Adherence to best descent profiles
An analysis of the relative vertical (in)efficiency at four major European airports

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This paper presents an assessment of the vertical efficiency in descent at four major European airports using best local practice for each flow as a reference. The motivation is to assess the potential for short term improvements through an increased adherence to these best practices. The assessment relies on the analysis of the vertical deviation to best descent profiles of each airport, in relation to the additional flight time as a proxy for the level of congestion. It focusses on the 50NM area around each airport and relies on six months of data from 2018 during day-time operations over more than 200 000 flights in total. The assessment reveals a triple relative inefficiency. Firstly, descent profiles significantly lower than best practices: the median vertical deviation for 10 minutes flight time exceeds 2300ft. Secondly, a degradation of descent profiles with the level of congestion: the median vertical deviation for 10 minutes flight time increases by 800ft per 1 minute additional time. Thirdly, a variability of descent profiles for a same level of congestion: the vertical deviation span (90% containment) for 10 minutes flight time is 2000ft or more for a same additional time. The detailed analysis per runway and per flow of the two airports having the highest vertical deviation reveals that while one shows consistent performances, the other one shows more variabilities. Further work should involve the identification of the causes of large vertical deviations and possible ways to reinforce adherence to best descent profiles.

Keywords: vertical efficiency, continuous descent, arrival sequencing

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I. Introduction

This paper presents an assessment of the vertical efficiency in descent at four major European airports using best local practice for each flow as a reference. The motivation is to assess the potential for short term improvements through an increased adherence to these best practices, with expected benefits in terms of fuel consumption or noise reduction.

The assessment relies on the analysis of the vertical deviation to best descent profiles of each airport, runway and flow, in relation to the additional flight time in the terminal area as a proxy for the level of congestion. It consists of analyzing the effect of the additional time on vertical deviations, and the variability of vertical deviations for a same additional time. It focusses on the 50NM area around each airport, and relies on six months of data from 2018 during day-time operations over more than 200 000 flights in total.

The paper is organized as follows: after a review of the state of the art, it will describe the data preparation and filtering. It will then present the results on the two indicators of additional time and vertical deviation separately, and on vertical deviation in relation to the additional time. It will finally present a detailed analysis per runway and per flow at two airports.

II. State of the art

The Performance Review Unit (PRU) of EUROCONTROL has developed a comprehensive framework to characterize the performances of the arrival management process, encompassing horizontal and vertical dimensions [1][2]. The horizontal dimension relies on the notions of unimpeded time and additional time in the arrival sequencing and metering area, an area of 40NM (extended to 100NM in some analyses) from the airport. The unimpeded time is the transit time in the area in non-congested conditions. The additional time is the difference between the actual transit time and the unimpeded time. It represents the extra time generated by the arrival management and "is a proxy for the level of inefficiency (holding, sequencing) of the inbound traffic flow during times when the airport is congested." The vertical dimension relies on the analysis of level and continuous descent/climb segments, with indicators such as distance and time flown level, median continuous descent/climb altitude, and percentage of flights performing continuous descent/climb [3]. Regarding continuous descent, a distinction is made for the start altitude: from cruise for fuel considerations, and from 7000ft or above for noise considerations. This methodology is used to assess and compare the performances of the arrival management at the main airports in Europe [4] and between Europe and USA [5]. A related FAA/EUROCONTROL study also investigated the potential benefits of reducing speed in cruise to absorb delays in terminal areas during congested periods [6].

On the US side, [7] examined the changes in terms of vertical efficiency before and after the implementation of new initiatives (optimized profile descent and metering to terminal area). The 30 main US airports were analyzed, for the years 2010 and 2015, with ~2000 flights per airport and per year. The analysis relies on a modeling to estimate the potential savings in time and fuel, considering three levels of congestion (based on airport acceptance rate). The results indicate a benefit for the airports with both initiatives implemented (in the order of 30% or more for fuel and time), higher than those with only one initiative (and higher than those with no initiative). For those with one initiative implemented, a significant effect of the congestion level was observed with generally lower benefits for higher level. A check was also performed using two standard metrics (distance in level flight and number of level-offs) showing globally consistent trends (optimized descent and metering over optimized descent; however metering only showing no/little benefits).

Other studies investigated potential applicability and options to increase the use of continuous descents during congested conditions, and assessed related benefits. In [8], the objective is to enable continuous descents during congested periods, avoiding conflict with other flows. Partial continuous descents are proposed (between FL250 and FL150) that remove conflicts with crossing traffic in enroute, and with departure traffic in the terminal area. It is shown that, for the airport considered, these constrained continuous descents provide benefits reduced by only 15% compared to unconstrained ones. In [9], two scenarios are considered (distance vs time constrained) reflecting uncongested and congested conditions. Track data from 25 major US airports are considered with a total of 480,000 flights. Modelling enabled the assessment of benefits in terms of distance, level and fuel. Results showed a potential benefit in an uncongested scenario (less than 100kg for 87% of the flights) but much less in a congested scenario (70-85%). These results may appear significantly different from those of the MITRE study. Reference [10] investigated the principles of continuous descents using a scheduling algorithm to remove conflicts strategically in a 4D concept and with different planning horizons. In [11], an analysis was conducted on New York and Paris areas.

The motivation for our work is to complement the absolute assessment of vertical efficiency developed by the studies presented above, by proposing a relative assessment based on best performers of each airport. While the generalization of continuous descents in all traffic conditions remains the ultimate goal, measuring deviations to best performers may reveal a potential for short term improvements through an increased adherence to local best practices without assuming modifications of route design or operating method. Note: measuring deviations to best performers may be seen similar to the method developed by the PRU to assess vertical enroute efficiency per city pairs [2] and is also inherent to the notion of unimpeded and additional times.

