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History's Slowest Digital Transformation: The Long Road to Flight Data Monitoring

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Abstract

Flight data monitoring (FDM) began in the flight test community in 1939 and entered the airline industry in 1974. In the 48 years since, however, very few operators have chosen to adopt this practice, which has shown clear safety benefits where it has found acceptance. While technical issues have created some obstacles, cultural issues have proven the greatest hindrance to wider FDM adoption. These cultural issues originated in the traits associated with pilots' personalities, especially distrust of the regulators and operators who would administer flight data analysis programs (FDAP) that used FDM information. U.S. regulators have relied on voluntary adoption, rather than regulatory mandates, to increase FDM participation, emphasizing the collective benefits of FDAP outputs in increasing the safety of flight for operators using that information. Leadership by both experienced and new employees, as well as regulators and other industry stakeholders, will best serve to increase FDM participation until it becomes ubiquitous.

Keywords: flight data monitoring, flight data analysis programs, N121JM, gatekeeper

Introduction

What if aviation safety experts used accident data to determine the most common types of aviation accidents? What if those experts then isolated the largest number of those accidents into particular phases of flight? What if they then studied the events in each of those phases of flight and determined clear patterns of behaviors that led to those accidents? What if, upon receiving this information, the companies operating those aircraft had a way to know whether those behaviors occurred in their own aircraft, even if no accident had occurred? What if they could identify the specific crew members who were practicing those behaviors and counsel or retrain them before an accident occurred? The collection and analysis of flight data has made each of these steps possible.

Aviation safety research has established that accidents developed from chains of precursor events in which one might intervene (Reason, 2016) and that accidents themselves only occurred a tiny fraction of the number of times when the conditions for the accident existed (SKYbrary, 2019). Operators and regulators began to collect and analyze flight data to locate those points of effective intervention by discovering the events where an accident might have occurred but did not.

Throughout its history, aviation safety relied largely on analog inputs, whether from human memory, video records of events, or cockpit voice recorders (CVR) and flight data recorders (FDR). In each case, the inputs served a reactive, rather than an active or predictive, purpose, where investigators or other researchers used the information after an event to analyze what had happened. These authorities could then make recommendations to other members of the aviation community on how to avoid the same or similar incidents in the future. The U.S. National Transportation Safety Board (NTSB) (n.d., paragraph 2) noted in its mission statement that they “determine the probable cause of the accidents that [they] investigate and issue safety recommendations aimed at preventing future accidents. In addition, [they] conduct transportation safety research.”

These efforts, to achieve the greatest accuracy, required the most discrete data possible about a particular event, but analog devices, especially with relatively short memories, only provided generic information without context in the terminal phases of the event in question. The use of CVR information often added some context to that process, but it only relayed what the cockpit crew perceived, not the facts associated with those perceptions. In the 1960s, as operators and manufacturers began adding devices to their aircraft with the intent of monitoring the performance of various systems, a wealth of data became available within their intended fields (e.g., autopilot accuracy, engine trend and discrepancy monitoring, etc.).

In the 1970s and early 1980s, about the same time as the development of the personal computer, a few airlines began to use these data sets to monitor the safety performance of individual crews, overcoming significant cultural obstacles to do so. Operators and regulators then assembled these data into larger datasets, the analysis of which led to the discovery of trends and potential accident chains that might have developed. While the use of flight data analysis (FDA) to document the behaviors of specific crews and industry/corporate trends became normal in small pockets of the U.S. aviation industry, the rest of American aviation continued to creep toward this standard, notwithstanding significant regulatory incentives and proven safety benefits in doing so.

The primary obstacles have been cultural hostility, failure to appreciate the value of this data in aviation safety, and the perceived difficulty/cost of implementation. The implementation elements have grown steadily less burdensome, and regulators, employers, employee unions, and industry associations have discussed the benefits of FDA, but the cultural issues remained. While many have not yet reached the level of accepting the role of data in improving safety, others have advanced still further, advocating for video recording in aircraft to give crews, employers, and regulators even more feedback.

Digital and Aviation Grew Up Together

The twentieth century saw the invention of both the airplane and the computer, each a revolution in its field. Suddenly, humans could travel farther and compute faster than anyone, except Jules Verne, might have imagined in the 1870s. Not only did ENIAC, the first computer, do more computations than everyone in history had done (Computer History Museum, 2022), the first aerial circumnavigation of the globe took only 175 days in 1924 (National Park Service, 2017) when Magellan's expedition by ship had lasted 3 years between 1519 and 1522 (Cartwright, 2021). As of 2022, of course, both computing and aviation had progressed so far as to render these advances to the role of signposts, rather than the achievements that they were.

