III. Findings

1. Principal Findings

1.1 The rate of fatal accidents in advanced technology Boeing and Airbus type aircraft, defined as the number of accidents per million departures, decreased by approximately 3.3% per year, between the years 1988 and 2002 – an overall decrease of 50%.

1.2 The majority of the accidents occurred in Southeast and East Asia, and involved airlines located in that area.

1.3 The manufacturer with both the largest number and the highest rate of accidents is the Airbus Company.

1.4 The leading risk category is CFIT, comprising 45% of all fatal accidents.
The greatest number of fatalities occurred in accidents categorized as LOC, 37% of the fatal accidents overall.

1.5 The main "primary cause" of the accidents is Human-FDC (59%), followed by Technical and Maintenance (22%).

1.6 The outcome of critical technical failures in advanced technology aircraft is loss of control.

1.7 The concept, design and features of Glass Cockpit aircraft have contributed directly to the occurrence of more than half of the accidents (52%).

1.8 In most of the fatal accidents involving advanced technology aircraft, the flight crew was failed to understand the behavior of the aircraft and its systems for one or more of the following reasons:
A. The pilot was "out of the flying loop"
B. Ineffective feedback to the pilot on the status of the aircraft's systems
C. Lack of knowledge, in some events, due to the crew's previous lack of experience or because no precedent existed, due to the entire airline industry's inexperience in the Glass Cockpit area.

1.9 In a significant number of accidents in the leading risk categories, CFIT and LOC, "lack of spatial orientation" is the evident source of safety failure.

2. Detailed Findings

2.1 Categorization of Causal Factors

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FDC is a primary or secondary cause in 78% of the fatal accidents involving advanced technology aircraft (59% primary, 19% secondary). Moreover, in the CFIT risk category, FDC is a primary or secondary cause in 100% of the accidents (83% primary, 17% secondary). Environment, technical, maintenance, ATC and Organization appear as primary causes in the CFIT accidents – 8% each, whereas organization is a secondary cause in 8% of the accidents and ATC in 16%.

In contrast, Technical Failure appears as a primary cause in 50% of the accidents in the LOC risk category, with FDC as the second most important cause, appearing as a primary cause in 40% and as a secondary cause in 20% of the LOC related accidents. Among the additional causes, Organization stands out as a factor in 40% of LOC-related accidents, 20% as a primary- and 20% as a secondary cause.

2.1.2 Technical Failure

Several of the fatal accidents involving advanced aircraft were caused by canalization of the pilots' attention i.e., focusing it exclusively on the technical failure instead of on flying the aircraft and maintaining situational awareness.

The "canalizing malfunction" contributed to the development of safety failure in 1/3 of CFIT- related accidents and in 1/5 of LOC- related accidents..

The pilots experienced difficulties in grasping the essence of the problem, as well as in improvising solutions to malfunctions related to airspeed and altitude indications (pitot, ADC system). The crew was unable to cope with the following malfunctions: "electric-fire" and "thrust reverser deployment".

2.1.3 Environment

Weather conditions exceeding the permissible limits for landing were the primary cause in two landing accidents and one CFIT-related accident, and were a secondary cause in two other accidents.

In the CFIT risk category, the weather conditions, mountainous area and lighting conditions contributed to the occurrence of the accidents. About 75% of those accidents occurred under IMC conditions. In the LOC risk category, the lighting conditions influenced the loss of control of the aircraft and created difficulties in regaining it. 70% of these accidents occurred at night, and 50% under IMC conditions. A positive correlation exists between the lighting conditions (night flight) and the failure of the crew's spatial orientation, which led to loss of control.

2.1.4 Air Traffic Controller (ATC)

The importance of ATC's role in the prevention of accidents increases with the volume of air traffic, i.e., the number of aircraft within a three-dimensional space per unit time. The ATC was a factor in 19% of the accidents – a primary factor in 11% of them: one on-ground, one midair collision, and one CFIT accident.

2.1.4.1 ***Communication:*** Safety failure involving improper communication by the controller contributed to the occurrence of 19% of the accidents. In total, 26% of the accidents were found to be a result of faulty communication skills, in two areas:

a) Non-verification of data transmitted by FDC, and improper controller's guidelines

b) Improper execution of the controller's instructions.

Communication failure could also be related to the poor quality of the ground and aerial communication devices, and that of audio systems in cockpits surrounded by a relatively high noise environment.

2.1.4.2 ***Other factors:*** Additional factors were found in this survey relating to ATC as well as to absence of radar and visual monitoring. However, these issues are not within the scope of this investigation.

2.1.5 Organization

2.1.5.1 *Manufacturer*

Aircraft Design: Airbus Company's large share of the accidents is the result of faulty aircraft design, which takes the pilot out of the automatic flight loop at a time when he does not have sufficient information about the flight situation. Most accidents of this kind fall within the LOC category. Overall, pilots were "bypassed" by the automation systems, in various types of aircraft, in 1/3 of the accidents.

