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Hazards and Risk Analysis for Helicopter Aerial Work Mission Profiles

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Ad Anna Maria,
ti cercheremo nel vento
e ci abbraccerai ancora.

Abstract

This following work is originated by the need to better investigate the human factors in the context of safety in rotorcraft aviation. In particular, the aim is to describe, along with the typical helicopter aerial work missions, the state of the art of the safety in order to outline the picture of the potential hazardous situations and the related safety standards. Great attention is paid to the perspective which allows to better understand the allocation of responsibilities within organizations, underlining the importance of organizational management in harmful occurrences.

Subsequently, the objective is to provide to the reader essential information about the mission analysis methodologies, suggesting a case analysis process developed on the basis of human-factors-oriented theories and taxonomies. In particular, some *milestones* of the human-factors-oriented analysis theories are mentioned, such as *SHELL Model*, *Reason's "Swiss Cheese" Model*, *HFACS Taxonomy* and more.

The suggested case analysis process is then tested on a case study, related to an actual helicopter accident, in order to experience the activity to read and interpret an accident technical report, to carry out a factual analysis from a human factors perspective, and performing a *'risk assessment'* analysis through the aforementioned analysis models SHELL and HFACS. The real goal of such activity aims to obtain a clear reconstruction of the events and allocation of responsibilities, in order to file some useful *safety recommendations* as a suggestion to make the safety standards even higher than they today are.

In conclusion, the involvement of the human factors in *safety critical* aviation software is addressed giving a better idea of the multiple sides of this matter. The writing of *functional requirements* and *use cases*, the *human-machine interface* guidelines and more are also discussed. Finally, the research face up with the possibility of implementing the aforementioned case analysis process in a software which can act as a *'Risk Assessor'*, with the aim to create a tool that can to some extent replace or help humans in the helicopter aerial work mission assessment, making GO/NO GO decisions once the mission scenario has been outlined by the user.

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Chapter 1

Introduction

1.1 The Helicopter, an Alternative Way to Fly

In the early years of the twentieth century a new era of the modern aviation world began. The 'revolution of flight' has deeply changed humanity, its way of life and its perspective of progress. The Wright Brothers, in 1903, were the first ones to realize the dream of flight by means of their airplane prototype called *'Wright Flyer'*. By comparison, the story of the Breguet Brothers appears clearly to be less popular, but definitely not less important compared to the Wrights' one. As a matter of fact, during the summer of 1907, the *'Gyroplane No.1'* constructed by the Breguets was able to take off and flight for a minute at a height of 60 cm. For the first time in history, a rotorcraft with a passenger on board could detach from the ground.

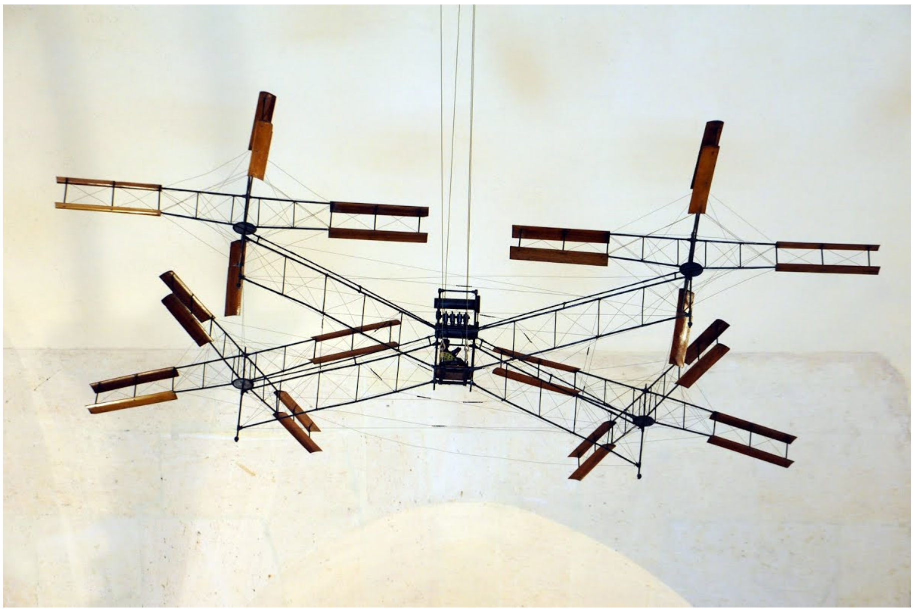

Fig 1.1.1: Breguet Brothers' Gyroplane No.1

Although airplanes and helicopters, or rather their ancestors, have seen the light almost at the same time, it is however true that the development of technology could not pursue a similar path for the two of these 'categories'. If on the one hand the fixed-wing aircraft configuration has always been well characterized and defined as we know it, the same cannot be claimed about rotorcrafts. The quest about the helicopter functional morphology protracted for years, and the path has been paved with numerous attempts and a great loss of human life. The motivation behind these difficulties has to be searched in an absent theoretical background, as well as in

technological limits of those times.[1]
During the following years many efforts have been accomplished in order to find a functional and controllable configuration. Igor Sikorsky, a Russian aviation pioneer, conceived the *'VS-300'*, the first classical-configuration helicopter type as it is intended today. It flew for the first time in 1939, with Sikorsky himself on board. The prototype was designed as a tubular fuselage, terminated by a tail boom, and equipped with both a main rotor and an anti-torque rotor.

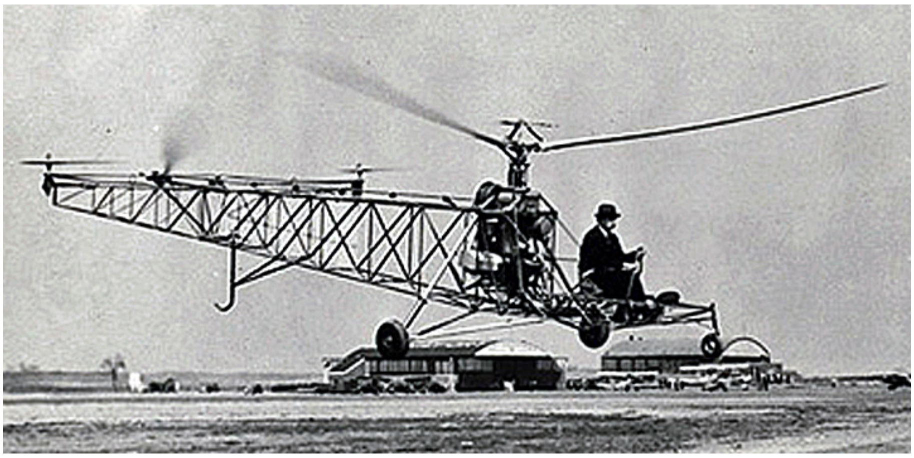

Fig 1.1.2: VS-300 First Flight

Only in years to come, as the theoretical knowledge has been refined and the engineering process evolved, it was possible to reach the target of a useful and reliable flying machine. Actually, the most of the rotorcrafts evolution could be directly traced to military use. During the World War II, the necessity of a discreet and adaptable flying vehicle was of primary importance to transport and support ground troops, to perform rescue activities and battlefield recognition, and to lead offensive missions.[1] Moreover, the progress made under propulsive units, aerodynamics, mechanics and materials technology made the definitive breakthrough in helicopter development easier. This made possible for rotorcrafts to partly recover the existing gap between them and fixed-wing aircrafts, which could already take advantage of better technological knowledge, reliability and utility.

Despite of all the improvements, even nowadays it can be noticed how helicopters still present a significant performance gap in comparison to fixed-wing aircrafts. Some performance parameters, such as maximum range, maximum payload and cruise speed appear to be strictly limited by main rotor and turboshaft engine features. Moreover, tight available space on a general helicopter limits the fuel tank volume, reducing endurance capabilities. These features and more can be compared, in order to highlight differences that occur between helicopters and airplanes.
The following diagrams are examples of performance valuation, obtained by comparing some rotorcraft and aircraft types, in order to illustrate how the performance gap is highlighted between the two categories. These differences need to be known while considering what kind of vehicle has to be preferred in order to perform a given mission. It appears evident how airplanes should be preferred in a perspective of a general transportation mission, as they can fly longer routes in a shorter time and carrying a greater payload. This fact can be considered consolidated independently from the specific aircraft type category.

In this context, it is questionable what kind of motivation persists for the aeronautical engineering to insist in the development of such a complex and apparently not so performing machine. The amount of efforts and funds spent on the scientific research cannot be justified only by

'philosophical fascination', as other flying vehicle concepts - autogyro, airship, aerostat balloon - have not been developed with the same dedication.
The answer lies in the word *'versatility'*. The helicopter is a flexible and adaptable vehicle, able to accomplish a wide range of roles and missions which a general airplane could not cope with.

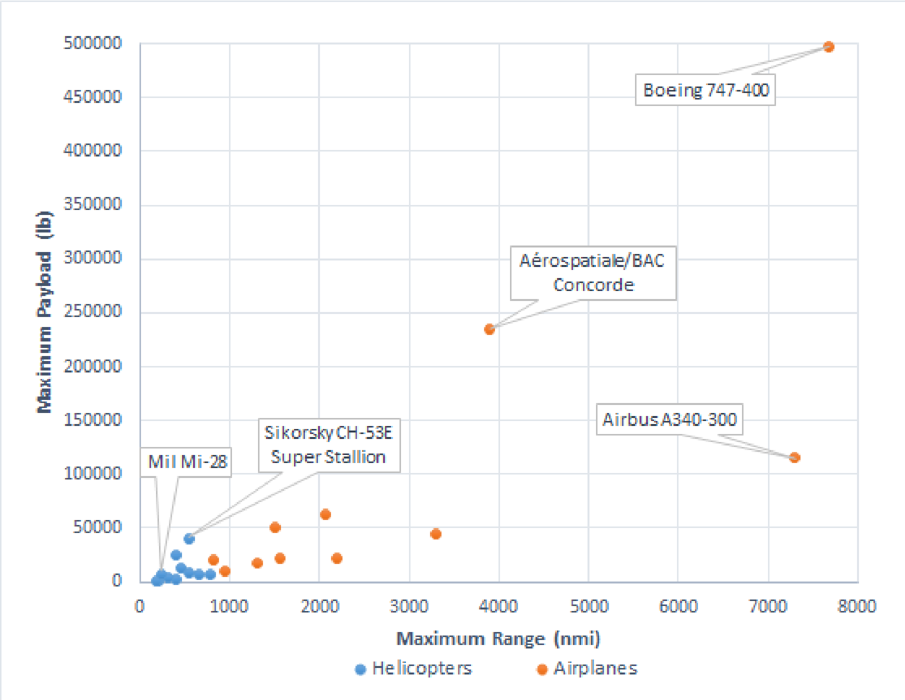

Fig 1.1.3: Maximum Range - Maximum Payload Diagram

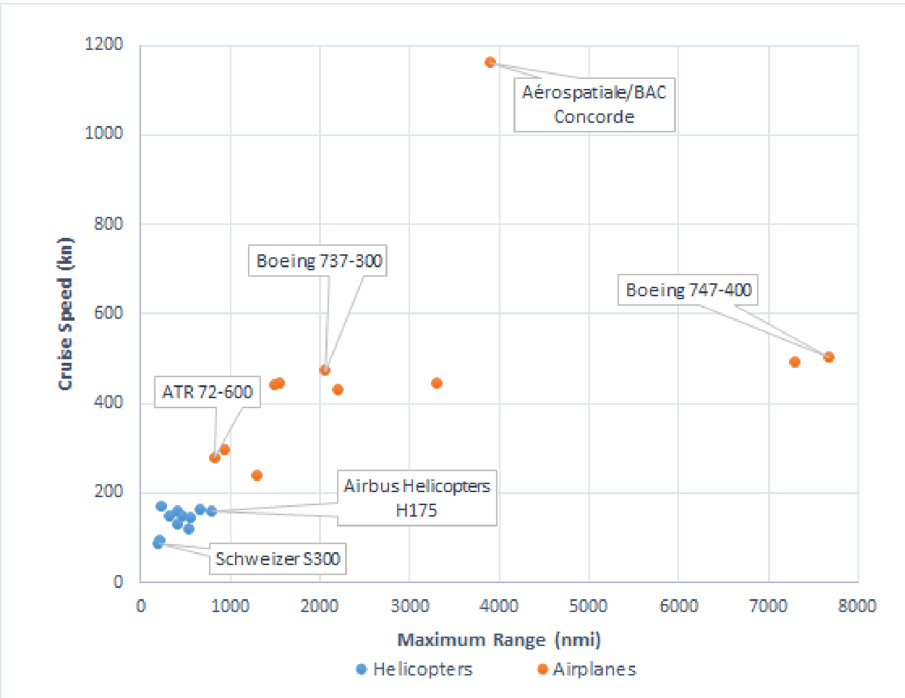

Fig 1.1.4: Maximum Range - Cruise Speed Diagram

In particular, there are two essential features which make the helicopter a *'one of a kind'* aircraft:

- Vertical Take Off/Landing
- Hovering

These particular operational capabilities make the helicopter a fundamental tool for aerial works and more, which can allow to perform different tasks in particular conditions and environments. Typical rotorcraft aerial activities are set out below.

1.2 Helicopter's Typical Missions

1.2.1 Sling Load Carrying

One of the most common practices conducted by helicopter consists in carrying objects by means of a hook, which is linked to the vehicle by a reinforced cable. This kind of operations are typically performed in adverse environment, such as mountain areas - where wood and general supply transportation is a common task - or in construction sites. Especially during the hooking phase and release phase it is necessary a ground crew to be present, as human help allows these critical moves to be safely carried out.

Fig 1.2.1: Sling load transport operation

1.2.2 Pipeline and Power Line Patrol Inspection and Maintenance

Oil and gas pipelines need a continuous supervision, in order to ensure maintenance, safety and efficiency. Helicopter emerges to be the best choice to accomplish monitoring missions in both terms of rapidity and cost, as well as accuracy. However, typical operating conditions expose the rotorcraft to several risks, due to the necessity to manoeuvre at low height and low speed. On board, operators make use of observation tools, such as sensors and cameras, and their intervention could be directly required in order to inspect pipes or to remove natural obstructions along the pipeline.[2][3]
Power lines, likewise oil and gas pipelines, need to be constantly monitored. In comparison to oil and gas pipeline monitoring, such activity adds risks as flying electric cables are involved.

Fig 1.2.2: Pipeline patrol operation

Fig 1.2.3: Overhead Power Line maintenance operation

1.2.3 Aerial Spraying Operation

Helicopters can adequately fulfil the necessity for crop fields to be sprayed with chemical pesticide, in order to preserve cultivation from pathogens and invasive insect species. As a matter of fact, rotorcrafts are particularly suited to this activity, as their range of motion allows low-level flying, moderate forward speed, high manoeuvrability in impervious and restricted areas. Similarly to the activities described above, such particular operating conditions add several operating risks to the helicopter employment. Pilots and ground crew operating in such contexts must be adequately trained and qualified, in order to maintain high safety standards.[2][3]

Fig 1.2.4: Pesticide spraying operation

1.2.4 Emergency Medical Service (HEMS)

Helicopter is an essential instrument for life safeguard when an immediate emergency assistance is needed, thanks to its ability to land on inaccessible areas. This kind of operations requires a vehicle able to ensure promptness, versatility, reliability, visibility and manoeuvrability. Typically, HEMS helicopters are fitted with medical tools and huge accommodation cabin space, in addition to wide side opening doors and sling-load capability. As rotorcrafts can be employed in mountain areas as well as in maritime areas, the wide range of operating conditions and risks (high altitudes and snow, in addition to wind, sand and sea salt) must be considered by manufacturers and stakeholders during HEMS helicopters design phase.

Fig 1.2.5: Alpine rescue service

1.2.5 Search and Rescue (SAR)

'Search and Rescue' missions are focused on the search of missing people and objects, in a wider sense of 'emergency' if compared to HEMS. The operating conditions and environments are similar to HEMS missions, although SAR activity proves to be firstly aimed to the 'environment exploration'. However, it seems to be clear as even SAR helicopters must be equipped with medical instruments and first aid operators on board.
An important additional risk factor is given by night operational activities, where visual references are reduced, and the use of sensors is required.[2][3] Similarly to HEMS mission, it can be required to operate sling load activities, in order to allow first aid operators to descend on terrain and take action.
Still, comparing to HEMS helicopters, SAR helicopters may need a greater endurance capability, as the searching operations can be generally conducted among wider and unspecified areas for longer time.

Fig 1.2.6: Canadian SAR service

1.2.6 Firefighting Service

Helicopters can operate alongside airplanes for firefighting purpose. Although load capability proves to be reduced in comparison to planes, helicopter can provide a more precise and versatile action. Depending on the helicopter type, the firefighting activity can be performed by means of an external bucket, linked to the vehicle (sling load), or carrying water or suppressant liquid directly on board. As a matter of fact, heavy lifter firefighting-type helicopters are provided by huge tanks and pumps in order to collect water from sources such as sea and lakes.
High visibility is one of the most important assets in support of the pilots, as both refilling and release operations require a certain degree of precision. Especially at the fire site, smoke can severely reduce visibility.
Pilots must be specifically trained to handle the amount of adverse factors, such as smoke, strong winds, refilling and release operations, hot temperature, debris and explosions. Considering all the adversity which can be encountered, an in-depth knowledge of the environment is required to pilots and operators.

Fig 1.2.7: Firefighting operation involving sling load

1.2.7 Imaging and Patrol Service

Aerial imaging activity, which helicopters are considered to be suitable for, can be useful in several respects. Police observation, territory, flora and sea observation, television networking and more can be accomplished by means of sensors and lenses which can be, in accordance to the needs, optical, thermal or infrared.[2][3]
The helicopter versatility allows to make observation flights with a certain degree of ease and smart mobility, above both urban and rural areas.

Fig 1.2.8: Massachusetts Police during aerial patrol operation

1.2.8 Civil Air Transport (CAT)

Civil air transport category contains general flight activities as leisure flight, business flight, training flight, VIP transportation and more. In this context, helicopter can be considered a mean of transport prerogative of wealthy society, diffused in various parts of the world, which allows low-medium range travels.

Fig 1.2.9: AgustaWestland AW109S Grand

1.2.9 Offshore

Offshore drilling platforms are typically located in remote and isolated areas over the sea. The fastest manner to transport people, material and supplying above these facilities lies in the use of a helicopter. What makes offshore transportation a hazardous mission are weather conditions, which typically can include low temperatures, strong winds and high waves.[2][3]
The approach phase is assumed to be particularly difficult, as weather conditions are compounded by the need to land above a restricted dedicated area, allowing no margin of error.

Fig 1.2.10: Personnel transportation on offshore platforms

1.3 Introduction to Risk Factors

During the presentation of the helicopter aerial major activities, reference has been made about how hazardous these situations can be. As a matter of fact, each time an aircraft - rotorcraft, in this particular case - leaves the ground, it is exposed to potential adverse factors that may affect the successful accomplishment of the mission in progress. Typically, aerial mission's failing evolves in harmful consequences, such as life and hull losses. As will be better examined in the following dissertation, each time an aircraft leaves the ground it is accepting the *'risk'* of flying.

With the aim to create a specialised organization in matter of aviation safety and development, *United Nations* in 1944 founded the *International Civil Aviation Organization - ICAO*, which was commissioned to regulate safety standards and recommendations, tracing the guidelines for the international aviation. Over the years, aviation has benefited from a massive improvement of safety standards, to such an extent that to date the aerial transportation results to be the safest mobility system in the world.
In *Annex 13 to the Convention on International Civil Aviation - Aircraft Accident and Incident Investigation*, ICAO for the first time defines what harmful occurrences as *accident* and *incident* are meant to be, and subsequently creates guidelines for an adequate investigation approach. The "accident" and "incident" definitions are hereby reported.

Accident. *An occurrence associated with the operation of an aircraft in which a person is fatally or seriously injured, and the aircraft sustains damage or structural failure, or is missing or completely inaccessible.*[4]

Incident. *An occurrence, other than an accident, associated with the operation of an aircraft which affects or could affect the safety of operations.*[4]

ICAO Annex 13 dictates guidelines to a complete and useful investigation work, which not only has the purpose to shed light on causes and legal liabilities, but mostly to identify failings in safety measures. The aim is to explore the unforeseen failures in the safety system, and, from them, to improve aviation "defences" from harmful events. Actually, in-depth and high standard investigation represents the key to a reliable and constantly improved safety framework.

The *European Aviation Safety Agency - EASA* is the European Union agency which assumes the role of responsibility for civil aviation safety on the EU area. EASA carries out the activity of certification, regulation, standardisation, investigation and monitoring. Moreover, EASA's mission consists in collecting safety-related data, as statistics represent an essential tool in safety research. In fact, with the aim to integrate safety recommendations by means of results coming from the updated statistics, safety analysts oversee the ongoing safety framework in EU. In particular, a wide analysis perspective allows a better interpretation and understanding about the safety trends.
As an example, diagrams below report some general statistics collected by EASA on helicopters accidents and incidents, published in the *EASA Annual Safety Review*[5] document. It can be observed how the data collecting and interpretation helps the analysts on focusing on particular subjects, such as aircraft type or missions, or flight phases, in order to unveil safety's critical matters. Moreover, statistics allow to follow up results and achievements obtained in relation to previous interventions in the course of time.

