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Regulatory Aspects of Passenger and Crew Safety: Crash Survivability and the Emergency Brace Position

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CONTENTS

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Ⅰ. Introduction

Barely more than a century has passed since the first passenger was carried by an aircraft. That individual was Henri Farman, an Anglo-French painter turned aviator. He was a passenger on a flight piloted by Léon Delagrange, a French sculptor turned aviator, and aircraft designer and manufacturer. Farman, with Delagrange at the controls, took to the air on the 28th of March 1908.[1] Aviation would never be the same!

Sadly, that would be true for another reason. Not quite six months later, the first passenger would be killed in the crash landing of an airplane. Lieutenant Thomas Selfridge of the United States Army, was an aviator and aircraft designer, who worked on some of the earliest flights and aircraft designs. On the 17th of September, he was the passenger in a demonstration flight by Orville Wright at Fort Myer, Ohio. The flight proceeded normally until, halfway into the flight and at an altitude of about 150 feet, a propeller suddenly split during a turn, the broken propeller then catching the aircraft's rigging. The plane ploughed nose-first into the ground, with the pilot and his passenger buried in the wreckage. Wright was rescued and found to have several major injuries but survived, although with chronic pain for the rest of his life. Selfridge had a fractured skull and underwent immediate neurosurgery but died about three hours after the accident.

Wright was able to investigate the accident and determined that the structure the broken propeller had caught was a wire that held the tail of the plane in place.[2] Selfridge's fractured skull was the result of impact against one of the wooden uprights of the plane. There was speculation that if he had been wearing some type of protective headgear, then his injury might not have been fatal. This finding apparently led to a recommendation that his Army pilot colleagues wear protective leather helmets.[3]

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1) Henry 'Henri' (1874-1958), Maurice Alain (1877 - 1964) and Richard (Dick) Farman (*-*). The Pioneers. Hargrave. Aviation and Aeromodelling - Interdependent Evolutions and Histories. http://www.ctie.monash.edu.au/hargrave/farman.html

2) Tragedy at Fort Myer. http://www.wright-brothers.org/History_Wing/Wright_Story/Showing_the_World/Tragedy_at_Fort_Myer/Tragedy_at_Fort_Myer.htm

3) Thomas Selfridge. https://en.wikipedia.org/wiki/Thomas_Selfridge

The first flight attendant or member of the cabin crew was Heinrich Kubis. In March 1912, as a 23-year-old, he started working as an air steward, looking after passengers and serving meals as a contract caterer on the DELAG Zeppelin LZ-10 *Schwaben*. He later served on the famous airship, LZ 129, *Hindenburg*, and survived death when it caught fire by leaping from a window when it neared the ground.[4]

Since then aviation has made phenomenal progress in its technical capabilities and its safety. In 2017, 4.1 billion passengers were transported by air, an increase of 7.3% from 2016. Fewer than 19 passengers died in five accidents, with some of the 19 being aircraft crew. All those accidents involved turboprop aircraft and there was also one crash of a cargo jet, without passengers.[5] Comparing these results to those of a decade ago show improvement, with 1566 total accidents in 2008, of which 275 were fatal, with a total of 494 fatalities, and a fatality rate of 1.21 for every 100,000 hours flown (which totalled 22,805,000 hours that year). Half a century ago, the statistics were grimly worse, with 4216 accidents, of which 719 were fatal. A total of 1556 individuals died and the fatality rate for every 100,000 hours flown was almost double that of the rate forty years later, at 2.06, admittedly with more hours flown (34,887,000).[6]

The reasons for the advance in safety are multiple. Just as there is no 'root' or single cause of aviation accidents, neither is there a single or root cause of aviation safety improvements, either for aviation safety overall or for passenger safety. This paper focus on the specific passenger and crew safety concept of crash survivability, including the emergency brace position, and on the regulations related to the passenger emergency brace position.

This focus will be facilitated through use of a model to classify the major contributing factors to the passenger brace position. Models show us how we understand and interact with the world around us, and help us think our way

4) Flight attendant. https://en.wikipedia.org/wiki/Flight_attendant

5) IATA releases 2017 Airline Safety performance. Press Release No.: 8. Date: 22 February 2018. IATA. https://www.iata.org/pressroom/pr/Pages/2018-02-22-01.aspx

6) General Aviation Safety Record - Current and Historic. AOPA. https://www.aopa.org/about/general-aviation-statistics/general-aviation-safety-record-current-and-historic

through problems. Models can often provide the equivalent to the concept of the phrase, “Use a picture. It’s worth 1000 words.”[7] However, despite the utility of this phrase, George Box, an economist, gave a clear warning with his statement, “Essentially, all models are wrong, but some are useful.”[8]

The Winnipeg model was first developed in 1995 - 1996[9] as part of the author’s activities as an Expert to the Crown, in the areas of human error and human factors, for the Pediatric Cardiac Surgery Inquest.[10] The model had to be able to handle the large amounts of information related to the twelve infants and young children, who were the official subjects of the Inquest, but also to be able to facilitate analysis at a more detailed level, as well as to be able to provide a one-page summary overview. Furthermore, because the deaths had occurred over nine months, demonstrating the passage of time was an additional requirement.

