Proximity versus dynamicity
An analysis of traffic patterns at major European airports

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This paper presents an analysis of proximity and dynamicity aspects between arrival flights at five major European airports representative of different types of operations. The analysis, purely data driven, relies on two existing indicators of proximity and dynamicity, in combination with the additional time representing the level of congestion, and at different time horizons. The analysis considers more than 300.000 arrival flights in total, in an area of 50NM around each airport. The analysis aims at assessing the exposure to small distance and small closure time (below 2 times the separation and 2 minutes). The main results are: (1) overall duration of exposure in the order of 4.0min for distance and 3.8min for closure time (95% percentile); (2) differences among the airports for similar levels of congestion by a factor of 2.3 for both distance and closure time (additional time in 0-5min); and (3) increase with the level of congestion for some airports by a factor of 1.8 for distance and 1.2 for closure time (additional time from 0 to 5min). The analysis at different time horizons provide more insight on the location and duration of exposure, in relation with the additional time. Future work will involve identifying the causes of the differences observed among the airports, as well as further analyzing traffic patterns with close proximity and high dynamicity. It will also involve extending the analysis to all flows in the area.

Keywords: proximity, dynamicity, exposure, terminal area, data analysis

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I. Introduction

This paper presents an analysis of the evolution of distance between arrival flights at five major European airports representative of different types of operations. The motivation is to characterize the exposure to close proximity and high dynamicity situations in dense and complex environments during peak and off-peak periods.

The analysis relies on two existing indicators of proximity and dynamicity (three dimensional ellipse distance and corresponding closure time), using the additional flying time as an indicator of the level of congestion, as introduced previously [1]. This paper presents an extension towards the assessment of exposure at different time horizons, and an initial view of traffic patterns with high exposure at two airports. The analysis considers more than 300.000 arrival flights in total, in an area of 50NM around each airport.

The document is organized as follows: after a review of related studies, it will present the indicators used and describe the data collection and preparation. It will then present the different views investigated: proximity and dynamicity exposure, evolution at different time horizons, influence of the congestion level, and traffic patterns with high exposure.

II. State of the art

The analysis of proximity and dynamicity between aircraft has been studied for a long time, mainly from two perspectives.

The first one is obviously safety with the development of indicators for measuring and classifying the severity of events with potential safety implications [2], as well as for the identification of factors to assess risk and predict potential infringement [3] typically for use in safety net tools [4] or in the Traffic Alert and Collision Avoidance Systems. Usually, both distance (horizontal and vertical or a combination of both [5]) and closure rate [2][6] are considered, with a focus on cases of close to separation infringement, to support provision of alerts or airborne resolution advisories. Tools and precursory metrics may be used to monitor the airspace as a function of the safety outcome [7][8]. The present study explores that field, relying on the existing notions of three dimensional ellipse distance and corresponding closure time.

The second perspective is complexity with a motivation to assess or predict controller cognitive effort and time pressure. Various dimensions are considered such as airspace, traffic and aircraft density. The proximity has been consistently considered as an important intrinsic indicator of the air traffic situation characteristic and used – through the definition of several metrics– to quantify the complexity of airspace [9][10]. Numerous studies emphasize the significant influence of air traffic complexity on controller's workload and attempt to correlate them with potential changes of the safety level [11][12][13][14]. The present study may be related to traffic density aspects in relation with time pressure for the controller.

III. Proximity and dynamicity indicators

A standard three dimensional ellipse distance encompassing both horizontal and vertical dimensions [3] is used as a basic indicator to assess proximity:

$$Ellipse\ distance\ = \sqrt{\left(\frac{horizontal\ distance}{3\ NM}\right)^2 + \left(\frac{vertical\ distance}{1000\ feet}\right)^2}$$

where 3NM and 1000 feet respectively refers to the horizontal and vertical separation minima applicable in the areas considered. It should be recalled that this is not an indicator of loss of separation (a value of 1 may not imply separation respected).

To capture the dynamicity aspect, we use a standard parameter of distance over closure rate denoted "closure time" (known as "tau" criterion in the collision avoidance literature), where the closure rate is defined as the derivate of the ellipse distance:

$$closure\ time = \frac{ellipse\ distance}{closure\ rate}$$

where:

$$closure\ rate = -\frac{d(ellipse\ distance)}{dt}$$

The closure time is an approximation of the time before minimum distance (closest point of approach) at far distance [18]. At small distance, it provides an indication of fast converging situations (close proximity with high closure rate resulting in small closure time).

To go beyond these pairwise indicators, we propose an indicator of *exposure* representing, for a given aircraft, the cumulated proximity (distance) and dynamicity (closure time) of all surrounding aircraft [1]. This indicator may be considered as a form of density index by representing the exposure to all values of distance or closure time. Considering a given aircraft, we sum up for the total flight duration of this aircraft in the 50NM area, the time spent at given distances (resp. closure times) to every surrounding aircraft (intruder) as shown in the figure below. We then normalize this time per 10min periods.