At the end of any accident investigation the related results are collected in order to enforce the just mentioned safety statistics. In fact, it is essential to further assess the obtained data in order

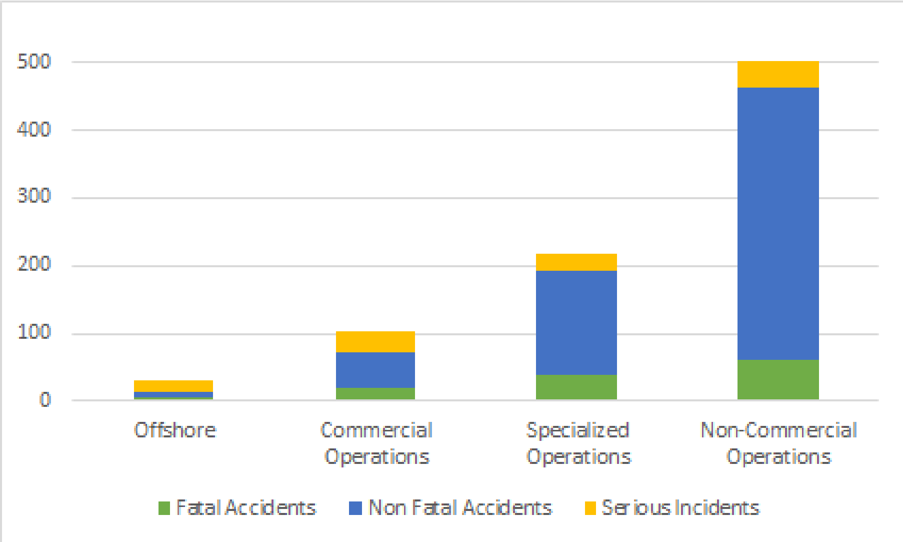

Fig 1.3.1: 2008-2018 Helicopter accidents and serious incidents on EU territory - Source: EASA

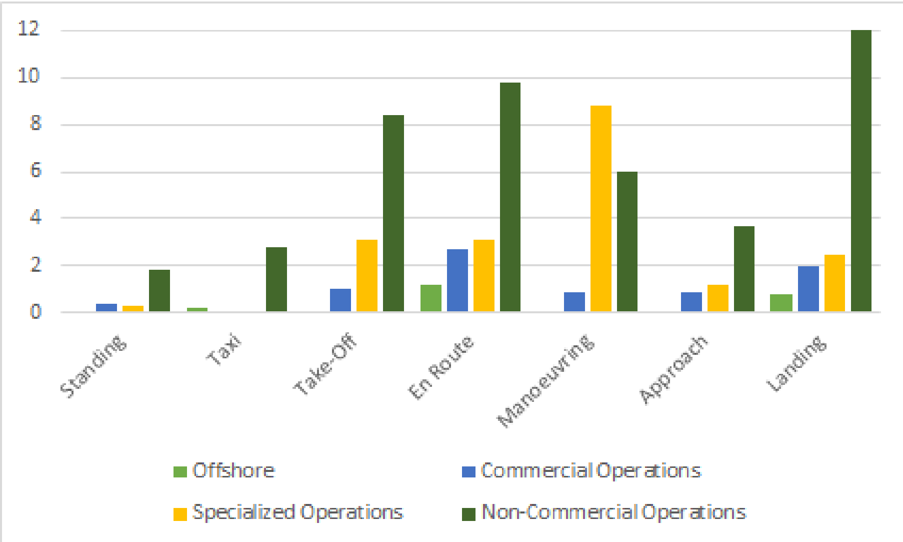

Fig 1.3.2: 2008-2018 Helicopter accidents and serious incidents by phase of flight - Source: EASA

to deepen what situational *risk factors* evolved in accident causes. Thus, only a complete and clear *taxonomy* of risk factors, in association with a functional analysis method, represents the first step to perform a thorough and wide analysis which can lead to file new safety-oriented regulations.

In relation to what has been affirmed, a diagram related to helicopters accidents and incidents causes, taken from last *EASA Annual Safety Review*[5] and referring to events on EU territory during 2014-2018, is here below reported. From data observation it can be noticed how many accident/incident casual factors may occur and combine before, during and after a mission.

In particular, this survey shows how recurrent and critical some casual factors are, so leading the way to the interpretation of safety information and trends. As an example, it can be noticed how casual factors such as *'Flight Path Management'*, *'System Reliability'*, *'Perception and Situational Awareness'* appear to be the most frequent contributing factors when a harmful event

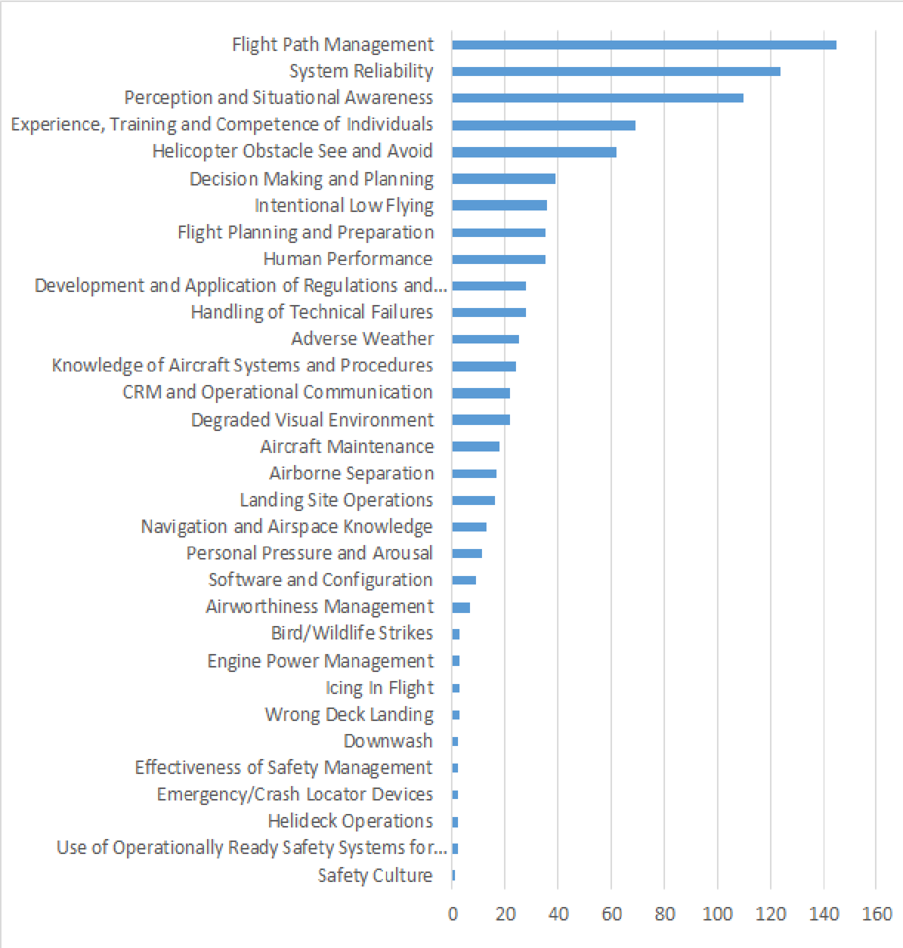

Fig 1.3.3: 2014-2018 Helicopter accidents and incidents causal factors - Source: EASA

occurs. On the basis of reviews and valuations, safety data analysts are hence responsible to notice any helpful information and initiate the research process which will lead to enact updated safety recommendations and regulations.

By observing risk factors listed in the previous chart, it can be noticed how most of those reported are referable to a factor class which involves the human error. From this point on, these will be referred as *'Human Factors'*.

The 'human factors' approach has thus reshaped the perspective about safety issues, opening the way to more efficient analysis methods, more specific findings and conclusions, and more useful safety recommendations which have been filed over the years. The following developments are therefore set out to introduce the 'human factors' framework and its role in safety scenario.

1.4 Introduction to Human Factors

At the dawn of aviation, accidents were typically attributed to adverse fate, as *'divine acts'*, or to natural causes. The interpretation given to flying at those days can be summarized as 'tempting fate'.[6] A 'beginning' of human factors consideration was given when, midway through the past century, the *'pilot error'* factor was introduced within safety framework in addiction to mechanical risk factors.

The 'human factors', in the meaning they are intended today, has been legitimized for the first time in history during the Istanbul Conference in 1975, conducted by the *International Air Transport Association - IATA*. On this occasion, Frank Hawkins presented for the first time his *'SHELL Model'*, a human factors analysis methodology which opened the way to consider the human being as an element set in a context. The context involves human relationships with other humans, aircraft, environment, where each one can play a role in the human operational performance. SHELL Model and more analysis methods will be widely described in the next chapter.

Nevertheless, the human factors issue has seen along the aviation history a slow and intricate evolution, in particular whether in comparison to the mechanical factors' one. As a matter of fact, unlike the tangible and quantifiable evidence surrounding mechanical failures, the evidence and causes of human error typically turn out to be qualitative and elusive.[7]

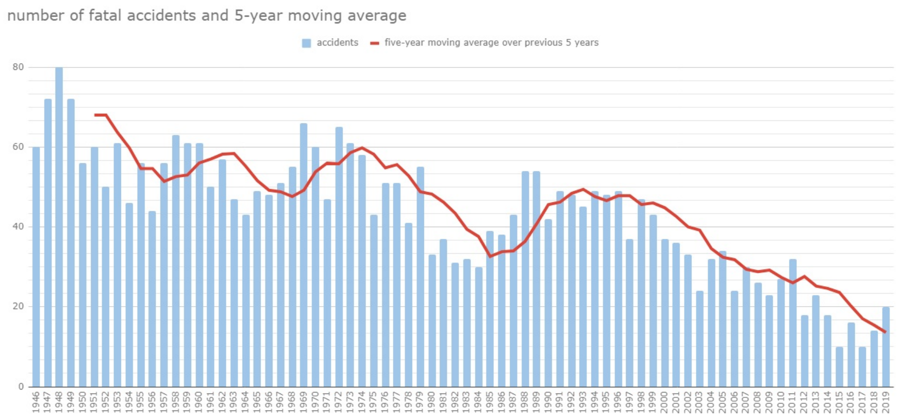

Fig 1.4.1: 1946-2019 Aviation fatal accidents per year - Source: aviation-safety.net

As the upper chart reports, harmful events have been reduced along the aviation history with a trend which mostly followed the technological progress. Aircrafts and rotorcrafts have benefited from the advanced and updated technologies, along with an aircraft-oriented safety perspective. This approach promoted research and implementation of more efficient safety measures related to components reliability. Moreover, redundancy science has been developed over the years in a perspective of enhancing the aircraft survival chances.

However, as the accident rate related to technical failures decreased throughout the years, the accident rate related to human errors did not attend the same level of improvement. Thus, as aircrafts have become more reliable, humans have played a progressively more important causal role in aviation accidents.[7] Therefore, over time the need to develop a wider human error culture in aviation began to make its way, highlighting the relevance of implementing a more human-oriented safety policy. As well as for technology issues, it became clear how human factors had to be better understood and analysed, in order to improve the knowledge and the awareness about human behaviour.

In the first instance, the investigative approach has focused exclusively on direct operators' mistakes and responsibilities. From this perspective, pilots, flight crew and air traffic control operators were the only humans considered to have a role in accidents occurrence. Actually, it is easier to associate responsibilities only to the very end of the operational chain, which ends within the aircraft cabin. In particular, the still limited awareness of human factors induced investigators to merely focus on *what* led to the event, in a sense of operating incorrect acts.

Similarly, theorists developed analysis models which were focused only on the pilot perception and situational awareness. The course of history then showed how this initial approach delivered significant improvements to aviation safety, as several lack of training, procedures, standards and performance were detected and corrected with the introduction of checklists, standard procedures, standard communication dictates and more. However, as only a partial side of human factors' scenario, this perspective has soon revealed its limited 'range of action' in increasing safety standards.

In later years, human factors analysts extended their outlook to the maintenance sphere, since several data indicated how critical for safety such framework had become. As a matter of fact, maintenance operators introduce risks in form of human errors each time they disassemble aircrafts components, in order to carry out inspections and repairs. The chart below[8] is referred to a statistical survey conducted by *Federal Aviation Administration - FAA* on general aviation, and shows the most common maintenance critical issues and their relevance on accidents, injuries and fatalities.

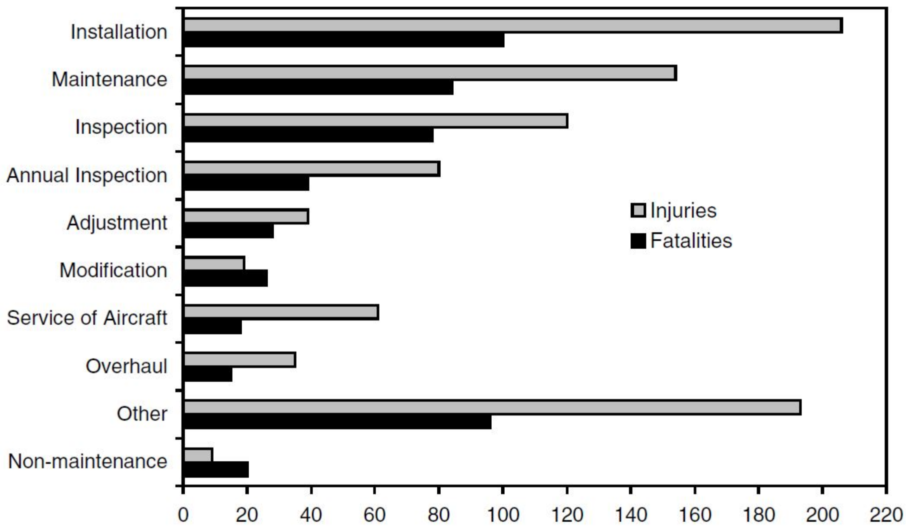

Fig 1.4.2: 1988-1997 Total fatalities and injuries by type of maintenance activity for GA maintenance related accidents - Source: FAA

The picture emerged was significantly alarming, as a significant range of maintenance-related errors and violations was brought to light. As a matter of fact, installation errors turned out to be the leading maintenance-related cause in aviation accidents.[8] Also, maintenance omissions, wrong component replacements, unsafe procedures, lack of supervision and more turned out to be common events.
To explain this statistical result, some assumptions should be considered. Firstly, the lack of awareness of maintenance involvement in disasters. Also, the increased aircraft technological complexity and the augmented economic competition among airlines. In particular, this last factor is responsible for inducing pressure on maintenance operators, as they have to accomplish tasks as soon as possible.[6]

Only in recent times, the human factors science enlarged its focus to supervisors, managers and decision-makers, tracing back the chain of command also to organizations and regulators. Finally, it became clear how safety liabilities in operations start from organizations' management boards. Actually, accidents and fatalities are preventable whenever organizations management would pay particular attention and resources on safety, as human errors represent a manageable issue within

the risk context. For this reason, companies must ensure the safety philosophy to be instilled in particular to managers, supervisors and operators in a training activity as well as training is performed for operating procedures, in order to educate managers to primarily consider safety standards, safety oversight and the constant updating of procedures.
On the opposite side, a lack of consideration for safety, often in favour of profit, can lead to a substantial increase in the probability that an accident may occur. It cannot be expected cabin crew, maintenance operators and air traffic controllers to work at their best way whenever company management is responsible for poor decision-making.

Thanks to the 'organizational safety approach', the human factors framework moved forward to a wider perspective. Investigative officers and safety experts overcame the limited interpretation of *'what happened'*, embracing the wiser *'why happened'* investigative approach, which allows to better trace the event genesis down to their roots. From this starting point, it became clear how psychology, ergonomics, sociology, physiology and more human sciences are involved in aviation safety and accident prevention. As an example, hardware and software human-machine interfaces had a significant evolution over the years, as their conceptual design has been continually improved thanks to ergonomics science progress.

Also, the management of work shifts, tasks and responsibilities has been considerably improved with the 'accident experience', as fatigue, overconfidence, performance anxiety, personal attitude and more factors were highlighted during the years. Factors related to decision-making and management skills became more noticeable as the automation and mechanical reliability increased in aircrafts and rotorcrafts. As a matter of fact, cabin operators assumed an increasingly supervisor role, to the detriment of active operator role, which requires higher cognitive capabilities, quick thinking and situational awareness.
In any case, when operating in poor or not adequate physiological condition, error probabilities increase, as well as lack of performance and attention, and misperception of hazards may occur.

The human factors science, thus, is still in process of development and understanding. Whereas mechanical and technical issues benefited from a solid scientific heritage, which led to a fast and efficient safety performance growth, the human behaviour science had not. The human factors, by the initial historic underestimation, have collected a limited amount of data over years which have often been misused, due to lack of experience and interpretation skills. Nowadays, a huge amount of human-factors-related doctrines has been formulated, in order to provide guidelines and adequate approaches for data analysis. Some of the most useful theories will be later reported, in order to clarify theoretical heritage of human errors and the related analysis methods.

1.5 Allocation of Responsibilities

As already mentioned above, aviation made an impressive step forward in safety when the importance of human factors within the organizational context has been recognized. The allocation of responsibilities and blame only to direct operators as cabin crews, maintenance operators and air traffic controllers surely represented the first step in human factors awareness. However, although this has resulted in a safety level noticeable improvement as training's and operations' care grew rapidly, it was not enough to guarantee neither adequate safety operational standards nor a fair allocation of responsibilities.

Even if standing above operating organizations and companies, safety responsibilities start from regulators. Regulators are in charge to instil the safety-oriented mentality in operators, in first instance by means of appropriate regulations. Regulations, dictates, but also safety culture shall not only pursue the target to avoid hazardous preconditions and system flaws, but also to open perspectives and to enhance safety perception to supervisors, managers, and directive board members. A clear and fair allocation of responsibilities which includes each organization level represents the most direct and functional way to make people aware of their role in safety, even if they are not piloting or maintaining an aircraft.

In order to deepen the matter related to regulations, and to better clarify what is meant with allocation of responsibilities, it is useful to refer to *Commission Regulation (EU) No 965/2012*, filed by European Union Commission, which is in charge to *"lay down technical requirements and administrative procedures related to air operations"*.[9]

Governments

By definition, governments have the administrative burden to design entities, referred as *Competent Authorities*, which assume powers and responsibilities to certificate operators and personnel and oversight the related operations. Certification and supervision activities then must be conducted by means of official government regulations. For these reasons, each state government is responsible for assigning areas of competence to each authority, coordinate them and ensure that required capabilities are fulfilled in order to adequately enable authorities in undertaking their role.

Authorities

Competent authorities are the entities which lead the regulatory hierarchy within the aviation framework. Such organization benefit from the work and knowledge of highly-specialized technical professional, which compose directive boards with the duty of regulate aviation in the territory under jurisdiction. In order to accomplish the multitude of activities and allow organizations, companies and stakeholders to perform their tasks and to discharge their responsibilities, authorities shall provide all legislative acts, standards, rules, technical publications and related documents to relevant personnel.
Hence, the competent authorities are responsible for establish and maintain management systems and safety. Policies and procedures shall be conceived in order to not only regulate safety, but even more importantly to instil the safety culture in operating entities and personnel. Authorities must ensure and constantly verify that organizations have a clear allocation of responsibilities, a sufficient number of personnel to perform tasks and make decisions, adequate facilities, knowledge, experience and training.

Operators and Companies

Operators, such as airlines, registered facilities and others, are responsible for the general conditions under which the flight and maintenance activities take place. In such context, they are required to establish internal policies and procedures, which have to be consistent with regulators' instructions and which have to be filed and specified to authorities. In particular, it is operators' and companies' responsibility to ensure that aircrafts/rotorcrafts and air/ground crew are trained, qualified and adequately equipped to operate, and to scrupulously allocate roles, tasks and responsibilities to personnel. Operators and companies must ensure the personnel to be aware of their roles, tasks and responsibilities. Also, operators and companies are responsible for properly supervising personnel's activities.
According to [9], the operator/company management system shall include:

- Clearly defined lines of responsibility and accountability throughout the operator, including a direct safety accountability of the accountable manager. The operator shall appoint an accountable manager, who has the authority for ensuring that all activities can be financed and carried out in accordance with the applicable requirements. The accountable manager shall be responsible for establishing and maintaining an effective management system.

- A person or group of persons shall be nominated by the operator, with the responsibility of ensuring that the operator remains in compliance with the applicable requirements. Such person(s) shall be ultimately responsible to the accountable manager.
- A description of the overall philosophies and principles of the operator with regard to safety, referred to as the safety policy.
- The identification of aviation safety hazards entailed by the activities of the operator, their evaluation and the management of associated risks, including taking actions to mitigate the risk and verify their effectiveness.
- A function to monitor compliance of the operator with the relevant requirements. Compliance monitoring shall include a feedback system of findings to the accountable manager to ensure effective implementation of corrective actions as necessary.