The indicators relying on level-offs presented above (altitude and distance) could have been considered for this relative assessment. However, to avoid any issue with the detection of level segments (in particular with the update rate up to 1 minute on the track data), we decided to consider the altitude deviation as the key element. By considering the deviation along flight time, this will also allow combining the two dimensions of altitude and duration into a single indicator.

III. Data filtering

The European airports considered are the four busiest in 2018: Amsterdam-Schiphol (EHAM), Frankfurt-Main (EDDF), London-Heathrow (EGLL) and Paris-Charles-de-Gaulle (LFPG). They are representative of different types of sequencing and metering (vectoring, tromboning, holding, ..) and runway use (single or multiple arrival runways).

The analysis focusses on the sequencing and metering area as defined by the PRU and enlarged to 50NM to fully encompass the sequencing of the four airports. Fig. 1 below shows the trajectories (2500 selected randomly) in the 50NM area with all runway configurations superimposed. In the following, only the parts of the trajectories within this area are considered.

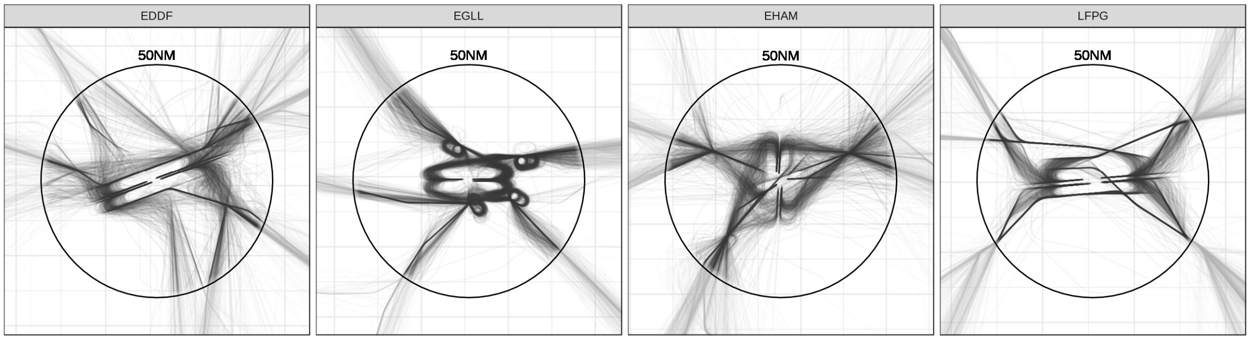

Fig. 1 Trajectories in 50NM area

The dataset consists of position reports with an average update rate of 30 seconds (1 minute for LFPG). It contains initially more than 520 000 arrival flights from April to September 2018.

Three filters have been applied to ensure representativeness of data: (1) daytime operations (7h-21h local time) to exclude night procedures; (2) most representative runways (at least 15% of arrivals to the airport), flows (at least 15% of arrivals to the runway) and flight levels at 50NM (at least 15% of flight levels); (3) 'normal' flights entering and exiting the area, excluding go-arounds, flights with exceptionally short or long flying time, or not flying over the final approach fix.

The final dataset contains more than 213 000 arrival flights (EDDF 52 355, EGLL 61 039, EHAM 59 242, LFPG 40 872). Fig. 2 shows the flows and altitudes at entry after filtering.

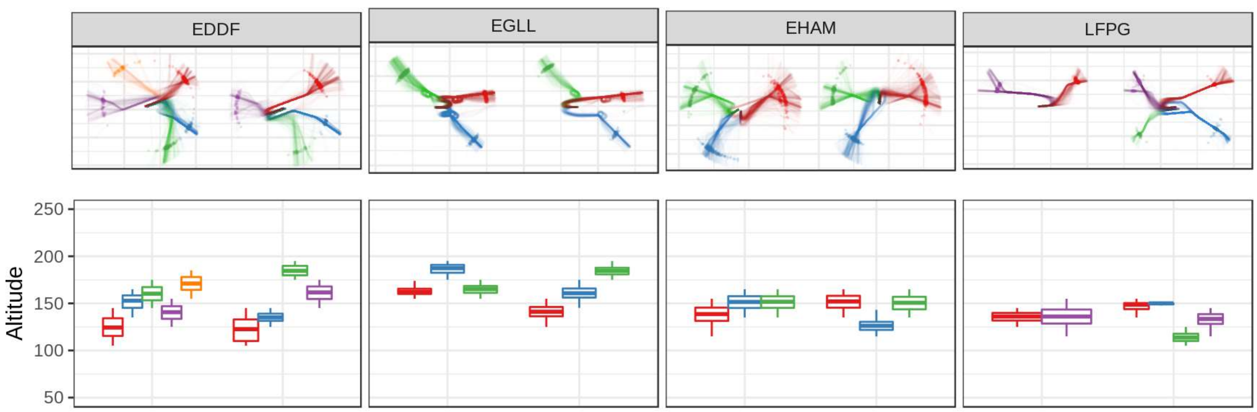

Fig. 2 Flows and altitudes at entry after filtering

Note: For LFPG, the reduced number of flights and the filtering out of the South arrival runway in Westerly configuration (26L) is due to the use of the departure runway (26R) during three months (change of ILS on 26L) leading to traffic below threshold (15%) for both runways.

IV. Additional time

The additional time in the terminal area is a proxy for the level of congestion and is used to assess (1) the effect of increasing levels of congestion on descent profiles, and (2) the variability of descent profiles for similar levels of congestion. The additional time is the difference between the transit time and the unimpeded time in the sequencing area [1][2].

The median and distributions of transit time and additional time for the dataset considered is shown in the next table and figures. The distribution of additional time is rather similar for three airports (EDDF, EHAM and LFPG) but differs significantly for the other one (EGLL) with a median value more than four times higher (it should be recalled that EGLL mostly operates with one arrival runway).