Weak points in the ***man-machine interface*** (MMI) within the automatic flight mode contributed to 40% of CFIT-related accidents and to 20% of LOC-related accidents.

The aircraft manufacturers contributed to the occurrence of approximately half of the accidents, consequent to inadequacies in the following areas: Company policies and procedures, human engineering of the cockpit and flight systems, inability to predict scenarios relating to glass cockpit failures, the low level of the aircrews' knowledge of the structure of the aircraft and its systems.

2.1.5.2 *Airlines*

One airline appeared as the primary factor leading to a fatal accident. Its inadequate maintenance policy resulted in failure of the horizontal stabilizer and loss of control of the aircraft.

Various airlines contributed to the occurrence of 11 additional accidents. Their contribution was expressed in three areas:

A. Absence of proper procedures
B. Erroneous policy, leading to the promulgation of inadequate procedures
C. Inadequate supervision

In the absence of airline SOP relating to malfunctions, pilots with insufficient experience in Glass Cockpit aircraft and who were not equipped with the proper tools, were called upon to cope with malfunctions, the risk factors of which had not been predicted by the airlines.

Airline SOPs contributed to the occurrence of seven (7) accidents, due to incorrect policy decisions that were based on economic considerations, or as a result of inadequate preparation for massive procurement of advanced aircraft. In several cases, these policies resulted in crews being manned with inexperienced crewmembers and assigning them to missions that were beyond their capabilities. As to inadequate supervision by the airlines, this study reveals faulty monitoring of individual pilots, as regards their sub-standard flying skills, previous flight violations, and abnormal mental states.

. The present analysis of fatal accidents in advanced aircraft indicates that three mental factors promote the occurrence of failures:
a) Stress;
b) Complacency; and
c) Over-motivation.

The three main barriers to failure of the human factor are: SOP, CRM and S/A, all of which are the responsibility of airline's management, in respect of the training of its pilots and the supervision of their level of performance. The investigation reports of several accidents revealed systematic organizational factors that may have contributed to the problematic operation of the crew.

In the recommendations of the accident reports, the airline managements were urged to initiate thorough modifications in procedures governing flight standards and norms, with the assistance of experienced airlines that enjoy a reputation for good flight safety.

2.1.5.3 ***Civil Aviation Authorities (CAA)***

A permit issued by the FAA, allowing an airline to lower the standard of its aircraft maintenance, led to the occurrence of one fatal accident (structure - LOC).

Permission by the CAA to relax requirements in the retraining and qualification of pilots on advanced technology aircraft was consequential in one fatal accident (CFIT).

CAA policy with regard to the installation of a GPWS warning system in passenger aircraft contributed to the non-prevention of one accident (CFIT).

Inadequate standardization in the design of the FCU of Airbus aircraft contributed to an operational error that resulted in one accident(CFIT).

Loose supervision of the airline and the flying skills level of pilots contributed to one accident (CFIT).

The Authorities made a significant contribution to the occurrence of three (3) fatal accidents; seven (7) additional accidents might have been prevented if proper regulations had been followed and “by the book” supervision had been imposed.

2.2 Risk Categories

2.2.1 CFIT

The accident rate of Airbus aircraft in the CFIT risk category is three times higher than the accident rate of Boeing aircraft.

All of the CFIT accidents occurred within the airports’ CTR boundaries.

5 of 12 CFIT-related accidents occurred during VOR/DME approaches, two (2) during descent prior to execution of approach, two (2) during circle to land, 1 during go-around and two (2) following takeoff.

The environmental conditions required “instrument flight" in 92% of CFIT-related accidents.

The weather contributed to the occurrence of 50% of the CFIT-related accidents. In 1/3 of the accidents adverse weather conditions were present.

The present study emphasizes the interconnections among: the topographic features of the approach area in mountainous regions, the type of approach process (VOR/DME), and weather and lighting conditions. Unlike the ILS process, no warning is provided on vertical deviation from the planned profile. In addition, the GPWS system is not perfectly reliable in mountainous areas.

2.2.2 CFIT – Human factors

2.2.2.1 The central components of the human factor that contribute to CFIT accidents are: SOP, CRM and S/A. Additional significant components are: inadequate preparation and misperception of aircraft’s behavior which, among other failings, are related to the lack of experience in flying glass cockpit aircraft. Half of the accidents occurred due to insufficient flying skills and inadequate control in the operation of aircraft systems.

2.2.2.2 57% of the CFIT accidents are Glass Cockpit related, i.e, they stem from the unique features of these aircraft.

2.2.2.3 In most of the CFIT accidents, the lack of situational awareness is related to poor spatial orientation (10/12) characterized by errors in the perception of the spatial location and sometimes by the non-identification of the flight path (50%), nose attitude or descent rate of the aircraft. Errors in vertical orientation were present in 75% of CFIT accidents and errors in horizontal orientation appeared in 25% of the accidents.

In two accidents there were orientation errors in both dimensions.