1.6 Human Factors, Helicopters and Organizations

As stated before, helicopters have rather been developed with the aim to accomplish flight missions which are typically more complicated than just moving people and goods. Aerial work, emergency missions, harsh environments expose rotorcrafts to major risks and tight error margins. In such context, human factors find the "best conditions" to arise in form of human errors, with a greater chance for a harmful event to occur.
Still, speaking of human errors, helicopter pilots cannot typically count on a high level of automation as commercial aviation aircraft pilots can do, as general flight conditions may often require manual piloting. Manual piloting demands for higher technical and sensitive skills, in addition to a deeper awareness of the vehicle response. Helicopters, by their very nature, tend to exacerbate the human factors conceding a smaller margin of error than fixed-wing aircrafts. A well-functioning automation typically may help to reduce risks, allowing pilots to pay more attention to flight parameters and automation systems supervision. Such circumstances reduce pilot's workload and fatigue, which represent major limitations of human performance.

Such assumptions make clear how essential are subjects as training, planning and safety policies within the rotorcraft's context. For such reasons companies and organizations, not only in the figure of pilots and maintenance operators, but also supervisors, managers and directive boards, are directly responsible for the safe carrying out of flight and ground activities. As such issue concerns both aircraft and rotorcraft aviation, the latter one more than the first still has a long way to go to instil the correct safety culture and allocation of responsibilities in airlines, companies, and organizations. Unfortunately, in this particular framework the trend is still the one to consider pilots, maintenance operators and air traffic controllers the most guilty in case of harmful events, if not the only responsible. Also, competent authorities may tend to evaluate human factors in rotorcraft accidents only as a operational personnel's affair.

For such reasons, in the following chapters the aspects concerning human factors, helicopters, organizations and their interrelationships will be better analysed. The purpose is to make a focus on the relevance of these subjects, in order to increase in the reader the awareness of such matters, to deepen the theoretical basis related to human factors, to give a practical demonstration of the use of human-factors-oriented analysis methods and taxonomies, to provide some suggestions and inspiration for future developments in a safety-oriented aviation world.

Chapter 2

Theoretical Background

2.1 Human Factors' Definition and Theory

'Human Factors' are defined as the whole of operations and procedures by which the human being acts in its working environment, and with objects, tools, facilities, other people, etc.[6]

The human factors science studies the characteristics of the human behaviour within the organizational context and the work environment, with the aim to get a better understanding of human nature and its implication within the aviation framework, to provide human performance and safety improvements.

First of all, human errors must be accepted as a common component of human nature. In relation to aviation safety, the best way to approach human errors is to consider that, sooner or later, they may occur. Therefore, procedures, systems, interfaces and whatever could be affected by human performance shall be designed following a *'human error tolerance'* approach.

The human performance takes place in a specific context, which is characterized by operational, social, organizational and environmental issues, and which affects them. With regard to human errors, it is common to refer to *'preconditions'* as the hazardous boundary conditions which lead people to misconduct and damaging acts. Preconditions can be referred to factual topics, such as organizational safety policy, systems weaknesses, weather conditions, as well as they can be referred to personality traits and operators' psycho-physical condition.

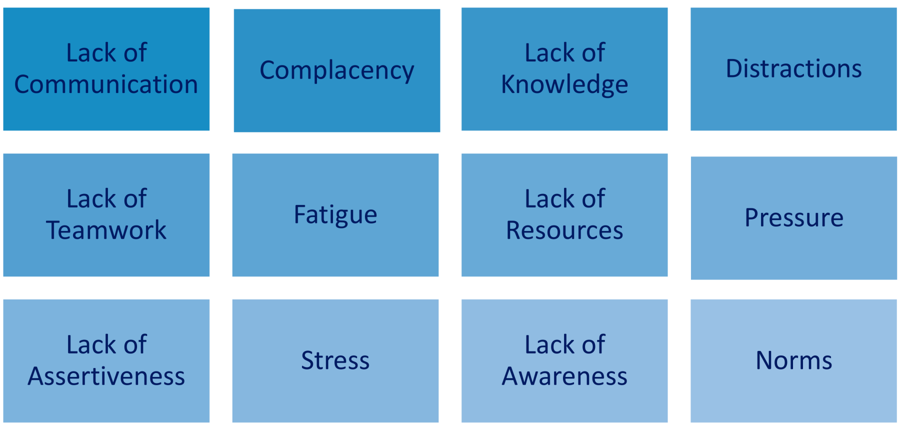

Fig 2.1: "The dirty dozen" preconditions categories

In the '90s, in order to help the preconditions analysis and investigation, *Transport Canada - Canadian Transport Federal Institution* introduced a 'preconditions classification', named as *'The dirty dozen'*, which claim to arrange twelve different precondition categories.

- **Lack of communication**: written and oral, it can lead to misunderstanding and misinterpretation.
- **Complacency**: related to single individual, it can lead to misjudgements.
- **Lack of knowledge**: low level of expertise, due to not adequate training or too short work experience in the field.
- **Distraction**: related to stress, lack of focus, rush or frequent outages.
- **Lack of teamwork**: ambiguity in roles and tasks definition, lack of trust, selfishness, miscommunications.
- **Fatigue**: sub-optimal psycho-physical condition, due to stress, excessive workload, insufficient rest.
- **Lack of resources**: incorrect or missing work tools, lack of personnel, time, quality and experience.
- **Pressure**: related to companies' business competitiveness, which often requires time containment in operations.
- **Lack of assertiveness**: accountability in expressing doubts and questions, proactive approach and moral integrity on work issues.
- **Stress**: need to maintain an adequate stress level, in order to accomplish tasks with concentration but no anxiety.
- **Lack of awareness**: low capacity to pay attention to the world surrounding, or rather *'tunnel vision'*.
- **Norms**: inadequate, outdated and hazardous work procedures.

It is essential to understand that human errors can be successfully managed by organizations and companies. However, to such purpose is it necessary a thorough understanding of the individual, organizational and institutional factors.[6]

The 'human errors theory' overview can be enriched with the *Skill - Rule - Knowledge Model* conceived by Jens Rasmussen in 1983. This human behaviour model classifies the individual decision-making ability within three categories.

- **Skill-based behaviour**: routine behaviour, related to repetitive activities for which dedication and thought process keep low.
- **Rule-based behaviour**: behaviour guided by procedures and norms.
- **Knowledge-based behaviour**: behaviour related to new and unforeseen circumstances, which the individual responds instinctively to, due to lack of known procedures.

The conceptual human behaviour framework provided by SRK Model has subsequently been enriched by James Reason with its *'Swiss Cheese Model'*, which will be better described later, and which reported a particular human errors' classification consisting in *'Active failures'* and *'Latent failures'*.

- **Active failures:** errors committed in operative circumstances, typically performing tasks, and which repercussions are immediate.
- **Latent failures:** errors committed in decisional circumstances, relative to valuations and estimates, and which repercussions will remain dormant until a triggering event will occur.

Basically, when a latent failure gets triggered, it becomes an active failure revealing its harmful effects. When this occurs, safety measures must contain the failure's impact. Whenever one or more active failures 'break down the walls', accidents are about to happen.

2.2 Hazard Identification

Often, an in-depth accident investigation reveals a number of not detected, misjudged or underrated warning signals, as operators, supervisors, managers and organizations neglect them and their potential effect.[6] In order to prevent such harmful events, as safety policy is a managerial topic, organizations have to outline a *'Safety Management System'* with the aim to define guidelines for hazard identification, risk assessment and management, and allocation of responsibilities within the company.

Generally, the 'hazard identification' activity is developed through the study and understanding of the different aerial works and missions.[2][3] Obviously, such activity is based on safety-managers experience and analysis perspective. The hazard identification is typically an iterative process, which has to be managed by means of both 'proactive' and 'reactive' concepts.

- 'Proactive' hazard identification is aimed to preview hazardous situations and risk factors related to the intended mission, prior to its performance. It can be carried out by means of brainstorming activity on safety recommendations and regulations, and by means of safety specialists' consultation. Typically, such activity is based on an intuitive logic.
- 'Reactive' hazard identification comes after accident, therefore it highlights hazards and safety weaknesses which may have occurred and which have already been proven. This sort of survey is performed by report analysis, witness interviews and inspections. On this case, the identification activity is based on a deductive logic.

Also, the hazard identification work - especially with the human factors perspective - can be performed by means of investigation techniques elaborated by international safety agencies. In this respect, the *ICAO Human Factor Digest n° 7*[10] represents a milestone in human factors investigation guidelines.

2.3 Risk Assessment and Management

Following the hazard identification, the successive stage is the *'Risk Assessment'* survey, which consists in evaluating the *'Risk Severity'* and the related *'Risk Likelihood'* associated to the hazardous events. Once the risk has been evaluated, it can be determined if such risk has to be considered *'acceptable'* or *'unacceptable'* for safety standards. If unacceptable, it becomes necessary to consider a risk mitigation strategy, which allows both a 'risk severity' and 'risk likelihood' reduction to an acceptable status.
It is important to understand risk assessment is not to be intended as an objective statistical research. It is a subjective valuation performed by safety managers, based on their experience and perspective.

Risk Severity	**Definition**	**Value**
Negligible	Superficial or no injuries, Negligible or no effects	A
Minor	Light injuries, Minor impact	B
Major	Serious injuries, Noteworthy local effects	C
Hazardous	Fatality, Effects difficult to repeat	D
Catastrophic	Multiple fatalities, Massive effects	E

Tab 2.1: Risk Severity Values

Risk Likelihood	**Definition**	**Value**
Frequent	Likely to occur many times	5
Occasional	Likely to occur sometimes	4
Remote	Unlikely to occur, but possible	3
Improbable	Very unlikely to occur	2
Extremely Improbable	Almost inconceivable that the event will occur	1

Tab 2.2: Risk Likelihood Values

Thus, risk assessment is performed by means of two scales of values, in terms of likelihood and severity. The two scales of values are combined with the following formula:

$$RiskFactor = RiskLikelihood \cdot RiskSeverity$$

The estimated *Risk Factor* is subsequently valuated by means of the *Risk Assessment Matrix* here below.

Likelihood \ Severity		Negligible A	Minor B	Major C	Hazardous D	Catastrophic E
Frequent	5	5A	5B	5C	5D	5E
Occasional	4	4A	4B	4C	4D	4E
Remote	3	3A	3B	3C	3D	3E
Improbable	2	2A	2B	2C	2D	2E
Extremely Improbable	1	1A	1B	1C	1D	1E

Tab 2.3: Risk Assessment Matrix

- Unacceptable Risk Level - Operations must be suspended and/or prohibited
- Tolerable Risk Level - Operations must introduce risk mitigation measures
- Acceptable Risk Level - Operations are valuated as safe, but a continuous monitoring activity is requested

On the basis of such risk valuation, it becomes necessary to set the related safety requirements, as well as an order of priority on achieving the targets. Typically, it is useful to perform a mitigation planning which includes a wide range of solutions according to cost-effectiveness benefits.

2.4 SHELL Model

SHELL Model has been adopted by ICAO as organizational model to be used for better understand and classify preconditions and hazards related to human factors. As risk assessment is useful to 'assign a quantity' to risk factors, SHELL Model concentrates on how such factors interact with people. As a matter of fact, the individual, represented as *Central Liveware*, is centered in a context which involves *Liveware*, *Hardware*, *Software* and *Environment*. The SHELL Model only considers interactions between the individual and each of these resources. Such model allows to catalogue factual data through a systemic analysis.[6]

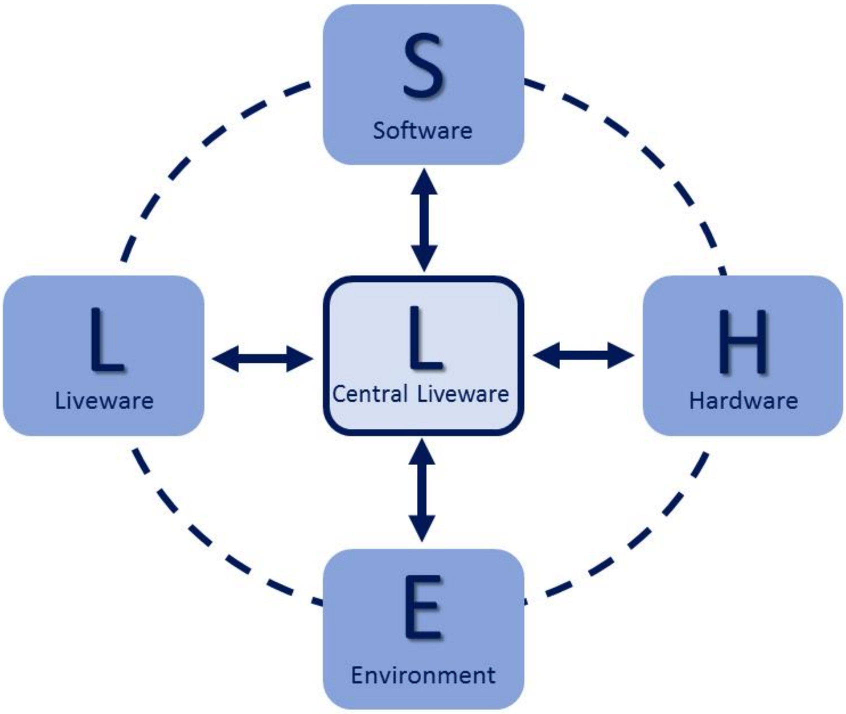

Fig 2.2: SHELL Model graphical representation

Liveware - Individual

The individual is centered in the model, as it is considered to be the most critical and most adaptable element within the system. It can be subject to several performance differences and limitations. As the individual is the centrepiece of the SHELL model, data collected are addressed to this central component. Some Liveware - Individual factors can be identified here below.

- Physical Factors
- Physiological Factors
- Psychological Factors
- Psycho-social Factors

Liveware - Liveware

The Liveware - Liveware interface concerns human relationships, which can be identified as Staff-Staff, Management-Management or Staff-Management relationships. As the individual is part of a team, and the team is part of a bigger system, the individual's performance can be conditioned by human practical interactions, such as communication (verbal and non-verbal) and visual signals, or also training, safety culture, workforce management, and more.

- Human Interface
- Personnel Management

Liveware - Hardware

The Liveware - Hardware interface represents the relationship between the individual and the machine. In general, the human-hardware interfaces must be designed considering the human physiology, including motor and sensorial limitations. It is also important to consider the human ability in adapting to sub-optimal or poor conditions, as such factor may hide critical issues.

- Equipment

Liveware - Software

The Liveware - Software interface includes all non-physical aspects of the system, such as procedures, manuals, check-lists, or also computer software interfaces. In general, software factors prove to be more difficult to find and to resolve than hardware factors.

- Human system interface

Liveware - Environment

The Liveware - Environment interface can be referred to each internal and external environment. Internal environment may include factors as temperature, ambient light, noise, air quality and more. On the other hand, external environment includes both the physical environment outside on the immediate work area as well as the broad political and economic constraints under which the aviation system operates.[2][3]. Originally, the related corrective actions were aimed to adapt the human to the environment. Only later it became evident how important can be adapting the environment to human capabilities.

- Internal Environment
- External Environment

2.5 HSI Model

Human System Integration is a processing model which provides to guide the systems' design process in order to consider and suit human capabilities and limitations. The design process guidelines are defined by certain human factors' domains which can be identified and classified. The following categorization is provided by the *Air Force Human Integration Handbook*[11]

Manpower

The number and the mix of personnel (military, civilian, and contractor) authorized and available to train, operate, maintain, and support each system acquisition.

Personnel

The human aptitudes, skills, knowledge, experience levels, and abilities required to operate, maintain, and support the system at the time it is fielded and throughout its life cycle.

Training

The instruction and resources required to provide personnel with requisite knowledge, skills, and abilities to properly operate, maintain, and support the system.

Human Factors Engineering

The comprehensive integration of human capabilities and limitations (cognitive, physical, sensory and team dynamic) into system design, development, modification and evaluation to optimize human-machine performance for both operation and maintenance of a system. Human Factors Engineering designs systems that require minimal manpower, provide effective training, can be operated and maintained by users, and are suitable and survivable.

Environment

Environmental factors concern water, air, and land and the interrelationships which exist among and between water, air and land and all living things.

Safety

Safety factors are design and operational characteristics that minimize the possibilities for accidents or mishaps to operators which threaten the survival of the system.

Occupational Health

Occupational Health factors are design features that minimize risk of injury, acute or chronic illness, or disability, and/or reduced job performance of personnel who operate, maintain, or support the system.

Survivability

The characteristics of a system that enable the crew to withstand man-made or natural hostile environments without aborting the mission or suffering acute and/or chronic illness, disability or death.

Habitability

Factors of living and working conditions that are necessary to sustain the morale, safety, health, and comfort of the user population which contribute directly to personnel effectiveness and mission accomplishment, and often preclude recruitment and retention problems.

In the analysis and investigation context, HSI Model provides a connection between SHELL Model and HFACS Model, which will be later explained. It represents a valuable tool for a more accurate recognizing of human factors in HFACS classifications.

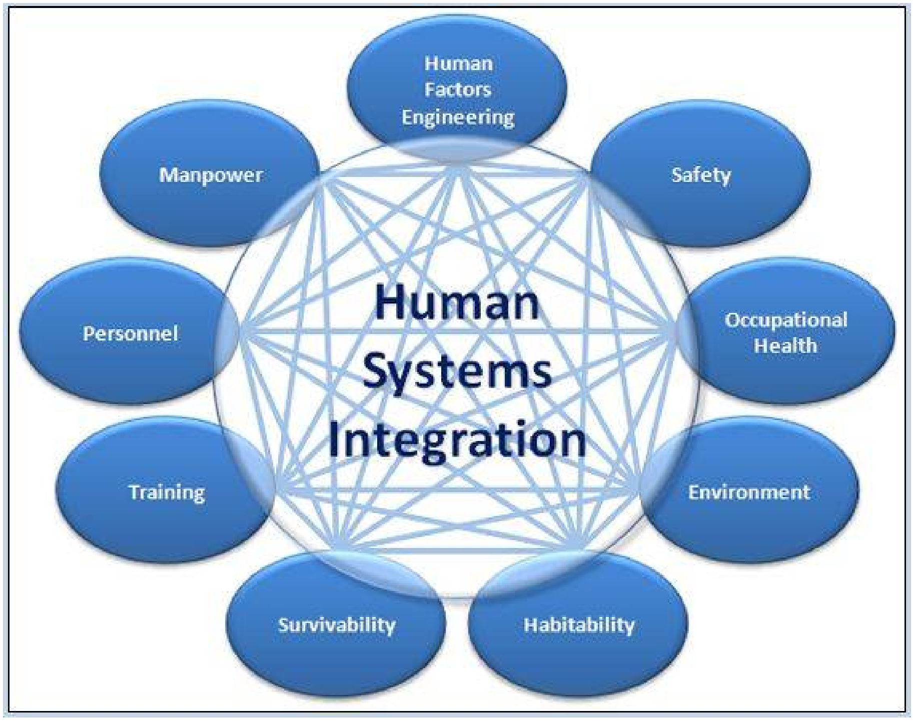

Fig 2.3: HSI Model graphical representation

2.6 Reason's "Swiss Cheese" Model

The "Swiss Cheese" model, introduced by James Reason in 1990, is considered to be a revolutionary model which underlines the importance of organizational issues relating to human errors' genesis. The Reason's theory states that human errors are not to be intended as an exception, but as an ordinary part of the human behaviour. As the human behaviour is normally influenced by the environment where the individual acts, it appears to be necessary to include the organizational context and the related safety culture within the analytical framework.
To get a better understanding about the Reason's theory it is important to underline that each accident or incident or dangerous situation can rely on several causes. From this perspective, several factors can be identified in any harmful event. Singularly, each of such factors may not directly lead to the accident, since the combination of these ones may be responsible of it, the so called "chain of events".
The Reason's model exploits the 'swiss cheese slices' allegory to identify and analyse the casual factors through which their concatenation lead to the accident.[6]. Each slice identifies a *'safety barrier'*, which consists in operative monitoring functions. Such safety barriers are aimed to ensure safety in operations, as they are projected to reveal, prevent, and reduce the harmful events and their effects. Safety barriers consist on procedures, monitoring, well-defined roles and responsibilities on each organizational level.
The holes in the cheese slices represent mistakes, slips, errors and failures in safety system. When adverse factors are able to overcome safety barriers, it is like the 'chain of events' passes through the slices' holes. If the whole 'safety barriers system' aligns its holes in a combination which allow the harmful events to realize a continuous chain, so accidents take place.
Each safety barrier/cheese slice represents an activity plan, as reported below:

- Organization management activities
- Work environment

- Operative personnel - work activities on aircraft
- Preventive safety measures

Reason's model underlines company's and managers' responsibilities in generating safety system failures, reducing safety barriers' efficiency.
In this context, the analysis perspective is focused on human factors and their role in such framework. However, the operative personnel, who directly works on aircrafts, is not considered as the direct and only responsible in case of accident, but rather a victim of prior poor management activities. Wrong management decision, which can be qualified as *'latent failures'*, are able to introduce within the chain of events some adverse factors. Typically, such factors carry with them dangerous effects which can reveal whenever certain *'active failures'*, intended as general operative failures, trigger them. It appears to be evident how more 'human error levels' are present, and how each of them can spill their own repercussions on the subsequent one.

