Analysis of en-route vertical flight efficiency

Technical report on the analysis of en-route vertical flight efficiency

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Abstract

This document describes the conceptual, mathematical and platform independent approach of the analysis of en-route vertical flight efficiency.

Keywords

Vertical Flight Efficiency
Data Processing

Contact: E-mail: sam.peeters@eurocontrol.int
Tel.: +32 2 729 00 68

Authority	Name	Unit
Document Author	Sam Peeters, Guglielmo Guastalla	PRU
Document Reviewer	Kevin Grant	PRU
Document Approver	Bernd Tiemeyer	PRU

Table of Contents

List of Figures

List of Tables

1 Introduction

1.1 General

This document describes the conceptual, mathematical and platform independent approach for the analysis of en-route vertical flight efficiency, as used by the Performance Review Unit of EUROCONTROL.

Since many years flight efficiency was targeted and monitored solely by reference to the horizontal profile of the aircraft's trajectory [1]. Stakeholders have indicated to be interested in the vertical aspect of flight efficiency as well. This need has been responded to in 2008 with a technical note estimating the impact of ATM on vertical flight efficiency [2]. Since 2015, the PRU is continuing this work by developing and testing possible performance indicators for vertical flight efficiency which might be proposed to be used in the future.

This document focuses on the analysis of en-route vertical flight efficiency. A separate document is available regarding the analysis of vertical flight efficiency during climb and descent [3].

1.2 Purpose of the document

This document is intended to present the methodology used by the Performance Review Unit for the analysis of en-route vertical flight efficiency.

1.3 Scope

This document provides a technical description on the methodology used in the analysis of the vertical profile of the aircraft's trajectory during the en-route phase of flight.

The objective of the methodology is to measure and observe vertical flight efficiency without highlighting specific reasons for the observed behaviour. More detailed case studies are needed to find out reasons for particular observations.

While this document focuses on the methodology itself, more results will be available in the Performance Review Report 2016.

1.4 Summary of the analysis information

En-route Vertical Flight Efficiency: Summary			
Current version status	Prototyping / Validation		
Version status and evolution	Conceptual Phase		Phase completed
	Technical Development		Phase completed
	Prototyping / Validation		Ongoing
	Monitoring	2017	N/A
	Target Setting	TBD	N/A
	Phase Out		N/A
Context	KPA : Efficiency Focus Area: Vertical Flight Efficiency Trade-offs: local and network performance		
Description	The en-route analysis provides the following results, per airport pair: • Total vertical flight inefficiency • Vertical flight inefficiency per flight		
Unit	Feet		
Used in	EUROCONTROL: Performance Review Report (as from PRR 2016)		

Table 1: Analysis summary

1.5 Acronyms and terminology

Term	Definition
FTFM	Trajectory information based on the last filed flight plan
KPA	Key Performance Area
GCD	Great Circle Distance
PRISME	Pan-European Repository of Information Supporting the Management of EATM
PRR	Performance Review Report
PRU	Performance Review Unit
RAD	Route Availability Document
SES	Single European Sky
VFI	Vertical Flight Inefficiency

Table 2: Acronyms and terminology

2 Methodology

2.1 Approach and assumptions

The general approach of the analysis is to compare the maximum altitudes in the flight plans of flights between a specific airport pair with the maximum altitudes of flights between similar airport pairs, hereafter called reference flights. Reference flights are flights between unconstrained (in terms of RAD restrictions) airport pairs which have a great circle distance close to the one of the examined airport pair.

Since the aircraft type has a significant influence on the nominal cruising altitude, the analysis is done using specific aircraft types with similar performance (e.g. only jet aircraft, turboprop aircraft …). Currently only Airbus and Boeing aircraft are considered since they account for the biggest portion of scheduled commercial flights.

The use of the maximum altitude in the flight plan leads to an underestimation of the vertical flight inefficiency because there can be lower cruise segments before or after the moment the maximum altitude is reached. These cruise segments can be even more inefficient since the fuel consumption at lower altitudes is in general higher.

To account for statistical uncertainty, the lowest and highest 10 percent of the flights (when sorted according to their maximum altitudes) are excluded.

2.2 General overview

The analysis is done in 4 major steps. First, the necessary data are extracted from the data source. Then the reference distributions are calculated such that they can be used for all the airport pairs under investigation. For each considered airport pair, the maximum altitudes in the flight plan are processed in order to be compared with the reference. In the last step the different metrics are calculated. The process is visualised in Figure 1.

Figure 1: Different steps of the analysis

The following paragraphs explain these steps in further detail.

2.3 Loading of the trajectories information

The data used for the analysis are downloaded from the PRISME database. FTFM data is used in order to assess the maximum altitudes in the flight plans. The most important data fields for the analysis are the altitude and time information.

2.4 Definition of the reference distribution

Reference airport pairs are airport pairs with a great circle distance (GCD) close to the great circle distance of the considered airport pair and which have no constraints in the RAD.

Reference distributions are calculated for buckets of GCD ranges, e.g. a reference is calculated for all airport pairs in the GCD ranges [0,10) NM, [10,20) NM, etc. This approach reduces the calculation time significantly since only one calculation is needed and the reference for a specific airport pair will be the one of the corresponding bucket.

The reference distribution is created using a large number of flights with no specific filtering except for the aircraft type. This is done in order to get a reference distribution irrespective of factors such as aircraft weights, weather phenomena, company policies…

The reference is based on the assumption that flights between airport pairs with similar GCDs, performed with a similar aircraft type, would file for similar maximum altitudes. The differentiating factor between the two sets of flights can be the presence of RAD constraints, scenarios, airline policy, mistakes in the flight planning system, etc., and if the distribution of the maximum altitudes of flights on the chosen airport pair doesn't follow the reference distribution, this could be an indication of inefficiency.

2.5 Distribution of the maximum altitudes

As is done for the reference, the distribution of the maximum altitudes flown on the considered airport pair is determined. Having the distributions of the reference and the considered flow on the airport pair allows for plotting a diagram as in Figure 2.

Figure 2 shows the histograms of the maximum filed altitudes both for the reference flights and the flights on the chosen airport pair. The numbers on the right of the bars indicate the number of flights while the length of the bar indicates the percentage of flights. E.g. the large blue bar at FL350 represents 260 flights, being 76.2% of the total number of flights on the chosen airport pair. The sum of the percentages corresponding to the lengths of the bars is 100% both for the blue and for the red bars. As can be seen from the values of the number of flights, there are a lot more flights in the reference distribution which makes it a stable reference.