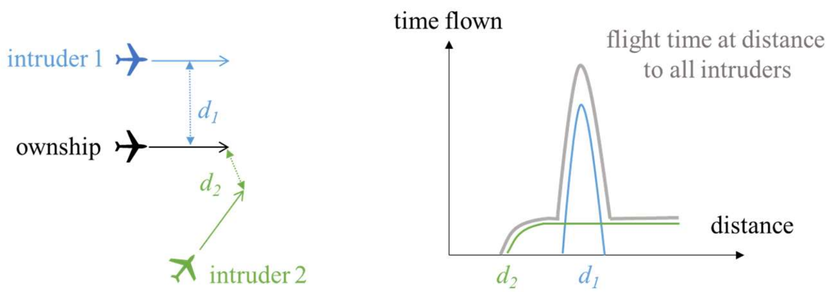

Fig. 1 Exposure to surrounding flights

IV. Data collection and preparation

The analysis considers traffic arriving at five major European airports: Madrid Barajas (LEMD), Frankfurt Main (EDDF), London Heathrow (EGLL), Amsterdam Schiphol (EHAM) and Paris Charles-de-Gaulle (LFPG). These are airports with a high number of daily movements [15] representative of different types of operations (tromboning, vectoring and holding stack at different distances). The dataset consists in position reports, initially collected with an average rate of 30s (60s for LFPG) and covering four consecutive months (between September and December 2018).

The analysis considers an area of 50NM radius around each airport (figure below) until 5NM from runway threshold. The 50NM area will constitute the focus area of the analysis (ownship in this area), but a larger area of 120NM is considered to capture all potential intruders.

A preliminary data preparation filtering out night operations (9pm-7am local time), flights suffering from data quality issues (e.g. lack of reports for an extended period of time) or reflecting exceptional cases (e.g. flight transiting between two local airports, calibration flights, go-arounds) is held first. Landing runway and localizer interception is then determined for each flight, using an algorithm relying on minimum distance and heading alignment with runway centerline [16]. To improve the position reports and obtain higher update rate, we used a model based on straight lines interpolation along linear segments and spline cubic functions for the curved parts [17]. At the end, the data set contains position reports for more than 300.000 flights (52.038, 70.178, 62.766, 67.552 and 61.384 respectively) updated every 15s.

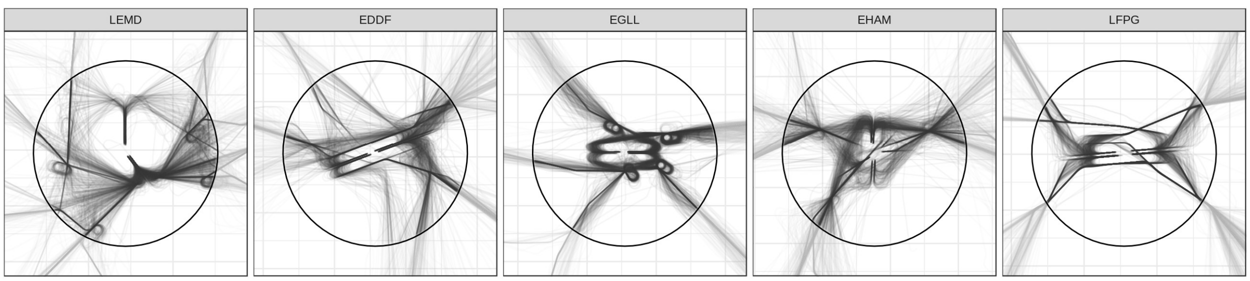

Fig. 2 Trajectory samples of the five airports within 50 NM

Within the 50NM focus area, the median transit time are as follows: LEMD 14.1, EDDF 15.8, EGLL 21.0, EHAM 14.3 and LFPG 15.6 minutes. Distribution is shown in the figure below. In the following, we will show views in “time to final” up to 25 minutes to encompass EGLL, however for the other airports, the representative time is around 15 minutes.

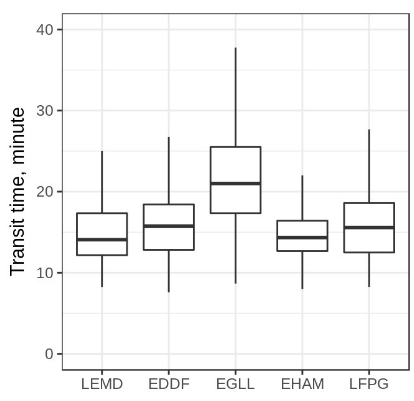

Fig. 3 Transit time distribution

V. Proximity and dynamicity exposure

This section presents an overall view of exposure in the 50NM area. The next figures show the exposure to all values of distance and closure time, with medians and 90% containment curves in orange (proximity, top) and blue (dynamicity, bottom), and sample dots for 2000 flights selected randomly. We may notice similar patterns among airports. The proximity exposure reaches a maximum around 5 distance units, with a quick decrease towards 1 and a slow decrease to the high distance values. The dynamicity exposure presents even stronger similarities among airports, with a maximum around 5 minutes closure time. Differences of amplitudes can be noticed for both.

