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Technology-push, market-demand and the missing safety-pull: a case study of American Airlines Flight 587

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Through a critical case study of the crash of American Airlines Flight 587, this paper draws upon 'the Social Shaping of Technology' (SST) approach to offer a reconceptualisation of the technology-push and market-demand model for High-Reliably Organisations (HROs), providing support for a third factor, called here a* 'safety-pull'. *A safety-pull is defined as organisationally supported reflexivity in which technology innovators and frontline operators collaborate to consider the potential implications of adopting new technologies in HROs and the complex ways this change may impact human operators' work performance, often in risky and unanticipated ways. In contrast to accidents occurring solely as the result of individual operator error, analysing the safety-pull provides a way to tease out the wide range of factors that can contribute to HRO failures and offers a new SST perspective through which to examine high-risk operations.

Keywords: the social shaping of technology (SST), high-reliability organisation (HRO), airline pilots, clumsy technology, flight simulation, automation confusion, high risk operations, technology failure, technology push, market demand.

'An improperly trained pilot can break any airplane.'

Airbus Vice-President of Safety

(Air Safety Week, 25 October 2005)

'Most pilots think that' there are systems that 'will protect the aircraft structurally' or 'there would be a limitation or a warning' if parameters were being exceeded that might damage the plane.

American Airlines Captain, A300 Fleet Standards Manager

(NTSB, 2004: 24)

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Introduction

How successful are high-risk industries such as aviation at technological innovation? Given the sophisticated design of modern jetliners, extensive training of airline employees and unforgiving operating environment, one might assume that air carriers are exemplary at developing new technologies and successfully integrating them into the processes and procedures of frontline operators. This assumption underpins research investigating several High-Reliability Organisations (HROs) which, like airlines, involve high-risk professions that must consistently operate in complex, dynamic and time-pressured environments in a nearly error-free manner (Roberts, 1990; Weick and Sutcliffe, 2001). For example, studies from medicine (Sexton *et al*., 2000; Makary *et al*., 2006), offshore oil (Flin, 1995; 1997), emergency response (Flin, 1996) and nuclear power (O'Hara and Roth, 2006) cite aviation as a performance model for their industries to emulate further perpetuating the view that aerospace designers, airline managers and frontline operators have perfected their collaboration processes. Yet, curiously, little empirical research has investigated this assumption. By examining the ways one airline developed and integrated new technologies and how these technology decisions impacted the day-to-day work performance of employees, this paper aims to challenge this assumption. It does so through the case study of a fatal airline accident and, as a result, makes two theoretical contributions. First, by examining the ways various stakeholders shaped the design and implementation of new technologies at a US air carrier, this study makes an empirical contribution to a growing body of research that explores 'the Social Shaping of Technology' (SST) in organisations (MacKenzie and Wajcman, 1985; Williams and Edge, 1996; Howcroft and Light, 2010; Holmstrom and Sawyer, 2011). Second, by analysing the emergent nature of technology in one high-risk profession, aviation, this study identifies dynamics that could potentially undermine workplace performance and threaten the reliability in a wide range of HROs. Little research to date has applied SST in the empirical study of an HRO.

A considerable literature from a variety of fields suggests that in order for new technologies to be successful there needs to be both a 'technology-push', supplying innovations based on new scientific discoveries, and a market-demand, 'pulling' products to market to fill industry needs (Mowery and Rosenberg, 1979; Dosi, 1982; van den Ende and Dolfsma, 2005; Godin and Lane, 2013). In this paper, I suggest a reconceptualisation of the technology-push and market-demand model for HROs by providing support for a third factor, called here a '*safety-pull*'. I define a safety-pull as organisationally supported reflexivity in which technology innovators and frontline operators collaborate to consider the potential implications of adopting new technologies in HROs and the complex ways this change may impact human operators' work performance in 'extreme contexts' (Hannah *et al*., 2009). In contrast to accidents occurring solely as the result of individual operator error, analysing the safety-pull provides a way to tease out the wide range of factors that can contribute to HRO accidents and offers a new SST perspective through which to examine high-risk operations. Through the safety-pull lens, for instance, it becomes clear that HRO failures often result from a complex, inter-organisational breakdown in collaboration that involves a variety of people in different roles at several levels within their respective organisations.

This paper applies this push–pull framework in an analysis of the crash of American Airlines Flight 587, an Airbus A300-600, which departed from New York City's John F. Kennedy International Airport en route to the Dominican Republic on November 12, 2001. Less than two minutes after takeoff, the aircraft encountered wake turbulence from a previously departing airliner and disintegrated inflight, killing all 260 onboard as well as five people on the ground (NTSB, 2004). After conducting a three-year study the National Transportation Safety Board (NTSB), the US agency tasked with investigating transportation related accidents, reported some surprising findings. In short, the NTSB concluded that the well-trained and highly experienced American Airlines pilots broke the airplane and their actions were caused in large part due to training they had received in American's state-of-the-art flight simulators.

The contrasting quotes above—one from the airplane manufacturer and the other from the airline customer—provide evidence that development of the A300 involved high levels of confusion between how aircraft designers, engineers and manufacturers intended their new technologies to be used and how airline trainers and pilot operators actually used their product. As a result, one NTSB (2004: 160) recommendation was that airlines consider 'The use of lower levels of automation, such as simulators without motion or simple computer screen displays' to provide pilot flight training because there is 'less danger of introducing incorrect information'. This article investigates the apparent incongruence behind this NTSB recommendation by analysing the SST dynamics surrounding the manufacturers' technological push to innovate, the airline industry's demand for advanced technology and the missing safety-pull.

'The Social Shaping of Technology' (SST)

Organisations today are increasingly challenged to engage in the selection, purchase and integration of new technologies that may, or may not, provide the competitive edge they need to excel in the marketplace. As a result, the social dynamics shaping the design and implementation of technology have attracted researchers' interest. Williams and Edge (1996: 866) noted that the SST domain is not a well-defined theory, *per se*, but rather a 'broad church' approach that recognises a number of different strands. More specifically, Mackay and Gillespie (1992) described two SST categories: studies that focus on 'micro' factors using social constructivist, systems and actor-network approaches, and those that focus on 'macro' factors such as the socio-economic forces that affect the nature of technological problems and solutions.

