Vesa Keinänen

WHEN SOMETHING GOES RIGHT;

HUMAN AS RECOVERY BARRIER IN AVIATION

UNIVERSITY OF JYVÄSKYLÄ
FACULTY OF INFORMATION TECHNOLOGY
2018

ABSTRACT

When Something Goes Right; Human as Recovery Barrier in Aviation
Jyväskylä: JYU University of Jyväskylä, 2018, 81 p.
Cognitive Science, Master's Thesis
Supervisor(s): Kujala, Tuomo

Telling the future as air traffic growth numbers is easier than telling it in safety occurrence numbers. At the technological forefront the aviation industry is capable to meet the challenges of increasing complexity where as the human operator is inherently the ambiguity solver. The technology has its 'mean time between failure' and so has the human - as long as these two don't materialize simultaneously there is a barrier to mitigate the effects of a flaw.

This research is made in spirit of continuously improved HF (human factors) framework to meet the future challenges of aviation safety occurrences. A less common angle, *inverse* investigation, was taken in purpose to embrace the people of 106 'human-friendly' aviation incidents by locating things that had gone *right*. The years covered are from 2000 to 2016, including pilots with experience from fifty flight hours to twenty-thousand, and aircraft from gliders to hundreds of times heavier transport aircraft. For the full picture, the human activity as a recovery barrier was identified and analyzed at the systemic level.

In four out of five of the cases the contextual cognitive activity of pilots, air traffic controllers or support personnel was found having been the resort of recovery barrier. As pilots intrinsically encounter the actual threats vis-à-vis, it is their cognitive strategies and workload that was evaluated. The contextual data from the investigation reports highlight the power of automatic pattern recognition followed by matching and executing a corresponding skilled action. If pattern is not recognizable, for example due to low experience, the situation should be approached as a problem solving *challenge*. The challenge orientation in crisis, emphasizing human capabilities and protecting from the stress-related high cognitive loads, is central as a training goal of the era.

As such, the inverse angle used for this investigation was discovered having great potential. Sheer attitude effect, especially when coming from the investigative authority, is expected to open new routes. New HF information with high value may become available when refining the executed workload experiment that indicated potential correlation to successful endings. It is possible to meet the future demand in safety investigation by adopting universal HF and workload tools in use, especially *when something goes right*.

Keywords: recovery, barrier, incident, severity, HF, human factors, flight safety

TIIVISTELMÄ

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Jyväskylä: Jyväskylän yliopisto, 2018, 81 s.
Kognitiotiede, pro gradu -tutkielma
Ohjaaja(t): Kujala, Tuomo

Ilmailun tulevaisuuden arviointi on yksinkertaisempaa lentoliikenteen kasvu- kuin lentoturvallisuuslukujen valossa. Siinä, missä ilmailuteollisuus teknologian suunnannäyttäjänä on valmis vastaamaan kompleksisuuden haasteeseen, on ihminen käyttäjänä vastuussa epäselvyyksien ratkaisemisesta. Teknologialle, ja ihmisellekin, on määritettävissä ”vikatiheys” - niin kauan kuin poikkeamat eivät tapahdu yhtäaikaisesti, on jokin turvamekanismi käytettävissä seurausten minimoimiseksi.

Tämä tutkimus on tehty jatkumona inhimillisten tekijöiden (HF, human factors) toimintaympäristön kehittämiselle; luomaan valmiuksia tulevaisuuden lentoturvallisuustapahtumien kohtaamiseksi. Lähestymissuunta valittiin *käänteiseksi* hyväksyen ehdoitta jokainen 106:ssa ”ihmismyönteisessä” ilmailun vaaratilanteessa läsnä ollut ihminen, ja hakien asioita jotka olivat menneet *hyvin*. Tutkimukseen sisältyy tapauksia vuosilta 2000 - 2016, lentäjiä 50 lentotunnista 20000 tuntiin sekä ilma-aluksia purjekoneista satoja kertoja raskaampiin kuljetuskoneisiin. Kokonaiskuvan saamiseksi ihmisen toiminnasta palautumisen turvamekanismeja on arvioitu systeemisellä tasolla.

Neljässä viidestä tapauksesta turvamekanismina on ollut tilanteen mukainen kognitiivinen toiminta joko lentäjien, lennonjohtajien tai järjestelmää ylläpitävien ihmisten aktiviteettina. Koska lentäjät kohtaavat turvallisuusuhan kasvotusten, erityisesti heidän kognitiiviset strategiansa ja työkuormansa arvioitiin. Tutkimusaineistossa korostuu suoritusteho, joka saavutetaan automaatiotasolla tunnistamalla tilanteen kuvio ja suorittamalla soveltuva taitopohjainen toimenpide. Mikäli kuvio ei hahmotu esimerkiksi kokemattomuuden vuoksi, on tilanne kohdattava ongelmanratkaisullisena *haasteena*. Haastekeskeisyys korostaessaan ihmisen kykyjä ja suojatessaan stressipohjaiselta kuormitukselta, on keskeinen ajanmukainen koulutusteema.

Tässä tutkimuksessa käytetty käänteinen lähestymistapa osoittautui lupaavaksi. Jos viranomainen hyödyntää vastaavaa käänteisyyttä, sen voidaan uskoa vaikuttavan yleiseen asenneilmapiiriin uutta keskustelua avaavana. Uutta ja arvokasta HF tietoa on mahdollista saada käyttöön jalostettaessa tehtyä työkuomakoetta, joka osoitti korrelaatiota lopputuleman menestyksellisyyteen. Tulevaisuuden lentoturvallisuustutkimuksen haasteisiin voidaan vastata ottaen käyttöön yleispätevät HF- ja työkuormatyökalut, joita käytettäisiin ennen kaikkea silloin, *kun jokin menee oikein*.

Asiasanat: recovery, barrier, incident, severity, HF, human factors, flight safety

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1 INTRODUCTION

1.1 Aviation safety progress

Those of us that travel by air probably recorded a welcome news flash right after the New Year 2018. The Aviation Safety Network (ASN, 2017) told that “2017 was safest year in aviation history”, based on airliner accident statistics. This news was very positive and naturally was distributed globally. Is such development as expected or not, really depends on the aspect. On the one hand, we know that automation has dramatically reduced the human error component, but on the other hand, the aviation has grown exponentially.

The ICAO (International Civil Aviation Organization) along with the Industry High Level Group (IHGL, 2017) recognizes that passenger transportation (RPK, Revenue Passenger-Kilometers) is in trend of doubling every 15 years. Their vision about the aviation is an enabler of equality in a global scale, meaning therefore not only growth in numbers but also in diversity. Considering the views of growth, one cannot expect to hear happy aviation safety reports every New Year. Even if the aviation became fully automated the human element remains as an essential part of the whole system.

Traditionally the efforts in flight safety have been put in preventing things going wrong. This is logically correct approach, and commercially imperative. We will not step our foot on such carrier’s airplane that has a frequent history of accidents and incidents. Yet this doesn’t take away the fact that things sometimes go wrong. When this happens, call it a “top event”, it means that the preventive steps have become history, and only the recovery elements are the ones available. This means that the investigation threshold has been exceeded, resulting to a research and analyses why and how things went wrong.

In this study, using a real source of aviation safety occurrences, one concentrates in locating the recovery barriers, and especially those that might reveal the human strength when coping with real threats and challenges. Such recovery qualities could perhaps be built in the system proactively or they could be refined by providing training for the sharp end operators.

1.2 Some things go right

We humans are well studied what comes to our weaknesses in multitasking environments, as aviation. Most of us can name at least one tragedy that has taken place in the recent history of aviation. But many of us also remember the other kind of accident, when something went right. Namely the US Airways flight 1549 on 15th of January 2009. The aircraft hit a flock of birds, damaging both of the engines, and was finally landed on Hudson River in New York. The story will stay alive, especially because everyone onboard survived. The angle selected for this research, respects human as an element, able to cope with the unexpected.

There lies an interesting paradox in the accident investigation field. The work on human factors tends to be the more analytic in those cases where no survivors remain. This is understandable for many reasons, not least for family members' peace of mind. Yet, the data available from disasters, being from secondary sources (recordings, eyewitnesses, analysis of wreck etc.), doesn't provide direct path to the cognitive states of people having faced the situation. Wouldn't we receive more factual human data from those cases where we can actually work together with crew members and passengers? These would be the cases *when something goes right*.

1.3 Investigative approach reversed

This research is done in order to approach the safety occurrences from a less conventional aspect. Using actual reported incident data with specific selection criteria, it may be possible to find, not the human weaknesses but strengths to be nurtured. There are multiple sources available to familiarize with aviation safety occurrences, both international and national. In this case the latter (i.e. Finnish) investigation data has been chosen not least thanks to its good availability.

As the approach of this research is inversed from the "traditional" the scoping plays an essential role. There is no possibility to put people at risk to get the kind of data required. Still, there are several sources that can be utilized for the purpose of evaluating human behavior or decision making as an element of systemic aviation safety. The source of raw data for this study is the public archives of the Finnish Transport Safety Agency (Trafi) containing national aviation accident and incident investigation reports.

This research has been carried out with supportive accent. Undoubtedly there are cases where people have made errors, sometimes self observed and sometimes also self corrected. Even in the cases of clear errors the *recovery* has been attended to as a main value of this research. People have been being looked as solutions, not problems.

1.4 Research questions

Finding how the human cognition might intervene in flow of (hazardous) events, calls for tools to recognize that there, in the first place, is an opportunity for cognitive control. A person must therefore perceive the conditions being such that without control the expected outcome deviates from the goal. Only then a human can start managing the flow of events. Term "flow" seems appropriate in the aviation as events take place only because the action is to move. Even when an aircraft of any type is hovering it moves in time, providing only a limited opportunity to stay in the air.

The first component of this study is searching indications of such cognitive patterns that are followed by people in the aviation system, when facing a critical situation. The second element of the research is identifying the human barriers from the systemic perspective. Knowing that the path to an incident has latent factors, the same assumption is considered relevant also for the recovery barrier activity.

It is a basic assumption that people's intentions are good and risk-avoiding; therefore human behavior patterns are meant to act as barriers in crisis. This study is made for purpose of identifying human behavior that supports recovery after so called top event. After this particular event a door for a consequence (incident, serious incident or even accident) is open. Therefore the barrier activity that is investigated should have resulted either into prevention of potential accident or minimizing its outcome.

The main research problem is to prove that there is source of cognitive mechanisms that lay behind the successful crisis behavior. Even as being theme-driven, two corresponding hypotheses are spelled to guide the research.

Hypothesis 1: There are effective, cognition limit avoiding, strategies of survival at any level of aviation experience.

Hypothesis 2: The contextual human barrier in aviation is effective when the load can be controlled.

1.5 Scoping

This research is limited to utilize true accident and incident data collected in Finland. The Safety Investigation Authority of Finland (SIAF) investigated incidents and accidents (http://www.turvallisuustutkinta.fi/en/index/otkes.html) are used as data pool from which a sufficient number of cases has been extracted. The published reports are based on investigators' analysis; thereby the angles and focal points vary, depending on the case but also on the investigators' background. The Safety Investigation Authority of Finland provides training for persons regarded suitable (SIAF, 2016) which naturally helps harmonizing the outcome.

106 cases have been selected (from the total of 211 cases familiarized), including various degrees of incidents and accidents including years 2000-2016 The selected incidents have been evaluated in order to locate some patterns that might lead to applicable conclusions. The chosen investigations were expected to reflect a positive human recovery barrier effect at some (systemic) level. The cases' selection was based on two qualification criteria.

(1) The accident or incident has resulted none or only minor injuries.
(2) There must have been a recognizable human factor affecting the outcome, either direct or indirect (e.g. systemic nature).

Thus all other cases (that have resulted to fatalities or serious injuries) were excluded and they are not commented at this research. Similarly, those accidents or incidents that, based on the published investigation report, indicate no identifiable human "barrier" were left out. These may have been purely technical investigations or cases where people, had for various reasons taken high probability risks, which then had realized. The contextual nature of source data is obvious.

1.6 Research anonymity

An indirect path is a common practice in real accident cases as investigators have to deal with interviews, records, recordings and remains of the accident aircraft. The reports are public documents and they have been processed into a data pool (with principles presented in paragraph 3.2) in order to support statistical analyses. No incident data has been searched beyond the publicly available source. Depending on the details provided by written reports, variable amount of estimates must have been made in order to compensate for circumstantial information.

The source data is anonymous by nature; no persons concerned are mentioned by name in the reports. This principle is also naturally applied to professionals in the investigation teams. Any analytical data produced, has been treated respecting the anonymity and humanity. Some examples used to define otherwise generic expressions are from the actual cases and some are fictive to provide an appropriate scenario.

2 HUMAN POWER IN AVIATION

When human is studied as an active agent in aviation the activity is generally looked through binoculars, showing safety through one lens and performance through the other. Therefore it is important to keep both eyes open if one wishes to capture the whole human power. People working in the field are expected to perform efficiently and safely at the same time. For those who have chosen aviation as a hobby the performance element is a perceived success when achieving one's own goals - safely. This chapter looks at the foundations of safety and performance of aviation from the human perspective.

2.1 Recognizing human strength

The accident report of the "Miracle of the Hudson" (NTSB, 2010) lists shortcomings, also concerning the crew knowledge (training) and performance, which then contributed to e.g. unusable aft rafts (after non-optimal forced landing on water). From the perspective of this research, the more interesting are the four survival factors listed:

(1) Decision making and resource management of the crew.
(2) Fortune of having an over-equipped airplane with forward rafts.
(3) Cabin crewmembers' performance in evacuation.
(4) Proximity and proper response of the helpers.

The Hudson case, even though inspiring, is not the explicit source of inspiration for this research but it certainly supports the importance of human activity in crisis. Three out four contextual factors on the list above are human centered, containing elements as decision making, resource management, (human) performance and response. The two "luck-elements" found are, capable helpers and extra technology (forward rafts), both readily available. Considering any major occurrence, there may be a number of these uncontrollable (?) factors of nature, which also could provide an intriguing insight for human in crisis.

2.2 From errors to proactivity

Where aviation growth and development are both exponential in nature, such have also been incident investigation and aviation safety culture advancements. There is no room to blame anyone, not anymore. Instead, the only purpose of the investigations is the prevention of accidents and incidents (ICAO, 2016). There is a clear path towards *proactive accident investigation* where cases become solved and prevented before them even happening; see e.g. the Proactive Integrated Risk Assessment Technique or PIRATe (Hayward et al., 2012). To pave this path, a proper foundation is needed. The human strength as a dynamic source of solutions needs to be part of the proactive process. Our scenarios should involve human at all stages of the event, from prevention to recovery.

2.2.1 Error classification

Independent of the no-blame investigations, locating the cause(s) for any safety event is paramount, helping to diminish the probability of future recurrence. Defining an error type is not really straight forward and there are various ways to fine-tune the human fallibility. Error classification by Reason (1990) for *slips*, *lapses*, *mistakes* and *violations* with descriptive framework can be considered as foundation for subsequent error analysis. The slips and lapses are connected to skill-based behavior, and mistakes occur both in rule- and knowledge-based performance (Rasmussen, 1983). For example the Human Factors Analysis and Classification System (HFACS) develops errors in three types and violations in two as shown in FIGURE 1 (Shappell & Wiegmann, 2000).

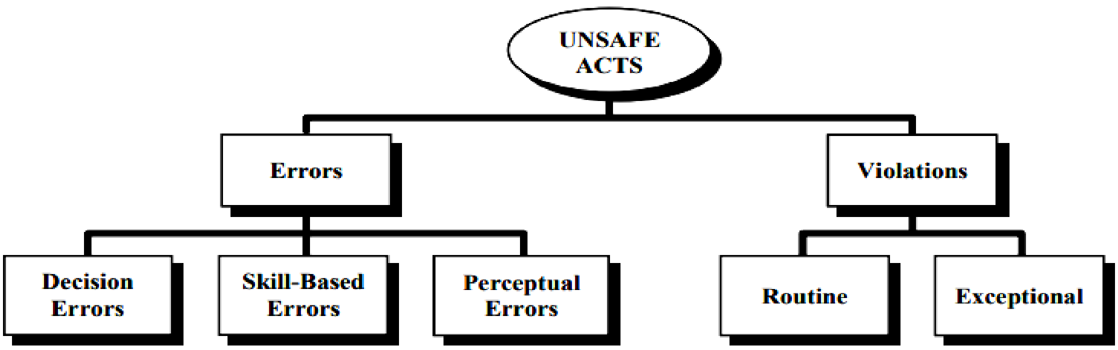


FIGURE 1 HFACS unsafe act categories

In the HFACS categorization the skill-based errors inherently include slips and lapses as failures of attention and memory. The decision errors can also be called mistakes as in Reason's (1990) taxonomy. For a desired resolution in aviation safety occurrence typology, perceptual errors (slips) are separated and the violations are divided in two categories. (Shappell & Wiegmann, 2000).

2.2.2 Reason's accident model

James Reason is not only recognized by the aviators but also many other professional groups as an ambassador of fair and healthy safety culture. He has presented the idea of dynamical path for accident depicted in FIGURE 2 (Reason, 1990).

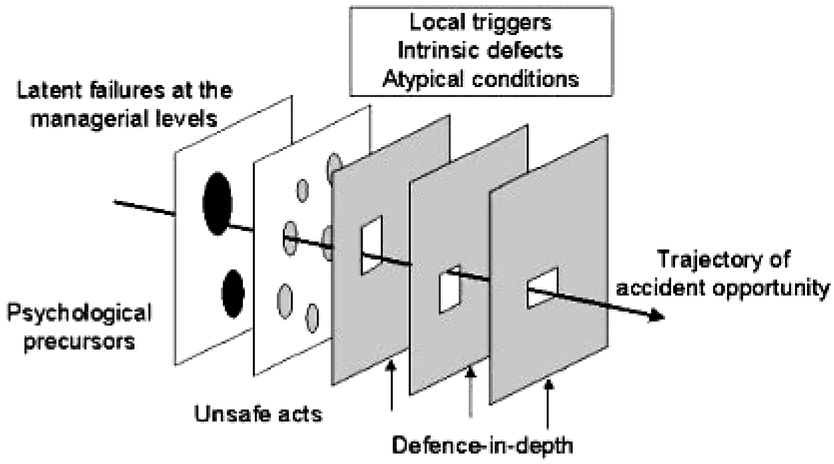


FIGURE 2 Accident causation by Reason

The well known "Swiss Cheese" model shows that the path to an accident involves openings at many levels of organization and activities. Therefore corrective actions should also cover the whole system. Later work has then provided the investigators with contemporary tools and methods to apply the principals of an organizational incident. Below (FIGURE 3) is a partial model of a proactive analysis using the PIRATe in aviation as a predictive tool (for full case schematics see Hayward et al., 2012).

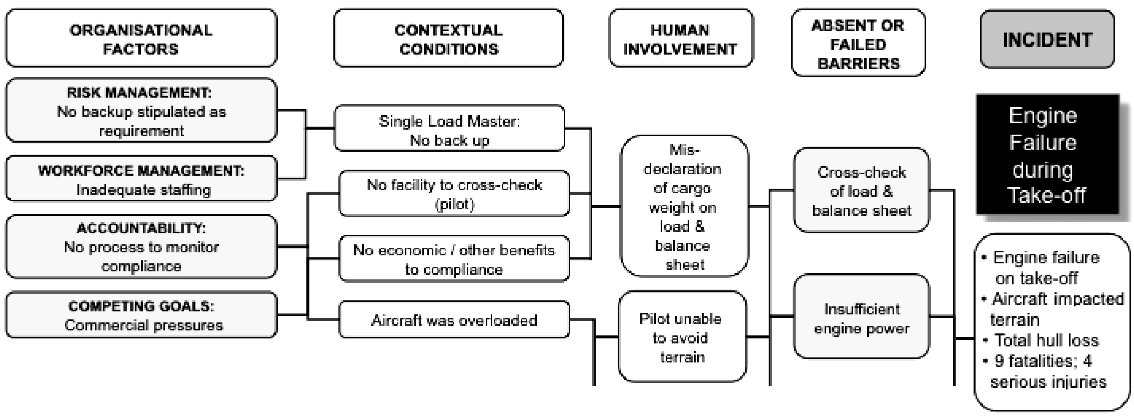


FIGURE 3 PIRATe example in Aviation

Similar Reason-derived approach the PIRATe (Proactive Integrated Risk Assessment Technique) can naturally be used for analyzing in depth the individual barriers available even *after* the "trajectory of accident opportunity" has reached its end. Another name for the *accident opportunity* is "top event".

2.2.3 Bowtie analysis

A method that clearly concentrates identifying the barriers, called "bowtie", was adopted and developed in 90's by gas industry (UK CAA, 2015). When used as a proactive tool the idea is to recognize the key elements that can prevent firstly the *top event* becoming reality and secondly minimize or prevent the *consequences*. The term's layout varies (bowtie, bow tie, bow-tie), yet all referring to classic shape of the graphic presentation (FIGURE 4).