2.2.2.4 A variety of mental factors, such as over-motivation, system-stress, and the like, affected the functioning of the pilots in 50% of the accidents.
Canalizing events contributed to the loss of orientation in seven (7) CFIT accidents; 4 of them occurred due to technical malfunctions, where crewmembers diverted their attention from the flight and lost orientation.

2.2.2.5 Failure to react properly to activation of a GPWS alert may arise from the following reasons: misinterpretion of a genuine alarm as false, unpreparedness, lack of skills, and/or a narrow window of opportunity.

2.2.3 LOC

2.2.3.1 The fatality rate in this risk category is close to 100%; there were no survivors in 9 of 10 LOC accidents. In two accidents, people who were not passengers of the aircraft, were also killed. In one accident, seven (7) of 271 passengers survived.

2.2.3.2 Six of ten accidents that resulted from LOC occurred during flight stages incorporating the following features: high power and/or low speed, while flaps/slats were extended or during retraction processes. Three accidents occurred following takeoff, and three accidents occurred during the go around stage. A single accident occurred during the cruise stage, due to a serious violation of discipline. The remaining three LOC accidents occurred as a result of extremely severe malfunctions during the climb or descent stage.

2.2.3.3 The primary cause leading to LOC accidents in advanced technology aircraft is ***technical failure***.

Half of theLOC accidents were caused by technical failures. Among them: an in-flight engine thrust reverser deployment, an uncontrolled fire in the entertainment system of the aircraft located inside the cockpit, a mechanical failure of the horizontal stabilizer actuator, an engine thrust control malfunction causing an uncontrolled asymmetry flight.

2.2.3.4 70% of LOC accidents occurred in the dark hours.

2.2.3.5 The two (2) accidents that occurred under VMC were structure-related.

2.2.3.6 50% of the LOC accidents occurred in Airbus aircraft, 30% in Boeing aircraft and 20% in MD aircraft.

2.2.3.7 36% of LOC accidents are defined as Glass Cockpit related; by which is meant that G/C related features contributed to their occurrence.

2.2.4 LOC – Human Factors

2.2.4.1 FDC is the second primary factor to LOC accidents (40%) and a secondary factor leading to 20% of these accidents.

2.2.4.2 The most common errors contributing to LOC accidents are:
A. SOP (70%)
B. Misperception of A/C behavior (70%)
C. Pilot is 'out of the loop' (60%)
D. Focus on canalizing malfunction.

2.2.4.3 In most LOC-related accidents, the pilots did not perform the action necessary to avoid loss of control upon reaching the maneuver limits.

2.2.4.4 The common operational error during recovery attempts is ***keeping the automatic flight systems engaged***. In three (3) LOC accidents involving bypass of the automatic flight system and its safeguards, the aircraft deviated from the maneuvering envelopes and lost control. In two (2) LOC accidents, a violation of SOP caused the loss of control (Egypt Air, Aeroflot).

2.2.4.5 The difficulty in identifying the development of unstable situations and improper execution of the recovery maneuvers are considered to be the safety failures responsible for the prevention of deviations from the flight envelope.

2.2.4.6 Most of the crewmembers involved in LOC accidents did not grasp the automatic responses of the flight system, its safeguards, and the reasons for system disengagement; moreover, they did not predict the behavior of the aircraft.

2.2.4.7 Most malfunctions resulting in LOC did not elicit the proper safety procedure.

2.2.5 Ground Collisions

The two (2) accidents under this category were influenced by environmental conditions: weather, visibility and lighting:
– Accident 1: Runway incursion by an aircraft that is not included in the research population. The accident was caused by a pilot orientation error under low visibility conditions.
– Accident 2: Takeoff on a closed runway.

The human factor – under low visibility conditions - failure to activate the following safety barriers:
A. Adequate previous learning and preparation;
B. In-depth briefing, putting emphasis on limitations and closures in the airport;
C. Prevention of loss of orientation by concentrating on continuous taxiing orientation, rather than preoccupation with nonessential issues;

D. Cross-check of ground positioning, using taxiways signs and markings by both crewmembers ;

E. Data verification and use of standard phraseology in communication with the Control Tower.

2.2.6 Landing

Two primary factors appear in landing accidents: adverse weather conditions and the pilots' improper decision to land while cross-wind velocity exceeds the permissible limits for landing. In addition, operational errors of the crew, originating in perceptional errors, leading to judgment errors, and resulting in skill-based errors. In the hard landing accident, poor visibility and problematic lighting conditions impaired the judgment of the PF. The runway-overrun accident involved misunderstanding of the stipulations and delays in activating the automatic braking system, which left the pilot "out of the loop".

2.2.7 Midair

Human Factors

The accident sheds light on a problematic communication failure as a factor leading to accidents, and emphasizes the importance of maintaining orientation with regard to converging traffic at the same cruise level, as well as of strictly following the TCAS guidelines when they conflict with the controller's instructions.

2.3 Human Factors –Summary of Findings

21 accidents were caused by human errors made by the crewmembers.

