"Accidents: The Current Which Lies Beneath"

Analysis of event severity of Flight Data Monitoring versus pilots' reporting rate during flight disruptions

Arthur Nichanian[1], Wen-Chin Li[2] and Graham Braithwaite[3]

[1, 2&3] Safety and Accident Investigation Centre, Cranfield University, United Kingdom

Author Biographies

[1] Arthur Nichanian (ISASI membership 61583680) is an airline pilot student based in Zurich. He holds an MSc. in Safety and Human Factors in Aviation from Cranfield University, UK, and a BSc. in Aeronautical Engineering from the ZHAW School of Engineering in Winterthur, Switzerland. He is the recipient of the third prize at the USAIRE Student Award 2021 whose subject was "What aviation for tomorrow's world?" and Best Student Project Award 2022 from the Chartered Institute of Ergonomics and Human Factors (CIEHF). CIEHF Graduate member, he is also a co-author of academic papers related to pilot proficiency during COVID and Flight Data Monitoring (FDM).

E-Mail: a.nichanian@cranfield.ac.uk

[2] Dr Wen-Chin Li is a Senior Lecturer at the Safety and Accident Investigation Centre, Cranfield University, United Kingdom. He is a Fellow, Chartered Ergonomist and Human Factors Specialist of the Institute of Ergonomics and Human Factors (CIEHF), and an Aviation Human Factors Specialist of the European Association of Aviation Psychology (EAAP). His expertise included Accident Investigation, Cross-cultural Research, Flight Deck Design, and Aeronautical Decision-making. He has published over 100 books, journal articles, and conference papers related to accident investigations, human factors, and aviation safety. Dr Li had supervised three MSc students at Cranfield University who won the ISASI Rudolf Kapustin Memorial Scholarship in recent years.

E-Mail: wenchin.li@cranfield.ac.uk

[3] Professor Graham Braithwaite (ISASI fellowship WO3644) is Director of Transport Systems - one of the eight industry-facing themes that make up Cranfield University, UK. His main research interests are in the fields of safety management, accident and incident investigation, human factors and the influence of culture on safety. He is the Accountable Manager for the University's flying operation which won the Queen's Anniversary Prize in 2019 – the highest honour for a UK University. In addition to his Cranfield role, Graham is the Independent Safety Adviser to the British Airways Board and for TUI Northern Region Airlines. He is a Fellow of ISASI and the Royal Aeronautical Society.

E-Mail: g.r.braithwaite@cranfield.ac.uk

Introduction:

Flight Data Monitoring (FDM), or Flight Operation Quality Assurance (FOQA) is the process of recording and analysing data from the aircraft's Quick Access Recorder (QAR). FDM is a powerful tool for airlines and regulators to analyse and quantify safety performance and is typically integrated into their Safety Management System (SMS). The exceedance events are classified into the EASA FDM categories, such as Controlled Flight Into Terrain (CFIT), Loss of Control In-flight (LOC-I), Mid-Air Collision (MAC) and Runway Excursion (RE). This classification enables a standardised event analysis, whose events can then be assessed through their severity [1]. It has been determined, based on the EASA FDM categories, that on average CFIT, LOC-I, and RE events present the highest severity [2]. In general, recurring events with a low severity are preferable to infrequent events but with a much higher severity level. Pilots' inputs on the controls are recorded, but it is difficult to perform a naturalistic decision-making analysis behind the sole inputs [3]. For this reason, pilots are usually encouraged to submit Air Safety Reports (ASRs) if they encountered any incident. The ASR consists of a form which is filled out by the pilots, containing information regarding the flight conditions (aircraft type, weather, flight phase) and a written description of the encountered event. The submission of an ASR can be mandatory for some events such as a Traffic Collision and Avoidance System resolution advisory; these requirements are laid down by ICAO [4]. Airlines can also make additional events mandatory to report, such as go-arounds.

The just culture principles must be strictly followed when handling ASRs, to maintain an adequate reporting culture within the organisation. A just culture ensures that the person reporting an honest error, or an unsafe condition does not get blamed so that the submitted feedback can contribute to improving safety. It thus contributes to an atmosphere of trust within people and a willingness to submit reports [5]. Moreover, the submitted reports and/or data need to be anonymised so that the persons involved cannot be blamed. However, deliberate unsafe actions (for instance reckless noncompliance) must still be sanctioned. To implement and maintain an effective just culture programme within an organisation, it must be documented and thus defined accurately and precisely. The reporting system must be linked to the just culture programme and closely monitored to identify any possible deviation. Mishandling of ASRs can lead to a loss of motivation to report, therefore preventing an organisation to learn from the encountered incidents [6]. Typically, ASRs are combined with FDM events to gain a broader understanding of a situation beyond the raw data, combining the data with the pilot's subjective assessment of the incident [7].

