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MAJOR AIR DISASTERS: ACCIDENT INVESTIGATION AS A TOOL FOR DEFINING ERAS IN COMMERCIAL AVIATION SAFETY CULTURE

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Abstract. The air transport evolution has been littered with major air disasters, the occurrence of which has not only had the negative effects inherent to any disaster. Air accident investigation has provided a wealth of knowledge that has advanced the aviation industry and its safety. International Civil Aviation Organization has exercised international regulatory leadership since 1947, developing tools with international cooperation, such as the air accident investigation methodology. ICAO has forged a change in perspective on safety attributions or factors in different historical eras, using this methodology to deepen the understanding of the causes and thereby achieve aviation safety improvement. Authors aimed to analyze, through a detailed study of the world's worst aviation accidents, their contribution to understanding the details of aviation safety culture. Beyond the technical issues and fatality rates, the necessary analysis is what knowledge researchers have gained from the beginning, exploring the attributions of reports and knowing what diverse factors have predominated in different eras. Descriptive analyzes of air disaster investigation have two objectives: to identify the beginnings of a global safety culture resulting from evolution in operational safety and to relate the different eras to the attributions of air accident investigations.

Keywords: air accident, air disaster, aviation psychology, aviation safety, human factors, International Civil Aviation Organization (ICAO), operational safety, organizational factor, preventive measures, safety culture.

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Introduction

Is safety culture present in commercial aviation worldwide? If so, at what particular time does an efficient safety culture appears in the commercial air transport industry? What technical, human, and organizational factors are characteristic in each of the diverse eras in which aviation safety has historically developed? Before the development of commercial aviation, as it is know nowadays, the Wright brothers marked a historic milestone in 1903 with the first powered flight in history (Bravo, 2016; Bridges, 1967; Burrel, 1992; Hawkes, 1992; Marimón, 1973); however, they were also protagonists of the first fatal plane crash, only a few years later, in 1908[1] (Bridges, 1967; GTD Engineering System & Software, 2010). This tragic first accident not only led to the evolution of its prototype but also served as a way to learn from its mistakes and caused, in short, an improvement in incipient air safety. These preventive measures came about before it was possible to speak of aviation security as such, before aviation was transformed into a globalized and profitable industry, and even before it became a mass air transport.[2]

The subsequent development of commercial aviation would not begin until the mid-twentieth century, although since then, the aeronautical industry has experienced exponential growth up to these days. Nevertheless, the evolution of the industry, like the pioneering Wright brothers, has not been accident-free since its inception. The numerous accidents have been caused by several factors, which present different importance depending on the historical era under study. Initially, most of the incidents were due to technical issues, giving way later to the human factor as the main precipitating one, and after the aeronautical industry implemented an endless number of technical improvements. When technological advances reached their maximum development, they generated the need to integrate man into the machine. Finally, a closer look at the last decades of the last century shows how organizational and institutional factors started to appear when the complexity of the industry began to need greater regulation.

[1] The aircraft piloted by Orville Wright broke down a propeller, resulting in the ensuing accident in which Lieutenant Thomas Selfridge, who was flying as a passenger, died.

[2] For example, the use of helmets by the U.S. Air Force pilots was made mandatory due to this accident (VAIU, 2017).

This study not only focuses on the search and definition of the beginning of a culture of aviation safety, as it is understood globally in other industries[3] (Institute for an Industrial Safety Culture, 2017, 2021) but dives into the history of aviation safety (International Civil Aviation Organization [ICAO], 2006, 2009, 2013a, 2018) through the reports on the most relevant accidents that have taken place. Air disasters tell the story of typical learning in a young industry (less than 100 years making its operations profitable) not exempt from certain dangers. The factors revealed have been distributed differently in different eras. Authors such as James Reason, Frank E. Bird, Edwin Edwards, and many others focused their studies on human error. Additionally, they contributed to causing a period of change in mentality that delimits two fundamental eras in the analysis and management of air accidents caused by the human factor. Thus, at the beginning of the 90s, this intersection or change of attribution concerning human error can be located; when it was first openly recognized that the operational context directly influences the performance of the human factor as a generator of incidents and accidents (ICAO, 2009).

A proper way to approach all these issues is to study the original investigation reports of past air accidents, as they represent a vast source of knowledge. To this fact is added that almost all of them are available, and their consultation is publicly accessible. The objective sought with this is to identify the specific beginning of the safety culture. Additionally, demonstrate the factors that have been predominant in every historical era of commercial aviation. The methodology of accident investigation (ICAO, 2001, 2011, 2012, 2015, 2016, 2020a, 2020c) has been extensively developed in air transport regulations and is as old as aviation. This development, its leadership, and international unification come from the hand of the International Civil Aviation Organization (ICAO, 2021), a specialized agency of the United Nations in everything related to aviation.

1. Safety culture and air disasters

Safety culture definition has evolved throughout the different editions of the ICAO Safety Management Manual. The initial editions (ICAO, 2006; ICAO, 2009) considered the terms *safety culture* and *organizational culture* as synonyms, referring to share beliefs, practices and attitudes. The third edition used the term *organizational culture* adapted to safety and with reference to the characteristics and safety perceptions among members interacting within a particular entity (ICAO, 2013a). In the latest edition, the definition links the operational safety with the human factor in the aviation system as how people behave in relation to safety and risk when no one is watching, which coincides with that used by the Institute for Industrial Safety Culture ([ICSI], 2021). Therefore, the definition is becoming universal and global. It is then that ICAO recommends accident investigation as a basic tool and methodology to analyze the real evolution of safety culture (ICAO, 2018), and does so under Article 37 of the Chicago Convention on Adoption of International Standards and Procedures "Aircraft in distress and investigation of accident" (ICAO, 1944, paragraph k).

Accident investigation is a post-accident analytical technique that can also serve as a reactive method of prevention (Rodríguez, 2012). This technique has been and is one of the pillars for the development of security in general. In the field of air transport, it has been of vital importance in the prevention of accidents, creating and promoting improvements in the design and manufacture of aircraft, training of personnel, protocols and in the development of extensive legislation. Investigations into major air disasters have promoted both reactive measures (recommendations) and preventive measures (increasingly complex global improvement system) (Lombardo, 2020).

Commercial aviation has proven to be able to evolve, acquiring knowledge from the investigation of its accidents. Furthermore, it has succeeded in integrating and managing this knowledge with high levels of operational safety, enough to guarantee the economic profitability of the sector. Regulatory leadership as a generator of safety culture is vital to understanding this evolution. ICAO has created a common language, internationally standardized management system processes, and generated policies, regulations, and manuals to increase the safety of operations. It could be argued that one of the most important contributions (technical, human, and organizational) that have marked the safety culture is the investigation of technical, human, and organizational errors in a high number of accidents (ICAO, 2018).

