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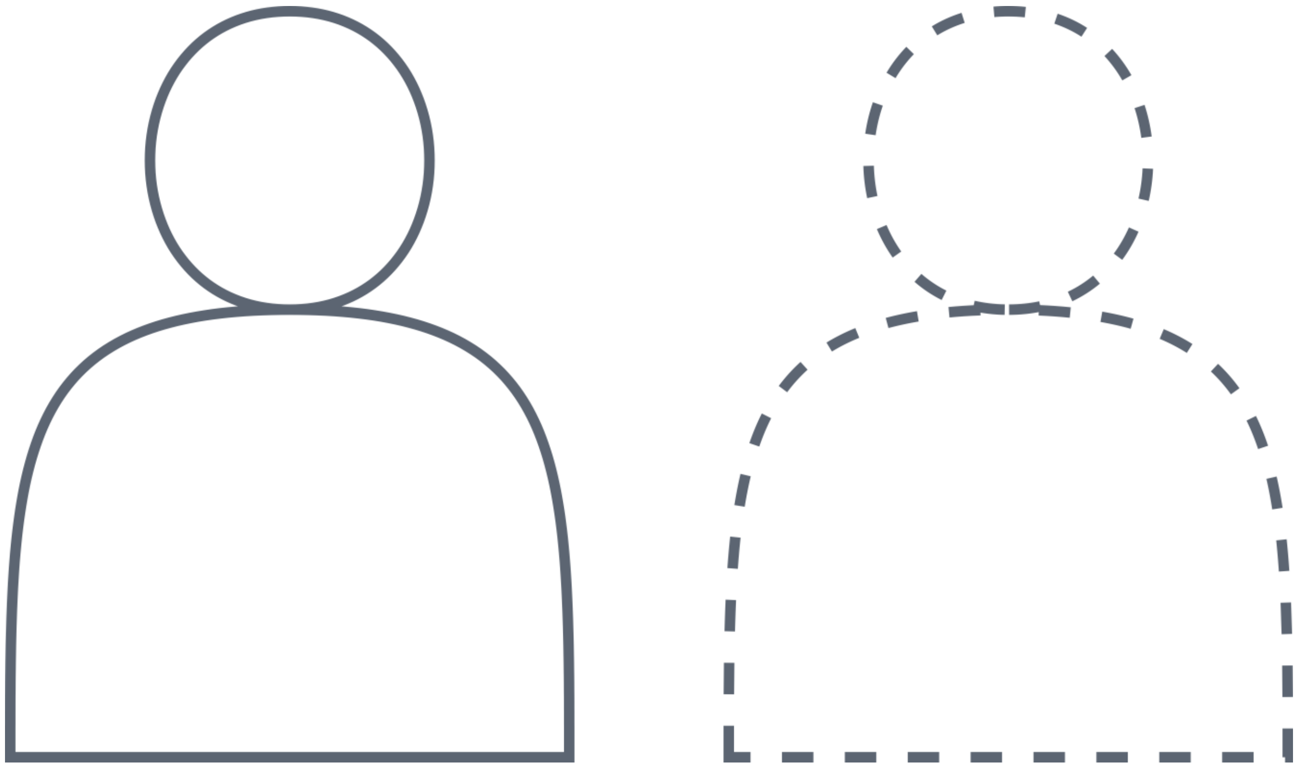

Single Pilot Operation on Large Commercial Aircraft

Identifying Key Challenges and Providing Solution Guidelines

Master's thesis in Product Development

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Abstract

The concept of Single Pilot Operation, hereafter referred to as SPO, on commercial aircraft, has been considered for a long time as a potential solution that can reduce airliner operating costs and increase overall efficiency. SPO occurs in many different contexts of aviation today, however, for large commercial aircraft such as the most common airliners of today, increased complexity, and safety considerations are the major obstacles to overcome and demonstrate the airworthiness of such airplanes in operation. This project explores and evaluates the feasibility of different SPO alternatives and their possible implication for new sustainable commercial aircraft. Using a product development process, different guidelines and recommendations are constructed which can be used for the implementation of SPO in a large commercial aircraft.

These guidelines and recommendations consist of different parts and can be roughly categorized into three areas: general needs and strategies, regulation and social acceptance, as well as configurations and functions. Human factors are also an important component in the work, influencing many parts of the project. While there is overlap in the content of these areas, gaining multiple perspectives on the subject of SPO provides a more comprehensive understanding of the subject.

The general needs and strategies provide important parameters for the project to which all solutions generated relate. The regulation and social acceptance area provides insight into how SPO relates to existing regulation and social perception by considering what possible opportunities and challenges there are, both today and in the future. The report's more technical detailed part is covered by the configuration and functions where practical elements of SPO are covered.

These different parts are covered throughout the report in different contexts to provide insights into the feasibility of SPO. As a result of scope limitations and uncertainties, the project aims to provide a good foundation for further work and investigation on the subject.

Keywords: Single Pilot Operation, SPO, Aircraft, Aeroplane, Commercial, Aviation, Human Factors, Automation, Risk, Safety, Flight Deck, Regulation, Roadmap, Product Development

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Adam Gundersen
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1 Introduction

Through the years flight crew members within the flight compartment of commercial transport aircraft have been reduced to the general minimum of today's conventional airliners, which is two pilots. Reducing the number of pilots even further to just one single pilot has become a discussed topic within the industry. Stakeholders such as authorities, airlines, and research institutes have shown interest in single pilot operations, hereafter referred to as SPO, which is a great step in towards the idea becoming a reality for larger aircraft which offers new possibilities and challenges for aircraft manufacturers. This thesis project will investigate if and how SPO can benefit an aerospace company without a legacy in the industry. In this section, an introduction will be given to the topic.

1.1 Background

Transitioning towards SPO in large commercial aircraft is today a highly debated subject. It has the potential to reduce costs for airlines and enable them to offer more departures by increasing overall operational efficiency. In a safety-oriented industry such as aerospace, SPO has to be approached carefully to ensure an equal level of safety as with two pilot, also known as dual pilot operations which hereafter will be referred to as DPO. The aviation industry has a strong legacy when it comes to safety [1]. Because of its extensive work with certification and procedures to maintain aircraft airworthiness, it can be considered as one of the safest means of transportation.

To succeed with an aircraft, it has to be an attractive business option from a long-term perspective which makes SPO relevant to investigate. For an organization without a legacy in the industry, such decisions can be made with less impact on previous work as well as implementing new design philosophies and methods which can be harder to transition towards in larger and more established firms. By exploring and evaluating the risks and opportunities associated with SPO, aerospace organizations may be able to decide if the concept of SPO is feasible and should be pursued or not. As the subject of SPO is already well-researched from many perspectives, there is a need for a detailed research project for more accurate evaluations.

When referring to a large commercial aircraft, the general definition for large used in this report comes from the type certificates for large aeroplanes which is the most commonly used for European airliners applies to aircraft with more than 19 passengers [2]. More about the type certificates and other regulations will be further explained and investigated throughout this report. This means that a large commercial aircraft can vary a lot in size. Worth noting, however, is that SPO can be considered especially suitable for smaller aircraft as flight crew cost will consequently be a larger fraction of the total flight cost allowing the SPO transition to have a larger financial impact than it would on larger aircraft. However, the actual financial benefit needs to be further analyzed and compared to the cost of developing and implementing SPO. If the development and implementation cost for withstanding equivalent safety levels for SPO as DPO outweigh the SPO savings, then the business model becomes unsustainable.

Another potential benefit of SPO is that it increases the operational efficiency which enables new business opportunities for the airlines. For example, SPO makes it easier to operate less popular routes in the case of a pilot shortage due to easier planning with limited pilot resources. With increased operational efficiency, it might also be possible to provide more frequent departures on already existing routes.

Most commercial aircraft manufacturers as well as aviation agencies are assessing the possibilities and risks with SPO [3]. Numerous indicators are suggesting that SPO is a matter of "when" rather than "if.". This makes it relevant for corporations within the industry to evaluate SPO to remain competitive in the foreseeable future, especially since aircraft usually have a long time in service.

Considering the economic advantages and potential drawbacks in other areas, such as uncertainty of overall feasibility, safety concerns, human factors, and regulatory challenges, more research projects are necessary for determining the feasibility of SPO.

1.2 Aim

The aim of the thesis is to provide guidelines and recommendations to support the decision-making process and early development of SPO. The recommendations and guidelines will be provided through a product development process systematically generating different ideas and configurations related to the topic. Configurations refer to various types of solutions for different operational principles. These will be evaluated on relevant aspects such as feasibility, safety, human factors, and regulation. The evaluation process will assess the different solutions from a present perspective, with the goal of possible implementation in the near future.

The format of the guidelines and recommendation produced will be a set of suggested needs, functions, suitable matrices and tables as well as figures and diagrams. To complement this, a technology roadmap will be provided, outlining a timeline for the implementation of different solutions. It will show how different strategies and time perspectives could possibly alter which solutions are most feasible.

1.3 Project Scope

SPO is a broad topic, and investigating all related subjects would quickly exceed the given timeframe for the project. For this reason, it’s important to establish the project scope and limitations to remain focused on the relevant areas of investigation. As there is plenty of earlier research on SPO in general, some earlier findings from related work will be interpreted and used in this project instead of redoing a similar analysis. This interpretation will be placed in the Theoretical Framework section and used as a basis for several of the evaluations and decisions made in the project.

This project is aimed to be a product development-oriented report rather than a purely research-based report. This means that practical and specific ideas about SPO will be evaluated and explored in a bit more detail compared to some of the earlier research that acts as a basis for this project.

While several findings in the report can be used for SPO in general for any large aircraft, some might not be universal depending on given constraints. One general development constraint in this project is to enable both DPO and SPO from either side of the flight deck in the same solution which can promote a smoother transition from DPO to SPO. This implies that the fundamental elements found in a traditional flight-deck layout will be used in this project as well.

The areas which will be focused on in this report are feasibility, safety, human factors, and regulation which are directly or closely related to the flight crew and the flight compartment/cockpit. While external factors also impact SPO such as training, operation regulation (Working schedule, routines, etc.), and the possibility to introduce new airport technology, these will be given a more limited amount of consideration and not fully investigated. Aspects such as ethics, political and public acceptance will partly be explored and evaluated in the research, however, these are major fields on their own so more consideration than what is given in this project should be explored. Detailed parts for the development of SPO are also precluded if they are assumed to be subject to high uncertainty which would not provide any result of true value at this stage. Politics and other regulatory decision-making processes which may impact the final solution will also be given a limited amount of consideration as there is high uncertainty regarding these assumptions.

In terms of feasibility, it has been decided to actively promote alternatives in decision processes which lower uncertainty and makes the solution more realistic within the near future. In this way, assumptions that stretch far in time do not necessarily favor the alternative, even if it promotes a higher level of performance. This is also true for regulation; alternatives that challenge regulation to a higher extent than others aren't favorable, even if they promise higher performance as they increase uncertainty and decrease feasibility. A technology roadmap will be provided to show how different strategies and time perspectives could alter which solutions are most feasible over a timeline.

In terms of function and requirements in the work, new requirements for SPO will not be decided. The reason for this is that it is necessary to obtain more detailed knowledge about the function than what can be done at this stage to provide accurate requirements. Requirements for functions that are not explicitly designed for SPO and already exist in aircraft today will neither be evaluated nor decided in this project.

1.4 Research Questions

After reviewing the project's context, aim and limitations, four research questions can be created which cover the fundamental parts. These questions will assist in keeping the process within the scope as well as make sure that the relevant subjects and areas is being researched.

RQ1 - What configurations for single pilot operation are best suited within given constraints and needs?

RQ2 - What functions would support single pilot operation?

RQ3 - Is single pilot operation a feasible alternative in the current environment?

RQ4 - How could the use of a single pilot be phased into operations?

RQ1 is a question which covers how a potential solution could work on the highest operational principles with the given constraints on the project. It includes a proposal of configurations and a selection of the most suitable one while still complying to the constraints and needs given for the project. RQ2 is related to RQ1 as it aims to provide several functions to enable the use of a selected configuration. RQ3 requires analysis of the environment where the solution would be implemented such as social and political acceptance, regulations, market, and the availability of technology which are all relevant for an implementation of single pilot operations. RQ4 requests how single pilot operations can be phased into operations, which is also a subject of high relevance when it comes to novel technologies in a competitive market such as the aerospace industry.

1.5 Glossary

Airworthiness – Defined by the MAA (Military Aviation Authority) master glossary as "The ability of an Air System or other Airborne Equipment or system to be operated in flight and on the ground without significant Hazard to Aircrew, ground crew, Passengers or to third parties; it is a technical attribute of materiel throughout its lifecycle" [4].

AMC – Acceptable Means of Compliance

ATC – Air Traffic Control

CRM - Crew Resource Management

CS – Certification Specification

DPO – Dual Pilot Operation

EASA – European Aviation Safety Agency

FAA – Federal Aviation Administration

FHA – Functional Hazard Analysis (Sometimes Function Hazard Analysis)

FTA – Fault Tree Analysis

GM – Guidance Material

HMI – Human-Machine Interface

OEP – Onboard Emergency Pilot (Defined in this report)

SOP – Standard Operating Procedure

SPO – Single Pilot Operation

2 Theoretical Framework

The concept of SPO has been continually discussed and researched throughout the recent years and intensifies even further as automation technology rapidly becomes better and more accessible. There are papers written and research being performed on the subject today and during the past couple of years. To move forward on SPO, the initial phase of this thesis was all about accumulating knowledge and information about previous research and investigations. In this chapter, relevant information from previous research is compiled and presented as a knowledge foundation.

2.1 SPO Incentives and Safety Considerations

There is strong competition between airlines that are continuously pushing the development of aircraft and business models to reduce overhead and sunk costs. One of the largest direct operating expenses in aviation is the flight crew costs which can reach fractions between 19-35% depending primarily on the size of the aircraft [5]. This naturally makes it an industry wide interest to reduce these costs which SPO solutions potentially can do. With the evolving industry of commercial aviation and the increase in flights, SPO could also provide some mitigation to pilot shortages [6]. While SPO has been discussed and researched for a long time, increased capabilities with automation make SPO closer to reality than ever. There are indicators that show that SPO is closing in on commercial aviation and that the industry is preparing for it, for example, there is new ongoing research contracted by EASA regarding SPOs which suggests that even the regulatory agencies see this as a real potential future with SPOs, and how they might need to revise their approval processes for such aeroplanes [7].

As previously stated, a main driving factor that influences the development of SPO is the flight crew cost savings enabled by reducing the number of pilots. It’s also important to consider the increased implementation and potential maintenance/reliability costs of the new technology needed for making SPO a reality. To this, there is also the increased cost of training pilots for using such technology in different SPO configurations. The significance of these costs is currently uncertain and will depend on various factors such as what kind of new technology is needed and how complex it will be for the pilot to use. However, the costs will most likely not neglect the savings of SPO for commercial aviation in the long run. Moreover, SPO would directly bring economic benefits if an SPO solution with its related technology, training, and operational cost with a significant reduction in flight crew cost [8].

As a large fraction of the cost is being allocated to the flight crew, implementing SPO thus becomes more beneficial with fewer hauled passengers which means that SPO is generally more cost effective on smaller aircraft [8]. Consequently, this makes air travel cheaper in commercial use, which targets a large customer group and allows for more route capabilities, more frequent flights, and a more economically viable product. It was found in the report *Design of a Single Pilot Cockpit for Airline Operations* that a range between 1.25 and 4.38 million dollars per aircraft could be saved with SPO [9].

2.2 Social Aspects and Acceptance

There are conflicting perspectives concerning the future of SPO, where some claim it is already technically feasible and ready for implementation while others claim that the technology is not ready yet, or at least not ready for non-standard operation and emergencies. Arguably, the lack of social acceptance for SPO remains one of the main barriers to getting it into operation. To get the social acceptance needed, the technology and operation of SPO must prove itself safe, and the advantages must outweigh the disadvantages.

Advantages of SPO are possible economic benefits, and consequently, it also presents the opportunity to offer more routes to the public due to increased affordability and flexibility [10]. However, the disadvantages when it comes to social aspects are several. Primarily, lack of trust in the safety technology itself could be one of the larger barriers, but factors such as how a potential solution is introduced and how it is used in operation can also be important for gaining social acceptance.

For example, if technology seems forced into the market by aircraft manufacturers and airlines for economic gains rather than implemented when matured, according to public perception, it may influence the overall demand for the SPO. The flip side to this is that it may be impossible to perfectly time the market and that public perception will not change unless exposed to working on an SPO concept. To ensure social acceptance, it is crucial to engage a key group of stakeholders, the pilots. This is particularly important because the safety of the initiative will directly affect their work environment.

From an economic perspective, an aircraft with SPO capability may lose its economic gains in terms of demand if there is low social acceptance due to trust-related issues in terms of aircraft airworthiness. Depending on how a solution for SPO is shaped, it will influence feasibility and trustworthiness. For these reasons, market research and product development will be highly dependent on the aspects of social acceptance and culture.

2.3 Technology and Human Factors

Today, commercial aviation is a globally operational system that operates around the clock where thousands of flights depart every day. For each flight, the public relies on safe departures and arrivals on schedule aviation is considered one of the safest means of transportation. Over the years aviation has been increasingly influenced by new automation technology to solve complex problems and allow aircraft to be safer and more efficient to operate. This has opened many new doors to aviation; however, it has also brought some new challenges to the table, many of them related to the subject of human factors. Human factors in this project follows the FAA definition, which defines it as a "*multidisciplinary effort to generate and compile information about human capabilities and limitations and apply that information to equipment, systems, facilities, procedures, jobs, environments, training, staffing, and personnel management for safe, comfortable, and effective human performance"* [11]. The subject of human factors is worked with all over the world in all kinds of industries. By having an effective human interface or involvement in equipment, services, or environment etc. the usefulness and efficiency can be significantly increased. Therefor human factors is an important part of developing a solution for SPO where one pilot alone will interact with a whole aircraft where effectiveness can be considered key to feasibility.

Developing aircraft for safer and more efficient operation is a constant work in progress, and behind every flight is a flight crew. The performance of an aircraft no matter how safe and high performing it may be, is limited by the integration and capability of the flight crew. Allowing the crew to efficiently interact with the aircraft and do their job without unnecessary obstacles is crucial to keep up with the commercial aviation standards of today.

For a possible implementation of SPO, relevant subjects to the research are operations, flight deck, and automation. The operations are important since they cover how the plane is used in terms of what tasks and activities are performed by the flight crew and why. This also makes automation important to investigate since it assists the crew and handles some of the tasks traditionally handled by the crew. The automation used in aircraft is continuously being developed and may solve certain SPO challenges in the future. Transitioning from two pilots down to one will affect how the pilot interacts with the aircraft in a handful of ways and it is therefore essential to look further into the layout and design of the flight deck. These subjects are all connected in one way or another and as illustrated in Figure 1 human factors are involved in all of them.

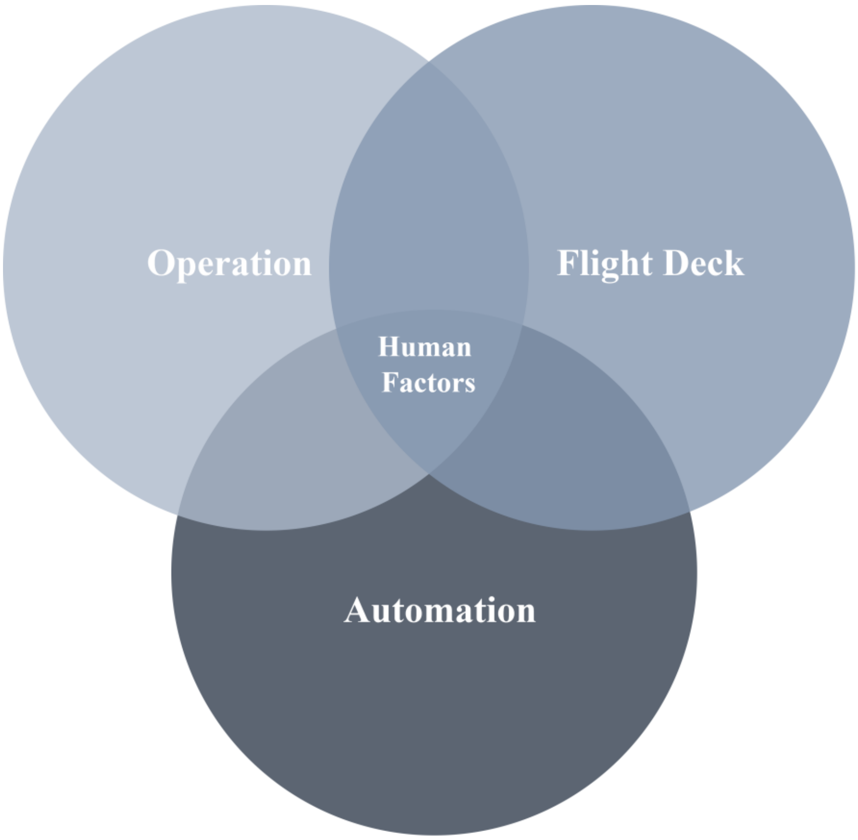


FIGURE 1 - DIAGRAM SHOWING HUMAN FACTORS INVOLVEMENT IN SPO RELATED SUBJECTS

2.3.1 Human Factors

The success of an aircraft being used by humans will be dependent on human factors. Through the years, human factors have become a key aspect in the design of aircraft and operations and within the military, it is considered one of the most important factors. The flight crew can affect the success of a flight in many ways, for example by human error where a person does something that should not be done or in a way that it should not be done. This could for example be due to physical restrictions like obstacles or a high cognitive workload. These situations as well as many more are human factors related. As illustrated in Figure 1, Human factors is in some way related to aircrafts operation, flight deck design, and automated systems since all these together make up the interface between human and aircraft.

Understanding human behavior is fundamental for succeeding with SPO. There are a couple of things to keep in mind as well as tools to utilize when designing for human involvement. Examples of important subjects to consider are workload where crew resource management (CRM) can be helpful as well as remembering tasks in critical situations where standard operational procedures (SOPs) can be used which will be further explained and described in the coming chapters.

2.3.2 Operations

This section of the report will outline some SPO-related operational aspects of aviation for organizations such as airlines. Specifically, it will cover how these organizations utilize an SPO capable aircraft, as well as the corresponding activities and procedures involved.

2.3.2.1 Organizational Aspects

When designing an aircraft, it is important to look at the organizational aspects of commercial airlines. These aspects may differ between airlines and how they use an aircraft. The organizations operating the aircraft have specific procedures for how the aircraft is maintained and operated, how these procedures will look depends on the design and potential SPO configuration of the aircraft. New levels of automation will potentially require a reduced amount of inspection and maintenance. However, it will also require new procedures and organizational configurations due to the novelty of the technology [12].

There are different configuration solutions proposed for SPO today [13] [14] [15] [16] where some require different levels of ground support. Implementing ground support will require an organizational change in operation with new functions, roles, and training. Implementing ground control solutions will also require new system architectures and adaptation of technology since this is not used today.

When it comes to reduced crew resources and only using one pilot there are many aspects that are influenced by this. SPO will generally require reallocation of some of the single pilots' procedures and tasks. However, when it comes to the single pilots' areas of responsibility some tasks must be done or at least be verified or trusted by the pilot in command [17]. One common example of this is the pre-flight walk around where the captain checks and verifies the aircraft. This could potentially be completed by a ground crew which would remove this task from the pilot's list of procedures. The walkaround, however, lies under the captain's responsibility since he/she is responsible for the flight. This could be problematic if someone else performs the walkaround and misses a fault. This could result in the pilot being left responsible for a failure due to the ground crew performing an incomplete inspection. One aspect of this is seeing it from the ground crew perspective where repetitively performing numerous walkarounds and in some cases during high workload scenarios might lead to missed detection of a fault. These aspects are thus relevant to consider when developing for SPO since the airlines using the planes might not be able to use the aircraft in service otherwise [13].

2.3.2.2 Crew Resource Management (CRM)

Crew Resource Management (CRM) is used to effectively distribute work among the flight crew and further improve safety and well-being during operations. Crew resources are the resource amount the crew onboard a plane can put into completing required tasks. To fulfill the tasks there must be enough crew resources to do so, which might be a challenge when it comes to SPO. Reducing the number of crew members reduces the number of immediately available crew resources which is why it becomes significantly important to manage the crew resources in an effective manner. One key goal with CRM is to ensure that teamwork always remains functional, and that situational awareness is not lost, which can be catastrophic during certain scenarios. CRM is a complex subject that includes factors such as decision-making, teamwork, communication, and problem-solving to name a few. Its strong relation to human factors makes it complex in a different way compared to other types of engineering issues and must be considered during the entire product development cycle of an aircraft.

In fact, poor CRM is the second most contributing factor with 33% of fatal airline accidents related to poor CRM within the period from 2002-2011 [18]. Poor CRM can be many different things, for example, forgotten or failed cross-checks, incomplete communication or coordination between flight crew or even remote personnel.

From an SPO perspective, there are many emerging challenges related to CRM. Major task reallocation must be considered and duties with responsibilities transferred elsewhere as simply moving all current responsibility from the pilot monitoring to the pilot flying would in abnormal and emergency situations greatly reduce performance and workload would become an even bigger issue than today. Consequently, depending on how the specific solution is designed, new kinds of tasks may be introduced for the pilot flying. This could involve tasks such as monitoring automation, communicating with remote personnel or similar. Some of these tasks may be repetitive and consequently could be considered "boring" which could be a potential issue from a human factor's perspective. New types of tasks mean that new types of CRM procedures are required which could require further pilot training in the case of SPO [13].

2.3.2.3 Standard Operating Procedures (SOPs)

When operating a commercial aircraft, there are plenty of procedures and training in place to ensure operational safety. These procedures have been developed and evolved over a long period of time by monitoring, researching, and investigating accidents to further improve efficiency and safety and are backed up by several regulations [19].

Standard Operating Procedures (SOP) are however not universal as they are different between aircraft and airlines, but they serve the same purpose, to generalize and standardize actions to be taken in different scenarios. This is to support the pilot by giving him/her guidelines to follow. SOPs promote the optimal use of the aircraft features but are also written to suit the flight deck design philosophy and related operation philosophy. The SOPs usually function as a template for individual airlines to further optimize their operations and how they use the aircraft.

One key element in SOPs are checklists that cover normal, several abnormal, and emergency situations. These checklists are today usually designed for the roles of pilot flying and pilot monitoring. They describe what certain action should be performed by whom and in what sequential order, as well as verify decisions and information by using cross-checks between the roles. Cross-checks help with reducing the risk of human error or action based on faulty information from example instruments and are a major part of aircraft operation. The checklist is also designed with Crew Resource Management (CRM) in mind to evenly and as logically as possible distribute workload between the roles.

Many of these checklists are covered in the physical so-called Quick Reference Handbook (QRH), but nevertheless, pilots still must be thoroughly trained to be able to handle many steps from memory without having to reflect upon certain decisions for an extended time. Failing to execute SOPs, either completely or partly, has still proven to be one of the main causes of accidents in the industry. If using SPO and a new type of sustainable aircraft, major changes from typical SOPs are to be expected to cope with new kinds of automated processes, new failures, changes in CRM strategies, and task rearrangements.

2.3.3 Flight Deck

The design and layout of a flight deck is an important part of the aircraft since this is where the machine is integrated with the human, commonly referred to as HMI (Human-Machine Interface). Hence, having an HMI that allows for piloting the aircraft successfully in the most efficient way possible is crucial. Consequently, the HMI should allow the flight crew to operate safely and with a workload not greater than necessary. If new technologies such as new automation systems and SPO configurations are being implemented, there is a significant change in how the pilot interacts with the aircraft and its systems. For this reason, it’s necessary to evaluate and optimize the flight deck of such an aircraft.

The flight deck of an airliner has numerous panels, levers, and switches that serve different functions and should be easily accessible. In a DPO configuration, certain elements in the flight deck have dual inputs, such as the flight controls with each pilot having their own pedals and yoke or sidestick. However, reducing the amount of equipment to match one less pilot can increase the likelihood of catastrophic outcomes as there is a higher risk of function loss/access. The reason for this is more single points of failure or that it may be impossible for a single pilot to regain control of the equipment if it has not been designed with single-pilot redundancy equipment. Even if redundancy equipment is present on the flight deck, but not optimized for SPO, it can be difficult for a single pilot to access/reach input for functioning equipment due to physical limitations.

When designing a flight deck, a human-centric approach should be applied to make the integration as effective as possible. The objective of human-centric design is to try to understand the variability constraints associated with the different ergonomic pilot aspects such as reachability or similar. The flight deck should therefore be designed to mitigate the risks from these drawbacks as well as allow the benefits to be fully used. In other words, the flight deck should, together with the human operate the aircraft in the safest and most efficient way where humans and automation fill in each other's gaps. It is also important to consider that all people are different and have different preferences, form factors, physical and cognitive abilities. For this reason, allowing people to adjust and arrange the flight department to a certain extent to fit their preferences is important since this will allow them to reach a higher potential in work performance [20].

2.3.4 Automation

Automation is increasingly used throughout most means of transportation and not least in aviation. The automatic functions are getting better all the time allowing for safer flight as well as reduced workload for pilots. Aircraft automation solutions come in a variety of automation levels from basic cruise control to more advanced automatic landing systems. The use of automated systems, which was initially viewed as emergency solutions or luxury add-ons is now considered standard in aircraft operations.

The main purpose of implementing automated processes is to reduce the pilot's workload by transferring some of the tasks to the system. Automation can be categorized into 6 different levels as suggested by [21] where level zero is an entirely manual operation and level 5 is a fully autonomous operation. By increasing the level of automation within the flight deck, pilots' working procedures move further away from actively controlling the aircraft and instead, move closer toward a monitoring and decision-making role. It has been discussed whether the implementation of automation in some cases even increases the pilot's workload due to the need of monitoring and handling of automated system [12]. In the paper *Human Factors in Highly Automated Systems*, R. McLeod points out another challenge which is that with increased automation comes reduced manual operation for the pilot and has therefore created concerns about a reduction in skill among pilots in commercial aviation [21]. During regular operations under normal conditions and with no faulty equipment, this is not an issue, however, whenever there is an emergency where the pilot must manually react and act the reduced skill and familiarization of the aircraft and operations might lead to catastrophic outcomes.

In L. Bainbridge's article *Ironies of Automation,* she writes (as cited in [21]) *"...a formerly experienced operator who has been monitoring an automated process may now be an inexperienced one"* [22]. This is important to keep in mind when implementing new technologies and automation in general but not least for aircraft due to the potentially catastrophic outcomes due to small errors or wrong actions. The fact that a pilot relies on automation to perform flight procedures also generates the possibility of an overreliance on automation. This essentially means that the pilot gains trust in the automated functions and intentionally or unintentionally violates procedures and activities such as monitoring the automated system and its outcome. This can also lead to the pilot being under-stimulated and therefore shifting thoughts or activities to subjects not related to the flight. These kinds of issues and possible activities are purely human factors related as well as very relevant when it comes to the implementation of SPO.

Automation can also increase safety by outperforming the pilot's ability to, for example to land the aircraft in reduced visibility or where the pilot's ability to operate is impaired. Automated systems are also immune to making human error which is the most common cause to commercial aviation accidents [23]. Therefore, automation is of high relevance when it comes to SPO where the conventional redundancy of two pilots is removed. When investigating the possibility of SPO it is important to look at cases where the single pilot's ability to react and control the aircraft is reduced or even neglected. In this case, one possible solution would be to have an automation system takeover, which will be further discussed in this report. With SPO the crew resources are naturally significantly reduced which is another problem where automation can assist by taking over tasks.

One of the most discussed issues with SPO is pilot incapacitation. This is likely due to the potentially catastrophic situation where the pilot is now unable to control the aircraft and there is no one else onboard with the required expertise, the aircraft is now flying on its own. In these cases, an automated landing system can mitigate concerns and skepticism as well as solve the problem to a certain degree. However, at this point in time, the required technology is not yet implemented and socially accepted for commercial aviation. In commercial aviation today, some large companies have landing assistance systems that are to a degree considered automated [24]. These systems allow the aircraft to touch down on the runway in poor weather conditions and really assist the pilot in bringing the aircraft down safely. However, these systems are not yet fully autonomous and are not capable of solving the situation of SPO pilot incapacitation since they still need a pilot to perform tasks in combination with automation.

If an automation system that is approved by agencies can navigate to a nearby runway and safely land the plane as well as alert ATC, it might be able to solve some of the challenges with pilot incapacitation in SPO. For such system to be implemented in commercial aviation, it has to comply with regulation and get social acceptance.

In summary, automation can be seen as a double-edged sword; if everything works as intended, it's a great tool to reduce workload and assist in various scenarios. However, in scenarios where the automation system doesn't work as intended, displays inconsistent behavior, or is put in a situation above its capability, the effect might be the opposite. As an automation system is complex and it leaves the operator a smaller chance to be able to troubleshoot the system and correct the potential issues, especially during high workload scenarios, aircraft in certain situations could be better off without automation.

2.4 Configuration for Single Pilot Operation

The concept of SPO has been discussed for several years and during that time many different approaches to how this can be solved have been presented. As technology rapidly evolves, especially around software and automation, the idea about what is possible and what risks there are constantly changing, however, one variable has remained the same, the ethical aspects of reduced human involvement during operation. This parameter is constantly challenged as technology becomes safer and more robust. There are different ways to approach SPO from a theoretical perspective, "configuration" is one approach that appears frequently within the subject. During the first brainstorming of the project, it was decided that the configuration approach would be used in this project as well in a way that suits the scope of this project.

An SPO configuration can in this case be seen as the most abstract level of solution approach to SPO where it is generally decided where and to whom a task is reallocated to avoid an increase in workload for the captain which could results in significantly increased risk. From the report [25], some of the preliminary findings from the meetings on which the report is based on it were that the participants generally saw two different possibilities on how to reallocate tasks. Most commonly, the concept of having one pilot on the ground replacing the co-pilot in the flight compartment was discussed. Another concept discussed was just the use of a single pilot, in other words, a true SPO without any help or assistance from another individual. On occasion, it was also discussed the concept of not having any pilot onboard at all as many of the problems and solutions related to SPO are also relevant for unmanned aerial vehicles (UAVs).

In the NASA Single Pilot Operation Technical Interchange Meeting, more specific configurations compared to [25] were discussed and evaluated. From the report, five different configurations are discussed, some with subcategories, which can be used to reallocate the tasks involved during operation to realize SPO. These configuration principles are also highlighted in Harris's paper *Single-pilot airline operations: Designing the aircraft may be the easy part*. Different research on SPO usually uses one of these variants or a modification of them, such as [8] and [26]. However, details on how these configurations are technically designed and solved are not described and the feasibility will depend on the detailed solution [13] [10].

In the report *Task allocation for single pilot operations: A Role for the Ground* by NASA [25], it was found that there are generally five areas of relevant issues that affect any type of SPO configuration. Automation issues, Operational issues, Pilot incapacitation, Communication/social issues, and Certification and approval issues. While the areas are somewhat overlapping, considering these elements may facilitate an efficient judgment and evaluation of different solutions.

2.5 Research and Development Tools and Strategies

Some more specific tools used within aviation which may not be considered general engineering knowledge are briefly explained in this section. These tools and strategies are used during the project and may be referred to throughout the report.

2.5.1 Accidentology and Accident Reports

Today air travel is very safe compared to other means of transportation, but it has not always been that way. When an aircraft takes to the air, it becomes more vulnerable than other means of transportation such as a car or a ferry. This vulnerability has caused widespread societal respect and sometimes skepticism toward aviation. This also means that it is crucial to prevent and mitigate failures since a minor fault can have catastrophic consequences. Even though aviation accidents today only occur at a small fraction of successful flights due to years of developing safer aircraft with more redundancies, accidents still happen. Every time an accident happens, the industry learns something which is used to prevent future accidents from occurring. Therefore, accident reports play a significant role in the development of safe aircraft and the theory of the subject, its causes, and consequences, are called accidentology.

More problems in aviation in general can lead to catastrophic outcomes and affect a large number of people and cause significant economic damage. This means that there are mostly detailed investigations performed into each accident with plenty of documentation. This makes accidentology a source of information that is useful in the development of safe aircraft. Analysis of accident reports allows developers to identify patterns, trends, and specific causes which helps identify safety risks and improve safety features which are all critical steps in the direction towards safer flight.

2.5.2 Aircraft System Classification – ATA 100

Aircraft are often complex products with various systems and subsystems. It is common for manufacturers of complex products to decompose the product into different systems or zones of the product to allow for easy navigation through a large amount of information. It can also be beneficial for companies to use standardized systems to easier interact with each other. ATA 100 is a numbering system proposed by the FAA that has been widely used and accepted within the aviation industry for many years and proposes a categorization of aircraft systems [27].

2.5.3 Design Guidelines in Aerospace - ARP4754A and ARP4761

SAE *International or former Society of Automotive Engineers* is a US based global developer of standards for engineering professionals. The organization has developed a framework called ARP (Aerospace Recommended Practice) as guidelines for developing civil aircraft. [28]

ARP4754A - *Guidelines For Development Of Civil Aircraft and Systems,* is used for Part 25 aircraft organizations and provides guidelines for the development processes and certification [29]. ARP4754 is intended to be used together with ARP4761 - *Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment*. ARP4761 provides a process for assessing the safety of a system being developed including useful methods for analysis and assessment [30]. Similarly, to SAE, EUROCAE *European Organisation for Civil Aviation Equipment* also has corresponding versions of the ARP documents. Corresponding to the ARP4754A is the ED79A and to the ARP4761 is the ED135, during this project only the SAE versions have been used.

2.5.4 Workload Assessment – The Bedford Scale

The Bedford scale is a commonly used method for assessing the workload of a pilot's tasks [31]. The method is initially a modified version of the Cooper-Harper rating scale which is used for assessing aircraft handling characteristics. There are a handful of tools available for workload assessment and the most common are the NASA TLX (Task Load Index) [32] and the Bedford scale. The NASA TLX is considered to be slightly more advanced and requires more detailed knowledge and experience about the tasks and operations in order to accurately assess them compared to the Bedford scale. Since the knowledge of the tasks to be evaluated in this project which is the potential functions to implement for SPO is limited and the experience is non existing the Bedford scale was chosen for workload assessments.