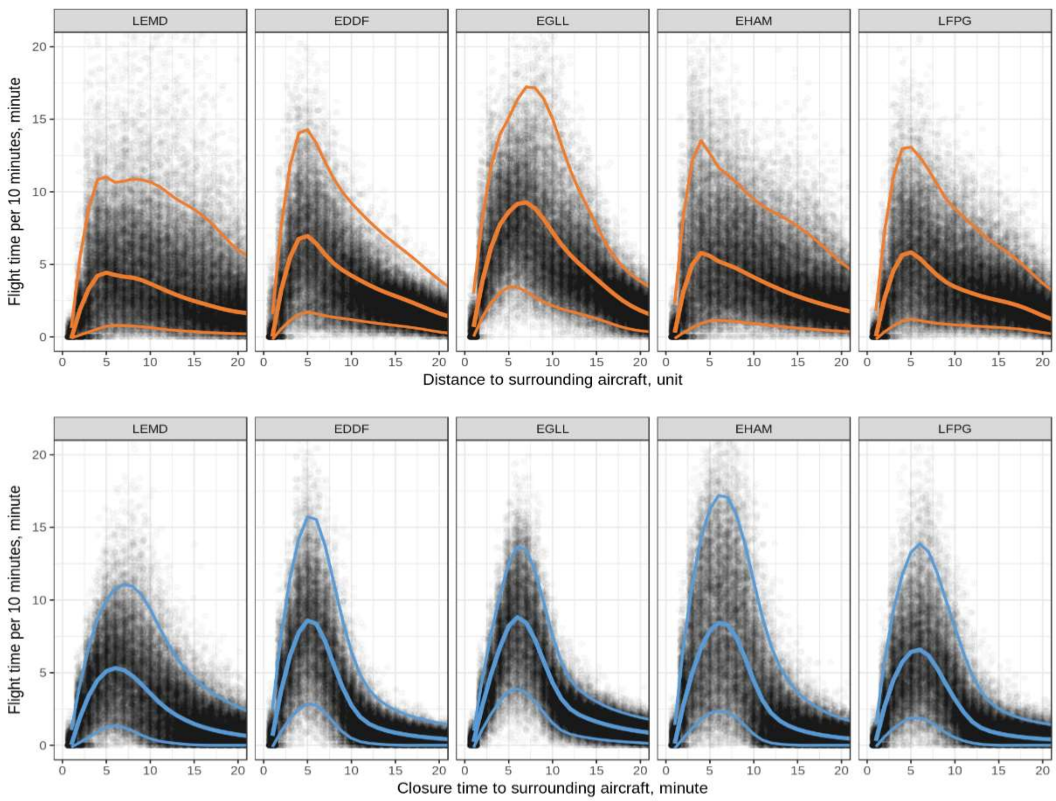

Fig. 4 Exposure to all distance (top) and all closure time (bottom)

We now focus on close proximity and high dynamicity situations. For that, we consider exposure to small distances (between 1.25 and 2 units) and small closure time (between 1 and 2 minutes) as shown in Fig. 5 (with medians and 90% containment). The proximity exposure highlights similarities among airports, with a very limited amount of traffic exposed below 1.25 distance unit (zero median). This exposure logically increases with distance, but with significant differences in amplitude among airports: the 95th percentile presents a factor greater than 2 whatever the distance between EGLL and LEMD. The same observation applies to dynamicity exposure: while the value below 1 minute is very low for all airports (median of 0 second, less than 30 seconds on 95% percentile), it shows significant differences for higher closure time, with a factor of more than 2 between EDDF and LEMD. We may notice that while one airport remains low for both indicators (LEMD), the highest for proximity and dynamicity are different (EGLL and EDDF respectively). This may relates to the structure of the traffic patterns and the nature of the operations, and will be investigated further in the next sections. In the following, we will keep the focus on exposure below 2 distance unit and below 2 minutes closure time.