This paper proposes a new SST perspective aimed at HROs that provides a way to analyse the variety of factors that may contribute to performance breakdown and accidents in high-risk fields. As a result the character, purpose and effectiveness of technologies and their social implications are problematised and available for analysis. It becomes clear how technologies and their societal impacts are co-shaped by a series of actions taken in research, innovation and application as well as by their historical, political and socio-economic contexts. Through this lens, technology does not emerge from linear pre-deterministic logic but rather innovates organically like a 'garden of forking paths' offering a variety of developmental routes and potential implementation outcomes (Williams and Edge, 1996: 866). Although there has been a significant amount of SST research investigating computer technology, software, and IT industries, few SST studies have analysed technologies in HROs effectively 'black-boxing' the emergent nature of new technologies in high-risk fields. This may seem surprising given some of the earliest technology studies were sponsored by the US Defense Department (Pinch and Bijker, 1984). Nonetheless, few SST studies focus on the complex interplay between social and technical factors during technology adoption in HROs and the ways this might impact frontline operators' performance in increasingly insidious ways.

HROs

After studying operations in risky professions such as air traffic control and nuclear aircraft carriers, Roberts (1989; 1990) was perhaps the first scholar to propose that existing organisational research offered little help in understanding the organising processes of hazardous industries. Coining the term 'high reliability organisation', Roberts noted how these risky organisations sustained excellent performance over long periods despite the inherent danger of their work. Elaborating further, Weick and Sutcliffe (2001) observed successful HROs share five key characteristics: a preoccupation with failure, reluctance to simplify, sensitivity to operations, commitment to resilience and deference to expertise. Interestingly, none of these five characteristics will be in evidence in the forthcoming analysis of Flight 587.

Another commonality is that HROs are often challenged to flexibly manage an unusually high number of unexpected events because their technologies are complex, operating environments ambiguous and systems tightly coupled. Particularly challenging is that one unexpected failure stresses different parts of the system in unusual ways (Fraher, 2011). These types of unpredictable, compound failures are so inevitable, Perrow (1984) argued, they should be called 'normal accidents' because they are the normal consequence of ever-evolving technologies generating increasingly complex responses. Yet rather than carefully considering SST, Roberts (1989: 123) cautioned, 'managers in high reliability systems encourage the development of technology as a panacea to ever increasing operational demands' knowing 'that the inherent limitations of those technologies can lead to serious problems'. Nonetheless, beyond these warnings, few empirical studies have investigated the social shaping of technology in this challenging HRO environment.

Aviation history

Although pilot training devices date back to before World War I, flight simulators as we envision them today emerged in the 1960s, developments paralleling rapid innovations in microelectronics and digital computers at the time (Rolfe and Staples, 1986). For many aircraft designers the goal was to automate as much as fast as possible and flight simulator developments followed suit (Billings, 1997). In 1973, advanced flight simulation was deemed so accurate, the Federal Aviation Administration (FAA) approved airline simulators for pilot training and certification of landing manoeuvres in lieu of actual airplane landings.

Yet, right from the start, some aviation researchers urged caution and a more thoughtful consideration of technological change and the way automation influenced the nature of people's work, often in unanticipated ways. For example, one of the first and best known study of function allocation between man and machine, Paul Fitts (1951) developed a list of human-automation challenges and assigned human-operators and machines tasks they are best suited to accomplish. However, my review of the original 1951 document reveals a different important contribution: Fitts' deep concern about the need for collaboration between technology designers and frontline operators—a concern underpinning the safety-pull.

For instance, Fitts cautioned, 'too often in the past important decisions about complex man-machine systems have been reached on the basis of hunches, guesses, and opinions' (xii). What is needed, Fitts noted, is 'a plan for active cooperation between engineers who design machines and scientists who study human behavior' (Fitts, 1951: v). When it comes to flight training, Fitts specifically noted, 'the most important question for the design and use of simulators is that of how faithfully and completely the operational task must be simulated if the device is to be valid' (79). What is important to take away from this discussion is how relevant Fitts' concerns about professional collaboration and simulator fidelity, voiced over 60 years ago, remains in discussions about technological developments in HROs today.

Fitts was not alone in his concerns, and over time, others voiced similar warnings about unchecked technological developments in aviation. For instance, a 1980 NASA study noted 'the question today is not whether a function can be automated, but whether it should be, due to the various human factor questions that are raised' (Wiener, 1980: 1). Similarly, Billings (1991: 4) observed 'during the 1970s and early 1980s . . . the concept of automating as much as possible was considered appropriate . . . [Since then] serious questions have arisen and incidents/accidents have occurred which question the underlying assumption that the maximum available automation is ALWAYS appropriate'.

Social and political changes were also influential. In 1978, the US Airline Deregulation Act was passed removing government control over industry operations and, as a result, new technologies thrived in the highly competitive marketplace as airlines scrambled to reduce costs and improve profitability by automating as much as possible. For example, a 1981 US government study found that transport aircraft could be safely flown by two pilots instead of three by replacing the flight engineer with advanced computers and automated systems, leading the way for a technology-push towards 'glass cockpit' and 'fly-by-wire' systems popular today (McLucas *et al.*, 1981). Meanwhile, the increased use and complexity of flight simulators in pilot training caused the FAA to establish an Advanced Simulation Plan to develop standardised criteria for the first time (Federal Aviation Administration, 1991).

What this historical overview reveals is the emergence of two competing perspectives about the adoption of new technologies in aviation that began over 60 years ago and largely continues today. One perspective supports automating everything as fast as possible relegating the frontline operator to a more passive role, if not eliminating the human altogether. The other perspective involves a more cautious, 'human-centered approach' (Billings, 1997) based on a safety-pull that requires collaboration and communication between designers and operators involved in proactive reflection about the ways that technological changes may influence the nature of frontline operator's work, often in risky and unanticipated ways.

Ironies of automation

In response to the airline industry's push to automate, several researchers identified ways that technological developments solved some problems yet created others (Bainbridge, 1983; Billings, 1991). For instance, as flight deck technology increased, researchers reported that pilots suddenly found their roles shifting from active operator to passive recipient when the airplane did not behave as expected.