Relative Work

Today's flying environment is characterised by its complexity and requires specific competencies among pilots which are prone to decay and as such require upkeep [8]. Pilots' proficiency can be divided into two categories: technical skills (such as manual flying skills) and non-technical skills (such as situation awareness and teamwork). The retention of these skills during the onset of the COVID-19 pandemic has been a challenge for pilots, airlines, and regulators. Studies have shown that there has been an increase in FDM event frequency which can be related to flying skills, therefore raising concern about a potential skill decay [9]. Through the quantification of operational threats, operators can adapt their procedures and/or establish training objectives for crews. During a flight, pilots constantly make decisions, i.e., based on their situational awareness project possible outcomes, and decide the appropriate course of action, according to the Threat and Error Management principles [10], [11]. This implies weighing the risks and the benefits implied in the various courses of action which is based on the balance between potential losses and perceived gains [12]. It therefore also involves the appraisal of one's capabilities [13]. Thus, risk perception varies from person to person and is dependent on various individual factors such as training and experience [14], [15] and on external factors such as the environment (place, time of the day, environmental conditions). Environmental and operational factors can act as stressors (time pressure, weather etc.) which are known to have an impact on decision-making [10]. Pilots' abilities to analyse risks are also based on the quality of observable information, i.e., on the available cues and their clarity or ambiguity. Ambiguous cues can lead to pilots misperceiving potential risks, therefore impairing their risk assessment [16], [17]. Increased risk tolerance has also been demonstrated to positively correlate with mental workload [18] and can have a negative effect on situation awareness [19]. An example of this correlation is the cognitive plan continuation bias which leads to a person continuing with an initial plan despite changing conditions. Several studies related to risk assessments of airline pilots demonstrated that pilots can be overconfident when operating in a dynamic environment. As their mental workload increases, they tend to underestimate environmental risks which in turn increases the likelihood of a higher risk-taking behaviour [20].

The perception and evaluation of risks also play a role in pilots' willingness to submit a report if they deemed that they encountered an incident. There appears to be a "self-protection" effect in pilots submitting a report: events related to the environment (such as procedures, weather, and hardware) are more likely to be reported than individual errors. Therefore, it is likely that the airline's distribution of reports is biased towards environmental factors whereas individual errors are to an extent less represented. This has an impact on the safety monitoring abilities of the airline [21]. Moreover, pilots are more likely to report events which they perceived to be of high risk rather than events deemed to be of a lower risk [21]. It is to be noted that the majority of studies involving the analysis of risk perception among pilots focus either on questionnaires or simulator experiments involving assessing a particular scenario. Few studies have been conducted that aim at focusing on flight operations instead of a closed, managed experiment with less variability. However, one study demonstrated significant correlations between pilots' risk tolerance and specific FDM exceedance events, such as long landings [20].

Method

FDM data comprising 3702 events among 123,140 flights was collected within a major European airline operating both short-haul and long-haul flights across 24 months between 2019 and 2021 including 398 events with an associated Air Safety Report (ASR). These ASRs are optionally submitted by pilots following an in-flight event that they considered hazardous, as having deviated from acceptable flight parameters, or where a safety report may benefit the airline and/or other pilots. The FDM events were classified by the airline into one of the four main categories according to EASA [1]: CFIT, LOC-I, MAC, and RE precursors. In addition to the classification, each FDM event features an associated common severity index score, on a linear scale starting from 0 upwards, which indicates the assessed severity of the event based on an algorithm that is different for each type of event. Two methods are used to determine the severity index of an FDM event. Discrete events such as a hard EGPWS warning (terrain avoidance system requiring an immediate maximum climb effort) is graded as 100. Deviations based on continuous indicators such as an overspeed event are based on the magnitude of the deviation; a higher deviation leads to a higher severity index score. Overall, reducing the severity levels is more crucial than the number of events [22].

Within the FDM dataset, for each event, information regarding the submission of an associated ASR from the pilots was provided. The proportion of submitted ASRs was correlated to the assessed severity of the FDM event as assessed by the airline. Occurrence frequencies (percentage of submitted ASRs), means, medians and standard deviations of different variables (such as severity index scores) were calculated as part of the exploratory data analysis. P-levels lower than 0.05 were considered to be statistically significant. Following an explanatory data analysis, The Shapiro-Wilk tests were used which suggested data heterogeneity and non-normality distributions among the severity index scores. Chi-square tests were used to compare the frequency of submitted ASRs to the FDM severity index scores, pandemic stages, and FDM event categories. The dependent variables here represent the frequency of submitted ASRs per event category, pandemic stage, and severity index. Finally, a new indicator was calculated to combine both the frequencies of occurrence and their severity. To emphasise the importance of reducing an event's severity over its occurrence frequency [22], the new indicator for each event category is equal to the monthly SI squared multiplied by the monthly occurrence frequency.

Results

Sample characteristics

Table 1 displays the evolution of the ASR reporting percentage for different ranges of SI for each stage. Table 2 displays the number of ASRs submitted for each event category. The percentage of ASRs submitted for five FDM occurrences from June 2019 to May 2021 is shown in Figure 1. The percentage of ASRs submitted per month started to fluctuate highly from March 2020 onwards compared to pre-pandemic trends.