SOP

SOP, the primary "failure barrier" in the prevention of unsafe acts that lead to accidents, was breached in all of the accidents. In 9 accidents, improper procedures led the crew to perform the unsafe act. In 4 accidents, the essential procedure did not exist.

Situational Awareness (S/A)

S/A failure was found as a critical component in the development of advanced aircraft accidents. Itappears in 21 accidents. In nine (9) of them, the pilot was bypassed by the aircraft's systems without understanding the implications of this activity. In part of these accidents S/A was compromised by the pilot's difficulties in tracking the sequence of changes in flight modes – or by errors in choosing the computerized modes, that resulted in the pilot's failure to recognize a faulty flight mode or an improper A/C system status.

Loss of spatial orientation

This failure appears in 21 accidents. In 15 of them, the crew was unaware of the loss of spatial orientation, and the primary perception error was in the vertical dimension. In five (5) accidents the crew was aware of the error but was unable to prevent the outcome.

Misorientation
In 83% of CFIT accidents and 30% of the LOC accidents the crewmembers were misled by defective spatial perception, and were unaware of the situation.

The critical stages are:
a. Disruption of the S/A maintenance sequence, due, among other causes, to: a canalizing event or malfunction, loss of external and internal cues, disparity between the real time situation of the A/C and the crew's perception of it as the result of an operational or flight error.
b. Fixation of the phenomenon, due to the adaptation to the newly created conditions and stabilization of the new, misleading picture.
c. Disregard of SOP designed to rescue the crew from the misperception and restore the real-time picture.

Disorientation
This type of lack of orientation is expressed by the absolute absence of one or more components of spatial orientation. While the crewmember is aware of not having orientation, he feels unable either to regain it or to control the situation. Disorientation appeared in three (3) CFIT accidents and in two (2) LOC accidents.

The phenomenon is characterized by enhanced stress and by a high rate of change in the sequence of steps taken in the attempt to regain orientation and control of the situation (flight envelope, flight path, etc.).

In most such events, the situation was detected and identified by a crewmember that was <u>not</u> flying the aircraft (PM).

Canalizing events
Canalization of the crew's attention away from flying the A/C and/or from maintaining spatial orientation is due to improper CRM. In several cases the canalizing feature developed when the attention of both crewmembers was concentrated on an attempt to overcome a technical malfunction (67% in CFIT accidents, and 33% in LOC accidents). In five cases, this phenomenon led to loss of orientation in the pitch level and resulted in an accident.

Flight-condition identification errors
For the detailed description of the various types of error, refer to Chapter II – 5.3.13.6. The most common are "flight path identification" and "rate of descent" errors (10 of each type), and are mainly found in CFIT and LOC-related accidents.

Pitch error was diagnosed as a factor leading to misorientation and contributing to the development of LOC situations.

Airspeed error also appeared in A/C's incorporating the old classic speed dials as well as in the new display (tape). It occurs because of instrumentation malfunctions, flight errors, or difficulties in flying the A/C under adverse weather conditions.

Flying the aircraft

Errors in flying the aircraft contributed to the occurrence of 14 accidents. They fall into four main groups:

a. Basic flight errors, poor skills due to the insufficient familiarity with the aircraft, its flying features, structure and limitations.

b. Maintaining automation when automation should have been disengaged.

c. Errors related to identification of flight condition, due to limiting environmental factors.

d. Errors in the operation of aircraft systems, switches and selectors.

Additional errors, distributed at random among the majority of the auto-flight functions located in the cockpit: Auto Thrust, TOGA, MCP (FCU), TMC and FMC (FMGS).

2.4 MMI

A substantial fraction of the 17 accidents involving MMI as a causal component occurred with Airbus aircraft (67%). The phenomenon of "bypassing the pilot", i.e. "Pilot out-of-the-loop" in highly automated systems, led to the occurrence of three (3) accidents involving these aircraft, whereas problematic operation of the TOGA/(F/D). functions resulted in five (5) accidents.

Errors at the interface between the pilot and the aircraft arise out of the pilots' failure to understand the functioning of the aircraft and its systems. This issue came up in 56% of CFIT accidents and in 41% of LOC accidents.

MMI also appears in connection with errors made by the crew in the operation of various systems of the aircraft, as well as in feedbacks in response to the activation of systems or their termination. In addition, the crew frequently, failed to comprehend ineffective feedbacks, indicating the crewmembers' lack of situational awareness and their misunderstanding of the aircraft's operation.

2.5 G/C related accidents

More than half of the accidents are attributed to the unique properties of Glass Cockpit (52%) aircraft: CFIT - 8, LOC - 5, Landing - 1. 79% of these accidents occurred in Airbus aircraft. These accidents are characterized by the crew's misunderstanding the functioning of the aircraft's systems.

This phenomenon stems from lack of knowledge and from difficulty in identifying and decoding the feedbacks on the status of the system, the activation of modes, their change, and the termination their operation.

The crewmembers' lack of experience in handling unfamiliar severe malfunctions is reflected in the accidents, as is that of the inexperienced manufacturer, who did not provide the proper SOPs.

