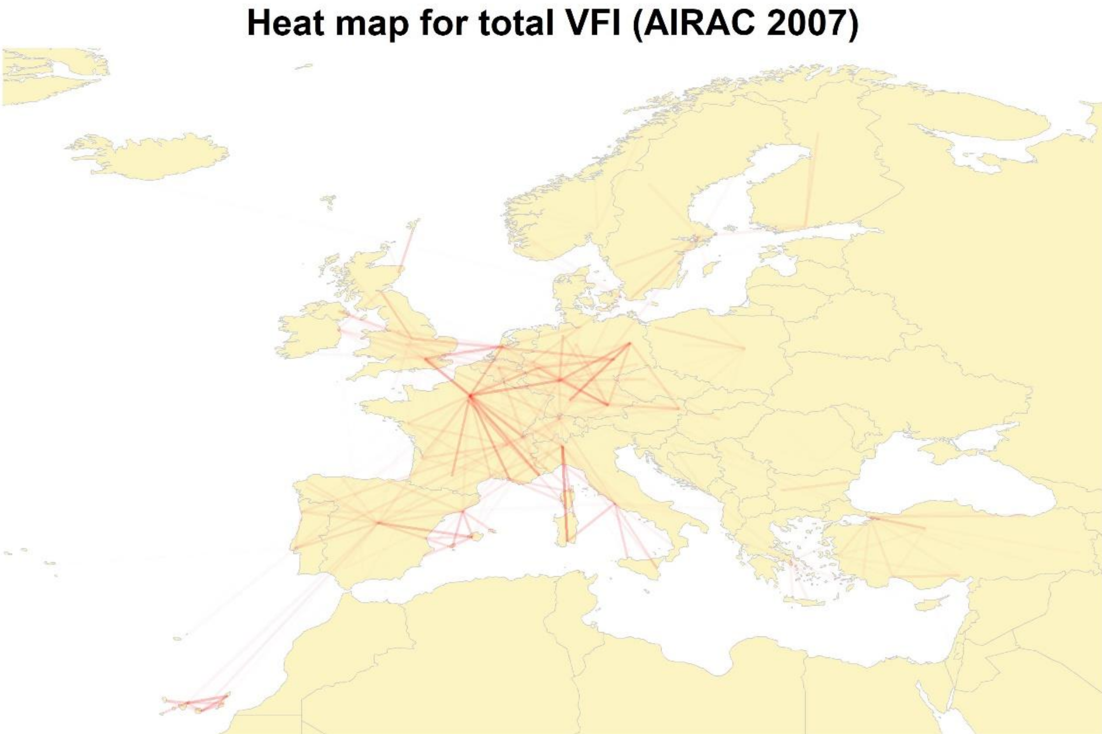

Figure 26: Heat map for total VFI during AIRAC cycle 2007

Due to the influence of the number of flights on the total en-route VFI and the low number of flights due to the COVID pandemic, it is more interesting to look at the average vertical flight inefficiency for this period. Nevertheless, the total VFI is always interesting to look at since it can be related to the amount of additional fuel used.

4.2.3 Average en-route vertical flight inefficiency

The overall average en-route vertical flight inefficiency has stayed quite stable over the past few years (Figure 27). However, when looking at the top 20 airport pairs in terms of total VFI in 2019, it is remarkable that there have been big increases during the summers of 2018 and 2019, which can be related to the initiatives taken by NM to tackle the capacity shortages during those periods.
The average VFI per flight values for the top 20 airports pairs in 2019 are much higher than the overall values, indicating that these airport pairs contribute a lot to the total VFI and that there are also a lot of airport pairs with a low or zero average VFI (as can be seen in 0).
Some airport pairs have an average VFI of more than 10,000 feet per flight, which results in an important inefficiency in terms of fuel. Detailed values per airport pair can be found in Appendix B.4.

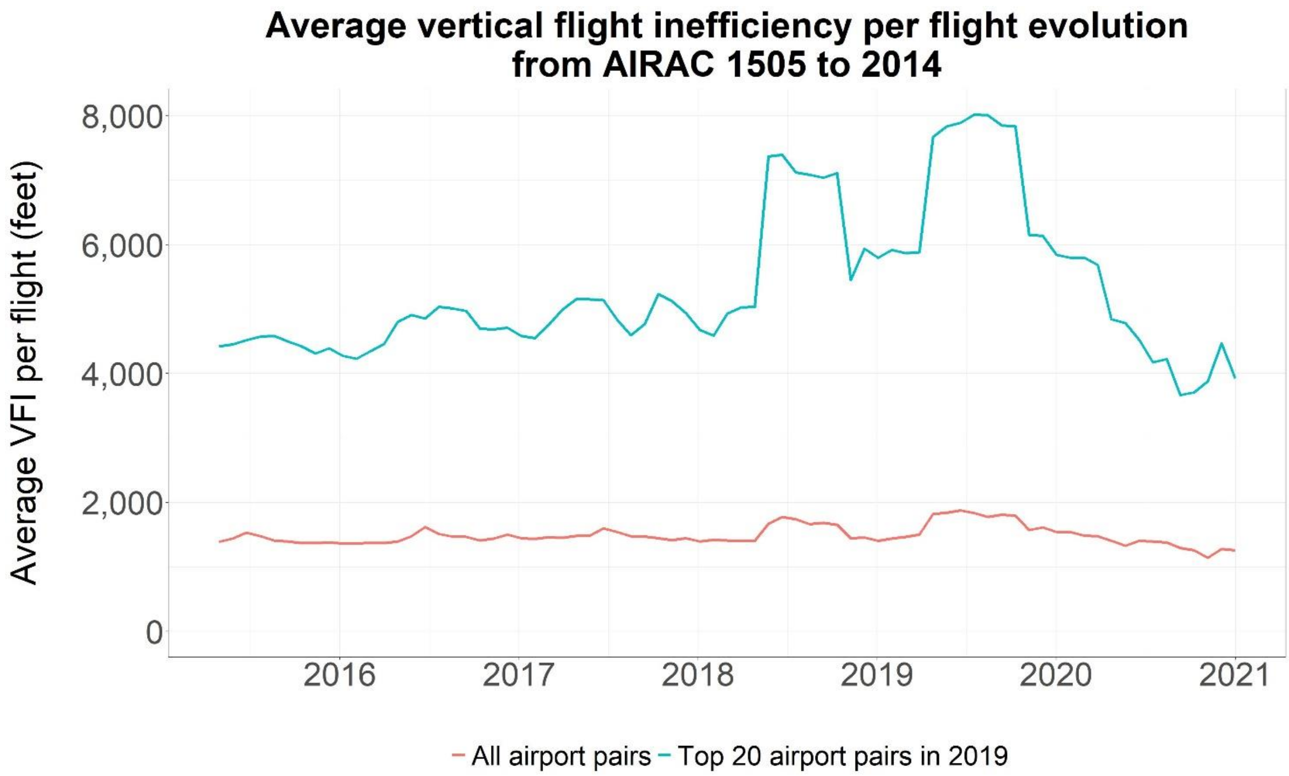

Figure 27: Evolution of average en-route vertical flight inefficiency per flight

Figure 28 and Figure 29 present the heat maps of the average VFI per flight during respectively AIRAC cycle 1907 and 2007. The colour scale is the same on both figures. The impact of the reduced number of flights resulted in a reduction of the average VFI for many airport pairs but a significant number of airport pairs still have a high average VFI during AIRAC cycle 2007. This means that despite the relaxation of a number of RAD constraints, many flights have still filed at (very) inefficient cruising altitudes. This could be due to many different causes: airline choice, difficulties for the airlines/CFSPs to adapt the flight planning tools regarding the RAD relaxations, airlines/CFSPs not being aware of the RAD relaxations …