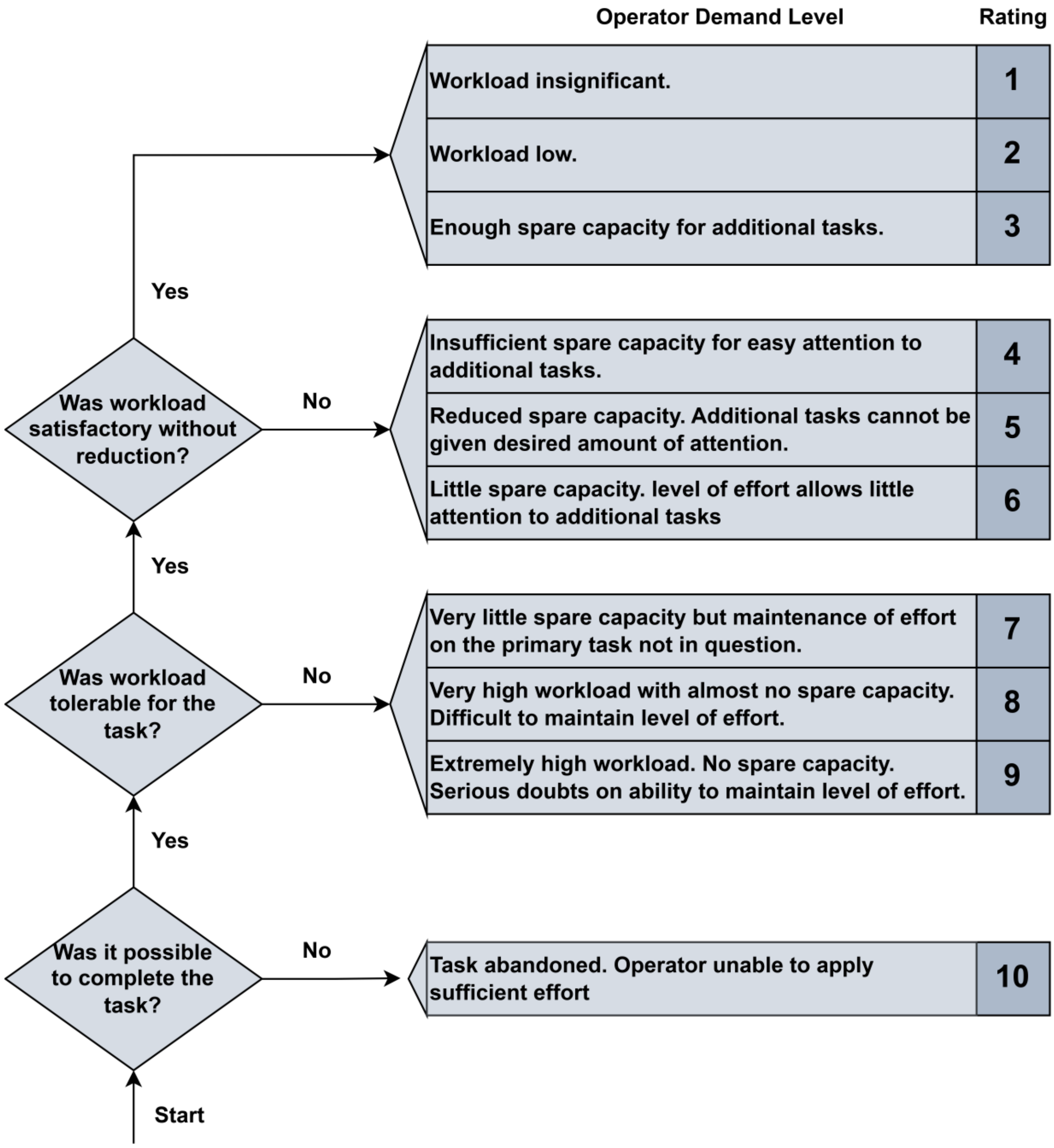


FIGURE 2 - BEDFORD SCALE MODEL

The Bedford scale can be used for a subjective assessment of the workload in different tasks or activities and result in a rating on a scale from 0-10 where high workload results in high numbers. The model is based on three questions that are generally asked to the operator which in the case of SPO suitably the single pilot flying. However in since this project is at an early state of the development of SPO, the authors answered the questions with the help of knowledge gained from relevant literature. The questions relate to whether the task was possible to complete, had a tolerable workload and satisfactory workload and the answer is either yes or no. By following the path of answering either yes or not in Figure 2, a workload rating of the specific task is attained.

2.5.5 Engineering Ethics

When engineering for SPO in aviation, ethics must be considered at major decision points as it will influence the solutions in several ways. When discussing engineering ethics, it is important to understand that there will be tradeoffs. These tradeoffs are not always easy or even possible to perfectly balance as it many times is a question of subject values and morals. These tradeoff decisions will many times directly impact how the solution works practically. Further on, typical questions that will arise during the subject of SPO is the area of responsibility for certain outcomes and decision owner. This is a natural consequence when automation is becoming increasingly used in operations. There are several aspects to consider when taking these decisions, technology readiness level and stakeholder acceptance are two of these which can provide guidance. Following a Code of Ethics or a specific ethics approach is another way.

There are plenty of approaches used and suggested in the world of engineering and implementation of automation [33], one used within engineering is the NSPE Code of Ethics provided by the National Society of Professional Engineers [34].

Depending on what decisions are made, these will ultimately have a strong relation to how values of safety and risk are considered in relation to opportunity. For every commercial flight, regardless of the operation, whether it’s either traditional DPO or SPO, the flight is subject to a certain level of risk, the question, however, becomes what level of risk is acceptable. With the help of engineering and evaluation, risks can be mitigated to further improve safety, however, reaching zero risks is just not possible. Reducing uncertainty is the keyword here, but ultimately, there are still subjective decisions that need to be made that will influence several aspects of the final solution.

2.6 Regulation and Certification

Certification of commercial aircraft and operations is complex and has long product development lead times where a new airliner takes several years to get certified. Therefore, when implementing SPO solutions as a novelty in the industry, certification will naturally be a significant phase in the process.

The aviation industry today is regulated by different authorities responsible for different regions of the world. Two significant ones are the EASA and FAA. EASA is responsible for the European region and FAA is for the American region.

EASA, being the European regulatory agency, provides comprehensive documentation regarding fulfilling the European Union’s laws for aircraft. The European Union’s laws are so called “hard laws”, meaning they are legally binding and must be fulfilled. EASA provides different soft-laws documentation that are meant to practically fulfill these laws, these are, Certification Specification (CS), Acceptable Means of Compliance (AMC), and Guidance Material (GM) [35]. Some of the more relevant hard laws which will be used in this project in combination with the related and applicable CS, AMC, and GM are:

- **For Basic Regulation** - Regulation (EU) 2018/1139 [36]
- **For Initial Airworthiness** - Commission Regulation (EU) No 748/2012 [37]
- **For Air Crew** - Commission Regulation (EU) No 1178/2011 [38]

- **For Air Operation** - Commission Regulation (EU) No 965/2012 [39]

In the North American region, Title 14 of the Code of Federal Regulations (14 CFR – Aeronautics and Space) is the regulation corresponding to the European Unions' "hard laws". The first chapter in 14 CFR is the Federal Aviation Administration, Department of Transportation which is the most relevant regulation to investigate at this stage. Further on within Chapter 1, the focus will be aimed towards Subchapter C – Aircraft, Subchapter D – Airmen, and Subchapter G – Air Carriers and Operators for Compensation or Hire: Certification and Operations.

Subchapter C includes parts for airworthiness that correspond to the Commission Regulation (EU) No 748/2012 but also general laws and rules of certification procedures similar to the Regulation (EU) 2018/1139. These general laws and rules are found in Part-21 located in Subchapter C. Subchapter G on the other hand includes regulations regarding aircraft operations and in that sense corresponds to the Commission Regulation (EU) No 965/2012. The corresponding American regulation to the Air Crew Commission Regulation (EU) 1178/2011 is subchapter D where training, criteria, and similar subjects are addressed for crew working on aircraft. Similarly, to the European hard laws presented above the relevant corresponding American laws treated in this project is:

- **For Airworthiness & Certification Procedures** – 14 CFR, Chapter 1, Subchapter C – Aircraft
- **For Airmen** - 14 CFR, Chapter 1, Subchapter D – Airmen
- **For Operations** – 14 CFR, Chapter 1, Subchapter G – Air Carriers and Operators for Compensation or Hire: Certification and Operations

EASA and FAA have divided their documentation into different smaller parts which are categorized to fit the hard laws but still provide increased practicality for developers of aircraft. This thesis will primarily investigate the regulatory sections regarding airworthiness and air operations since these are the most related to SPO. A noteworthy section and a good example are Part CAT which is a part of the air operations regulations provided by the EU and EASA [40]. Similarly, FAA has corresponding parts which will be explained further in the following sections.

2.6.1 Basic Regulation and Aircrew/Airmen

The EUs basic regulation for aviation can be considered as a set of principles for all other regulation documents which EASA provides. The EASA Aircrew and FAA Airmen regulations provide content that covers elements such as pilot qualification which is partly out of scope for this project. For these reasons, unless any obvious regulation with a direct correlation with SPO is found, these parts won't be further elaborated upon.

2.6.2 Airworthiness

Aircraft are generally classified based on their size and field of operation. Large commercial aircraft lies within the CS-25 classification (*Large Aeroplanes*, EASA, [2]) or Part 25 (*Airworthiness standards: Transport Category Airplanes*, FAA, [41]) which is the type certificates which will be of focus in this report. For smaller commercial aircraft, there is another classification which is CS-23/Part 23(*Normal-Category Aeroplanes*, EASA/FAA).

The CS-25 provides a framework that specifies what is required of an aircraft to have it certified and brought into service. EASA also provides AMC 25 which contains acceptable means of compliance and can be used as guidelines for testing and validating that the aircraft meets the CS-25 criteria. As stated, EASA CS-25 is active for the European region while FAA part 25 fills a similar purpose for the American region and has a corresponding section to the AMC 25 called AC 25 for Advisory Circular.

Since SPO is an emerging topic and still considered novel. The CS-25/Part 25 regulations are still primarily designed for configurations with two pilots; however, it can be discussed whether some chapters are obstacles for SPO or not which will be further discussed in the section Regulatory Landscape Analysis and Forecasting

2.6.3 Operation

In the world of commercial aviation, there are as stated a handful of regulation sections. Apart from airworthiness, this report will also investigate the operation of aircraft. These regulations provide criteria required of aircraft and procedures depending on their field of operation. The aircraft operations certification is also provided by the authorities where the regulation for the European region is published in the Commission Regulation (EU) No 965/2012 [39] and for the American region in 14 CFR Chapter 1, Subchapter G.

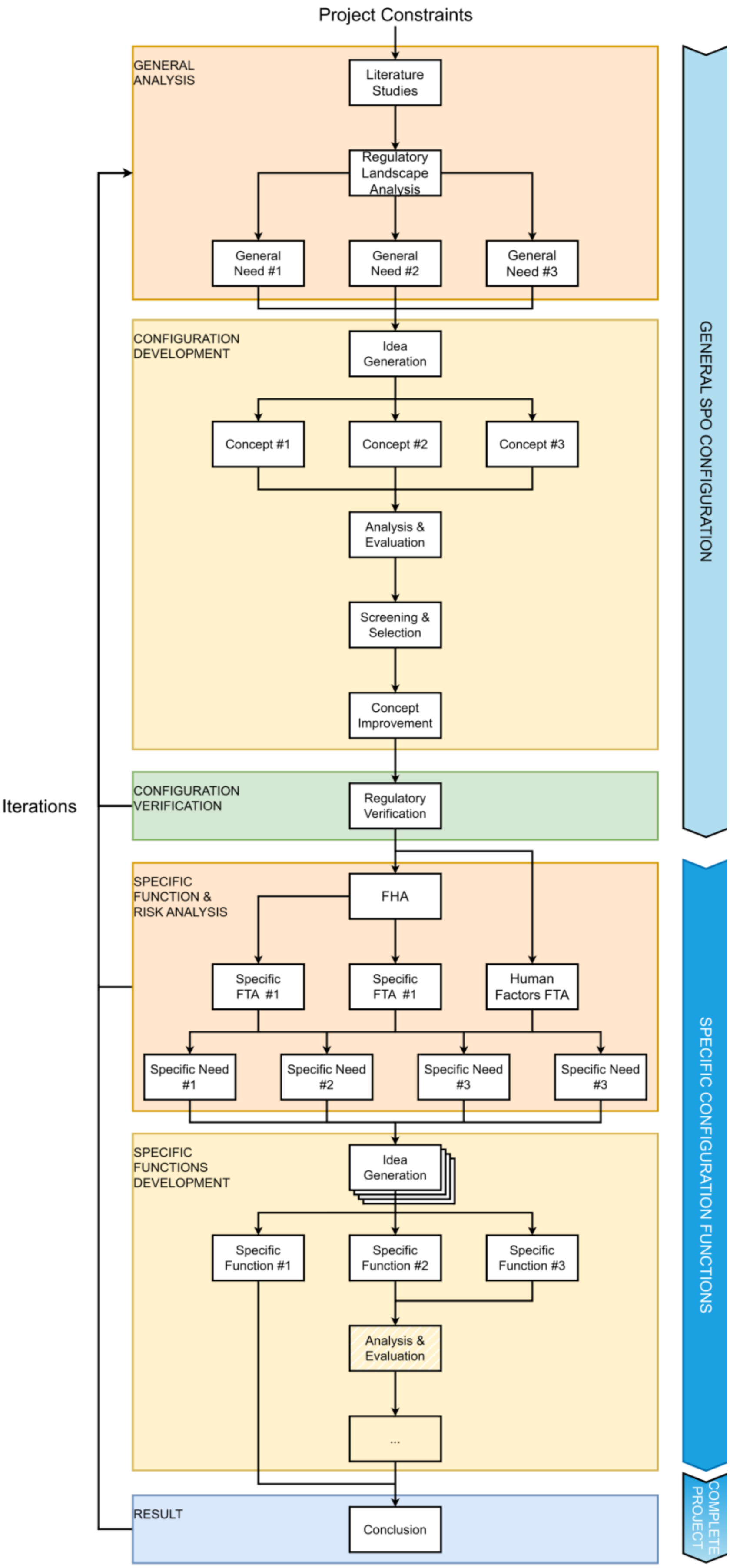
Depending on what kind of operations the aircraft will be used for there are different rules and regulations. EASA has a section called Part-CAT – *Commercial Air Transport Operations* which is relevant for SPO in commercial aviation. There is also a section called Part-ORO – *Organisation Requirements for Air Operations*, this section is also relevant and will be further explained in the section Regulatory Landscape Analysis and Forecasting

For the FAA there are two similar sections called Part 121 – *Regularly Scheduled Air Carriers* and Part 135 – *Air Carrier and Operator Certification* which should be considered as well.

The regulations cover areas such as flight operations, maintenance, aircraft performance, required equipment, and emergency procedures but also include flight crew-related criteria such as CRM and training which makes it important to consider for the implementation of SPO.

3 Methodology

To answer the research questions, the project will be divided into several different stages with related activities. While the different stages are presented in sequential and logical order, the development process has been iterative and flexible. Because of the iterative approach, the process has evolved to become what it is today, an outline of the final process can be seen in Figure 3. In the flow chart diagram, the different steps are tied to different headings in the report. The iterations made are not explained as independent processes. If an iteration is made that changes the result, elaboration is made on that specific change in the heading where the change occurred.



FHA - Functional Hazard Analysis
FTA - Fault Tree Analysis

FIGURE 3 - PROCESS FLOWCHART FOR THE PROJECT

3.1 General SPO Configuration

The project started with an extensive research phase that was used to build up a theoretical framework that was used throughout the project. The framework is based on previous research on the subject of SPO as well as literature and document studies in related fields. It also holds information on how to use suitable methods and tools commonly used for similar applications. The theoretical framework did not only assist in brainstorming ideas and making project decisions, but the process itself creating the framework facilitated an understanding and knowledge basis of the subject.

When the theoretical framework was established, the next step was to analyze the regulations related to SPO for a large commercial aircraft. The regulatory landscape analysis used the different regulation documents highlighted from the theoretical framework to understand what criteria may affect SPO and what precautions are necessary for developing an SPO solution. This involved specifying and explaining how and why regulation could potentially impact SPO solutions.

Continuing from the research phase, the next phase was the system development of a suitable SPO configuration. The configuration in this context refers to the highest operation principles, meaning answering questions such as where and when people will be needed, what tasks are automated, and to which level. Further, this could be explained as dividing areas of responsibilities. It was found during the early discussions that the use of different configurations would be a pillar of this research.

The first activity in the development of a configuration was to construct different general needs to be used throughout the project for shaping the solution for SPO. These needs could also be considered general SPO strategies. These general needs were found by interpreting project constraints and analyzing the regulatory landscape for SPO in commercial aviation.

Once the list of different general needs had been established the process continued by brainstorming on different configuration concepts for SPO. This brainstorming was based both on the explored system needs and findings from the theoretical framework. These generated configuration concepts were then analyzed on the parameters of political, economic, social, and technological through a PEST analysis. The use of the PEST method facilitated an effective evaluation of the different generated solutions. The analysis was then compiled into an evaluation matrix where the concepts receive ratings based on the PEST analysis by converting qualitative to quantitative data and the most promising one was chosen for further analysis and improvement. The final concept was then validated towards the relevant regulations found in the regulatory landscaping section.

3.2 Specific Configuration Functions

Once the configuration was decided, a new development cycle was initiated with the purpose of adding technical details for the selected configuration. These details are in the form of specific functions related to flight compartment equipment. These functions have a clear connection to human factors as it is considered one of the more crucial safety aspects when it comes to transitioning to SPO.

This next development cycle began with a Functional Hazard Analysis (hereafter referred to as FHA) which is based on potential failure conditions which are believed to be more severe or have a higher frequency of occurrence for SPO compared to DPO. The failure conditions included in the FHA were found by literature and document studies, accidentology, and internal company discussions. Parts of the risk assessment process in ARP4761 were then used in this project, see Figure 4, where the failure conditions in the FHA were further analyzed by decomposing them using several specific Fault Tree Analysis (hereafter referred to as FTA). By using specific FTAs, it was made possible to find the leading causes of these different failure conditions. The way these failure conditions were decomposed was by using principles from the *Human Factor Analysis and Classification System* (HFCAS) and technical failures as two major categories to be able to explore different kinds of problems. The decomposition was in some cases limited since a leading cause might be out of scope or relevance to the project or too complex to be evaluated at this time.

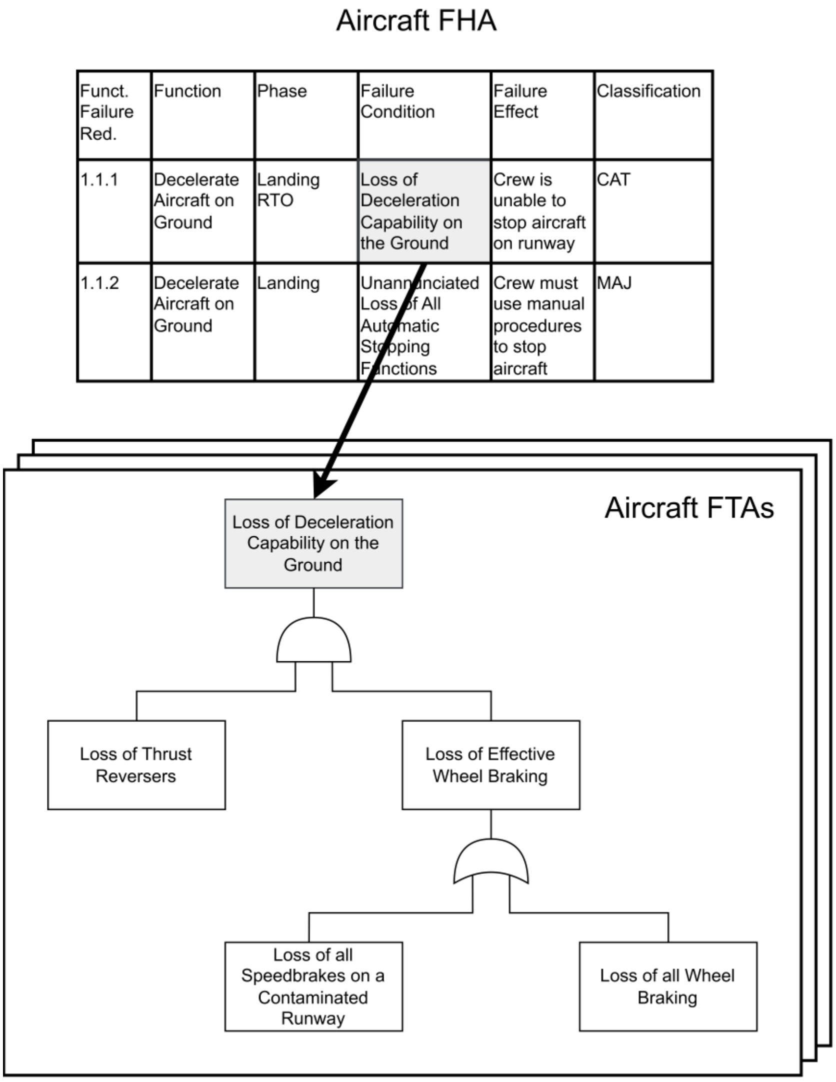


FIGURE 4 - PART OF AN RISK ASSESSMENT PROCESS EXAMPLE [30]

Another type of FTA with a similar structure was made to specifically address human factors related to needs and function. This tree, however, used another perspective by having human factor as a main cause of a problem in a general accident rather than a technical one, the tree was thus not inherited from the FHA but delivered the same kind of result and covered different grounds. It was designed with both SPO and DPO in mind which made it possible to find risk scenarios that were more critical for SPO compared to DPO.

These specific FTAs and the human factor FTA resulted in different needs; this time more specific ones compared to the general ones at the beginning of the project. The main purpose of these specific needs was consequently to address different safety risks and gaps with SPO to be able to address them with new functions. In contrast to the earlier phase where the general needs were used for brainstorming different configuration alternatives, this time these specific needs were used for brainstorming specific functions. The functions' main purpose was to remove or mitigate these possible accident leading causes. While some functions that were found were not novel, the performance and requirements of these functions can be more critical in SPO.

To further develop the specific functions which would be the next step in approaching a final solution was to find alternative sub-functions for the specific functions. Due to the limited time of the project, this was done for only one specific function with the main purpose of providing guidelines and an example to follow for future work. Brainstorming allowed for sub-functions to be designed for the specific function which was then evaluated through an FHA and a Bedford Assessment.

The findings from this second development cycle were specific functions that should be considered when designing for SPO with the selected configuration. Several of these functions are also applicable to SPO in general. As there were many needs/gaps explored in the FTAs, not all functions that were found to address these were analyzed or evaluated in detail, due to the project timeframe. Nor have all needs/gaps been fully covered with function at this stage, for the same reason.

3.3 Complete Project

Following this second development cycle, a result and conclusion were made on the important findings of the project. Most notably, these findings include a nuanced description of the selected configuration and the specific function and how they relate to existing regulation, safety, human factors, and feasibility. The result and conclusion were also supplemented with a possible SPO roadmap to help map out the different configurations and functions over a timeline.

4 Regulatory Landscape Analysis and Forecasting

In the early stages of a product development project, one of the first steps is product planning with its related activities such as identifying and analyzing the business environment. Like with many developments project, SPO also has a high level of uncertainty. In the book *Product design and Development*, the authors present ten types of product development projects [42]. Because of the wide scope of the project, it fits into several of the different types but generally, the product can be considered as a high-risk product development process and a complex system development process. While the concept of SPO is not new, there is still plenty of uncertainty with the concept from different aspects such as feasibility, safety, human factors, and regulatory aspects which is partly why it fits the high-risk product classification. With these types of projects, uncertainty and risk is to be expected, and in an attempt to partly reduce the regulatory uncertainty, an evaluation of the regulatory landscape is conducted.

Doing an analysis of the regulatory landscape and forecasting the future for SPO is crucial as aviation is a highly regulated industry. By analyzing the existing regulation and the landscape in general, it becomes easier to assess and better predict the potential impact SPO will have on the feasibility of the product. Further on, by understanding the regulatory environment, forecasting future regulatory trends becomes more attainable. This is important for this project as SPO (or fully autonomous operation) is more considered as a when question rather than an if. This analysis aims to find potential obstacles with certain solutions which may pose regulatory challenges. The purpose of the landscape analysis consequently becomes to minimize risks by adapting to suitable needs and strategies.

The EASA and FAA regulatory regions have similar criteria and regulations when it comes to aerospace certification which makes it easier for manufacturers to certify aircraft in more regions than its origin. There are also other regions with local regulations, for example Asia. However, during this project, only the EASA and FAA regulations will be analyzed. Only when there is a deviation between EASA and FAA regulations related to SPO, the American regulations will be addressed. From the four different regulation parts described in the theoretical framework, the basic regulation and aircrew/airmen parts will not be analyzed and evaluated in detail. This is because, from these regulations alone, there has not been any content found which directly prohibits the use of SPO under normal operation, or nothing which indirectly does so within a reasonable distance to the subject, which leaves little room for further evaluation. The airworthiness and operations sections of the regulations will be analyzed from a SPO perspective. The sections presented and discussed within this report is in some way related to SPO where it for example can be considered an obstacle, enabler, or guideline.

4.1 Airworthiness

In this section, the regulatory landscape from an initial airworthiness perspective is analyzed and evaluated. Airworthiness is defined by the MAA (Military Aviation Authority) master glossary as "*The ability of an Air System or other Airborne Equipment or system to be operated in flight and on the ground without significant Hazard to Aircrew, ground crew, Passengers or to third parties; it is a technical attribute of materiel throughout its lifecycle*" [4]. To certify an aircraft, it needs to be proven that it is airworthy. How this should be proven and what criteria and rules are required to call it airworthy is specified by regulatory authorities depending on the region all around the world. Depending on the type of aircraft as well as other parameters such as size and field of operation the proven airworthy aircraft receives a type certificate. In this chapter airworthiness regulations will be discussed from a SPO perspective where both EASA and FAA regulations will be investigated.

4.1.1 European Union Safety Aviation Agency (EASA)

EASAs CS-25 is the certification basis for a large commercial aircraft, with that classification comes specific regulatory challenges. From the official EASA certification specifications, many of the regulations are either directly or indirectly affected by the type of operation (SPO or DPO). However, the regulations are not always easy to interpret and are not always directly linked to a single specific condition, meaning that several certifications are applicable for the same area but use different perspectives. Translating this to regulation for SPO, there are however some certifications that do in fact have a stronger correlation toward technical and human factors aspects that are affected by SPO, these can be seen in Table 1.

Equipment Installation	
25.1302	Installed systems and equipment for use by the flight crew
25.1309	Equipment, systems, and installations
25.1321	Arrangement and visibility
25.1303	Flight and navigation Instruments
25.1307	Miscellaneous equipment
25.1329	Flight Guidance System
25.1301	Function and installation
Equipment Operation	
25.1523	Minimum flight crew
25.1525	Kind of operation
Design and Construction	
25.671	General
25.771	Pilot compartment
25.777	Cockpit controls

TABLE 1 - RELEVANT CS-25 SECTIONS FOR SPO

Of these different certifications, **25.1309** and **25.1523** can be considered as the most relevant certifications which should be considered early in the evaluation process, this is because these certifications fall into the scope of most of the other certifications. When analyzing the certification basis, there is no statement that directly prohibits the use of SPO. From **25.1523** – *Minimum flight crew,* the following criteria for fulfilling this specific certification are *"The minimum flight crew must be established (see AMC 25.1523) so that it is sufficient for safe operation, considering – (a) The workload on individual crew members; (b) The accessibility and ease of operation of necessary controls by the appropriate crew member; and (c) The kind of operation authorised under CS 25.1525. The criteria used in making the determinations required by this paragraph are set forth in Appendix D.* When interpreting this regulation, no specific arguments, neither in the specification itself in **Appendix D**, explicitly imply that two pilots are required for operation. Instead, the flight crew needs to be dimensioned to fulfill safe operation on different several different aspects such as workload and more human-centric approaches described in **Appendix D**.

In the certification specifications (CS) for large airplanes, nothing directly addresses the specific number of persons in the flight crew, however, it's widely understood in the industry that a large airplane is operated by at least two individuals. The regulatory document often refers to the captain and first officer as distinct roles with separate responsibilities that operate in different zones. There is no indication found within the document that rules out a combination of these roles into one individual with increased responsibilities, provided that the requirements outlined in section 25.1523 are met. Depending on what system support is available for the single pilot flying, there is a high possibility for **25.1523** to be fulfilled during SPO if a safe operation can be demonstrated for the authorities. In fact, requirement **25.771** – *Pilot compartment* says, *"If provision is made for a second pilot, the aeroplane must be controllable with equal safety from either pilot seat."* which can be interpreted as DPO is not required.

Specification **25.1302 -** *Installed systems and equipment for use by the flight crew*, covers how different equipment, and their related systems can fulfill the **25.1523** requirements in a safe way with respect to human factors. However, it's mentioned in the document with the related AMC (Acceptable Means of Compliance) that showing compliance with human factors is difficult and that a structured approach is needed. The **25.1302** specification does however not directly disallow SPO but does state criteria that require specific consideration which may prove challenging to fulfill from an SPO perspective, but it's highly up to interpretation.

In the AMC, several of the related equipment certifications are also listed, some of which are included in the list above which indicate that **25.1302** is a more general and higher-level certification compared to the others. These related listed requirements and the AMC itself are thus highly relevant to take into consideration when developing a specific operation configuration. A particularly interesting part of the AMC is the statement that if applicants involve the authorities early in the design phase, they can gain a significant advantage, something which should be crucial for successful SPO implementation.

As of today, no current **CS-25** aircraft which is approved for SPO during normal operation has been found with a type certificate from EASA. There is however another EASA classification for normal aeroplanes, **CS-23** which is for aircraft smaller than the large aeroplanes captured by the CS-25 certification. Today there are several **CS-23** planes with a type certificate that enables operation with a minimum flight crew of one, thus operation with a single pilot is fully possible from these types of aeroplanes. The question that arises from this conclusion is, what actual differences are there between these aircraft?

CS-23 and **CS-25** have several things in common but also many things that make them differ. From a manufacturer's perspective, one notable difference is that **CS-25** requires a more comprehensive and time-consuming certification process as there is a bigger need for more documentation and testing. The main reason for this is that **CS-25** aircraft are considered more complex as the planes have more systems onboard. This statement alone, however, is debatable as size alone is a simplified approach to determining an aircraft complexity.

Aircraft has grown in complexity as more and more automated systems are implemented, this automation can make aircraft more confusing to understand, especially when the system fails, but the increased complexity does have significant advantages. As one of the main issues with SPO is workload related problems, automation can play a crucial part in relieving pilots of work and handling different scenarios without any human intervention, and with that, human error related accidents become less likely. In other words, the more technology advances, the less need there is for DPO.

Technology leaps are however not isolated to **CS-25** aeroplanes, in fact even normal airplanes today are equipped with sophisticated safety related technology to make them easier to operate. While the level of technology typically differs between normal and large airplanes, it is hard to justify the need for DPO on large airplanes from a technology perspective only, especially when regulation is designed with a certain level of technology in mind. However, the question of SPO and DPO is not as black and white as looking at technology capabilities only, there are more ethical concerns linked to the problem.

With the **CS-23** type certificate, a maximum of 19 passengers is allowed, this limit does not exist for the **CS-25** which is likely one of the stronger reasons why DPO is still used in all **CS-25** airplanes. This is due to the fact an accident related to the lack of pilot redundancy is considered worse as more lives potentially can come to harm. This could be seen as society's acceptable level of risk and consequences, where we more or less accept the SPO related issues in normal aircraft but not for large aircraft, setting aside the technical aspects. However, to be consistent, these acceptable limits (which translate to passenger limits) should reasonably move as technology progresses, which increases the level of safety. However, the difficulties then become assessing and proving the increased level of safety as well as socially accepting these changes.

4.1.2 Federal Aviation Administration (FAA)

The airworthiness criteria provided by the FAA can in most scenarios be considered equivalent to the EASA criteria, this is managed by a bilateral agreement between the two parties. Certification reviews and agreements can supplement cross-regional scenarios. However, there are some significant differences that are important to consider during the development and implementation of SPO. As previously stated, the corresponding airworthiness certification type to **CS-25** is **Part-25**. When comparing the **CS-25** chapters discussed in the previous section to the corresponding **Part-25** sections there are many similarities. As for SPO implementation, there is no section in **Part-25** either which precludes it. Nonetheless, it is clearly specified in **Part-25, 25.1523** similar to the **CS-25**, **25.1523** that the minimum flight crew must be sufficient for safe operation and handling the workload of the tasks needed.

CS-25 and **Part-25** are type certificates which makes it convenient to have them similar since it allows for manufacturers to minimal effort to certify an aircraft for multiple regulatory regions. The two regulations have many similarities and some differences, however, when it comes to SPO the two have almost identical approaches and criteria.

4.2 Operation

As type certificates for aircraft are only a part of the regulation applied for aviation, there are many more regulatory aspects to take into consideration. Aircraft operation is one element that must be taken into consideration when considering the implementation of SPO.

4.2.1 European Union Safety Aviation Agency (EASA)

Looking beyond the soft laws produced by EASA and observing the actual European laws, no directives have been found that directly prohibit an aircraft from being designed and used for a single pilot during normal operations. In fact, if one observes the **Commission Regulation (EU) No 965/2012**, which regulates the operation of an aircraft.

As stated in the theoretical framework, aircraft operations are regulated by the same authorities as the type certificates, EASA. EASA has multiple frameworks for air operations whereas **Part-CAT -** *Commercial Air Transport Operations* provides a general framework for all kinds of aircraft. For commercial aircrafts, **Part-ORO -** *Organization Requirements for Air Operations* is also relevant. **Part-CAT** and **Part-ORO** both belong to the regulation group for Air Operation which is directly related to the European law earlier mentioned. EASA provides more frameworks for aircraft and operations development, however for this project of investigating SPO possibilities for a large commercial aircraft, **Part-CAT** and **Part-ORO** are the most important sections to further investigate. Similarly, to EASA, the FAA also provides regulations for aircraft operations which will be covered in the following section.

In general, there is no section in either **Part-CAT** or **Part-ORO** that directly precludes SPO. However, there are a few sections related to the subject which could be considered either guidelines or obstacles to implementing SPO. This section presents an analysis of these related sections from an SPO perspective.

Part-CAT contains rules and requirements which need to be complied with for commercial air transport operators to ensure operation safety. **Part-CAT** applies to both aeroplanes and helicopters for commercial air transport which means transportation of either cargo or passengers with commercial intentions. The part is not restricted to any specific type of aircraft such as **CS-23** or **CS-25** and therefore contains a broad and general set of rules and requirements to cover different types and sizes of aircraft. It contains operational requirements of among others, procedures, qualification and training, maintenance, and safety systems. As stated, there is no section in **Part-CAT** that directly precludes the implementation of SPO.

However, there is one specific section important to keep in mind: **CAT.IDE.A.135 -** *Additional equipment for single-pilot operation under IFR* states *"Aeroplanes operated under IFR with a single-pilot shall be equipped with an autopilot with at least altitude hold and heading mode."*. This requirement specifies that to allow the plane to be flown by one pilot there is a need for an autopilot with altitude hold and heading mode. These modes are common on modern larger airplanes and are essential for SPO to reduce the workload of the single pilot as well as allow him/her to perform other duties during the cruise. In general, **CAT.IDE.A.135** provides a minimum level for the automation needed. It could be discussed whether the specified autopilot requirement provides enough automation for a large commercial aircraft to be safely flown by one single pilot only.

Part-ORO, just like **Part-CAT**, originates from **Commission Regulation (EU) No 965/2012**. **Part-ORO** provides a framework with organizational rules and requirements for air transport operations. It applies to organizations such as airlines, airports, and maintenance parties to ensure airworthiness and safe operations of commercial aircraft. Worth mentioning is that it does not apply to a specific aircraft type but rather the organizational operations. Similarly, to **Part-CAT** there is no section in **Part-ORO** precluding SPO entirely but in the flight crew section **ORO.FC.200 -** *Composition of flight crew* states the following:

"(a) There shall not be more than one inexperienced flight crew member in any flight crew.

(b) The commander may delegate the conduct of the flight to another pilot suitably qualified in accordance with Annex I (Part-FCL) to Regulation (EU) No 1178/2011 provided that the requirements of ORO.FC.105(b)(1), (b)(2) and (c) are complied with.

(c) Specific requirements for aeroplane operations under instrument flight rules (IFR) or at night.

- *(1) The minimum flight crew shall be two pilots for all turbo-propeller aeroplanes with a maximum operational passenger seating configuration (MOPSC) of more than nine and all turbojet aeroplanes.*
- *(2) Aeroplanes other than those covered by (c)(1) shall be operated with a minimum crew of two pilots, unless the requirements of ORO.FC.202 are complied with, in which case they may be operated by a single pilot."*

The (a) section mentions having no more than one inexperienced flight crew member, which in the case of SPO would generally mean a single pilot. For SPO to be implemented an experienced pilot would be required which leaves no room for inexperienced flight crew members. SPO is likely to require new sets of criteria and rules where having a restriction to experienced flight crew might be necessary. There are drawbacks to this kind of restriction where, for example, the inexperienced flight crew have a harder time accumulating experience. However, the majority of flights are still likely to be DPO in the coming decade where flight crew can gain experience before taking on SPO flights on their own.