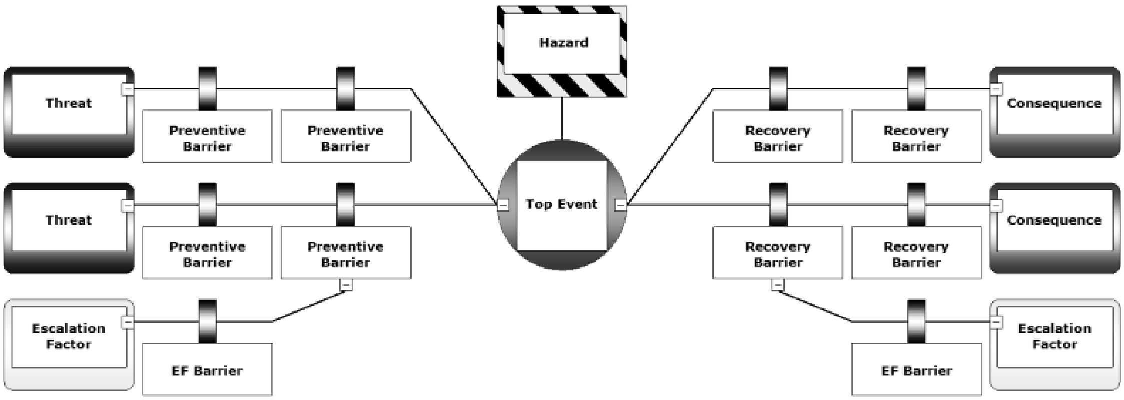


FIGURE 4 Bowtie "skeleton"

More than one *threat* could lead to a single *top event* which then could have several *consequences*, each path requiring an analysis of the *barriers* (also called controls) and their possible *escalation factors* or "weaknesses". The *barriers* in this analysis can thereby exist both before and after the *top event*. Thus the barriers are meant either to prevent the *top event* or to mitigate the *consequences*.

The bowtie method doesn't easily open up by itself, but there are plenty of public sources available for more details. The key is to start by recognizing of a *hazard* and a corresponding *top event*. *Hazard* is normally something we have to live with, like "ground operations at poor visibility". If the hazard was uncontrolled it could lead to a *top event* as an "incorrect lineup position". *Threats* would describe why the top event might take place, being for example a "loss of crew situation awareness". And finally the *consequences* are the possible outcomes that we want to avoid; "collision on ground". The public safety pressure is naturally on the left side of all top events. In this research, however, the focus is on barriers after top events and even after some consequences.

Some conventions apply when using the bowtie terms described above (see e.g. UK CAA, 2015). The terms are quite generic, why they appear in other contexts as well and possibly with different tone. Terms like 'threat' and 'hazard' have their semantic values and a level of synonymy. These terms are thus best understood by the context where they appear.

2.2.4 Mitigating risks

Although the systemic analysis is welcome, it is the end user at the sharp end (pilot or air traffic controller) who is in charge of the real-time control of *flow of events*, and has to make the decisions with the capacity and data available. Even when a system is enforced to be more error-tolerant the end user should have the best tools for effortless control and unbiased reasoning.

Aircraft production is highly controlled activity, particularly when commercial passenger aircraft are designed. Aviation authorities have ruling and guidelines covering activities of the design organizations and their eventual campaign of airworthiness. By its nature this activity has to be proactively error-minimizing; already because any major finding in final proving phase may affect the whole production line and delivery schedule. EASA (2016a) example document for design organization flight test program provides one easily adaptable model of the proactive planning. The point of interest is in the mitigation, including both the aspects of occurrence probability and the possible consequences' *severity* (example at TABLE 1 by EASA, 2016a).

TABLE 1 Risk mitigation (in flight test)

RISK						MANAGEMENT		
Hazard	**Cause**	**Effect**	**Probability**	**Severity**	**Risk**	**Mitigation**	**Emerg. Proc.**	**Risk**
The aircraft enters unrecoverable spin during stall test	The unknown flight characteristics above αcritical	Crash, and fatal injuries to the flight crew	3; Improbable, but may occur	A; Destruction of equipment, fatalities	3A	Parachute wearing; Minimal safe altitude to 6000′ AGL; Canopy jettison system installation	If the spin is unrecoverable before 1500′ the aircraft must be abandoned.	3D

The probability and severity are estimated for each test separately using case-specified classification tables. An estimate of 'untreated' risk is established firstly and after a mitigation activity a 'residual' risk is extracted. The residual risk should naturally be considered acceptable for all parties before the test can be performed. In the example above, the planned aids and procedures don't actually reduce the *probability* due to unknown flight characteristics. They will remain unknown until the test results become available. However the precautionary measures will limit the *consequences* only to the aircraft. If the undesired conditions are realized, and the aircraft enters to unrecoverable spin, the crew then performs the *prepared* emergency procedure by using the installed canopy jettison system and abandoning the aircraft.

Decision making is definitely less complicated in the 'preplanned' emergency than in a scenario where safety is at stake and there are possibly passengers on board. This challenge has not been evaded in the aviation; on the contrary it has been heavily invested on. Recognizing that things may go wrong is a standard in the professional aviation. Preparing for extremely hazardous situations is possible with the modern high-fidelity simulators. What is the issue then? A major issue, not difficult to deduce, is that there exists an infinite number of cases versus a very limited time to practice.

2.3 Human as barrier

It must be kept in mind that all safety occurrences have systemic elements as depicted in the PIRATe example (FIGURE 3). Therefore, the most effective human barrier (for the situation) could be located in somewhere else, either physically or temporally. Considering the real-time immaterial barriers, the chain of cognitive events is interesting as a whole, including a possible error, its detection (direct or indirect) and the barrier activity. These factors together enlighten the mechanisms and successfulness of the barrier.

Hollnagel (1999a, 1999b) lists barriers covering the system level, and identifies some requirements for their effectiveness. The forms of barriers act to prevent, control, protect and minimize; either preventing an event to occur or minimizing the consequences due to latent conditions at system or organizational level (Hollnagel, 1999b; Reason, 1990). Can a human replace any of the listed functionalities, is certainly a question worth visiting. Using a slightly different angle, human barrier could be considered as a replacement for the non-human barriers of different nature: material, functional, symbolic and immaterial (Hollnagel, 1999a; 1999b).

A human is not at best use as an actual *material* or hard barrier, but we can create the same effect, by exclusively preventing an *exceedance*. Such function, however, would consume human resources for one goal, as guarding only against too low altitude. As soon as multiple preventing barrier tasks are allotted to single individual, interference of the tasks may become an issue. Due to multiple reasons human as a physical barrier replacement in aviation is uneconomic, at the least. By contrast, the human operating as a *functional* (or logical) barrier is something that could be considered inherent. Specific conditions needs to be fulfilled - both signal and memory data requirements need to be satisfied (Norman & Bobrow, 1975) - before process activation, even an automated one. This logic also works reversely when we allow the events to proceed without intervening as long as the "flow" remains as expected.

Symbolic barrier activity is also quite common in interpersonal activity. Manipulations of symbolic structures stand behind the heuristic effectiveness of human problem-solving ability (Newell & Simon, 1976). This effectiveness, and the virtue of being able make predictions, will help the human in recognizing the symbolic triggers and patterns, leading to meaningful representations (Saariluoma & Salo, 2001). In this respect humans are capable, as entities compiling representations, both acting according to perceived meanings and transmitting representations to other humans. Thus, especially the team performance as a recovery barrier would be related to the members' capability to process and provide symbolic barrier elements.

Where *immaterial* barriers are referred in form of (published) rules (Hollnagel, 1999a; 1999b) a human as an immaterial barrier looks quite plausible. There is a vast number rules that we follow internally without paying explicit attention. Personal values, ethics and cultural norms affect the way we perceive things around us. The more ambiguous a perception is the more the social or internal forces affect the apprehension (Moskowitz, 2005). For the human-based values to work effectively they need to be as coherent as possible.

The most challenging conditions for a human to work as a barrier are those, where all perceived information comes only through artificial symbolic presentations, instead of clear visual perception of the world. In great number of incidents over the world the pilot or pilots have been unable to conceive aircraft flight parameters or nature of the problem. Yet the investigation, even based on circumstantial data, clears the 'mystery'. This indicates that the people could have been provided with well prioritized and clearer dynamic data, instead being forced to make time-consuming interpretations and iterations.

2.4 Coping with the complex and dynamic

2.4.1 Cognitive bottlenecks

An essential obstacle to understand both from training and mission assignment point of view is the existence of cognitive bottlenecks. Obviously flying includes a great number of procedures that the pilot must be capable of doing without a cognitive overload. Maintaining a desired flight path is amongst the required skills, just like maintaining the lane is a requirement in driving a car. The process slowing down is often a consequence of processing capacity or data availability limits (Norman & Bobrow, 1975). In normal piloting situation the decision making is heavily dependent on data available; and workload is nominally arranged such that no capacity-limited situations should occur.

Different classes of aviation (e.g. ICAO, 2009) require quite different crew training and structuring. Commercial air operations on large aircraft require a minimum of two pilots, preferably full time in the cockpit (EASA, 2016b). This solution combined with an organized flow - things advancing according to flight plan and checklists - may be expected to control well the processing requirements. In multi-pilot context even the basic flying is "outsourced" just to cope with the complexity. Due to capacity or data (related to mental contents; Saariluoma, 2001) potentially limiting the processing, there should be ways to handle the complexity on various modalities.

Whether a single or multi-pilot crew, any deviation can quickly increase the demand for processing power. The multi-tasking requirement will naturally start using any reserve capacity if the basic level of performance on the necessary flight path control is maintained high. If this requires the use of manual resources, as often is the case in emergency situations (evasive maneuver, recovery from unusual state, forced landing), then another possible bottleneck might become limiting. The theory of *Threaded Cognition* (Salvucci & Taatgen, 2008) indicates that the resource conflicts might create even more important interference than the procedural bottleneck which is generally being considered as the central bottleneck.

Aviation includes a great amount of traffic-coordinating communication, consisting of standardized phraseology. Any breakdowns in the messages would decrease the data validity. This is a central area affected by increased workload; to compensate, pilots tend to simplify the messages (deviating from the standard) where air traffic controllers might produce correct but long verbal instructions (Wickens, 2007). The result could therefore be ambiguity to the controller, and data overflow to the pilot. Deviating from the standard phrasing, or loading the working-memory, would also reduce the situation awareness when the language patterns remain vague.

In the critical situations there must be means of allocating resources to essential problem. This would mean reorganizing the goals or even resetting them. To make timely and logical goal adjustments, firstly there must be a motivator to redirect the attentional resources, and secondly the new information should indicate that human interference has become necessary. The attention itself may be a challenge in case of long-lasting and (normally) uneventful flow as the long-haul intercontinental flights. An interaction, between sustained attention (or vigilance) due to fatigue and workload, has important connection to performance (Hitchcock et al., 1999; Hörmann et al., 2015). Considering the situation in aerial work, the case might be different when the pilot-operator may have to cut trees on a helicopter only at 100 feet above the ground. This would require a high sustained attention as the 400 kV power lines are only 50 feet away from the hanging rotary saw. In both cases the performance might me a limiting factor but for very different reasons.

Cognitive strategies help coping with the critical situations in various ways. In case of signal clarity, and attentional reserves available, a rapid perception can be expected. Another, highly important issue is the interpretation of the meaning (i.e. apperception), in order to take worthwhile action. It is logical that both the apperception and action need to be co-learned to minimize the effect of chance. Correct assimilation of the situation needs to be complemented by correct mitigation or barrier procedure to maximize the successfulness of the performance. The time span of a critical situation may vary from few seconds to several hours like in cases of 'failure of the only engine at takeoff' or 'failure of one of the two engines over mid-Atlantic'. The strategies should be different; it wouldn't make sense to start analyzing the situation when the only option is an immediate forced landing. Vise versa, it wouldn't be wise just rapidly secure one of the engines over an ocean, and take a risk of wrong "diagnosis".

2.4.2 Adopting skills

Pilot's level of expertise is an important variable, considering his or her ability to interpret the situation at hand. The lesser the experience the more the basic piloting as controlling flight path is expected to require attention. Ackerman's (1988) theory divides the learning of moderately complex yet consistent skill in three phases (FIGURE 5). Initially *general ability* (cognitive processing) is dominant, speed is slow and errors occur. Then, a successful production compilation supported by *perceptual speed ability*, takes place as associations are formed. Finally, when the production is compiled, the skill performance is tuned by *psychomotor ability*.

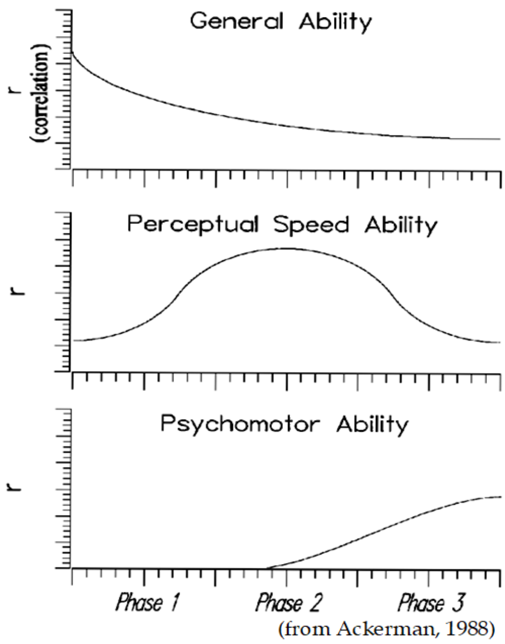


FIGURE 5 Ackerman's ability-skill learning relation

Thereby it can be expected that the survival strategies and the mechanisms of errors are different, depending the personal level of automatism. A prioritization of tasks can be successfully accomplished only (if coincidence is excluded) when the situation is known (situation awareness) and the actions don't sacrifice "staying on the lane"; the primary task still being the maintenance of safe flight path, not to forget the altitude and airspeed either.

Learning new things is expected to be effective at the beginning but fine-tuning of skill at later stages requires more repetitions. For example the ACT-R cognitive architecture (Anderson et al., 2004) has adopted an empirically viable logarithmic increase of activation level in repetitive exercise of declarative information. Furthermore the ACT-R supposes a minimum threshold value for activation, being an interesting aspect in this context. A real-life problem in the surprising anomaly might be that only limited number emergency procedures actually are retrievable either due to limited (brief, infrequent, etc.) or ineffective practice.

Especially in case of private aviators there is no company safety organization to maintain certain level of readiness, just the individual him or herself. For these individuals the safety network, in form of local flying club and fellow pilots, most probably, appear anything else but organized. From the perspective of managing a new and challenging situation the creativity, being obtained by the *general ability,* might be the only source available. The benefits of *perceptual speed* and *psychomotor ability* may not be disposable due to short time span of the event.

2.4.3 Cognitive load control

It is of interest to search for indications of workarounds to overcome possible production or modal resource bottlenecks. One of the important mechanisms releasing capacity for unprepared activities is high level of automaticity on some compulsory task. Once again an analogy for changing the car location within road edges is maintaining control and changing flight path effortlessly as needed. Such automated threads of activity can be controlled based on automated contention-scheduling when the schemas are well specified (Norman & Shallice, 1980). This capability clearly requires high level of flexibility to maintain the activity under control of functional rules; otherwise the demand of processing power will have to increase.

The long-term working memory (LT-WM or LTWM), reducing the short-term memory attentive load, is known to provide the experts with performance superiority (e.g. Ericsson & Kintsch, 1995). Some important limitations, however, apply to utility of professionalism when encountering the 'unexpected'. Oulasvirta & Saariluoma (2006) list the important properties and conditions of the LTWM; and those closely connected to aviation are *domain-specificity*, *practice-dependence, meaningfulness* and *organization* (retrieval structure). Due to these constraints the critical situations may, or may not, be successfully cleared by the well-established 'cue-to-response' structure of the professional.

Attentional resources become at use when the compatibility of the learned schemas doesn't perform in the situation or when the context is perceived as dangerous (Norman & Shallice, 1980). Challenge is greatest in time-compressed situations as the attention might not be able locate a proper solution before the time runs out. The less effective the actions are perceived the more attention there is needed to solve the problem. This might induce frustration, and furthermore elevate level of stress, especially if the time-limit is perceivable. As a result an attentional narrowing takes place (Wickens, 1996), having consequences to performance. All of this emphasizes the importance of high expertise in the most serious and time-critical emergencies in order to avoid bottlenecks.

2.4.4 Multi-tasking

Multi-tasking requirement is a "built in" requirement in the aviation, knowing that there are a number of conditions that need to be fulfilled any time the aircraft is moving. There are several parallel threads of cognition included in the total flow of activities satisfying a number of goals, which as a process is well described by Salvucci & Taatgen (2008).

Tasks come with different levels of demand, ranging from automated operations to complex ones, thereby creating a total demand or interference (Wickens 2008), which can be considered as the mental workload. We have some cross-modal abilities that help overcome the bottlenecks, namely visual-manual and aural-vocal tasks are generally performed well simultaneously. A pilot flying is an ideal example; he or she is well able to control the flight path manually, based on the visual data, and simultaneously communicate via voice radio to maintain higher level of situation awareness.

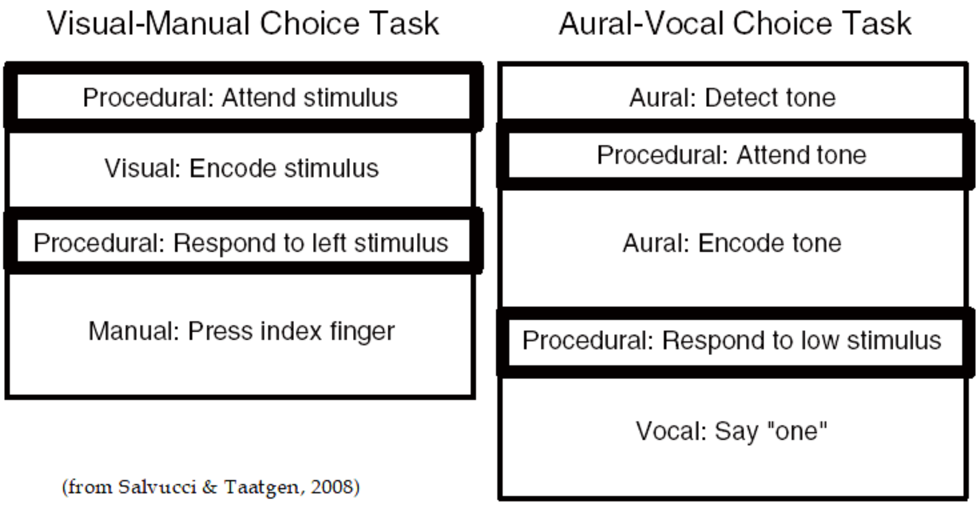


FIGURE 6 Perfect time-sharing example

The principle of least effort for cognitive effectiveness is strongly supported in multi-tasking environment. If proper heuristics (i.e. schemas) are available those would be used in time-limited decision making, otherwise systematic processing will be required to close the sufficiency gap (Moskowitz, 2005).

Where multi-tasking might come naturally as such it can be expected that the increase of processing requirement due to sudden secondary task may start interfering the base-level performance. If the primary task is piloting and the emerging secondary task is for example time-critical decision making (containing search of supporting data), the concept of *urgency* (modeled by Salvucci & Kujala, 2016) provides an interesting reference. Should the secondary task complexity or priority increase, as sometimes the case is in dynamic emergencies, the relative urgency might also increase, thus reducing the probability in resuming to piloting. As the primary task still remains as the major thread in the task continuum, there needs to be a control that holds the balance between changing urgencies and prevents any of the main goals falling below activation threshold. One such control could be the situation awareness, running as a latent thread as of a check-list with somewhat similar urgency law than the *driving* (Salvucci & Kujala, 2016).

