Flight safety during Covid-19: A study of Charles de Gaulle airport atypical energy approaches

Gabriel Jarry[a], Daniel Delahaye[a], Eric Feron[b],

[a]*ENAC, Université de Toulouse, 7 Avenue Edouard Belin, 31400 Toulouse*
Email: {gabriel.jarry, daniel.delahaye}@enac.fr
[b]*King Abdullah University of Science and Technology,*
Division of Electrical, Computer and Mathematical Science and Engineering,
Thuwal, 23955, Saudi Arabia
Email: eric.feron@kaust.edu.sa

Abstract

During the COVID-19 period and particularly during lockdown, the number of speeding offences on the roads have tended to increase. Likewise in the air, deviation from nominal operations have shown to become more frequent. This paper proposes to evaluate the impact of COVID-19 on the pilot/controller system, especially during the critical approach and landing phases. To study the influence of COVID-19, an existing energy atypicality metric is applied on a reference period before COVID-19 and compared to the COVID-19 period. Trends, statistics, and specific flights are illustrated and analyzed, underlying an increase in glide interceptions from above and high speed approaches.

Keywords: COVID-19, Anomaly Detection, Energy Management, Aircraft Safety, Atypical Approaches

1. Introduction

1.1. Operational Motivation

In March 2020, as a result of the coronavirus pandemic, many airports and borders were closed, and the number of flights has gone done drastically world-wide. The reduction in traffic offered the potential for less stringent constraints on the air transportation system operations, including reduction of Air Traffic constraint and workloads, and more freedom for flight crews to manage approaches and landings.

Approach and landing are critical phases of flight; accidents occurring during these phases account for 47 per cent of the total number of accidents and 40 per cent of fatalities each year [1]. In addition, a large majority of accidents follow significant deviations from nominal approaches, such as atypical airspeed or atypical altitude [2]. It is then interesting to ask how the air traffic system has behaved during the drastic reduction of traffic caused by COVID-19, especially as it pertains to airport approaches. Has there been a reduction of the number of atypical behaviours or has the relaxation of constraints implied an increase of the number of atypical behaviours ?

In order to be able to measure and compare the COVID-19 period with a reference period it is necessary to have a metric. In the following section, a state of the art of the different studies on anomaly detection during approach and landing is given.

1.2. State of the Art

Anomaly detection and safety analysis in aviation consists of two worlds that coexist around two data sources. On the one hand, there is the world of the airlines with all the flight data logged on Flight Data Recorders. On the other hand, the world of Air Navigation Service Providers and National Supervisory Authorities, which mainly use radar or ADS-B data. These two worlds are relatively independent, yet the few shared initiatives have already shown very rich results and analyses, which encourages deeper collaborations.

From the flight deck point of view, the literature reports various algorithms that have been designed to detect anomalies or recover from undesirable situations. In particular, Li et al. have developed two methodologies based on dimensional reduction (PCA) and outlier scoring (DBSCAN) or density estimation [3, 4, 5]. In addition, work has also been carried out on the detection of anomalous flight deck data using multiple kernel [6], active learning [7], or recurrent neural network methods [8]. Recently, Andreu et. al. have developed a methodology suitable for the flight deck that proposes recovery trajectories when aircraft present over-energy [9].

From ANSP perspective, which implies using radar available parameters, there are different initiatives, such as a recent work by Singh et al. [10] that proposed a detection of outside boundaries parameters using sparse variational gaussian process only for the final approach. Focusing on the energy management, Jarry et. al. proposed to provide post-operational detection of atypical behaviour in the total energy of the aircraft by using unsupervised learning [11]. This algorithm combines a sliding window with a functional data analysis tool called functional principal component analysis and an outlier scoring as illustrated in Figure 1. Each point on a trajectory is assigned a coefficient between 0 and 1. The higher the coefficient, the more atypical the energy management at that point is. The atypicality characterizes the fact that at a point, the total energy of an aircraft does not behave like the majority of the flights that allowed the construction of the model. This methodology was validated against flight data records from airline safety offices and safety events [12]. It showed a significant correlation between the atypical energy behaviors and airline safety events. In particular, while unstabilized approaches represent between 3 and 4% of typical flights, they account for 50.4% of atypical flights between 5NM and the runway threshold [12].

In addition, the methodology was compared to the detection of anomalies with the help of generative adversarial networks [13] in a similar way to an auto-encoder. The methodology presents similar results with the advantage of giving a local atypicality score and is more flexible since it is deterministic and not subject to the potential problem of neural network convergence. An atypical approach may not be unsafe. However, accidents and events related to safety often happen as part of atypical approaches.

