Transformational Phenomena as Predictors of Aircraft Accidents: What Goes Around Comes Around

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Abstract

The Future Aviation Safety Team (FAST) is a multidisciplinary international group of aviation professionals that was established to identify possible future aviation safety hazards. The principle was adopted that future hazards are undesirable consequences of changes, and a primary activity of FAST became identification and prioritization of possible future changes affecting aviation. In 2004, the team finalized a list of 'Areas of Change' (AoC), presenting nearly 150 specific changes that could potentially influence aviation safety. To verify if the AoCs identified in 2004 have indeed become relevant for aviation safety, the FAST analysed worldwide fatal accidents that occurred between 2004 and 2014. The results of the analysis demonstrate that changes catalogued many years previous were directly implicated in the majority of fatal aviation accidents over the past ten years.

Keywords: aviation safety, prognostics.

1. Backgroud

In the 1990s, the Joint Aviation Authorities, Europe (JAA) and the Federal Aviation Administration, USA (FAA) sponsored a number of groups to develop interventions aimed at improving safety of the global aviation system. To further this effort, in early 1998 the JAA launched the JAA Safety Strategy Initiative JSSI (JSSI, 2000). The JSSI mission was the continuous improvement of aviation safety in Europe in particular and worldwide in general, leading to further reductions in the annual number of aviation accidents and thus fatalities, irrespective of the fact that air traffic will continue to grow. Safety improvements are first achieved through identification of causal factors, or hazards, and then taking the necessary steps to eliminate, avoid, or mitigate these hazards. Hazards are defined as events and/or conditions that may lead to a dangerous situation or events and/or conditions that may delay or impede the resolution of such situations. Three complementary approaches are currently used to identify hazards that affect safety of the global aviation system:

- The "Historic" approach is based on accident and incident investigation and analysis. It uses proven investigative techniques to discover all facts pertinent to a past aviation incident or accident, and thus identify opportunities for improvements meant to avoid future, similar accidents.

- The "Diagnostic" approach is targeted at identifying accident pre-cursors within the larger collections of information in various aviation safety reporting systems. There are many diagnostic processes in use within the global aviation system.

- A "Prognostic" or "Predictive" approach is aimed at discovering future hazards that could result as a consequence of future changes inside or outside the global aviation system and then initiating mitigating action before the hazard is introduced.

In 1999, the JSSI Steering Group established a dedicated working group to develop and implement methods and processes to support the systematic identification of these latter future hazards. That group was called the Future Aviation Safety Team (FAST) and continues to operate today. The FAST core team includes about ten aviation professionals with various backgrounds and expertise from Europe, the U.S. and Canada. Over the years of its existence, the composition of the FAST has changed but several members (including the authors) have been part of FAST since the beginning. In 2004, Bob Kelly-Wickemeyer, Chief Engineer, Safety & Certification, Performance & Propulsion (Boeing retired) credited the FAST with the originating the forensic-diagnostic-prognostic safety triad described above (Kelley-Wickemeyer, 2004). This paradigm has since been embraced by the International Civil Aviation Organization (ICAO, 2013).

2. Areas of change

At the start of FAST, the principle was adopted that future hazards are undesirable consequences of future changes, and the primary objective of FAST became identification and prioritization of possible futures. The team finalized a list of 'Areas of Change' (AoC), presenting nearly 150 specific changes that could potentially influence aviation safety (JSSI, 2000). In this context, changes must be understood as broadly as possible. An AoC is a description of the change, not an identification of the hazards that result from the change. AoCs were subsequently prioritized on numerous criteria, i.e., nature and scope of the change, any trends or profiles present or anticipated timing of the considered change and interactions with other areas.. Prioritization was done using the AHP process (Saaty, 2006) in a series of workshops with approximately 90 aviation professionals. The AoC that came out of this process as the future change with the highest priority was ‘Reliance on automation supporting a complex air transportation system’ (FAST, 2001).

The FAST AoC list is re-audited on a regular basis by the FAST core team. In addition, the FAST core team continuously monitors the aviation system and the external environment for new AoCs that may arise – so-called “horizon scanning.” The FAST AoC list is publicly available on a website hosted by the Netherlands Aerospace Centre NLR (http://www.nlr-atsi.nl/fast/aoc/) and currently includes 120 AoCs.