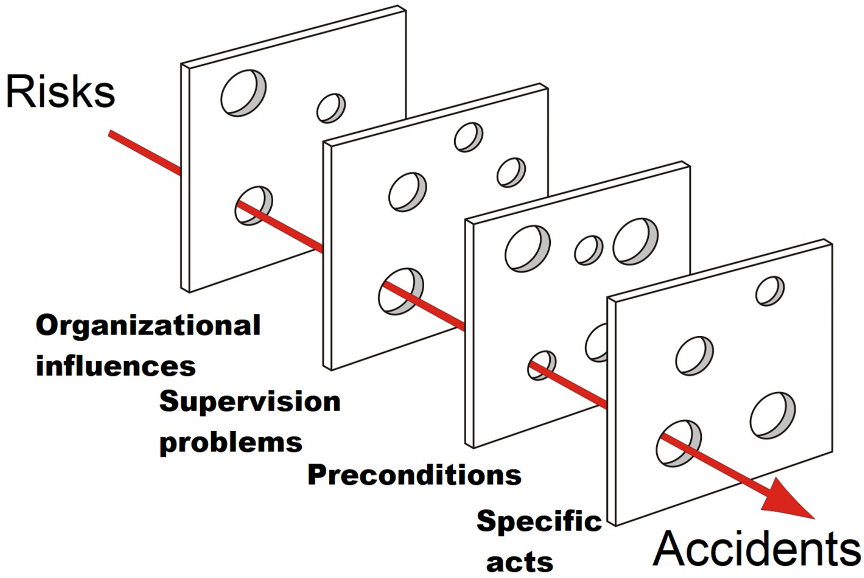

Fig 2.4: Reason's 'Swiss Cheese' Model

Taking into consideration the Reason's model in an investigative perspective, the approach to accident causation is based on the assumption that there are fundamental elements of all organizations that must work together harmoniously if efficient and safe operations have to occur.[7] According to such theory, and evaluating a strategical approach to it, it is recommended to start the analytical process from the active failures - *'Specific/Unsafe Acts'* - which directly turned out in the accident. Subsequently, the investigation process must proceed backwards along the whole chain of events, considering first *'Unsafe Preconditions'*, and then moving to latent failures identifiable in managing levels, such as *'Supervision Problems'* and *'Organizational Influences'*. What makes the Swiss Cheese model particularly useful in accident investigation is that it forces investigators to address latent failures within the causal sequence of events as well.[7] The Reason's model represents a versatile investigative tool, since its theoretical formulation allow to adapt it to each particular situation. Cheese slices and holes are not to be intended as a consolidated paradigm, but rather an adaptable way to visualize particular issues and levels, in order to create a functional agreement with the case. The ability in developing a correct and complete situational framework, with the aid of Reason's model approach, falls within the competence of investigating officers.

2.7 HFACS Model

As the Reason's model came into use in investigative organizations, it revealed not only its usefulness and versatility, but also conceptual limitations. The theoretical approach promotes the approach versatility, as well as it fails to identify the exact nature of the holes in safety barriers, and what such barriers really are. As a result, analysts, investigators, and other safety professionals have had a difficult time applying Reason's model to the 'real world' of aviation.[7]

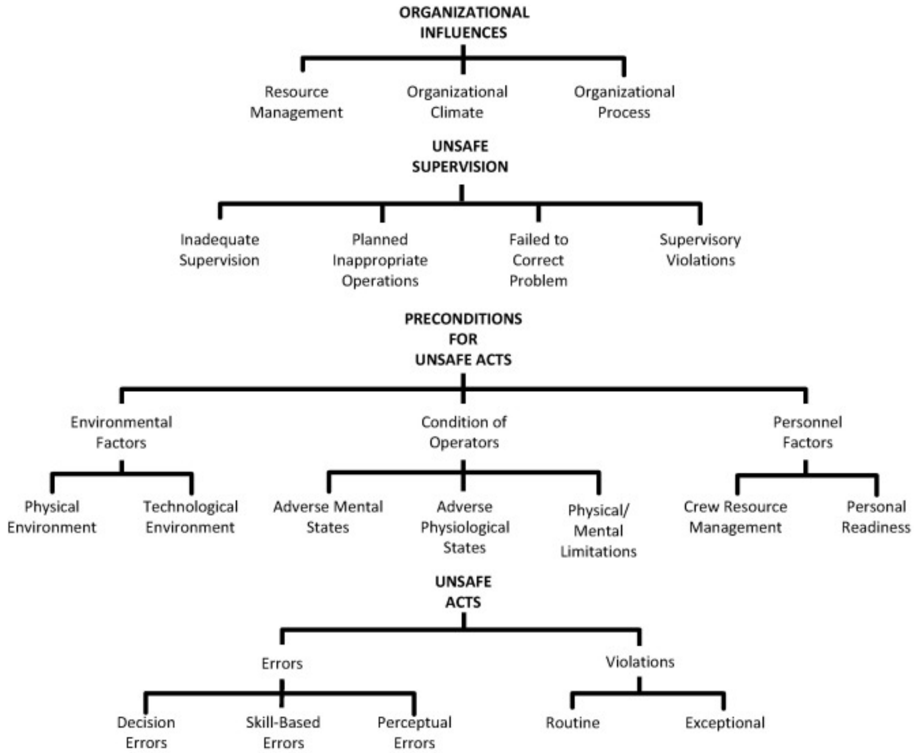

Fig 2.5: HFACS taxonomy

On this basis, Scott Shappell and Douglas Wiegmann developed between '90s and 2000 the *Human Factors Analysis and Classification System - HFACS*. The HFACS model was conceived in order to assign a detailed taxonomy of organizational levels and the related typical error categories, building around the Reason's model's foundations a more specific and clear model for the benefit of investigative officers.
In the same manner as Reason's model, the error is described and analysed through the human factors' perspective. In particular, it describes four levels of failure, each of which corresponds to one of the four layers contained within Reason's model.[7]

Unsafe Acts

The unsafe acts are typically related to aircrew and any direct flight operator, such as air traffic controllers and similar. It is possible to classify unsafe acts into two categories: *'errors'* and *'violations'*. 'Errors' represent unintentional acts or the failing in achieving the desired outcome from an activity. On the other hand, 'violations' represent the wilful disregard for the rules and regulations that govern the safety of flight.[12]
Subsequently, even these categories can be extended to better distinguish errors and violations characteristics. Errors include three basic error types, such as *skill-based*, *decision* and *perceptual*. Violations can be divided in *routine* and *exceptional*.

Preconditions for Unsafe Acts

Once the unsafe acts have been clarified, the investigation process must look for preconditions which allowed to unsafe acts to take place. As a first step, three major subdivisions of unsafe aircrew conditions were developed: *'conditions of operations'*, *'environmental factors'* and *'personnel factors'*. 'Conditions of operations' are typically related to adverse mental and physiological states and limitations, while 'environmental factors' are referred to physical and technological factors. 'Personnel factors', instead, can be associated to crew resource management and personal readiness.

Unsafe Supervision

Entering the unsafe supervision subject, the chain of events is traced back to its management level, where latent failures are common contributing factors to harmful events. As professional guidance and oversight are essential ingredients of any successful organization, it becomes clear how important can be to define a complete scenario of supervision failures. In particular, it is possible to distinguish *'inadequate supervision'*, which can be related to motivation and skills issues, *'planned inappropriate operations'*, which are about incorrect or insufficient supervision planning, *'failed to correct problem'*, which refers to those instances when deficiencies are "known" to the supervisor but allowed to continue unabated, and *'supervisory violations'*, when existing rules and regulations are wilfully disregarded by supervisors.

Organizational Influences

Each organization is responsible for conceive and instil in supervision and operational levels the best possible safety culture. Whenever lack of safety consideration or fallible decisions take place, such organizational errors often go unnoticed because of their latent state. 'Resource management' errors are typically referred to situations where human, equipment and monetary resources are not adequate to guarantee an efficient safety care. 'Organizational climate' can be referred to the work environment which companies create from top levels to operational levels, and how it can affect work performance. 'Organizational process' refers to corporate management, decisions and rules that govern the everyday activities within an organization.

2.8 'Case Analysis' Process

The methodologies which have just been reported are able to provide to safety analysts, investigators and users some fairly detailed algorithms on which to base their analysis. What really make a difference in the quality of the investigation and its related results, as well as the analysts' experience, is the *'case analysis' process* which is adopted. The 'case analysis' process consists in a sequence of methodologies developed in order to compose a more complex and structured analysis procedure, which may allow analysts to obtain multi-faceted and exhaustive results.
One of the purposes of this thesis consists in explaining and suggesting a particular case analysis process, based on some of the methodologies listed before.

1. **Event Analysis**: The first stage of the suggested case analysis process consists in a in-depth case evaluation, which starts from the factual data gathering and data interpretation. In this particular phase the analysts should take advantage of their personal experience in the investigation field, opening their perspective and *reading between the technical report's lines*, in order to figure out the whole factual sequence which led to the harmful event. They shall identify not only the unsafe acts, but also the latent preconditions which activated in the particular event sequence.

In this first phase of the analysis it is essential to adopt an approach which will guide the analysts along the whole investigation process. In this case, it is recommended a *human-factors-oriented* perspective, which can guide the analyst in the investigation of each unsafe act and precondition, by means of an approach which focuses on human acts and decision-making. Moreover, once the factual interpretation ended, the analysis shall continue with the *risk assessment* procedure, in order to assign an estimated *risk factor* to each condition that had implications in the occurrence.

2. **SHELL Model**: Once the case's preconditions have been traced and assessed, it is recommended to use the *SHELL Model*, in order to start the process which will lead to the allocation of responsibilities. In particular, the SHELL Model firstly defines the human interfaces' categories, allowing to allocate each precondition to its proper context. The schematization of preconditions helps to outline a more accurate definition of the failings, which will make easier for the user to orient within the HFACS taxonomy.

3. **HFACS Model**: The factual analysis concludes with the use of the HFACS Model, which includes its own factual taxonomy. At this point, acts and preconditions related to the event get an accurate name, description, and the correlation with the organizational hierarchical level responsible for the flaw. It is essential to realize how HFACS taxonomy is important in the achievement of analysis' results, as it opens the way to a complete and fair allocation of responsibilities. This one last thing must be intended as an occasion to improve the safety framework in each aviation context, rather than a mere allocation of blame.

4. **Risk Mitigation and Safety Recommendations**: Following the data investigation, it is essential to capitalize the findings which have been revealed with a proactive phase of the analysis, which consists in the conception of *safety recommendations* based on the case features, that may bring some improvements of the safety framework by means of suggestions, proposals and regulations.

In order to provide a demonstration of the use of such case analysis process, a real case study will be analysed in the following chapter.

Chapter 3

Case Study and Results

3.1 Forewords

Scope of this case study is to describe the aircraft incidents/accidents where possible by means of scientific methods leading to useful Safety Recommendations. Nevertheless, our goal is not to reinvestigate the accident, since we were not privy to all the facts and findings of the case, and does not intend to substitute in any case the official incident investigation. Instead, we used only those causal factors determined by the AAIB and CAA.
It is also important to note that: the case study is presented for illustrative and training purposes only, so while we have attempted to maintain the spirit and accuracy of the AAIB report by citing specific findings and analyses; in the interest of compactness here we have only presented those details necessary to support the causes of variability and contributing factors associated with the accident.
The reader is so advised that this report is for academic use only and is speculative in nature to describe the use of several analytical methods. Methods applied are based on:

- ICAO Circular 240-AN/144 -1993 Human Factors digest n.7 Investigation of human factors in accidents and Incidents.
- Wiegmann A., & Shappell, A. A Human Error Approach to Aviation Accident Analysis: Ashgate 2003. & D.o.D./USAF Human Factors Approach to Accident Analysis the human factors analysis and classification system.
- ICAO Annex 13.Manual of aircraft accident & incident investigation & and ICAO Doc 9576 Manuals.

Official report of the accident described below is available on website *www.gov.uk*, *'Air accident monthly bulletin December 2010'*.

3.2 Event Summary

On 22 September 2009, during a training flight with 2 persons on board, the helicopter *Schweizer 269C-1 'G-LINX'* suffered an in-flight emergency and subsequently crashed 1.2 NM west of Stalmine, on the eastern bank of River Wyre (Lancashire, UK). Both occupants have been fatally injured. The complete description of the event, the event pictures, the related and detailed information can be found in *Appendix A*, at the end of this report. Also, in *Appendix B* will be contained detailed information on Schweizer 269/Schweizer 300 helicopter type.

3.3 Event Analysis

As in *Appendix A* the whole factual information was reported, what it follows here below is a thorough analysis of the occurred facts. The aim of this process consists in elaborating a factual interpretation by the human factors perspective, revisiting the chain of events in order to trace a detailed framework of the preconditions and human error at every organizational and operational level.

No flight plan was presented to ATC before take-off.
As Private Pilot's Licence flights fall into the category of general aviation, a detailed flight plan was actually not required by Civil Aviation Authority.
However, a thorough planning of the flight should be processed during a briefing, in order to evaluate the flight path, environmental conditions and potential emergency occurrences. Considering the circumstances, it is possible that the instructor, as he used to perform the same flight mission several times during that period, has developed a sense of overconfidence in his piloting skills, helicopter health state and not apparent threats that such mission could involve.

'G-LINX' crashed at an approximate distance of 8 NM from Blackpool Airport, from where the rescue service departed in search of the wreckage. The rescue operation started at 11.04 am, but only at 11.52 am 'G-LINX' was localized. Given the low distance, if ATC had been able to consult a detailed flight plan, the rescue vehicles could operate in a more efficient and quick way.

While flying to the north of Blackpool Town, a witness saw the 'G-LINX' emitting "five or six puffs of black smoke".
Black smoke may be a sign of a general engine trouble, which can consist in a fatal engine failure as much as in a harmless incomplete fuel combustion. However, assuming that such occurrence could be confirmed, the black smoke would indicate a potential lack of maintenance/incorrect maintenance. Also, assuming that an engine malfunctioning was happening, it appears clear that pilots did not notice it as they continued their path towards Knott End-of-Sea. No alarm drew pilots' attention to the black smoke emission and the potentially related engine failure.

While flying above the sands approximately 1 NM north of the coast, a witness in Knott End-of-Sea watched the 'G-LINX' manoeuvring for several minutes at low heights.
Radar records confirmed that 'G-LINX' "twice climb to a height of a few hundred feet before descending again to a height consistent with having either landed or entered a low-level hover."[13] The pilot instructor's purpose, referring to recorded flight data, was to lead practice autorotations. However, flying at low heights above the sand in windy conditions represents a hazardous operation, as the sand can be aspirated in engine filters and components leading to a seizure. Despite the wreckage examination reported the engine filters to be clean, with no evidence of sand, such action is not to be neither intended as safe or recommended.

It is not clear if such activity was common to the other instructor pilots employed in the RFC. However, it appears evident that no one in the RFC had supervised on 'G-LINX' pilot instructor's behaviour and attitude. As the flight path was intentionally oriented to reach the sandbanks, it can be assumed that it was not the first time that such activity was led by the instructor pilot.

After leaving Knott End-of-Sea, 'G-LINX' moved toward the south, flying along the east bank of the river at approximately 400 ft. Then, an unspecified in-flight emergency occurred.

The *Civil Aviation Publication (CAP) 421 – 'Basic flying instructor (helicopter) handbook'* document contains conventions to practice autorotation procedure and the related flight preconditions to reach before any attempt. In particular, instructors are usually taught that when conducting a practice autorotation or engine-off landing the aircraft should be positioned into wind at the correct speed, no lower than 300 ft agl. As several other PPL instructors were consulted, it was stated that a practice autorotation would not normally be initiated below 1,500 ft.

During the investigation the AAIB consulted several instructors, the CAA Flight Operations Inspectorate and Staff Flight Examiners. All commented that "whilst a successful downwind landing is possible in favourable circumstances, it is always preferable to land into wind, especially in the event of engine failure. To do so requires sufficient height to re-position the helicopter if it is not already heading into wind and the existence of suitable terrain in the landing direction. If forced to land downwind a pilot would be presented with an unfamiliar situation and might be tempted to reduce the high apparent ground speed by applying aft cyclic control. This could result in an airspeed below that for minimum rate of descent."[13]

However, when the in-flight emergency occurred, the rotorcraft was then approximately 0.5 NM east of the west (upwind) bank of the River Wyre. Moreover, it can be affirmed that the instructor pilot was aware of recommended flight preconditions for a successful autorotation manoeuvre, as he used to conduct practice autorotation attempts in his instructor's activity. Also, the analysis of recorded manoeuvres on sands revealed to be coincident with practice autorotation, and revealed how both attempts were made heading into wind starting from an appropriate height. Another instructor, who operated the RFC from which the flight originated, affirmed that "when flying along the River Wyre he would do so approximately half a mile east of the high tide line to allow sufficient space for a dry landing into wind in the event of an engine failure."

Given the circumstances, why the instructor pilot did not maintain safety height and distance from the east side of River Wyre? And still, the last attempted manoeuver was an emergency autorotation or a failed practice autorotation?

As the recorded flight path confirms, the instructor pilot did not put the 'G-LINX' in proper conditions to attempt a successful autorotation procedure before the crash to happen.

The 'out of optimal conditions' practice autorotation hypothesis should be considered, as an analysis of previous training flights revealed the instructor pilot used to perform practice autorotation in proximity of the crash location. However, such theory seen to be excluded as the evidence underlines the uselessness of such training unexpected procedure. The instructor pilot never tried to attempt practice autorotation out of optimal conditions, nor any of other instructors interviewed affirmed that they would attempt a similar procedure.

An in-flight engine failure may explain an emergency autorotation, which ended up in the worst. However, it appears possible that the instructor pilot did fail into maintain a flight condition which might allow a good outcome of the manoeuvre.
If the engine hasn't shown any kind of problem before the shut-off, it can be assumed that the instructor pilot was deliberately flying at low altitude and too close to the riverside. In such case, the pilot did not consider the possibility that an in-flight emergency may occur.

If the engine has shown malfunctioning while 'G-LINX' leaving Knott End-of-Sea, why the instructor pilot would not prefer to attempt an emergency autorotation further from the riverside?

Among the possibilities, there was also the one to go back to the sandbanks, which were closer. However, even if a previous malfunctioning could explain the low height, it would not explain why the helicopter was led to an area which was not compatible with the persistent wind conditions. As resulted from investigation, the 'G-LINX' had to attempt a downwind autorotation which ended with the loss of control of the machine.

A possible explanation for the occurrence lies in the fact that the crash area was an area where usually the pilot instructor and his colleagues used to lead practice autorotation. There is a possibility that the instructor pilot chose to fly the helicopter onto a well-known area in order to attempt an emergency autorotation, making a misjudgement in the situational evaluation. Such error of assessment could be explained with an excessive workload and a stressful situation caused by the emergency.

The fuel injector servo and the right magneto maintenance issues.
By the wreckage examination emerged that the fuel injector servo and the right magneto showed some 'poor maintenance' state. In particular, the right magneto malfunctioning has been investigated as a potential cause for the engine shut-off. However, an in-depth test revealed that the right magneto could not cause the accident by itself.
By the way, such findings revealed the maintenance activity on the rotorcraft showed some flaws. In particular, the right magneto was worn more than normal, and misplaced. As the maintenance report confirmed the rotorcraft was regularly revised and it was declared as free of defects, it can be assumed that the helicopter's owner did follow a correct schedule for maintenance operations. On the other hand, the fuel injector servo and the right magneto issues can be traced back to an incomplete maintenance revision by maintenance operator, or even to an incomplete/incorrect maintenance procedure set by maintenance organization. Unfortunately, it is not possible to obtain more detailed information about on this issue to better understand the source of the maintenance failing.

The engine idle rpm and idle mixture issue.
The investigation revealed that the instructor pilot was not aware of the engine idle rpm and idle mixture test, which was contained on Schweizer 269C-1 Flight Manual. Actually, the 'G-LINX' checklist contained a contained a test procedure which was not coincident in parameters and flight phase to the manual's one, which only involved the idle rpm check.

As six different Schweizer 269C-1 flight instructors from different training organizations were interviewed about the issue, it was revealed that only one of them was aware of the idle mixture check contained on flight manual. It was found out that some variation of the idle speed check was carried out as part of pre-takeoff checks. Some of them just checked for a needle split and that the engine did not stop, but did not check for a specific rpm.[13]
Moreover, the pilots employed by the maintenance organization were also not aware about the idle mixture setting check or the pre-shutdown idle speed check in the Pilot's Flight Manual, and therefore had not performed them.