The most catastrophic plane crash in history, in terms of fatalities, was the one that occurred, in 1977, at the airport of Los Rodeos (Tenerife, Spain), in which two Boeing 747 collided, with a fatal balance of 583 deaths (BBC Mundo, 2013; Helmreich, 2006; Ranter, 2015). The principal cause was the unauthorized take-off of the pilot of one of the aircraft operated by KLM (Koninklijke Luchtvaart Maatschappij). However, its technical analysis shows how an innumerable chain of events and technical, human, and organizational errors contributed to the outcome. Firstly, the bomb warning at Las Palmas airport caused the diversion of all flights to the nearby Tenerife Norte airport -Los Rodeos-, which also had only one runway, without ground radar and damaged runway lights. Secondly, the appearance of very dense fog and the presence in Los Rodeos tower of only two air traffic controllers, absolutely overwhelmed by the excessive traffic of that day at the airport. Finally, the linguistic confusion and cancellation in radio communications, the rush syndrome, the lack of recent flight hours of the KLM pilot, and the organizational pressure of the policies of the operator of that company formed the perfect combination for the disaster. As the only positive aspect, we can stay with the fact that the

[3] Based on organizational culture with "shared beliefs, practices, and attitudes" (International Civil Aviation Organization, 2009, pp. 2–28).

subsequent investigation into this accident would cause substantial changes in international regulations and dozens of recommendations for air operation (ICAO, 2013b). Before Los Rodeos, the airlines modified the training for pilots in command, creating the management of resources in the cabin (Crew Resource Management [CRM]), which has continued in constant evolution (Muñoz-Marrón, 2018). Airlines also created awareness of the problem of the hierarchy in the cabin (Comisión Investigación de Accidentes e Incidentes de Aviación Civil España, 1977).

Accident and catastrophe are different terms. The Royal Spanish Academy of Languages (RAE) differentiates between an accident "eventual event or action that results in involuntary damage to people or things" (RAE, 2020a, definition 2), and a catastrophe "event that produces great destruction or damage" (RAE, 2020b, definition 1). The World Health Organization (WHO) also adds an aspect related to the risk process by defining catastrophe or disaster in English as a "serious disturbance of the functioning of a community or society that causes widespread human, material, economic or environmental losses that exceed the capacity of the affected community or society to cope with the situation with its own resources" (World Health Organization, 2008, p. 22). That is, catastrophe not only as a result of a natural hazard, but as a risk process in which several elements appear (the existence of a danger, vulnerability and insufficient measures). In air transport there is no definition of the term catastrophe, but the WHO definition complies with both definitions, both that given by the RAE, and the definition internationally institutionalized by the WHO: *Inherent danger of flying*; *vulnerability that entails a means of air transport and insufficient measures of the technical, human or organizational type, that cause a serious disturbance of the system producing human losses and great destruction.*

Understanding that a catastrophe goes far beyond an accident and that there is no definition or aeronautical term to define it, it is important to delimit the parameters on which the industry bases to differentiate the "catastrophe" from the plane crash. It is crucial to be clear about which accidents are considered air disasters to understand how these have driven research and the construction of a culture of operational safety in the air transport industry. The definition of serious air disaster used throughout this paper is limited to the definition contained in the ICAO regulation: commercial flight accidents (general aviation, military, helicopters, and Remotely Piloted Aircraft System [RPAS] excluded), where the aircraft is economically unrecoverable or of the hull loss type[4] (excluding fatal type accidents). Excluded too are kidnappings and sabotage due to the unexpected nature of the event and the lack of relationship with operational safety (*safety management*), and since they are more linked to the physical security measures at airports (*security*). These measures are adopted to avoid the intentional damage of some people against others whose regulation, contained in Annex 17 of the safety of the ICAO (ICAO, 2020b), is periodically amended in response to evolving threats.

2. Periods in the evolution of operational safety

It is essential to analyze the different periods and times through which air transport has passed, what normative publications and technical advances have occurred in each of them, and what objectives have been priorities. The rules and regulations that have been necessary to formulate since the creation of the ICAO (in 1947) in its objective to guarantee flight safety are also important issues to consider. The establishment of the structure of this timeline is crucial, as it will delimit the periods of evolution and changes in mentality in terms of safety while, at the same time, checking the behavior and trend concerning the occurrence of primary air disasters worldwide. In short, it will be the line of argument and the constant that will test the hypotheses.

To establish these periods (Figure 1), has been taken as a reference the structure of ICAO technical publications, specifically the Operational Safety Manual (ICAO, 2006; ICAO, 2009; ICAO, 2013a; ICAO, 2018), using all its editions. This manual is a document that provides guidance and detailed information on international safety standards, best practices, and procedures (ICAO, 2006).

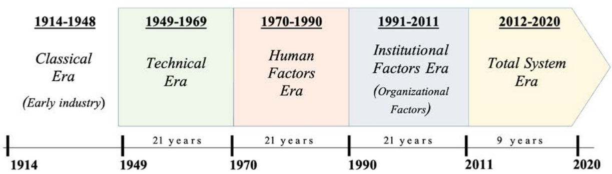

Figure 1. Operational safety evolution reference periods

3. Hypotheses

ICAO Safety Management Manual, 2nd edition, (ICAO, 2009) delimits two clear periods in terms of the errors produced by the human factor: before and after the early 1990s. This second edition defines a specific time point at which there is a significant change of mentality in relation to the analysis and management of accidents. At the beginning of the 90s, the organization recognized, for the first time, that people work within defined operational contexts. Although previously, scientific literature was available in this regard (related to the influence of a given operative context over performance and execution), it was not until the 90s that the aeronautical world publicly and officially recognized this fact. This milestone marks the beginning of the so-called "era of the organization" in which

[4] A hull loss is an event in which the aircraft is destroyed or damaged with no possibility of economic repair.

operational security begins to be seen from a systemic perspective, thus encompassing organizational, human, and technical factors (ICAO, 2009).

Considering that, the present paper aims to test the following hypotheses:

Hypothesis 1. The beginning of the safety culture is established in the 90s, coinciding with the beginning of the "institutional era". Therefore, during this period, considerable regulatory development in the number of publications of the four established periods can be expected, together with a drastic reduction in the number of accidents and mortality in commercial aviation.

Hypothesis 2. The attributions about causes and recommendations in the investigation of accidents:

- H 2.1. There will predominantly be technical type attributions during the technical era.
- H 2.2. There will predominantly be human type attributions during the human factors era.
- H 2.3. There will predominantly be organizational type attributions during the institutional era/total system era.

Hypothesis 3. From 1949 to 2020, technical factors or errors will follow a decreasing trend, while both human and organizational factors will follow an increasing trend.

4. Method

The objective of this analytical-observational study is to identify the specific period where an efficient safety culture appears through a detailed analysis of the literature and existing data. In addition, based on the accident investigation reports, this work tries to find the relationship between each of the established reference periods (as far as operational safety evolution is concerned) and the attribution of the causes of air accidents that occurred in each of them.

Two types of variables are used that, functioning as dependent variables (DV), have a direct relationship with the object of study:

- Quantitative variables: (1) the number of ICAO regulatory publications; (2) the global commercial aviation mortality rate; (3) the global commercial aviation air accidents rate; and (4) the global commercial aviation high mortality air accidents rate (accidents with more than 49 victims).
- Qualitative variables: (1) the accident attribution of causality in the investigation reports.

The data collected for both sets of variables (quantitative and qualitative) were analysed using each reference period as a time frame. The analysis of the results provided by the quantitative variables serves to identify, in a concrete way, the starting point of the operational safety culture in each of the eras.

ICAO publications have been chosen as a frame of reference because ICAO is one of the most important regulatory bodies in the aviation sector worldwide. ICAO has always created its own regulatory standards, adapting to the evolution of the sector. A constantly changing and increasingly complex sector that has been able to take on the challenges posed by major air disasters, using them as a learning and knowledge tool to increase safety culture. The number of ICAO regulatory publications (quantitative variable 1) is in the line with the number of changes in operational safety, and is one way of determining safety culture in terms of its importance in generating a shared ways of doing and thinking (ICSI, 2021).

The rest of the statistics rates (quantitative variables 2, 3, and 4) have been chosen because they are all considered to be one of the many consequences of poor safety cultures over the years, and inform us about significant changes in the overall trend, in order to provide us with interesting global information to integrate with the qualitative variable. The operational safety aims to reach the utopia of *zero accidents* and the safety culture changes people's behaviour in order to achieve as few accidents as possible, because safety culture and the quest for zero air accidents are closely related.

