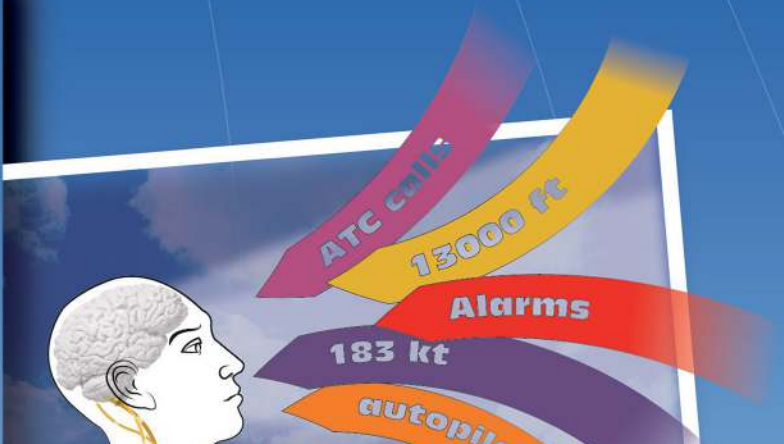
LES DOSSIERS

SITUATIONS INATTENDUES

Prévention / protection – Assistance aux équipages de l'aviation civile de transport

UNEXPECTED SITUATIONS

Prevention / protection – Assistance to civil air transport crews



AAE Dossier # 49

2020

SITUATIONS INATTENDUES

Prévention / Protection
Assistance aux équipages de l'aviation civile de transport

UNEXPECTED SITUATIONS

Prevention / Protection
Assistance to civil air transport crews

AAE Dossier 49 **2020**

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FOREWORD

The world of air transport is severely affected by a dual crisis – the search for "decarbonisation" and the sudden, more tricky question of managing the COVID-19 pandemic – and certain issues will persist regardless of developments. In order to move forward in technical areas, AAE is endeavouring to identify avenues for progress.

This dossier deals with one of these avenues, that of safety, an aspect which is increasingly important as advances in the automatic systems of aircraft replace the humans tasked with their operation. More specifically it looks into human operational behaviour in the face of unexpected situations, which are fairly frequent and potentially dangerous, despite increasingly thorough planning of air transport missions. New aircraft configurations already announced only make this study more relevant.

While the field of ergonomics is now well apprehended in the cockpit, this is much less the case for behavioural aspects, which are difficult to characterise. The base document underpinning this dossier highlights most of the sensitive cases requiring action in terms of behaviour, whether directed at humans, pilots, or systems (which are inherently more easily adaptable than humans). It also reveals the limits of the action of artificial intelligence in replacing human behaviour.

The study is an original one, and is intended to be effective. Based on a highly detailed analysis of five accidents, chosen for their complementarity, it characterises both the human deficiencies and the faults in the systems involved. This led to recommendations which are easily transposable, by affinity, to the operational use of any aircraft.

There are two types of recommendations: general ones, to increase awareness as to the importance of research now needed on human behaviour; and specific ones *regarding improvements to current systems, especially in the hypothesis of single pilot operations.*

The dossier follows on from previous AAE studies into the evolution of automation in air transport. It aims to provide assistance to manufacturers, training centres and certification authorities in the area of human and systems integration in aeronautics.

Anne-Marie Mainguy
President of the Air and Space Academy (AAE)

EXECUTIVE SUMMARY

Unforeseen events represent some of the greatest dangers in civil aeronautics. This observation comes from the pilots themselves. However, accident analysis shows that ***the unexpected, whether foreseeable or not***[1]*, also impacts crew behaviour due to the effect of surprise induced by a potentially dangerous, fast-moving situation.*

The challenge for AAE was to recommend safety enhancement measures based mainly on this finding, even though other causes of incidents and accidents can be observed. The basic assumption adopted was that accidents caused by unexpected situations have "envelope" characteristics incorporating many of these other causes, an assumption which was borne out.

Given the impact of this issue on safety, and the large number of technical and human parameters to be processed to ensure credibility, the decision was taken to draw up a dossier that could be used above all as a complementary guide by industrialists, users and training centres, as well as by certification authorities for the design and operations preparation of the next generation aircraft.

This dossier, which follows on from AAE dossiers that have dealt with increasing automation in civil aeronautics (and in particular the move towards a single pilot crew, since this must be considered), clinically analyses current shortcomings, both human and systems-based, in the proper handling of these unexpected situations. The study puts forward solutions to (1) prevent the risk of inappropriate reactions, and (2) assist crews in their corrective actions. It conclusively demonstrates the need for system designers and regulatory authorities to take better account of the major parameter that is human behaviour.

1 It is possible for a situation to be generally foreseeable, but for its unexpected occurrence to surprise the pilot.

The solutions suggested include adjustments to the pilot/aircraft interface as well as a review of basic piloting. Judged to be necessary today with the two-pilot crew, these will be all the more imperative in the framework of Single Pilot Operations (SPO), as well as with the increased constraints incurred by globalisation of the fleet.

Another avenue for improvement involves better processing of incidents of all kinds. Clearly the various players – airlines, manufacturers and authorities – continuously use feedback to improve safety. However, there are still millions of cases where pilots resolve risky situations with no apparent difficulty. Knowledge of these cases could be an advantage within a context of increased aircraft automation and for mitigating risks, particularly those inherent in reducing the number of pilots on board.

The dossier contains four parts:

1- *Introduction*
2- *Basics*
3- *Recommendations*
4- *Analysis and detailed proposals*

with an appendix and glossary.

1. INTRODUCTION

GOAL OF THE STUDY

The goal of this study is to define, to the best of our analyses, the prevention of critical unexpected situations, the mitigation of their effects and the necessary assistance to the crew for the remaining situations, by correcting deficiencies observed during accidents. As these deficiencies involve the integration of crew behaviour in the operational use of the aircraft, especially in the pilot/cockpit systems interface, the two Human and Systems agents are considered.

The study concerns civil aeronautics, particularly transport aviation. Military aviation, which, more often than not and as a matter of principle, is involved in unexpected missions, is probably ahead of the curve when it comes to dealing with the unexpected. It should also be noted that military pilots are subject to special recruitment, individual monitoring and specific tactical training in a cockpit environment that is also specific. A similar separate study on military aviation would probably be worthwhile.

However, the subject of this study could also prove of interest for the military because, contrary to the fundamentally fragmented nature of military aviation, civil aviation is fundamentally global and the concepts of behaviour dealt with here apply to human beings wherever they may be.

PRELIMINARY REMARKS

Why such a study?

The AAE conference of November 2011, "Air Transport pilots facing the unexpected", clarified that, through their interaction with human characteristics, unforeseen situations are one of the most serious dangers of aviation. The studies that followed this conference showed that it was in fact the ***unexpected, predictable or not*** *that was involved.*

Following on from the discussions on the subject, AAE published two dossiers, one in 2013, no. 37 "Dealing with unforeseen situations in flight" and another in 2018, no. 42 "More automated, connected aviation by 2050".

Here, the unexpected refers to situations triggered by an event whose unexpected and sudden nature, combined with a surprise effect of varying intensity, is likely to adversely affect the reaction of the pilots. It is possible that a situation is generally foreseen or foreseeable, but that its unexpected occurrence surprises the pilot.

Fast-moving situations are the most dangerous. But those unfolding more slowly can also become critical, as shown by two of the examples analysed(2).

Observing the persistence of problems and the slowness in implementing corrective actions, a new study was launched, that of prevention and assistance in resolving these dangerous situations. The study more especially addresses those directly concerned by the problem, serving as a sort of guideline for use by manufacturers, users, training centres as well as by certifying agencies regarding the design and operations preparation for the next generation of aircraft.

Indeed, despite the efforts of many "whistle-blowers", despite the concrete results of studies, irrefutable experimental results and accident reports, the aeronautical community remains subject to imperatives other than safety, even if the latter must always be considered the essential imperative. Most airlines deal with human factors to the best of their ability, but it took the double disaster of the B737 MAX for the aviation community to agree that human aspects of safety should be dealt with appropriately, beyond the frequent formulaic referral to pilot negligence or incompetence as the primary causes.

It is worth noting that regulations today consider human problems only in terms of aspects easy to formulate: ergonomics, skills, knowledge and procedures. Human behaviour, which is both a source of negative operational deficiencies and of positive recovery from critical situations (often overlooked), is not objectively taken into account properly.

2 Asiana Airlines 214, featuring both the slow-moving and fast-moving unexpected; Germanwings 18G semi-fast-moving.

For example, EASA's CS25 and FAA's FAR25 talk only sparingly about behaviour as such, or psychological problems.

The question arises, however: why are we so concerned about better understanding the behaviour of a pilot destined to be replaced by automation? The answer is twofold.

On the one hand, we have limited our soothsaying perspectives to 2050, and until then there will always be at least one pilot on board.

On the other hand, in Dossier no. 42 we imagined five possible scenarios for the evolution of the pilot/automation duo, ranging from the current situation to that of a single pilot on board a necessarily autonomous aircraft. Intermediate scenarios mention operational assistance from the ground. However, in the light of the technical, human and organisational problems posed by these intermediate scenarios, and noting the strong reluctance of aircraft manufacturers to entrust immediate safety functions to the ground, it is likely that there will be a rapid transition to scenario 5, that of the autonomous aircraft with a single onboard pilot, with experimentation on short-haul flights showing the way. This scenario, the most ambitious, appears to be the goal to envisage.

This solution will not be capable of completely preventing the occurrence of unforeseen or even unexpected situations, despite the introduction of machine learning, and it will require in-depth knowledge of the human functions to be reinforced or eliminated (such as the tunnel effect[(3)]) by automation.

Items to be dealt with

For years we have been aware of the factors causing these human dysfunctions. Their material and human aspects are closely linked without our objectively being able to deal with them separately. Thus:

- *with regard to systems, the presentation of information unsuited to the awareness of fast-moving and dangerous situations, time parameters unsuited to perceptions and rapid corrective action for these situations under stress, the presentation of failures and alarms with insufficient prioritisation, the lack of information on the imminence of risk situations, all point to the need to significantly modify the cockpit interface;*
- *concerning pilots, the limitations inherent in dynamic mental processes (effect of surprise, stress, chronological sequencing of conscious actions, saturation of short-term memory, parasitic focus of attention known as the tunnel effect), point to the need to change certain selection and training orientations.*

Regulatory requirements play a major role in these orientations and are therefore concerned.