Analysis of SI scores and ASR submissions

Chi-square tests were used to determine significant associations between the SI scores and ASR submissions. Results show that there is a significant association between the SI intervals and ASRs submitted at stage 1, $X2\ (3) = 52.773$, $p < 0.001$. There is also a significant association between the SI score intervals and the number of ASRs submitted at stage 2, $X2(3) = 41.316$, $p < 0.001$. Moreover, there is a significant association between the SI interval and ASRs submitted at stage 3, $X2(3) = 15.201$, $p < 0.005$ (Table 1).

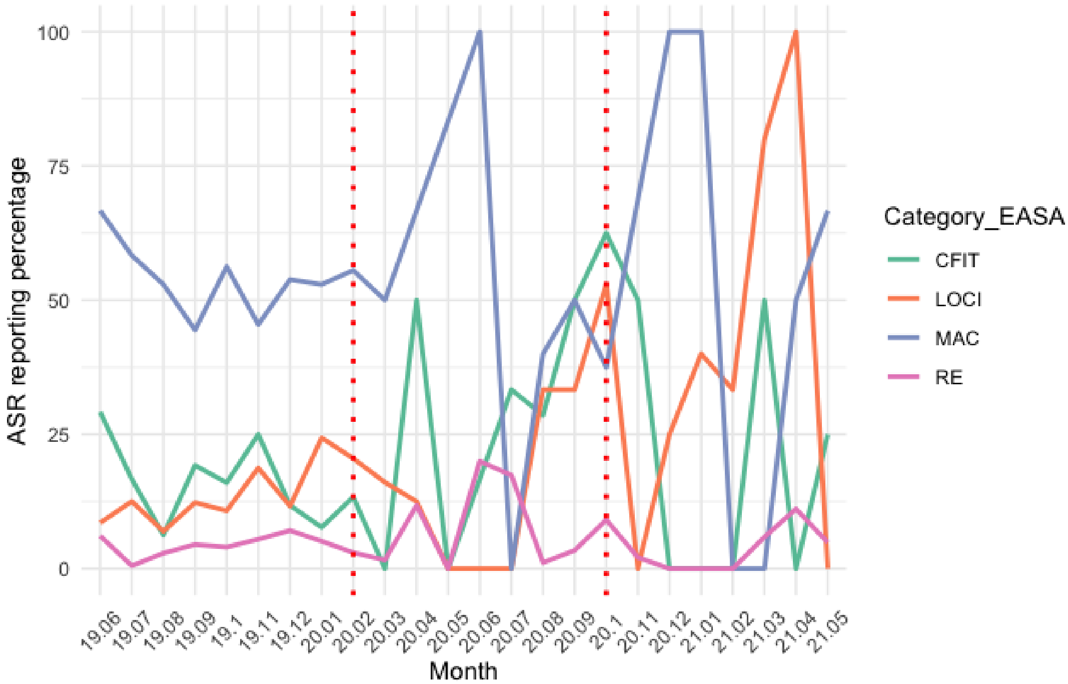

Figure 1: The percentage of ASR reports submitted by pilots among CFIT, LOCI, MAC, and RE based on FDM occurrences from June 2019 to May 2021

Table 1: Number of ASR submitted for each severity index interval and percentage of ASRs submitted

SI Interval	No ASR submitted	ASR submitted	Percentage of ASRs submitted
Stage 1			
0 – 24	535	93	14.81%
25 – 49	971	58	5.64%
50 – 74	313	46	12.81%
75 – 262	202	43	17.55%
Total	2021	240	10.61%
Stage 2			
0 – 24	220	30	12.00%
25 – 49	382	17	4.26%
50 – 74	152	14	8.43%
75 – 298	177	45	20.27%
Total	931	106	10.22%
Stage 3			
0 – 24	93	11	10.58%

25 – 49	139	14	9.15%
50 – 74	64	7	9.86%
75 – 190	56	20	26.32%
Total	352	52	12.87%
Total stages			
0 – 24	848	134	13.65%
25 – 49	1492	89	5.63%
50 – 74	529	67	11.24%
74 - 298	435	108	19.89%
Total	3304	398	10.75%