There was no requirement for the maintenance organization to check the idle speed and the idle mixture settings during the post-maintenance engine ground run. As a matter of fact, neither the maintenance organization nor the manufacturing company through the Maintenance Manual explained a clear procedure to perform such operation. However, according to the Pilot's Flight Manual, pilots should have been performing the related check at the end of the last flight of the day. It appears clear how among the Schweizer piloting community in the UK the awareness of these procedures had to be low.

How is it possible that Schweizer 300/Schweizer 269C-1 instructor and maintenance pilots ignored the idle rpm and mixture test, even if it was clearly contained in Pilot's Flight Manual?

It may be supposed that the CAA, as the major organization responsible for the whole Pilot Licences program, did not set adequate examination standards referring to the pilots' knowledge about flight test procedures for the particular rotorcraft type. Moreover, no one in CAA monitored the RFC's pilot instructors, operations, vehicles and procedures.

Also the RFC appeared to not pay sufficient attention to pilots' activities, training, procedures and checklists.

The aircrew was composed by an instructor pilot and a student pilot.
As the purpose of the flight was a training for the student pilot, in order to obtain Private Pilot's Licence, it is quite normal that the latter could be an inexperienced first officer.

Investigations revealed that the instructor pilot decided to fly the 'G-LINX' in some hazardous situations, such as the practice autorotation manoeuvres performed on a sandbank. Moreover, it emerged that in the flight final moments the rotorcraft was not led to an adequate height and position, referring to the river.
The student pilot should notice these in-flight hazardous situations, and offer his opinion in order to avoid the ongoing hazards. However, as he was trained by the instructor who he was flying with, it is possible that he might not acquire an adequate risk awareness referring to such situations. Moreover, it appears to be understandable that the student could be not comfortable in expressing doubts to a flight instructor about his piloting decisions.

Investigator assumed as a potential cause of in-flight engine shut-off an erroneous closure of the throttle done by student pilot. Such assumption could not be confirmed from the evidence, but several instructors stated how inexperienced students use to close the throttle abruptly, and that on certain occasions it may result in an in-flight engine stopping.

3.4 Identified Preconditions

The thorough analysis performed on the case showed that it was not possible to trace back the in-flight emergency actual causes, neither most of the acts that may have led to the fatal crash. Therefore, the following list of preconditions which made the accident situation contains both proven facts and speculations.

PC1 - The CAA did not require a detailed flight plan for general aviation flights.

PC1.1 - The instructor pilot did not neither file a flight plan, nor he may have led a pre-flight briefing, due to his habit to accomplish similar flight missions in that period.

PC1.2 - As a flight plan was not filed, the rescue personnel had no available information concerning the flight path. Consequently, the rescue teams have reached the crash site only after a relatively long time.

PC2 - The student pilot was an inexperienced pilot.

PC2.1 - The student pilot may have shown hesitation in expressing doubts on ongoing hazardous situations.

PC2.2 - The student pilot could cause the engine shut-off by closing the throttle abruptly, during a practice autorotation attempt.

PC3 - A witness affirmed that the ‘G-LINX’ was emitting black smoke while flying towards the sandbank.

PC3.1 - No alarms in the cabin reported the ’smoke-related’ problem to the pilots.

PC4 - The instructor pilot flew the ’G-LINX’ on a sandbank in order to perform practice autorotation.

PC5 - The pilots did not maintain safety height and safety distance from the east side of River Wyre. When the emergency occurred, they could only attempt a downwind emergency autorotation.

PC 5.1 - An eventual in-flight emergency, and the related stressful condition, may led the pilots to misjudge the situation and the best available conditions for the emergency autorotation attempt.

PC6 - The crash might be caused by an unexpected ’out of optimal conditions’ practice autorotation, and the following loss of helicopter’s control.

PC7 - The in-flight engine shut-off caused by student pilots by closing the throttle abruptly has emerged as a common issue in practice autorotation training activity when it is performed by means of a Schweizer 300 helicopter type.

PC8 - The instructor pilot was not aware of the engine idle rpm and of the idle mixture test, which procedures were reported in Schweizer 269C-1 Flight Manual.

PC9 - The ’G-LINX’ checklist contained a not adequate procedure related to an idle rpm test, and no one in the RFC organization had the task to carry out a regular inspection on it.

PC10 - Although the engine idle rpm test and the idle mixture test were reported in Schweizer 269C-1 Flight Manual, no maintenance procedure has been implemented in Schweizer 269C-1 Maintenance Manual by the manufacturer.

PC11 - The maintenance organization was not required to check the idle speed and the idle mixture settings during the post-maintenance engine run, whenever such items were not directly involved in a maintenance intervention.

PC12 - The ’puffs of black smoke’ and more maintenance issues could be an indicator of a lack of maintenance performed on the rotorcraft, although the maintenance report confirmed the ’G-LINX’ was free of defects.

PC13 - The CAA did not perform adequate formation, training and monitoring activities on UK RF’s instructor pilots, operations, vehicles and procedures.

PC14 - The RFC owner of the ’G-LINX’ did not perform adequate monitoring activities on its instructor pilots, referring to their professional attitudes and performances.

PC15 - The RFC owner of the ’G-LINX’ did not perform adequate monitoring activities on its operations, vehicles and procedures standards.

3.5 Risk Assessment

Preconditions	Phase	Hazard	Risk Assessment			
			Risk	Likelihood	Severity	RF
PC1 PC1.1 PC1.2	Planning Phase	Improper Emergency Plan	Mission Aborted	2	E	2E
PC1 PC1.1 PC2.1 PC11	Planning Phase	Modify Procedures	Incorrect Planning	4	C	4C
PC1.1 PC4 PC6	Flight Operations	Pilot Fatigue	Excessive Confidence	4	B	4B
PC1.1 PC8	Pre Flight Operations	Pilot Inattention	Pilot Lapses	3	C	3C
PC2 PC2.1 PC2.2	Pre Flight Operations	Improper Air Crew Training	No compliance with License Standard	3	C	3C
PC2.1 PC4 PC5 PC5.1	Flight Operations	Pilot Fatigue	Pilot Misjudgment	3	B	3B
PC3 PC9	Pre Flight Operations	Improper Ground Crew Training	Unrecognized Item During Visual Check	3	D	3D
PC3.1	Design Phase	Manufacturer Design Issue	Missing Alarm	3	D	3D
PC4 PC5 PC5.1 PC6	Flight Operations	Pilot Fatigue	Improper clearance with ground/water	3	E	3E
PC5	Flight Operations	Unfamiliarity with Landing Zone	No Situational Awareness	2	D	2D
PC7	Design Phase	Manufacturer Design Issue	Failure to Correct Known Problem	2	D	2D
PC10	Design Phase	Manufacturer Recommended Procedures	Missing Procedure	2	D	2D
PC12	Pre Flight Operations	Improper Ground Crew Training	Crew Lapses	3	C	3C
PC13 PC14 PC15	Organization	Organizational Activities	Inadequate Monitoring	3	D	3D

Tab 3.1: Risk Assessment

3.6 SHELL Model and HFACS

L	PC1 - The CAA did not require a detailed flight plan for general aviation flights.
	Liveware - Liveware: Regulatory Agency Regulation OC001 - Unit/Organizational Values/Culture
L	PC1.1 - The instructor pilot did not neither file a flight plan, nor he may have led a pre-flight briefing, due to his habit to accomplish similar flight missions in that period.
	Liveware - Individual: Planning Pre-Flight Liveware - Individual: Overconfidence PP109 - Mission Planning PP110 - Mission Briefing PC206 - Overconfidence
L	PC1.2 - As a flight plan was not filed, the rescue personnel had no available information concerning the flight path. Consequently, the rescue teams have reached the crash site only after a relatively long time.
	Liveware - Liveware: Crew Interaction Co-ordination OP002 - Program and Policy Risk Assessment PP109 - Mission Planning
L	PC2 - The student pilot was an unexperienced pilot.
	Liveware - Individual: Knowledge Skills/Techniques PC104 - Confusion PC204 - Emotional State
L	PC2.1 - The student pilot may have shown hesitation in expressing doubts on ongoing hazardous situations.
	Liveware - Individual: Anti-authoritative, resigned personality Liveware - Liveware: Crew Interaction Pairing PP102 - Cross-Monitoring Performance
L, H	PC2.2 - The student pilot could cause the engine shut-off by closing the throttle abruptly, during a practice autorotation attempt.
	Liveware - Individual: Knowledge Skills/Techniques Liveware - Hardware: Instrument Design PE204 - Controls and Switches AE103 - Procedural Error
L,H	PC3 - A witness affirmed that the 'G-LINX' was emitting black smoke while flying towards the sandbank.
	Liveware - Liveware: Supervision Quality Control Liveware - Hardware: Motor Workload SI003 - Local Training Issues/Programs PE202 - Instrumentation and Sensory Feedback System
H	PC3.1 No alarms in the cabin reported the 'smoke-related' problem to the pilots.
	Liveware - Hardware: Alerting and Warnings PE202 - Instrumentation and Sensory Feedback System
L, L	PC4 - The instructor pilot flew the 'G-LINX' on a sandbank in order to perform practice autorotation.
	Liveware - Liveware: Operational Supervision Liveware - Individual: Risk Taking SI004 - Supervision Policy PC206 - Overconfidence AV001 - Violation Based on Risk Assessment

L, L	PC5 - The pilots did not maintain safety height and safety distance from the east side of River Wyre. When the emergency occurred, they could only attempt a downwind emergency autorotation.
	Liveware - Individual: Inattention Liveware - Liveware: Crew Resource Management PC101 - Inattention AE201 - Risk Assessment During Operations
L	PC5.1 - An eventual in-flight emergency, and the related stressful condition, may led the pilots to misjudge the situation and the best available conditions for the emergency autorotation attempt.
	Liveware - Individual: Information Processing and Judgment PC504 - Misperception of Operational Conditions
L	PC6 - The crash might be caused by an unexpected 'out of optimal conditions' practice autorotation, and the following loss of helicopter's control.
	Liveware - Individual: Overconfidence Liveware - Individual: Information Processing and Judgment PC206 - Overconfidence PC210 - Misplaced Motivation PC504 - Misperception of Operational Conditions PP111 - Task-In-Mission Re-Planning AV001 - Violation Based on Risk Assessment
H	PC7 - The in-flight engine shut-off caused by student pilots by closing the throttle abruptly has emerged as a common issue in practice autorotation training activity when it is performed by means of a Schweizer 300 helicopter type.
	Liveware - Hardware: Instrument/Controls Design PE204 - Controls and Switches
L, S	PC8 - The instructor pilot was not aware of the engine idle rpm and of the idle mixture test, which procedures were reported in Schweizer 269C-1 Flight Manual.
	Liveware - Individual: Knowledge Procedures Liveware - Software: Standard Operating Procedures SI003 - Local Training Issues/Programs AE103 - Procedural Error
L, S	PC9 - The 'G-LINX' checklist contained a not adequate procedure related to an idle rpm test, and no one in the RFC organization had the task to carry out a regular inspection on it.
	Liveware - Liveware: Personal Operational Support Liveware - Liveware: Quality Control Liveware - Software: Checklists OP003 - Procedural Guidance SI004 - Policy
S	PC10 - Although the engine idle rpm test and the idle mixture test were reported in Schweizer 269C-1 Flight Manual, no maintenance procedure has been implemented in Schweizer 269C-1 Maintenance Manual by the manufacturer.
	Liveware - Software: Manuals OR008 - Informational Resources/Support OP003 - Procedural Guidance

L, S	PC11 - The maintenance organization was not required to check the idle speed and the idle mixture settings during the post-maintenance engine run, whenever such items were not directly involved in a maintenance intervention.
	Liveware - Liveware: Crew/Organization Task Assignment Liveware - Software: Regulations OR008 - Informational Resources/Support 0P003 - Procedural Guidance
L	PC12 - The 'puffs of black smoke' and more maintenance issues could be an indicator of a lack of maintenance performed on the rotorcraft, although the maintenance report confirmed the 'G-LINX' was free of defects.
	Liveware - Liveware: Crew/Organization Task Assignment Liveware - Liveware: Organizational Supervision SI003 - Local Training Issues/Programs
L	PC13 - The CAA did not perform adequate formation, training and monitoring activities on UK RF's instructor pilots, operations, vehicles and procedures.
	Liveware - Liveware: Personnel Training Liveware - Liveware: Quality Control OR006 - Accession/Selection Policies OP004 - Organizational Training Issues/Programs OP006 - Program Oversight/Program Management
L	PC14 - The RFC owner of the 'G-LINX' did not perform adequate monitoring activities on its instructor pilots, referring to their professional attitudes and performances.
	Liveware - Liveware: Personnel Training Liveware - Liveware: Quality Control OR006 - Accession/Selection Policies OP004 - Organizational Training Issues/Programs OP006 - Program Oversight/Program Management SF001 - Personnel Management
S	PC15 - The RFC owner of the 'G-LINX' did not perform adequate monitoring activities on its operations, vehicles and procedures standards.
	Liveware - Software: Standard Operating Procedures/Directives/Checklists Liveware - Software: Situational Awareness OC005 - Organizational Structure OP002 - Program and Policy Risk Assessment OP006 - Program Oversight/Program Management SF002 - Operations Management

Tab 3.2: SHELL Model and HFACS

3.7 Risk Mitigation

At the end of the investigation process all roles and responsibilities have been clarified. To really make productive and useful the work done, it is necessary to embrace a proactive perspective on the event, in order to perform a mitigation analysis of the risks that may have been revealed and found. The risk mitigation process is essential in turning hazards in safety defences.
However, it is important to maintain a realistic approach when performing risk mitigation activity, since it is necessary to understand that risks are part of aviation activities, and they cannot be completely eliminated.

Defence Analysis

Physical defences: These include objects that discourage or prevent inappropriate action, or that mitigate the consequences of events (for example, squat switches, switch covers, firewalls, survival equipment, warnings and alarms).

Administrative defences: These include procedures and practices that mitigate the probability of an accident (for example, safety regulations, SOPs, supervision and inspection, and personal proficiency).

Risk Mitigation Strategies

Exposure avoidance: The risky task, practice, operation or activity is avoided because the risk exceeds the benefits.

Loss reduction: Activities are taken to reduce the frequency of the unsafe events or the magnitude of the consequences.

Segregation of exposure (separation or duplication): Action is taken to isolate the effects of the risk or build in redundancy to protect against the risks, i.e. reduce the severity of the risk (for example, protecting against collateral damage in the event of a material failure, or providing back-up systems to reduce the likelihood of total system failure).

Effectiveness

Engineering actions: The safety action eliminates the risk, for example, by providing interlocks to prevent thrust-reverser activation in flight.

Control actions: The safety action accepts the risk but adjusts the system to mitigate the risk by reducing it to a manageable level, for example, by imposing more restrictive operating conditions.

Personnel actions: The safety action taken accepts that the hazard can neither be eliminated nor controlled, so personnel must be taught how to cope with it, for example, by adding a warning, a revised checklist and extra training.

Preconditions	PC1 - PC1.1 - PC1.2
Hazard Description	Missing Mission Planning
Assigned RF	2E - 4C
Mitigation Measures	Regulators should require also for general aviation and training flights to file and submit at least a minimal flight plan to the ATC or RFC, in order to evaluate the flight mission and get information about rotorcraft path and site position.
Defence Analysis	Administrative
Risk Mitigation Strategies	Loss Reduction
Effectiveness	Control Actions
New Risk/Hazard	Incorrect/Incomplete Mission Planning
Revised Risk Assessment	2D - 3C

Preconditions	PC 2.1
Hazard Description	Poor Crew Management due to inexperience/hesitation
Assigned RF	4C
Mitigation Measures	Training activities should focus more on the importance of crew cross-surveillance in operations. Students should be encouraged in giving advices. Part of the student's training should consist in checking 'on purpose-wrong' instructor operations and correct him.
Defence Analysis	Administrative
Risk Mitigation Strategies	Loss Reduction
Effectiveness	Control Actions
New Risk/Hazard	Student persistent hesitation
Revised Risk Assessment	3C

Preconditions	PC 2.2 - PC7
Hazard Description	Recurrent problem with abruptly closure of throttle
Assigned RF	3C - 2D
Mitigation Measures	Throttle control system should be enhanced by means of a metering device, such as a servo-throttle control, in order to avoid the engine shut-off when the throttle closure is abruptly performed.
Defence Analysis	Physical
Risk Mitigation Strategies	Segregation of Exposure
Effectiveness	Engineering Action
New Risk/Hazard	Incorrect throttle feedback, Reliability issues
Revised Risk Assessment	2C - 2D

Preconditions	PC3 - PC12
Hazard Description	Poor engine maintenance
Assigned RF	3D - 3C
Mitigation Measures	Improve maintenance procedures and checklists, in particular on items on which problems were found. Personnel should be trained to check carefully and more frequently such items.
Defence Analysis	Administrative
Risk Mitigation Strategies	Loss Reduction
Effectiveness	Control Actions/Personnel Actions
New Risk/Hazard	Wrong maintenance operations
Revised Risk Assessment	2D - 2C

Preconditions	PC4 - PC6
Hazard Description	Deliberate Hazardous Behaviour
Assigned RF	4B - 3E
Mitigation Measures	Improve experienced pilots' training and refresher courses. Improve organizational oversight activity, providing a better focus on pilots' behavior and attitude observation.
Defence Analysis	Administrative
Risk Mitigation Strategies	Loss Reduction
Effectiveness	Control Actions/Personnel Actions
New Risk/Hazard	Reiterated Hazardous Behavior
Revised Risk Assessment	3B - 2E

Preconditions	PC5 - PC5.1
Hazard Description	Misjudgement/Improper clearance with ground/water
Assigned RF	3B - 3E
Mitigation Measures	Pilots should be required to file a flight plan considering that potential in-flight emergencies may occur during each flight phase and/or above each overflown area. This operation aims to improve awareness of hazardous flight preconditions during the pre-flight phase.
Defence Analysis	Administrative
Risk Mitigation Strategies	Loss Reduction
Effectiveness	Control Actions
New Risk/Hazard	Incorrect/Inadequate emergency planning
Revised Risk Assessment	2A - 2D

Preconditions	PC8
Hazard Description	Test procedure unknown to pilots
Assigned RF	3C
Mitigation Measures	During examination, regulator's examiners shall deepen the aspirant pilots' knowledge in relation to pre-flight and post-flight helicopter's test procedures. Pilots should demonstrate a thorough knowledge of rotorcraft's Flight Manual.
Defence Analysis	Administrative
Risk Mitigation Strategies	Exposure Avoidance
Effectiveness	Control Actions/Personnel Actions
New Risk/Hazard	Forgotten test procedures
Revised Risk Assessment	1C

Preconditions	PC9
Hazard Description	Wrong procedures on checklist
Assigned RF	3D
Mitigation Measures	Organizations should periodically supervise checklists and the related procedures. Supervisor must ensure that checklists contain the same procedures reported in flight manual and maintenance manual by manufacturer.
Defence Analysis	Administrative
Risk Mitigation Strategies	Exposure Avoidance
Effectiveness	Control Actions/Personnel Actions
New Risk/Hazard	Wrong procedures on checklist
Revised Risk Assessment	1D

Preconditions	PC10
Hazard Description	No correspondence among Flight Manual and Maintenance Manual
Assigned RF	2D
Mitigation Measures	Manufacturer should in any case check if procedures contained in Flight Manual and Maintenance Manual are matching. Such issue should also be considered by regulators when proceeding with type certification.
Defence Analysis	Administrative
Risk Mitigation Strategies	Exposure Avoidance
Effectiveness	Control Actions
New Risk/Hazard	No correspondence among Flight Manual and Maintenance Manual
Revised Risk Assessment	1D

Preconditions	PC11
Hazard Description	Essential maintenance check not required
Assigned RF	4C
Mitigation Measures	Regulators should enforce the check procedures' schedule, in order to avoid harmful occurrences due to not revisioned items.
Defence Analysis	Administrative
Risk Mitigation Strategies	Loss Reduction
Effectiveness	Control Actions
New Risk/Hazard	Missed maintenance revision
Revised Risk Assessment	3C

Preconditions	PC13 - PC14 - PC15
Hazard Description	Not adequate safety culture from regulatory organization/ company/airline/facility
Assigned RF	3D
Mitigation Measures	Safety culture should be instilled by regulators to companies and facilities, and from these to operational personnel. Whenever still not existing, a safety board responsible for conceiving safety training activities and courses should be formed. Each aviation company and individual should be firstly inspired by regulators in to improve its safety culture.
Defence Analysis	Administrative
Risk Mitigation Strategies	Loss Reduction
Effectiveness	Control Actions
New Risk/Hazard	Improved but still not adequate safety culture
Revised Risk Assessment	2C

3.8 Safety Recommendations

To conclude the analysis, some critical circumstances that emerged during the investigation will be now discussed and deepened in order to obtain some useful safety recommendations. Such statements should be intended as suggestions to enhance the community safety level, on the basis of information and data revealed from the case study.