Less well known, the first FDRs emerged in 1939 at the Marignane flight test center in France (Villamizar, 2022), although Charles Lindbergh used a crude altitude recorder on his 1927 transatlantic solo flight (Janes, 2014). Using first photographic and then mechanical recording techniques, FDRs evolved from analog devices dedicated to recording flight test data (Janes, 2014; Villamizar, 2022) when aircraft grew more complicated during the advent of civilian jet airliners.

The primary purpose of FDRs had also shifted to the facilitation of investigations into aircraft accidents, with the U.S. Civil Aeronautics Board mandating their installation on newly built, larger aircraft in 1957 (Fisher, 2017). The Federal Aviation Administration (FAA), established in 1958, added a CVR requirement to the same aircraft in 1965 and made both mandatory on all commercial aircraft in 1967, covering the most recent 30 minutes of flight. The most advanced commercial FDR at the time, a "crash proof" analog device, using a metal wire as its storage medium, recorded eight instrument readings 24 times per second. In the 1990s, the technology advanced from metal wire for data and magnetic tapes for voice to solid-state media that could record hundreds of parameters and two hours of voice recordings, combining the CVR and FDR into a single combined digital cockpit voice and data recorder (CVDR). With the availability of this technology, the FAA mandated recorders that could report at least 88 different characteristics on all aircraft manufactured after August 2002, and the European Union Aviation

Safety Administration (EASA) expanded the voice recording requirement from two hours to 25 hours, effective in 2021 (Villamizar, 2022). However, the earliest mentions of big data's use in aviation safety still referred to its role in aircraft accident investigation (Low, 2019).

Beginning in the 1960s, in a parallel, but unassociated, effort, manufacturers and airlines began installing recorders on aircraft that would monitor system performance parameters and discrepancies. Fuel computers began recording engine performance; aircraft instruments began remembering exceedances of defined limitations (personal recollection[1]), and, interestingly, aircraft systems began monitoring the accuracy of instrument landing system approaches flown by the aircraft's autopilot (de Courville, 2019). Aircraft monitoring technology advanced and became more digital, as did the means of communicating that data back to the operator and manufacturer, evolving into real-time or nearly real-time monitoring of the aircraft, a phenomenon that came to public attention in the aftermath of the 2009 disappearance of Air France Flight 447 over the Atlantic Ocean (Bureau d'Enquêtes et d'Analyses, 2012).

The Environment Surrounding the Birth of Flight Data Monitoring

de Courville (2019) explained that the regulator-mandated continuous monitoring of the aircraft autopilot's accuracy during approaches into the densest fog or other low visibility phenomena created a new question. Safety advocates pondered whether they might also analyze the collected data to review less-demanding approaches or the other phases of flights, essentially monitoring crew actions and decision-making, to identify occasions that had almost been accidents. Pilots rebelled; Orwell's "Big Brother" had arrived in the cockpit.

In 2007, the Air Line Pilots Association, an international pilot's union, published a study detailing the "Pilot Personality" in a list of 24 traits. Along with the many traits that made pilots

[1] The author has flown many aircraft produced between 1959 and 1990, witnessing the different generations of these systems throughout that experience.

better at their jobs, the list included several characteristics seemingly chosen for their hostility to improving performance via FDA programs (FDAP) conducted by their employer, including:

- self-sufficient
- difficulty trusting anyone to do a job as well as themselves
- suspicious
- intelligent, but not intellectual
- short-term goal orientation and not long-term goal driven
- bimodal (black/white, on/off, good/bad, safe/unsafe)
- tend to modify the environment instead of their behavior
- do not handle failure well
- low tolerance for personal imperfection
- long memories of perceived injustices
- avoid introspection (as cited in Weiss, n.d., paragraph 3)

In essence, airlines and other operators intended to introduce employer-driven, detailed oversight of a group of intelligent, suspicious, self-sufficient individuals who would avoid introspection and deny any effort to change their habits, rather than the circumstances, regardless of the potential long-term gain in safety. Pilots and their labor unions perceived that their employers and regulators would use discrepancies in the data, judged by people with little or no flying experience, as a basis for dismissal of the offending pilot(s) (de Courville, 2019). To accommodate these cultural traits, some of the early FDRs and CVRs even had a switch with which the crew could delete the stored data upon safely reaching their destination (Villamizar, 2022), since, presumably, a safe arrival meant that there would be no accident investigation requiring that data.

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Recognizing the enormous potential safety benefit that FDA might provide, representatives from both the pilot unions and two airlines involved in the low visibility approach program, Air France and British Airways, concluded flight data monitoring (FDM) agreements in the 1970s. Air France began publishing an FDM bulletin of “the most interesting events,” but without the context that pilot input might have provided (de Courville, 2019, p. 1). Because pilots only had access to their own flight data when contacted about an error, their attitudes toward FDAP did not improve, and FDAP did not spread widely in the industry.