On the other hand, the qualitative variable is used to analyze the relationship between this variable and the types of causality attributions of air accidents in the investigation reports for the period 1949–2020.

Air accident investigation reports have been employed for the study of qualitative variables. These reports present a standardized structure since the beginning of commercial aviation (ICAO, 1970, 2020c), making them an excellent analysis tool. This structure included in the "ICAO Annex 4 – Mandatory content research report according to Annex 13 and relationship with the technical (FT), human (FH) and organizational (FO) factors involved" (ICAO, 2020a, 2020c) shows that the essence of the report itself has not changed. And although the attributions included in them are difficult to measure, in order to quantify their analysis objectively, a triple classification of the causes and recommendations contained in these research reports has been made. Thus the categorization aims to identify which of the factors: (1) technical (material safety condition, factors related to airworthiness status of the aircraft, system design, meteorology and navigation systems), (2) human (safety-related actions or omissions constituting dangerous acts that jeopardize operational safety), or (3) organizational (cultural, economic, organizational, and management activities with direct and indirect influences on aircraft operation, such as resources and financial viability, management policies and practices, communications, certification safety oversight and regulatory framework, etc.), can be attributed to the occurrence of each of the accidents analyzed.

5. Procedure

Two types of analysis have therefore been developed. The first is descriptive concerning quantitative variables to test hypothesis 1. The second is through the qualitative analysis of the historical attributions of significant accidents to test hypotheses 2 and 3.

As for the quantitative descriptive analysis corresponding to hypothesis 1, the safety culture eras of evolution differ in the number of years: 21 years for the technical, human and institutional factors, and 9 years for the total system era. The annual average, which facilitates comparison between periods, is used for each variable to unify and compare the results. In addition, to conclude if the jump from one era to another is significant, three *Stevens' t-tests* (bidirectional and assuming unequal variances) have been performed beyond the graphical representation of each variable. These tests have been completed for each of the three consecutive inter-era jumps (specifically between two eras): technique-human factors, human-institutional and institutional-current factors. This methodology, employed for each quantitative variable of the theoretical model, allows us to check which jump between the eras has statistical significance. *Stevens' t-test* for two samples is an appropriate method of checking whether the differences observed in the graphical representations are significant.

To test hypothesis 1, about the beginning of the safety culture in the 90s, has been made a count (editions and total amendments during the period 1949–2020) of ICAO publications (Chicago Convention and Annexes from 1 to 19) that regulate international commercial aviation (the two documents on operational safety and accident investigation that develop Annex 13 and 19 have been taken into account respectively and others that significantly comply with the Chicago Convention). Regarding mortality and accident rates, there are few organisms with all the data available, so those provided by the Aviation Safety Network (ASN) database have been used (Ranter & Lujan, 1996). The ASN is a private and independent body that covers accidents and safety issues of commercial, military, and private aviation.

In order to test hypotheses 2 and 3, the conclusions of investigation reports of a sample of accidents that meet the requirements of the definition of major catastrophes framed in commercial aviation have been analyzed, excluding military accidents, general aviation, and hijackings. To have a uniform sample and thus be able to compare results with respect to the different times, the criterion of choosing the accident with the highest number of fatalities per year between 1949–2020 has been followed. The sample has been extracted from the Aviation Safety Network ASN database (Ranter & Lujan, 1996). From among 23000 records, 71 hull-loss accidents have been selected, the deadliest per year of the period (with more than 49 victims), that is, 21 for each past era: technical era (Figures 2 and 3), human era (Figures 4 and 5), and organizational factors era (Figures 6 and 7) and 8 for total system era (Figure 8)[5].

From original investigation reports, information on the conclusions of every accident (leading causes, contributing causes, and recommendations) was collected. Once each category is defined, all the sources and recommendations are classified according to one of the three categories. That is, whether they are technical, human, or organizational issues. To provide an example, Figure 9 shows the first four accidents in the sample and their classification according to the procedure described.

	DATE	AIRCRAFT TYPE	AIRLINE	Fligtnumber	RUTE	Occupants	Fatalities	CRASH SITE	COUNTRY	AGENCY REPORT
1.	June 7, 1949	Curtiss C-46D	Strato-Freight	-	San Juan, Puerto Rico – Miami (FL), USA	81	53	10 km (6.3 mls) W off San Juan-Isla Grande Airport (SIG)	Puerto Rico	(Civil Aeronautics Board, 1950)
2.	December 12, 1950	Avro 689 Tudor 5	Fairflight	-	Dublin Airport, Ireland – Llandow RAF Station, United Kingdom	83	80	Near Llandow	United Kingdom	(ICAO, 1951)
3.	December 16, 1951	Curtiss C-46F	Miami Airlines	-	Newark (NY), USA – Tampa (FL) USA	56	56	4 km (2.5 mls) WSW of Newark International Airport, NJ (EWR)	USA	(Civil Aeronautics Board, 1952a)
4.	April 11, 1952	Douglas DC-4	Pan Am	526A	San Juan, Puerto Rico – New York, USA	69	52	18 km (11.3 mls) NW off San Juan-Isla Grande Airport (SIG)	Puerto Rico	(Civil Aeronautics Board, 1952b)
5.	February 14, 1953	Douglas DC-6	National Airlines	470	Tampa (FL), USA – New Orleans (LA), USA	46	46	Mobile, Alabama	USA	(Civil Aeronautics Board, 1954)
6.	August 16, 1954	Bristol 170 Freighter 21E	Air Vietnam	-	Hanói (Vietnam) – Saigón (Vietnam)	55	47	Near Pakse, Champasak	Laos	(Hubert, 1990)
7.	October 6, 1955	Douglas DC-4	United Airlines	409	Denver, USA – Salt Lake City (UT) (USA)	66	66	Medicine Bow Peak, Wyoming	USA	(Civil Aeronautics Board, 1957)
8.	June 20, 1956	Lockheed L-1049E-55 Súper Co	LAV	253	New York, USA – Caracas, Venezuela	74	74	65 km (40.6 mls) SE off New York, NY	USA	(ICAO, 1956)
9.	August 11, 1957	Douglas DC-4	Maritime Central Airways	-	Keflavik, Iceland – Goose Bay, Canada	79	79	7,2 km (4.5 mls) W of Issoudun, Quebec	Canada	(ICAO, 1957)
10.	August 14, 1958	Lockheed L-1049H-01-06-162 S. Co	KLM	607E	Shannon, Ireland – Gander, Canada	99	99	180 km (112.5 mls) W of Shannon, Ireland	Atlantic Ocean	(Ranter y Lujan, 2021e)