No flight plan was presented to ATC before take-off.
The analysis revealed that the pilots did not file any flight plan. It can be also assumed that not even a pre-flight briefing has been performed, as no one in RFC and ATC had knowledge of 'G-LINX' flight mission.

The *CAP 694 - The UK Flight Planning Guide*[14] states that:
"An FPL may be filed for any flight".

Furthermore, in the case list of missions which a flight plan is necessarily required for, there is no specific mention for PPL training flights.
PPL training flights, on account of the inexperience of students and of the practice emergency manoeuvres which are typically performed in such situations, should require a better consideration as hazardous missions by regulator organizations.

In the present case, the real motivation that conducted to the in-flight engine stoppage has not been detected. However, whatever the circumstances were, an approximate rotorcraft position was unknown to ATC. Such situation led to a 45 minutes long wreckage searching operation, while the helicopter crashed just few NM from the airport. Even if AAIB case report[13] states that pilots died instantly, it appears clear how in general a timely aid can make a difference.

Still, a complete and adequate flight plan should consider potential emergency situations and the related in-flight preventive actions. If an emergency situation has never been experienced or supposed to occur, the chances to succeed decrease.

No less importantly, filing a complete and adequate flight plan would be an essential training activity for students, consisting in learning how to file one and its relevance referring to safety issues.

For these reasons, it can be recommended:

"A detailed and complete flight plane must be filed in case of PPL training flights, in order to reduce potential harmful events and circumstances, guarantee prompt rescue services and educate the PPL's students to a better consideration for the safety."

The student pilot may have hesitated in recognizing instructor pilot's misjudgments, errors and/or violations and in correcting him.

Crew resource management in aviation has always been one of the most important human factors involved in accidents, although along with other human factors was not duly considered if not in more recent times.
Nowadays, crew communication issues have made major improvements, thanks to the crew resource management training programs and procedures that have been studied along the years.
In particular, it is well known how problematic can be situations where crew pairing and seniority are cause of bad situational assessment and management.

By the case analysis, it can be supposed that certain mistakes, such as misjudgments, errors and violations have been committed by the instructor pilot. And still, it can be supposed that the student pilot did not dare to correct his instructor, as he may felt not legitimate to express opinions.

CAA reports in Pilot Private License for Helicopters' guidelines the human performance and communications as common subjects in theoretical knowledge examination.[15] However, no mention to such issues is made when practical training activities are described.

For these reasons, it can be recommended:

"Regulator organizations should enhance the crew resource management training also in PPL training activities, theoretical and practical. Particular attention should be paid to seniority issues, with the help of well-trained instructors, who should instill in students the necessary confidence to express their opinions."

In-flight engine shut-off has emerged as a Schweizer 300's common issue when students have to close the throttle for practice autorotation.

Referring to Schweizer 300 engine idle setting and practice autorotation manoeuvres, from the AAIB investigation has emerged that:

"It is not necessary to close the throttle abruptly but instructors commented that students sometimes did so and that on occasion this had resulted in the engine stopping."[13]

The Schweizer 300 family, and in particular the Schweizer 269C-1 type, are known to be forgiving towards piloting errors. In fact, such ability is recognized to be one of the most appreciated features of Schweizer 300, as it makes the type recommended for training activity.

However, there is the possibility that such 'errors recovery skill' can hide a major issue relative to the throttle closure, as the related engine shut-off can be recovered when flying in optimal autorotation preconditions. If, on the other hand, the engine shut-off due to the abrupt closure of the throttle happens when the rotorcraft is out of correct autorotation preconditions, the Schweizer 300's forgiving nature may be not enough to recover from such situation, in particular when in real emergency situation.

For these reasons, it can be recommended:

"Schweizer 300's manufacturer should reconsider the throttle device design, in order to make it more reliable in emergency and training situations, when unexperienced and/or troubled pilots may regulate it abruptly."

The black smoke, the fuel injector servo and the right magneto maintenance issues has emerged although the helicopter was officially declared 'free of defects'.
From AAIB Accident Report[13] no more detailed information are available, however it can be clearly affirmed that something went wrong with 'G-LINX' maintenance activities. As it is not possible to have a deeper and full picture of the situation, it can be supposed that distractions came both from maintenance operators and maintenance supervisors.

For these reasons, it can be recommended:

"The maintenance organization should review and enhance its operational procedures, operators' and supervisors' skills and attitude, in order to avoid a recurrence of similar unnsafe situations."

The instructor pilot had deliberately flown the 'G-LINX' over a sandbank at low heights, getting intentionally the helicopter in a hazardous situation.
To fly helicopters at low heights above the sand is commonly known as an unsafe act, as such situations typically evolve in a engine or/and moving parts seizure. In fact, sand can easily infiltrate in air intakes and exposed junctions due to rotor's and wind's air flows and related circulation. Moreover, if such operative situation gets reiterated for a long time and multiple occasions, it can also damage rotor blades due to sandblasting.

It is not clear why the instructor chose to perform practical autorotation above the sand, neither if it used to. It can also be supposed, even though it seems unlikely, that the last attempted manoeuvre has been performed in a particular 'out of safe preconditions' practical autorotation attempt.

However, from investigation emerged that nobody in the RFC supervised on the instructor pilot's attitude. In fact, no one noticed how he was not used to file flight plans, but used to deliberately fly in proven hazardous situations. As reported in AAIB Accident Report:

"The RFC from which the accident flight originated did not have training or operating manuals and did not maintain formal training records for each of its students. Consequently it was not possible to determine the minimum height at which its instructors were expected to operate the aircraft in cruising flight or when initiating practice autorotations."[13]

Not only it can be considered a lack of personnel supervision, but also a lack of written personnel procedures by the RFC.

For these reasons, it can be recommended:

"The registered facility should review and enhance its personnel operational procedures and its supervision activities on personnel's attitude and skills, in order to avoid a recurrence of similar unnsafe situations."

The flight instructor was not aware of engine idle rpm test and of engine idle mixture test, although such procedures are contained in Schweizer 269C-1 Flight Manual.
As emerged from AAIB's investigation, the general awareness of the engine idle rpm test and the idle mixture test was found to be insufficient within the UK Schweizer 300 pilot community.

Such issue is not to be considered only a pilot's skills matter or a RFC problem, but rather a regulator problem.

The requirements for the licensing of helicopter pilots and flight instructor helicopter pilots are set out in the *Joint Aviation Requirements Flight crew licensing (Helicopter)*, known as JAR-FCL 2. In *Appendix 1 to JAR–FCL 2.320E* is stated that:

"The skill test for a FI(H) rating [...] comprises oral theoretical examinations on the ground, pre-flight and post flight briefings and in-flight FI(H) demonstrations during skill tests in a helicopter."

However, the skill test lists in JAR-FCL 2 do not contain any mention to post-flight procedures skill test, neither to helicopter type's flight manual. What can seem just a detail has instead evolved in a community issue. In fact, the engine idle tests are post-flight tests, and they are well described in Schweizer 300's Flight Manual, but they are mostly unknown not only to private pilots, but also to instructor pilots.

For these reasons, it can be recommended:

"Regulations for Private Pilot Helicopter License and Flight Instructor Helicopter License should be reviewed, in order to give a better consideration to all test procedures contained in flight manuals, in particular to post-flight procedures."

The engine idle rpm test and the engine mixture test are contained in Schweizer 300's Flight Manual, but no mention to such test and related checks is contained in Schweizer 300's Maintenance Manual.

The AAIB Accident Report stated that:

"There was no specific requirement to check engine idle speed or idle mixture setting. The Schweizer 269C-1 maintenance manual did not specify such a check either, unless the settings had been adjusted."[13]

For some reason, the helicopter manufacturer decided to not set a tight schedule for the engine idle speed and engine idle setting, although it considered the related test procedures and stated that these had to be performed in every post-flight routine at the end of the day.

Also, neither the regulator responsible for the type certification had noticed that a non correspondence was present in flight and maintenance manuals.

This issue led to a misinterpretation of the engine idle subject. In particular, it also emerged that the regulator did not require to maintenance organizations to perform the engine idle rpm check and the engine idle mixture check unless the engine idle would be directly involved in a maintenance intervention.

For these reasons, it can be recommended:

"Manufacturers must ascertain that flight manual and maintenance manual are consistent for the type, referring to pilot test procedures and related maintenance checks, in order to guarantee an adequate consideration of the issues when scheduling maintenance activities."

"Regulators responsible for type certification must ensure that manufacturers had correctly filed flight manual and maintenance manual, in accordance with test procedures and checks indicated in both ones."

Regulators did not impose a tight safety culture in training aviation framework, leaving too much leeway to registered facilities.
The AAIB Accident Report stated that:

"In the UK, training for the issue of a PPL is conducted at Registered Training Facilities (RFC). RFCs are required to register with the CAA and to certify that they comply with certain required conditions but no approval is required. No inspections are carried out, no training or operations manuals are required and it is not necessary for the RFC to maintain formal training records, although some choose to do so. Registration remains valid until either the CAA is informed that PPL training is to cease or the CAA establishes that training is not being carried out safely or is not in compliance with JAR-FCL"[13]

It is evident how the registered facilities are not adequately monitored and legitimate by the regulator in carrying on their operations. When regulator leaves a so wide freedom of action to registered facilities, it is natural that the latter ones do not use to consider safety and regulations as their first targets in operations. In such conditions, the safety standard in operations, procedures, training and attitude is inevitably set to decline.

For these reasons, it can be recommended:

"Regulator must heavily review and enhance its Registered Training Facilities certification and license retention standards. Regulator must schedule frequent and thorough inspections, require for certified training and operation manuals, and require for the RFC to maintain formal training records. The RFC certification should have a deadline, and renewed only after inspection by regulator supervisors."

Chapter 4

Software Requirements for Implementation

4.1 Automation and Safety Analysis

It has already been mentioned in this dissertation how the use of computers and automated technologies has rapidly increased in the aviation context during the years. Nowadays, the term *'automation'* represents an endless domain of implementations and intelligent systems, such as auto-pilot and auto-management systems, flight and maintenance training simulators, airline management tools and more.

However, in the world of aviation, the safety analysis and investigation represents a sphere of activities where automation did not replace the human's experience and critical thinking skills. In fact, even if investigative activities are performed with the aid of theories and methodologies, the human ability to interpret data represents an essential skill that cannot be fully replaced by computers' computing power. Nonetheless, in this *'age of automation'*, the main question is:

Can the computing power replace the human's experience in conducting an analysis process?

This question opens the discussion about one of the main objectives of this dissertation, which consists in starting an investigation about the possibility to implement a complete safety-oriented case analysis process in a software. In particular, the aim is to find the way to exploit to some extent the hardware's computing capabilities in order to perform an automated risk assessment analysis. The software should be seen as a helpful tool which may support, by giving an assessment based on its particular algorithm and information database, the analysis process conducted by human analysts in relation to typical aerial missions.
With particular reference to the main argument of this thesis, the software tool's final goal should consist in to assess risks which may be involved in a typical helicopter aerial work mission, in order to outline an exhaustive risk scenario and provide to a human decision maker the whole information needed to make GO/NO GO decisions.

4.2 Safety-Critical Software

Before delving into the analysis, it is necessary to provide a better explanation about this particular typology of aviation software and how they are typically conceived by software developers. In fact, the relationship between software and human factors, as the software represents the contact point between human's ability to think and hardware's ability to compute, needs to be deepened.

As software are made by manufacturers, and they are thought by customers and stakeholders to accomplish needed tasks, it is clear how the human factors are included in such framework from way back in their creation and use. For such reasons, it can be referred to an 'art of modelling' aviation software, which nowadays has been further developed and consists in a official documentation containing mandatory guidelines to follow in order to create any aviation software.

In cases such as the one described in the previous section, aviation software are referred as *safety-critical system*. A safety-critical system, in general, is a system whose operation or failure to operate can lead to a hazardous state. Referring to systems as aviation software, it can be affirmed that safety-critical software are those intended to recover from hazardous states, or intended to mitigate the severity of an accident, or still intended to process data or analyse trends that lead directly to safety decisions, and more.
On this matter, the official guidelines to safety-critical software development are contained in *DO-178C, Software Considerations in Airborne Systems and Equipment Certification*. Published in 2011 by *Radio Technical Commission for Aeronautics - RTCA*, in cooperation with *European Organisation for Civil Aviation Equipment - EUROCAE*, this is the primary document by which the certification authorities such as *FAA*, *EASA* and *Transport Canada* approve all commercial software-based aerospace systems.

The following sections of this chapter aim to deepen just a few facets that the relationship software-human being can show. First of all, it will be treated the topic related to *functional requirements for implementation*, as a general guidance to write functional requirements and generate *use cases*. Subsequently, will be addressed the *human-machine interface* issue, as the representative of all non-functional requirements that can be considered during the software development. In conclusion, a suggestion of a 'human factors safety analysis' software will be presented.

4.3 Functional Requirements and Use Cases

Functional Requirements

Each software, especially the safety-critical software, originate by the need to perform tasks by means of a computer. As has already been said, tasks and requirements can originate by customers, stakeholders, manufacturers and more, in order to accomplish related activities.
Hence, the tasks that is asked the software to perform represent the functional requirements for the software implementation. Functional requirements specify functionality of the system to obtain desired performance. Looking for a better definition for functional requirements, it can be affirmed that they define precisely what inputs are expected by the software, what outputs will be generated by the software, and the details of relationships that exist between those inputs and outputs.[17]

However, writing requirements represents the first step in the human factors' involvement in software developing. As a matter of fact, the information about requirements is handed by customers to software developers. Thus, it is essential for the requirements to be written in such a way that they result to be clear, understandable, unambiguous. If not, the first leak in the system can reside here. In order to perform a correct functional requirements writing, some basilar guidelines are here below reported from [17] in order to meet DO-178C dictates.

- *Identify each requirement*: Each requirement must be reported individually, in a concise but complete way. It has to be considered that whenever a requirement is not declared, the software will not implement the related functionality.
- *Minimize redundancy*: Redundancy, in addition to an unnecessary documents' elongation, may open to ambiguity, manifold interpretations, and other dysfunctional issues.
- *Organize the requirements into logical groupings*: In particular, whether the software will be supposed to be a multitasking one, it is essential to clarify all the different task groupings by logical order.
- *Aim for comprehensibility by customers and users who are not software experts*: The target should always be the comprehensibility of written requirements. It can be not only useful, but also essential, to write requirements in order to make the information comprehensible to people who is not expert in software developing.
- *Document requirements that can be tested*: As such software are involved in safety-critical missions, it is essential for the requirements to be tested when the software is done. Whenever a requirement turns out to be impossible to test, then the related functionality cannot be implemented.
- *Identify safety requirements*: Requirements can have a scale of priorities, and safety-related requirements are undoubtedly the most important ones.
- *Implementation free*: each requirement should state what is required without identifying how to implement it. In general, requirements should not specify design or implementation.

It can also be useful to complete the functional requirements list with an overview, which should introduce the reader to the project idea, and with a document containing a more detailed explanation of the requirements, which can also be filed by means of examples and diagrams.

Use Cases

When the functional requirements list is complete, the information can be gathered and summarized in documents named as *use cases.* In particular, a use case represents a methodology which can be exploited to better identify, clarify, and organize requirements.
In general, a use case gathers a set of possible interactions between the software and its users, following the logical sequences, referring to tasks and goals expected from the software. Use cases can be used to better organize functional requirements, but also they contribute to model user interactions, record scenarios from events to goals, describe the main flow of events, and describe multiple levels of functionality.[17]

Use Case:
Description:
Related System Goals:
Primary Actor:
Preconditions:
Postconditions:
Main Success Scenario:

Tab 4.1: Use Case Model

To correctly file a use case, it is necessary to follow the instruction below.

- *Use Case Title*: The use case title must define the normal operation context.
- *Description*: A more detailed description of use case's normal operation context.
- *Related System Goals*: System goals are the expected targets that should be accomplished by means of the system.
- *Primary Actor*: The primary actor is the entity who initiates and utilizes the system.
- *Preconditions*: Preconditions are the pre-existing conditions in which the system starts working.
- *Postconditions*: Postconditions are the conditions left by the system after fulfilling its tasks.
- *Main Success Scenario*: The main success scenario consists in the description of operations carried out by primary actor and the system under optimal circumstances, following the correct temporal/logical sequence.

In conclusion, a use case helps to define the primordial idea of software operations and functions. From the use case a first software architectural concept is conceived, based on the normal operation scenario with high-level requirements and goals. Obviously, the use case represents a starting point for the software development, as more detailed information about low-level and non-functional requirements, secondary tasks, architectural issues and various complication will arise with the continued operation. The use case has therefore to be intended as a project guidance, which can change and evolve in the process.

4.4 Human-Machine Interface

One of the most important and interesting issues which bonds software and human factors is represented by the *human-machine interface - HMI*. The HMI is a wide branch of human factors' science, which for the most considers subjects as ergonomics, physiology, trend of human error, and more.

In aviation history some HMI issues have been known since the very beginning of operations, as they come from human basilar needs: comfortable seats, clear readability and easy access to flight instruments, proper application of strength on control bars.
However, piloting activity changed over the years, as new technologies and solutions made their own income in aviation. HMI began to involve an increasing multitude of factors, details and related requirements, which include also the software implementation and all the facets that may have a role in the relationship with human users.
Speaking of human factors and software, the HMI development has met a great momentum when automation has taken hold in aircraft and rotorcraft cabins. Unfortunately, the understanding of human-related issues for HMI has followed over the years a path which was marked by several accidents and loss of life, as many were the harmful events which HMI has emerged to have a role in.
For such reasons, aviation software engineers and developers must assume a human-factor-oriented perspective while developing new safety-critical systems, and always ask themselves the question: *"What in software interface, architecture, general features may lead pilots and/or users to error?"*

In order to better understand the HMI subject, some important issues in human-machine software interface are here below discussed.

Screen Design

The display screen is the means by which software interacts and communicates with users. Typically, the screen design activity is guided by those which are considered to be the software primary functions. The screen design activity includes several issues, as such development work will result in the screen interface architecture.
The general target is to make the information exchange among software and human as clear, simple, fast but complete as possible. As a matter of fact, human errors may be generated by misunderstandings, excessive/missing amount of information, and the excessive workload that managing software may require. Hence, such functional targets are reached by means of several dictates, the most important of which are discussed here below.

- *Language and Vocabulary*: In order to avoid misunderstandings and/or illegibility due to language, text messages must be written in a universal and familiar language, such as English. Syntax, simplicity and clarity of words and abbreviations are essential.
- *Visual Architecture*: The screen must be easily readable. Text messages density must be adequate, and each item - such as options, information, command entry areas, prompts, advisory messages - shall be distinctive in location, format and arrangement.
  Moreover, it is essential for data entry to be easy and user-friendly. It is necessary to develop a design which averts the human error risk, for example in such situation where two opposite data inputs are placed close to them.
- *Reduced Workload*: Screen design should ease the user's work, making it simpler and lighter. Hence, it is essential that software is provided by a directly usable form, with operation title and context always clear and listed.
  Particular attention shall be also paid to user's fatigue and mood, as a difficult software operational mode and a reiterated request for data entry may irritate users.
- *Color*: Humans tend to associate colors to information and the related relevance. An adequate use of colors in text messages and information displaying can be useful to speed up the cognitive process and enhance the users' responsiveness.
  However, colors also bring along with them several downsides. Color combinations, number of colors, brightness, lightness and contrast shall be carefully targeted, since such items can tire and/or confuse users. For example, background colors should be achromatic colors, such as black or dark grey, in order to maximize the visibility of foreground colors and avoid eye fatigue. Still, due to the same reasons, the number of colors shall be reduced under a recommended maximum.

Interaction

The interaction between software and user can be considered as the heart of the HMI problem. Data input and data output are what gives meaning to software, allowing the user to explore and exploit the functions implemented. These ones are precisely what guide the software developers in the interaction method selection. Some of such methods are reported here below.

- *Question & Answer*: This interaction type is suited to not particularly demanding situations, such as routine data entry, well-known data entry, limited question-answer sequence, no need for an instantaneous computer's response. Question & Answer method can also be the right choice in near real-time situational simulators, which can be used in land-based training activities.

- *Form Filling*: The Form Filling approach turns out to be the best method when software functions require a flexible data input and a related data drafting process. Software which implement Form Filling data exchange are typically slow in their elaboration and response, and because of its features they can be considered not suited for unexperienced users.

- *Menu Selection*: Such method is suited for software which do not require any data in input, but only a selection among their available features. Typically, the software response is fast, but it is necessary for the user to have at least a little knowledge about software functions.

- *Command Language*: Command Language interaction type is required when software have a wide range of functions and requires and require codified data entries, especially if data entry sequence can change in the course of using. The user shall be highly trained to manage such software and the related interactions.

For each of this interaction methods, and for those which are not included in the list, it is necessary for developers to adequately treat subjects as consistency, clarity, number of options, appropriate response, and every issue that may prove to be a potential trigger for human error.

