POLITECNICO DI TORINO

Corso di Laurea Magistrale
in Ingegneria Aerospaziale

Tesi di Laurea Magistrale

Hazards and Risks Analysis on Helicopters Offshore and Firefighting Mission Profile

Relatore Accademico
Ch.mo Prof. Giorgio Guglieri

Candidato
Adriano Finocchiaro

Relatore Esterno dell'Industria
Ch.mo Ing. Marco Gajetti
Deloitte Consulting S.r.l., Aviation and Transportation

A.A. 2017/2018

RINGRAZIAMENTI

Alla mia famiglia, da sempre fonte di sostegno e supporto per avermi fatto andare avanti e credere in ciò che facevo anche durante le difficoltà.

A mio padre, che da Lassù spero possa essere fiero di me e di ciò che sto compiendo.

Grazie al Prof. Giorgio Guglieri per avermi permesso di scrivere questa Tesi e di essere sempre stato disponibile per chiarimenti, consigli e di avermi fatto avvicinare al mondo elicotteristico.

Grazie all'Ing. Marco Gajetti per avermi seguito giorno per giorno con estrema disponibilità durante la stesura di questa Tesi e di essere stato pronto a consigliarmi per migliorarmi. Lo ringrazio inoltre per avermi fatto ampliare la visione sulla branca della Safety.

Grazie al Com.te Fabio Bocola per aver fornito e condiviso la propria esperienza al fine di migliorare ulteriormente lo studio effettuato, suggerendo modifiche accurate.

Grazie al Ten. Col. Giuseppe Fauci, Direttore della "Aeronautica Militare – Rivista Sicurezza del Volo" per aver gentilmente concesso informazioni aggiuntive nello caso applicativo della Tesi, migliorandone il contenuto.

Grazie alla mia collega Carmen, per aver collaborato allo sviluppo di questo documento e di aver condiviso con me questo studio.

ABSTRACT

Human Factor is considered one of the major contributors to the causes of aviation incident; the interaction between man and machine therefore carries a series of risks and jeopardizes the safety of operations right from the planning stage.

During the evolution of aviation, several methods were developed to identify the aviation incident and the consequent mitigation of them (models such as HFACS, SHELL).

In the rotorcraft field, however, there are mechanics (and consequently hazards) which are more complex than those in the fixed wing. The versatility of use of the helicopter, leads it to operate in missions of complex execution by the human, with the consequent increasing of the risks.

This document initially aims to present a general overview of the missions which the helicopter is involved, and then analyse in detail the aerial work of Firefighting and Offshore transport.

The in-depth analysis of the chapters mentioned is intended as a starting point for the identification of possible risks linked to the execution of these missions, in order to carry out what is defined as "Risk Assessment". This method will allow an immediate overview of most of the risks and hazards contained, evaluating them in order of severity and likelihood.

Following the guidelines set by the ICAO Digest No. 7, the Risk Assessments can be linked to the SHELL model, which contains a wide analysis of the human factor, classifying it according to human-machine-environment interactions. The direct link SHELL-HSI-HFACS will eventually provide nanocodes that will be useful for future mitigations related to the analysis carried out.

In conclusion, this Thesis wants to analyse the case study of a helicopter incident in order to evaluate the effectiveness and the accuracy of the results which can be obtained through this methodology, identifying the degree of risk through Risk Assessment, its link with the SHELL and the related nanocodes in the HFACS model.

ABSTRACT (Italiano)

Il Fattore Umano è considerato uno dei maggiori contributi nelle cause di incidente aereo; l'interazione tra uomo e macchina quindi porta una serie di rischi e pregiudica la sicurezza delle operazioni sin dalla fase di pianificazione.

Nel corso dell'evoluzione dell'aviazione quindi, si è sempre cercato di sviluppare dei metodi utili all'identificazione delle cause di incidente aereo ed alla conseguente mitigazione di esse (modelli come HFACS, SHELL).

Nel campo dell'ala rotante tuttavia, vi sono meccaniche (e di conseguenza future cause) più complesse di quelle presenti nell'ala fissa. La versatilità d'impiego dell'elicottero, porta esso ad operare in tipologie di missioni di complessa esecuzione da parte dell'uomo, con il conseguente rischio ed aumento delle criticità.

Questo documento vuole inizialmente esporre una panoramica generale delle missioni in cui l'elicottero viene coinvolto, per poi analizzare nel dettaglio il lavoro aereo di *Firefighting* e trasporto *Offshore*. L'analisi approfondita dei capitoli in questione, vuole dare spunto per l'individuazione di possibili rischi legati all'esecuzione di tali missioni, al fine di poter eseguire quello che viene definito come "*Risk Assessment*". Tale metodo permetterà di avere una panoramica immediata della maggior parte dei rischi contenuti. valutandoli in ordine di *severity* e *likelihood*.

Seguendo le linee guida dettate dall'ICAO Digest No. 7, si possono collegare i *Risk Assessment* con il modello SHELL, il quale contiene una visione approfondita del fattore umano suddividendolo in base alle interazioni uomo-macchina-ambiente.

Il diretto collegamento SHELL-HSI-HFACS fornirà infine dei nanocodici che saranno utili per delle future mitigazioni legate all'analisi effettuata.

Questa tesi infine, vuole analizzare il *case study* di un incidente elicotteristico al fine di valutare l'efficacia e la bontà dei risultati che si possono ottenere mediante tale metodologia, identificando il grado di rischio, il collegamento con lo SHELL per poi attribuire i relativi nanocodici tramite il modello HFACS.

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LIST OF ACRONYMS

ACRONYMS	DEFINITION
ALARP	As Low As Reasonably Possible
AOP	Area Observation Platform
BEP	Break-Even Point
CAT	Civil Air Transport
CFIT	Controlled Flight Into Terrain
CoG	Center of Gravity
DoD	Department of Defense
EVS	Enhanced Vision Systems
FF	Fire Fighting
FPSOs	Floating Production, Storage and Offloading facilities
FRF	Final Risk Factor
HEMS	Helicopter Emergency Medical Service
HFACS	Human Factor Analysis and Classification System
HSI	Human System Integration
ICAO	International Civil Aviation Organisation
IFR	Instrument Flight Rules
IMC	Instrumental Meteorological Conditions
INCOSE	International Council on Systems Engineering
LOC	Loss Of Control
MEL	Minimum Equipment Level
METAR	METeorological Aerodrome Report
MOUs	Mobile Offshore Units
MTOW	Maximum Take Off Weight
NVG	Night Vision Google
PIC	Person In Charge
RF	Risk Factor
SAR	Search And Rescue
SHELL	Software Hardware Environment Liveware
SL	Sling Load
TAF	Terminal Area Forecast
TOW	Take Off Weight
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions

1. Introduction

The first use of the helicopter on civil and industry environment started soon after the World War II, when the technology applied on fixed wing were far more well-known. Despite this gap, helicopter established soon a reliable way to operate in much more extensive fields of work than the airplane.

The use of helicopters in industrial and civilian environments carries hazards where, in certain cases, may leads to fatal consequences. The affirmation of these rotorcrafts in a continuous expanding field drives, in a certain way, to develop and improve a risk assessment not only on helicopter itself, but also on the environment where it operates.

Nowadays, the main tasks where helicopter is used are mostly the following:

- Aerial Work;
- Helicopter Emergency Medical Service (HEMS);
- Offshore;
- Search and Rescue (SAR);
- Imaging;
- Patrol;
- Fire Fighting;
- Civil Air Transport.

Many studies have been conducted by numerous agencies in order to obtain statistics regarding severity and occurrence of accidents in the several areas of helicopter use.

The EASA has recently conducted a *Safety Review* which collects meaningful data concerning fatal incidents or not ones in certain aerial works. Figure 1 and Figure 2 show the data gathered.

As can be see, the general trend of both fatal and non-fatal accidents has had a progressive reduction over the years. This has been possible because of the continuous introduction of standards and regulations through the time.

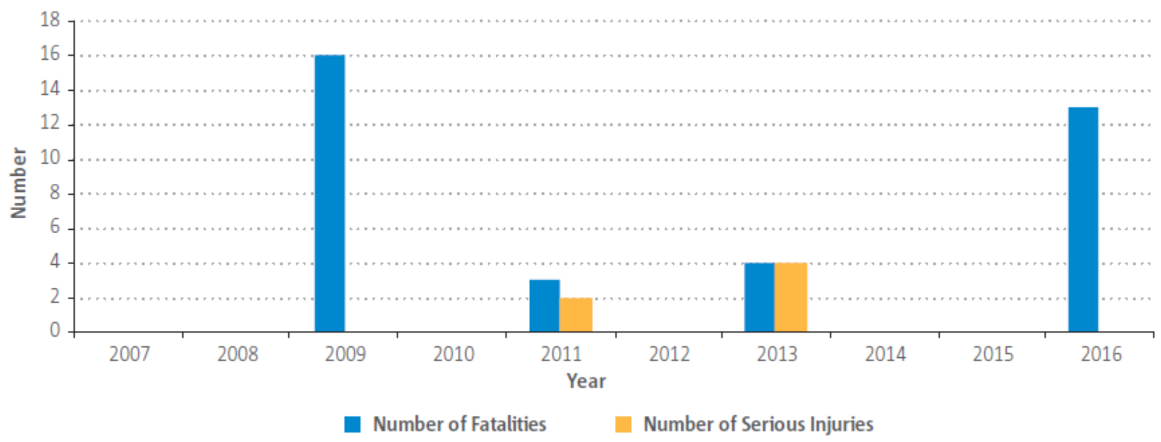


Figure 1 – Offshore fatalities and serious injuries 2007-2016 (EASA, 2017).

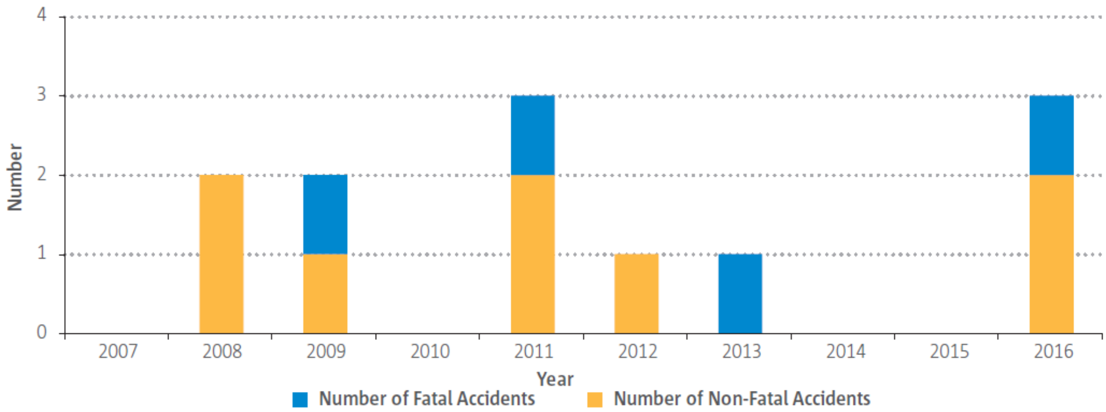


Figure 2 – Offshore Fatal and Non-Fatal Accidents 2007-2016 (EASA, 2017).

The aim of this study is to develop a method of helicopter incident analysis, which is a result of a combination of models.

Many of the aerial works carried out by a helicopter have a limited planning time, this makes the quick identification of the Hazards a great advantage. The development of this study allows to quickly identify possible Hazards that may appear in a specific mission and the risks in which they can derive.

During the years, many agencies have tried, through the development of different methods, to cope the hazard assessment and link them with their root cause.

In this study, the main hazards associated with each aerial work have been studied at first. Then, the risks derived from each Hazard have been identified. In addition, through the use of the *Risk Assessment*, it has been possible to give a value to each of them.

Once the risks have been identified and evaluated, the risks have been linked to the human factors that cause them by using the *SHELL* and *HSI* model. Subsequently, *HFACS* will identify the corresponding code related to the human factors analyzed. Because of this, the most effective mitigations of each Hazard are reached more briefly.

Nonetheless, it cannot leave aside the fact that the safety is affected by the economy. Although not all events become catastrophic (so called *Missed incident*), physical damage to the plane is not necessary to develop a safety recommendation.

Regardless of the nature and type of accident (fatal or non-fatal), mitigations or preventive barriers are therefore necessary in order to avoid the same event in the future.

These mitigations can range from the simple warning of greater attention to a more complex change (i.e. more visible signals or rewriting a procedure). Thus, entails to link the eventual mitigation with the business costs. Consequently, it will weight on the profile of the company in an onerous way. This will, therefore, lead to choices on the possible protective action to be taken by modifying it partially or totally.

According to the expected cost, a mitigation can be either developed, partially developed or even refused and ignored, making the risk will repeat itself over the time.

1.1. Cost and Risk relation

In practical terms, the only analysis of hazards and risks related to it, is not limited to simple theoretical mitigation, it also extends to its implementation.

In a business context and management of a company that provides aerial work, the risk assumes a real cost, influencing the company profile.

It is therefore clear that in order to avoid the emergence of problems such as penalties or increases in insurance premiums, risk mitigation must be implemented and this involves the investment of company capital.

In both case of accident or incident, the company (in relation of the entity of the damage) must pay a certain amount of money related to the *insurance*. This contains a portion of costs called *uninsured costs*, which are difficult to calculate (Woods, 2003).

Accident may be considered like icebergs; its direct costs are in fact visible and exactly calculated, on the other hand, the hidden ones are heavier (in terms of costs) and are not immediately determinate (Woods, 2003). Concerning the insurance, Woods underline how "*It should be noted that accidents generate insurance premium increases for the entire industry, although the companies having the accidents have by far the largest increases"* (Woods, 2003).

Examples of uninsured costs may be exposed on the table below, referring to Woods:

Type of Uninsured Cost	**Description**
Insurance Deductibles	Not recoverable money which is payed as deductible at the moment of the buying of the aircraft
Lost time and Overtime	Time (and the related cost) spend after accident in order to return on nominal condition
Cost of investigation	Cost of the assignment of the inspector to assess the dynamics of the accident
Cost of hiring and training replacement personnel	Costs to hire replacement personnel due injuries or absence
Loss of use of equipment	Money lost due damage or loss of effectiveness of the equipment
Cost of rental or leasing	The cost related to the fees of rental or lease

Table 1 – Examples of Uninsured Costs.

Safety Manager also have to deal with two different kinds of cost: fixed and variable. The former do not change and must be taken into account whether or not the aircrafts fly or not. The latter ones are for examples the cost of fuel. The total cost so it is the sum of fixed and variable cost.

There are also direct and indirect costs which can influence the possibility (on the side of the Safety Manager) to apply mitigation and even the introduction of a safety program.

Safety programs are part of the cost included in the industry profile cost, and its presence can avoid certain condition of accident or even incident, in order to avoid the increasing of the insurance (in terms of costs).

Despite the advantages, aviation safety program are often in friction with the industry policy, due the fact it has a cost. Depending of the job to be performed, safety programs may be considered with a certain weight in relation to the environment which it is allocated (Woods, 2003).

2. Mission Analysis: General Description

2.1. Aerial Work

Aerial Work includes a wide range of task which can be carried by helicopters, these may depends on the industries/agencies who request the services; most of them consists to transport material through a hook (called *sling loads*), line connections, patrol and maintenance services (Civil Aviation Authority, 2006).

2.1.1. Sling Load Carrying

It is the most common task performed by the helicopters, it consists to carrying different types of load (such as pipeline parts, material and so on) or vehicle (mostly used in military environment). The movement from a place to another is achieved through the use of a hook which link the load to the aircraft.

These kinds of tasks require also a ground crew in order to maintain the required clearance and operate in a safety environment; as a matter of fact, *sling load* are considered a critical task to perform.

The following Figure 3 show a typical use of the helicopter in different operations.

Figure 3 – Civil application of Aerial Work.

Figure 4 – S-64 Skycrane during posing operation of a powerline.

2.1.2. Pipeline Patrol and Maintenance

Oil and gas pipeline inspections are tasks accomplished in order to ensure the highest standards of efficiency and safety. The use of helicopters allows cost/efficiency savings as these operations can be carried in a short time with a high grade of accuracy. Such operations are considered critical due the fact are carried out at low heights and low speeds, where the helicopter is subject to different hazards.

Generally, these aircraft travel at speeds of 60 knots of forward speed above or to the side of the pipeline right-of-way at 100 to 500 above the ground level and flown following the ground contour. At this speed, the rate of closure is 105 feet per second to an obstacle, so this require a high grade of concentration and focus for both pilot and operator. A typical inspection of a pipeline involves, in fact, operators who, through tools such as cameras and sensors, inspect pipes and possibly remove natural obstructions along the pipeline. (Helicopter International Association, 2015)

Figure 5 – Inspection of a pipeline in USA.

2.1.3. Power Line Inspection and Maintenance

Power line consist of visual inspection of electric utility's structures, conductors, and identifying natural or artificial obstruction elements that pose hazards to the reliability of the system (Helicopter International Association, 2015).

As well as the pipeline maintenance, low altitude and speed are involved in these tasks; plus, these inspections require a hovering phase in order to allow to the operator the visual inspection and eventually maintenance/removing on the power line infrastructure (Helicopter International Association, 2015).

The presence of cables increases the risks of these tasks, where the pilot must be fully aware of the surrounding environment.

Figure 6 – Power line inspection of cable and main structure maintenance.

Figure 7 – Powerline Inspection Phase.

2.1.4. Aerial Spraying Operation

Rotorcraft used for Spraying Operation can provide the spreading of chemical pesticide in order to protect the crop fields from insects and bugs which may cause severe damage to the agriculture.

Helicopter is quite reliable on these environments due its ability to manoeuvre in smaller or irregular field, guaranteeing a precise distribution of the chemical compounds.

Operation conducted at low speed and altitude however, contains hazards equipollent to the other types of aerial work listed so far. Thus require, as a matter of fact, proper certification, equipment and crew in order to ensure a safe work environment (NSW- Department of Primary Industries, 2011).

Figure 8 – Helicopter during spraying operation (left) and pesticide refuelling (right).

2.2. *Helicopter Emergency Medical Service (HEMS)*

Helicopters are used in serious medical emergency transport activities as air ambulances in order to reach the hospital as soon as possible, to transport organs or patients to another facility. These tasks, in order to be performed at best, impose certain size characteristics of helicopters and interior layouts to ensure the wounded's survival during transport.

These aircraft operate predominantly in adverse environments and are particularly suitable for high mountain altitude rescue, as well as the maritime areas. However, the mountain environment involves a series of hazards that increase mission criticality such as strong winds along the slopes, low temperatures, rising dust and snow (Airbus, 2014).

Figure 9 – HEMS Operation in different environment and services.

2.3. *Search and Rescue (SAR)*

Search and Rescue Missions involves helicopter in quite similar circumstances of the HEMS; these task however are not always focused on the wounded transport, but on helping people who are in harsh terrain, situations of imminent danger or that are missing due accidents.
The operating environment is similar to air ambulance; the aid of the injured or even the demands for aid on the high seas, brings the helicopter to operate under low altitude conditions in the presence of water which, when lifted, may lead to critical engine damage.

Additional hazards must be considerate during night operations, where visual references are reduced, and the use of sensors is required. Even more, operating crew are often dropped by a winch, which can be assumed as a little sling load, adding an additional risk factor.

Figure 10 – SAR helicopter used by the Coast Guard.

2.4. Imaging and Patrol Service

Photogrammetry is a common task which the helicopter is considerate suitable for.

The acquisition of orographic images of the territory, flora and sea observations through sensors and lenses, provide to the local authorities a particular degree of detail in relation to the required task, both visible, thermal or infrared spectrum.

Helicopter patrol is indicated for areas with high concentrations of people, especially in large cities.

Patrolling services are used by local police authorities to control the territory and traffic information, while television networks for possible image capture (Industries, 2012).

Figure 11 – PZL Kanya Police layout with Winch and Searching Lights.

2.5. *Civil Air Transport (CAT)*

Passenger transport helicopters are used for low-medium-range travel of people or cargo inside it. Its use is more or less affirmed in various parts of the world; it is very common to move VIP staff or to use helicopters for recreational and leisure flights.

Helicopters employed on this category generally works in environment where it is assumed minor hazards are present than those listed so far.

Example of CAT categories are:

- Recreational Flight;
- Leisure Flight;
- Pilot Training;
- Business Transport;
- VIP Transport.

Figure 12 – AW189 VIP layout for passenger transport.

Figure 13 – Luxury Layout for VIP transportations.

2.6. Fire Fighting Service

In addition to planes, helicopters are used for firefighting to extinguish low-moderate extension fires. The possibility to carry moderate amounts of water through the bucket, allows to operate both in dense bushes and in open fields.

Hazards linked to this operating environment are mainly low visibility caused by smoke, strong winds and limited spaces. Being involved in situations of immediate emergency, the pilot must be aware of the surrounding environment and operate as fast as he can.

Figure 14 – Bucket transport during firefighting operation.

Figure 15 – Bucket Refilling during Firefighting Operations.

2.7. Offshore

Offshore includes a series of task performed by the helicopter which purpose is mainly the transport of material or people to a fixed location (such as oil platforms) or mobile (vessel).

These activities allow to reach places far away from the coast in relatively short periods, where high waves or strong currents prevent them from reaching them by boat.

However, the use of helicopters in such environments requires particular attention from the pilot and ground crew, as landing areas are small and raised, increasing the risk of landing; these tasks are also often performed overnight with reduced visibility (CAA, 2012).

Working in areas close to the polar circle, strong winds, low temperatures, and slow approaches, involve hazards that need to be considered.

Figure 16 – Landing over oil platforms.

3. Mission Analysis

The purpose of the previous chapters was to overview the most common tasks performed by the rotorcraft, describing their main tasks and the environment where it is involved.

On this chapter, it will be described the most performed tasks in detail, underlining their main components, parties and crew involved. A wide vision of the work environment will be listed also, as well as a brief list of hazards which may be found on it.

3.1. Firefighting

Helicopter firefighting is the suitable response to wildfire; by carrying bucket filled with water, it represents a reliable and low-cost way to counter these fires.

The bucket is rapidly filled with water and carried at high cruise airspeeds; cargo hooks are used for these kind of tasks, which allow a wide category of helicopters to be best suited. The bucket used are light weight, useful when operating in remote region or far from firefighting resources (Eggleston, 1998).

Firefighting not only involve the releasing of water, but also the carrying of firefighters and aerial coordination to the whole firefighting team composition (Bosch, 2010).