3 Tunnel effect: mental blocking phenomenon focusing on one element of the actions to be carried out, preventing the perception of what is happening around.

Mental limitations are identified characteristics of the human part of the Human/Systems tandem and, like the physical limitations of the material part of the systems, they should be taken into consideration in studies and projects, and in real operations.

In other words, studies are to be defined and launched with the corresponding regulatory objective.

The Human agent

According to accident analyses, crews are implicated in more than 50% of the causes of accidents. When human characteristics and limitations are introduced into the analysis of accident reports, as in this study, we are led to consider the functioning of the "Human agent" similarly to that of the "Systems agent", in a manner disconnected from notions of responsibility.

But a captain/pilot is responsible for the proper conduct of the mission, and each pilot is responsible for the proper execution of their tasks: hence the tendency to orient negative human involvement towards pilot negligence, error or incompetence, and therefore towards failure to carry out actions for which they are responsible. Any aspect of subjective judgement is absent from the study but has naturally been left in the appendix containing extracts of official reports.

METHOD

To ensure that this study is not the nth of its kind, and therefore potentially useless, we have chosen a scientific and clinical type approach, working on actual examples. The choice was thus made to analyse the causes of major aviation accidents and incidents.

The purpose of this analysis is to highlight human problems and system deficiencies observed in accidents in order to propose solutions.

Due to the delicate nature of this analysis and to the need for precision, the number of cases studied was necessarily limited. The selection was restricted to five different types of cases so that their diversity could encompass most of the causes of accidents resulting from unexpected situations.

Despite their fortunately low numbers, the analysis of these accidents offers a surprising compendium of deficiencies to correct.

Official reports of accidents and major incidents were the sources of information for the study. Our analysis sheds light on, or even reveals, some specific elements that were not highlighted in the reports. This is inevitable in any study whose objective goes beyond the simple search for causes. This does not mean, however, that this study calls into question the official reports written with the best information available at the time, or the certification of the aircraft concerned.

By nature, the aircraft analysed were of the A320, A380, B777 and A330 generation. Later-appearing aircraft such as the B787 and A350 may contain some of the improvements recommended in this dossier, sometimes partially, but this does not invalidate the many recommendations still to be applied.

CASES STUDIED

Their numbering will be used as an index in the following texts (for example, "case 4" will concern case no. 4, US Airways 1549).

1) Asiana Airlines 214, 06/07/2013 (use of automation)

A B777 performs a visual approach, ILS without "Glide", in San Francisco, on autopilot (AP + AT)[(4)]. At the start of the approach at 4800 ft, ATC requires speed reduction. The PF[(4)], whose co-pilot (PM) is an examiner, has difficulty managing the automatic descent. A false manoeuvre forces the PF to finish in manual control. But an oversight by the PM leaves the engines idling. The unmonitored speed decreases and the aircraft stalls in the short final approach despite a late go-around.

2) Air France 447, 01/06/2009 (loss of information due to icing)

An A330 is flying between Rio de Janeiro and Paris at a cruising altitude of 35000 ft. Shortly before encountering a large cloud mass, regularly encountered on the route followed, the captain goes to rest after having entrusted the control of the aircraft to the first co-pilot, the PF, the second co-pilot becoming the PM. The probes freeze and as a result the automated systems disconnect. The PF has difficulty regaining control manually, allowing the altitude to increase and the speed to decrease. The profusion of alarms associated with the absence of speed indication and the lack of correct intervention by the PM lead to an uncorrected stall, with irrecoverable loss of control .

3) Qantas QF32, 04/11/2010 (engine explosion)

An A380 is climbing after taking off from Singapore. At around 7000 ft, engine 2 explodes. Debris batters the aircraft, piercing tanks, making most equipment and its connections unavailable. The crew, the PF captain and the first PM co-pilot manage the situation for more than 50 minutes thanks to the ECAM, in an atmosphere of continuous alarms and continuous correction of failures. The help of extra pilots fortunately present in the cockpit is necessary. Landing is successfully performed under manual control with the flight controls and brakes in degraded modes and damaged control surfaces.

4 C.f. Glossary

4) US Airways 1549, 15/01/2009 (ingestion of birds)

On the initial climb after taking off from La Guardia, an A320 encounters a flight of geese around 2,000ft and loses thrust from both engines. Ditching on the Hudson is successfully executed, completing a flight managed by both pilots in the best possible way according to the circumstances.

5) Germanwings 18G, 24/03/2015 (suicide)

In flight between Barcelona and Düsseldorf an A320 is cruising at 38,000 ft. The captain leaves the cockpit in response to natural needs, leaving his co-pilot at the controls. Shortly after, the aircraft goes into descent under autopilot control with the cockpit door intentionally locked from the inside. Having detected the path anomaly, ATC tries unsuccessfully to contact the crew, and alerts National Defence. Attempts to force the door fail and the aircraft crashes.

Note: Case 5 concerns a mental health problem of the pilot. Since it concerns health, it could be compared to the case of physiological failure dealt with in Dossier 42, with the difference that suicide is an active aggravating action while failure is passive. As this passive effect was addressed in Dossier 42, the aggravating active effect requires a new approach addressed in this dossier.

2. BASICS

In this study, the facts show that what is concerned is Human/Systems Integration (HSI). The recommendations are valid under current operational conditions but they are of increased interest in the case of a single pilot on board.

These recommendations are based on the analysis results detailed in chapter 4. However, to facilitate their understanding, some summary results based on this detailed analysis will be given here.

REMINDERS

Full automation?

Focusing solely on human errors and deficiencies in accidents can lead to the desire to remove the human element from aircraft, in other words switch to "full automation". This would lead to passing over and failing to acknowledge the thousands of daily occurrences of crews' reactions correcting dangerously deteriorating situations. These occurrences are often not spoken of because in the end everything went well.

A significant proportion of these events go into the feedback from experience used by the airlines. However, many of such very numerous positive interventions are not known or exploited, and would be useful to improve current operations, and mandatory for the development of a "fully automatic" approach operating at an acceptable level of safety.

Basic principle

In the development of an aircraft and its systems, safety must prevail over commercial or other considerations. This reminder of a basic principle, which fortunately is widely followed, should however be recalled in the light of recent accidents.

Other principles

The aim is indeed to prevent the risks associated with unexpected situations (foreseeable or not) and to assist the crew in their correction. The two agents, Human (the crew) and Systems (increasing automation), are involved simultaneously. In reality, what is concerned is their integration in which the interfacing of the cockpit is the basic element.

It is worth recalling some basic concepts and principles:

- *Leave to humans what they can do better than automation, and to automation what it can do better than humans, as techniques and knowledge evolve.*
- *Consider integration according to mental "mechanisms": perception of information, processing/choice, decision/action, control.*
- *Take into account the limitations of the crew agent (chronological sequencing of conscious actions, saturation of short-term memory, parasitic focus of attention, particularly in stressful conditions) in the same way as the limitations of automated systems.*
- *Humans remain what they are, non-modifiable; adapt selection criteria to the actual requirements of operations, and adapt training programmes to immutable basic teaching principles (teach the necessary and sufficient, teach through practice, check the level of skills acquired). Adapt the technical resources to the defined human and educational requirements.*

CHARACTERISTIC BEHAVIOURS

In the five cases studied, flight path control was the major immediate concern, with basic behavioural characteristics clearly appearing.

Chapter 4 focuses mainly on studying the details of dysfunctions. However, it is also easy to define classes of behaviour that must be taken into account in HSI, especially in SPO "Single Pilot Operation", behaviours summarised here.

Interestingly, our case selection has addressed two extreme types of professionalism: cases 1 and 2 involve crews with seemingly mediocre performance skills (despite meeting recruitment criteria and training standards), and cases 3 and 4 reveal highly professional crews. Case 5 is specific to abnormal behaviour.

Since it is unrealistic to think that pilot selection will improve significantly in the future, the recommendations relate to the minimum level of selection practised worldwide.

1) Asiana Airlines 214 (failure)

The operating pilot (PF) was confronted with the execution of an approach under conditions giving them some concerns for its execution. From the outset, the PF's mental preparation was called into question following a request from ATC, hence mental anxiety favourable to errors and omissions.

Subsequently, the "manual" operation of complex automatic controls designed primarily for fully automatic use led to errors that were not sufficiently perceived and corrected due to complicated interfacing and the lack of assistance from the co-pilot, the "Pilot Monitoring, PM". At the end of the approach, manual visual control without speed control caused a tunnel effect focus of attention. The "wake-up" with final alarms was too late to avoid the impact before the landing strip.

Moreover, the PF did not understand the interactions between the three available energy components expressed by speed (V), altitude (Z) and thrust (T).

It is in this set of causes that the overall requirements of a system interface are to be found, taking into account the perception function necessary for a correct interpretation of the situation.

2) Air France 447 (failure)

The PF, co-pilot placed in a position of responsibility in a potentially difficult weather situation, was anxious to act correctly, hence a certain anxiety reducing his mental awareness.

The sudden roll movement upon autopilot disconnection led the PF to prioritise control of this movement and thus to enter Pilot induced oscillations (PIO). Controlling the path of the aircraft was a priority for him, but the oscillation "disconnected" him from the other flight parameters through the tunnel effect.

Then, the combination of alerts and alarms, the apparent contradictions of different data, the limited assistance of the PNF (PM) plunged him into irreversible confusion.

He, too, did not understand the interactions of the three energies expressed by V, Z and T.

The major points arising from this example concern the systems that could have played a role preventing this confusion: firstly, the smooth continuity of the flight path despite the deterioration of the condition of the flight control systems, then the clear presentation of the situation.

3) Qantas QF32 (success)

The first action of the PF was to ensure that the flight path was maintained.

Finally, the delicate manual operation of the degraded flight controls was possible thanks to his skill.

Meanwhile, the failures of all aircraft systems (except oxygen) led to enormous sorting and action work, for which the crew needed to reflect despite the gradual deterioration of the systems and the profusion of unnecessary alarms.

The two-man crew, very efficient, often required the help of the other pilots fortunately present in the cockpit.

The main points to remember are the fortunate continuous automatic flight path control during the corrections of the potentially catastrophic situation, the need to have a clear presentation of the situation and the remaining possibilities, that of maintaining easy manual control of the flight path. And especially the decision of the PF captain to focus on what remained usable to save the aircraft and its passengers.

4) US Airways 1549 (success)

The loss of thrust made controlling the flight path a vital priority.