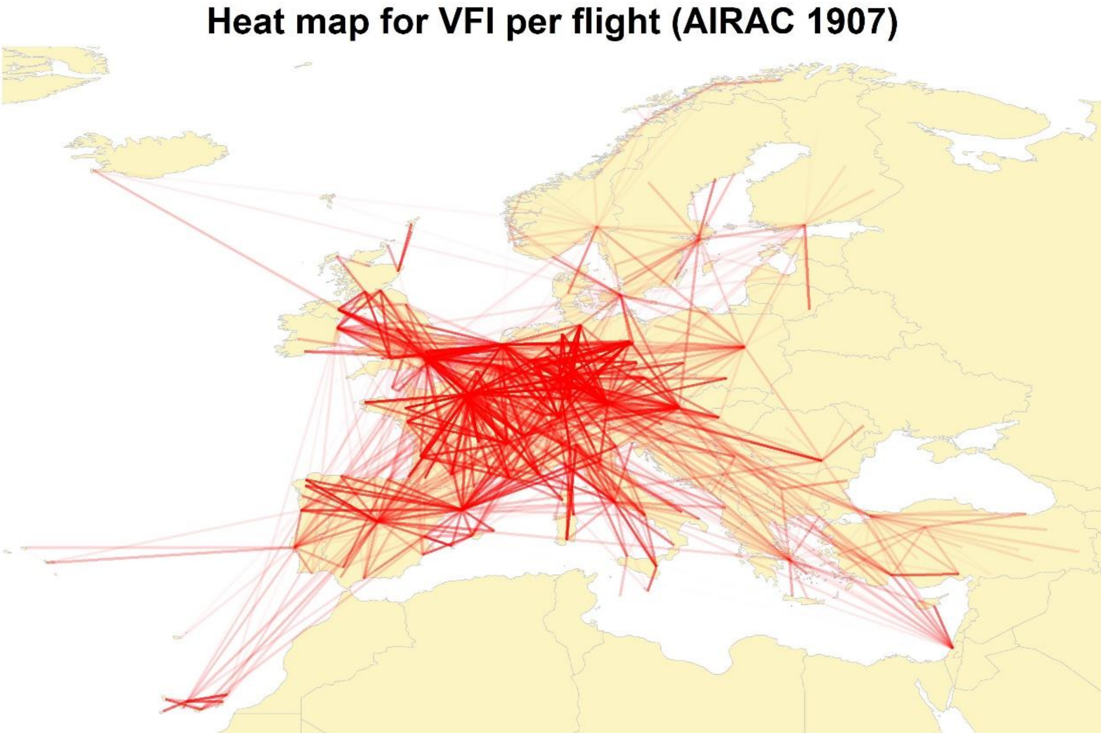

Figure 28: Heat map for average VFI during AIRAC cycle 1907

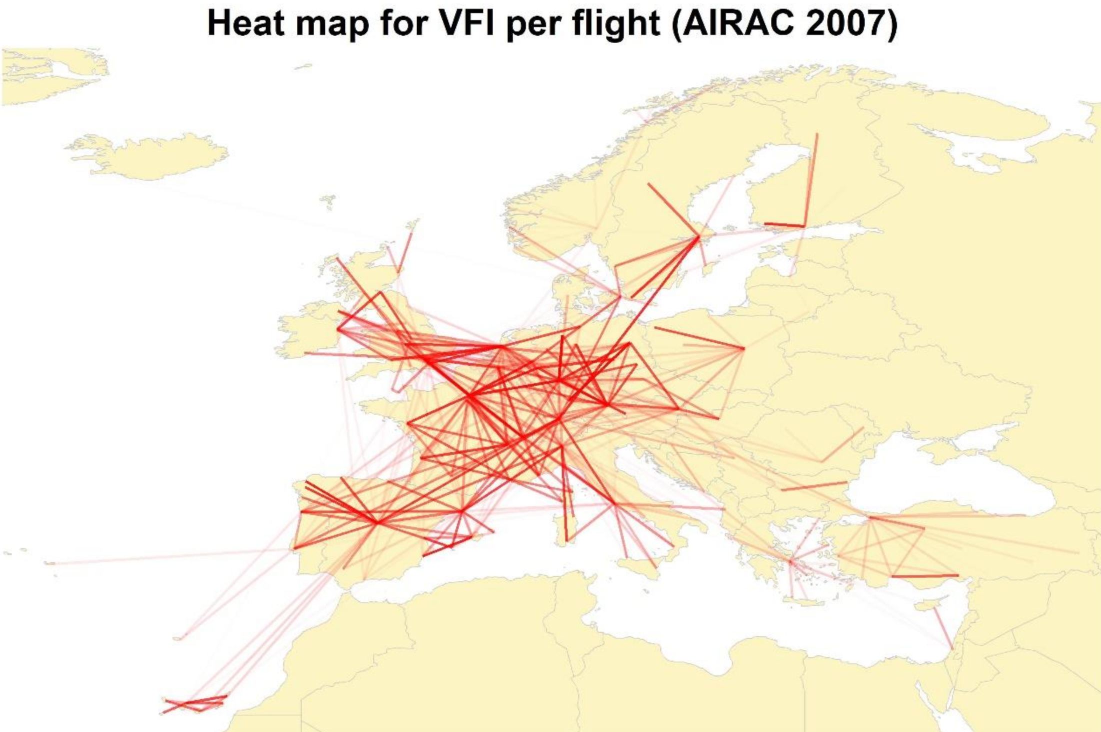

Figure 29: Heat map for average VFI during AIRAC cycle 2007

4.2.4 Top 20 airport pairs in 2019

The top 20 airport pairs in terms of total en-route vertical flight inefficiency in 2019 are mainly located under MUAC and Karlsruhe ACC airspace. All of these airport pairs had RAD constraints during the full year of 2019.

This is reflected in Figure 30 showing the vertical trajectories during AIRAC cycle 1907: nearly all flights have a maximum altitude at or below FL300. The red lines indicate the lower limits of MUAC and Karlsruhe ACC airspace (FL245 and FL315 for some parts of Karlsruhe ACC). Figure 31 shows the vertical trajectories during AIRAC cycle 2007. These trajectories go much higher which is a result of RAD relaxations. However, there are still quite a number of flights staying at relatively low altitudes. This is in line with the values in Figure 27: the average VFI has decreased in AIRAC cycle 2007 but was still much higher than the overall average VFI.
The RAD relaxations could not be monitored so it is impossible to know which flights have been constrained and for which period.