2.4.5 Situation awareness

In order to make correct actions to recover from a novel crisis situation one needs to understand the present situation and consider possible solutions available. Both of these factors are part of situation awareness (SA), possibly on a very dynamic flow of events. Endsley (1995) breaks the SA in her theoretical model of situation awareness in three levels; *perception*, *comprehension* and *projection* of future (FIGURE 7), each level requiring more cognitive processing

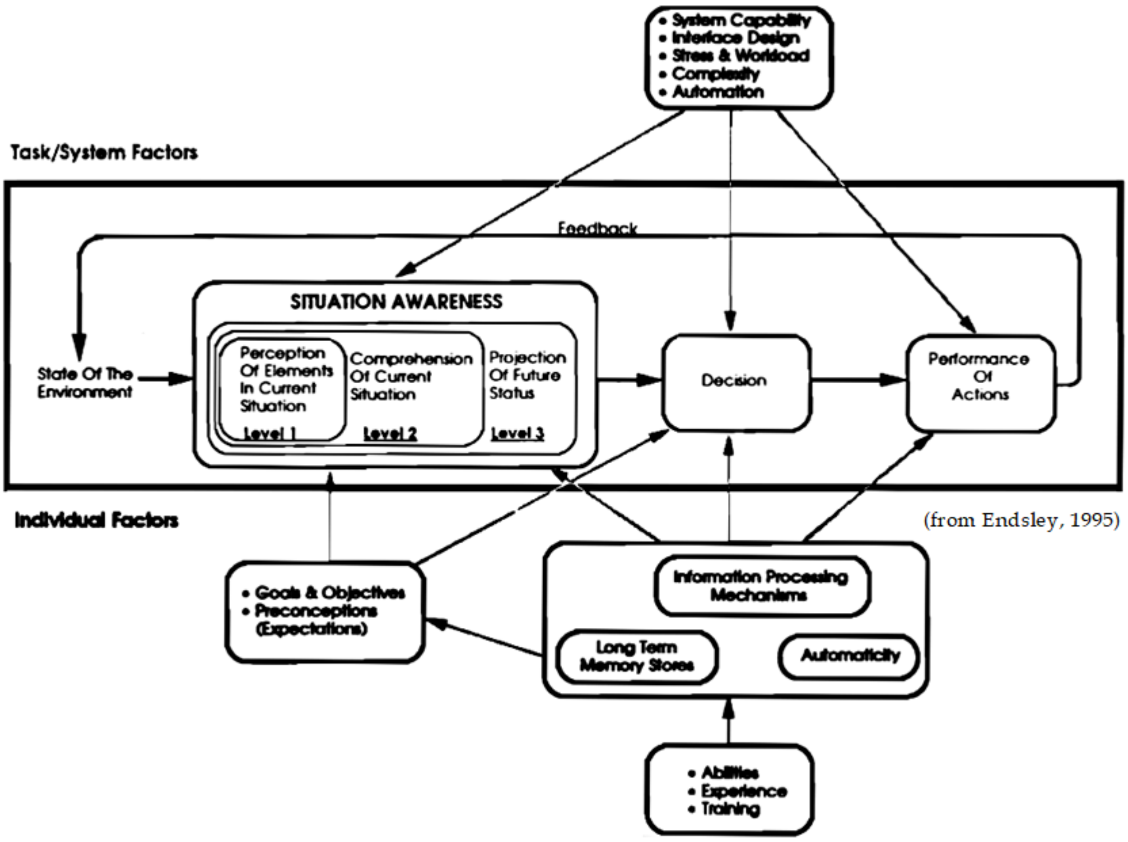


FIGURE 7 Endsley's model of situation awareness (SA)

A successful understanding of the situation requires a number of elements, like spatial, temporal, system and environmental SA, avoiding overload and underload; both detrimental for the SA (Endsley, 1999). SA strongly supports the data need in decision making, thus reducing the risk of data-limited processing. Evidently, the mental contents must be used to construct the situation awareness. The mental contents, therefore, have to be connected to the level of SA required to cope with the issue. Endsley & Rodgers (1997) extract a correlation of workload, SA and use of information from air traffic control task. As the workload was increased the errors increased and the subjects started compensating by narrowing down the SA (to the essential).

The first level, *perception,* calls for trigger or cue unambiguity (Norman & Shallice, 1980), especially in the context of an impending incident or accident. It can be anticipated that a proper perception assists in choosing a rewarding path, either for the action or for building a higher level of SA (if required in order to solve the problem). An action, based on perception only, falls in the category of skill-based, automated behavior (Rasmussen, 1983). The strength of such activity could be anticipated especially in handling of an aircraft where a constant feedback system allows continuity and therefore perceptive level of SA remains satisfied. One could expect good performance in cases where a demand of only the present skill-based performance is increased, like evading a collision when already actively controlling a vehicle. For example; a pilot suddenly perceives a flock of birds straight ahead; 1) implicitly triggering a flow of events' control, 2) initiating a pull back of the control stick to stay clear of the birds.

The term "perception" in context of the SA might be a not descriptive enough when the flow control mode is exceeded and explicit decisions need to be made. In order to apply higher rules a *comprehension* level of the SA must prevail. When the automaticity doesn't provide an implicit solution, knowledge and perceptual information will be associated constructively for the apperception (Laarni et al., 2001; Saariluoma, 2001). There still is the unambiguity requirement in order to correctly associate the perceived information. Increasing the signal expectancy improves the detection (Posner et al., 1980), thereby clarifying the cognitive process. A mental assimilation that takes place can provide a meaningful and effective source for, either implicit or explicit, decision making. The latter type might be either rule- or knowledge-based (Rasmussen, 1983). For example; after our pilot just intuitively evaded birds, a gust causes a short auditory beep; 1) this sound is recognized as stall warning, 2) confirmed from the airspeed indicator and interpreted as slow speed condition, and 3) resulting to nose lowering and increasing the power.

The mental contents and their relevance can be seen as closely related to concept of situation awareness. Considering future *projection* of SA there, naturally, is a need to weigh the possible strategies for a cost-effective solution. The decision making in aviation is a dynamic process. If a good strategy is chosen the choice would alleviate the workload by an increased predictability of the following events. Choosing between the strategies is possible only if the SA is 'correct'. A relevant subset of environment needs to be chosen (Endsley, 1995). Thereby if an SA thread 'runs' constantly the update rate for various components can vary based on their dynamics. Expertise can be expected to provide more effective SA exclusion and higher selection of resolutions or components. For example; now that our pilot is back on steady flight the next turn puts a weather system on the route and 1) considering the darkness of the clouds, 2) remembering the lake area behind with the lots of gulls, 3) checking the fuel state and current position 4) the pilot *decides* to land on near-by airfield, refuel and wait for the weather to improve.

2.4.6 Decision making

Determining an action in evolving situation, and maintaining the control, calls for a consistent SA. If this consistency is disturbed a new strategy must be defined. The more there are options to choose from, the more the working-memory will be needed judging the rationality and utility of the decision. A descriptive decision making often outweighs the normative practice due to excessive number of possible solutions in latter case. (Laarni et al., 2001).

A lone pilot is mostly alone also when the unexpected happens, perhaps forced to very fast decision making. Depending on the urgency there might not be any other option than to minimize the consequences; and the following few seconds will determine what are the consequences when movement has stopped. An example of best-case scenario could be an aircraft impacting ground well flared, structure absorbing the kinetic energy and then people stepping out after opening their seatbelts. All the action has taken place based on some rule and skill-based sensorimotor (or sensory-motor; Rasmussen, 1983) performance. The best performance can naturally be achieved when the apperception is based on perception of the *essential* cues, and there is a corresponding rule available. A less perfect performance, but still tolerable, might be achieved by simply adopting single-tasking like visual-manual control and following the learned airplane control rules. In this option the aircraft might end up hitting the ground with control stick aft, in full aerodynamic stall, but at least wings level. The consequences then would depend on the structure.

Fast decisions, in order to be optimal, suppose fast decision making. The time available is a foundational constraint, which should be conceived. Decision making strategies must be different for short and long time span actions. It would certainly be optimal if a situation could be treated after a comprehensive weighing of options. However, the decisions in emergencies must often be made swiftly, intuitively. A naturalistic decision making by Klein & Klinger (1991) explains well decisions that professionals make in true situations, perhaps not for the optimal but still successful outcome. A Recognition-Primed Decision (RPD) strategy, representing the naturalistic model in the simplest (most time-compressed) form includes: 1) experiencing the situation, 2) recognizing the typicality and 3) implementing a typical action (Klein & Klinger, 1991; Klein 1993). Considering that the implemented action should be *typical*, the person implementing should have enough experience in classifying the cases and responses. When there is more time, more mental-fitting may be practiced before the decision.

Even though human decision making would generally be based on intuitive pattern or feature recognition, cases where no pattern was intuitively available would promote shift to the normative or functional-relational seeking side of cognitive continuum (Hammond, 1988). Based on Ackerman's theory (1988) the general ability is expected to be a major benefit when a totally novel situation is presented. There might be various reasons why a pattern was not available, perhaps due to insufficient experience or arbitrary or restricted data. These pattern-weak situations might be confronted either by making a judgment based on a normative analysis or (time-permitting) waiting for a recognizable pattern to form as a consequence of situation dynamics.

2.4.7 Deduction and problem-solving

In many cases limited data decision might be less successful as a strategy than delayed response, matching with a recognizable pattern. For example an aircraft might have been flying perfectly so far but now the air speed indication is showing a gradual decay, breaking the projected model of situation. Instead of increasing the power setting, which has been sufficient so far, maybe checking for the *pitot tube* (pressure sensor) for freezing, and turning on the forgotten heater switch, resolves the only deviation in otherwise good pattern. The obviousness tends to guide human reasoning which is mostly known for its weaknesses in reasoning, but only when the information is 'misleading'.

Like Wason (1968) showed in his known experiment with the double-sided cards, the subjects choose a positive confirmation about the given truth, even if previously primed to the contrapositive solution. Because the knowledge-based performance is sensitive to unreliable practical heuristics like the confirmation-bias and bare availability of information (Reason, 2000; Laarni et al., 2001) some compensatory measures are needed. Data availability is generally better and more detailed at the professional end of aviation, where designers' freedom is less affected by the end user economy. Surely people can and should be made conscious about the non-exclusive and biased human deduction. Yet, in a threat situation the information availability and logical reasoning can both be expected to suffer from the increased attentional demand.

If the information availability doesn't provide elements for 'clear' deduction, either a false assumption results or a new problem is induced. As problem-solving calls for *developing* novel approaches (Laarni et al., 2001) it is applicable to such situations where forcing constraints, like time or control, limit only minimally the cognitive processing. Depending on the nature of occurrence and its relation to a person's expertise for such situation, a solution might be discovered intuitively or it might be painstakingly challenging. Or, it might be both, starting by an autonomous phase (e.g. after an aural low altitude warning) with an initial response (stop descent), leading to reasoning or problem-solving (find out why did the unexpected warning come on). When a trigger becomes observed that can be perceived as the *surface feature* of a (forced) task where the actual requirements, when apperceived, represent the *depth feature* as described by Hammond (1988). Normally such depth features might be irrelevant as long as the surface requirements become satisfied. However when the subject is tasked by the *conditions* the surface and the depth might not have a cognitive continuity. If the low altitude warning comes on as expected the surface characteristics are sufficient, if not the depth features will have to be solved.

2.4.8 Cognitive power of team

The more complex the aviation the more elaborate *models* with varying utilities should be evaluated before decisions are made. One viable consideration is forming a team, capable of handling complicated aviation deviations. It can be asked, if a team then equivalent to a flight crew; the answer being both yes and no. In sense of facing challenges, every person helping to solve an issue could be considered as a team member committed to that specific case. Logically, there must be a continuous restructuring of networks due to ever changing situations. Any subject, interacting with another (aviator, air traffic controller, ground crew…) via means of real-time communication, belongs to a network of communication. The network should serve a common goal in order to benefit all members' input. Furthermore, in the context of incident decision making the real-time element is certainly a 'must'.

Team (SA) situation awareness can be considered as an expanded awareness in multi-pilot environments, resulting to a shared mental model that serves as a mutual reference for activity (Endsley, 1999). The crew resource management (CRM) has originally served better control of cockpit resources, having gradually evolved towards managing and even benefitting from the inevitable existence of error (Helmreich et al., 1999). Even though the crew cooperation, task-sharing, task management and the shared SA are essential, they might serve mostly the information needs.

Interestingly, task-sharing between the crew members has commonalities with individual subject's multi-tasking principles (e.g. Salvucci & Taatgen, 2008). Crew members may be perceived having parallel (threads of) activities synchronized by information exchange. The predetermined and scheduled rules are executed as flow of events; a specific cue (e.g. line up on runway) initiates a corresponding check list activity. Same methodological flow control, including the individual task-sharing, is extended to involve the emergencies as well. In most urgent emergencies, supposing that they are covered check lists, a controlled flow management takes place. From the perspective of cognitive continuum, this rule-controlled task sharing operates at the functional-relational (Hammond, 1988) side of the cognition.

An adaptive form of integration of human intuitiveness and creativity into social intelligence is often needed in situation that cannot be assimilated to any previous format. A theory of interactive team cognition (ITC) by Cooke et al. (2013) provides an angle that emphasizes the team activity as a source of adaptation and ability to reach the goals. Undoubtedly, a wider pool of cognitive models and activation values would support to wider variety of dynamic solutions. The communication between team members, correlates well with team productivity, somewhat surprisingly more than the amount or contents of information transmitted (Cooke et al., 2013). In respect to the adaptability there should be a common goal and motivation to reach it a critical component is a team member able to provide timely communication. Lack of motivation, fortunately, isn't an issue when human safety is at stake. Unconstrained communication serves well when good advice is needed.

Reason (1990) discusses about error inducing simplification biases that problem solvers might become adjusted to. Many of these (availability heuristic, confirmation bias, fragmented review process and causality simplification) are obviously sustained by the limitations of human individual and therefore avoidable by wider perspective of a team. The CRM as an organized training program should mitigate the personality constraints which are well known to exist between cultures, age groups and position holders. Certainly some teams are more effective than others; teams that composed of collectively oriented individuals are also more communicative (Salas et al., 2008), and the communication, explicit and implicit, of the mental models is the key as Entin & Serfaty (1999) proved in their study. They also showed that as a product of improved team performance also a more effective stress management can be achieved.

2.5 Performing with stress

The presence of stress cannot be overlooked in cases where an operator perceives that his or her ultimate goal of finishing a successful mission becomes threatened. The more obvious it is that success turns into loss of safety the more probable that a corresponding element of stress arises. Maintaining vigilance is a stressor as such; due to high continuous performance demand, sustained attention consumes capacity (Hancock & Warm, 1989; Eysenck et al., 2007), reducing the responsiveness to secondary tasks or cues. This is analogous to operations requiring constant situation awareness as would be the case in high risk aerial work, flight instruction or air traffic controlling.

If the situation creates anxiety, threat to a current goal consumes working memory capacity by increasing the stimulus-driven attention 'at the cost of' goal-driven according to *Attentional Control Theory* by Eysenck et al. (2007). By the theory (even though anxiety is generally not welcome in decision making) a high-anxious subject is more receptive to threat-related stimuli which may improve performance when a stimulus requires a timely response. Stress as such may therefore be beneficial as long as it is proportional to situation. If attention requirements are maintained in the comfort zone (e.g. optimal information rate and structure) the subject's adaptability to stress level doesn't reduce the performance (Hancock & Warm, 1989). There is always the "golden rule" of priorities "aviate (i.e. fly), navigate, communicate and manage" (e.g. FSF, 2000) that provides a pragmatic stress-relief tool when the attentive control needs a focal point.

The physical stressors may be mitigated by technology solutions as cockpit ergonomics and preparatory systems (emergency oxygen, life rafts etc), whereas the mental elements may be more difficult to control proactively. There are measurable stress indicators such as increased search activity, attentive sensitivity to stimulus and distracted scanning (Vine et al., 2014) but no practical anticipatory technology is available yet. However, training humans to account for the stress has been demonstrated quite viable both on team and individual level (e.g. Entin & Serfaty, 1999, Fornette et al., 2012).

A possibility to provide training for handling stressful situations in aviation, no doubt, deserves a look. From the perspective of surviving a threatening situation, arranging one without actually risking safety is challenging. By logic, training should support a trainee pilot in his or her abilities to analyze and cope with a threatening situation in the air. A simulator environment is dualistic if the stress factor is considered. There is no real presence of physical threat of aircraft being destroyed or someone being hurt, yet the training situation can be made stressful in many ways. Simulator as a stress environment has provided concrete correlation to emergency performance when an extra stress element of passing the annual pilot evaluation was used (Vine et al., 2014). In commercial aviation the simulators are certainly effective and often the only practical threat environments for stress-related training.

3 RESEARCH METHODS

The accident and incident investigation reports concentrate solving three levels of cases; incidents, serious incidents and accidents (ICAO, 2016). Even though the reports are formally comparable the contents provide very little data that could be statistically grouped as such. The source data heterogeneity encourages using a qualitative type of research, however an effort has been made in order to locate also quantitatively definable results. One of the major challenges has been grouping the data in logical manner. Without full knowledge of the peoples' motivations, knowledge and mental states, some uncertainties will remain.

Profound human factors (HF) analysis in the investigation reports would have provided a great benefit in locating the cognitive mechanisms needed in this study. Especially in technical-based incidents, the investigations often concentrate in solving the technical reasons, leaving HF to lesser attention. Contextual information has consequently played an important role for the analysis. The (barrier) methods used by the "subjects", in this case the people involved in the accident or incident, should be understood. This is what Newell (1973) urges in his *First Injunction of Psychological Experimentation*. His workaround for the problem provides a practical solution - knowing the *goal*, *environment* and analyzing the *performance* of the subject, it is possible to make conclusions.

3.1 Analyzing human

Contextual information has played an important role in locating the cognitive mechanism for this study due variation in human factors (HF) analysis of the investigation reports. Especially in technical-based incidents the investigations have logically concentrated in solving the technical reasons, leaving HF to lesser attention. There is however some data commonality in almost all incident reporting, helping to cover the main elements requested by Newell (1973).

Firstly, the range of possible *goals* of a person or persons can be narrowed down by the nature of occurrences under investigation, all of them having an element of threat. Thereby the goal is expected to be related with the severity (hazardous, major or minor) and contextual circumstances (*environment*). The perceived expectancy of the situation has inevitably provided a reference for goal setting. The goal in such crisis would logically be located somewhere between survival and regain of control of the situation. One would also expect some goal modulation having taken place in some cases due to highly dynamic flow of events.

Secondly, the *environment* has both static and dynamic elements in the occurrences concerned. This information has been quite well extractable from the investigation reports that normally contain essential background information about the conditions (weather, air data, technology involved, means of communication etc.).

Thirdly, the *performance* of the persons involved, can be interpreted either as the success or the strategy of the activity (i.e. performing). The success can be estimated comparing the outcome data with the contextually indicated outcome potential which is a common practice in the investigations. Elements as perceived threat, stress, case complexity, situation ambiguity and real-time demands (time, control, reasoning etc) have served as estimators of chosen strategies and performing in general. The more arduous the task has been the higher the expectations from the performer have been; therefore the experience has been used as a capability indicator. From the piloting point of view there are two available indications of expert capability; the flight experience (flight hours or type of pilot's licence) and the type of activity the subject is performing (from recreational to professional aviation).

3.2 Data grouping

3.2.1 Classes of general outcome and severity

In order to locate possible regularities the case data has been grouped, using various classifications. The occurrences are generally classified, according to ICAO (2016) accident investigation document definitions, either as;

- accident,
- serious incident or
- incident.

An example classification of accident by ICAO (2016) is such occurrence in which "a person is fatally or seriously injured". Serious incident has the same ingredients as accident - the difference "lies only in the result. Finally, an incident is an occurrence that "affects or could affect the safety of operation".

Severity grouping is connected to individuals' goal control though not exclusively; certainly the circumstances and dynamics have their effect.

Second classification has been made, based on the cases' severity. This data was not generally retrievable from the reports but was relatively clearly definable by comparing the outcome details to ICAO (2013) Safety Management Manual scale:

- A = catastrophic (0 cases by default),
- B = hazardous,
- C = major,
- D = minor or
- E = negligible (0 cases by default)

As an example, the *major* severity class is defined by ICAO (2013) corresponding to "a significant reduction in safety margins, a reduction in the ability of the operators to cope with adverse operating conditions as a result of an increase in workload or as a result of conditions impairing their efficiency".

3.2.2 Aviation class and crew experience level

Crew aptitude can be used explaining capability to handle complex and out of the ordinary occurrences in aviation. The crews' task capability can be estimated from following experience level variables.

- flight experience (flight hours or FH)
- pilot licence
- aviation class

There is seemingly a strong connection between the form of aviation and licensing, partially as built-in limitations. For example EASA (2016c) sets the maximum aircraft mass of 2000 kg for a LAPL (Light Aircraft Pilot Licence) holder. Furthermore, the commercial air transport requires either a CPL (Commercial Pilot Licence) or an ATPL (Airline Transport Pilot Licence), CPL privileges being more limited than ATPL. The pilot licences concerned are: *BPL* (Balloon Pilot Licence), *SPL* (Sailplane Pilot Licence), *LAPL* (Light Aircraft Pilot Licence), *PPL* (Private Pilot Licence), *CPL* (Commercial Pilot Licence) and *ATPL* (Airline Transport Pilot Licence). As a curiosity, there is a number of corresponding national licences expected to be reverted to EASA licences by April 2018 (Trafi, 2017). Because the pilot licences are directly associable to aviation class, the *flight hours* (FH) has been considered as a more accurate experience level indicator than the licence class.

The *aviation classes* were analyzed in order to reflect the skill and cognitive involvement required in the operations. For example ICAO (2009) classifies the (civil) aviation activities, having provided a foundation to fine-graded classification (TABLE 2) criteria which would reflect the corresponding piloting challenges.

TABLE 2 Types of aviation

Aviation Class [1]	**Category of Aircraft** [2]	**Certification Specification (CS)** [3]	**Note**
Recreational A/C Pleasure Flying	Parachute or non-aircraft	Non-EASA regulated	-
	Hang glider		-
	Gyroplane		APL
	Ultralight (vs. EASA Microlight)		≤ 450 / 495 kg (land/sea), UPL
	Balloon	CS-31GB/HB/TGB	-
	(Powered) Sailplane	CS-22A/B/C	-
Plane/Helo Pleasure Flying →	Aeroplane & Small rotorcraft	CS-23 & CS-27	≤ 5670 / 9 pax & ≤ 3175 kg / 9 pax
Light Commercial → Air Transport [4] →	Commuter (twin-engined prop)	CS-23	≤ 8618 kg / 19 pax
Commercial Air Transport	Large aeroplane & Large rotorcraft	CS-25 & CS-29	> CS-23 & > CS-27
Plane Aerial Work & Flight Instruction	Aeroplane	as applicable	-
Helo Aerial Work & Flight Instruction	Rotorcraft	as applicable	-

1) Modified from ICAO (2009) classification.
2) For definition see EASA (2016c) FCL.010.
3) For CSs see EASA (2018) web pages.
4) May be carried out both on Aeroplane & Small rotorcraft and Commuter category.