Table 1 Median transit and additional time (minute)

Airport	Transit time	Additional time
EDDF	15.0	1.4
EGLL	19.6	5.7
EHAM	13.8	1.2
LFPG	15.1	0.9

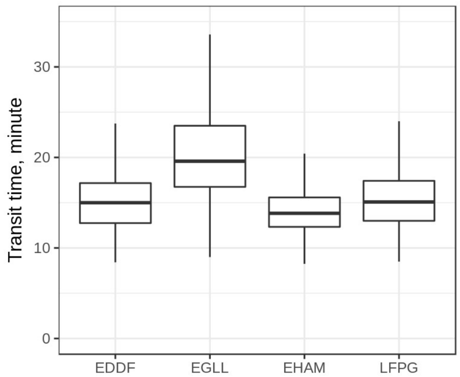

Fig. 3 Distribution of transit time

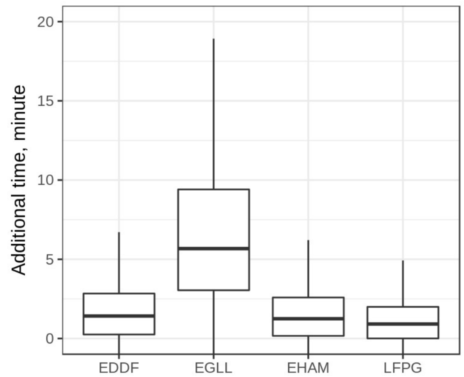

Fig. 4 Distribution of additional time

The next figures show trajectories (2500 selected randomly) with additional time, highlighting how and where path extension is achieved (all runway configurations superimposed).

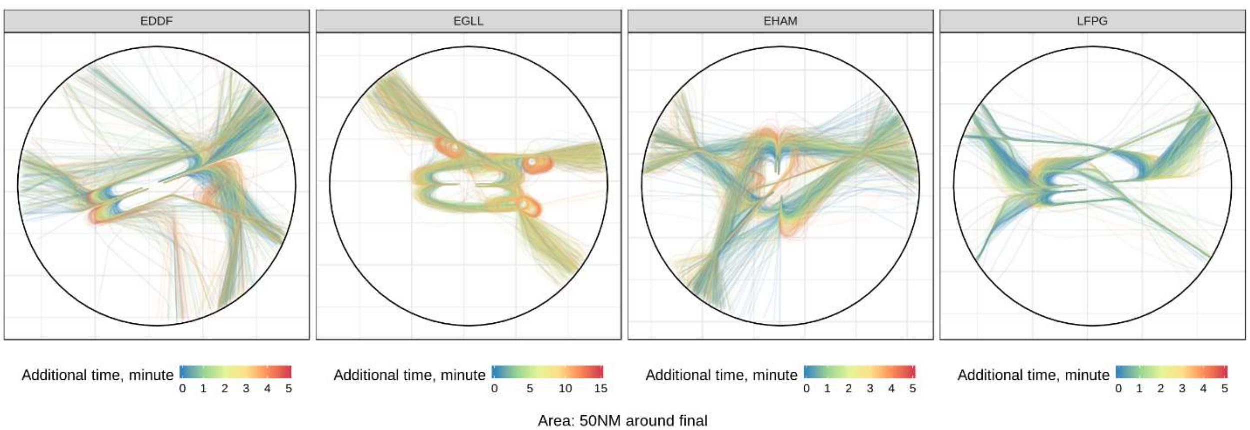

Fig. 5 Trajectories with additional time

V. Vertical deviation

The analysis relies on vertical deviations to reference profiles based on best performers of each airport. A reference profile is defined for each arrival flow. An arrival flow encompasses the arrival flights to the same runway and from the same entry arc (determined by statistical clustering) and altitude at the 50NM. For each flow, the reference profile at a time to final t is the 90th percentile of the altitude of the flown profiles at time to final t or at a closer time to final t' < t.

Thus, a reference profile is not a profile actually flown, but a succession of multiple portions of flown profiles, generally in non-congested conditions (i.e. with a short transit time) and extended to the largest transit time (see following figures). Note: the reference profiles thus defined represent approximately 2% of flown profiles (±200ft).

The vertical deviation is then defined as the difference between the altitude of the corresponding reference profile and the current altitude (see figures below). It can be noticed that, for a short period, some profiles may be higher than the reference, thus leading to a negative vertical deviation.

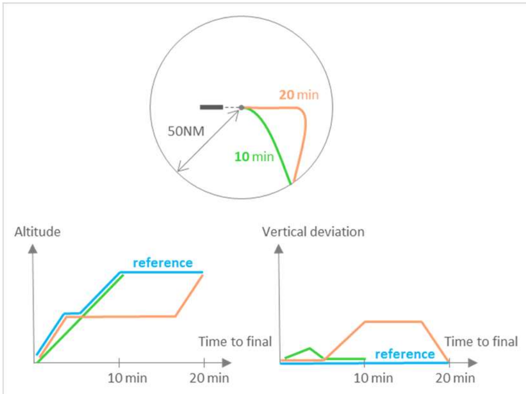

Fig. 6 Reference profile and vertical deviations for two simple profiles

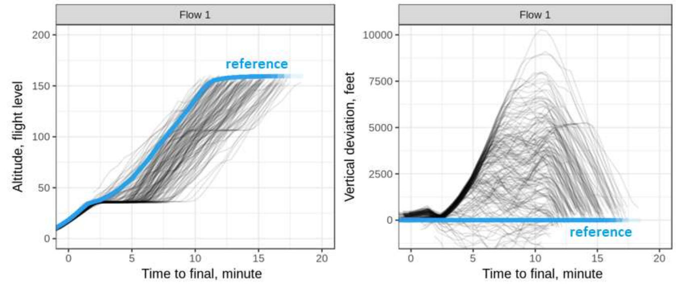

Fig. 7 Reference profile and vertical deviations for an arrival flow

The following figures show the vertical profiles and vertical deviations (2500 selected randomly) as a function of time to final, with median, 5% and 95% containment (calculated on the full set of trajectories and displayed until median transit time).