The captain, who quickly became PF after the bird strike, had a vital reaction not mentioned on a checklist unsuitable for the event, the start-up of the APU, which made it possible to manually operate the aircraft in normal mode until the impact on the Hudson.

This flight control was difficult because it was mentally shared with decisions vital to continued flight, and disrupted by external messages and system alarms.

Teamwork was the best that could be hoped for in these circumstances.

The major points to remember are the immediate reaction outside the specified procedures to maintain the operating integrity of the systems (APU), and the ability of the PF to make vital path choices despite the disruptive environment.

5) Germanwings 18G (failure)

This case of suicide is too specific for operational behaviours to be taken into account. However, the problem of vital control of the flight path arises when considering forced automation.

SPECIFIC ACTIONS

*These are the 40 actions (**Sx** and **Hy**) presented in the boxes of the headings of the fourth part. They are detailed, specific to the purpose of each heading and do not require an additional summary.*

However, major recommendations can be made.

3. RECOMMENDATIONS

With regard to pilot/aircraft integration, the problems of these two agents and their solutions are closely intertwined. An attempt at simplification has been made by dividing recommendations under two headings, Human and Systems.

Obviously, these recommendations are based on examples of two-pilot manned aircraft. It will of course be necessary for the designers of future aircraft working on single-crew member cockpit to interpret the meaning of the requested improvements and to provide them with equivalent solutions (in "Equivalent safety means" certification).

HUMAN SIDE

Improve consideration of human behaviour[5]

It is worth noting that the vast majority of those problems detected which require correction concern mainly human behaviour in the face of unexpected dangerous events. While physiological and cognitive ergonomics have made enormous progress over the past 50 years, the dissemination of knowledge about behaviour under mental strain has not. However, our knowledge about which mental characteristics entail the activation of behaviours qualified as deficiencies leading to accidents, and often hastily attributed to errors or even human mistakes, is increasing and becoming more precise. This study uncovers these characteristics without any possible dispute.

First, there is the effect of surprise that causes stress and the focusing of attention, or even sideration, then the combination of mental characteristics: chronological

5 Behaviour: all objectively observable reactions of an individual. Here, the subject's response to a stimulus.

sequencing of conscious mental actions with saturation of short-term memory, dangerous focus of attention with reduction of the vision cone, and audio-visual mental saturation, to name but a few.

1- Scientific consideration of human operational behaviour will lead to a breakthrough in understanding human/systems integration, where today this behaviour is diluted in the heterogeneous set of human factors.

Characterising the decisive elements

It is necessary to define, to characterise by qualitative or measurable parameters, the functions and elements governing operational behaviours and their mental limitations. From these we derive the rules and principles to be adopted to remain below these limitations, noting that the general behaviour of pilots can influence their operational behaviour.

To do so, the causes of dysfunctions must first be identified. They will then be taken as references or as bases for characterisations of functions and parameters usable by system designers.

This characterisation can be conducted both for mental dynamic characteristics (duration of short-term memory, maximum rate of information processed chronologically, levels of alarms perceived during the execution of tasks, mixed perception of physical parameters and representations of system states, etc.) and for physical parameters of systems (types of display, synthetic combinations of parameters, choice of significant and relevant information, alarms, etc.).

These two aspects, mental and physical, must be looked at together in the search for values, rules or principles.

Classic psychology and ergonomics are at the limit of their possibilities in this respect, especially as regards the search for measurable parameters. They must give way to neurosciences, neuropsychology and neuro-ergonomics.

2- The aeronautical community must deal with and characterise human mental limitations in unexpected situations with potentially dangerous developments in the same way as it deals with those of material systems, since this is fundamental to safety.

This consideration of human operational behaviour must be reinforced at the design department and flight test levels. To do so, it is essential that the personnel responsible for designing, developing and testing systems acquire the necessary basic skills[6].

3- The characteristics of human operational behaviour must be taken into account at system design level.
More precisely, when pilot action is planned, the system must be designed around it, and not the other way around.
Regulations must clearly consider behaviour as important a topic as ergonomics.

Need to improve cockpit interfacing

Human intervention must be simple and intuitive regardless of the complexity of automated functions, including when carrying through procedures.

The presentation of parameters for correct awareness of a dangerous unexpected situation must enable immediate perception of the relevant elements. A simplified display is desirable. This will inevitably lead to redesign of displays, in particular those of the PFD (Primary Flight Display) and the FMA (Flight Mode Annunciator).

More specifically, this presentation of parameters must not be limited to the present unexpected situation, but must, as far as possible, anticipate imminent risky situations, so that the pilots are as little surprised as possible and thus best prepared for these situations.

4- The display of parameters must allow immediate situational awareness, but must also anticipate situations of immediate risk.
This should realistically take into account human capabilities and limitations for the entire global pilot population at their minimum capability levels.

6 AAE is studying evolving aeronautical skills.

Reorientation of pilot selection and training

The rarity and dangerousness of risky situations require that pilots demonstrate great self-control, an innate basic quality that can nonetheless be partially improved by appropriate training. It must be detected upon selection, especially in the case of a single pilot on board.

However advanced automation may be, it will never eliminate the need to regain direct control of the situation, in particular that of the flight path in manual control[7]. Physical and mental skills neglected in favour of automation must be regained in training and maintained in commercial operations, which does not eliminate the obligation to select and use automation in all its normal or degraded operating modes[8].

This requires reviewing the basic qualities and skills in selection and training. It raises the question of the rigour of the players – airlines, training centres and authorities – when there is a shortage of pilots and applicant pilots to recruit. The clear risk arising from this is a relaxation of hiring criteria, not to mention the eternal financial problem of training, which is always too expensive because in accounting terms a pilot in training is considered unproductive.

5- Self-control in critical situations becomes an important element in selection and training. This implies, from basic training on, programmes based on reaction to unexpected events.
The pilot's skill in direct flight path control must be maintained through practice.
The same applies to the use of automatic controls in all their normal or degraded operating modes.

SYSTEMS SIDE

Since humans remain unchanged, and their training comes up against their brain's limitations, the part mainly involved in pilot/aircraft integration is Systems. The many critical points are detailed in chapter 4.

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7 Manual control is understood as being the **direct and immediate** action of the pilot on the evolution of the velocity vector and simultaneously on the management of the three energy parameters (speed, altitude, thrust) using manipulators (levers, steering wheels, sidesticks, etc.), through flight and engine control systems.

8 Only trying to memorise operating procedures without understanding and practising them is contrary to basic instruction as applied to the use of dynamic functions of complex systems.

Basic precautions

Current safety analyses make for sophisticated predictions. However, they may be less efficient in cases of combinations of unforeseen failures. As a general rule, systems whose malfunctions may affect flight safety are designed to have a high level of availability and to be "fail-passive" in the event of a failure. However, it is necessary to remain vigilant with regard to deviations or failures, because examining new or statistically excluded risks increases the volume and difficulty of the cases to be dealt with.

The handling of flight path management and the operational integrity of systems are major points.

6- In systems design, safety analyses must take into account all risks operationally detected, including new ones or those statistically deemed to be of low occurrence.
Flight path management and control of system integrity are major points.
In this regard, the analysis of these risks involves the collection and processing of information drawn from the LOSA, OFDM/FOQA[9] databases of airlines and manufacturers, made available without restriction to designers..

An efficient system such as ECAM at Airbus analyses combinations of system failures. However, it is necessary to go beyond its current design to deal with combinations of complex situations and immediately give pilots the reliable information necessary to act as best as possible with the remaining availabilities.

It should be noted that the growing number of parameter sensors raises the question of their reliability, whether the sensors themselves or their connections to systems. Data prioritisation and substitution solutions must therefore also be provided.

7- Automatic failure analysis systems, such as the Airbus ECAM, must be perfected to take into account complex failure combinations, and give pilots a summary view of the operational possibilities remaining available.

9 For LOSA (Line Operation Safety Audit) and OFDM/FOQA (Operational Flight Data Monitoring or Flight Operation Quality Assurance), they should be adapted to the detection of "threats" corrected by the crew.

Unintentional departures from the operational flight envelope are frequently observed after automatic controls go into degraded modes.

> ***8- Display in a manner clearly perceptible under stress any removal of flight envelope protection.***

Operational cases insufficiently dealt with

As a general rule, shortcomings arise from technical difficulties in dealing with these cases, which have often received partial solutions. Technical advances, the introduction of AI in particular, should enable their resolution from now on. They are mentioned here in this perspective.

Flight path management transition

In the event of sudden loss of an automatic flight control system, control of the flight path is vital.

> ***9- The flight control systems must be designed to maintain a stable flight path with a minimum of functions (heading, altitude, speed, and thrust) to enable the current flight path to be pursued and the risky situation to be corrected in the event of automatic control failure.***

Go-around

Go-around is a relatively unpractised manoeuvre since, unlike landing, it is not intuitive. It could be configured to trigger automatically depending on the landing circumstances, based on flight path analysis on short final approach (height, speed and speed gradient, vertical speed, attitude, heading, deviations from the desired flight path). A prediction of touchdown and remaining distance on the runway could be used as a condition for automatic or manual triggering of go-around.

Whether automatic or manual, the go-around manoeuvre must be controllable, with thrust levels allowing a normal climb speed: a moderate thrust/weight ratio should therefore be used, with automatic retraction of the high lift devices at the correct speeds in the climb phase.

> ***10- The operational need for go-around must be clearly indicated to the pilot, and/or triggered automatically.***
> ***Manoeuvring must be controllable, with appropriate vertical speed and automatic retraction of surfaces according to speed.***

Manual control, energy exchanges

The simultaneous processing of the three energies (kinetics/speed, potential/altitude, internal/thrust) is carried out by current automation systems (AP + AT). Often pilots do not master it in manual control, especially when flying in the vertical plane.

However, manual control will always be necessary, especially in emergency situations.

11- A manual control system must be developed and standardised that clearly displays the simultaneous control of the three energies.

Flight director

In manual control, the selection and use of the flight director may be dangerous when other automatic controls are connected to it, AT in particular.

Goal-based flight path control, with the help of the velocity vector, should be favoured.

12- The flight director in its current version is only a substitute for the AP, becoming dangerous when in manual control its functions do not match the pilot's intentions. The principle and objectives of the flight director must be redefined according to the tasks assigned to manual control.