Audio and Verbal Display

Audio and Verbal displays are typically implemented in aircraft and rotorcraft software which are developed to manage airborne systems or flight data. Such items consist in audio warnings, which turn out to be necessary in case of hazardous situation and/or emergency. A general audio signal consists in a repetitive alarm sound, which has to be accompanied by a visual text reporting information about the outstanding conditions. On the other hand, verbal signals directly provide a brief statement, which has to be clear and simple in order to solicit an appropriate and immediate response by users.
To better evaluate audio and verbal signals implementation in software it is possible to make a categorization of audio and verbal displays.

- *Tones*: Audio tones are preferable for status indication and automatic communication referred to short and limited information. In particular, tones represent the best solution in case of routine situations. However, it is necessary for the user to learn the meaning of each tone and make the correct association to the related information.

- *Complex Sounds*: Non periodic complex sounds, as well as tones, are particularly indicated for brief and immediate communication. However, such sounds are preferable in case of uncommon situations, in order to work as alarms. It is essential to assign a unique tone to each alarm, and it is necessary for the user to learn each the meaning of each one. Users must be capable to make the correct association with the information as fast as possible.

- *Speech*: Speech represents the most articulated case for verbal displays, and it is appropriate when information has to be qualitative and quantitative at the same time, as the meaning of the alarm is intrinsic in signal. Speech alarms are intended to provide multidimensional information, in some cases giving users a solution advice.

Still, audio and verbal displays must be evaluated in their duration and frequency, in order to avoid disturbing occurrences for users. In fact, it is not only necessary for such alarms to be clear and simple, but also to provide information without interfere or cause problems to users. Loudness and sound frequencies may become a strong disturbance for humans, especially in case of emergency, and reduce the quality of users' performance. Also, the alarms management and power off shall not interfere with ongoing operations.

Error Management

In reference to human error, one of the most important features that an aviation software must provide is a certain tolerance and detection ability for mistakes and slips which users may enter in the system. Software must check and detect eventual human errors in data input, as soon as possible. The error detection shall be communicated to users with a clear message, which contains the complete information about the error. In fact, not only it is necessary to make users aware of their own errors, but also provide them the possibility to stop the ongoing process, correct the wrong action and input the proper information/command.
In order to provide an adequate error tolerance, in particular when users must perform a vital decision and entry the related input to software, it is mandatory to require a confirmation before implementing any action. Such feature will not protect users from making wrong choices, but at least will protect users from typing or misunderstanding errors, limiting the human error range.
Another desirable software functionality would be the one which consists in tracing user's errors and make a valuation about user's decision-making ability. Especially in case of essential systems, it is necessary for the software to recognize a difficult ongoing situation and provide users some kind of help. Depending on cases and situations, help may consist in simple detailed information texting, which may support users in their decision-making activity, or in an active help, interrupting wrong data entry and relieve users in operations and activities. Also, the same users should be able to request some automated help, in case of confusion, limited decision-making capabilities, excessive workload and unusual situations.

4.5 Suggestion: Risk Scenario Assessor

Once that some of the mandatory guidelines for aviation software developing have been provided and discussed, it is possible to make an attempt to conceive a software able to perform an assessment of the risk scenario related to particular aerial work missions.

Software Concept Description

The idea is to conceive a risk scenario assessor software, which contains both an algorithm and a database of potential risks related to the particular mission features.

This software shall be able to ask to users to select a particular mission, the related working and environmental conditions for the case study, and other details that may assume a main role in the mission scenario. Also, the software shall take in input the whole information in order to gather enough data and elaborate the risk assessment analysis of the scenario.

The analysis' algorithm shall be based both on a human-factors-oriented taxonomy and on an exhaustive risk categorization of helicopter's typical aerial missions. In doing so, the software can make accurate risk database surveys and provide a thorough risk evaluation for the case study.

Software's output shall consist in a list of potential risks related to the described mission scenario, each one accompanied by a quantitative risk factor, in order to provide to users a full picture of the situation and an advice about a GO/NO GO final decision to make.

For these reasons, the software is required to be a *near real time 'what if'* simulator, and must be considered as a *safety-critical system*. Moreover, its interface must be designed following HMI general dictates.

Functional Requirements

The first step of software conceiving consists in the analysis and the discussion of customers/stakeholders software concept. By the description above, it is possible to set the following points.

- *Near real time software*: This feature is typical of telecommunication and computing software - the required software belongs to the latter one. In general, near real time software introduce a time delay due to information processing, between the occurrence of an event, or an input, and the response's display. In this case, such requirement can be interpreted as a non-need to get a real time situational elaboration and response, which is a typical feature of flight simulators and airborne system management software.
- *'What if' simulator*: The 'what if' simulation is a typical tool application which is used to determine in advance the consequences of operator-initiated actions. In fact, these systems are particularly useful in case of decisional-making training and evaluation. In this case, such feature will be exploited in order to put users in the condition to reason about decisions to make.
- *Safety-critical system*: As discussed in this chapter's introduction, safety-critical systems are software typically involved in safety-related issues management. This requires the software to be designed and tested fulfilling tight regulations and dictates.
- *HMI dictates*: HMI dictates are essential when designing safety-critical systems. However, in this particular case the basilar needs for use by humans can be associated with commercial needs, in order to make the product attractive for customers.
- *Human-factors-oriented analysis methodology implementation*: Since the scope of this software is to provide an automated safety analysis by means of a human-factors-related perspective, it is essential to conceive the software's algorithm on a proven and reliable analysis methodology.

Given the circumstances, it is now possible to write software's functional requirements.

1. The software shall be developed following the *safety-critical mission* regulations.
2. The software shall be a *near real time 'what if'* simulator.
3. The software shall be able to show users questions and related answers.
4. The software shall be able to input users' answers and use it in assessment process.
5. The software shall base its analysis on a reliable human-factors-oriented methodology and taxonomy.
6. The software shall base its analysis on a reliable risk assessment database specialized in helicopter's aerial missions.
7. The software shall be able to output the results of a risk assessment analysis and an appropriate advice about the mission's risk level.
8. The software shall be developed following the HMI dictates.

Use Case

Use Case:	Risk Scenario Assessor for Safety Analysts
Description:	This use case describes the risk assessment activity of helicopter's typical aerial missions, in order to provide to safety analysts exhaustive information and advice in relation to the mission's risk level.
Related System Goals:	To support safety analysts in the proactive analysis of helicopter's aerial missions feasibility, providing an exhaustive mission's risk assessment based on a human-factors-oriented perspective. The analysis results should help safety analysts in making GO/NO GO decisions.
Primary Actor:	Safety Analyst
Preconditions:	A safety analyst is in charge to evaluate the feasibility of a particular helicopter's aerial mission. Such evaluation shall be based on the mission's expected risks and conditions. The analysis shall be performed from a human-factors-oriented perspective.
Postconditions:	Safety analyst has obtained an exhaustive risk assessment of the particular mission. The working conditions and environment have been evaluated by the software, which provided a complete list of potential risks. Each of them has been accompanied by a quantitative risk factor. The analyst is now able to make a GO/NO GO decision.
Main Success Scenario:	1. Safety Analyst activates software. 2. Software submits to safety analyst a list of questions in order to outline the mission scenario. 3. Safety Analyst answers to software's queries, selecting the expected conditions for the mission. 4. On the basis of analyst's answers, software gathers data and lists the potential risks that may be related to the case study from its risk assessment database. 5. Software outputs a list of potential risks and the related risk factor, in addition to an automated text message containing a decision-making suggestion. 6. The safety analyst, in view of the above, makes a final decision about the mission's feasibility.

Tab 4.2: Risk Scenario assessor's use case

Case Study Conceptual Design - Example

An example of the software conceptual design is provided below.

The initiation of the procedure should be dedicated to collecting the essential mission's data, such as type mission, weather conditions, flight zone's features, and more. Each menu selection should recall from database some potential risks which are related with the entered data.

```
Select the type of mission:
1.Sling Load Carrying
2.Pipeline and Power Line Patrol Inspection and Maintenance
3.Aerial Spraying Operation
4.Emergency Medical Service (HEMS)
5.Search and Rescue (SAR)
6.Firefighting Service
7.Imaging and Patrol Service
8.Civil Air Transport (CAT)
9.Offshore
```

Fig 4.1: Type mission selection

```
Select the day/night condition:
1.Day
2.Night
```

Fig 4.2: Day/Night condition

```
Select the terrain characteristics:
1.Lowland
2.High-Mountain
3.Jungle
4.Water
5.Sand
```

Fig 4.3: Terrain Characteristics

```
Select the weather conditions:
1.Calm Weather
2.Rain
3.Wind
4.Storm
5.Intense Cold
6.Extreme Heat
```

Fig 4.4: Weather conditions

```
Did the pilot file a flight plan?
1.Yes
2.No
```

Fig 4.5: Flight plan information

Once the general conditions of the mission have been defined, the software should move to collecting data with reference to cabin crew or operational personnel. Here below a couple of examples are reported.

```
Did the have enough rest before take-off?
1.Yes
2.No
```

Fig 4.6: Pilot fatigue information

```
Is the pilot familiar with the flight zone?
1.Yes
2.No
```

Fig 4.7: Flight zone awareness

When the operational data collecting is complete, the human-factors-oriented analysis methodology should guide users through a deeper perspective, asking for information related to operational oversight and management.

```
Did the airline/organization check pilot's licence?
1.Yes
2.No
```

Fig 4.8: Pilot's skills oversight

```
Did the airline/organization filed adequated checklists?
1.Yes
2.No
```

Fig 4.9: Checklist updating

```
Hazard: Possible impact with helicopter - LOC - CFIT (NIGHT)
Risk Assessment: 4E
SHELL Model: Terrain Feature Obstacles
PE1XX Physical Environment
-------
Hazard: Mountain operations - Adverse pressure gradient along the valley (NIGHT)
Risk Assessment: 4D
SHELL Model: External Weather - Turbulence
PE105 WIND BLAST
-------
Hazard: Mountain operations - Adverse weather - LOC - Upset (Icing) (NIGHT)
Risk Assessment: 4E
SHELL Model: External-Weather-Actual and Forecast
AE206 DECISION-MAKING DURING OPERATION
-------
Hazard: Meteorological Charts not updated (NIGHT)
Risk Assessment: 3C
SHELL Model: Written Information-Maps and Charts
OP003 PROCEDURAL GUIDANCE/PUBLICATIONS
-------
Hazard: Improper emergency plan (NIGHT)
Risk Assessment: 2E
SHELL Model: LL-Worker Management-Personnel-Managerial Operating Pressure
PP109 MISSION PLANNING
-------
Hazard: Unfamiliarity of landing zone (NIGHT)
Risk Assessment: 3D
SHELL Model: Individual-Psychological Factors-Experience-Night Time
SP003 LIMITED RECENT EXPERIENCE
-------
Hazard: Pilot Fatigue (NIGHT)
Risk Assessment: 4E
SHELL Model: Individual-Psychological Factors-Experience-Night Time
AE206 DECISION-MAKING DURING OPERATION
-------
Hazard: Organizational Activities - Inadequate Monitoring
Risk Assessment: 3D
SHELL Model: LL-Worker Management-Personnel-Managerial Operating Pressure
OP006 PROGRAM OVERSIGHT-MANAGEMENT
-------
GO/NO GO decision suggestion: NO GO
```

Fig 4.10: Final Output

At the end of the process, users should obtain in output a list of potential risks, accompanied by the related risk factor. A final sentence should indicate to users the best decision to make.
For the example provided it has been assumed a HEMS mission, during night, on high-mountain terrain, strong wind conditions and with no flight plan filed. It has also been assumed that the pilot had not rest enough before take-off and it is not familiar with the flight zone. Still, the airline did not check pilot's licence neither pre-flight checklists prior to mission.

Chapter 5

Conclusions and Future Developments

This dissertation has been written with the aim of providing a starting point in the study of the relationship between helicopters and safety, in the particular perspective of human factors. The human factors perspective in aviation safety, as well as the rotorcraft's evolution in the aviation history, have been both characterized by an uncertain and slow development, making of them two young and fascinating sciences with the need to be deepened especially in their particular connection.

In particular, as several arguments has been mentioned, one of the purposes was to make the reader aware of the extent and all the different perspectives that the *'helicopters - human factors'* subject can reveal.

In the Chapter 1 of this thesis, after the historical introduction it has been discussed how the relevance of human factors in safety has been progressively found out all over the years. Moreover, it has been shown how statistics and data interpretation have been essential in such context.

Nowadays, the attention is slowly getting out of the aircrafts and rotorcrafts cabin in order to focus also on supervisors, managers and organizations responsibilities. All this is the result of a wise perspective in the data interpretation that tries to enlarge the vision of the preconditions which led to the harmful occurrences. However, during the bibliographic research it has emerged that the annual statistical data reviews, such as [5], are used to report as accident causes only unsafe acts, poor decision-making acts or technical issues. It is evident how such data are reported only from the *'operational issue'* perspective, and thus they need to be interpreted, as they do not actually reveal whether and to what extent organizations are involved in harmful occurrences. There is typically no sign of items such as *'Missing or unclear regulations'*, *'Insufficient funds allocation for safety standards'*, or *'Poor safety culture within the organization'*.
Even if it was not one of the purposes of this research work, it should be considered as an inspiration for a future development the attempt to re-think the way and the categories in which safety data are addressed, gathered and reported, adopting from the beginning a more *organizational-oriented* perspective. The aim is the evaluation of a different approach to statistical surveys, in order to focus the attention and list more specifically those organizational issues which have been found out to be cause of accidents.
Still, speaking of statistics, has emerged how the general aviation suffers a lower attention in comparison to the commercial aviation. As the latter is more related with fixed-wing aircraft, we understand how those got the most benefit from the higher safety standards requested and developed all along the aviation experience. It would be advisable to concentrate more attention to the general aviation and to the related rotorcraft aviation, in order to increase reliability standards in a sector that appears lagging behind the others.

The Chapter 2 of this dissertation aimed to give to the reader a summarized overview of the most important analysis methodologies which can be related to the human factors approach in investigation. The bibliography related to such theories can be easily considered as endless, hence it would be too obvious to affirm that the study of the main analysis methods should be deepened. The real point is to understand that these methodologies become useful tools only when the experience and the talent of investigators know *how* to use them, combining procedures in order to ensure satisfactory analysis results. As mission analysis and accident investigations are not mathematical equations, and they have not a single specific result, it is essential for an analyst to understand how to orientate the thorough knowledge of these analytical methods in order to conceive its own case analysis process. The last one has been described and subsequently implemented in the following case study should be better discussed and evaluated, in order to find possible improvements and even more ways to obtain useful safety recommendations.

The Chapter 3 has been dedicated to the investigation of a case study which involved a flight training helicopter. The most important and educational facet of such activity has been the need to learn how to *'read between the lines'* of factual data and technical reports, in order to get a wider interpretation to facts and retrace the whole chain of events. The practice to interpret technical data appears to be necessarily related to the quality of work of investigators who operate on the field, as the most information are collected, the best can be the reconstruction of the events. In this particular case, the data collected in the report allowed a good reconstruction of the events, even if some shortcomings impeded an even more accurate analysis. As a matter of facts, no information were available about the pilots psycho-physical condition, neither about the RFC managers and their oversight activities, or about the maintenance and test scheduling. Hence, it would be recommended to better educate investigators to the relevance of collecting event information with more attention to human factors, in order to give to safety analysts more elements and allow them to make a better outline of the general picture.
The risk assessment procedure has been based on a previous analysis work, the result of which is represented by a risk assessment table reported in [2] and [3]. Such table turned out to be an essential and useful tool in the assessment of risk factors, and it would be highly recommended its use in other investigations in order to test it and increase its range of utility by the direct application in case study solving. As this risk assessment table is oriented to helicopters typical aerial missions and the main actors of them, such as pilots and the same helicopter, it would be also highly suggested to complete it with a list of potential risks directly related to operational personnel such as maintenance operators and air traffic controllers. Moreover, it would be also highly recommended to enlarge the potential risks collection and assessment to risks directly coming from organizations, in accordance with what has been said all along this thesis.

The argument that has been addressed along the Chapter 4 is the one with the greatest development potential throughout this thesis. In the *'era of automation'*, the investigative activity still cannot renounce to human experience and critical thinking. However, it is required the development of technologies and tools that can improve the quality and the breadth of the safety analysis.
What is really important to realize is that the contact point between computing power and critical thinking is represented by the *algorithm*. The algorithm is what helps humans to think more as computers, making order and articulating the analysis process, as well as it helps computers to think more as humans, giving them the instruction to exploit the computing power with a sense.
Speaking about all the arguments that in this chapter have been discussed, maybe an entire thesis would not be enough to fully describe all the facets that human factors and software can

show in their connection, neither to develop the suggested *'risk assessor'* software which has been reported in the form of example.
First of all, a strong recommendation for future developments is the one to pursue the study and the implementation of a software which concept can start from the suggested example. It would also be important to evaluate the benefits that such automation can bring to the mission analysis activity, as well as the commercial aspect of this activity.
Moreover, it can be suggested to enlarge the research and development activity also to other software concepts which may assume a major role in the investigators and safety analysts training in relation to the human factors approach. As a matter of fact, it is possible to consider a concept of software which can guide the aspirant investigator through a solid and proven analysis process, by means of case studies, implemented human-factors-oriented methodologies and the HFACS taxonomy.

Back to the analysis of the accident, we dealt the accident model as an epidemiological causal model using a description of the air transport operator (using the Reason model) according to which, the systems are defined in relation to their structure, the latter formed by multiple components with distinct interfaces on various organizational and technological levels.
The model assumes that accidents are the result of a combination of latent hazards and unsafe acts that continue to propagate sequentially. The model considers a variety of factors, including environmental and organizational effects. The application of the model allows to search and create security barriers and defenses along the chronology of events (contributing factors). The model draws conclusions from latent factors that sometimes do affect the system outcome not directly. The model is a great step forward compared to the simple cause and effect linear model and allows us to trace previously invisible conditions of systemic inadequacy.
However, with the evolution of technology and industrial philosophy, we assume that in the near medium future (5-10 years) the most suitable model to represent an air transport operator is the socio-technical system (currently not completely mature).
With the concept of socio-technical system, for the first time we come to see the organization of an aeronautical transport company not as a system almost-rigidly determined by technologies, but rather as an organization where, based on the interaction capacity of the management, human factors, administration, there is the possibility to choose the most suitable organizational solution to meet the needs of the relationship between intrinsic safety and production-economic efficiency ratio.
In this context, the extent of the corporate operational situations to which even a safety event belongs such as *"predictability - unpredictability; tranquility - turbulence"* will no longer be easily studied and predictable with pseudo linear barrier models and complex methods (based on resilient engineering, FRAM) will be needed to study the safety events that develop within this type of company.

In conclusion, this work outlined the state of the art of a matter which offers many opportunities for development in several respects. The hope is to encourage the research in statistics, analysis methodologies, case analysis processes, risk assessment algorithms, software and each context which can contribute to make the helicopter aerial missions each day safer, closing the gap with the fixed-wing commercial aviation.

Appendix A: Case Study Information

Helicopter Information

Fig A.1: Schweizer 269C-1, G-LINX

Aircraft Type and Registration	Schweizer 269C-1, G-LINX
No & Type of Engines	1 Lycoming HIO-360-G1A piston engine
Year of Manufacture	2006
Capacity	2 passengers (1 crew)

Tab A.1: Helicopter data

Flight Information and Event Description

1. On 22 September 2009, at 10.42 am 'G-LINX' helicopter, with two people on board – 1 crew and 1 passenger – departed from Blackpool Airport. The purpose of the flight was not officially declared.

2. It can be supposed the purpose of the flight was training, since the pilot was a flight instructor, while the passenger was a Private Pilot's Licence student. They had already flown together in order to accomplish some training flights.

3. Immediately after take-off, the helicopter headed west and reached the Blackpool coastline.
4. Afterwards it turned north, flying along the littoral. It climbed to approximately 1400 ft.
5. The helicopter reached the town of Bispham, then it turned his path heading to Knott End-of Sea. During this phase of the flight, the whole condition was consistent with a normal flight routine.
6. At 10.50 am ‘G-LINX’ reached Knott End–of–Sea. It crossed the coast of the town and initiated a descending manoeuvre, turning left and heading west.
7. The helicopter reached the sandbank located north the Knott End–of–Sea coast.
8. The helicopter manoeuvred for several minutes above the sands. Twice, it climbed to an altitude approximately of 200 ft and then descended to an altitude consistent with having either landed or entered a low-level hover.
9. In this phase, the helicopter flew at heights not above 400 ft. Both descents were conducted heading into wind, with very similar descent rate (1,570 ft/min) and ground speed (35 kt).
10. At 11.00 AM, ‘G-LINX’ left the sandbank and headed south, in order to move towards the mouth of River Wyre. When it left Knott End–of–Sea, it was flying at 200 ft.
11. Subsequently, while the helicopter was continuing its path along the east bank of the river, it climbed to 430 ft and reached a cruise speed of 60 kt.
12. At 11.02:23 am, ‘G-LINX’ called Blackpool APC (Approach Controller) for a “MAYDAY” emergency. The communication was spoken by the instructor, and included the aircraft call sign, approximate position and the word “FAILURE”.
13. At 11.02:31 am a second call from ‘G-LINX’ to APC was effected, but it merely consisted in background noise. No verbal communication was performed during this call.
14. At 11.04 am, after several unsuccessful attempts made by Blackpool APC to communicate with ‘G-LINX’, the emergency procedures have been activated.
15. At 11.52 AM The ‘G-LINX wreckage was found by a Police air support helicopter, in proximity to the east bank of the Wyre River. Both occupants were found fatally injured.