Transformations affecting the future aviation system come in two distinct categories.

- Progressive or rapid-onset physical, functional, and procedural changes that stakeholders plan for the aviation system with the deliberate intention of improving throughput, safety and/or efficiency/economics.

- Unintentional technological innovation, shifting operational tasks, subtle changes in organizations or actors in the system, and contextual factors external to aviation itself that can nonetheless influence the robustness of the support systems upon which operational safety depends.

Areas of Change are not strictly limited to the future. They may have begun in the past and actually cease at some point in the future. They also may have begun now and continue into the future, or be not yet in place but begin at some near, mid- or far-term timeframe.

Changes affecting future aviation safety can come from either within the system or from events and circumstances outside aviation – the contextual environment in which aviation operates. Therefore, aviation stakeholders know some transformations, but not others. Those not recognized within the aviation community may nevertheless be known to organizations outside aviation.

Areas of Change are not hazards per se, but may when combined with other technologies, operational concepts or related AoCs be the catalysts for new hazards or modify the probability or severity associated with existing hazards.

3. Verification of Areas of Change relevance

To verify if the AoCs identified in 2004 have indeed become relevant for aviation safety, the FAST analysed worldwide fatal accidents that occurred between 2004 and 2014. The Aviation Safety Network database (https://aviation-safety.net/database/) was used as the initial source of accident information. All fatal accidents involving commercial operations with fixed wing aircraft with a maximum take-off weight heavier than 5,700 kg were included in the analysis. Military, ferry/positioning, air ambulance and agricultural operations were excluded. For each accident, the team determined it if one or more AoCs (with a maximum of three) could be associated with the occurrence. An association does not necessarily mean that the change caused or contributed to the accident. It merely indicates that the AoC was relevant in the sequence of events that ended-up as an aircraft accident. In addition to the Aviation

Safety Network, the team consulted public and non-public sources such as aircraft accident investigation reports, articles in professional magazines (Flight, Aviation Week & Space Technology, etc.) to obtain information relevant for each accident.

The total set included 247 fatal accidents. AoCs were assigned to 178 accidents (72%). For the remaining 69 accidents, none of the AoCs was considered relevant, or a link could not be made because of lack of detailed information about the accident. Of the 120 AoCs that are currently on the list, 43 (36%) could be associated with one or more accidents.

The nine most frequently assigned AoCs are listed in Table I. Note: the automation-related AoC that was given the highest priority in 2004 ended up in this top-eight.

Table I: Area of Change frequency across accident set (FAST AoC number).

Area of change	Accident count
Socio-economic and political crises affecting aviation (AoC-265)	48
Operation of low-cost airlines (AoC-125)	44
Smaller organisations and owners operating aging aircraft (AoC-252)	42
Reliance on automation supporting a complex air transportation system (AoC-013)	40
Increasing operations of cargo aircraft (AoC-114)	39
Increasing reliance on procedural solutions for operational safety (AoC-282)	19
Operational tempo and economic considerations affecting flight crew alertness (AoC-205)	16
Accelerated transition of pilots from simple to complex aircraft (AoC-122)	10
Decreasing availability of qualified maintenance staff at stations other than home base of operations (AoC-256)	8

4. Discussion on most frequent Areas of Change

In the following sections, each of the Areas of Change listed in Table I is briefly discussed.

4.1 Socio economic and political crises affecting aviation

The vast majority of the 48 accident aircraft linked to this top scoring AoC come from African operators. The high accident rate in ‘failed states’ such as Sudan and the Democratic Republic of Congo is unacceptable and should be given highest priority by the international aviation community. The strength of the economy of the country of the operator is a dominant influence factor, explaining for most of the differences in accident rates across geographical region (Visser, 1997). This finding indicates that addressing the traditional 'human factor' will not succeed in bringing down accident rates worldwide if the economic environment in which individual airlines operate (the 'prosperity factor') is left untouched.