Bainbridge (1983) argued that one of the 'ironies of automation' was that replacing easy tasks with technological solutions did not lessen the human operator's workload and, in fact, made the difficult parts of the operator's task even more difficult. She observed that the more advanced an aviation control system was, the more likely that technology designers—not frontline operators—were the root source of the problem. Numerous studies and accident reports documented the unfortunate consequences of this role confusion as human operators struggled to diagnose what the airplane was doing. 'What's it doing now?' and 'I've never seen that before' became frequently reported aircrew comments in performance studies of technologically advanced flight decks (Wiener, 1989). Valuable time was often lost in an emergency as aircrew attempted to reorient themselves in order to overcome aircraft control problems without understanding what originally caused the situation or why.

Expanding Bainbridge (1983) and Billings' (1991) work, Sarter (1994) and Sarter and Woods (1997) argued that the airline industry trend towards increased automation that included higher levels of machine authority and autonomy created new opportunities for aircrew confusion and mistakes. They described this performance breakdown as an 'automation surprise' when aircraft systems did not behave as human operators expected in dynamic real-time environments. In another irony of automation, this cognitive dissonance often occurred in exactly the kind of unusual situation in which advanced technologies could have proven most valuable to their human operator. Instead, the operator is doubly-burdened to sort through a confusing, dangerous and potentially escalating situation. Wiener (1989) called this technology 'clumsy' when it hindered operator performance instead of helping.

Extant studies of automation surprises and clumsy technology typically focus on the ways that pilots mis-programme or misunderstand their aircraft systems, for example, selecting a drastic 3,300 foot per minute decent rate instead of a comfortable 3.3 degree glide path to landing. What is less often investigated is the ways that technologically advanced training, such as that received by the accident copilot in American Airlines state-of-the-art flight simulators, can also create clumsy, flight deck surprises leading to performance breakdown when aircraft systems do not respond as anticipated.

The research approach

This article predominantly draws on the 7,981 pages of empirical material compiled by the NTSB during its investigation of the crash of Flight 587.[1] The purpose of the NTSB's investigation was to determine root causes of the accident in order to avoid future occurrences, not to assign blame. Therefore, NTSB testimonies were particularly forthcoming. In addition to archival sources, I interviewed four senior captains who ranged from 25 to 36 years of commercial airline employment experience (mean of 29.5 years) as a way of providing more vivid and personalised accounts of airline employees' experiences of technology changes over the years. I also drew on a wide range of secondary sources such as newspaper articles, professional magazines and online sources to triangulate findings and support my conclusions.

My decision to focus on this material was influenced by the growing popularity of case studies to examine the impact of new technologies in the workplace such as Crump and Latham's (2012) study of an accident and emergency department, Dawson and Gunson's (2002) analysis of Dalebake bakeries, Moulton and Forrest (2005) survey of control room operators in Australia, Preece *et al*. 's (2002) study of the Royal Navy and Boyd and Bain's (1998) evaluation of flight attendants. As Dawson and Gunson (2002: 44) observed there is a need for empirical 'research that can chart the unfolding and emergent character of technology' at work.

As a former United Airlines pilot myself, I was able to analyse this empirical material in great depth. To begin with, I read and re-read the archival material breaking the data down into more manageable chunks, highlighting significant milestones, and then created a timeline of significant aviation industry developments (see Table 1). Following Alvesson and Kärreman's (2007: 1265) suggestion to 'aim for more creative ways of theorizing' my process was to look for surprises and incongruences in the data as I sought to identify points of tension or 'mysteries' to solve. For instance, I wondered how the Airbus Vice-President of Safety could testify at the NTSB hearing that an improperly trained pilot can break any airplane, whereas the American Airlines A300 Fleet Standards Captain testified that most pilots think that there are protective systems that would become activated if safe parameters were exceeded. Examples of competing interpretations of reality such as these, held by a variety of people in different roles at several levels within their respective organisations, signalled areas worth investigating further. Through this process, a complex image of the contributing factors in the crash of Flight 587 emerged, factors that will be discussed in detail in the next sections.

The case of American Airlines Flight 587

The morning prior to the accident proceeded uneventfully. The pilots arrived early and conducted their normal routines, and then taxied for takeoff behind a Japan Airlines (JAL) Boeing 747. After completing their checklists, Flight 587's seasoned captain transferred aircraft control to his copilot to make the takeoff. An experienced and conscientious first officer, the copilot recognised the potential to encounter wake turbulence behind the previously departing heavy 747 and asked the captain: 'You happy with that distance?'

> The captain replied 'we'll be all right once we get rollin'. He's supposed to be five miles by the time we're airborne, that's the idea.'
>
> 'So you're happy', the copilot inquired again.
>
> 'Yeah'.
>
> 'Take off check's complete, I'm on the roll. [I've got the controls.] Thank you sir.'

Flight 587 lifted off the runway about one minute and forty seconds behind the JAL jet, following the aircraft on a climbing left turn for departure. Yet the larger, heavier 747 scribed a wider turning radius causing the smaller, more nimble Airbus to remain inside—and most critically, downwind from—the 747's turn. Meanwhile, the American

Table 1: Significant United States aviation industry and related simulator technology developments