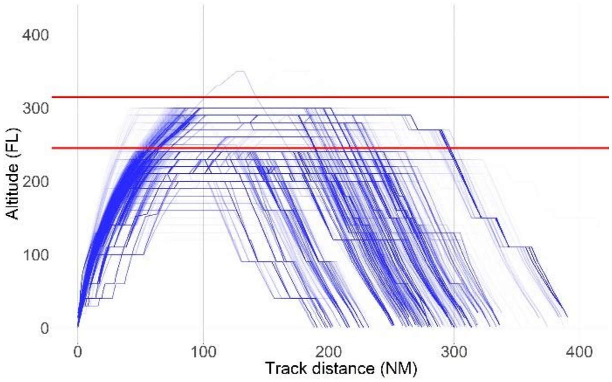

Figure 30: Vertical trajectories during AIRAC 1907

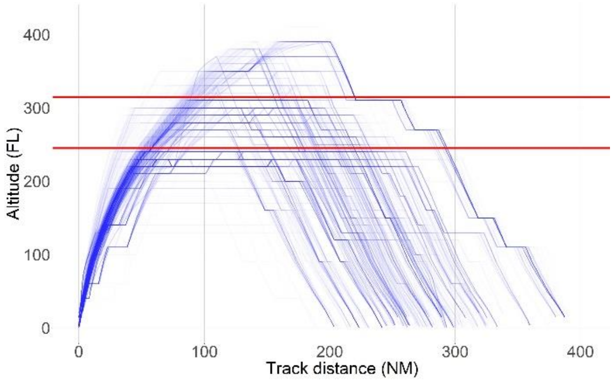

Figure 31: Vertical trajectories during AIRAC 2007

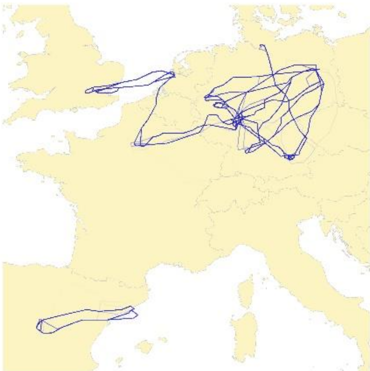

Figure 32: Lateral trajectories during AIRAC 1907

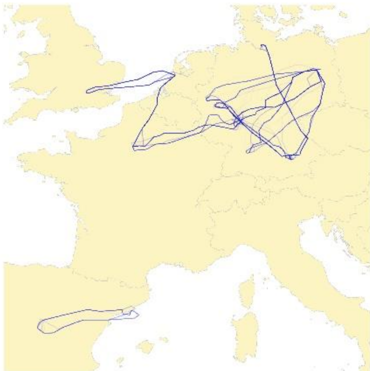

Figure 33: Lateral trajectories during AIRAC 2007

Figure 32 and Figure 33 show the lateral trajectories on the top 20 airport pairs during respectively AIRAC cycle 1907 and 2007. It appears that some routes are not used anymore during AIRAC cycle 2007. This could be due to the RAD relaxations and/or higher availability of the shorter routes due to the lower amount of traffic.
The trajectories in both figures have the same colour scale so the reduction of the number of flights can also be seen.
The results for the average VFI per flight for the top 20 airport pairs in 2019 are presented in Figure 34. Some of these airport pairs have a much lower average VFI in 2020 while others have only changed slightly. This is in line with the earlier observation related to Figure 30 and Figure 31. On some airport pairs, the results are very different depending on the direction (e.g. flights on EDDK-EDDM see a reduction of 4200 feet while the flights on EDDM-EDDK see almost no change). Since the airlines in both directions are usually the same, it can be assumed that the reason for this observation is that there was no RAD relaxation for a specific direction.

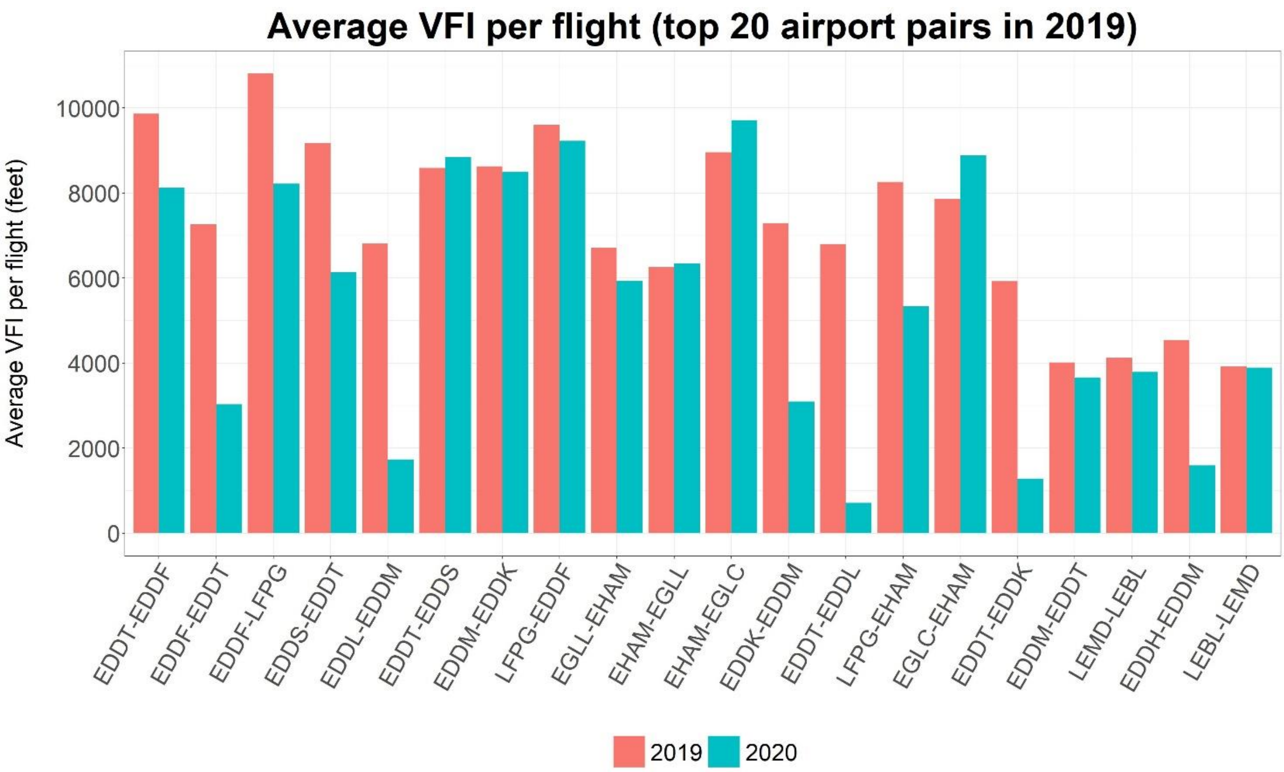

Figure 34: Average VFI per flight for the top 20 airport pairs in 2019

Numerical results for more airport pairs can be found in Appendix B.4.

