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

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ARTICLE INFO

Keywords:
COVID-19
Anomaly detection
Energy management
Aircraft safety
Atypical approaches

ABSTRACT

During the COVID-19 period and particularly during lockdown, deviations from nominal operations have shown to become more frequent. To confirm this observation this paper proposes to evaluate the impact of COVID-19, and more generally of crises that lead to a sharp drop in traffic, on the pilot/controller system, especially during the critical approach and landing phases. To study the influence of this type of crisis on flight operations at Charles De Gaulle airport, an existing energy atypicality metric is applied on a reference period before COVID-19 and compared to the COVID-19 period. Whereas the traffic at Charles De Gaulle airport has decreased by around 90% on April 2020, the obtained statistics underlined an increase in the atypical flight ratio of around 50%. This trend can be explained in part by the appearance of glide interceptions from above as a result of trajectory shortening, and an increase in the proportion of high speed 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. Travel restrictions were imposed for both domestic and international flights. On 9 March 2020, Italy was the first country to introduce national lock-down situation. On 11 March 2020, the US banned travellers from China, Iran and 26 EU member states (Salcedo et al., 2020). On 17 March 2020, the EU closed the borders of 26 of its member states to almost all visitors from outside the EU (Salcedo et al., 2020). As a result, the number of operations at Roissy Charles-De-Gaulle was reduced by 90% in April 2020 compared to April 2019. 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 (Jackman, 2014). In addition, a large majority of accidents follow significant deviations from nominal approaches, such as atypical airspeed or atypical altitude (Tremaud, 2000). It is then interesting to ask how the air traffic system has behaved during the drastic reduction of traffic caused by COVID-19 crisis, 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 (Li et al., 2015; Li et al., 2016; Li et al., 2011). In addition, work has also been carried out on the detection of anomalous flight deck data using multiple kernel (Das et al., 2010), active learning (Sharma et al., 2016), recurrent neural network methods (Nanduri and Sherry, 2016), and support vector regression (Lee et al., 2020) or multivariate gaussian mixture models (Li et al., 2018). Recently, Andreu et al. have developed a methodology suitable for the flight deck that proposes recovery trajectories when aircraft present over-energy (Andreu Altava et al., 2019).

From ANSP perspective, which implies using radar available parameters, there are different initiatives, such as a recent work by Singh et al. (2020) 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-operative detection of atypical behaviour in the total energy of the aircraft by using unsupervised learning (Jarry et al., 2020). This algorithm combines a sliding window with a functional data analysis tool called functional principal component analysis and an outlier scoring as illustrated in Fig. 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 (Jarry et al., 2019). It showed a significant correlation between the atypical energy behaviors and airline safety events. In particular, while unstatistical approaches represent between 3% and 4% of typical flights, they account for 50.4% of atypical flights between 5 NM and the runway threshold (Jarry et al., 2019).

In addition, the methodology was compared to the detection of anomalies with the help of generative adversarial networks (Jarry et al., 2019) 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.

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 only 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 (Jarry et al., 2020) 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 2 NM. A score greater than 0.7 is equivalent to a deviation from the mean functional principal components analysis coefficient greater than 3e under Gaussian distribution hypothesis. Equivalently, with no prior knowledge on the statistical distribution, it corresponds to a score that is in the area where the probability density is hundred times lower than the maximum probability density.

In addition, other classical operational metrics were computed, such as the interception distance on the runway centreline, or the exceeding of altitude limits (Jarry et al., 2020) (based on the interception altitude and deviation from 3°glide path) and ground speed limits (Jarry et al., 2020) (based on approach speed normal interval and on 3°glide path deceleration (SKYbrary, 2019)). Three categories, green, orange, and red, are defined using altitude and speed limits. These categories enable analysing the causes of energy atypicalities.

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 Fig. 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. In order to assess the statistical significance of this increase, a χ² independence test was conducted. The two variable tested are: first a flight being atypical (0 or 1), second, this flight occurred during COVID-19 lock-down (0 or 1). If the H₀ hypothesis “the two variables are independent” is rejected it will mean that the two variables are sta-

![Fig. 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.](image-url)
tistically dependent and that this increase is statistically significant. The result of the χ² independence test gives a χ² score of 69.6 and a p-value of 7.22 × 10⁻¹⁷. The test concludes to reject the H₀ hypothesis, and assesses that the increase is statistically significant.

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 Fig. 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 Fig. 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. Besides, the atypical ratio on runways 27R and 26L appears to be similar, if not declining, during the COVID-19 period. Fewer shortened trajectories are observed. One might ask whether there is not an operational reason why less shortening is observed for these two runways.