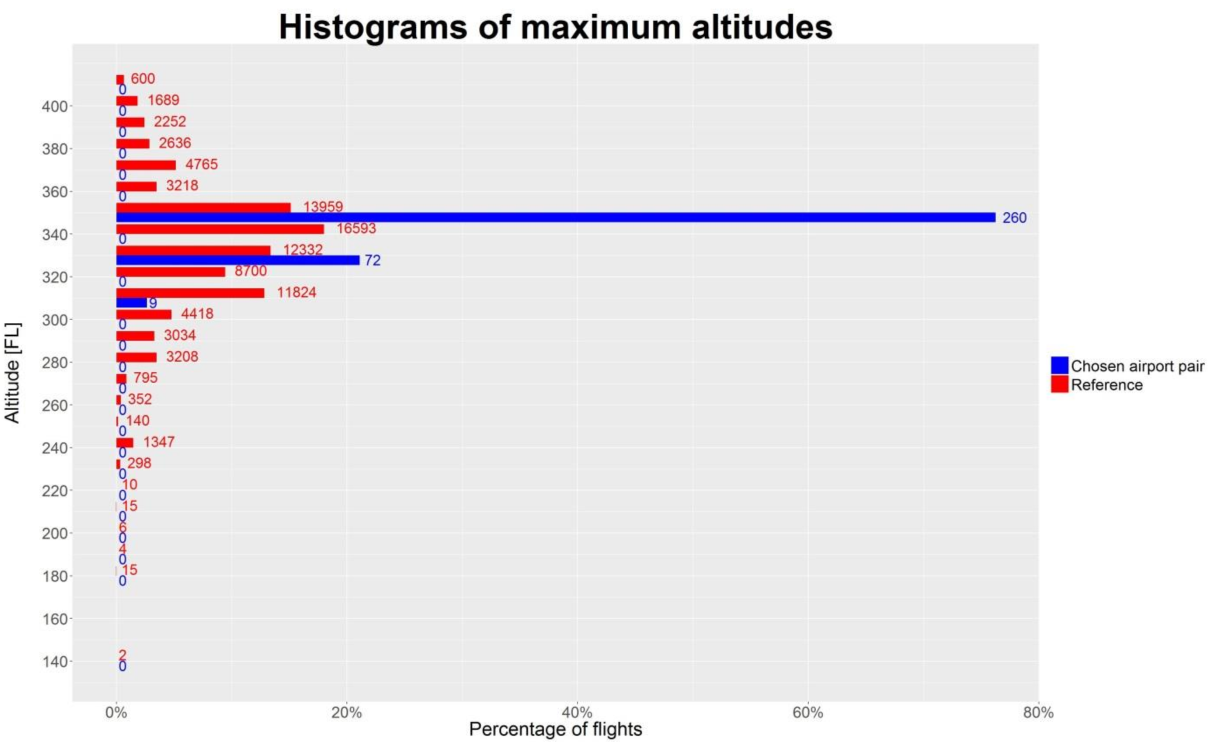

Figure 2: Example distribution of maximum altitudes

The data in Figure 2 can be represented differently, using percentiles as shown in Figure 3. To obtain this, the percentages from Figure 2 are simply put successively. E.g. the percentages of the chosen airport pair (blue bars: 2.6% at FL310, 21.1% at FL330 and 76.2% at FL350) are plotted at their respective altitudes to get the blue line in Figure 3. The same is done for the reference.

The example represents an airport pair on which, in general, flights are filing higher than the reference. There are however some percentiles where reference flights are filing higher than the flights on the considered airport pair. Only this part is used in the calculation of vertical flight inefficiency (VFI) in order to flag only the inefficiencies. The red shaded area in Figure 3 indicates the VFI. The dark grey areas on the left and right highlight the percentiles that are excluded to account for statistical uncertainty as mentioned before in 2.1.

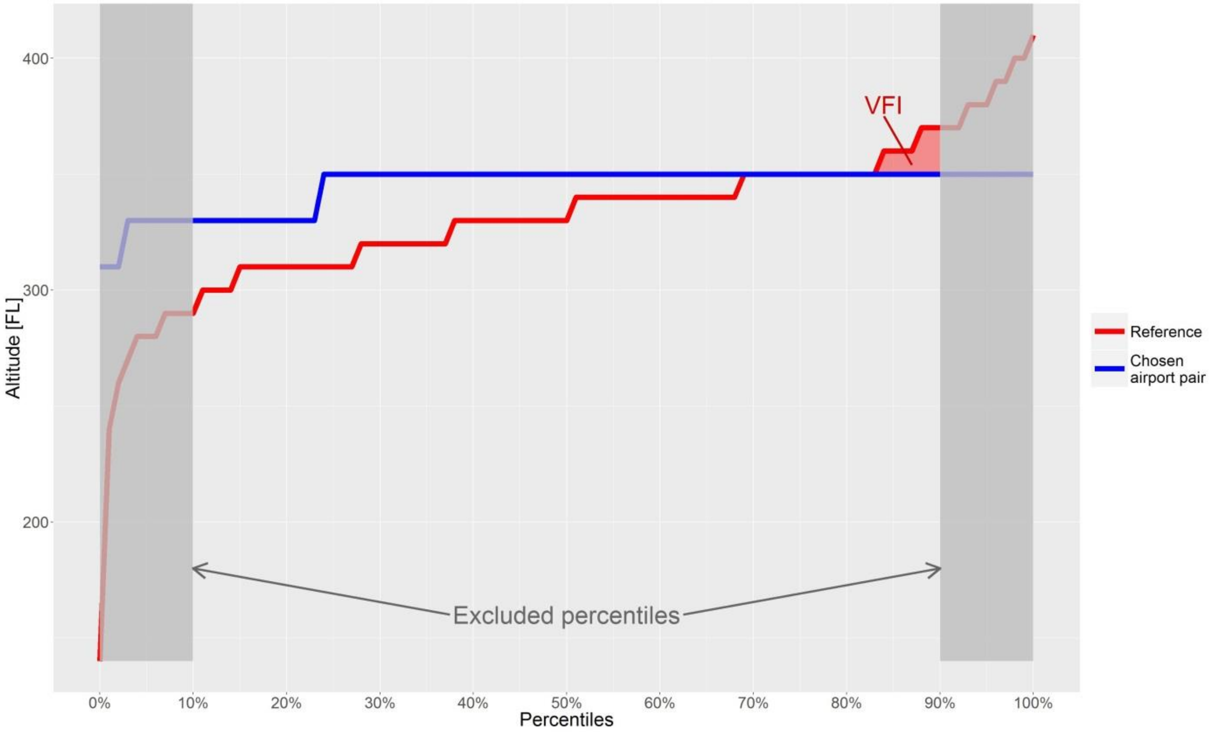

Figure 3: Example distribution of maximum altitudes

2.6 Calculation of the metrics

The VFI is calculated using the percentiles as shown in Figure 3. For each percentile range, the altitude value of the airport pair is subtracted from the reference value. When the airport pair value is higher than the reference value, the result of the subtraction is negative. This might appear as if the flights are more efficient than the reference flights. Nevertheless, the focus is put on finding the inefficiencies so negative values are set to 0.