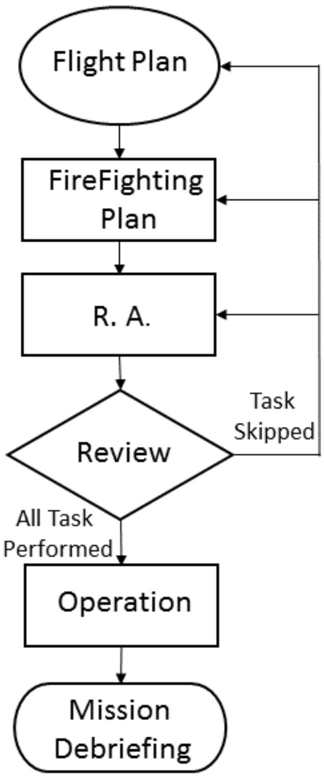
Examples of helicopters used on Firefighting operations are listed in Table 2. For further details see APPENDIX I.

Manufacturer	Model	Engine	MPLW [kg]	MTOW [kg]
Bell	B-204	1 x Lycoming T53-L-11A	1360	4310
Bell	B-212	1 x PW PT6T-3	2267	5080
Boeing	CH-46	2 x T58-GE-16	2270	11000
Mil	Mi-26	2 x Lotarev D-136	20000	56000
Sikorsky	S-64	2 x Pratt & Whitney T73-P-700	9072	21000
Sikorsky	S-70	2 x T700-GE-701D	4072	9979

Table 2 - Main Helicopters Involved on Firefighting Operations.

3.1.1. Firefighting Operations

Operations to be carried for a typical firefighting emergency are listed in Table 3.



Task	**Description**
Flight Plan	Whenever possible, knowledge of the take-off area, pick-up and drop zone is performed to a better understanding and awareness of the task. These operations include also the use of flight charts, local maps and forecast weather.
FireFighting Plan	Define the correct sequence to carry from the take-off to the drop zone, indicating flight level, airspeed, level of fuel, operator actions.
R. A.	Process which involve the identification, mitigation and corrective action of hazards during each phase of the task. Once the hazard is identified, mitigation actions are performed and only after this, the acceptance/abort choice is chosen.
Review	Internal process which involves a series of checks that confirms if all the previous tasks has been carried out in the correct way. If some tasks are missing or skipped, repeat the process at the point where it is necessary; otherwise, continue with the next procedure.
Operation	Phase which involves the execution of all the previous task planned. Pilot and personnel are deployed after the briefing and check phase; helicopter reach the pick-up area and fill the bucket with water, travelling to the drop zone and releasing the water.
Mission Debriefing	Process which assess the operation carried, underlining possible future hazards and post mission inspection.

Table 3 – Main Operations during a Firefighting Tasks.

A detailed explanation of these tasks in terms of responsibilities may be described by the following Figure 17 (AIRCARE, 2012).

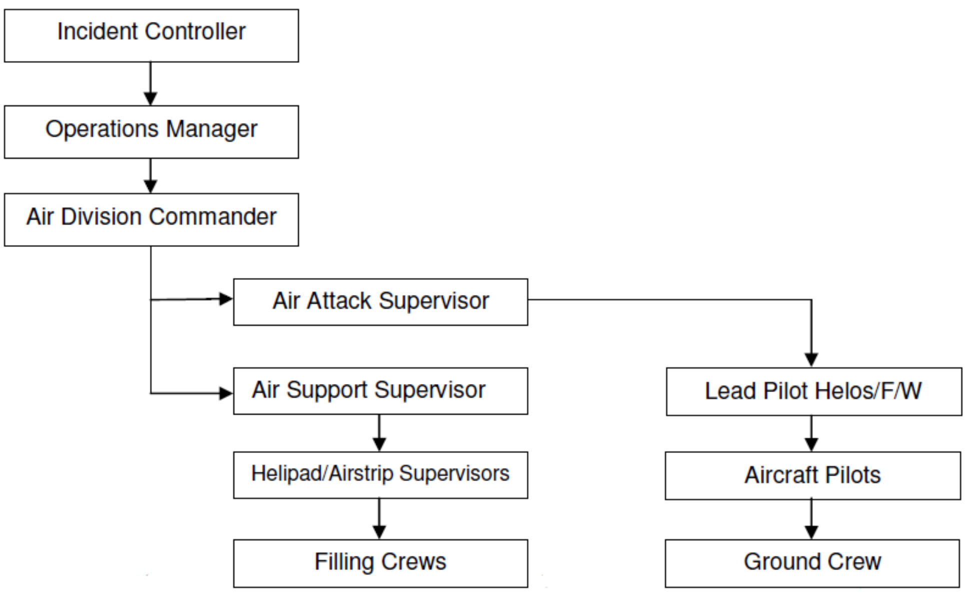


Figure 17 – Sequence of responsibilities during a large event.

In summary, during a large event, the call received by the controller will starts a chain of events which will divide the whole crew in support and attack team. One will lead the main coordination of the entire operation, the other one will execute the tasks assigned.

The main figure which will affect the entire operation is the PIC (*Person in Charge)*. He is the person responsible for aircraft operations, normally IC, Operations Manager ADC or AAS depending on the circumstances e.g. the size and stage of the fire (AIRCARE, 2012). The main tasks which he should fulfil are:

- Appoints (Personnel, task and aircraft);
- Authorizes (give the clearance to the whole activities performed in the previous point);
- Organizes (Briefing, Communication Plan and so on);
- Manages and Monitor.

3.1.2. Equipment

The main equipment which characterize the Firefighting environment is the bucket. It will be loaded with water and then dropped on the fire site.

This item, as mentioned by the AIRCARE, shall have an emergency jettison system in the event it is jettisoned in flight. These controls shall break away without interfering with the pilot or the main or tail rotors. Buckets also shall have dipping capability and be able to be transported to the fire inside the helicopters before its uses (AIRCARE, 2012).

Category of buckets are listed below:

- Bambi Bucket: Wide used collapsible bucket type operating since 1983; (SEI Industries)
- HeliFIRE Monsoon Bucket: Collapsible and free-standing monsoon buckets used by New Zealand Firefighters; (Monsoon Bucket)
- FAST Bucket: Variable Drop, firefighting bucket that allows the pilot to select drop patterns for bush fires to canopy fires.

Figure 18- Bambi and FAST solution buckets on action.

Other equipment provided may be (AIRCARE, 2012):

- A foam injection unit capable of delivering a specified percentage of fire suppressant to each load of water with the amount of suppressant being controlled by the pilot.
- Ground support vehicle which can provide sufficient aviation fuel to allow aircraft to complete the shift or the mission.

For extensive fire or distress situation, it may be necessary to deploy an AOP (Area Observation Platform). According to the AIRCARE document (AIRCARE, 2012), the criteria of its deployment are:

- When more than three helicopters are attacking a fire;
- When helicopters of different type (large heavy lift vs medium lift) are working on the same sector;
- When a fixed wing aircraft is deployed to a fire where any number of helicopters are also deployed;
- At the discretion of the lead pilot for example when terrain and visibility create unacceptable risk;
- In any fire situation where the Person in Charge suspects there may be concerns around safe, efficient and effective aircraft use.

In terms of operations, the AOP is regulated by the following statement:

"The AOP shall remain at a level above the fire fighting aircraft and at a height agreed in consultation with the lead pilot. The AOP circuit direction should be opposite to that of fire fighting aircraft. Where the AAS requires a closer ground-truthing of fire fighting safety, effectiveness and efficiency or requires a landing at any point, the AOP shall inform aircraft on the sector of these requirements. The AOP will maintain radio communications with other aircraft including the Lead Pilot and utilize a safe approach and departure profile to the target as agreed." (AIRCARE, 2012)

3.1.3. Night Operations

Fire fighting operations during the hours of darkness add an additional risks and these are carried out if life or significant property is threatened.

Night flying requires the direct approval of the Incident Controller. These particular operations involves and require a strong Risk Profile and Assessment; in other words, significant and additional conditions should be considerate. AIRCARE suggest to considerate the following statement (AIRCARE, 2012):

- The ability to maintain continual visual reference to the ground;
- The position of smoke relative to the aircraft's flight path;
- The number of aircraft engaged on the fire front as pilots have to concentrate more on their actual flying leaving less resource for dealing with congestion;
- Pilot fatigue as the increased concentration level required at night.

It is vital that no lights are shined at the aircraft or pilot during any phase of the operation, including refuelling.

For night operations there shall always be at least two aircraft deployed. Aircraft shall display navigation and anti-collision lights during the hours of darkness.

AIRCARE also suggest the following requirements for non NVG equipped pilots:

- No pilot shall commence firefighting on a new fire front during the hours of darkness. It is important that firefighting commences during the hours of daylight when all hazards can be identified;
- When flights into darkness are anticipated pilots shall pay particular attention to circuit patterns and climb profiles relative to terrain so that when the hours of darkness arrive, pilots know the lie of the land and have established their flight paths to provide adequate clearance from terrain and other hazards;
- The fill point shall be illuminated with lights that are positioned so as not to compromise the pilots' night vision. To this end vehicle lights shall be dipped and rotating hazard lights switched off;
- Unless instructed otherwise by the lead pilot, lights at the fill point shall remain on constantly until flying operations are terminated as these lights provide a reference that is critical to the pilots;
- The pattern pilots fly shall enable them to see either the fill point or the fire front at all times.

3.1.4. Use of NVG

The use of NVG is a mitigating factor to many of the risks associated with flight by night and their use is recommended. As well as the non-NVG Operations, before attempting a night NVG operation, pilots shall carry robust risk assessment.

It is remarked when NVG are utilized:

- The operator shall hold an AOC;
- The pilot shall meet NVG currency requirements;
- The aircraft shall be certified for NVG use.

For operations under NVG pilots may require different lighting requirements to those for unaided night operations (AIRCARE, 2012).

3.1.5. *Firefighting Crew Components and Minimum Certification Required*

During helicopter lifting tasks, the helicopter organization deploys a series of professionals which are part of the flight crew and of the ground crew:

<table>
<tr><th>Crew Member</th><th>Description</th><th>Certification</th></tr>
<tr><td rowspan="4">Lifting Contractor (Company)</td><td rowspan="4">Provide trained pilot, equipment and ground crew. Identify load and lift configuration and conduct the site risk assessment.</td><td>Regulation (EU) 965, Annex 8, Subpart E:
AMC1 SPO.SPEC.HESLO.100
AMC1 SPO.SPEC.HEC.105</td></tr>
<tr><td>Regulation (EU) 965, Annex 8, Subpart AOC:
ORO.AOC.100</td></tr>
<tr><td>FAR Part 133
FAR 27 / FAR 29</td></tr>
<tr><td>CS 27 / CS 29</td></tr>
<tr><td rowspan="2">Lifting Contractor (Pilot)</td><td rowspan="2">Execute the lift tasks, review and check the risk assessment, cooperate with the operator with communication signals.</td><td>Regulation (EU) 965, Annex 8, Subpart E:
AMC1 SPO.SPEC.HESLO.100
AMC1 SPO.SPEC.HEC.105</td></tr>
<tr><td>Regulation (EU) 965, Annex 8, Subpart AOC:
ORO.FC.005</td></tr>
<tr><td>Lifting Contractor (Operator)</td><td>Check communication equipment; coordinate with the pilot, knowing the emergency procedures.</td><td>Regulation (EU) 965, Annex 8, Subpart E:
AMC1 SPO.SPEC.HESLO.100</td></tr>
</table>

Table 4 – Firefighting Crew Members and Certification.

3.1.6. *Firefighting Hazard*

Due the fact the water bucket is linked to a cargo hook, it represents a sling load; so it carries similar hazards related to sling load operations.

Job	Hazard	Risk Assessment
Planning Phase	Incorrect Choice of Primary Hook	Possible Hook Failure
Flight Operation	Presence of Natural Obstructions	Possible Impact LOC - CFIT
Flight Operations	Presence of Other Aircraft	Possible Impact with Other Aircraft LOC - CFIT
Flight Operations	Presence of Smoke	Low Visibility LOC - Upset

Table 5 – Examples of Major Hazards of Firefighting.

Figure 19 – Water bucket release during a firefighting mission.

Figure 20 – Helicopter during Night Operation.

3.2. *Offshore*

Offshore operations were developed since the ’60, when oil and gas companies started to build oil and gas platforms over the ocean; the transport of personnel and equipment became a matter of efficiency and fast travel.

Offshore installations have steel structures, cranes or semisubmersibles elements positioned from 40 to over 300 (referring for instance to the North Sea) miles offshore (Morrison, 2000). These far distances lead to the use of helicopters. Offshore operations may be summarized below.

- Crew and personnel transport;
- Shuttle services between two platforms;
- Medical transport services;
- Firefighting.

Peculiarity of these tasks is the 24 hours services; in fact, night and day operations are carried every day.

3.2.1. *Offshore Environment*

The background context which connect offshore installation to the need to positioning such structures far away from the shores is the demand of natural resources, for instance:

- Natural gas;
- Oil (defined as crude oil);
- Condensate (compressed gas which condensate due high pressure).

Due the high pressure condition which could be found on deep water seas, resources of this kind may be found through the drilling of the terrain under these depth.

Helicopters during offshore operations have to deal with the intrinsic nature of the platform itself; Mobile Offshore Units (MOUs) or Floating Production, Storage and Offloading facilities (FPSOs) implies different approaching phases and planning due their different configurations (Morrison, 2000).

Figure 21 – Example of MOUs.

Figure 22 – Example of FPSOs.

3.2.2. Helideck Analysis

The helideck is the main environment where the helicopter execute its tasks. Consist of an elevated platform constructed in order to allow the landing and take-off of the aircraft; further safety measurements are provided in order to enhance the safety level such as *safety net* or *safety edge*.

The most important value which will be determine the size and area of the helideck is the *D-Value*; it represents the length of the main helicopter (from the tip of the rotor blade to the extreme final point of the tail rotor) that will define the radius of the helideck (CAA, 2012).

Examples of helicopters used on Offshore operations are listed in Table 6. For detailed layouts see APPENDIX I.

Manufacturer	Model	Engine	MPLW [kg]	MTOW [kg]	D-Value [m]
Agusta Westland	AW-109	2 x PW206C	680	3175	13.05
Agusta Westland	AW-189	2 x GE CT7-2E1	2722	8600	17.60
Airbus Helicopters	AS-350	1 x Arriel 2B	1078	2250	12.94
Airbus Helicopters	H-215 (AS-332)	2 x Turbomeca Makila 1A2	4500	9150	18.70
Airbus Helicopters	EC-155 B1	2 x Arriel 2C	900	4950	14.30
Bell	B 206	1 x Allison 250	658	1541	11.95
Bell	B 412	1 x PW PT6T-3D	3000	5397	17.13
Bell	B 407	1 x Allison 250-C47B	1065	2272	12.70
MBB	BK 117	2 x Lycoming LTS 101-750B-1	900	3350	13
MBB	Bo 105D	2 x Allison 250-C20B	400	2500	12
Sikorsky	S-76B	2 x Arriel 2S2	1170	5307	16
Sikorsky	S-92A	2 x GE CT7-8A	3629	12565	20.88

Table 6 - Main Helicopters Involved on Offshore Operations.

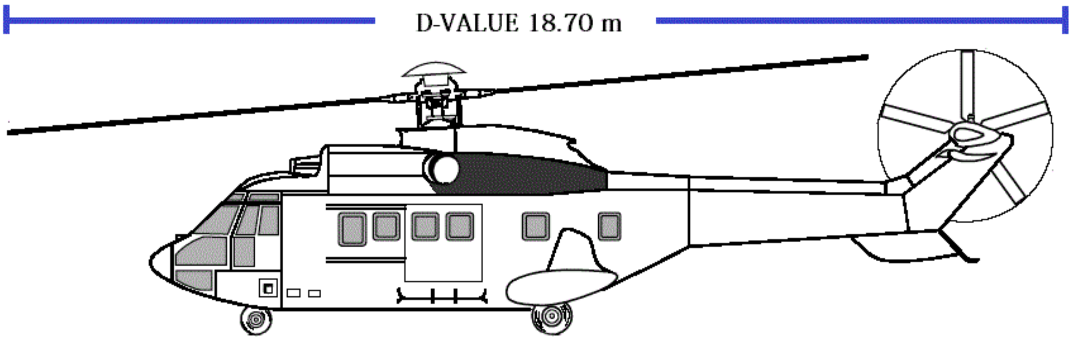


Figure 23 – D-Value of AS-332 Super Puma.

Helideck net and safety edge have an assigned value in relation of the D-Value of the helicopter associated with the respective offshore installation; although this, minimal requirements must be respected whenever there is the need of a net installation in relation of the size of helideck. CAP 437 provide a wide range of D-Value and minimal criteria concerning the size of the edge and net on platform. Table 7 show the three minimal criteria (CAA, 2012) and it is remarked how the net may be circular rather than square; no-standard sizes may be allowed for specific model or needs.

Helideck Size	Area
Small	9 x 9 m
Medium	12 x 12 m
Large	15 x 15 m

Table 7 – Minimal standard dimension of Safety Net.

Figure 24 – Layout of a Safety Edge.

Figure 25 – Typical Safety Net installation.

Standard markings and symbol must be adopted in order to fulfil the standardisation of helidecks. The following figure shows specific pattern of colour and position, it can be noticed the *No-Landing Zone* marked in red and white in order to signalling the heading segment where the helicopter must not lands (CAA, 2012).

Figure 26 – CAP437 standard markings.

The CAA provides also the minimal standards required for offshore installation where the only winch is allowed to operate and the helideck is not installed (CAA, 2012). An example of a winch landing zone is the following:

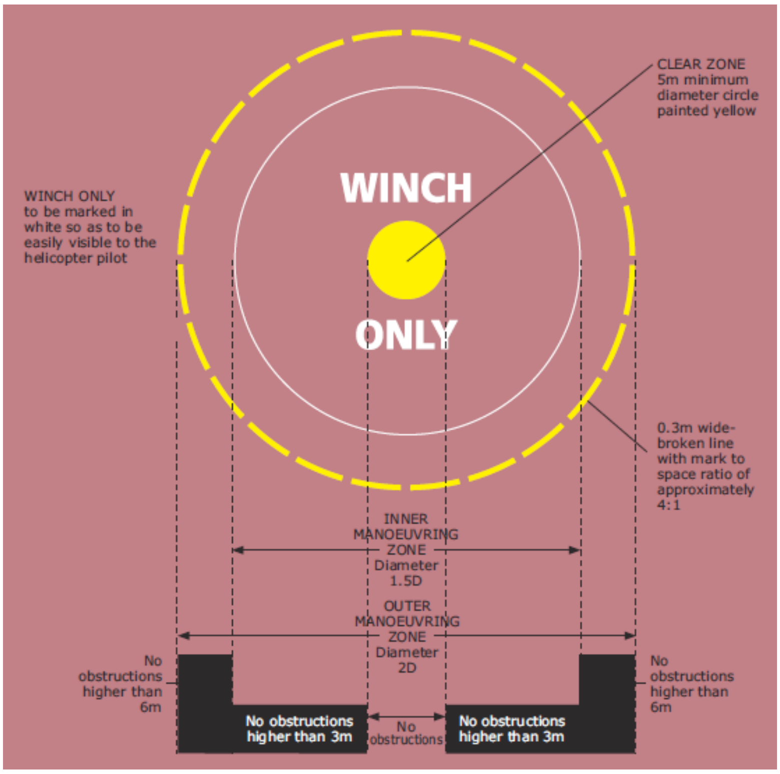
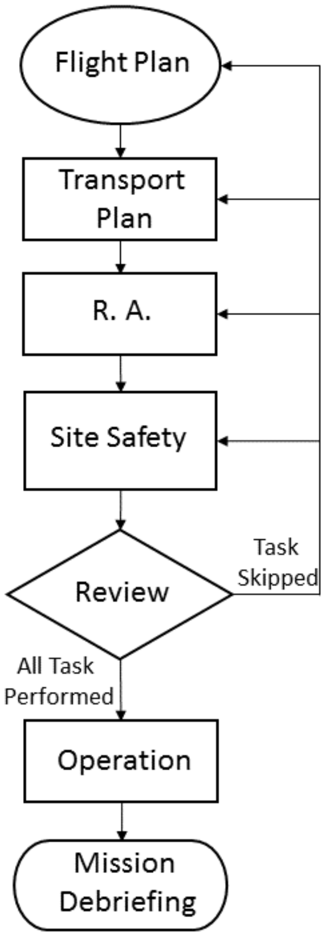


Figure 27 – Winch Only Zone according to CAP437

Different size and even type of landing zone in offshore installation will leads to different environment and hazards profile analysis. The winch landing zone for instance is used in wind turbine installation, so strong wind and precision approach during the day must be considered.

3.2.3. Offshore Operations

Offshore main operations consist to transport MOUs or FPSOs personnel from a place to another, which may be between two installations or the land. Typical tasks performed are shown in Table 8.



Task	Description
	Knowledge of the take-off and landing area is performed to a better understanding and awareness of the task. These operations include also the use of flight charts, local maps and forecast weather.
	Define the correct sequence to carry from the take-off to the landing zone, indicating flight level, airspeed, level of fuel, operator actions.
	Process which involve the identification, mitigation and corrective action of hazards during each phase of the task. Once the hazard is identified, mitigation actions are performed and only after this, the acceptance/abort choice is chosen.
	Following the Risk Assessment, corrective actions on site are performed in order to guarantee a certain level of safety. During pre-flight checks, integrity and compliance with the standards are carried to ensure the accomplishment of the task.
	Internal process which involves a series of checks that confirms if all the previous tasks has been carried out in the correct way. If some tasks are missing or skipped, repeat the process at the point where it is necessary; otherwise, continue with the next procedure.
	Phase which involves the execution of all the previous task planned.
	Process which assess the operation carried, underlining possible future hazards and post mission inspection.

Table 8 – Main Operations during Offshore Tasks.

3.2.4. Offshore Crew Components and Minimum Certification Required

Equipment carried on the helicopter are made ad hoc for the operations and the mission environment; emergency locator, thermal suit and floating devices are the standards equipment of helicopters involve in offshore operations.

Crew on offshore operations may vary depending on the tasks which shall be carried, but generally the main figures are listed in Table 9 (UKOOA, 2005).