Figure 2. Sample of accidents 1–10. Technical era, 1949–1969

5 There is no sample in 2017 that meets the established criteria.

	DATE	AIRCRAFT TYPE		Flightnumber	RUTE	Occupants	Fatalities	CRASH SITE	COUNTRY	AGENCY REPORT
11.	June 26, 1959	Lockheed L-1649A Starliner	TWA	891	Milano-Malpensa, Italy – Paris-Orly, France	68	68	32 km (20 mls) NW of Milano, Lombardy	Italy	(Italian Republic Ministry of Defense Board of Inquiry, 1960)
12.	December 16, 1960	Douglas DC-8-11	United Airlines	826	Chicago (IL) – New York (NY) USA	77	90	New York, NY	USA	(Civil Aeronautics Board, 1962)
13.	September 10, 1961	Douglas DC-6B	President Airlines	-	Shannon, Ireland – Gander (NL), Canada	83	83	1,5 km (0.9 mls) S off Shannon Airport	Ireland	(Minister for Transport and Power of Ireland, 1963)
14.	June 3, 1962	Boeing 707-328	Air France	007	Paris, France – New York, USA	132	130	Paris-Orly Airport	France	(Ministere des Travaux Publics et des Transports France, 1965)
15.	November 29, 1963	Douglas DC-8-54F	TCAL	831	Montreal, Canada – Toronto, Canada	118	118	Sainte-Thérèse-de-Blainville, Quebec	Canada	(Commision of Inquiry of Canada, 1964)
16.	September 2, 1964	Ilyushin Il-18V	Aeroflot Krasnoyarsk	721	Moscow, Russia – Yuzhno-Sakhalinsk, Russia	93	87	26 km (16.3 mls) NW of Yuzhno-Sakhalinsk Airport, Sakhalin oblast	Russia	(Ranter y Lujan, 2021g)
17.	May 20, 1965	Boeing 720-040B	PIA	705	Dhahran, Sudi Arabia – Cairo, Egypt	127	121	20 km S of Cairo International Airport	Egypt	(ICAO, 1965)
18.	February 4, 1966	Boeing 727-81	All Nippon	60	Sapporo, Japam – Tokio, Japan	133	133	12 km (7.5 mls) ESE of Tokio-Haneda, Kantō	Japan	(Ranter y Lujan, 2021i)
19.	April 20, 1967	Bristol 175 Britannia 313	Globe Air	-	Bombay, India – Cairo, Egypt	130	126	3,5 km (2.2 mls) S of Nicosia Airport	Cyprus	(Ministry of Communications and Works of Nicosia, 1967)
20.	April 20, 1968	Boeing 707-344C	South African Airways	228	Windhoek, Namibia – Luanda, Angola	128	123	5 km (3.1 mls) E of Windhoek-Strijdom International Airport	Namibia	(Ministry of Transport of Pretoria, 1968)
21.	March 16, 1969	DC-9-32	AVENSA, op.por VIASA	742	Maracaibo, Venezuela – Miami (FL), USA	84	155	Maracaibo	Venezuela	(Ranter y Lujan, 2021f)

Figure 3. Sample of accidents 11–21. Technical era, 1949–1969

	DATE	AIRCRAFT TYPE	AIRLINE	Flightnumber	RUTE	Occupants	Fatalities	CRASH SITE	COUNTRY	AGENCY REPORT
22.	July 3, 1970	DH-106 Comet 4	Dan-Air Services	1903	Manchester, UK – Barcelona, Spain	112	112	Sierra de Monserrat	Spain	(Ministerio de Comercio e Industria España, 1971)
23.	July 30, 1971	Boeing 727-281	All Nippon	058	Sapporo, Japan – Tokio. Japan	162	162	Shizukuishi, Tōhoku	Japan	(AircraftAccidentInvestigation Commission Ministry of Transport Japan, 1971)
24.	October 13, 1972	Ilyushin Il-62	Aeroflot, International	217	Leningrad, Russia – Moscow, Russia	174	174	11 km (6.9 milles) N of Moskva-Sheremetyevo Airport	Russia	(Hubert, 2021b)
25.	January 2, 1973	Boeing 707-3D3C	Alia, op.for Nigeria Airways	-	Jeddah, Saudi Arabia – Lagos, Nigeria	202	176	Kano International Airport	Nigeria	(Ranter y Lujan, 2021b)
26.	March 3, 1974	DC-10-10	THY	981	Paris, France – London, UK	346	346	Bois d'Ermenonville	France	(France Secretariat D'etat Aux Transports, 2021)
27.	August 3, 1975	Boeing 707-321C	Alia	-	Paris, France – Agadir, Morocco	188	188	Agadir, Souss-Massa-Drâa	Morocco	(Hubert, 2021a)
28.	September 19, 1976	Boeing 727-2F2	THY	452	Istambul, Turkey – Antalya, Turkey	154	154	Isparta, Región Mediterránea	Turkey	(Hubert, 2021d)
29.	March 27, 1977	Boeing 747-121	Pan Am	4805	Tenerife, Spain – Las Palmas, Spain	248	335	Tenerife-Norte-Los Rodeos, Canary Islands	Spain	(Comisión Investigación de Accidentes e Incidentes de Aviación Civil España, 1977)
30.	January 1, 1978	Boeing 747-237B	Air-India	855	Bombay, India – Dubai, United Arab Emirates	213	213	3 km (1.9 mls) W off Bombay-Santacruz Airport	India	(Ranter y Lujan, 2021a)
31.	May 25, 1979	DC-10-10	American Airlines	191	Chicago (IL), USA – Los Angeles (CA), USA	271	273	Chicago-O'Hare International Airport, IL	USA	(National Transportation Safety Board, 1986)

Figure 4. Sample of accidents 22–31. Human era, 1970–1990

	DATE	AIRCRAFT TYPE	AIRLINE	Flightnumber	RUTE	Occupants	Fatalities	CRASH SITE	COUNTRY	AGENCY REPORT
32.	August 19, 1980	Lockheed L-1011 TriStar 200	Saudi Arabian	163	Riyadh, Saudi Arabia – Jeddah, Saudi Arabia	301	301	Riyadh International Airport	Saudi Arabia	(Presidency of Civil Aviation Kingdom of Saudi Arabia, 1982)
33.	December 1, 1981	DC-9-81 (MD-81)	Inex-Adria Aviopromet	308	Ljubljana, Slovenia – Ajaccio, France	180	180	24 km (15 mls) SE of Ajaccio-Campo dell'Oro Airport	France	(Ministere des Transports France, 1983)
34.	July 9, 1982	Boeing 727-235	Pan Am	759	New Orleans (LA), USA – Las Vegas (NV), USA	145	153	1,4 km (0.9 mls) E of New Orleans International Airport, LA	USA	(National Transportation Safety Board, 1983)
35.	November 27, 1983	Boeing 747-283B	Avianca	011	Paris, France – Madrid, Spain	192	181	Madrid-Barajas, Madrid	Spain	(Comisión Investigación de Accidentes e Incidentes de Aviación Civil España, 2021)
36.	October 11, 1984	Tupolev Tu-154B-1	Aeroflot, East Siberia	3352	Krasnodar, Russia – Omsk, Russia	179	178	Omsk Airport	Russia	(Hubert, 2021c)
37.	August 12, 1985	Boeing 747SR-46	Japan Airlines JAL	123	Tokio, Japan – Osaka, Japan	524	520	26 km (16.3 mls) SW of Ueno Village, Tano district	Japan	(AircraftAccidentInvestigation Commission Ministry of Transport Japan, 1987)
38.	March 31, 1986	Boeing 727-264	Mexicana	940	Mexico City, Mexico – Puerto Vallarta, Mexico	167	167	Las Mesas	Mexico	(Ranter y Lujan, 2021h)
39.	May 9, 1987	Ilyushin Il-62M	Polish Airlines LOT	5055	Warsaw, Poland - New York, USA	183	183	6 km (3.8 mls) SE of Warszawa-Okecie Airport	Poland	(Ranter y Lujan, 2021d)
40.	March 17, 1988	Boeing 727-21	Avianca	410	Cúcuta, Colombia – Cartagena, Colombia	143	143	25 km (15.6 mls) NW of Cúcuta-Camilo Daza Airport	Colombia	(Ranter, 1999)
41.	June 7, 1989	DC-8-62	Surinam Airways	764	Amsterdam, Netherlands – Paramaribo, Suriname	187	176	3 km (1.9 mls) W of Paramaribo-Zanderij International Airport	Suriname	(Commission of Inquiry of Suriname, 1989)
42.	February 14, 1990	Airbus A320-231	Indian Airlines	605	Bombay, India – Bangalore, India	146	92	0,7 km (0.4 mls) W of Bangalore-Hindustan Airport	India	(Court of Inquiry of Karnataka, 1990)