The model was therefore structured on the basis of three pre-existing models. First, the triad of the healthcare concept of “Quality Assurance” was used. This was defined by the late Professor Avedis Donabedian, who determined that determining and assuring the quality of healthcare required the healthcare system to be defined in terms of three elements: Structure, Process and Outcome. Structure represents the starting blocks of the system and includes “administrative and related processes that support and direct the provision of care”. Structure is “concerned with such things as the adequacy of facilities and equipment; the qualifications of medical staff and their organization; the administrative structure and operations of programs and institutions providing care; fiscal organization and the like”.[11] Process refers to all the activities carried out, including the actions

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7) Study Shows a Picture is Worth 84.1 Words, not 1000. Sevell + Sevell. Web Design + Marketing. https://www.sevell.com/news/study-shows-picture-worth-841-words-not-1000

8) Box, GEP. Science and Statistics. Journal of the American Statistical Association 1976; 356 (71): 791-99. doi:10.1080/01621459.1976.10480949

9) Davies, JM. Application of the Winnipeg Model to Obstetric and Neonatal Audit. Topics in Health Information Management 2000;20:12-22

10) Sinclair, Associate Chief Judge Murray. The Report of the Manitoba Pediatric Cardiac Surgery Inquest: An Inquiry into Twelve Deaths at the Winnipeg Health Sciences Centre in 1994. http://www.pediatriccardiacinquest.mb.ca/pdf/pcir_intro.pdf

and behaviours of patients and personnel alike. Outcome refers to the end results of Process (the activities), as influenced by the underlying Structure. (Some readers might recognize the engineering equivalent of this model to the classic 'Input - Process - Output' of that domain.) In addition, because the structural elements must be in place to allow procedural events and results to occur, the model incudes the concept of the passage of time, thus facilitating reactive review of incidents and accidents, as well as proactive analysis for system safety.

To that chronology-based skeleton was then added a system-based view of the basic components of the system. These were derived from a model developed by the late Professor Robert L. Helmreich, Professor of Psychology at the University of Texas at Austin. Professor Helmreich was a Technical Advisor to the Commission of Inquiry into the Air Ontario Crash, presided over by the Commissioner, The Honourable Virgil P. Moshansky. The Inquiry investigated what had occurred before, during and after, and the underlying contributory factors to the crash of Air Ontario Flight 1363 on March 10, 1989.[12] In that crash, a Fokker 128-1000 Fellowship twin jet made a scheduled departure for Winnipeg, Manitoba after a stop for passengers and fuel in Dryden on the way from Thunder Bay, Ontario. The plane crashed less than a minute after take-off, struck trees, broke apart in the landing and then was badly damaged in the post-crash fire. Twenty-one of 65 passengers and three of four crew members died, including the pilot and co-pilot.[13]

Although the plane had accumulated snow and ice on the wings during the stop in Dryden, the Inquiry did not stop at that point and blame the cockpit crew but delved into the underlying contributory factors. Professor Helmreich provided a model of how, in any given situation, the actions and behaviours of the flight crew

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11) Donabedian, A. (1966). Evaluating the Quality of Medical Care. The Milbank Quarterly, 44(3), 166-203.

12) Moshansky, The Honourable V.P., Commissioner. Commission of Inquiry into the Air Ontario Crash at Dryden, Ontario. Final Report. Volume 1. Parts 1-4. The Honourable V.P. Moshansky, Commissioner, ed., Ottawa: Ministry of Supply and Services, 1992. http://publications.gc.ca/collections/collection_2014/bcp-pco/CP32-55-1-1992-1-eng.pdf

13) Air Ontario Flight 1363. https://en.wikipedia.org/wiki/Air_Ontario_Flight_1363

would be determined by a “number of simultaneously operating factors”. The four factors that he assigned were what he called the crew environment, the physical environment, the organizational environment and the regulatory environment.

- The **crew environment** included: interpersonal coordination and communications, including cockpit, cabin and ground personnel, and individual characteristics of crew members - training, experience, motivation, personality, attitudes, fatigue, and stress, both from the immediate operational situation and significant personal life events.
- The **physical environment** included: Meteorological and operating conditions and the aircraft, including its condition and capabilities.
- The **organizational environment** included: the culture and behavioural norms of the organization, including morale, policies and standards; organizational stability and change; and available resources.
- The **regulatory environment** included: operational standards and supervision.[14)]

The importance of this four-component model was inclusion of the role of the regulator in the accident, which contributed to the Commission of Inquiry identifying “numerous safety-related deficiencies and failings” in the “regulatory domain of Transport Canada”.[15)]

What Professor Helmreich omitted from his model, however, was any mention of the passengers. These 65 individuals were central to the operation of the flight and therefore an important contributing factor to the decision-making by the cockpit and cabin crews. For that reason, when the Helmreich model was incorporated into

14) Helmreich RL. Human Factors Aspects of the Air Ontario Crash at Dryden, Ontario: Analysis and Recommendations to the Commission of Inquiry into the Air Ontario Crash at Dryden, Ontario. Final Report. Technical Appendices. The Honourable V.P. Moshansky, Commissioner, ed., Ottawa: Ministry of Supply and Services, 1992.

15) Moshansky, The Honourable V.P., Commissioner. Commission of Inquiry into the Air Ontario Crash at Dryden, Ontario. Final Report. Volume 1. Parts 1-4. The Honourable V.P. Moshansky, Commissioner, ed., Ottawa: Ministry of Supply and Services, 1992. http://publications.gc.ca/collections/collection_2014/bcp-pco/CP32-55-1-1992-1-eng.pdf

the Winnipeg model, the passenger component was added.

The third contributor to the Winnipeg model was Professor James Reason, now Professor Emeritus, Department of Psychology, University of Manchester. The Reason model was originally formulated in the late 1980s and early 1990s as a series of visibly spaced layers of the system, starting with “Fallible Decisions”, and followed in sequence by “Line Management Deficiencies”, “Psychological Precursors of Unsafe Acts”, “Unsafe Acts” and “Inadequate Defenses”. The model soon evolved, with the first four layers reduced to three (related to the organization, workplace and person), and with the single defensive layer increased to three. Initially the first three layers had one or more irregularly positioned holes, and the defence layers bore one square opening. By 1997, the model was simplified, with four system layers, with hazards, some holes representing latent conditions and others active failures, and losses. The model was not so simplified that a system had only those four layers, rather, there were “successive layers of defences, barriers and safeguards”. Each of the layers again had one or more irregularly shaped and positioned holes. Through these holes, and therefore through all the layers of the system, an arrow representing the “trajectory of accident opportunity” could pass.