The crewmembers' lack of experience is an important component in the course of the accident, and indicates their lack of sufficient maturity to adapt to the conceptually new operation of Glass Cockpit systems. It is characterized by an insufficient level of knowledge and by a vague understanding of the logic behind the activity of automatic systems.

The relative ease of flying advanced technology aircraft, their high degree of automation and their improved reliability were found to affect the mental state of the crewmembers, by inducing complacency, but – on the other hand –generating stress as soon as difficulties with the operation of the computerized systems appear.

IV. Conclusions

1. General

1.1 The development of advanced technology aircraft based on computerized systems has reduced the rate of fatal accidents in civil aviation significantly. The continuous reduction in the rate of fatal accidents involving those aircraft indicates that lessons have been learned by the aviation industry and that “childhood diseases” are being overcome.

1.2 The “Organization”, by which is meant the national authorities, the manufacturers and airline managements, have made a significant contribution to the trend towards greater safety, but have also contributed to the occurrence of a substantial number of accidents, stemming from failures in the following areas: policy, aircraft design, setting of procedures, training outlines, prediction of failures, and crew oversight..

1.3 The main risk categories, CFIT and LOC, incorporate well defined characteristics of failure, which can be isolated and neutralized.

1.4 **T**he primary factor leading to accidents – ***failure of`Human-FDC***, occurred in areas in which the crew had no experience with aircraft malfunctions or unfamiliar “finger errors” and in obstacles introduced by components of the “organization”. A small portion of the accidents were a result of unusual violations.

1.5 The second factor - ***Technical & Maintenance malfunctions***, which is mainly related – directly or indirectly – to the aircraft’s flight controls, acts by influencing either the aerodynamic features of the aircraft or the flight instruments. In most cases, the end-result of technical failures is the aircraft’s loss of control.

1.6 Not all of the weak points were detected during upgrade to advanced technology aircraft, especially those in the area of MMI, which is based on a new operational concept. As a result, more than half of the accidents were “Glass Cockpit related”.

1.7 Environmental conditions had major efect on the occurrence of the accidents, especially due to loss of spatial orientation during IMC and poor lighting.

1.8 The majority of the accidents occurred within the airport C.T.R area, during the first or last moments of the flight. Faulty communication with the ATC, which contributed to the occurrence of approximately 20% of the accidents, stemmed mainly from limited skills

1.9 In all CFIT accidents, FDC was either a primary (83%) or a secondary factor (17%). Most of them occurred during approach segments, including: VOR/DME (42%), circling (17%) and in IMC conditions. Environmental conditions as well as mountainous topography were considered to be a critical causal factor in this category of risk.

1.10 The nonexistence of warnings about vertical deviation from the NON-ILS descent profile prevents the crewmembers from maintaining vertical orientation during the process.

1.11 The effectiveness of GPWS deteriorates in mountainous areas due to false alerts. Since these topographic conditions dictate non-precision approaches, a more reliable warning system (like EGPWS) is essential for avoiding CFIT accidents.

1.12 In the event of difficulties with spatial orientation, the window of opportunity for response to GPWS `Pull Up` warnings is very narrow. Sometimes, the crew tends to make mistakes. A system is required for maintaining the crew's situational awareness in the vertical dimension before the appearance of the `Terrain Terrain` alert..

1.13 The poor skill level of the crews in maintaining spatial orientation – coupled with misidentification of loss of orientation and its regain – is a central component in crewmembers' errors.

1.14 Descent rates that were incompatible with the approach procedures were not identified properly by the crewmembers. Advance warning of rapid deviation from the NON-ILS safe approach profile is required.

1.15 Over-motivation to accomplish the mission at all costs was manifested in repeated unsuccessful attempts to land under meteorological conditions that did not conform to the manufacturer's specifications. There is no firm policy to place an explicit limit on the number of abortive approaches attempted during adverse weather conditions.

1.16 The high level of reliability of the automation in Glass Cockpit aircraft and the relative ease of flying these aircraft induces complacency, which expresses itself in loose monitoring of flight modes, failure to cross-check system data against additional raw data, and over-reliance on the automatic systems of the aircraft during flight.

1.17 The aberrant mental state of a crewmember, known as `system stress` was demonstrated by his difficulties in operating the computerized system at low altitude, his mental stress intensifying with time as long as the problem persists.

1.18 The formulation of normal procedures, as well as of emergency procedures for scenarios of accidents requiring corrective actions that have not yet been included in them, yet should be reevaluated.

1.19 The understanding of `situational awareness` in advanced technology aircraft exhibited by most of the aircrews discussed in this survey and their attitude toward it are incompatible with the philosophy behind the operation of these aircraft. This conclusion arises from the analysis of crewmembers' failure to monitor the sequence of changes and understand them, as well as from the accumulation of errors encountered after choosing the wrong computerized modes and their "blind reliance" on aircraft's automation, especially concerning its flight. The most problematic type of impaired situational awareness is loss of spatial orientation.