The result of the percentile range is then multiplied by the number of flights corresponding to the percentile range (e.g. if the width of the percentile range is 1%, the number of flights corresponding to the percentile range is 1% of the total number of flights on the airport pair).

Summing up over all percentile ranges gives the total vertical flight inefficiency. The vertical flight inefficiency per flight value is then calculated by dividing the total vertical flight inefficiency by the number of flights on the considered airport pair (the number of flights for this calculation step is 80% of the total number of flights on the airport pair since the lowest 10% and highest 10% of the flights are not used).

Table 3 summarises the formulas used for the calculation of the VFI metrics.

Table 3: Formulas used for the calculation of the results

Result	Formula
Total vertical flight inefficiency (Total VFI)	$\sum_i max\left(L_{ref,i} - L_{act,i}, 0\right) * n_{act,i}$
Vertical flight inefficiency per flight (VFI per flight)	$\frac{\sum_i max\left(L_{ref,i} - L_{act,i}, 0\right) * n_{act,i}}{\sum_i n_{act,i}}$

With:

i	Percentile range
$L_{ref,i}$	Flight level of the i[th] percentile range over all reference flights in the GCD bucket around the GCD of the considered airport pair
$L_{act,i}$	Flight level of the i[th] percentile range over all flights on the considered airport pair
$n_{act,i}$	Number of flights on the considered airport pair in the percentile range

3 Error description

The error in the results depends on the accuracy and precision of the available data. The altitude information is represented in flight levels (100 feet), so the highest attainable precision is 100 feet.

The metrics presented above have to be considered as lower bounds of the vertical flight inefficiency since the analysis only takes into account the maximum flight level in the flight plan. Consequently, any lower flight levels during the cruise phase are not accounted for. These lower altitudes might be due to other restrictions and/or lower optimal cruising altitudes related to the aircraft's weight.

4 Results

Table 4 presents the numerical results of the 20 most inefficient flows in the EUROCONTROL area during the AIRAC 1505 cycle (30/04/2015 until 27/05/2015). Apart from the total VFI, also the VFI per flight is mentioned, giving an indication of how much lower a flight on the considered airport pair is filing with respect to the reference flights.

It is worth noting that the 687 flights from Airport A to Airport B, having the highest total VFI, file 5325 feet lower than the reference flights which is more or less half of the VFI per flight for flights from Airport H to Airport D (10600 feet). However, there are only 248 flights on this airport pair which results in a lower total VFI value.

Table 4: Top 20 airport pairs in terms of total VFI

Airport pair	Total VFI [feet]	VFI per flight [feet]	Number of flights	GCD [NM]
Airport A - Airport B	2926620	5325	687	308.6
Airport C - Airport D	2505820	8975	349	214.9
Airport D - Airport C	2287440	8100	353	214.9
Airport E - Airport F	2151600	4075	660	260.6
Airport G - Airport C	2137920	6550	408	199.7
Airport H - Airport D	2103040	10600	248	241.1
Airport D - Airport H	1968300	10125	243	241.1
Airport H - Airport G	1903660	4675	509	352.4
Airport I - Airport B	1894860	3988	594	364.7
Airport J - Airport H	1882440	4150	567	233.9
Airport K - Airport L	1877760	8150	288	235.1
Airport G - Airport M	1856915	10136	229	189.1
Airport C - Airport G	1793760	5550	404	199.7
Airport F - Airport E	1629360	3100	657	260.6
Airport N - Airport C	1582200	6750	293	196.7
Airport O - Airport P	1578240	3600	548	197.3
Airport H - Airport J	1561914	3425	570	233.9
Airport G - Airport H	1493520	3675	508	352.4
Airport K - Airport J	1459920	3300	553	258.7
Airport D - Airport G	1442280	5050	357	187.6

The following paragraphs discuss a number of examples in more detail.

5 Case studies

5.1 Airport A - Airport B

The airport pair with the highest total VFI is Airport A - Airport B. The flights on this airport pair file on average 5325 feet lower than the reference flights. There is a RAD restriction at FL345 but almost 80% of the flights are filing (significantly) lower. This is clearly visible in Figure 4. Further investigation revealed that one airline flying on this airport pair was filing FL280 maximum. The airline was contacted about this observation and it appeared that their flight planning system still contained an old restriction at FL285 which is no longer applicable. The airline's flight planning system has been updated so they could file up to FL340 now.

Figure 5 shows the percentiles of the maximum filed altitudes. Here it is again clear that the RAD restriction is not the main reason for the vertical flight inefficiency.