As this methodology allows the detection of trajectories presenting atypicalities in approach energy management, it is a good candidate metric to quantify if the COVID-19 period has induced changes in aircraft approach behaviours.

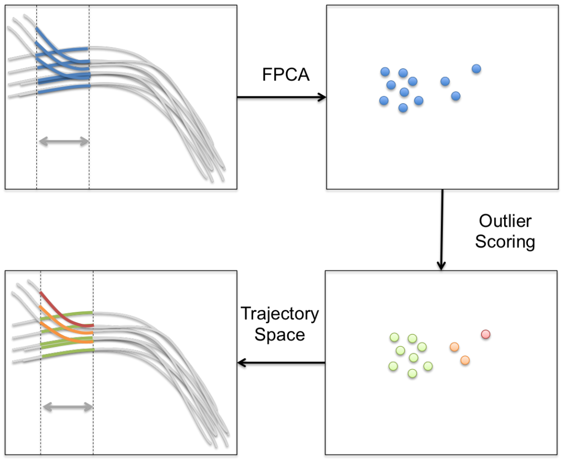

Figure 1: Illustration of the methodology for detecting atypical trajectories. A sliding window is applied on all trajectories. The dimension is then reduced by applying a Functional Principal Component Analysis decomposition on the portions of such trajectories. An outlier detection and scoring is applied on the decomposition vector space, which allows to assign to each trajectory portion a score between 0 and 1, determining the local atypicality.

The paper is divided into three parts. First, the methodology, data, and model used are detailed. Second, trends, overall results are illustrated, and some specific landing cases are presented. Finally, a discussion is proposed in order to analyze the results obtained.

2. Data and Methodology

The data studied in this paper are radar data at Roissy-Charles-de-Gaulles airport (CDG) from the French Air Navigation Service Provider (DSNA); Among all airports whose operations are assigned to DSNA, CDG was chosen because it was the only airport that maintained sufficient traffic during the Covid outbreak to obtain statistically representative results. The data was collected during two time periods: a reference period before COVID-19 from 01 to 31 May 2019 (accounting for 21 895 landings), and a study period under COVID-19 from 16 March to 20 April 2020 (accounting for 4 583 landings). The reference period covering May 1st to May 31st was the available period that best respected the seasonality studied during the COVID-19 period. The data contains landing trajectories (longitude, latitude, altitude, ground speed, vertical speed) as well as meta-information such as aircraft type, airline, and the runway used.

The methodology consists of constructing an energy atypicality model [11] from the available data covering the reference period before COVID-19 and applying it to the two periods respectively. The model continuously gives an atypicality score between 0 and 1 along the trajectory. The closer the score is to 1, the more the energy management at this point does not behave like the majority of the flights in the learning set. A threshold is then set so that statistical studies can be carried out. Following prior work, a flight will be considered atypical if it scores above 0.7 during more than 2NM. A score greater than 0.7 is equivalent to a deviation from the mean functional principal components analysis coefficient greater than 3σ under Gaussian distribution hypothesis.

In addition, other classical operational metrics were computed, such as the interception distance on the runway centreline, or the exceeding of altitude limits [11] (based on the interception altitude and deviation from 3° glide path) and ground speed limits [11](based on approach speed nominal interval and on 3° glide path deceleration [14]). Three categories, green, orange, and red, are defined using altitude and speed limits. These categories enable analysing the causes of energy atypicalities.

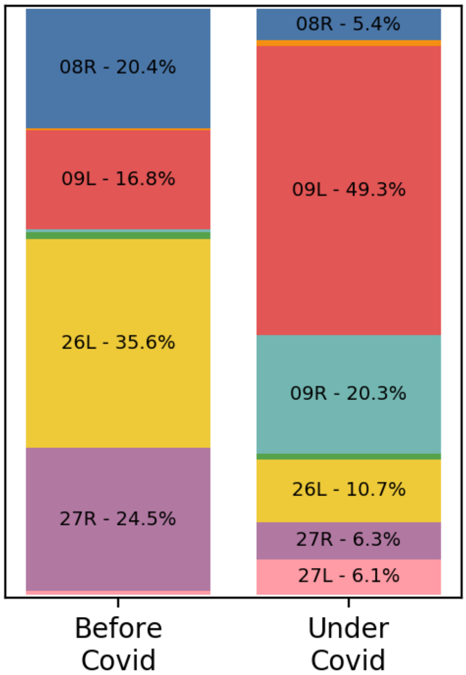

Figure 2: Distribution of runway QFU usage before and during COVID-19. Each runway has a different colour, and the percentage corresponds to the ratio of runway use to total flights for the period. The COVID-19 period shows a change in the use of runways, whereas before COVID-19 both pairs are used with the outer runways for landing and mostly in a west-facing configuration. During the COVID-19 period, the south pair was quickly closed and a majority configuration facing east was observed linked to weather conditions.