1.20 The aircrews' unfamiliarity with situations of misorientation and their insufficient preparation for them decreased their ability to maintain correct spatial perception, and have thus led to the fatal results in most of the CFIT accidents and in several of the LOC accidents.

1.21 In the leading risk categories, **`lack of spatial orientation`** stands out as a significant crew error. Because adequate safety barriers against it have not been developed, the aircrews are not trained to identify it, and – possibly – do not have the proper means to practice it in simulators.

1.22 The accidents that occurred as a result of a spatial orientation problem of the disorientation type were characterized by inadequate CRM, which included a partial or complete breakdown of inter-crew communication.

1.23 Accidents that evolved from failures in basic flying skills include errors originating in difficulties to integrate with the automatic flight system, in the deterioration of motor skills, as well as in errors in flight status identification – mainly within the pitch level. The common errors are: keeping automation engaged when it should have been disengaged, as well as misidentifying the operation of the various modes.

1.24 The fatality level of accidents involving Loss of Control of advanced technology aircraft mandates increased immunity against loss of control as a result of:
a. Technical malfunctions;
b. Operational errors made by the crewmembers.

1.25 The ground-collision accidents were related to poor weather conditions and pilot-controller interface problems. Critical communication failures oblige the modification of communication procedures when deterioration of meteorological conditions (poor visibility, storm, etc.) occurs.

1.26 The technological means incorporated in advanced aircraft allow the monitoring and prevention of mid-air collisions, but no system for warning the crewmembers against collisions on the ground exists in today's aircraft.

1**.27** Provision of "real time" information to the crews, concerning the calculated location of the aircraft's stopping point on the runway during landing and aborted takeoff, may facilitate the crewmembers' prevention of overrun-type accidents.

1.28 Pilot bypass, i.e., exclusion of the pilot from the aircraft's auto-flight loop, is a central problem in Airbus aircraft. It is illustrated by the crew's inability to understand the aircraft's behavior and its implications.

1.29 During the upgrade of aircrews from the old generation aircraft to the new technology aircraft,which incorporats a different operational concept, a minimal time interval is required in order to allow them to adapt themselves to it.

The G/C operational concept includes: a different operational philosophy, new displays and symbols, manipulation of computer terminals, a different monitoring logic, as well as an altered mode of crew coordination.
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1.30 A period of adaptation is critical for internalizing the following safety aspects:

a) The ability to absorb and digest information on the status of the aircraft and its systems; and
b) the cooperation of the crew.

The operational aspects of the newer aircraft differ in these respects from those of the older generation. Even a sparse sequence of errors is enough to turn a safe flight into an unsafe one.

2. The Manufacturer

2.1 Aircraft manufacturers contributed to the occurrence of approximately half of the accidents, by virtue of the following: policies and procedures, human engineering of the aircraft's cockpit and systems, unpredicted malfunctions related to G/C, and the aircrews' level of knowledge concerning the aircraft's structure and systems.

2.2 The absence of adequate emergency procedures to handle critical malfunctions in advanced aircraft is due, for the most part, to their novelty. The implications of the lack of adequate written emergency procedures for coping with these malfunctions surprised the manufacturers as well. Several of the solutions adopted as a result of conclusions drawn from the accidents were:

- Return to basic flight rules regarding in-flight functions of instruments and flight control problems;
- Integration of the Unreliable Airspeed procedure in the QRH (in view of the Aero Peru 603 and Birgen Air 301 accidents);
- Supplementing procedures for situations beyond the scope of the non-normal checklist.

2.3 "Weak" logic:
The diagnosis of malfunctions by the crew should be carried out in a simple and efficient manner.
Faulty "Warning" logic:

- Simultaneous appearance of Stick Shaker with Over-speed in real and spurious ADC/Pitot malfunctions;
- Appearance of insignificant messages for the preliminary analysis, (the messages are not an unequivocal indicator and are not specifically directed at the actual malfunction);
- The priority order of vocal warnings during simultaneous appearance of multiple severe warnings does not necessarily provide the warning relevant to the most critical risk in a given situation.

2.4 Feedbacks

The implications of the lack of situational awareness, due to the absence of feedback to the crew as to the status of the aircraft and its systems, are evident. This phenomenon may results from the absence of visual cues that failed to capture the attention of the crew.

The activation of any system is not necessarily a result of an involuntary initiative taken by the crew. An involuntary and unpredictable flight - mode change might become a safety problem. Visual feedback messages that appeared while the crew is concentrating on a canalizing event were not always detected.

2.5 Misperception of the aircraft's operation

This problem is a central contributing factor to the occurrence of accidents and is the main issue in the man-machine interface in Glass Cockpit aircraft.

The problems detected within the MMI area were:

A. "Machine Language". Its status and activities were illegible or incomprehensible, required "translation", i.e. additional decoding of FMA and CDU codes, This problem mainly concerned pilots inexperienced in Glass Cockpit aircraft.