Depending on what the means of propulsion are, (c)(1) may not apply due to the turbo-propeller or turbojet criteria. The maximum operational passenger seating configuration will also exceed what is specified in (c)(1) on a large commercial aircraft. (c)(2) states that aeroplanes not covered by (c)(1) which applies to the CS-25 category may be operated by a single pilot if it complies with the requirements of **ORO.FC.202**. **ORO.FC.202 -** *Single-pilot operations under IFR or at night* states the following:

"In order to be able to fly under IFR or at night with a minimum flight crew of one pilot, the following shall be complied with:

(a) The operator shall include in the operations manual a pilot's conversion and recurrent training programme that includes the additional requirements for a single-pilot operation. The pilot shall have undertaken training on the operator's procedures, in particular regarding:

(1) engine management and emergency handling;

(2) use of normal, abnormal and emergency checklist;

(3) air traffic control (ATC) communication;

(4) departure and approach procedures;

(5) autopilot management, if applicable;

(6) use of simplified in-flight documentation;

(7) single-pilot crew resource management.

(b) The recurrent checks required by ORO.FC.230 shall be performed in the single-pilot role on the relevant type or class of aircraft in an environment representative of the operations.

(c) For aeroplane operations under IFR the pilot shall have:

(1) a minimum of 50 hours flight time under IFR on the relevant type or class of aeroplane, of which 10 hours are as commander; and

(2) completed during the preceding 90 days on the relevant type or class of aeroplane:

(i) five IFR flights, including three instrument approaches, in a single-pilot role; or

(ii) an IFR instrument approach check.

(d) For aeroplane operations at night the pilot shall have:

(1) a minimum of 15 hours flight time at night which may be included in the 50 hours flight time under IFR in (c)(1); and

(2) completed during the preceding 90 days on the relevant type or class of aeroplane:

(i) *three take-offs and landings at night in the single pilot role; or*

(ii) *a night take-off and landing check."*

This can be seen as **ORO.FC.202** specifies requirements that need to be complied with for SPO to be implemented. Section (a) provides requirements for what additions are needed in the operations manual as well as pilot training. It is required that the pilot has undertaken SPO procedure training specifically regarding section (a) (1-7).

The (b) section specifies that recurrent checks according to **ORO.FC.230** shall be performed in the single-pilot role, which will be further discussed later in this section.

(c) specifies pilot requirements for operations under IFR regarding minimum IFR flight hours overall in the aircraft type as well as performed takeoffs and landings in the past 90 days in IFR conditions. This requirement could be discussed as to whether it is relevant or not for this thesis and design for SPO in general, however, since the configuration of the crew and automation solutions is still uncertain this should be kept in mind. (d) is similar to (c) however the difference is that the minimum flight hours, takeoffs, and landings should be performed at night.

Overall **ORO.FC.202** provides requirements for SPO under IFR as well as at night in terms of training, operation procedures, and familiarization with the aircraft type. When it comes to implementing SPO, the section does not preclude it but rather provides requirements for it.

Section (b) refers to **ORO.FC.230 -** *Recurrent training and checking* which states the following.

(a) *"Each flight crew member shall complete recurrent training and checking relevant to the type or variant of aircraft on which they operate.*

(b) *Operator proficiency check*

(c) *Line check*

(d) *Emergency and safety equipment training and checking*

(e) *CRM training"*

ORO.FC.230 requires that each flight crew member which in SPO will be the single pilot flying undergoes recurrent training and checking to ensure fitness for duty on the aircraft type. The training and checking required includes (b), operators' proficiency checking which ensures that the pilot has or still has the proficiency required for operating the aircraft safely and efficiently. This is important in the case of SPO since there is no co-pilot available to correct or help perform valid actions which can be seen as reduced redundancy. Line checking is also required to ensure that the pilot can fly the aircraft type for commercial line flight according to the operations manual, which also is important due to the reduced number of flight crew members.

Pilots are also required to go through training in the location and procedures of how the emergency and safety equipment should be used. This is regularly checked, which ensures that the flight crew is always well-prepared for potential emergency situations. The last requirement is CRM training which is significant for SPO since the crew resources are reduced from two pilots to one. Training and checking are to be performed recurrently according to specified time periods ensuring the flight crew is fit for duty at all times. In general, **ORO.FC.230** is essential for all flight operations but could be argued to be specifically more significant for SPO and should always be kept in mind when operating the aircraft. The section does not preclude the implementation of SPO but states clear requirements of what needs to be complied with.

From this regulatory investigation, no evidence has been found in either **Part-CAT** or **Part-ORO** which implies that EASA directly prohibits SPO**.**

4.2.2 Federal Aviation Administration (FAA)

Similarly, to the European Union and EASA, the American region also has operational regulations. These regulations are provided by FAA in 14 CFR, Chapter 1, Subchapter G – Air Carriers and Operators for Compensation or Hire: Certification and Operations. When analyzing Subchapter G there are a couple of parts specifically relevant to large commercial aircraft and the implementation of SPO. The two most interesting sections further investigated are **Part-121 –** *Operating Requirements: Domestic, Flag, and Supplemental Operations* and **Part-135 –** *Operating Requirements: Commuter and on Demand Operations and Rules Governing Persons onboard Such Aircraft*. These parts are Operating Requirements meaning that they need to be complied with to operate the aircraft under the specified circumstances and procedures.

Part-121 is a regulation that applies to large commercial aircraft during air carrier operations primarily focused on scheduled transportation of cargo or passengers. When it comes to the commercial airlines of today most flight in the American region is operated under **Part-121**. When it comes to SPO from the perspective of FAA it seems to be much less promising than from the analysis done on EASA. In fact, **Part-121** has a regulation that of today does not allow SPO. FAA **121.385** Composition of flight crew states *"(c) The minimum pilot crew is two pilots, and the certificate holder shall designate one pilot as pilot in command and the other second in command."* This means that it is required to have a "pilot crew" of two pilots which clearly can be seen as an obstacle to most SPO solutions. However, it does not specify that both pilots need to be present on the flight deck at all times.

121.543 Flight crewmembers at controls, section (a), states that each crewmember must be seated and fastened using a seatbelt at his/her assigned duty station during the whole flight. However, section (b) provides some exceptions where flight crewmembers are allowed to unstrap and leave their station. It is stated that.

(b) *"A required flight crewmember may leave the assigned duty station—*

- *(1)* *If the crewmember's absence is necessary for the performance of duties in connection with the operation of the aircraft;*
- *(2)* *If the crewmember's absence is in connection with physiological needs; or*
- *(3)* *If the crewmember is taking a rest period, and relief is provided"*

The first point states that a crewmember is allowed to leave their station if it is necessary for the "*performance of duties in connection with the operation of the aircraft*". It is, however, not further. explained or defined what this means and what kind of duties it applies to. It can be argued. that the general understanding of duties in connection with the operation of the aircraft is the kind of task that allows for the safe and efficient operation of the aircraft. However, what tasks could be executed by a flight crewmember outside the flight compartment is likely required to be discussed and motivated by FAA. To conclude section **121.543**, it is required to have two pilots onboard the aircraft during operations however both pilots might not always be required to be present within the flight compartment during the whole flight. **Part-121** does not directly preclude SPO, however, it is providing some potential obstacles and challenges with the development and implementation.

Within subchapter G there is another section called **Part-135** *Operating Requirements: Commuter and on Demand Operations and Rules Governing Persons onboard Such Aircraft* which is also reasonable to investigate in the case of SPO. It has a lot of similarities to **Part-121,** however instead of regulating scheduled aircraft transport operations **Part-135** covers air taxi fashioned on demand operations. There are some differences in safety requirements between the two parts where the general understanding is that the **Part-121** criteria are tougher to comply with than the ones of **Part-135**.

When it comes to SPO, section **135.89 -** *Pilot requirements: Use of oxygen* is relevant to keep in mind. The section does in no way preclude or turn down SPO however it touches upon some interesting and important aspects of the pilot's oxygen mask. The section states that if one pilot leaves their duty station when at altitudes above 25,000 ft MSL, the remaining pilot shall wear an oxygen mask until he/she returns. The main idea of these requirements is that there should always be a pilot on the flight deck who in emergency situations won't need to don an oxygen mask alone. It mitigates the risk of an oxygen mask being tricky to put on or even being faulty and causing the single pilot to not be able to breathe. If during a SPO flight, there is only one pilot present it could be argued that he/she should wear an oxygen mask during the whole flight. According to the section, if a pilot is flying above 35,000 ft MSL and does not possess an approved quick-donning type mask, they must continuously wear a secured and sealed mask. This implies that the pilot must either wear an oxygen mask throughout the flight or keep an easily accessible quick-donning mask nearby.

Related to SPO and minimum flight crew is also **135.169 -** *Additional airworthiness requirements.* It covers the airworthiness of aircraft according to *(a)* which states that in order to operate a commuter category airplane that fits the category of a large airplane three specific **Part-121** sections need to be complied with. These sections are not SPO related and are therefore not further investigated in this project. The *(b)* section on the other hand refers to small airplanes with more than 10 passengers and requires compliance with **Part-135 Appendix A 16** *Minimum flight crew.* The appendix section provides guidelines for what is required from the minimum amount of flight crew. The section refers to FAR **23.1523** which is a corresponding section to **25.1523** found in **CS-25** and **Part-25** however this one is from another lighter-regulated aircraft type. **Appendix A** 16 Minimum flight crew section states

16. *"**Minimum flight crew**. In addition to meeting FAR 23.1523, the applicant must establish the minimum number and type of qualified flight crew personnel sufficient for safe operation of the airplane considering —*

   (a) Each kind of operation for which the applicant desires approval.

   (b) The workload on each crewmember considering the following:

      (1) Flight path control.

      (2) Collision avoidance.

      (3) Navigation.

      (4) Communications.

      (5) Operation and monitoring of all essential aircraft systems.

      (6) Command decisions; and

   (c) The accessibility and ease of operation of necessary controls by the appropriate crewmember during all normal and emergency operations when at the crewmember flight station."

To conclude, section **Part-135** does in no way preclude SPO but can rather be seen as guidelines for what needs to be fulfilled by the flight crew in the sense of duties but also workload, and CRM. These guidelines are useful for the development and evaluation of solutions and concepts for SPO.

4.3 Regulatory Landscape Conclusion

As a conclusion to the regulatory landscaping neither EASA nor FAA strictly say no to the implementation of SPO in any of the investigated chapters and parts. Some criteria can be seen as challenging obstacles, but also as guidelines and requirements needed to comply with in order to make SPO a reality, as can be seen in Table 2. Findings from this landscape analysis should be kept in mind during the process of developing and implementing SPO for large transport aircraft in order to mitigate bargaining discussions with the authorities as well as to provide the maximum possible safety within the operation.

Airworthiness EASA	
25.1302	Installed systems and equipment for use by the flight crew
25.1309	Equipment, systems, and installations
25.1321	Arrangement and visibility
25.1303	Flight and navigation Instruments
25.1307	Miscellaneous equipment
25.1329	Flight Guidance System
25.1301	Function and installation
25.1523	Minimum flight crew
25.1525	Kind of operation

25.671	General
25.771	Pilot compartment
25.777	Cockpit controls
Airworthiness FAA	
25.1523	Minimum flight crew
Operations EASA	
CAT.IDE.A.135	Additional equipment for single-pilot operation under IFR
ORO.FC.200	Composition of flight crew
ORO.FC.202	Single-pilot operations under IFR or at night
ORO.FC.230	Recurrent training and checking
Operations FAA	
121.385	Composition of flight crew
121.543	Flight crewmembers at controls
135.89	Pilot requirements: Use of oxygen
135.169	Additional airworthiness requirements

TABLE 2 - COMPILED LIST OF EASA AND FAA REGULATIONS RELATED TO SPO

5 General SPO Configuration

The SPOs configuration is used to provide a general solution to SPO from a holistic perspective. Since the subject of SPO is broad, selecting a suitable configuration is necessary to determine the main constraints with a general solution that can be used for further development. It is possible that there is more than one suitable configuration or that different configurations perform well in different scenarios. It is therefore important to evaluate and select one that suits the specific aircraft and its type of operations.

To develop a suitable configuration, a preliminary analysis was done to discover the general needs for a single pilot configuration which gave insight into the main things to consider when implementing SPO. As stated in the 2 Theoretical Framework there are some existing ideas and concepts available on the subject where the use of some new technologies and functions is introduced.

When developing a new configuration, various product development methods and procedures can be used to assess what needs to be solved, what ways are there to solve it, and which way is optimal depending on the specific scenario. The final configuration is then analyzed from the CS-25 certification perspective as well as verified to the project's general needs.

5.1 General Needs

Based on the project constraints, literature and document studies, internal company discussions, and project iterations, a list of general needs has been developed through interpretation. These general needs cover the fundamental aspects of the project and will serve as a guide for all the proposed solutions and recommendations. They are intentionally broad due to the uncertainty associated with SPO in commercial aviation, and they can be viewed as strategies to follow during the development process. To avoid restricting the solution space, the decision was made not to specify the needs any further. Therefore, the primary objective of this list is to ensure that all the project outcomes can satisfy these fundamental high-level needs. The list of needs can be seen in Table 3 below.

ID	Title	Description
N1	Prevent single point of failure to affect equipment	Equipment Failure is generally worse in SPO as there is less pilot redundancy and crew resources. Therefore equipment needs to have redundancy solutions in order to not allow a single point of failure to have catastrophic outcomes.
N2	Enable both SPO and DPO	Solutions should be optimized for SPO but also work for DPO to align with current and future regulation as well as to make for an easier transition and implementation.
N3	Optimize for left side SPO while still delivering full right side SPO capability	Standard SPO is to be Performed from the left seat, however, all critical inputs and outputs for operating the aircraft should be possible to utilize from right hand seat as well without difficulties or increased risk.
N4	Prevent or minimize conflicts with regulations	Complying with regulations is essential. However, conflicts with regulations is time-consuming and costly and should therefore be avoided as much as possible.
N5	Provide a solution which is technically feasible within the near future	Implementation should be feasible within the near future. This means that the technology shouldn't be futuristic but should be rather similar to today. This also relates to keeping costs within reasonable amounts to ensure that SPO is still profitable.
N6	Provide a consistent standardized interface	The pilot to aircraft interface should be consistent in order to reduce the workload, confusion and the overall cognitive activity required.
N7	Prevent pilot incapacitation from having catastrophic outcomes	Pilot incapacitation is likely to occur at some point in time and it is therefore crucial to be prepared by for example automated or remote operation solutions
N8	Provide ergonomic use of critical inputs from both sides	Critical switches, levers and other equipment should be ergonomically positioned for easy and effortless access for the pilot. Critical inputs refer to inputs which are mission critical such as manual control, communication etc.
N9	Ensure pilot is fit for duty	In SPO there is no first-officer able to notice suspicious behavior from captain. Neither is there a redundancy similar to in DPO where the first officer is always ready to assist and take control of the aircraft if something unexpected occurs.

TABLE 3 - GENERAL NEEDS AND STRATEGIES

When combining the scope, limitations, and constraints of the project with the literature research, several conclusions can be made that consequently generate these general needs. These needs might have a major impact on the flight deck layout and the configuration solutions. For example, the fact that the solution should be feasible within the near future and enable both SPO and DPO results in a flight compartment that needs to have two seats from where the aircraft can be safely operated from. However, SPO will have a dedicated seat for the operation which is the left-hand side which means that the functionality will differ between the seats, as seen by the need N3.

In N3, Elements that can be considered optimized for flight deck design are most notably safety and related aspects such as easily accessible redundancy equipment for critical inputs (flight control, etc.) from the left-hand side. However, non-critical inputs which can be used to enhance the operation but are not used frequently may be placed in more ergonomic and accessible positions from the left-hand side compared to the right-hand side.

To fulfill N1 while still complying with N3, redundancy could be provided by either having three independent pieces of equipment where two is accessible and optimized for the left-hand seat and one which is accessible and optimized from the right-hand seat. Alternatively, there can be two independent pieces of equipment where both are accessible from the left-hand side and at least one is accessible from the right-hand side since this mitigates that a single point of failure for example either failure of the equipment or human error to cause catastrophic outcomes.

In these listed needs, there are several which can directly or indirectly be considered as tradeoffs, hence, focusing on excelling in one area may limit the potential for success in another. It will be hard to perfectly balance these tradeoffs while being consequent, and the balance point is highly subjective and depends on the desired goals and related ethics. However, it’s essential to consider both sides in tradeoff situations to make SPO solutions turn out as intended.

5.2 Idea and Concept Generation on Different Configurations

The idea generation on the system configuration for SPO was done by a brainstorming session based on earlier literature studies while still applying new creative thoughts. The main purpose of the brainstorming session is to open a space for different solutions that address the gaps and challenges of SPO while taking into consideration the different “Ns” (General Needs) in Table 3. During the brainstorming session, it was concluded that using different configurations would be an effective system to find different ways for how a general SPO solution could work. The configuration is in its most basic form a framework for how different types of tasks are shared between different people and/or systems. In addition to this, the framework also shows who has the primary, secondary, and possibly third responsibility over these tasks and what capability the specific person/system has in performing the related tasks.

5.2.1 Task Groups

It was decided that the different task groups were to be arranged on a high level to ensure that most of the tasks within the flight crew's responsibilities are included, the categories used can be seen in Table 4. Because of the wide scope of each of the categories and the uncertainty of the future SOPs, there are likely cases where certain tasks would fit in one or more of the categories. Because of the possibility for task overlaps, the model is prone to further improvement once more detailed SOPs have been determined with related CRM work and workload analysis.

The different task groups used are Aviate, Navigate, Communicate, and System Management, a categorization system that is commonly used within the aviation industry [43]. A representation of these task groups and their overlap is illustrated in Figure 5. However, to be able to assign different types of tasks more specifically to different people/systems, these categories were expanded to sub-categories as either simple or advanced. Simple task groups refer to those which have a higher standardization and predictability whereas advanced task groups are the opposite. Advanced task groups also involve tasks that have a higher likelihood to create hazardous events if executed incorrectly during critical scenarios. Typical scenarios for the advanced task groups could be but are not limited to very high workload situations, pilot incapacitation, or severe technical failure.

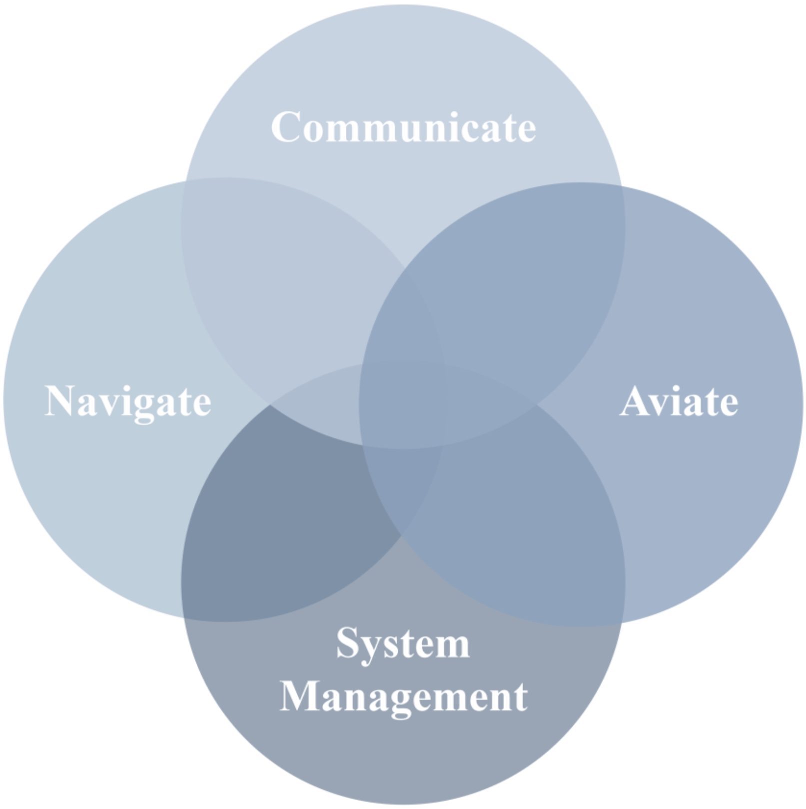


FIGURE 5 - TASK GROUPS REPRESENTATION

5.2.1.1 Aviate

The task group Aviate includes tasks that are directly related to controlling the trajectory of the aircraft such as roll, pitch, and yaw inputs. Tasks that are closely associated with direct aircraft control, such as auto-pilot settings, are also included in the task group. While many aviate tasks can be considered advanced due to the amount of information that needs to be processed, the specific scenario and preconditions will decide if the task is to be considered a simple or advanced task. Bad weather, complicated terrain, traffic, and technical failure are examples of situations that can potentially require more information processing and more advanced techniques to be able to aviate and thus be classified as advanced in this case. For the simple aviation task group, scenarios such as normal cruise, approach, and decent are some examples that would fit into the category. Other scenarios with predictable patterns such as normal landing and takeoff could also potentially fit into this group depending on what technology is available and used. This means that situations that fit in the simple category are in some cases more advanced than what automation handles today, however, this project is conducted with a near future timeline in mind which leaves room for novel automation solutions to be implemented.

5.2.1.2 Navigate

The Navigate task group contains tasks that increase situational awareness in the aircraft. Such tasks are to make decisions on where to fly the aircraft and what to avoid. This is done by processing information from the environment such as visuals, instruments, and communication. Navigate is in many ways a precondition to enable safe and correct aviate, so there is an overlap in terms of specific tasks between this group and aviate. Complicated navigation tasks are those that require extensive sensor data and/or information processing that depends on many different factors or that have uncertainty. Simple navigating tasks are the opposite such as applying waypoints in the system, entering holding patterns, and other relatively straight forward duties.

5.2.1.3 Communicate

Communication includes tasks that cover both data-link communication and ordinary voice communication. When messages are transmitted or received as expected in a regular and standardized format, these can be considered simple communication. Advanced communication is primarily unique messages that require more knowledge about the current situations and input which are more difficult to interpret and potentially can require a complicated response. Ultimately, communication either is purely for informational purposes or to request/recommend certain actions to be taken. If it’s the latter case and the automation would have responsibility for the task group, the rest of the configuration system will either enable automation to act itself or request input from another actor.

5.2.1.4 System Management

System management refers to both the ability to read sensor data, perform calculation and monitor processes but also the ability to send certain commands to the aircraft, which doesn't directly affect the control over the aircraft. System management thus also includes the possibility to verbally communicate within the cockpit, monitor and verify the aircraft system, change certain avionics settings, and similar activities. The advanced task group for system management covers executing commands and interpreting complicated aircraft data whereas the simple category is for more traditional monitoring and callout such as airspeed, V1, etc. Many systems management tasks do change the precondition of the flight and can thus indirectly alter the navigation and aviation trajectory of the aircraft. This means that there is overlap between the different task groups and specific tasks must be assigned to a group with consideration. Consequently, it's important that if automation is handling system management tasks, there should be layers of security. In addition to this, it's also important to provide clear information to the other actors about what the automation is doing and why to enable humans to detect wrong decision errors and regain control.

Task Groups	Example Scenarios
Aviate - Simple	Passive Flying - Normal Cruise etc
Aviate - Advanced	Active Flying - Take-Off, Landing, Pilot Incapacitation, Technical
Navigate - Simple	Avoid terrain
Navigate - Advanced	Avoid bad weather
Communicate - Simple	Standardized Messages
Communicate - Advanced	Unique Messages, Receive Vocal
System Management (Verify / Monitor / Calls / Commands) - Simple	Basic digital data, Airspeed, Altitude
System Management (Verify / Monitor / Calls / Commands) - Advanced	Visual, Weather, Fire, Vocal

TABLE 4 - ACTIVITIES CLASSIFICATION SYSTEM

5.2.2 Actors

It was determined that there would be 3 different types of actors that could take responsibility over task groups, either an onboard pilot (referred to as "Pilot"), an onboard automation system (referred to as "Auto"), or an external operator of some kind (referred to as "External"). To decide in the order the responsibility over the different task groups, letters were used from A to C and to decide the corresponding capability to perform the tasks the numbers 1 to 3 were used as seen in Figure 6. It's important to understand that these numbers are primitive and lack accuracy from a more detailed perspective. Because each of the task categories is a group of more specific tasks, when for example one of these groups is classified with the number 2, it means that most of the tasks within that group can be performed but not all. Where for example the number 3 would indicate that only a few of the related tasks would be able to be performed. A dash (-) indicates that there is little or no capability at all to perform tasks within the task group.

5.2.3 Responsibility Priority and Task Capability

The reason for using primary, secondary, and third responsibility for different task groups is to show how responsibility would be transferred when an increased workload or limit of capability would affect the safety of the operation. The responsibility scheme is designed for normal procedures and doesn't take the technical possibility into consideration even if there is such support. For example, if the tasks within *Aviate – Advanced* can be performed externally, there is also likely that tasks within *Aviate – Simple* can be performed. This would mean that some specific tasks would overlap between groups, but the idea with the framework is not to show what's possible, but rather how it should be done with the specific configuration in mind.

A = Primary, B = Secondary, C = Third
1 = Full Capability, 2 = Limited Capability, 3 = Low Capability, - = No Capability

FIGURE 6 - RESPONSIBILITY AND CAPABILITY CLASSIFICATION SYSTEM

5.2.4 Configuration Generation

From this framework, it became possible to generate different types of configurations with their own strengths and weaknesses. In total, four different configurations were generated with the aim to differ as much as possible in their operation while still applying a logical synergies mindset to ensure the configuration is practically usable. It was found that the pilot will generally have better capability to perform tasks that require more creativity, but automated systems have the possibility to perform repetitive tasks better and thus can reduce the workload. Within SPO, many tasks will still be performed by an automated system even if it is not as capable as the pilot for that specific task. The purpose is then to reduce the workload of the pilot and keep the person focused on more critical decision-making tasks. This phenomenon can be seen in the framework when a task group has a higher priority compared to the capability, such as *A2* or *B3*.

Figure 7 provides an overview of the generated concepts, presenting a bar plot diagram that outlines the distribution of resources available for accomplishing different tasks among the different configurations for each actor, and compares them to the DPO baseline. In other words, this shows the workload capability but cannot be interpreted as safety levels as it depends on several more factors. As can be seen, the different configurations take different approaches to replace the loss of a secondary onboard pilot. The diagram is not exact in terms of comparable values between the configurations and only provides a general model for the distribution, and as can be seen, concept C provides less total capability to perform different tasks compared to the DPO baseline whereas concept D has more capability.

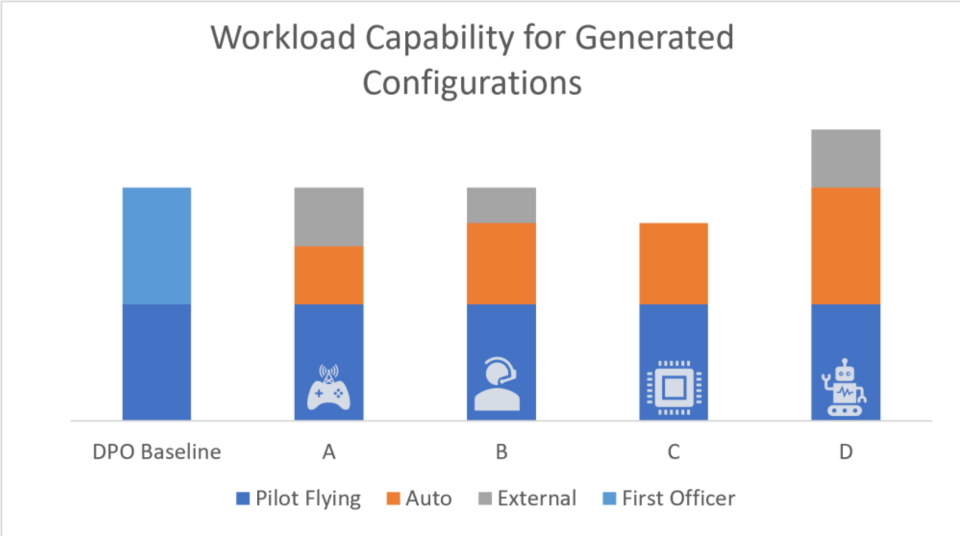


FIGURE 7 - CONCEPT OVERVIEW

It was also found during the brainstorming session that ethics can dramatically change how the different configurations behave in terms of who or what system has the authority to make different decisions. If the framework were to be evaluated with different ethical principles, it would significantly affect the functionality of the different configurations in various situations. To ensure a formal and impartial approach toward the configuration development, ethical considerations are not further elaborated or evaluated during the development process as ethics can be considered as a subjective topic. Instead, an ethical model has been created which can be applied to all configurations. This model is further explained in section Discussion and Conclusion. The different generated concepts are described in more detail in the headings below.

5.2.5 Concept A - Remote Assistance with Control Authority

In this concept, the main idea is to transfer the pilot monitoring role in traditional DPO configuration partly toward an external operator and partly toward onboard automation. The single pilot onboard should focus on tasks related to controlling the aircraft whereas others are taken care of by the automated system onboard if technically possible, otherwise, the external operators manage these tasks. The external operator should always be available to relieve the onboard pilot from tasks to reduce the workload if the situation requires it. There will also be SOPs that require both the external pilot and onboard pilot to perform certain tasks together, not just in non-nominal situations. While the configuration is designed with one external pilot in mind, it's possible to further organize the ground operations to allow for more efficient use of resources where a group of external operators would share a larger number of aircraft to further increase efficiency. Several external operators could also join forces on a single aircraft to increase knowledge and reduce workload among the involved ones to increase safety or handle emergency situations. The framework for this specific configuration can be seen in Table 5.

A = Primary, B = Secondary, C = Third 1 = Full Capability, 2 = Limited Capability, 3 = Low Capability, - = No Capability

SPO Configuration - Concept A

Task Groups	Example Scenarios	Pilot	Auto	External
Aviate - Simple	Passive Flying - Normal Cruise etc	B2	A1	C3
Aviate - Advanced	Active Flying - Take-Off, Landing, Pilot Incapacitation, Technical	A1	C3	B2
Navigate - Simple	Avoid terrain	C1	A3	B2
Navigate - Advanced	Avoid bad weather	A1	C3	B2
Communicate - Simple	Standardized Messages	B1	A2	C2
Communicate - Advanced	Unique Messages, Receive Vocal	A1	-	B2
System Management (Verify / Monitor / Calls / Commands) - Simple	Basic digital data, Airspeed, Altitude	B2	A1	C3
System Management (Verify / Monitor / Calls / Commands) - Advanced	Visual, Weather, Fire, Vocal	A1	C3	B2

TABLE 5 - CHARACTERISTICS OF CONCEPT A

5.2.5.1 Aviate

Practically, this configuration uses both automation within the aircraft and an external operator to assist the pilot. During normal operations such as taxiing, cruise, take-off, landing, and go-around, the pilot actively controls and flies the plane with traditional assistance and autopilot systems. There is a potential downside to the configuration. As the solution relies on different types of new and advanced technologies, there is a risk that the concept could conflict with existing regulations and therefore be less feasible.

5.2.5.2 System Management

Another responsibility for the onboard automation system is to be able to perform certain standard operating procedures together with the onboard pilot in a collaborative manner to reduce workload. The idea is to mitigate work in a similar way to a first officer would during DPO. This can for example involve tasks and activities such as collaborative cross-checks, monitoring and vocally communicating aircraft and operational status. Moreover, the automation would also have the capability and responsibility to partly monitor and manage the aircraft towards a higher degree than being done today so that the system is able to spot and call out inconsistencies and potential or actual problems in general. In this way, the system can allow the pilot to redirect his or her focus when needed. More importantly, the use of automation allows the pilot to maintain a more consistent performance over a longer period.

For the automation to be allowed to perform one or a sequence of tasks, either immediately or when a certain condition is fulfilled, it would have to be allowed by the external operator or the onboard pilot. This ensures that there is consistent human involvement and reduces the risk of overreliance on automation. This could practically be achieved by providing a console to the pilot where information with what tasks the automation wants to conduct and why (Sensor Data, Conditions, Scenario, etc..) followed with an accept or decline option for the pilot. This console could also potentially be integrated with solutions for the cross-check's collaborative tasks.

5.2.5.3 Communication and Navigation

In addition to this, the automation would also be able to monitor and manage the aircraft in such a way that it is able to perform a set of typical ATC transmissions that may be used during normal operation to provide the ATC with necessary information. This requires the system to be able to navigate to a high degree, but the primary responsibility of the navigation remains with the pilot.

5.2.5.4 Scenarios

In the case of an emergency where the pilot onboard would become incapacitated or is for some reason unable to perform the tasks of the role, an external operator would be able to take over control of the aircraft. This would allow the remote operator to perform the necessary tasks to bring the aircraft safely to the ground or finish the mission. The external operator would also be given the responsibility to manage the aircraft systems if required by the scenario as well as handle the necessary communication. In other words, the external operator would be able to take over the aircraft in a similar way as pilot monitoring would be during DPO. However, the main difference is that there would be a limit depending on the technology used regarding what an external pilot would be able to achieve remotely.

An external pilot would most likely have reduced situational awareness compared to traditional pilot monitoring in DPO, due to technology limitations such as limited sensor data and possible data delays. However, there could also be potential upsides with remote pilot during critical scenarios; for example, additional support on the ground can be used to further decrease workload and use additional knowledge which can be applied when there is a need to solve a specific problem.

In too high workload scenarios, the responsibility for advanced communication is transferred to the external operator as well. While simple system management is performed by the automation system, complicated tasks will also be transferred in the case the onboard pilot is incapacitated. During normal operation if the onboard pilot reaches max workload, the external pilot takes over complicated system management rather than the automation system as it will likely involve complicated tasks which it would limit the capability to perform them correctly.

5.2.6 Concept B - Remote Assistance without Control Authority

Similarly, to Concept A, Concept B also uses an external operator to handle certain tasks. The external operator does not have primary responsibility for any task group, but should, just like in Concept A, be available at all times to assist the onboard pilot. There are also likely specific tasks that should be done in a collaborative and/or parallel manner between the onboard pilot and external pilot as a part of the SOPs. The framework for this concept can be seen in Table 6.

A = Primary, B = Secondary, C = Third
1 = Full Capability, 2 = Limited Capability, 3 = Low Capability, - = No Capability

SPO Configuration - Concept B

Task Groups	Example Scenarios	Pilot	Auto	External
Aviate - Simple	Passive Flying - Normal Cruise etc	B2	A1	-
Aviate - Advanced	Active Flying - Take-Off, Landing, Pilot Incapacitation, Technical	A1	B2	-
Navigate - Simple	Avoid terrain	C1	A3	B2
Navigate - Advanced	Avoid bad weather	A1	B3	C2
Communicate - Simple	Standardized Messages	B1	A2	C2
Communicate - Advanced	Unique Messages, Receive Vocal	A1	-	B2
System Management (Verify / Monitor / Calls / Commands) - Simple	Basic digital data, Airspeed, Altitude	B2	A1	C3
System Management (Verify / Monitor / Calls / Commands) - Advanced	Visual, Weather, Fire, Vocal	A1	C3	B2

TABLE 6 - CHARACTERISTICS OF CONCEPT B

5.2.6.1 Aviate

The main difference between this concept and the previous one is that the external pilot doesn’t have the possibility to perform the duties within the aviate task group, which includes the possibility to directly control the aircraft trajectory. Instead, the same task resources are achieved by using more sophisticated automation equipment which does have higher capability compared to Concept A. This means that it can handle emergency situations such as pilot incapacitation, however, the automation system is not intended to fully replace a human being, only when absolutely required. By using more advanced onboard automation systems instead of a remote operator with control authority there is less need for technology that requires stable, secure, and high-speed data-link communication. The ability to control and affect the aircraft remotely comes with large vulnerabilities when it comes to cyber security which is one area where this concept outperforms concept A. There is also less need for complicated systems which can provide situational awareness to a human being remotely. However, instead, there is a need for other types of technical equipment which can be used to safely land the aircraft or complete the mission without any onboard pilot.

5.2.6.2 System Management

While the external pilot lacks the possibility to directly control the aircraft, under normal operation he or she still serves the purpose of assisting the pilot flying with system management. Usually, this assistance is required during high-workload scenarios when there is a situation where different system management tasks need to be performed that the automation system onboard cannot handle.

5.2.6.3 Communication and Navigation

Tasks regarding communication and navigation are similarly distributed as in Concept A with the exception that advanced navigation tasks performed by automation have a higher responsibility priority compared to Concept A. Navigation is mainly an automation systems job but should be overlooked by a human. Standardized communication is usually performed by the automation system, otherwise transferred to the onboard pilot and as the last option toward the external pilot.

5.2.6.4 Scenarios

While it could be argued that the theoretical concept is somewhat less safe due to the lack of an extra human being who has the possibility to directly control the aircraft, it greatly increases the safety in terms of malicious external remote access from unauthorized parties. In addition to this, the fact that the automation system only needs to be able to handle critical situations such as landing the aircraft to escape danger, the configuration could also potentially be less expensive than Concept A.

5.2.7 Concept C - Automation Assistance without Remote Assistance

This configuration is the simplest and has the highest technological readiness of all four as it incorporates the least number of new functions. The concept does not use any remote assistance to perform tasks and thus relies on the onboard pilot and the use of automation technology. It is important to note that this configuration clashes with FAA section **121.385c** *Composition of flight crew* Which states that *"The minimum pilot crew is two pilots"*. However, regulation specifics are likely to change with time and require some pushing to be revised. This clash should be considered when selecting a configuration but should not hinder innovation. This makes the concept in general feasible from the technological and economic perspective. The fact that few new functions are incorporated would also make the certification process more straightforward compared to other configurations. As the automation technology used in the concept is limited it cannot fully replace a second onboard pilot in terms of capability. This consequently means that there is fewer resources available in the aircraft in total to perform different tasks which can potentially increase workload, both mental and physical, compared to the baseline with DPO as illustrated in Figure 7. The framework for this configuration is shown in Table 7.