3. Study

3.1. Observations

The first observation that can be made about the COVID-19 period is that the distribution of runway QFU usage is changing as illustrated in Figure 2. For the period before COVID-19, the two runway pairs are used with the outer runways for landing and a majority of landings facing west (runway 26L and 27R). During the COVID-19 period, the South runway pair was quickly closed and the North runway pair was mainly used, particularly in the eastward facing configuration (runway 09L and 09R accounting for 70% of the total operations), probably due to weather conditions.

The reference period shows a rate of atypical flights at 6%. During the COVID-19 period, the rate goes up to 9.4%, representing a 56% increase. This increase can be explained in part by the change in configuration and the increased use of runway 09R, which already had a high rate of atypical flight before COVID-19 as shown in Figure 3. In addition, the high ratio on inner runways (26R, 27L, 08L, 09R) is generally explained by the use of a procedure known as the "bayonet" procedure, which is illustrated in Figure 4. The aircraft is initially lined up on final for the outer runway and may be cleared to change and land on the inner runway generally to minimize taxi time. This procedure generally induces a phase of energy atypicality because the glide paths are not aligned.

In view of these initial results, which show a majority use of the north runway doublet facing east, the following section focuses on a detailed study of the approach and landings on runways 09L and 09R before and during COVID-19. The total flight volume is relatively similar: there are 3 809 flights before COVID-19 and 3 189 flights during COVID-19, which can be compared;

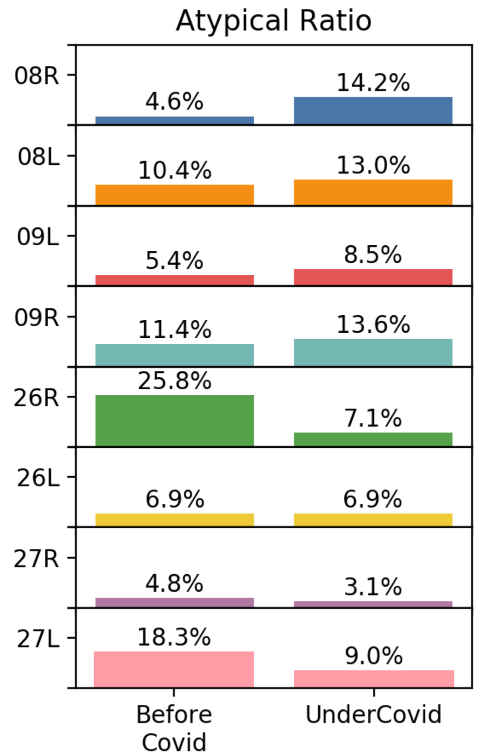

Figure 3: Distribution of trajectory atypical rate per runway QFU before and during COVID-19. The high ratio on inner doublet runways (26R, 27L, 08L, 09R) is generally explained by the use of a procedure known as the "bayonet" procedure. The aircraft is initially lined up on final for the outer runway and may be cleared to change and land on the inner runway generally to minimize taxi time, which generally leads to a phase of energy atypicality because the glide paths are not aligned.

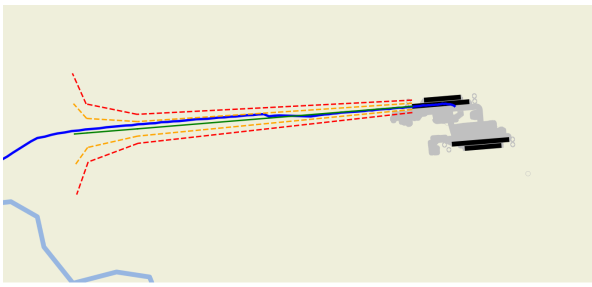

Figure 4: Illustration of a bayonet procedure. The aircraft was initially lined up on final for the outer runway 09L and was cleared to change and land on the inner runway 09R. This procedure is generally used to minimize taxi time.

3.2. Detailed analysis of runway 09L and 09R approaches

First, the lateral management of trajectories will be studied.