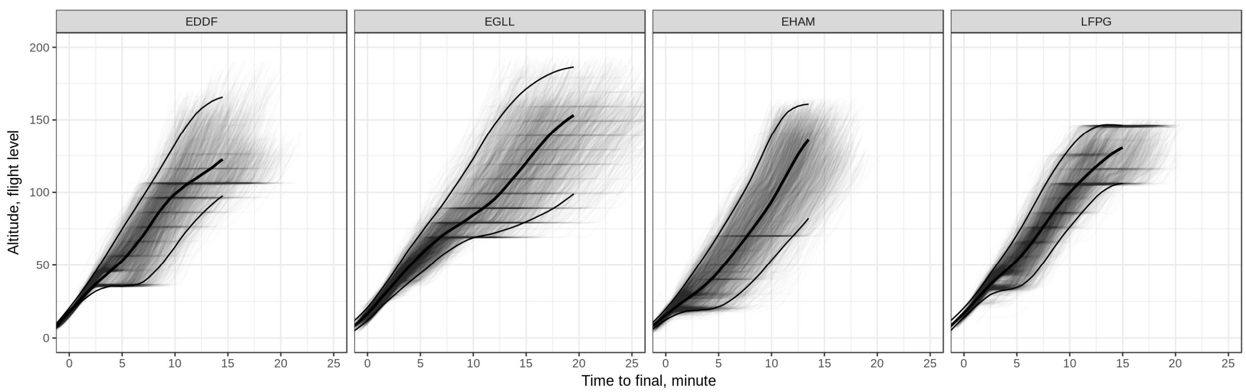

Fig. 8 Vertical profiles (median and 90% containment)

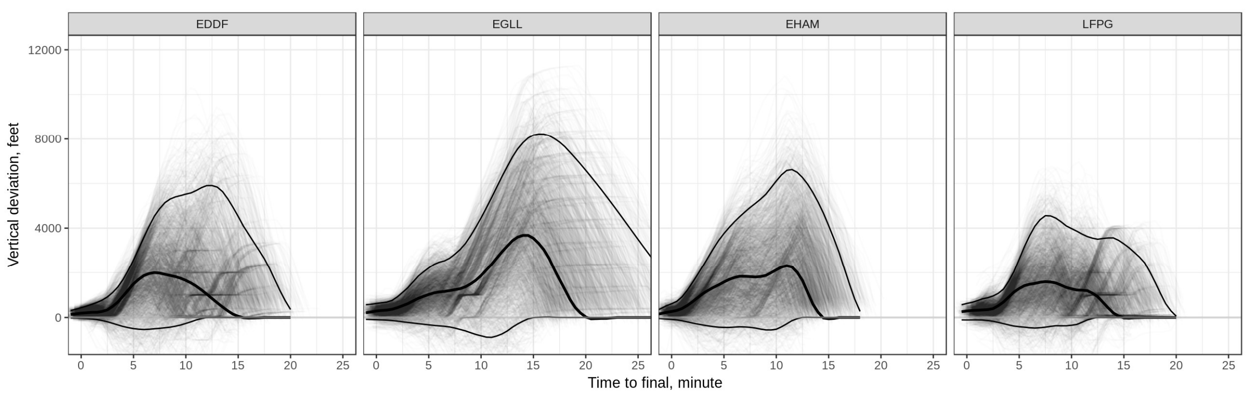

Fig. 9 Vertical deviations (median and 90% containment)

We can notice that the 95% (highest) altitude curves are quite similar among the airports for the range 0 to 10 minutes to final with an altitude around FL130-FL140 at 10 minutes, and around FL70-FL80 at 5 minutes. Beyond 10 minutes, the 95% altitude curves continue to increase for three airports, but remains constant at FL150 for one (LFPG).

The main difference is on the 5% (lowest) altitude curves having a significantly different shape with a flat part starting at 2000ft for one (EHAM), at 4000ft for two (EDDF and LFPG) and at FL70 for the last one (EGLL). This flat part reflects the (lowest) altitude of the path extension.

Regarding vertical deviation, the difference of shape among the 95% (highest) curves is directly related to the difference of shape among the 5% (lowest) altitude curves. The 95% maximum values range between 5000ft and 8000ft. It can be noticed that the 5% (lowest) deviation curves go slightly negative reflecting that some profiles are better than the reference ones. The duration of the deviations represents the transit time.

These views of vertical deviation suggest to consider the surface of the curves to capture the whole deviation during transit time (note: by definition the deviation curves are 'closed', i.e. start and end at zero, thus defining a surface). This will constitute our key indicator, still denoted vertical deviation and expressed in feet × 10 minutes, that combines in a single value both altitude and duration.

The following table and figures show the medians and distributions of the vertical deviations (the table also shows the median value for the common range of additional time [0-5min]). Overall, the average value for the four airports is 2320 ft×10min which may appear significant. Three airports have values lower than the average (EDDF, EHAM, LFPG) and the other one much higher (EGLL). The differences tend to reduce when considering the common range of additional time, with in particular EGLL decreasing below EHAM, which becomes the airport with the highest deviation.

Table 2 Median vertical deviations (feet x 10 minutes)

Airport	**Vertical deviation**	
	Full range	***Common range***
EDDF	1810	1760
EGLL	3700	1860
EHAM	2200	2150
LFPG	1580	1580

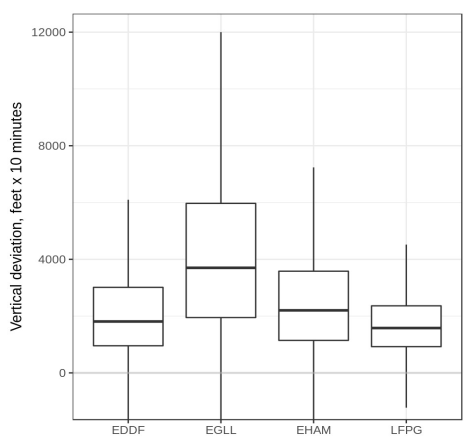

Fig. 10 Distribution of vertical deviations

VI. Vertical deviation and additional time

This section investigates the relation between vertical deviation and additional time. The following figures show the vertical profiles and vertical deviations (2500 selected randomly) with additional time (display up to 95%, leading to 5.5 minutes for LFPG, 6 minutes for EDDF and EHAM, 15 minutes for EGLL; note a different scale for EGLL).