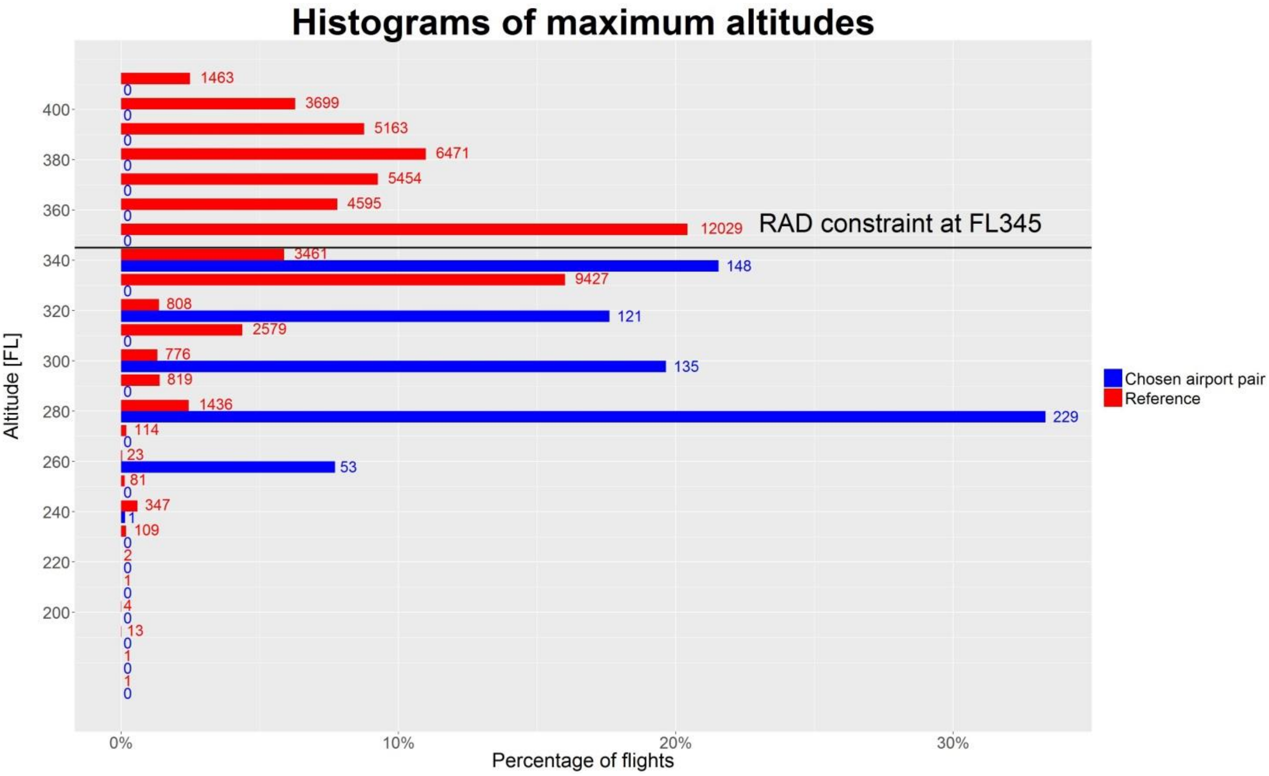

Figure 4: Histograms of maximum altitudes of the reference and flights from Airport A to Airport B

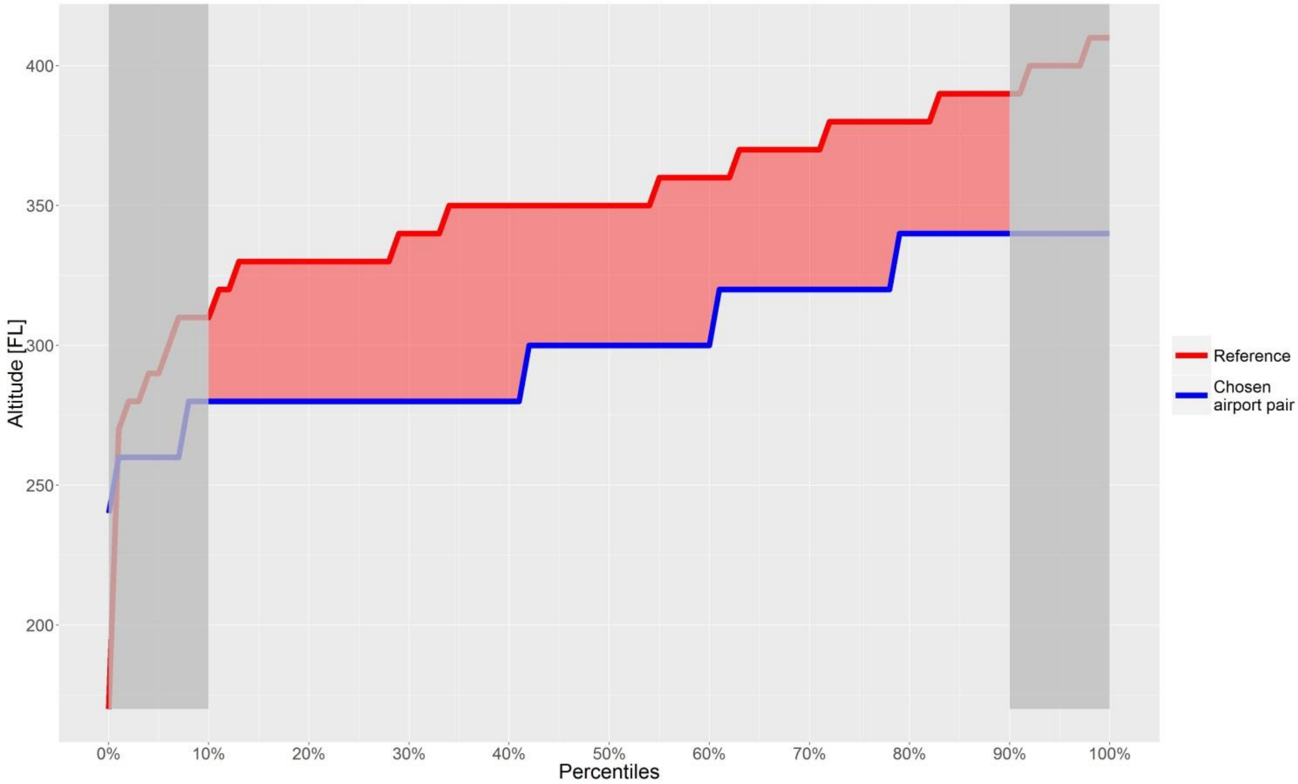

Figure 5: Distribution of maximum altitudes of the reference and flights from Airport A to Airport B

5.2 Airport H - Airport D

Flights from Airport H to Airport D experience the highest amount of vertical flight inefficiency on a per flight basis: they file on average 10600 feet lower than the reference flights. This inefficiency is probably the result of the applicable RAD restriction which is active all day long and doesn't allow the flights to file above FL245.

The effect of the restriction is very clear in Figure 6 and Figure 7. 70 percent of the flights have FL220 as their maximum altitude while most of the remaining 30 percent of the flights file up to FL240. The reason for the large amount of flights at FL220 is not clear. Potential reasons are letters of agreement, other restrictions, company policy…

There are 6 flights not adhering to the RAD restriction so these might be exceptional flights. Nevertheless, these flights are not taken into account since they fall in the top 10% of flights.