Figure 5 shows the lateral profiles of all atypical flights before (top figure) and during (bottom figure) COVID-19 period at Charles de Gaulle Airport landing on runway 09L and 09R. It can be seen that over the period before COVID-19 the energy atypicality is usually localized on the final phase when the aircraft is aligned with the runway extended center line. During the COVID-19 period, the phases of atypicality start earlier during downwind leg or base leg. In addition, the appearance of shortening of the trajectory is observed. The shortening of trajectories with a southerly approach is not at all present in normal times since the approach to Le Bourget Airport is located in this area. However, during this period of COVID-19, Le Bourget airport was closed, the constraint was no longer present, and this type of approach was possible. This trend is confirmed by the distribution of interception distance from runway threshold illustrated in Figure 6, where the interception distance distribution shifts from the 15NM to 20NM area to the 10NM to 15NM area and even less for atypical flights. Furthermore, it is illustrated that the phases of atypicality during the COVID-19 start upstream while the aircraft are still on base leg or downwind.

The shortening of trajectories may appear to be consistent with the drastic reduction in traffic, which facilitates direct trajectories. This nevertheless implies a mutual consensus among pilots and air traffic control, whose initiation remains unknown. In addition, it implies an anticipation on energy management since shortening the trajectory also reduces the distance remaining to the threshold. The large phases of energy atypicity imply that this induced over-energy has not always been taken into account. This is confirmed by the altitude profiles illustrated in Figure 7. On top of the Figure are illustrated vertical profiles on runway 09L and 09R of atypical flights before COVID-19 and at the bottom vertical profiles under COVID-19. There is an appearance of altitude profiles with glide interception from above that was not or only slightly present in the period before COVID-19. The distribution of altitude warning areas illustatred in Figure 8, confirms this trend. The ratio of atypical flights in the orange and red altitude areas increased for the COVID-19 period from 40% to 53%. In addition, there are two clusters for atypical flights. Those in the green area, for which the atypicality is not due to the potential energy, the factor comes from the kinetic energy, and those in the red area with high

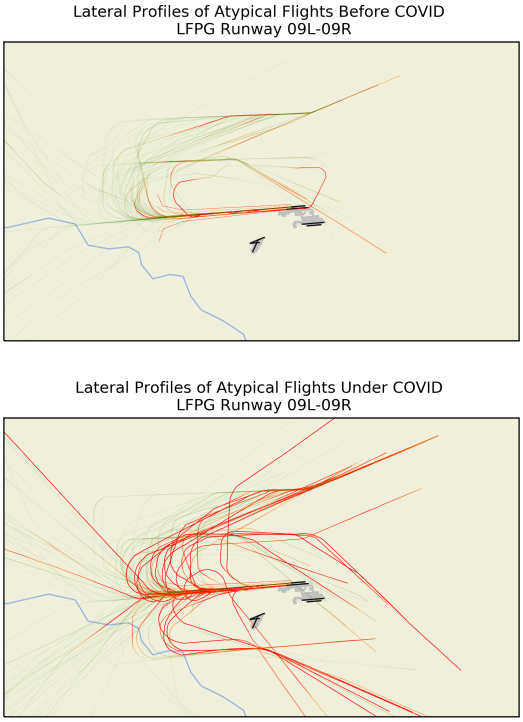

Figure 5: Lateral profile of atypical flight before (top) and during (bottom) COVID-19 period at Charles de Gaulle Airport Runway 09L and 09R. The color of the trajectories is proportional to the local atypical energy coefficient (green for 0, orange for 0.5 and red for 1). The colored dashed lines are fixed operational limits to allow a better understanding of the situation. During the COVID-19 period there is a shortening of trajectories with a significant number of localizer interception downstream of the intercepting chevrons. The energy atypical zones (in red) also start earlier already on the base leg or even in downwind.

potential energy and possibly also a high kinetic energy.

This is reflected in the distribution of flights by ground speed limit areas illustrated in Figure 9. Already before the COVID-19, the atypical flights have a high ratio of flights with ground speeds in the orange and red areas and this ratio increases during the COVID-19 period. Overall, the arrivals in 09L and 09R are quite fast already before the COVID-19 and the shortening of trajectories and glide interceptions from above probably reinforced this trend. In addition, the number of flights in the orange and red zones during COVID-19 has increased, despite the fact that there are slightly fewer flights operating on runways 09L and 09R during this period.