Angle of attack

***This is a vital aerodynamic parameter**. A reliable and redundant means must provide an angle of attack value (measured and/or calculated) that is sufficiently precise for operational needs.*

This value and the approach to limits must be properly presented on the instrument panel, if not on the PFD, to be used appropriately (the angle of attack indicator was present on Mercure, and that of Concorde was routinely and effectively used).

To ensure validity in training of the approach to stall on the flight simulator, the use of flight test measurements would appear to be necessary.

13- Angle of attack is a vital parameter. It must be presented as such on the instrument panel in order to be used appropriately.

Alarms

The problems associated with sound and other alarms are not new. Simultaneous sound alarms create an atmosphere of stress that reduces mental abilities, especially when the sounds are not associated with rapid visual recognition of their cause. A multitude of flashing indicator lamps and corresponding aural alarms do not allow any system to stand out clearly and can lead to mental saturation.

It is necessary to better define a hierarchy in the importance of the consequences of failures both in the presentation and nature of simultaneous alarms.

14-Current alarm systems are not suited to complex combinations of situations and can aggravate them by disturbing crews. The problem should be reviewed in its entirety.

DIFFICULT PREVENTION OF A SUICIDAL ACT

15-The problems to be resolved are:

- ***communication and use of medical data considered confidential but which may alter operational behaviour;***
- ***detection of psychological anomalies by the professional entourage;***
- ***protection of the cockpit against threats from inside and outside;***
- ***complete autonomy of the aircraft and its safe triggering in the event of a suicidal act.***

4. ANALYSIS AND DETAILED PROPOSALS

The results of our analysis have been grouped under different headings according to the operational problem category.

*In the following summary, these results are referred to according to the five previously mentioned accidents to which they belong (**case x**, **case y**, etc.).*

For more details, please refer to the basic document placed on the AAE website (in French only), grouping together the five analyses and their initial summary:

DOSSIER 49 BASE DOCUMENT[10]***:*** **Le traitement des événements "inattendus/imprévus" au cours des missions des avions de transport**

*For each heading, the possible solutions are divided into two types: systems **Sx** (22) and Human **Hy** (18) and shown in a box.*

SITUATION MANAGEMENT AIDS

*It seems obvious that knowledge of one's position within the airspace (proximity to a diversion site) and weather conditions are essential in emergency situations (**cases 3, 4**), although planning thereof is not possible. Paradoxically, in **case 1**, weather conditions requiring that the pilot focus on a full instrument approach could have prevented the problems.*

10 C.f. AAE website, section Documents and Media, direct link:: https://cutt.ly/0f0u9KP

Space management

*The proximity of a diversion site or a surface usable for landing (or ditching) and available altitude are also favourable elements (**case 3, 4**), but equally uncertain.*

The Garmin G3000NX project on Piper M600, together with those of Cirrus and Daher, of autonomous landing on a nearby field, are to be followed with interest.

S1

Altitude and proximity of a diversion site or a surface usable for landing (or ditching) are favourable but uncertain elements. The immediate detection of landing sites in a database, with their operational and meteorological conditions of use, is a necessary condition as soon as a critical situation occurs.

This requires access to parameters stored in the system memories; heading, distance and time to the closest "landable" fields, with real-time updating of their weather and use conditions, thanks to a permanent in-flight calculation, immediately offering the best diversion if necessary. These parameters should take into account the status of the aircraft, its actual flight configuration, the available energy, as well as the operational state of the chosen landing site.

H1

This assistance may never be perfect and the assessment and choice by pilots from among the proposed solutions will remain essential, for example in estimating the probability of success.

*Good visibility and good weather conditions are obviously favourable (**cases 1, 3, 4**) to the correct management of situations, but are uncertain.*

*However, the risks of critical conditions should not be underestimated (**case 2**).*

S2

The assessment of weather conditions according to their short-term or potential risks should be improved in terms of presentation and in-flight handling, in particular by summarising the situation with appropriate alerts.

Improving the effectiveness of weather radars as a decision-making aid must remain a goal, particularly for detecting and avoiding hail, extreme frost, severe turbulence and tornadoes.

H2

Avoiding dangerous weather situations requires both the maintenance of good practical knowledge of the phenomena by pilots and the correct use of weather radars.

Available time management

*The time available to correct a situation is the key success parameter when it is used correctly (**case 3, 4**). However the survival time imposed by the entire situation is often limited (**cases 1, 2, 4**). Note **case 3** where the centre of gravity position drifted towards an excursion from the flight envelope.*

Automatic failure correction

*This is in principle the best means of safety: for example, the extinguishing of a fire in a tank (**case 3**).*

*However, it can be dangerous in combinations of unforeseen failures: fuel transfer to a pierced tank (**case 3**).*

S3

Current safety analyses make for sophisticated forecasting. However, they may be faulty in unexpected failure combinations: e.g. fuel transfer to a pierced tank.

All systems whose malfunctions may affect flight safety must be designed to have a high level of availability and be fail-passive in the event of a failure. This is already the fundamental rule of the profession, but deviations or shortcomings can occur.

How can a system be designed that analyses combinations of complex system situations and automatically adapts to them? ECAM (Electronic Centralized Aircraft System), dedicated to displaying aircraft system status, is a step in the right direction, but has its limits.

Even if a system is capable of immediate reaction, the pilot must be informed with the possibility of taking control over any corrective action.

Stress control

The effect of surprise is stress, of varying degrees of intensity depending on individuals and circumstances, which reduces mental capacity to solve perception and decision-making problems, thus increasing the time needed to do so. This state of stress, or shock, is exacerbated when a multitude of alarms, some the consequence of others, occur simultaneously.

*Personal experience and capability as well as crew training can help overcome this disability (**cases 3, 4**), but inadequate training and experience reduces the capacity for resistance (**cases 1, 2**).*

*One specific subject is the definition of operational procedures, which appear satisfactory in terms of their application to situations when the time required is available (time which is never quantified or specified in design), but which are difficult to carry out in a fast-changing situation and under stress (**cases 1, 2, 3, 4**).*

S4

Mental capabilities and limitations, now familiar, must be included in the design of interfaces between automation and crew, with a realistic estimation of the time and skill required to apply the operational procedures under stress. For example, certification authorities must quantify the time required to apply normal and especially non-normal operational procedures.

Action is required with regard to system designers and their authorities. Whenever a pilot is considered in the operational functioning loop, the system must be built around them. Adaptation to humans must take into account their corresponding mental limitations which, despite being known, are not applied correctly. The CS 25 regulation in this respect is far from being sufficient.

The procedures used in critical situations must be adapted in terms of presentation and execution time under stress. If the pilot needs to choose actions, the thought process must not exceed two levels of causes/consequences.

H3

Resistance to stress should be one of the mandatory characteristics for pilot selection.

Preparation for unexpected situations must begin in basic training and continue throughout the pilot's career. Resistance to stress is innate but appropriate training can improve it, for example through experience acquired in training on cases of unexpected difficult situations.

This requires the systematic introduction of "surprise" into training programmes, in type qualification and in continuing training as well as in basic training. Practical cases can be replicas of concrete cases; large numbers of them are present in the databases. The important thing is to introduce the initial surprise. In fact, the inclusion of the surprise element in the field of training is the major area in which we must innovate, one that may be difficult to manage in the programmes but not impossible.

Simulators (FFS, Full Flight Simulator) seem to be the best practical tool for this, although trainees know that they are safe in an aircraft on the ground, and also that a "surprise" will be inflicted on them.

There are already training centres where the instructor can introduce random programmes, but this practice is far from being widespread.

Introducing or maintaining solo flights and the practice of certain disciplines such as stunt-flying and gliding make it possible to train and educate pilots in decision-making under stress. These practices, introduced in some training centres, must be encouraged very early on in the pilots' curriculum.

S5

Although it is the most advanced of simulators, the FFS is still far from providing a sense of risk in the planned surprises. A study on the subject should be carried out.

FLIGHT PATH MANAGEMENT AIDS

It is worth recalling that this is the vital part of the air mission par excellence.

Automatic flight path control continuity

*This averts sudden manual takeover, reducing the corresponding heavy mental load (**case 2**) and greatly alleviating the preoccupation with flight path control (**cases 3, 4**), whilst maintaining the mental capacity to deal with corrections.*

S6

Design control systems which, in the event of automation failure, maintain a stable flight path with a minimum amount of functions (heading, altitude, speed, thrust), for example with several independent sources of parameters (measured or calculated) allowing the pursuit of the current flight path.

Automation design

*Automatic controls are designed for a defined mission with minimal pilot intervention. If the actual intervention does not correspond exactly to what is planned, an in-depth knowledge is required of the possibilities, limitations and compatibilities of the assembled functions (**cases 1, 2**). Use is no longer intuitive and leads to errors (**case 1**).*

*Surprisingly, a system designed to simplify the human task complicates it by requiring complicated (**case 1**), costly training.*

*Psychologically this leads pilots to depend heavily on automation. A case in point is the insufficient monitoring of control parameters on approach (**case 1**).*

*Operational use must be designed for the actual global pilot population and must therefore be simple and intuitive (**case 1**).*

S7

Automation design must take into account human capabilities and limitations for the entire world population of pilots at their minimum skill levels.

Human interventions and their results must be simple and intuitive. Mental factors and their limitations are of major importance in both cockpit interfacing and system design.

Certification authorities must ensure proper system/pilot integration by taking into account mental factors and their limitations.

H4

Training in automation must be not only theoretical but also and above all practical (simulation of difficult cases).

Training without direct practice is a delusion.

Automatic go-around

*Go-around is not an intuitive manoeuvre in a situation where landing is the final imperative. Go-around during a non-stabilised landing could save a situation that has become dangerous (**case 1**). However, while this manoeuvre is recommended in terms of simple "airmanship" or by regulations, it is rarely seen as a priority by pilots dealing with situations involving a high mental load, trying to respect scheduling or commercial considerations, or simply subject to trivial and personal imperatives unrelated to the mission.*

If it occurs automatically, it allows the pilots to take the time for correct mental recovery of the actions.

S8

Its triggering could be made automatic depending on the landing circumstances, based on the flight path analysis of a short final approach (height, speed and speed gradient, vertical speed, attitude, heading, deviations from the desired flight path). Since the decision may not be optimal in all cases, the pilot would need to have the possibility of reassuming control.

Prediction of touchdown and available landing distance could provide a solution.

However, the pilot's triggering of the automatic manoeuvre provides time to control the situation, with thrust levels taking into account the aircraft thrust/weight ratio and, in the climbing phase, with the required automatic retraction of the surfaces at the correct speeds.