Classification of various forms of aviation are far from universal, varying based on the general authority and national practices. The certification specifications or CS's (EASA, 2018) define the required characteristics, including the handling qualities and human interface, and performance for all EASA controlled aircraft categories for official certification. The EASA specifications are highly similar compared to for example the Federal Aviation Authority (FAA) regulations and they have to be so for the use of common global airspace. Definition wise it is good to perceive that term *aircraft* (or *A/C*) covers all flying apparatus able to sustain altitude (without ground effect) where term *aeroplane* refers to only fixed wing engine-driven aircraft (e.g. EASA, 2016c).

The classes of aviation in TABLE 2 coarsely follow the ICAO (2009) lines with some terminology chosen to profile the general non-commercial pleasure flying. A sub-classification is made in pleasure flying between the traditional aeroplane (*plane*) and helicopter (*helo*) classes, and the lightest end called simply as *recreational A/C*. The commercial side of aviation consists of *light commercial* (normally multi-engined commuter aeroplanes) and *commercial* air transport (large aircraft). *Aerial work* and *flight instruction* (on aeroplanes and helicopters) are both considered containing more continuous commitment either on the job at hand or as instructional involvement; why grouped together.

The classification as described above was evaluated against the cases and it was found well representative. Due to perceived typology and limited number of cases per aviation class, however, a more robust grouping into *aircraft* classes was eventually chosen. Both pilot experience and aircraft requirements (mass, speed and complexity) have been considered when crossing of lines was made in order to form the following classes:

- recreational A/C
- SE (single-engine) airplane
- helicopter
- ME (multi-engine) airplane
- large airplane

There is a continuous evolvement at the lightest end of the aviation, but perhaps an ability to carry maximum of two persons due to mass restrictions is a typical feature in the *recreational A/C* class. The lightest class of aviation includes strongly a recreational element and is practiced mostly on sailplanes and ultra- or microlight aircraft. The following aircraft class includes *SE* (single-engine) *aeroplanes* that typically are light aeroplanes able to carry three or four persons. All *helicopter* cases are included in one class (instead of dividing between the types of operations). The solution is supported by the number and typology of the rotary wing cases. Next two classes are multi-engined both; the lighter *ME* (multi-engine) *aeroplanes* and *large aeroplanes* (CS-25 certified). Even though *ME aeroplanes* (capable to short to mid-range operations) have been used to light commercial transport, aerial work and light instruction, the operating demands are reasonably similar. Finally, the *large aeroplanes* are operated in the most complex and controlled class of aviation (i.e. commercial air transport), thus being system wise highly equipped to meet the demands.

3.2.3 Error and its recognition

Error itself has not been regarded an "issue" nor has its origin, due to approach chosen for the research. However the presence of error is considered too valuable to be omitted just for the general scoping. Main reason for this choice is actually a result of the same human recovery-oriented approach; in order to recover there must be something to recover from. Most often the deviation or failure is of human origin, but sometimes the nature might 'assist' in form of harsh conditions. If not for the general purposes of this research but as an interesting dimension of the subject, the knowledge of (possible) type of error and its detection have been grouped. The grouping (TABLE 3) follows Reason's (1990) division in errors and detection mechanisms.

TABLE 3 Error types and detection mechanisms

Type of Error	Note	Error (or Top Event) Detection [1)]
Slip	skill-based	Self-monitoring
Lapse	skill-based	Environmental error cueing
Mistake	rule/knowledge-based	Detection by other people
Violation	-	
Systemic	organization /"nature"	

1) Error might present itself as a top event (see 2.2.3 Bowtie analysis).

A possible error involved is mostly appointed in the investigations' conclusions. In some occasions, perhaps rightfully, the incident reports don't name the origin of the deviation and the contextual sourcing has been used in such cases. The four error mechanisms as per Reason (1990) plus a systemic (e.g. organizational) error source are considered to provide with an adequate resolution (TABLE 3). Intentionality is used as a border line; slips and lapses are (unintended) *execution failures*, and mistakes are *planning failures* (of intended action). The cognitive stages are conveniently merged to error types - *execution* for slips, *storage* for lapses and *planning* for mistakes. For this reason no further break-down in skill-, rule- and knowledge-based (Rasmussen, 1983; Reason, 1990) errors has been regarded necessary. There are actually no conceptual contradictions, when classifying errors according to various practices as for example it the HFACS categorization (2.2.1); just slightly different grids.

For continuity, emphasis has also been put in understanding the error detection mechanisms. Detection of "top event" (see bowtie 2.2.3) has been considered closely analogous to error detection. In case the error detection has been assimilated as top event, it must have played a role in further processing. The division of detection is made in three categories based on Reason's (1990) error detection approach: *self-monitoring*, *environmental error cueing* and *detection by other people*.

3.2.4 Systemic barrier origin

Theme being *Human as Recovery Barrier in Aviation*, the systemic barrier origin in each case has been elemental. High interest is naturally on flight crew actions as recovery barrier. Yet the barrier, even though having been active in the context, might have been established earlier. This approach relates to systemic nature of aviation safety occurrences in general. The primary barrier origin has been searched for each case on systemic principle. The used human barrier origins are:

- flight crew
- external agent
- operator
- platform designer
- HTI designer

Flight crew has been chosen as generalizing term that covers both an individual pilot and a multi-pilot crew. The large aeroplane category is invariably operated by multi-pilot crew, which apparently makes barrier analysis challenging. From the barrier point of view, a case where one of the pilots is a source of error and the other one is a location of barrier, however, doesn't differ from a case of a single pilot who has to deal with his or her own error. When an *external agent* (e.g. air traffic controller or ground support personnel) is considered, this person or human unit is a real-time barrier enabler same fashion as the flight crew. The remaining three barrier origins are of systemic nature due to quality that they all - *operator* (normally the company), *platform designer* (aircraft company or private designer) and *HTI (Human-Technology Interface) designer* - have been creating latent barriers that simply stand by trigger conditions of activation. When the conditions are fulfilled the barrier, for example stall warning system, becomes active.

3.2.5 Determining barrier effectiveness

The effectiveness of a barrier is an indicator the utility of the chosen strategy or one dictated by the conditions. A straight forward way to approach the barrier activity effectiveness, based on often indirect investigation report data, would simply be leaning on the general outcome and severity. This perspective proves to be even too simplistic as it excludes the circumstances that may for example limit the time available for treating a safety threatening situation. On the other hand, the concept of *severity* (well explicated in ICAO SMM, 2013) provides an eligible angle with measurable conditions. For instance a case with "major equipment damage" associates to "hazardous" outcome.

The solution chosen for the barrier effectiveness estimate is accomplished using a proactive risk mitigation process (described in 2.2.4) reactively and reversely. The *mitigation* (EASA 2016a: "actions to minimize, understand, prepare or respond to causes of the hazards") covers the systemic level activity and *emergency procedures* explain the contextual actions. If both of these were non-effective by design then the residual risk would equal to untreated risk. TABLE 4, modified from EASA (2016a) risk management example, presents a method used to extract a value representative for the barrier (activity) effectiveness.

TABLE 4 Reverse path to potential incident outcome

RISK		MANAGEMENT		
Severity	***Potential Severity* ~~(untreated) Risk~~**	**Mitigation**	**Emerg. Proc.**	***Case Severity* ~~(residual) Risk~~**
A; Destruction of equipment, fatalities	~~3: Improbable~~ **A: Catastrophic**	Pre-flight check the stall warning system for proper function.	If stall warning activates reduce angle of attack and increase power.	~~3: Improbable~~ **D: Minor**

A working tool is achieved by using the severities to replace the risks. The outcome severity of an incident, or *case severity*, is known result after the barrier (activity) has been utilized, therefore being used to replace the residual risk. By backtracking the risk mitigation flow, a *potential severity* is acquired. Thus the effectiveness of risk management can be defined by difference between the *case severity* and *potential severity*, expressing how well the barrier has performed. Presence of the *probability* also belongs to the full concept of r*isk* but it can be omitted from the severities as all the cases represent the reality, making the issue of probability irrelevant. An example of non-effective barrier would be: omitting the stall warning and simply maintaining aircraft attitude, resulting to stall and eventual (hopefully wings level) *Controlled Flight Into Terrain* (CFIT). The example shown in TABLE 4 presents an imaginary case with a *minor* outcome thereby indicating that barrier has been effective and reduced the severity three levels from A to D; the stall warning system functionality has been checked pre-flight and a trained, *mentally prepared,* recovery performed.

3.2.6 Activation of barrier process

Identifying the cognition's role in crew involvement and the triggering condition has high importance in grouping the incident cases. The first step necessary for any activity, willed or unwilled, must be a cue or trigger strong enough to be detected. In order for a signal to become detected, the attention, either top down or bottom up, is required. The attentive ability may be enhanced by expectancy, cueing and proximity (Posner et al., 1980). However, the trigger indicating a safety threat is often clearly above the threshold required for detection. Especially cases of a major malfunction are (normally) highly detectable, yet the signal might not be unambiguous, even when obvious.

Detection media leading to an activation of a recovery (barrier) process has been divided in six cases (TABLE 5). The classification is made, based on typical manifestations that have broken the prevailing situational continuity.

TABLE 5 Trigger detection media

Detection via	Effect	Example
primary signal	bottom-up pop-out	failing engine begins run intermittently, causing vibration and rapid deceleration
secondary signal	bottom-up pop-out	selecting flap up instead of down increases angle of attack and triggers low speed warning
internal model	top-down pattern conflict	rate of descent increases even when the collective is pulled further back
preparation	top-down pattern recognition	due to earlier cases crew monitors and recognizes slow depressurization
communication	e.g. prospective memory retrieve	landing aircraft pilot reports final, alerting ATC which just allowed a crossing runway takeoff
vigilance	weak signal detection	radar controller visually scans the radar screen and notices an aircraft at too low altitude

Neither the list of detection media, nor the division used, is considered exclusive. Also the data that can be used for consideration of threshold-exceeding signal varies a lot between the cases. (1) *Primary signal* has been the most recognizable form the investigation reports, even when based on the contextual descriptive information. Acute changes of states have generally been well observed for example as sounds, vibrations, rapid changes or flight path. (2) *Secondary signal* has often been clear as well, but not directly indicative as such, thereby demanding for attentive capacity for ambiguity removal. (3) The *internal model* dissonance from the actual situation has expectedly required either constant situation awareness or a more profound disorder to reveal itself. (4) Aviation community sometimes benefits from the *preparation*, which has shown in cases where the crew has been prepared to a certain malfunction already experienced. (5) *Communication* has been used as a means of focusing the attention, either actively by another person, or passively when the receiving party has (implicitly) acquired a forgotten or otherwise essential data. (6) *Vigilance* or sustained attention, even when known to be consuming, has (as expected in aviation) been practiced in many cases, having lead to detection of weak discontinuities.

3.2.7 Threat management - stress and processing

There are various cognitive strategies that could be used in order to solve the impending crisis situation. The stress is expected to be an important factor to performance, therefore distracting the normal patterns. Therefore the required mental force cannot be considered analogous to the level of automaticity. Even if the activity is fully automated processing might be limited for example due to working memory, being consumed by stress-related contents.

The level of cognitive load reflects the level of stress involved, where non-adaptive stress (or overarousal) would be clearly performance limiting. A long span study (1972 - 1988) of military accident investigations revealed via direct and indirect data that cognitive failures (overarousal, cognitive failure, distraction, inappropriate model, disorientation, visual illusion) had been important contributors to incident outcome (Chappelow, 1988). In the same study it was found that the acute stress (i.e. overarousal in 26% of cases) was either provoked by mechanical failure or coping with a situation at hand.

Both under- or overarousal are effectively performance reducing based on theory (Hancock & Warm, 1989) and statistics (Chappelow, 1988). Considering the various degrees of threats in this study, only the overarousal is considered as situations have supposedly been perceived as threatening. An example of the meaning of the *perceived* threat is a case where a pilot, having being occupied with air traffic communication, did not realize that a serious damage of flying surface had already occurred. The pilot simply kept flying the aircraft, compensating the failure degraded flying qualities with normal control techniques. Only after having perceived the situation, the pilot started working to solve the case.

For the purpose of this study, the cognitive methods are connected to goals and attentive capacity available for the solution and decision, naturally being promoted by optimal arousal. The degrees of cognitive processing, when coping with the threat, have been classified, based on situation promoted stress level (TABLE 6). Some elements that have considered to covariate with cognitive management are the stress level, level of automaticity in action control, perceived effect of control and expectancy. Some more personality and emotional state related properties have been left out from the consideration of cognitive processing, due to very little of contextual data of the type. However these properties as motivation, determination and mental focus will be analyzed separately.

TABLE 6 Stress and cognitive processing

Stress	Cognitive processing	Action control [1)]	Control effect	Expectancy
very high	forced control by intuition	automatic	poor	poor
high	forced control by skill / knowledge	automatic	moderate	marginal
moderate	autonomous processing	automatic/willed	fair	non-optimal
moderate	situational processing	willed	fair	non-optimal
fair	systematic processing	willed	good	irrelevant
nominal	team processing	willed	good	irrelevant

1) By Norman & Shallice (1980).

Term 'forced flow control' (referring to flow of events) is chosen to describe those cases where a person has been provided with a minimalistic amount of freedom of dealing with threat. Typically such cases have been major mechanical failures (e.g. engine or flight control system failure), reducing dramatically energy management or controllability.

Considered as most cognitively consuming, are cases where the main goal has simply been avoidance of catastrophe. It is assumed that very high mental load has resulted due to weak control, poor expectancy and high stress. In such cases the tool of minimizing the consequences has supposedly been *forced* (flow of events) *control by* sheer *intuition*. The term intuition refers to lack of corresponding mental models which is compensated by performing, based on schema with highest activation. A situation of such type could be; an engine failure at low airspeed *and* altitude combined with little or no possibility to choose the landing site, why experiencing very little control over the events.

On the next category of cognitive performing a less stressful event has allowed the subject to apply a known rule or principal. These are cases where the main goal has been minimizing an obvious outcome. High mental load has prevailed due to reduced control, moderate expectancy and high stress. There would have been a *forced* (flow of events) *control* but this time assisted *by* beneficially perceived *skill* or *knowledge*. An example of such occurrence might be; an engine failure at low airspeed *or* altitude, providing visual reference for positioning the aircraft on more optimal attitude or location with the benefit of having (perhaps marginal but) positive control. There is no distinct border line between the first two forced patterns as experience and conditions play a role in the perception of control and expectancy

An autonomous pattern has been recognized in cases where a proper interpretation of trigger signal has been combined with an implicit functional schema. A clear signal has been combined to a rule serving a specific short-term goal. Considerable mental load has likely existed, either for the signal suddenness or the action follow-on requirements. When an *autonomous processing* has taken place, it is expected that the situation awareness has also become disrupted, needing to be reestablished. Such situation would take place when; a crew receives an unexpected TCAS (Traffic Collision Avoidance System), calling for (mandatory) evasive maneuver indicated by Resolution Advisory (RA) which results to avoiding a potential collision but disturbing the planned flight path and revealing a problem.

Higher level of cognitive processing has been used in cases where an unsafe drift must have been undone. Based on the understanding of the difference between prevailing and expected situation, a new goal has been activated. Mental load solving the mismatch between two patterns has expectedly been considerable as the solution must have provided an improvement with high reliability. A consciously controlled *situational processing* has been performed in order to resume a state of events within the 'nominal' limits. An example of situation processing is; an air traffic controller who locates an aircraft at night commencing a takeoff on taxiway instead of runway, requiring firstly a self-confirmation and secondly a decision based on the best projected outcome before the action (giving an order to stop) takes place.

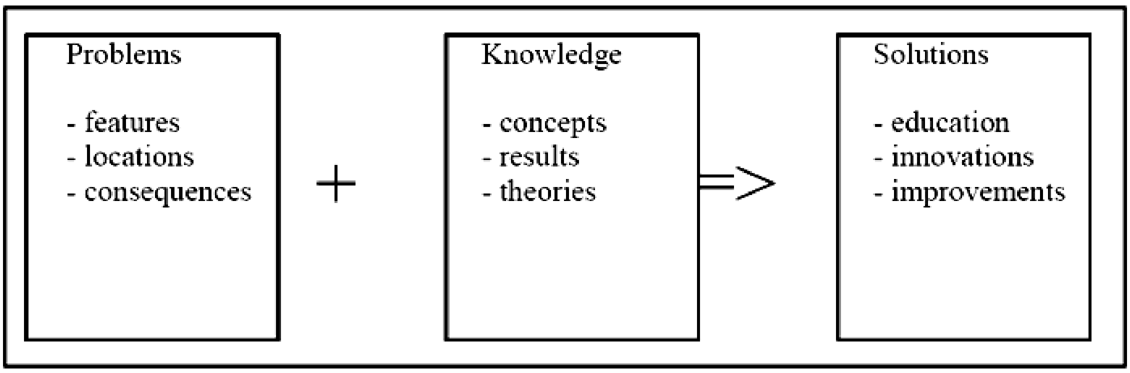
The less stressful the situation, the more the subject has been expected to become involved in a problem solving process. Assumably such cases that have allowed use of general capacity for naturalistic decision making (see 2.4.6) may be considered moderately stressing, at the most. A close to optimal arousal has enabled a consciously controlled *systematic* and case-unique *processing*, including analysis and evaluation of various solutions before the action, the solution is attended to and the threat or expectancy is just peripheral. For example; an inexperienced pilot, having trouble with the engine losing its power, turns back towards 'home' and flies along a road both for navigation and emergency landing, tries every imaginable engine recovery procedure, yet finally ends up landing on the road, damaging the aircraft but saving the day.

Thanks to the aviation professionals (pilots, air traffic controllers and ground personnel) forming teams via communication, this important stress-relieving networking has been available for some complex decisions. This kind of *team processing* has provided a framework for a high level systematic processing with parallel threads controlled by number of individuals in real-time. Such case for example is; a crew solving together a “nose landing gear fails to extend” issue, whilst technicians on ground check for system details, air traffic control (ATC) clears the airspace and coordinates the runway foaming, finally leading to successful (and secured) landing - though only the main landing gears extended.

3.3 Data analysis principles

The main goal has been, via empirical analysis, to recognize cognitive strategies that have provided the human barrier necessary for recovery. For this goal the most important information to be found has been the cognition's role in human involvement. When comparing this information with the expected level of performance, contiguous to Newell’s (1973) *processing limits*, an opportunity has unfolded to locate logical flows or strategies adopted in different types of cases.

Saariluoma (2005) calls for explanatory design. This, in his opinion, doesn’t eliminate creativity; on the contrary it supports creativity by making it an integral property of the explanatory frameworks generalized in FIGURE 8. He posits three approaches - *capacity*, *emotions* and *apperception* - each of them providing grounds for different types of knowledge-based solutions.



(from Saariluoma, 2005)

FIGURE 8 Explanatory framework schematics

Typical survival strategies and the systemic location of the human barriers are being analyzed from the utility perspective; firstly having considered against the theoretical background in order to determine explanatory logic, and finally the pragmatic inputs are evaluated. Any input that can provide *solutions* has been regarded valuable as an integral part of systemic analysis.

Due to the inhomogeneity of the source data it has been challenging to form distinct groups of *typical* cases. However, the number of the cases has been satisfactory; sufficient to bring out interesting phenomena and solutions. Some individual cases also provide with more details, thus assisting to locate missing pieces of puzzle needed to support general analysis.

The incident investigations mostly serve as sources for capacity- and data-based approaches but seldom for emotion-based activity. Thereby conclusions of emotional elements, having rarely been reasoned in technically oriented investigations, are difficult to substantiate. The easily discernible human-technology interaction tends to prevail over the emotional issues.

3.4 Data management and resolution

The data extracted from the reports has been filtered using the principals described earlier and the applied classifications have enabled the usage statistical tool. Number of classes in various independent and dependent variables is such that both cross-tabular and regression analysis have been possible. The IBM SPSS Statistics Version 24 (Release 24.0.0.2) has been utilized throughout this report both for statistical analyses, production of corresponding tabular data and base level graphical imagery.

All 106 cases have been classified and grouped. For containment of the analysis the piloting issues have received most of the attention in some investigative dimensions (e.g. workload). Adequate data from the pilot(s) involved has been available in 85 cases. In order to produce manageable data tables for correspondence testing, such resolutions have been pursued that would provide possible patterns but not too small cell counts. The lowest resolution data are involved with the general outcome, the severity, the barrier effectiveness (or performance) and the error detection, all having three (3) classes. For the rest of the variables, five to six (5-6) classes or numeric scale (flight hours) are used. Any finer grading would be difficult to support due number of cases and contextual nature of data provided. The following chapter concentrates to obtained data and its analysis.

4 RESULTS - CHALLENGED BY THREATS

A total of 211 reports have been evaluated against the scope of research, and 106 cases were considered consistent with the selection criteria. These cases, undergone through categorization and classification, involve real people having been challenged by the conditions of varying levels of threats and stress. A mentioning of term 'threat' is needed due to its use both as a construct of risk management tool (e.g. bowtie) but also as a general concept. Threat, when used conceptually, needs to be kept separate from the analysis tools' definitions. A threat is interpreted as an abstract (in situations where preventive barriers have been ineffective) indicative to an imminent loss of safety. When the loss of safety is apperceived in increased level of stress is expected.

Even though the selection criteria exclude all the cases with direct human suffering, some of the occurrences studied, presumably, have resulted to negative aftermath. The cases having this peculiarity would especially be the ones where straight path between a human error and a consequence is recognizable. In the commercial aviation, all deviations may look bad through the shareholders' lenses. As flawlessness is expected simultaneously an extra stress factor is introduced in the system.