5 CONCLUSIONS

This document describes the results for vertical flight efficiency during all phases of flight during 2019 and 2020.
The data needed for the analysis of the climb and descent is very complete and available for all States, except for Turkey. The data coverage has improved the last few years which has improved the completeness of the results. All States that submit data are submitting data at the correct update rate.
The average time flown level has decreased with respect to 2019, although the decrease is relatively low for the Paris airports. The observations for the Paris airports have been discussed with Air France and DSNA. The specific reasons for the observations and temporary and future solutions have been provided. Level flight related to noise has reduced as well, but to a lesser extent than for the full profile.
Continuous descents until the runway started at much lower altitudes than continuous climbs. Nevertheless, the median CDO altitudes generally improved while the median CCO altitudes didn't change a lot.
The shares of unimpeded flights have changed similarly to the average time flown level per flight.
The fuel benefit pool during descent is in the order of magnitude of 10 times larger than during the climb. Flights to/from the top 30 airports account for 66% of the total benefit pool of the descent phase and 57% of the climb phase, which is quite significant.
For the en-route vertical flight efficiency analysis, the RAD is an important impacting factor. During the COVID period, many RAD restrictions have been relaxed. This could be observed mainly in the average en-route vertical flight inefficiency per flight.
The top 20 airport pairs in terms of total vertical flight inefficiency in 2019 have been looked at in more detail. These airport pairs are located mainly below MUAC and Karlsruhe UAC airspace. The flights on those airport pairs are quite constrained in normal situations but some improvements could be observed during the COVID period. However, a lot of inefficiency could still be seen.

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7 APPENDICES

Appendix A Number of flights available and fit for purpose

Airport	Available flights	Flights fit for use	Share of flights fit for purpose
EHAM	372235	370314	99.5%
EDDF	363049	360412	99.3%
LFPG	362565	360324	99.4%
EGLL	341305	339520	99.5%
LEMD	295758	293543	99.3%
EDDM	279140	277405	99.4%
LTFM	255035	24340	9.5%
LEBL	233400	232134	99.5%
LIRF	206469	205653	99.6%
LOWW	194821	194007	99.6%
LSZH	187098	185453	99.1%
ENGM	187015	186079	99.5%
EGKK	182572	180932	99.1%
EKCH	180733	179990	99.6%
LTFJ	176287	37429	21.2%
LGAV	164613	163109	99.1%
LIMC	163291	162244	99.4%
EIDW	162371	161517	99.5%
EBBR	160167	159070	99.3%
ESSA	159441	158608	99.5%
LPPT	154967	153107	98.8%
LFPO	153024	151950	99.3%
EDDL	152113	150509	98.9%
LEPA	146762	146151	99.6%
EGSS	141867	140092	98.7%
EPWA	136904	135858	99.2%
EGCC	134695	133548	99.1%
EFHK	133597	130895	98.0%
LTAI	133323	4646	3.5%
LSGG	128842	127872	99.2%
EDDT	125788	124100	98.7%
LLBG	110417	97852	88.6%
EDDK	109480	106791	97.5%
LFMN	105931	104884	99.0%
EDDH	104573	103128	98.6%
EGGW	102135	100835	98.7%
LKPR	100203	99399	99.2%
LEMG	98758	97290	98.5%

EDDS	91148	88676	97.3%
EGPH	88645	87692	98.9%
LROP	87257	84194	96.5%
LHBP	84925	84228	99.2%
LTBA	83005	33775	40.7%
LFLL	80700	80187	99.4%
UKBB	78893	78214	99.1%
ENBR	75290	65564	87.1%
LFML	74614	73739	98.8%
EGBB	71242	70342	98.7%
LPPR	71052	70339	99.0%
LTAC	69353	1260	1.8%
LEAL	69110	68644	99.3%
EDDP	68476	67028	97.9%
LFBO	68318	67016	98.1%
LIME	66860	66154	98.9%
EDDB	66621	64677	97.1%
LIPZ	64828	63879	98.5%
GMMN	64003	22209	34.7%
LIML	62422	61967	99.3%
EVRA	60864	60254	99.0%
LFSB	59854	58861	98.3%
LTBJ	59085	12487	21.1%
ELLX	58281	57041	97.9%
LIRN	57715	57070	98.9%
EGPF	57010	55852	98.0%
EGNX	55526	54453	98.1%
LICC	55029	52225	94.9%
ENZV	54076	44223	81.8%
LIPE	53360	52921	99.2%
LYBE	52517	51428	97.9%
LEIB	52472	52231	99.5%
LFBD	52141	51174	98.1%
EGLC	52035	51585	99.1%
LEVC	51767	51341	99.2%
LBSF	47596	46827	98.4%
ESGG	46694	46490	99.6%
EDDV	45743	43952	96.1%
EGGD	45328	44616	98.4%
EPKK	45321	44320	97.8%
LFRS	45238	44493	98.4%
ENVA	43755	43518	99.5%
LFPB	43437	42478	97.8%

LEZL	42915	41305	96.2%
LPFR	42553	42162	99.1%
LCLK	42429	41868	98.7%
LMML	41240	40316	97.8%
LGTS	41164	39042	94.8%
LICJ	40974	40720	99.4%
EBCI	39771	38748	97.4%
LGIR	39090	38541	98.6%
LIRA	38624	37722	97.7%
EGPD	37822	36964	97.7%
EGAA	37171	36757	98.9%
ENTC	36781	36373	98.9%
EBLG	35708	34724	97.2%
ESSB	35224	35032	99.5%
EDDN	34455	32546	94.5%
ENBO	34279	32542	94.9%
EYVI	33553	33175	98.9%
LEBB	33356	33223	99.6%
EPGD	33348	33069	99.2%

Appendix B Numerical results

Appendix B.1 Descent

Airport	Number of analysed flights		Average time flown level per flight (min)		Median CDO altitude (feet)		Percentage of CDO flights	
	Full year	COVID period	Full year	COVID period	Full year	COVID period	Full year	COVID period
EHAM	117372	80347	2.1	1.7	3900	4378	30.0%	32.9%
LFPG	109768	73169	5.2	4.9	4301	4427	4.0%	4.5%
EDDF	105229	69441	4.1	3.4	4984	5016	7.8%	10.3%
EGLL	102167	65443	4.1	2.6	7985	8003	19.2%	25.6%
LTFM	24674	20969	0.5	0.5	35000	35000	71.4%	71.6%
LEMD	82235	49975	1.9	1.7	6250	6104	31.5%	32.2%
EDDM	71438	41648	3.5	2.6	4953	4975	10.9%	16.3%
LTFJ	13668	9344	0.2	0.2	37000	37000	90.5%	91.1%
LEBL	60787	37701	1.4	1.4	11000	10180	38.8%	39.0%
ENGM	60851	41886	0.6	0.5	28000	29000	62.1%	67.1%
LGAV	54121	41176	1.2	1.2	7000	7304	40.6%	42.1%
LOWW	53678	33677	1.8	1.4	6514	9700	34.4%	38.5%
LSZH	52099	33019	2.2	1.9	9938	10000	20.7%	23.7%
LIRF	51407	31225	1.2	1.0	18770	19015	42.9%	45.4%
EKCH	48883	29969	1.0	0.8	13000	15000	50.2%	53.8%
LIMC	45911	30784	2.3	2.1	4372	4444	24.0%	26.9%
EBBR	45321	29091	2.9	2.6	4035	4101	18.5%	21.3%
LPPT	44214	28173	1.0	0.9	24968	24933	55.0%	55.5%
EIDW	43183	27015	1.5	1.0	14000	20000	46.0%	52.2%
ESSA	42697	26121	1.0	0.9	5200	6972	42.5%	45.6%
EGSS	41773	27974	2.7	2.4	13043	16000	24.2%	28.5%
LFPO	42202	26041	6.1	5.7	4082	4150	2.6%	2.6%
EGKK	39506	20831	3.6	2.7	9000	11988	18.6%	22.8%
EPWA	39505	24652	1.1	0.9	19000	21000	51.1%	55.6%
EDDL	38758	23560	1.9	1.5	7143	9142	27.3%	30.4%
LSGG	38779	23911	2.7	2.5	14000	15000	19.4%	22.1%
EDDK	37629	28319	2.3	1.9	7063	8967	29.2%	32.1%
LEPA	38108	30345	1.2	1.2	11000	10890	46.6%	46.0%
EFHK	35504	20483	0.8	0.6	21000	22000	60.2%	65.5%
EGCC	32692	19674	1.5	1.1	13057	20043	43.0%	49.6%
LFMN	32969	24722	2.7	2.7	3288	3302	19.7%	17.8%
GCLP	32195	22224	1.3	1.2	7000	8000	47.1%	49.0%
LTAI	596	321	1.3	1.4	32000	34000	58.4%	57.0%
EGGW	31313	21806	3.6	3.3	5230	5304	12.6%	14.1%
ENBR	28894	22492	1.6	1.7	16000	16000	72.0%	72.5%
EDDP	30101	24751	2.8	2.8	4470	4675	18.0%	18.6%
EDDH	29127	19081	1.6	1.5	3125	3198	33.3%	35.9%