Crew Member	Description	Certification
Duty holders	Installation Operators and vessel owner.	UK CAA, CAP 437
		Certificate HLAIR and HLAC
Helideck Operator	Technical support specialist. Helideck crew responsible of the compliance of the helideck.	UK CAA, CAP 437
		Certificate HLAIR and HLAC
Helicopter Landing Officers (HLOs)	Crew responsible of activities concerning marshalling, radio communications and signalling.	UK CAA, CAP 437
Emergency Crew	Develop an emergency plan and coordinate with the local emergency services.	UK CAA, CAP 437
Contractor (Company)	Provide trained pilot, equipment and ground crew. Identify load and lift configuration and conduct the site risk assessment.	UK CAA, CAP 437
		Regulation (EU) 965, Annex 5, Part-SPA, Subpart k: SPA.HOFO
Contractor (Pilot)	Execute the inspection tasks, review and check the risk assessment, cooperate with the operator with communication signals.	UK CAA, CAP 437
		Regulation (EU) 965, Annex 5, Part-SPA, Subpart k: SPA.HOFO
Contractor (Operator Crew)	Check communication equipment; coordinate with the pilot, knowing the emergency procedures and performed the maintenance procedures.	UK CAA, CAP 437
		Regulation (EU) 965, Annex 5, Part-SPA, Subpart k: SPA.HOFO

Table 9 – Offshore Principal Crew Members and Certification.

3.2.5. Offshore Hazard

Offshore environment may be considerate "hostile" in relation of a series of factors; far distances from the coast and oil/gas platforms involve also equipment and structures which represents hazards for helicopter operations. Examples of structures are:

- Cranes;
- Fixed Structures;
- Pylons;
- Night Operations;
- Strong Wind;
- Small Helidecks.

Especially on oil platforms, flare and smoke are considerate the major hazards during approach phase.

Job	Hazard	Risk Assessment
Flight Operations	Presence of Structures	Impact with Structures LOC - CFIT
Flight Operations	Presence of Safety Net	Possible Twisting with Landing Gear LOC - Upset
Flight Operations	Unstable Helideck	Helicopter Instability LOC - Upset
Flight Operations	Inadequate Light Signal	LOC - CFIT

Table 10 – Examples of Major Hazards in Offshore Operations.

Night and day operations implies different uses of certain equipment; in order to mitigate accident during these missions, helicopters may be provided with (Ross & Gibb, s.d.):

- Enhanced Vision Systems (EVS);
- Synthetic Vision;
- Platform Visual Landing System;
- Helideck Lighting Systems.

Figure 28 – Synthetic Vision.

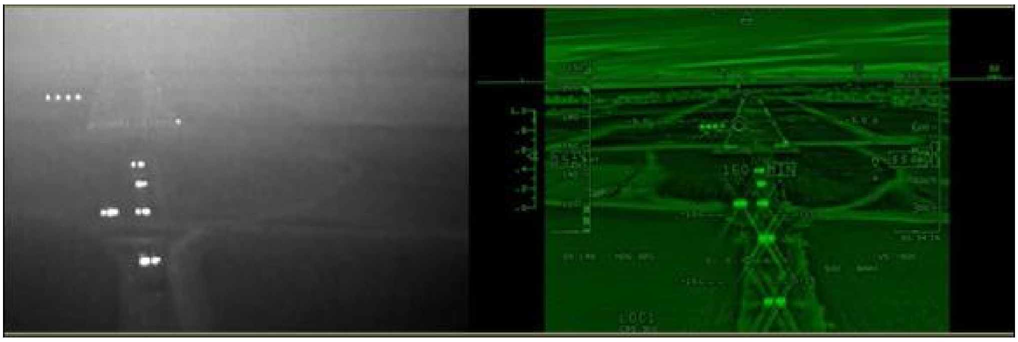


Figure 29 – EVS.

Figure 30 – Helideck Lighting System.

The critical environment, the adverse weather and even the cycle day/night, imply a certain degree of communication G/B/G (Ground/Board/Ground); marshalling instruction are provided in order to guide the pilot to a correct landing procedure. In order to avoid misinterpretation or confusion from the pilot, marshalling signals are standardised (CAA, 2012). Although this, misinterpretations or rushing procedure sometimes led to incident, so marshalling signal may be considered a risk as well (defined as *lack of communication* or *incorrect marshalling signal*). An example of the pattern followed is shown on Figure 31:

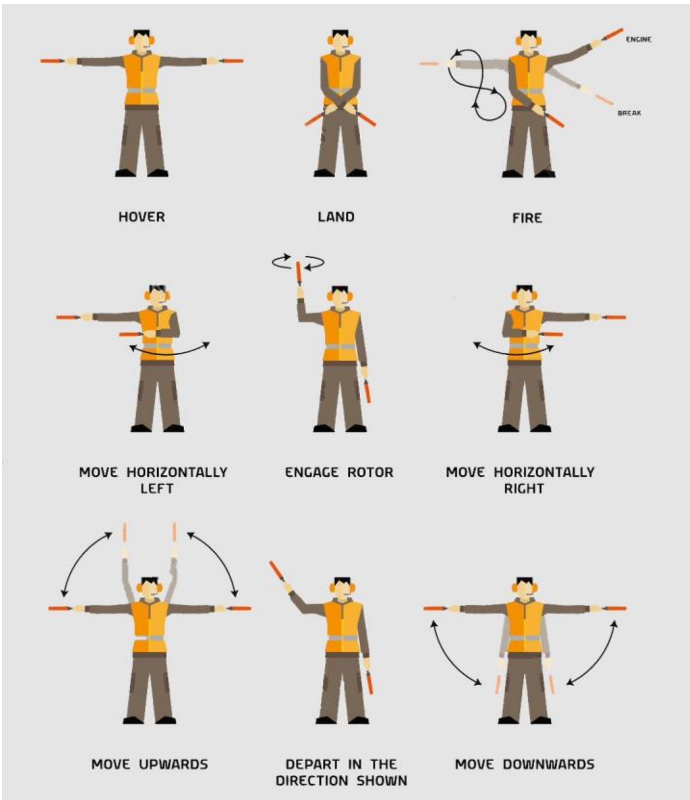


Figure 31 – Index of Marshalling Signals.

In terms of data collected in offshore operations, John Spouge conducted a wide study on this field, involving for instance UK and Norway. In this book he collected a deep study concerning the risk assessment and risk factory which led to incident and accident during the period of his publications. The following tables shows the stage and the severity of some incident analysed, in order to identify some of the cause and risk factor of accident occurred (Spouge, 1999).

Mission	**Accident in North Sea (1970-95)**	**Accident in UK Sector (1980-95)**
Passenger Flight	75	45
Training Flight	4	2
Winching Operations	3	3
SAR	3	2
Maintenance Flight	1	0
Total	85	52

Table 11 – Helicopter Accidents per Missions.

Flight Stage	**Accident in North Sea (1970-95)**	**Accident in UK Sector (1980-95)**
In-Flight	38	22
Take-Off	7	3
Landing	15	8
Hover	5	0
Helideck Offshore	11	5
Ground Heliport	9	7
Total	85	45

Table 12 – Flight Stage of Helicopter Accidents.

4. Hazard Analysis and Evaluation

4.1. Introduction

The next step in the study of helicopter missions is to initially assess the hazards present in each work. In this section, it will be explained the main methods involved in the hazard analysis, and how they have been used. Therefore, the analysis will lead to the final assessment of the risks and the human factors involved.

The main models used in this analysis are:

- *Risk Assessment*
- *HSI* Model
- *HFACS* Model
- *SHELL* Model

Each method will be described in the following subsections for a better understanding of the analysis. Once the models are defined, it will proceed to explain the development of the analysis.

4.2. Hazard Identification – Methodology

The identification of potential hazards is the main focus of this report. These have been identified in relation to the various aerial work involved.

The list of potential hazards has been developed through the study and understanding of the different aerial works involved (Sling Load, Firefighting, HEMS and Offshore). Identifying hazards is a process that requires a certain level of knowledge of the types of mission. They can be obtained through primary and secondary sources. The definition of these two types of sources were inspired by the ICAO Model (ICAO, 1993).

- Primary Sources: Consultation and interview of specialists in the sector.
- Secondary Sources: Regulations, amendments and incident report provided by ANSV, EASA and NTSB.

In the preliminary phase secondary sources were used, while primary ones were used as verification.

The process of developing such hazards is an iterative one. The in-depth analysis of the reports found, allowed to identify a specific set of these. This review process ended with real distinction between the hazards in common to all works (named *General Hazards*) and those specific to each one.

An example of Secondary Sources consulted has been the report published by EASA in 2017. An extract of this report, *''Annual Safety Review''*, which analyse the Aerial Work is shown in Figure 32 (EASA, 2017).

Safety Issues	Total number of occurrences in 2012-2016 per safety issue				Key Risk Areas (Outcomes and precursors)				
	Incidents (ECR data)	Serious Incidents	Non-Fatal Accidents	Fatal Accidents	Aircraft Upset	Terrain Collision	Ground Damage	Obstacle Collision in Flight	Unsurvivable Aircraft Environment
Operational									
Flight Planning and Preparation	72	0	0	1	●	●	●	●	●
Control of the Helicopter Flight Path and Use of Automation	2	0	0	1	●	●		●	
Handling of Technical Failures	12	2	1	0	●	●		●	●
Airborne Separation	54	0	0	0		●		●	
Bird/ Wildlife Strikes	44	0	0	0	●				
Icing in Flight	7	0	0	0	●				
Approach Path Management	5	0	0	0	●	●		●	
Helicopter Obstacle See and Avoid	4	0	0	0		●		●	
Degraded Visual Environment	1	0	0	0	●	●	●	●	
Icing on Ground	1	0	0	0	●				
Intentional Low Flying	0	0	0	0	●	●		●	
Management of the Dynamic Landing Environment	0	0	0	0				●	
Management of the Static Landing Environment	0	0	0	0				●	
Use of Operationally Ready Safety Systems for Helicopters	0	0	0	0	●			●	●

Figure 32 – Types of Operation and Risks in Offshore Operations.

Another example of these sources is reported in Table 13, which represents an extract provided by the NSW Government (NSW- Department of Primary Industries, 2011).

Description of Task	The task involves planned and short notice callout to at risk areas as part of emergency management. Heights flown shall be a minimum of 500ft AO unless landing, sling loading, winching, taking off or due stress of weather. Landings and take-offs at non-aerodromes will be required. Tasks may require the carriage of non-Government/Operator personnel, animals, fodder and equipment.
Number of and type of engines	Fixed wing aircraft may have either piston or turbine engine(s). Helicopters shall be turbine powered. Single or multi-engine turbine shall be used for moving people. Winching of people shall only be conducted in multi-engine turbine powered helicopters with Class 2 performance. Sling loading of materials and animals maybe conducted with single or multi turbine engine helicopters. Single engine piston shall be used for moving animals and equipment only (i.e. no passengers).
Task profile (sequence)	• Callout • Planning include map reconnaissance for hazards, assessments of takeoff and landing areas, aircraft and passenger support availability where appropriate. • Briefing including update of hazards as shown on appropriate map, flight following procedures, weather, task objectives, landing/take-off areas, communications, aerial risk assessment. • Contact landowner/manager if being picked up (include briefing on appropriate clothing) and/or utilising their land. • Fuelling when required. • Conduct Crew and passenger brief. • Start/Taxi/Take-off. • Transit to area of operation at a height commensurate with conditions and regulatory requirements but in any case, at a height not below 500 feet (ft) Above Obstacles (AO). • Conduct route and area of operations identification, aerial hazard survey, and pre-descent brief prior to descent below 500ft AO to Helicopter Landing Sites (HLSs) or non-certified Aircraft Landing Areas (ALAs) or aerodromes. • Conduct area surveillance if descending to conduct a winch (hoist) or sling load activity. Requires authorisation, risk assessment and hazard identification before attempting task and descent below 500ft AO. • Descend to the HLS or ALA commensurate with task objectives, authorisations, and conduct further hazard/target identification if required. • If operating to a certified aerodrome, conduct operations in accordance with standard regulatory, advisory and Company procedures and documentation. • Communicate with Air Services as required by standard regulatory, advisory and Company procedures and documentation. • Communicate with LCC or Operator (as approved) for flight following and/or task update. • Transit to operating base/fuelling area. Conduct pre-landing brief. • Land / Shut Down. • Debrief and report.

Table 13 – Task on Aerial Transportation.

4.3. Risk Assessment

Risk assessment is a tool that allows identification and evaluation of risks in several of the types of aerial work. The main steps which should be performed, may be summarized as:

- Identify jobs of each operation: determinate all the main tasks which compose the entire Job.
- Identify the critical situation of each job that have potential hazards in terms of injury or ill health.
- Determine the risk associated with each hazard, assessing their severity and Likelihood.
- Assign a risk score.

According to FAA, hazard is defined by "A present condition, event, object or circumstance that could lead to or contribute to an unplanned or undesired event, such an accident.'', this definition implies an accurate investigation process in every single aerial work, where their main hazards was identified.

Hazard analysis can be obtained also through external sources such as:

- Accident and incident reports;
- Technical publications from manufacturers (for instance Safety Bulletins);
- ANSV Italy, NTSB USA, safety Information Bulletins, safety alerts and other safety publications from EASA, the European Commission, the National Aviation Authorities, ICAO, Eurocontrol, the FAA and other authorities worldwide.

Following the ICAO guidelines, risk assessment is carried out using two scales of values in terms of likelihood and severity (ICAO, 2013). Assigned values used in this study are shown in the Table 14 and Table 15.

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

Table 14 – 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

Table 15 – Risk Likelihood Values.

The two scales of values are combined with the following formula:

$$Risk\ Factor\ (RF) = Likelihood \cdot Severity$$

Where, *Likelihood* is defined as how likely the risk will result in an incident and *Severity* is defined as how serious the result of the incident might be in terms of injury or loss.

Each Risk is associated with one risk factor depending on their likelihood and severity, that allows it to be placed within a matrix defined as *Risk Matrix*.

Severity / Likelihood		Negligible	Minor	Major	Hazardous	Catastrophic
		A	B	C	D	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

Table 16 – Risk Matrix.

In the Risk Matrix, there are three main zones where the RF may be positioned. Table 17 defines each of them.

Zone	Definition
Red	Unacceptable Risk Level (Prohibit or suspend the operation).
Yellow	Tolerable Risk Level (Introduce appropriate mitigation resources).
Green	Acceptable Risk Level (Risk controlled, continuous monitoring).

Table 17 – Risk Zone Definition.

4.4. SHELL Model

The *SHELL* model is a conceptual method of human factors analysis that clarifies the involvement of the human in aviation and its relationships between aviation system resources, environment and the human subsystem itself.

As mentioned in the ICAO Digest no.7, "Each component of the *SHELL* model (software, hardware, environment, Liveware (Individual)) represents a building block of human factors studies" (ICAO, 1993). The human individual block is located at the center of the *SHELL* model, because it interacts directly with the other blocks and itself.

However, these elements must be carefully adapted and matched to this central component to accommodate human limitations and avoid stress and breakdowns (incidents/accidents) in the aviation system.

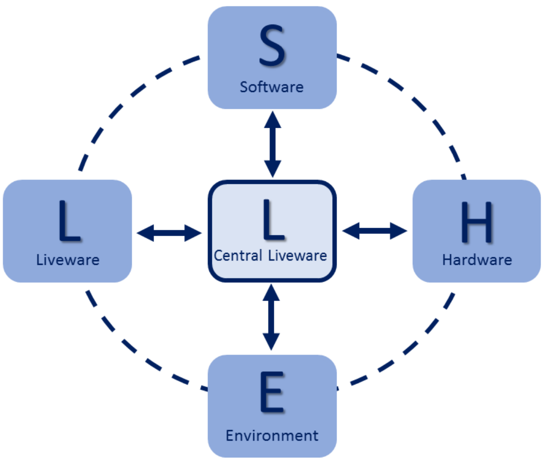


Figure 33 – SHELL Model Scheme.

SHELL Components	Definition	Factors
Liveware Individual	It is the centrepiece of the SHELL model. Data collected are addressed to this central component and it can be broken down into four categories factor.	• Physical Factors • Physiological Factors • Psychological Factors • Psychosocial Factors
Liveware - Liveware	This interface is the relationship between the individual and any other persons in the workplace. Staff-management relationships also fall within the scope of this interface, which can significantly affect human performance. Data requirements involves human interactions such as communication (verbal and non-verbal) and visual signals.	• Human Interface • Worker Management
Liveware - Hardware	This interface represents the relationship between the human and the machine. Data requirements span from cockpit, workstation configuration, display to control and seat design as well as configuration.	• Equipment
Liveware - Software	The Liveware-software interface reflects the relationship between the individual and supporting systems found in the workplace. Data requirements involves regulations, manuals, checklists, publications, standard operating procedures and computer software design.	• Human System Interface
Liveware - Environment	This interface is the relationship between the individual and the internal and external environments. The internal environment includes temperature, ambient light, noise and air quality. The 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. Data requirements may also include weather, terrain and physical facilities as well as infrastructures and economic situation.	• Internal • External

Table 18 – SHELL Model Factors ICAO Defined (ICAO, 1993).

4.5. HSI Model

Human system integration (*HSI*) is defined by INCOSE (International Council on System Engineering), as *"The interdisciplinary technical and management processes for integrating human considerations within and across all system elements; an essential enabler to systems engineering practice"*.

The *HSI* model provides the recognition of seven major domains to each the human factor can be classified. In Figure 34 it is shown how these domains converge into the definition of *HSI* itself.

This system allows to connect the *SHELL* model with *HFACS* model, providing a useful tool for a more accurate recognizing of human factor in the *HFACS* classifications.

Figure 34 – HSI Model.

The seven domains which characterizes this model are defined in Table 19 (Nicholas S. Hardman & John Colombi, 2009).

***HSI* Domains**	**Factor Definition**
Human Resources	The manpower domain determines the number and type of personnel required to operate and support a system. Support includes functions such as maintenance, sustainment, and training. Many civilian organizations call these ***human resources***.
Personal Capabilities	The personnel domain determines the knowledge, skills, and abilities and the physical, cognitive and sensory capabilities required of the humans in the system. The personnel community defines these parameters for the system and determines how to best obtain and maintain an adequate pool of qualified persons. The U.S. Army calls it personal capabilities and it is related to ***human resources*** in civilian organizations.
Training	The training domain determines the necessary infrastructure and system components to provide system personnel with the requisite attributes for optimal system performance. This includes individual and unit training programs, training systems, and retraining schedules.

Ergonomics	The human factors domain addresses how to incorporate human characteristics and limitations into system design for optimal usability. The issues of this domain are often divided into the following categories: • Cognitive— response times, level of autonomy, cognitive workload limitations. • Physical— ergonomic control design, anthropomorphic accommodation, workload limitations. • Sensory— perceptual capabilities, such as sight, hearing, or tactile. • Team dynamic— communication and delegation, task sharing, crew resource management. Much of U.S. industry calls this "human factors engineering (HFE)" and European and Asian organizations generically refer to it as "ergonomics". The methods and tools of this domain are the most mature of all the HSI domains.
System Safety	The system safety domain evaluates the characteristics and procedures of systems in order to minimize the potential for accidents. Safety studies affect system design by advocating features that eliminate hazards when possible and manage them when they cannot be avoided. Such features include sub-systems for system status, alert, backup, error recovery, and environmental risk.
Physical Environment	The health domain evaluates the characteristics and procedures of systems that create significant risks of injury or illness to humans. Sources of health hazards include: • noise, temperature, humidity, • CBRNE (i.e.: chemical, biological, radiological, nuclear, and explosive substances) • physical trauma, and electric shock.
Habitability	The habitability domain evaluates the characteristics and procedures of systems that have a direct impact on personnel effectiveness by maintaining morale, comfort, and quality of life. These characteristics uniquely include: • climate control, • space layout, • support services.

Table 19 – HSI Domains Definitions (Colombi & Hardman, 2009).

4.6. HFACS Model

The Human Factors Analysis and Classification System (*HFACS*) model was developed by Department of Defence (DoD) as a tool that classifies, through the use of taxonomy, human factors placing them on four levels of classifications. The human factor is, therefore, no longer seen solely under the operator's behaviour, but it is also involving the organization to which it belongs.

In Figure 35 is listed the hierarchy of the *HFACS* model.

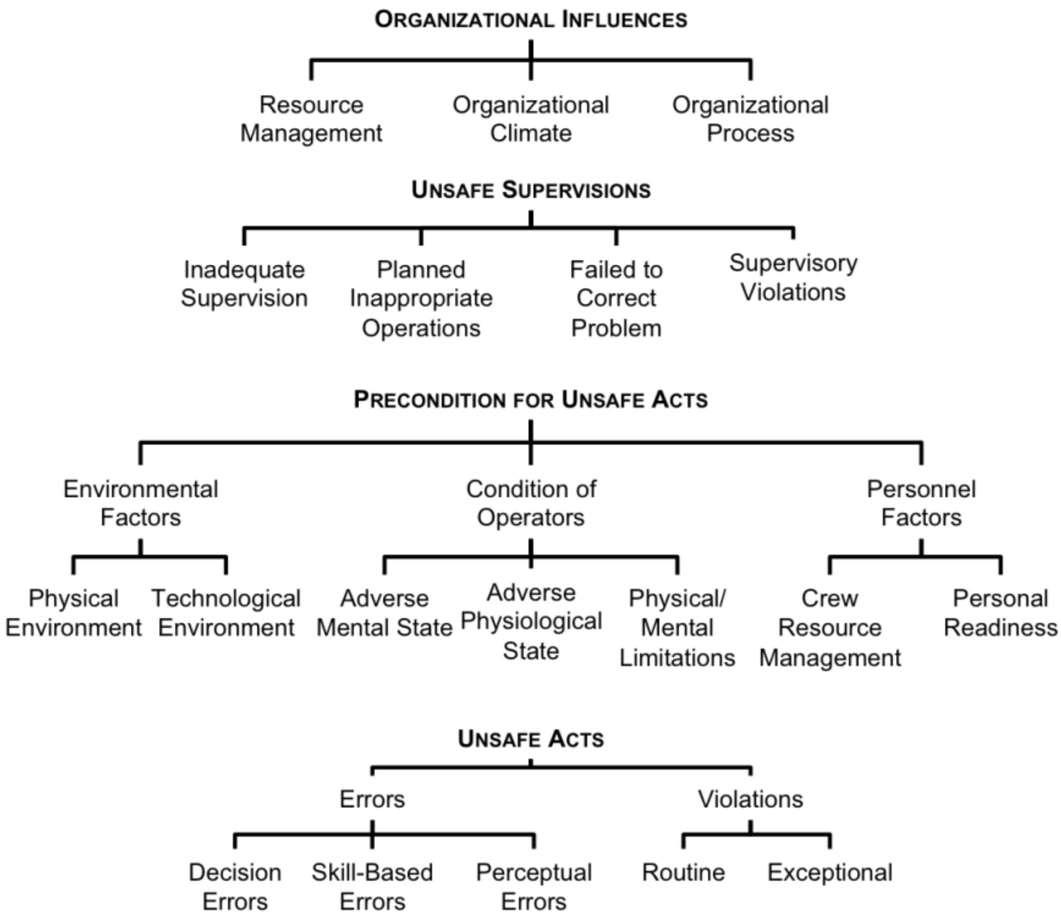


Figure 35 – HFACS Hierarchy.