Year	Event
1914	First commercial airplane flight in United States
1930	Edwin Link patents the first flight trainer for student aviators called a Link Trainer.
1937	American Airlines is first air carrier to purchase Link Trainer for pilot training.
1938	Civil Aeronautics Board (CAB) established, in part, to license and regulate commercial aviation industry; regulates industry for next 40 years.
1939-45	WWII increases demand for large numbers of pilots and Link Trainer becomes integral part of basic flight training. Link asked to design other simulators for bomb-dropping, celestial navigation, aerial interception, radar and emergency drills.
1948	Curtiss-Wright develops first full simulator for a commercial airline: the Boeing 377 for Pan American Airways. No motion or visual systems were included, but the simulator replicated the 377's appearance and behaviour in all other respects.
1949	After WWII, accuracy of Link Trainer motion called into question and electronic analogue computers become popular.
1951	Fitts List developed considering whether a human operator or machine perform certain functions better leading to study of man-machine interface and MABA/MABA lists.
1958	Federal Aviation Administration (FAA) established to support aviation industry developments
Late 1950s	Reduced cost and increased availability of microelectronics resulted in shift away from analogue towards digital simulators that provided more real-world motion and visual displays.
1968	Cardiology patient simulator 'Harvey' developed for University of Miami
Late 1960s	Flight simulators achieved their present day form, programmed by computers to mimic modern airplane cockpit design and performance.
1970s	Wide range of technological developments introduced on the flight deck to aid flight crew situational awareness such as expanded aural and visual warnings, Terrain Awareness Warning Systems (TAWS) and Electronic Flight Instrument System (EFIS).
1973	FAA approves visual flight simulators for pilot training and certification of landing manoeuvers in lieu of actual airplane landings (FAR 121.439).
1973-79	Fuel crisis required optimisation of aircraft navigation capabilities and performance management computers called Flight Management Systems (FMS) designed to improve operational efficiency.
1978	US Airline Deregulation Act removed government control over routes and fares and allowed free-market influences to dictate aviation industry developments.
1978–1983	Influx of new airlines quickly entered deregulated industry increasing competition and challenging major airlines dominance.
1979	Aviation industry recognises human factors continue to play part in 70% of accidents prompting NASA to conduct Human Factors study of cockpit automation.

Table 1: *Continued*

Year	Event
1980	Increasing complexity of flight simulators causes FAA to establish Advanced Simulation Plan and National Simulator Evaluation Program to develop standardised criteria.
1980	NASA study questions prevailing assumption at the time 'that automation can eliminate human error' and asks 'whether it is possible that cockpit automation may have already passed its point of optimality' (Weiner and Curry, 1980: 2).
1981	President's Task Force on Aircraft Crew Complement study found transport aircraft could be flown by two-pilots versus traditional three member crew, replacing flight engineers duties with advanced computer technology and automated systems.
1982	Based on NASA research, Boeing 767 introduced first two-crew 'glass cockpit' replacing old-fashioned electromechanical 'steam gauge' instruments with 'glass' cathode ray tube displays.
1983	Attempting to compete with Boeing, Airbus released A300-600 jetliner; the accident aircraft.
1983–1993	Major airlines grew quickly in deregulated environment through merger, acquisition and bankruptcy of newer air carriers; ten largest airlines held 97% market share by 1991.
1984	American Airlines commits to total flight simulation aircrew training, certifying pilots with no actual airplane time in model.
1985	Effectiveness of computer simulations in medical practice demonstrated.
1985–1988	Over 30,000 commercial pilots hired to meet employment needs of industry expansion putting younger, less experienced pilots in the cockpit of nearly every US air carrier.
1987	Accident copilot takes first training flight and completes 90-day commercial pilot certification programme.
1988	Airbus delivers first A300-600R to American Airlines.
1989	NASA study finds pilots report 'mixed feelings' about technological developments and often felt 'out of the loop', losing situational awareness and a sense of what the airplane automation was doing (Wiener, 1989).
1991	FAA issues Advisory Circular 120-40B: Flight Simulator Qualification outlining flight simulator certification process to ensure and flight test standards accurately represent airplane data within specified tolerances.
1991	Accident copilot hired by American Airlines.
1991	NASA issues report urging for collaboration between aircraft manufacturers, airlines and pilots and developments of more 'human-centered' aircraft design (Billings, 1991).
1992	Researchers find pilot 'automation surprises' common on 'glass cockpit' flight decks.
1993–2000	Buoyed by strong national economy and increased demand for air travel, US airlines pursued wave of expansion, extensive hiring of new employees and purchasing of aircraft.
1996	*White House Commission on Aviation Safety and Security* recommended airline industry aim to reduce aviation accidents by 80% by 2007; key area to improve is to minimise *Controlled Flight into Terrain* and *Loss of Control in Flight* events.

Table 1: *Continued*

Year	Event
1996	Eighty aviation industry representatives met to improve safety and discuss pilot training strategies in light of the *White House Commission's* recommendation
1996	American Airlines instituted the *Advanced Aircraft Maneuvering Program* (AAMP) as mandatory annual training for all its pilots.
1997	Both accident pilots attended AAMP and then repeated training annually thereafter.
1997	Memorandum written to American Airlines by an industry consortium of experts from Airbus, Boeing, McDonnell-Douglas and the FAA warned about the dangers of AAMP and training pilots to use the rudder in *airplane upset* recovery.
1997	American Airlines Flight 903 experienced an *airplane upset* due to excessive rudder input; aircraft response similar to Flight 587.
1997	American Airline's Manager of Flight Operations-Technical sent a letter to American's Chief Pilot voicing grave concerns about AAMP, in particular, training pilots in flight simulators to apply excessive rudder.
1997	American Airline's A300 Technical Pilot sent a letter to the Airbus Chief Pilot raising concerns about AAMP teaching pilots to inappropriately use rudder during a wake turbulence encounter.
1997	Consortium of aircraft manufacturers sent a letter to American Airlines Chief Pilot voicing concerns about the fidelity of flight simulators to teach *aircraft upset* recovery and use of rudder.
2001	Crash of American Airlines Flight 587
2002	Airbus stops manufacturing the A300-600 model

pilots ran through their 'after takeoff checklist' and checked-in with New York Departure Air Traffic Controllers on the radio. This was the flight's last communications.

Immediately after beginning their left turn, Flight 587 hit a pocket of disturbed air as the northwesterly winds drove JAL's wake into the climbing Airbus' departure path, like waves rocking a boat.

'Little wake turbulence, huh?' the captain inquired to his copilot.

'Yeah,' increase speed to 'two fifty, thank you'.

Fifteen seconds later, Flight 587 had a second encounter with JAL's wake.

'Max power!' the first officer exclaimed in a strained voice.

'You all right?' The captain said, tension beginning to rise.

'Yeah, I'm fine.'

'Hang on to it, hang on to it!'

Sound of a snap.

'Let's go for power, please' the first officer pleaded.

Sound of a loud thump, a bang and a human grunt. A roaring noise started, increasing in amplitude. The airliner's tail had just separated from the body of the plane.

'Holy [expletive]' the first officer screamed increasing his aggressive flight control inputs, slamming the yoke from left to right while simultaneously jamming both rudder pedals to their limits. 'What the hell are we into? We're stuck in it!'