EDDT	29441	16562	1.5	1.3	3152	3464	26.0%	29.3%
LEMG	27858	19879	1.0	1.0	25000	19000	54.1%	52.9%
LLBG	22664	12581	1.2	1.3	7524	5967	42.4%	41.0%
LROP	24715	15804	1.2	1.2	19000	19000	48.3%	48.9%
LKPR	24731	15078	2.2	1.9	10040	13000	27.8%	30.9%
EDDS	23478	14901	3.3	3.0	6120	7962	16.1%	18.0%
LHBP	23626	14579	2.0	1.6	19361	20000	33.4%	38.5%
LFML	23448	16041	2.6	2.5	7958	6943	27.3%	26.4%
EGPH	22575	13598	1.0	0.9	17000	17000	45.6%	48.3%
LTAC	596	357	0.2	0.2	38000	38000	73.8%	70.9%
LFLL	22458	13919	2.3	2.3	4621	3594	22.0%	18.0%
EGNX	21175	17001	1.6	1.4	16970	17000	41.0%	43.5%
GCXO	21534	15945	0.8	0.9	8000	8000	57.9%	55.0%
LPPR	21465	14546	1.2	1.1	27000	29000	46.1%	47.9%
EDDB	20723	14633	1.5	1.4	6008	6019	28.8%	30.7%
ENZV	19297	14652	2.5	2.5	13000	12000	73.0%	73.7%
LTBJ	3785	3056	0.2	0.1	39000	39000	89.0%	89.9%
LFBO	20032	12636	1.6	1.7	3259	3200	30.4%	28.2%
LIML	20071	11535	1.7	1.5	3623	3398	27.9%	30.0%
ELLX	19851	14311	2.5	2.2	15033	15919	33.5%	34.9%
LIME	18979	11778	2.1	1.9	31000	31989	39.0%	44.9%
LEAL	18402	12767	1.3	1.3	26000	28033	44.5%	45.6%
EBLG	17802	15198	2.9	2.8	3355	3465	16.5%	17.5%
LFSB	17220	11910	2.9	2.9	6815	6837	17.6%	17.2%
EVRA	17360	11197	1.0	1.0	24000	22000	55.5%	52.9%
LBSF	17193	12570	1.4	1.2	21000	21000	47.1%	49.3%
EGBB	17194	10064	2.2	1.8	10000	13060	31.1%	36.1%
LICC	17098	12733	0.7	0.7	33000	33000	60.5%	59.9%
LIPZ	17089	11465	2.0	1.9	10017	10000	33.8%	35.6%
LYBE	16599	11883	1.7	1.6	3992	4156	38.7%	40.0%
ENVA	16674	12480	0.4	0.4	24000	24000	77.1%	78.7%
LTBA	7533	6522	0.3	0.3	37000	37000	80.9%	81.9%
LFPB	16295	12505	9.3	8.9	3287	3308	0.9%	1.1%
ENTC	16173	12857	0.6	0.5	17000	18000	75.2%	77.3%
LEIB	15771	13663	2.1	2.2	11000	11000	41.0%	39.7%
LEVC	15397	10286	1.2	1.1	19000	19000	50.8%	51.3%
LIRN	15260	10169	1.1	1.2	12957	12921	42.7%	41.9%
LIPE	14672	9142	2.0	2.0	27932	28000	41.0%	44.2%
EGPF	14397	9014	1.4	1.4	5680	5872	39.0%	40.4%
LFBD	14459	9398	2.1	2.1	3850	3500	32.1%	31.5%
ENBO	14006	11069	0.4	0.4	13000	13000	77.8%	79.5%
GCRR	14429	10105	0.6	0.6	11000	11000	64.3%	66.5%
GCTS	13968	8258	1.0	0.9	10000	10000	51.5%	53.1%

LICJ	13905	10597	0.7	0.7	29000	29000	60.7%	60.4%
EPKK	13053	8118	1.1	1.1	25000	25000	53.1%	55.2%
LEZL	12839	8476	1.3	1.4	31000	31000	53.4%	50.2%
EDDV	12553	8529	1.8	1.6	5042	9955	32.7%	37.3%
LIRA	12473	8687	1.1	1.1	30000	29000	51.6%	52.3%
LGTS	12041	8946	0.5	0.5	34000	34000	74.9%	74.4%
LFRS	12440	8188	2.0	1.9	3134	3198	27.2%	26.8%
EBCI	11898	7946	3.2	2.9	6332	11984	20.5%	24.5%
LPFR	12172	10185	0.6	0.6	37000	37000	62.0%	62.2%
EGPD	11625	7933	1.8	1.8	4263	3993	37.2%	36.8%
LMML	11712	8034	1.0	1.1	23000	17000	51.4%	49.2%
EGGD	11930	7609	2.6	2.0	15031	15987	27.9%	33.4%
LCLK	11870	8489	1.0	0.9	26000	26000	50.6%	52.5%
ESGG	11981	7104	0.9	0.8	14171	16000	50.8%	53.1%
GCFV	11853	8265	0.7	0.6	9000	9000	60.7%	62.6%
LGIR	11347	10303	0.3	0.3	34000	35000	75.9%	75.9%
EGAA	11327	7991	0.9	0.9	18000	18000	52.3%	53.4%
EPGD	10673	7285	0.9	0.9	24000	24000	57.8%	58.6%
LDZA	10526	7531	1.6	1.4	13000	14983	42.8%	46.4%
LIEE	10371	8376	1.2	1.3	29000	27000	48.2%	47.3%