Excluding hijackings and external attacks, a mere one in 16 million passengers has been killed on the airlines of the world's 30 wealthiest states and territories during the past 15 years (Economist, 2015). Significant changes in aviation technologies, functions and procedures even if well-intended need to be introduced with great care to avoid destabilizing this safety record. The Aviation Team Looking Ahead at Safety (ATLAS) operating under the aegis of the U.S. Commercial Aviation Safety Team (CAST) meets regularly to assess potential safety impacts of nearer-term changed proposed for introduction in the U.S. In contrast, for carriers of the 30 poorest jurisdictions, the rate was 57 times higher, at one in 283,000 passengers.

4.2 Operation of low cost airlines

This group is about small, low cost airlines that operate anywhere between 3 and 15 aircraft, not the well-established large low cost carriers such as Southwest, easyJet or RyanAir. The regional spread of accidents associated with this group is more diverse than the previous group and includes two accidents in the US and one in Europe.

Analysis of the 42 cases also showed that at least half of the airlines had one or more prior accidents. This suggests that continued airline oversight by the authorities appears to be a difficult issue.

4.3 Smaller organisations and owners operating aging aircraft

Aircraft airworthiness is defined by the remaining service life, measured in years, flight hours and quantity of take-offs and landings; each assessed independently. This is why some aircraft age relatively quickly, due to frequent flights on shorter routes. In theory, there is no concept of an 'old aircraft' in terms of aviation: it is either operable or inoperable. If it is authorized to operate, it should be as safe as an absolutely new airplane. Nevertheless, critical knowledge to carry out operations, maintenance and inspection of older aircraft types, in terms of know-how and know-why, appears to be fading with time.

4.4 Reliance on automation supporting a complex air transportation system

In 2004 the FAST conducted a study of the topic, "Increasing reliance on flight deck automation" at the behest of the JSSI (FAST, 2004a). This study resulted in 21 prioritized (out of 286) hazards that were divided in 4 themes:

- Theme I: Global Air-Ground-Space System Issues
- Theme II: Flight Crew-automation Interactions Issues
- Theme III: General Threats
- Theme IV: Absence of Human Agent (On Board).

The results of further FAST work confirmed these findings, and also the existence of "weak signals", defined as information which could anticipate an event but remains difficult to understand and interpret because of their ambiguous, uncertain and fragmentary characteristics (Guillaume, 2011). Examples of weak signals identified by FAST are a) that there will be problems with maintaining “hands-on” currency due to future advances in flight deck automation and b) that stress and fatigue will increase rapidly when the flight crew does not understand what flight deck automation is asking the aircraft to do. This information came from a pilot survey among more than 190 respondents, with a mean of 10,000 flying hours and 20 years in the business (FAST, 2004b).

Although the increasing reliance on flight deck automation has been a major factor in the current favourable safety record of western commercial aviation, the misuse/misunderstanding of automation has been implicated in certain high-profile accidents, see Table II.

Table II: Overview of automation surprise in high-profile accidents

	Colgan Air Q400 Feb 12, 2009 (NTSB, 2010)	**Turkish Airlines B737-800 Feb 25, 2009 (DSB, 2010)**	**Air France A330 June 1, 2009 (BEA, 2012)**	**Asiana B777 July 6, 2013 (NTSB, 2014)**	**Air Asia A320 Dec 28, 2014 (KNKT, 2015)**
Automation surprise	Crew surprised by stickpusher operation and responded inappropriately.	Crew unaware that auto-thrust reduction was triggered by faulty radio altimeter.	Aircraft response to control input when in alternate law at high altitude not understood by crew.	Crew failed to recognise that selection of the autopilot mode cancelled the auto-thrust speed protection.	Crew failed to recognise that pulling the circuit breakers in-flight keeps the aircraft in alternate law.

In each of the accidents listed in Table II automation surprises led the crews away from appropriate action. It is yet unclear whether revised training - e.g., upset recovery training-, new procedures or design changes can prevent the occurrence of such cases in the future, because we do not fully understand human decision making in unusual situations (Lamme, 2010). The FAST position has been that better understanding and research into human behaviour and decision making in normal and off-nominal conditions will help to reduce these types of accidents. Such knowledge is relevant for improving flight training and flight deck design.