Figure 5. Sample of accidents 32–42. Human era, 1970–1990

	DATE	AIRCRAFT TYPE	AIRLINE	Fligtnumber	RUTE	Occupants	Fatalities	CRASH SITE	COUNTRY	AGENCY REPORT
43.	July 11, 1991	DC-8-61	Nationair, Nigeria Airways	2120	Jeddah, Saudi Arabia – Sokoto, Nigeria	261	261	2,8 km (1.8 mls) S of Jeddah-King Abdulaziz International Airport	Saudi Arabia	(Presidency of Civil Aviation Kingdom of Saudi Arabia, 1991)
44.	September 28, 1992	Airbus A300B4-203	Pakistan I. Airlines PIA	268	Karachi, Pakistan– Kathmandu, Nepal	167	167	18 km (11.3 mls) S of Kathmandu-Tribhuvan Airport	Nepal	_____ (Ranter y Lujan, 2021j)
45.	May 19, 1993	Boeing 727-46	SAM Colombia	501	Panama City, Panama – Medellín, Colombia	132	132	60 km (37.5 mls) NW of Medellín	Colombia	_____ (Ranter y Lujan, 2021k)
46.	April 26, 1994	Airbus A300B4-622R	China Airlines	140	Taipei, Taiwan – Nagoya, Japan	271	264	Nagoya-Komaki International Airport	Japan	(AircraftAccident Investigation Commission Ministry of Transport Japan, 1996)
47.	December 20, 1995	Boeing 757-223	American Airlines	965	Miami (FL), UAS – Cali, Colombia	163	159	Buga, Valle del Cauca	Colombia	(Grupo de Investigación de Accidentes Autoridad Civil Aérea Colombiana, 1996)
48.	November 12, 1996	Boeing 747-168B	Saudi Arabian	763	New Delhi, India – Dhahran, Saudi Arabia	312	312	5 km (3.1 mls) from Charki Dadri, Haryana	India	(Goverment of India Ministry of Civil Aviation, 1997)
49.	September 26, 1997	Airbus A300B4-220	Garuda	152	Jakarta, Indonesia – Medan, Indonesia	234	234	25 km (15.6 mls) SSW of Medan, North Sumatra	Indonesia	(National Transportation Safety Committee of Indonesia, 1997)
50.	September 2, 1998	MD-11	Swissair	111	New York, USA– Geneva, Switzerland	229	229	9 km (5.6 mls) SW off Peggy's Cove, NS	Canada	(Transportation Safety Board of Canada, 2003)
51.	August 31, 1999	Boeing 737-204C	L.Aéreas.P. Argentinas LAPA	3142	Buenos Aires, Argentina – Córdoba, Argentina	100	65	Buenos Aires-Jorge Newbery Airport	Argentina	(Junta de Investigación Accidentes Aviación Civil Argentina, 2000)
52.	January 30, 2000	Airbus A310-304	Kenya Airways	431	Abidjan, Cote d'Ivoire – Lagos, Nigeria	179	169	2,8 km (1.8 mls) S off Abidjan-Felix Houphouet Boigny Airport	Cote d'Ivoire	(France Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile, 2002)

Figure 6. Sample of accidents 43–52. Organizational factors era, 1991–2011

	DATE	AIRCRAFT TYPE	AIRLINE	Fligtnumber	RUTE	Occupants	Fatalities	CRASH SITE	COUNTRY	AGENCY REPORT
53.	November 2, 2001	Airbus A300B4-605R	American Airlines	587	New York, USA – Santo Domingo. Dominican Republic	260	265	Belle Harbor, New York	USA	(National Transportation Safety Board, 2004)
54.	May 25, 2002	Boeing 747-209B	China Airlines	611	Taipei, Taiwan – Hong Kong	225	225	45 km (28.1 mls) NE off Penghu islands, Taiwan [Taiwan Strait]	Pacific Ocean	(Taiwan Aviation Safety Council, 2002)
55.	December 25, 2003	Boeing 727-223	UTA	141	Cotonou, Benim – Kufra - Beirut, Libya	163	141	Cotonou Airport	Benin	(France Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile, 2003)
56.	January 3, 2004	Boeing 737-3Q8	Flash Airlines	604	Sharm el-Sheikh, Egypt – Cairo, Egypt	148	148	15 km (9.4 mls) S off Sharm el Sheikh	Egypt	(Egyptian Ministry of Civil Aviation, 2006)
57.	August 16, 2005	DC-9-82 (MD-82)	West Caribbean Airways	708	Panama City, Panama – Fort de France, Martinique	160	160	Near Machiques, Zulia	Venezuela	(Junta Investigadora Accidentes de la Republica Bolivariana Venezuela, 2005)
58.	August 22, 2006	Tupolev Tu-154M	Pulkovo	612	Anapa, Russia – Saint Petersburg, Russia	170	170	45 km (28.1 mls) NW of Donetsk	Ukraine	(Russian Interstate Aviation Committee, 2007)
59.	July 17, 2007	Airbus A320-233	TAM Brasil	3054	Porto Alegre, Brazil – São Paulo, Brazil	187	199	São Paulo-Congonhas Airport	Brazil	(Centro de Investigação e Prevenção de Acidentes Aeronáuticos CENIPA, 2009)
60.	August 20, 2008	DC-9-82 (MD-82)	Spanair	5022	Madrid, Spain – Las Palmas, Spain	172	154	Madrid-Barajas Airport	Spain	(Comisión Investigación de Accidentes e Incidentes de Aviación Civil España, 2011)
61.	June 1, 2009	Airbus A330-203	Air France	447	Rio de Janeiro, Brazil – Paris, France	228	228	160km NNW off São Pedro and São Paulo Archipelago	Atlantic Ocean	(France Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile, 2012)
62.	May 22, 2010	Boeing 737-8HG (WL)	Air India Express	812	Dubai, United Arab Emirates – Mangalore, India	166	158	Mangalore-Bajpe Airport, Karnataka	India	(Goverment of India Ministry of Civil Aviation, 2010)
63.	January 9, 2011	Boeing 727-286	EU blacklist Iran Air	277	Tehran, Iran– Urmia, Iran	105	78	8 km (5 mls) from Urmia (Orumiyeh) Airport	Iran	_____ (Ranter y Lujan, 2021c)