The Reason model is now more commonly known as the Swiss Cheese Model, because of the visual similarity of the flawed layers of the system, with their irregular holes, looking strikingly similar to layers of a type of cheese. It was this similarity that led the (late) Dr. Rob Lee, an aviation psychologist and then Director of the (previously named) Bureau of Air Safety Investigation or BASI (and now the Australian Transport Safety Bureau or ATSB), to say to Jim Reason that his model should be known as the “Swiss Cheese Model”. The name has stuck.[16)]

In his model, Reason described how what he termed “latent failures” contributed to the evolution of accidents in complex socio-technological systems. These latent failures, later renamed as latent conditions, were those system deficiencies and flaws

16) Reason, J., Hollnagel, E., and Paries, J. Revisiting the “Swiss Cheese Model of Accidents”. EEC Note 13/06. Project Safbuild. Eurocontrol Experimental Centre. .http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.80.5369&rep=rep1&type=pdf

that lurked in the system until the decisions and actions of workers, combined with local triggering factors, came together to provoke catastrophe. Reason likened the latent conditions to “resident pathogens”, invoking the similarity with cancer cells lurking in a patient’s body, to emphasize the importance of these flaws, which were the results of decisions made in the past. For example, the Commission of Inquiry into the Dryden accident determined that there were a number of these system deficiencies, including flying with an unserviceable Auxiliary Power Unit (APU), a lack of an available external power unit at the Dryden Airport, refueling the airplane using the technique known as “hot refueling” (which involves keeping one engine running during the refuelling procedure), and doing so with the passengers on board. Including the concept of latent factors into the Winnipeg model contributed to ensuring that it provided a systems approach to the problem(s) under scrutiny, rather than focusing and allaying blame on one or more ‘persons’, such as the pilots, or as in the Winnipeg Inquiry, the pediatric cardiac surgeon.

The Winnipeg model therefore consists of a model with three phases: Structure, Process and Outcome, and five major components: Passengers or Patients; Personnel; Environment / Equipment; Organization(s) and Regulatory Agencies. Examples of the latter include Transport Canada, which is responsible for aviation pilot and personnel licensing, aircraft and airport operations, drones, incident reporting, air travel and air worthiness,[17] and the Korean Ministry of Land, Transport and Maritime Affairs, which regulates aviation through the Aviation and Security Act.[18]

Although the Winnipeg Model is best conceptually viewed as a dynamic illustration, the working version is a simple table, known as the SAFER MATRIX, with Structure, Process and Outcome positioned along the horizontal axis and the five system components positioned on the vertical axis. The fifteen cells can then be populated with the factors determined to contribute to the problem under consideration, for example, passenger safety, the emergency brace position and the regulatory environment.

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17) Aviation. Transport Canada. https://www.tc.gc.ca/en/services/aviation.html

18) Aviation Security Act. Korean Laws in English. Ministry of Government Regulation. http://www.moleg.go.kr/english/korLawEng?pstSeq=52720

Ⅱ. Passenger and Crew Safety and Crash Survivability, including the Emergency Brace Position

While passengers and crew can potentially be injured or die during a flight, for example, from turbulence and/or from endogenous conditions, such as coronary artery disease, most injuries and fatalities occur during planned or emergency return of the aircraft to the ground. Not all of these landings are necessarily 'crashes', as shown by recent occurrences of landings short of the runway and runway excursions, in which passengers and crew have been injured or killed.

An example of a landing short of the runway is that of Air Canada 624 at Halifax, Nova Scotia on March 29, 2015. This was a regularly scheduled flight from Toronto, Ontario, with 133 passengers and five crew. The Airbus A320-211 had landed in "stormy" (winter conditions) at 225 metres short of the runway threshold. The impact of the airplane destroyed the Instrument Landing System Localizer (ILS-LOC) antenna array, as well as the power supply to the airport. The aircraft then continued airborne before striking the ground twice more, and sliding along the runway, before stopping some 580 metres past the runway threshold. There was no post-crash fire but the airplane lost its port engine and all landing gear.[19)]

Another example of a landing short of the runway is that of the recent crash of Air Niugini Flight 73, which landed in a lagoon, some 460 metres short of the runway at the Chuuk International Airport, Weno Island, Chuuk State, Federated States of Micronesia. The Preliminary Investigation Report stated that, of the 12 crew and 35 passengers on board, six passengers were seriously injured, and one passenger was fatally injured. Those seven passengers were all seated near the rear of the aircraft. During the impact with the water of the Boeing 737-800, both the landing gear and the rear fuselage behind the wing separated. The aircraft then sank in about 30 metres of water in the lagoon. There was no

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19) Air Canada Flight 624. https://en.wikipedia.org/wiki/Air_Canada_Flight_624

post-impact fire. The passenger who died was "initially unaccounted for" and his body was found in the wreckage of the plane three days after the accident.[20]

An example of a runway excursion is that of Air France 358 at Toronto, Ontario on August 2, 2005, at the end of the regularly scheduled flight from Paris. The Airbus A340-313E landed in heavy rain, on Toronto Pearson's shortest runway (2700 metres) and then slid another 300 metres, past the end of the runway and down into a creek's ravine, stopping before the major highway that borders part of the airport.[21] "When the aircraft left the runway, it bounced violently and repeatedly until it came to an abrupt stop in the ravine. On each impact, occupants were propelled upward from their seats; a minimum of three distinct impacts were reported." With each of these secondary impacts, passengers hit their heads against either the seat-back in front and/or the sidewall panels of the cabin. A post-crash fire destroyed much of the aircraft, but not before all 297 passengers and 12 crew evacuated the plane. Twelve individuals were injured, with some of those injuries suffered during the impact of the landing and some from the evacuation.[22]

In events such as these three crash landings, the probability of a passenger or crew member surviving similar accidents is high. But what determines crash survivability? There are three questions that need to be answered to help determine this.

