Off the Accident Site and Into the Hangar:
Incident Investigation Using Structural Health Monitoring

Submission for the 2018 ISASI Rudolf Kapustin Memorial Scholarship
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13 April 2018

Improvements in aviation safety arise mainly from two places: pre-accident and post-accident. Post-accident, the air safety investigation, examines the sequence of events that led to an accident. The recommendations that emerge are invaluable to aviation safety. Pre-accident, namely regulators, operators, maintenance, and manufacturers, strives to improve how to detect and repair flaws. The procedures developed keep aircraft airworthy and safer for longer.

Thanks to decades of improvements in both areas, commercial aviation accidents and incidents have decreased steadily. This begs the question: what comes next for air safety investigation? Incidents still occur daily, but there is usually little investigation into their circumstances. Yet these incidents present an opportunity to investigate why they happen, why they did not develop into an accident, and what could be done in the future to prevent them. In the case of non-accident structural faults, a promising technology emerging from the pre-accident realm, continuous structural health monitoring (SHM), could assist in preventing future occurrences.

SHM – The New Big Data

The declining number of commercial aviation accidents and incidents lends itself not only to air safety investigations, but also to developments in ensuring continued airworthiness during an aircraft's lifetime. The aviation industry has come a long way from the days of safe life and fail safe maintenance philosophies, an era which generally neglected in-service ageing effects, and contributed to a number of accidents, such as those involving the De Havilland Comet[1]. In 1988, following Aloha Airlines Flight 243, there was a shift towards modern, damage-tolerant maintenance procedures[2]. Current methods revolve around the non-destructive inspection (NDI) of structures at specified intervals[13]. The future of aviation will see the utilization of big data to further our knowledge and propel the industry forward, evidenced by the theme of the American Institute of Aeronautics and Astronautics (AIAA) SciTech Forum

in January 2018, "Seizing the Next Digital Transformation"[14]. This future will unquestionably include the integration of continuous SHM into aircraft.

The rapid development of SHM is a key research area for aviation safety, and provides numerous benefits. From a damage perspective, it can offer early detection of small cracks and flaws, pinpointing of damage initiation sites, and eventually multiple-site damage detection and monitoring[3]. Not only is damage detection possible, but also the collecting of information regarding loads and the operating environment[4]. Combined with flight data, a more representative picture of an aircraft's lifetime can be established. Over this lifetime, this information has the potential to assist in establishing patterns and connecting the dots.

Already, advancements in SHM have shown promising results. In 2009, Airbus outfitted an A380 with surface-bonded and sandwiched SHM sensors for conducting full-scale fatigue tests[3]. Extensive academic research into sensing systems, including Acoustic-Ultrasonics, Fiber Bragg Grating, and Comparative Vacuum Monitoring (CVM) continues to push the field forward[4,5]. In 2017, a pilot program involving Boeing, Delta Air Lines, and Sandia National Labs began in-service validation of CVM[6]. In conjunction, the Federal Aviation Administration (FAA) began conducting a study into the development and implementation of SHM certification[6]. Future research will undoubtedly see the refinement of these systems, and their eventual use in daily operations. Neglecting this development would be a missed opportunity for air safety investigations.

The Changing Face of Air Safety Investigations

Air safety investigation is not a static field. Every incident and accident presents new challenges, and more knowledge is gained on how to improve investigations. More comprehensive investigations, better recommendations, increased collaboration between involved parties[7]. These changes have been critical to the decline of commercial aviation fatalities in recent years. However, the focus of air safety investigations has historically centered on post-accident analysis. This reveals the paradox of air safety investigation: investigations improve, aviation safety improves, therefore fewer accident investigations are necessary. With no signs of this trend stopping, how can air safety investigations continue to contribute positively to aviation safety? In short, the post-accident analysis model as a standalone is unsustainable and demands a shift in focus.

Nothing ever occurs in isolation. A major accident is hardly ever a single component failure or crew oversight, but rather the disastrous combination of multiple factors. In a post-accident investigation, it may be virtually impossible to determine every contributing factor. Given only the information from an accident site, flight recorder data, various records, and witness statements, the investigation seeks out probable cause and makes recommendations, highlighting the most safety-critical factors. Changes arising from investigations help to prevent the accident with a similar chain of events, but not the one with a different failure path. This is where taking a proactive approach is critical, by looking at incidents, and collecting and analyzing relevant data over long periods of time.

Aviation incidents, non-accident events which affect the safety of operations[7], still occur on a daily basis. These incidents are reported, but unless they fall under the category of "serious incident", they are very rarely given a second look. Even reporting agencies give little attention to incidents. It is not difficult to find information about the number of accidents and fatalities in commercial aviation. Incident statistics are not so easily obtainable. But planes do not fly in a vacuum. An incident could easily become an accident under the right circumstances. Therefore, it is critical to understand why these incidents occur, why they did not become accidents, and subsequently recommend changes. Some organizations have already begun this process, for instance the Australian Transport Safety Bureau (ATSB), which developed the Systemic Integrated Analysis Model (SIAM)[8], and the FAA, which collects and analyzes information with the Aviation Safety Information Analysis and Sharing (ASIAS) system[9].