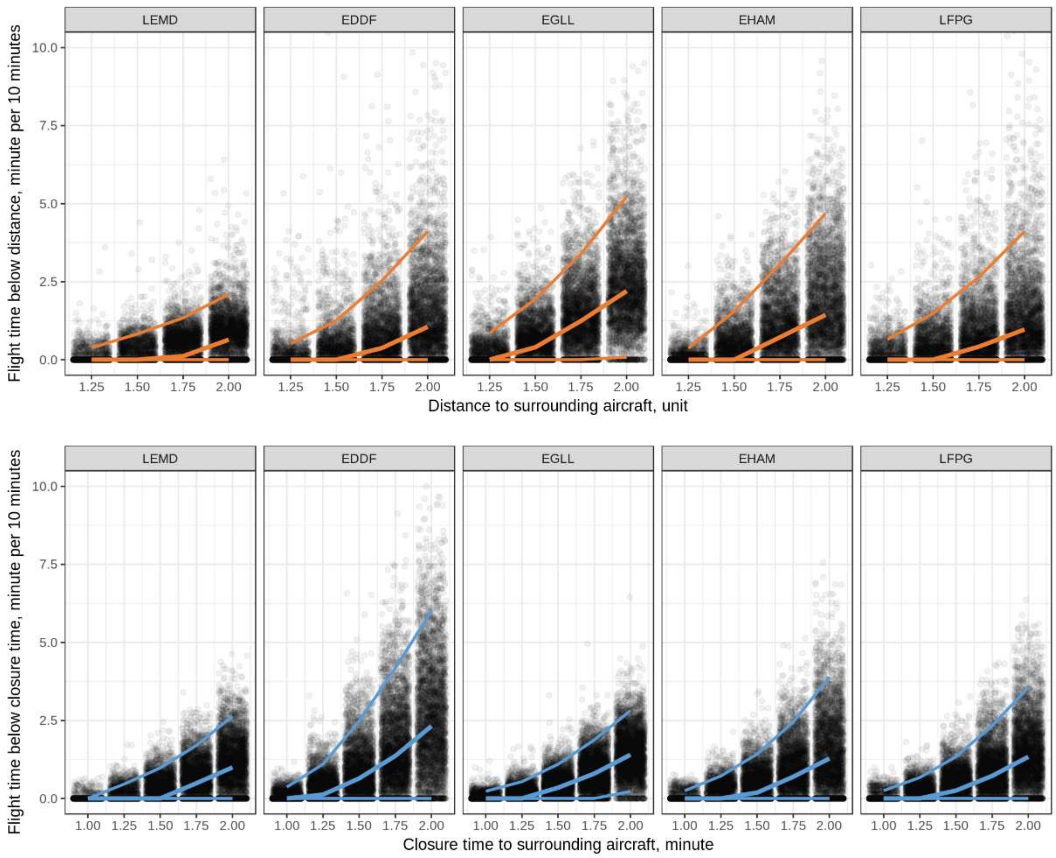

Fig. 5 Exposure to small distances (top) and small closure time (bottom)

VI. Evolution at different time horizons

To get more insight, we propose a view of exposure at different time horizons. Precisely, we display the number of surrounding aircraft in close proximity (resp. high dynamicity) to a given ownship, in relation with ownship time to final. This is intended to provide indication on exposed situations in terms of (temporal) location, duration and magnitude.

Fig. 6 (top) shows the distribution of close proximity. We may notice similarities for proximity with a peak near final (3-5min to final) of the 95% percentile curves. This may relate to the proximity induced near intercept and when established. This peak decreases to zero at 10min to final, except for one airport (EGLL). This may be explained by the quasi-systematic use of holding stacks inducing long lasting proximity. Median curves are positive for two airports, with EGLL being the highest, probably due to tight spacing when established.

Fig. 6 (bottom) gives the dynamicity view. We may also notice a peak of the 95% percentile curves near final, however with the exception of EGLL showing a lower but constant exposure. The highest exposure are for the airports operating with independent parallel approaches (EDDF, EHAM and LFPG). The medians remains at or close to zero.

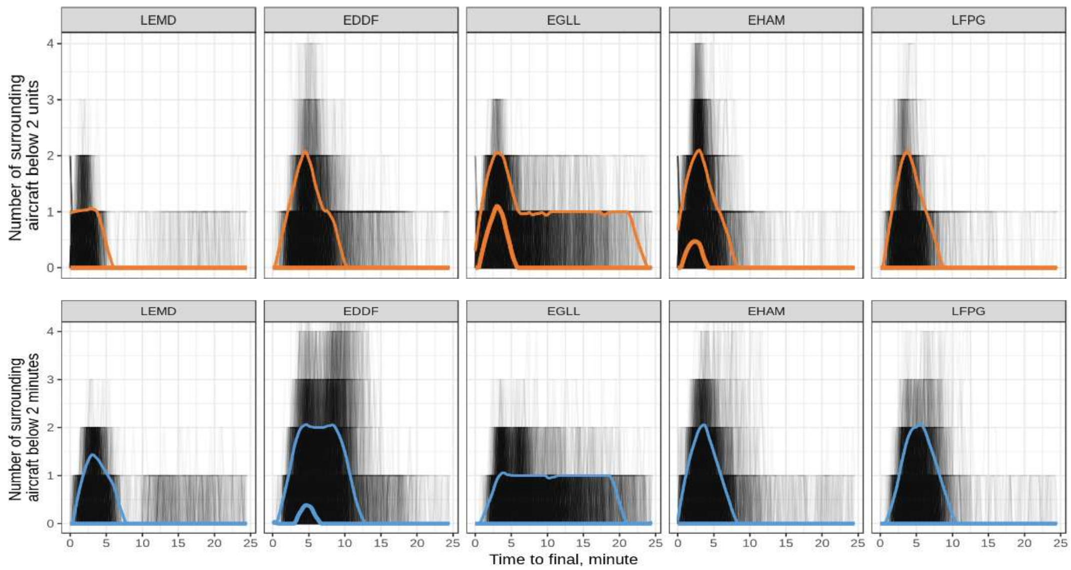

Fig. 6 Proximity (top) and dynamicity (bottom) exposure

To refine our observations, we split the views by distinguishing two situations: ownship and intruders landing on same or on different runways. Fig. 7 (top) reveals how the peak exposure previously identified actually results from overlapping interactions on different landing sequences. EGLL operating mostly with a single arrival runway (up to 6 arrivals per hour on departure runway), shows no exposure on "other runway". For the others, exposure results from both contribution of same and other runway(s). Similar observations can be made on the dynamicity view (Fig. 7 bottom) with the contribution of both same and other runway(s), except for EGLL.

