UNIVERSIDADE DA BEIRA INTERIOR
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Application of an Unmanned Aircraft System in Search and Rescue Missions

The case of Guarda Nacional Republicana

(versão revista após defesa)

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Dedicatory

To my mother Luciane.

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Abstract

It is known that the quickness and effectiveness of Search and Rescue (SAR) missions are crucial to their success. This study has the purpose of understanding how the application of an Unmanned Aircraft System (UAS) in SAR missions, could bring improved outcomes and be an added value to the procedures that are already performed by SAR teams.

In this study, the results were obtained by performing a series of field trials, based on the recreation of real SAR scenarios and the implementation of an operational plan proposal, with recordings of time lapses at different phases of the operation. The reports of the real scenarios were provided by the teams of the Grupo de Intervenção, Proteção e Socorro (GIPS), who are under the command of the Unidade de Intervenção (UI), specialized in this type of missions. Both GIPS and UI are dependent on *Tenente General Comandante Geral* of the Guarda Nacional Republicana (GNR). A survey developed by the National Aeronautics and Space Administration (NASA) was also applied at the end of each trial in order to evaluate the workload index of the participants in the trials.

Throughout this research, conclusions are obtained taking into account the difference of an UAS operation between day and night periods, the improvements to the current procedures, but also the limitations of this system, such as the measures that should be taken when this system is applied in SAR missions. Conclusions were also based on the replies to the surveys.

The focus of this case study was the use of an UAS in SAR missions performed in a mountain environment, well known by its adverse weather conditions. This study proved that, under these kinds of conditions, the use of the UAS was not always possible due to their own limitations and the validation of the proposed operational plan was obtained.

Keywords

UAS, SAR Missions, Operational Plan, SAR Scenarios, Operators, Workload Evaluation, Procedures Implementation, Operational Phases, Field trials, GIPS, GNR.

Resumo

Sabe-se que a rapidez e eficácia na realização de missões de busca e salvamento, são fatores cruciais para assegurar o seu sucesso. Um dos principais objetivos deste estudo é perceber se, a aplicação de um Unmanned Aircraft System (UAS), neste tipo de missões, pode ou não acarretar evoluções e por sua vez melhorias aos procedimentos já anteriormente realizados pelas equipas de busca e salvamento.

Os resultados deste estudo foram alcançados através da realização de ensaios no terreno, tendo como base a recriação de cenários reais de busca e salvamento que tivessem já ocorrido. Através da implementação de uma proposta de plano operacional, foram também retirados diversos tempos de desempenho em diferentes fases da operação. Os relatórios dos cenários reais foram disponibilizados pelas equipas do Grupo de Intervenção, Proteção e Socorro (GIPS) que, estão sob o comando da Unidade de Intervenção (UI) especializadas neste tipo de missões. Tanto o GIPS como a UI estão dependentes do *Tenente General Comandante Geral* da Guarda Nacional Republicana (GNR). Foi também aplicado um inquérito desenvolvido pela National Aeronautics and Space Administration (NASA) para avaliar o índice de carga de trabalho dos participantes no final de cada um dos ensaios.

Ao longo desta pesquisa, foram tiradas conclusões sobre a diferença na operação de um UAS entre o período diurno e noturno, as melhorias sentidas nos procedimentos usados atualmente, assim como as suas limitações e medidas que devem ser tomadas quando aplicado em missões de busca e salvamento. Também são retiradas conclusões a partir das respostas obtidas ao inquérito.

Este caso de estudo tem, como foco, as missões de busca e salvamento realizadas em ambiente montanhoso bem conhecido pelas suas condições climatéricas adversas. Foi também verificado que na presença destas condições a aplicação de um UAS nem sempre é possível, devido as limitações próprias do equipamento e obteve-se a validação do plano operacional proposto.

Palavras-Chave

UAS, Missões de Busca e Salvamento, Plano Operacional, Cenários de Busca e Salvamento, Operadores, Avaliação da Carga de Trabalho, Implementação de Procedimentos, Fases Operacionais, Ensaios no Terreno, GIPS, GNR.

Resumo Alargado

Introdução

Atualmente o ramo da aviação tem aparecido continuamente associado às diferentes áreas da nossa vida quotidiana. Os Veículos Aéreos Não Tripulados (VANTs), conhecidos em todo o mundo como “drones”, são possivelmente o melhor exemplo da considerável evolução que a aviação tem vindo a sofrer nos últimos anos.

