

Aviation Safety Concerns for the Future

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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. Since 2004, FAST has been maintaining a catalogue of ‘Areas of Change’ (AoC) that could potentially influence aviation safety.

The horizon for such changes is between 5 to 20 years. 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. An ex-post analysis of the AoCs identified in 2004 demonstrates that changes catalogued many years previous were directly implicated in the majority of fatal aviation accidents over the past ten years.

This paper presents an overview of the current content of the AoC catalogue and a subsequent discussion of aviation safety concerns related to these possible changes. Interactions among these future changes may weaken critical functions that must be maintained to ensure safe operations. Safety assessments that do not appreciate or reflect the consequences of significant interaction complexity will not be fully informative and can lead to inappropriate trade-offs and increases in other risks.

The FAST strongly encourages a system-wide approach to safety risk assessment across the global aviation system, not just within the domain for which future technologies or operational concepts are being considered. The FAST advocates the use of the “Areas of Change” concept, considering that several possible future phenomena may interact with a technology or operational concept under study producing unanticipated hazards.

Keywords: Aviation Safety, Emerging Risks, Change Management

1. Background

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 “Forensic” or “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 similar accidents in the future. This is like an aviation autopsy.
- 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. These are like stethoscopes on the chest of the live aviation “patient.”
- 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. The process is like suggesting lifestyle changes to help someone live longer and more productively.

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 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.

In the earliest days of the FAST, a 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 Areas of Change 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 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 versus Accident Count (FAST AoC number).

Description of 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

Frequency of occurrence of individual Areas of Change across the accident set examined.

4. Aviation Safety Concerns for the Future

The analysis described in the previous section demonstrates that changes catalogued many years previously were directly implicated in the majority of fatal aviation accidents over the past ten years. It is therefore relevant to consider the current AoC list for identifying possible aviation safety concerns for the future. The safety concerns that have been identified by the FAST as most pertinent are described in the following sections.

4.1 In-Service Inertia

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 Air Ground Space (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.

4.2 The Prosperity Factor

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. This may require a dedicated task force (e.g. similar to a Joint Safety Implementation Team) to develop and recommend a detailed action plan for industry and government to support poorer countries to implement recommended safety enhancements, e.g. improved weather predictions, new runway safety features for critical runways, less non directional beacon approaches, replacement of the old

fashioned Instrument Landing System (ILS) by the much cheaper and more advanced Microwave Landing System (MLS).

4.3 Cosmic Cycles of Accidents

Organisations do not have memory. They forget how early programs phases were driven, what the difficulties were, and quasi systematically, they fall prey to the same errors. Critical knowledge to carry out operations, maintenance and inspection, in terms of know-how and know-why, appears to be fading with time. Between two programs involving new systems and new management, there may be several decades. Lost competencies and complexity of industrial structures affect primarily early phases of a program, leading to insufficient or wrong assumptions affecting the entire life cycle. Each and every program may repeatedly suffer from the same disease. like Halley's comet appearing in the sky periodically. This is especially a problem where safety relies on procedural solutions, such as ground icing and upset & recovery training including stall training. Drift into failure of an organisation is hard to recognise because it is about normal people doing normal work in (seemingly) normal organizations, not about obvious breakdowns or failures or errors (Dekker 2005).

4.4 Next Generation of Pilots

There will be problems with maintaining "hands-on" currency due to future advances in flight deck automation. 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). Fewer commercial pilots will have a military background and consequently may lack experience with recovery from unusual attitudes or unexpected situations.

4.5 Safety Oversight

Analysis of 42 accidents involving small low cost airlines showed that at least half of the airlines had one or more prior accidents (Smith et al 2016). This suggests that continued airline oversight by the authorities appears to be a difficult issue. Both ICAO and EASA intend to implement Performance Based Regulation (PBR) and Performance Based Oversight. PBR revolves, amongst other things, around the definition of so-called Key (safety) Performance Indicators (KPI). However definition of KPI's does require knowledge of the past, i.e. *know-why* of the requirements. Currently, there is no known repository of why the rules have been designed as such, including later modifications. And when we forget the past, we will be doomed to do it again.

4.6 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, see http://nlr-atsi.nl/fast/downloads/FAST_AC13_Hazard_Summary_May_12_06.pdf.

Two main conclusions from this study where:

- 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 favorable safety record of western commercial aviation, the misuse/misunderstanding of automation has been implicated in certain high-profile accidents, see Table II.

Table II: Automation Surprise in Fatal 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)
Manner by which automation surprise was evident	Crew surprised by stick-pusher 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 recognize that selection of the autopilot mode cancelled the auto-thrust speed protection.	Crew failed to recognize that pulling the circuit breakers in-flight keeps the aircraft in alternate law.

Automation surprise as a contributing factor in recent, high-profile, fatal aviation accidents.

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

5. Technology Watch Items.

An integral part of the FAST methodology is the definition of so called Technology Watch Items (TWI). TWIs can provide tell-tale signals if a postulated future is coming about. They include not just technical items, but “social science” items and business/affordability perspectives.

Back in 2004, the FAST report also suggested examining other fields of technologies such as “eSafety of road and air transport”. Today, self-driving cars are tested by Google and are already in service from Tesla. As could be expected, “eSafety” is already an issue if only for

a recent set of accidents. While a potential list of issues that spring to mind would be rather long, there are two that could have an immediate spin-off to the Aerospace Industry, notably:

- a) Emergence of viable business models and markets, for instance for car insurance and product liability. The automotive industry could move to e.g. all risk insurance for all vehicles thus creating time to solve the issue whether this would be a driver- or manufacturer mistake. Likewise, carmakers must find ways to obtain acceptable product liability insurance. In the past (before 1994¹), single piston engine aircraft makers reverted to producing aircraft kits that were only 49% complete. This put the assembler of the 51% remaining aircraft “in charge” of ultimate product liability, otherwise costs of litigation were unsurmountable.
- b) Rapid advances in artificial intelligence including self-learning systems enabling detection and avoidance of unusual objects on the road. There is a tremendous amount of work ongoing in this area. In light of these technology advances, today’s verification and validation tools used to certify software systems need radical improvement. Many future systems will feature non-deterministic behaviour that is not amenable to analysis by conventional methods. This is primarily driven by the vast number of permutations that defy conventional verification and validation techniques.

6. Conclusions.

The results of the analysis presented in this paper demonstrate that changes catalogued many years previously 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

¹ This practice stopped after “*The Aviation Revitalization Act*” on 1994

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 does one contrast the potential benefits of intentional changes being adopted by stakeholders for safety and efficiency objectives against the potential unintended, adverse consequences of those changes that arise from unforeseen interactions with other elements of the aviation system?
4. How do the Areas of Change, in isolation or in combination, affect the robustness or resilience of the risk controls (barriers) being considered?
5. 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.
6. Technology Watch items may become tell-tale indicators that certain futures are coming about and it may help to look into other technologies as well.
7. Are there weak signals that should be acted upon? A great deal of work is currently taking place to improve our ability to sense and recognize signals of change in conditions or processes that are weak (or buried in noise) but operationally significant.

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, avoided or mitigated in the future. The FAST Areas of Change inventory will be a great help in this endeavour.

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