H5

In training, go-around must be presented as a normal manoeuvre not restricted to engine failure configurations. The danger must be stressed of high values of thrust/weight ratios in go-around with all engines operating.

A method sometimes adopted in training is to consider go-around as the final objective of an approach, with a landing only if all the required conditions are met.

Manual direct control

Manual control involves direct, immediate action by the pilot to change the velocity vector and simultaneously manage the three energy parameters (speed, altitude, thrust) by means of manipulators (levers, steering wheels, sidesticks, etc.), via flight control systems and engines, currently without direct action on the flight control surfaces.

In the eight "Golden rules" of the Airbus Training course, No. 6 says: "When things don't go as expected – TAKE OVER". Unlike supporters of full autonomy, other more realistic individuals foresee the likelihood of being overwhelmed by the use of complex automatic controls, or by their "improbable failures" (within the meaning of CS 25-1309). The solution is manual control.

This manual takeover allows "mental readjustment" to the current flight situation and provides the mental comfort of a known case (provided that it remains memorised through practice), with time to restore the right flight conditions.

*This is what the PF (Pilot flying) tried to do on approach (**case 1**). The problem came from the special procedure (based on perfect agreement between the two pilots) for recovering the incompletely applied automatic thrust. The use of visual flight when the speed was not controlled led to the tunnel effect.*

*Also note that the sudden disconnection of automatic controls can lead to a difficult resumption of manual control (**case 2**) also leading to the tunnel effect.*

But, like any precise manual action, manual control requires the maintaining of physical and mental skills through sustained practice, which becomes difficult with the intensive use of increasingly advanced and reliable automation, often more accurate than pilots. There is then a strong temptation to opt for "full automation" *and impose it in the operational use of aircraft, with the claimed benefits of reduced training and operating costs.*

*The result is difficulties handling relatively simple cases of manual control occurring unexpectedly, due to lack of experience (**cases 1, 2**).*

*Conversely, the pilots who maintained their experience of manual control saved the situation (**cases 3, 4**) thanks to the accuracy of their control.*

It is safe to say that cases of a "major", "hazardous" or even "catastrophic" nature (within the meaning of CS 25-1309), requiring manual or direct takeover control, will still occur for decades, in addition to those not provided for in design.

We are therefore faced with a dilemma:

- *either we continue to neglect the necessary manual control skills, and we formally accept the impossibility of recovering cases involving catastrophically changing situations;*
- *or we admit the need to properly train pilots in manual control, which has a cost.*

Pilots cannot be expected to properly manage their manual control options if they are denied the means to acquire and maintain the necessary skills.

S9

The voluntary or non-voluntary transition from autopilot to manual control must be simple and intuitive in stressful situations to allow for both flight path and thrust control. For thrust control, it is possible to imagine, for example, that if the AT function (Autothrust) remains in service upon disconnection of the AP (Autopilot), it automatically switches to "selected speed" mode at its value upon AP disconnection.

The involuntary passage must be seamless, immediately perceived and recognised by pilots in stressful situations. The sudden disconnection of the automatic controls can lead to difficult and dangerous recovery under manual control.

H6

Basic pilot training should focus on recovery manoeuvres in difficult situations. This also applies to type qualification.

As some already do, airlines should require a minimum of manually controlled landings, with and especially without AT, and not systematically require all-automatic landings.

Corresponding requirements from the authorities should provide this minimum basis, which is the case for the FAA.

Low speeds, high angles of attack, stall

Angle of attack is the key parameter for the aerodynamic operation of aircraft. The difficulty of its exact measurement prevents it from currently being a flight control parameter.

This handicap is compensated for by carrying over its operational limitations to the corresponding value of the indicated airspeed (aerodynamic) which is a classic control parameter, with longitudinal attitude limitations for specific flight cases.

Directly related to angle of attack is the dangerous phenomenon of airstream separation leading to the loss of wing lift at a value corresponding to the maximum angle of attack.

The strategy of protecting the aircraft by preventing it from reaching the physical limits of its flight envelope is good in itself. On the other hand, accidents due to stalling have not ceased despite warning systems when approaching this maximum angle of attack (visual, auditory, tactile, automatic protection by movement of control surfaces). In theory a pilot would never experience their plane stalling, but as we know, reality contradicts this belief.

Here are the facts.

- *In pilot training, the very notion of maximum angle of attack is diluted in favour of that of limit speed, well identified on the PFD. This mentally introduces a diffuse notion of danger due to a lack of indication of limit angle of attack and confusion on the action to take when the protections are triggered (**cases 1, 2**).*
- *A sound alarm must be doubled with the view of the alarm's original element or parameter. For stall, the only corresponding visual information is on the speed scale, not the physical parameter itself, the angle of attack (**case 2**).*
- *At high altitude, there may be confusion between altitude-related phenomena and those due to approaching stall (**case 2**).*
- *Few basic training courses teach recovery from real stalls, or from spin, since in theory it would be impossible to reach these situations. The result is the non-recognition of warning phenomena, and the ignorance of recovery manoeuvres (**cases 1, 2**). It should be noted that in basic practical training, stalls are generally performed on propeller and straight-wing aircraft, phenomena quite different from sweepback wing and jets. Realistic flight simulator (FFS) programmes are required to teach stall recognition. However, it is not necessary for the simulated parameters to strictly reproduce these phenomena which are by nature variable.*
- *Practical protection is linked to the configuration of automation, flight controls in particular. The deterioration of their operating modes, particularly in a failure situation, can go unnoticed because pilot training stresses the impossibility of reaching the limits of the flight envelope, without insisting on this*

*deterioration. When it does occur, it is certainly indicated by alarms and messages but they can sometimes go unnoticed in the chaos of a problematic situation (**cases 1, 2, 3**).*

*On the other hand, pilots who had received correct basic training and had experience were able to integrate this notion of limited angle of attack into their corrective operations (**cases 3, 4**).*

*Despite the permanent demands of the accident enquiry bureaus, the specific indication of the angle of attack is not mandatory on instrument panels (**cases 1, 2, 3, 4**). It is difficult to imagine that with current technical parameter measurement and calculation means it is impossible to provide pilots, and systems (**case 2**), with a reliable indication of this parameter, whether measured or calculated (angle between the known aircraft wing reference and the velocity vector, currently displayed to the pilot).*

S10

Design a reliable and redundant means of providing a measured and/or calculated angle of attack value accurate enough for operational needs.

It is hard to imagine that today, with the abundance of data and algorithmic computing possibilities, we cannot provide pilots and automatic controls with a reliable indication of this parameter, measured or calculated (angle between the known wing reference and the velocity vector currently presented to the pilot on the PFD).

This value and the approach to limits must be properly presented on the instrument panel to be used under stress (the use of the angle of attack indicator on the Concorde was routine and effective).

Similarly, the flight envelope protection removals must be clearly visible under stress.

The introduction of stall parameters in the flight simulator requires the use of flight test measurements.

H7

Few basic training courses teach the recovery from real stalls, or even from spin, since in theory it would be impossible to reach these situations. The result is a lack of recognition of warning phenomena, and an ignorance of recovery manoeuvres. Realistic flight simulator (FFS) programmes, complementary to those practiced on early aircraft, are necessary to teach the recognition of stall phenomena. However, it is not necessary for the simulated parameters to strictly reproduce all the characteristics of these phenomena, which are by nature variable.

Practical protection is linked to the configuration of automation, flight controls in particular. The deterioration of their operating modes, particularly in a failure situation, can go unnoticed because pilot training stresses the impossibility of reaching the limits of the flight envelope, without insisting on this deterioration. When it does occur, it is certainly indicated by alarms and messages but they can sometimes go unnoticed in the chaos of a difficult situation.

In basic training, and as a refresher for type qualifications, it is necessary to:

- *emphasise the fundamental role of angle of attack;*
- *teach the variations in angle of attack and corresponding indicated airspeed according to the weight, load factor, altitude, number of Mach, aircraft configuration;*
- *teach the phenomena precursory to approaching the maximum angle of attack;*
- *teach the phenomena due to buffeting at high altitude and distinguish them from stall;*
- *teach recovery from real stalls on initial training aircraft, then in simulation on FFS in type qualification with different values of weight, load factor, altitude, M (number of Mach), and configuration.*

Flying in the vertical plane – Energy exchanges

Movement in the air involves exchanges between the kinetic energy of the aircraft (which can only fly with speed) and its potential energy (it is moving at altitude). This is thanks to the input of internal energy provided by the engines (their thrust). Horizontal and vertical flight path control results from the combination of these three energies. They are balanced by acting on the flight controls and thrust controllers.

*Flight in the horizontal plane (accelerations), with no potential energy variation, is fairly well controlled. On the other hand, flying in the vertical plane has always been difficult (**case 1, 2**) with the classic parameters expressed in units that do not facilitate mental calculation of exchanges and correspondences (for example, a slope at 3° is equivalent to 5/100, and a vertical speed of approximately 800 ft/min at 160 kt indicated airspeed at low altitude). Moreover, the correspondence between Indicated speed (aerodynamic) – Actual speed – Altitude – Mach number is not obvious, especially when adding wind. But it is fortunately taken into account by automation (AP and AT).*

*Education in mental computing (tedious... but how practical it can be in emergency situations!) has given way to the use of pocket calculators and complex charts and tables of figures, followed by calculators (FMS, Flight management system, tablets and others). There remains the problem of sorting, inserting and checking parameters, which takes time and attention (**cases 3, 4**).*

*In manual control, simultaneous processing of speed, altitude, vertical speed and thrust is sometimes lacking (**cases 1, 2**). However, pilots with experience in this type of flying are proficient in this processing (**cases 3, 4**).*

*Traditionally, the control of engine thrust is separated from that of the flight path, which may explain its omission (**cases 1, 2**). The principle of changing habits by using total energy, including the processing of internal energy simultaneously with the other two, would certainly be a step forward (**case 1, 4**) but requires precise definition (**case 1**).*

S11

The simultaneous processing of the three energies is carried out by current automation systems (AP + AT).

However, manual control will always be necessary, especially in emergency situations. It is therefore necessary to develop a manual control system that synthetically takes into account the control of the three energies.

H8

In basic training it is necessary, through practical exercises, to teach the changes and correspondences between Indicated speed (aerodynamics) – Actual speed – Altitude – Mach number.

It is necessary to insist on the practical teaching of the simultaneous processing of speed, altitude and vertical speed, and thrust, and to use mental calculation for conventional situations (for example in approach).