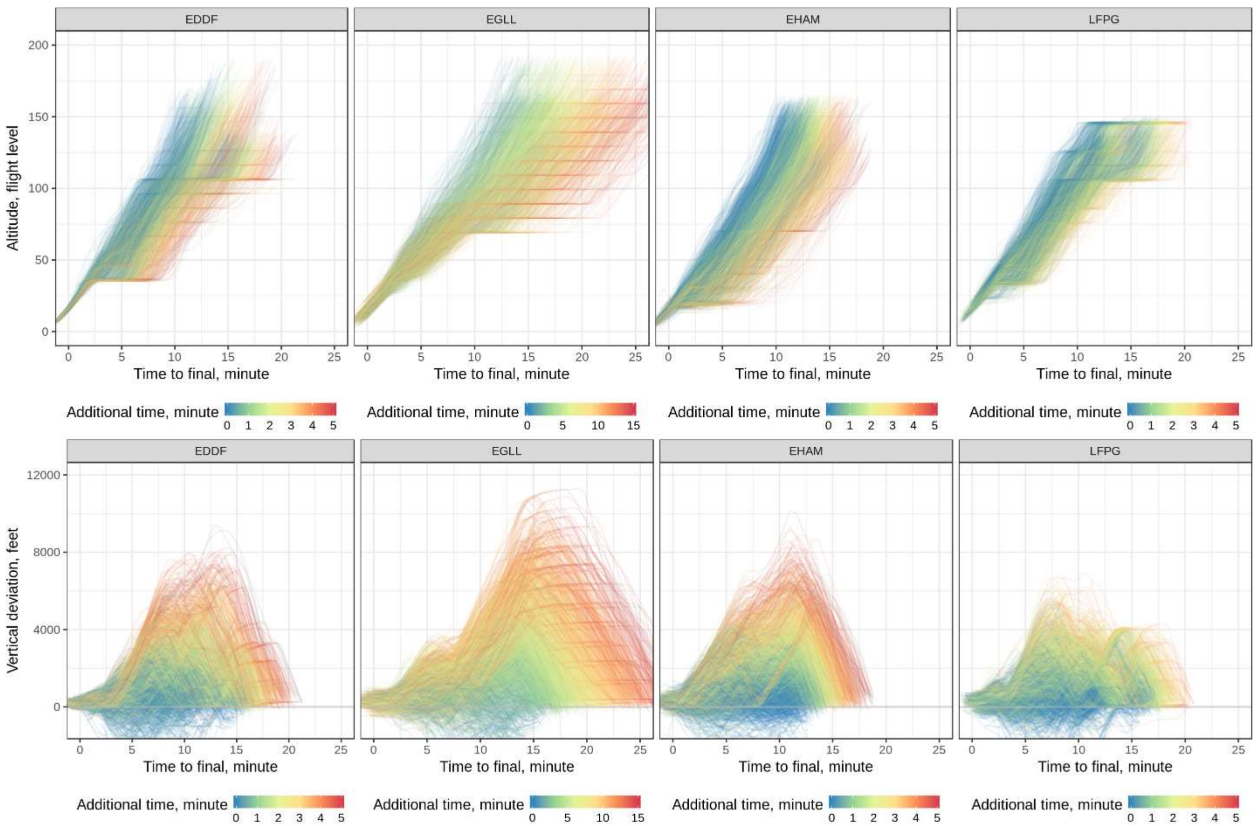

Fig. 11 Vertical profiles and vertical deviations with additional time

The following figures show the median vertical deviations per additional time. All these figures suggest that generally profiles degrade and deviations increase when additional time increases. It may be noticed that the profiles with negative deviations are mostly at no additional time.

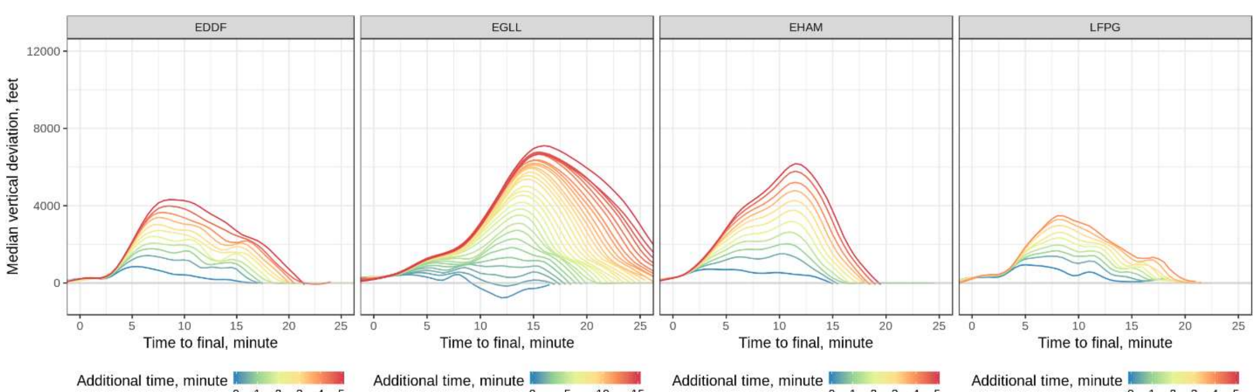

Fig. 12 Vertical deviations with additional time (median)

To go further in the analysis, the following figures show the vertical deviation as a function of the additional time, with median, 5% and 95% containment (displayed until 95% additional time; note a different scale for EGLL). These figures reveal a double inefficiency. Firstly, an increase of vertical deviation with the additional time: the median vertical deviation increases by 800ft×10min per 1 minute additional time (4000ft×10min increase from 0 to 5 minutes additional time). Secondly, a variability of descent profiles for a same level of congestion: the vertical deviation span (90% containment) is 2000ft×10min or more for a same additional time (2000ft×10min for 0 minute additional time, 4000ft×10min for 5 minutes). For the common range of additional time, the four airports show similar trends in terms of increase and variability. We may notice the medians starting close to zero for zero additional time, and negative deviations for low additional times.