First, was the crash physiologically survivable? Because the aircraft that was in motion had to come to a complete stop, were the gravitational or G forces of deceleration transmitted to the passenger or crew member greater than those of normal human tolerance? There are some accidents in which the speed and angle of impact are such that human tolerance is exceeded, leading to sudden death. An example of

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20) Preliminary Report. TC & I. Air Niugini Limited. P2-PXE. Boeing 737-8BK. Chuuk Lagoon, 1,500 ft (460 m) Before the Runway 04 threshold. Chuuk State. Federated States of Micronesia. September 28, 2018. https://bloximages.newyork1.vip.townnews.com/postguam.com/content/tncms/assets/v3/editorial/c/fc/cfcc15ac-da55-11e8-becb-8f578a860216/5bd51950b0853.pdf.pdf

21) Air France Flight 358. https://en.wikipedia.org/wiki/Air_France_Flight_358

22) Aviation Investigation Report. A05H0002. Runway Overrun and Fire. Air France. Airbus A340-313 F-GLZQ. Toronto / Lester B. Pearson International Airport, Ontario, 02 AUGUST 2005. Transportation Safety Board of Canada

this type of accident includes SwissAir Flight 111, which left John F. Kennedy Airport in New York City bound for Geneva, Switzerland on 2 September 1998, with 215 passengers and 14 crew members. Less than an hour into the flight, the pilots detected smoke in the cockpit. A decision was made to dump fuel in preparation for an emergency landing at the Halifax International Airport. Twenty-one minutes after smoke was first detected, the McDonnel Douglas MD-11 crashed into the sea near St. Margaret's Bay, Nova Scotia, at a speed of 555 kilometre/hour or 154 metre/second and with a force of about 350g. In an instant, the aircraft disintegrated.[23]

The second question determining crash survivability is related to whether or not the structure around the occupants remained more or less intact. This question applies to both the cabin and to the cockpit. An example of an accident in which parts of the passenger cabin were differently affected with respect to structural integrity is that of the Kegworth Air Disaster. On January 8, 1989, British Midlands Flight 92 was *en route* from London Heathrow Airport to Belfast, Northern Ireland. After determining that an engine blade had fractured and smelling smoke in the cockpit, the pilots mistakenly shut down the functioning engine. The plane was diverted to the East Midlands airport but had slowed to 185 kilometres/hour just before crossing the M1-Motorway. The tail of the Boeing 737-400 struck the ground. The plane bounced, crossing the motorway and then striking the far-side embankment. The speed on this second impact was between 150 and 185 kilometres/hour at an impact force of between 22 and 28 g. The plane then broke into three sections. There was no post-crash fire. All eight crew members survived, although both pilots suffered spinal injuries, resulting in paraplegia. Of the 118 passengers, 87 initially survived but eight later died. Thirty-nine passengers died in the crash. [24] There were more fatalities in two sections of the plane: in the forward section of the passenger cabin and in the area just behind the wing, both areas where the floor had collapsed.[25]

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23) Swissair Flight 111. https://en.wikipedia.org/wiki/Swissair_Flight_111

24) The Kegworth Air Disaster. https://en.wikipedia.org/wiki/Kegworth_air_disaster

25) Report on the Accident to Boeing 737-400 GOB-ME near Kegworth, Leicestershire on

Third, were the passengers and/or crew able to escape from the aircraft wreckage or was it possible to rescue them, before the crash site was consumed by fire or sank, or the post-crash conditions became so intolerable as not to support life? Possibly the best example is that of the fiery crash of the Zeppelin Hindenburg on May 6, 1937, near Lakehurst, New Jersey on May 6, 1937. The *Hindenberg* had left Germany three days earlier for the United States. As the *Hindenberg* attempted to dock in shifting winds at the Lakehurst Naval Station, fire broke out somewhere in the rigid, hydrogen-filled 'balloon'. With the flames spreading, the Hindenburg sank quickly to the ground, stern first. Thirteen of the 36 passengers, 22 of the 61 crewmen and one ground crew member died as fire consumed the airship, with victims being burned to death, succumbing to smoke inhalation, or dying from injuries caused either by leaping from too high a height or by falling debris as the structure collapsed. Some individuals were more fortunate, although many survivors were badly burned. A few survivors were rescued by those on the ground. As the airship sank close to the earth, Heinrich Kubis (the world's first flight attendant or member of the cabin crew) encouraged and helped passengers and other crew to jump from the windows. He then jumped to safety, landing without injury.[26)][27)] He not only saved passengers' lives but also demonstrated that the primary concern of the cabin crew is the safety of their passengers. (While cabin crew members have typically been thought of as "focused on the evacuation of an aircraft in the event of an accident", they also work proactively to help ensure safety, by dealing with small fires (such as from smart phones) and disruptive passengers, and informing the cockpit crew of abnormal situations.[28)]

However, the final survivability of the passengers and/or crew crash of an aircraft does not determine crash survivability That is, crash survivability is not based on

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8 January 1989. Aircraft Accident Report 4/90. Air Accidents Investigation Branch. Department of Transport. London: HMSO. https://www.jesip.org.uk/uploads/media/incident_reports_and_inquiries/Kegworth%20Aircrash.pdf

26) Heinrich Kubis. The First Flight Attendant. 25 November 2016. https://www.aviationcv.com/aviation-blog/2016/heinrich-kubis-first-flight-attendant

27) *Hindenburg* Disaster. https://en.wikipedia.org/wiki/Hindenburg_disaster

28) Cabin Safety. Safety. ICAO. https://www.icao.int/safety/AirNavigation/OPS/CabinSafety/Pages/default.aspx

occupants actually surviving the crash. For example, on October 30, 1941, Northwest Airlines Flight 5 was *en route* from Minneapolis, Minnesota and Fargo, North Dakota when the Douglas DC-3A-269 crashed into an open field about four kilometres east of the Fargo Airport. All 12 passengers and two of the three crew were killed.[29] Only the captain survived, having been thrown clear of the wreckage,[30] in what would otherwise be deemed a non-survivable accident.