Appendix B.2 Climb

Airport	Number of analysed flights		Average time flown level per flight (min)		Median CDO altitude (feet)		Percentage of CDO flights	
	Full year	COVID period	Full year	COVID period	Full year	COVID period	Full year	COVID period
EHAM	117262	80269	0.3	0.3	35000	36000	80.9%	82.2%
LFPG	109748	73140	0.4	0.4	33947	34000	75.0%	75.4%
EDDF	105212	69432	0.4	0.3	33000	34000	75.4%	78.4%
EGLL	101623	65116	0.7	0.4	33000	35000	59.4%	68.4%
LTFM	24170	20643	0.2	0.2	34000	34000	89.2%	89.7%
LEMD	81853	49927	0.4	0.3	33000	34000	82.6%	84.2%
EDDM	71344	41513	0.5	0.5	33000	34000	71.4%	73.6%
LTFJ	13020	9088	0.3	0.3	36000	36000	83.6%	83.6%
LEBL	60972	37820	0.9	0.8	32000	31978	68.8%	70.0%
ENGM	60927	41916	0.1	0.1	35000	34998	92.2%	93.2%
LGAV	54096	41117	0.2	0.2	29000	27000	88.8%	89.3%
LOWW	53754	33693	0.5	0.4	35000	35000	78.6%	80.6%
LSZH	52076	33028	0.6	0.5	32000	33000	73.4%	76.2%
LIRF	51506	31232	0.2	0.2	34000	34000	87.1%	88.0%
EKCH	48866	29945	0.2	0.2	35828	36000	89.0%	90.2%
LIMC	45968	30811	0.4	0.4	35000	35000	78.3%	80.8%
EBBR	45310	29066	0.6	0.5	34000	35000	73.1%	76.6%
LPPT	44366	28206	0.3	0.2	36000	36057	86.9%	88.1%

EIDW	43265	27080	0.2	0.2	35000	35961	85.9%	87.0%
ESSA	42822	26202	0.2	0.2	36000	36000	90.2%	91.2%
EGSS	41911	27933	0.5	0.4	35000	35000	69.4%	74.6%
LFPO	42119	26014	0.5	0.5	35000	35000	73.5%	72.0%
EGKK	39597	20856	0.6	0.5	33007	35000	60.2%	65.9%
EPWA	39496	24638	0.1	0.2	34000	35000	90.3%	90.7%
EDDL	38548	23542	0.4	0.4	33991	35000	78.6%	80.1%
LSGG	38957	24044	0.5	0.5	32000	31060	74.1%	75.3%
EDDK	38155	28692	0.4	0.3	33000	33000	80.4%	82.6%
LEPA	38072	30313	0.5	0.5	31000	33000	83.1%	82.9%
EFHK	35358	20410	0.3	0.3	35000	35639	80.1%	80.2%
EGCC	32972	19827	0.3	0.3	35000	35050	81.4%	83.3%
LFMN	32760	24607	0.4	0.4	34000	34000	76.8%	75.3%
GCLP	32399	22400	0.1	0.1	12000	11000	92.2%	93.5%
LTAI	487	261	4.2	3.5	31000	31000	46.6%	48.7%
EGGW	31100	21638	0.5	0.4	35000	36005	68.2%	73.9%
ENBR	23672	17980	0.2	0.2	23011	23000	94.7%	95.2%
EDDP	30417	25011	0.3	0.3	32000	32000	86.8%	87.7%
EDDH	29391	19357	0.4	0.4	34952	35000	85.6%	86.1%
EDDT	29245	16420	0.3	0.3	34000	35000	81.6%	83.0%
LEMG	27849	19903	0.3	0.4	36000	37000	86.7%	86.3%
LLBG	22847	12676	0.6	0.6	34042	36000	71.9%	70.5%
LROP	24857	15987	0.4	0.4	35492	36000	84.1%	85.0%
LKPR	24672	15030	0.5	0.5	34965	35000	75.4%	77.5%
EDDS	24016	15387	0.8	0.8	31000	33000	74.7%	77.0%
LHBP	23649	14552	0.6	0.5	35956	36000	75.9%	78.2%
LFML	23348	15939	0.4	0.4	33000	33000	80.0%	78.9%
EGPH	22564	13536	0.2	0.2	35000	35000	88.0%	89.9%
LTAC	250	176	0.5	0.4	38000	38000	79.2%	83.0%
LFLL	22497	13933	0.5	0.4	30000	30000	75.5%	75.3%
EGNX	21450	17207	0.2	0.2	29000	30000	88.3%	89.3%
GCXO	21478	15910	0.1	0.1	10000	10000	93.2%	94.2%
LPPR	21601	14619	0.6	0.6	34000	36000	76.2%	78.0%
EDDB	20582	14498	0.4	0.4	36000	36000	79.5%	81.8%
ENZV	13833	10084	0.2	0.2	29000	29000	95.3%	95.7%
LTBJ	3939	3180	0.4	0.3	38000	38000	82.2%	82.7%
LFBO	20084	12657	0.4	0.4	32000	32000	80.6%	80.9%
LIML	20086	11549	0.4	0.3	33982	34000	79.4%	82.7%
ELLX	19501	14086	0.4	0.4	31000	31000	83.0%	84.3%
LIME	18987	11770	0.5	0.4	37000	37000	78.5%	80.7%
LEAL	18405	12765	0.6	0.5	36000	37440	77.6%	78.6%
EBLG	18019	15321	0.3	0.3	33000	33000	84.3%	85.8%
LFSB	17045	11812	0.7	0.6	33000	34000	70.8%	72.8%

EVRA	17358	11188	0.3	0.3	36000	36000	82.2%	80.8%
LBSF	17149	12539	0.3	0.3	36000	36000	84.4%	85.2%
EGBB	17231	10051	0.3	0.3	29000	32000	79.2%	81.3%
LICC	15856	11736	0.2	0.2	36000	36000	90.9%	90.8%
LIPZ	16812	11243	0.5	0.4	35000	35000	80.1%	83.1%
LYBE	16649	11912	0.5	0.5	34000	34025	79.1%	80.3%
ENVA	16775	12558	0.1	0.1	29000	28000	95.1%	95.9%
LTBA	6021	5210	0.3	0.3	36000	36000	83.0%	83.8%
LFPB	16407	12625	1.1	1.0	26000	26000	58.9%	59.9%
ENTC	16380	13028	0.1	0.1	20508	19966	94.4%	95.2%
LEIB	15771	13660	0.3	0.3	27000	29000	85.0%	84.3%
LEVC	15394	10299	0.5	0.5	33000	32003	80.6%	82.3%
LIRN	15288	10202	0.3	0.3	36000	36000	85.9%	86.3%
LIPE	14788	9195	0.6	0.7	35027	36000	80.6%	81.6%
EGPF	14453	9055	0.3	0.3	29000	27000	87.6%	88.6%
LFBD	14437	9370	0.5	0.5	31000	31000	78.9%	79.5%
ENBO	14033	11079	0.1	0.1	17000	17000	95.6%	96.2%
GCRR	14419	10103	0.2	0.2	14000	12000	88.5%	90.3%
GCTS	14021	8288	0.1	0.1	36000	36000	92.1%	93.7%
LICJ	13988	10668	0.2	0.2	36000	36000	91.5%	91.2%
EPKK	13064	8142	0.3	0.3	36000	37000	86.0%	86.9%
LEZL	12888	8509	0.4	0.4	34001	35000	87.8%	88.9%
EDDV	12803	8770	0.5	0.5	31000	32000	82.6%	84.3%
LIRA	12527	8739	0.4	0.4	36000	36000	83.2%	84.4%
LGTS	12254	9136	0.3	0.3	34000	34053	87.0%	86.8%
LFRS	12180	8028	0.4	0.4	33000	33000	78.3%	77.9%
EBCI	11884	7938	1.1	0.9	35000	36960	58.7%	62.3%
LPFR	12189	10174	0.2	0.2	38000	38000	88.5%	89.3%
EGPD	11990	8235	0.2	0.3	23000	19000	91.2%	91.9%
LMML	11808	8085	0.4	0.4	38000	38000	87.1%	86.7%
EGGD	11960	7638	0.5	0.5	32992	34963	72.3%	74.1%
LCLK	11968	8553	0.6	0.5	36000	36000	77.8%	80.1%
ESGG	11994	7120	0.2	0.2	35000	35000	89.7%	90.2%
GCFV	11805	8204	0.2	0.2	24000	12000	89.7%	91.6%
LGIR	11372	10326	0.2	0.2	36000	36000	88.9%	88.5%
EGAA	11273	7961	0.2	0.2	27000	25000	90.0%	90.7%
EPGD	10676	7290	0.2	0.2	36000	36000	90.7%	91.5%
LDZA	10556	7532	0.3	0.3	25000	25000	86.9%	87.9%
LIEE	9618	7714	0.3	0.3	32000	33000	87.2%	87.6%