B. "Pilot Bypass". The activation of automatic systems that deprive the operating crew of adequate information about the relevant conditions and their implications induces 'system stress', which reduces their efficiency.

C. Logical failures in the insertion of data into the navigation terminals. The pilots experience mental pressure as a result of their inability to understand the reasons for the failure during the operation.

D. Logical failures in the design of the automatic flight system interface (FCU) exist in the models of Airbus aircraft designed in the 80s. The failures were manifested by the unification of selectors' functions and displays, which caused inexperienced Glass Cockpit pilots to err.

E. Lack of means for establishing and maintaining spatial orientation and for quick and easy regain of spatial orientation in case it is lost. Hence, the high frequency of misorientation, a state in which the crew is unaware of the erroneous orientation and its consequences.

2.6 Safeguards

The protective measures developed by the manufacturers in the process of learning from previous accidents were intended to permit an uninterrupted flight until a critical instant is reached, at which point the crew has to respond in order to avoid the risk factor while staying within a reasonable safety margin. A crucial conclusion reached in this study is that, in order to maintain situational awareness and – if necessary – prepare for the critical stage, it is essential that a mechanism for warning the crew ***at an early stage*** - be incorporated in the aircraft.

It can be concluded, on the basis of this investigation, that during the critical state, the activities performed are not always performed in the order required for optimal performance, whether by skipping one of the activities (AA-965, Kenya Airways 431), by poor coordination between the crewmembers or by their tardy response to the situation.

3. The Airline

3.1 The faulty execution of the upgrade to advanced technology by some of the airlines is characterized by nonconformance of company policies and procedures with the demands of the upgrade, inadequate supervision of crewmembers, and – at times – shortcuts taken in the process of absorbing new technology, all of which resulted in accidents.

3.2 The airlines should nurture, encourage and deepen the knowledge and understanding of the aircrews of the steps by which the primary barriers to failure of the human factor: CRM, SOP and S/A, are built up.

3.3 The mental factors influencing the occurrence of accidents of G/C aircraft included **over-motivation**, **complacency** and **stress**. The airline management has the ability to influence the attitude of the crews by adopting adequate policies and supervising their implementation. The EgyptAir 990 airline accident (Oct. 31st, 1999) must shock the airlines and awake them to the importance of tracking and monitoring mental health of the aircrew members.

3.4 Crewmembers' Skills

The low level of skills of the crewmembers in flying the aircraft was found to be a key component in causing the accidents covered by this survey. The areas requiring the improvement of the crewmembers' proficiency are, as follows:

A. Dealing with scenarios according to which malfunctions in Flight Instruments appear without malfunction flags.

B. Dealing with scenarios in which malfunctions require recovery from 'stick-shaker' and 'over-speed' warnings, and – in particular – the ability to distinguish between real and spurious malfunctions before taking corrective action.

C. Scenarios where the visual conditions or flight simulator motion lead to loss of spatial orientation – either misorientation or disorientation, which is a crucial factor in the CFIT and/or LOC risk categories.

D. Situations of uncontrolled flight in which only limited response time is available, since the situation is irreversible or unrecoverable.

E. A canalizing malfunction during VOR/DME approaches in mountainous areas, under IMC conditions.

F. Go-around at low altitude and airspeed, in an aircraft of low landing weight, combined with lack of spatial orientation (unpredictable shift from VMC to IMC) and faulty performance of the automatic pilot.

G. Illustrations should be provided representating the risk categories discussed in the present research.

3.5 The elements requiring skill improvement at the perceptual level are:

A. Dealing with canalizing events

B. Techniques for maintaining situational awareness with respect to:
1) Vertical dimension
2) Spatial orientation
3) Aircraft systems status
4) Aircraft flight modes

C. Identification of flight instrument (altimeter and VSI) malfunctions, distinguishing between genuine and spurious malfunctions, as well as switching to manual flight.

4. Civil Aviation Authorities (CAA)

4.1 The governmental authorities are fully responsible for orchestrating the acceptance of the new generation of advanced technology aircraft. Their oversight should include: risk analysis, changes in standards of aircraft design, conformance of ground and aircrew knowledge requirements to the demands of advanced technology, changes in operational policies as well as of procedures and limitations.

4.2 The massive procurement of aircraft by the airlines and the burden of retraining their crews induce them to exert pressure on the authorities in order to obtain concessions and exceptional permits, thus reducing flight safety.

4.3 The laxity of the Authorities' supervision of the airlines was implicated in the occurrence of several fatal accidents.

4.4 A great technological gap exists between the old-generation approach instrumentation in airports located in mountainous areas and the systems of advanced technology aircraft. This gap contributed to the occurrence of fatal accidents during approach to land.

V. Recommendations

1. Recommendations to CAA

1.1 Prepare for the procurement of new generation aircraft by revision of the regulations, modification of requirements with regard to proficiency and flying skills, detection of new weak points, and modification of procedures and limits.

1.2 Adapt the standard of cockpit design in advanced technology aircraft, in order to eliminate the safety hazards enumerated in the findings of this research.