The three factors determining crash survivability are therefore

- Physiological crash survivability of the passenger and crew members;
- Physical structural integrity of the part of the aircraft in which the passengers and crew are seated;
- The possibility of escape or rescue from the wreckage.

Of these three factors, passengers and crew are not able to influence the speed or angle of impact of a crash landing. Nor are they able to influence the physical structural integrity of that part of the aircraft in which they are seated. (The only possible exception lies in determining which items are placed in overhead bins, on the grounds that some items could become airborne in a crash landing and therefore represent a source of head and other injuries.)

What passengers can do, however, is to maximize their possibility of being less injured in a crash and therefore increase their probability of being able to escape from the wreckage. There are a few things that passengers can do, starting with dressing as though they needed to evacuate the aircraft. Passengers should wear trousers and long-sleeved shirts, both made of low-flammability materials such as cotton and wool, as well as lace-up shoes that will not come off in a crash or as they climb out of and run from the wreckage. Passengers should also pay attention to the safety briefings and memorize the number of rows to the closest and to an alternate exit.[31]

29) Northwest Airlines flight 5 (1941). https://en.wikipedia.org/wiki/Northwest_Airlines_Flight_5_(1941)
30) Northwest Airlines. https://en.wikipedia.org/wiki/Northwest_Airlines#Fatal_accidents
31) Lallanilla M. How to Survive a Plane Crash. Tech. Scientific American. 9 July 2013.

The one thing that both passengers and crew can do is to adopt an emergency brace position. Doing so has been shown to reduce the probability of injuries and death and thus contribute to survival.[32] Cherry and colleagues used statistics from 17 passenger aircraft accidents for 1993-1996 to calculate what could happened to 100 occupants in a single accident. The first impact was thought to lead to the deaths of 20% and to serious injuries in another 20%, with a further 20% suffering only minor injuries, leaving 40% alive and uninjured. If there were to be a subsequent fire, then the percentage of survivors would be decreased from 80% to 70%, with 25% suffering serious injuries/burns and 45% with minor injuries. These calculations helped to demonstrate that passengers need to be able to evacuate the aircraft wreckage, lending further weight to hence the importance of the brace position.[33]

In assuming an appropriate "brace-for-impact" position, an individual pre-positions his/her body against whatever he/she is most likely to be thrown against. The brace position therefore serves two purposes. First, bracing reduces flailing, which is the violent and involuntary movement of the upper and lower parts of the body around the central point of the tethering lap seat-belt. Flailing occurs in response to the deceleration of the aircraft associated with its first or primary impact with the ground or water. Second, bracing reduces injuries from any secondary impact(s) that might occur, for example, as in the Kegworth Air Disaster (See above.)

There is no one emergency brace position that is suitable for all passengers and crew, because of numerous factors. These include:

- Passengers' physical size and characteristics;
- Crew members' physical size and characteristics;

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https://www.scientificamerican.com/article/how-to-survive-a-plane-crash/

32) National Transportation Safety Board. (1979, October 4). Safety recommendations A-79 -76 through -78 [Letter to Honorable Langhorne M. Bond, FAA, from James B. King, NTSB]. Washington, DC. http://www.tc.faa.gov/its/worldpac/techrpt/asf81-2.pdf

33) Cherry, R., Warren, K., & Chan, A. (2000). A benefit analysis for aircraft 16-g dynamic seats. April, 2000 (Report No. DOT/FAA/AR-00/13). Washington, DC: US Department of Transportation, Federal Aviation Authority. http://www.fire.tc.faa.gov/pdf/00-13.pdf

- The cabin and seating (class, manufacture, direction, pitch, presence or absence of non-collapsible tables; associated restraint systems;
- Direction, speed and force of impact.[34]

However, the basic position for any passenger seated facing forwards in the economy section of an aircraft and with only a lap (two-point) seat-belt requires the passenger to flex, bend or lean forward over the legs in some manner, while at the same time prepositioning the body (mainly the head) against any surface that it would otherwise strike, such as the seat or bulkhead wall ahead. Because cabin crew seats are equipped with different restraints, most often a four-point harness style, the basic brace position is different for members of the cabin crew. In fact, cabin crew routinely adopt a 'pre-brace' position for every take-off and landing. This position involves sitting upright in the crew seat, often with the arms folded across the abdomen, and allows the cabin crew member to be prepared for any emergency that might arise, including adopting without delay a full brace position.

Passenger brace positions have evolved somewhat since they were first described in the literature in the mid-1960s. Brace position research began in the mid-1960s at the American Federal Aviation Authority (FAA) Civil Aerospace Medical Institute (CAMI) in Oklahoma City. The most important initial studies related to the brace position were those carried out by engineer Dr. John J. Swearingen on impact-related facial injuries and tolerance. It was also Dr. Swearingen who observed that in "airline crashes it is important for the passengers to remain conscious so that they can escape rather than be asphyxiated or burned to death even though otherwise uninjured."[35] This statement, made thirty years ago, remains true today.

In 1967, Dr. J.D. Garner, also an engineer at CAMI, conducted a series of crash impact tests and determined that the ideal brace position was one in which

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34) Requirements and Guidance for operators. CAP 789. Safety Regulation Group. Civil Aviation authority. 18 February 2011. https://publicapps.caa.co.uk/docs/33/CAP%20789.pdf

35) Swearingen J. Evaluation of head and face injury potential of current airline seats during crash decelerations. FAA. 1966. https://www.faa.gov/data_research/research/med_humanfacs/oamtechreports/1960s/media/AM66-18.pdf

the body was flexed and with the head resting on the arms, which were crossed on the back of the seat in front. Further work was carried out in the early 1970s by Dr. John Chandler, again at CAMI. He investigated the head-strike zone, which is the area around the passenger or crew member that should be kept clear to avoid the head striking anything were the individual to flail during impact.