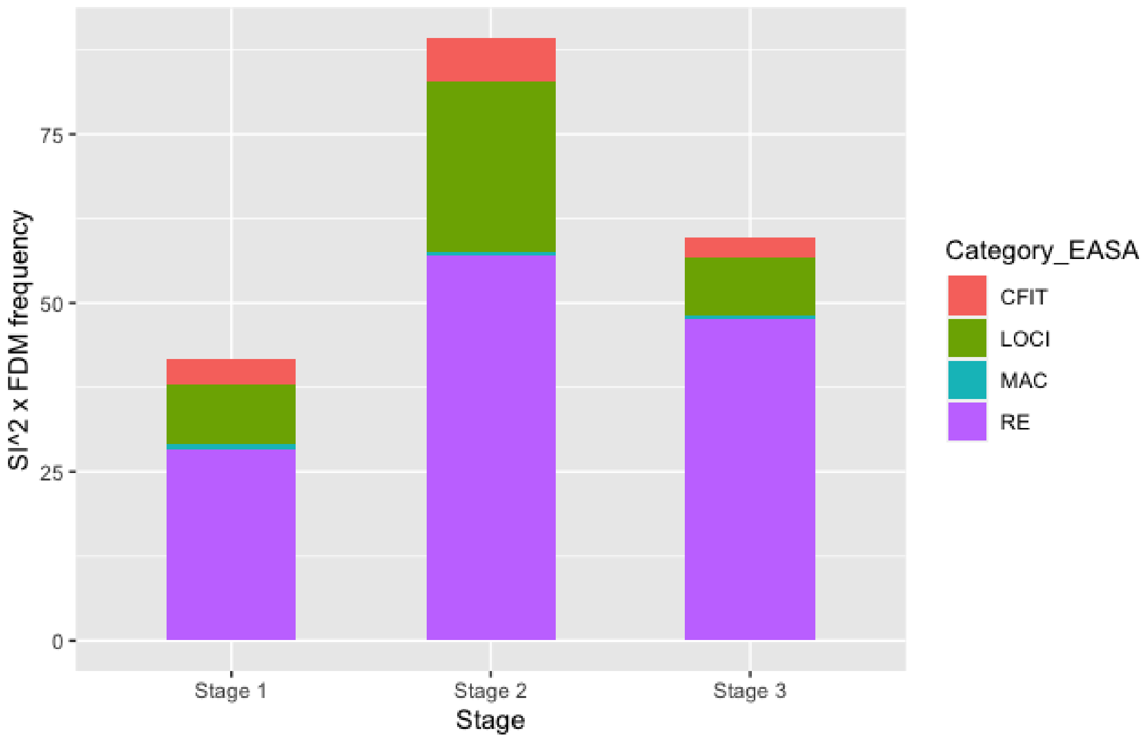

Figure 2: SI scores squared multiplied with their respective occurrence frequency over the three stages and five EASA categories

There is a significant association between the FDM event categories and the submitted ASRs. X2(3) = 482.0, $p < 0.001$. Runway Excursion events were the less reported event type by pilots, however, these feature the highest average severity index scores, whereas MAC events (which include mandatory reporting events) feature a comparatively lower severity index. The ASR reporting percentage remained at fairly steady levels before the COVID onset and started to fluctuate highly from March 2020 onwards, except for RE events (figure 1). Overall, the reporting percentage increased for CFIT, and LOC-I events, especially in the third stage, but not for RE events. Furthermore, the reporting rate is slightly higher on the long-haul fleet compared to the short-haul fleet, although not significant (X2(2) = 0.014, p > 0.5 - table 3). However, there was no significant association between the reporting rate and the three stages neither for the short-haul fleet (X2(3) = 0.048, p > 0.5), nor for the long-haul fleet (X2(3) = 0.11, p > 0.5).

Table 2: Cross-tabulation of the submitted ASRs for each FDM event category over the three pandemic stages

		Stage 1	**Stage 2**	**Stage 3**	**Total**
CFIT	ASR	33	13	9	55
	No ASR	164	68	20	252
	Percentage	16.75%	16.05%	31.03%	17.92%
LOC-I	ASR	76	52	21	149
	No ASR	500	209	37	746
	Percentage	13.19%	19.92%	36.20%	16.65%
MAC	ASR	71	14	8	93
	No ASR	57	14	9	80
	Percentage	55.47%	50.00%	47.06%	53.76%
RE	ASR	60	27	14	101
	No ASR	1300	640	286	2226
	Percentage	4.41%	4.05%	4.67%	4.34%
Total	ASR	240	106	52	398
	No ASR	2021	931	352	3304
	Percentage	10.61%	10.22%	12.87 %	10.75%

Table 3: ASR reporting rate for short-haul and long-haul aircraft

		Stage 1	**Stage 2**	**Stage 3**	**Total**
Short-haul fleet	ASR	184	79	28	291
	No ASR	1731	791	215	2737
	Percentage	9.61%	9.08%	11.52%	9.61%
Long-haul fleet	ASR	56	27	24	107
	No ASR	290	140	137	567
	Percentage	16.18%	16.17%	14.91%	15.88%