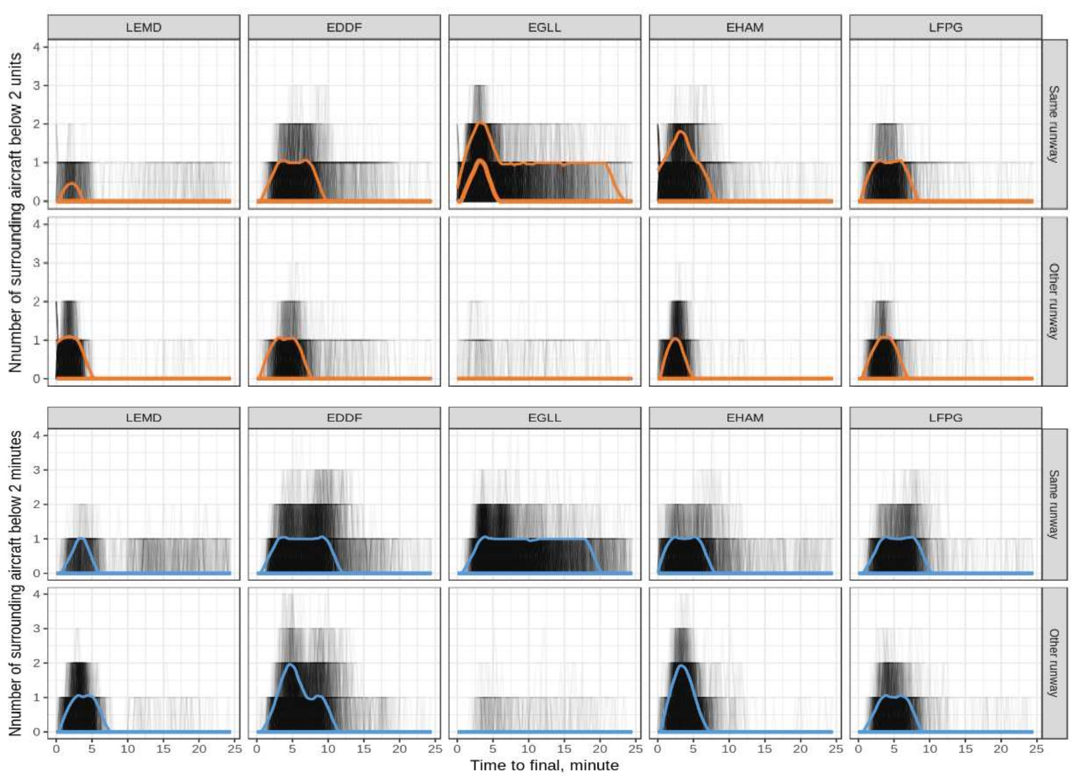

Fig. 7 Per-runway proximity and dynamicity exposure

VII. Influence of the congestion level

This section investigates the effect of the level of congestion on proximity and dynamicity exposure. We use the additional time indicator, defined by the EUROCONTROL Performance Review to measure the level of congestions [19]. This indicator relies on the notion of unimpeded time, which represent the transit time observed in non-congested conditions to cross the arrival sequencing and metering area (an area of 40NM from the airport, extended to 100NM in some analyses). The additional time is the difference between the actual transit time and the unimpeded time determined for the considered flow (defined as a pair of entry point and landing runway).

Fig. 8, below provides median and additional time distributions within the 50NM area computed from our dataset. Distributions are rather similar for four airports (LEMD, EDDF, EHAM and LFPG) but differ significantly for the other one (EGLL) with a median value more than four times higher.

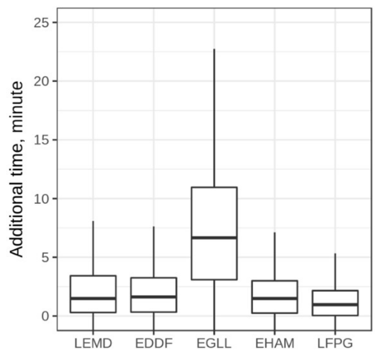

Fig. 8 Additional time distribution

To conduct our analysis, we combine the additional time of a given flight with its associated proximity and dynamicity exposure, as introduced in a previous work [1]. Fig. 9 shows the exposure (95% flight time percentile) along x-axis for proximity and y-axis for dynamicity, in combination with the additional time (from blue to red).