The next series of studies emerged from the Kegworth Air Disaster and involved both sled impact testing (with anthropomorphic dummies as the test subjects) and computer simulation. The studies focused on the optimal brace position for passengers facing forwards in economy seats, restrained only with lap belts. In this position, the passenger sits flexed forward with the head against the seat in front. The hands are placed on the back of the head, with the non-dominant hand covering the dominant hand and the fingers kept unlinked. The elbows are tucked in. The feet are positioned as far back under the seat as possible. This position became known as the Kegworth brace position, was adopted by the UK Civil Aviation Authority (CAA) in August 1993 and remains the CAA recommended brace position for all forwards-facing, lap-belted passengers in UK airlines to date.[36)]

Starting in 1991 and continuing into 2004, a group in Germany, TUV, conducted a series of sled impact tests for both passenger and crew brace positions. The passenger position required the passenger to extend his or her legs under the seat in front and/or to brace the legs against the supports of the seat in front. The body was to be bent forwards, with the head braced against the seat in front and resting on the arms or hands that were crossed on the seat back. The crew brace positions were essentially like the basic cabin crew pre-brace position but with some minor differences depending on whether or not the cabin crew member was seated facing forwards or backwards and in a single or a double crew seat.[37)38)39)40)]

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36) Brownson P, Wallace WA, Anton DJ. A modified crash brace position for aircraft passengers. Aviation Space & Environmental Medicine. 1998; 69(10): 975-978.

37) Sperber M & Bancken M. Verletzungspotential an rückwärts gerichteten Flugbegleiterstationen unter dynamischen Notlandebedingungen. FE-Nr.: L-4/2004-50.0306/2004. Endberich. Bundesministerium fur Verkehr, Bau und Stadtentwicklung. TUVRheinland. Koln, September 2007.

38) Verletzungspotential an rückwärts gerichteten Flugbegleiterstationen unter dynamischen

Most recently, Amanda Taylor and her engineering colleagues at CAMI carried out a series of sled impact tests. They determined that the optimal position was identical to the Kegworth position but with one exception. Rather than positioning the hands on the back of the head with the elbows tucked in, the arms were to be extended down to the lower legs, which could be grasped by the hands.[41]

Most recently, an international group of experts - in aviation, engineering, clinical medicine and human factors - formed IBRACE or the International Board for Research into Aircraft Crash Events on November 21, 2016.[42] The purpose of the group is to produce an internationally agreed, evidence-based set of brace-for-impact positions for passengers and cabin crew in a variety of seating configurations, with results to be submitted to the International Civil Aviation Authority (ICAO) through the ICAO Cabin Safety Group (ICSG). The experts determined that decisions about the brace position should be 'evidence-based', in a way that is similar to the concept known as "evidence-based medicine".[43] In healthcare, the best decisions are made on the basis of individual clinical expertise, plus the best available external evidence and with discussion with the patient (and sometimes the family). With the brace position, clinical experience comes from studies of the injuries and post-mortem

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Notlandebedingungen. FE-Nr.: L-4/2004-50.0306/2004. Anhang zum Endbericht. Bundesministerium für Verkehr, Bau und Stadtentwicklung. TUVRheinland.

39) Sperber M & Bancken M. Protective Brace / Safety Positions for Passengers and Cabin and Cockpit Crew in Emergency Landing Conditions or Aborted Take-Off. FE no. L-3/2006 - 50.0319/2006 - Report. Federal Ministry of Transport, Building and Urban Affairs. TUVRheinland. Cologne, 19 December 2007.

40) Sperber M, Schäbe H, Masling D, Toth D, Küting J, Demary M, Wodli G. Carriage by Air of Special Categories of Passengers. Contract Number: EASA.2008.C.25. Final Report. TUVRheinland. Cologne. 09.11.2010.

41) Taylor A.M., DeWeese R.L., Moorcroft D.M. Effects of Passenger Position on Crash Injury Risk in Transport-Category Aircraft. Conducted by the Civil Aerospace Medical Institute (CAMI), FAA, Oklahoma City). DOT/FAA/AM-15/17. Office of Aerospace Medicine, Federal Aviation Administration (FAA). Washington, DC. September 2015. Revised 11/19/2015.

42) International Board for Research into Aircraft Crash Events. .https://en.wikipedia.org/wiki/International_Board_for_Research_into_Aircraft_Crash_Events

43) Sackett D.L. Evidence-Based Medicine. Science Direct 1997; 21 (1): 3-5. https://www.sciencedirect.com/science/article/pii/S0146000597800134

examinations of those injured and/or killed in aviation accidents. The best available external evidence comes from the research studies of the brace position, as well as the engineering knowledge and studies of the passenger and crew seating, restraints and cabin structure. While it is not possible to speak with all passengers about their choices, it is possible to consider their requirements and preferences and add that information to the decision-making process.

With respect to the recommendations for the best brace positions, the brace position experts could not come to agreement as to which of the positions from previous research should be chosen as 'the' passenger brace position. The experts determined that more research was needed to distinguish between, for example, the Kegworth position and the CAMI position. While awaiting funding to carry out more sled impact testing and computer simulation studies, members of IBRACE were able to contribute evidence-based recommendations for these two passenger brace positions (Kegworth and CAMI), as well as the TUV cabin crew brace positions. The recommendations, together with bespoke illustrations of the positions, were published in the 2018 ICAO Manual on Information and Instructions for Passenger Safety.[44]

Ⅲ. Regulations, and their gaps, relating to the emergency brace position

Once on board an aircraft, passengers ideally learn about the emergency brace position from the cabin crew, when they deliver the normal pre-flight briefing to passengers, either by showing a video and/or by speaking and demonstrating to passengers. Typically, the pre-flight briefing includes information about the use of the seat belt, oxygen masks, safety lighting strips, exits and life jackets. Some

44) ICAO. Manual on Information and Instructions for Passenger Safety. Document 10086. First Edition. Montreal: ICAO; 2018.

airlines also describe and demonstrate the emergency brace position while other airline companies do not.