The main domains of *HFACS* model are defined, according to Hardman and Colombi, as:

- ***Organizational Influences:*** Are factors in a mishap if the communications, actions, omissions or policies of upper-level management directly or indirectly affect supervisory practices, conditions or actions of the operator(s) and result in system failure, human error or an unsafe situation.
- ***Unsafe Supervision:*** Is a factor in a mishap if the methods, decisions or policies of the supervisory chain of command directly affect practices, conditions, or actions of individual and result in human error or an unsafe situation.
- ***Precondition for Unsafe Acts:*** Are factors in a mishap if active and/or latent preconditions such as conditions of the operators, environmental or personnel factors affect practices, conditions or actions of individuals and result in human error or an unsafe situation.
- ***Unsafe Acts:*** Are those factors that are most closely tied to the mishap, and can be described as active failures or actions committed by the operator that result in human error or unsafe situation.

Each subdomain is classified by an identification code, the following table summarizes the definition of them and its code. (Colombi & Hardman, 2009)

Domain	Factor	Code	Description
Organizational Influences	Resources/Acquisition Management	ORxxx	Is a factor in a mishap if resource management and/or acquisition processes or policies, directly or indirectly, influence system safety and results in poor error management or creates an unsafe situation.
	Organizational Climate	OCxxx	Is a factor in a mishap if organizational variables including environment, structure, policies, and culture influence individual actions and results in human error or an unsafe situation.
	Organizational Process	OPxxx	Is a factor in a mishap if organizational processes such as operations, procedures, operational risk management and oversight negatively influence individual, supervisory, and/or organizational performance and results in unrecognized hazards and/or uncontrolled risk and leads to human error or an unsafe situation.
Unsafe Supervision	Inadequate Supervision	SIxxx	Is a factor in a mishap when supervision proves inappropriate or improper and fails to identify hazard, recognize and control risk, provide guidance, training and/or oversight and results in human error or an unsafe situation.
	Planed Inappropriate Operations	SPxxx	Is a factor in a mishap when supervision fails to adequately assess the hazards associated with an operation and allows for unnecessary risk. It is also a factor when supervision allows non-proficient or inexperienced personnel to attempt missions beyond their capability or when crew or flight makeup is inappropriate for the task or mission.
	Failed to Correct Known Problem	SFxxx	Is a factor in a mishap when supervision fails to correct known deficiencies in documents, processes or procedures, or fails to correct inappropriate or unsafe actions of individuals, and this lack of supervisory action creates an unsafe situation.
	Supervisory Violation	SVxxx	Is a factor in a mishap when supervision while managing organizational assets wilfully disregards instructions, guidance, rules, or operating instructions and this lack of supervisory responsibility creates an unsafe situation.
Preconditions for Unsafe Acts	Environmental Factors	PExxx	Are factors in a mishap if physical or technological factors affect practices, conditions and actions of individual and result in human error or an unsafe situation.
	Condition of Individuals	PCxxx	Are factors in a mishap if cognitive, psycho-behavioural, adverse physical state, or physical/mental limitations affect practices, conditions or actions of individuals and result in human error or an unsafe situation.
	Personnel Factors	PPxxx	Are factors in a mishap if self imposed stressors or crew resource management affect practices, conditions or actions of individuals and result in human error or an unsafe situation.

Unsafe Acts	Errors	AExxx	Are factors in a mishap when mental or physical activities of the operator fail to achieve their intended outcome as a result of skill-based, perceptual, or judgment and decision making errors leading to an unsafe situation. Errors are unintended.
	Violations	AVxxx	Are factors in a mishap when the actions of the operator represent wilful disregard for rules and instructions and lead to an unsafe situation. Violations are deliberate.

Table 20 – HFACS Tiers.

4.7. Process Followed

Once the main models, that will be involved in this study, are been defined, the sequence of how they will be used is described in this section.

The Figure 36 shows the main steps taken to develop a method of studying helicopter incidents.

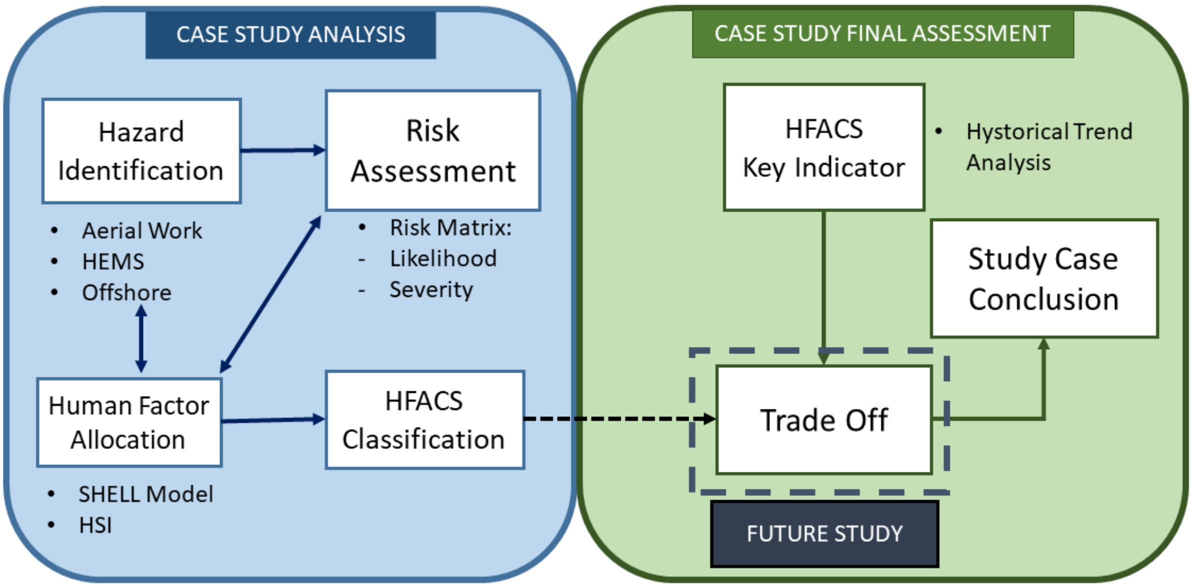


Figure 36 – Hazard Analysis Flow Chart.

Following the previous figure, the first step to be performed will be the hazard identification for each type of helicopter work studied. Once the hazards are defined, *Risk Assessment* will be performed evaluating the relative RF associated with the proper *Likelihood* and *Severity.*

The areas of involvement in human factors of each hazard can be defined using the *SHELL* model. Then this evaluation will be linked with *HSI* model.

Defined the keys area in terms of *HSI* and *SHELL*, they will provide a direct link to *HFACS* model. Its taxonomy will be used in order to collocate each previous evaluation in the proper *HFACS* level and code.

Once the Mission Analysis is concluded, the results obtained will be compared with the hazard statistics published by external sources such as ICAO, NTSB, Eurocontrol, in order to assess the effectiveness and consistency of the study. Risks and hazards will be updated if it is necessary, with the aim of having a more accurate evaluation.

The final part will be dedicated to case studies of helicopter accident, which will be evaluated according to the phases and model used so far.

5. Study Results

Described the main methodologies and phases developed within this thesis, the next phase will be the application of these models and the evaluation of the results.

The results have been divided according to the different aerial works studied. Each type of them has therefore been submitted to de cycle of study described in the previous section. For this reason, the first step will be the potential hazard identification along the risks associated. Note how each hazard has been distinguished between day and night, this is because of the same risk assumes a more dangerous value during the night for different human factors (day/night alternation, circadian cycles, etc). Therefore, a more severe evaluation will be assigned.

The *Risk Assessment* will be carried out, where each risk will be evaluated with a certain level of likelihood and severity. The product of these two elements will be the Risk Factor. Each Risk has its RF associated that allows it to be positioned in the Risk Assessment Matrix.

Once the *Risk Assessment* has been carried out, and taking into account both the risk and the hazard, the *SHELL* Field identification is conducted. Notice that, each hazard may have more than one *SHELL* domain associated, this is because the risks linked with each hazard also affect the identification of the *SHELL* itself.

Last step will be the association between *SHELL* model and *HSI* domains, which will follow the final correlation with *HFACS* level and subdomain.

A significant number of hazard were found associated with all the types analysed. In order to make the study more specific, these common hazards have been included in the General Hazard section.

The following tables will show the results finally obtained. These tables have a large size; therefore, it has been decided to implement the results in A3 format.

General Hazard

Job	Task	Hazard		Risk Assessment				SHELL Model		HSI	HFACS 1	HFACS 2	HFACS 3	HFACS 4
		Day	Night	Risk Identification	Likelihood	Severity	Risk Factor	SHELL Model	Relating Factors					
Planning Phase	Check Weather Conditions	Meteorological Charts not updated	Meteorological Charts not updated	Unknown weather conditions - Entering IMC	3	C	3C	E	External-Weather-Weather Briefing	Safety - Environment Habitability	PE1XX PHYSICAL ENVIRONMENT			
								L	Individual-Psychological Factors-Information Processing-Forgetting	Personal Capabilities - Training	PC402 MEMORY ABILITY / LAPSES			
	Identify load, the adequate fuel, development of the emergency plan	Improper fuel plan	Improper fuel plan	Insufficient Fuel	2	B	2B	L	Individual-Psychological Factors-Planning-Pre-Flight	Training - Ergonomics	PP109 MISSION PLANNING	PP110 MISSION BRIEFING	AE102 CHECK LIST ERROR	
				Different weight	3	C	3C	L	LL-Controllers-Supervision	Training - Ergonomics	PP102 CROSS MONITORING PERFORMANCE	PP101 CREW TEAM LEADERSHIP		
		Improper emergency plan	Improper emergency plan	Mission aborted	2	E	2E	L	Individual-Psychological Factors-Planning-Pre-Flight	Training - Ergonomics	PP109 MISSION PLANNING	PP110 MISSION BRIEFING	AE102 CHECK LIST ERROR	
								L	LL-Worker Management-Personnel-Managerial Operating Pressure	Personal Capabilities - Training - Human Resources	OC001 UNIT / ORGANISATIONAL VALUES / CLIMATE			
								L	Individual-Psychological Factors-Training-Emergency Procedures	Training - Personal Capabilities	OP004 ORGANISATIONAL TRAINING PROCESS	SI003 LOCAL TRAINING ISSUE / PROGRAMS	PC401 LEARNING ABILITY / RATE	
	Analysis of Pick-up and Drop zone and Enroute	Unfamiliarity pick up and drop zone (Pilot disorientation)	Unfamiliarity pick up and drop zone (Pilot disorientation)	Incorrect action	3	B	3B	E	External-Other Factors-Terrain/Water Features Obstacles	Safety - Environment Habitability	PE1XX PHYSICAL ENVIRONMENT			
		Unfamiliarity enroute environment (Pilot disorientation)	Unfamiliarity enroute environment (Pilot disorientation)	Plan lapses	3	B	3B	E	External-Other Factors-Terrain/Water Features Obstacles	Safety - Environment Habitability	PE1XX PHYSICAL ENVIRONMENT			
Pre-Flight Operations	Pre-Flight Checks	Improper ground crew training	Improper ground crew training	Skipping check list item	3	C	3C	L	Individual-Psychological Factors-Training-Ground	Training - Personal Capabilities	OP004 ORGANISATIONAL TRAINING PROCESS	SI003 LOCAL TRAINING ISSUE / PROGRAMS	PC401 LEARNING ABILITY / RATE	
				Unrecognised item during visual check	3	D	3D	L	Individual-Psychological Factors-Training-On the Job	Training - Personal Capabilities	OP004 ORGANISATIONAL TRAINING PROCESS	SI003 LOCAL TRAINING ISSUE / PROGRAMS	PC401 LEARNING ABILITY / RATE	
				Crew Lapses	3	C	3C							
		Pilot Inattention	Pilot Inattention	Pilot Lapses	3	C	3C	L	Individual-Psychological Factors-Attention- Inattention/Distraction	Physical Environment - Ergonomics - Safety - Training	PC101 INATTENTION	PC106 DISTRACTION		
								L	Individual-Psychological Factors-Attitudes-Confidence-Overconfidence	Personal Capabilities	PC206 OVERCONFIDENCE	OC003 PERCEPTION OF EQUIPMENT		
	Fuelling	Improper refuelling	Improper refuelling	Accidental spark - possible fire ignition	2	E	2E	E	External-Infrastructure-At the gate-Refuelling Equipment	Environment Habitability	OR002 AIRFIELD RESOURCES			
				Fuel spray - possible fire ignition	2	E	2E	L	Individual-Psychological Factors-Attention-Inattention	Physical Environment - Ergonomics - Safety - Training	PC101 INATTENTION			
				Environmental spill - possible fire ignition	2	D	2D							
				Improper fuel level	3	D	3D							

Flight Operations	Take-Off - Landing /Enroute	Unfamiliarity of landing zone		No situational awareness - Incorrect action	2	D	2D	L	Individual-Psychological Factors-Perception-Disorientation-Spatial	Ergonomics - Personal Capabilities	PC508/PC509/PC510 SPATIAL DISORIENTATION	AE301 ERROR DUE TO MISPERCEPTION		
								E	External-Other Factors-Time of Day	Safety - Environment Habitability	PE1XX PHYSICAL ENVIRONMENT	AE2XX JUDGMENT AND DECISION MAKING ERROR		
			Unfamiliarity of landing zone	No situational awareness - Incorrect action	3	D	3D	L	Individual-Psychological Factors-Experience-Night Time	Personal Capabilities - Training	SP003 LIMITED RECENT EXPERIENCE	SP004 LIMITED TOTAL EXPERIENCE	SI003 LOCAL TRAINING ISSUES / PROGRAMS	PC405 TECHNICAL / PROCEDURAL KNOWLEDGE
		Foreign object on take-off / landing zone	Foreign object on take-off / landing zone	Rotor blade impact - LOC - CFIT	3	E	3E	E	External-Other Factors-Terrain Feature Obstacles	Safety - Environment Habitability	PE1XX PHYSICAL ENVIRONMENT			
				Air filter obstructed - LOC - Upset	2	D	2D	L	Individual-Psychological Factors-Perceptions-Reaction Time (All)	Ergonomics - Personal Capabilities	PPP111 TASK - MISSION IN PROCESS REPLANNING	AE301 ERROR DUE TO MISPERCEPTION		
		Presence of birds on take-off / landing zone		Rotor blade impact - LOC - CFIT	2	E	2E	E	External-Other Factors-Terrain Feature Obstacles	Safety - Environment Habitability	PE1XX PHYSICAL ENVIRONMENT			
				Broken windshield - LOC - Upset	2	D	2D	L	Individual-Psychological Factors-Attention-Inattention	Physical Environment - Ergonomics - Safety - Training	PC101 INATTENTION			
				Airframe damage - LOC - CFIT	2	E	2E	L	Individual-Psychological Factors-Perceptions-Reaction Time (All)	Ergonomics - Personal Capabilities	PPP111 TASK - MISSION IN PROCESS REPLANNING	AE301 ERROR DUE TO MISPERCEPTION		
		Pilot Fatigue		Pilot misjudgement	3	B	3B	L	Individual-Physiological Factors-Fatigue-Activity Level	Personal Capabilities - Ergonomics	PC306/PC307 FATIGUE	AVXXX VIOLATIONS		
				Excessive confidence	4	B	4B	L	Individual-Physiological Factors-Fatigue-Duty-Duty Hours	Personal Capabilities - Ergonomics	PC306/PC307 FATIGUE	AVXXX VIOLATIONS		
				Improper clearance with the ground/water - LOC - CFIT	3	E	3E	L	Individual-Psychological Factors-Experience-Night Time	Personal Capabilities - Training	SP003 LIMITED RECENT EXPERIENCE	SP004 LIMITED TOTAL EXPERIENCE	SI003 LOCAL TRAINING ISSUES / PROGRAMS	PC405 TECHNICAL / PROCEDURAL KNOWLEDGE
				Pilot misjudgement	4	B	4B	E	External-Other Factors-Time of Day	Safety - Environment Habitability	PE1XX PHYSICAL ENVIRONMENT	AE2XX JUDGMENT AND DECISION MAKING ERROR		
			Pilot Fatigue	Excessive confidence	5	B	5B							
				Improper clearance with the ground/water - LOC - CFIT	4	E	4E							
		Adverse weather - Strong wind / Presence of cumulus		Helicopter instability - LOC - Upset	3	D	3D	E	External-Weather-Turbulence	Safety - Environment Habitability	PE105 WIND BLUST	PE103 VIBRATION	PE1XX PHYSICAL ENVIRNOMENT	
				Heavy turbulence - LOC - CFIT	2	E	2D	E	External-Other Factors-Wind Blast	Safety - Environment Habitability	PE1XX PHYSICAL ENVIRONMENT			
			Adverse weather - Strong wind / Presence of cumulus	Helicopter instability - LOC - Upset	4	D	4D							
				Heavy turbulence - LOC - CFIT	3	E	3E							
		Persistent rain (Low visibility In Flight)		LOC - Upset	2	C	2C	E	External-Weather-Visibility	Safety - Environment Habitability	PE101 VISION RESTRICTED BY			

											METEO CONDITION			
				Mission aborted	3	C	3C	L	Individual-Physical Factors-Sensor Limitations-Vision-Visual Threshold	Ergonomics - Personal Capabilities	PC503 ILLUSION / VISUAL	PC314 VISUAL ADAPTATIONS	AE301 ERROR DUE TO MISPERCEPTION	
			Persistent rain (Low visibility In Flight)	LOC - Upset	3	D	3D							
				Mission aborted	4	D	4D							
		Persistent rain (Low visibility- TO & Land)	Persistent rain (Low visibility- TO & Land)	LOC - Upset	2	D	2D	E	External-Weather-Visibility	Safety - Environment Habitability	PE101 VISION RESTRICTED BY METEO CONDITION			
				Mission aborted	3	D	3D	L	Individual-Physical Factors-Sensor Limitations-Vision-Visual Threshold	Ergonomics - Personal Capabilities	PC503 ILLUSION / VISUAL	PC314 VISUAL ADAPTATIONS	AE301 ERROR DUE TO MISPERCEPTION	
				LOC - Upset	3	E	3E							
				Mission aborted	4	E	4E							
		Low Temperature - Presence of ice	Low Temperature - Presence of ice	Engine failure - LOC - CFIT	2	E	2E	E	External-Weather-Whiteout	Safety - Environment Habitability	PE111 BROWNOUT / WHITEOUT			
				Sleet on windshield - Low visibility	3	D	3D	E	External-Weather-Actual and Forecast	Safety - Environment Habitability	AE2XX JUDGEMENT AND DECISION MAKING ERROR	PE1XX PHYSICAL ENVIRNOMENT		
				Engine failure - LOC - CFIT	3	E	3E	E	External-Weather-Visibility	Safety - Environment Habitability	PE101 VISION RESTRICTED BY METEO CONDITION			
				Sleet on windshield - Low visibility	4	D	4D							
		Weather change	Weather change	IIMC (Inadvertent IMC)	2	C	2C	E	External-Weather-Actual and Forecast	Safety - Environment Habitability	AE2XX JUDGEMENT AND DECISION MAKING ERROR	PE1XX PHYSICAL ENVIRNOMENT		
								L	Individual-Psychological Factors-Information Processing-Judgement	Personal Capabilities - Training	AE2XX JUDGEMENT AND DECISION MAKING ERROR			
		Rotor downwash	Rotor downwash	Presence of ground effect - LOC - Upset	3	C	3C	H	External-Other Factors-Terrain/Water Features Obstacles	Safety - Environment Habitability	PE1XX PHYSICAL ENVIRONMENT			

Aerial Work – Fire Fighting														
Job	Hazard		Risk Assessment				SHELL Model		HSI	HFACS 1	HFACS 2	HFACS 3	HFACS 4
	Day	Night	Risk Identification	Likelihood	Severity	Risk Factor	SHELL Field	Relating Factor					
Plan Phase	Incorrect choice of Primary hook	Incorrect choice of Primary hook	Inadvertent hook release	3	E	3E	L	Individual-Psychological Factors-Attention- Inattention	Physical Environment - Ergonomics - Safety - Training	PC101 INATTENTION			
			Possible hook failure	2	E	2E	L	Individual-Psychological Factors-Planning-PreFlight	Training - Ergonomics	PP109 MISSION PLANNING	PP110 MISSION BRIEFING	AE102 CHECK LIST ERROR	
Flight Operations	Presence of natural obstruction (Restricted mobility)		Possible impact with helicopter - LOC - CFIT	3	E	3E	E	External-Other Factors-Terrain Feature Obstacles	Safety - Environment Habitability	PE1XX PHYSICAL ENVIRONMENT			
		Presence of natural obstruction (Restricted mobility)	Possible impact with helicopter - LOC - CFIT	4	E	4E	L	Individual-Psychological Factors-Perceptions-Reaction Time (All)	Ergonomics - Personal Capabilities	PPP111 TASK - MISSION IN PROCESS REPLANNING	AE301 ERROR DUE TO MISPERCEPTION		
	Presence of other Aircraft		Possible impact with other aircraft - LOC - CFIT	2	E	2E	E	External-Other Factors-Other Air Traffic	Safety - Environment Habitability	PE1XX PHYSICAL ENVIRONMENT			
		Presence of other Aircraft	Possible impact with other aircraft - LOC - CFIT	3	E	3E	L	LL-Crew Interactions-Coordination	Training	PP1XX			
	Excessive swing load	Excessive swing load	Helicopter instability - LOC - Upset	3	D	3D	H	Workspace- Layout	Ergonomics - Safety - Physical Environment	OC003 PERCEPTION OF EQUIPMENT	ORXXX RESOURCES ACQUISITION MANAGMENT		
			Inadvertent load release	3	E	3E	L	Individual-Psychological Factors-Training- Flight	Training - Personal Capabilities	OP004 ORGANISATIONAL TRAINING PROCESS	SI003 LOCAL TRAINING ISSUE / PROGRAMS	PC401 LEARNING ABILITY / RATE	
	Improper load definition (Mass and size)	Improper load definition (Mass and size)	Excessive TOW	4	B	4B	H	Workspace- Layout	Ergonomics - Safety - Physical Environment	OC003 PERCEPTION OF EQUIPMENT	ORXXX RESOURCES ACQUISITION MANAGMENT		
			Helicopter instability - LOC	3	D	3D	H	Equipment-Workspace-Motor Workload	Ergonomics - Safety - Physical Environment	PE108 MANEUVERING FORCES IN FLIGHT	PC403 ANTRHOPOMETRIC / BIOMECHANICAL LIMITATIONS		
			Cable breaking	3	E	3E	L	Individual-Psychological Factors-Knowledge-Skills/Techniques	Training - Personal Capabilities	SI003 LOCAL TRAINING ISSUE / PROGRAMS	PC405 TECHINICAL / PROCEDURAL KNOWLEDGE		
			Engine overload (aborted mission)	4	B	4B							
	Hook not secured (ground handling)	Hook not secured (ground handling)	Inadvertent hook release	3	E	3E	L	LL-Crew Interactions-Coordination	Training	PP1XX			
			Cable release	3	E	3E	S	Written Information-Standard Operating Procedures	Personal Capabilities - Training - Safety	OP003 PROCEDURAL GUIDANCE / PUBLICATION	OR008 INFORMATIONAL RESOURCES / SUPPORT	AE103 PROCEDURAL ERROR	
	Presence of powerline		Wire strikes - LOC - CFIT	3	E	3E	E	External-Other Factors-Terrain Feature Obstacles	Safety - Environment Habitability	PE1XX PHYSICAL ENVIRONMENT			
			Impact with structure -LOC - CFIT	2	E	2E	L	Individual-Psychological Factors-Training-Problem Areas	Ergonomics - Personal Capabilities	OP004 ORGANISATIONAL TRAINING PROCESS	SI003 LOCAL TRAINING ISSUE / PROGRAMS	PC401 LEARNING ABILITY / RATE	