Appendix B.3 Fuel benefit pool in climb and descent

	Descent		Climb	
Airport	Total additional fuel (kg)	Average additional fuel per flight (kg)	Total additional fuel (kg)	Total additional fuel (kg)
EHAM	2267109.0	19.3	98672.1	0.8
LFPG	6818993.6	62.1	221852.3	2.0
EDDF	4892620.4	46.5	218041.4	2.1
EGLL	5510863.9	53.9	796622.2	7.8
LTFM	83156.1	3.4	16221.7	0.7
LEMD	1078213.7	13.1	106502.5	1.3
EDDM	1442888.5	20.2	93645.4	1.3
LTFJ	4553.6	0.3	6265.0	0.5
LEBL	628183.4	10.3	189121.4	3.1
ENGM	238003.8	3.9	10803.7	0.2
LGAV	360549.5	6.7	23731.7	0.4
LOWW	563906.9	10.5	54062.8	1.0
LSZH	617938.0	11.9	80503.9	1.5
LIRF	500144.7	9.7	32790.8	0.6
EKCH	286231.5	5.9	14039.1	0.3
LIMC	924904.2	20.1	60493.9	1.3
EBBR	1076854.8	23.8	108842.0	2.4
LPPT	270033.5	6.1	19092.3	0.4
EIDW	497195.1	11.5	28041.9	0.6
ESSA	224787.9	5.3	9640.3	0.2
EGSS	945808.5	22.6	112605.5	2.7
LFPO	2312218.0	54.8	121361.9	2.9
EGKK	1108651.5	28.1	148384.7	3.7
EPWA	202852.6	5.1	7010.3	0.2
EDDL	426618.8	11.0	45529.7	1.2
LSGG	469297.4	12.1	46270.4	1.2
EDDK	739261.9	19.6	52589.5	1.4
LEPA	242347.0	6.4	77692.7	2.0
EFHK	168933.5	4.8	12466.6	0.4
EGCC	314387.0	9.6	31086.4	0.9
LFMN	380569.1	11.5	29150.0	0.9
GCLP	213250.5	6.6	6409.7	0.2
LTAI	3146.1	5.3	4339.4	8.9
EGGW	779313.1	24.9	69711.1	2.2
ENBR	23651.7	0.8	1178.4	0.0
EDDP	1157155.9	38.4	27875.5	0.9
EDDH	237337.8	8.1	15905.9	0.5

EDDT	287190.7	9.8	21690.6	0.7
LEMG	140268.1	5.0	19712.9	0.7
LLBG	347244.2	15.3	73350.5	3.2
LROP	176755.4	7.2	16895.0	0.7
LKPR	288365.7	11.7	27372.4	1.1
EDDS	346503.2	14.8	43288.2	1.8
LHBP	220109.0	9.3	24826.3	1.0
LFML	273496.3	11.7	22871.5	1.0
EGPH	117900.2	5.2	7613.4	0.3
LTAC	249.6	0.4	189.9	0.8
LFLL	262840.2	11.7	34108.9	1.5
EGNX	219484.6	10.4	15698.8	0.7
GCXO	36228.6	1.7	3058.6	0.1
LPPR	137341.1	6.4	43170.4	2.0
EDDB	157664.3	7.6	15734.6	0.8
ENZV	17990.4	0.9	1450.8	0.1
LTBJ	3035.3	0.8	5817.0	1.5
LFBO	181084.9	9.0	25420.4	1.3
LIML	139495.8	7.0	17328.7	0.9
ELLX	486026.1	24.5	28306.1	1.5
LIME	202607.4	10.7	21277.3	1.1
LEAL	140709.1	7.6	44222.7	2.4
EBLG	826696.3	46.4	38397.5	2.1
LFSB	254594.4	14.8	36352.9	2.1
EVRA	41766.7	2.4	2681.0	0.2
LBSF	122517.5	7.1	10302.8	0.6
EGBB	187589.7	10.9	16517.9	1.0
LICC	90038.3	5.3	6046.6	0.4
LIPZ	206690.7	12.1	14894.2	0.9
LYBE	128801.0	7.8	9257.1	0.6
ENVA	20545.6	1.2	1250.7	0.1
LTBA	17897.0	2.4	6902.1	1.1
LFPB	251115.1	15.4	21171.4	1.3
ENTC	25953.8	1.6	1369.3	0.1
LEIB	151859.6	9.6	11176.2	0.7
LEVC	69811.0	4.5	15437.5	1.0
LIRN	110590.5	7.2	8949.6	0.6
LIPE	122687.0	8.4	14072.1	1.0
EGPF	65176.9	4.5	4502.8	0.3
LFBD	128491.8	8.9	21226.8	1.5
ENBO	13443.3	1.0	912.5	0.1
GCRR	48892.0	3.4	11748.0	0.8
GCTS	122956.3	8.8	3846.5	0.3

LICJ	57224.7	4.1	5666.9	0.4
EPKK	66286.9	5.1	6432.1	0.5
LEZL	66487.3	5.2	7890.5	0.6
EDDV	88811.5	7.1	9812.6	0.8
LIRA	53472.7	4.3	9539.6	0.8
LGTS	21907.6	1.8	5780.1	0.5
LFRS	109497.1	8.8	15837.3	1.3
EBCI	196485.4	16.5	49276.1	4.1
LPFR	39695.4	3.3	4582.4	0.4
EGPD	35774.4	3.1	2575.6	0.2
LMML	58385.6	5.0	6735.9	0.6
EGGD	115849.1	9.7	15241.4	1.3
LCLK	73972.7	6.2	19680.9	1.6
ESGG	46778.1	3.9	2847.0	0.2
GCFV	40505.0	3.4	6049.4	0.5
LGIR	25354.3	2.2	5823.8	0.5
EGAA	40178.5	3.5	4078.9	0.4
EPGD	45268.7	4.2	2073.0	0.2
LDZA	65873.0	6.3	7156.4	0.7
LIEE	67113.2	6.5	8665.6	0.9