Energy management seems to be different depending on the airline. Figure 10 illustrates the

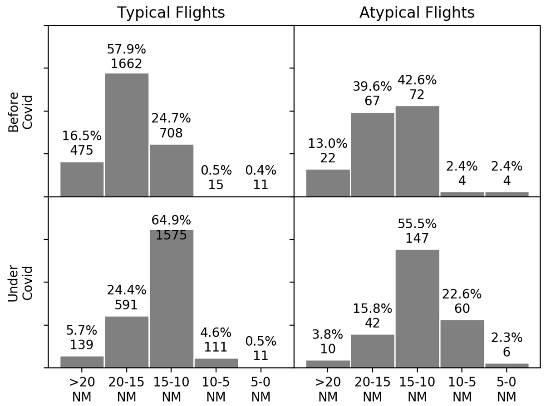

Figure 6: Distribution of localizer interception distance (NM) for typical and atypical flight under and before COVID-19 for runway QFU 09L and 09R. There is a decrease in the average localizer interception distance from the runway centreline during the COVID-19 period.

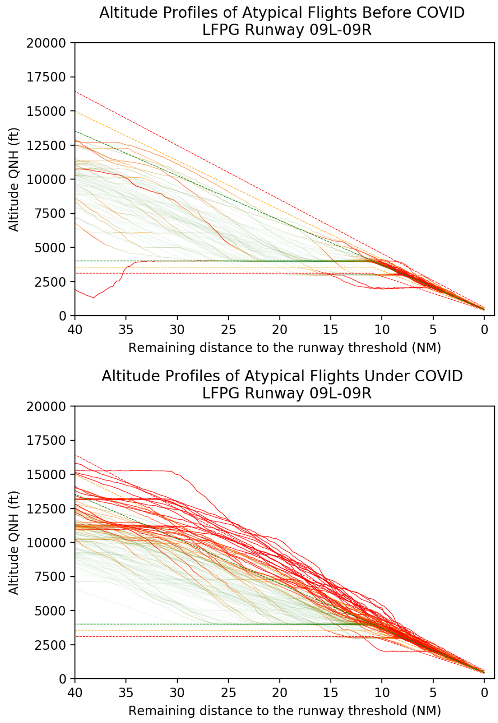

Figure 7: Vertical profile of atypical flights before (top) and during (bottom) COVID-19 period at Charles de Gaulle Airport Runway 09L and 09R. For the COVID-19 period, there is the emergence of glide interceptions from above that were not or only slightly present in the period before COVID-19. The color of trajectories is proportional to the local atypical energy coefficient (green for 0, orange for 0.5 and red for 1). The colored dashed lines are published operational limits and deviation from them.

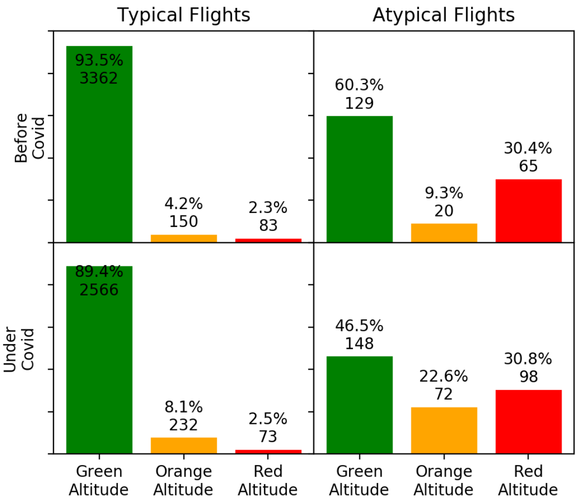

Figure 8: Distribution of altitude areas for typical and atypical flights under or before COVID-19 for runway QFU 09L and 09R. Green category corresponds to flights without any point above or under the altitude orange dashed line limit. Orange category corresponds to flight with at least on point in the altitude orange to red dashed line area, and Red category to flights with at least on point in the altitude Red dashed line area. These operational limits are represented in the altitude profile in Figure 12

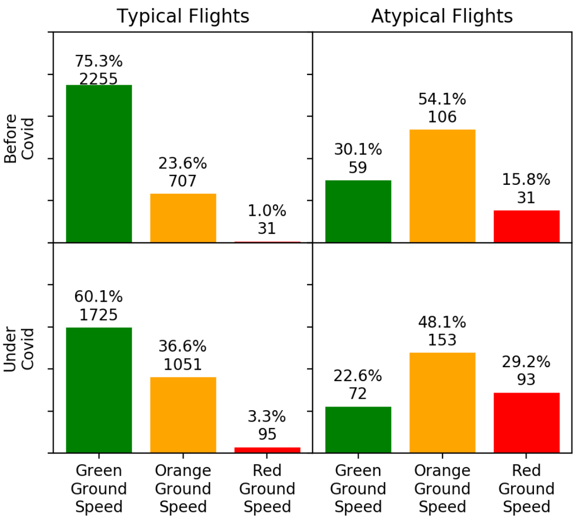

Figure 9: Distribution of ground speed areas for typical and atypical flights under or before COVID-19 for runway QFU 09L and 09R. Green category corresponds to flights without any point above or under the orange ground speed dashed line limit. Orange category corresponds to flight with at least on point in the orange to red ground speed dashed line area and Red category to flight with at least on point in the Red ground speed dashed line area. These operational limits are represented in the ground speed profile in Figure 12