		Presence of powerline	Wire strikes - LOC - CFIT	4	E	4E	L	Individual-Psychological Factors-Perceptions-Reaction Time (All)	Personal Capabilities - Training	PPP111 TASK - MISSION IN PROCESS REPLANNING	AE301 ERROR DUE TO MISPERCEPTION		
			Impact with structure -LOC - CFIT	3	E	3E	L	Individual-Psychological Factors-Experience-Night Time		SP003 LIMITED RECENT EXPERIENCE	SP004 LIMITED TOTAL EXPERIENCE	SI003 LOCAL TRAINING ISSUES / PROGRAMS	PC405 TECHNICAL / PROCEDURAL KNOWLEDGE
	Mountain operations - Adverse pressure gradient along the valley	Mountain operations - Adverse pressure gradient along the valley	LOC - Upset (Strong wind)	4	D	4D	E	External-Weather-Turbulence	Safety - Environment Habitability	PE105 WIND BLUST	PE103 VIBRATION	PE1XX PHYSICAL ENVIRNOMENT	
	Mountain operations - Adverse weather		Mission aborted	3	D	3D	E	External-Weather-Actual and Forecast	Safety - Environment Habitability	AE2XX JUDGEMENT AND DECISION MAKING ERROR	PE1XX PHYSICAL ENVIRNOMENT		
			Engine compromised - LOC - Upset	3	E	3E	L	Individual-Psychological Factors-Knowledge-Skills/Techniques	Training - Personal Capabilities	SI003 LOCAL TRAINING ISSUE / PROGRAMS	PC405 TECHINICAL / PROCEDURAL KNOWLEDGE		
		Mountain operations Adverse weather	Mission aborted	4	D	4D							
			Engine compromised - LOC - Upset	4	E	4E							
	Inadequate load line	Inadequate load line	Possible impact between load and natural environment - LOC - CFIT	3	D	3D	H	Workspace- Layout	Ergonomics - Safety - Physical Environment	OC003 PERCEPTION OF EQUIPMENT	ORXXX RESOURCES ACQUISITION MANAGMENT		
			System Center of gravity	4	C	4C	L	Individual-Psychological Factors-Planning-PreFlight	Training - Ergonomics	PP109 MISSION PLANNING	PP110 MISSION BREAFING	AE102 CHECK LIST ERROR	
			Excessive load swing - Helicopter instability - LOC - Upset	4	C	4C							
	Load not secured	Load not secured	Inadvertent release	2	E	2E	L	Individual-Psychological Factors-Attention- Inattention/Distraction	Physical Environment - Ergonomics - Safety - Training	PC101 INATTENTION	PC106 DISTRACTION		
							L	Individual-Psychosocial Factors-Mental pressure	Personal Capabilities	PC204 EMOTIONAL STATE	PC205 PERSONALITY STYLE		
	Hook electrical failure (Failing to release load)	Hook electrical failure (Failing to release load)	Aborted mission (electrical failure)	3	B	3B	H	Equipment-Control (All)	Ergonomics - Safety - Physical Environment	PE202 INSTRUMENTATION AND SENSORY FEEDBACK SYSTEMS	PE205 AUTOMATION	PE204 CONTROL AND SWITCHES	AE201 RISK ASSESSMENT DURING OPERATIONS
	Sea Environment - Presence of vessels on pick-up zone (Bucket strike)	Sea Environment - Presence of vessels on pick-up zone (Bucket strike)	LOC-CFIT	2	E	2E	E	External-Other Factors- Water Features Obstacles	Safety - Environment Habitability	PE1XX PHYSICAL ENVIRONMENT			
	Sea Environment - Presence of high waves (Bucket toiled by the current)	Sea Environment - Presence of high waves (Bucket toiled by the current)	Helicopter instability - LOC - Upset	3	D	3D	E	External-Weather-Actual and Forecast	Safety - Environment Habitability	AE2XX JUDGEMENT AND DECISION MAKING ERROR	PE1XX PHYSICAL ENVIRNOMENT		
	Presence of flames - High air temperatures (Decreasing engine performances)	Presence of flames - High air temperatures (Decreasing engine performances)	LOC-CFIT	2	E	2E	L	Individual-Psychological Factors-Information Processing-Decision Making	Personal Capabilities - Training	AE206 DECISION MAKING DURING OPERATION			
	Presence of smoke	Presence of smoke	Low visibility - LOC - Upset	4	B	4B	E	External-Weather-Visibility	Safety - Environment Habitability	PE101 VISION RESTRICTED BY METEO CONDITION			
			Air intake obstructed - LOC - Upset	2	D	2D							

Offshore													
Job	Hazard		Risk Assessment				SHELL Model		HSI	HFACS 1	HFACS 2	HFACS 3	HFACS 4
	Day	Night	Risk Identification	Likelihood	Severity	Risk Factor	SHELL Field	Relating Factor					
Flight Operation	Presence of Structures (Restricted mobility)		Impact with structure - LOC - CFIT	2	E	2E	E	External-Other Factors-Terrain Feature Obstacles	Safety - Environment Habitability	PE1XX PHYSICAL ENVIRONMENT			
							E	External-Other Factors-Time of Day	Safety - Environment Habitability	PE1XX PHYSICAL ENVIRONMENT	AE2XX JUDGMENT AND DECISION MAKING ERROR		
		Presence of Structures (Restricted mobility)	Impact with structure - LOC - CFIT	3	E	3E	L	Individual-Psychological Factors-Perceptions-Reaction Time (All)	Ergonomics - Personal Capabilities	PPP111 TASK - MISSION IN PROCESS REPLANNING	AE301 ERROR DUE TO MISPERCEPTION		
	Presence of safety net	Presence of safety net	Possible twisting with landing gear - LOC - Upset	3	D	3D	E	External-Infrastructure-Aerodrome-Airfield Facilities	Environment Habitability	OR002 AIRFIELD RESOURCES			
	Presence of safety edge		Possible twisting with landing gear - LOC - CFIT	2	E	2E	E	External-Infrastructure-Aerodrome-Airfield Facilities	Environment Habitability	OR002 AIRFIELD RESOURCES			
		Presence of safety edge	Possible twisting with landing gear - LOC - CFIT	3	E	3E	L	Individual-Psychological Factors-Knowledge-Skills/Techniques	Training - Personal Capabilities	SI003 LOCAL TRAINING ISSUE / PROGRAMS	PC405 TECHINICAL / PROCEDURAL KNOWLEDGE		
	Unstable helideck due to high waves	Unstable helideck due to high waves	Helicopter instability - LOC - Upset	4	B	4B	E	External-Weather-Turbulence	Safety - Environment Habitability	PE105 WIND BLUST	PE103 VIBRATION	PE1XX PHYSICAL ENVIRNOMENT	
							E	External-Weather-Actual and Forecast	Safety - Environment Habitability	AE2XX JUDGEMENT AND DECISION MAKING ERROR	PE1XX PHYSICAL ENVIRNOMENT		
							L	Individual-Psychological Factors-Knowledge-Skills/Techniques	Training - Personal Capabilities	SI003 LOCAL TRAINING ISSUE / PROGRAMS	PC405 TECHINICAL / PROCEDURAL KNOWLEDGE		
	Presence of flames - High air temperatures (Decreasing engine performances)	Presence of flames - High air temperatures (Decreasing engine performances)	LOC-CFIT	2	E	2E	L	Individual-Psychological Factors-Information Processing-Decision Making	Personal Capabilities - Training	AE206 DECISION MAKING DURING OPERATION			
							E	External-Weather-Turbulence	Safety - Environment Habitability	PE105 WIND BLUST	PE103 VIBRATION	PE1XX PHYSICAL ENVIRNOMENT	
	Presence of smoke	Presence of smoke	Low visibility - LOC - Upset	4	B	4B	E	External-Weather-Visibility	Safety - Environment Habitability	PE101 VISION RESTRICTED BY METEO CONDITION			
			Air intake obstructed - LOC - Upset	2	D	2D							
	Inadequate light signal	Inadequate light signal	LOC-CFIT	4	C	4C	E	External-Infrastructure-Aerodrome-Lighting, Markings	Environment Habitability	OR002 AIRFIELD RESOURCES			

6. Case study

In order to show the strong relation between the results achieved and the practical study, an Incident Report has been analysed using the methods listed so far.

6.1. Forewords

Scope of these reports is to describe the aircraft incidents/accidents where possible by means of scientific methods leading to useful Safety recommendations.

Methods applied are based on:

- ICAO Circular 240-AN/144 -1993 Human Factors Digest n.7 Investigation of human factors in accidents and incidents.
- DOD/USAF Human Factors Approach to Accident Analysis the human factors analysis and classification system.
- Chapter 5: Study Results.
- ICAO Annex 13: Manual of aircraft accident & incident investigation (ICAO, 2016).

These methods should help aviation analyst to distinguish all the systemic and organizational factors, human factors, technical factors which concur to create the unsafe environment which the event could take place.

Future safety recommendation are used to define improvement in safety policy aiming to reduce (or avoid) repetition of same incident/accident.

The information contained in this report are for study purpose only and does not intend to substitute in any case the official incident investigation. In accordance with ICAO Annex 13 it is not purpose of this Aircraft incident investigation report to apportion blame or liability. The sole objective of the investigation is the prevention of accidents and incidents.

Description of incident can be found in AMI "Rivista Sicurezza del Volo RSV 300/2013" (Militare, 2013)

6.2. Table of content

- Event summary
- Event description
- Information
- Identified Preconditions
- Analysis
- Findings
- Risk Assessment
- SHELL Factual Data Gathering

6.3. Event Summary

During a MEDEVAC night drill on the Sicilian coast, an AB-212 of the Italian Navy splashed on the sea at 1 km of distance between the military patrol boat Libra. Due to immediate intervention of the nearby boat, there was not any causalities and all the crew were rescued in time.

6.4. Case Study: Helicopter HH 212 Italian Navy – CFIT

In this Section will be applied the notions and methods explained so far, in order to give a practical example of how these models, linked between each other, may provide a good degree of risk analysis (as well as future mitigations) in helicopter incident.

Following ICAO Digest No. 7 (ICAO, 1993); at first will be described in detail the history of the incident, then all the elements will be analysed. Achieved this step, a Risk Assessment will be initialised; this will be concatenated with the identification of the single causes in the SHEL Model, HIS Domain and in conclusion with the HFACS Model.

6.5. Event description

An HH-212, on duty at MIATM (Malta, current callsign MICCD), and its mixed Italian/Maltese crew, took off at 04h00 UTC from Malta to Sigonella Airbase (LICZ) , in order to participate at an international training mission off the Sicilian coast.

The transfer flight, initially scheduled for the previous Friday, had been reprogrammed for Monday, the day of the accident, due to a failure of the helicopter e subsequent maintenance intervention.

At the Sigonella airbase, the crew attended the general briefing of the training missions.

The mission briefing scheduled the training divided on two sorties in which to simulate MEDEVAC (Medical Evacuation) recoveries of personnel from Libra during navigation: one in the afternoon and the other one at night.

The crew was therefore busy until lunchtime and had the chance to have a moment of rest only in the early afternoon, close to the afternoon mission.

- The first mission took place without any problems, with a passage in order to deploy the rescue crew and the stretcher by a winch, with a subsequent recovery passage.
- The second mission, which should be executed at night, provided the same profile as the previous one;
- The weather conditions were good, the wind was calm and the sea with no waves.

The helicopter took off from Sigonella Airbase at 18h48 UTC taking 30 minutes for reach the ship Libra, which was intercepted about at 32 NM direction SE from Augusta.

After having transhipped the rescue crew with a winch on the ship, the helicopter moved away for a subsequent operation of second approach on the same ship.

A right traffic circuit was then carried out, maintaining an altitude of about 200 ft. In the downwind section, the helicopter was forced to orbit for about 10 minutes because the Libra ship's bridge was unable (red bridge) due to the nautical traffic.

Received the authorization to approach (green bridge) by the ship, the helicopter continued the rectangular circuit and, completed the downwind section, it turned in the final at a speed of about 60 knots.

The final manoeuver was carried out manually, without the aid of the autopilot, for training reasons and to avoid excessive stabilization time necessary due to the moving vessel.

During the final approach phase, the helicopter began a progressive loss of altitude that led him to impact with the sea surface at 19h48 UTC (CFIT).

The helicopter impacted the sea surface at a distance of about 1 km from the “Libra” with a pitched down attitude and banked to the right.

The personnel of the "Libra" noticed the impact of the helicopter and immediately launched the "MAY DAY". The MAY DAY was received by a HH- 3F helicopter and by naval units that were operating nearby the area. The HH-3F helicopter (crew) confirmed the ditching of the HH-212 and its position.

The two pilots they managed, albeit with great difficulty, to get out of the aircraft.

The Winch Operator unconscious, was brought back to the surface by one of the two pilots and the rescue floats were activated. In this phase, the two pilots lent also the first aid to the non-commissioned officer by practicing CPR, allowing him to resume an autonomous breathing. One of the pilots was looking for use the light strobe (provided in the life jacket) encountering few difficulties on its activation due to the presence of a tape on the switch, managing to make only 5/6 flashes. All this was however sufficient to allow the identification and recovery of the survivors.

6.6. Information

Time of Incident	19h48 UTC	
Crew Flight Time (h)	**1° Pilot**	**2° Pilot**
On HH-212	234	630
Mission Hours on last 6 Months	91	54
Overall Total	2289	3204
Certification	**1° Pilot**	**2° Pilot**
	SF.260,TW AST, T38,UH-1H, HH-3F, AB-205, NH-500E, AB 212	AB-47G2, AB-206A, AB204B, NH-500C,AB 212, ALOUETTE III
METAR	30013KT 9999 FEW020 SCT090	Wind 300°/13 KTS Visibility over 10 Km, Clouds occupies the sky for 1/8 at 2000 ft and for 3/8 at 9000 ft

Table 21 – Main incident information.

Figure 37 – Image of an HH-212.

Crew	4 (Pilot, Co-pilot, Crew chief, gunner)
Capacity	8
MTOW	4762.2 Kg
Engine	2 x PW T400-CP-400
Power	1342 KW
Max Speed	130 kts

Table 22 – HH-212 Specification.

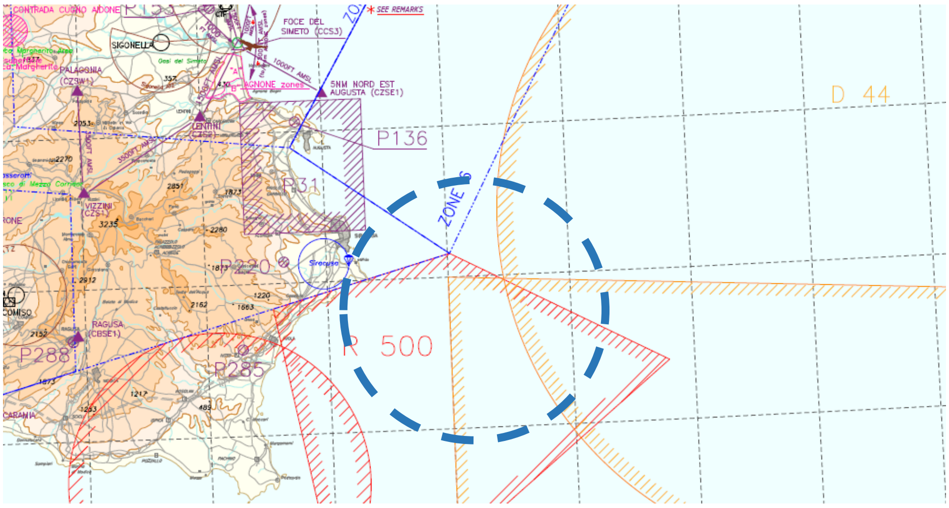


Figure 38 – Magnification of Incident Site (AIP-ENR-6-3.13).

Figure 39 – Libra Patrol Boat.

Name	Libra (P402)
Class	Cassiopea – Patrol Boat
Cruise Speed	20 Kts
Power	5507 KW
Weapon	1 cannon Melara 76/62, 2x gunners 25/80 mm, 2x gunners 7.62 mm
Crew	64
Endurance	3300 NM
Dimension	79.8 x 11.8 m

Table 23 – Libra characteristics.

Figure 40 – HH-3F (S-61B) Helicopter came to provide aid.

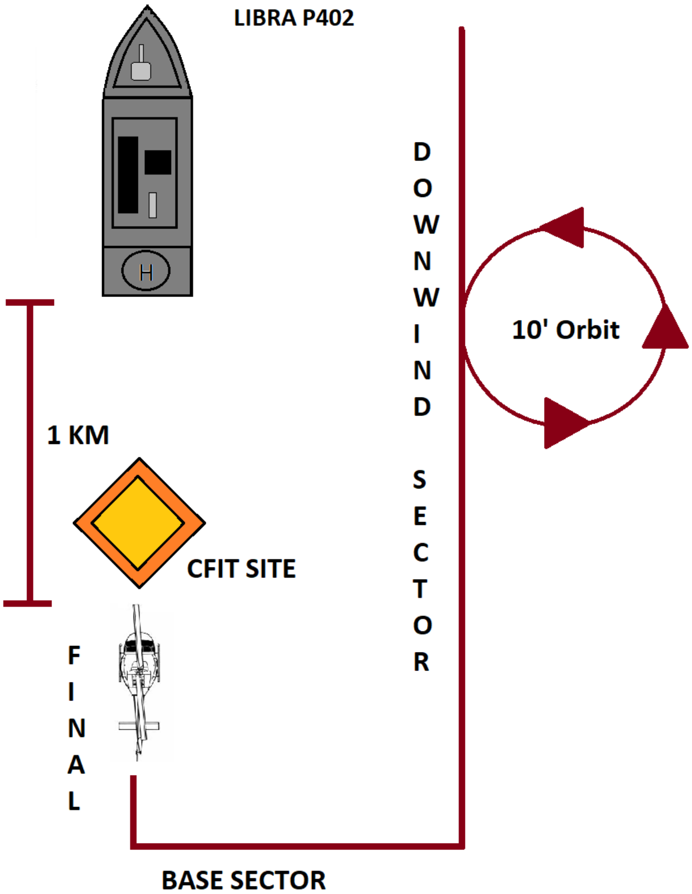


Figure 41- Representation of the incident.

6.7. Identified Precondition

Prior to identify the main issue which led to the CFIT, it is helpful to have also the environmental context where the incident occurred. There are in fact certain phrases in event description which represents the so called "Precondition"; they represents the initial point of conducting the analysis.

Precondition No.	Description
PC0 (A1)	During the briefing phase it was decided that, given the night conditions, the system of Low Altitude Warning of the Copilot altimeter radar would have been set in in order to alert the crew at 20 ft, while that of the Pilot would have been set to 30 ft.
PC1	The transfer flight, initially scheduled for the previous Friday, had been reprogrammed for Monday, the day of the incident
PC2	The crew was therefore busy until lunchtime and had few chance to have a rest
PC2.1	They had short rest only in the early afternoon, close to the afternoon mission
PC3	The second mission, which should be executed at night
PC3.1	The weather conditions were good, the wind was calm and the sea with no waves, but no moon and natural horizon were visible.
PC4	The manoeuver was carried out manually, without the aid of the autopilot, for training reasons
PC5	The helicopter began a progressive loss of altitude that led him to impact with the sea surface at 19h48 UTC (CFIT), at a distance of about 1 km, with a slightly cabred attitude and banked to the right.
PC6	Co-pilot said he was busy monitoring radio calls, speaking with ATC station, following the navigation and monitoring the fuel consumption.
PC6.1	In particular the Pilot recalled how in the downwind section, after flying holding circuit before receiving clearance to approach the ship, his attention had been seized by the fuel level, just under 800 lbs in that moment (next so at bingo set at 750 lbs).

Table 24 – Preconditions Table

6.8. Incident Analysis

A1 During the briefing phase it was decided that, given the night conditions, the system of Low Altitude Warning of the Co-pilot altimeter radar would have been set in in order to alert the crew at 20 ft, while that of the Chief Crew would have been set to 30 ft.

A2 Furthermore, it was made clear that the Co-pilot should have intervened autonomously raising the collective, if the low altitude signal of the system set to 20 ft.

A3 The particular environmental conditions (almost mirrored sea, calm wind, cover cloud that made the moon and stars invisible) made it practically the horizon is indefinable, with no possibility of distinguishing between sea and sky.

A4 Therefore, all operations from take-off until the completion of the downwind section were performed with an instrumental conduct, to then pass sight in the final phase.

A5 During the final phase of the approach, the impact occurred unexpectedly, without any of the crew having noticed the approach to water.

A6 The pilot reported he focused his attention to the ship, where illuminated bridge was visible, to evaluate the closing rate and not to have noticed the flashing of any warning lights or any anomaly on board before impacting with the water.

A7 Co-pilot said he was busy monitoring radio calls, speak with the control bodies, follow the navigation and the amount of fuel. In particular he recalled how in the downwind section, after having made holding circuit before receiving permission to approach the ship, his attention had been captured by the fuel level, just under 800 lbs in that moment (next so at bingo set at 750 lbs).

A8 The Co-pilot also claimed to have noticed, during the last moments, the lighting almost simultaneous of both Low Altitude Warning lights, without however having the time to intervene on the commands.