In type qualification, manual control with direct thrust control (without AT) must be taught.

Flight director, FD

The flight director, FD, is a universally recognised manual flight aid. Its continued existence for more than 50 years proves its usefulness. In fact it is a replica of the autopilot. It gives the pilot the same orders as the AP gives to the flight controls to follow the control functions selected by this pilot, directly to the mode control panel (MCP) or via the FMS.

*To follow FD orders, a human pilot must simply manipulate the flight controls so that the longitudinal and lateral attitudes coincide with the requests displayed on the PFD in order to follow the flight path requested by the selection of functions. This is a closed pilot/flight controls loop action, with almost direct damped control of the longitudinal and lateral attitudes with a short response time of the human-aircraft pair. In the cases analysed (**cases 1, 2, 3, 4**) this standard type of FD was concerned.*

The FD can be used as a check on the PFD for correct operation of the AP. Or, with the AP disconnected, it gives the pilots the reference of the correct tracking in manual control of the selected functions, for example ILS approach without GLIDE reference.

The advantage that ensured its survival is twofold:

- *the task of manually positioning a point on crossed bars is as easy as possible;*
- *there is no need to think, as the requested order developed by automatic controls is deemed reliable.*

By habit, and unfortunately through teaching, it has become the "reference" for tracking the desired flight path, to the point that the mandatory verification of the conventional primary parameters of flight, speed, pitch, altitude, vertical speed, ILS position, etc. is forgotten. In the event of a problem, pilots turn to the flight director, because in an emergency consulting the normal parameters requires attention, takes time and has become difficult due to lack of practice. This is what makes the FD dangerous because experience shows that frequently in complex situations its indications do not match the intentions of the pilots.

*In current automation systems, the AP and AT functions are interconnected allowing the tracking of complex flight paths where speed evolves according to the type of flight path (for example when climbing from the ground to cruising altitude). If the AP is disconnected, the FD can continue to give the same orders as those selected for the AP, with the AT still connected. This is an aid if pilots manually follow the FD indications exactly; however confusion will result if they do not (**cases 1, 2**). If forgotten, the obligation to deliberately disconnect the FD becomes dangerous in this case (**case 2**).*

In our analyses, two cases proved to be dangerous:

- *the PF (**case 1**) correctly disconnected the AP which required an unexpected manoeuvre, and wanted to continue manually with speed control by the AT, which was possible, but with a special selection manoeuvre imposed by the B777 system: disconnection of the two FDs, on the right and left. In the confusion, one of the FDs remained connected, preventing the recovery of speed control by the AT, ultimately causing the stall;*
- *the sequence of situations (**case 2**) led to changes in FD modes, admittedly logical but unexpected. Apparently the PF chose to follow the inappropriate indications of his FD, which aggravated the situation.*

*There is a significant deficiency in technical documentation and especially in training on the use of complex automatic systems, in the numerous combinations and situations (**cases 1, 2**). The dull reading of texts and passive vision of on-screen procedures bear no comparison with the instruction needed to react to complex unexpected situations. Only manipulations on the simulator can imprint reflex-type actions in the memory. But this has a cost.*

S12

The independence of the FD and AT functions in manual control seems necessary, except under the operation of the flight envelope protections with automatic takeover of the AT. One solution would be to cut off the display of the FD on the PFD upon disconnection from the AP, with possible but voluntary takeover by the pilot, associated with mode selection revision.

Modes associated with the velocity vector (FPV, FPD) should be preferred.

The role and objectives of the FD are to be revised in manual control, aiming for target-based flight path control using the velocity vector, the automatic controls being controlled by the choice of the pilot and not the opposite as is currently the case.

H9

There is a significant lack of technical documentation suitable for practical operational use, particularly on the subject of complex interactions between systems and their potential dangers. Another deficiency concerns training in the use of complex automatic systems, especially in the numerous combinations and situations. The dull reading of texts and the passive vision of on-screen procedures bear no relation to the instruction needed to react to complex unexpected situations.

Only manipulations, on the simulator and in flight, can imprint reflex-type actions in the memory.

One flight mode, used on Airbuses beginning with the A310, is flight path control by the "Flight Path Vector", FPV, which is none other than the velocity vector in ground references. This mode has the advantage of directly controlling what the pilot is looking for, the orientation of the aircraft velocity vector. On the other hand, in relation to attitude control, the pilot-aircraft control loop includes an additional element, the movement of the aircraft itself with its inertia following the pulses of the flight controls, which gives a slightly increased loop response time.

The flight director is also adapted to this mode, and takes the name of "Flight Path Director", FPD. It is shown as a small line with a central point, on which the FPV is placed in the form of a circle with small wings.

This mode greatly simplifies the perception of flight path changes. It is compatible with the head-up display, HUD.

In training, it is good to guide operations towards the habitual use of the velocity vector.

It is also necessary to insist on the practical teaching of the associated FD and AT, through practical exercises on simulators, if possible reproducing real cases of incidents.

Automatic protection systems

They have been mentioned previously. They provide good protection at the limits of the flight envelope, but they have their own limitations.

They alone constitute an important and difficult subject for study. Important points include:

- *their operating thresholds and limits;*
- *their reliability, itself a function of potential deficiencies in their operating parameters and associated sensors;*
- *immediate recognition of their action or their absence by the pilot;*
- *the absence of abnormal operation in all circumstances.*

S13

An in-depth analysis should be carried out into the limitations in degraded flight control modes of automatic protection systems. Cross-checking important parameters from dissimilar sources must be introduced when necessary.

Unusual, sensitive cases – use of collected data

Accidents are uncommon, sensitive cases, some more so than others.

*Thus, **cases 3 and 4** required a great deal of self-control on the part of the PFs, caught in precarious flight situations with no possibility of a go-around, and the vital necessity of succeeding, with no other hope.*

How does one learn for this? How does one prepare?

Stress management has already been mentioned. The cases involving loss of thrust of the two engines at low altitude, and landing in a degraded system and structure configuration, are not isolated and should be used as a basis for FFS sessions to train reflexes in unexpected situations.

*Cases of rare but catastrophic situations must be treated with at least as much care as those of common situations, because they require immediate and unambiguous access to the procedures that are appropriate to them (**case 4**).*

*Moreover, it is noted that for many accidents, precursor incidents have been recorded in manufacturers' and airline's databases and in official collection systems (**case 1**). How do we exploit this "big data" involving millions of cases?*

The issue of widespread, global exchanges of incident data in order to obtain forecasts of accident occurrence is far from being resolved.

One might note that this problem has been recognised for more than 40 years, with no solution apparently having been found. Is it still difficult and expensive in the current AI era? One might also note that its resolution is necessary if we are to fuel the AI learning faculty that can thus be used wisely.

*Finally, in Dossier 42, it was noted that for one accident recorded worldwide, there were approximately five million cases of recovery from risky situations by crews of which nothing was said because there were no consequences, since the pilots had done their job. Having access to information on these cases would undoubtedly help orient research in how to assist pilots. Dozens of flights are monitored worldwide on a daily basis using procedures to check the behaviour of crews, such as Line Operations Safety Audits (LOSA) and Operational Flight Data Monitoring / Flight Operation Quality Assurance (OFDM/FOQA) (**case 1**). But their current goal is to focus on where improvements are necessary, rather than recording what has been successfully resolved. However, it should not be difficult to introduce this new objective into these procedures.*

Most airlines record and utilise observed incidents, but the exchange of this data is not systematic enough to learn all the lessons from these incidents and to better detect potentially dangerous trends.

S14

Exceptional but potentially catastrophic situations must be treated with care as they involve immediate and unambiguous access to the appropriate procedures (e.g. loss of engines at low altitude). They must be subject to specific studies in order to give pilots vital operational advice (e.g. longitudinal attitude on impact).

LOSA and OFDM/FOQA must be used to collect cases when situations were corrected by crews, and to systematically exchange this information within the aeronautical community to detect potentially dangerous trends and learn all the lessons from these situations.

Finally, it is necessary to find the methods and means of using the many global incident collection banks in order to detect potential occurrences of accidents, and to derive preventive measures.

H10

With the aim of educating pilots in unexpected and unusual situations, scenarios of accidents and serious incidents must be used in the FFS, even those characterised as unlikely.

SITUATIONAL AWARENESS AIDS

General

In the “Stress control” section, we recalled the importance of human operational limitations. Situational awareness aids must take this into account, with characteristic *attributes that enable practical, usable solutions, which are not specified by current regulations for example.*

These aids comprise three elements, in order: flight path control, recognition of the disruptive event, consideration of the damage status. Note that the second is not necessarily possible in an emergency.

*In a previous study, we saw that visual information was the priority source of information to be processed, but that sorting through it during surprising, stressful situations was difficult and subject to error (**cases 1, 2, 3**).*

Use of flight and flight path parameters

*These are concentrated and detailed on the PFD and on the engine settings screen. The relevant parameters in an emergency situation must be sorted from among the thirty or more that are presented on the PFD and the engine screen, then assembled mentally to have a correct idea of the situation and its evolution, either successfully (**cases 3, 4**) or unsuccessfully (**cases 1, 2**).*

The ideal would be an immediate synthesis of these relevant parameters. In fact, the HUD (Head up display) provides a de facto presentation of this concentration/selection of flight parameters, with the indication of energy control and an external vision.

The usable parameters have been transferred from "head down" to "head up" with its constraints, and it would probably be useful to do the reverse transfer now with the operational experience of the HUD. For this study, the essential vital parameters of speed, heading, altitude, angle of attack, spatial position and energy are concerned.

It is important not to forget that the mental phenomenon of focusing conscious attention (tunnel effect) also restricts the amplitude of visual perception.

S15

The relevance of how information is concentrated on the HUD must be studied to bring HUD operational experience to bear in changes to PFD parameters.

Synthetic representation is to be used wherever it can be applied. One must not forget that the mental phenomenon of conscious attention focus also restricts the amplitude of visual perception. Of course, on their request, pilots will be able to access detailed parameters.

Simplified graphics could present operational solutions to specify the position of the aircraft in its flight envelope, indicating how to return to it if it has deviated. Current standards need to be revised in favour of ease of perception.

H11

In training, insist on visual scanning education.