atypicality ratio before and during COVID-19 for the seven major airlines operating at CDG. The airlines are anonymized and ordered by atypical ratio. Some airlines have a low ratio during COVID-19 period, the low ratio is maintained or slightly increased for the COVID-19 period (airlines A3 and A7). Other airlines like A8 have a high ratio initially that increases during the COVID-19 period, and some airlines have a high ratio that decreases (A1) or increases (A2) during the COVID-19 period. The level of implementation of energy monitoring and training might be different from one airline to another, which may affect the observed atypical ratio.

An analysis by aircraft type family can also be carried out. The atypical ratio of the 7 major aircraft type families operating at CDG is illustrated in Figure 11. The result indicates that all aircraft type families have an atypicality ratio that increases during the COVID-19 period except for the B777 family. This result is linked to the airline results presented above. B777 is operated by different airlines and in particular A1, whose average atypical ratio decreased during this period.

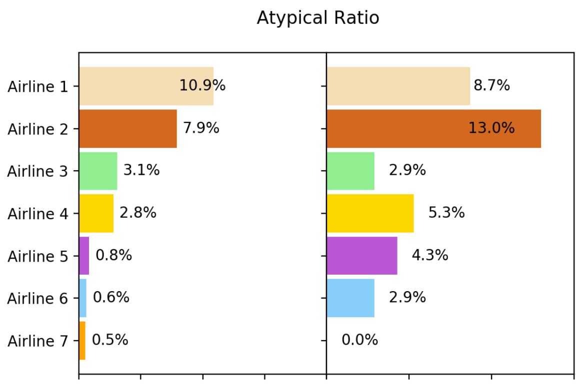

Figure 10: Distribution of the typical ratio of the 7 major airlines at CDG under or before COVID-19 for runway QFU 09L and 09R. The airlines are indexed by Atypical Ratio before COVID-19. There is a disparity in energy management and therefore atypicality depending on the airline. Some airlines have a low ratio even before the COVID-19 which is maintained or slightly increased (airlines A3 and A7), others such as A2 have a high ratio which increases during the COVID-19, and finally A1 has a high ratio which decreases during the COVID-19.

3.3. Flight analysis

Two flights are now analysed to explore the behaviours observed in the previous study.

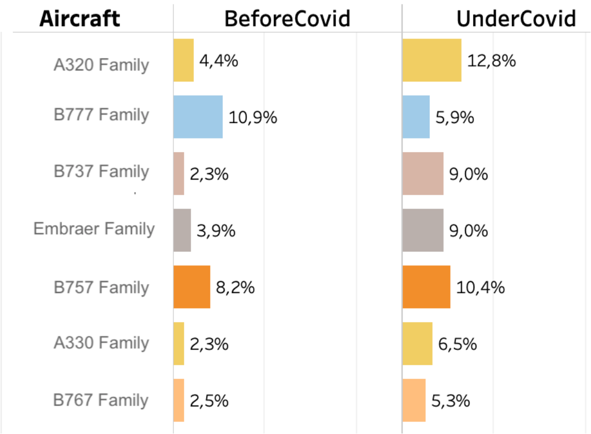

Figure 11: Distribution of the atypical ratio of the 7 major aircraft type families operating at CDG under or before COVID-19 for runway QFU 09L and 09R. It is observed that all aircraft type families have an atypicality ratio that increases during the COVID-19 period except for the B777 family that decreases.

High Speed Approach. The first flight is an approach to runway 09L of an A320 aircraft. A rapid arrival behaviour is observed. Figure 12 shows on top the lateral trajectory, in the middle the altitude profile, and the speed profile at the bottom. The lateral and vertical profiles of the trajectory are compliant with the interception altitude and chevrons and follow properly the 3° glide path. The ground speed profile shows that the ground speed was maintained at 230kts up to 5NM and then was sharply reduced just before stabilization. It is observed that the atypical areas starts at 10NM since the aircraft conserves its kinetic energy whereas the usual behaviour at 10NM is a reduction in kinetic energy.