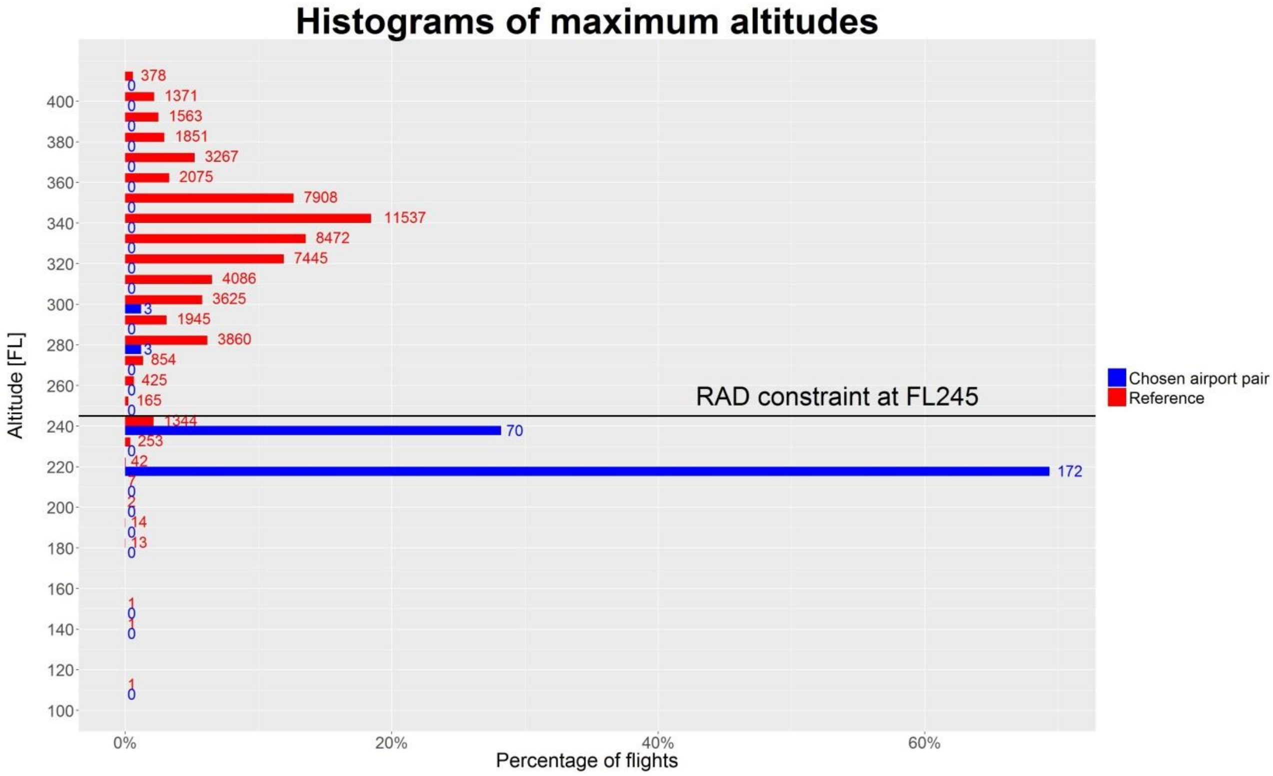

Figure 6: Histograms of maximum altitudes of the reference and flights from Airport H to Airport D

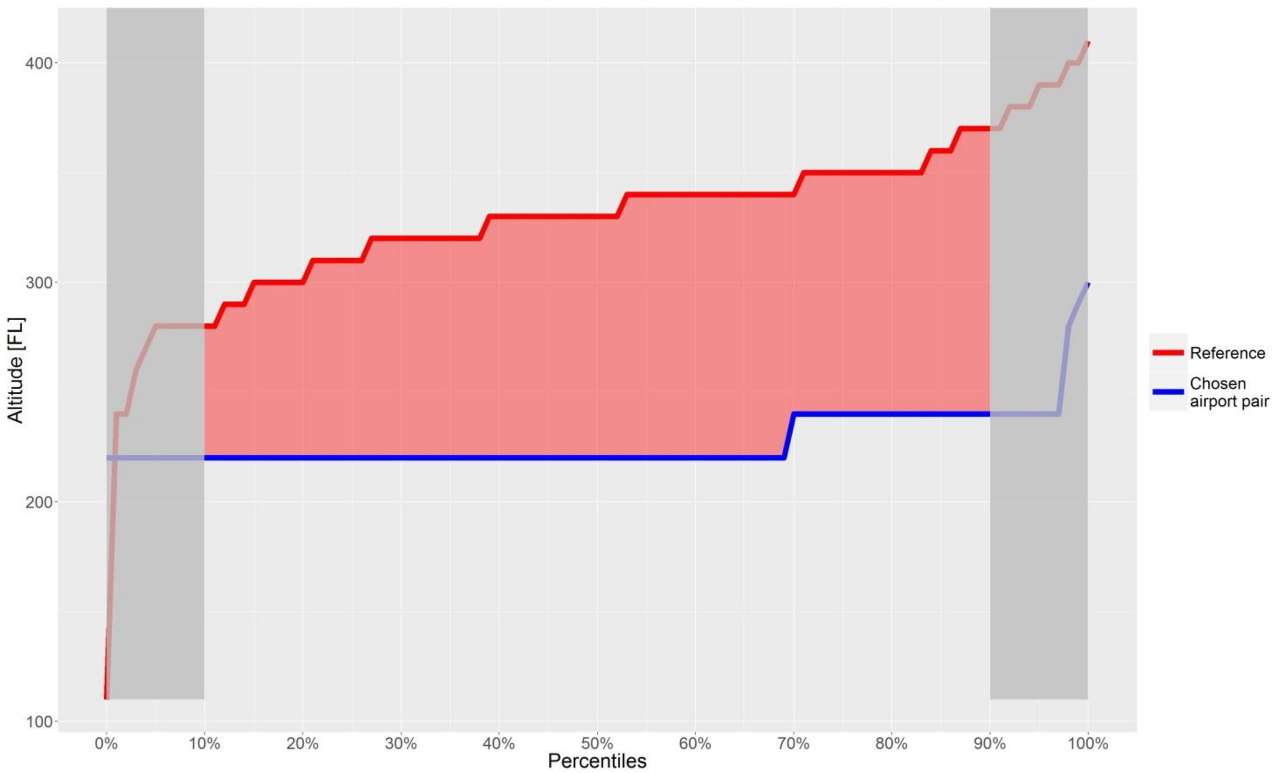

Figure 7: Distribution of maximum altitudes of the reference and flights from Airport H to Airport D

5.3 Airport G – Airport C

The airport pair Airport G - Airport C has an important amount of vertical flight inefficiency. In this case the main cause seems to be a RAD restriction limiting the flights at FL235 as can be seen on Figure 8 and Figure 9. Almost all flights are filing at FL230, just below the RAD restriction.

On average flights are filing 6550 feet lower than the reference flights.