Relevant Elements of Safety Theory

Just Culture

Understanding the issues behind the mistrust that inhibited the growth of FDM among professionals who would benefit directly from its safety enhancements first required an understanding of just culture. James Reason discussed this concept at length.

Primarily, a just culture provided “an atmosphere of trust in which people are encouraged, even rewarded, for providing essential safety-related information” (Reason, 2016, p. 195) but also established clear definitions of acceptable and unacceptable actions. Reason (2016, p. 205) also called “a wholly just culture…an unattainable ideal,” so both management and employees would have to share a basic belief in the likelihood of a just outcome, rather than the bimodal thinking identified as a common pilot trait. When evaluating a safety-related event, therefore, the organization needed to discern the employee’s intent; their physical, mental, and emotional conditions leading up to the event; the environment in which event occurred; their competence to perform their duties; the effectiveness of their training; the applicability and suitability of the organization’s policies and procedures to the situation facing the employee; and any other factors that may have influenced the employee’s decision(s) or the event’s outcome(s).

Only then could the organization determine the acceptability or unacceptability of the employee's decisions or actions (Reason, 2016).

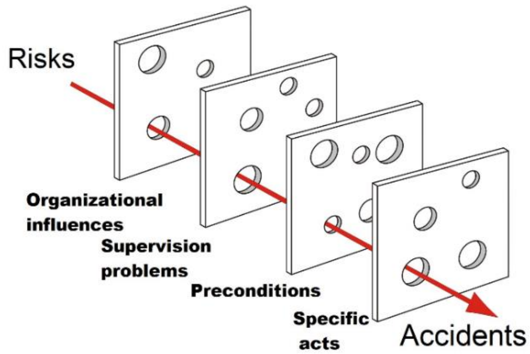
Reason (2016) also noted that, even if no safety event occurred, failures to address flaws in any of these areas also indicated a lack of justice. Organizations could no longer judge an employee or an event simply because of the outcome. If one accepted that an organization would behave in this way, then one might consider the possibility of participating in an FDM agreement with that employer.

Why Analyze and Act on Data?

Over the many decades of study into aviation and industrial accidents, at least two relevant models of accident theory have emerged, Reason's Swiss cheese model and Herbert Heinrich's accident pyramid. As depicted in Figure 1, the Swiss cheese model provided a visual diagram to demonstrate the different layers of organizational structure intended to prevent an accident. Accidents then occurred when failures in each layer aligned with no intervention to break the accident chain (Reason, 2016).

Figure 1

Reason's Swiss Cheese Model

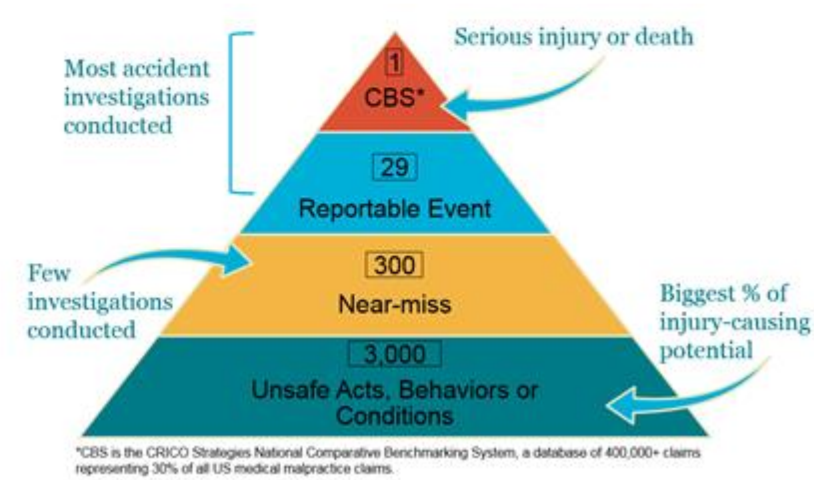


Note. Reprinted from *Leadership lessons on project management: What project sponsors can learn from Swiss cheese*, by L. Cristini et al., 2020, paragraph 4. (https://www.projectmanagement.com/blog-post/63782/Leadership-Lessons-on-Project-Management--What-Project-Sponsors-Can-Learn-from-Swiss-Cheese). Copyright 2020 by Project Management.com.

During his studies of industrial accidents in the late 1920s and early 1930s, Heinrich's data indicated that the conditions for an accident occurred approximately 300 times without harm compared to each actual accident that caused harm, as shown in Figure 2 (SKYbrary, 2019).