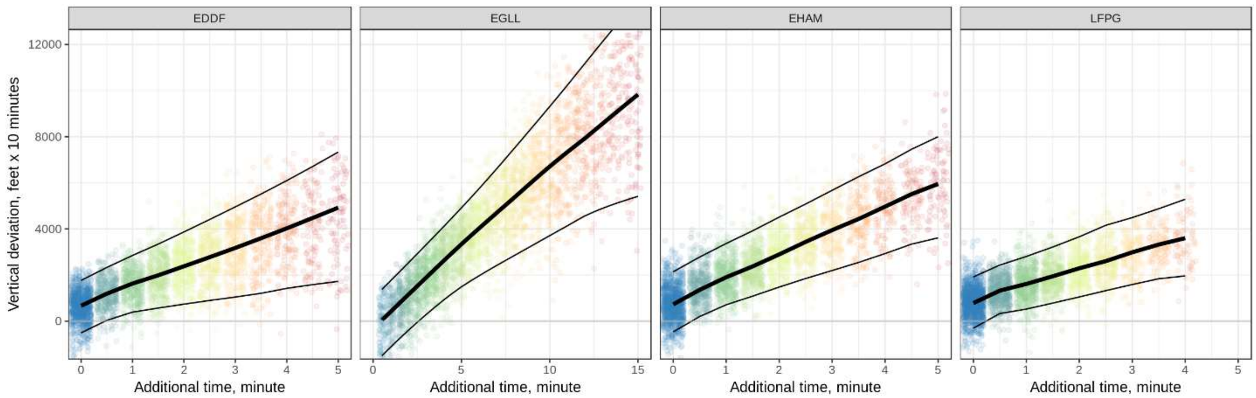

Fig. 13 Vertical deviations and additional time (median and 90% containment; different scale for EGLL)

The cause of the first inefficiency (degradation) is directly related to the sequencing and possible solutions exist to reduce the additional time in terminal area (metering and speed management upstream) or to maintain aircraft altitude during path extension (dedicated procedure). The cause of the second one (variability) remains however unclear and may be due to different factors: change of sequence order, traffic separation, wind, workload, interpersonal differences (controllers or flight crews). This should be investigated in future work with the analysis of large vertical deviations and possible ways to reinforce adherence to best descent profiles.

VII. Case study

This section presents a detailed analysis of the two airports having the highest vertical deviation (EGLL and EHAM with respectively 3700 and 2200ft×10min). For each we selected the two most representative runways corresponding to a different configuration (EGLL 27R and 09L, 33% each; EHAM 06 and 18R, 25% each) and the three main flows associated (representing at least 85% for each runway). We present hereafter a view per flows of trajectories, vertical profiles, vertical deviations, additional time and vertical deviations. We also present a measure of vertical deviation per additional time. In the following, to simplify the reading and as there is no ambiguity, units will be omitted.

For EGLL, runway 27R, there are two base flows ending with a “S” shape vectoring, making them similar to a short downwind (flows #1 and #2), and one downwind flow (flows #3). For runway 09L, the two base flows become long downwind, and the short downwind remains. We may notice altitude differences at entry among the flows, and also for a same flow between configurations. Flow #1 shows differences between configurations with additional time (6.2 vs 4.2) and vertical deviation (3750 vs 2830), however with limited variation of deviation per additional time (610 vs 680). Flow #2 is similar to flow #1, with similar differences of additional time (6.5 vs 4.4), vertical deviation (4670 vs 3750) and vertical deviation per additional time (720 vs 850). For flows #1 and #2 having similar patterns per configurations, the long downwind with a lower altitude at entry results in less additional time and less deviation than the “S” base. The difference between #1 and #2 is a lower altitude at entry (median and spread) in both configurations for #1, resulting in a lower deviation. Flow #3 looks like a short downwind in both configurations, however shows differences in terms of additional time (5.1 vs 8.0) and deviation (3630 vs 5470), but a similar vertical deviation per additional time (710 vs 680).

For EHAM, runway 06, there is a downwind flow with N/S alternate routes (flow #1), a “straight-in” base with limited extension (flow #2) and a 90° base (flow #3). For runway 18R, the “straight-in” base becomes a downwind with long level segment at low (intercept) altitude, and the two other flows a 90° base, one with long level segment at low (intercept) altitude. We may notice altitude differences among the flows, and between configurations for flows #1 and #2. Flow #1, although having different patterns between configurations, shows similar additional time (0.9 for both), vertical deviation (2650 vs 2320) and vertical deviation per additional time (2880 vs 2520). Flow #2, with different patterns (straight-in vs downwind) and entry altitudes, shows significant difference in additional time (0.4 vs

1.7), vertical deviation (1230 vs 2800) and vertical deviation per additional time (2920 vs 1640). Flow #3, with a 90° base and similar entry altitude, shows similar additional time (1.5 vs 1.7) but different vertical deviations (2290 vs 3240) and vertical deviation per additional time (1530 vs 1940).