A = Primary, B = Secondary, C = Third
1 = Full Capability, 2 = Limited Capability, 3 = Low Capability, - = No Capability

SPO Configuration - Concept C

Task Groups	Example Scenarios	Pilot	Auto	External
Aviate - Simple	Passive Flying - Normal Cruise etc	B2	A1	-
Aviate - Advanced	Active Flying - Take-Off, Landing, Pilot Incapacitation, Technical	A1	B2	-
Navigate - Simple	Avoid terrain	B1	A2	-
Navigate - Advanced	Avoid bad weather	A1	B2	-
Communicate - Simple	Standardized Messages	B1	A2	-
Communicate - Advanced	Unique Messages, Receive Vocal	A1	B3	-
System Management (Verify / Monitor / Calls / Commands) - Simple	Basic digital data, Airspeed, Altitude	B1	A2	-
System Management (Verify / Monitor / Calls / Commands) - Advanced	Visual, Weather, Fire, Vocal	A1	B3	

TABLE 7 - CHARACTERISTICS OF CONCEPT C

5.2.7.1 Aviate

During normal operation, the aircraft uses traditional auto-pilot automation to perform cruise-related tasks. For more complicated maneuvers and tasks such as landing, responsibilities are still with the onboard pilot. While automation has a limited capability to do some tasks related to advanced aviation, these should only be used when necessary as they cannot provide the same kind of performance as a pilot can.

5.2.7.2 System Management

The system management technology is like the one in Concept A and B to reduce the onboard pilot's workload, with the reservation that this concept is aimed at not incorporating a significant number of new functions. For this reason, cross-functions in collaborative manners, automatic callouts, instrument monitoring, and similar tasks are well suited for this concept. A similar solution with a console as suggested in Concept A could be one way to achieve these types of tasks in a similar way. A similar approach used in Concept A where the pilot needs to approve a specific task or a task sequence to be performed by the onboard automation system should be incorporated in this concept as well. Because the automation system has a low capability to perform advanced tasks, these are reserved for the onboard pilot and not transferred to the automation is absolutely needed.

5.2.7.3 Communication and Navigation

Simple tasks regarding communication and navigation are primarily performed by the automation system and advanced tasks by the onboard pilot. In this concept, however, the automation system has a low capability to manage advanced communication, meaning that there will be low system support for managing unique and non-standardized communication.

5.2.7.4 Scenarios

While the automation system has a limited capacity to handle advanced aircraft control-related tasks, the concept is intended to be capable of emergency landing and similar tasks to escape immediate danger for the occupants. Such systems are today already increasing rapidly in technology readiness level and are expected to be relatively affordable to implement into new aircraft within the near future. By having such capability, in scenarios such as pilot incapacitation or specific technical failures, which can be considered the most severe circumstances, an equivalent safety level as with DPO could possibly be achieved. While this automation may not be as capable as a secondary pilot, if the system is sufficiently robust, it could provide an equivalent level of safety to a DPO. Furthermore, a system incorporating this automation would likely be better equipped to handle situations involving rapid depressurization and resulting flight crew hypoxia.

Another critical scenario with this configuration is procedure violation. If the pilot decides to take control of the aircraft and is locked inside the flight compartment, there is no second pilot as a last line of defense to prevent the actions. In other words, the onboard pilot has full authority over the aircraft in this configuration. Depending on the ethical approach used, there is a possibility for automation systems to partly mitigate this type of problem. Generally, for this configuration, there could also be complications in demonstrating safety from an operational perspective as it reduces redundancy in some aspects and relies on specific automation technology to enable equivalent safety levels as with DPO.

5.2.8 Concept D - Advanced Automation Assistance with Remote Assistance

This configuration is the most advanced of all four alternatives. It has both an external operator with the authority to control the aircraft and a sophisticated automation system that is used throughout most of the operation. Because there is an onboard pilot, a sophisticated automation system, and an external pilot, the concept would have more capability to perform more tasks compared to a traditional DPO configuration. This would further reduce workload and likely in some cases also reduce human errors. An illustration of this can be seen in Figure 7.

As a result, the onboard pilot has a greater responsibility to monitor the aircraft while the automation system can do most of the tasks required with great accuracy. This, however, does not exclude the onboard pilot completely as the idea is that there still will be areas of responsibility where the pilot still has primary responsibility. The automation system will mainly serve as a workload-relieving system and be used when required to ensure and maintain human involvement in the operation. For situations where there is high creativity and information processing required, the aim of the automation system is not to match the human capability in this scenario which is why there is also an external operator. The external pilot will function as another layer of redundancy and can intervene when necessary. Because of the major changes in the onboard pilot’s role and how the aircraft would function with this type of configuration, new kinds of procedures and training would likely be necessary. The framework for this configuration can be seen in Table 8.

A = Primary, B = Secondary, C = Third
1 = Full Capability, 2 = Limited Capability, 3 = Low Capability, - = No Capability

SPO Configuration - Concept D

Task Groups	Example Scenarios	Pilot	Auto	External
Aviate - Simple	Passive Flying - Normal Cruise etc	B2	A1	-
Aviate - Advanced	Active Flying - Take-Off, Landing, Pilot Incapacitation, Technical	A1	B2	C2
Navigate - Simple	Avoid terrain	B1	A2	C2
Navigate - Advanced	Avoid bad weather	A1	B2	C2
Communicate - Simple	Standardized Messages	B1	A2	C2
Communicate - Advanced	Unique Messages, Receive Vocal	A1	B3	C2
System Management (Verify / Monitor / Calls / Commands) - Simple	Basic digital data, Airspeed, Altitude	B2	A1	C3
System Management (Verify / Monitor / Calls / Commands) - Advanced	Visual, Weather, Fire, Vocal	A1	B2	C3

TABLE 8 - CHARACTERISTICS OF CONCEPT D

5.2.8.1 Aviate

The advanced related aviate tasks would as in the other concept mainly be performed by the onboard pilot, however, the automation system is thought to be noticeably better in this configuration to be able to perform certain tasks with higher accuracy. In terms of passive flying phases of operation such as cruise, the automation system would have a similar function as today’s auto-flight systems where the onboard pilot only monitors the system.

5.2.8.2 System Management

Simple system management tasks are performed by both the pilot and the automation system, whereas advanced system management tasks are left to the pilot automation needs to take over. This configuration thus further helps to decrease the pilot's workload. A similar system described in concept A to allow the system to perform certain tasks and understand why could also be used in this configuration to the same to prevent overreliance on automation and increase system awareness. However, the greater complexity of the automation system in this configuration means that its implementation would have a larger impact on the overall design solution.

5.2.8.3 Navigate and Communicate

Like the system management task group, the onboard pilot has primary responsibilities over the advanced tasks in this group and for the simpler task groups, the primary responsibility is with the automation system. The related actors' capabilities to perform the different tasks are also seen in the framework in Table 8.

5.2.8.4 Scenarios

In the case of pilot incapacitation, the aircraft has good capability to handle itself and perform necessary emergency landing with good accuracy. By having an additional external pilot, like this concept has, in the case of an emergency it would allow the external pilot to monitor how the aircraft automation is handling the emergency and take over control if necessary. This arguably makes the aircraft at least as safe as DPO. Increasing automation to the level that this concept purposes would require significantly more consideration in the ethical aspects as the automation system would have more critical decisions to make. Further, the concept also requires a significant amount of cyber-security for the same reason. All these factors can reduce the overall technical and economic feasibility of this concept.

5.3 Analysis and Evaluation of Configurations

To evaluate the four concepts, a PEST analysis was conducted on all four. The analysis specifies how the different concepts perform from a political, economic, sociological, and technological perspective [44]. The four parameters are important to consider when evaluating the implementation of a new technology and procedure since all parameters are relevant and can affect the performance of an SPO configuration.

The tool is an effective way to be able to explore the major differences between the concepts in this project as all the different needs discovered in section 5.1 already is integrated into these four categories. By using the different criteria in the PEST model for analysis and evaluation rather than the needs discovered earlier, it allows for more effective judgment for the different concepts. This is because the general needs are more specific compared to the PEST criteria. If using the general needs as evaluation criteria, it would be necessary to obtain more detailed knowledge to evaluate the concept correctly. This is difficult at this stage which is why the PEST model provides a better overall comparison between the concepts. In Table 9 to Table 12, the PEST analysis of concepts A-D is presented, and the aspects found positive and negative of each concept are marked with a plus sign respectively a minus sign.

Political

Configuration A	Configuration B
+ Provides equivalent safety as DPO. Number of operators is not limited to 2 induvial as more support can be used from the ground. More human involvement makes the concept less political challenging. - Regulation agencies and governments might be skeptical to the technical novelty. - Tackling current regulation with the new functions to be implemented may require a lot of convincing. Especially if the implementation is within the near feature.	- Regulation agencies and governments might be skeptical to the technical novelty and the reduced human involvement. - Technological implementation is feasible today, however great novel certification is required.
Configuration C	**Configuration D**
+ Less development of automation systems is needed compared to other alternatives which means fewer certification obstacles. - Regulation agencies and governments might be skeptical in terms of safety when relying on one pilot alone which means that extensive testing and proof of safety is required. - Pilot health and fitness for duty significantly important requiring more rigorous and frequent health checks.	- Being new to market with a highly complex system makes it hard to convince people on safety, especially for organizations with no or very limited legacy. - Regulation agencies will likely need to use a very detailed certification processes that will take a long time in order to proof the aircraft airworthiness due to the novelty of technology. This will challenge the feasibility of delivering a solution within the near future time span.

TABLE 9 - POLITICAL SECTION OF THE PEST ANALYSIS

Economic

Configuration A	Configuration B
+ Significant operational savings. + Reduces risk of losing market share against competitors if SPO is avoided and competitors have SPO capabilities in future. - Requires advanced new function and technology which will be costly to implement. - High uncertainty technology uncertainty might make it hard motivate fundings for project.	+ Significant operational saving. + Good mix between opportunity and risk. Investments will be for new but less complicated functions.
Configuration C	**Configuration D**
+ Significant operational savings. + Does not involve many new system function which makes it a more economical alternative from a development perspective - Could potentially require higher pilot skills to handle higher workload which require greater salaries.	- Do involve many new system function which makes it a very expensive solutions from a development perspective. - Technology cost might not justify the operational savings. - Investment risk can be hard to motivate when considering regulation and technology uncertainty. + From a long term perspective, pilot training cost can possibly be reduced as less flying skill is required due to increased amount of system functions.

TABLE 10 - ECONOMIC SECTION OF THE PEST ANALYSIS

Social

Configuration A	Configuration B
- Social Acceptance is Difficult as much rely on technology automation and lack of human verification. - Pilots working space and duties will change dramatically. Monitoring operation will be most of the job. - Skepticism of the aircraft able to be controlled by someone not onboard. + Provides human redundancy could make passengers feel safer.	- Social acceptance might be difficult because the lack of pilot redundancy. - Pilot incapacitation is a major concern, more so than in other configuration as there is fewer system function to support this scenario.
Configuration C	**Configuration D**
- Pilot incapacitation is a major concern, more so than in other configuration as there is fewer system function to support this scenario. - Skepticism towards the pilot flying ability to function during high workload and emergency scenarios. Pilot generally will experience a higher workload in certain situations. - Social acceptance might be difficult because the lack of pilot redundancy.	- High technology novelty can lead to that the feeling of sitting in an experimental aircraft might be hard to avoid. - Pilots and pilot associations might feel that their line of work is being threated. + Easier to reach social acceptance with higher safety.

TABLE 11 - SOCIAL SECTION OF THE PEST ANALYSIS

Technological

Configuration A	Configuration B
+ Provides human redundancy in case of pilot incapacitation or violation of operating procedures. - Requires development and implementation of new technology for remote control, might not be feasible within near future. - Sophisticated cyber security systems needed.	- New and yet untested functions required to be certified. - Very high demands on the flight automation, critical in single pilot incapacitation and violation. + Remote communication likely to be feasible with todays technology. + Reduces risk of team error
Configuration C	**Configuration D**
+ High technical feasibility as only a few new functions regarding communication and control is required. - High reliance on existing flight automation, critical in single pilot incapacitation. - High cognitive and physical workloads on pilot due to relatively few new SPO related functions compared to other alternatives. - Few new potential communication technology mishaps due to little new technology. + No risk of team error during the actual flight.	+ Greatly reduces workload. + One of the safest ways to operate and configure for single pilot operation. + Advanced technology provide redundancy when needed. - Higher system complexity consequently result in increased probability of some sort of failure. - Overreliance on automation can be an issue. - Difficult for pilots to troubleshoot highly automated systems. - Feasibility within near future is likely to be challenging due to the need of not yet developed technology.

TABLE 12 - TECHNOLOGICAL SECTION OF THE PEST ANALYSIS

It can easily be seen by observing the figures that there is a large variety between the concepts in cost, feasibility, political and social acceptance. While concept C could potentially be implemented within the coming years concept D is likely to require many more years to be implemented into service due to the amount of change and novel technology. It can also be seen that having social acceptance is important mainly because passengers need to trust the configuration and the captain of the plane, otherwise, there will be no passengers and the configuration will not work in commercial service.

5.4 Screening and Selection of Concepts

The screening process of concepts underwent two cycles. In the first cycle, the four initial concepts were evaluated. From this initial screening, it was found that one concept had particular weaknesses which could be fixed with a revised concept. The concept was revised and replaced with a previous configuration in a second screening round to be able to select the final concept with the highest potential for the given assumptions and constraints of the project. The evaluation and selection of concepts were done using evaluation matrices which used relative scoring to rank the concepts and allow for clear comparison. While the use of relative scoring has its downside, as small and large differences become invisible in the matrix which might produce skewed results, it still had reasons for being used. Mainly, the use of relative scoring ensures that biased opinions regarding scoring with a high level of uncertainty don't affect the result. For example, it's easier to determine if one concept is more costly than another, but it's more difficult to say how much more expensive this uncertainty which would be required without relative scoring. In this section, the elimination and selection process is further explained.

5.4.1 First Screening

The SPOs configuration is the basis of the whole solution so to continue with the project one of the concepts needs to be selected. To strategically select which solution to use an evaluation matrix was used. The matrix provides a clear and simple way of comparing the concepts to each other within different areas. The criteria which were used in the matrix for comparing the concepts are the ones addressed in the PEST analysis. The configuration concepts receive a subjective score by the authors in the evaluation matrix dependent on how well they perform in the areas presented in the PEST. A greater number means that it is more politically or socially accepted, that it is more affordable, or that it has a higher technological readiness. The score for each concept is then summed up providing each alternative a total score where the concept with the highest score is considered most suitable. The evaluation matrix over alternative A-D can be seen in Table 13.

Criteria \ Concept	A	B	C	D
Political	2	1	0	3
Economic	1	2	3	0
Social	3	1	0	2
Technological	1	2	3	0
Total	7	6	6	5

TABLE 13 - RESULT OF FIRST EVALUATION

Table 13 shows that concept A is the most suitable of the four seen from the PEST perspective. Concept A scores relatively high in the political and social areas, which relates to the fact that it is the configuration with the most human involvement in the controls of the aircraft. Human involvement plays a large role in the general acceptance of safety. It is common knowledge that one of the biggest challenges with autonomous vehicles such as example, cars is to make people feel safe being inside or around them since there is no human in command. The same principle applies to aircraft where for concept A, a backup solution is that a ground-based pilot remotely takes over control of the plane and returns it safely to the ground. Due to the novelty of the automation needed for autonomous flight, the concept might not yet be accepted by the general public as providing the feeling of safe transportation even though safety is the main priority and this kind of solution would not be implemented before proven safe.

However, concept A was less successful in the economic and technological areas. The configuration requires novel technology for external operator's communications with the pilot as well as for the ability to control the aircraft in real-time. As of today, there is no certified method of remotely controlling a commercial aircraft with passengers. Due to the risks involved in the remote-control technology, it will likely require years of testing and evaluation to prove that it is feasible as well as safe to use. There are a handful of risks involved in remotely controlling the aircraft, for example, loss of communication between the remote operator and the aircraft or even external parties taking control of the aircraft remotely with malicious intent. To mitigate these risks and ensure safety, sophisticated technological solutions are needed.

Concept B is compared to concept A more beneficial in the economic and technological areas. This is primarily due to not requiring equally as much novel technology and not as advanced technology since no remote control is used. It is also important to consider that the remote operator does not need to be an educated pilot in concept B as it would in A. The operators' tasks will in this case only be assisting the pilot and not flying or controlling the aircraft. In the social and political areas, however, concept B scored lower than A. This can roughly be related to the fact that it is now only one human pilot trusted to control the plane.

Concept C, which is the most basic solution, naturally performed well in both the economic and the technological areas. This is a natural outcome of there being a limited amount of novel technology since this will increase the development time and cost. There are also significant savings in operational costs due to not having an external operation. However, having a cost-efficient and technologically feasible configuration comes with the tradeoff of receiving low scorings in the political and social areas. Concept C comes with a lower human redundancy in controlling the plane, but it also lacks the ability for the pilot to communicate and discuss with an internal or external operator about how decisions and actions should be made. This means that there is only one human being trusted with the whole flight procedure. It is also important to consider that this single pilot will not have any workload relief from an external operator, meaning that the pilot's cognitive and maybe also physical workload will be higher.

Concept D is compared to the other solutions a significant step towards automation. It rewrites the role of the pilot from controlling the aircraft to monitoring the automated systems. Due to the great amount of novel technology required to make this concept reality the economic and technological areas receive low ratings. The development of the technology will be both costly and time-consuming, which might make concept D the safest and most efficient configuration in the long run. However, since this project aims for a solution in the coming years, the technology required might not be developed in time.

5.4.2 Configuration Revision and Second Screening

As seen in the section before, Concept A was found the most suitable solution of the four according to the evaluation. However, since concept C had such a low scoring in the political and social areas it was decided to revise concept C to better cover these areas. The improved configuration was called C2 and is once again compared against A, B, and D with relative scoring, as seen in Table 14.

The idea of concept C2 is to address the political and social drawbacks of concept C and improve it to receive a higher score without mimicking concepts A or B. The main factor giving concept C its low scoring is the fact that the whole flight is dependent on one human's decisions and capabilities only. By increasing human involvement, the scoring of concept C would increase. The other concepts have solved this by having a remote operator supporting the pilot in workload and decision-making, or even controlling the aircraft. For concept C2 increased human involvement is achieved by using an onboard crew member which can provide redundancy and workload relief if needed.

This means at least one person in the cabin crew requires additional training for controlling the aircraft in case of pilot incapacitation. The person also needs to be able to perform certain pilot-related activities to relieve the workload. To also be useful in the cabin, traditional cabin crew training would also be required. From this point and forward in the report, this backup crew member will be referred to as OEP, short for Onboard Emergency Pilot. The idea of the OEP is to take on the role of cabin crew and only assist the pilot or take over the control of the aircraft in non-normal operations and emergency situations. This could potentially mean that the OEP works in the cabin the whole flight, assists the pilot in high workload situations such as takeoff or landing, or even takes control of the plane due to pilot incapacitation. Ordinary flight routines such as cross-checks and system monitoring are, however, not a part of the OEP role description, even if competence exists from training.

This concept creates a new function within the flight crew which naturally will put higher demands on the individual and therefore increase operational cost. Nonetheless, there will be savings in development costs due to the remote control and communication of the other concepts not being required. The concept will also have a higher technology readiness level and from that perspective, a shorter time to market which allows swifter SPO implementation. Since the general needs point toward that the aircraft should have the ability to be flown with a DPO configuration as well as with full SPO support from both seats there will be no required changes to allow the OEP to be seated. Aside from the changes in the description above, the concept will have a similar function to concept C as described earlier. The evaluation result for the new concept A, B, C2, and D can be seen in Table 14.

Criteria \ Concept	A	B	C2	D
Political	1	0	2	3
Economic	2	3	1	0
Social	2	0	3	1
Technological	1	2	3	0
Total	6	5	9	4

TABLE 14 - RESULT OF SECOND EVALUATION

As can be seen here, the revised concept C2 did score the highest with a significant increase in political and social areas, however to the cost of a reduced score in economics. This is primarily due to the increased operational costs of having an OEP on each flight.

Concept C2 is the most feasible within the given constraints and timeline scope and provides the best redundancy and safety in the sense of human pilot control since there always are two persons in the flight crew with the ability and authority to safely land the plane. There is a need for increased automation to relieve the pilot's workload but in situations where something unexpected happens, the OEP is always there to assist. The increased operational cost is significant but is a price that must be paid to implement SPO within the next decade.

5.5 Final Concept Description and Improvement

Concept C2 was ultimately chosen as the final solution based on its performance in the preliminary evaluations, which indicated it to be the most promising alternative. However, it can and should be questioned if the concept can be classified as a true single-pilot configuration since there are technically two crew members with the authority and experience to fly the aircraft onboard. The difference between C2 and a conventional DPO configuration is that the main flight crew is reduced by one person. Consequently, the OEP will in regular situations be in the cabin and not the flight compartment performing pilot tasks which makes it a hybrid solution between DPO and SPO. Some suggest calling the kind of configuration “reduced crew operations” which could be reasonable since the crew is reduced but the number of pilots is the same as dual pilot operations. However, this depends heavily on what the role and terms will be for the OEP.

5.5.1 Flight Crew Role

The flight crew of option C2 will include a certified pilot taking on the captain role, and the OEP. What is required by the OEP depends on multiple factors such as regulations and organizational factors. However, the primary idea of the OEP is based on having a cabin crew member with the ability to fly the plane in critical situations such as if the captain is incapacitated. However, the OEP could also be useful in situations where the captain experiences a high cognitive or physical workload. This would allow the OEP to not only assist the captain in emergency situations but also to provide workload alleviation whenever it is needed.

For this to become a reality regular cabin crew training will naturally not be enough to prepare the OEP for controlling the aircraft and relieve the captain’s workload. For situations where the OEP takes over the flight controls the minimum essential activities would be to alert emergencies, fly the aircraft to an airport nearby as well as conduct a landing. This would in general be considered to require a pilot’s license, however, the activities needed would only be a fraction of what is taught for traditional commercial pilots. For workload alleviation, the OEP would conveniently have some knowledge of SOPs and other basic procedures that can be taken care of to assist the pilot. What kind of procedures and activities this would include is uncertain at this point and requires further investigation, which is considered out of scope for this project.

For the OEP to perform the required activities both pilot and cabin crew training would be required according to the regulations of today. To test the configuration and phase it into operation a certified pilot could take on the role of OEP as a starter. This would likely not be directly economically beneficial compared to DPO however it could prove that implementation of the configuration is feasible and increases social and political acceptance.

For the OEP to be as financially efficient as possible the least amount of training required for the task would be preferred. The OEP could therefore potentially be a future type of crew role with its own specific training and certification since full pilot training would be too comprehensive.

5.5.2 Automation

Comparing the configuration options proposed, the technology readiness level is highest for C2 meaning that it requires the least amount of new automation technology to become reality. The configuration will not require remote control abilities such as option A and neither live communication nor data transfer support for a remote co-pilot such as option B. Finally, it will definitely not require the amount on novel technology as the D configuration, however, C2 will need new technology and automation systems in some fields to allow a single pilot to control the aircraft with reasonable workload and CRM. The most significant factor to why C2 has the highest readiness level is that there is no real need for automation to handle situations like pilot incapacitation since these situations are handled by the OEP. This means that automation development for C2 is limited to pilot workload alleviation.

Other than the conventional automation used within commercial aviation the pilot workload needs to be further relieved due to less crew resources. This can be done in various ways by having automation take care of different tasks usually performed by the pilot. What tasks and activities can and should be handled by automation is at this stage not entirely certain but depends on various factors such as the task's complexity, importance, and severity if made incorrectly. Activities related to SOPs such as checklists could be automated to some degree. An example of this could be having a virtual voice reading the list to the pilot and waiting for him/her to confirm verbally or physically with a button before moving on to the next step(s) in the list.

There are different automation levels of autopilots used today and more advanced and autonomous systems are being developed. One example of a relatively advanced system is the automatic landing system. These autonomously can bring the aircraft to the airport and land it on the runway which would be essential for most SPO configurations but is not strictly required by C2 since the OEP has the possibility to take control of the aircraft and land it. Technologies such as automated landing are not fully established in commercial aviation today and therefore the social acceptance level is questionable. However, when this kind of system is being used more frequently and is becoming more accepted and proved to be safe the configuration used for SPO should be revised.

5.5.3 Flight Compartment

For the OEP to be able to normally work in the cabin but in emergency situations quickly reach the flight deck there are new demands on the crew, operations, and the aircraft itself. Since the OEP will operate both in the cabin and the flight compartment the design of the flight compartment and the way the OEP can enter is critical. For example, the OEP is required to be able to quickly enter the normally locked flight compartment and get seated and strapped into the pilot's seat. This means that the flight compartment door needs to be designed in a way that it can be easily used by the OEP and not used by non-permitted individuals which might be a challenging design task. It also means that the seat and harness must be easy to use and not too complex to be quick and require minimum workload for the OEP to use when in critical situations.

It is also important to consider the accessibility for the OEP to reach the seat easily and quickly after entering the flight compartment. Therefore, it needs to be a free passageway without any obstacles between the seat and the flight compartment door. However, this can be challenging to achieve in cases where, for example, a jump seat is being used. Flights where the jump seat is used, however, are not considered very common, and therefore, dependent on the frequency of these scenarios, the solution could be to always have two pilots when flying with a jump seat.

The subject of flight compartment doors is widely discussed and there are many incidents and accidents where the flight compartment door is involved. The door is designed to keep unauthorized individuals outside of the flight compartment which means that it should not be possible to open from outside/cabin. However, the cabin crew is sometimes needed to enter the flight compartment to assist or communicate with the flight crew, this can however be solved by having the flight crew unlock the door from inside to allow the cabin crewmember to enter.

A common subject within aviation incidents is pilots violating rules and procedures. An example of this is locking the flight compartment door from inside while the second pilot is on, for example, a toilet brake. This is similar to the Germanwings Flight 9525 incident in 2015 where the First Officer locked the flight compartment door leaving the captain unable to enter. The pilot then proceeded with crashing the aircraft killing all 150 occupants [45]. This leaves the violating pilot alone in the flight compartment which is a catastrophic situation in cases where the pilot has malicious intents.

The common way of solving this issue is having a cabin crew member step inside the flight compartment when one of the pilots leaves in order to always have at least two crewmembers inside. However, when it comes to SPO the pilot will in most cases be alone in the flight compartment. This means a couple of things; First is that in case the pilot has malicious intent there is nothing stopping him/her from performing these violations. Second is that in case of pilot incapacitation, the pilot might not be able to unlock the door and let the OEP inside which could also result in catastrophic scenarios. Third is that in critical situations where OEP assistance is required in the flight compartment, the pilot might be under a high workload and therefore unable to unlock the door. These are all situations that need to be considered when developing an SPO and OEP-friendly aircraft design.

When it comes to the other aspects of designing the flight compartment for the C2 configuration the needs and requirements need to be further investigated in a human factor’s manner. This, however, is a deeper level of development that is not covered within this report.

5.6 Regulatory Verification of Developed Configuration

To ensure that the finalized configuration can be used for further development, the concept needs to be verified from a regulatory perspective. As the concept at this stage is purely theoretical and has been designed based on general needs, it becomes practically unnecessary to verify that these needs are complied with. However, external requirements such as regulation which has not been the main source for the development of configurations now need verification to ensure that the configuration can be realized or determine what potential obstacles and challenges needs to be handled.

Similarly, to the regulatory landscaping, this section will be decomposed into two subsections, Airworthiness and Operation depending on what regulatory element is discussed. The configuration selected will be verified primarily against the regulations presented in Regulatory Landscape Analysis and Forecasting

However, some new regulations are also discussed due to having relevant correlations to the specific configuration which was still uncertain during the regulatory landscaping.

5.6.1 Airworthiness

In order to allow for SPO the aircraft needs to be certified for operation with one pilot alone where some airworthiness certification criteria become relevant to consider. It is important to make sure that these criteria are fulfilled, and if not, address what would be needed to do this. The criteria are presented in the landscaping, and they will in this section be used for verifying that the selected concept C2 fulfills them. This section will thus verify the configuration can comply with both EASA and FAA certification criteria.

In the CS-25 category, there are a handful of criteria found which is considered significant for SPO implementation as presented in Table 1. The C2 configuration involves one pilot present at the flight deck during nominal conditions and does not have a remote operator to assist with workload, however, the OEP has the ability to assist in critical situations. This makes it important to have other kinds of workload alleviation solutions to allow the pilot to focus on controlling the aircraft, which is where automation comes in. The criteria require that the pilot is not loaded with more tasks and workload than he/she is capable of handling which means that further investigation of workload and task allocation between pilot and automation is required. However, managing the tasks efficiently should allow the pilot to operate without too high a workload, and therefore the configuration should not clash with the related certification criteria such as 25.1302, 25.1309, and 25.1323. The other criterion in the table is not specifically more applicant to the C2 configuration than other configurations and is mostly related to technical equipment on a more specific level than what the configurations include.

FAR 25 provided by FAA provides similar criteria as CS-25 by EASA when it comes to airworthiness. There is no occurring difference in the two regulations which is considered significant for the C2 configuration which means that the C2 configuration can be considered compliant with airworthiness certifications criteria from both the EASA and FAA perspective.

5.6.2 Operation

The regulations for aircraft operations are important to consider when verifying the configurations since they involve different allocations of operational tasks. These are the criteria that determine crew, task, and authority-related subjects which are highly relevant in the context of SPO. In this chapter, the EASA and FAA regulations are divided into separate sections.

5.6.2.1 European Union Safety Aviation Agency (EASA)

EASA Part-CAT and Part-ORO have relevant sections for verification of the C2 configuration. This section will go through the significant sections and evaluate whether the configuration fulfills them or not. Some of the sections are not presented in the regulatory framework due to the fact that their relevance surfaced after the configurations were evaluated in the screening processes. These will be introduced and presented when discussed in this section.

A part-CAT section that became relevant after the selection of the C2 concept is **CAT.IDE.A.125** *Operations under VFR by day – flight and navigational instruments and associated equipment* which states the following;

(b)Whenever two pilots are required for the operation, an additional separate means of displaying the following shall be available for the second pilot:

(1)Pressure altitude;
(2)Indicated airspeed;
(3)Vertical speed;
(4)Turn and slip;
(5)Attitude; and
(6)Heading.

This section is not clashing with the configuration but rather provides useful guidelines for what is required by the flight deck in order to support critical situations where the OEP is seated within the flight compartment. It clearly indicates that additional separate instruments of the stated kind are required which lies in line with the general needs N2 and N3. Another section that is very similar is; **CAT.IDE.A.130** *Operations under IFR or at night – flight and navigational instruments and associated equipment*, Which provides very similar requirements but for a different scenario. This is also important to consider when developing a flight deck. The same thing goes for the **CAT.IDE.A.135** presented in the regulatory landscaping.

Part-ORO provides a couple of important and relevant sections, not least for C2. The first one is **ORO.FC.100** *Composition of flight crew:* which states the following: *(d)The flight crew member may be relieved in flight of his/her duties at the controls by another suitably qualified flight crew member.*

This section touches upon relieving the pilot from flight deck duties. It states that a flight crew member may be relieved by a suitably qualified flight crew member which in the C2 configuration will be the OEP. What defines a qualified flight crew member is at this point uncertain but should be considered when further defining the OEP role. This could potentially also be seen as an indication that the OEP role can be tolerated and accepted by regulations. Further on **ORO.FC.200** *Composition of flight crew* presented in the regulatory landscaping is also related to what can be delegated to another crew member which can be useful to consider.

Related to the subject is also **ORO.FC.A.201** *In-flight relief of flight crew members* which provides several situations where the commander may delegate the conduct of the flight to other crew members. These situations are for example above a specified altitude or to a flight crew member with a specified type of training. The ORO section is very much in line with the OEP implementation but can only be seen as a first step in developing the role as well as certifying it. These three sections which all touch upon the subject of having another crew member relieve the pilot should be seen as a start for the implementation of an OEP as well as potentially a sign that it may be feasible in the near future from a regulatory point of view.

When it comes to the rest of the operation regulations provided by EASA in the table there is no significant relevance to the C2 compared to the other configurations, thus C2 is considered compliant with them. This concludes the operation regulations from the EASA standpoint and renders the C2 configuration considered verified for operation. However, this is only an early concept and the configuration and OEP role will require further development and definition as well as being iteratively verified and ultimately approved by the authorities before being implemented.

5.6.2.2 Federal Aviation Administration (FAA)

While the airworthiness regulations provided by the FAA and EASA are very similar, the operation regulations differ in some sections. When it comes to types of operations the interesting bits for this project are **Part 121** and **Part 135** as stated in the regulatory landscaping and theoretical framework. As discussed in the regulatory landscaping **121.385** *Composition of flight crew* states *"(c) The minimum pilot crew is two pilots, and the certificate holder shall designate one pilot as pilot in command and the other second in command."* As mentioned, these criteria should in general be seen as an obstacle for SPO but could potentially be what separates C2 from the other concepts. It is not specified whether the two pilots are required to be present at the flight deck at all times which means that if the OEP can be considered a pilot, the configuration should be compliant with the criteria. Nonetheless, this should be further investigated, evaluated, and discussed with the regulatory agency. The definition of the OEP role is also required to be developed and defined in order to fully determine whether it is compliant or not.

The rest of the sections presented in the regulatory framework are not significant in relevance for C2 compared to the other SPO concepts as well as the configurations level of detail, therefore C2 is considered compliant with these criteria. This also means that C2 can be considered verified for operation regulations from an FAA standpoint with some notes for further development and investigation of how the OEP role will look and what it will include.

6 Specific SPO Functions

In this part of the report, the process of determining the specific SPO functions of the previously selected configuration is explained. This involves analyzing potential failures and associated risks which would have a more significant impact on the SPO configuration compared to DPO. The analysis will allow for functions to be made for preventing or mitigating these risks. This process results in a list of specific functions to be considered when implementing the selected configuration to provide safe and efficient operation.

6.1 Function and Risk Analysis

To be able to understand the challenges with specific configurations decided earlier in the process, a new function analysis in the form of a new risk analysis is done to decompose the related configuration risks into smaller and more manageable problems. The method used to decompose is first a Functional Hazard Analysis (FHA) followed by several specific Fault Tree Analysis (FTA) for each specific failure condition in the FHA related to the defined configuration. Secondly, a Fault Tree Analysis (FTA) specifically for Human Factors is completed. These methods align with the part of the process used in ARP4761 and are adjusted and implemented accordingly to fit the scope of the project.

6.1.1 Functional Hazard Analysis (FHA)

The FHA is an early step in the safety assessment process described in ARP4761. It is highlighted as an important and useful method for mapping different risk scenarios by connecting specific hazardous outcomes and it is the condition in which this scenario might happen. Further, each of these scenarios is also classified as either MIN (Minor), MAJ (Major), HAZ (Hazardous), or CAT (Catastrophic) depending on the severity the problem is considered to have if it occurs [30] [2]. In this report, these classifications are preliminary and made subjectively without any validation, based on early estimates and typical industry levels.

Analyzing risks and judging different scenarios can be a complex process where different outcomes are linked to what can be described as a chaotic network of causes and outcomes. Hence, a systematic approach will be used to incorporate subjective factors for an initial assessment of which failure scenarios may pose a higher risk when SPO is implemented instead of DPO. There are different methods that can be used to find these failure conditions, in this project, a decomposition of the aircraft components following the ATA classification system is used [27]. A comprehensive evaluation of potential SPO-related failure scenarios can be conducted by systematically reviewing the different aircraft components, utilizing intuitive thinking and qualitative analysis, and studying accident data and relevant literature, including a prior internal technical report on SPO. This approach allows for a broad spectrum of potential failure conditions to be identified.

By using the ATA classification system, it makes it possible to easily connect the relevant stakeholder to the different failure conditions which consequently allows assigning internal departments to specific related safety work. However, it's important to recognize that ATA can be restrictive in some cases and will not provide complete coverage of all failures. For each failure condition presented in this FHA, closely related certification sections from EASA CS-25 are also provided to give more details for the relevant stakeholders regarding how the failure condition partly impacts the regulation which can be used in future work. The FHA is composed as illustrated in Table 15 where one example row is presented, and the complete FHA can be seen in Table 20 in Appendix A.

Functional Hazard Analysis							
Function Failure Referenc	ATA - Function	Failure Condition	Failure Effect	Related CS-25	Subjective SPO Classification	Typical DPO Classification	Remarks
	25 - Equipment						
5		Loss of seat fixation	Pilot unable to control aircraft	1301,1302,1523, 785	CAT	MAJ	In a DPO scenario, the PM has the authority and possibility to operate the aircraft. However, in an SPO scenario, a failure of the seat restraint system would be deemed a catastrophic event.

TABLE 15 - FHA EXAMPLE

The FHA includes a large number of failure conditions which were later screened down. The remaining failure condition are marked as included in the list. The reason why screening was done was due to the fact that handling that large amount of conditions would reduce the detailed focus on the rest of the reports due to the limited time scope as well as some of the conditions not being relevant for the investigation of SPO. It was decided to keep failure conditions related to the interface between pilot and aircraft which means flight deck layout, flight deck automation, and similar subjects due to their relevance for SPO. This left failure conditions such as loss of control surface to be precluded.

6.1.2 Fault Tree Analysis (FTA)

The Fault Tree Analysis (FTA) is a common tool used both in aviation and other industries. The tool decomposes a specific outcome or scenario into several factors which can be the cause of that particular outcome. This is visualized in a tree diagram with gates to illustrate the problem and its causes [46]. The outcome can be decomposed into several levels to provide a more detailed understanding of the fault. The method delivers similar use cases to the more product development traditional function-means or black-box analysis, but FTA in comparison provides a more problem-oriented perspective towards products as well as systems [42] [47]. The method can therefore provide valuable insights into the system's weakest points as well as where redundancy and new functions should be applied to prevent certain outcomes.

This analysis is particularly useful for analyzing complex products such as aircraft. The FTA method is included in the ARP4761 safety assessment process and used during preliminary system safety assessments, which makes it ideal for this subject at this stage given the novelty and uncertainty surrounding this topic [30]. The assessment is limited in detail for this reason; however, the analysis seeks to be broad in scope by adopting a holistic perspective. This practically results in FTAs which don't fully decompose a failure condition into very small parts. To decompose further, advancement in aircraft design would in many cases be required to provide accurate and valuable information.

6.1.2.1 Specific FTAs

Each specific tree is analyzed separately (thus, no common fault problems are considered) and originates from the unique fault conditions from the previously performed FHA.