1.3 Avoid concessions on safety requirements to the airlines in the course of their procurement of advanced technology aircraft, in view of the possibility that there may be "childhood diseases" that have yet to be discovered.

1.4 Assess inspection norms concerning the airlines, manufacturers, ATC and crewmembers, with regard to the changes that have arisen as aresult of the introduction of advanced technology aircraft.

1.5 Upgrade the technological requirements concerning approach-guidance instrumentation in airports located near mountainous areas, in recognition of the potential risks underlying inaccurate approach in those areas.

1.6. Modify the standards of communication procedures when deterioration of meteorological conditions occurs in and around the airport. The modifications should include: a slower rate of data transmission, data verification in readbacks, initiated report of ground reference points, etc.

2. Recommendations to the Airlines

In purchasing new generation aircraft, which are based upon an operational concept that is significantly different from that of the old generation aircraft, it is recommended that the airlines exert themselves in the following directions:

2.1 Assess the risks involved in the operation of a new technology and prepare for them by initiating suitable preventives.

2.2 Adjust the absorption rate of new aircraft to the human resources available, as well as to the company's retraining and training capabilities, without compromising safety standards or reducing the length of the training period.

2.3 Adapt the assignment of aircrew to the difficulty level of the mission and its conditions. Specifically, do not position inexperienced crew in a complex mission under extreme weather conditions.

2.4 Define specific limits to the period required for the adaptation of crewmembers during their upgrade to advanced aircraft.

2.5 Modify the focus points and reformulate the procedures for dealing with situational awareness and CRM in G/C aircraft. This changes are required in order to eliminate misperception of the systems operation, which imperils the safety of the aircraft.

2.6 Set a policy for the prevention of the "mental side effects" of flight in advanced aircraft, such as: complacency, system stress, and over-motivation, which are behavioral phenomena that contribute to flight operation errors in G/C aircraft.

2.7 Modify the subject matter of training in simulators in accordance with the conclusions of this research.

2.8 Develop effective barriers for the avoidance of human error, and augment the aircrews' knowledge and understanding of their utilization.

2.9 Limit the number of unsuccessful approaches to land in adverse weather conditions.

3. Recommendations to the Manufacturer

3.1 Analyze the types of malfunction that cause rapid loss of control over the aircraft and take steps for their prevention by formulating appropriate procedures and training of the crewmembers.

3.2 Keep the pilot "within the automation loop", using easily comprehensible visual feedbacks as well as audio feedbacks. Provide complementary information to the pilot on issues requiring his intervention, i.e., decision intersections, for instance, the actual distance available for landing.

3.3 Develop means for illustrating real and spurious malfunctions in simulators <u>without the appearance of failure flags</u>.

3.4 Improve the quality of the operational instructions, in order to allow the crewmembers to attain greater proficiency in the following flight areas:

1) Dealing with canalizing situations
2) Maintaining situational awareness regarding:
   a. Spatial orientation, especially in the vertical axis
   b. Aircraft flight modes
   c. Aircraft systems status.
3) Identifying malfunctions in flight instruments – ASI VSI and Altimeter, distinquishing between genuine and spurious malfunctions, switching to manual flight.

3.5 Provide means of maintaining the cockpit crew's spatial orientation, especially with respect to the vertical axis: altitude in relation to the topography, descent rate incompatible with aircraft` height (AGL), and abnormal pitch angle.

3.6 Develop a technique to prevent distraction of the FDC's attention by a malfunction, by encountering difficulty in activating a system, or by the necessity to cope with a canalizing event.

3.7 Develop an airborne system to alert the crewmembers of an impending collision between aircraft on the ground.

3.8 Improve the quality of the audio systems as well as that of the communication equipment in the cockpit, and reduce the environmental noise.

3.9 Improve the system of feedback to the crew concerning those flight modes that are defined in this investigation as injurious to situational awareness. Extend the use of vocal messages, which are less selective than visual messages. The latter, being omni-directional, may bypass the visual limitations of the FDC.

3.10 ***Feedbacks:***
STOPPING MARGIN.
The value displayed as representing the distance left until the end of the runway or the stopway should be calculated from the point of the aircraft's reaching a complete stop:

A. In the final approach – from 50ft height and below; in case the value is negative, the "go around" announcement should appear.

B. On takeoff, from brake release until liftoff or until the aborted takeoff process is terminated.

- Once TOGA is selected, a vocal warning should be provided, announcing the activation of TOGA.

3.11 **Switches**

- Integrate vocal warning on asymmetric power status; while the power is in Auto Thrust Mode and the throttles are motionless (Airbus). An option for throttle movement should be maintained.

- The simultaneous appearance of 'stick-shaker' and 'over-speed' should be prohibited, whether the malfunction is real or simulated.

In in order to prevent operational errors, logics should be designed to allow two separate safeguards for one dual-function switch/selector. Once throttles are activated during any stage of the flight, the 'speed brakes' should be automatically activated to the "down" position (retracted). A message and warning should appear upon failure of the function.