'Get out of it, get out of it!' the captain demanded. But to no avail. What both pilots failed to recognise was that the first officer's erratic flight control inputs were amplifying the airplane's motion, not the wake turbulence. Although the jet was flying well below the airplane's *maximum manoeuvring speed*, the first officer exceeded the airplane's designed aerodynamic load limits. The airliner broke apart and impacted the ground moments later.

The NTSB conducted three computer recreations to determine how much the previously departing 747's wake turbulence contributed to the crash. Results confirmed that Flight 587 did encounter about 80% of the 747's initial vortex strength causing some lateral forces on the tail. Yet, investigators classified this wake as 'typical turbulence' and reported that the high aerodynamic loads that led to structural failure were pilot induced. Therefore, the NTSB concluded, the probable cause of Flight 587's inflight break-up was 'the first officer's unnecessary and excessive rudder pedal inputs' (NTSB, 2004: 160). If the first officer had stopped his flight control inputs the natural stability of the aircraft would probably have neutralised the motion and this disaster could have been averted.

Discussion

Applying the SST analytical approach, I will now investigate the social, political and economic factors that contributed to the crash of American Flight 587 years before the 2001 accident. As Americans' Chief Pilot explained in his NTSB testimony after the accident:

> You have to put this [accident] in the context of the world the way it was back in 1996-'97. We had several airplanes roll over on their backs and go straight in [to the ground] . . . And the industry as a whole, and American Airlines particularly, were very concerned about the capability of pilots in general to not so much handle—well, I suppose that's part of it. But to—[we wondered] what they would do in the event that they got put in this situation (NTSB, 2004; Chief Pilot interview: p. 672).

To understand the urgency of the Chief Pilot's concerns, it is important to look even further back in history.

New types of pilots

After the US Airline Deregulation Act was passed in 1978, the airline industry expanded very quickly requiring the extensive purchase of new airplanes and record hiring of employees. Between 1985 and 1988 alone, nearly 30,000 commercial pilots were hired in the United States. To contextualise this information, consider the fact that there are only about 70,000 commercial pilots currently employed in the entire American aviation industry (see Fig. 1). In 1989, the organisation *Future Aviation Professionals of America* estimated US airlines would hire another 32,000 pilots by the year 2000, and the FAA estimated airline fleets would increase by 25% or nearly 4,200 additional commercial aircraft (*New York Times*, November 22, 1987).

This rapid aviation industry expansion exhausted the available labor supply and put younger, less experienced pilots in the cockpit of nearly every US air carrier. Contributing to the pilot shortage was the mandatory retirement of large numbers of experienced Vietnam-era pilots at age 60, competitive bonuses paid to keep military pilots in the service and the high cost of civilian flight training. To overcome this pilot paucity, airline executives negotiated with aviation universities to promote professional pilot educational programmes while simultaneously reducing previous standards for age, vision, height/weight and experience. For example, in 1986 most major airlines only hired college graduates. By 1989, one new hire pilot in 10 had no college diploma and significantly less aviation experience than the generation prior.

Flight 587's copilot was hired by American Airlines 10 years prior to the accident at the age of 24. Growing up in an aviation family, he dropped out of college after only one year to follow in his father's footsteps and pursue a piloting career. In 1987, his father began to teach him to fly in a small single-engine propeller-driven airplane. Just a few

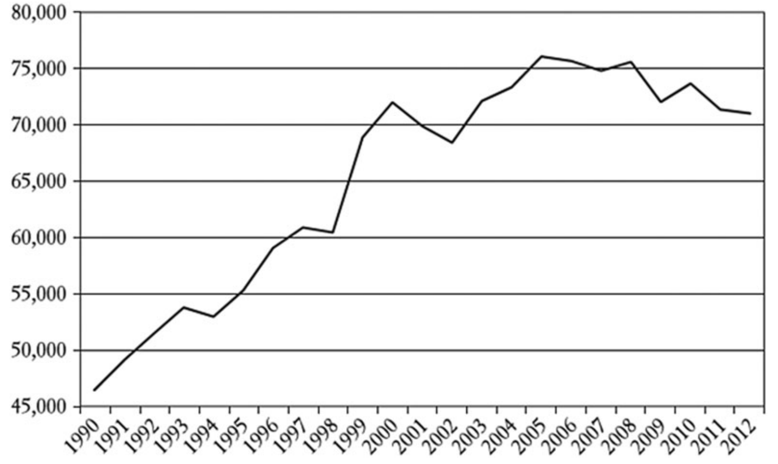

Figure 1: US Commercial Pilot Employment 1990–2012[i]
[i]*Compiled by author using data from Research and Innovative Technology Administration (RITA), US Bureau of Transportation statistics http://www.bts.gov/programs/airline_information*

months later, he completed a 90-day accelerated training programme, earning the required licenses to work as a civilian flight instructor and was later hired by a series of commuter airlines. In 1991, just four years after his very first training flight, the accident copilot was hired by American Airlines and assigned the three engine turbojet Boeing 727, a huge step up from the small airplanes he was accustomed to flying. This rapid career progression was not atypical for the industry at the time as the number of commercial airline pilots increased by two-thirds between 1990 and 2000.

These employment challenges caused many major airlines like American, accustomed to hiring military pilots with thousands of operational hours flying high-powered equipment, to increasingly rely on less experienced civilian sources for employees. Although many of these civilian pilots, like the accident copilot, possessed comparable *amounts of flight time* to military pilots, often the *type of aircraft*—light single-engine and small multi-engine airplanes—and *flying environment*—often visual or simulated instrument flight in familiar, local areas—limited their exposure to the fast-paced pressures of scheduled air service flying complex aircraft in inclement weather, unfamiliar airspace and non-routine operations (Fraher, 2014). As American's Chief Pilot eluded to in the previous quote, many aviation industry leaders worried about the safety implications of this rapid industry expansion, associated market-demand for pilots and the ramifications of putting less experienced pilots in control of large powerful passenger jets. I will return to this important point later in my analysis.