This view reveals differences among airports: considering a range of additional time values common to all airports (0-5 minutes interval), we can see that the exposure is in the order of 4.0min for distance and 3.8min for closure time. For similar levels of congestion (0-5 minutes) the exposure differs among the airports by a factor of 2.3 for both distance and closure time (between 2.1min to 4.8min for distance, and 2.6min to 6.1min for closure time). The sensitiveness to the level of congestion may also present important difference: while the exposure remains almost constant at some airports, others are subject to an increase by a factor of 1.8 for distance and 1.2 for closure time (additional time from 0 to 5min), leading to an exposure (95% percentile) up to 4.6min for distance and 3.8min for closure time (at 5min of additional time). It confirms the initial trends obtained in a previous work on a limited data set.

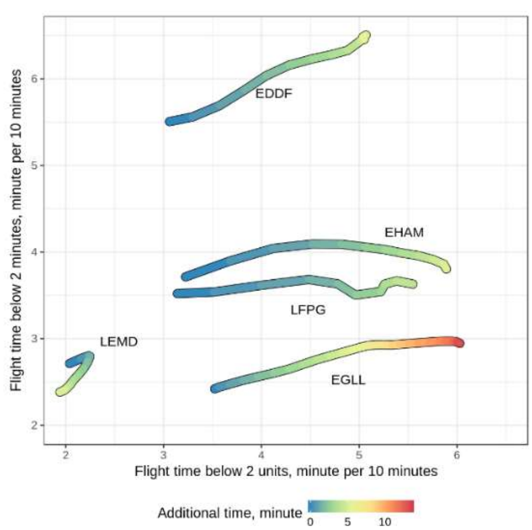

Fig. 9 Proximity and dynamicity exposure with additional time

The following figures provide the view at different time horizons shown previously, in relation with the additional time. The effect on proximity is clearly visible in Fig. 10 (top), in particular for same runway, except for LEMD which remains unchanged. For EDDF, EHAM and LFPG we can notice higher and larger peaks, reflecting more flights involved and for longer periods as additional time increases. This may be explained by path extension and intercept further upstream. For EGLL, we can notice longer periods, which may be explained by the longer use of holding stacks; we may also notice the peak on other runway for high additional time, which may reflect the occasional use of departing runway during congestion.

The effect on dynamicity is also visible in Fig. 10 (bottom), with similar observations. We may see an effect also on other runway for EDDF and LFPG, which may be cause by simultaneous interception on parallel runways generating high closing times.

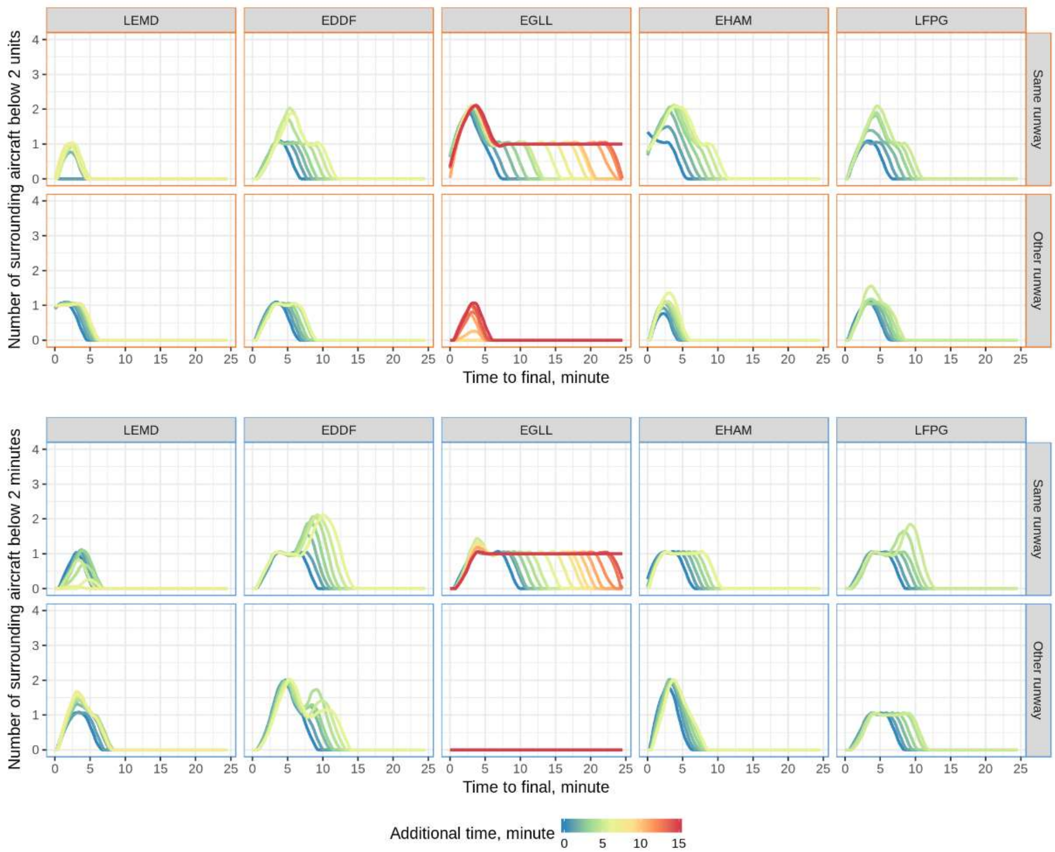

Fig. 10 Per-runway proximity (top) and dynamicity (bottom) exposure in relation with additional time

We would like to highlight at this stage that the proposed approach opens a field of possibilities to investigate and refine understanding of exposure cases. We may for instance consider additional decompositions, typically between base and downwind flows, or focusing on a particular runway configuration.