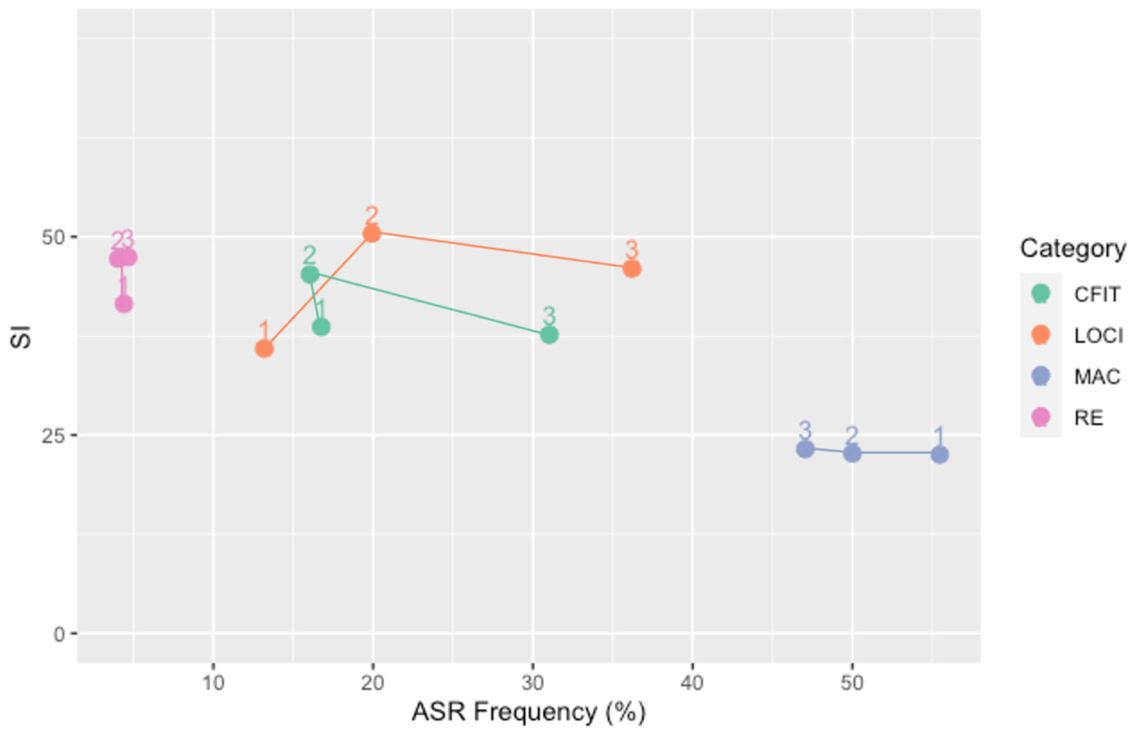

Figure 3: ASR submission percentage versus severity index for each EASA category and stage

Discussion

The results also demonstrate significant associations between the ASR submissions and the FDM exceedance severity index scores (Table 1). Events with a low severity index or with a high severity index are more prone to be reported. This discrepancy increased in stages 2 and 3, although the percentages overall remain low. Furthermore, no differences between fleets appear to exist, indicating no influence of the aircraft type nor the type of operation (short-haul or long-haul) on pilots' willingness to submit an ASR (table 3). At first glance, it seems to contradict the results of Sieberichs & Kluge (2018) who found that the higher the perceived risk, the higher the likelihood of the event being reported [21]. The higher percentage of lower severity events which are reported can be explained by the higher percentage of MAC events reported, as they feature a relatively low overall severity index score (Figure 1; Table 1 & 2). The results from Figure 3 indicate resilience within the airline. The average SI for CFIT and LOC-I events decreased from stage 2 to stage 3 while the frequency of ASR increased, possibly indicating better feedback from the pilots to the airline's flight safety department. The decrease in the MAC event reporting rate can be explained by the reduced frequency of TCAS resolution events from stage 1 (49% of all MAC events) to stage 3 (35%). MAC events consist either of TCAS resolutions, which are mandatory to be reported, and altitude deviations, which are not. Therefore, the decrease in TCAS resolution event frequency can explain the drop in the overall reporting rate. These results might also indicate that pilots tend to better recognise external factors concerning their flight (such as potentially conflicting traffic) rather than internal ones (such as a high rate of descent on the final approach).

However, RE events remain the events with the lowest reporting rate (4.34%, table 2) and a comparatively high severity index, which increased during the pandemic. RE events feature many different factors ranging from technical aspects (system malfunctions) to organisational aspects (crew training, SOPs, communication) and environmental factors (weather, runway state) [23]. RE remain a key risk factor and as such have been integrated into the 2023-2025 ICAO Global Aviation Safety Plan [24]. RE event severity and frequency remain comparatively high and with a steadily low reporting percentage. RE events are sensitive to skill decay as they require both a high level of manual flying skills and non-technical skills from pilots such as teamwork and situation awareness to properly manage the aircraft's energy. The identification of threats linked to RE can be challenging as these occur during the take-off and approach and landing phases where the workload is already high. Therefore, unanticipated threats during these flight phases can pose a greater safety risk. A study by Jarry (2021) [25] demonstrated that the ratio of atypical approaches (such as glide slope interception from above and high energy approaches) increased by 50% at Paris Charles De Gaulle Airport, France although the traffic had declined by 90%. This increase is due to the shorter approaches offered by ATC to the pilots, which optimised the flight paths but also created new threats, which could have had an impact on flight safety. These threats may have not been perceived by ATC, pilots, and airline safety management in the first months following the pandemic onset. With hindsight, pilots indicated that the flying environment due to the COVID-19 pandemic increased in complexity [26]. Moreover, due to the uncertainty following the pandemic onset, they did not necessarily seek to maintain their proficiency by themselves and while technical skills such as manual flying skills were regained quickly, it took longer to regain non-technical skills such as the management of information and workload management [26]. Risk factors related to flight operations can be perceived differently depending on pilot experience, workload, and state (such as fatigue). Risk perception can also be influenced by dynamically changing conditions, where outcomes are uncertain [16], [27]. Studies have shown that humans prefer to choose options related to known outcomes over unknown outcomes, even if the unknown outcome's utility is potentially better [28]. Furthermore, RE events feature a wider range of possible situations than the other four EASA categories, and with fewer warnings (e.g., compared to a GPWS warning for a CFIT event). The increase in reporting rate for LOC-I and CFIT events and their subsequent decrease in severity index during the third stage (figure 2) indicates that the relevant safety measures have been taken collectively within the airline to address potential risks and strengthen the reporting culture. This finding is corroborated by the evolution of the $SI^2 \times$ frequency indicator of each event category (figure 2), which tends to decrease from stage 2 to stage 3. Following an initial disturbance (as the pandemic started to spread – stage 2), both the airline's safety and training departments as well as the pilots were able to cope with the threats which arose from this new flying environment. Uncertainty and stress have been demonstrated to have a greater effect on pilots with a comparatively lower experience. Had no training measures and procedures been in place, it is reasonable to expect that the SI would have stayed constant or even increased from stage 2 to stage 3 while the reporting rate wouldn't necessarily have increased. As the pandemic started different concerns emerged among airlines, regulators, and pilots. Airlines and regulators were concerned about safe and organised flight operations whereas pilots' concerns focused prominently on the uncertainties regarding their job stability and fatigue. The airline was able to implement both training sessions and operational measures on an organisational level because of its previously accumulated safety experience and by following the regulator's guidelines. By taking into account the concerns, influences, and actions related to the task of operating an aircraft and addressing them, the airline increased team resilience and each pilot's resilience (figures 2, 3, and 4) [29], [30]. These may also have had a positive impact on pilots' abilities to recognise potential new threats and encourage their reporting, thus contributing to the airline's informed culture. These results can also prove useful to airlines which employ a high number of seasonal or freelance pilots and pilots whose flying hours fluctuate highly from season to season. Similarly, aircraft operators flying in very changing environments on an ad-hoc basis (such as corporate aircraft or medevac aircraft) might profit from these results as identifying threats in highly changeable environments can be challenging [31], [32].