Figure 7. Sample of accidents 53–63. Organizational factors era, 1991–2011

	DATE	AIRCRAFT TYPE	AIRLINE	Fligtnumber	RUTE	Occupants	Fatalities	CRASH SITE	COUNTRY	AGENCY REPORT
64.	June 3, 2012	DC-9-83 (MD-83)	Dana Air	992	Abuja, Nigeria – Lagos, Nigeria	153	159	9,3 km (5.8 mls) N of Lagos-Murtala Muhammed International Airport	Nigeria	(Accident Investigation Bureau of Nigeria, 2012)
65.	November 17, 2013	Boeing 737-53A	Tatarstan	9363	Moskva, Russia – Kazan, Russia	50	50	Kazan International Airport	Russia	(Russian Interstate Aviation Committee, 2015)
66.	December 28, 2014	Airbus A320-216	Indonesia AirAsia	8501	Surabaya, Indonesia – Singapore, Singapore	162	162	Karimata Strait, Java Sea	Indonesia	(Komite Nasional Keselamatan Transportasi Republic of Indonesia, 2015)
67.	August 16, 2015	ATR 42-300	Trigana Air Service	267	Jayapura, Indonesia – Oksibil, Indonesia	54	54	16,7 km (10.4 mls) NW of Oksibil Airport, Papua	Indonesia	(Komite Nasional Keselamatan Transportasi Republic of Indonesia, 2017)
68.	November 28, 2016	Avro RJ85	LaMia	2933	Santa Cruz, Bolivia – Medellín, Colombia	77	71	18 km (11.3 mls) S of Rionegro/Medellín-José María Córdova Airport	Colombia	(Grupo de Investigación de Accidentes Autoridad Civil Aérea Colombiana, 2017)
69.	October 29, 2018	Boeing 737 MAX 8	Lion Air	610	Jakarta, Indonesia – Pangkal Pinang, Indonesia	189	189	15 km (9.4 mls) N of Tanjung Bungin, Jakarta	Indonesia	(Komite Nasional Keselamatan Transportasi Republic of Indonesia, 2019)
70.	March 10, 2019	Boeing 737 MAX 8	Ethiopian Airlines	302	Addis Ababa, Ethiopia – Nairobi, Kenya	157	157	50 km (31.3 mls) ESE of Addis Ababa-Bole Airport	Ethiopia	(Ethiopian Directorate of Aircraft Accident Investigations, 2020)
71.	May 22, 2020	Airbus A320-214	PIA	8303	Lahore, Pakistan – Karachi, Pakistan	99	98	1,4 km (0.9 mls) E of Karachi-Jinnah International Airport	Pakistan	(Aircraft Accident Investigation Board Pakistan, 2020)

Figure 8. Sample of accidents 64–71. Total System era, 2012–2020

			MC – Main Cause, CC – Contributory Cause, R – Recommendation *Factor type: T – Technical, H – Human, O – Organizational*	FACTOR		
	DATE	CODE	CONCLUSIONS EXTRACTED FROM THE FINAL REPORT	*T*	*H*	*O*
1.	7-Jun.-49	MC-1	*Loss of power from the* right engine from catching fire before the aircraft reached the optimal ascent speed with a single engine, caused it to lose altitude and crash into the sea.	X		
		CC-1	*Overload condition* of the aircraft.	X		
		R-1	The CAB (Civil Aviation Board) *revoked the license* of the operator Strato-Freight Inc.			X
2.	12-Dec.-50	MC-1	*Center of gravity out of bounds* on the Airworthiness Certificate (too aft)…	X		
		MC-2	… and *insufficient control* in conditions of low speed and acute instability.		X	
		R-0	There's none.			
3.	16-Dec.-51	MC-1	*Loss of power of* the right engine, caused by the failure of the fastening bolts of cylinder No. 10, causing a fire in flight that became uncontrollable.	X		
		R-0	There's none.			
4.	11-Apr.-52	MC-1	*Improper maintenance* of the company by not changing the engine No. 3…			X
		MC-2	… which resulted in its *failure immediately* after takeoff.	X		
		MC-3	The captain's persistent action in attempting to restore an ascent, without using all available power, *caused the critical loss* of power from another engine. He went into loss.		X	
		MC-4	*Defective engine parts*.	X		
		R-1	It was recommended, in the future, to *inform* passengers about the *location* and *use* of flotation equipment and *emergency exits* before flights over water.			X
		R-2	*Provide boats and life jackets* in appropriate locations, ready to be used.	X		

Figure 9. Method of classification of causes and recommendations in the different factors

6. Results

The results obtained vary depending on the type of variable. For quantitative variables, annual averages have been calculated (ICAO publications, air accident victims, accidents, and high mortality accidents) for each era. For the qualitative variables corresponding to the attributions, the percentages of the factors (technical, human, and organizational) have been calculated to see how they change, both for each era and the entire period (1949–2020).

The results, in terms of the count of ICAO publications (Table 1), show a more prominent era leap than the rest: specifically, the jump from the technical era to the human factors era. The analysis, carried out through *Stevens' t-test*, of the average number of publications confirms that this jump does represent a statistically significant increase in the average number of annual publications from the technical period to the human factors (t = 3.32; $p < 0.002$). The increase, although progressive during the later eras, is not significant, nor is the jump to the institutional era (t = 0.69; $p > 0.50$), nor that of the jump to the current era (t = 0.52; $p > 0.61$).

The dispersion by era of total world accident total victims (period 1949–2020) shows (Table 2) a downward trend in recent times. It also places the highest number of deaths, almost thirty thousand, in the human factors era. The highest decline occurs between the institutional stage and the total system one. It is possible to observe two significant periods of change by performing the *t-test* between the averages of the consecutive eras. The first locates between the era of human factors and the institutional era (t = 2.96; $p < 0.005$), while the second situates between the institutional era and the present (t = 6.45; $p < 0.001$). Therefore, it should affirm that from the time of human factors until today, mortality has been decreasing significantly. However, there is no statistical significance between the technical stage and the human factors one (t = 1.82; $p > 0.08$), although an increase in mortality is observed.

Table 1. International Civil Aviation Organization (ICAO) Publications (1949–2020) and Annexes (amendments and editions) by safety era

	Evolution eras in operational safety			
	TECHNICAL	HUMAN FACTORS	INSTITUTIONAL	TOTAL SYSTEM
Total number of publications	147	205	221	104
Annual Average	7.00	11.90	10.52	11.56

Table 2. Commercial aviation worldwide accident victims by safety era (1949–2020)

	Evolution eras in operational safety			
	TECHNICAL	HUMAN FACTORS	INSTITUTIONAL	TOTAL SYSTEM
Total number of fatalities	24331	29068	20945	2890
Annual Average	7.00	11.90	10.52	11.56

Table 3. Commercial aviation worldwide accidents by safety era (1949–2020)

	Evolution eras in operational safety			
	TECHNICAL	HUMAN FACTORS	INSTITUTIONAL	TOTAL SYSTEM
Total number of accidents	1400	1189	910	165
Annual Average	66.67	56.62	43.33	18.33

Table 4. Commercial aviation worldwide high mortality accidents by safety era (1949–2020)

	Evolution eras in operational safety			
	TECHNICAL	HUMAN FACTORS	INSTITUTIONAL	TOTAL SYSTEM
Total number of accidents	136	184	142	21
Annual Average	6.52	8.76	6.76	2.33

Table 5. Technical, human, and organizational factors by evolutionary eras (1949–2020)

	Type of factor				
	Technical Factors	Human Factors	Organizational Factors	Without Determine	Total
TECHNICAL ERA	42	26	20	16	104
Causes:	28	23	2	4	57
Main	23	16	1	2	42
Contribute	5	7	1		13
Undetermined				2	2
Recommendations	14	3	18	–	35
No recommendation	–	–	–	12	12
HUMAN FACTORS ERA	88	47	90	9	234
Causes:	27	36	13	–	76
Main	16	22	2	–	40
Contribute	11	14	11	–	36
Recommendations	61	11	77	–	149
No recommendation	–	–	–	9	9
INSTITUTIONAL ERA	113	83	353	2	551
Causes:	37	66	25	–	128
Main	11	34	6	–	51
Contribute	26	32	19	–	77
Recommendations	76	17	328	–	421
No recommendation	–	–	–	2	2
TOTAL SYSTEM ERA	19	29	169	3	220
Causes:	11	18	17	–	46
Main	2	4	3	–	9
Contribute	9	14	14	–	37
Recommendations	8	11	152	–	171
Open Investigation	–	–	–	2	2
Year without Accident	–	–	–	1	1
Total	262	185	632	30	1109

The total number of accidents per era, during 1949–2020, decreases more uniformly and progressively at the beginning of the institutional era. This trend is maintained in the total system era too. The *t-test* of averages confirms that the three changes between consecutive eras are statistically significant (t = 2.89; p < 0.01; t = 3.60; p < 0.001 and t = 8.45; p < 0.001, respectively). Regarding the averages in Table 3, it can be observed that the most relevant decline occurs between the institutional era and the current period (total system).