There also is the pragmatic issue of total air traffic flow. Any perturbation will have more effect in airspace where tolerances are small, culminating naturally in the narrows of flow at terminal phases of flight near airfields. The air traffic control (ATC) task load correlates highly with an increased number or activity-demanding traffic (Endsley & Rodgers, 1997; Manning et al., 2002). Small deviations tend to escalate as individual developments remain unnoticed in vast amount of continuously changing information. This tendency has been perceivable in the occurrences both in the air and on the ground.

Considering the people, there are some that have avoided a loss of life just by a meter or second, and some that have had the luxury of a clear safety margin. Some individuals have been struggling a few extremely long seconds and some have 'chewed over' the situation for tens of minutes. But all of them have come out still capable of giving their input for aviation. This chapter will discuss some of the interesting findings, based on indicated facts, circumstantial inference, quantitative and qualitative analysis.

4.1 Basic data distribution

The source data has been grouped based on several variables as described in paragraph 3.2. Some generalizations have been made in order to achieve an organized data structure, after having analyzed the applicability and possible limitations in using generalized expressions. The data analysis begins from the general properties of the sample data, containing the base level identification of groups and frequencies, presented in the following sub-paragraphs. The first goal was to find an independent variable that could be used to express a general level of complexity, requirements and expertise as such. The *aircraft class* was considered a potential key, being well accessible in the source data.

4.1.1 Aircraft class indicating experience and form of aviation

In 85 of the 106 cases there has been usable information of the pilot or crew flight hours (FH). When the pilot or cockpit crew (average) flight hours are plotted against the aircraft class a clear correlation is perceived as shown on FIGURE 9 (a power scale is used on Y-axis for improved low hour resolution). The aircraft classes are placed at a simple first order ordinal scale (Recreational A/C = 1, SE Aeroplane = 2, etc), based on the flight hour distribution at each class. It is well understood that the aircraft classes cannot be arranged to generic order per se; a dependant is needed. This time the flight hours has been used, leading to quite distinct classification and enabling more collective data management.

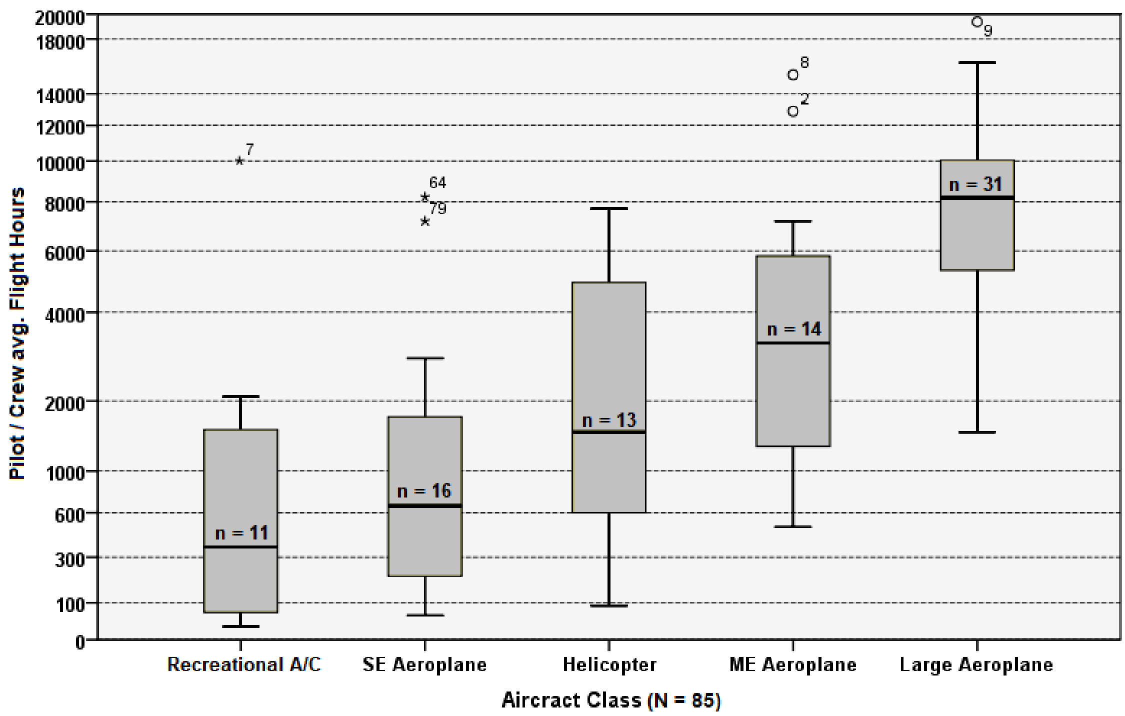


FIGURE 9 Crew flight hours vs. aircraft classes

A multiple regression analysis was we used to test if the aircraft classes would reliably correlate with the flight experience, presented as flight hours (FH). An exponential model [$y \approx 146{,}6 \cdot e^{(0{,}757x)}$] provided the best fit. The results indicated that the aircraft class explained 45.6% of the FH variance ($R^2 = .462$, $F(1,83) = 71.36$, $p < .001$). It was found that the used aircraft classification significantly correlated with pilots' flight hours ($\beta = .680$, $p < .001$). Aircraft classes can be used work generic indicators of pilot experience level in this source data sample.

The other check of applicability concerns how well the aircraft class represents the more detailed (and more multifaceted) aviation classification (explained in 3.2.2). Nominally each aircraft class would possess properties that especially adjusted to certain form of aviation. However, as shown in below (TABLE 7), with five (5) aircraft classes and six (6) aviation classes a total match may not be fulfilled.

TABLE 7 Aviation classes vs. aircraft classes

Aviation Class	**Recreational A/C**	**SE Aeroplane**	**Helicopter**	**ME Aeroplane**	**Large Aeroplane**	**Total**
Recreational A/C PLF (Ultra / Sail)	11	0	0	0	0	11
Plane & Helo Pleasure Flying	0	8	2	1	0	11
Fixed Wing AW & FI	0	6	0	9	1	16
Helicopter AW & FI	0	0	13	0	0	13
Light Comm. Air Transport	0	2	0	7	0	9
Commercial Air Transport	0	0	0	1	45	46
Total	11	16	15	18	46	106

A cross-tabulation analysis was used to test the correspondence of *aircraft* classes with the *aviation* classes, and the relation between these variables was found significant, χ^2 (20) = 315,0, $p < .001$. Aircraft classes thus reflect the aviation classification. Three *aviation classes* each are almost exclusively covered a 'corresponding' *aircraft class* - recreational A/C, helicopter and large aeroplane (indicated by the underlined values in TABLE 7). The SE and ME aeroplanes are used more widely across pleasure flying, aerial work, flight instruction and light commercial air transport purposes. Multi-engine operation, requiring a more advanced training, is mostly connected to the commercial pilot licence (CPL); in 17 of the ME cases the crew has had the CPL. The SE aeroplanes have been used in various forms of aviation (including 9 PPL and 7 CPL crews), however 14 of the SE cases have been operated under visual flight rules, reflecting a lower level of general complexity. As a summary, the aircraft classes can well be used to describe a combination of the aviation demand and level of expertise required.

Finally a linear model was checked using both the crew flight hours [FH] and aviation class [AvC] as independents for the aircraft class [AcC]. Purpose of the model was to verify the usefulness of aircraft classification as a universal indicator. The result provided a model [$AcC = -1{,}367 + 0{,}005 \cdot FH + 2{,}258 \cdot AvC$], explaining 76,9% of the *aircraft class* variance ($R^2 = .774$, $F(2,82) = 140.6$, $p < .001$). It was found that the even a simplistic linear model significantly predicts aircraft class when using both pilots' flight hours ($\beta = .141$, $p < .028$) and aviation class ($\beta = .794$, $p < .001$).

Based on the analysis as whole, use of *aircraft class* is seen as a good indicator of pilot experience and related requirements is those aviation classes included in this study. As noted the SE and ME aeroplane classes do represent reflect more about the level of required expertise that a specific aviation class. The aircrafts classification is therefore used as a generalizing indicator (applicable this sample), providing a path through the piloting and operating requirements knowledge to level of cognitive challenges encountered.

4.1.2 Outcome of the cases

ICAO (AAI) Aircraft Accident Investigation (2016) criteria have been used for incident classification. Some of the investigation reports do not mention the classification, and some of them (especially the earlier cases) might use different criteria. Therefore a harmonization has been made, using the ICAO (2016) AAI Attachment C case examples. Approximately one third of the cases (n = 34 / 32%) are classifiable as accidents, half (n = 54 / 51%) as serious incidents, and the remaining cases (n = 18 / 17%) as incidents. The accidents have accumulated to lighter aviation as 29 (85%) of the 34 accidents have taken place at *recreational A/C*, *SE aeroplanes* or *helicopters*. Thanks to cases' selection criteria, degree of human injuries could be disregarded from the differentiation criteria and 'only' mechanical damage or degree of threat has been examined.

A severity classification of the incidents was made on ICAO (2013) Safety Management Manual (SMM) basis. 29 cases (27%) are considered *hazardous*, 58 cases (55%) *major* and in 19 cases (18%) minor; no *catastrophic* nor *negligible* cases are included. A clear but not very surprising correlation between the incident classification and severity exists; inherently accidents are connected to more severe consequences than incidents. To confirm this impression a cross-tabulation analysis was made to test how well the incident *classification* would correspond with the *severity*. The relation between these variables was found to be significant, $\chi^2\,(8) = 43{,}10$, $p < .001$. Thereby the perceived correspondence between the two outcome scales (incident class and severity) is confirmed. Broadly speaking, outcome classification of the cases is considered quite unambiguous, especially if compared to cognitive states of the people involved.

Possible correlation between the severity and aircraft classes was anticipated being enlightening, knowing that the aircraft classes present well the pilot or crew experience. The correspondence was tabulated for comparison (TABLE 8) with the actual and expected counts (in parenthesis) of the cases.

TABLE 8 Incident severity vs. aircraft classes

Severity	**Recreational A/C**	**SE Aeroplane**	**Helicopter**	**ME Aeroplane**	**Large Aeroplane**	**Total**
Hazardous	7 (3)	7 (4)	10 (4)	5 (5)	0 (13)	29
Major	4 (6)	7 (9)	2 (8)	12 (10)	33 (25)	58
Minor	0 (2)	2 (3)	3 (3)	1 (3)	13 (8)	19
Total	11	16	15	18	46	106

In order to verify the magnitude of correlation, a cross-tabulation analysis was made to test incident *severity* against *aircraft class*, and the relation was found to be significant, χ^2 (8) = 43,10, $p < .001$. Thereby the correspondence can be confirmed. The interesting cells in TABLE 8 are underlined; emphasizing that light end of aviation has undergone the most severe incidents whereas no hazardous occurrences exist in large aeroplanes (analogous to commercial air transport). This emphasizes the benefit of mental capabilities to low experience (private) pilots and helicopter pilots as the cases are challenging from the start.

4.1.3 Presence of error

Before looking closer at the human barrier it is beneficial discuss how various types of errors have been presented in the incidents. Once again it is reminded that both the errors and their consequences are at the perimeter of this research. What is interesting is to see if the various error types correlate to type of aircraft concerned in incidents, especially if the degree of planning or intentionality (described in 3.2.3) would show up differently. All the cases have been presented in TABLE 9. It should be noted that the *error types* include all analyzable errors, meaning that the *mistakes* include all definable human sources; pilots, air traffic controllers, mechanics or latent agents. Thus this is not a just a presentation of the pilot errors.

TABLE 9 Aircraft class vs. error type

Error Type	**Recreational A/C**	**SE Aeroplane**	**Helicopter**	**ME Aeroplane**	**Large Aeroplane**	**Total**
Slip	2	4	0	3	13	22
Lapse	0	3	1	3	8	15
Mistake	7	5	8	8	15	43
Violation	0	0	1	2	4	7
Systemic	2	4	5	2	6	19
Total	11	16	15	18	46	106

There is a concentration of occurrences on the large aeroplane (n = 46) covering 43 % of all cases, whereas the proportions on other aircraft classes vary between 10 and 17 %. This concentration in the commercial air transport, most probably has its origins in conditions; firstly, on the well established incident reporting culture in commercial aviation and secondly, on the simple fact of higher numbers of commercial operations in general.

A cross-tabulation analysis was performed to test if certain *error types* would be more predominant in some *aircraft* classes. The relation between these variables was not significant, χ^2 (16) = 16,19, $p < .397$. Therefore systematic, aeroplane class driven, error type pattern is not supported by the data included.

Deeper analysis of the errors falls outside of the scope of this research. Yet for general interest, a more thorough look at the error *origins* was made after it was noticed that mechanical issues show regularly at lighter end of aircraft. There were 13 cases in 'recreational A/C & SE aeroplane & helicopter' sub-group due to *maintenance* or *support* issues, explaining 31% of the 'light' aircraft occurrences. Technical reasons were actually three times more common than in the 'mid-to-heavy' sub-group of 'ME & large aeroplane' where only 11% of cases had a technical origin. A second issue was located in the recreational A/C class where the proportion of *pilot* errors was twice as high as in 'SE aeroplane & helicopter' sub-group, and three times higher than in 'ME & large aeroplane' sub-group. The other side of coin is that the pilots in recreational A/C class also had statistically the lowest flight hours (as discussed earlier). Thereby it is supported that the experience reduces error frequency, as expected by theory.

4.1.4 Systemic barrier origin

The determination of barrier (activity) is a logical follow-up after the error mechanism is understood. There is a clear difference in dispersion of *systemic* origin of recovery barrier, when comparing the aircraft classes with each other. FIGURE 10 represents the five aircraft classes on the X-axis, each partitioned according to most prominent barrier origin. The Y-axis is scaled proportionally and the absolute counts of each barrier cases are shown individually.

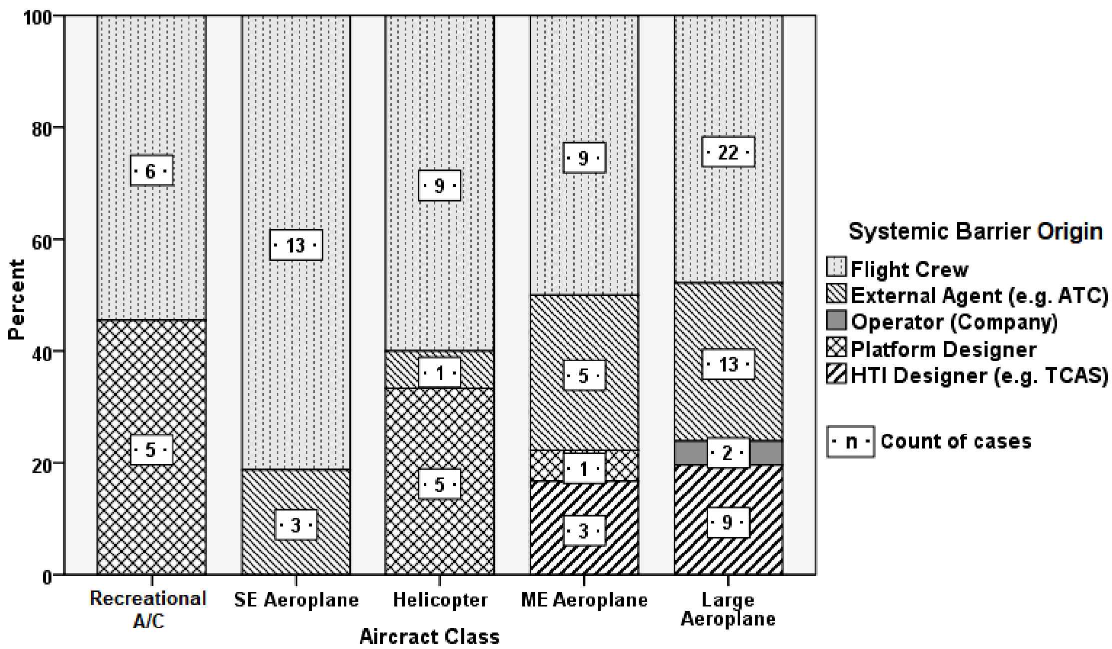


FIGURE 10 All incidents according to aircraft class involved

The activity of *flight crew* (either individual pilot or crew) has been a salient barrier in each aircraft class (56 % of all cases), making the flight crew most significant single barrier origin. An operator as a barrier shows only minimally but the other barrier origins appear frequently, nevertheless being unevenly divided. To estimate the degree of dependency between the *aircraft class* and the outcome control by various *barrier origins* a cross-tabulation analysis was made The relation between the variables was found to be significant, χ^2 (16) = 46,05, $p < .001$, indicating that the barrier origins at various aircraft classes really are unevenly distributed.

ME (Multi-Engine) aeroplanes and large aeroplanes, both regularly operated in commercial aviation environment, show higher presence of HTI (Human-Technology Interface) designers and external agents (most often the air traffic controllers) as systemic barrier origins. The TCAS (Traffic alert and Collision Avoidance System) was identified in 9 out of 12 cases as the primary source for separation control between aircraft. Also other effective HTI designer provided barriers appeared; such as low speed and low altitude warning devices. The TCAS (further discussed later) is a widely spread implementation of ACAS (Airborne Collision Avoidance System) concept, and it has been enforced by ICAO (2010) in large aeroplanes.

At the light end, both recreational A/C (sailplanes and ultralight) and helicopters have often benefitted from the platform designers' input. On individual cases' base, the platform structural integrity has indeed been an important feature, minimizing consequences when a ground collision is imminent. Analogous to all latent protections the conditions need to be optimal, even for the structural design to be effective. Additionally, another issue is apparent in the light aircraft; a total absence of cases where the HTI designers' solution would have been a recovery barrier. Some caution is needed before conclusions are made. There is now straight answer to a question if such HTI controlled cases in the pleasure aviation are reported in the first place.

4.1.5 Barrier effectiveness

At the next stage, the cases are classified giving each an effectiveness estimate that would reflect the barrier strength. Due to circumstantial nature of data, no attempt to fine-grained analysis is made. The effectiveness class has been acquired by a linear reduction from potential case severity (varying from E = negligible to A = catastrophic) to actual severity rating (varying from D = minor to B = hazardous).

It is reminded that none of the cases have actually been rated *catastrophic* even if the aircraft has been destroyed. The level of destruction has been mostly contained to a single aircraft at the light end of the aircraft spectrum. There are no such cases in the source data where the damages would have reached societal proportions. This chosen policy somewhat disagrees with ICAO SMM (2013) list item "Equipment destroyed" as a description for "A" risk level. Reasoning behind this exclusion is the fact that severe injuries have been avoided even in the accident cases as explained in the scoping (1.5). This positive human element has outweighed aircraft destruction. The aircraft by its reformation has actually presented as a *latent* barrier originated from the *platform designer(s)*. Furthermore, if a case resulting to 'only' material destruction, whilst having a potential for human losses (like the "Miracle of Hudson"), was rated catastrophic, how would a real catastrophe be rated?

Barrier effectiveness has been allowed integer values from 0 to 4 reflecting the difference between the actual and potential severity. For example a case that has a *minor* (D) severity rating instead of the potentially *hazardous* (B), indicates barrier effectiveness of +2 (two increments). A natural question is if barrier *origin* or crew *experience* would correlate as such with the *effectiveness*. Therefore cross-tabulation analyses were performed separately for both independents. First, a cross-tabulation analysis was used to test if the *systemic barrier origin* would correspond with the *barrier effectiveness*. The relation between these variables was not statistically significant, χ^2 (12) = 13,84, p = .310. A second cross-tabulation analysis was used to test *flight hours* (of crew acting as barrier, n = 72) would correspond with the *barrier effectiveness*. The relation between these variables was not statistically significant either, χ^2 (186) = 188,6, p = .432. Thereby neither systemic barrier origin nor flight hours explains the barrier effectiveness as such. The second result is more interesting, as it indicates that the pilot experience doesn't automatically mean a higher effectiveness in mitigating the outcome.

4.1.6 Time constraint

Given a generous amount of time, many of the incidents might have resulted to less serious consequences. Time is perceived as a critical determinant for in-depth situation analysis and decision making. The time frame of cognitive activity has been possible to acquire, using either time data provided in report or resorting to case description. For example, if a light power line harvesting helicopter loses all engine power at height of 100 ft, within the following 15 seconds the aircraft most probably will be stationary on ground. In this example as an unavoidable result of main rotor low inertia, that pilot should immediately assume an autorotation for forced landing.

Time constraint accounts for *temporal demand* which is naturally higher when lesser time is available for decision making and recovery process. The cases are grouped in classes according to time constraint, indicating how much time has been allotted for a human solution from the moment of trigger perception. There is a varying degree of ambiguity in the source data why the determined time constraints for individual cases are rather at the less limiting end of the possible time line. In real time-compressed situations even three seconds might be too long. The applied *cognitive time frame* classes and the number of cases in each class are as listed below.

- < 5 sec / 11 cases
- 5 - 14 sec / 39 cases
- 15 - 29 sec / 29 cases
- 30 - 59 sec / 6 cases
- 60 - 119 sec / 2 cases
- 120 - 299 sec /12 cases
- 300 - 1199 sec / 6 cases
- > 1200 sec / 1 case

Those cases with very short time (< 5 seconds) for cognitive compliance cannot be put in a single category, except of course for the rush effect. There are cases of collision avoidance, last second refused landings and low altitude emergencies. In 4 of these time-compressed cases pilots have acted as barriers (none of them having less than 700 hours of flight time). On the other hand, the barrier origin has been systemic in 5 cases; either *platform* or *HTI designer(s)*.