Figure 2

Incident Ratio Model: Adapted from Heinrich's Theory



Note. Reprinted from *Blog Post: Leveraging the largest patient safety learning engine* by M. Paskavitz, 2018, p 1. (https://www.candello.com/Candello-Blog/Leveraging-the-Largest-Patient-Safety-Learning-Engine). Copyright 2024 by The Risk Management Foundation of the Harvard Medical Institutions Incorporated, CRICO, and Affiliates.

The improved collection of flight data afforded operators and regulators the opportunity to intercede and misalign the holes in the Swiss cheese or improve detection of the 300 near-misses before an accident occurred. Not only could the FDA have alerted organizations to the existence of known risks in their operations, the FDA might also have alerted them to risks not previously recognized.

Benefits of a Flight Data Analysis Program

The European Operators Flight Data Monitoring (EOFDM) forum (2019) identified many safety benefits of an FDAP.

- elevated safety awareness

- improved standardization
- improved situational and operational awareness for the organization and the crews
- elevated transparency of safety reporting
- improved safety assurance by measuring operational compliance
- improved safety audit performance by demonstrating awareness of potential hazards, as well as effectiveness of mitigation
- Improved monitoring of safety performance indicators
- Improved management of change by determining whether employees had implemented the changes effectively, as well as by detecting unintended negative consequences

Other sources indicated FDA's positive effect on an organization's efficiency, especially in the areas of fuel consumption, training, maintenance, and demonstrated regulatory compliance (SKYbrary, 2022).

Components of an Effective Flight Data Analysis Program

Flight Data Monitoring Agreement

After a clear explanation of an FDAP's benefits, the next step in dealing with the obvious cultural obstacle to program acceptance became the FDM agreement between the company and the employees whose performance it monitored. As in the first of these agreements, between Air France and its pilot union in 1974 (de Courville, 2019), adherence to these agreements formed the foundation of trust between these normally adversarial groups.

EASA (2016) regulations required that agreement to include the FDAP's goals, the protections afforded to the data collected in the FDAP, the individuals (defined by position) who could access the data and for what purpose, the individuals (defined by position) who could access the identifying information associated with that data, the means of obtaining feedback from crew members involved in noteworthy events, various elements associated with data security and retention, the process for reviewing the data and publishing information based on the data, the manner of counseling or retraining crew members based on the FDA, and the conditions under which the crew's gross negligence or a significant continuing safety concern might prompt the removal of confidentiality.[2]

Flight Data Analysis Equipment

A successful FDAP included specialized equipment at several levels of the organization. While operators could download data from CVDRs, the industry developed a new technology referred to as the quick access recorder (QAR). A solid-state memory device without the crash-resistance of a CVDR, the QAR provided rapid and simple downloads of many flights worth of data collected on more than 2,000 parameters at higher sample rates. After downloading the data on an established schedule that did not interfere with flight or maintenance operations, the organization also needed a software application to render that data into a readable form for analysis, which the FAA (2004) called a ground data replay and analysis system (GDRAS). The GDRAS allowed for the definition of parameters of interest, the comparison of the data within the download to threshold values for those parameters, and the output of reports based on that information.

Flight Data Analysis Organization

Each participating operator or regulator required an FDAP monitoring team, comprising members of the pilot group, the safety team, and the organization. Under the guidance of a management level steering committee, the monitoring team then established the specific

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[2] Please see Appendix B for the full text of the applicable EASA regulation.

procedures for the FDA, including definition of the parameters of interest and suitable threshold values for those parameters. The monitoring team would determine those parameters and thresholds by using existing safety data, operations and flight manuals, standard operating procedures, and regulatory requirements. Upon receiving the flight and event data reports, the monitoring team could then identify areas of concern, recommend corrective actions, and monitor the effectiveness of those actions (FAA, 2004).

Among the members of the monitoring team, the gatekeeper performed the most critical role to the credibility of FDAP. Normally a member of the pilot group, the gatekeeper, maintained data security and served as the only person who could link the data to an individual flight or crew. The gatekeeper could then provide context for a noted data point by interviewing the crew if the monitoring team sought that information (FAA, 2004).

Regulator Participation

As recommended by the International Civil Aviation Organization (ICAO) (2021), a successful FDAP involved the operator, its employees, and the regulator. State regulators understood that a national scale FDAP would have a multiplicative effect on FDA's safety benefit, as it would agglomerate data from numerous operators and provide otherwise unavailable information on a broad scale about hazards and their associated risks. The regulator, in order to receive data from an operator's FDAP, needed to comply with the same elements mandated by the FDM agreement, specifically that the regulator could not use information gained through the FDAP to punish the operator or the crew(s). The FAA outlined these protections in 14 C.F.R. § 13.401.e (2002), in that "except for criminal or deliberate acts, the Administrator will not use an operator's [Flight Operational Quality Assurance (FOQA)] data or aggregate FOQA data in an enforcement action against that operator or its employees" if the operator were a participant in an FAA-approved FOQA program.