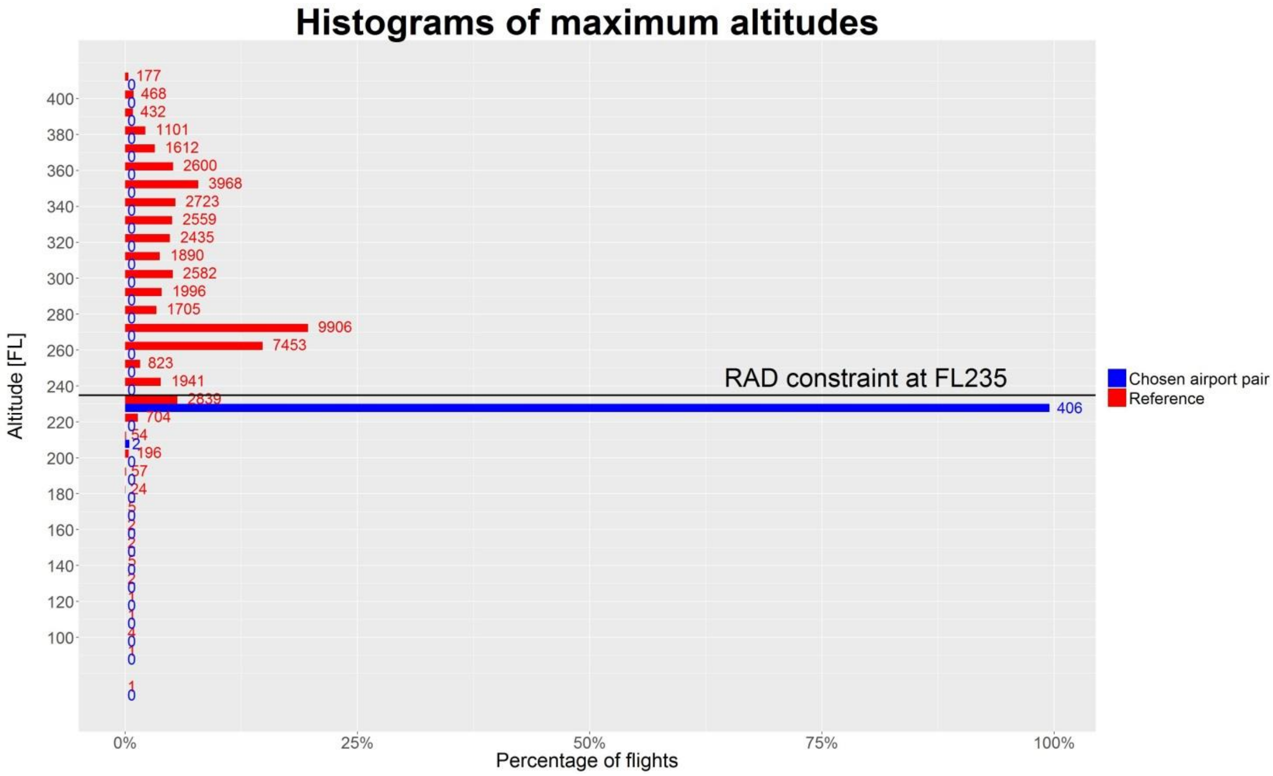

Figure 8: Histograms of maximum altitudes of the reference and flights from Airport G to Airport C

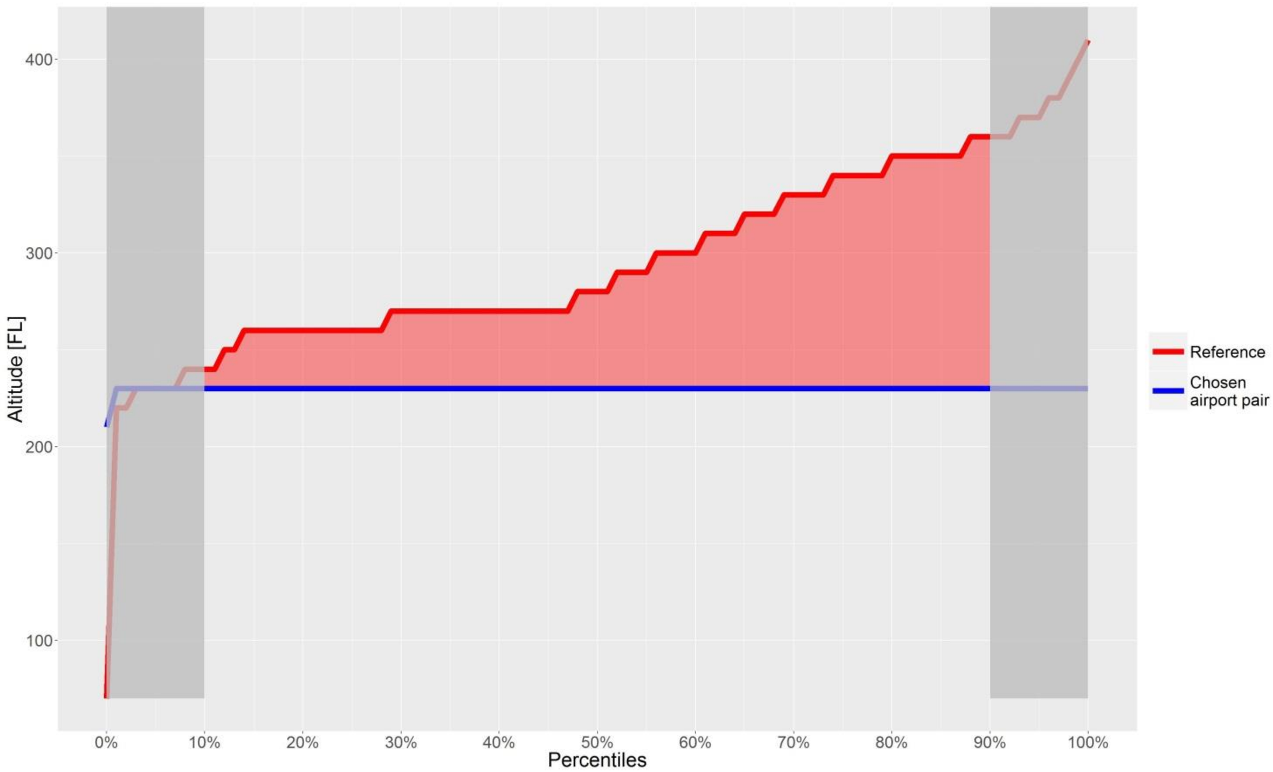

Figure 9: Distribution of maximum altitudes of the reference and flights from Airport G to Airport C

5.4 Airport Q - Airport R

The methodology does not only highlight inefficiencies due to RAD restrictions. For example, the traffic flow from Airport Q to Airport R has a vertical flight inefficiency of 6820 feet per flight. However, the RAD contains no restrictions for this airport pair in the considered time period.

Figure 10 and Figure 11 show clearly that the flights are filing lower than the reference flights so there must be another reason. It is suspected that there is a restriction applicable to these flights since they are all filing at the same altitude. However, there were no ATFCM measures (scenarios) active for these flights so for the moment the exact reason remains unclear.