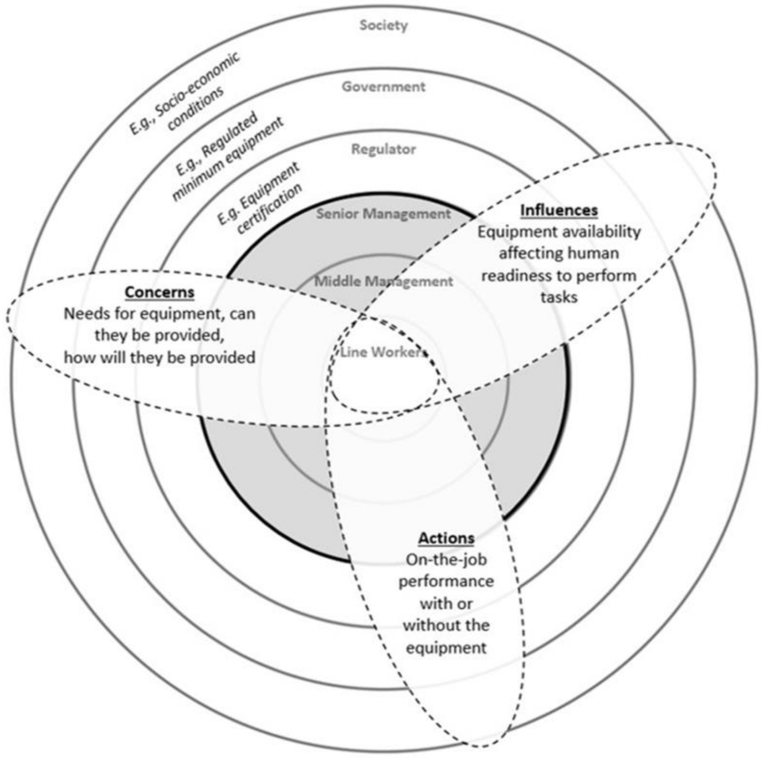

Figure 4: Ripple model of safety culture indicating the levels of influence on a line worker. The meta-categories of concerns, influences and actions can have an impact on human performance [30]

Finally, these findings can provide information for future data analysis tools such as the Universal Virtual Flight Data Recorder (UVFDR) [33]. As UVFDR aims at a real-time data analysis while the aircraft is in flight, highlighting differences between the data-driven risk analysis and individual risk perception can be useful to improve flight pattern analysis and provide useful assistance to the pilots. Understanding and resolving differences in risk perception between the actors involved would ensure a better and more importantly shared situational awareness between the pilots and the ground analyst. Text-recognition algorithms could also be used to integrate the ASR text content within the FDM data analysis before its usage by a flight data analyst.

Limitations

Outlier detection such as FDM is a useful tool for detecting safety-critical events due to its ability to monitor degradation in mechanical systems [34]. FDM as of today is however inherently limited due to it focusing on the absence of safety instead of its presence. As the flying environment's complexity increases, operators are dependent on the fact that exceedance events need first to occur before remedial actions can be taken. Weather disruption could also trigger an increase in FDM occurrences which would normally be related to manual flying skills and could bias the results. Finally, the data in this study does not indicate the content of the Air Safety Reports. No conclusion can therefore be made regarding the quality of the reporting in terms of content. Only the presence or absence of an ASR for each FDM could be determined.