New flight control designs

In the mid-1980s, aircraft manufacturer Airbus, eager to compete with Boeing, responded to pilot requests to improve aircraft handling by developing its A300-600 model. In a classic example of a technology-push, this new jet incorporated advanced features designed to assist pilots inflight, for instance, making it easier to move the rudder pedals at higher airspeeds, similar to power steering in a car, while protecting the airplane by limiting the amount of rudder the pilot can deflect. Ironically these two changes substantially increased flight control sensitivity, making the A300-600 *twice as responsive* to rudder pedal inputs at 250 knots than at 135 knots. At moderate speeds, such as that of Flight 587 during the inflight break-up, the pilot can deflect the rudder to maximum, hitting the stops by moving pedals just 1.2 inches—nearly imperceptible amounts. However, this increased sensitivity only partially explains the accident copilot's flight control inputs. We are still left with the fundamental question—what happened?

New training protocols in flight simulators

In the early 1990s safety analysts predicted that even if aviation industry accident rates remained constant, the anticipated 3–4% annual industry growth would result in a near doubling of US air crashes by the turn of the 21st century (Gore, 1996). In global terms, this meant an airline crash every week worldwide by 2015. These statistics combined with the mysterious mid-air explosion of TWA Flight 800 in 1996, and the inflight fire onboard ValuJet Flight 592 that same year, to cause President Bill Clinton to create the *White House Commission on Aviation Safety and Security* with Vice-President Al Gore in charge.

Gore's (1996) Commission recommended the aviation industry aim to reduce aviation accidents by a factor of five within a decade by re-engineering the FAA's regulatory process and certification programmes. One area targeted was a type of pilot error that industry analysts identified as contributing factors in over 70% of all airline fatalities: *Controlled Flight into Terrain*, which is when a fully-functioning aircraft is inadvertently flown into the ground, and *Loss of Control in Flight*, which is when pilots unintentionally exceed safe manoeuvring parameters in what is termed an *airplane upset*, such as American Flight 587 experienced. Motivated by the Gore Commissions' recommendations, airlines were eager to address the high number of accidents in this area and many proactively modified their training ahead of the FAA's slow regulatory change process.

Airline pilot instructors found that although some pilots, particularly military experienced, received aerobatic training early in their careers, many civilian trained pilots had not. Particularly important was the fact that few airline pilots had received airplane upset training in the large, multi-engine transport jets that they currently flew. Taking the lead, American instituted the *Advanced Aircraft Maneuvering Program* (AAMP) as mandatory annual training for all its pilots. During AAMP, pilots read materials, watched videos and discussed hazardous inflight situations in the classroom, and then practiced recognition and recovery techniques in the flight simulator. Pilots were instructed that the rudder could be used to assist in controlling the airplane's roll angle during recovery and in certain extreme situations, even full rudder inputs are appropriate. This seemingly mundane training point became pivotal in the accident analysis of Flight 587. Consider the following.

One simulator event, particularly relevant when analysing the accident copilot's actions, was the *Excessive Bank Angle Exercise*. This flight simulator scenario began with the instructor informing the crew that 'They were following a heavy jet', some specifically stated a 747 (NTSB, 2004: 82). As the instructor issued wake turbulence warnings, the simulator momentarily rolled 10 degrees in one direction then past 90 degrees in the opposite direction while inhibiting the pilots' flight control inputs until an *airplane upset* condition occurred. The instructor who provided the accident copilot's most recent training taught that recovery was 'better when the pilots got on the flight controls earlier' (NTSB, 2004: 83) and 'a little bit' of rudder was necessary to recover properly. Yet, by inhibiting pilots' flight controls, the exercise encouraged aggressive inputs that would not necessarily match those required in a real airplane. One has to wonder, could this flight simulator training have primed the copilot's response to conditions encountered onboard Flight 587?

'One strange tendency'

The NTSB (2004) interviewed dozens of pilots who had flown with the accident copilot. One captain recalled that he was 'nice, polite, courteous, and very cooperative in every way'. Another captain recalled he was 'always in a good mood, and got along with everybody', 'a very competent pilot who flew the airplane well'. Yet, one captain disagreed. Similar to the others, he found the accident copilot to be 'a real gentleman', 'a perfectionist who worked hard' and did 'everything by the book'. 'However', the captain added 'he had one strange tendency: to be very aggressive on the rudder pedals'. On one flight, this captain recalled, the copilot encountered some wake turbulence and over responded, pushing the rudder 'to full stops', which dangerously yawed the jet side-to-side. 'It was a very aggressive maneuver', the captain said, and he 'had never seen any other pilot do this'. Once on the ground, the pilots discussed the incident, and the captain explained the inputs were 'quite aggressive' and created 'heavy side-loads', which could damage the plane. Yet, the copilot was 'adamant that he was complying with AAMP', the captain recalled, and 'insisted that AAMP gave him directions to use rudder pedals in that fashion'.

In sum, the previous discussions highlighted how socio-economic factors, political influence and legislative changes in the 1970s stimulated the aviation marketplace by reducing regulations and increasing competition in the airline industry. Aggressive industry expansion created market-demand that led to employee shortages in the 1980s and 1990s and put less seasoned pilots in key roles on the flight deck. Meanwhile airplane manufacturers engaged in a technology-push that resulted in development of larger, more technologically advanced aircraft that demanded sophisticated piloting skills that increasingly relied on flight simulator training. Developments in microelectronics and digital computers provided an additional technology-push as flight simulators became accepted as the safest, fastest and least costly way of training pilots in these new skills while also presenting an image of cutting-edge modernisation and industry sophistication (Rolfe and Staples, 1986; Kamel, 2006). As Dekker and Woods (2002: 240) observed, in aviation 'there was a time when the question of what to automate had a simple answer: automate everything you technically can'. The human implications of this 'technological push' were often an afterthought in the evolutionary paradigm (van den Ende and Dolfsma, 2005).

Fully committed to total simulation

Pilot simulator training expanded from a procedural focus on checklists and emergencies to encompassing all aspects of flight in full motion simulators with sophisticated graphic displays. American Airlines was proud to be at the forefront of these technological changes. Consider this 1984 quote from an aeronautical magazine:

> At American Airlines we are fully committed to total simulation. All transition (conversion) training is accomplished in the simulator with no actual airplane time until the individual's first line flight [ie a revenue producing flight with passengers onboard] . . . Experience shows that this total simulator training fully prepares the individual for his first line trip under supervision, *with no exceptions* [emphasis added] (Rolfe and Staples, 1986: 232–233).