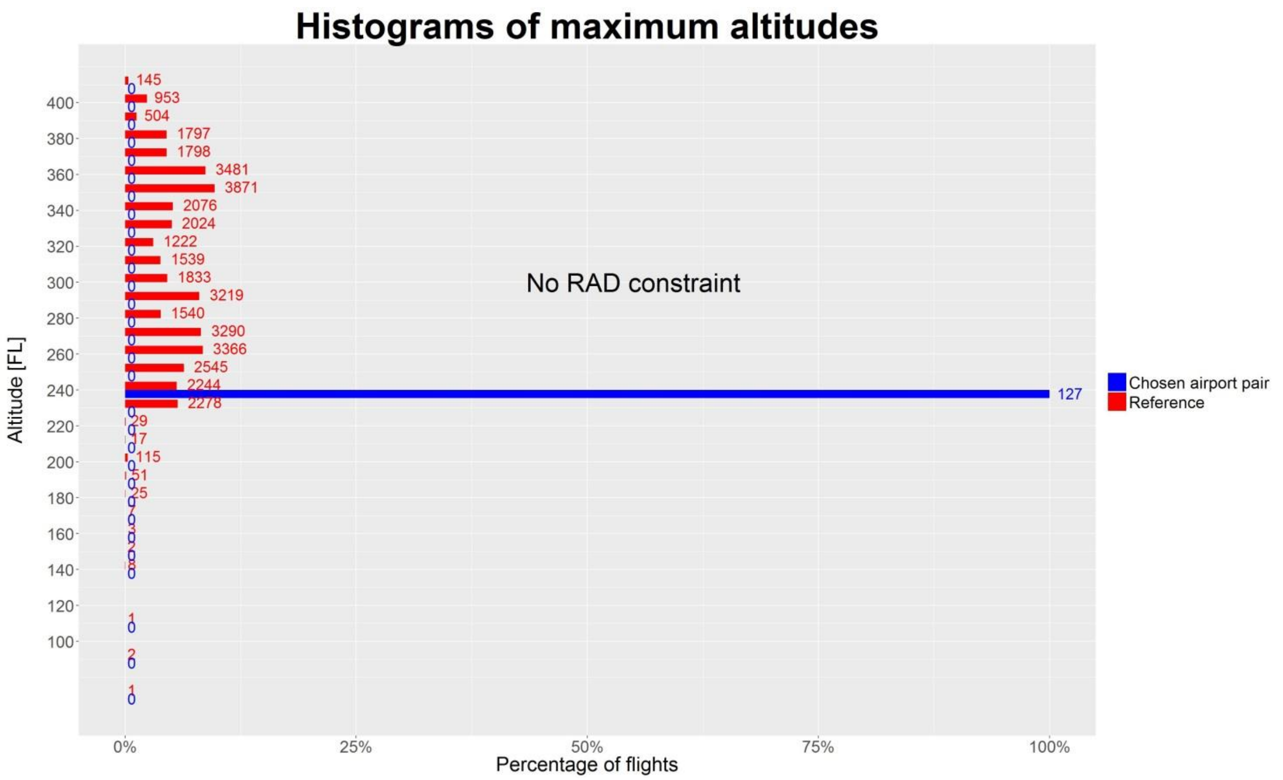

Figure 10: Histograms of maximum altitudes of the reference and flights from Airport Q to Airport R

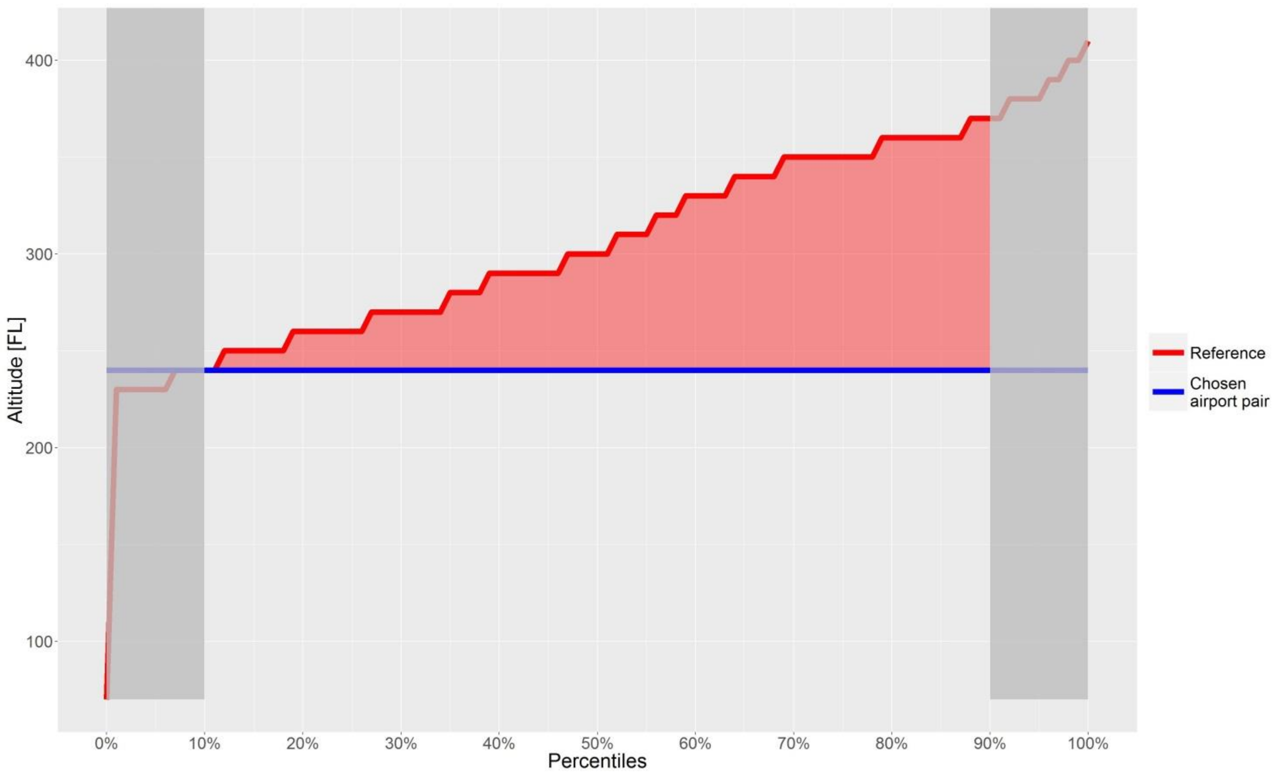

Figure 11: Distribution of maximum altitudes of the reference and flights from Airport Q to Airport R

5.5 Airport S – Airport T

The last case study considers the traffic flow from Airport S to Airport T. There is no vertical flight inefficiency according to the methodology which is in accordance with the distribution of maximum altitudes as shown in Figure 12 and Figure 13. The flights are always filing higher than the reference flights so they are not impacted although there is a RAD restriction restricting flights to FL365 from 06h00 to 21h00. Almost all flights that file above FL365 are filing in this time frame so according to the RAD they should not be allowed to file this high. The reason for this deviation remains unclear.