A higher number of accidents in the human factors era can be observed (Table 4), looking at the results of high mortality accidents (those with more than 49 deaths) for each stage, with 184 out of a total of 483 accidents (occurring from 1949 to 2020). The sum of high mortality accidents reflects more accidents in the human factors era, producing its highest decrease during the total system period, starting in 2012 (Table 4). Regarding annual averages, it is posible to find a vast decline in high mortality accidents, especially in the total system era. The *t-test* between the means of consecutive stages confirms that the only statistically significant drop occurs between the institutional era and the total system era (t = 5.08; p < 0.001). The rest of the jumps between stages are not statistically relevant, nor the increase in high mortality accidents that can be seen between the technical era and the human factors one (t = 1.76; p > 0.086), nor in the decrease between the latter and the institutional period (t = 2.02; p > 0.025).

The descriptive analysis of the quantitative variables shows that hypothesis 1, which places the beginning of the safety culture in the 90s, is only fulfilled and partially concerning mortality (the jump to the total system era is also significant). This analysis shows the most significant jump between eras for all quantitative variables and consequently places an efficient safety culture as of 2011.

Regarding the qualitative variables established for hypotheses 2 and 3, the numerical results corresponding to the 71 accident investigations of the period 1949–2020, which are selected according to the established criteria, offer a total of 1109 causes and recommendations, classified according to technical, human, or organizational factors. They are all listed in Table 5, and their graphical representation by era is presented in Figure 10.

The general analysis of the classification of causes/recommendations by technical/human/organizational factors of catastrophic accidents of the period 1949–2018 shows (Figure 11) a high percentage of the human factor as responsible both in determining causes (53.5%) and

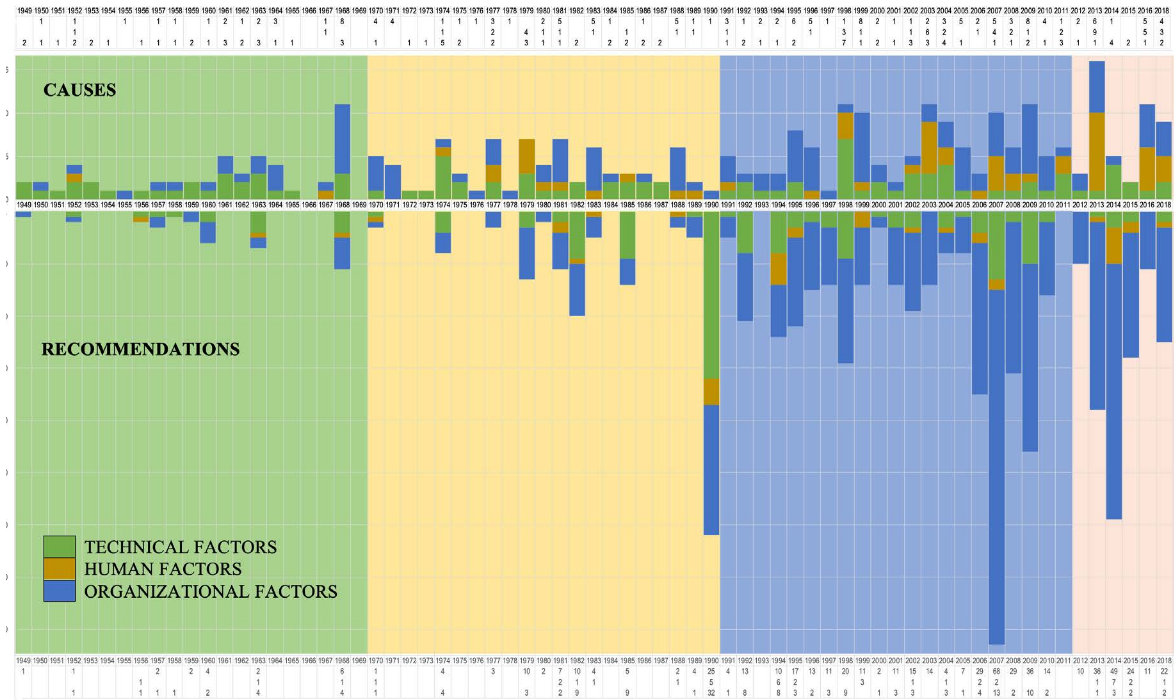

Figure 10. Method of classification of causes and recommendations in the different factors. Period 1949–2020

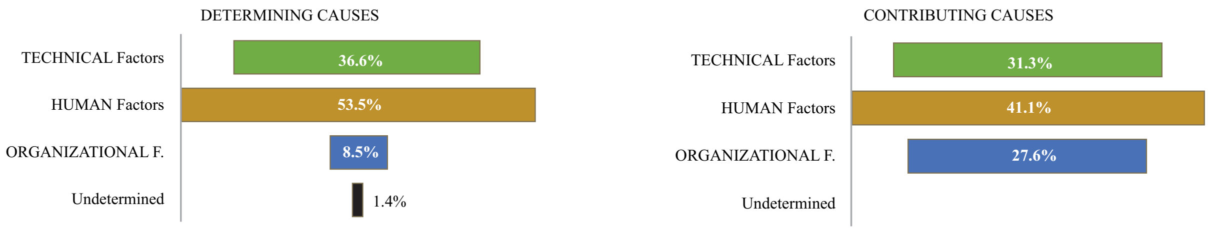

Figure 11. Percentages of technical, human, and organizational factors in the "causes" (1949–2018)

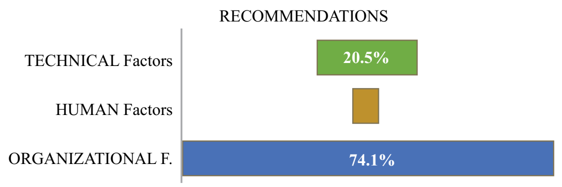

Figure 12. Percentages of technical, human, and organizational factors in the "recommendations" (1949–2018)

in contributing causes (41%). After the human factor, the technical is the second type of cause, both in determinants (36%) and in taxpayers (31.3%). Organizational factors are more present as contributing causes (27.6%) than as determinants (8.5%).

Regarding the recommendations of the report, it can be concluded that in the face of human and technical factors as a cause of accidents, the preventive measures issued were of an organizational nature (74.1%). Normative regulation and managerial and institutional control are imposed as recommended main measures in human and technical failures (Figure 12).

Hypothesis 2 tried to find out if technical, human, and organizational factors or errors have a correspondence to the technical (hypothesis 2.1), human factors (hypothesis 2.2), and institutional eras (hypothesis 2.3). The results show that most of the attributions in the technical period are technical factors, which would comply with hypothesis 2.1. However, in the era of human factors, hypothesis 2.2 is not met since the most numerous attribution errors are organizational ones. The majority of attributions are also fulfilled according to hypothesis 2.3 since, in both eras (institutional and total system), organizational factors are predominant (Figure 13).

With regard to the evolution of factors or errors from 1949 to nowadays, hypothesis 3 is fulfilled in that it predicts a decrease in technical errors and an increase in organizational errors, both in absolute value and in percentage. However, it is not fulfilled as far as human factors are concerned since the percent of human factors does not grow but has a decreasing tendency (the absolute values of each period first increase and then decrease).