VIII. Highly exposed traffic patterns

The last part of our analysis focuses on the analysis of situations subject to high proximity or dynamicity exposure. The previous steps illustrated how this method may provide statistical characterization of various levels of exposure. We may thus isolate situations subject to particularly high level of exposure. This section provides an initial analysis of those highly exposed flights, considering two airports (EGLL and EDDF) having respectively the highest exposure values in proximity and dynamicity.

For each airport, we represent a chronological view of the situations observed during one week (from 09th to 23rd September 2018). A color scheme is used there to reflect the number of intruders simultaneous involved. We also represent, in that view, the flights having cumulated the highest exposure time (more than the 95% percentile time calculated for the period) through horizontal lines. This allows to assess temporal distribution of highly exposed flights during the week. At last, we provide next to this a representation, for the highly exposed flights, of the lateral and vertical profiles, supporting geographic, temporal and vertical localization of the situation encountered.

Fig. 11 shows the overview of proximity (top left) and dynamicity (bottom left) events for EGLL: those events generally seem smoothly distributed during the period, with almost continuous sequences of occurrences reporting a same level of exposure (2 intruders). The weekly and daily distribution of the highly exposed flights (horizontal lines) looks more variable and reports some days subject to relatively quiet exposure activity. Emergence of groups of highly exposed flights can be seen, but they generally remain associated with small exposure intensity. A few examples however lead very punctually to higher exposure simultaneity (e.g. up to 4 aircraft involved in dynamicity occurrence, on 2018-09-21, around 2pm).

The lateral profiles shown in Fig. 11 (top right) reveal that high proximity and dynamicity rather limited in intensity, but spread over a large area. The occurrences showing highest number of intruders (2 or more) are mainly located in the vicinity of the runway center lines, but may also appear in the upstream parts, up to the stacks. Vertical profiles (bottom right) show the presence of highly exposed proximity situations widely diffused at any altitudes. Some higher density may however be noticed along level segments and in the lower parts (below 5000 feet). Distribution of dynamicity events is quite similar, although slightly confined in lower bands (below 10000 feet).

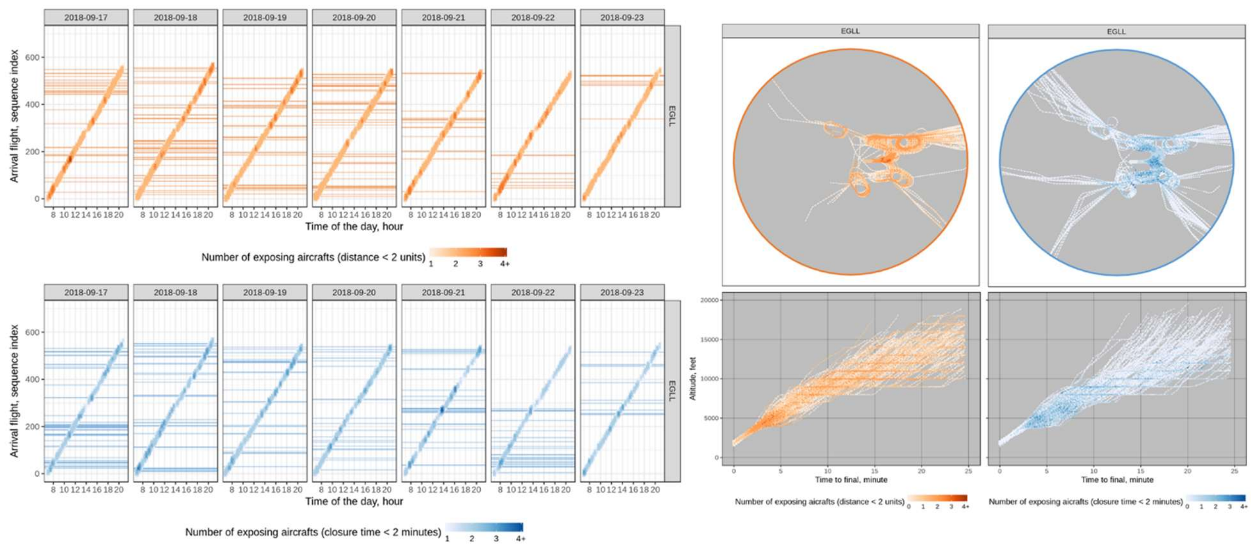

Fig. 11 EGLL highly exposed traffic

Fig. 12 provides the overview of proximity (top left) and dynamicity (bottom left) events for EDDF. Important variability is visible there during the week, with some days subject to intense proximity exposure. This variability is also present within the day, with some periods (e.g. 9am, 6pm) regularly subject to higher level of exposure, and some other (e.g. between 2pm and 4pm) usually more quiet. We can see, from the horizontal lines, that the highly exposed aircraft, when grouped, are usually leading to an important number of intruders. In spite some similarities regarding temporal distribution of those flights may be found between proximity and dynamicity, only a small number of flights are actually present in both exposures.