This representation of 'total simulation' pilot training 'with no actual airplane time' until passengers were onboard a revenue generating flight is an excellent example of assumptions about technology at the time. That is, these statements reflect a discourse of inevitability based on an embedded assumption that technological changes will inevitably lead to improved workplace skills and unquestionably facilitate the social progress that new hiring practices in the post-deregulated airline industry environment demanded. Flight simulators are depicted as the perfect training solution for every pilot in every scenario—'*no exceptions*'.

In an eerie foreshadowing of the crash of Flight 587, Bainbridge (1983) identified two important concerns about flight simulators that may help us understand the NTSB's recommendation that airlines consider the use of lower levels of automation in pilot flight training: First, she noted:

> There are problems with the use of any simulator to train for extreme situations. Unknown faults cannot be simulated, and system behavior may not be known for faults which can be predicted but have not been experienced. This mean that training must be concerned with general strategies rather than specific responses (Bainbridge, 1983: 777).

Second, Bainbridge (1983: 776) cautioned that the designers of 'present generation of automated systems, which are monitored by former manual operators, are riding on their skills, which later generations of operators cannot be expected to have'. Neither of these warnings was heeded.

The missing safety-pull

In 1996, five years before the crash of Flight 587, 80 aviation industry representatives met to improve safety and discuss pilot training strategies in light of the Gore Commission's challenge to reduce accidents. Yet right from the beginning there were conflicts between airline pilot trainers and the manufacturer test pilots. As airlines like American had been confidently running large numbers of pilots through their flight simulator programs since the 1960s, they 'naturally considered themselves to be the experts', the Airbus Chief Pilot recalled. Therefore, airlines were reluctant to accept 'the technical advice given by the manufacturers' (Wainwright, 1996: 3). Three areas of differing opinion quickly emerged, documented in a 1997 memorandum written to American by an industry consortium of experts from Airbus, Boeing, McDonnell-Douglas and the FAA, foreshadowing the crash of Flight 587 (NTSB Attachment H, 1997).

First, as American Airlines flew eight different types of airliners, pilot trainers wanted simple, reproducible procedures that were easy to teach to all pilots flying any model of airplane. Yet, given the infinite aerodynamic possibilities presented by the varying airplane designs, the manufacturers' test pilots were uncomfortable with the trainers' one-size-fits-all approach. They felt it encouraged rote, procedural-based pilot responses to complex unpredictable scenarios and preferred instead a more cognitive learning approach.

Second, there was a difference of opinion regarding the emphasis of rudder during upset recovery. 'Based on our experience as test pilots', the Airbus Chief Pilot cautioned, 'we are very wary of using the rudder' in recovery because 'it is the best way to provoke a loss of control' situation (Wainwright, 1996: 6). However, the test pilots had great difficulty convincing the airlines of this danger because pilot trainers always responded that their techniques 'work in the simulator'. This response squelched further critical inquiry, stalling the debate and leading manufactures' to their third concern: The role of flight simulators in teaching *airplane upset* recovery at all.

As computerised systems simulators are only as realistic as the data programmed into them, the manufacturers argued, and they doubted the fidelity of the simulators when flying outside the normal parameters of everyday operations. The Airbus Chief Pilot recalled:

> We manufacturers were very concerned over the types of maneuvers being flown in [airline flight] simulators and the conclusions that were being drawn from them. Simulators, like any computer system, are only as good as the data that goes into them. That means the data package that is given to the simulator manufacturer. And we test pilots do not deliberately lose control of our aircraft just to get data for the simulator [programmers to use]. And even when that happens, one isolated incident does not provide much [useful] information (Wainwright, 1996: 6).

Similarly emphasising this point, the Vice President of Training for Airbus noted that manufacturers had visited airline training sites and tested their simulator fidelity: 'We discovered that the simulators in some fairly simple maneuvers were not representative of what the airplane should actually be doing' (NTSB Public Hearing Day 1, October 29, 2002: 287). Although the test pilots tried to persuade airline trainers that flight simulators should *not* be used in AAMP because inaccuracies could foster negative training and excessive rudder use and could lead to departure from controlled flight, just like the crash of Flight 587, airline representatives argued against them. The Airbus Chief Pilot recalled, pilot trainers' 'answer was always the same; but it works in the simulator!' (Wainwright, 1996: 6).

Four warning signs surfaced the following year—a full four years before the crash of Flight 587—that should have alerted pilot trainers, the FAA, industry leaders, airline executives and aircraft manufactures to the brewing trouble aboard the technologically advanced Airbus A300-600. The first incident involved rudder pedal excursions on jets inflight which resulted, in some cases, in vertical stabiliser damage just like Flight 587. The most severe example occurred when another American Airlines jet, Flight 903, experienced an *airplane upset* on a trip from Boston to Miami injuring a passenger and flight attendant before pilots regained control in time for a safe landing.

Referencing this incident, the second warning sign was a letter sent to American's Chief Pilot by a fellow American captain and Manager of Flight Operations-Technical. In this 1997 memo, the captain voiced 'grave concerns about some flawed aerodynamic theory and flying techniques' presented during AAMP (NTSB Additional Correspondence, 2003: 14). He noted Flight 903's incident occurred as the result of 'excessive rudder inputs by the crew, which is exactly what they were taught' in AAMP. 'Our simulators are training devices only', and our approach is 'wrong, dangerous, and directly contrary to the stated concern' of the airplane designers.

Similarly another experienced American captain and A300 Technical Pilot raised a third warning, bypassing his own Chief Pilot and sending a letter directly to the Airbus Chief Pilot, stating: 'I am very concerned that one aspect of' AAMP 'is inaccurate and potentially hazardous', that is 'in the event of a wake turbulence encounter' instructors teach that 'THE RUDDER should be used to control roll' [emphasis in original]. The Airbus Chief Pilot faxed his response the next day: 'I share your concern over the use of rudder' and 'will be pleased to talk' (NTSB Exhibit 2-S, 1997). Yet, nothing substantive seemed to come from any of this.