For many aircraft and ground ATC and space systems now in use, there is a lost appreciation for the fact that these technology systems will be in production and operation far longer than ever conceived by their designers. This in-service ‘inertia’ acts as a moderator/constraint to automation evolution. Largely due to airline economic factors, the life span of commercial aircraft and their flight decks is known to be much longer than commonly imagined. The projected future fleet of more than 22,000 Boeing 737 and Airbus 320 single-aisle aircraft by 2025 is an example (Airbus, 2015; Boeing, 2015). Thus manufacturers may have reduced incentives to produce aircraft that push technology/automation envelopes. The same constraints will be true for the ground and space “nodes” of the future AGS system under development within the Single European Sky Air traffic management Research (SESAR) and U.S. NextGen air traffic control modernization programs – both highly dependent on automated systems. Increasing heterogeneity will remain a significant factor/disruption to be recognized and appreciated. It will also require preventive action. Designers, researchers, regulators, and operators may have left the aviation industry long before the last derivative enters service and hence essential information on the subtleties of automation design, related training, and operational lessons learned may be lost.

4.5 Increasing operations of cargo aircraft

Cargo aircraft are disproportionately represented in accident statistics. Nearly all of the fatal cargo accidents in the last decade have involved feeder and ad hoc carriers (GAO, 2009). A study conducted by the Netherlands Aerospace Centre (NLR) and the U.K. Civil Aviation Authority (CAA) in 2000 (Roelen et al, 2001) indicated that there were 2.5 accidents per million large cargo airplane flights in North America, which is nearly five times higher than the accident rate for passenger flights in North America and more than twice as high as the accident rate for cargo flights in Europe.

Cargo flights are not required to meet the same regulations as those for passenger flights. For instance, cargo airline pilots are excluded from the more stringent flight and duty time regulations imposed in the US in 2014.

4.6 Increasing reliance on procedural solutions for operational safety

There is a belief construct that says “we are safe because we followed the rules”, but it's not that simple. For example, except for very few aircraft that have special protections, safety of flight under winter operations is entirely procedure based. A simple instruction (e.g., perform "a tactile check" on the wings) when in ground icing conditions is not enough to prevent accidents. A deeper study is required why certain lessons learned – not just winter operations, but also in other aspects of operation and maintenance - apparently fade away, and the authorities need to investigate if current regulations are indeed adequate. How decisions are made and in what context are of paramount importance. We must better understand the interactions among humans, technical systems and the overall socio-technical context in which the two operate together. This is also where Safety Management Systems (SMS) and mature safety cultures come into play (Fox, 2012).

4.7 Operational tempo and economic considerations affecting flight crew alertness

Flight crew fatigue is traditionally managed by pilot rest and duty limits. FAR Part 117, enacted January 2014, was the first major revision to pilot rest and duty limits in the US in more than 60 years. The regulations are based on scientific knowledge of the effects of fatigue, sleep and circadian rhythms on the human body. ICAO and IATA promote fatigue risk management as a means of ensuring that relevant personnel are performing at adequate levels of alertness. In an FRMS an operator continues to have flight and duty time limitations but these are identified through their own FRMS processes, specific to a defined operational context, and are continually evaluated and updated in response to their own risk assessments and the data the operator is collecting (ICAO, 2011). It is therefore of paramount importance that pilots are free to report instances of fatigue. However, an FAA Office of Inspector General report (FAA, 2011) found that pilots might not be reporting all instances of fatigue. The report noted that, of 33 air carrier pilots interviewed by OIG researchers, 26 (79 percent) said that, at some time, they had been fatigued while on duty; nevertheless, only eight pilots notified their air carrier of their condition. Among the reasons cited for not reporting fatigue was the fear of punitive action from their employers.