The specific FTAs constructed in this project are based on some assumptions which are required to understand for the analysis to make sense. The FTAs are built upon a general framework which is expanded as needed depending on the failure condition. This framework consists of first dividing a fault condition into either a Human Factor related problem or a technical error. Although technical errors can be caused by human error, they are categorized in this way for the sake of simplicity in order to facilitate effective management of the problem and related functions.

Further on, the framework divides the human factors into usually two branches, either "*Captain*" or "*First Officer*" as a human error can be explained as two individual systems. These two branches are always considered equal, meaning all potential fault reasons for the *captain* are the same for the *First Officer*, unless specified otherwise. This is however not illustrated in the FTA figures for increased readability. It is also assumed that there is always an *AND* condition between these two branches unless specified otherwise, meaning one person can always correct the other person's mistakes. This is of course a simplified assumption from reality as some actions are irreversible, but this is no worse than for conventional DPO, so not too much focus has been spent on tackling these potentially related issues as it considered out of scope.

Returning to the technical errors, there are either two or three branches in this framework, which is zone divided into *Left Hand Side, Right Hand Side,* and potentially a *Common* depending on the fault condition. It is divided this way as it suits the way the configuration is set up for the SPO and accessibility to redundancy equipment. Technical failures in general are complex with many levels, so this is normally not fully analyzed and decomposed. In fact, most of the deepest level nodes shown in the diagram do have fault reasons themselves which are recommended to further decompose for a better understanding of the failure and how it can be mitigated. For this reason, the technical error usually just decomposes into Mechanical, Electronic, and/or Software Errors as further decomposition would require significantly more research and data.

An extract from the complete FTA is shown in Figure 8 where one failure condition is decomposed. From this extract, it can be seen how the framework is used practically. The blue boxes which can be seen in the illustration contain the functions which tackle that specific sub-problem, these are generated in the next stage of this report and thus further explained in that section. The full comprehensive diagram of all the FTAs with unique failure conditions can be seen in Figure 23 in Appendix B.

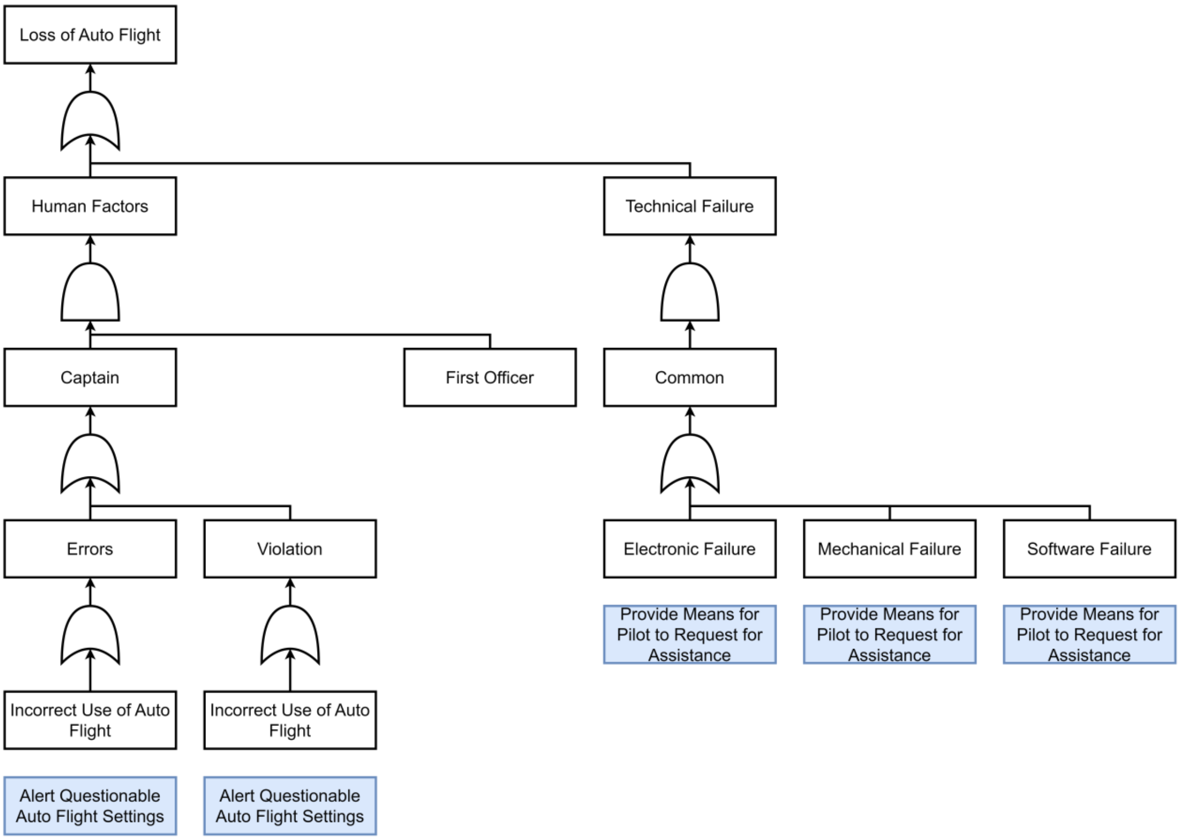


FIGURE 8 - SPECIFIC FTA EXAMPLE

6.1.2.2 Human Factors FTA

To identify human factors-related issues with the selected SPO configuration, an FTA of a general aircraft accident with human error as the main cause was constructed, see Figure 30 in Appendix B. The FTA is used to determine the technical need and functions for addressing emerging gaps from a transition from DPO to the selected SPO configuration. The FTA was decomposed with inspiration from the well-known HFACS model. From the HFACS, human factors issues related to organizational problems and supervisory factors are considered as well [48], however, this extends outside of the project scope and is therefore not expanded any further as it will not have any or little influence over decisions in the project. The FTA includes a secondary pilot to find possible DPO-related concerns as well as a collaborative error. Since the specific FTAs are only created from a handful of failure conditions, some critical scenarios have certainly not been found. The failure conditions from the FHA are all ATA100 based and are therefore strongly linked to technical failures which is why the Human Factors FTA was created where human factors and human error-based problems also surface.

From this FTA, it becomes evident how one less pilot decreases redundancy and thus increases single points of failures in human factors to having catastrophic outcomes. The absence of redundancy in the form of an extra pilot becomes particularly critical in situations such as pilot incapacitation, where the pilot is unable to perform their duties due to various reasons. The same thing applies for pilot violation where a pilot has malicious intent. In these cases, catastrophic outcomes need to be prevented or mitigated in other ways by, for example, having the OEP of the C2 configuration step in or a remote pilot step in and take over the control. However, a pilot violation is still possible in today's dual pilot operation but is harder as there will likely be resistance by the other pilot.

The human factor FTA also indicates that team-related errors with SPO configuration are less of an issue since there is less communication required between the captain and the OEP compared to the traditional DPO configuration. Examples of team-related errors include miscommunication and cultural and status-related issues. As these collaboration issues are a significant problem in today's aviation, this provides an incentive for the SPO configuration.

6.2 Specific Functions Required

In the specific FTAs, the failure condition was decomposed into smaller more specific causes leading to the condition. The HF-FTA (Human Factor Fault Tree Analysis) also resulted in causes for failures but from a human factors perspective of a decomposed general accident. Through the analysis, it was possible to interpret the different functions required to reduce the likelihood of the failure condition as well as the general accident occurring. These functions were generated through a process of brainstorming ideas to close the SPO safety gaps, and while some functions may be applicable to SPO in general, or even DPO, the function's main aim and purpose is to serve and support the selected configuration. Several of the functions also occur on multiple causes and FTAs and are thus a shared function between these. The function specification can be seen in Table 21within Appendix C. Worth noting is that the human factors FTA presents collaboration errors as stated in the previous section. These collaboration errors are frequently occurring for conventional DPO flights today but will be mostly mitigated with SPO which is why they are neglected from being further used for developing functions in this project.

The function specification contains a large number of functions tailored to mitigate or prevent the occurrence of failures and errors for SPO and the C2 configuration. In the specification, the correspondent fault, failure, or error is also presented together with what FTA the function origins from. The function specification does a good job of presenting why the functions are created by showing what problems they solve; however, this specification is not as efficient for presenting the functions only which is why the function list was created. This list presents only the function in chronological order and can be seen in Table 22 in Appendix C. While all the functions in this list do have a more detailed level compared to the general strategies and needs, their exact level of detail is not completely consistent throughout the list as different degrees of novelty and uncertainty for the failure condition make the level of detail of function differ. An illustration of this is shown in Figure 9 below.

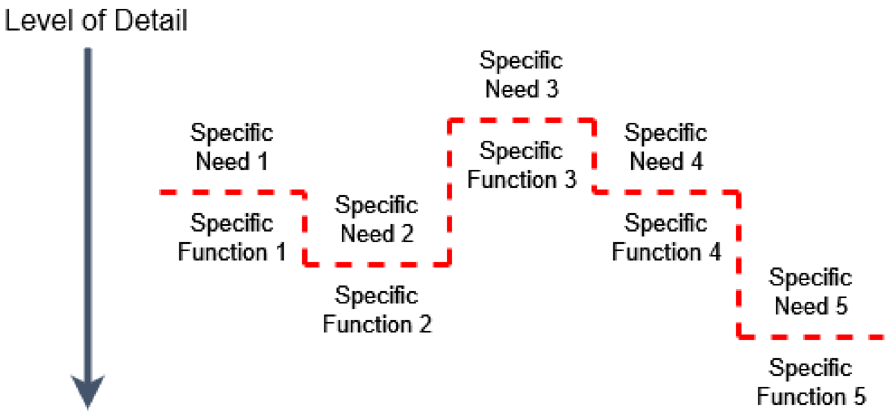


FIGURE 9 - FUNCTIONS AND LEVEL OF DETAIL ILLUSTRATION (EXAMPLE ONLY)

For example, the failure condition *Loss of ability to reach or interact with switch/display/lever* is less specific than *Loss of proper stick input*. This implies that the functions created from the two FTA decompositions will also differ in the level of specificness. This can be seen for example in the functions *Provide position of critical displays within pilot visual range* and *Provide position of stick within reach from both seats*. The latter function is more specific in terms of defining what exact equipment (the stick) and more details of the position being both seats. The first function is not as specific since it leaves the equipment definition at the level of critical displays meaning that it can be whatever display or displays that turn out to be important for the flight. It also has a vague description of the position where it refers to the pilot. In order to further decompose or specify this function certainty of what displays will be considered critical is needed as well as knowledge about the potential positioning of the pilot within the flight compartment.

6.3 Sub-Functions

In this section one of the functions previously presented will be further developed into sub-functions or solution concepts. This means that the function will be decomposed into a more specific detail level of how the function would be executed. Due to the limited time of the project, only one function will be decomposed and further developed, however, this section will function as an example of how the other functions also can be further developed in the future.

The function which will be decomposed in this section is F39 *Provide automated crosschecking*. The reason why this function was chosen to start with is that it works really well with the processes of decomposing and assessing creating a clearer case to later be used as an example or guideline. This function is designed to alleviate the pilot's workload throughout the flight by assisting with cross-checking, checklists, and similar procedures.

The section will also include an FHA for determining the severity of failures within the sub-functions. This is important in order to evaluate if the functionality is safer than not having it at all. The main purpose of the selected function is to relieve the pilot's workload and in order to verify that this is actually done the sub-functions will be assessed using the Bedford Scale presented in Workload Assessment – The Bedford Scale .

The function is in this case decomposed into three sub-functions with some key differences. The sub-functions are designed to fulfill the task of the function but provide more detail on how it should be done. These sub-functions can be seen as early concepts of a solution for providing automated crosschecking alleviation. The three sub-functions was generated by brainstorming with inspiration from the industry and can be seen in Table 16 together with a case example of how they would be used in operation.

Function ID	Function	Example Task: Reduce airspeed to 100kts		Remark
		Automation	Pilot	
F39	**Provide automated crosschecking**			
F39.1	Provide automatic alert, verification and confirmation of tasks	Vocalized "Reduce airspeed to 100kts"		Pilot is relieved of keeping track and reading checklist and verifying when task metric is reached. Also provides redundant verification.
			Throttle down to reduce speed	
		Verifies 100kts is reached, Vocalized "Airspeed 100"		
			Verifies 100kts is reached, Vocalized "Check" or verifies by button	
		Confirms task completion		
F39.2	Provide automatic verification of tasks		Read task from display	Pilot is relieved of verifying when task metric is reached. Also provides redundant verification.
			Throttle down to reduce speed	
		Verifies 100kts is reached, Vocalized "Airspeed 100"		
			Verifies 100kts is reached	
			Confirms task completion by button or vocalizing "Check"	
F39.3	Provide automatic alert, execution, verification and confirmation of tasks	Vocalized "Request to reduce airspeed to 100kts"		Pilot is relieved of going through list, executing tasks and verifying metrics.
			Approve or deny request	
		If approved: Throttle down to reduce speed	If denied: Throttle down to reduce speed	
		Verifies 100kts is reached, Vocalized "Airspeed 100"		
			Verifies 100kts is reached, Vocalized "Check" or verifies by button	
		Confirms task completion		

TABLE 16 - SUB-FUNCTIONS WITH EXAMPLE TASK

As seen in Table 16 the sub-solutions are named after the origin function with an additional decimal which specifies the sub-function number. Throughout this section, the sub-functions will be referred to by their function id meaning F39.1, F39.2, or F39.3.

F39.1 involves more automation than F39.2 which brings a greater workload alleviation but is likely to cost more to implement. When compared to F39.3 it involves less automation and is therefore likely less expensive. The sub-function includes having automation taking care of potential lists of procedures which greatly reduces the pilot's workload of reading through lists. The automation alerts the pilot of the next task which he/she can then execute. In the example presented in the table, the task is to reach a certain metric which in that case will be verified by automation when reached. The automation will alert the pilot that it has verified the metric. Before the task can be confirmed and the next task in a list is initiated the pilot also needs to verify that the metric is reached. This prevents the automation from misinterpreting data and moving on before an important task is finished. The pilot verification can be done either vocally by for example saying "check" or by pressing a verification button.

F39.2 has less automated assistance but still provides workload alleviation for the pilot. When comparing this sub-function to F39.1 the difference is that it does not include handling lists of tasks such as checklists and SOPs which means that the pilot needs to read the lists manually. However, the lists should be presented digitally on a convenient display to make it efficient for a single pilot to use. F39.2 assists in verifying and keeping track of when, for example, a metric is reached in the same way as F39.1. This both reduces the workload as well as provides redundant verification of task completion. The automation vocally verifies and when the pilot also can verify that the task is completed, he/she can now complete the task and move on to the next.

F39.3 is the most complex sub-function and is similar to F39.1 but can also perform automated execution of tasks. At this level of detail, the specific tasks that are allowed by the automation are not defined but the idea is to allow automatic execution of basic tasks which is important in high workload scenarios and that provides workload relief for the pilot. Examples of the tasks could be reducing throttle input, lowering the landing gear, or deflecting the flap. F39.3 is the most complex and workload-alleviating of the three, however, it is also likely to be the most expensive.

6.3.1 Sub-Functional Hazard Analysis (Sub-Function FHA)

The sub-functions were analyzed by brainstorming potential failure conditions and compiling an FHA which is seen in Table 17. The failure conditions are presented together with failure effects and approximated classifications of severity as described in Functional Hazard Analysis (FHA) . The FHA also presents the severity of not having any of the functions implemented. This is based on the idea that the nominal case is a slightly too high workload which leaves the no function severity on MIN (Minimal).

Sub-Functional Hazard Analysis

ID	Function	Failure Condition	Failure Effect	Subjective Classification	Remarks
F39.1	**Provide automatic alert, verification and confirmation of tasks**			**No function-> MIN**	
C1		Loss of vocal output	Manual operation and a slight confusion and workload increase	MIN	Means that the checklist will have to be followed manually, workload similar as without function.
C2		Loss of automatic verification	Manual operation and a slight confusion and workload increase	MIN	Means that the pilot will have to verify alone. Reduces redundancy, workload similar as without function.
C3		Loss of automated list handling	Manual operation and a slight confusion and workload increase	MIN	Means that the list has to be followed manually. Workload similar to without function.
F39.2	**Provide automatic verification of tasks**				
C1		Loss of vocal output	Manual operation and a slight confusion and workload increase	MIN	Means that the checklist will have to be followed manually, workload similar as without function.
C2		Loss of automatic verification	Manual operation and a slight confusion and workload increase	MIN	Means that the pilot will have to verify alone. Reduces redundancy, workload similar as without function.
F39.3	**Provide automatic alert, execution, verification and confirmation of tasks**				
C1		Loss of vocal output	Manual operation and a slight confusion and workload increase	MIN	Means that the checklist will have to be followed manually, workload similar as without function.
C2		Loss of automatic verification	Manual operation and a slight confusion and workload increase	MIN	Means that the pilot will have to verify alone. Reduces redundancy, workload similar as without function.
C3		Loss of automated list handling	Manual operation and a slight confusion and workload increase	MIN	Means that the list has to be followed manually. Workload similar to without function.
C4		Loss of automatic task execution	Pilot not aware of task being incomplete	CAT	Means that automation has failed to do what it was supposed to do or done it incorrectly.

TABLE 17 - FHA OF SUB-FUNCTIONS

The three sub-functions have the two failure conditions C1 and C2 in common. This means that these two failures have a possible occurrence for all three and is therefore not possible to avoid them without creating a new sub-function or reconstructing them. Both C1 and C2 have the severity classification MIN which means that the occurrence of one of these conditions is not significantly worse than not having the function. As stated in the failure effects, however, the conditions can lead to confusion which might occur when the failure happens before the pilot understands what is wrong and how to act. If one of these failures occurs the pilot will need to turn the system off and manually follow the list of tasks, which will not be more than a slight increase in workload compared to not having the sub-function at all. C1 and C2 are all the failure conditions found for F39.2 which mean that its severity will not exceed having the sub-function implemented and could therefore be seen as a feasible solution. However, if C1 or C2 is combined with overreliance on automation the outcomes can be catastrophic.

F39.1 provides automated list handling which potentially can result in the failure condition C3. Similarly to C1 and C2, C3 has the severity classification MIN. This is due to the failure effect being similar where the pilot is required to disable the system and manually proceed with the tasks. Since only the three failure conditions C1, C2, and C3 were found for F39.2, all with the severity MIN, the sub-function can be considered feasible from a risk aspect.

F39.3 has the capability of executing tasks and procedures which means having the authority to affect parts or parameters of the flight. This provides workload relief under nominal conditions; however, it can potentially lead to failure condition C3. This failure condition touches on the subject of the automation not performing what It is supposed to or not performing it correctly. Examples of this can be not folding out the landing gear when asked to or even deflecting the flaps when asked to fold the landing gear. This kind of scenario can easily have catastrophic outcomes, which is why this failure condition has a severity classification of CAT. F39.3 is the only sub-function with a failure condition classified significantly worse than for an operation without any of the sub-functions implemented. This could generally be seen as a sign that this solution is not safe enough for implementation. However, if the probability of occurrence is extremely small, the sub-function might still be a feasible option but would require extensive research, testing and proof before being implemented.

It is important to consider that the FHA only analyzes the severity of potential scenarios. There are more parameters to evaluating a function such as the actual occurrence of the scenarios, the actual usefulness of the function as well as the implementation cost.

6.3.2 Sub-Function Workload Assessment

The function providing automated crosschecking workload alleviation aims to provide workload allocation for the pilot to allow him/her to focus on other required tasks. It's important to evaluate different solutions on how they fulfill their purpose before implementation. This can be done in various ways but as described in Workload Assessment – The Bedford Scale the Bedford is the most suitable method for this project and at this stage in the development process when workload is a main issue. The scale can be applied to this case where the workload of the different scenarios will be determined for the different sub-functions. By using comparison, one can determine which alternative provides the most workload alleviation which translates to which alternative offers the highest performance.

Since the sub-functions are designed to relieve workload there is no way to directly assess their impact on the workload in an isolated event. However, by applying the different sub-functions to a scenario where multiple tasks are executed simultaneously creating workload, a Bedford assessment can be applied. This section will explain a possible scenario and walk through the tasks that the pilot is required to perform. The scenario will then be analyzed using the Bedford scale once for each of the sub-functions which will ultimately lead to relative workload ratings for the functions.

The scenario is in this case a SPO aircraft about to perform a landing in poor weather conditions. The pilot controls the airplane towards the runway while the thick rain reduces the visibility significantly. The aircraft is lined up with the runway when ATC alerts that an emergency on the ground has left the runway unusable for the moment. The pilot now needs to perform a go-around. Right before the message the pilot's workload is considered high for a regular flight but when the information about the go-around is received the workload increases even more. The pilot now has to control the aircraft trajectory and communicate with ATC about how and where to go to approach the other runway. In addition to this, the go-around adds a few tasks such as retracting the flaps which were deflected for landing, throttle up to accelerate, climb to a safe altitude. This new list of tasks is where the sub-functions proposed can alleviate the pilot's already high workload. Having to perform all of these tasks alone could potentially be too much for the pilot while having the alleviating functions could make the situation manageable.

Applying F39.1 to this scenario would help in alerting or reminding the pilot of what tasks need to be executed such as adjusting flaps and throttle. The execution will be done by the pilot and when the flaps are in the correct position, airspeed is increasing and ultimately the correct altitude is reached the automation will handle verification together with the pilot making sure that the tasks are completed. When following the Bedford scale chart presented in Figure 2 this is likely to pass the first question whether it was possible or not to complete the task. The fact that the pilot was not required to go through the list while communicating with ATC and controlling the aircraft allowed him/her to focus on the tasks required. This could be considered as the workload being tolerable which means that the second question in the Bedford chart is also passed. The workload is considered tolerable however because the pilot still has a relatively high workload with many tasks to handle it cannot be considered satisfactory without reduction which puts the F39.1 scenario on a workload rating somewhere from 4-6. The spare capacity of the pilot at this point is significantly limited and is not considered enough to focus on additional tasks which is why the F39.1 scenario receives the workload rating of 6.

When it comes to F39.2 there will be less workload alleviation than in the previously presented scenario. The pilot is in this case required to manage the list of tasks and is only provided relief by automation in verifying tasks. In this case, the verification of for example flap deflected to the correct setting and safe altitude reached will be provided. These verifications can seem to be naturally done by the pilot anyway, however in high workload scenarios this allows focusing on other tasks and trusting the automation with monitoring. Applying the Bedford chart the first question is passed since the task will be possible to complete, however not to a tolerable workload due to the need of managing the list and making sure required tasks are completed. This leaves the F39.2 scenario with a rating of 7-9. Since the tasks can be executed but at the limit of the pilot’s capability the F39.2 scenario receives a rating of 8.

Finally, sub-function F39.3 involves the greatest amount of automation with the feature of executing tasks. In this scenario, the tasks of deflecting flaps and adjusting the throttle could be beneficially controlled by automation to relieve the pilot’s workload. However, controlling the trajectory of the plane to climb in altitude is suitably done by the pilot due to the potential severity of incorrect input. Similarly, to F39.1, F39.3 will manage the list of tasks and acknowledge the pilot of what task is required. However, the sub-function capability of executing the tasks if approved by the pilot provides even further workload alleviation compared to the other scenarios. When applying the Bedford chart, this scenario easily passes the first two questions with “yes”. The third question about whether the workload was satisfactory without reduction or not can be answered “yes” if the pilot’s approval of automation executing tasks can be done without significant interference with other physical inputs or communications. This means that the workload can be considered satisfactory without reduction if the pilot can approve vocally which in this case interferes with the ATC communication or has a hand free for verifying with a button, which suits this case well. Therefore, in this scenario, the workload rating received is 3 due to the workload still being significant but not too high for completing additional tasks.

The three ratings are dependent on the specific scenario and could in other cases likely differ slightly. For example, the F39.3 is likely to answer "no" on the third question in the Bedford chart in cases where interfering tasks make approval of execution unfeasible or even heavier in workload than executing the task manually. However, the value added by performing the Bedford workload assessments on the different sub-functions is to be able to compare them to each other. As stated, the workload rating represents how well the sub-functions alleviated workload in a high workload scenario and can be seen as a usefulness rating. The assessments proved F39.3 to be the most effective sub-function in providing workload relief for the pilot in this kind of scenario. This, however, does not naturally mean that the solution is the one that should be implemented since other factors are important to consider.

6.3.3 Sub-Function Evaluation

To conclude the section, three sub-functions have been created and evaluated through an FHA and a Bedford assessment. This has provided an insight into what risks are involved in the different sub-functions as well as how well they fulfill their purpose of alleviating workload. To briefly summarize the results F39.3 provides the greatest workload alleviation, however it has the risk of providing catastrophic outcomes. F39.1 comes next in the workload alleviation scale and is expected to be equivalently safe to not having the function at all, meaning that this can be a promising option. The last one is F39.2, which provides less workload alleviation than the other two but is still as safe as F39.1. From the parameters analyzed in this section, F39.1 seems to be the most suitable solution at this point.

However, which sub-function alternative should be selected also depends on other factors such as cost, which is related to how novel the technology is, but also social and political acceptance. For example, F39.1 can seem like a better solution than F39.2, however, the latter will be less costly to develop and implement which might suit the aircraft developer better. Functions like F39.3 where automation executes certain tasks can often receive skepticism from political and social standpoints. A PEST analysis could potentially be a good addition to the evaluation allowing further assessment to build a solid basis for a qualified selection of sub-function alternatives. This means that to make the final decision, further research, and analysis need to be executed.

7 Result

In this part of the report, the result of the project is presented. This result is aimed to answer the established research questions in the *Introduction* which are: **RQ1** - *What configurations for single pilot operation are best suited within given constraints and needs?* **RQ2** - *What functions would support single pilot operation?* **RQ3** - *Is single pilot operation a feasible alternative in the current environment?* **RQ4** - *How could the use of a single pilot be phased into operations?* For a more nuanced perspective on the answers, see Discussion and Conclusion.

7.1 General Needs and Strategies

These general needs and strategies have been found through relevant literature and document studies as well as iterations throughout the project. The needs and strategies have served numerous purposes during the work of shaping different solutions. In many ways, they act as boundaries when generating both SPO configurations and specific functions to ensure that they effectively target the actual main problems. The needs are broad to ensure that the solution space is not limited more than necessary. By general needs it means "general" in the saying that is relevant for all solution concepts in this project, but not necessarily universal for all possible solutions. In Table 3 from Appendix C, the list of the general needs is presented with remarks for further explanation. These general needs and strategies provide the necessary preconditions to answer **RQ1**, **RQ2,** and **RQ3**.

7.2 Regulatory Findings

Throughout the project numerous regulations were found which may be relevant for implementation of SPO on large commercial aircraft and have been analyzed and investigated. This has been done with focus on aircraft operational within American and European airspace, thus the regulatory authorities studied are EASA and FAA. The two authorities or agencies include a large number of regulations for all kinds of aircraft and all kinds of operations. Therefore, the analysis was further focused on the relevant type of certification for airworthiness of aircraft which is Part-25 for FAA and CS-25 for EASA. Further, the relevant operation regulations were also analyzed which for the FAA were found to be Part-121 and Part-135 and for EASA Part-CAT and Part-ORO. Table 18 presents the sections found significantly relevant for the project from the Regulatory Landscape Analysis and Forecasting as well as the Regulatory Verification of Developed Configuration.

Airworthiness EASA	
25.1302	Installed systems and equipment for use by the flight crew
25.1309	Equipment, systems, and installations
25.1321	Arrangement and visibility
25.1303	Flight and navigation Instruments
25.1307	Miscellaneous equipment

25.1329	Flight Guidance System
25.1301	Function and installation
25.1523	Minimum flight crew
25.1525	Kind of operation
25.671	General
25.771	Pilot compartment
25.777	Cockpit controls
Airworthiness FAA	
25.1523	Minimum flight crew
Operations EASA	
CAT.IDE.A.125	Operations under VFR by day – flight and navigational instruments and associated equipment
CAT.IDE.A.130	Operations under IFR or at night – flight and navigational instruments and associated equipment
CAT.IDE.A.135	Additional equipment for single-pilot operation under IFR
ORO.FC.100	Composition of flight crew
ORO.FC.200	Composition of flight crew
ORO.FC.A.201	In-flight relief of flight crew members
ORO.FC.202	Single-pilot operations under IFR or at night
ORO.FC.230	Recurrent training and checking
Operations FAA	
121.385	Composition of flight crew
121.543	Flight crewmembers at controls
135.89	Pilot requirements: Use of oxygen
135.169	Additional airworthiness requirements

TABLE 18 - COMPLETED LIST OF RELEVANT REGULATION SECTIONS

The regulation sections should be considered during the continued design and development of SPO to avoid legal clashes. The sections have been used within section Regulatory Verification of Developed Configuration to verify that the C2 configuration is at this time compliant with the regulations which it was found to be. The assessment of regulations is fundamental in answering **RQ3** since the feasibility of SPO is highly dependent on legal aspects.

7.3 Suggested Configuration

In this section, the configuration concept that showed itself to be the most promising one in the development and screening process is described. The suggested configuration was the only one retained from the screening process as it was deemed the most promising option within the given project assumptions, constraints, and needs. While this configuration was concluded to be the best alternative in this project, different assumptions, constraints, and needs would drastically change this result. The section thus mostly answers **RQ1** and **RQ2**.

7.3.1 Overview

The suggested configuration in this project is where SPO is achieved by using an onboard-emergency-pilot (OEP) to assist the captain (main onboard pilot) and improved automation systems for certain tasks. In nominal cases, the emergency pilot would not be needed for flight deck duty, and the onboard pilot would be able to independently manage and control the aircraft. However, in non-nominal cases where the workload is increased, the onboard pilot has the ability to request assistance which allows the OEP to enter the flight compartment to relieve tasks from the captain. In the case of pilot incapacitation, there is a verification system which monitors the status of the captain. Unless there is an adequate response to this system from the captain, the OEP is alerted and allowed access into the flight compartment.

The OEP is intended to fully replace the cabin crew which means that the OEP needs to have significantly more training. This new role is not designed to fully replace the pilot as shown in Figure 10, thus the training and cost would be less by comparison. With the help of automation systems, a smaller number of tasks would be required to be mastered by the OEP to perform the necessary operations.

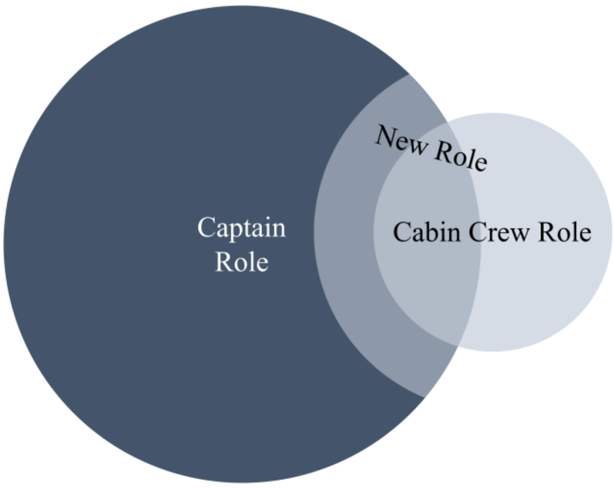


FIGURE 10 - KNOWLEDGE DIAGRAM

To ensure that the captain can in nominal cases independently manage and control the aircraft, an improved automation system is used to increase awareness during the operation and a better understanding of the environment. This is achieved by using hardware and software of reasonable sophistication and complexity within the industry today and in coming years, but has not yet been implemented into commercial aviation. Mainly, these automated systems would replace some of the responsibilities of a traditional pilot monitoring role.

Automation has the capability to perform automated cross-checking and tasks between the captain and the computer, monitor system parameters use annunciation to a higher degree than before. The automation system incorporates a solution where a specific task or a set of tasks can be performed automatically, given the captain's approval. Using a clear information system, the captain is shown parameters in a way that he/she can understand why the automation system wants to perform a set of tasks. By having this type of automation system, peak workload is reduced for the captain and the OEP in non-nominal situations and the risk of making decision errors is reduced.

By having an OEP, there are significantly fewer risks involved in the operation, mainly with pilot incapacitation which is in many ways considered the most critical aspect of SPO. Consequently, there is less need for novel and advanced automation systems which would be required without an OEP to maintain a similar level of workload capability in different scenarios. This makes the C2 configuration more feasible as it would likely have fewer regulatory conflicts, better social acceptance, and be more economic due to less need for new technology compared to other configurations. While the additional cost required to incorporate a new type of role for this configuration would make it more expensive from both a training and operational perspective compared to other SPO configurations, it's still believed to be the best alternative given the timeframe and safety requirements.

7.3.2 Functions

In this part, the functions required for the implementation of the suggested SPO configuration are presented and described. In section 6.2 the potential failures and faults related to the suggested C2 configuration are used for the development of specific functions. The word "specific" means that these functions are created for the suggested concept primarily, but some can still be useful for other configurations as well. The functions are ultimately compiled into a final list of functions, presented in Table 22. Each function is rendered from one or more faults found in FTAs and therefore solves different problems which potentially could occur with the C2 configuration. Therefore each function presented in the list should be included in the final SPO solution. Implementing the functions means developing ideas or solutions which by implementation execute the specific function intended.

The process of developing solutions, or a little less specifically, sub-functions for the functions, has during this project been done on one function only due to the limited time. This, however, works as a guiding example of how further development can or should be executed. The sub-functions developed originate from the specific function F39 *Provide automated crosschecking alleviation* included in Table 22. The function was decomposed into three different sub-functions, which were later evaluated using a detailed FHA as well as Bedford scale workload assessments. This process is presented and illustrated in Sub-Functions . The evaluation was a first step in selecting a final sub-function where knowledge about the risks involved as well as the usefulness was gained. However further analysis is required in terms of cost, technology, political and social acceptance to allow for a qualified selection.

7.4 Other Configuration Alternatives

In this part, the other configurations generated in the report are briefly described and contrasted with the suggested configuration. As the suggested concept was concluded to be the most suitable alternative for this project, the other generated concepts may still hold value for other cases which is why they are included in the result. A bar diagram of the different configuration's workload capacity can be seen in Figure 7. The concepts are described in further detail in the section Table 22 found in Appendix C.

7.4.1 Concept A

This configuration achieves SPO by having both new advanced automation technology and remote-control capability. The automation system alleviates the workload from the onboard pilot and can perform many nominal and non-nominal tasks such as emergency landing. The remote-control capability provides redundancy and can mitigate workload which the automation system does not have the capability to execute. The remote-controlling pilot can also be involved during the entire flight, as the role of pilot monitoring would further monitor aircraft and assist the onboard pilot when needed. This concept maintains a similar workload capacity as DPO and has high human involvement, but is more vulnerable to cyber threats.

7.4.2 Concept B

This SPO configuration uses new advanced technology, similar to concept A, but does not have full-remote control capability, so instead this configuration relies on an emergency landing system in the case of pilot incapacitation. Remote operation allows for tasks such as system management, communication, and navigation to alleviate the workload, but does not have control authority over the aircraft. Consequently, there is less human involvement, but the solution is also less exposed to cyber threats.

7.4.3 Concept C

Concept C is the most straightforward configuration solution to SPO compared to today's DPO. SPO is achieved by replacing the second pilot with minimal new technology for lighter workload alleviation. Technology that has the capability to perform emergency landings in many, but not all, situations is also provided. The solution is economically feasible but reduces the flight crew workload capability in general and requires the captain to always be seated in the cockpit. The concept may be challenging from a regulatory and social acceptance standpoint for demonstrating its similar safety to DPO operation, as it may not be possible. The demonstration of safety should, however, always be required before implementation of a concept.

7.4.4 Concept D

Concept D is an SPO configuration where the traditional pilot role has transformed into more of a monitoring role. Monitoring is the main responsibility and while the onboard pilot should have similar training and be equally ready to take over control of the aircraft, the automation system has the primary responsibility over most nominal and non-nominal tasks. The automation system is hence sophisticated but likely very expensive. In addition to this advanced automation system, there is also a remote-control capability for redundancy situations. The solutions are complex, expensive, and challenging to develop and make feasible, but promise a higher degree of workload capability compared to today's DPO which may be in public opinion's favor.

7.5 Technology Roadmap

Presented in Table 12 is a technology roadmap for SPO. The roadmap includes a compilation of the findings throughout the project and is presented as a possible implementation timeline. The roadmap also uses the configuration generated in the project to further show how SPO practically could change over time. This roadmap answers **RQ1, RQ3,** and **RQ4**. The roadmap provides brief explanations and descriptions of where aspects such as technology, social acceptance, and regulations are expected to be in the future and what kind of configuration would suit this point in time the best. The technology roadmap can therefore be used as a guide to what configuration should be developed and implemented depending on when and in what environment the aircraft will operate.

Technology & Automation

Near Future

It is anticipated that the current level of automation in aviation will remain unchanged in the near future. Although advanced technology and sophisticated automation system may be able to fly an aircraft in many different situation and offer remote control capabilities, these systems are likely to have a low readiness level and may not be suitable for commercial aviation.

However, there is a possibility of introducing new automation systems that can alleviate lighter workloads and enable some SPO configurations. Such automation systems could include enhanced system monitoring capabilities and enable collaborative cross-checks between on-board pilot and computer.

Emergency auto-land systems with limited capability could possibly also be implemented in aircraft within near future to maintain equivalent safety between SPO and DPO

[Intermediate]

Further in into the future, automation systems are expected to reach a level where they can handle many nominal situations to a greater extent. This will likely result in a shift of the captains role from controlling to monitoring. While the improved capabilities of automation system could may handle emergency situations better than before, there may still be limitations of these systems.

Specifically, these systems are not believed to be capable of the same level of creativity as humans, meaning that they may not be able to think outside the box which in some situations is crucial. Therefore, it is still generally believed that certain tasks are best performed by humans, and that human involvement and supervision will remain a necessary part of commercial aviation in the future.

It is also possible that this supervision could be achieved remotely.