In 2008, the FAA (2019) also established the Aviation Safety Information Analysis and Sharing (ASIAS) program to receive and analyze data from voluntary sources, including FOQA and numerous others, accepting both digital and analog inputs. As participation increased and the number of submissions grew, ASIAS bore more resemblance to a "big data" resource that would benefit many areas of the aviation industry.

The investigation into the 2014 destruction of a Gulfstream IV at Bedford MA demonstrated the potential benefits of participation in such programs. After an FDR review showed that the crew had skipped the flight control check in their checklist, which appeared to have been a critical factor in the accident sequence, NTSB investigators reviewed the information on the aircraft's QAR that contained data going back 175 flights. They discovered that the crew had only accomplished this critical item on 2% of those flights. The operator did not have an FDAP, so the operator had not read or analyzed the data on the QAR. In its review of the investigation, the Board members then requested that the National Business Aviation Association (NBAA) study existing FDM databases to determine the prevalence of missed flight control checks in business aircraft operations (NTSB, 2015).

The resulting NBAA (2016) study of applicable FOQA data indicated that, between January 2013 and December 2015, crews accomplished only a partial flight control check on 15.62% of flights and failed to accomplish any form of flight control check on 2.09% of flights, the opposite of the accident crew's QAR data. The NBAA study also showed that compliance improved in the immediate aftermath of the FAA-mandated special emphasis training on the

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importance of flight control checks, the regulator's immediate response to the initial findings of the investigation (Ott, 2021).

Participation by Smaller Operations

While large U.S. airlines operating under 14 C.F.R. § 121 (Part 121) were well known, few were aware that 1,840 companies held certificates as 14 C.F.R. § 135 (Part 135) charter operators, flying almost 11,470 aircraft. Of those Part 135 companies, 54% operated only one or two aircraft and 89% operated 10 or fewer aircraft (FAA, 2022c). Corporate flight departments and private owners, operating aircraft of equal or greater complexity, also existed in units, as a rule, of five or fewer aircraft. FDAP design, in and of itself, did not account for these smaller organizations that operated so few aircraft. Without a large staff or complex IT infrastructure, and not generating a critical mass of data, such small operators could not manage or benefit from an independent FDAP.

Solutions, however, have arisen from both commercial and regulatory organizations, including companies and not-for-profit groups, according to a quick internet search. As a rule, these organizations provided the analytic backbone of an operator's FDAP, both by serving to accumulate data from multiple operators to improve analytic validity and by providing the GDRAS functionality necessary to accomplish that analysis. Moreover, most offered to serve as a conduit for the submission of operator data into larger, regulator-maintained databases, affording those smaller operators the benefits of that participation.

Flight Data Analysis Program Adoption

ASIAS data (2022; see Appendix C) indicated that 47 Part 121 (or their non-U.S. equivalent) air carriers participated in the program as of October 31, 2022.[3] The same document

[3] As of March 2022, the FAA (2022a) indicated that 99 companies held Part 121 air carrier certificates.

indicated that more than "150 General Aviation and On-Demand Part 135 Air Carriers" also participated. Of the 81 operators listed in that group (72 chose to remain anonymous), only 34 were Part 135 operators, a participation rate of 2%. In fact, one company, operating under two Part 135 certificates, constituted 36% of the Part 135 fleet used by these 34 operators (FAA, 2022c). There were no statistics available to describe the number of general aviation operators, a category that included, among others, corporate aviation, personal business aircraft operation, and private aircraft ownership. However, the estimated 210,024 aircraft registered in the U.S. in 2020, of which only 5,884 were Part 121 and 11,400 were Part 135 (FAA, 2022c; Salas, 2022), suggested that this category was more than 10 times larger than the combined airline and charter industry, especially when one considered that most general aviation operators did not have large fleets of aircraft. ASIAS data also indicated that, among business aircraft, generally Part 135 aircraft and general aviation aircraft used for business purposes, fewer than 10% provided data to ASIAS (J. Mittelman, personal communication, November 30, 2022).

Moreover, turbine powered (i.e., jet and turbo-propeller) business airplane manufacturers only offered FDM capability as standard equipment on 6% of their 35 models of new aircraft, as shown in Figure 3 (J. Hennig, personal communication, December 2, 2022; NTSB, 2022).