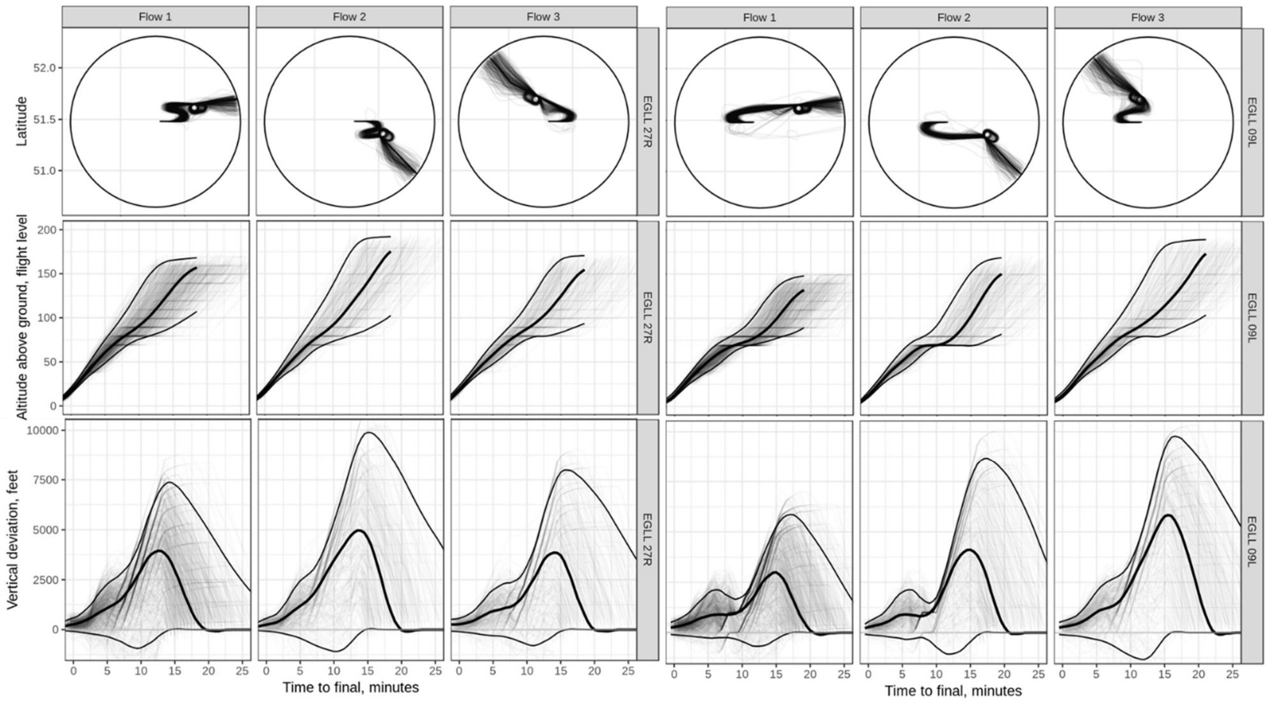

Fig. 14 EGLL 27R and 09L, trajectories, vertical profiles and vertical deviations (median and 90% containment)

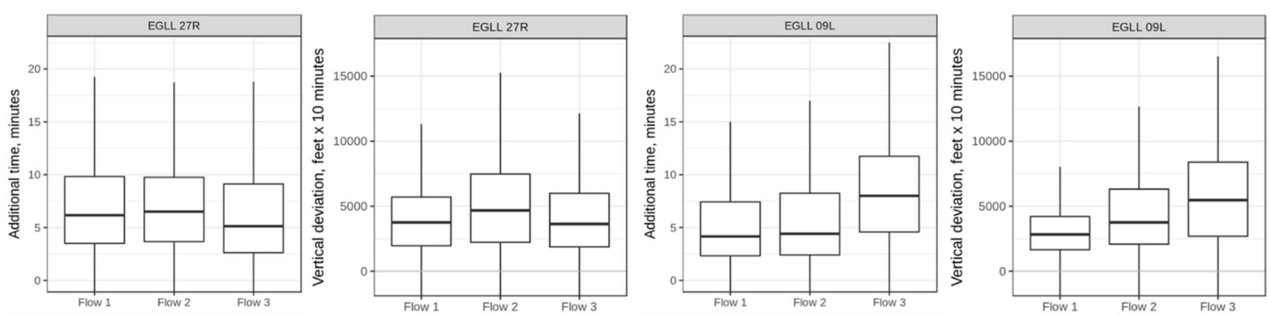

Fig. 15 EGLL 27R and 09L, distribution of additional time and vertical deviations

Table 3 EGLL 27R and 09L, median vertical deviations (feet x 10 minutes)

Airport	Runway	Flow	Median additional time (minutes)	Median deviation (feet x 10 minutes)	Deviation/additional time
EGLL	27R	1	6.2	3750	610
		2	6.5	4670	720
		3	5.1	3630	710
	09L	1	4.2	2830	680
		2	4.4	3750	850
		3	8.0	5470	680