Status of automation – FMA, Flight mode annunciator

*We have seen that it would be good to maintain the continuity of automatic flight path control, even reduced to basic stabilities (**cases 2, 3**).*

*We have also seen previously that in the chaos of a mentally complex situation, salvation comes from the simple use of a system indicating a simple manoeuvre, for example the FD used regularly in routine operation (**case 2**). This depends on its indications remaining reliable amid the deterioration caused by the sudden event; otherwise the situation worsens (**case 2**).*

*Pilots accustomed to using and/or checking basic parameters buck this trend (**cases 3, 4**).*

*However, knowledge of the status of the operating or available modes is necessary. This is the objective of the FMA (Flight Mode Annunciator). It is used successfully when there is enough available time (**cases 3, 4**), but despite its presence on the PFD it goes unnoticed when, through focused attention, an urgent situation requires the priority use of the immediate action parameters (**case 2**).*

Suitable for normal situations, the FMA is not appropriate to emergency situations with stress. This problem remains to be solved.

S16

Knowledge of operating modes must be possible in stressful situations, as the current solution is not effective in fast-moving, time-limited situations.

Hence the following simultaneous obligations:

- *the relevant information, and just that information, must be presented in a simplified way so that it is immediately perceived and used unambiguously;*
- *the "images" must be in the pilot's field of view with correct visual affordance[11];*
- *the newly designed system must not simply replace that used in normal situation; it must be in continuity so that there is no cognitive discontinuity of perceptions when the unexpected occurs;*
- *the principle of operational affordance must be considered so that the simplified display of the situation suggests actions to correct this situation, and does not require significant recurring training.*

H12

Intensive training on the current FMA will only ever have limited value for stressful situations.

11 Affordance: quality of suggesting an action

Systems status – ECAM, EICAS

*Due to unfamiliarity with EICAS, only ECAM will be mentioned here (**cases 2, 3**).*

*The ECAM system is efficient but requires strict discipline in the distribution and execution of tasks by a two-pilot crew (**cases 2, 3, 4**).*

ECAM is a major help, but its software – its AI, because this is what it is – has been found wanting due to the unexpected volume of influx of information, the absence of systems information (breaks in links), or its use which becomes erroneous given a combination of failures.

***Case 3** is the most significant in terms of the number of operations processed.*

While simultaneous system damage and failures were managed to the best of this certified software, the overall reduction of complex situations was not possible.

Endless multi-page lists of unavailable systems are not an effective aid when available time is limited. Procedures for handling a few simultaneous failures had to be applied to the multitude of failures, resulting in initial saturation, followed by the endless application by the crew, the FO (First Officer) in particular, of the procedures presented.

In the complex situation of affected systems, the ECAM software could not take into account all combinations of failures or lack of information. A case in point: the red ENG2 FIRE alarm, transitory due probably to the destruction of the detector in engine zone 2, went unnoticed by the captain.

This resulted in real or apparent inconsistencies in messages and checklists leading to doubts about their validity. For example, the request for cross-feed of fuel to pierced tanks.

The crew was obliged to assess the validity of the instructions in each of the hundred messages received. An example would be the requested cut-off of the "yellow" hydraulic pumps of engine 4.

*Likewise, in **case 2** one observes a false indication given by the ECAM following the disappearance of basic information, which led to a mental disruption of the co-pilot's actions.*

The Systems Display, SD, was a major help, essential in forming an opinion on the status of the systems, in monitoring the changes created by application of checklists, in assessing the appropriateness of doing so, in carrying out a situation assessment. It was used continuously, with the pages either automatically presented by the ECAM, or called up by the pilots.

This finding is important because it demonstrates that information provided through diagrams and drawings is processed mentally in a concise and rapid manner, and is more effective than texts, necessarily composed of abbreviations.

Knowledge of systems status is necessary for two main reasons, immediate resolution of dangers (flight path, fire, leaks, pressurisation, etc.) and knowledge of the means available for a diversion to a fall-back location with landing in a precarious situation.

The list of systems rendered unavailable is shown but, with long lists, it is difficult to identify what remains available to fly and land. Breaking with the procedure of following the ECAM indications, the PF in ***case 3*** *decided to sort through what allowed them to land. This is indeed what would be needed urgently, with a new orientation of the system software.*

*Other vital information includes landing parameters and their limitations with degraded flight controls, damaged high lift devices, a weight and centre of gravity outside limits, inoperative brakes (****case 3****), and possibly limited thrust, in a situation without FMS and for unpredictable runway conditions. This information must be obtained quickly by the crew of two alone, which was not possible in* ***case 3*** *(use of additional pilots fortunately present in the cockpit).*

S17

It is likely that Airbus used the extensive information from the QF32. The problems involved related to the simultaneous nature of failures, the suppression of links, the repetition of "ghost" failures, and procedures made dangerous. How can all this be taken into account? The answer lies with the manufacturer, but leaves the question of certification of complex software and upgrading aircraft fleets.

In the complex perception and handling of systems, graphic displays are better than text presentations, which necessarily include abbreviations.

The long list of unavailable systems must be known, but ***knowing what remains available (especially control systems) is vital and this knowledge must be acquired effortlessly, immediately.***

Other vital information includes landing parameters and their limitations with degraded flight controls, damaged high lift devices, a weight and centre of gravity outside limits, inoperative brakes, and possibly limited thrust, in a situation without FMS and for unpredictable runway conditions. This information must be obtained quickly by the crew of two, which in one case was not possible (use of additional pilots in the cockpit). Not to mention any extrapolation to the case of a single onboard pilot.

H13

As with the above, the definition and development of ECAM systems must take into account human limitations under stress.

Alarms

Alarm problems are as old as aeronautics. Their nature has followed the dual development of aircraft systems and their own technology. Their strategy has also evolved based on safety experience.

*The problems associated with sound alarms are not new. Simultaneous sound alarms create an atmosphere of stress that reduces mental abilities, especially when sounds are not associated with rapid visual recognition of their cause. An alarm alone is generally handled correctly, two simultaneous alarms are more difficult to handle, and three require relatively uncommon mental concentration (**cases 1, 2, 3, 4**).*

The multiplication of alarm lights and sounds do not allow each system to stand out, hence the mental saturation. It is probably necessary to better define a hierarchy as to the importance of the consequences of failures, and for the presentation and nature of simultaneous alarms.

The main problems found in the analyses are as follows.

- *The noise environment of simultaneous alerts is confusing (**case 2**) when the latter are not associated with positive visual confirmation (indicator or clear contrast). Sound saturation limits mental possibilities if confronted with immediate emergency action. In addition, their repetition causes mental discomfort in the execution of conscious acts, when they exist precisely to help raise awareness of the situation.*

  The presence of two stop buttons (MC, Master caution, and MW, Master warning) introduces the risk of selecting the wrong one in an urgent situation.
- *The "Stall" alarm is visually linked only to the observation of the speed scale (**case 2**) and not to the presentation of the physical phenomenon (indication of angle of attack). Apparently this is not enough (**case 1, 2**). It should be noted that the automatic controls provide protection when approaching a stall only when the flight control configuration is not degraded.*

  As a general rule, alarms referring to control parameters are associated with specific presentations of these parameters (amber or red segments, or other) which cannot be missed if everything presented by the PFD is carefully monitored. This is not the case under stress. Something directive (affordance) is required.
- *The audible repetition of alarms is useless after their voluntary shutdown when visual indications persist (**case 3**).*
- *The continuous repetition of alarms is unnecessary and stressful when it is impossible to solve the related problem (**case 3**). However, it would then be necessary to clearly indicate this impossibility (**cases 3, 4**).*

S18

The occurrence of a major sound alarm must be accompanied by an unambiguous display of the corresponding parameter, on the PFD or elsewhere.

For alerts/alarms (visual and sound) in dynamic situations, the presence of coloured markings to show limits on PFD scales does not sufficiently draw attention to the parameter concerned in unexpected situations. Increased contrast (or even a temporary mask) would be a solution to avoid searching and sorting.

The problems arising from simultaneous visual and sound alarms, their priorities, their repetition, their override, and the ensuing "visual and sound chaos", must be solved. Sorting by importance? That would depend on the situation.

Too many sound alarms? Increase the number of voice alerts (artificial voice)?

When major alarms occur, must the incriminated parameters be presented on the same screen, alongside their normal representation?

H14

Many studies have already been devoted to alarms but the solutions are still far from satisfactory despite improvements made over decades. There is a need for a study on processing, on correlating sound alerts and areas concerned, in situations of stress, taking into account human limitations.

Procedures

Procedures are an effective operational aid. However their use is subject to human limitations.

*In unexpected, dangerous and fast-moving situations, the use of "look elsewhere" procedures, when they are not directly available to pilots, is illusory (prohibitive access and sorting time). Training and discipline cannot go against this requirement (**case 2**).*

*A checklist that is not adapted to the situation, where only a few elements are relevant and completion of the list is impossible, can lead to a waste of precious time (**case 4**).*

S19

All procedures, especially those used infrequently, must be accessible quickly and simply on a screen in direct view of the pilots.

Particular care must be taken with checklists of rare situations.

Teamwork

The obvious:

- *in unexpected situations, teamwork, with each person knowing their tasks and communicating with the other, gives a concrete positive result (**cases 3, 4**);*
- *conversely, the contrary leads to disaster (**cases 1, 2**).*

*Alternating PF/PNF roles while handling a long situation appears to reduce the stress of the two pilots (**case 3**).*

*However, the concept of a two-person crew was exceeded on several occasions (**case 3**):*

- *the density of the actions led the second co-pilot to closely monitor the actions of the PF and PNF (or PM, Pilot Monitoring). We do not know what was said, but we can assume that errors were corrected and that relevant opinions were expressed.*
- *the difficulty of consulting performance documents in an abnormal situation with unforeseen configurations, and the time taken to obtain the landing parameters, required entrusting the task to the other pilots present. An urgent review of rapid access to such parameters is needed.*

*In **case 1**, the third pilot (Observer) intervened in a relevant manner but without any reaction from the PF.*

*On the other hand, the poor choice of task priorities mentally disconnected the PNF from their primary task of assisting the PF (**case 2**). Or was this due to their sense of professional inadequacy in a two-pilot crew?*

*The instructor pilot does not intervene early enough to recover a degraded situation (**case 1**). Poor estimate of risk?*

H15

In training, emphasis must be placed on dealing with unexpected situations in pairs, in particular on the FFS.

Airlines should monitor the personal development of the pilots in terms of operational psychology. Individual monitoring of the difficult situations actually experienced could be considered to make better use of the experience acquired at the level of the airline.