6.8.1. Assumptions

The purpose of this analysis is assumed that the helicopter does not have to be mounted on Libra ship but had to operate with a winch on the vertical of the bridge itself, this implies a difference in height. between the helicopter deck of the Libra ship and the level of the calm sea of about 10-15 ft.

With regard to the events following the accident, the rescue services were prompt and decisive for the safety of the crew, especially if we consider the immediate intervention of the two pilots in the resuscitation of the specialist.

6.9. Findings

F1 The helicopter was efficient and suitable to carry out the assigned mission; furthermore the maintenance and the technical prescriptions had been carried out and applied with the scheduled times. The technical problem that occurred on the previous Friday, positively resolved during the same day, did not affect in any way accident.

F2 The crew was "expert" (CE ITO and CP qualified as Head Crew) and in possession of the psychophysical and professional requisites suitable for carrying out the mission.

F3 However, the degree of training showed that the Co-pilot, although in possession of the qualifications and requirements, had some expired qualifications (paper instrumental and ready to use SAR).

F4 The meteorological conditions were such as to allow the execution of the mission; however the calm sea (absence of foam), the absence of moon and horizon natural may have contributed to increasing the workload and favoured the spatial disorientation of the crew.

F5 The mission had been properly planned, but the change of the original planning has led the crew to perform in one day both the transfer and the operational mission.

F6 The day of the accident therefore the crew activity started very early (wake up around 04h30 local), with multiple activities of preparation for the mission and without possibility of to carry out an adequate rest period this may have affected in terms of fatigue on psychophysical efficiency.

F7 Due to the particular environmental context (late night, lack of horizon visible, lack of stars), the crew during the last approach focused his attention essentially on the bridge of the ship without an effective cross-check with the radar altimeter and without the proper application of CRM basic principles (Task Sharing). In these conditions the crew did not perceive the progressive and rapid loss of altitude up to the impact with the sea.

F8 The absence of Moon and natural horizon may have contributed to increase the workload and have favoured Spatial Disorientation (SD Class I- Unrecognized).

F9 When the crew was in water one of the pilots tried to use the light strobe (provided in the life jacket) encountering few difficulties on its activation due to the presence of a scotch tape on the light strobe switch.

6.10. Risk Assessment

The first step to take to perform the assessment is the identification of the hazards which have contributed to the beginning of the incident. The methodology used in this study case is the same described previously, using as an input the Report provided. Preconditions identified will helps to find the most closest hazards and risks found on Chapter 5.

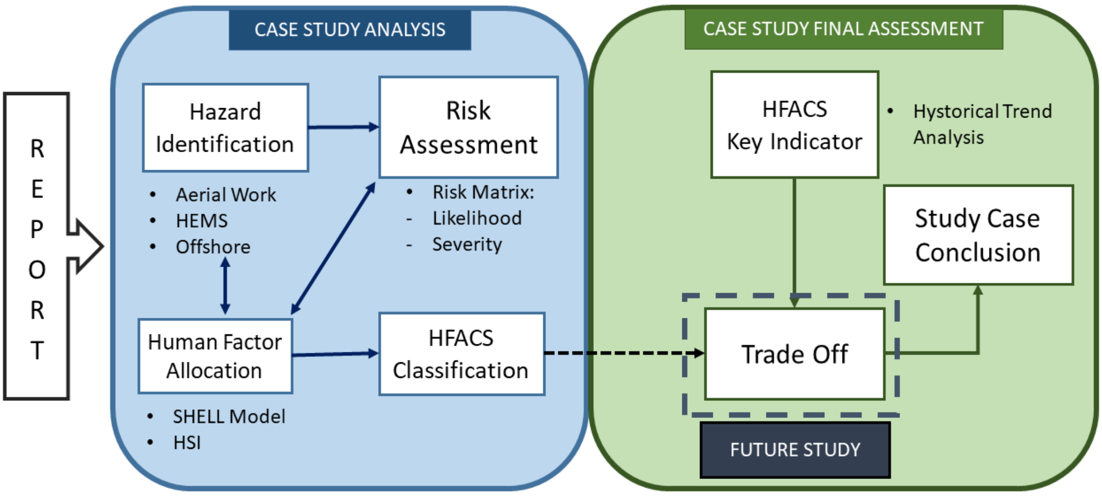


Figure 42 – Flowchart and method used in the Incident Analysis.

Risk Analysis							
Precondition Unsafe Acts	**Operation**	**Phase**	**Hazard**	**Risk Assessment**			
				Risk	**Likelihood**	**Severity**	**RF**
PC4 PC2	General Hazard	Flight Operation	Pilot Inattention (Night)	Pilot Lapses	3	C	3C
PC0	General Hazard	Planning Phase	Establish different procedures	Incorrect Planning Pilot Misjudgement	4	C	4C
PC4 PC2	General Hazard	Flight Operation	Unfamiliarity with Landing Zone (Night)	No Situational Awareness Incorrect Action	3	D	3D
PC2 PC1 PC4	General Hazard	Flight Operation	Pilot Fatigue (Night)	Pilot Misjudgement	4	B	4B
PC2	General Hazard	Flight Operation	Pilot Fatigue (Night)	Excessive Confidence	5	B	5B
PC2	General Hazard	Flight Operation	Pilot Fatigue(Night)	Improper Clearance with the ground/water (LOC-CFIT)	4	E	4E
PC3	General Hazard	Flight Operation	Low Visibility (Night)	LOC-Upset	3	E	3E
PC4 PC5	General Hazard	Pre-Flight Operation	Improper Ground/Air Crew Training	Unrecognised item during visual check	3	D	3D
PC4 PC5	General Hazard	Pre-Flight Operation	Improper Ground/Air Crew Training	Crew Lapses	3	C	3C
PC5 PC3 PC4	HEMS	Flight Operation	Sea Medical Operation (Night)	Helicopter Instability LOC – Upset	3	D	3D

PC6	General Hazard	Flight Operation	Co-pilot [Attention to fuel level instead radar altimeter]	Pilot Lapses	3	C	3C

Table 25 – Risk Assessment Results.

As well as the precondition factors, the analysis paragraph contains specific sentences which have a direct link to the SHELL Model:

SHELL MODEL				
SOFTWARE	**HARDWARE**	**ENVIRONMENT**	**LIVEWARE People**	**LIVEWARE Organisation**
	F9. When the crew was in water one of the pilots tried to use the light strobe (provided in the life jacket) encountering few difficulties on its activation due to the presence of a scotch tape on the light strobe switch.	**A3.** The particular environmental conditions (almost mirrored sea, calm wind, cover cloud that made the moon and stars invisible) made it practically the horizon is indefinable.	**A6.** The pilot reported he focused his attention to the ship, where illuminated bridge was visible, to evaluate the closing rate and not to have noticed the flashing of any warning lights or any anomaly on board before impacting with the water.	**F3.** However, the degree of training showed that the Co-pilot, although in possession of the qualifications and requirements, had some expired qualifications (paper instrumental and ready to use SAR).
		F4. The meteorological conditions were such as to allow the execution of the mission; however the calm sea (absence of foam), the absence of moon and horizon natural may have contributed to increasing the workload and favoured the spatial disorientation of the crew.	**A7.** Co-pilot said he was busy monitoring radio calls, speak with the ATC, follow the navigation and the remaining fuel. In particular he reported how in the downwind section, after having made holding circuit before receiving permission to approach the ship, his attention had been captured by the fuel level, just under 800 lbs in that moment next so at bingo set at 750 lbs.	**F6.** The day of the accident therefore the crew activity started very early (wake up around 04h30 local), with multiple activities of preparation for the mission and without possibility of to carry out an adequate rest period this may have affected in terms of fatigue on psychophysical efficiency.

			F4. The meteorological conditions were such as to allow the execution of the mission; however the calm sea (absence of foam), the absence of moon and horizon natural may have contributed to increasing the workload and favoured the spatial disorientation of the crew.	
			F7. Without an effective cross-check with the altimeter radar and without the proper application of basic principles of CRM.	

Table 26 – SHELL Model linked to the Incident Analysis.

On the Preconditions side, the SHELL Model could be applied as well, the classification show the following results:

SHELL MODEL			
SOFTWARE	**HARDWARE**	**ENVIRONMENT**	**LIVEWARE**
		PC3 The second mission, was executed at night.	**PC0 (A1)** During the briefing phase it was decided that, given the night conditions, the system of Low Altitude Warning of the Copilot altimeter radar would have been set in in order to alert the crew at 20 ft, while that of the Pilot would have been set to 30 ft.
		PC3.1 The weather conditions were good, the wind was calm and the sea with no waves, but no moon and natural horizon were visible.	**PC1** The transfer flight, initially scheduled for the previous Friday, had been reprogrammed for Monday, the day of the incident.

			PC2 The crew was therefore busy until lunchtime and had few chance to have a rest.
			PC4 The approach manoeuver was carried out manually, without the autopilot, for training reasons.
			PC6.1 In particular the Pilot recalled how in the downwind section, after flying holding circuit before receiving clearance to approach the ship, his attention had been seized by the fuel level, just under 800 lbs in that moment (next so at bingo set at 750 lbs).
			PC6 Copilot said he was busy monitoring radio calls, speaking with ATC stations, following the navigation and monitoring fuel consumption.

Table 27 – SHELL Precondition Analysis.

The Hazard and the previous Table leads to the following SHEL Model and HFACS Domain:

E	**A3.** The particular environmental conditions (almost mirrored sea, calm wind, cover cloud that made the moon and stars invisible) made it practically the horizon is indefinable. **E - External-Weather-Actual and Forecast** **AE206 DECISION MAKING DURING OPERATION** **E - External-Weather-Weather visibility** **PE101 VISION RESTRICTED BY METEO CONDITIONS** **E- External-Other Factors-Terrain/Water Features Obstacles** **PE102 PHYSICAL ENVIRONMENT**
E	**F4.** The meteorological conditions were such as to allow the execution of the mission; however the calm sea (absence of foam), the absence of moon and horizon natural may have contributed to increasing the workload and favoured the spatial disorientation of the crew. **E - External-Weather-Weather visibility** **PE101 VISION RESTRICTED BY METEO CONDITIONS**
L	**F4.** The meteorological conditions were such as to allow the execution of the mission; however the calm sea (absence of foam), the absence of moon and horizon natural may have contributed to increasing the workload and favoured the spatial disorientation of the crew. **L - Individual-Psychological Factors-Disorientation** **PC508 SPATIAL DISORIENTATION**
L	**F3.** However, the degree of training showed that the Co-pilot, although in possession of the qualifications and requirements, had some expired qualifications (paper instrumental and ready to use SAR). **LL-Worker Management-Supervision-operational supervision** **SI001 SUPERVISON INADEQUATE**
	F6. The day of the accident therefore the crew activity started very early (wake up around 04h30 local), with multiple activities of preparation for the mission and without possibility of to carry out an adequate rest period this may have affected in terms of fatigue on psychophysical efficiency. **L - Individual-Physiological Factors – Fatigue activity level** **PC306 FATIGUE**

L	**A6.** The pilot reported he focused his attention to the ship, where illuminated bridge was visible, to evaluate the closing rate and not to have noticed the flashing of any warning lights or any anomaly on board before impacting with the water. **L - Individual-Psychological Factors-Knowledge-Skills/Techniques** **AE103 PROCEDURAL ERROR** **L - Individual-Psychological Factors-Training-flight** **SI003 LOCAL TRAINING ISSUE / PROGRAMS** **PC106 DISTRACTION** **L - Individual-Psychological Factors-Attitudes-Confidence-Overconfidence** **PC206 OVERCONFIDENCE** **OC003 PERCEPTION OF EQUIPMENT** **L- Individual-Psychological Factors-Experience-Night Time** **SP003 LIMITED RECENT EXPERIENCE** **PC405 TECHNICAL / PROCEDURAL KNOWLEDGE**
L	**A7.** Co-pilot said he was busy monitoring radio calls, speak with the ATC, follow the navigation and the remaining fuel. In particular he reported how in the downwind section, after having made holding circuit before receiving permission to approach the ship, his attention had been captured by the fuel level, just under 800 lbs in that moment next so at bingo set at 750 lbs. **L - Individual-Psychological Factors-Knowledge-Skills/Techniques** **AE103 PROCEDURAL ERROR** **L - Individual-Psychological Factors-Attitudes-Confidence-Overconfidence** **PC206 OVERCONFIDENCE** **OC003 PERCEPTION OF EQUIPMENT**
L	**F7.** Without an effective cross-check with the altimeter radar and without the proper application of basic principles of CRM. **Liveware-Liveware Crew Interactions- Coordination** **PP102 CROSS MONITORING PERFORMANCE**
H	**F9.** When the crew was in water one of the pilots tried to use the light strobe (provided in the life jacket) encountering few difficulties on its activation due to the presence of a scotch tape on the light strobe switch. **H –Liveware interface Workspace communication equipment** **PE208 COMMUNICATION EQUIPMENT**
S	**F9.** When the crew was in water one of the pilots tried to use the light strobe (provided in the life jacket) encountering few difficulties on its activation due to the presence of a scotch tape on the light strobe switch. **S – Liveware – Software Interface – Written Information - Checklist** **AE102 CHECKLIST ERROR**

Table 28 – SHELL – HFACS Relations results.

L	**PC0 (A1)** During the briefing phase it was decided that, given the night conditions, the system of Low Altitude Warning of the Copilot altimeter radar would have been set in in order to alert the crew at 20 ft, while that of the Pilot would have been set to 30 ft. **L - Liveware-Psychological Factors - Confidence – Confidences In Equipment** **PC208 COMPLACENCY**
L	**PC1** The transfer flight, initially scheduled for the previous Friday, had been reprogrammed for Monday, the day of the incident. **L - Liveware-Psychological Factors – Planning – Pre Flight** **PP109 MISSION PLANNING**
L	**PC2** The crew was therefore busy until lunchtime and had few chance to have a rest. **L - Liveware-Physiological Factors – Fatigue – Sleep – Crew Rest** **PC307 FATIGUE - PHYSIOLOGICAL/MENTAL**
E	**PC3** The second mission, was executed at night. The weather conditions were good, the wind was calm and the sea with no waves, but no moon and natural horizon were visible. **E - Liveware-Environmental – External – Other Factors – Time Of Day** **E- Liveware-Environmental – External – Weather – Weather Visibility** **PE102 VISION RESTRICTED BY METEOROLOGICAL CONDITIONS**
L	**PC4** The approach manoeuver was carried out manually, without the autopilot, for training reasons. **L Liveware-Liveware – Personnel – Personnel Training** **SI003 LOCAL TRAINING ISSUES/PROGRAMS**
L	**PC6** Copilot said he was busy monitoring radio calls, speaking with ATC stations, following the navigation and monitoring fuel consumption. **L Liveware-Psychological Factors – Workload – Task Saturation** **PC103 COGNITIVE TASK OVERSATURATION** **L Liveware-Psychological Factors – Attention – Channelized Attention** **PC102 CHANNELIZED ATTENTION** **L Liveware-Psychological Factors – Workload – Prioritization** **AE202 TASK MISPRIORITIZATION**
L	**PC6.1** In particular the Pilot recalled how in the downwind section, after flying holding circuit before receiving clearance to approach the ship, his attention had been seized by the fuel level, just under 800 lbs in that moment (next so at bingo set at 750 lbs). **L Liveware-Psychological Factors – Attention – Fixation** **PC106 DISTRACTION**

Table 29 – Precondition HFACS-SHELL Analysis.

6.11. Safety Recommendation

Safety recommendations are mandatory advice which comes from the analysis and its purpose is to suggest the proper changes to execute in order to mitigate the risks came from the assessment:

- Check the validity of the crew's qualifications before each operation.
- Apply rigorously the SMA-OPR-003 ("Directive for the service of flight of the aeronautical crews")and possibly modify service schedules of the crews on the basis of operational stress. In order to guarantee rest periods for the crew.
- Is the procedure for overnight approach helicopter to ship effective and safe
- Carry out the equipment check procedure (MEL) before a mission in order to find any anomalies in the loaded devices (see strobe-light).
- Intensify training for night flight by sea to mitigate the effect of spatial disorientation near the sea surface.
- Emphasize through training the importance of coordination between pilot and co-pilot (task-sharing).
- Pay more attention to operational risk management, regarding the choice of the crew and the procedures to be followed.
- Improve awareness of the physical limits of the aircraft, and set flight parameters in limit situations in order to remain in the flight envelope. (Case of altitude alert).

6.12. Risk Mitigation

When Risk Mitigation is applied, they have to be managed to a level "as low as reasonably practicable" (ALARP). The extension of the action taken to reduce the risk may vary depending also from administration process and its effectiveness.

Basing on the guidelines described by Gajetti and Karrer (Gajetti & Karrer, 2009), it is possible to classify the possible mitigation on different aspect, before to assign the new Risk Factor code:

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).

Table 30 – Defence Analysis Table.

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).

Table 31 – Risk Mitigation Strategies Table.

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.

Table 32 – Effectiveness on Risk Mitigation Table.

Basing on this information, the most critical Risks (Red Zone) have been analysed and subsequently mitigated in the following tables.

Referring Code	F6 – PC2
Hazard Description	Pilot Fatigue
RA	5B – 4E
HFACS Nanocode	**Description**
PC306 PHYSICAL FATIGUE (OVEREXERTION)	Physical Fatigue (Overexertion) is a factor when the individual's diminished physical capability is due to overuse (time/relative load) and it degrades task performance. (The effects of prolonged physical activity, or the effects of brief but relatively extreme physical activity, either of which taxes a person's physical endurance or strength beyond the individual's normal limits.)
HFACS Nanocode	**Description**
PC307 FATIGUE PHYSIOLOGICAL/MENTAL	Fatigue - Physiological/Mental is a factor when the individual's diminished physical or mental capability is due to an inadequate recovery, as a result of restricted or shortened sleep or physical or mental activity during prolonged wakefulness. Fatigue may additionally be described as acute, cumulative or chronic.
HFACS Nanocode	**Description**
PC508 SPATIAL DISORIENTATION	Spatial Disorientation is a failure to correctly sense a position, motion or attitude of the aircraft or of oneself within the fixed coordinate system provided by the surface of the earth and the gravitational vertical. Spatial Disorientation (Type 1) Unrecognized is a factor when a person's cognitive awareness of one or more of the following varies from reality: attitude; position; velocity; direction of motion or acceleration. Proper control inputs are not made because the need is unknown.
Mitigation	
Due to short interval between sorties, it should be recommended to increase the lapse of rest in order to cope with the symptoms of the fatigue.	
Defence Analysis	Administrative
Risk Mitigation Strategies	Loss reduction
Effectiveness	Control actions
New Risk/Hazards	Extended interval rest will shift operation and overload duties
Revised Risk Assessment	
4B – 3D	

Referring Code	A6 – PC4
Hazard Description	Improper Ground/Air Crew Training
RA	3D
HFACS Nanocode	**Description**
SP003 LIMITED RECENT EXPERIENCE	Limited Recent Experience is a factor when the supervisor selects an individual who's experience for either a specific manoeuver, event or scenario is not sufficiently current to permit safe mission execution
HFACS Nanocode	**Description**
PC405 TECHINICAL / PROCEDURAL KNOWLEDGE	Technical/Procedural Knowledge is a factor when an individual was adequately exposed to the information needed to perform the mission element but did not absorb it. Lack of knowledge implies no deficiency in the training program, but rather the failure of the individual to absorb or retain the information. (Exposure to information at a point in the past does not imply "knowledge" of it.)
HFACS Nanocode	**Description**
SI003 LOCAL TRAINING ISSUE / PROGRAMS	Local Training Issues/Programs are a factor when one-time or recurrent training programs, upgrade programs, transition programs or any other local training is inadequate or unavailable (etc) and this creates an unsafe situation.
Mitigation	
Reducing interval of audit and eventual training will guarantee the clearance of the qualification.	
Defence Analysis	Administrative
Risk Mitigation Strategies	Loss reduction
Effectiveness	Control actions
New Risk/Hazards	Operator may be affected by the pressure of constant checks
Revised Risk Assessment	
2D	

Referring Code	A3 – F4 – PC3 – PC4
Hazard Description	Sea Medical Operation (Night) – Low Visibility (Night)
RA	3E – 3D
HFACS Nanocode	**Description**
PE101 VISION RESTRICTED BY METEO CONDITIONS	It is a factor when it is determined by the investigator that icing or fogging of the windshield/windscreen or canopy restricted the vision of the individual to a point where normal duties were affected.
Mitigation	
Improving Cockpit Panel, provide adequate equipment in order to counter the hazards encountered during night operations	
Defence Analysis	Physical
Risk Mitigation Strategies	Loss reduction
Effectiveness	Personnel Actions
New Risk/Hazards	Increasing of focused tasks while operating in night environments
Revised Risk Assessment	
3D – 3C	

Referring Code	F7 – PC4 – PC2
Hazard Description	No Situational Awareness - Incorrect Action
RA	3D
HFACS Nanocode	**Description**
AE206 DECISIONMAKING DURING OPERATION	Decision-Making During Operation is a factor when the individual through faulty logic selects the wrong course of action in a time-constrained environment.
HFACS Nanocode	**Description**
PP102 CROSS MONITORING PERFORMANCE	Cross-monitoring performance is a factor when crew or team members failed to monitor, assist or back-up each other's actions and decisions.
Mitigation	
Introducing further cross-checking before conducting operation in critical phase will reduce the event of missing information and focused attention	
Defence Analysis	Administrative
Risk Mitigation Strategies	Segregation of exposure
Effectiveness	Control Actions
New Risk/Hazards	Possible tasks delayed and saturation of duty
Revised Risk Assessment	
2C	

Referring Code	F3
Hazard Description	Improper Ground/Air Crew Training
RA	3C
HFACS Nanocode	**Description**
SI001 INADEQUATE SUPERVISION	Is a factor in a mishap when supervision proves inappropriate or improper and fails to identify hazard, recognize and control risk, provide guidance and/or oversight, and result in Human Error or Unsafe Condition.
Mitigation	
Reducing interval of refresh training and a better understandings of the culture of a correct supervision will guarantee the compliance of the qualification.	
Defence Analysis	Administrative
Risk Mitigation Strategies	Loss reduction
Effectiveness	Control Actions
New Risk/Hazards	Operators may be affected by the pressure of constant checks and supervision
Revised Risk Assessment	
2D	

Referring Code	PC0
Hazard Description	Establish different procedures
RA	4C
HFACS Nanocode	Description
PC208 COMPLACENCY	Complacency is a factor when the individual's state of reduced conscious attention due to an attitude of overconfidence, undermotivation or the sense that others "have the situation under control" leads to an unsafe situation.
Mitigation	
In case of training reasons it is proposed to establish different procedure, which shift from the normal ones, creating ad hoc checklist/written procedures before the flight should reduce the complacency. Further In-flight Briefing and "Challenge and Response" checklist may be useful to reduce the "have the situation under control" bias.	
Defence Analysis	Administrative
Risk Mitigation Strategies	Loss reduction
Effectiveness	Personnel Actions
New Risk/Hazards	Possible lapses or forgetting if the procedures are too similar to others
Revised Risk Assessment Trend	
3B	

Referring Code	F9
Hazard Description	Improper Ground/Air Crew Training
RA	3D
HFACS Nanocode	**Description**
SI001 INADEQUATE SUPERVISION	It is a factor when communication equipment result inadequate or unavailable to support mission demand. This include electronically, optical or physically blocked Transmission, Communication and can be voice, light data or multi-sensory.
HFACS Nanocode	**Description**
AE102 CHECKLIST ERROR	Checklist Error is a factor when the individual, either through an act of commission or omission makes a checklist error or fails to run an appropriate checklist and this failure results in an unsafe situation.
Mitigation	
Underlining the importance of MEL and the consequences of no compliance of its equipment with further training regarding it.	
Defence Analysis	Administrative
Risk Mitigation Strategies	Loss reduction
Effectiveness	Control Actions
New Risk/Hazards	None
Revised Risk Assessment	
2D	

Table 33 – Risks Factor Mitigated.