This type of approach is atypical in the sense that the speed reduction appeared much later than normal, which also raises questions about safety. The aircraft was probably stabilized, nevertheless the interest of the tool is to highlight events that are not always monitored so that safety aspects can be checked. The ground speed in final is an important criteria, because high-speed combined with bad weather conditions has been observed in crashes such as the runway overrun of the Hermes Airline Flight 7817 at Lyon Saint-Exupéry on March 29, 2013 [15], or the Pegasus Airlines Flight 2193, which overran Istanbul runway on February 5, 2020 [16, 17].

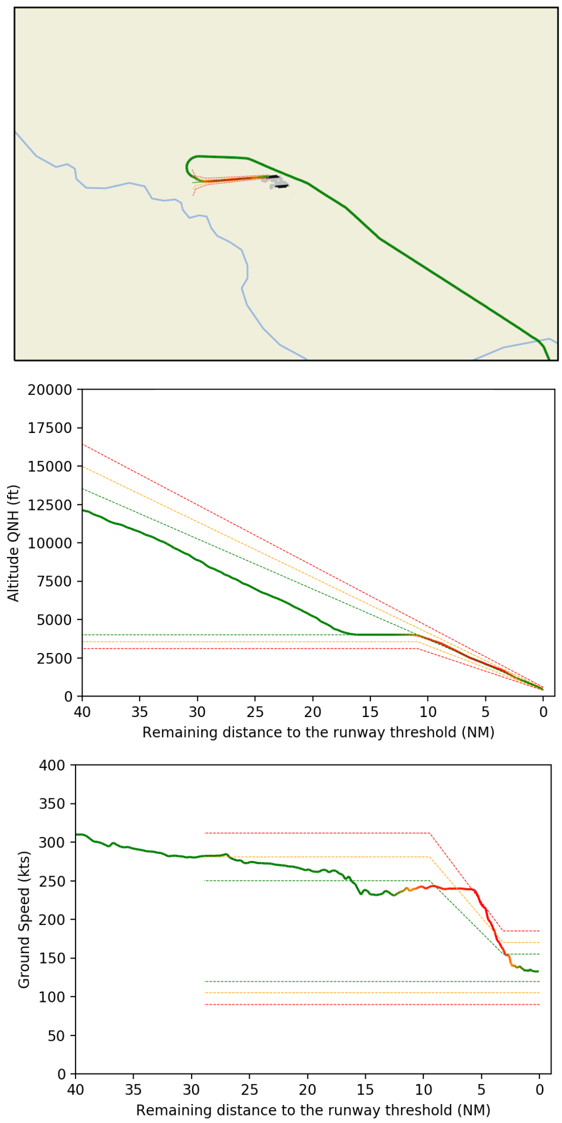

Figure 12: Illustration of a late speed reduction A320 landing on runway 09L. The top graph shows the lateral trajectory, the middle graph shows the vertical profile and the bottom graph shows the ground speed profile. It can be seen that the aircraft maintains 230kts ground speed up to 5NM before sharply reducing speed. The color of the trajectory is proportional to the local atypical energy coefficient (green for 0, orange for 0.5 and red for 1). The colored dashed lines are fixed operational limits to allow a better understanding of the situation.

Approach with Glide Interception From Above. The second case, illustrated in Figure 13, is an A320 approach on runway 09R with a trajectory shortening associated with a glide slope interception from above. The aircraft was initially on a downwind leg, the base leg turn is anticipated, and the aircraft takes an interception heading that brings it well beyond the interceptions chevrons. The ground speed remains in the nominal, but the shortening of trajectory results in a late glide interception from above recovered at only 5NM to the runway threshold.

Glide Interceptions From Above and shortening of the trajectory have been observed in various air crashes. In February 2009, the Turkish airline flight 1951 intercepted the glide from above following a trajectory shortening. An altimeter defect caused it to stall on final and crash before the runway [18]. Furthermore, on July 6, 2013, a Boeing 777-200ER operating Asiana Airlines Flight 214 struck a seawall at San Francisco International Airport (SFO) in San Francisco, California. The National Transportation Safety Board in charge of the investigation, concluded that the visual approach was flown in poor condition, including a glide interception from above, an air traffic control requirement to maintain 180kts to 5NM, and an airspeed management mode activated by the pilot leading the aircraft into a stall on short final [19].

4. Discussion

In this section, possible uses of the technology are discussed.. This paper presents the use of a post-ops methodology for the analysis of energy atypicality in the context of a study of the COVID-19 period.