The following two time frames (covering a window from 5 to 29 seconds) include the majority of all occurrences; 68 cases (64%). Most of the real-time human barrier activity has taken place here, pilots showing as barriers in 34 cases and air traffic controllers in 16 cases.

Intuitively, the time allotted to manage a novel situation seems like a major determinant. The cognitive time frame was therefore tested for correlation with the previously discussed factors: aircraft class (4.1.1), case severity (4.1.2), barrier systemic origin (4.1.4) and barrier *effectiveness* (4.1.5). First cross-tabulation analysis tested if the *cognitive time frame* would correspond with the *aircraft class*. The relation between these variables was not statistically significant, χ^2 (28) = 32,52, p = .254. Second cross-tabulation analysis tested if the *cognitive time frame* would correspond with the *case severity*. The relation between these variables was not statistically significant, χ^2 (14) = 21,43, p = .091. Third cross-tabulation analysis tested if the *cognitive time frame* would correspond with the *barrier origin*. The relation between these variables was found statistically significant, χ^2 (28) = 84,27, $p < .001$. Fourth cross-tabulation analysis tested if the *cognitive time frame* would correspond with the *barrier effectiveness*. The relation between these variables was not found statistically significant, χ^2 (21) = 26,15, p = .201.

Even though a statistically significant association was located between the time frame and barrier origin it is mostly explained by the classification structure and distribution of the latent barriers (platform and HTI) across the time lines below 30 seconds. Therefore the finding has no meaningful explanatory value. Nevertheless, time is an indirect factor, accountable to learning (Ackerman, 1988), for example. In case of total unpreparedness for solution-demanding situation the processing capacity would be the main tool available. The more elaborate the solution the more time it can be expected to take. As time was not discovered a clearly explanatory correlate to success, other determinants, especially of human origins, will be looked at next.

4.2 Contextual human barriers

The flight crew (individual pilots and crews) as well as external agents (air traffic controllers and support personnel) form the core when considering the real time active barrier performance. Factors like activating of triggering conditions and cognitive management of the threat are evaluated for possible patterns and utility. Contextual information of the cases has mostly been used to extract the flow of events (conditions and activity) and the corresponding mental demand (e.g. level of stress and cognitive mechanisms).

The investigation reports have been compiled into structures that obviously have supported the particular case at hand. Possible use for other analytic purposes has not supposedly been used as a factor. Investigators are professionals in their field of expertise which has probably guided the scoping of contents around the case essentials. For the purpose of this research an optimal baseline would have been an incident investigation reporting template with consistent human factors (HF) analysis. Some 15% of chosen reports include in-depth HF analysis where the majority of reports discuss about the 'activity' of the people involved. Nonetheless, even the activity when well described provides a reasonably solid foundation for deductions.

4.2.1 Staying alert

The data almost invariably contains occurrences where some person or persons have realized that the flow of events has deviated from the original expectations. This moment has acted as divider which after a new goal must have been set. As discussed earlier the trigger detection media has been grouped according to actualized mechanism (3.2.6). There was an appreciable variation in distribution of the activation media at cases of different outcome severities. TABLE 10 lists both the actual and expected counts (in parenthesis) of the cases. Barrier activation media to case severity was investigated in order to find possible correlation between the *alertness* in general and the outcome as indicated by *case severity*.

TABLE 10 Barrier activation media vs. case severity

Severity	**Primary Signal**	**Secondary Signal**	**Internal Model**	**Prepa-ration**	**Communi-cation**	**Vigilance**	**Total**
Hazardous	23 (13)	3 (3)	0 (5)	1 (1)	2 (2)	0 (5)	29
Major	19 (25)	5 (6)	14 (9)	1 (2)	5 (5)	14 (11)	58
Minor	4 (8)	2 (2)	3 (3)	2 (1)	2 (2)	6 (4)	19
Total	46	10	17	4	9	20	106

A cross-tabulation analysis was made to test the degree of dependency between the *barrier activation media* and the *case severity*. The relation between the variables was found to be significant, χ^2 (10) = 30,52, p = .001. The case outcome thereby is reflecting the barrier activation media.

The most dominant of the six activation media was the *primary signal*, accounting for 46 of all cases (43%). Cells of interest are underlined at TABLE 10. A clearly visible pattern is the high number of hazardous cases preceded by primary signal. Some 23 (79%) of the 29 hazardous occurrences, are connected to primary signal as activator, indicating bottom-up (sudden) activation. On the other hand, those activation media connected with alertness - internal model, preparation and communication - show only in 1 case (3%) of the 29 hazardous occurrences.

Cases based on actual *preparation*, are generally rare, but disruption of *internal model* and *vigilance* (or sustained attention) as deviation discovery tool are common within the non-hazardous cases. This indicates a potential that voluntary top-down activation may provide the subject with readily available situational analysis for a more successful reasoning and decision making. Thus a strategy that supports early detection of potential threat (e.g. constantly maintained situation awareness) might lead to a higher degree of cognitive processing.

Sudden bottom-up activation seems to be connected to an incident with more severe consequences. However, the connection cannot be regarded as indicator of causation between the two; the activation media depends also the signal origin. In aviation a sudden and intense signal itself might be a consequence of something that inherently reduces the odds. A valid question is if the poor odds and their occurrence could be better prepared for?

4.2.2 Cognitive real-time strategies

A plausible relation of situational stress to cognitive processing opportunities has been used, when evaluating possible strategies for each case. The term 'opportunity' is chosen due to pronounced lack of directly reported HF data. Conditions between the cases vary, and generally they have been explained to a degree that allows a reasonable estimate of cognitive strategies' distribution across the data. High stress levels have been connected to lower expectancy of outcome, lower control of situation, lower levels of cognitive processing and lower level of will in action (discussed in 3.2.7).

As with the case of barrier activation, the real-time cognitive processing is estimated against the outcome *severity* as presented in FIGURE 11. A graphic presentation of two supposedly ordinal variables was considered more indicative as a table as it clearly visualizes a tendency between the variables. The graphic presentation does not express causality to one direction or another, simply a connection between two phenomena.

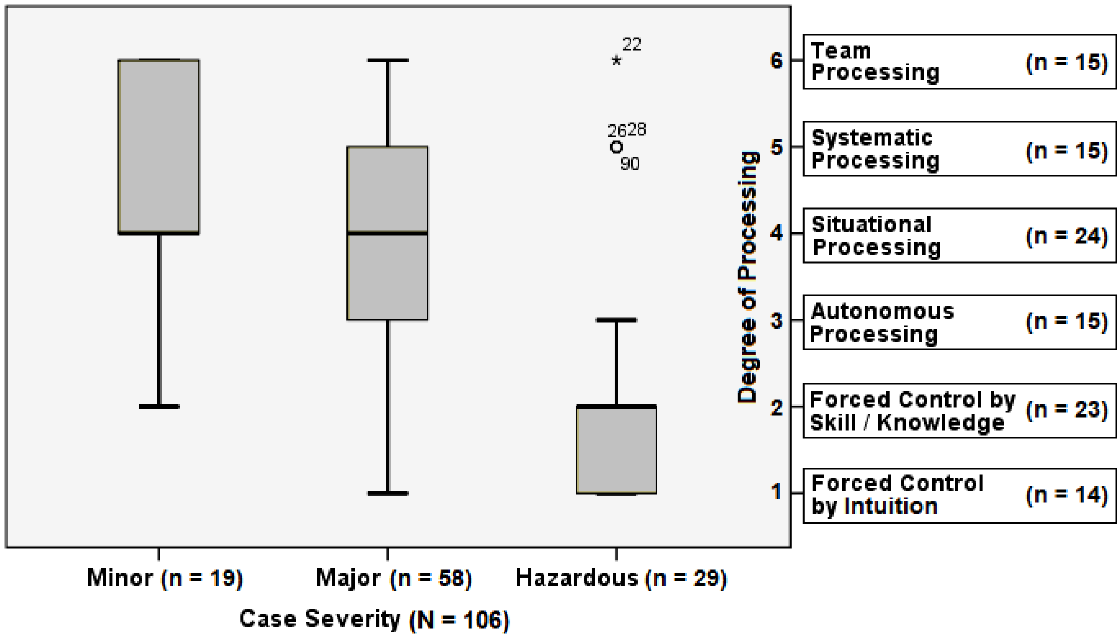


FIGURE 11 Degree of processing vs. case severity

There are certainly several components interacting with parallelism, yet some patterns can be outlined. The forced adaptation to threatening situations appreciably coincides with the more serious outcome, and the more detailed cognitive processing is linked to milder consequences. Sudden bottom-up activation seems to be present in those incidents that have resulted to more severe consequences. However, the connection cannot be regarded as an indicator of causation between the two; the activation media depends also the signal origin. In aviation a sudden and intense signal itself might be a consequence of something that inherently reduces the odds. Therefore it is not the signal but its origin that also needs some consideration. Question is if the poor odds and their occurrence could be better prepared for.

A cross-tabulation analysis was made to confirm the dependency between the degree of *processing* and the case outcome *severity*. The relation was found to be significant, χ^2 (10) = 42,93, $p < .001$. The case outcome thereby is correlating with the degree (or depth) of processing. As noted earlier the time as a constraint has at least an indirect means of affecting the barrier activity, one credible mechanism would be via stress level. There is the expectancy of the outcome which as a stress factor could either enhance or reduce the processing.

Another interesting correspondence was located between the degree of *processing* and *aircraft class*. As earlier discussed (4.1.4) the *platform designer* has been a welcome barrier especially for the light aviation (sailplanes, ultralights and helicopters) where the hazardous ground collisions have taken place. The heavier end (commercial aviation) have benefitted from the HTI designers' ingenuity in form of technology alerting systems (traffic proximity, low speed and low altitude warnings). Dependency between the degree of *processing* and the *aircraft classes* was analyzed, and was found to be significant, χ^2 (20) = 60,25, $p < .001$. The aircraft classes thereby correlate with the degree of processing.

To understand this correlation a coupling between two variables should be noted. The uneven distribution (see TABLE 8) of aircraft classes versus cases severity emphasizes the lighter end aviation as a subject of more challenging problems. As the severity also correlates with the degree of processing, the co-effect is logical. To study cognitive typologies at different aircraft classes a more detailed look of the most prominent severity class, namely the *major*, is taken.

4.2.3 Typologies in cognitive processing

The incidents in hazardous severity class involve mostly the light aircraft, and minor severity class is occupied by the large aeroplanes. Most of the aircraft classes are however well spread in the *major* severity class. In this study, with total of 58 cases (55% of all cases), it is the mode value (M_o) and provides a wide variety of events. When a major severity classification is used ICAO (2013) refers to significant reduction in *safety margins* and reduction to *cope with adverse operating conditions* (workload or conditions impairing efficiency). As the major severity class is investigated it means that the recovery barriers actually may have prevented hazardous or even catastrophic outcomes.

The box-plot visualization of the major cases is presented in FIGURE 12. Bar widths reflect the cases' frequencies in corresponding aircraft classes. There are only two helicopter cases in this severity class why only a small square in the middle column is displayed. The degrees of processing show numerically (1 to 6) for readability; the legends are available in the preceding sub-paragraph. Not all, but those from the total 58 major cases that offer standpoints to behavioral typologies, are discussed. The number of cases under scrutiny at each aircraft class is indicated in parentheses.

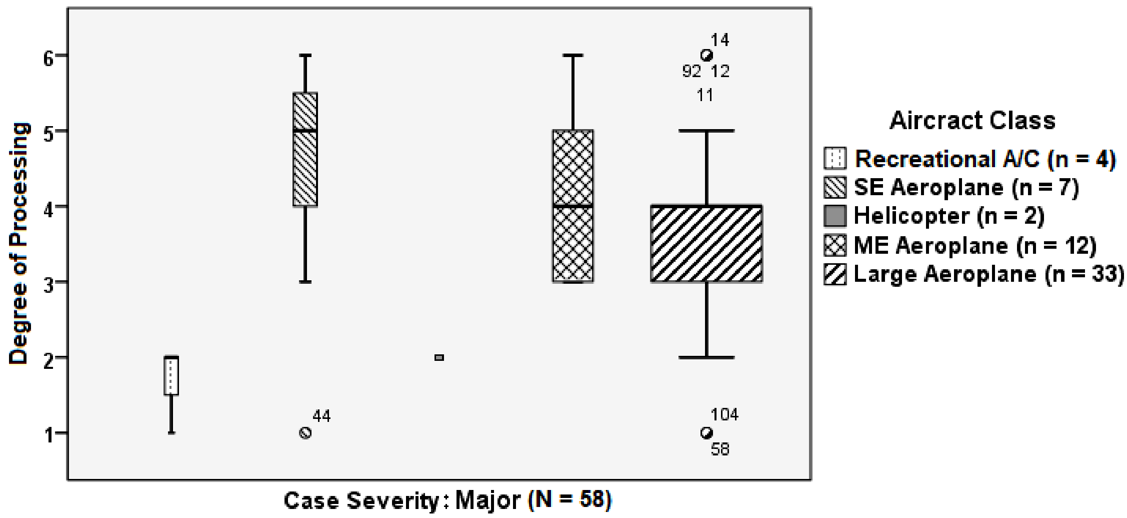


FIGURE 12 Processing vs. aircraft class in major occurrences

The *recreational A/C* class contains two (3) time-critical cases and one (1) control-critical case and pilots in all of these cases have encountered highly limiting conditions. Term 'time-critical' is self-explanatory but 'control-criticality' is used to describe that a continuum of imperative choices persists as long as ambiguity prevents reaching a solution. In three cases the data for successful recovery has been provided by an activated model, conditions allowing for *forced control by skill/knowledge*. In the fourth case, real-time threat avoidance has been made resorting to *forced control by intuition*, until matching an acceptable model. The pilot in this case has been under heavy stress for extended period of time, until having achieved the missing data for safe solution. Management of these incidents leads to prove of virtue in operating within the limits of personal skills and knowledge. Preferably skills and knowledge should contain a clear margin to operating requirements, which is a major training aspect.

In *SE aeroplane* class four (4) cases of total seven are associated with a severe malfunction, forcing to land. These are interesting from the decision making perspective; they can all be classified as 'choice-critical' due to goal reset. Options have been weighed against each other and solved by *systematic or team processing*. No supportive experience nominator exists between the cases, except that three (of the four) SE aircraft pilots were actually quite inexperienced (FH_{AVG} = 150 h). In their cases an estimate of recognition primed decision making (RPD) cannot be supported due to missing expertise, but still the events were successfully managed. The RPD assumes an option availability (Klein, 1993), which seemingly has been replaced by reasoning the evolving situation. The fourth, experienced pilot (FH > 2000 h) recognized the failure and applied a model for an RPD typical solution that proved to be successful. When the conditions allow for higher processing the opportunity is worth taking.

There were two (2) cases in *helicopters* classifiable as major occurrences (showing only as a small square in FIGURE 12). The cases are exceptions to mostly hazardous helicopter occurrences (in which the platform designers have been providers of the ultimate barrier). Both of the situations have been time-critical as well as control-critical; appreciably common constraints in low altitude operation or with low separation to any physical object in general. A commonality in both of these cases is a *forced control by skill* with a clear goal in outcome minimization. Even though most of the helicopter incidents have been more severe they share the presence of continuous situation management until the 'movement has stopped'. The ground proximity adaptation and operational experience outside the safe airfield environment are most obviously invaluable assets, when compared to aeroplane pilots who may lack models and expertise (training and practice) applicable to off-airfield crisis management.

When proceeding to *ME aeroplanes*, the multi-engine configuration has presented as an absence of time-critical malfunctions in the major severity class. Higher redundancy in form of doubled systems is presumably indicated by such three (3) technical failures that, from the point of decision making, have been choice-critical. Not being limited by excessive forcing constraints (time or control), a new goal has been set and reached with *systematic or team processing*. Environment wise the commercial aviation exposes the ME aeroplanes to more complex air traffic situation. In seven (7) of the total of twelve major cases the incidents involve air or ground traffic conflict, either handled by the crew (5 cases) or external agent (ATC in 2 cases). The threat (i.e. collision) avoidance in the ME aeroplane class emerges with several variations, yet all requiring a means of the "counterpart" key properties' identification. An *autonomous processing* solution has been supported in the cases with unambiguous trigger. Additionally systematic analysis has been resorted to, when solving cases of initial ambiguity. One of the most interesting cases involved a serious lateral control asymmetry, where the pilot was initially highly challenged (control-critical). Using second person assistance with controlling difficulties (dual flight controls) the pilot was able to engage higher processing and reason a way to land the faulty aircraft. If an action would be taken based on non-confirmed threat, the expectancy of its effectiveness would naturally be weakened. If conditions initially are unfavorable for resolution, as soon as constraints permit a higher level of cognitive processing should be applied.

In the class of *large aeroplanes* there are some typical elements like multi-pilot crew requirement, high level of automatization and integration into controlled flow of dense air traffic. 31 percent (n = 33) of all the cases are definable as large aeroplane major severity occurrences. In 14 of these the conditions have supported use of *situational processing*. Typically a drift from safe conditions has taken place, being captured by vigilance or threshold exceeding deviation from an internal (SA) model. The barrier origins have been either flight crew (n = 16), external agent (n = 10) or HTI designer (n = 7). Cases encountered by the pilots have been treated using the highest applicable level of processing; from the control-critical (intense) keeping of a strongly drifting aircraft on runway, to choice-critical cabin pressurization problem management with *team processing*. The most common potential outcome has been a collision; for instance to another aircraft or vehicle or ground. Collision avoidance (n = 18) effectiveness in the large aeroplanes has mostly been achieved by air traffic controller activity and HTI designer provided technology solutions (e.g. TCAS). The same cognitive drift from logic to intuitive processing has taken place both in the ME and large aeroplanes in cases of automated processing. The on-off type artificial signals have not provided much contribution after initial occurrence, therefore requiring expertise to apperceive the signals' meanings. When a self discovered deviation initiates the real-time human barrier processing, there seems to be a considerably smaller component of ambiguity than in such case where a warning system has triggered. This supports the benefit of maintaining constant SA including both the evolving air traffic flow and the systems' status. Especially the air traffic controllers have shown important benefit the attentive capacity in recognizing deviating patterns.

A naturalistic decision making that would fit well with higher cognitive processing doesn't appear much in the occurrences on the more advanced commercial aircraft. The possibility for team processing and advanced risk management culture proactively mitigates probability of totally novel situations. Whether the crew or air traffic controller, they mostly have standardized decisions even for deviations. The rarity of unseen conditions could therefore be regarded as a training challenge at the regulated commercial aviation.

4.2.4 Strengths of communication and team processing

It would make perfect sense perfect sense that an activity initiated by *communication* would automatically lead to team formation as a communicative entity. This, however, has not been a tendency; communication (in 9 cases total) has initiated various strategies. The communication has primarily served as (direct or indirect) alerting mechanism, informing about limit proximity or its exceedance. Even if the nature of communication has been quite elementary without continuity as team cognition it reveals strength of human communication when indicating deviations that have not been protected by technology. There are a few cases where plain communication monitoring has served as an indirect means for creating a mental representation of the environment, and revelation of a departure from the intended flow of events. This indicates that there is a built-in value in human conversation, providing meanings that are larger than the actual semantic contents of the phrases. The more actively people are attending to communication the more there is sensitivity to perceive deviations.

The team cognition (in 15 cases) has proved its power especially in multi-pilot aviation, having been intuitively used when managing with technical or pilot capability degradations. When looking at the general complexity of the cases (referring to number of steps or decisions required), those technical malfunctions (n = 7) that have been worked out as team are generally more complex than the other cases. They typically involve analyzing non-fixable system failures as a stuck landing gear. Certainly the better availability of team processing leads to use of it, especially if the situation complexity requires more processing. As earlier discussed, the team processing can be considered a way to control parallel threads of activity. In case of single person, reaching the capacity limitations would lead to slowing down which in a time-critical task results to reduced performance. Actually this slowing down would inherently enforce using team processing to compensate the slowing down of processing. In short, the complex commercial air traffic benefits from the processing power reserves harnessed by team activity; thus the driving mechanism is less important than the sensitivity to recognize possible slowing down of the processing and proactive commitment to invest more capacity into process.

An atypical decision making pattern that has been used by air traffic controllers in some cases of collision avoidance, deserves to be mentioned. This selective activity is connected both to communication and team processing. It is parallel to first level of recognition-primed (situation control) process, resulting to a decision *not to* interfere with a clearly erroneous flight crew activity. In such cases the controller has evaluated the potential outcome, should the aircraft crew flow control be disrupted, and chosen a secondary mitigation strategy. When an aircraft crew is either taking off or landing against expectations and a working vehicle occupies the runway, the vehicle driver is commanded to clear the runway and the aircrew (perceived as highly occupied) is excluded from the process. Such activity consists of selective communication and selective team processing that are made possible by 'god's eye view' (Ackermann, 1996), including the constructs of an outside perspective to the prevailing situation and an understanding of the mental contents of the people involved.