The fourth alert surfaced a few months later when the industry representatives sent their important 1997 memo to American's Chief Pilot. In an effort to collaborate, they once again voiced 'concern' about AAMP's 'excessive emphasis on the superior effectiveness of the rudder for roll control' and the fidelity of flight simulators in upset training (NTSB Attachment H, 1997). Six weeks after receiving this memo American's Chief Pilot responded defensively: 'Let me say this one more time', he emphasised, 'we do not advocate the introduction of large sideslip angles' [emphasis in the original] in AAMP and the proper use of rudder 'is very clearly explained' in our training. In closing, the Chief Pilot inferred that manufacturers should mind their own business by emphasising that American is 'charged' with 'real life' responsibilities, unlike Airbus 'which is technically and optimally controlled' like 'academia' (NTSB Attachment H, 1997).

This certainly seems a curious response to an offer of collaboration about a potentially life-threatening issue and NTSB investigators delved into this unusual communication exchange. Inquiring whether the manufacturers found American's response 'an open invitation for further dialogue', Airbus Vice President of Training replied wryly: 'We did not' (NTSB Public Hearing Day 1, October 29, 2002: 312). And little more seems to have occurred on the subject until the fateful crash of Flight 587 in 2001.

Conclusion

Much remains unsettled about the Flight 587 disaster. American Airlines charges that the crash was mostly Airbus's fault because the A300-600 was designed with unusually sensitive rudder controls that few pilots were aware of. Airbus charges that the crash was mostly American's fault because AAMP did not train pilots properly about the aerodynamic theory of *airplane upsets* and the handling characteristics of large multiengine airplane rudders. And American Airlines, Airbus and the NTSB blame the accident crew for pilot error, citing in particular, the 'first officer's unnecessary and excessive rudder pedal inputs' (NTSB, 2004: 160). Conspicuously unaddressed in the analysis of Flight 587's crash is the missing safety-pull. Of the eighteen findings and eight recommendations' in Flight 587's final NTSB accident report, not one directed aircraft manufacturers and frontline operators to improve their communication, work more collaboratively to develop technology or create new methods by which to periodically exchange information across their organisational boundaries, creating a feedback loop between technology designer, manufacturer and operator. To understand this oversight, it is important to appreciate the competing perspectives about new technology adoption that came to dominate in aviation.

American Airlines' adopted the perspective to automate everything possible even though this approach included known performance risks as pilots often found their roles shifting from active operator to passive recipient when the airplane did not respond as anticipated. Although experienced test pilots warned against incorporating unverified performance simulations into pilot training scenarios, American Airlines' very public commitment 'to total simulation. . . . *with no exceptions*' reveals a lot about their confidence in the fidelity of new technologies and commitment to using the flight simulator for pilot training in AAMP as a way to positively impact pilot's work performance.

What seems missing from this discussion is an awareness of the SST risk factors identified by aviation researchers decades before the crash of Flight 587 about the ways that new technologies solve some problems yet also created new opportunities for confusion, mistakes and performance breakdown (Bainbridge, 1983). Numerous studies documented how pilots suddenly found themselves confused, asking 'What's it doing now?' when the airplane did not behave as expected in dynamic real-time environments (Wiener, 1989). Similar statements were made by the accident flight crew moments before the crash of Flight 587 when, for example, the copilot exclaimed 'What the hell are we into?' as he jammed the rudder pedals to their limits, confused by the lack of anticipated aircraft response. Although this flight deck 'surprise' led to the catastrophic performance breakdown that caused this fatal crash, it is important to emphasise how the accident pilots' expectations about aircraft performance were erroneously established through 'clumsy' flight simulator training in American's AAMP.

A lack of SST awareness and assumptions that technological innovations have solved, or will soon address, all of the aviation industry problems remain pervasive. Kelly (2004), for example, reflected this common feeling when he noted that 'during the last four decades the [airline] industry has accomplished a revolution' through 'robust technological solutions' that have dramatically improved air safety including 'new methods and standards for training of flight crew' (p. 3). This optimistic interpretation then becomes frequently cited as the justification for a technology-push in a wider range of other HROs. While there are undoubtedly examples where airlines have excelled in technology adoption over the years, this study of Flight 587 supports the need for a less exuberant and more reflexive approach to technology adoption. I hope the introduction of the concept of a safety-pull will help facilitate these more critical SST conversations and provide a lens by which to consider the variety of factors that typically contribute to confusion, mistakes, and performance breakdown in HROs.

Implications for research and practice

Considering the influence of a 'safety-pull' in technological innovation is important not only for aviation, but a wide range of other HROs that have recently incorporated simulator training largely based on the purported success of pilot training in the airline industry. For example, in medicine it is widely recognised that simulators can provide a helpful educational platform where novices can repeatedly practice medical procedures until a desired level of proficiency is achieved before performing the operation on a live person. Although medical task-trainers such as the CPR mannequin 'Resusci-Annie' have been in use since the 1960s, Satava (1993) was the first to recommend simulation in surgical training. Since then worldwide enthusiasm for expanding simulation-based learning in medicine has been growing, creating market-demand. Several universities teamed up with aerospace developers in a technology-push to devise some of the first full-scale human simulators. This technology-push originated from aviation companies eager to find peacetime applications for their technological developments in light of the US reduction in military spending (Cooper and Taqueti, 2004).

Medical simulation studies have demonstrated medical students perform faster with fewer mistakes after simulator training compared with a control group, a process called

VR (virtual reality) to OR (operating room) transferability (Gallagher and Cates, 2004). However, attempts to produce validity and reliability data in medical simulation training have only been partially successful leading some scholars to suggest that 'medicine must ultimately accept simulation on the basis of faith or common sense similar to the aviation industry' (Rosen, 2008: 159). Yet, other researchers, such as Buckley *et al*. (2014), remain concerned, in particular, about whether the skills obtained through simulator training are directly transferable to the ambiguous real-life clinical environment. The findings of this case study of Flight 587 support the validity of this more cautious approach. Until critical aspects of VR skill transfer can be effectively measured in the live OR setting, a strong safety-pull seems warranted.

Note

1. See the following weblink for all NTSB empirical materials: http://dms.ntsb.gov/pubdms/search/hitlist.cfm?docketID=32764&CFID=314066&CFTOKEN=85134161

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