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;

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

First, the lateral management of trajectories will be studied. Fig. 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 situations 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 Fig. 6, where the interception distance distribution shifts from the 15 NM to 20 NM area to the 10 NM to 15 NM 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. 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 Fig. 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 COVID-19 start upstream while the aircraft are still on base leg or downwind.

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of altitude warning areas illustrated in Fig. 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 potential energy and possibly also a high kinetic energy.

This is reflected in the distribution of flights by ground speed limit areas illustrated in Fig. 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. Fig. 10 illustrates the 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. If atypical energy management such as high energy during final induces additional risks such as unstable approaches, it is questionable why some airlines have a lower atypical ratio and whether they pay more attention to energy management on approach. However, it is difficult to know the true factors that may have impacted these observations, as each airline may have managed the crisis differently. Some airlines privileged flights performed by flight instructors, while others continued to fly all the pilots. In the same way, some airlines decided to fly their pilots on simulators, while others preferred to stop the simulator as well to limit costs.

3.3. Flight analysis

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

**High Speed Approach.** The first flight is an approach to runway 09L of an A320 aircraft. A rapid arrival behaviour is observed. Fig. 11 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 glide path. The ground speed profile shows that the ground speed was maintained at 230 kts up to 5 NM and then was sharply reduced just before stabilization. It is observed that the atypical areas start at 10 NM since the aircraft keeps its kinetic energy whereas the usual behaviour at 10 NM 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 (d’Enquêtes et Analyses, 2015), or the Pegasus Airlines Flight 2193, which overran Istanbul runway on February 5, 2020 (Three dead, 2020; Pegasus Airlines Flight 2193 overruns runway in Istanbul, 2020).

**Approach with Glide Interception From Above.** The second case, illustrated in Fig. 12, 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 5 NM 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 (Board, 2009). 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, causing the aircraft to lose its flight path and eventually shortening the trajectory.

**Fig. 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 Fig. 11.

**Fig. 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.
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 180 kts to 5 NM, and an airspeed management mode activated by the pilot leading the aircraft into a stall on short final (Hart et al., 2013).

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 similarly highlighting an overall increase in atypicality during the COVID-19 period compared to the baseline period before COVID-19. In addition, the analysis and conclusions that can be drawn require a statistically significant data set. In the case of this platform, the number of flights considered seems to be consistent. Other French platforms could have been studied, but the low number of approaches would have made the analysis less relevant.

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. An automatic analysis of all flights could be developed. It would then allow to follow the evolution in the context of

Fig. 11. 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 230 kts 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.

Fig. 12. Illustration of an A320 glide interception 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.
of a crisis or a particular event and to issue recommendations if necessary. 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 mon-

Finally, it is important to underline that the observations made in this study are intrinsically linked to the drastic reduction in air traffic caused by the COVID-19 pandemic. This reduction has permitted a greater use of visual approaches on a platform that normally presents very constrained operations. It can therefore be assumed that the training of pilots and the fact they make little use of these procedures under normal circumstances may have had an impact on the observed operations. In addition, one can question the levels of vigilance and prac-
tice due to a greater number of flights carried out in simulators in some airlines, while other airlines have preferred to stop simulator flights to reduce costs. Further investigations could be carried to evaluate the impact of such human factor components on the observed atypical behaviors.

5. Conclusions

In this paper, an evaluation of the impact of crises, which lead to sharp drop in traffic, was conducted during the approach and landing phases. 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. These results emphasized that crises that lead to a drop in traffic should be subject to increased vigilance during the approach and landing phases. Similarly, trajectory shortenings should be monitored more closely so that it does not produce atypical or unstable approaches.

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 unstable approaches for the period of COVID-19 (IATA, 2020). Safety recommenda-

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-operative analysis with the integration of machine learning tools (Jarry et al., 2020) in order to propose a complete tool for the analysis of the energy management of approach trajectories from ground side. Finally, other studies could be conducted in order to analyse the potential impact of COVID-19 on pilot and controllers human behaviors such as fatigue, time pressure or training.

CRediT authorship contribution statement

Gabriel Jarry: Conceptualization, Methodology, Software, Investigation, Data curation, Visualization, Writing - original draft, Writing - review & editing, Supervision. Eric Feron: Conceptualization, Methodology, Writing - original draft, Writing - review & editing, Supervision. Daniel Delahaye: Conceptualization, Methodology, Writing - original draft, Writing - review & editing.

Acknowledgement

The authors would like to thank the environmental office of the French ANSP (DSNA) for providing the data needed for the study and the French NSA (DSAC) for supporting the research work.

References