Neither the communication nor the team processing can be addressed an 'asymptote' for optimization. Nevertheless it is strongly supported that they are related by an element of *relieving the stress* and therefore unleashing working memory for the processing. To achieve this, a common goal is needed trough a descriptive communication which after team processing can be used effectively. The other aspect discovered can be interpreted as projected situation awareness (3rd level SA by Endsley, 1995), including the perceived *awareness of other peoples' situation*. In order to make necessary and time-critical decisions on behalf of the others the internal model must be fit for a coincidental case, calling for high level of expertise.

4.3 Latent human barriers

The two major latent human barriers have made their presence in two contextual functions, being either *protecting* or *indicating* (see Hollnagel, 1999a). As the approach is human-centered, both of these barrier functions are looked at the perspective of a latent human barrier activity. Depending almost exclusively whether an occurrence has taken place in light aviation or the commercial transportation, the barrier function has been different. 29 of the 34 cases that could be classified as accidents occurred at the light end of the aircraft spectrum (*recreational A/C, SE aeroplanes* and *helicopters*), and none at the *large aeroplanes'* class. In the more severe accidents the main barrier function has been a physical protection. Then again, the heavy end (*ME* and *large*) aircraft, have been protected by technology with a presence of various HTI solutions.

4.3.1 Platform designer protecting light aviation

As self-evident as it sounds the aircraft are vehicles operated by human beings thereby suspects to incidents where humans need protection. Whether the issue of physical protection has been raised due to technical failure or pilot action the physical barriers have been necessary against high decelerations and outside substances (hard objects and water immersion). 11 instances are considered such that the major barrier function has been achieved by structural (crash) protection. Additionally the structural integrity has been a part of minimizing the outcome severity in 9 cases. The light end aircraft have been typically connected to lower flight experience (4.1.1) and the lack of expertise naturally narrows down the selection of *recognizable* anomalies and therefore the applicable procedures. This is ultimately 'compensated' by crash structure.

The older airplanes and helicopters, being operated either for pleasure flying or for aerial work, have been suspect to technical problems. A perceived lack of maintenance reflects, again, tight economy. The effort versus safety is not a simple equation to solve. That has already been apparent in road traffic where, despite of the governments' incentives, people choose to drive their old vehicles. The fact that pilots often start their career or flying hobby on light aircraft cannot be much affected. Their training cannot be expedited over a certain limit either due to human learning capabilities. As human errors take place, intelligent thinking used to understand the inexperienced pilots' form of life is essential part of latent protection at every stage of the activity. The *platform designer* has a highly important role as a latent human barrier. Yet, the data doesn't provide an answer if the protection has been achieved by a systematic design or not, hopefully the answer is *yes*.

The cases that have resulted to accidents indicate three short-term goal settings when the pilots have been forced to control a flow unavoidably leading to crash situation. First aspect, quite natural as such, has been the pilots' avoidance of direct hit with large objects (big trees, rocks etc.). Secondly they have been working to minimize the impact by reducing the collision speed, and thirdly they have been working to maintain the aircraft (wings or rotor plane) at horizontal. Aircraft crash design and testing are not an unheard or recently emerged activities. For example NASA has made full-scale testing on composite airframes since 1980's, leading to well controlled programs, not only on high end products, but on some general purpose aircraft as well (Jackson et al., 2004). There is a central view of understanding the people needing the best protection, and how these people act when the physical protection becomes necessary.

4.3.2 HTI designer protecting professionals

The latest technology is blooming where the economy is more secured. Actually sufficient resources are a prerequisite for involvement in the commercial air transport (carried out by the *ME* and *large aeroplanes*). The balancing between human and technology performance has shown up in the 12 cases where an *HTI designer* has presented as a latent human barrier. The TCAS (Traffic alert and Collision Avoidance System) has been effective in most of these incidents but also a few activations of self protection alerts (ground proximity, attitude and low speed) have been signaling of deviation. Protective technologies have proven to be highly attentive, leading initially to a (desired) automation level processing. Yet, the trigger by itself has not been perceived informative enough in unexpected situations; there has been a tendency to seek confirmative data. Even if the signal meaning is well known the pilots have been looking for *reason* why such a protection function had activated (e.g. a low altitude warning). After a TCAS signal the crew has often searched for visual contact to the 'threat' aircraft. Once a mental correlation has been formed the evasive actions have seemingly been confirmed as successful.

The TCAS has been widely activated in commercial air traffic why a short visit to the system is provided. For example the Eurocontrol (2017) ACAS (Airborne Collision Avoidance System) guide describes the advanced logics utilized in three-dimensional environment, including the capability to also recognize ground traffic with an operating system. FIGURE 13 depicts a head-on case where two aircraft are on collision course. If no activity takes place until the TCAS threshold is reached both aircraft crews receive a command (Resolution Advisory or RA) to maneuver their aircraft. The system provides the pilot with an aural signal and traffic display already before an actual maneuver is required. When the flight path needs to be changed a specific aural callout is provided, and augmented with a detailed vertical speed command on an IVSI (Instantaneous Vertical Speed Indicator). (Eurocontrol, 2017)

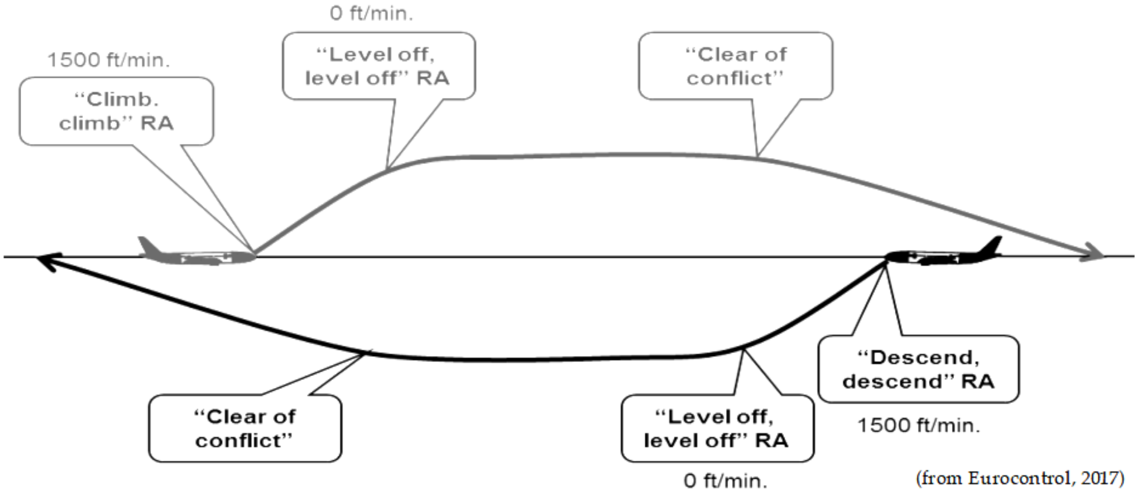


FIGURE 13 TCAS (RA) Resolution Advisory

Even though the TCAS evasive maneuver is strongly enforced by the authorities (e.g. ICAO, 2006) the Eurocontrol (2017) radar observation data from year 2014 indicated (only) 75% of pilot compliance to initial RA's vertical speed resolution value. Furthermore, it was found that 8% of the responses had been opposite indeed. All of this seems to leave an element of doubt that there still remains ambiguity if a system. For some reason the advanced algorithms and high safety impacts are not considered dominant enough. Two central elements need to be stressed - training and expertise.

On a general level, when a technology (auditory, visual or haptic) has stepped in, the crew has been activated by the provided signal strength. Warning system has triggered (as supposed) a cognitive processing but with some degree of uncertainty, perhaps reducing the effectiveness of the mitigating actions. This is paradoxical because warning systems, if anything, are *symbolic* barriers indicating an exceedance. Therefore very little doubt should remain about the origin of the exceedance. Obviously the warning systems don't innately symbolize how and why the present state has been wound up, letting the user to find out the cause. If indeed one feels committed to problem-solving instead of decision making valuable time may be lost. Human explicit and implicit communication is worth studying for the HTI.

Another area of interest is why the HTI-designers' ingenuity has not shown its full potential in the light aircraft classes, at least not amongst these selected incidents. The barrier technology solutions are mostly planned to activate before some dangerous conditions (perhaps leading to an incident investigation) are even reached. However, the cases that have resulted to accident in lighter aviation support an assumption that the economy also plays an important and safety reducing role. The level of technology solutions has been low, even in the newer designs. Logically this is quite odd as those who truly would benefit from extra protection don't have onboard something that could be called as virtual 'flight instructor'.

4.4 Workload experiment

With the flow of events comes the flow control activity which has to be present at all times until the threat has been dealt with. When the activity demand is in balance with the subject's capabilities the workload would logically allow for capability reserves. If there is a reserve cognitive capacity it can then be used for keeping up and ahead of the events at hand. This is why workload is considered highly interesting as a factor affecting the capability to handle the unexpected. The workload as concept will provide an estimate of total human commitment. As different workload values would make no sense as such, they need to be harmonized by using common scaling and weighing for certain task typologies. In this case the tasks contain human activity under, not only stressing, but threatening conditions. It is for the interest of the specific task type why a workload experiment is made.

There is no doubt that the most accurate input for workload analysis would be achieved from the direct source, meaning subjects themselves. Second best source would be documented data, consisting of the non-interpreted information provided by subjects. Contextual data with sufficient resolution, as the more comprehensive incident reports, also provides with the components needed. However, the case data used for this research sparsely discusses about the detailed workload issues or provides a quantitative value. Thus values of workload have been obtained from the contextual information.

A NASA (1986) TLX original scaling has weighting was initially chosen to serve as baseline. The elements used (see TABLE 11) in this experiment have been interpreted and estimated one by one for each case on contextual basis. The used TLX template is one of many possible solutions to estimate total workload, there is no absolute solution.

TABLE 11 NASA TLX example composition

Component	ID	Weight
Mental Demand	MD	5
Physical Demand	PD	3
Temporal Demand	TD	1
Performance	OP	2
Effort	EF	3
Frustration	FR	1
Overall Workload	OW	15

A major challenge has been the determination of the actual values for each component. Without having an opportunity to interview the subjects, the data is limited. However, the case descriptions have mostly been found useful for one approach also recommended by the FAA (2000) as a *Scenario Process Tool*. It encourages the user mentally creating a *flow of events* as they should be, and then involve a realization of things going wrong. In this experiment the second, non-optimal, flow of events is already provided by the incident reports. This allows various estimates to be made over the inputs, processing and outputs of the subject(s) in the real event. This property has been used to collect pieces for the workload puzzle.

4.4.1 Workload components

There are six components, which are weighted task type dependently (NASA, 1986), applying similar weighting profiles for similar types of tasks. All of the cases in this experiment had a common feature of coping with a threat with potentially tangible and serious consequences. TLX has been analyzed by NASA (1986) in target acquisition with varying degrees of time, control and decision demand, and has been found quite robust. Therefore no attempt has been made to form different groups; all real-time activity (in different aircraft classes) has been estimated using the same weights. Instead of using a percentage scale to rate the individual components from zero to one hundred (0…100), a rough integer scale of one to five (1 - 5) has been generally used due to contextual nature of the experiment. Only temporal demand is given half-values being the only one numerically definable component.

The component of highest interest is the *mental demand* (MD). Data of the investigation reports has been interpreted in order to locate the most obvious cognitive path or process utilized. This has been discussed earlier in context on the cognitive processing (4.2.2). Classifying the mental demand (MD) follows inversely the previously used processing classification; the *forced* mental activity is considered most demanding (rating 5) and the *willed* (low stress) team processing least demanding (rating 1). It may feel intuitive that long-lasting problem solving would be mentally more demanding than a quick collision avoidance process. However, if this threatening collision avoidance lasts as long as solving the challenge of jammed nose landing gear, the difference becomes clear. As earlier described, the stress level has been considered a representative cognitive determinant in threat environment. Time-criticality has not been used as an attribute of mental demand as it already is a separate workload component discussed later as *temporal demand*.

The *physical demand* (PD) has been estimated based on the subject activity. In case the barrier activity is achieved in static environment the physical demand is estimated low. Such activity would be for example not crossing the runway when another aircraft is landing (rating 1). The other end of physical demand is a result of for example flight control malfunction, forcing to simultaneous use of dual-controls (rating 5). Rest of the cases can naturally be placed between such endpoints, as long as the physical activity is definable. The size and aircraft type are important as well - at the light end of the aviation (including helicopters) the forces are generally small. There is expectedly an effect between at least two physical performance properties, namely force and precision which both are essential when controlling an aircraft. A choice was made to include the precision demand as part of the *effort*.

Temporal demand (TD) is the only numerically quantifiable task load component. The classification as earlier described in time constraint discussion (4.1.6), is used to represent time as se separate constraint in the task load. Cases demanding a rapid solution (less than 5 seconds) were given a highest rating (5) and the rating was brought down gradually as more time was available. Temporal demand, even though quite quantifiable as numbers, carries a rush element. This is somewhat similar to control-critical activity where a pilot would be denied rest periods due to continuously high demand. Time span doesn't therefore always coincide with the pace. In this experiment the pace factor is connected to stressfulness, therefore it is included in the *mental demand*.

The success, called *performance* (OP), is expected to reflect the level of satisfactory of managing the case at hand. No such inferences were discussed in the investigation reports, making this work load component as one of requiring indirect approach. Barrier effectiveness, however, has been discussed before as an improvement from the potential to actual outcome (see 4.1.5). This successfulness has been applied as an objective indicator of activity performance. If actual outcome has been at least three levels less severe than the potential (eg. actual = D/minor and potential = A/catastrophic) then a low workload value (1) has been used. The workload OP value then increases step by step if a barrier has provided with less improvement to the potential severity.

The *Effort* (EF) is an interesting construct, expected to combine both mental and physical level of work. This combination is analogous to a workload perceived by the person him or herself. Once again, very little of direct data concerning own perspective, has been available. Therefore an estimate of case complexity as a whole has been made. When multiple steps have been required in course of actions the complexity and thus the *effort* has been ranked high. For example, if an aircraft control is lost at night the conditions complicate the recovery as the pilot will be able to only resort to artificial attitude information. The procedure of stall recovery by itself includes a series of procedures, perhaps contained in an experienced pilot's well learned models. However, when complicated by lacking of external references, the recovery must be verified at all steps by using an artificial attitude (and adjusting the control inputs accordingly) until the aircraft is back on level flight again. The higher the effort may also be expected when technical problems reduce performance of a highly integrated system, hence requiring cross-checking the possible side effects to other systems.

Lastly, the *frustration level* (FR) component should (per TLX definition) consider concepts as security, irritation, stress and relaxation. For the reason of threat environment the stress level has been used as a marker of *mental demand*. Consequently, security (or certainty) has been regarded as main indicator of frustration in the experiment. In order to contextually estimate such dimension, a general level of unambiguity has been utilized, reflecting the situational prerequisites to manage the goal. The reports provide an impression of the ease in interpreting the flow of events. Once again, there should not be direct overlap with some other component like *temporal demand*. For example when a seaplane pilot lands on water and the aircraft rapidly falls over the nose, short duration is not convergent with low level of ambiguity. There might be great sense of ambiguity because the landing gear has been firstly checked being up, but then selected down as a part of automatic but misplaced 'dry land' landing schema. Thus the frustration level is kept apart from the temporal demand.

4.4.2 Workload and severity connected

Only the pilots' activity is presented as they form the largest homogenous group from the standpoint of barrier origin, although all cases were provided with a workload index. A table, containing 85 pilot cases with their estimated workload components, was formed and analyzed as a statistical procedure. First goal was to apply NASA (1986) schedule as such with the example weights. After these initial results a co-product was made in order to define how the used conventions and ratings would best describe general *outcome* of the sample cases. The outcome severity (minor, major or hazardous) was considered as a one of the most reliable and universally extractable data from all investigation reports, therefore providing a solid reference level.

The constructed three variants of workload, including the six 'original' TLX components were found indicative when compared to outcome severity. Actually any correspondence can be considered interesting as the case *severity* is a coarse ordinal representation with only five steps total (from 5 = negligible to 1 = catastrophic). For the purpose of analysis a logical approach was chosen, using integers 5 to 1 for the severity and decimal values from 1,0 to 5,0 to describe the workload. Comparing to the original TLX scale, index 1,0 equals to 0% and 5,0 equals to 100%.

A regression analyses was used as tool. Initially, it was tested if the TLX workload model (NASA, 1986) would reliably correlate with the outcome severity, and later if there would be more optimal weightings available. Only linear correlations were used due to *dependent* (case severity) coarseness, with only three possibilities occurring: 2 = hazardous, 3 = major or 4 = minor. This low resolution understandably reduces the examined models' fit. The corresponding 85 cases are visualized in FIGURE 14, representing the first examination with the original TLG weightings. There is quite an obvious support for testing various linear fit models.

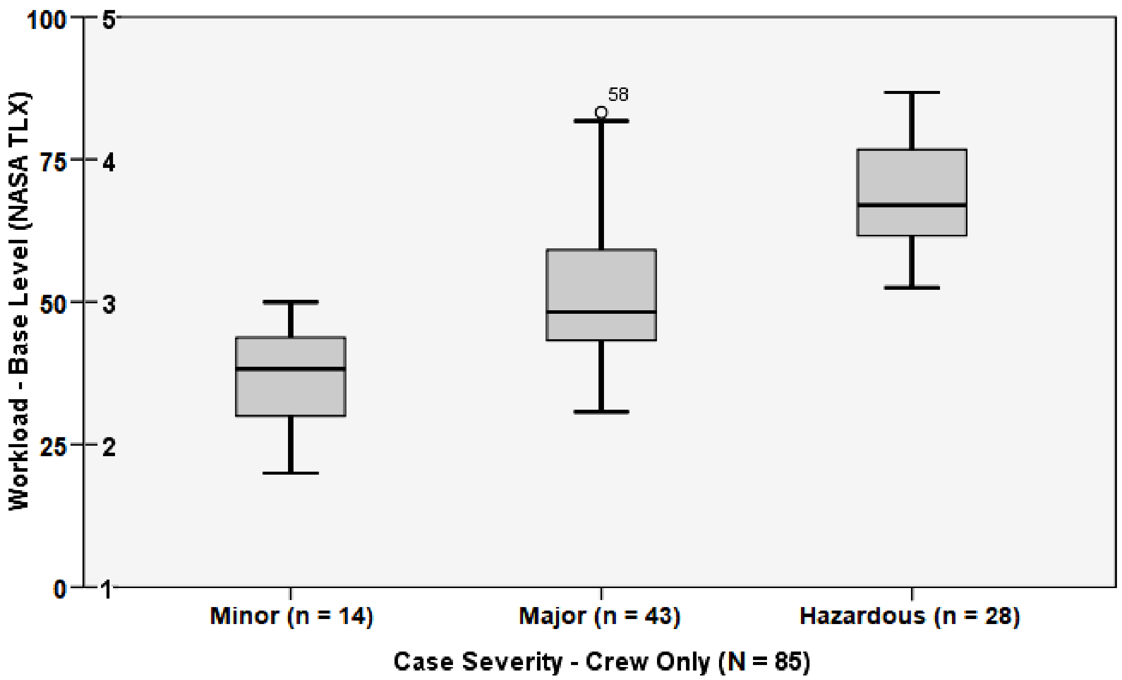


FIGURE 14 Basic level TLX vs. case severity (crew only)

A cross-tabulation analysis was used to test how a classified TLX *workload* (rounded to closest integer) would correspond with the *severity* classes. The relation between these variables was significant, χ^2 (4) = 35,81, $p < .001$. TLX therefore corresponds to case severity. Then a linear model check on base level values was made, and it was found that the TLX explains 42,5% of the severity variance ($R^2 = .431$, $F(2,87) = 17.12$, $p < .001$). The originally-weighed workload correlated significantly with case severity ($\beta = -.657$, $p < .001$)

The a best-fit linear regression model was the second computed model, providing a higher degree of explanation (64,4%), but giving an excessive weight on performance component. The model valued performance up as high than all the remaining five components together [$W_{OP} \approx W_{(MD+PD+TD+EF+FR)}$]. On the other hand, the mental demand was given only a small weight [$W_{MD} \approx 6\%$]. Therefore it is expected that the performance and the mental demand, as estimated, have some shift between each other (discussed more later).

Finally a third simple model was computed. The so called *equally-weighted* workload model [$W_{MD} = W_{PD} = W_{TD} = W_{OP} = W_{EF} = W_{FR)}$] was found to explain 49,1% of the severity variance ($R^2 = .497$, $F(1,83) = 19{,}74$, $p < .001$). This third simplified linear workload model also significantly correlated with case severity ($\beta = -.705$, $p < .001$). Due to contextual determination of the independents this workload calculation is concerned least biased.

4.4.3 Discussion on the workload experiment

NASA (1986) original TLX provided a correlation with the case severity ratings. The statistically computed best fit model didn't seem 'plausible' because the performance (OP) received a weight (W) as large as the remaining five components together. A simple model, consisting of all six NASA TLX workload components, was constructed. This simplified model was considered more appropriate already because the experiment is based on contextual data with varying degree of reliability and variable scales are coarse by nature. For curiosity a test was made with all of the 106 cases, having been weighted using same scales, and the same level of positive correlation was demonstrated.