The Future Air Safety Team (FAST), a collaborative group of various aviation professionals, works to establish Areas of Change (AoC) within the aviation industry[10]. One such AoC identifies, "Increased need to monitor incident and accident precursor trends," pointing to the development of programs such as ASIAS. They caution, however, that while these systems can help build knowledge about what happened, identification of why things happened may be more difficult[11]. Knowing "why" could be the difference between an incident and an accident. This requires the acquisition of data and information that can help identify "why".

SHM and Air Safety Investigations: A Way Forward

In the not-so-distant future, commercial aircraft will be host to thousands of onboard sensors, providing detailed information about the state of the airframe, engines, hydraulic systems, and observed loads. Though the focus has remained squarely on the impact for maintenance and operations, safety boards should be equally invested in SHM's development.

The future of air safety investigation will see safety boards taking on a more proactive role in aviation safety in the absence of accident data points. Without this change, a vital component of aviation safety will be lost. ASIAS and SIAM are already leading the way, providing a framework for establishing trends and finding links between various incidents. And while general trends can already be established, continuous SHM data can provide a more in-depth view of the exact state of an aircraft up to and during an incident. This will help fill in the gaps, and from here air safety investigators can establish patterns, searching for both commonalties and abnormalities.

Parallel to incident investigation, the incorporation of long-term SHM data analysis into air safety investigations provides a unique opportunity to study the health of composite structures over their lifetime. Though composite materials are now being increasingly used in aviation, there is still uncertainty about their behavior after several years in service[12]. SHM integration could offer insight information about the continued airworthiness of composite-based aircraft and recognize trends that could potentially be disastrous in the future.

Despite these immense benefits, this combination is not without its potential pitfalls. An influx of data, particularly quantitative data, can be a comforting presence. However, it will be critical to exercise caution and not rely exclusively on analytical systems. A good investigation begins with good investigators. Additionally, a new collaboration between aviation safety specialists, SHM experts, and big data analysts must be established. With this, it will be critical for all parties to understand the issues and limitations of each other's fields. It will also be important to acknowledge that, while a vast amount of information will be available, monitoring every square millimeter of structure is virtually impossible. This links with an overreliance on data sans a human presence. Continuous SHM data will provide another set of data points, some helpful, some not. It is the job of investigators to take this information and use it as one of many tools, rather than a silver bullet.

Conclusion

Though the full integration of continuous SHM into commercial aviation is still several years away, that does not mean safety boards should be standby. To be able to take full advantage of SHM in air safety investigations, a platform must be ready. This will mean strengthening existing programs by ensuring they are prepared to handle this type of data, stimulating the development of incident investigation programs, and working to further this collaboration not only amongst safety boards, but also with regulators, operators, and data specialists.

The declining number of major commercial aviation accidents presents the field of air safety investigation an incredible opportunity. One could choose to continue as normal, or to consider what will be important in the future. The future of air safety investigation will depend on investigating non-accident events and monitoring trends in order to continue contributing positively to aviation safety. To do this, SHM must be an integral part of that future.

References

1: Federal Aviation Administration. “Accident Overview.” *Lessons Learned*, lessonslearned.faa.gov/ll_main.cfm?TabID=1&LLID=28&LLTypeID=2.

2: *Aloha Airlines, Flight 243 Boeing 737-200, N73711, near Maui, Hawaii April 28, 1988*. National Transportation Safety Board, 1989.

3: Paget, Christophe, et al. “Validation of SHM Sensors in Airbus A380 Full-Scale Fatigue Test.” *Wiley Online Library*, 15 Sept. 2009.

4: Speckmann, H. “Structural Health Monitoring (SHM).” 2007, PowerPoint file. www.easa.europa.eu/sites/default/files/dfu/IMRBPB%20IMRBPB%20April%2008%20presentation.pdf.

5: Stehmeier, H. & Speckmann, H. (2018). *Comparative Vacuum Monitoring (CVM) Monitoring of fatigue cracking in aircraft structures.*

6: Swindell, Paul, et al. “Integration of Structural Health Monitoring Solutions onto Commercial Aircraft via the Federal Aviation Administration Structural Health Monitoring Research Program.” 2017, doi:10.1063/1.4974616.

7: *Annex 13 to the Convention on International Civil Aviation: Aircraft Accident and Incident Investigation*. ICAO, 2001.

8: Lee, R. (2001). *New Directions in Air Safety.* www.iasa.com.au/folders/Publications/pdf_library/newdir.pdf.

9: Hueto, G. “ASIAS Overview.” 2013, PowerPoint file. www.icao.int/APAC/Meetings/2013_APRAST3/ASIAS%20brief%20GH%2005%202013.pdf.

10: “FAST.” *FAST Overview*, NLR Safety Institute, 2017, www.nlr-atsi.nl/fast/overview/index.html.

11: “FAST.” *FAST AoC_138*, NLR Safety Institute, 2017, www.nlr-atsi.nl/fast/aoc/aoc_138.html.

12: Office, U.S. Government Accountability. *Aviation Safety: Status of FAA's Actions to Oversee the Safety of Composite Airplanes*. U.S. Government Accountability Office (U.S. GAO), 20 Oct. 2011, gao.gov/products/GAO-11-849.

13: *ATA MSG-3*. Air Transport Association of America, 2002.

14: “SciTech 2018 Archive.” *SciTech 2018 Archive: The American Institute of Aeronautics and Astronautics*, scitech.aiaa.org/2018archives/.