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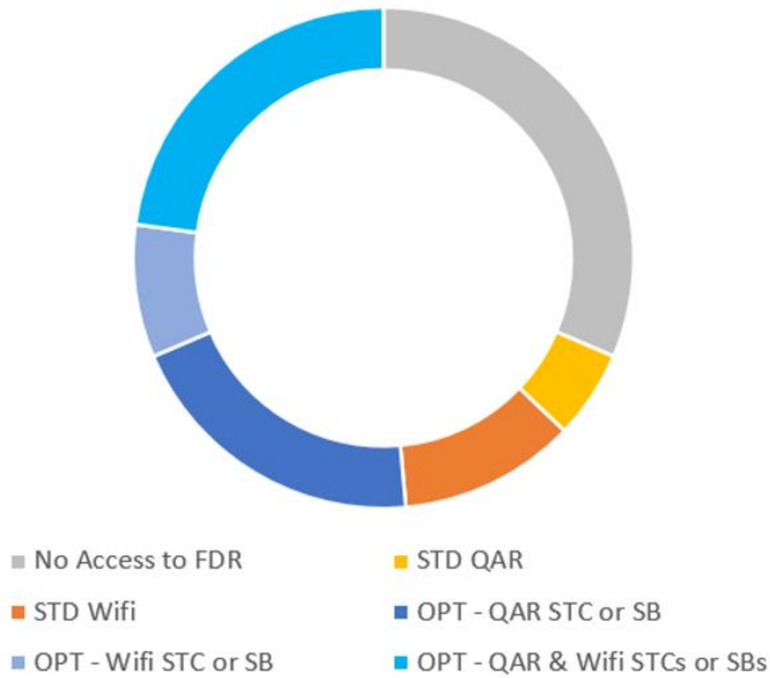
Figure 3

General Aviation Manufacturers Association (GAMA) Survey of Flight Monitoring Capability on Turbine Airplanes in Production as of October 2022



Note: FDR – Flight Data Recorder, STD – Standard Equipment, OPT – Optional Equipment, STC – Supplemental Type Certificate, SB – Service Bulletin; STC and SB indicated that the FAA had approved a means of installing FDM equipment aboard one or more aircraft models.

Analysis and Recommendations

Given the well-defined benefits of FDAP participation, the inadmissibility of its contents as evidence in regulatory actions, except in certain extreme cases, and its 48-year history of success, the limited use of FDAP by U.S. operators seemed inexplicable. According to FDM experts, operators' distrust of regulators, employees' distrust of employers and regulators, the cost of participation in both time and affordability, and the complexity, unavailability, and/or unsuitability of FDM equipment for many aircraft explained why many operators did not participate (J. Mittelman, personal communication, December 4, 2022).

While ICAO and aviation regulators like FAA and EASA have made significant efforts to break down these barriers, they have not overcome such well-established rationalizations and factual issues with FDM acceptance. Unfortunately, they could not have altered the “long memories of perceived injustices” cited by Weiss (n.d., paragraph 3.20) that reside within the older generations of the existing pilot population, whether those pilots were the victims of actual injustices or simply the receivers of lore passed down from earlier generations. Another factor in the generational issues was that the management teams at aviation organizations, both corporate and labor, also belonged to older generations that ascribed to more adversarial attitudes between employees/unions and corporations, as well as their regulators.

Moreover, lightweight, affordable FDM equipment with independent power supplies only recently began entering the market (Mittelman, personal communication, December 4, 2022), so some of the technical arguments have not had time to recede. These developments would likely have the greatest effect in the helicopter community, which suffered both a relatively high accident rate and greater weight sensitivity due to payload limitations (Helicopter Association International Safety Working Group, personal communications, 2019-2023).

How could the proponents of FDAP overcome these perceived cultural and technical issues to increase operator participation and, thereby, increase the dataset in ways that would benefit the greater aviation industry?

First, it was necessary to accept that, both in terms of perception and technical issues, certain insurmountable obstacles existed. Some companies and individuals would never trust their regulators and/or employers. Some operators/aircraft owners believed that they could not afford the cost of either FDAP participation or the cost of adding FDM equipment to their aircraft. They also believed that some aircraft were either too old, too weight- or space-constrained, and so on for the reasonable accommodation of existing or yet to be developed FDM systems, or so rare in design or sheer numbers that the FDM system manufacturers could not justify the expense of developing systems for so few installations.

Second, history has forced us to stipulate that money and time dedicated to research and development could overcome the remaining technical issues for almost all aircraft, especially newer models with relatively standard electrical configurations or as previously limited only by size and/or weight, where Moore's Law[4] would prevail.

Having set aside the technical issues, only the cultural issues remained, and recent history has provided two models for overcoming entrenched attitudes toward new developments in the world of aviation safety – public advocacy, assisted by financial incentives and generational change, and regulatory mandate.