Considering from the workload analysis perspective, the goal-setting is not conventional when a threat must be dealt with. The goal might not be noble, like a promotion, it could be *survival* - nothing more, nothing less. It is therefore a matter of definition how strongly does the component of performance (OP) appear in a threat context. In order to avoid simplistic assumptions the performance (OP), having shown as 'too' powerful component, deserves second look. Determining the OP, travelling backwards a risk management schedule (see 3.2.5), extracts the performance from the mitigation of outcome severity. Travelling from the actual to the potential outcome is a viable indicator of activity (or human barrier) effectiveness. The task at hand has not been volunteered nor has it been ordered by someone; it can be considered having been as an extra obstacle on the path that has to be dealt with. It is therefore possible that some mental elements as *motivation*, *determination* and *focus* show in the performance (OP) when using the barrier effectiveness as an indicator. These elements are even more challenging to point out from circumstantial data.

Consideration has also been made how such an experiment could provide a more detailed outcome. It is obvious that accurate workload estimate is achievable from the individual him or herself but some components are measurable as long as the reductions can be well established. For example pilots' performance is often evaluated by the flight instructor. It is worth mentioning that the correspondence was reached between all three workload models and the case severity, independent of the used component weightings. As long as a context-dependent workload is always done according to similar principals, coverage of all elements and avoidance of their overlapping is seemingly more important as the exact weightings.

NASA (1986) has found a good correlation between the individual ratings whether given contextually or retrospectively. Therefore it is more of a question how to extract the proper information afterwards as long as the key issues have been covered. The most important asset for any third party analysis would be a homogenous HF reporting structure, containing all the ingredients, independent of the causation or the outcome of the reported incident. That is, incidents of purely technical nature and minor severity of outcome would also benefit from standardized HF analysis. An HF 'template' would be especially valuable if the human activity has been optimal.

5 DISCUSSION

5.1 Summary

This research is an analysis of 106 cases, covering three categories of aviation safety occurrences; accidents (n = 34), serious incidents (n = 54) and incidents (n = 18). More indicative distribution in severity classes by ICAO (2013) has been adopted for analysis purposes. Division by severity results to 29 hazardous cases (27%), 58 major cases (55%) and 19 minor cases (18%). The basic principle has been 'border-crossing', in order to refresh the angle how a mandatory non-programmable element, namely human, could be regarded as an asset for safety even at incidents resulting from the human imperfections.

In general the humans at different systemic origins have appeared as barriers with high power when mitigating outcomes of threatening situations. It is obvious that human strengths will be difficult to replace but there are several ways to support the human both as a preventive and recovery barrier. Aviation is strongly a multi-tasking element which sets requirements to all the operators; most prominently to those in the cockpit and at the air traffic control working stations.

The analysis has provided patterns that can generalized in three case manifestations of condition specificity and human activity. The first two modes come with higher degrees of performance requirements, sometimes asking for processing up to a level of becoming data or resource-limited (as per Norman & Bobrow, 1975). A connection to higher stress levels is obvious when the cognition needs to control a flow of events with a narrow margin to serious threat. Such limiting conditions for processing have correlated with modest success, whereas the more elaborate and less constrained processing has indicated correlation to less severe outcomes. Various cognitive strategies as well as systemic human barrier dimensions have been analyzed in the previous chapter. The results are finally summarized and further developed in the following paragraphs.

5.2 Human barriers in action

The first, most critical and most serious mode of occurrences, presents in those conditions where a subject (often a lone pilot) encounters a *sudden threat* which clearly diverts from the projected flow of events. Such change could result from a severe technical failure or unexpected drift out of the safe envelope. The most demanding cases have the elements to promote high stress levels due to low expectation of success and low freedom in controlling the events. People that have encountered these critical situations have simply acted on automatic control level (as defined by Norman & Shallice, 1980); controlling of the flow of events as forced. *Skill* and *knowledge* seemingly improve odds in cases of *forced control* as applicable rules are available instead of resorting to more arbitrary *intuition*. There is uncertainty of the possible individual startle recovery effectiveness (Thackray, 1988) which plays an important role in time-compressed situations, yet the training is expected to improve the results. This skill border shows clear in the data; helicopter pilots (in general) and higher experience pilots in light aviation have been able to make timely appropriate decisions in situations prone to induce high stress. Another split condition manifests, depending if highly constrained incident occurs at the light aircraft classes or at the high technology large aircraft.

The sudden and low control cases at the light end have been ultimately protected by the latent human barriers, namely platform designers. Recreational A/C (ultralight and sailplanes) and helicopter class share all the cases where the recovery barrier activity has taken place on the drawing board in form of built-in crash protection. Some of the reasons leading to crashes have been discussed earlier, yet they are not at the scope of this study. What is important is that the game is not over even if the contextual barriers are unsuccessful to prevent an accident. At the same time, the overall technical reliability in the commercially maintained aeroplanes is roughly three times higher compared to low budget aircraft; certainly explaining some of the success at the commercial side. Nevertheless, when *forced control* has been used in the large aeroplanes the expertise benefit has been obvious. Even the poor expectancy cases have not resulted to accidents in the commercial transport (ME and large aeroplanes), indicating the force of expertise.

The second mode of occurrences is in connection to perceived *excessive deviation* calling for the process of apperception via constructive association (Laarni et al., 2001; Saariluoma, 2001). Two mechanisms are recognized, depending on the trigger conditions; either *autonomous* or *situational processing*. The trigger mechanisms vary from clear signals to non-conformant pattern detection as the situation awareness becomes disturbed.

The cautionary systems are expected to trigger a rapid (autonomous) reaction, exploiting the most direct recognition-primed decision (RPD) as defined by Klein (1993). The warnings expectedly are to keep things simple; staying at the functional-relation seeking (Hammond, 1988) end of the cognition.

Drift to the other end of continuum, pattern seeking, is a consequence if the data is ambiguous. Such indications were found when pilots had to solve cases where trigger signal was weakly connected to conditions.

The high technology doesn't assist the professional users in large aeroplanes as much as would be desirable, leaving the sharp end representatives in highly important safety role. An adopted strategy that controls the ambiguity is the early detection, preventing drifts to excessive threat levels. A situational processing has enabled finding deviations at early stages without having to solve a novel and ambiguous pattern. This strategy is in use at the professional end, especially large aeroplane crews and air traffic controllers match the situation to "related schemata" (Endsley, 1999). To achieve earlier discovery of deviations there needs to be a higher base level activity in form of vigilance and communicative sensitivity, both of which are better achievable by teams committed to task-sharing.

The *third* mode of the cases is best characterized by a top-down (willed or conscious, as per Norman & Shallice, 1980) *goal control* whilst continuing efficient management of the situation. As the earlier two modes have possibly resulted to conflicts at multi-tasking level, in this type there is a higher degree of freedom in form of processing reserves. There are no constraints that would either compress the attentive control of parallel cognitive threads or force increasing the number of active threads (for threaded cognition see Salvucci & Taatgen, 2008). Occurrences with the most successful outcome were typically dealt with *systematic* and *team processing*, which both are especially effective in cases with novel conditions and promote (not necessarily intuitive but analytical) pattern seeking (Hammond, 1981). The level of threat has provided the subject with an optimal stress, enabling (near) optimal psychological adaptability for high performance (Hancock & Warm, 1989). Therefore the word 'threat' can conveniently be replaced by 'challenge'. A highly positive phenomenon in this typology is the systematic processing as performance enabler for inexperienced light aircraft pilots. With an opportunity to test various solutions in practice and using communicative team support, even potentially catastrophic cases reached non-hazardous outcomes.

Team performance serves both the data and processing requirements, and team formation is natural in the aviation thanks to the communicative means. Not everyone is needed to share the same mental model (and it wouldn't be economic either) but managing the stressful more complex conditions with interaction (Cooke et al., 2013) presents as a powerful human activity. This activity refines when a threat is commonly recognized, and the effectiveness is retained by upkeep of a coherent and up to date mental model of the situation, serving also as a means of more effective communication (Endsley, 1999; Entin & Serfaty, 1999). Thus the communication will effectively funnel, concentrating and supporting the core of the flow of events and excluding the non-essentials.

5.3 Workload - extracting challenge from threat

It was assumed and also interpreted by analyzing the contextual case data that stress level correlates somewhat inversely with success in threat situation (outcome severity). For a more comprehensive understanding of the interconnections an experiment of workload was then made. This was also an experiment made in purpose to enlighten a possibility that a non-time consuming questionnaire presented post incident could be helpful when trying to understand the pilot or crew behavior. The case severity, as a solid success indicator of the outcome, was used to estimate its possible association to workload. The workload was defined using all six components (Mental Demand, Physical Demand, Temporal Demand, Performance, Effort and Frustration) of the original NASA (1986) TLX, using circumstantially solved correlates from the source data.

It was discovered that there exists a clear correlation between the actual severity and contextually defined workload. Three different workload variants were tested each having different weightings; first assimilation was made using original NASA (1986) TLX example weights, second was made using the SPSS optimized model and the third used equal weights for each six components. All three models indicated a clear correlation to case severities (hazardous, major or minor). An essential question is how to interpret the perceived correlations; is there a causal relationship between the workload and outcome severity? It sounds somewhat simplistic to state that weaker success would be a result of higher workload.

When looking at the individual workload components it became apparent that the statistically best fit model would highly emphasize the *performance* (OP) and obviously reduce the weight of *mental demand* (MD). The MD was exclusively determined by situation related stress level and OP by the case severity minus potential severity. The OP thus uses the severity as a reference, perhaps reflecting to the result. On the other hand, the OP is also assumed to reflect some implicit mental elements of success. The 'unknown' factors are potentially more individual and context related variables like motivation, mental focus and determination. These might counteract the contextual stress factors and keep down the perceived threat level, resulting to both more optimal stress and performance. Finding evidence of 'anti-stress' elements is one step further and would require more than the contextual data available.

The rules of social facilitation (experimented by Blascovich et al., 1999) don't without hesitation apply to survival-based stress-related situation, but the perceived ability to meet the situational demand is a plausible source for improved performance. Thereby, the improvement would result from the positive angle; treating the potential threat as a challenge. Using the social facilitation dimension as such has also a purpose. It encourages forming of supporting (instead of judging) teams. When the individual demand is lowered both a lower workload and higher performance will be logical outcomes. A study performed in flight simulator stress environment by Vine et al. (2014) was able to demonstrate the *challenge* benefit using airline pilots as subjects. The important finding was the positive correlation between (1) self-perceived degree of resources to cope an engine failure situation and (2) the actual performance measured both by the recorded data or the instructor evaluation. However, the presence of instructor-evaluator as possible social stressor should not be undermined as a potential non-situational stressor.

When considering the self-perceived abilities from not from the perceiver but threat angle another explanation reveals. The inexperienced pilots' success in challenging situations may actually be promoted by the reduced perception of threat. In novel situation the reference of actual threat level might be as ambiguous as the situation itself because only the 'task' surface features (see Hammond, 1988) are identified. The ability to cope is perhaps peripheral, and the top-down goal control supersedes the threat-oriented bottom-up high workload option. Use of general abilities is a viable process to avoid data-limited decision making in situations requiring creativity. The challenge-oriented approach therefore creates supportive climate for low experience low workload conditions.

The MD is appreciably the highest relevance factor in the workload concept but its sub-components are troublesome to determine on contextual basis. Along with the model determination uncertainties the 'challenge-orientation' might explain the more pronounced OP component in the statistically optimized model. This imbalance however becomes less important when the workload is estimated as a whole. The total workload variation will remain descriptive as long as all sub-components are included in the model.

5.4 Latent human barrier activity by design

There are two scales in HTI challenge that require consideration from the situation awareness perspective, covering all of Endsley's (1995) three SA levels (perception, comprehension and projection). When deviations take place in the condensed terminal airspaces they have an increasing potential to escalate even when the humans do their best. The smaller scale challenge is encountered by the individuals coping with threat situation ambiguities. The HTI designers are in central position to by-pass the human capacity limits at air traffic interaction level and to solve the ambiguity issues at own ship level.

The HTI designers have managed, based on the case data analyzed, in providing indications and cautions that are well perceivable. They have the clarity and strength required to capture the user's attention bottom-up, thus initiating the real-time recovery activity. Yet there are indications that deeper understanding of the situation may not be achieved and subject is left working out the rest of the challenge by him or herself. Furthermore it was noticed that the presence of HTI designers' barrier activity is scarcely seen in light aviation. In order to reduce the need for crash protection the technology should be harnessed to support the lower experience pilots. The flight path protection (e.g. stall margin, fuel sufficiency and glide ratio calculation) would have helped mitigating the severity, more than the sheer crash protection. The lack of expertise naturally narrows down the selection of *recognizable* anomalies and therefore the applicable procedures. This is ultimately 'compensated' by crash structure.

Even that this research only uses cases with no severe human injuries 20 (or 19%) of the cases have at least partially profited of the platform structure as a protection. A third (31%) of the 'light' aircraft (recreational A/C & SE aeroplane & helicopter) incidents were related to maintenance or support issues, which may prove hard to remove as cultural reformation is expected. The traditional general aviation flight hours have fallen whilst the ultra light hours have been steadily increasing, and in addition the national authority emphasizes operator-centered safety management (Trafi, 2014). This may prove complicated because the light aircraft (e.g. ultra- or microlight) are enablers of low-cost aviation hobby. Thus it is expected that individuals by becoming owners of these aircraft become the also the 'accountable' *operators* without having operator resourcing or commitment.

5.5 Conclusions

Shift to challenge-orientation

The aim of this study has been finding the human as source of recovery in critical situations at aviation. The study includes analysis of 106 cases from public Finnish investigations reported as incidents, serious incidents and accidents; with an added success factor of 'no human casualties or serious injuries'. It has been demonstrated that human barrier activity takes place both as real-time and in latent manner. Such recovery strategies that reflect lower (i.e. nominal) stress levels were found to correlate with less severe outcomes.

Earlier in this research two hypothesis were made: (1) there are effective, cognition limit avoiding, strategies of survival at any level of aviation experience, and (2) the contextual human barrier in aviation is effective when the load can be controlled. These hypotheses are not considered being as major contribution of this research, but they have been set to maintain a guideline. Both of them, nonetheless, have been positively confirmed by the data. (1) Firstly, a top-down goal adjustment and subsequent systematic processing on individual or team level assimilates to less severe consequences at all experience levels. This successful reasoning strategy is related to analytical pattern seeking (Hammond, 1981). (2) Secondly, the highly constrained occurrences have been resulted to less severe outcomes when the subjects have been able choose a proper model instead of using arbitrary intuitive solution. This RPD-related (Klein, 1993) advantage comes as a product of training and experience.

A less 'dramatic' and perhaps cued onset of the problem seems to be connected to higher processing. Dividing the attention is not one of the human strengths and cueing markedly improves signal perception (Posner et al., 1980; Hitchcock et al., 1999). After perception the human symbolic power needs to be supported either by further information received, or acquired. Use of general abilities in form on intuitiveness is a viable process *conditions permitting* as a strategy to avoid data-limited decision making in situations beyond skills or knowledge. Higher level processing is beneficial especially for lower experience pilots who lack the expertise of recognizing depth features of novel situations.

Adopting challenge- and success-oriented attitude throughout the aviation-related training programs (instead of inducing threat) will result to better performance as stress levels remain optimal. Such indications were present in the data when top-down goal reset had retained the workload at low levels. A new situation requires new goals in form of decisions that release capacity for the situation control allowing efficient multi-tasking.

Designers challenged

Human ability to handle vast amount of dynamic data is error prone. As the commercial air traffic is growing exponentially (e.g. IHGL, 2017) the requirements will and must develop to more automatism-dependent direction, beneficiaries being the flight crews as much as the air traffic controllers. If the sharp end users are expected to adopt challenge-orientation in difficult situations the technology designers are expected to promote this orientation both at the individual user and the aviation system level.

Problematic of ambiguity in the annunciations (e.g. visual, auditory or haptic) is a challenge when rapid decisions are needed. Due to processing requirements, the discovery of the internal state of the system (in this case the aircraft) is both time consuming, and highly challenging as the system internal state is non-static. If the cautionary systems are designed using the depth features of instead of the surface condition, they might provide the pilot with an intuitively unambiguous support. Presentation of the essential world and the expected flow of events call for *epistemologically adequate* system discussed at dawn of the AI by McCarthy & Hayes (1969). The concept of adequacy connects for instance to production and presentation of flow of task related events, reducible to time or distance between the events (Kujala et al., 2016). The system can be provided with the power to handle the superficially random occurrences and present them in logical pace and order for rapid apperception of what still functions, instead of what doesn't.

The HTI designers' barrier activity has been significant especially in preventing mid-air collisions that compose a salient threat in condensed airspace. However as any technology, the ACAS architecture also needs persistent refining for more effective utilization. Considering the air traffic growth, what looks critical should actually be perceived as a new potential. Over the US airspace alone there are some 5000 IFR (Instrument Flight Rules) aircraft in the air at peak hours (FAA, 2017). The air traffic density can be interpreted as source for intelligent networking, for example swarm logics to be used in order to prevent escalation of single aircraft deviations. An infrastructure exists already for a safety network (that as a by-product ensures also against ground based surveillance system level malfunctions).

The 'users' of HTI protection belong to the most experienced group of pilots, the ones who operate large aeroplanes, where the cognition is often used to match the situation with a specific pattern. These aeroplanes are constantly being evolved on multiple levels, not just for the safety but for the effectiveness as well. The HTI designers are able to develop systematic protections for almost any deviation that is detectable by technology. Therefore the AI features should be targeted to provide the inexperienced aviators with adjustable level of interference - comparable to virtual flight instructor. An intelligent and subtle supervision of the flow of events should be adjusted to human adaptability.

Training to culture

Training is needed for permanent changes and this requirement is well covered by the regulation in licensing including the training authorizations. An interesting training aspect brought in the light was the good readiness of helicopter pilots to perform emergency landings. When such procedure is practiced the result is exactly what is needed in low control situation; an automated selection of the best action. The fixed wing aircraft are as susceptible for off-runway forced landings why the same readiness should be provided very early in pilot training.

Pragmatic training devices are needed and they can be used to simulate threats at least to a certain extent. Aviation simulations come at various levels, but they may not be adequate for the most challenging training needs. The EASA (2012) for example requests from the higher fidelity Full Flight Simulators (FFS) a "sound of a crash" when "landed in excess of limitations". Fulfilling this requirement literally excludes the use human recovery barrier activity when simulation simply results to a crash. Exceeding the landing limitations in real life doesn't and shouldn't be the end of the game. The more the simulators can replicate the real world the better are the conditions when preparing the pilots to every imaginable and unimaginable occurrences. Furthermore such unlimited simulations enable refining the best practices and meeting the incidents as challenges instead of threats.

Training culture as well should be exclusively challenge-oriented if the benefits are to be implemented to real life. Imposing threats in training is natural when simulating critical scenarios. However, making the *training situation* (pass-fail) as a threat serves only as an indicator of the perceived ability to meet conspecifics' expectations (Blascovich et al., 1999), therefore not meeting the demands in true situations. Threat related training needs to be provided for low experience aircraft pilots especially for countering the sudden onsets of critical failures (Hilscher et al., 2005; Landman et al., 2017). It is important to build confidence both to all team members and to own abilities to cope the threat (Fornette et al., 2012; Vine et al., 2014), as the perceived ability is a key motivator for success.

Establishing cultural preventive defense mechanisms for the light aviation will take time and effort. Therefore what cannot be readily fixed by training can be mitigated by proactive aircraft design. Unbiased information about (1) successful behavior strategies and (2) defensively equipped aircraft, may be produced. A data pool of safety indicators is quite possible the same way as for instance the ATSB (Australian Transport Safety Bureau) National Aviation Occurrence Data Base provides any user with an opportunity to review data and run cross-tabular statistics online. The metadata properties only need to comply with the demand, and the authorities have the knowledge required to meet this demand.

Success investigated

The inverse approach used in this research can be recommended also as an investigative angle, even if it takes resources. Investigating "*when something goes right*" provides an interesting potential in itself, promoting positive tone in the aviation community. Learning from successful recovery strategies enhance the perceived abilities of those who might be exposed to threats in future. An analytic program, SIAM (Systemic Incident Analysis Model), has been initiated in Australia with one of the information goals being "what were the recovery measures that prevented an incident becoming an accident" (Lee, 1996). The tool doesn't exist anymore, but as an investigation authority program it indicates early recognition how computer databases could be used to produce pragmatic preventive data from the recorded success factors.

The contextual workload experiment included in this research showed potential also as a practical element that can be used for incident investigations. Real emergency workload data would be appreciable, and the non-disastrous cases, would provide an easily reachable source to analyze the area between threats and challenges. The workload estimate even if made retrospectively provides a high correlation when visually re-creating the earlier task (NASA, 1986). Collected data would eventually provide a way to create a more discrete contextual workload tool. When properly adjusted the workload, indicating a true situation as perceived by the actual people themselves, is expected reveal new patterns and cognitive strategies that would provide at least two major contributions. Firstly, the statistical knowledge of scientifically confirmed successful strategies may be used to improve safety-related and HF training at all levels. Secondly, the extracted behavioral data may be used to fill gaps in such investigations that are dependent on circumstantial evidence.

The less severe safety occurrences are the ones with great potential to keep up with the new challenges brought by emerging technologies. There is always the possibility that the human is unable to manage with the complexity, but there is the other possibility that the technology may not manage the simplicity. Searching for the strengths cannot be considered as substitutive to searching for the weaknesses in the system, they are both needed. The failed controls bring forth questions but the successful human barriers may provide the answers. Collecting and analyzing the safety data needs new approaches in order to learn to see when something goes right.

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