Appendix B.4 En-route

	2019 (AIRAC cycles 1901-1913)			**2020 (AIRAC cycles 2001-2014)**		
Airport pair	Number of movements	Total VFI (feet)	VFI per flight (feet)	Number of movements	Total VFI (feet)	VFI per flight (feet)
EDDT-EDDF	8012	63203814	9861	2546	16536640	8119
EDDF-EDDT	8010	46525884	7261	2539	6148666	3027
EDDF-LFPG	4711	40728110	10807	1955	12862639	8224
EDDS-EDDT	5485	40240666	9171	1798	8821796	6133
EDDL-EDDM	7131	38845531	6809	3045	4227103	1735
EDDT-EDDS	5472	37595125	8588	1800	12733063	8842
EDDM-EDDK	5302	36601290	8629	2215	15056520	8497
LFPG-EDDF	4744	36450119	9604	1938	14301158	9224
EGLL-EHAM	6564	35245146	6712	2747	13043469	5935
EHAM-EGLL	6555	32802707	6255	2731	13849192	6339
EHAM-EGLC	4537	32513914	8958	1211	9408253	9711
EDDK-EDDM	5576	32476356	7280	2470	6103490	3089
EDDT-EDDL	5349	29074052	6794	1604	907481	707
LFPG-EHAM	4369	28866839	8259	2661	11361139	5337
EGLC-EHAM	4521	28426401	7860	1206	8569330	8882
EDDT-EDDK	5649	26780096	5926	1713	1753692	1280
EDDM-EDDT	8332	26743459	4012	2321	6788833	3656

LEMD-LEBL	8042	26524467	4123	3183	9651360	3790
EDDH-EDDM	7127	25911252	4545	3231	4118844	1593
LEBL-LEMD	8069	25292228	3918	3185	9919813	3893
EGLL-EBBR	3129	23145887	9247	1244	8496609	8538
EDDH-EDDF	5422	22655127	5223	2182	5248972	3007
EGLL-LSGG	4865	22155601	5693	1756	8750005	6229
EHAM-LFPG	4367	21950386	6283	2665	3855417	1808
EDDM-EDDL	7091	21820418	3846	3051	3908530	1601
EDDF-EDDH	5414	21238457	4904	2195	735064	419
EGKK-EHAM	3648	21117113	7236	1045	6165667	7375
LFBO-LFPO	7806	20897483	3346	3103	5977597	2408
LFPG-EGLL	4614	20186770	5469	1924	8752354	5686
LSZH-EDDT	4674	19143427	5120	1418	3206660	2827
EHAM-EGKK	3642	18618363	6390	1044	5289092	6333
EDDH-EDDS	3385	18467160	6819	1500	912305	760
EDDF-EHAM	4090	18049186	5516	2016	5893911	3654
GCLP-GCRR	7345	17947244	3054	4640	11283358	3040
LFPG-EDDL	2821	17882160	7924	706	4289910	7595
LEPA-LEMD	7021	17793938	3168	3801	9755415	3208
LECO-LEMD	2788	17722985	7946	1209	8704232	8999
LFMN-LFPO	6828	17686852	3238	3387	7745804	2859
EDDK-EDDT	5615	17538976	3904	1695	3622764	2672
GCRR-GCXO	3427	17524625	6392	2311	10981733	5940
LEPA-LEBL	8023	17366920	2706	4260	7914227	2322
LEBL-LEIB	4086	17200346	5262	2068	8300530	5017
EDDL-LSZH	3747	16955621	5656	1129	2408643	2667
EDDT-EDDM	8324	16661668	2502	2319	3369010	1816
EGGW-EHAM	2883	16538146	7171	804	4726488	7348
EGLL-LFPG	4614	16494990	4469	1911	8155270	5334
LEBL-LIMC	3108	16422001	6605	811	4254450	6557
LPPR-LEMD	4417	16307032	4615	1550	4602578	3712
EDDL-LFPG	2820	15984002	7085	706	3830723	6782
EDDM-EDDV	2799	15928880	7114	1191	4800744	5039
EDDM-EDDH	7126	15832664	2777	3227	20150	8
LEBL-LEPA	8144	15810814	2427	4346	6968849	2004
EHAM-EGGW	2834	15580546	6872	815	4156155	6374
EDDF-LOWW	4362	15229855	4364	1910	1551951	1016
EDDT-LOWW	4013	15169929	4725	1170	4032213	4308
EDDT-LSZH	4671	15096298	4040	1415	2951320	2607
EHAM-EDDF	4098	15054198	4592	2036	2078167	1276
EDDS-EDDH	3376	14944144	5533	1499	190418	159
LSZH-LSGG	3146	14767371	5868	1161	5112690	5505
GCXO-GCRR	3415	14731015	5392	2314	9172386	4955

LEMD-LEPA	7160	14668174	2561	3818	8280652	2711
EDDW-EDDF	1724	14442490	10472	501	4490020	11203
EGBB-EHAM	3424	13519968	4936	1273	6159427	6048
LFLC-LFPG	1365	13358128	12233	320	3072896	12004
GCLA-GCXO	7415	13264670	2236	4533	8411810	2320
LEMD-LPPT	6210	12904551	2598	2406	4923178	2558
EDDS-EHAM	2039	12901904	7909	991	4928558	6217
EDDF-EDDM	5075	12893130	3176	2156	4871222	2824
LFPO-LFML	3609	12779494	4426	1600	4428825	3460
EBBR-EGLL	2894	12663950	5470	992	5113128	6443
GCLP-GCFV	5983	12626399	2638	4005	8435662	2633
LPPT-LEMD	6179	12611572	2551	2401	5235054	2725
EGJJ-EGKK	2806	12555290	5593	780	1971331	3159
GCRR-GCLP	7040	12386711	2199	4647	7647025	2057
LSGG-LSZH	3162	12347262	4881	1213	4432528	4568
LFBO-LFPG	3854	12135050	3936	2568	8209663	3996
EIDW-EGPH	3223	12134508	4706	1020	3684764	4516
LFLL-LFPG	2238	12129417	6775	1261	7415724	7351
EGPH-EIDW	3206	12071329	4707	1024	4412809	5387
LICC-LIRF	6385	11975124	2344	3020	2673904	1107
LFPO-LFBO	7807	11935612	1911	3098	2986048	1205
LEMH-LEBL	2792	11819128	5292	1559	5930358	4755
GCXO-GCFV	2537	11812637	5820	1803	8098065	5614
EDDH-EDDL	2774	11805717	5320	1089	5508210	6323
LOWW-EDDT	4018	11717403	3645	1171	3638890	3884
EDDM-EDDW	2077	11600467	6982	980	1850942	2361
LSZH-LFPG	3137	11532989	4596	741	2364520	3989
LEIB-LEBL	4095	11526411	3518	2067	8120035	4911
LSGG-EBBR	2771	11510504	5192	893	2931232	4103
LFRS-LFLL	2482	11337236	5710	1231	4840880	4916
LFPG-EGBB	2130	11305870	6635	570	3105480	6810
LFPG-LSGG	3029	11182504	4615	1124	4125268	4588
LOWW-EDDF	4561	11157092	3058	2107	118890	71
LEST-LEMD	2295	11146508	6071	947	4808062	6346
EDDN-LFPG	1211	10883510	11234	262	2424510	11567
LFRS-LFPG	1807	10730830	7423	593	3498075	7374
EDDG-EDDM	1573	10580908	8408	418	2819893	8433
LFBD-LFLL	2556	10568346	5168	1224	4179425	4268
EGPD-EGPB	4139	10454931	3157	2885	5820189	2522
GCLP-GCXO	8011	10345188	1614	5711	7289458	1595