Far Future

In the far future, it is believed that automation systems will reach a level where it can handle most nominal and many non-nominal situations. Increased system capabilities with more sensor data and automation "creativity" are enabling factors for this.

Human involvement would in that case likely be limited to supervising the systems and making decisions, which could change the way which pilots are trained. With these types of responsibilities, there may be less need for a second pilot.

Remote control capabilities can also be a possibility in the future if there is a strong and reliable connection to enable accurate situational awareness. With this technology, scenarios such as pilot incapacitation would be less of a concern in SPO. However, cyber security will be a bigger issue, as well as rule violations.

Regulation & Social Acceptance

Near Future

Regulations related to SPO are expected to follow the technology readiness level as regulatory agencies closely monitor the progress of this technology.

Pushing for change is still necessary to ensure progress. At this stage, some new types of technology for SPO may require new certification processes to demonstrate equivalent level of safety between SPO and DPO.

Social acceptance of SPO is still a challenge at this point. However, introducing SPO on shorter routes and smaller planes is believed to be a good transition. Additionally, enabling planes to operate with both DPO and SPO can ease a possible transition.

[Intermediate]

As technology continues to advance and human involvement becomes less necessary, it is expected that many more ethical and responsibility-related questions will arise than what is seen today. Therefore, completely unmanned aircraft (UAVs) are unlikely to become a reality, especially if the automation system does not have a similar level of creativity and performance as a human.

As a result, it is believed that regulations will still require pilots to have full pilot training and responsibility over the aircraft, and the authority of automation will still be limited, even if the system has the technical capability.

Skepticism will still exist for SPO solutions, and in the event of an accident, blame could likely be aimed towards automation and technology errors rather than human error.

Far Future

The regulation surrounding SPO in commercial aviation is challenging to predict if/when technology has advance this far. Nevertheless, it is likely that the political and social landscape will play a vital role in determining the different certification aspects of such aircraft.

If/When technology reaches this point, other solutions such as UAV is also like being discussed to a high degree which could potentially change the regulatory environment and social acceptance for SPO.

SPO regulations is therefore believed to address even more ethical principles to cover subject such as overreliance on automation and accountability.

Concepts & Feasability

Near Future

For implementing SPO, there are different approaches and path that can be considered. If a near future implementation of SPO is desired, Configuration C2 may be suitable even if it may require new types of flight crew roles and training.

However, if automation systems can be used in a way that they can demonstrate equivalent safety levels as with DPO without a new flight role and that some relevant regulation becomes more similar between CS23 to CS25 aircraft, it might be worth considering the concept of Configuration C instead.

Another strategy that can be used is to wait for further technological improvements that could enable the use of a different and more advanced SPO configurations in the future.

C2

C

[Intermediate]

If the implementation of SPO happens when technology has advanced to this level and the regulatory landscape is in a similar condition, Concept A is believed to be the more feasible solution. It offers a balanced mix of human involvement and automation. However, the technology required for Concept A is complex and may require several new considerations and functions.

Depending on the rate of new technological development, it may be worthwhile to wait until an even more advanced configuration can be implemented to improve operational cost efficiency.

A

Far Future

As Concept D is the most advanced configuration, with both remote control capability and sophisticated automation systems that can manage non-nominal situations with high performance, it is a suitable configuration for the far future.

With remote control capability, ethical concerns can be better handled, and thus, it can receive high public acceptance. With advanced on-board automation systems, it enables efficient SPO with high safety.

In many ways, Concept D is a further improved version of Concept A, which means that if Concept D is feasible, so should Concept A be.

D

FIGURE 11 - SPO TECHNOLOGY ROADMAP

8 Discussion and Conclusion

In this part, some thoughts, and findings regarding possible flaws with the result and recommendations for future work are discussed and concluded. Complementing aspects of the result chapter are also discussed to provide a broader conclusion of the topic. The chapter includes a summary that concludes the complete project as well as connects the project findings to the initial research questions.

8.1 Ethical Model for Configurations

The configuration framework generated and the related priority sequence for the different configurations does not take into consideration the ethics and morals behind the decisions in the different task groups. The discussion of ethics is complex and subjective, but it will influence how the operation of a single pilot flying is done and the related functions and solutions. It was found during the idea generation process for the different configurations that in practice, ethics will influence who has the final say in different decisions, what process will be automated and what decision the pilot flying will be informed about. In contrast to dual pilot operations, where there are two pilots' opinions and external inputs from radio communication, in SPO one person's judgement has the potential to determine a critical decision alone which could be a big risk when it comes to procedure violation.

To put this in the context of system development of the configurations, another independent framework was created during the idea generation process. This framework can be used along with the system configuration framework to decide which person(s)/system(s), has the last say in decisions based on majority voting. However, it is important to consider that this model would not be useful in system configurations where only the pilot has the authority to make decisions, as there are no alternative commands to be considered. This framework can be seen in Table 19.

The framework generated consists of a weight and score model where a decision, either yes (1), no (-1), or neutral (0) multiplied by the specific persons/systems voting weight. In SPO, the different decision-makers could be the pilot itself, the onboard automation system as well as external decision-makers on the ground. Depending on the ethics and values, these different decision makers will have different weights in their decisions. Below are some different possible weighting arrangements with examples.

Decision Scores
Yes = 1, No = -1, Netural = 0

Ethical Model - Alternative #1	Pilot	Auto	External	Total	Outcome
Score Model	4	1	2		
Example Input	1	-1	-1		
Example Score	4	-1	-2	1	Yes

Ethical Model - Alternative #2	Pilot	Auto	External	Total	Outcome
Score Model	2	1	4		
Example Input	1	-1	-1		
Example Score	2	-1	-4	-3	No

Ethical Model - Alternative #3	Pilot	Auto	External	Total	Outcome
Score Model	2	0	1		
Example Input	1	-1	-1		
Example Score	2	0	-1	1	Yes

Ethical Model - Alternative #4	Pilot	Auto	External	Total	Outcome
Score Model	1	0	2		
Example Input	1	-1	-1		
Example Score	1	0	-2	-1	No

Ethical Model - Alternative #5	Pilot	Auto	External	Total	Outcome
Score Model	4	2	3		
Example Input	1	-1	-1		
Example Score	4	-2	-3	-1	No

Ethical Model - Alternative #6	Pilot	Auto	External	Total	Outcome
Score Model	3	2	4		
Example Input	1	-1	-1		
Example Score	3	-2	-4	-3	No

TABLE 19 - ETHICAL MODEL FOR SPO CONFIGURATIONS

As can be seen, depending on how the ethics model is configured, the same type of decisions will result in a different output. The weighting is designed to ensure there are no possible ties in decision-making even if there is a neutral response from one of the decision-makers. The models above also cover both cases when the automation system has the possibility to make decisions (value is above 0) and cases when automation does not have the possibility (value is 0). Worth mentioning is that this is only an extract of some possible decision models and that there are plenty more arrangements possible depending on the system configuration used and which system ethic that is desired. However, since this question cannot be answered completely objectively, it was in this thesis project decided that decisions regarding the configuration will not use this ethical model as a basis.

8.2 Human Factors

Throughout the process of investigating obstacles with SPO, it became evident that human factors play a crucial role. In DPO, the secondary pilot or first officer is used for addressing various human errors and limitations. However, for SPO to ensure safety and maintain a comparable level of workload, the integration of automation systems becomes necessary. Nonetheless, the concept of human factors involves a wide range of considerations, making it challenging to make specific functions as the problems are not very specific at this stage. Consequently, many errors associated with human factors give rise to needs and strategies that should be considered when developing other functions, rather than designing isolated technical human factor functions.

For this reason, many functions which already exist on today's typical DPO commercial aircraft are the same for SPO but with other performance requirements to ensure equivalent safety levels. This can for example be things such as headset durability or button sizes. Some indication of how performance requirements can be determined are given in the remarks for the generated functions in the project, however, for functions that already exist in DPO aircraft, no requirements or remarks guiding how to set an appropriate requirement have been determined, which is something that should be looked in to during future work.

8.3 Operational Aspects

Initially, it was determined that operational aspects would largely fall outside the scope of this project as less suitable for a product development project. However, as progress was made, it became apparent that its impact was more significant than originally anticipated. While technical solutions can be the answer in some cases to problems that occur with SPO, many other problems were believed to be better suited with solutions that involved operational changes such as new safety routines for increased overall feasibility. However, as operational aspects were not included in the project, some of these aspects have not been considered any further. It also appears that to provide detailed technical solutions to support SPO, there is a need for determining more specific operational principles to be able to design technical solutions which can provide support for these.

8.4 Configurations

The configurations and their related task allocation are a simplified version of reality. The framework used to generate this concept provides an effective overview of different aspects of solutions. However, a more detailed function flow analysis needs to be created to understand, hence reducing uncertainty, regarding how different tasks interact with each other. Currently, tasks in the framework are classified as either simple or advanced in the groups aviate, navigate, communicate, and system management. As previously mentioned in the report, the overlap between these groups needs to be addressed in future work. In addition, these tasks also need to be seen from a bigger picture to understand how they interact with each other by looking at when and in what order they occur and their impact on mental and physical workload.

8.5 Functions and Requirements

The specific functions generated in the project have been found through risk assessment processes and human factor analysis. However, these are preliminary, and there are most certainly many more new functions relevant for SPO in commercial aviation which have not been discovered in this work. The ones that have been constructed require more evaluation, such as cost and safety, to justify a possible implementation or replacement of existing functions. To do this, the functions need to be further specified with alternative sub-functions and solutions. Future work should also focus on finding more sub-functional alternatives to the functions presented and using tradeoff studies to show which may be more promising. In addition to this, requirements also need to be determined in future work, both for new SPO-related functions and requirements for existing functions. The need to adjust requirements in existing functions may be a need for increased performance in certain areas with SPO. Some of the given remarks in the function list indicate what type of performance might be required for that function.

8.6 Regulation and Social Acceptance

The aviation industry is in general a slowly changing industry where new solutions and innovations take years to implement. The airspace regulations are no different, meaning that a large amount of the regulation sections of today were created a long time ago for an industry that looked significantly different from the aviation industry of today. This touches upon the challenge of getting novel technology and solutions such as SPO accepted and certified since most regulations are based on aircraft having at least two pilots during operation. The regulations are of course important to comply with, however, at some point, the industry is likely to comply with solutions such as SPO which potentially could lead to revised sections within the regulations. The regulations are often strongly related to social acceptance where for example if SPO were to be socially accepted this would help push the regulations in the same direction. However, social acceptance for solutions such as electric aircraft which will allow for more sustainable travel is likely to be socially accepted before SPO. With new technology being proven to work and to be safe the social acceptance of SPO will also increase and in that manner, help push the regulations.

8.7 Summary

As automation and safety technology advance, the idea of using SPO in commercial aviation is becoming more compelling. In this project, a function and risk analysis along with literature studies has been conducted to explore and clarify the general obstacles and challenges with SPO. From this, general needs and strategies were found, which made it possible to design a framework for dividing tasks between the flight crew and automation. The framework was then used to generate different theoretical configuration concepts for SPO. These concepts were evaluated with certain assumptions and constraints in mind. The concepts were then utilized in an evaluation process that reduced the number of concepts to a final one. This final concept was then further improved with specific functions using function analysis methods in the form of risk assessments. This product development process answered RQ1 - *What configurations for single pilot operation are best suited within given constraints and needs?* and RQ2 - *What functions would support single pilot operation?*

By addressing RQ3 - *Is single pilot operation a feasible alternative in the current environment?* and RQ4 - *How could the use of a single pilot be phased into operations?* Our research has found that SPO can be achieved in different ways, but it requires thorough analysis and evaluation to ensure the safety and feasibility of such solutions. Today, human factors are a key challenge for successful implementation, and using technology as a fallback for issues such as pilot incapacitation, high workload, and decision error and violation is complex and requires ethical considerations.

The report provides preliminary suggestions on the potential path of SPO in the future, as well as theoretical concepts that could potentially lead to practical solutions. Nonetheless, there remains significant uncertainty surrounding the subject, which must be minimized to advance further. To reduce this uncertainty, it is necessary to conduct thorough testing of developed functions and systems in future work to be able to validate and verify parameters to ensure the feasibility of the concepts.

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10 Appendix

10.1 Appendix A – Functional Hazard Analyses

Functional Hazard Analysis (SPO Related Failure Conditions)

Function Failure Reference	ATA - Function	Further Development	Failure Condition	Failure Effect	Close Related Certification	Subjective SPO Classification	Typical DPO Classification	Remarks
	21 - Air Condition							
1		PRECLUDED	Loss of cabin pressurization	Unpleasent conditions and the need of rapid descent to safe altitude		MAJ	MAJ	Rapid descent would be required in case of unintended depressurization. A slight increase in workload for SPF but not hazardous if no other problems occur
	22 - Auto Flight							
2		INCLUDE	Loss of autoflight	Increased workload	1301,1302,1309,1329,1523,672,904	HAZ	MAJ	The pilot workload is increased. During SPO the pilot cannot be relied on to perform other occurring tasks accurately
	23 - Communication							
3		INCLUDE	Loss of communication system	Loss of pilots ability to communicate and receive assistance From external parts	1301,1302,1307,1309,1431,1523	HAZ	MAJ	In DPO, the PM provides redundancy, however, in SPO communication is lost.
4		PRECLUDED	Loss of transmission system	Loss of external communication and assistance		HAZ	HAZ	Loss of connection to ATC reduces the safety of approaching the runway to a hazardous level for both SPO and DPO

25 - Equipment							
5	INCLUDE	Loss of seat fixation	Pilot unable to control aircraft	1301,1302,1523,785	CAT	MAJ	In a DPO scenario, the PM has the authority and possibility to operate the aircraft. However, in an SPO scenario, a failure of the seat restraint system would be deemed a catastrophic event.
6	INCLUDE	Loss of ability to reach or interract with switch/display/lever	Lack of ability to control certain elements of the aircraft such as engage/disengage critical systems	1301,1302,1309,1523,685,777	MAJ-HAZ	NSE	If The PF is unable to reach the switch/lever/display the PM has it within reach in DPO. However, In SPO the PF will not be able to access it.
26 - Fire Protection							
7	PRECLUDED	Loss of fire extinguishing system	Requires manual extinguishing, workload, reduces flight compartment crew		CAT	HAZ-CAT	In DPO the PM can leave the flight compartment to manually put out the fire, However In SPO the pilot is not likely to be able to leave the flight compartment.

27 - Flight Controls							
8	INCLUDE	Loss of proper stick input	Loss of flight control(s)	1301,1309,1302,1523,685,771,777,779	CAT	MAJ	Loss of stick input is to be considered as missing control input or wrong input. In DPO, the PM in this case has the ability to take over the command of the aircraft. In SPO, a loss of control input would be considered a catastrophic event.
9	INCLUDE	Loss of proper pedal input	Loss of flight control(s)	1301,1302,1309,1523,685,771,777,779	CAT	MAJ	Loss of pedal input is to be considered as missing control input or wrong input. In DPO, the PM has in this case the ability to take over the command of the aircraft. In SPO, a loss of control input would be considered a catastrophic event.
10	INCLUDE	Loss of proper dedicated NWS input	Loss of nose wheel steering capability	1301,1302,1309,1523,685,745,771,777,779	MAJ-HAZ	MAJ	Mitigated by the differential braking capability but in DPO also by the redundancy of having PM control NWS.
11	INCLUDE	Loss of proper trim switch input	Loss of flight control, unsteady flight	1301,1302,1309,1523,685,771,777,779	MIN	MIN	Mitigated by the pedestal back-up switch but in DPO also by the redundancy of having PM controls for trim.
28 - Fuel							
12	PRECLUDED	Loss of fuel dump ability	Fuel dump not performed in example emergency landings		HAZ-CAT	HAZ-CAT	Depending on the situation can lead to catastrophic events no matter the size of the flight crew.

31 - Indicating / Recording Systems							
13	INCLUDE	Loss of indication systems	Loss of important information	1301,1302,1303,1305,1309,1321,1322,1323,1329,1523	HAZ	MAJ-HAZ	In cases where the situation could be solved with increased workload, the risk would be lower for DPO.
14	PRECLUDED	Loss of central warning system	System failures might not be detected		HAZ-CAT	MAJ-CAT	In cases where the situation could be solved with increased workload, the risk would be lower for DPO.
15	PRECLUDED	Loss of automatic data broadcasting system	Atc, other aircraft and airline have reduced understanding about aircraft sitation		MAJ	MIN	For DPO additional emergency communication and alerting can be done by PM to mitigate risk, for SPO the flight is continued without broadcast.
16	PRECLUDED	Loss Of Ability To Engage With Indicators	Unable to visually observe certain events results in that information gets lost		HAZ	HAZ	Information loss for both DPO and SPO due to the information not being presented to the flight crew.
32 - Landing Gear							
17	PRECLUDED	Loss of wheel breaking	Loss of ability to effectivly stop aircraft		CAT	CAT	Catastrophic for DPO and SPO.
18	PRECLUDED	Loss of NWS	Loss of aircraft control on ground		MAJ-HAZ	MAJ	Catastrophic but differential braking helps mitigate the risk.

33 - Lights							
19	PRECLUDED	Loss of indicator lights	Loss of important information		HAZ	HAZ	In cases where the situation could be solved with increased workload, the risk could be lower for DPO.
20	INCLUDE	Inappropriate flight compartment lighting	Fail to find critical components or switches	1301,1302,1309,1523,771	HAZ-CAT	MAJ-HAZ	For SPO stress, reduced focus, sleepiness, and ability to face workload might occur. In DPO the PM could assist lowering the risk.
34 - Navigation							
21	PRECLUDED	Loss of navigation data	Unable to navigate and position aircraft		CAT	HAZ-CAT	Navigation has to be done manually by example communicating with ATC which increases workload significantly. In DPO the PM could help reduce the pilot’s workload.
22	PRECLUDED	Unable to provide new digital flight plan	Outdated flight plan		MAJ	MIN	Increased workload where SPO and DPO PM assist could manage the changes.
35 - Oxygen							
23	INCLUDE	Oxygen mask failure	Lack of oxygen to pilot risk incapictiation. Function is usually used in high workload sitations such as emegency.	771,1523,1447,1445,1441,1438,1436,1309,1302,1301	CAT	HAZ	In DPO there is a second pilot to assist in controls not risking the aircraft. In SPO this would be considered catastrophic.

46 - Information System							
24	PRECLUDED	Loss of aircraft information	Reduced capability to monitor and verify aircraft status		HAZ	HAZ	In cases where the situation could be solved with increased workload, the risk could potentially be lower for DPO.
55 - Stabilizers							
25	PRECLUDED	Loss of ability to trim elevator	Reduced ability to control flight		HAZ	MAJ	Flying out of trim increases the workload for PF. In DPO the PM can assist with tasks or control. For SPO the situation can have hazardous consequences since the SPF cannot be relied on to perform ideally in other tasks.
56 - Windows							
26	INCLUDE	Inability to visually observe certain external events	Unable to visually observe certain events means information gets lost.	775,773,1523,1321	HAZ-CAT	MAJ-HAZ	Loss of situational awareness from visual observation is problematic for DPO and SPO, however, it is more likely that an external event is noticed by DPO than SPO.

TABLE 20 - FHA OF SPO RELATED SITUATIONS

10.2 Appendix B – Fault Tree Analyses

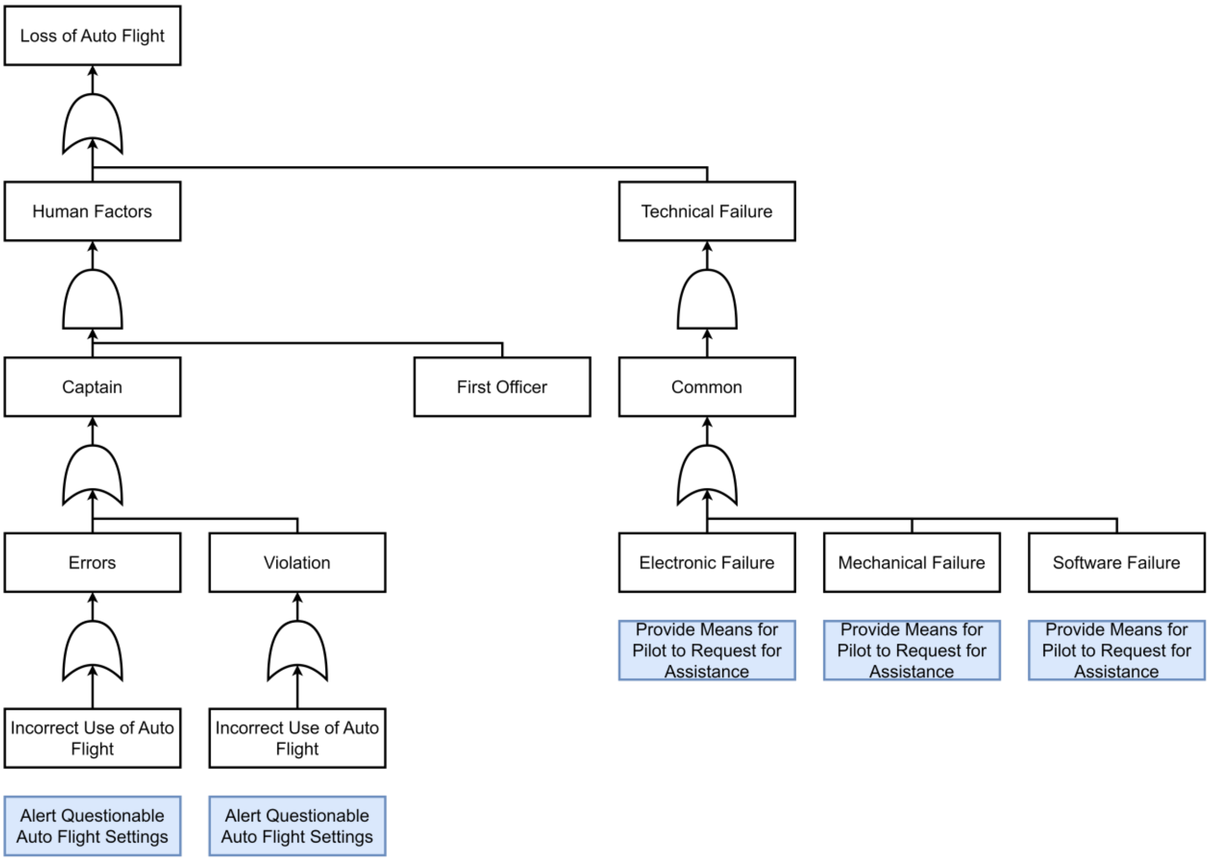

Figure 12 - FTA: Loss of Auto Flight (FHA Reference #2)

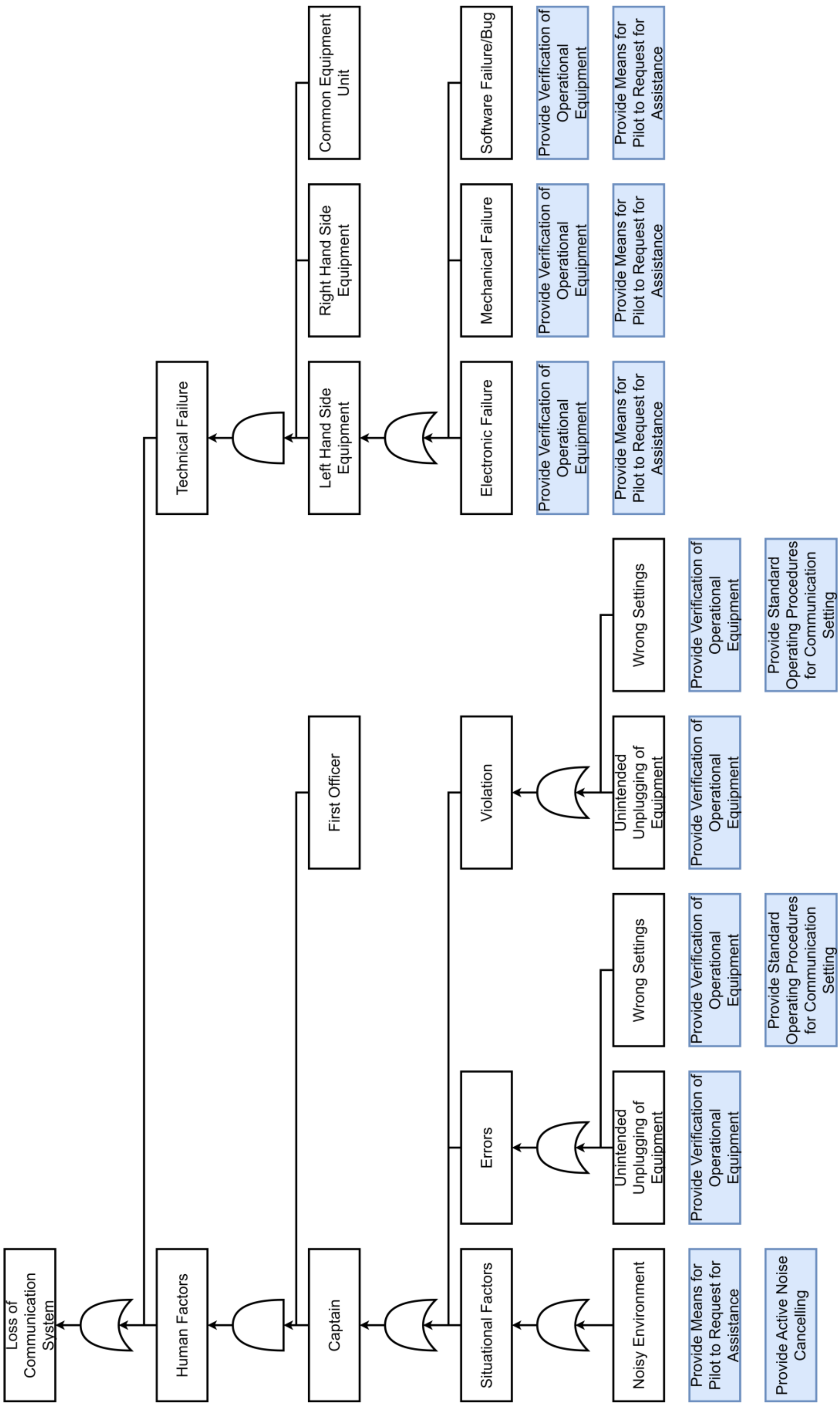

FIGURE 13 - FTA: LOSS OF COMMUNICATION SYSTEM (FHA REFERENCE #3)

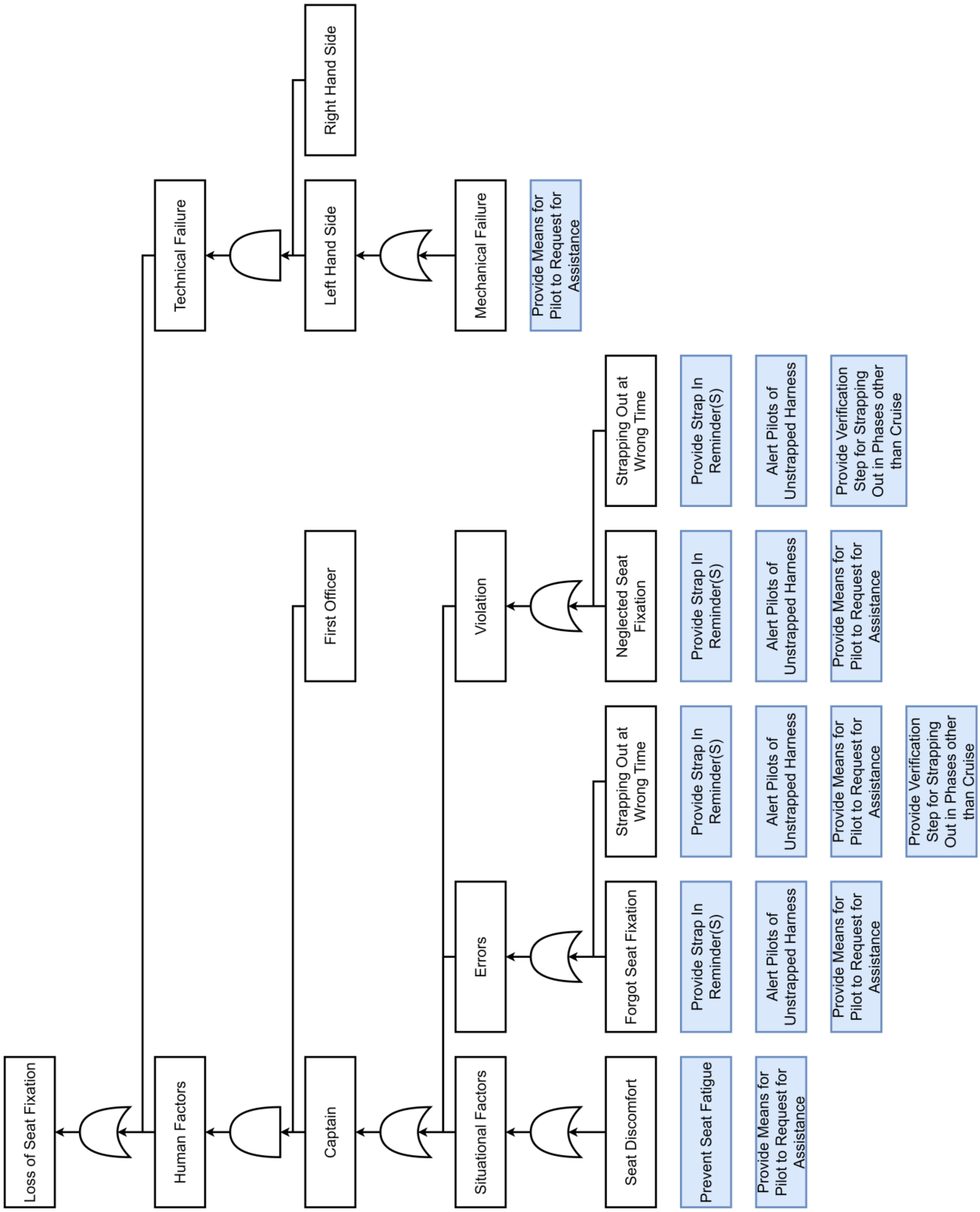

FIGURE 14 - FTA: LOSS OF SEAT FIXATION (FHA REFERENCE #5)

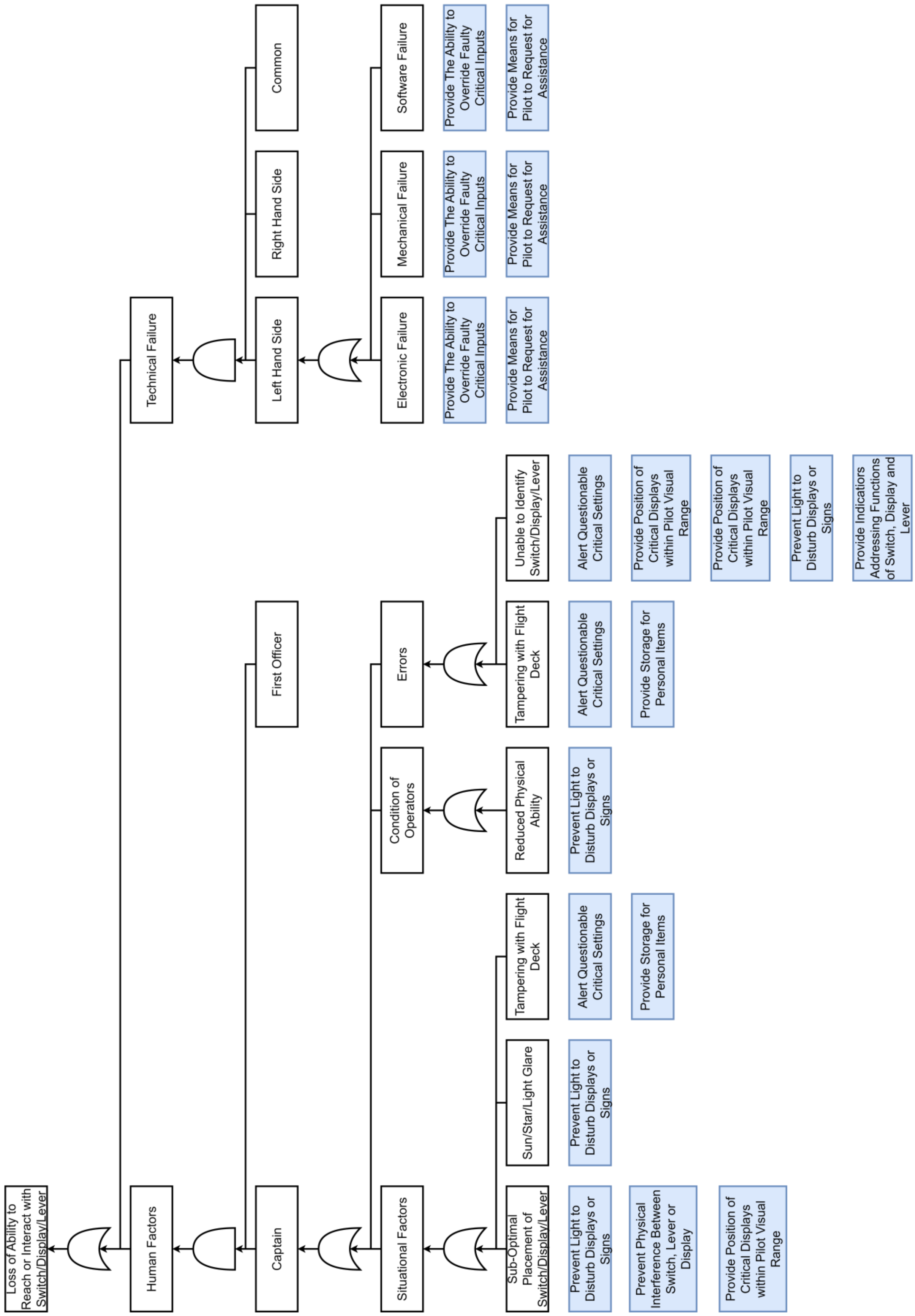

FIGURE 15 - FTA: LOSS OF ABILITY TO REACH OR INTERACT WITH SWITCH/DISPLAY/LEVER (FHA REFERENCE #6)

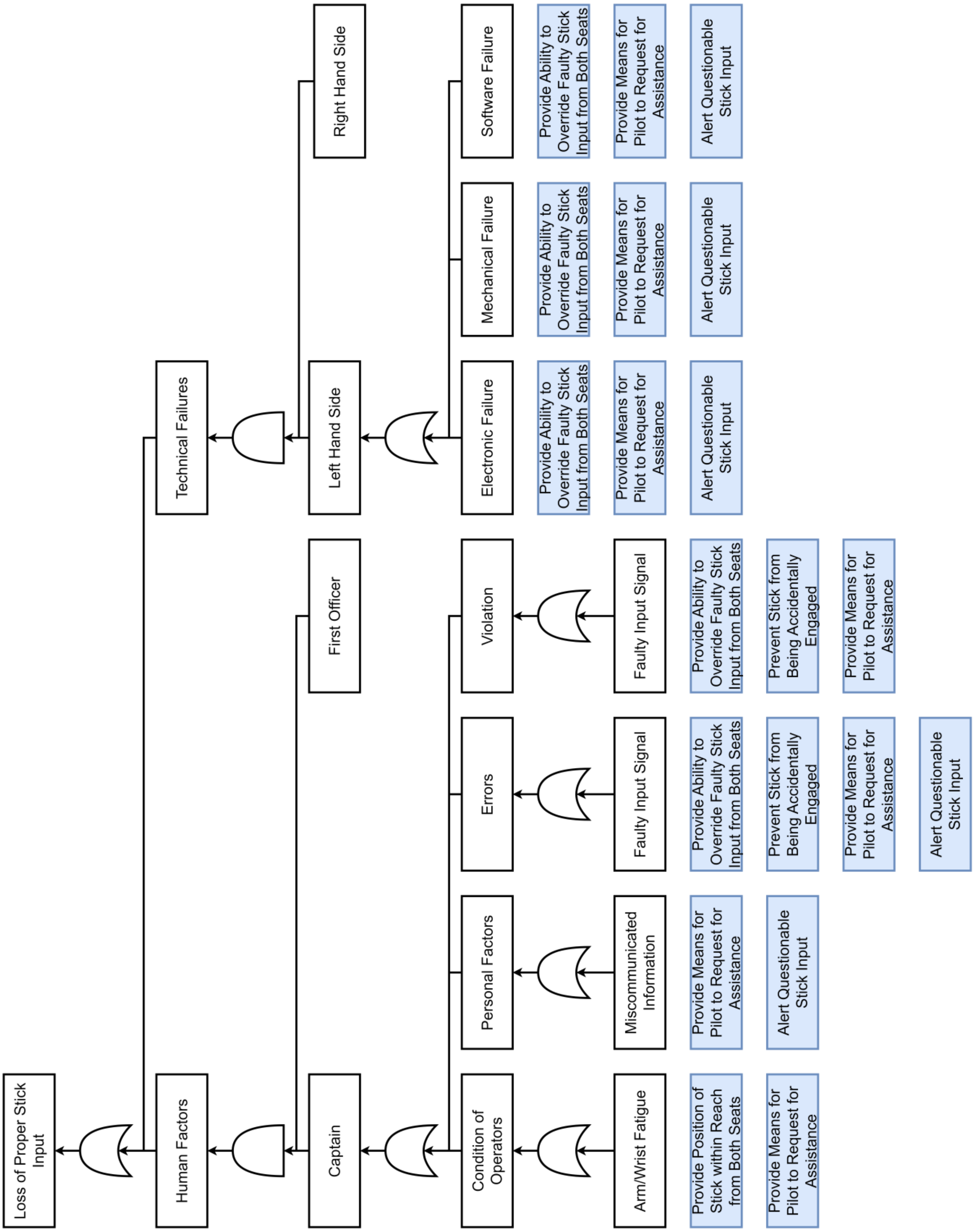

FIGURE 16 - FTA: LOSS OF PROPER STICK INPUT (FHA REFERENCE #8)