Regulatory Mandate

The imposition of a regulatory mandate appeared simple from an outside perspective and required little in the way of leadership. The regulatory agency simply enacted a rule to require something of obvious safety benefit. Many safety developments (e.g., seat belts, FDRs, CVRs, etc.) became standard through this methodology.

As a recent example, the FAA mandated the adoption of safety management systems (SMS) by Part 121 air carriers in 2015 (Safety Management Systems, 2015). The issues with this

[4] Intel co-founder and former CEO Gordon Moore postulated that "the number of transistors on a microchip doubles every two years," and the cost of the associated computers will decrease over the same period (Tardi, 2022, paragraph 1).

new requirement arose quickly. First, the regulation created a broad mandate that required significant expense, adding numerous personnel for development, implementation, and operation of the SMS, exceeding the capability and capacity of smaller air carriers. Second, the regulation did not conform with the ICAO Annex 19 standard (ICAO, 2016) or Doc 9859 guidance for SMS (ICAO, 2018), which created issues for operators already in compliance with ICAO standards. Third, the FAA did not have enough capacity to handle the new mandate (i.e., enough inspectors sufficiently trained to provide effective SMS auditing for the limited number of Part 121 operators; Ott et al., 2022).

To date, the FAA has avoided mandating FOQA, choosing instead to encourage participation both through FOQA's safety benefits and the incentive of protecting the information in the data from outside publication or enforcement action. The lack of a FOQA mandate rendered possible ICAO conflicts moot, but the first and third issues remained, especially the question of regulatory capacity, which would have to include managing the sheer bulk of data generated by all of the operators (J. Mittelman, personal communication, December 2, 2022). Further, some experts attributed the industry's improving safety record to the shift from mandatory safety initiatives to the maturing Voluntary Safety Programs provided by the FAA (Logan, 2012).

A regulatory mandate seemed an ineffective tool in creating the effective, safety-oriented growth of FDAP.

Augmented Public Advocacy

Experts have long lamented the slow, uneven progress of cultural change. Reason (2016) even said that anyone who considered that they had an effective safety culture was almost certainly incorrect. Unlike a sudden regulatory mandate, cultural change was often the work of generational change, as witnessed in so many areas of digital transformation and social media. Cultural change in these arenas resembled erosion more than explosion. FDAP functioned as an important step in a digital transformation of aviation safety that, like other modernizations, required leadership to succeed.

The low rates of FDAP adoption in the U.S. indicated that, with the exception of a few industry leaders who found that the benefits of FDAP outweighed the potential negatives, most of that leadership would have to come from the younger generations in aviation, individuals who have come into their professional lives more comfortable with both digital technologies and sharing their experiences with a wider audience via social media (Indeed Career Coaches, 2022). While pilots in these younger generations have had the same general traits ALPA reported (Weiss, n.d.), they have also had these generational advantages to moderate the effects of those traits that were incompatible with FDAP adoption. As noted in Figure 4, at least 15 large training providers (i.e., flight schools, university flight departments, and 14 C.F.R. § 142 training centers) were participating in ASIAS (2022), further accelerating this process by making FDM a normal part of flying for many students and their instructors.

All three groups, the regulators, the operators, and the employees, have generally complied with the tenets of FDM agreements. The long-held perceptions that miscreant regulators or operators would use the data against companies and employees, respectively, or that rogue employees would use the shelter of regulatory protection to behave badly, has proven untrue, with only a few extreme exceptions (Logan, 2012). The perceptions of such inequities, however, remained the province of pilots whom ALPA recognized as having “long memories of perceived injustices” (Weiss, n.d., paragraph 3.20).

Other incentives have also helped. Aviation insurers have recognized operators' FOQA participation as beneficial both to safety and to loss prevention, which often had the effect of a net reduction in the cost to insure a participating operator, notwithstanding the other factors that go into such determinations. Also, industry experts, investigative agencies, and regulators have appeared at numerous conferences to advocate on behalf of FDAP. Like the insurers' incentives, these educational efforts have contributed to the gradual acceptance of FDAP among those members of the industry in crossover generations.

The offer of protected participation or anonymity in ASIAS, as well as the regulatory protection of FOQA data, have also offered incentives to an operator who might have feared that FDAP participation would have created a large pool of material for the use of plaintiffs' attorneys in legal proceedings against the operator. In fact, the proven value of FDAP participation might have resulted in a reduction in potential liability for those enrolled operators, as other advanced safety programs have demonstrated (J. Mittelman, personal communication, December 4, 2022).

The polled manufacturers in the GAMA survey cited in Figure 3 also indicated that many of the 31% of aircraft with "No access" to FDM were models just finishing their production runs. They stated that the successor models would have FDM available or installed (J. Hennig, personal communication, December 2, 2022). The ease of access on the new models would also reduce one of the obstacles to FDAP participation by many operators.