The results of hypotheses 2 and 3 on human factors (which factors predominate at the time of human factors and the trend of the same during the period 1949–2020) raise the need for a more detailed analysis, separating causes and recommendations, in a similar way to the study carried out of determining causes, contributing causes and recommendations. Those relating to causes and recommendations show in isolation that human factors have a predominant weight in the former but not in the latter. Human factors are increasing in the causes until the institutional era and then decreasing in the present stage. Human factors predominate in the causes (Figure 14), while organizational factors predominate in the recommendations (Figure 15).

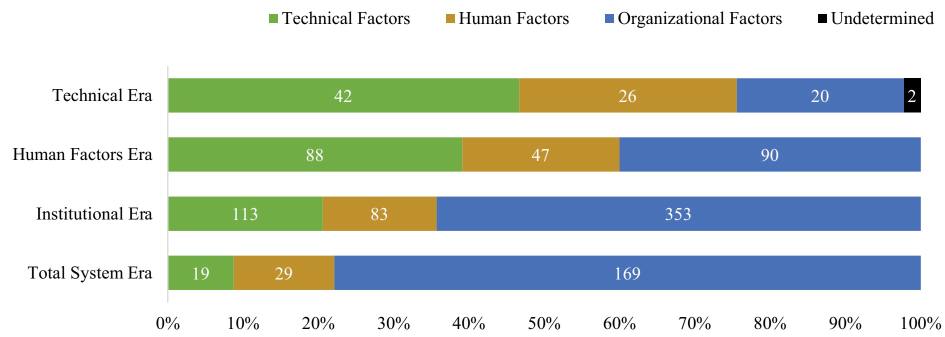

Figure 13. Type of predominant factor in the conclusions of the report by era and their evolution

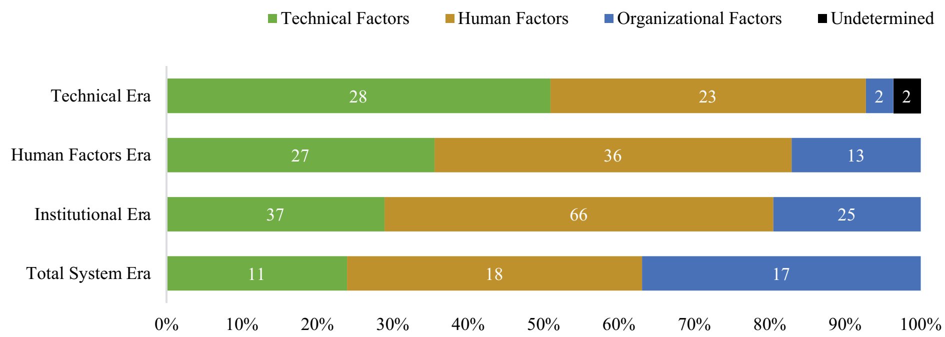

Figure 14. Type of predominant factor in "causes" of the reports by era and their evolution

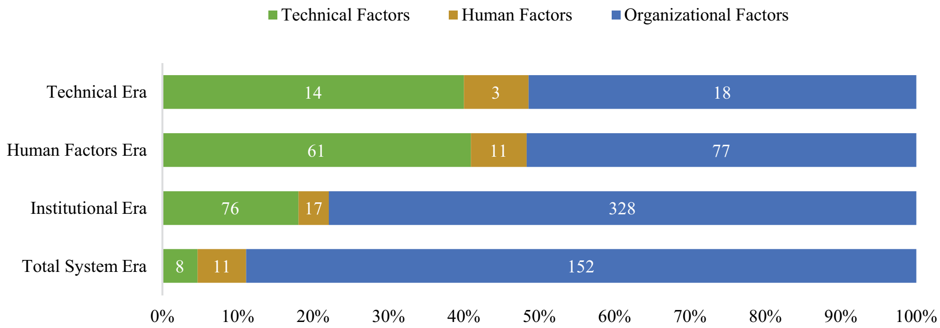

Figure 15. Type of predominant factor in "recommendations" of the reports by era and their evolution

Conclusions

Another identified moment of change is located in the 70s and has as protagonist the vast increase in the normative development promoted by the ICAO. The transition between the technical era and the human factors era turned out to be the peak of the development of regulated aviation publications. This moment is prior to the period identified as significant in the proposed theoretical model (early 90s). The evolution of standards (SARPs) and procedures (PANS) of the Annexes has its highest increase just after the technical era. The reason justifying these results could be the urgent need, during the technical stage, for an integration between the human and technology factors (man-machine). Although, for the establishment of definitive conclusions, it will be necessary to wait for the results of new research.

Regarding the study of causes and recommendations, it is relevant to highlight that it is necessary to study both report conclusions in isolation (on the one hand, causes and, on the other hand, recommendations). Treating both attributions together distorts the behavior of the results in terms of human factors. In general, human factors predominate in the causes of the reports analyzed. On the contrary, organizational factors predominate in the recommendations throughout the period studied. The conclusion that emerges is that accidents caused by human factors generate in the investigations the issuance of safety recommendations of the organizational type. On the other hand, the pattern of technical factors is an explicit decrease, both in causes and recommendations.

From the results drawn from the analysis conducted, it is concluded that there is a fine line between the definition of a human error or factor and an organizational error or factor. Fatigue, for example, is a human factor, causing numerous errors, but the responsibility for not appearing on the scene is an organizational one. Another important conclusion of the study, without doubt, is that all the catastrophes studied have been a relevant advance for the air transport industry, but what will happen when there are no high-impact accidents? Will it be possible to continue learning? Undoubtedly, the current cornerstone to prevent accidents in the future, which answers this question, is the study of incidents. In the first edition of the International Civil Aviation Organization's (ICAO, 2006) Operational Safety Manual and in Frank Bird's theory, it was believed that the factors or causes that contribute to major catastrophes can be present in incidents and, therefore, these can be detected before grave damage occurs. This statement reflected by ICAO constitutes "the Heinrich/Bird safety pyramid" of the 70s (Arnau, 2021). After learning from vast accidents, today, the safety pyramid of the 70s by Heinrich and Bird makes sense and is now more helpful in understanding the future of operational safety. There is no denying that critical accidents have produced and continue to produce relevant changes in the industry. However, nowadays, the industry seeks these changes hand in hand with the area of eventual knowledge, located at the base of the pyramid and directly related to daily operations, information on events, hazards, and systemic deficiencies.

The top of the pyramid is almost explored and constitutes the level of genuine knowledge provided by accident investigation. But the lower base is an unexplored area and represents a great learning opportunity through the optimization of data capture mechanisms (Martínez, 2016). Currently, there is more travel in learning about incidents than in studying fatal accidents or catastrophes, mainly because they occur less and less frequently. In this way, the systems of mandatory notification of almost any event or Aviation Data Reporting Program (ADREP) provide a large amount of information, typical of big data. Incident reporting and big data analysis research seem to be the future, making learning about the incident increasingly valuable so that it never becomes a major catastrophe (ICAO, 2006).

Therefore, the clearest recommendation that arises from all the results obtained in this study is to promote voluntary incident reporting systems within a positive safety culture (fair culture) and not to stick exclusively to mandatory reporting events. The safety culture is fundamental for achieving the voluntariness of making available to the global system all operational safety events to be studied as big data and thus be able to make more accurate predictions and recommendations (recommendations on the operational safety of global interest or SRGC).

Disclosure statement

No financial, professional, or personal interests from other parties were reported by the authors. All the opinions presented in this article belong to their authors and do not necessarily represent the opinion or official position of the Spanish Air and Space Force or Stimulus Consulting.

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