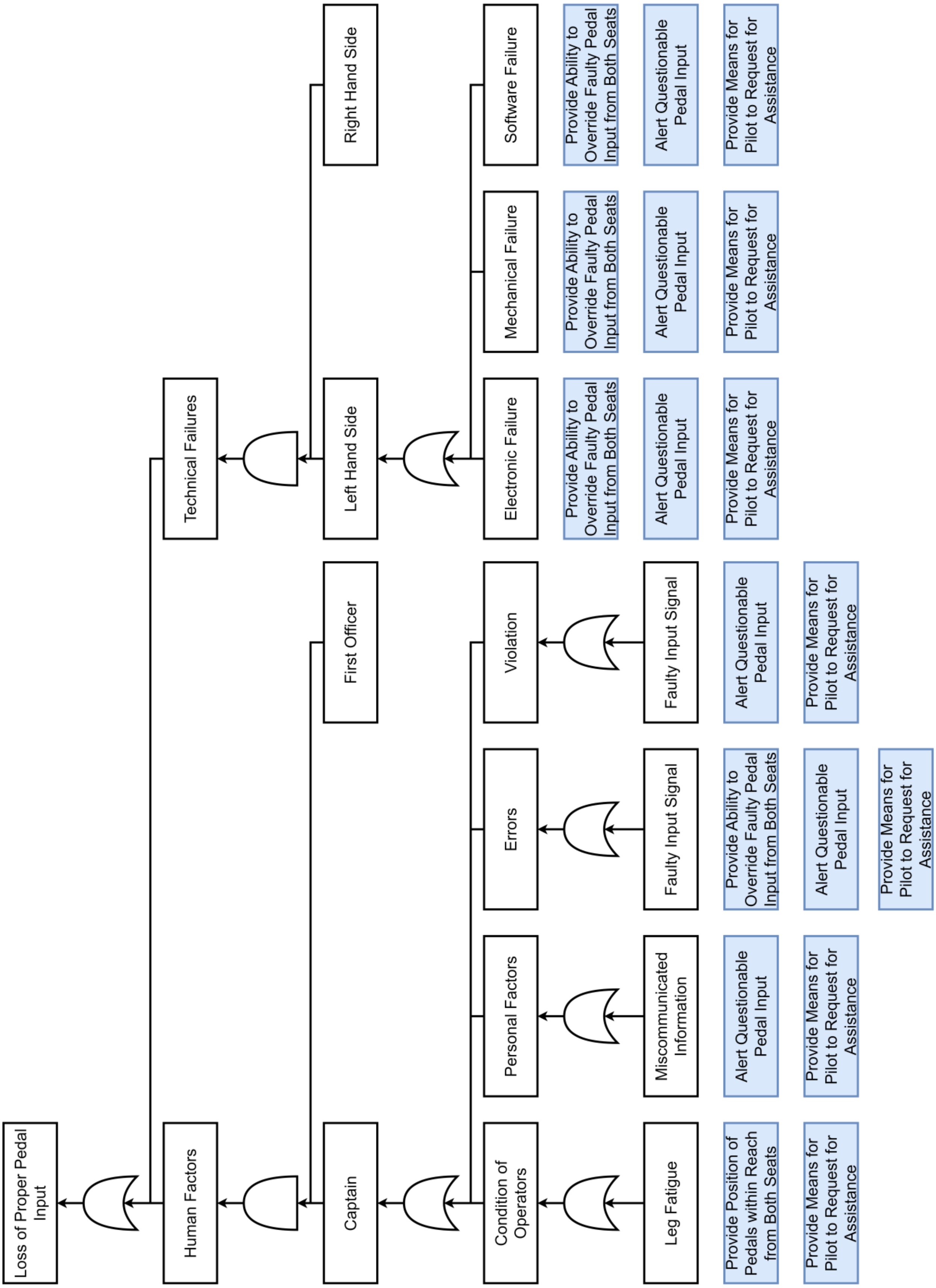

FIGURE 17 - FTA: LOSS OF PROPER PEDAL INPUT (FHA REFERENCE #9)

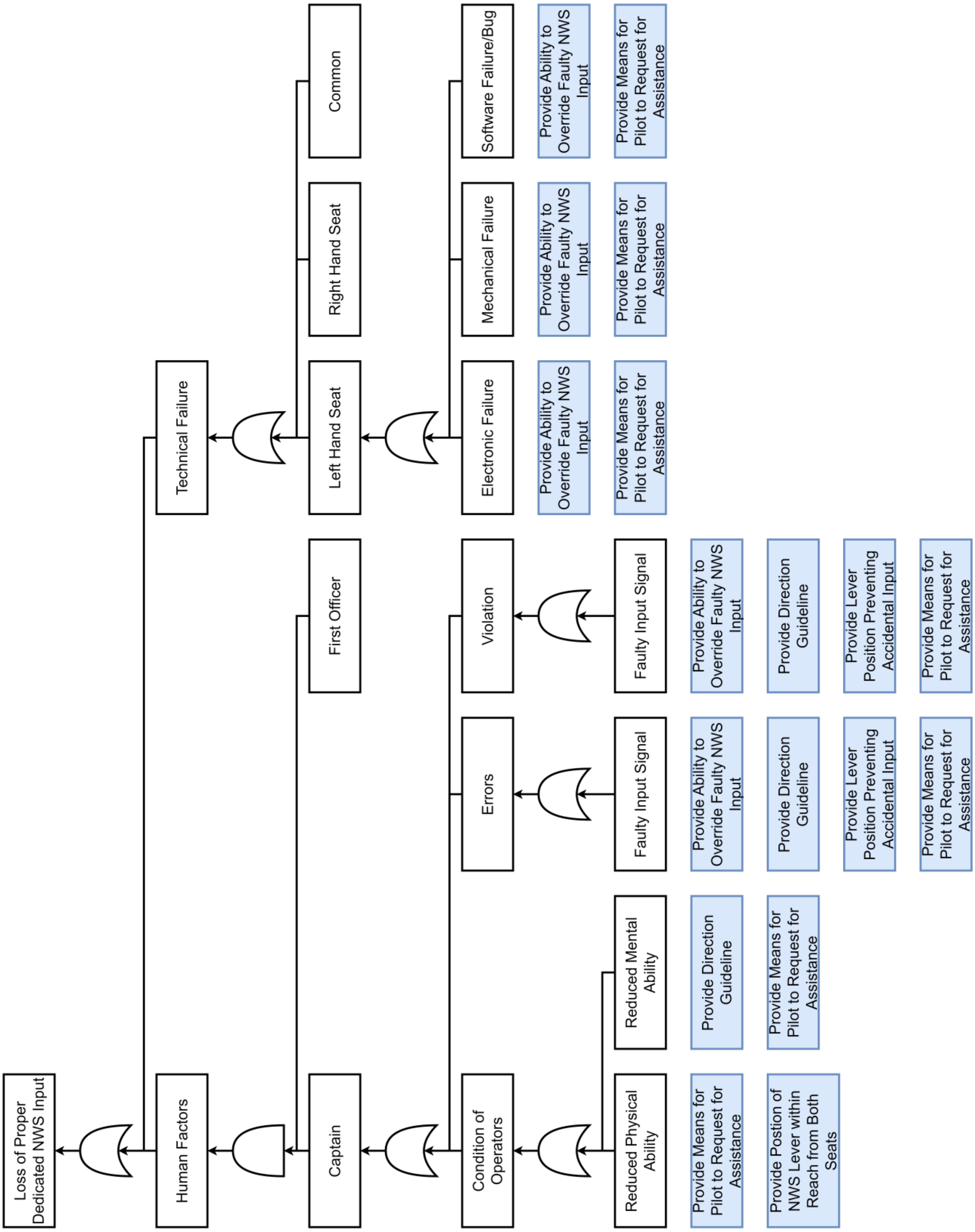

FIGURE 18 - FTA: LOSS OF PROPER DEDICATED NWS INPUT (FHA REFERENCE #10)

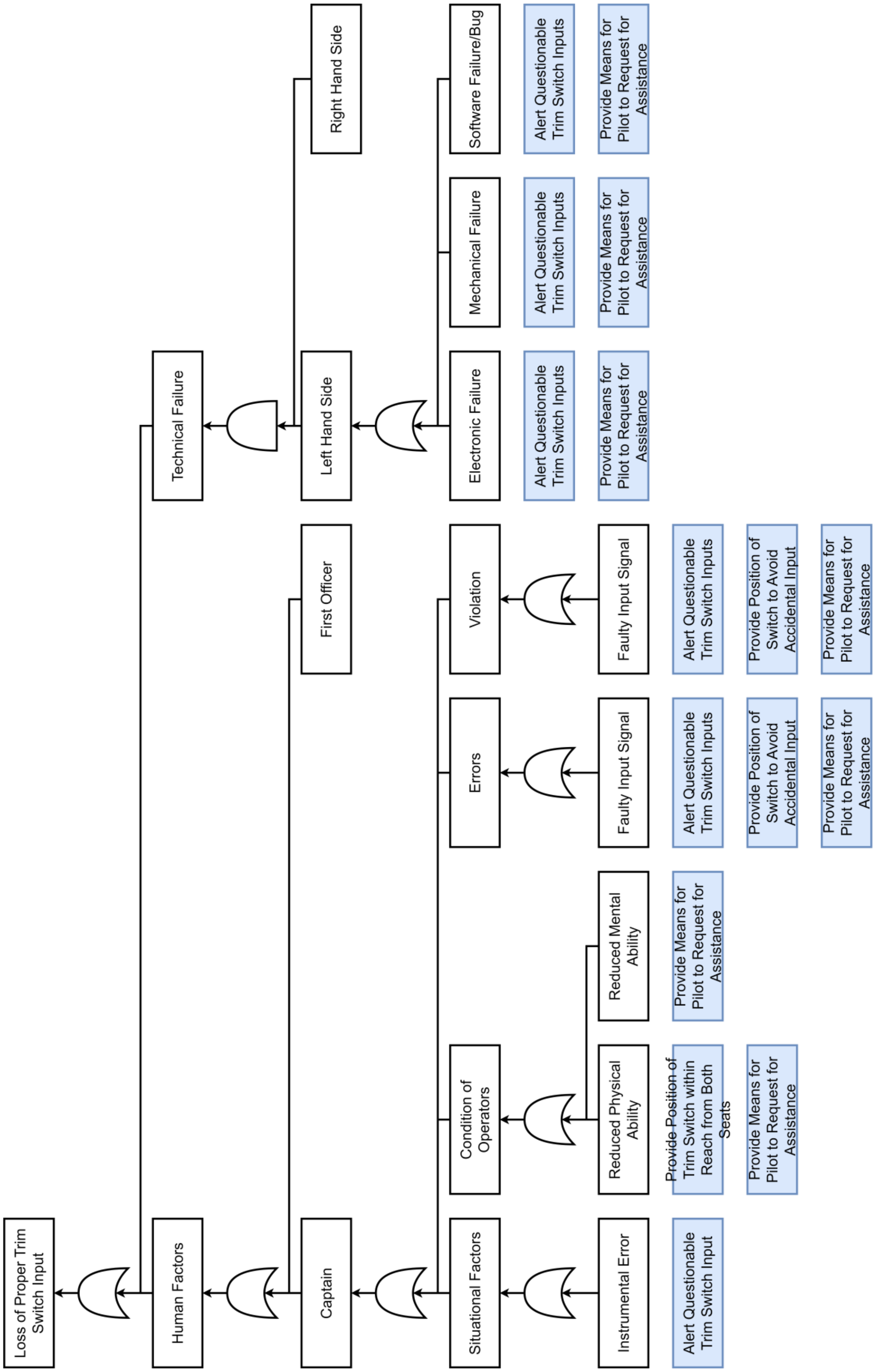

FIGURE 19 - FTA: LOSS OF PROPER TRIM SWITCH INPUT (FHA REFERENCE #11)

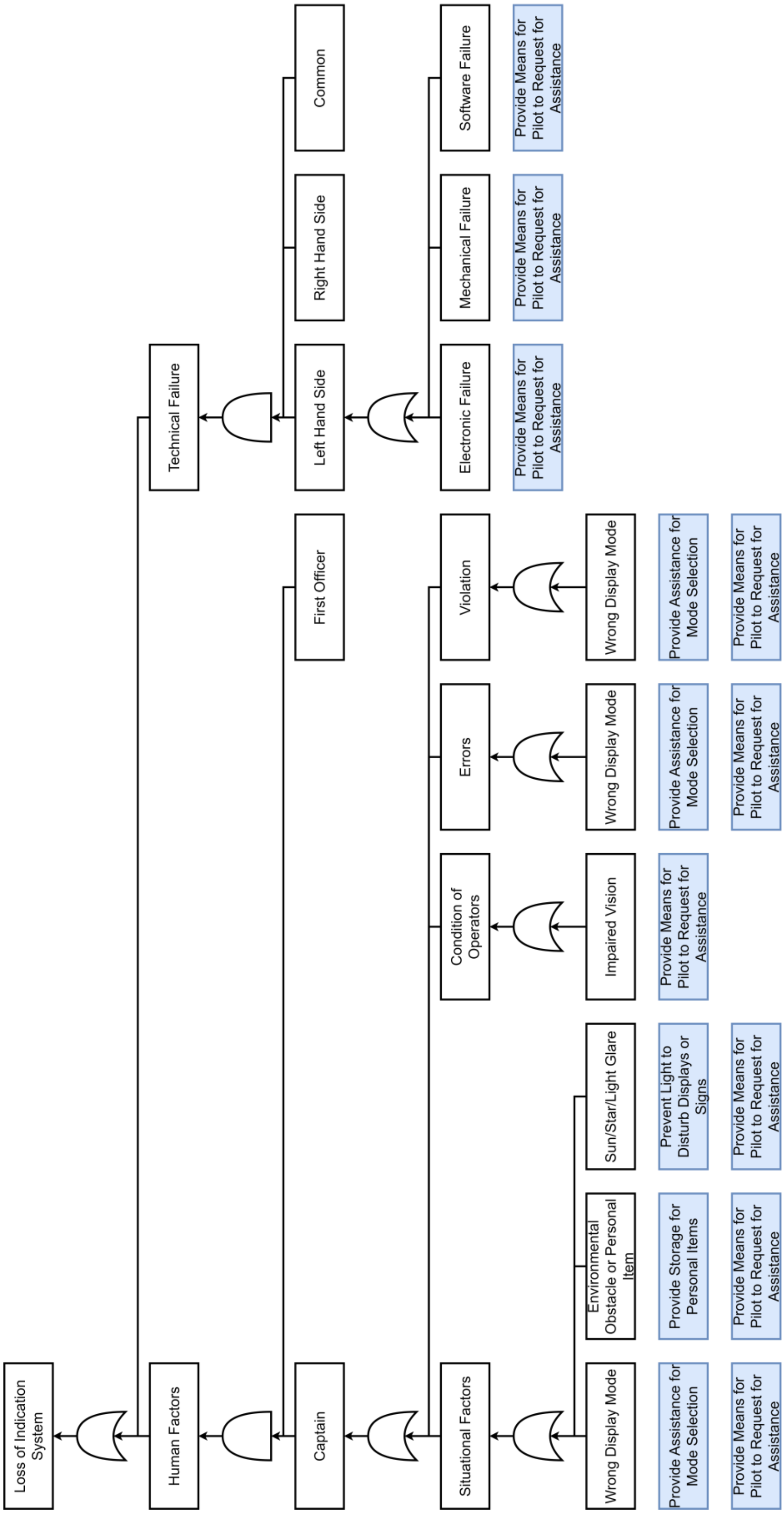

FIGURE 20 - FTA: LOSS OF INDICATION SYSTEMS (FHA REFERENCE #13)

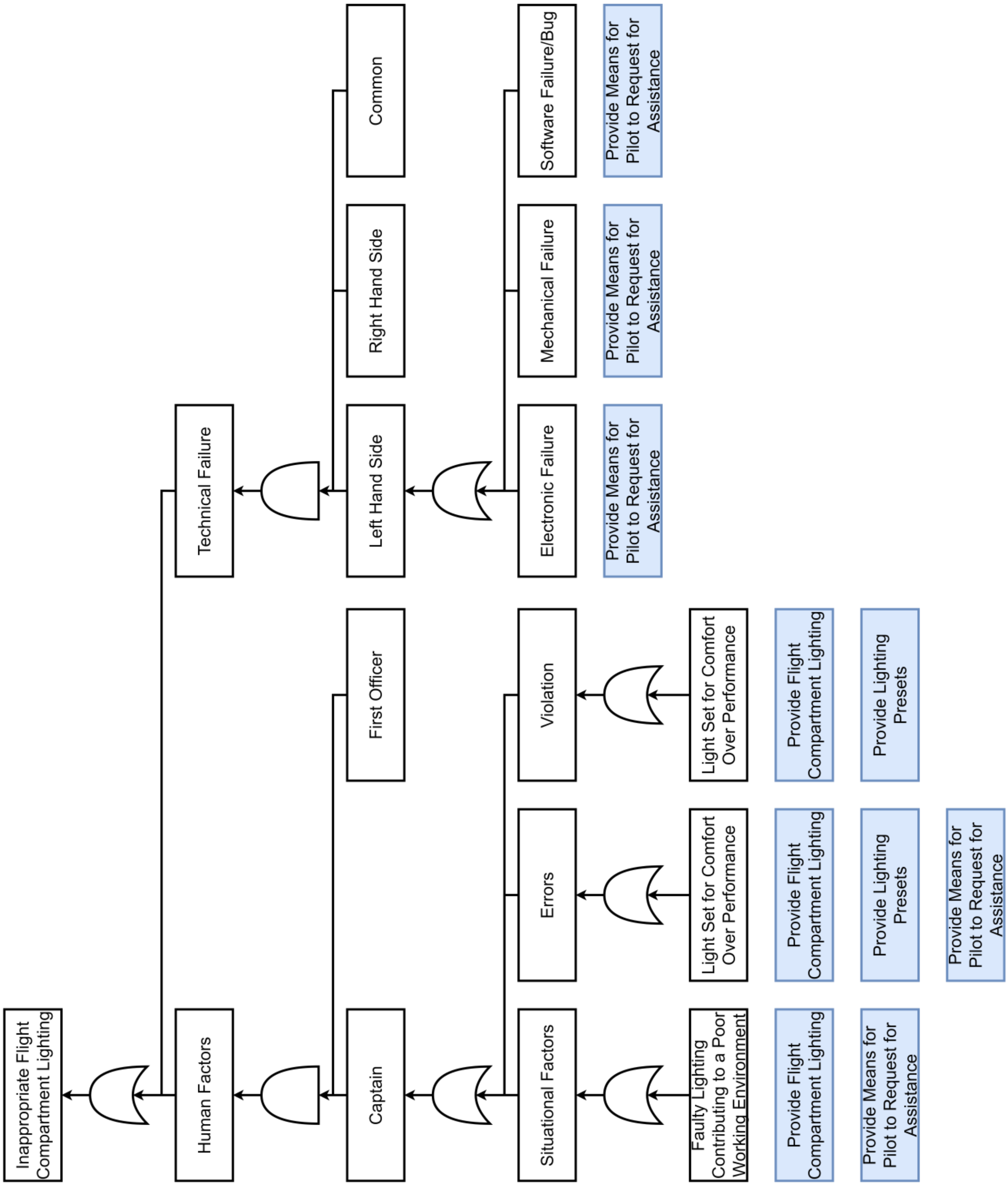

FIGURE 21 - FTA: LOSS OF INAPPROPRIATE FLIGHT COMPARTMENT LIGHTNING (FHA REFERENCE #20)

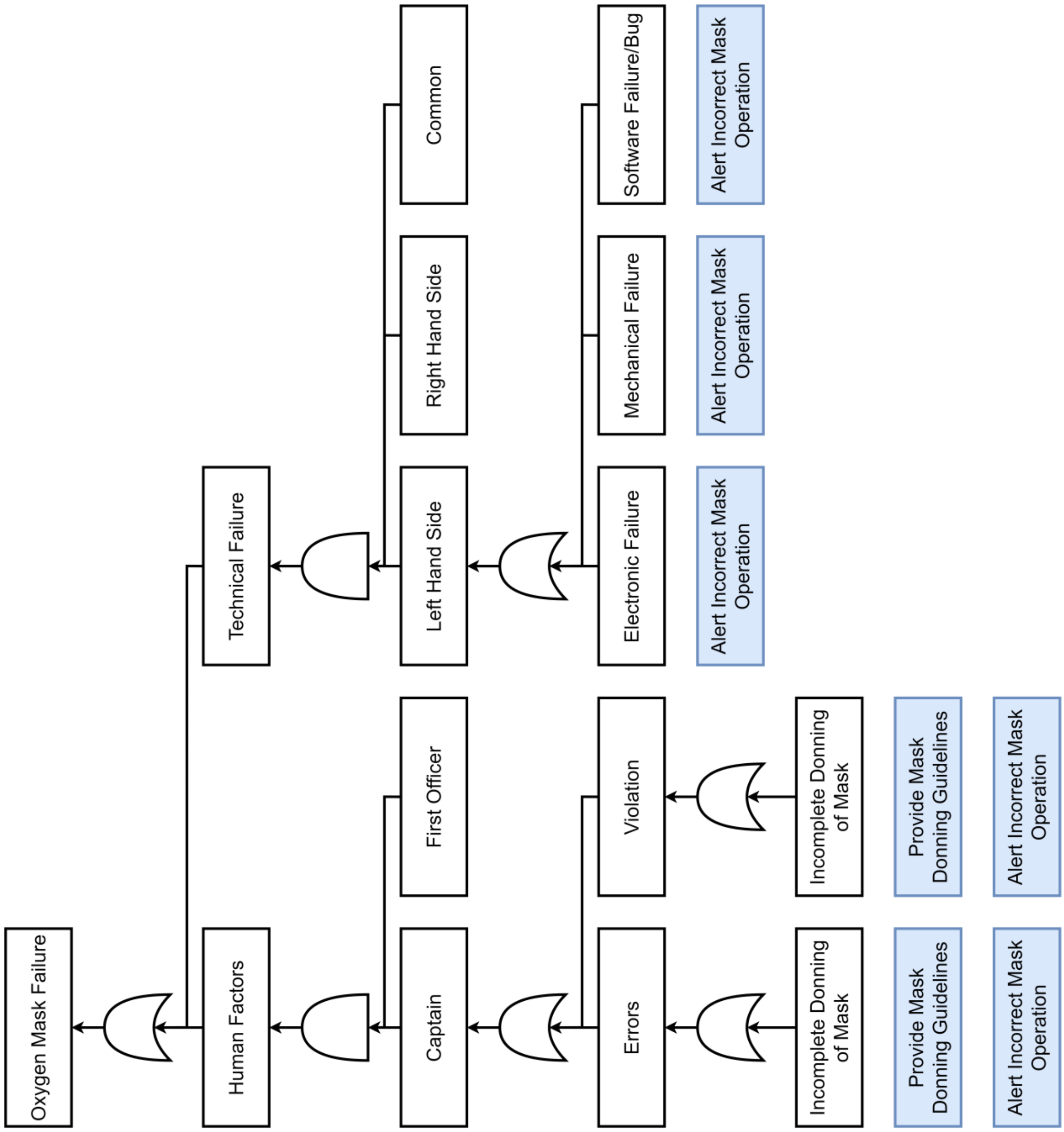

FIGURE 22 - FTA: OXYGEN MASK FAILURE (FHA REFERENCE #23)

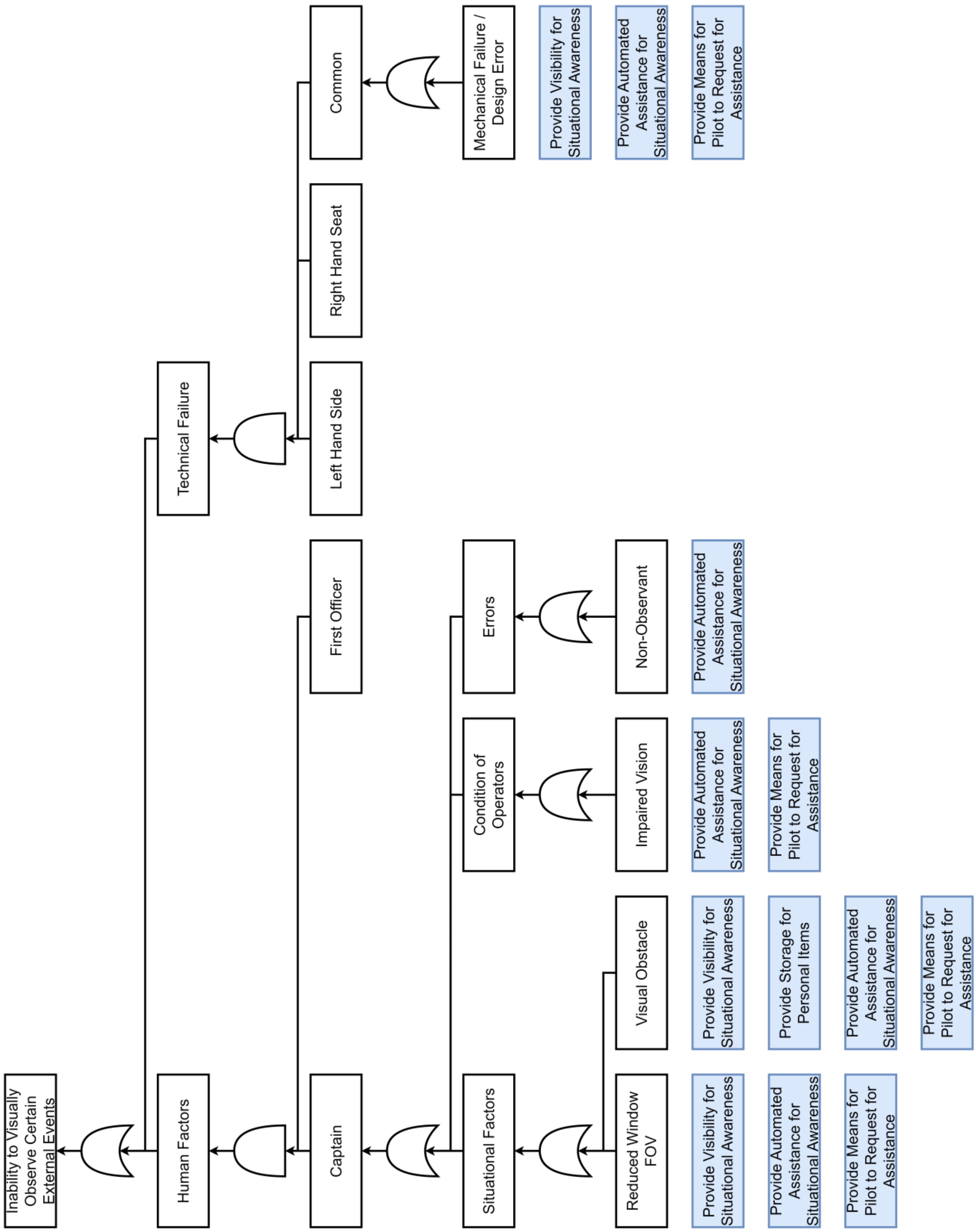

FIGURE 23 - FTA: INABILITY TO VISUALLY OBSERVE CERTAIN EXTERNAL EVENTS (FHA REFERENCE #26)