Whether or not passengers are informed about the emergency brace position in the pre-flight briefing depends on the airline company. Currently, most airline companies in the United Kingdom, large parts of Asia, and in Australia and New Zealand do provide an in-person or video description and demonstration. In contrast, passengers in North America do not learn about the emergency brace position unless an emergency is declared and there is enough time to instruct the passengers. Were there to be a sudden emergency, however, there might not be sufficient time to do so, let alone to prepare the cabin for an emergency landing, which includes ensuring that passengers' seat belts are correctly positioned, and that seat backs, tray tables and other items that might fly loose and pose a hazard to passengers and crew are secured.

The information that airline companies provide to passengers in the pre-flight briefings and the passenger safety cards is primarily determined by the civil aviation regulations of each country. In fact, there is almost a "universal absence of national regulations mandating inclusion (of information about the brace position) in the passenger preflight briefing or safety cards". Despite this absence, as stated above, airlines in some countries do inform passengers about the brace position. A few countries, such as Canada, Australia and the United Kingdom, require airlines to provide passenger safety cards with information on the passenger brace positions. Transport Canada, for example, requires those illustrations for each type of seat and restraint system.[45] In contrast, a draft of proposed amendments of the European Commission Regulations state that "the operator should consider including the following information in its safety briefing material", with the information including the brace position with respect to "appropriate method to the applicable facing direction" and "alternative brace positions for e.g. expectant mothers, passengers with lap-held infants, tall or large individuals, children, etc.".

45) Transport Canada. (2012b). Standard 725.44: Safety features card and supplemental briefing card. Part VII: Commercial Air Services, Aviation Regulations (CARS). Ottawa, ON. http://www.tc.gc.ca/eng/civilaviation/regserv/cars/part7-standards-725-2173.htm

However, the phrase, “should consider” makes it clear that information about the passenger emergency brace position is optional and is not required. [46)]

Why do countries not mandate the airline companies that operate in their jurisdictions to provide information about the passenger emergency brace position in both the pre-flight briefings and in the passenger safety cards? The answer to this question is not known but one reason would appear to come from the fact that Annex 6 to the Convention on International Civil Aviation does not describe anything about the passenger emergency brace position. This document clearly stipulates the international standards and recommended practices for informing passengers of the location and use of seat belts, emergency exits, and cabin emergency equipment. However, the brace position is not mentioned.[47)]

Material that is in an Annex becomes part of a SARP or Standards and Recommended Practices, which are then translated into regulations at the ‘State’ (or country) level. Each State that is signatory to the Chico Convention is obliged to implement the Standards, in order to ensure safe international flight. Information that is in a Manual, such as in Doc 10086, Information and Instructions about Passenger Safety, is considered a recommendation and not a regulation. Therefore, to ensure that all passengers are provided with this information before take-off, changes would have to be made to the relevant Annex.

What ICAO would need to do would be to “develop and mandate new international standards to achieve compliance from all air carriers”, both in the preflight passenger briefing and on safety cards. These standards could be incorporated as a paragraph (4.2.12.5) in Annex 6 to the Convention on International Civil Aviation, Part I, International Commercial Air Transport-Aeroplanes. The new provision could state: “*The operator shall ensure that passengers are given preflight instruction about how*

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46) AMC1 CAT.OP.MPA.170 Passenger briefing. Annex to Decision 2017/008/R ‘AMC and GM to Part-CAT — Issue 2, Amendment 12’. https://www.easa.europa.eu/sites/default/files/dfu/Annex%20to%20Decision%202017-008-R.pdf

47) International Civil Aviation Organization. (2010). Operation of aircraft. Annex 6 to the Convention on International Civil Aviation, Part I International Commercial Air Transport: Aeroplanes (9th ed). Montreal, Canada.

to adopt the brace position for an emergency landing or impact of the aircraft. The operator shall also ensure the same information about how to adopt the brace position will also be included in the passengers' safety cards."[48)]

Why is it important that passengers learn about the brace position before take-off on every flight? Passengers need to know what to do and how to carry out those actions, ideally spontaneously and appropriately. One of the basic concepts in aviation safety is that the cockpit and cabin crew need to prepare for the unexpected. Emergencies do not occur on schedule but having the right knowledge, skills and experience in carrying out the correct procedures in an emergency has been shown to be life-saving. (This is also true in healthcare.) Both the cockpit and the cabin crew learn about and practice drills for the most common, and some uncommon, situations. (This is where the benefit of studying previous accidents has been shown to be enormously beneficial.) There is no reason why passengers should not similarly prepare. However, passengers need to be provided with information about the brace position and even, potentially, with an opportunity to practice bracing. Expecting passengers to react perfectly in an unanticipated emergency goes against the 'Be Prepared' safety training concept of the rest of the aviation system.

The issuing of brace-for-impact commands is slightly different in an emergency. In such a situation, the cabin crew might shout commands such as "Bend over, grab ankles" or "Head down, stay low," as they did in the crash of Air Canada 624 (described above). Because no emergency was expected, passengers and cabin crew were not braced when the primary impact occurred. Thereafter, some of the passengers had braced for landing, either spontaneously or after hearing the shouted command, "Bend over, keep your head down", given by the Flight Service Director, as well as by some off-duty Air Canada flight attendants who were in transit on the aircraft. Some passengers did not hear any command while "others did not know how to properly brace themselves, not having read the passenger safety card". Most of the injuries sustained by the passengers were consistent with not adopting a brace

48) Yoo KI, Davies JM. A request for regulatory revision: Instructions for passenger bracing for emergency landings. Aviation Psychology and Applied Human Factors 2015;5:45-51

position. In all, 26 individuals were taken to hospital, including both pilots and one member of the cabin crew, although all were released the same day.49)

In the case of the Air France runway excursion in Toronto in 2005, passengers experienced a different situation. As the plane left the runway and bounced into the ravine, the "cabin crew did not instruct passengers as to what actions they should take relevant to the emergency at hand, that is, they did not instruct passengers to assume brace-for-impact protective positions". Neither European regulations nor Air France's emergency procedures required the cabin crew to shout any form of "brace command" in the event of an unexpected accident. "Air France cabin crew are only required to shout BRACE commands in prepared emergency landings." In contrast, Transport Canada regulations require that airlines' cabin crew manuals and cabin crew training programs include procedures for cabin crew to shout BRACE commands at the first indication of a potential accident,50) and without waiting for the Captain to issue a 'brace for impact' command. The utility of the Transport Canada regulations was made clear in the case of Air Canada 624.