4.8 Accelerated transition from pilots from simple to complex aircraft

Worldwide economic pressures to recruit needed pilots for Part 121 operations will likely result in more rapid transition of trainees from simple to complex aircraft. Current certification standards may need to be revisited in light of this phenomenon. Training curricula must provide the skills needed for command of complex, advanced aircraft. This phenomenon is evident in proposals for Multi-Crew Pilot License (MCPL). Potential concerns are the following (ECA, 2013):

- There is no relevant Air Traffic Control (ATC) simulated environment available to date,
- The currently approved MPL syllabi meet the minimum requirement of 12 real landings and even less in some cases,
- Some currently approved MPL syllabi do not include real Instrument Flight Rules (IFR) flight,
- Some currently approved MPL syllabi do not include asymmetric flight in real aircraft,
- MPL syllabi introduce a global training syllabus timescale reduction, including little to no consolidation time (i.e. time to allow for reinforcing the just acquired skills,
- There is a limited sample of MPL graduates flying the line today,
- There is no proof of capability for a MPL license holder to upgrade to captaincy (no MPL trainee has graduated to Captain yet, and no requirement for Pilot in Command (PIC) task analysis),
- There is scarce/limited data feedback on the performance of MPL cadets and pilots.

4.9 Decreasing availability of qualified maintenance staff at stations other than home base of operation

It is known that technical defects are more often documented in the aircraft technical logbook during flights to a home base than during flights away from home base (Hakkeling-Mesland et al, 2005). The non-availability of qualified maintenance staff at outstations is one of the possible explanations for this phenomenon; pressure to complete flights maybe another.

5. Conclusion

The results of the analysis presented in this paper demonstrate that changes catalogued many years previous were directly implicated in the majority of fatal aviation accidents over the past ten years. Areas of Change as utilized in this paper form a predictive approach that combines the following dimensions (Cagnin and Scapola, 2007):

- Look forward, e.g. through forecasting, trend analysis, gaming and scenarios, futurist writing, etc.
- Look across, e.g. through systemic thinking across multiple domains that reflect technology convergence.
- Look backwards, through historical analogy, previous future-oriented studies, trend, analysis, etc. History is important, although it shouldn't be the sole basis for the identification and analysis of future risks.
- Finally, there also needs to be a) a concerted effort "to prepare" the recipient of the prognostic message(s) and b) continued processing of signalled problems in a follow on team. This is an essential strategy for success.

One major difficulty with the assessment of future risks is to predict the future system with enough certainty and provide a good, complete and trustable description of the future. Although the future can never be entirely predicted, certain changes are likely to happen, such as the introduction of 4D trajectory management and System Wide Information Management (SWIM) into Air Traffic Management. These 'solid' elements can then be combined with less certain elements (e.g. demographics, fuel price changes, socio-technical-cultural factors, etc.) to form various scenarios from collections of future changes.

Collections of changes affecting aviation such as maintained by the FAST can be important catalysts for assessment of the following predictive safety questions:

1. How do the Areas of Change, in isolation or in combination, introduce or affect the hazards and risks from traditional system safety assessments?
2. Are there novel emergent hazards generated by interactions between and among AoCs that could adversely impact the safety characteristics of the future system being assessed? Interactions among these future changes –may weaken critical functions that must be maintained to ensure safe operations. Critical functions are defined as potential pathways leading to successful management of emerging risk rather than simply preventing failure. Assessments that do not appreciate or reflect the consequences of interaction complexity will not be fully informative and can lead to inappropriate trade-offs and increases in other risks (IRGC, 2010).

3. How do the Areas of Change, in isolation or in combination, affect the robustness or resilience of the risk controls (barriers) being considered?

4. The use of AoCs provides a different view on accidents as they happen worldwide since it triggers questions like a) how does the industry ensure information availability for operations, maintenance & overhaul, b) if human factors work will not bring down world-wide accident rates in view of the economic environment, we should review and consider change to the current safety efforts addressing e.g. 'loss of control' accidents.

5. Are there weak signals that should be acted upon?

Areas of Change help an analyst adopt a prospective mind-set: an ability to project oneself into the future; i.e. reflect within a framework that is unknown or uncertain. Many FAST Areas of Change that were identified in 2004 are correlated with the examined set of fatal accidents over the past ten years. The "Prognostic" or "Predictive" approach so in vogue these days aims to uncover such correlations, and the present analysis demonstrates the value of such a look-ahead. Examining future changes enables discovery of future hazards by using collections of change inside or outside the global aviation system. Once such hazards have been identified, mitigating actions can be initiated before the hazard appears. Prognostic hazard identification informs design processes so that the hazards can be eliminated from the future, avoided in the future, or mitigated in the future. The FAST Areas of Change inventory will be a great help in this endeavour.

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