Date & Time (UTC)	22 September 2009, 11.03 am
Location	East bank of River Wyre, near Stalmine, Lancashire
Type of Flight	Training
Persons on Board	Crew - 1 Passengers - 1
Injuries	Crew - 1 (Fatal) Passengers - 1 (Fatal)
Nature of Damage	Aircraft destroyed
Commander’s Licence	Commercial Pilot’s Licence
Commander’s Age	38 years
Commander’s Flying Experience	1.524 hours (of which 894 were on type)
	Last 90 days - 59 hours
	Last 28 days - 12 hours
Information Source	AAIB Field Investigation

Tab A.2: Flight information

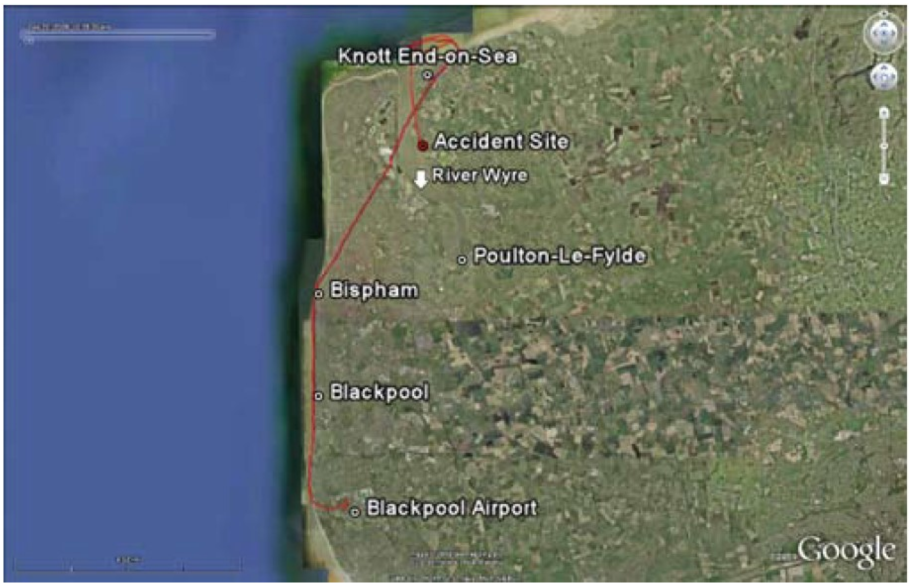

Fig A.2: Flight Path

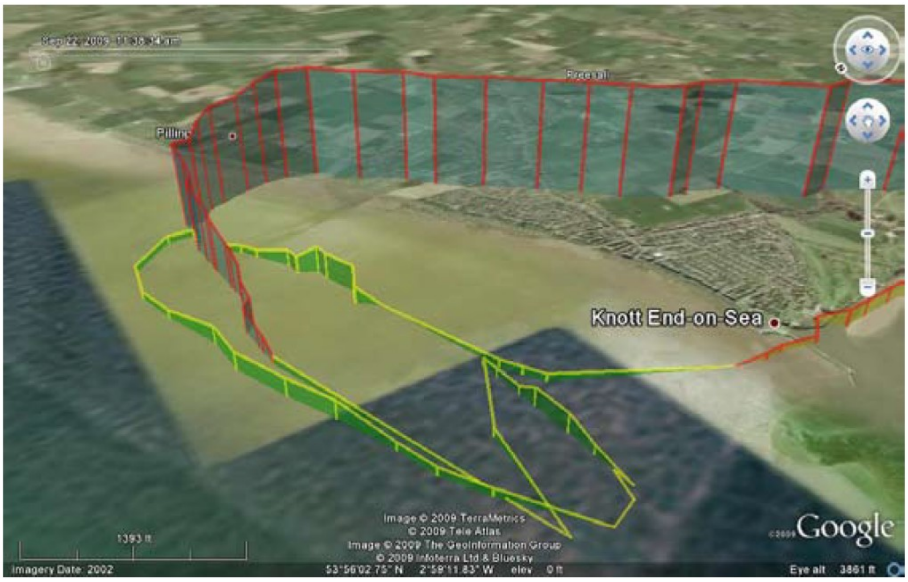

Fig A.3: Detailed flight path above the sandbank

Pilots Information

An instructor pilot and a PPL student pilot were board the 'G-LINX'.
The instructor pilot, who represented the commander on board, was 38 years old and in possession of the Commercial Pilot's Licence. He can be considered as an experienced pilot, as he collected 894 flight hours on Schweizer 269 type.
No particular information in relation to the student pilot is available.

The instructor pilot and the student pilot used to fly together several times, in order to perform some training flights. Moreover, further investigation revealed the instructor pilot used to fly above the field area located near to the east bank of the River Wyre, typically with the purpose to perform practice autorotation.

Recorded Information

'G-LINX' was not equipped with an accident-protected data or voice recorder, nor was it required to be.[13]
'G-LINX' was equipped with a Garmin GNS 430 combined GPS, navigation and VHF communications unit. Unfortunately, no GPS routes were recorded by the unit, even though it was still active at the time of the impact. The final GPS position was coincident with the wreckage position, which indicates that the unit was electrically powered until the crash occurred.
Two radar sites, one located in St Annes - approximately 8 NM south of the accident site - and Great Dunn Fell - approximately 50 NM to the north-east - were active during the 'G-LINX' last flight. Both radars recorded 'G-LINX' manoeuvring in the vicinity of Knott End-on-Sea, then tracking towards the River Wyre, heading to south. About 1.5 NM south of Knott End, 1.2 NM west of the village of Stalmine, the helicopter altered its path moving towards east and descending. It disappeared from radar shortly thereafter. The final radar positions were within 45 metres of the accident site.

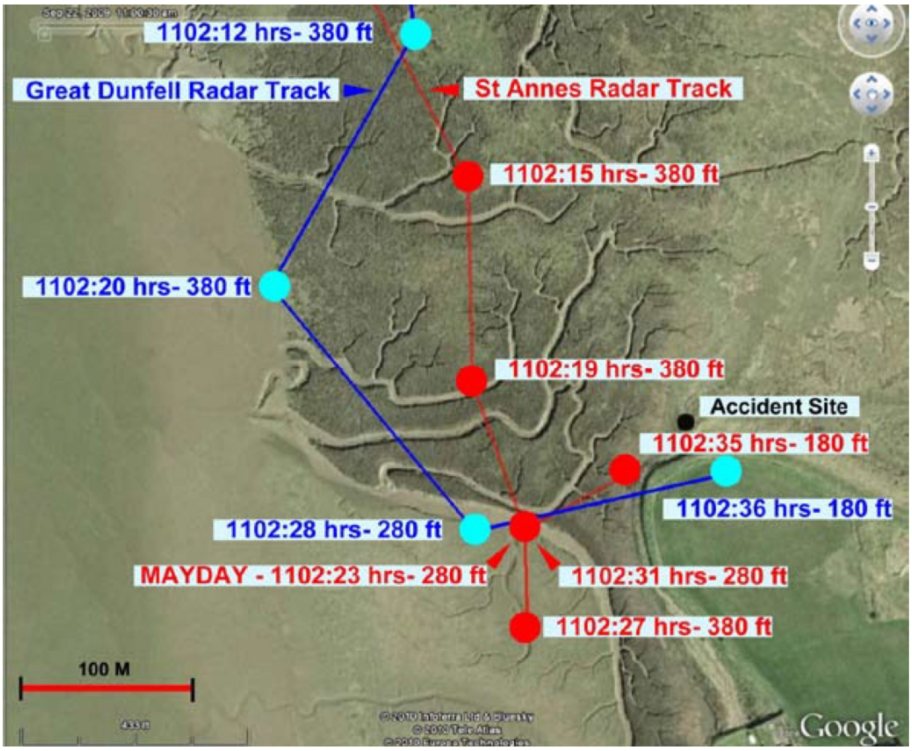

Fig A.4: Radar recorded positions

Meteorological Information

At 10.37 am the aerodrome controller reported to 'G-LINX', while issuing taxi instructions, the wind was from 270° at 15 kt, gusting to 26 kt. Later, at 10.50 am, meteorological conditions reported at Blackpool Airport included surface wind from 260° at 20 kt, visibility of 10 km or more and scattered cloud with a base at 2,000 ft. The air temperature was 16° C and dew point 11° C. At 11.20 am a further report indicated that meteorological conditions were not in process to change during the morning.[13]

Radio Transmissions

On Blackpool Radar frequency five radio transmissions were recorded between the helicopter 'G-LINX' and the Blackpool APC. The first three communications were performed just moments after the take-off and climbing phase, at 10.42 am. These communications could be described as "normal routine" calls. Later, at 11.02:23 am and 11.02:31 am, the last two radio communications were performed. The first one was a "MAYDAY" call, followed by the APC acknowledgment and by the second transmission, which only consisted in a "open microphone" call. By the analysis led on communication calls between 'G-LINX' and Blackpool APC several details were revealed.

- During the 'MAYDAY' call, the instructor pronounced the word "FAILURE". However, he could not give more precise information about what kind of failure was detected.
- The instructor "sounded calm and his voice held no sense of panic during the 'MAYDAY' call."
- By the background noise analysis during the last two calls, the main rotor has been detected it was reducing its rotational speed. It was found out that it was rotating at an approximate speed of 340 rpm, 50 rpm below the main rotor low speed warning system activation point. Moreover, no engine sound was revealed.

Testimonials

An eye-witness, located in Blackpool, confirmed that he saw, just a few minutes before 11.00 am, the 'G-LINX' flying inland, north of the town, and emitting "five or six puffs of black smoke".
Another eye-witness, located in Knott End-of-Sea, reported that the helicopter was operating above a sandbank, 1 NM north of the coast approximately. The 'G-LINX' was manoeuvring in a right hand circuit for several minutes. Twice, it climbed to a height of a few hundred feet and descended to a height consistent in either landing or entering in a low-level hover. Subsequently, the helicopter moved heading towards south, following the east bank of River Wyre.
No other reports of the event were found.

Wreckage Examination

The wreckage of 'G-LINX' crashed on the eastern bank of the River Wyre, 1.2 NM west of Stalmine. By the first analysis performed on site, it was observed that the 'G-LINX' hit the ground on a heading of approximately 173° (M), probably slightly nose up with some left bank. The wreckage had very limited spread, which suggests that the helicopter had a very low forward speed at the impact. Both the skids and seat pans have been severely damaged, which lead to assume that the helicopter impacted the ground with a high vertical speed.
On the contrary, the main rotor blades were found to be intact. Some mud splatters on the tips of the blades indicate that some rotation was still present at the impact.
A more detailed wreckage examination showed that the 'G-LINX' state of health was overall good and in compliance with flight activity. Flying controls, rotary drive components, fuel system, instruments, switches and air intake have been examined and revealed to be free from defects. However, during the engine examination two issues reported below were revealed.

- The fuel injector servo did not pass the flowmeter limit test when it was tested in "0 lb/hr airflow and mixture control set to 'RICH'" conditions. A flow rate of 32.25 lb/hr was observed, while the specifications range for the fuel flow rate was 23.0 lb/hr minimum to 31.0 lb/hr maximum.

Fig A.5: 'G-LINX' wreckage

- The right magneto was found with worn and misplaced electrical contact points. Consequently, the right magneto was not capable to produce consistent steady sparks when engine running below 1,500 rpm.

Organizational Information

In the UK, training for the issue of a PPL is conducted at Registered Training Facilities (RFC). RFCs are required to register with the CAA and to certify that they comply with certain required conditions. However, no approval is required. Moreover, it appears that no inspections are performed, as well as no training or operations manuals are required. For the RFC is not necessary to keep any kind of formal training record.
Registration remains valid until either the CAA is informed that PPL training is to cease or the CAA establishes that training is not being carried out safely or is not in compliance with JAR-FCL.[13]
The RFC from which the accident flight originated did not have any training or operating manual. Also, such RFC did not keep formal training records for each of its students.

Helicopter Flight Manual and On Board Checklist

The Schweizer 269C-1 Pilot's Flight Manual contains a procedure entitled "'Pilot's Check of Idle Mixture, Idle Speed, and (Helicopters with Fuel Injected Engine – HIO-360-G1A) Fuel Boost Pump'". The procedure states that "this check of idle mixture and idle speed shall be accomplished at the end of the last flight each day, prior to engine shutdown". The purpose of this test is to verify the correct setting of idle speed and idle mixture, since an incorrect setting of these parameters could lead to engine stoppage in flight if idle is selected. However, on the Schweizer 269C-1 maintenance manual no mention was reported in reference to an idle rpm and idle mixture check, unless the settings had been adjusted.

However, the 'G-LINX' checklist found on board did not contain any mention to the mentioned test. In such checklist it was found out that a test similar to the idle speed check was included in the pre take-off checklist section. By comparison with the flight manual test procedure, the checklist test instructions were found to be not clear nor detailed. As a matter of fact, the rpm limit parameter was not coincident with 1,400 rpm, which was the rpm limit imposed by the aircraft manufacturer.

Maintenance Report

The helicopter was maintained by an EASA Part-145 approved maintenance organisation. Its last annual maintenance inspection was completed on 21 July 2009 when the helicopter had accumulated 289 flight hours (18 hours prior to the accident)[13].
'G-LINX' was maintained in accordance with the Light Aircraft Maintenance Programme (LAMP). The technical log did not contain any mention to open deferred defect.

Referring to the 'engine idle rpm and idle mixture check and test' issue, the LAMP procedure for Schweizer 269C-1 did not contain any specific requirement to check engine idle speed or idle mixture setting. In fact, there were no entries in any of the maintenance worksheets of an adjustment having been made to the engine's idle rpm setting or idle mixture setting.

Appendix B: Schweizer 300

Introduction to Schweizer 300 Family

In 1955, at the beginning of rotorcraft era, the *Hughes Tool Company's Aircraft Division* realized that the demand for a low-cost, lightweight, two-seat helicopter was rapidly growing. In fact, at that time the rotorcraft market was missing a helicopter type which was smart in accomplishing some tasks as training, agriculture work and general utility missions.
The development of first Schweizer 300 type, which was named Model 269, started in the same 1955. The prototype was able to perform its first flight on 2 October 1956, although it required another four years to finally enter production in 1960 with a reviewed version named Hughes 269A.

As the 269A model gained success in rotorcraft aviation, its developing continued with the 269B model, which was marketed as Hughes 300 and that introduced an enhanced three-seats configuration.
By means of a Hughes 300 prototype an endurance record was set in 1964, when two pilots performed a 101 hours long flight. The particular story is that the pilots were alternating at controls and refuelling in ground-effect hovering, and to ensure no cheating, eggs were attached to the bottom of the skid gear to register any record-ending landing.

In 1970 the Hughes 300C, also known as Hughes 269C, made its debut on the rotorcraft market. The 269C model represented such a new era for Hughes 300 family, as the new *Lycoming HIO-360-D1A* engine introduced an enhanced power of 190 hp, which allowed the use of an increased rotor diameter. The final result was a payload increase of 45% compared to previous variants.

The Hughes 300 history opened a new chapter in 1984, when McDonnell Douglas purchased Hughes Helicopters. Two years later, in 1986, the Schweizer company acquired by McDonnell Douglas the helicopter type rights. Since then, the type assumed the Schweizer 300 denomination.

The history of Schweizer 300 then continued with two more rights property changes. In 2004 Sikorsky Aircraft decided to acquire the type rights, in order to complete its helicopter line which was missing a lightweight model. Subsequently, in 2018, type certificate for the Schweizer 300 product line was sold by Sikorsky Aircraft to Schweizer RSG, which today is producing Schweizer 300 variants in Fort Worth, TX. In particular, the new property continued the model developing with the S333 variant, which entered production in 2020.

Nowadays, the Schweizer 300 family represents a milestone in the history of helicopter, as it revealed its essential role in general aviation as well as in military and police rescue field during a more-than-60 years long history.

Schweizer 300CBi Features

Features here below reported are referred to Schweizer 300CBi type, according to the current type variant manufactured by Schweizer RSG corresponding to 'G-LINX' type. Such characteristics must be intended in standard day, sea level, maximum gross weight conditions.

Performance	
Maximum speed (VNE)	94kts. 174km/hr
Maximum cruise speed (vh)	80kts. 148km/hr
Hover ceiling, In-Ground-Effect (1700 lb)	7,000 ft / 2,133 m
Hover ceiling, Out-of-Ground-Effect (1700 lb)	4,800 ft. / 1,463 m
Range (long range cruise* speed @ 4,000 feet)	32.5 gallon
(no reserve)	64.0 gallon
Weights	
Maximum takeoff gross weight	1,750 lb. / 794kg
Empty weight, standard configuration	1,102 lb. / 500 kg
Useful load	648 lb. / 294 kg
Dimensions	
Fuselage length	22.19 ft. / 930 kg
Fuselage width	4.25 ft. / 1.30 m
Fuselage height	7.17 ft. / 2.18 m
Overall length (rotors turning)	30.83 ft. / 9.40 m
Overall height (to top of tail rotor)	8.72 ft. / 2.65 m
Width (canopy)	4.25 ft. / 1.30 m
Main rotor Diameter	26.83 ft. / 8.18 m
Main landing gear tread (fullycompressed)	6.54 ft. / 1.99 m
Accomodations	
Normal cabin seating (training)	2 passengers
Maximum certified cabin seating (utility)	3 passengers
Cabin length	4.75 ft. / 1.45 m
Cabin width	4.92 ft. / 1.50 m
Powerplant	
Type	Textron Lycoming HIO–360-G1A
Powerplant ratings (per engine, standard day, sea level)	180 shp / 134 kw
Fuel Capacity	
Standard fuel capacity	32.5 US gal - 123.03
Extended range capacity	64.0 US gal - 242.27

Tab B.1: Helicopter data

Schweizer 300CBi in Training Activities

Since the first appear on aviation scenario, the Schweizer 300 family has been involved in rotorcraft training activities. Its characteristics had usually made the Schweizer 300 one of the most suitable rotorcraft in such framework, even if the design was developed not only for training.

The Robinson R22 helicopter has always represented the most widely used type for training in the world, thanks to its reliability, quickness and cost effective. Actually, it was hard to any kind of helicopter to compete with R22 within the training activities.

Fig A.1: Schweizer 300Cbi - 269C-1

Therefore, in 1995, the Schweizer 300 manufacturing company decided to increase the attractiveness of its product by releasing the Schweizer 300CBi version on the aviation market. Such type variant, also known as 269C-1, has been developed with the aim to compete with R22 on the rotorcraft training field.

First of all, the commander pilot's position was moved from the left seat to the more traditional right seat. Them, the manufacturing company installed a less-expensive, lower-powered engine with a higher *'Time Between Overhauls' - TBO*, and reduced the gross weight. Schweizer also extended the TBO on several major components and changed others to make them more accessible for servicing. These changes allowed it to make the 300CBi more reliable and to lower both the selling price and the operating cost. These features made the Schweizer 300CBi an even more serious competitor for R22. Moreover, Schweizer produced a complete ground training package, in partnership with Jeppesen-Sanderson, which included textbooks, self-test exercises, training aids, and a course syllabus.

One of the Schweizer 300 family typical feature is that the engine, transmission, and flight control assemblies are exposed and easy to see and touch. There are eight V-belts, tightened by means of an electric actuator, that connect the normally aspirated, 180-horsepower Lycoming HO-360-C1A engine to the transmission. Also, the main rotor flight control tubes and swash plate assembly are highly visible. This allows the student to observe the flight control system which conducts inputs to the three-blade, fully articulated rotor system.
The two-blade tail rotor is driven by a single drive shaft, which is installed inside the tail boom and connected to the upper drive pulley. A bearing and dampener assembly is located at the midpoint, in order to support the shaft and reduce vibration. A small door on the side of the tail boom allows for inspection.

Inside the cockpit, one of the most valuable features is represented by the wide visibility. The pilot can look back and see the main rotor drive assembly and the tail rotor. The cabin is wide and comfortable, allowing the largest of students plenty of elbow room.
The Schweizer 300CBi has been designed to guarantee a better stability and solidity in comparison to other lightweight helicopters. In general, the Schweizer 300CBi is pleasingly forgiving in

Fig A.2: Schweizer 300CBi's Engine

Fig A.3: Schweizer 300CBi's Control Panel

case of errors and botched manoeuvre, granting the students the necessary time to straighten out by themselves, without the instructor having to take the controls.
The 'forgiving nature' of the 300CB is one characteristic that is reported to be the most appreciated by students and instructors, as it is a common idea in the training facilities community and flight schools that the 300CB allows students to meet the FAA's practical test standards faster.

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