The lateral profiles (Fig. 12 top right) reveal that proximity exposure are mostly present in the intercept area. Events involving an important number of intruders (3 aircraft and more) are enclosing runway center lines. They typically reflect the close proximity interactions encountered with parallel runways operations. For dynamicity, events showing high level of simultaneity (4 aircraft or more) are mainly present at the entry of the final turn, and tend to point downwind flights entering into the trombone shapes from both north and south sides. Vertical profiles (Fig. 12 bottom right) show that almost all proximity exposure situations occur below 5000 feet (only a few rare proximity events are present a higher level). Proximity events involving a significant number of intruders are aligned aver the interception levels. On the contrary, the dynamicity exposures are mainly present above 5000 feet, with a more disparate vertical diffusion.

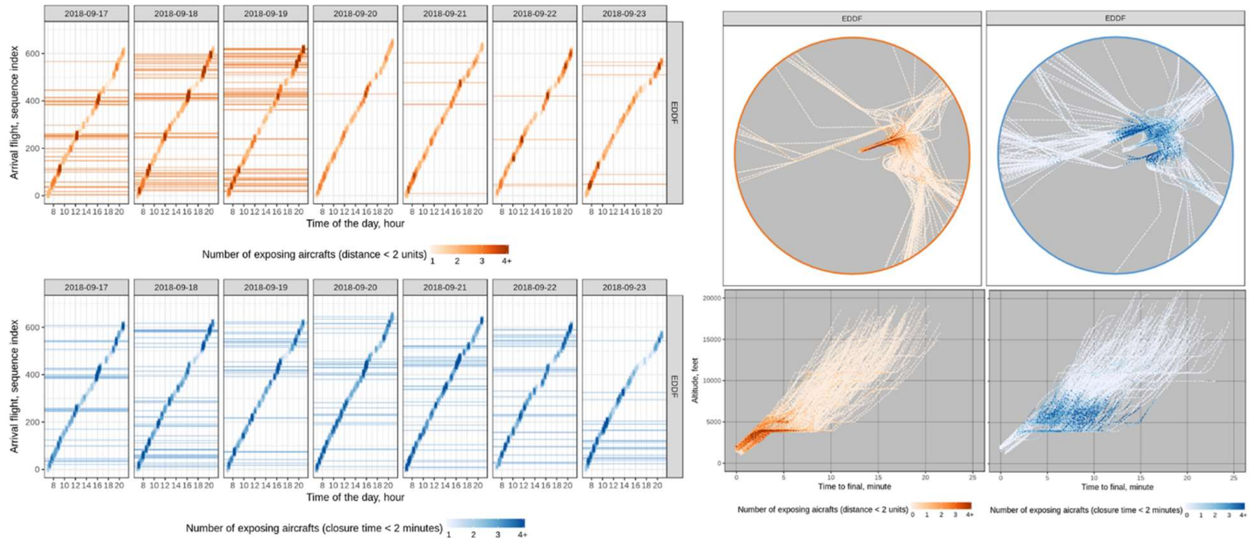

Fig. 12 EDDF highly exposed traffic

IX. Conclusion

This paper presented an analysis of proximity and dynamicity aspects between arrival flights at five major European airports representative of different types of operations. The analysis relies on two existing indicators of proximity and dynamicity, in combination with the additional time representing the level of congestion, and at different time horizons. The analysis considers more than 300.000 arrival flights in total, in an area of 50NM around each airport.

This analysis aimed at assessing the exposure to small distance and small closure time, respectively below 2 times the separation and 2 minutes. It confirms the initial trends obtained in a previous work on a limited data set. Overall, the duration of exposure (95% percentile) is in the order of 4.0min for distance and 3.8min for closure time (additional time in 0-5min). It reveals that for similar levels of congestion the duration of exposure differs among the airports by a factor of 2.3 for both distance and closure time (additional time in 0-5min). The analysis also reveals that the sensitiveness of exposure to the level of congestion differs among the airports. While the duration remains almost constant at some airports, others are subject to an increase by a factor of 1.8 for distance and 1.2 for closure time (additional time from 0 to 5min).

The analysis at different time horizons provide more insight on the location and duration of exposure, in relation with the additional time. The additional time generates higher and longer peaks near final for three airports (independent parallel approaches), longer periods for one airport (holding and single landing runway) and no effect for the other one (dependent parallel approaches). The detailed analysis of high exposure cases on two airports reveals significant variabilities among the days considered.

Future work will involve identifying the causes of the differences observed among the airports, as well as further analyzing traffic patterns with close proximity and high dynamicity. It will also involve extending the analysis to all flows in the area (e.g. departures, flows to other airports in the vicinity).

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