Another factor has come into play that would further reduce opposition to FDAP in that mandatory Automatic Dependent Surveillance – Broadcast (ADS-B) systems (ADS-B Out equipment and use, 2010; ADS-B Out equipment performance requirements, 2010; FAA, 2022b) on many aircraft "report detailed information about an aircraft's identification, position, altitude, and velocity to other aircraft and ATC" (Textron Aviation, 2022). The ready availability of this information to regulators and anyone using a flight tracking website would help desensitize pilots and operators to the sharing of flight data (Norman, 2021).

While painful, incomplete, and uneven, augmented public advocacy seemed likely to produce the best outcomes for the adoption and acceptance of FDAP.

Summary

Despite their long history and obvious positive outcomes, FDAPs remain a digital transformation in progress, yet to become normal within the aviation industry, advancing only slowly for 50 years. Like any other digital transformation or cultural change, persuading operators and pilots to share data for their benefit and for the benefit of the industry has required leadership, education, and generational change to continue spreading in the industry. Flight training providers, especially the 15 already participating in ASIAS, will form the foundation of this change, which will grow even greater as more training providers develop FDAPs. When former students and staff of these programs advance in their careers, they will note and discuss the absence of FDAP at their new organizations, and where applicable, act as young advocates for FDM.

Expanding these efforts through the work of leaders, both young and old, especially as more case studies arise that support the effectiveness of FDA in the reduction of accidents, provides the best means of improving the rate of FDAP adoption. As with any such tool, regulators, operators, and safety professionals must exercise care to use examples where FDA has made a positive difference whenever possible, rather than using exceptions in the data just to tell crews that they have made more mistakes (i.e., solely for negative reinforcement). As with most transformations, caring, enthusiastic, and engaged leaders who emphasize FDM's demonstrated and potential benefits will advance the case far more effectively.

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Appendix A

Glossary of Abbreviations

ADS-B	Automatic Dependent Surveillance – Broadcast
ASIAS	Aviation Safety Information Analysis and Sharing program
ATC	Air Traffic Control
C.F.R.	Code of Federal Regulations
CVDR	Combined Digital Cockpit Voice and Data Recorder
CVR	Cockpit Voice Recorder
EASA	European Union Aviation Safety Agency
EOFDM	European Operators Flight Data Monitoring forum
FAA	Federal Aviation Administration
FDA	Flight Data Analysis
FDAP	Flight Data Analysis Program
FDM	Flight Data Monitoring
FDR	Flight Data Recorder
GAMA	General Aviation Manufacturers Association
GDRAS	Ground Data Replay and Analysis System
ICAO	International Civil Aviation Organization
ISASI	International Society of Air Safety Investigators
NBAA	National Business Aviation Association
NTSB	National Transportation Safety Board
OPT	Optional equipment
Part 121	14 C.F.R. § 121 Operating Requirements: Domestic, Flag, and Supplemental Operations
Part 135	14 C.F.R. § 135 Operating Requirements: Commuter and on Demand Operations and Rules Governing Persons on Board Such Aircraft
QAR	Quick Access Recorder
SB	Service Bulletin
STC	Supplemental Type Certificate
STD	Standard equipment

Appendix B

Applicable EASA Flight Data Monitoring Regulation

Part-ORO – Subpart AOC – AMC1 ORO.AOC.130 Flight data monitoring – aeroplanes

k. The procedure to prevent disclosure of crew identity should be written in a document, which should be signed by all parties (airline management, flight crew member representatives nominated either by the union or the flight crew themselves). This procedure should, as a minimum, define:

1. the aim of the FDM programme;
2. a data access and security policy that should restrict access to information to specifically authorised persons identified by their position;
3. the method to obtain de-identified crew feedback on those occasions that require specific flight follow-up for contextual information; where such crew contact is required the authorised person(s) need not necessarily be the programme manager or safety manager, but could be a third party (broker) mutually acceptable to unions or staff and management;
4. the data retention policy and accountability including the measures taken to ensure the security of the data;
5. the conditions under which advisory briefing or remedial training should take place; this should always be carried out in a constructive and non-punitive manner;
6. the conditions under which the confidentiality may be withdrawn for reasons of gross negligence or significant continuing safety concern;
7. the participation of flight crew member representative(s) in the assessment of the data, the action and review process and the consideration of recommendations; and
8. the policy for publishing the findings resulting from FDM. (EASA, 2016)

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Appendix C

U.S. FDAP Participants (ASIAS Program Only)

Figure 4
ASIAS Stakeholders as of October 31, 2022 (ASIAS, 2022)