Risk assessment should be taught to pilots, especially instructors.

The problem of the single onboard pilot remains to be dealt with. What help could they find on board to support their decisions?

Communications

Internal

*The deficiencies noted are the absence of a direct emergency call system to a pilot at rest (**case 2**) and the non-detection of calls from cabin staff in audibly and visually chaotic situations (**case 3**).*

*The reports do not provide any information on visual exchanges by hand gestures and indications between crew members, a common practice in fast-changing situations that saves communication time for immediate action. This certainly helped in **cases 3 and 4**.*

External

*The deterioration of the systems prevented external assistance from being received at a crucial time (**case 3**).*

S20

An automatic alarm-activated signal should be installed in the rest area.

Reliable alert systems between cockpit, cabin crew (visual contrast and sound problem), and operational centres are necessary.

H16

A study should be carried out to estimate the positive influence of gestures between pilots.

SPECIAL CASE (NO. 5)

Detection

The co-pilot's mental problems were not detected by the crew.

The first anomaly was detected by ATC (Air Traffic Control) with the non-compliant flight path approximately three minutes after descent.

The second was the impossibility of entering the cockpit about four minutes after it was closed.

"External" detection was faster than internal detection by about one minute.

National Defence was informed about five minutes after the start of the descent manoeuvre.

The cockpit door could not be opened or fractured.

The impact occurred about 11 minutes after the start.

S21

The role of ATC is essential in detecting flight path anomalies. Although intervention was rapid, an automatic flight path and communication anomaly detector could alert more quickly.

The problem of the invulnerability of the cockpit door in both directions (danger from the cabin due to terrorism, internal danger of suicide) poses a problem of responsibility in the direction choice of the lock override.

H17

When training air traffic controllers, emphasis must be placed on the rapid detection of flight anomalies (flight path, messages).

Prevention

This is a question of mental health, of detecting abnormalities that can be latent and go unnoticed during initial selection, training and operation. Doctors, and the entourage of pilots, whether professional or not, detect warning signs, but medical secrecy, the lack of liaison between personal medical practitioners and professional, and the desire to preserve the privacy of each individual, are all obstacles that need to be assessed and circumvented in order to obtain a global consensus on the actions to be defined and applied.

It is accepted that known suicidal cases showed signs of abnormal crew behaviour, which were detected in this case but considered insufficient for requiring an occupational leave of absence.

Peer assistance programmes, based on trusted relationships that allow individuals in situations of weakness to find help among their professional entourage (Hans Rahmann: Peer Support Programs, Stifung Mayday) should be mentioned. Should these types of programmes be introduced into CRM?

On the aircraft side, the solution is either physically controlling the suicidal person in the cockpit (by gas?), or making the aircraft fully autonomous, which requires only electrical (protected) connections between the cockpit and the systems.

However responsibility (on board, on the ground?) for launching such probably irreversible measures remains to be defined.

S22

Whatever the solution, control of the individual or autonomy of the aircraft, detailed studies are required before the problems to be solved can be concretely applicable.

H18

The problem of detecting psychological problems calls for a worldwide consultation. The responsibility of the person triggering the irreversible security process remains.

APPENDIX: CREW PERFORMANCE

It is not our place to judge the incriminated crews, but a few words on the official statements issued regarding them are required.

The comments expressed in the investigation reports of the five accidents studied concern crew performance. Failure to perform actions under their responsibility is sometimes clearly mentioned.

Here are some excerpts.

Asiana 214, case 1

The opinions summarised below are those of two NTSB investigators (W and S) who spoke personally at the end of the report as provided by the rules of this organisation.

- ***W***

"As stated in the probable cause statement, **this accident was caused by the crew's mismanagement of the airplane's descent during the visual approach**. In my view, this is the critical finding, and other articulated factors in the statement serve either as examples of mismanagement or as attempts to explain why it occurred. Fundamentally, though, this accident occurred due to crew mismanagement; efforts to deemphasize or excuse the crew's substandard performance in operating the aircraft are not justified by the evidence adduced from the investigation."

"**Automation technology is intended to aid flight crews in executing their responsibilities; it is not intended to replace a well-trained and proficient crew**. When automation fails or does not react as expected, it remains incumbent upon the crew to be prepared and able to fulfil their responsibility of operating the aircraft safely."

- ***S***

"There was uninformed conjecture that placed the crew's competency in question. As I stated in the board meeting, **this accident is not one about crew competency**. After all, the pilot flying had nearly 10,000 flight hours and had been a captain and instructor on the Airbus A320. The instructor pilot had 12,000 flight hours, including over 3,000 in the Boeing 777, and was selected from many to join the elite instructor corps of Asiana. Pilots simply don't make it far in their careers if they lack competency.

Contrary to what some may believe, **this accident is not just another "pilot error" accident**. Like most accidents, the causation of this accident is complex and involves the interaction of several elements of the system. It involves a set of circumstances that came together on this day to produce a tragic outcome."

Comments

For W, regardless of the aircraft and its certified systems, pilots must safely operate them in all situations. The problem mainly concerns the human part (selection and training).

For S, the pilots are experienced but are placed in a context beyond their normal possibilities. The problem concerns both the system (environment, cockpit, operation) and their capabilities.

It is rare to see two such conflicting views expressed in an official report.

AF 447, case 2

"Causes of the accident" section of the BEA report

*"*The blocking of the pitot probes with ice crystals during cruising was a phenomenon known but poorly controlled by the aeronautical community at the time of the accident. From an operational point of view, the resulting total loss of air data was a failure listed in the safety model. After initial reactions coming under "basic airmanship", it was supposed to be diagnosed by the pilots and managed if necessary by protective measures on the attitude and thrust indicated in the associated procedure. *"*

Comment

Although carefully drafted, it is stated that the pilots were not up to the "referenced" situation. Here too, the human part is mainly involved.

Qantas QT32 and US Airways 1549, cases 3 and 4

No negative comments on crew behaviour.

Germanwings 18G, case 5

Everything points to the suicidal co-pilot.

General comment

Despite certain opinions clearly citing the inefficiency of the crews, except for cases 3 and 4, all the reports nevertheless highlight the deficiencies of the systems that accompanied the accidents. So tackling their correction is not open to criticism.

*It is no less true that: "*When automation fails or does not react as expected, it remains incumbent upon the crew to be prepared and able to fulfil their responsibility of operating the aircraft safely*".*

This declaration therefore contains the two areas of this study, the systems aspect and the human aspect.

GLOSSAIRE / *GLOSSARY*

Affordance	Qualité de suggérer des actions / *quality of suggesting actions*
AI	*Articificial intelligence*
AP	*Autopilot* – pilote automatique
AT	*Autothrust* – automanette, conduite automatique des moteurs
ATC	*Air Traffic Control* – Organisation du contrôle aérien
BEA	Bureau d'enquêtes et d'analyses pour la sécurité de l'aviation civile (*French Civil Aviation Safety Investigation and Analysis Bureau*)
Big data	Banques de données
Buffeting	Phénomène vibratoire lié à l'instabilité d'écoulement de l'air / *irregular oscillation of part of an aircraft, caused by turbulence*
Cdb	Commandant de bord (*captain)*
Cds	Conscience de situation
Cpt	*Captain* (commandant de bord Cdb)
CRM	*Crew Resources Management*
ECAM	*Electronic Centralized Aircraft Monitoring (Airbus)*
EICAS	*Engine Indicating and Crew-Alerting System (Boeing*)
FD	*Flight Director* – directeur de vol
FFS	*Full Flight Simulator* – simulateur de vol complet
FMA	*Flight Mode Annunciator* – indicateur de modes
FMS	*Flight Management System* – système de gestion de vol
FO	*First officer* – copilote
FOQA	*Flight Operation Quality Assurance*
FPD	*Flight Path Director* – directeur de vol avec vecteur vitesse
FPV	*Flight Path Vector* – vecteur vitesse
GLIDE	Pente d'approche ILS / *ILS approach slope*
HUD	*Head Up Display* – vision tête haute
HSI	*Human Systems Integration*
IA	Intelligence artificielle
IHS	Intégration Homme-Systèmes
ILS	*Instrument Landing System* – système de guidage radio d'atterrissage
LOSA	*Line Operation Safey Audit*
M	nombre de Mach / *Mach number*
MC	*Master Caution* – alarme de mise en garde
MCP	*Mode Control Panel*
MW	*Master Warning* – alarme de danger immédiat
PF	*Pilot Flying* – pilote en fonction
PFD	*Primary Flight Display* – instrument primaire de vol
PM	*Pilot Monitoring*, pilote de surveillance, id° PNF
PNF	*Pilot Not Flying* – pilote non en fonction de pilotage, id° PM
Rdg	Remise de gaz
SD	*System Display* – écran de schémas de systèmes
SPO	*Single Pilot Operation* - pilote unique à bord

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Imprimerie LES CAPITOULS

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Le monde du transport aérien est sévèrement touché par une double crise, celle due à la recherche de la « décarbonation » et celle plus soudaine et plus difficile à gérer liée à la pandémie COVID-19, et certains problèmes demeureront présents quelle que soit l'évolution. Pour tenter de progresser dans les domaines techniques, l'Académie s'attache à proposer des chemins vers des solutions.

Ce Dossier 49 traite de l'un d'eux, concernant la sécurité. Il s'agit du comportement opérationnel humain face aux situations inattendues, cas assez fréquent pouvant devenir potentiellement dangereux malgré la planification de plus en plus poussée des missions de transport aérien. L'étude est originale et se veut efficace. D'après l'analyse très détaillée de cinq accidents, choisis pour leur complémentarité, elle a permis de caractériser les déficiences humaines et les défauts des systèmes impliqués. L'ensemble a conduit à des recommandations aisément transposables par affinité à l'utilisation opérationnelle de tout avion.

The world of air transport is severely affected by a dual crisis – the search for "decarbonisation" and the more sudden, trickier question of managing the COVID-19 pandemic – and certain issues will persist regardless of developments. In order to move forward in technical areas, AAE has endeavoured to identify avenues for progress.

This dossier deals with one of these avenues: safety. More specifically it looks into human operational behaviour in the face of unexpected situations, which are fairly frequent and potentially dangerous, despite the increasingly thorough planning of air transport missions. The study is an original one, and is intended to be effective. Based on a highly detailed analysis of five accidents, chosen for their complementarity, it characterises both the human deficiencies and the faults in the systems involved, leading to recommendations which are easily transposable to the operational use of any aircraft.

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