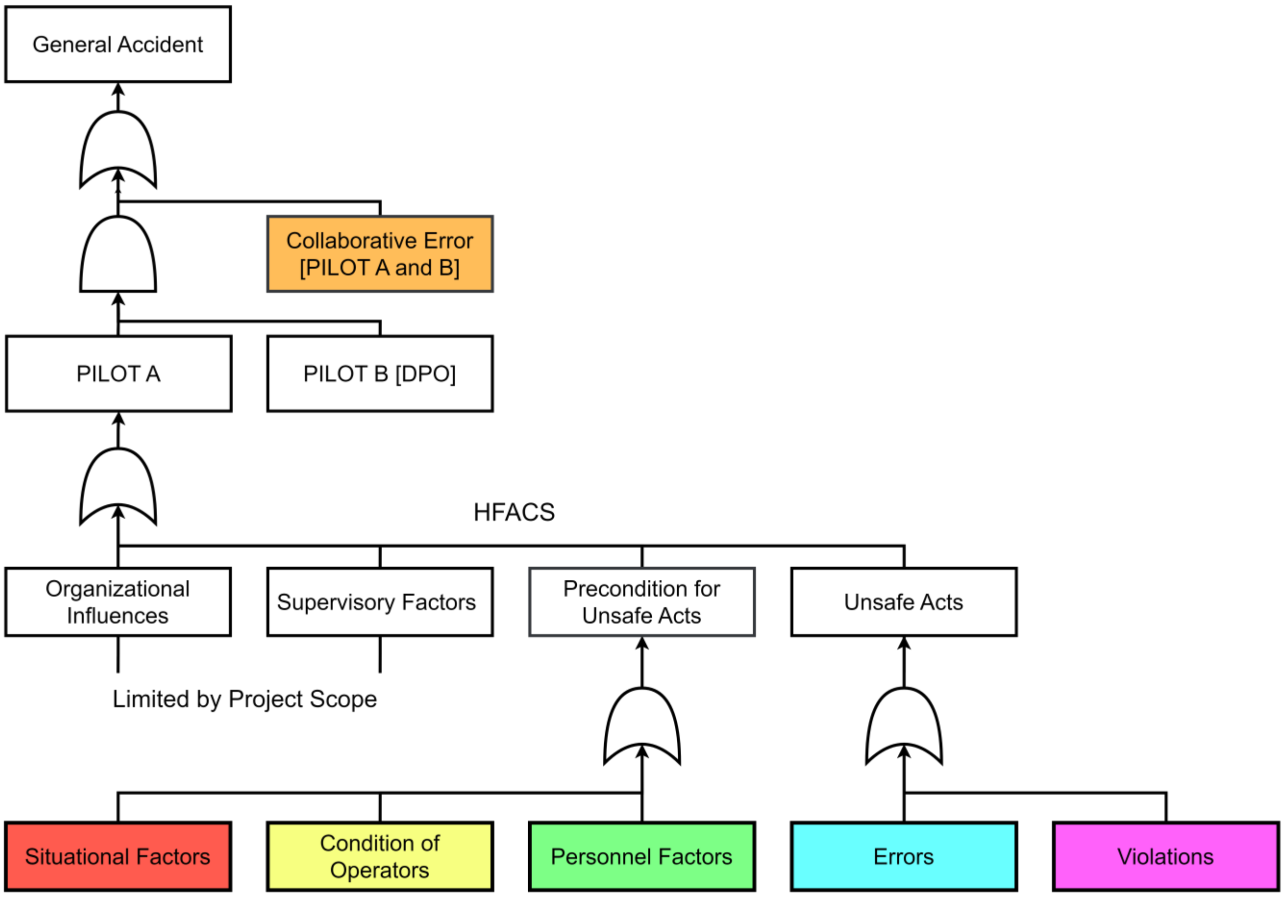

FIGURE 24 - HUMAN FACTORS FTA: MAIN

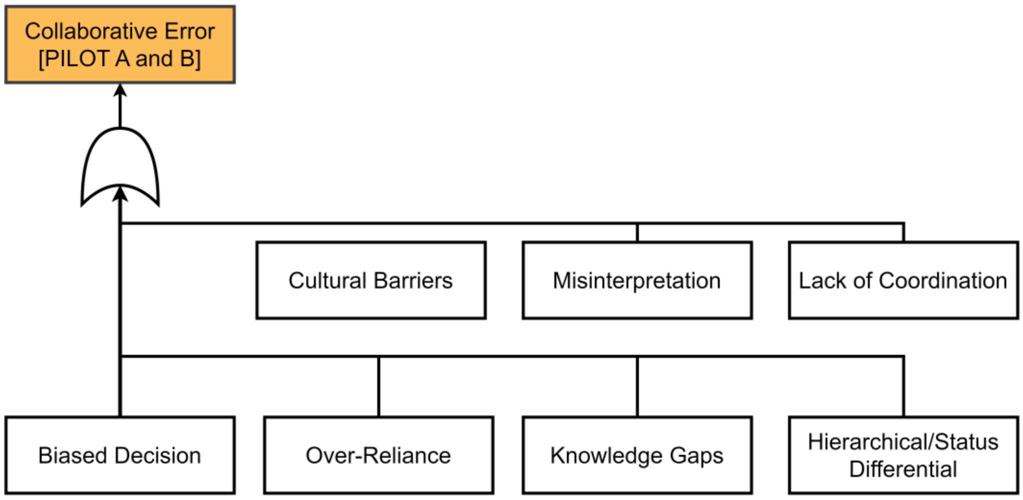

FIGURE 25 - HUMAN FACTORS FTA: COLLABORATIVE ERROR

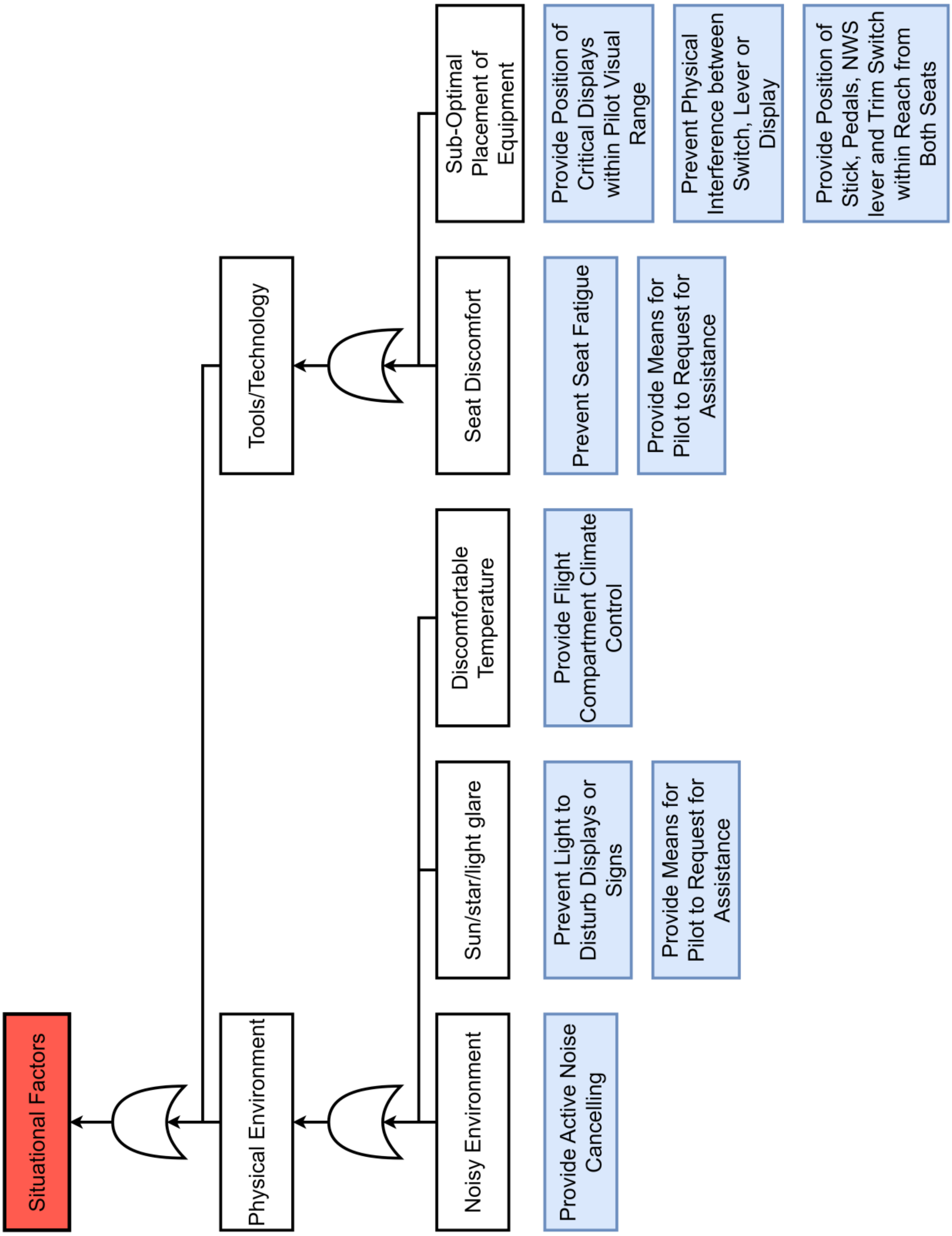

FIGURE 26 - HUMAN FACTORS FTA: SITUATIONAL FACTORS

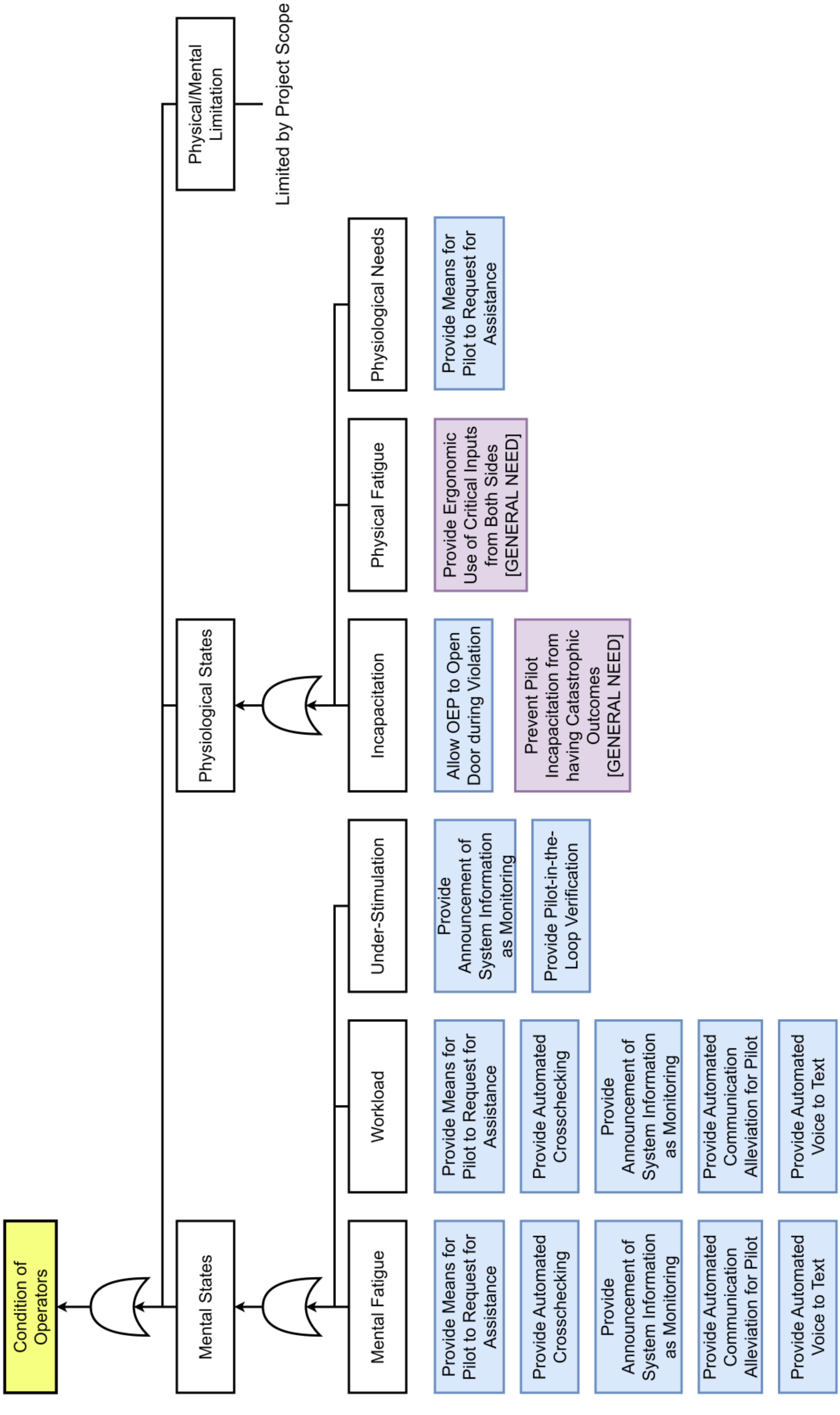

FIGURE 27 - HUMAN FACTORS FTA: CONDITION OF OPERATORS

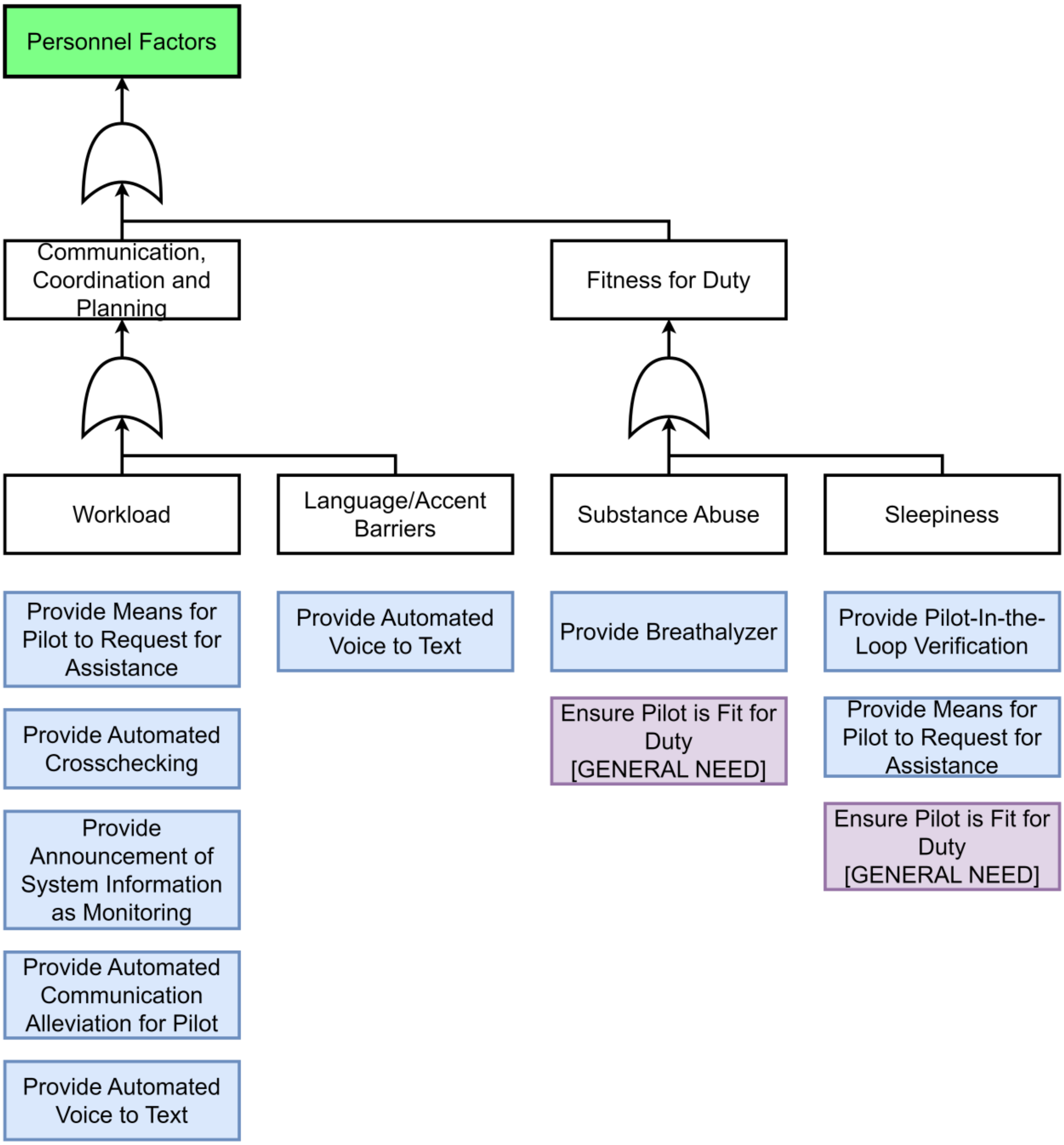

FIGURE 28 - HUMAN FACTORS FTA: PERSONNEL FACTOR

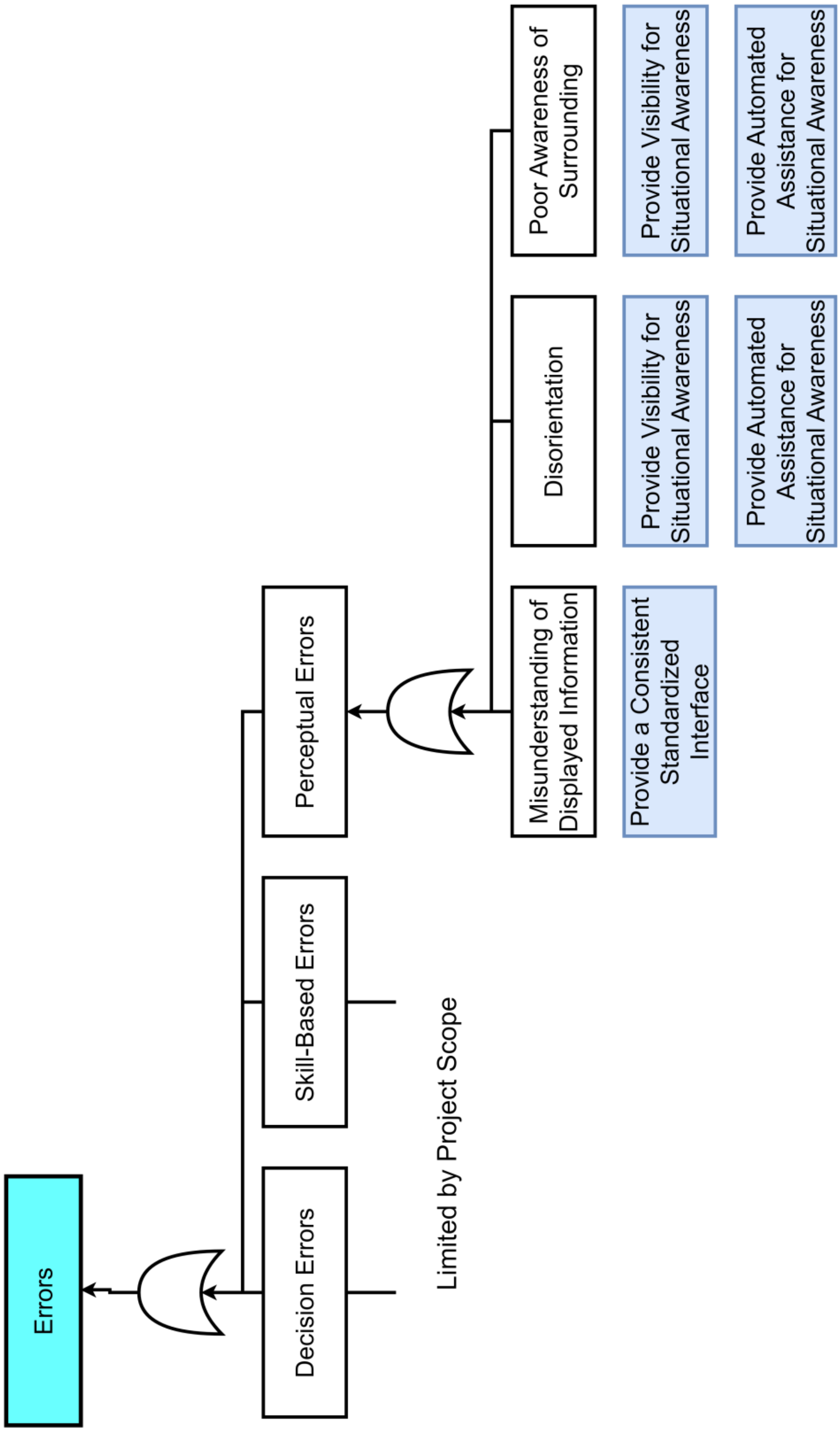

FIGURE 29 - HUMAN FACTORS FTA: ERRORS

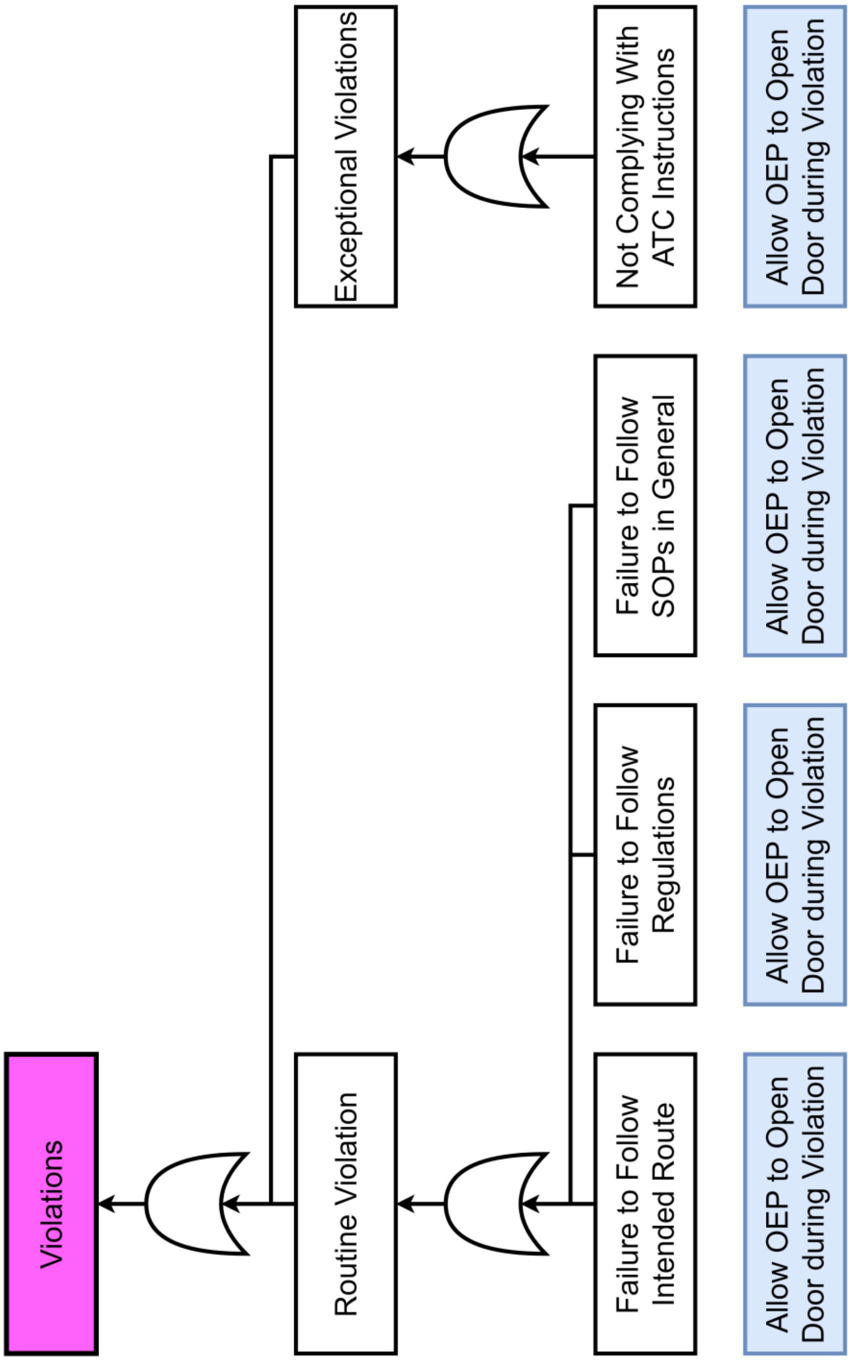

FIGURE 30 - HUMAN FACTORS FTA: VIOLATIONS

10.3 Appendix C - Functions, Needs and Strategies

SPECIFIC FUNCTIONS FOR SPO				
Failure Source	**ID**	**Function Name**	**Corresponding Fault**	**Function Description**
2. Loss of auto flight	F1	Alert questionable auto flight settings	Incorrect use of auto flight	Alert pilot of suspicious or inappropriate auto flight settings to prevent flight in inefficient or situationally unsuitable modes. This can also alleviate some workload since it takes away the need for the pilot to monitor and make sure that the right mode is used.
	F2	Provide means for pilot to request for assistance	Electronic failure, Mechanical failure, Software failure	The single pilot flying should have the means to call for assistance when needed, for example in case of increased workload due to auto flight failure. For the C2 configuration, this would mean requesting OEP support.
3. Loss of communication system	F3	Provide verification of operational equipment	Electronic failure, Mechanical failure, Software failure, Unintended unplugging of equipment, Wrong settings	A verification that the equipment is functional would allow for a potential malfunction to be acknowledged before and not during a critical situation.
	F4	Provide standard operating procedures for communication settings	Wrong settings	SOPs for what settings should be used in different situations and a specific technical routine to handle the communication equipment mitigate the risk of the wrong settings being used.
	F5	Provide active noise cancelling	Noisy enviroment	This would allow for the active canceling of noise and unwanted sounds allowing the pilot to focus on the tasks without unnecessary disturbances. This will also reduce communication errors since it will be easier and clearer to understand what for example the ATC operator says.
	F2	Provide means for pilot to request for assistance	Noisy environment, Electronic failure, Mechanical failure, Software failure	The single pilot flying should have the means to call for assistance when needed, for example in case of increased workload due to auto flight failure. For the C2 configuration, this would mean requesting OEP support.
5. Loss of seat fixation	F6	Prevent seat fatigue	Seat discomfort	The pilot should be comfortable to a satisfactory degree throughout the whole flight removing the need for unstrapping for eventual relief or leg stretching.
	F7	Provide strap in reminders	Forgot seat fixation, Neglected seat fixation, Strapping out at wrong time	Remind pilots to strap in to prevent forgetting the harness.
	F8	Alert pilot of unstrapped harness	Forgot seat fixation, Neglected seat fixation, Strapping out at wrong time	Makes sure that the pilot is aware of not being strapped in. An alert could both assist in remembering to strap in as well as provide a for example disturbing or annoying sound or light which is removed simply by strapping in.
	F9	Provide verification step for strapping out in phases other than cruise	Strapping out at wrong time	Added task needed for strapping out when in a critical phase reduces the risk of the pilot being unstrapped when it can lead to catastrophic outcomes.
	F2	Provide means for pilot to request for assistance	Seat discomfort, Forgot seat fixation, Neglected seat fixation, Mechanical failure	The single pilot flying should have the means to call for assistance when needed, for example in case of increased workload due to auto flight failure. For the C2 configuration, this would mean requesting OEP support.

7. Loss of ability to reach or interact with switch/display/lever	F10	Provide ability to override faulty critical inputs from both sides	Electronic failure, Mechanical failure, Software failure	Allows the pilot to always take control in the case a function is not behaving as expected. Critical inputs refer to inputs that are mission-critical such as manual control, communication, etc. Frequently used input inputs refer to inputs that aren't mission-critical but are still used frequently during standard operating procedures.
	F11	Alert questionable critical settings	Tampering with flight deck, Unable to identify switch/display/lever	Alerting the pilot of questionable inputs increases awareness of potentially faulty pilot or automation inputs. Questionable inputs could be inappropriate or suspicious inputs for the current flight phase or situation.
	F12	Provide position of critical displays within pilot visual range	Sub-optimal placement of equipment, Unable to identify switch/display/lever	The pilot should be able to see and interact with the displays without increased workload or restraining focus. This is required from both sides according to general needs.
	F13	Prevent physical interference between switch, lever or display	Sub-optimal placement of equipment	A switch, lever, or display is not allowed to block or cover another. For example, an engaged lever cannot block a display disabling the pilot from accumulating important information. Input can neither be difficult to use nor interact with when considering physical human interaction.
	F14	Prevent light to disturb displays or signs	Sun/star/light glare, Reduced physical ability, Unable to identify switch/display/lever	Light sources such as the sun, stars, city lights, or flight compartment lights must not disable the pilot from seeing screen information, which consequently makes it difficult to properly interact with the respective input.
	F15	Provide indicators addressing function of switches, displays and levers	Unable to identify switch/display/lever	It should be clear to the pilot what each switch, lever, and display means and what they do to avoid confusion or leaves the pilot unaware of what equipment should be used.
	F16	Provide storage for personal items	Tampering with flight deck	This mitigates the risk of personal items ending up in a position where flight controls or other important switches, displays, or levers are interfered with.
	F2	Provide means for pilot to request for assistance	Reduced physical ability, Faulty input signal, Electronic failure, Mechanical failure, Software failure	The single pilot flying should have the means to call for assistance when needed, for example in case of increased workload due to auto flight failure. For the C2 configuration, this would mean requesting OEP support.
9. Loss of proper stick input	F17	Provide position of stick within reach from both seats	Arm/wrist fatigue, Sub-optimal placement of equipment	The stick and its potential armrest should be positioned in a way that it can be reached and operated by the pilot without physical fatigue of the pilot's arm, hand, and wrist.
	F18	Provide ability to override faulty stick input from both seats	Faulty input signal, Electronic failure, Mechanical failure, Software failure	Allow the pilot to actively select stick input in case one of the inputs is putting out inappropriate signals. An example of this could be a mechanical/electrical error or a loose object in the cockpit causing stick input on the other side from the pilot.
	F19	Alert questionable stick input	Miscommunicated information, faulty input signal, Electronic failure, Mechanical failure, Software failure	Provide something that alerts the pilot of suspicious stick inputs. For example, inappropriate pitch inputs would allow the pilot to address the problem at an earlier stage.
	F20	Prevent stick from being accidentally engaged	Faulty input signal	Prevent the pilot from unintentionally getting in contact with the stick.
	F2	Provide means for pilot to request for assistance	Arm/wrist fatigue, Miscommunicated information, Faulty input signal, Electronic failure, Mechanical failure, Software failure	The single pilot flying should have the means to call for assistance when needed, for example in case of increased workload due to auto flight failure. For the C2 configuration, this would mean requesting OEP support.

10. Loss of proper pedal input	F21	Provide position of pedals within reach from both seats	Leg fatigue, Sub-optimal placement of equipment	The pedals should be positioned to mitigate the risk of confusion and leg fatigue for the pilot.
	F22	Provide ability to override faulty pedal input from both sides	Faulty input signal, Electronic failure, Mechanical failure, Software failure	Allow the pilot to actively select pedal input in case one of the inputs is putting out inappropriate signals.
	F23	Alert questionable pedal input	Miscommunicated information, faulty input signal, Electronic failure, Mechanical failure, Software failure	Provide something that mitigates the risk of the pilot using the pedals wrong or something else affecting the steering of the rudder. A questionable input can be something that seems suspicious or inappropriate for the current flight phase or situation.
	F2	Provide means for pilot to request for assistance	Leg fatigue, Miscommunicated information, Faulty input signal, Electronic failure, Mechanical failure, Software failure	The single pilot flying should have the means to call for assistance when needed, for example in case of increased workload due to auto flight failure. For the C2 configuration, this would mean requesting OEP support.
11. Loss of proper dedicated NWS input	F24	Provide position of NWS lever within reach from both seats	Reduced physical ability, Sub-optimal placement of equipment	Mitigate the chance of fatigue or unnecessary challenging operation by using the NWS lever. The lever should be easily accessed from both seats.
	F25	Provide ability to override faulty NWS input	Faulty input signal, Electronic failure, Mechanical failure, software failure	The pilot should have the ability to with the NWS lever Provide control of the nose wheel no matter what potential automation or pedal steering is inputting.
	F26	Provide direction guideline	Reduced mental ability, Faulty input signal	Provide something that shows the pilot what input will result in what outcome, for example turning the lever clockwise means turning right.
	F27	Provide lever position preventing accidental NWS input	Faulty input signal	Prevent the pilot from unintentionally getting in contact with the NWS lever causing unwanted nose wheel output.
	F2	Provide means for pilot to request for assistance	Reduced physical/mental ability, Faulty input signal, Electronic failure, Mechanical failure, Software failure	The single pilot flying should have the means to call for assistance when needed, for example in case of increased workload due to auto flight failure. For the C2 configuration, this would mean requesting OEP support.
12. Loss of proper trim switch input	F28	Provide position of trim switch within reach from both seats	Reduced physical ability, Sub-optimal placement of equipment	The trim switch should be positioned within reach and easy access of the pilot to mitigate the risk of confusion and physical fatigue.
	F29	Alert questionable trim switch input	Instrumental Error, faulty input signal, Electronic failure, Mechanical failure, Software failure	Alert the pilot if questionable trim inputs are applied. Should not prevent output but if suspicious or inappropriate for the situation or flight phase it should be alerted to provide awareness.
	F30	Provide position of switch to avoid accidental input	Faulty input	Prevent the pilot from unintentionally getting in contact with the trim switch.
	F2	Provide means for pilot to request for assistance	Reduced physical/mental ability, Faulty input signal, Electronic failure, Mechanical failure, Software failure	The single pilot flying should have the means to call for assistance when needed, for example in case of increased workload due to auto flight failure. For the C2 configuration, this would mean requesting OEP support.

14. Loss of indication system	F31	Provide assistance for mode selection	Wrong display mode	Indicating guidelines should help the pilot be in the correct display mode through all phases to make sure the correct information is shown and as little excessive information as possible.
	F16	Provide storage for personal items	Environmental obstacle or personal item	This mitigates the risk of personal items ending up in a position where flight controls or switches are disturbed.
	F14	Prevent light to disturb displays or signs	Sun/star/light glare, Reduced physical ability, Fatigue, Unable to identify switch/display/lever	Light sources such as the sun, stars, city lights, or flight compartment lights must not disable the pilot from seeing screen information, which consequently makes it difficult to properly interact with the respective input.
	F2	Provide means for pilot to request for assistance	Wrong display mode, Environmental obstacle, Sun/star/light glare, Impaired vision, Electronic failure, Mechanical failure, Software failure	The single pilot flying should have the means to call for assistance when needed, for example in case of increased workload due to auto flight failure. For the C2 configuration, this would mean requesting OEP support.
22. Inappropriate flight compartment lighting	F32	Provide flight compartment lighting	Faulty Lighting contributing to a poor working environment, Light settings for personal comfort over operations optimized	Lighting is important to see and operate within the flight compartment. The lighting should be comfortable and not restrain the eyesight of the flight crew leading to fatigue. Neither should it be relaxing potentially causing sleepiness.
	F33	Provide lighting presets	Light settings for personal comfort over operation optimized	The lighting inside the flight compartment should be set to the most ergonomic setting to reduce confusion and mental fatigue. Further on, the most ergonomic setting will depend on situational aspects such as time of day and weather. The guidelines or presents provided by this function are aimed to handle these situational aspects with ease.
	F2	Provide means for pilot to request for assistance	Faulty Lighting contributing to a poor working environmen, Light set for comfort over performance, Electronic failure, Mechanical failure, Software failure	The single pilot flying should have the means to call for assistance when needed, for example in case of increased workload due to auto flight failure. For the C2 configuration, this would mean requesting OEP support.
25. Oxygen mask failure	F34	Provide mask donning guidelines	Incomplete donning of mask	Clear instructions should be provided for the pilot to ensure that the mask is donned correctly. This mitigates the risk of the mask being wrongly used and therefore not fulfilling its function. In critical and stressful situations tasks such as donning can be hard and complicated.
	F35	Alert incorrect mask Operation	Incomplete donning of mask, Electronic failure, Mechanical failure, Software failure	It should be made clear when the mask is correctly donned and functioning, for example, with no leakage. This would allow the pilot to be aware of the faulty mask and switch to another or adjust the donning.
29. Inability to visually observe certain external events	F36	Provide visibility for situational awareness	Reduced window FOV, Visual obstacle, Mechanical/design error, Disorientation, Poor awareness of surrounding	Windows should allow the pilot to see what is needed to see within reasonable limits. This is important to keep in mind for SPO since there are only two eyes instead of four providing situational awareness.
	F16	Provide storage for personal items	Visual obstacle	This mitigates the risk of personal items ending up in a position where the pilot's vision is reduced.
	F37	Provide automated assistance for situational awareness	Reduced window FOV, Visual obstacle, Impaired vision, Non-observant, Mechanical/design error, Disorientation, Poor awareness of surrounding	Assistance in situational awareness would be helpful by for example notifying the pilot of the surrounding. An example of this could be radar for longer ranges or cameras for shorter ranges. This could assist in detecting terrain, other aircraft, bad weather, etc.
	F2	Provide means for pilot to request for assistance	Reduced window FOV, Visual obstacle, Impaired vision, Mechanical/design error	The single pilot flying should have the means to call for assistance when needed, for example in case of increased workload due to auto flight failure. For the C2 configuration, this would mean requesting OEP support.

Human Factors	F38	Provide flight compartment climate control	Discomfortable temperature	The temperature, air quality, etc. should provide comfort to a satisfactory level. Allowing for automated or manual control reduces the risks of discomfort leading to a violation.
	F2	Provide means for pilot to request for assistance	Mental fatigue, Workload, Sleepiness, Physiological needs	The single pilot flying should have the means to call for assistance when needed, for example in case of increased workload due to auto flight failure. For the C2 configuration, this would mean requesting OEP support.
	F39	Provide automated crosschecking	Workload, Mental fatigue	Automated crosschecking would require the pilot to together with an automated system follow checklists or operating procedures. An example could be automatic vocal asking the pilot questions which he/her then needs to respond to with the required data etc for example airspeed or flap deflection. This would reduce the pilot workload significantly.
	F40	Provide announcement of system inormation as monitoring	Workload, Under-stimulation, Mental fatigue, Overreliance on automation	Instead of having to frequently go through flight information parameters such as checking altitude, heading, temperatures etc, relevant information can be automatically vocally announced reducing the workload of monitoring the processes. This can also help to stay alert and focused.
	F41	Provide automated communication allevation for pilot	Workload, Mental fatigue	Automatic communication of basic messages in either vocal or text could help reduce the pilot's workload of communicating with external parties. This could be done for inputting or outputting signals, or both.
	F42	Provide pilot-in-the-loop verification	Under-stimulation, Sleepiness	A system that frequently requires the pilot to verify his/her presence could reduce under-stimulation problems as well as help stay focused and provide awareness of the current situation. Could beneficially be combined with F40. This would also help detect incapacitation.
	F43	Provide automated voice to text	Language/accent barriers, Workload, Mental fatigue	Misinterpretation of critically communicated information has the potential to be catastrophic. Therefore having automated text or subtitles generated from the communicated audio could help the pilot understand difficult messages. Could potentially also be vocally repeated with an easier-to-understand voice and accent.
	F44	Provide breathalizer	Substance abuse	Potential drug abuse in SPO is much more serious due to the lack of pilot redundancy. Requiring breath testing preflight could prevent pilots from operating the aircraft under the influence of alcohol.
	F45	Allow OEP to open door during violation	Failure to follow intended route, Failure to follow regulations, Failure to follow SOPs in general, Not complying with ATC instructions, Incapacitation	In case of the pilot violates route, routines, regulations, instructions, etc, or is incapacitated this should be evaluated if critical or not. If critical the flight compartment door should be partly unlocked to where the OEP has access to the flight compartment.
Collaboration errors		**Mitigated by SPO**	Cultural barriers	
			Misinterpretation	
			Lack of coordination	
			Biased decision	
			Over-reliance	
			Knowledge gaps	
			Hierarchical/status differential	

TABLE 21 - FUNCTION SPECIFICATION WITH SOURCE

List of Specific Functions		
ID	**Function Name**	**Function Description**
F1	Alert questionable auto flight settings	Alert pilot of suspicious or inappropriate auto flight settings in order to prevent flight in inefficient or situationally unsuitable modes. This can also alleviate workload since it takes away the need for the pilot to monitor and make sure that the right mode is being used.
F2	Provide means for pilot to request for assistance	The single pilot flying should have the means to call for assistance when needed, for example in case of increased workload due to auto flight failure. For the C2 configuration, this would mean requesting OEP support.
F3	Provide verification of operational equipment	A verification that the equipment is functional would allow for a potential malfunction to be acknowledged before and not during a critical situation.
F4	Provide standard operating procedures for communication settings	SOPs for what settings should be used in different situations and a specific technical routine to oversee the communication equipment mitigate the risk of the wrong settings being used.
F5	Provide active noise cancelling	This would allow for the active canceling of noise and unwanted sounds allowing the pilot to focus on the tasks without unnecessary disturbances. This will also reduce communication errors since it will be easier and clearer to understand what for example the ATC operator says.
F6	Prevent seat fatigue	The pilot should be comfortable to a satisfactory degree throughout the whole flight removing the need for unstrapping for eventual relief or leg stretching.
F7	Provide strap in reminders	Remind pilots to strap in to prevent forgetting the harness.
F8	Alert pilot of unstrapped harness	Makes sure that the pilot is aware of not being strapped in. An alert could both assist in remembering to strap in as well as provide a for example disturbing or annoying sound or light which is removed simply by strapping in.
F9	Provide verification step for strapping out in phases other than cruise	Added task needed for strapping out when in a critical phase reduces the risk of the pilot being unstrapped when it can lead to catastrophic outcomes.

F10	Provide ability to override faulty critical inputs from both sides	Allows the pilot to always take control in the case a function is not behaving as expected. Critical inputs refer to inputs that are mission-critical such as manual control, communication, etc. Frequently used inputs refer to inputs that aren't mission-critical but are still used frequently during standard operating procedures.
F11	Alert questionable critical settings	Alerting the pilot of questionable inputs increases awareness of potentially faulty pilot or automation inputs. Questionable inputs could be inappropriate or suspicious inputs for the current flight phase or situation.
F12	Provide position of critical displays within pilot visual range	The pilot should be able to see and interact with the displays without increased workload or restraining focus. This is required from both sides according to general needs.
F13	Prevent physical interference between switch, lever or display	A switch, lever, or display is not allowed to block or cover another. For example, an engaged lever cannot block a display disabling the pilot from accumulating important information. Input is neither difficult to use nor interact with when considering physical human interaction.
F14	Prevent light to disturb displays or signs	Light sources such as the sun, stars, city lights, or flight compartment lights must not disable the pilot from seeing screen information, which consequently makes it difficult to properly interact with the respective input.
F15	Provide indicators addressing function of switches, displays and levers	It should be clear to the pilot what each switch, lever, and display means and what they do to avoid confusion or leaves the pilot unaware of what equipment should be used.
F16	Provide storage for personal items	This mitigates the risk of personal items ending up in a position where flight controls or other important switches, displays, or levers are interfered with.
F17	Provide position of stick within reach from both seats	The stick and its potential armrest should be positioned in a way that it can be reached and operated by the pilot without physical fatigue of the pilot's arm, hand, and wrist.

F18	Provide ability to override faulty stick input from both seats	Allow the pilot to actively select stick input in case one of the inputs is putting out inappropriate signals. An example of this could be a mechanical/electrical error or a loose object in the cockpit causing stick input on the other side from the pilot.
F19	Alert questionable stick input	Provide something that alerts the pilot of suspicious stick inputs. For example, inappropriate pitch inputs would allow the pilot to address the problem at an earlier stage.
F20	Prevent stick from being accidentally engaged	Prevent the pilot from unintentionally getting in contact with the stick.
F21	Provide position of pedals within reach from both seats	The pedals should be positioned to mitigate the risk of confusion and leg fatigue for the pilot.
F22	Provide ability to override faulty pedal input from both sides	Allow the pilot to actively select pedal input in case one of the inputs is putting out inappropriate signals.
F23	Alert questionable pedal input	Provide something that mitigates the risk of the pilot using the pedals wrong or something else affecting the steering of the rudder. A questionable input can be something that seems suspicious or inappropriate for the current flight phase or situation.
F24	Provide position of NWS lever within reach from both seats	Mitigate the chance of fatigue or unnecessary challenging operation by using the NWS lever. The lever should be easily accessed from both seats.
F25	Provide ability to override faulty NWS input	The pilot should have the ability to with the NWS lever Provide control of the nose wheel no matter what potential automation or pedal steering is inputting.
F26	Provide direction guideline	Provide something that shows the pilot what input will result in what outcome, for example turning the lever clockwise means turning right.
F27	Provide lever position preventing accidental NWS input	Prevent the pilot from unintentionally getting in contact with the NWS lever causing unwanted nose wheel output.
F28	Provide position of trim switch within reach from both seats	The trim switch should be positioned within reach and easy access of the pilot to mitigate the risk of confusion and physical fatigue.

F29	Alert questionable trim switch input	Alert the pilot if questionable trim inputs is applied. Should not prevent output but if suspicious or inappropriate for the situation or flight phase it should be alerted to provide awareness.
F30	Provide position of switch to avoid accidental input	Prevent the pilot from unintentionally getting in contact with the trim switch.
F31	Provide assistance for mode selection	Indicating guidelines should help the pilot be in the correct display mode through all phases to make sure the correct information is shown and as little excessive information as possible.
F32	Provide flight compartment lighting	Lighting is important in order to see and operate within the flight compartment. The lighting should be comfortable and not restrain the eyesight of the flight crew leading to fatigue. Neither should it be relaxing potentially causing sleepiness.
F33	Provide lighting presets	The lighting inside the flight compartment should be set to the most ergonomic setting to reduce confusion and mental fatigue. Further on, the most ergonomic setting will depend on situational aspects such as time of day and weather. The guidelines or presents provided by this function are aimed to handle these situational aspects with ease.
F34	Provide mask donning guidelines	The pilot should provide clear instructions to ensure the mask is donned correctly. This mitigates the risk of the mask being wrongly used and therefore not fulfilling its function. In critical and stressful situations tasks such as donning can be hard and complicated.
F35	Alert incorrect mask Operation	It should be made clear when the mask is correctly donned and functioning, for example, with no leakage. This would allow the pilot to be aware of the faulty mask and switch to another or adjust the donning.
F36	Provide visibility for situational awareness	Windows should allow the pilot to see what is needed to see within reasonable limits. This is important to keep in mind for SPO since there are only two eyes instead of four providing situational awareness.

F37	Provide automated assistance for situational awareness	Assistance in situational awareness would be helpful by for example notifying the pilot of the surrounding. An example of this could be radar for longer ranges or cameras for shorter ranges. This could assist in detecting terrain, other aircraft, bad weather, etc.
F38	Provide flight compartment climate control	The temperature, air quality, etc. should provide comfort to a satisfactory level. Allowing for automated or manual control reduces the risks of discomfort leading to a violation.
F39	Provide automated crosschecking	Automated crosschecking would require the pilot to together with an automated system follow checklists or operating procedures. An example could be automatic vocal asking the pilot questions which he/her then needs to respond to with the required data etc. for example airspeed or flap deflection. This would reduce the pilot workload significantly.
F40	Provide announcement of system information as monitoring	Instead of having to frequently go through flight information parameters such as checking altitude, heading, temperatures, etc., relevant information can be automatically vocally announced reducing the workload of monitoring the processes. This can also help to stay alert and focused.
F41	Provide automated communication alleviation for pilot	Automatic communication of basic messages in either vocal or text could help reduce the pilot's workload of communicating with external parties. This could be done for inputting or outputting signals, or both.
F42	Provide pilot-in-the-loop verification	A system that frequently requires the pilot to verify his/her presence could reduce under-stimulation problems, help stay focused, and provide awareness of the current situation. This could be beneficial when combined with F40. This would also help detect incapacitation.

F43	Provide automated voice to text	Misinterpretation of critically communicated information has the potential to be catastrophic. Therefore having automated text or subtitles generated from the communicated audio could help the pilot understand difficult messages. Could potentially also be vocally repeated with an easier-to-understand voice and accent.
F44	Provide breathalyzer	Potential drug abuse in SPO is much more serious due to the lack of pilot redundancy. Requiring breath testing preflight could prevent pilots from operating the aircraft under the influence of alcohol.
F45	Allow OEP to open door during violation	In case of the pilot violates route, routines, regulations, instructions, etc., or is incapacitated this should be evaluated if critical or not. If critical the flight compartment door should be partly unlocked to where the OEP has access to the flight compartment.

TABLE 22 - COMPILED LIST OF SPECIFIC FUNCTIONS

DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2023
www.chalmers.se

CHALMERS
UNIVERSITY OF TECHNOLOGY