Conclusion

This study shows that the airline and its pilots demonstrated resilience as threats relating to LOC-I and CFIT events were properly identified after a few months following the pandemic onset. This led to both a decrease in FDM event severity and an increase in reporting rate for these two categories. However, additional measures need to be implemented to address safety risks from runway excursion precursors in line with the ICAO Global Aviation Safety Plan 2023-2025. These findings highlight the gap between the perceived severity during a flight by pilots and the actual data-driven indexed event severity within an airline's SMS. Bridging the gap between perceived and indexed severity can help safety managers to improve risk analyses and pilots better recognise potential threats. Finally, it can also facilitate developing campaigns to encourage pilots to submit ASRs for events which they may have considered to be of less relevance otherwise. Currently, FDM is a part of every major airline's safety and reporting culture, which is non-punitive, and with protected data sources. There is a constant feedback process among individual crewmembers, the flight safety department, pilot unions, and airline management. Crew's trust in an airline safety management system and FDM Programme is paramount in ensuring its effectiveness and contribution to aviation safety.

References

[1] EASA, 'Developing standardised FDM-based indicators', 2016. Accessed: Aug. 04, 2021. [Online]. Available: https://www.easa.europa.eu/sites/default/files/dfu/EAFDM__standardised_FDM-based_indicators_v2_Ed2017.pdf

[2] N. Borjalilu, P. Rabiei, and A. Enjoo, 'A Fuzzy TOPSIS Based Model for Safety Risk Assessment of Operational Flight Data', *International Journal of Aerospace and Mechanical Engineering*, vol. 12, 2018, doi: 10.5281/zenodo.2022699.

[3] M. Stogsdill, 'When Outcomes are not Enough: An Examination of Abductive and Deductive Logical Approaches to Risk Analysis in Aviation', *Risk Analysis*, 2021, doi: 10.1111/RISA.13681.

[4] ICAO, ‘Doc 9859 Safety Management Manual’, 2018. Accessed: Aug. 27, 2021. [Online]. Available: https://store.icao.int/en/safety-management-manual-doc-9859

[5] J. Reason, *Managing the Risks of Organizational Accidents*. Routledge, 2016. doi: 10.4324/9781315543543.

[6] J. Fearson, *Operational safety*. Routledge, 2017. doi: 10.4324/9781315566450-21.

[7] G. Walker, ‘Redefining the incidents to learn from: Safety science insights acquired on the journey from black boxes to Flight Data Monitoring’, *Saf Sci*, vol. 99, pp. 14–22, Nov. 2017, doi: 10.1016/j.ssci.2017.05.010.

[8] D. Harris, *Human Performance on the Flight Deck*. CRC Press, 2016. doi: 10.1201/9781315252988.

[9] W.-C. Li, A. Nichanian, J. Lin, and G. Braithwaite, ‘Investigating the impacts of COVID-19 on aviation safety based on occurrences captured through Flight Data Monitoring’, *Ergonomics*, pp. 1–39, Dec. 2022, doi: 10.1080/00140139.2022.2155317.

[10] G. A. Klein, ‘A recognition-primed decision (RPD) model of rapid decision making.’, in *Decision making in action: Models and methods.*, Westport, CT, US: Ablex Publishing, 1993, pp. 138–147.

[11] A. Merritt and J. Klinect, ‘Defensive Flying for Pilots: An Introduction to Threat and Error Management’, Dec. 2006. Accessed: Jul. 12, 2023. [Online]. Available: https://skybrary.aero/sites/default/files/bookshelf/1982.pdf

[12] E. Gullone and S. Moore, ‘Adolescent risk-taking and the five-factor model of personality’, *J Adolesc*, vol. 23, no. 4, pp. 393–407, Aug. 2000, doi: 10.1006/JADO.2000.0327.

[13] D. R. Hunter, ‘Risk Perception and Risk Tolerance in Aircraft Pilots’, Sep. 2002. Accessed: Jan. 06, 2022. [Online]. Available: https://apps.dtic.mil/sti/citations/ADA407997

[14] V. J. Brown, ‘Risk Perception: It’s Personal’, *Environ Health Perspect*, vol. 122, no. 10, Oct. 2014, doi: 10.1289/ehp.122-A276.

[15] G. Wachinger, O. Renn, C. Begg, and C. Kuhlicke, ‘The Risk Perception Paradox-Implications for Governance and Communication of Natural Hazards’, *Risk Analysis*, vol. 33, no. 6, pp. 1049–1065, Jun. 2013, doi: 10.1111/j.1539-6924.2012.01942.x.

[16] J. Orasanu, U. Fischer, and J. Davison, ‘Risk perception and risk management in aviation’, *Teaming Up: Components of Safety Under High Risk*, pp. 93–116, Jan. 2017, doi: 10.4324/9781315241708-7/RISK-PERCEPTION-RISK-MANAGEMENT-AVIATION-JUDITH-ORASANU-UTE-FISCHER-JEANNIE-DAVISON.