The construction of the model is an important criterion because it obviously influences the final atypical flight rate and whether an atypicality is detected. Nevertheless, another model has also been built using flight data on Paris Orly airport platform and the results with this other model are similar highlighting an overall increase in atypicality during the COVID-19 period compared to the baseline period before COVID-19.

This type of analysis can be used within the framework of safety management systems and in particular within the framework of measures taken in the event of a crisis. For example, it is possible to imagine precautionary measures taken into account in the context of a low volume of air traffic, the closure of the Le Bourget aerodrome, or weather conditions involving a majority use of the doublets facing east. The various ANSP operators and airlines have already shown their interest in this type of analysis, particularly in this post-COVID-19 recovery period.

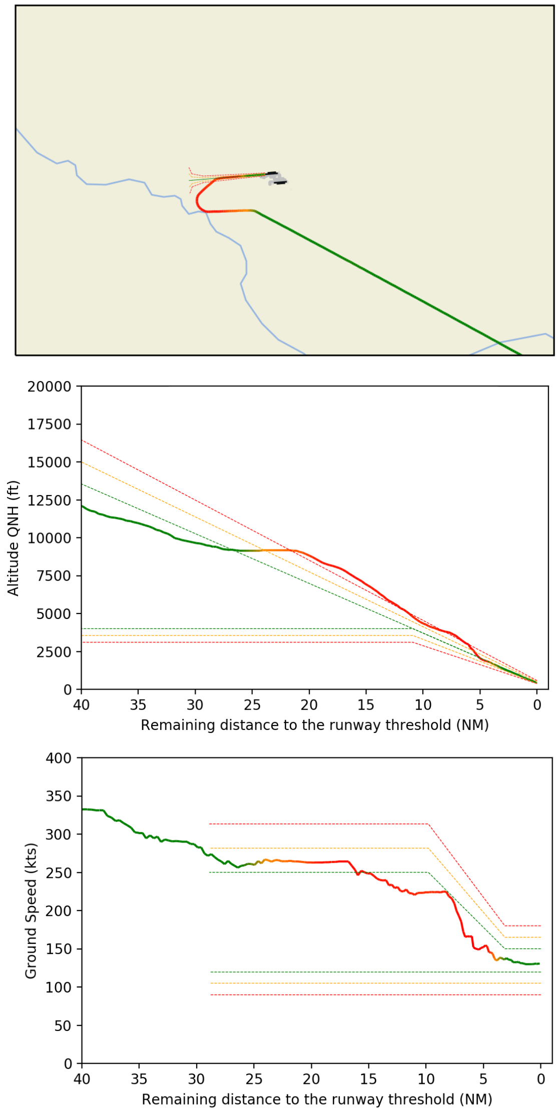

Figure 13: Illustration of an A320 glide inteception from above on runway 09L. The top graph shows the lateral trajectory, the middle graph shows the vertical profile and the bottom graph shows the ground speed profile. It is observed that the aircraft shortened its trajectory, which led it to a glide path interception from above, which is not recovered until 5NM from the runway threshold. The color of the trajectory is proportional to the local atypical energy coefficient (green for 0, orange for 0.5 and red for 1). The colored dashed lines are fixed operational limits to allow a better understanding of the situation.

It is important to specify that this methodology brings a different and new perspective for the analysis of flights but in no way replaces the existing investigation methods. Flight atypicality does no necessarily imply consequences on flight safety. It is a complementary aspect to be taken into account in a safety analysis. The results from this study show that the atypicality metric seems relatively consistent for the monitoring of an airport platform or events related to energy management.

5. Conclusions

In this paper, a comparative analysis of the approaches at Roissy-Charles-De-Gaulles Airport, over the periods before and during the COVID-19 was presented. This analysis is mainly based on the use of an energy atypicality metric on approach and landing.

The study shows an overall increase in approaches with energy atypicality, generally associated with shortening of trajectories, glide interceptions from above and approaches with late speed reductions. The metric seems appropriate for monitoring energy management on approach and landing. The complementary vision to the classical flight analysis techniques allows to bring an additional dimension on the situation awareness. Moreover, the results obtained seem to be consistent with the latest figures published by IATA on the sharp increase in the rate of unstabilized approaches for the period of COVID-19 [20].

Future works will aim to continue the analysis on the post-COVID-19 recovery period, and the elaboration of the methodology real time extension. In addition, future works will consist in completing the post-operational analysis with the integration of machine learning tools [21] in order to propose a complete tool for the analysis of the energy management of approach trajectories from ground side.

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