6.13. *Annex 1: Final Risk Factor Evaluation*

Once the RF is evaluated, it might be propaedeutic to assess the Final RF in order to give an univocal value of the overall evaluation. Basing on the mathematical formula of the algebraic average, it is possible to obtain the final result:

$$FRF = \frac{\sum RF}{Total\ Count\ RF}$$

The FRF obtained is the following:

FRF	Consideration
4C	Red Zone = Unacceptable Risk Level (Prohibit operations/ Strong mitigation must be adopted)
3D	Red Zone = Unacceptable Risk Level (Prohibit operations/ Strong mitigation must be adopted)

Table 34 – FRF Results.

The final results indicate that the mission is in the Red Zone. However, two consideration must be done:

- The incident was during a drill, so despite of the elevated risk, the operation was conducted either way in order to train the pilot to cope with that specific situation and environment.
- Safety Recommendations will improve the latent safety and low the level of the FRF in a more suitable zone of the Risk Matrix.

If mitigations are applied, FRF shall be updated with the new evaluation. It will results a decreasing of its value.

$$FRF = \frac{\sum Updated\ Risk\ Factor}{Total\ Count\ Risk\ Factor}$$

FRF	Consideration
3C	Yellow Zone = Tolerable Risk Level (Introduce appropriate mitigation resources)

Table 35 – Updated FRF Table.

6.14. *Annex 2: Spatial Disorientation*

Spatial Disorientation this type of human factor is divided into three classification (Militare, 2013):

- SD Class I (Unrecognized): The pilot does not recognize that his perception of orientation is incorrect and, therefore, does not perform any manoeuvers to correct aircraft attitude and/or recovery.
- SD Class II (Recognized): The pilot, while identifying the state of disorientation, is unable to perform any corrective action to recover aircraft attitude.
- SD Class III (Incapacitated): The DS is recognized but the pilot is unable to react, prevention is based on the availability of fully automatic recovery systems (activated by the computer) or semiautomatic recovery system (activated by the pilot).

6.15. Annex 3: Hypothetic Risk Scenario: Inaccurate Fuel Planning

Basing on the analysis code A7, the co-pilot at the time of the incident was focused to check the fuel level due to its proximity to Bingo.

This may suggest improper fuel planning during pre-flight and briefing operations.

Adding this risk as one of the main ones of the incident, would a better fuel planning suppress the "Channelized Attention" of the co-pilot to the fuel indicators during the approaching phase?

The main purpose of this Annex is to hypothesize what would have changed by analysing a scenario where the HH-212 would have the fuel tank full.

It must be noted that this Annex represents a hypothetical scenario, no data concerning this topic has been presented or indicated in the official report. Therefore, this hypothesis represents a purely theoretical analysis performed for academic purposes.

Adding a new risk defined as *Improper fuel planning"* based on the A7 sentence, Risk matrix is modified in the following way:

Risk Analysis						
Analysis	Phase	Hazard	Risk Assessment			
			Risk	Likelihood	Severity	RF
A7	Planning Phase	General Hazard Improper fuel plan	Insufficient Fuel	2	D	2D

Figure 43 – Insufficient Fuel RF.

Adding this RF to the previously data concerning the calculus of the FRF (before the mitigation process), the result obtained is the following:

FRF	Consideration
4C	Red Zone = Unacceptable Risk Level (Prohibit operations/ Strong mitigation must be adopted)
3D	Red Zone = Unacceptable Risk Level (Prohibit operations/ Strong mitigation must be adopted)

Figure 44 – Updated FRF with Improper fuel plan.

The updated FRF shows no variation concerning the zone of the Risk Matrix. Therefore, still significant mitigation must be adopted in order to reduce the risk.

This Risk Scenario is performed with an approximation of the HH-212 performance and fuel consumption. Performance are assumed as operating in Standard Condition in order to conduct a first resolution of the scenario.

The realistic scenario must be evaluated using the curve of performance and power of the specific helicopter. In other words, evaluation of temperature, altitude and weight at the moment of the accident should be taken into account.

It is clear that the hypothesis of full fuel loaded on board will affect the load and balance of the helicopter. Stability and response to its different weight should be considered.

To demonstrate the presence of an incorrect planning, we took the data of the HH-212 aircraft regarding the hourly consumption, autonomy and capacity of the tank.

HH-212 Specification	
Tank Capacity	821 lt
Fuel Consumption	380 lt/h
Autonomy (Hrs)	2h 9m

Table 36 – HH-212 Fuel Consumption Specifications.

In relation to the data obtainable from the analysis and the specifications, the accident occurred one hour after take-off, therefore 380 liters of fuel had already been consumed.

According to official statements, the fuel remaining at the time of impact was about 362 liters, for a total fuel load of 742 liters.

Knowing that the total capacity is about 821 liters, the aircraft was missing about 79 liters of fuel corresponding to 12 minutes and 28 seconds.

Mission Start	18:48 UTC
CFIT Incident	19:48 UTC
Flight Time	1 h (380 lt used)
Fuel Remaining @19:48 declared	362 lt

Table 37- Mission Data used for calculation.

$$Fuel\ on\ Board\ @18:48 = 380 + 362 = 742\ lt$$

$$Fuel\ Gap = Tank\ Capcity - Fuel\ on\ Board\ @18:48 = 821 - 742 = 79\ lt \rightarrow 12\ m\ 28\ s$$

Calculations performed show how, in case of maximum fuel on board, at the time corresponding to the CFIT, the helicopter would have an additional autonomy of 12 minutes before reaching the Bingo.

This could have nullified the Channelized Attention of the co-pilot, as he would have seen that he was still in a condition of regular operations and could have been aware of Altitude Warning and correcting the altitude by acting promptly.

In terms of response, ADS-33 identify different types of response in relation to the task carried and suggest the operational range basing on the input and defining the kind of response type (ADS-33, 2000).

Furthermore, if the HH-212 was multi-blade and not rotor twin blade, its dynamic response to an action of collective would have ensured a better manoeuvre regarding altitude regaining.

7. Concluding Remarks

This study underlines how the helicopter represents a very reliable way to perform tasks where other vehicle or time schedule are insufficient. Services as Civil Air Transport or surveillance patrol are fundamental civil services where the helicopter is used as a way to support authorities or carry people from a place to another.

Tasks as HEMS, Aerial Work or Offshore are, on the other hands, fundamental operations where further investigation concerning Hazards Analysis and Risk Assessment must be performed; hostile environment present in these operations are too critical to not be considered, as well as the presence of human.

In this study, a method has been developed that allows associating the potential hazard of a given aerial work of the helicopter with the corresponding human factor.

First, the potential hazard of each aerial work has been identified. Afterwards, the associated risks have been defined, as well as their respective Risk Assessment. Each risk has associated a Risk Factor, which allows it to be positioned in the Risk Assessment Matrix.

Once the Risk Assessment has been carried out, with both the risk and the hazard the SHELL field involved have been identified. Thanks to these and to the HSI model it has been possible to connect both, the risk and the hazard with the respective human factor, HFACS model.

The practical application on a case study therefore constitutes, in a practical context, the main input factor that starts the execution of the described methodology.

In summary, the study characterized in this thesis constitutes the creation of a direct and iterative link between hazards and human factor.

The link just mentioned can therefore lead to future mitigations in terms of human factor. Being an iterative method, once the human factor is mitigated, it is possible to mitigate the hazard in terms of Risk Factor, lowering its value in the risk matrix. If the risk and therefore the hazard is mitigated, the entire operating environment of the aerial work will also undergo a change in relation to the solution obtained.

In addition, this developed method is a standardized referral that allows to measure the safety of the system.

However, it should be noted that, as far as the above discussion is very extensive and well characterized, in practical terms the mitigations and the design of a Safety Program will be strongly linked to the possibility of investing in them.

In fact, it is performed an iterative process which leads to the right compromise between effective mitigation and implementation availability.

Factor that could strongly influence is also the impossibility of a company to reach the Break-Even Point, which is the point where the expenses and the revenues are equal (Gajetti & Maggiore, 2013).

If the BEP is not achieved through the introduction of mitigations (hence investments on safety), they could also be discarded on the basis of managerial choices.

Basing on what has been reiterated therefore, an effective mitigation, following a careful analysis, may not be feasible, making the identified risk persist.

8. Future Works

The study developed serves to define all the possible hazards and human factors involved in the analysis of a helicopter accident. The method has been developed in a general manner for each aerial work. In the future, it would be possible to use this method to characterize specific missions.

It allows to describe the helicopter incident in a standardized way using the HFACS model. In addition, the fact of using a standardized method gives the possibility of comparing accidents with others. This methodology allows to associate the human factor of each aerial work with the Hazard potential that they have been able to create.

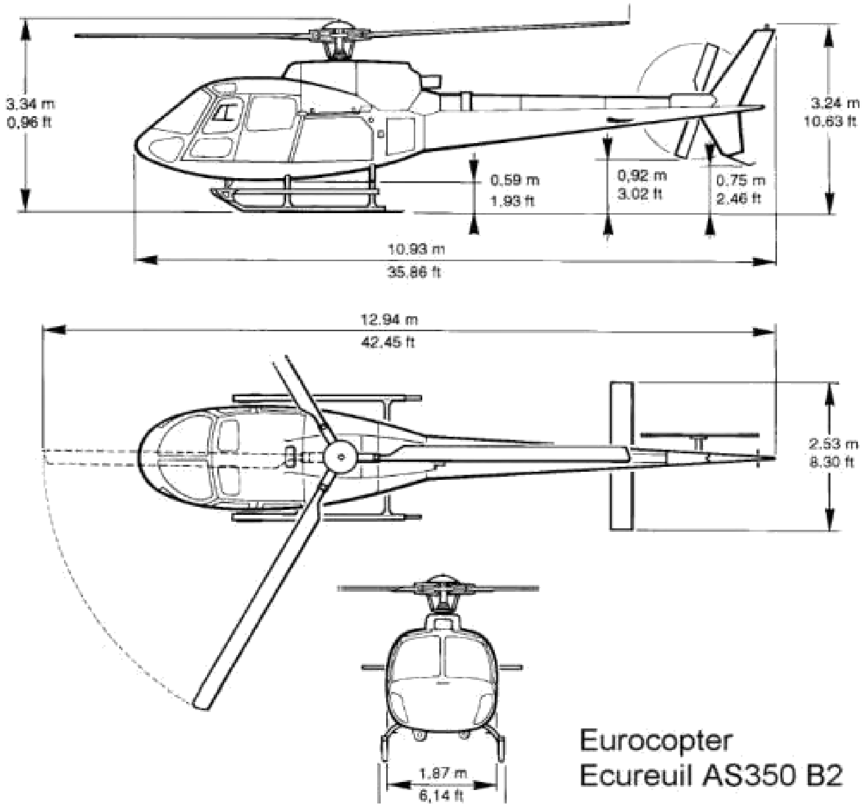
In addition, the method used should be compared with the analysis performed by agencies such as ICAO, EASA or NTSB, in order to verify the effectiveness of the study carried out.

This phase of Trade Off will therefore allows to re-evaluate the data found and refine the mitigations proposed in the field of safety. When many aerial incidents have been analysed using the same method, this may will being a standardized method.

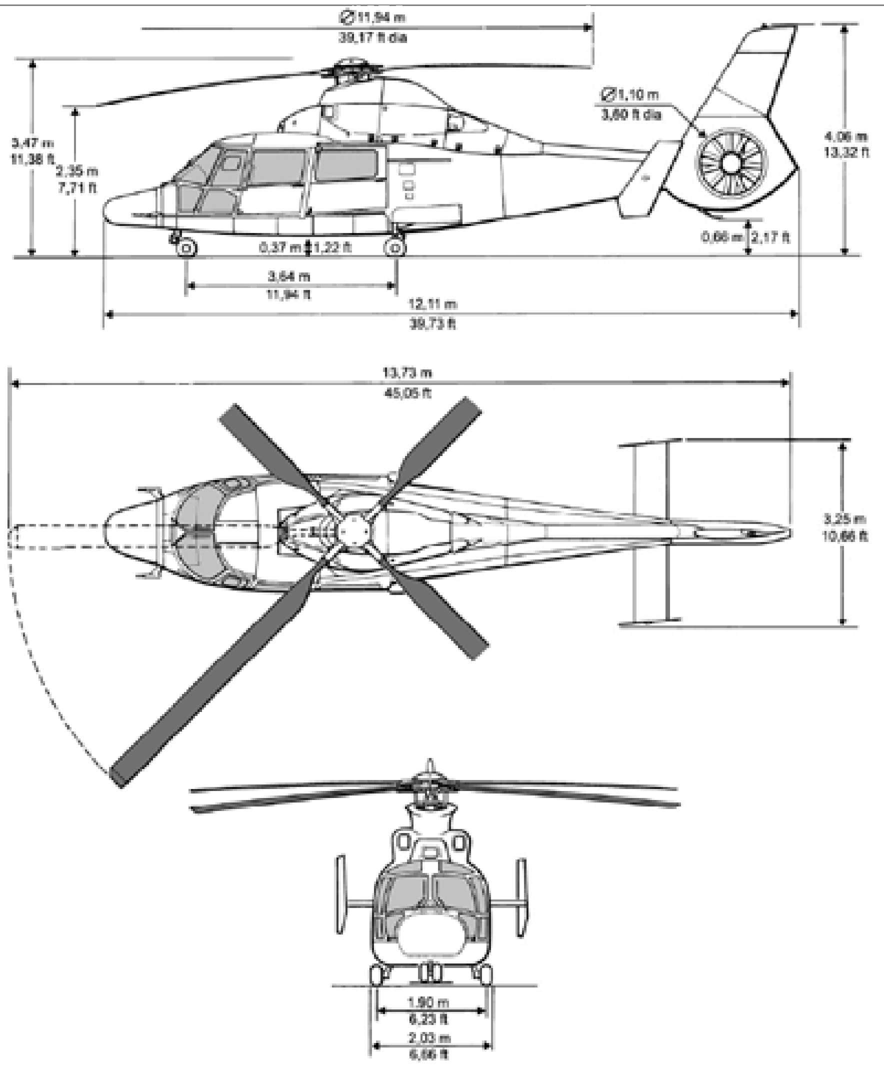
APPENDIX I

Table of Helicopters in Three Views

Here are listed the main types of helicopters used in wide Aerial Works and Offshore Environment. The following layouts may be found at https://www.the-blueprints.com

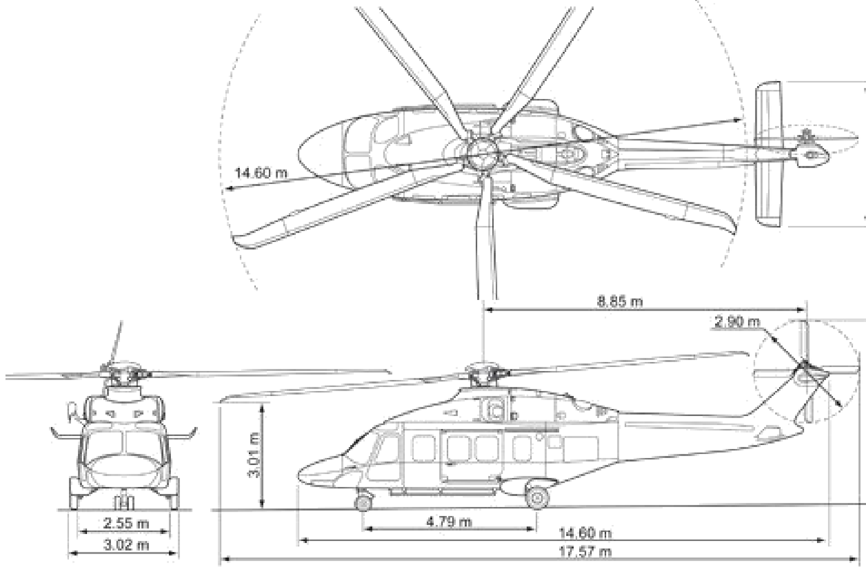
Model	Layout
AS-350	

AS-365

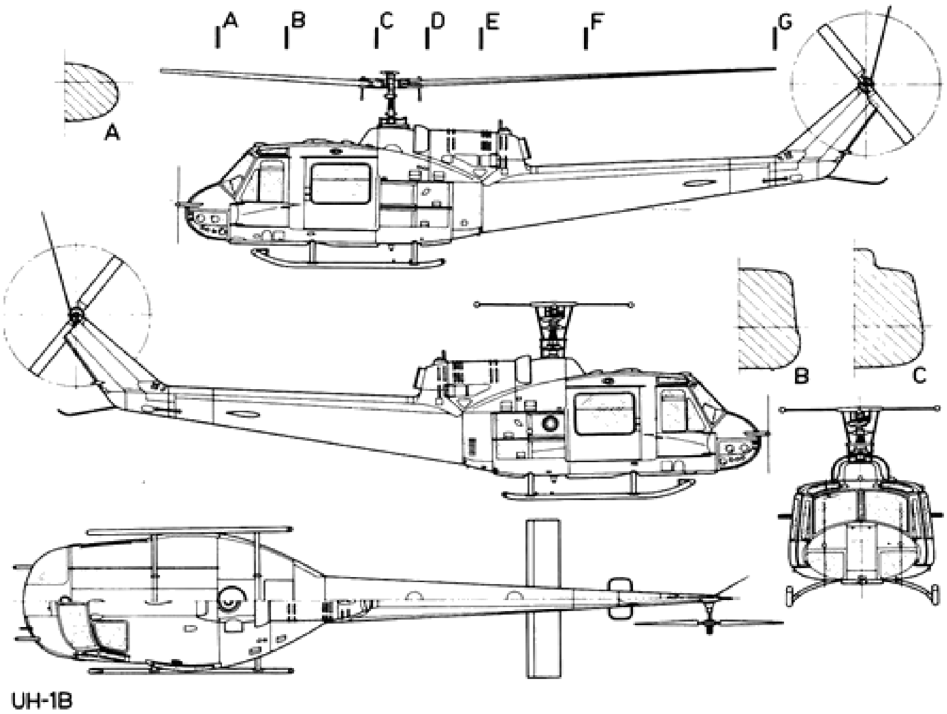

Ø11,94 m
39,17 ft dia
3,47 m
11,38 ft
2,35 m
7,71 ft
Ø1,10 m
3,60 ft dia
4,06 m
13,32 ft
0,37 m
1,22 ft
0,66 m
2,17 ft
3,64 m
11,94 ft
12,11 m
39,73 ft
13,73 m
45,05 ft
3,25 m
10,66 ft
1,90 m
6,23 ft
2,03 m
6,66 ft