The examples of Air France 358 and Air Canada 624 can be compared, using the Winnipeg Model.

Table: System-view comparison of Air France 358 and Air Canada 624

	Structure	Process	Outcome
Passengers • Air France (AF) • Air Canada (AC)	AF: 297 AC: 133	AF: Passengers did not brace AC: Some passengers braced	AF: 9 passengers "received serious injuries as the result of the impact AC: 20 passengers received "minor injuries"

49) Aviation Investigation Report A15H0002. Collision with terrain. Air Canada Airbus Industrie A320-211, C-FTJP. Halifax/Stanfield International Airport, Halifax, Nova Scotia 29 March 2015. Transportation Safety Board of Canada, 2017 http://www.bst-tsb.gc.ca/eng/rapports-reports/aviation/2015/a15h0002/a15h0002.pdf

50) Aviation Investigation Report. A05H0002. Runway Overrun and Fire. Air France. Airbus A340-313 F-GLZQ. Toronto / Lester B. Pearson International Airport, Ontario, 02 AUGUST 2005. Transportation Safety Board of Canada

	Structure	Process	Outcome
Personnel (Cabin Crew)	AF: Did not receive any training or recurrent training about issuing a brace command in an unplanned emergency landing AC: Received both training & recurrent training about issuing a brace command in an unplanned emergency landing	AF: No cabin crew member issued any brace command AC: One working cabin crew member and a few 'in transit' cabin crew members shouted brace commands.	
Environment / Equipment	AF: Airbus A 340 AC: Airbus A320	AF: Runway excursion into a ravine, bounced 3 times AC: Landed short of the runway, bounced and slid	
Organization(s)	AF: Did not have any procedures requiring cabin crew to shout brace commands in unprepared emergency landings AC: Had procedures for cabin crew to shout brace commands at the first indication of a potential accident		
Regulatory Agencies	AF: European Commission had no regulations requiring airlines to have procedures for cabin crew to shout brace commands in unprepared emergency landings AC: Transport Canada had requirements for airlines to have procedures for cabin crew to shout brace commands at the first indication of a potential accident AF & AC: ICAO's Annex 6 made no mention of the brace position		

Obviously, the two accidents are not perfectly comparable but they are enough alike to allow them to be compared. The function of this Table is to demonstrate the existence and influence of problems at a system level, particularly at the regulatory level, which then influence the organizations over which they have control. In turn the organizations pass along these regulatory deficiencies in the ways in which airline companies' employees are instructed and trained. The employees (in these cases, the cabin crew) then act in specific ways that affect the passengers' actions and behaviours. These system-level problems are Professor James Reason's "latent conditions", which remain hidden until unmasked by a series of events, fortunately in neither of these specific accidents leading to tragedy.

Ⅳ. Conclusions

Aviation's safety record continues to improve yearly, especially with respect to passenger and crew injuries and deaths. However, although the number of accidents has decreased over the decades, there are still many events, such as landings short of the runway and runway excursions, both of which pose threats to passenger and crew safety. Surviving any kind of aviation accident depends on the physiological threat and stress of the impact(s), the extent to which the physical structure surrounding the passengers and crew remains intact, and the ability of the passengers and crew to be able to escape the wreckage. The one action that both passengers and crew can carry out to help decrease the likelihood of crash-related injury or death is to assume an emergency brace position. Doing so has been demonstrated over several decades to improve survivability. While cabin crew are taught (and then might have to teach passengers in an emergency about the emergency brace position), passengers in many parts of the world never learn about the brace position unless they are involved in an emergency in which there is time to prepare for the landing. This lack of provision of information is related to the fact that most airlines do not provide information in the preflight safety briefing and some do not even provide the information in the passenger safety cards. Many countries do not require their airlines to do so, a fact, which in turn, is related to the lack of mention of the brace position in ICAO's Annex 6. Until standards and recommended practices are changed at the highest world level, passengers will continue to be deprived of this vital, life-saving information that they can use, potentially to help save their own lives.

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Abstract

Regulatory Aspects of Passenger and Crew Safety: Crash Survivability and the Emergency Brace Position

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Aviation's safety record continues to improve yearly, especially with respect to passenger and crew injuries and deaths. However, although the number of accidents has decreased over the decades, there are still many events, such as landings short of the runway and runway excursions, both of which pose threats to passenger and crew safety. Surviving any kind of aviation accident depends on the physiological threat and stress of the impact(s), the extent to which the physical structure surrounding the passengers and crew remains intact, and the ability of the passengers and crew to be able to escape the wreckage. The one action that both passengers and crew can carry out to help decrease the likelihood of crash-related injury or death is to assume an emergency brace position. Doing so has been demonstrated over several decades to improve survivability. While cabin crew are taught (and then might have to teach passengers in an emergency about the emergency brace position), passengers in many parts of the world never learn about the brace position unless they are involved in an emergency in which there is time to prepare for the landing. This lack of provision of information is related to the fact that most airlines do not provide information in the preflight safety briefing and some do not even provide the information in the passenger safety cards. Many countries do not require their airlines to do so, a fact, which in turn, is related to the lack of mention of the brace position in ICAO's Annex 6. Until standards and recommended practices are changed at the highest world level, passengers will continue to be deprived of this vital, life-saving information that they can use, potentially to help save their own lives.

Key words : Aviation's safety record, emergency brace position, Annex 6, Passenger and Crew Safety, ICAO

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