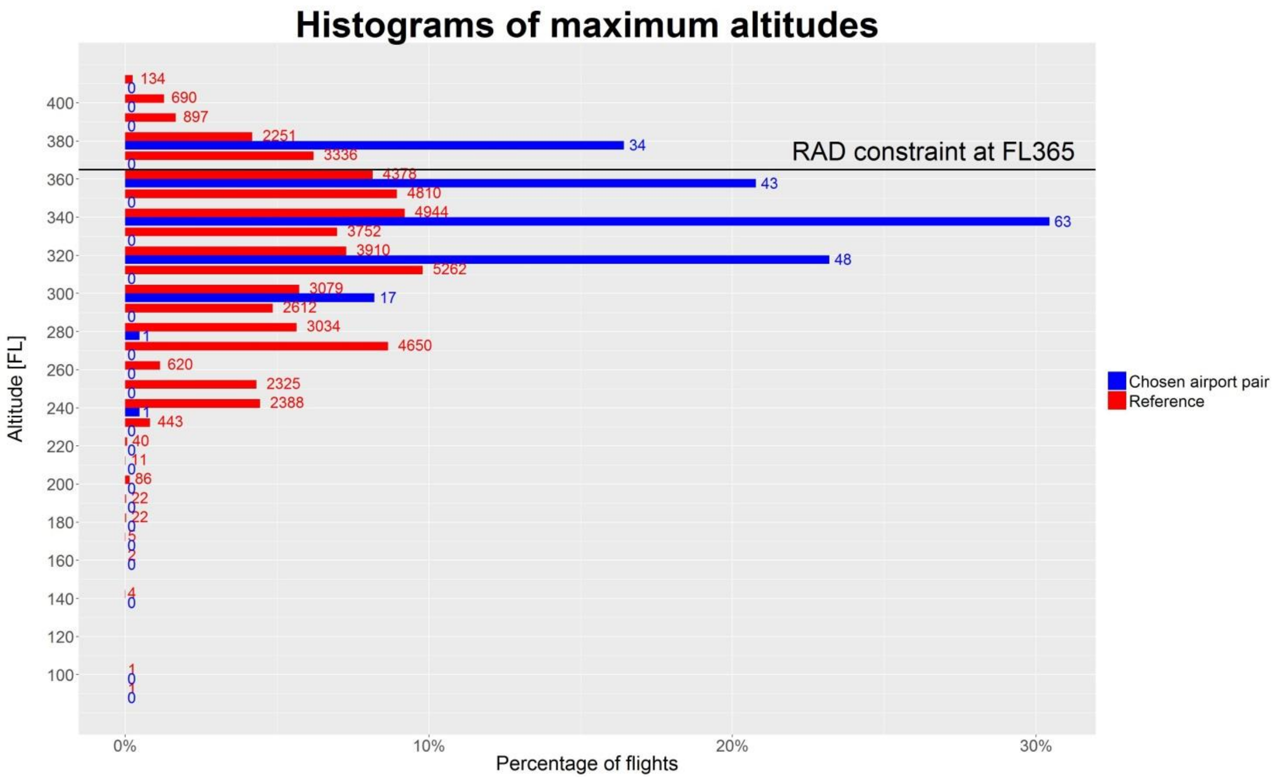

Figure 12: Histograms of maximum altitudes of the reference and flights from Airport S to Airport T

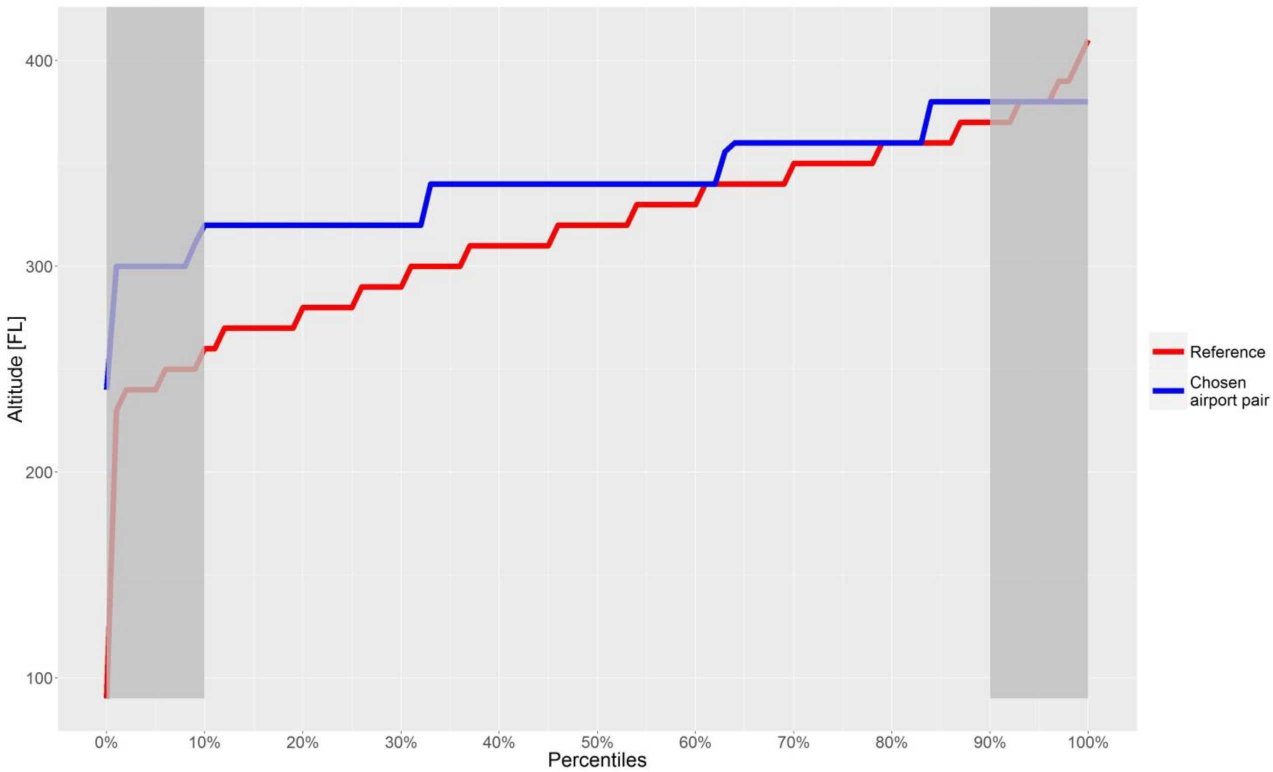

Figure 13: Distribution of maximum altitudes of the reference and flights from Airport S to Airport T

6 References

[1] Performance Review Commission, "Performance Review Report 2015," 2016.

[2] Performance Review Commission, "Vertical flight efficiency," Brussels, 2008.

[3] EUROCONTROL, "Analysis of vertical flight efficiency during climb and descent," 2016.

7 Revision History

Edition	Description	Comment
00-01	New draft – all pages	New document
00-02	Review	
00-03	Update to be submitted for consultation	
00-04	Second review	