AW-109

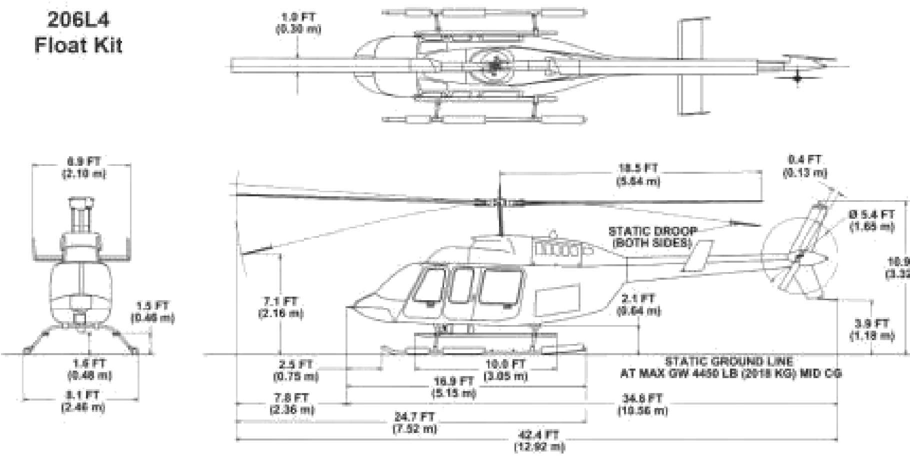
AW-189



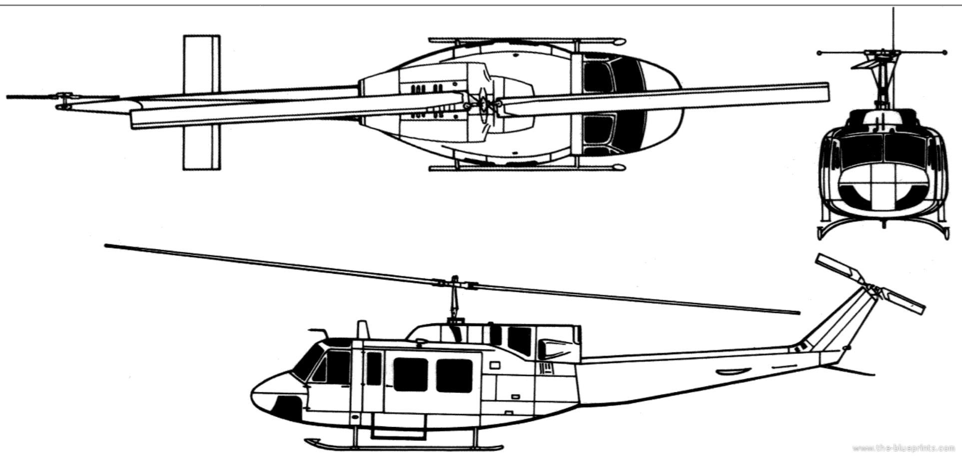
B-204



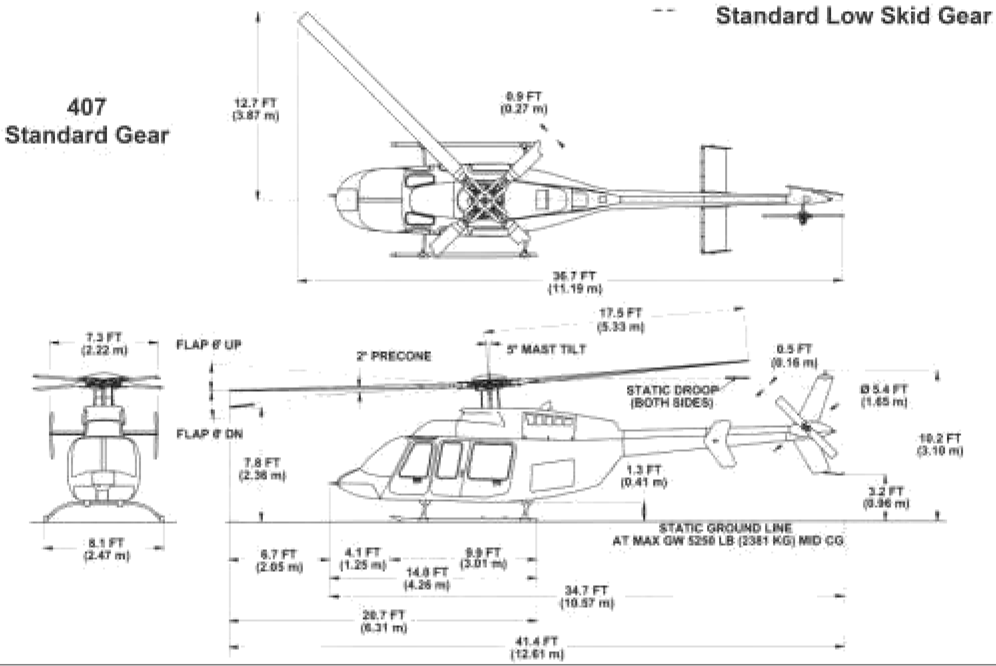
B-206



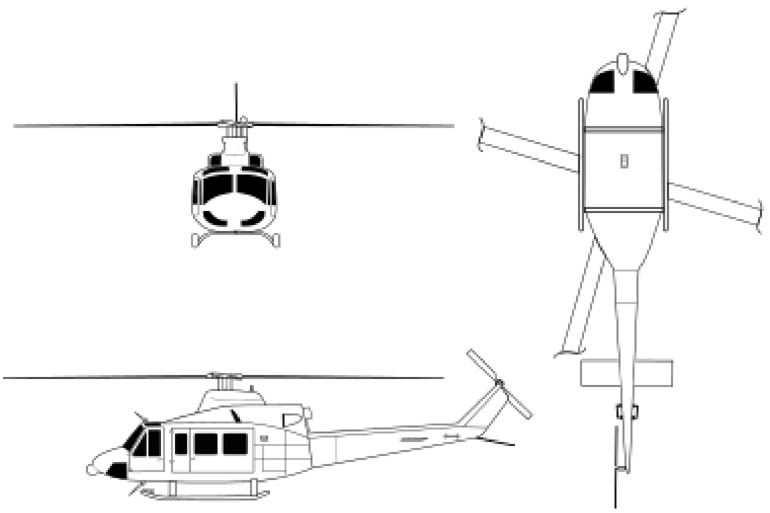
B-212



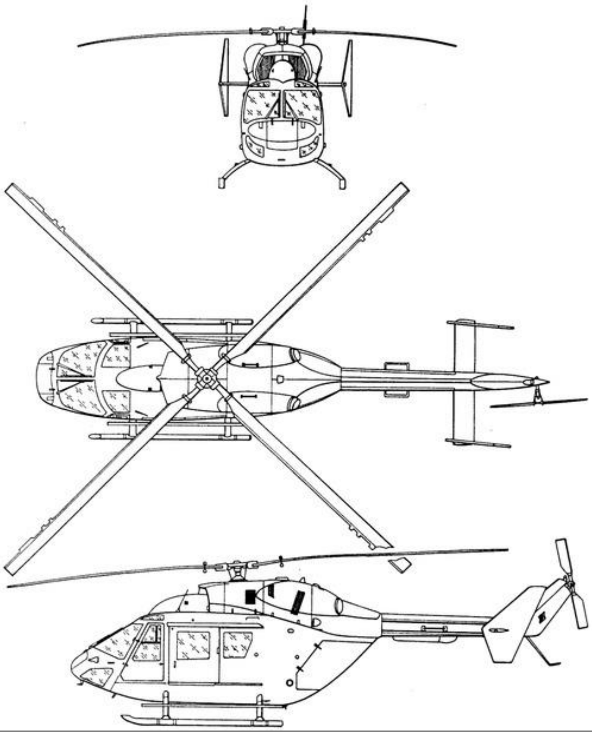
B-407



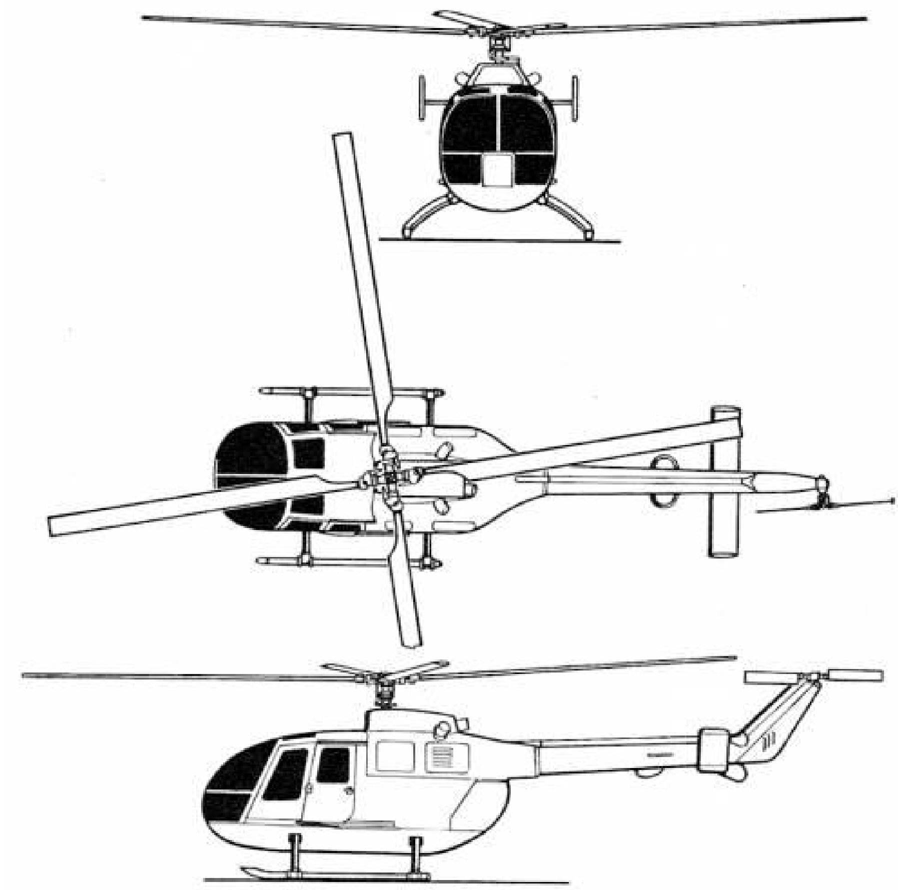
B-412



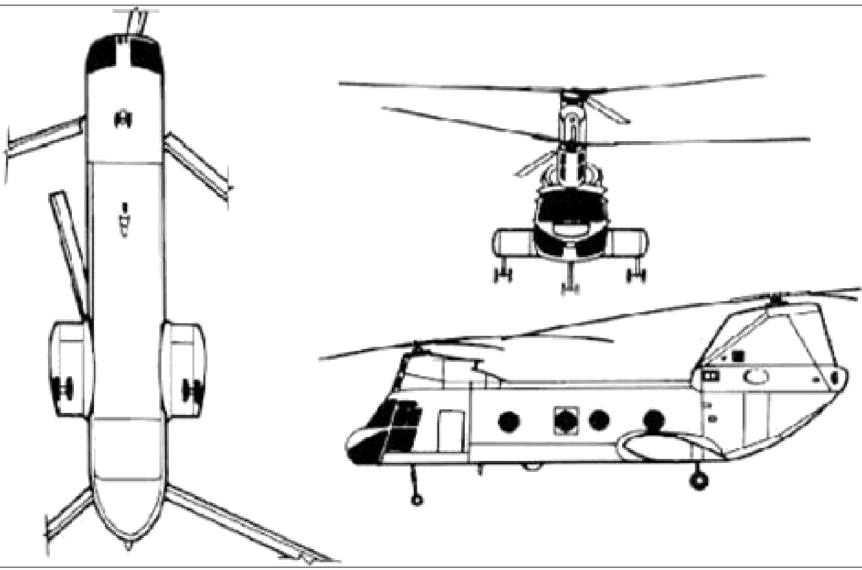
Bk-117



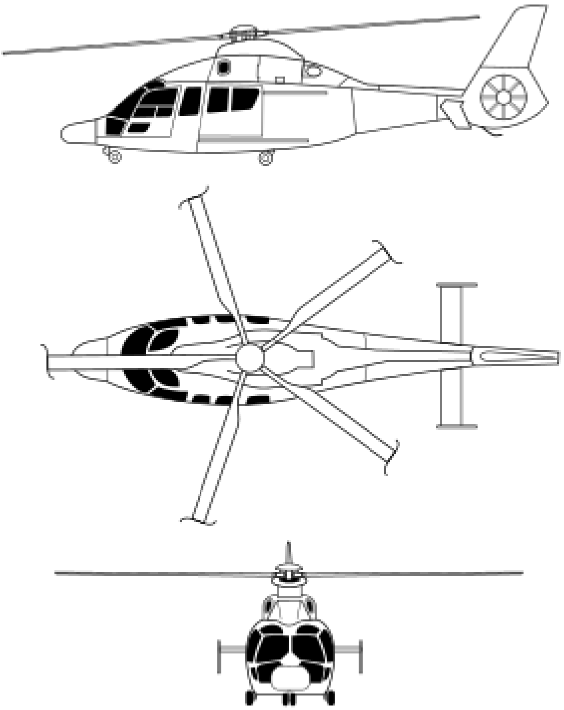
Bo-105

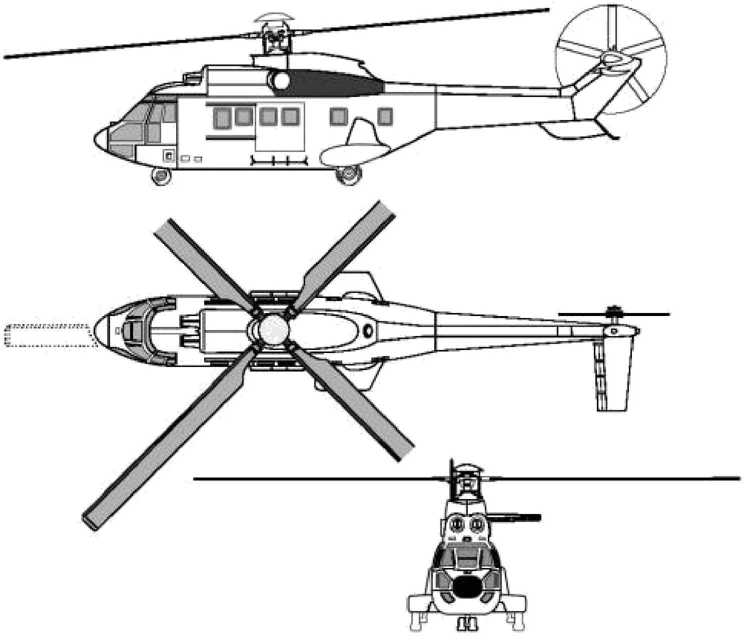
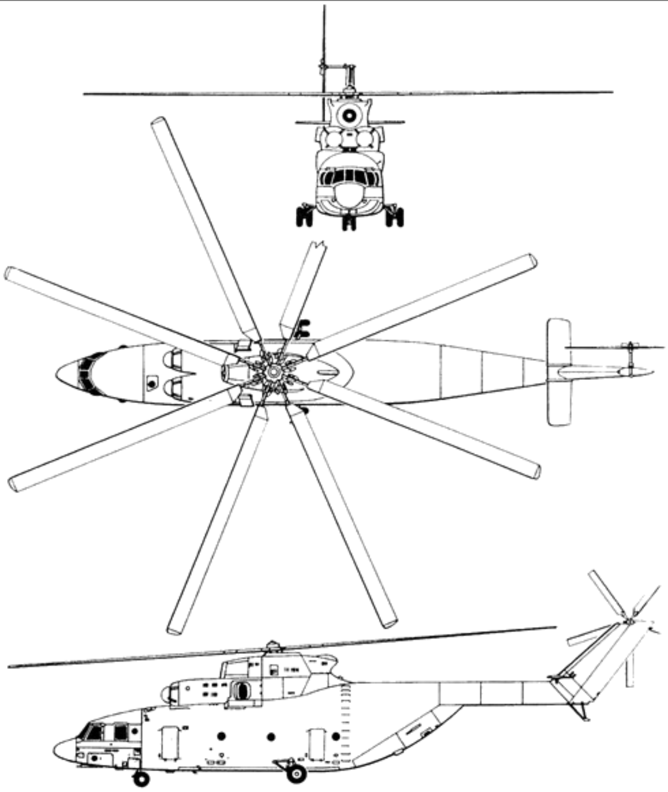


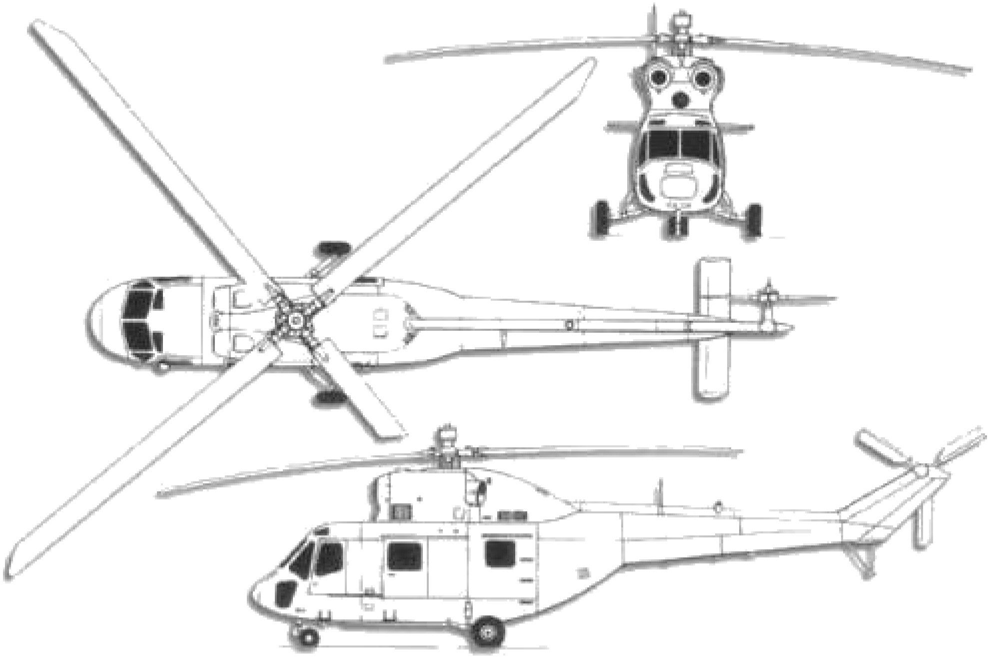
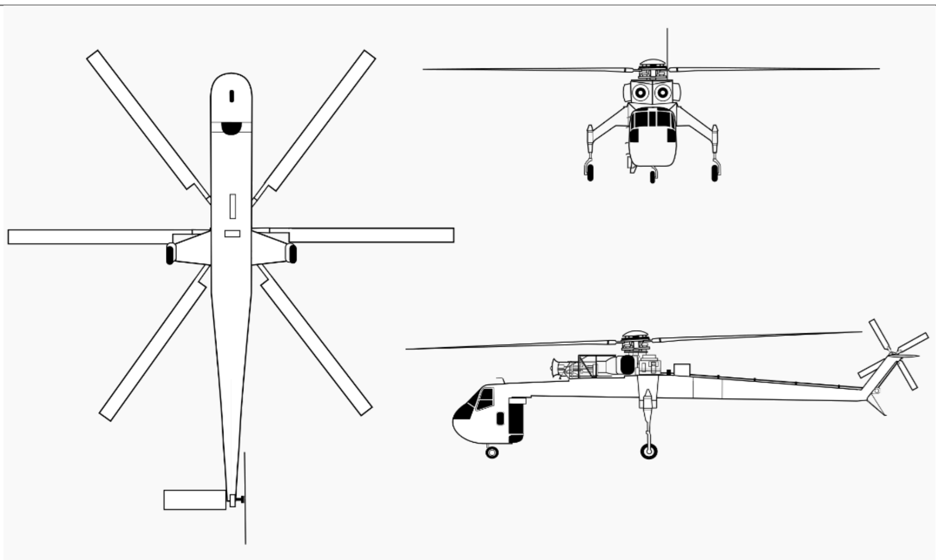
CH-46

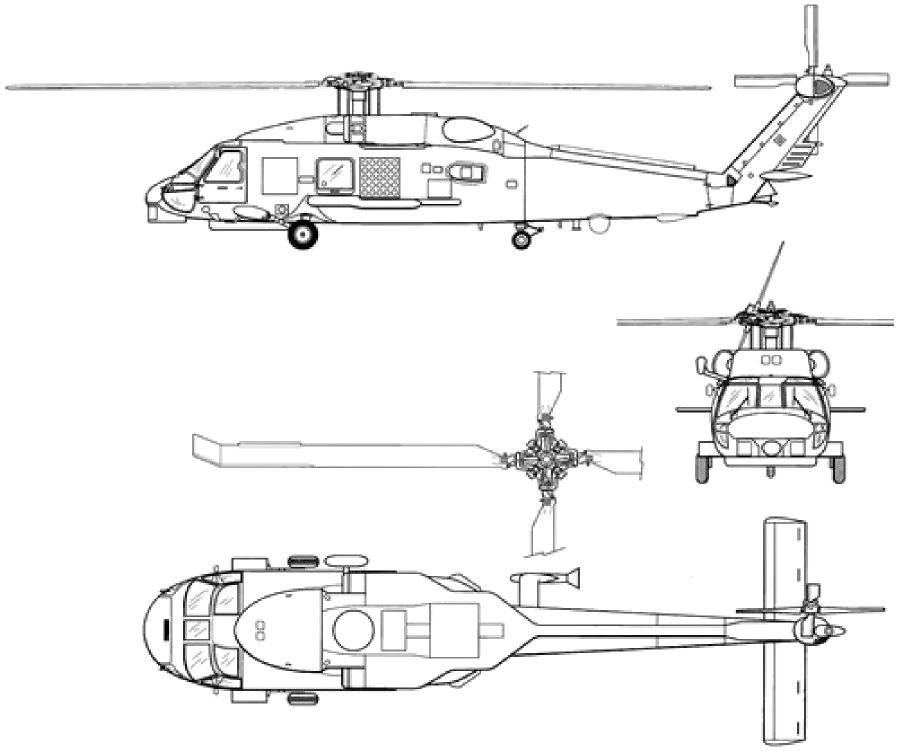
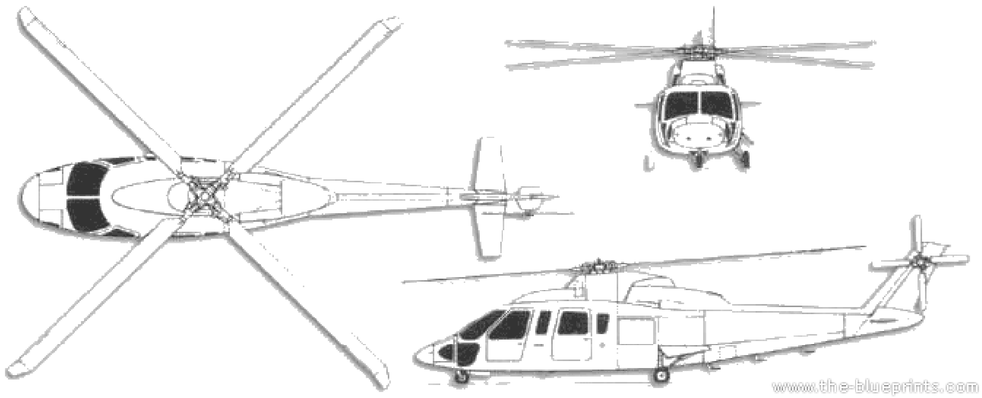
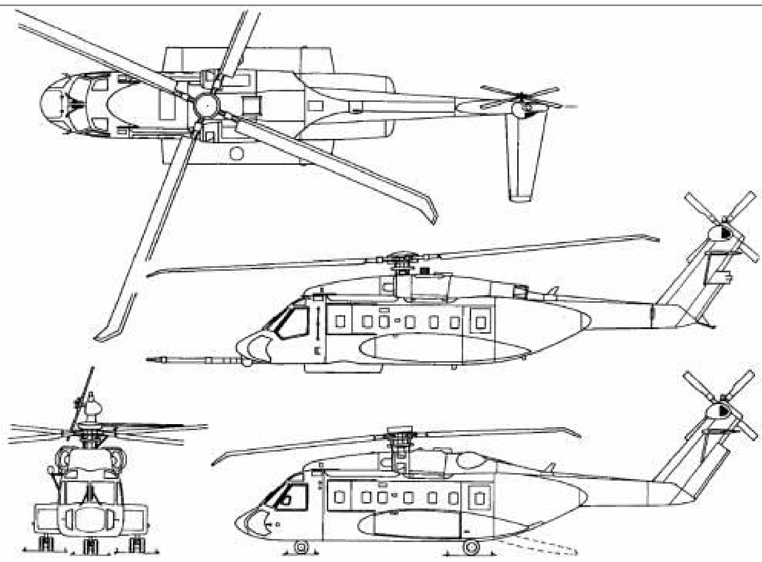


EC-155



H-215 (AS-332)	
Mi-26	

PZL Kania	
S-64	

S-70/ UH-60	
S-76	
S-92	

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