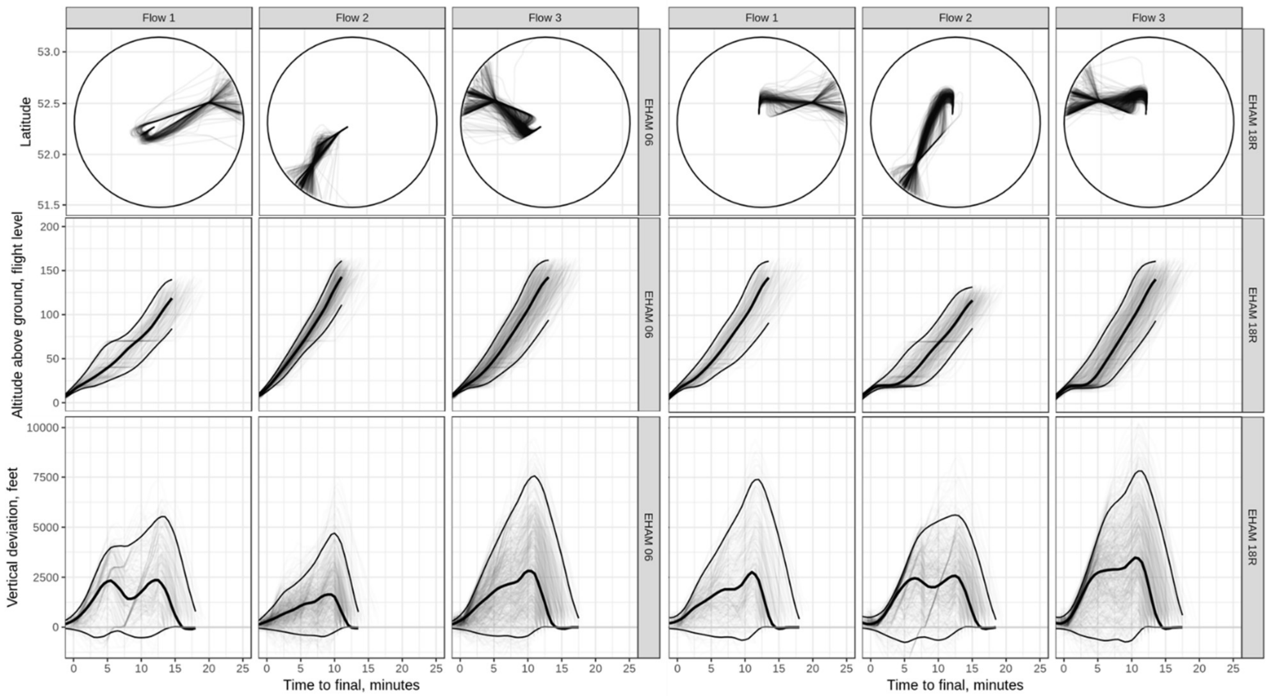

Fig. 16 EHAM 06 and 18R, trajectories, vertical profiles and vertical deviations (median and 90% containment)

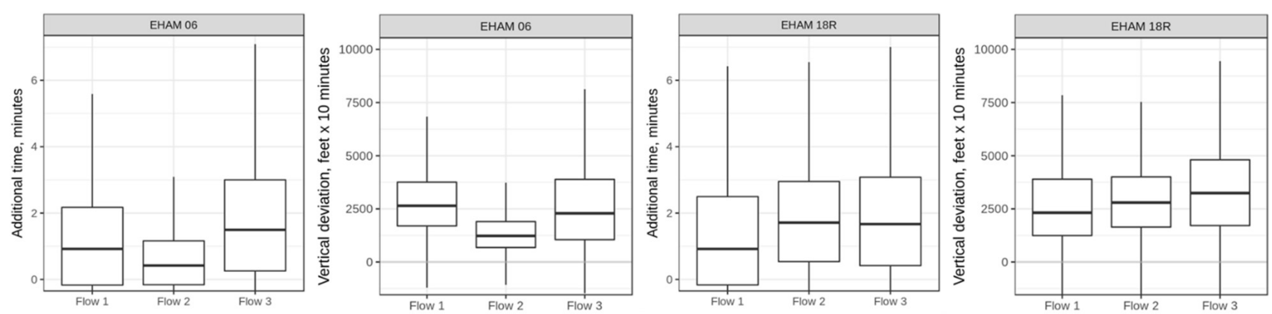

Fig. 17 EHAM 06 and 18R, distribution of additional time and vertical deviations

Table 4 EHAM 06 and 18R, median vertical deviations (feet x 10 minutes)

Airport	Runway	Flow	Median additional time (minutes)	Median deviation (feet x 10 minutes)	Deviation/additional time
EHAM	06	1	0.9	2650	2880
		2	0.4	1230	2920
		3	1.5	2290	1530
	18R	1	0.9	2320	2520
		2	1.7	2800	1640
		3	1.7	3240	1940

Overall, for EGLL, additional time and vertical deviation vary by a factor of 2, and vertical deviation per additional time by a factor of 1.4. In contrast, for EHAM, additional time, vertical deviation and vertical deviation per additional time vary by larger factors of 4, 2.6 and 1.9 respectively. EGLL appears to have more consistent performances among the flows than EHAM, which shows more variabilities. This would however require further investigations, taking into consideration the intercept altitude, analyzing the effect of potential external factors (environmental constraints, meteo, runway closure, ..) and complemented by feedback from operational staff.

VIII. Conclusion

This paper presented an assessment of the vertical efficiency in descent at four major European airports using best local practice for each flow as a reference. The assessment relies on the analysis of the vertical deviation to best descent profiles of each airport, runway and flow, in relation to the additional flight time in the terminal area as a proxy for the level of congestion. It consists of analyzing the effect of the additional time on vertical deviations, and the variability of vertical deviations for a same additional time. It focusses on the 50NM area around each airport, and relies on six months of data from 2018 during day-time operations over more than 200 000 flights in total.

The assessment reveals a triple relative inefficiency. Firstly, descent profiles significantly lower than best practices: the median vertical deviation for 10 minutes flight time exceeds 2300ft. Secondly, a degradation of descent profiles with the level of congestion: the median vertical deviation for 10 minutes flight time increases by 800ft per 1 minute additional time (4000ft increase from 0 to 5 minutes additional time). Thirdly, a variability of descent profiles for a same level of congestion: the vertical deviation span (90% containment) for 10 minutes flight time is 2000ft or more for a same additional time (2000ft for 0 minute additional time, 4000ft for 5 minutes). The detailed analysis per runway and per flow of the two airports having the highest vertical deviation reveals that while one shows consistent performances, the other one shows more variabilities.

Further work should involve the identification of the causes of large vertical deviations and possible ways to reinforce adherence to best descent profiles.

Acknowledgments

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