[17] W. C. Li, L. W. Li, D. Harris, and Y. L. Hsu, ‘The application of aeronautical decision-making support systems for improving pilots’ performance in flight operations’, *Journal of Aeronautics, Astronautics and Aviation*, vol. 46, no. 2, pp. 114–123, 2014, doi: 10.6125/14-0324-789.

[18] L. Wang, S. Gao, W. Tan, and J. Zhang, 'Pilots' mental workload variation when taking a risk in a flight scenario: a study based on flight simulator experiments', *International Journal of Occupational Safety and Ergonomics*, vol. 29, no. 1, pp. 366–375, Jan. 2023, doi: 10.1080/10803548.2022.2049101.

[19] M. R. Endsley and W. M. Jones, 'Situation awareness, information dominance, and information warfare', pp. 40–41, 1997, [Online]. Available: https://www.researchgate.net/publication/235167825_Situation_Awareness_Information_Dominance_Information_Warfare

[20] L. Wang, J. Zhang, H. Sun, and Y. Ren, 'Risk cognition variables and flight exceedance behaviors of airline transport pilots', *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, vol. 10906 LNAI, pp. 725–737, 2018, doi: 10.1007/978-3-319-91122-9_57/TABLES/4.

[21] S. Sieberichs and A. Kluge, 'Influencing factors on error reporting in aviation - A scenario-based approach', *Advances in Intelligent Systems and Computing*, vol. 597, pp. 3–14, 2018, doi: 10.1007/978-3-319-60441-1_1/FIGURES/4.

[22] M. Holtom, 'FOQA - Flight Data Analysis of Aircraft for Flight Safety', *PIA Air Safety Publication*, 2007. https://www.theairlinepilots.com/forumarchive/flightsafety/foqaflightdataanalysis.php (accessed Nov. 30, 2021).

[23] Y.-H. Chang, H.-H. Yang, and Y.-J. Hsiao, 'Human risk factors associated with pilots in runway excursions', *Accid Anal Prev*, vol. 94, pp. 227–237, Sep. 2016, doi: 10.1016/j.aap.2016.06.007.

[24] ICAO, 'Doc 10004 Global Aviation Safety Plan', Montreal, 2022. Accessed: Jul. 13, 2023. [Online]. Available: https://www.icao.int/safety/GASP/Documents/10004_en.pdf

[25] G. Jarry, D. Delahaye, and E. Feron, 'Flight safety during Covid-19: A study of Charles de Gaulle airport atypical energy approaches', *Transp Res Interdiscip Perspect*, vol. 9, Mar. 2021, doi: 10.1016/j.trip.2021.100327.

[26] A. Mizzi, G. Lohmann, and G. Carim Junior, 'The Role of Self-Study in Addressing Competency Decline Among Airline Pilots During the COVID-19 Pandemic', *Human Factors: The Journal of the Human Factors and Ergonomics Society*, Jul. 2022, doi: 10.1177/00187208221113614.

[27] X. You, M. Ji, and H. Han, 'The effects of risk perception and flight experience on airline pilots' locus of control with regard to safety operation behaviors', *Accid Anal Prev*, vol. 57, pp. 131–139, Aug. 2013, doi: 10.1016/J.AAP.2013.03.036.

[28] D. Ellsberg, 'Risk, Ambiguity, and the Savage Axioms', *Q J Econ*, vol. 75, no. 4, p. 643, Nov. 1961, doi: 10.2307/1884324.

[29] W. T.-K. Chan and W.-C. Li, 'Development of effective human factors interventions for aviation safety management', *Front Public Health*, vol. 11, May 2023, doi: 10.3389/fpubh.2023.1144921.

[30] F. J. J. Morley and D. Harris, ‘Ripples in a Pond: An Open System Model of the Evolution of Safety Culture’, *International Journal of Occupational Safety and Ergonomics*, vol. 12, no. 1, pp. 3–15, Jan. 2006, doi: 10.1080/10803548.2006.11076666.

[31] J. A. Le Pine, J. A. Colquitt, and A. Erez, ‘Adaptability to changing task contexts: effects of general cognitive ability, conscientiousness, and openness to experience’, *Pers Psychol*, vol. 53, no. 3, pp. 563–593, Sep. 2000, doi: 10.1111/J.1744-6570.2000.TB00214.X.

[32] C. Macrae, ‘Making risks visible: Identifying and interpreting threats to airline flight safety’, *J Occup Organ Psychol*, vol. 82, no. 2, pp. 273–293, Jun. 2009, doi: 10.1348/096317908X314045.

[33] CGI, ‘CGI to lead the development of a cloud-based Universal Virtual Flight Data Recorder | CGI.com’, *CGI Press release*, Jun. 15, 2023. https://www.cgi.com/en/cgi-lead-development-cloud-based-universal-virtual-flight-data-recorder (accessed Jul. 06, 2023).

[34] V. J. Hodge and J. Austin, ‘A Survey of Outlier Detection Methodologies’, *Artif Intell Rev*, vol. 22, no. 2, pp. 85–126, Oct. 2004, doi: 10.1007/s10462-004-4304-y.