Os VANTs são dispositivos de alta tecnologia com um potencial de aplicação quase ilimitado, gradualmente em todo o mundo, este tipo de aeronaves tem sido aplicado para os mais diversos fins, sendo um deles as missões de busca e salvamento. Esta dissertação estudou nomeadamente missões de busca e salvamento que tiveram lugar em ambiente de montanha. Apesar deste tipo de aeronaves já ter sido utilizado neste tipo de missões, ainda que na maioria delas apenas com o propósito de teste, já foram também aplicadas em situações reais provando que podem fazer a diferença. Aliás, como pode ser verificado no artigo “First Report of Using Portable Unmanned Aircraft Systems (Drones) for Search and Rescue” [1][1].

Em ocorrências específicas, os VANTs podem ser transportados num veículo de patrulha e quando operados por alguém com a experiência e treinamento adequados, podem ter uma grande influência na taxa de sucesso das missões de busca e salvamento. Comparando a utilização deste tipo de aeronaves com os procedimentos que são usados atualmente neste tipo de missões, é esperado que com o uso das mesmas a busca pela pessoa desaparecida consiga ser efetuada de forma mais rápida e eficaz. Esta é uma das conclusões que foi retirada no artigo “The potential use of unmanned aircraft systems (drones) in mountain search and rescue operations” [2][2].

A implementação de um VANT além de poder ser um fator decisivo para melhorar a taxa de sucesso das missões de busca e salvamento, acarreta uma melhoria significativa no que diz respeito a não colocar em risco a vida dos membros que as realizam. Este estudo iniciou-se, com o objetivo de concluir se, de facto, a aplicação deste tipo de aeronaves pode ser o próximo passo para as missões de busca e salvamento em Portugal.

[1] Equals [1] in the references content
[2] Equals [3] in the references content

Enquadramento da Dissertação

Os VANTs têm sido aplicados com diversos propósitos em todo o mundo e, têm vindo a revelar cada vez mais a sua utilidade. No decorrer dos últimos anos o uso deste tipo de aeronaves em missões de busca e salvamento tem sido uma das suas mais diversas aplicações; de acordo com o inquérito realizado e exposto no artigo "Unmanned vehicles while becoming smaller and smarter are addressing new applications in medical, agriculture, in addition to military and security" [3][3], 88% dos civis aceitam a sua aplicação em missões de busca e salvamento.

Nas mais diversas situações, as pessoas que integram as equipas de busca e salvamento, colocam as suas vidas em risco. Com o recurso a este tipo de aeronaves, os procedimentos têm tudo para se tornarem mais seguros, podendo também realizar várias tarefas que os seres humanos consideram como "dirty, dully or dangerous" [4][4].

De uma maneira geral, os VANTs possuem diferentes níveis de autonomia que, podem variar desde sistemas controlados manualmente até sistemas totalmente autónomos. No caso de serem controlados manualmente, a sua operação é feita através de controlo remoto com o envolvimento de um ou mais operadores. Se o sistema for totalmente autónomo, nenhuma intervenção será necessária e a aeronave seria controlada desde a descolagem até à aterragem através do piloto automático [5][5]. Sendo o VANT apenas um dos elementos que integra o UAS que será utilizado no caso de estudo desta dissertação.

Tendo em conta o tipo de asa, os VANTs, podem ser classificados em duas grandes categorias: asa fixa e asa rotativa [6][6]. A categoria de asa rotativa, quando comparada com a de asa fixa, permite que o veículo fique estacionário no ar, esta capacidade é essencial quando se monitoriza continuamente a mesma área. Não necessita de uma pista ou qualquer tipo de mecanismo para ser lançado [7][7]. Esta categoria compreende diferentes tipos de configurações, como helicópteros e multicopters (quadcopters, hexacopters e octacopters).

No que diz respeito aos multicopters, conhecidos por conferir uma maior manobrabilidade ao operador, os quadcopters apresentam o melhor equilíbrio entre o peso máximo da carga útil transportado e o custo. Este tipo de configuração é frequentemente utilizado porque pode transportar uma quantidade significativa de peso sem aumentar drasticamente o preço do

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[3] Equals [8] in the references content
[4] Equals [9] in the references content
[5] Equals [14] in the references content
[6] Equals [23] in the references content
[7] Equals [24] in the references content

produto; por exemplo, um hexacopter ou um octacopter pode transportar cargas mais pesadas, mas o preço do equipamento também é mais elevado [8][8].

Avaliando a segurança da operação, o hexacopter e o octacopter são uma escolha mais confiável devido ao maior número de motores, na eventualidade de ocorrer uma falha de um ou mais motores, os outros ainda são capazes de manter o voo, permitindo que o operador consiga ainda aterrar a plataforma em segurança [8][9].

Quando aplicados em missões de busca e salvamento, os VANTs apresentam também limitações que precisam de ser tidas em conta de maneira a conseguir usufruir das suas valências da melhor forma. O tempo de voo é uma das limitações mais importantes neste tipo de missões. Os ambientes de montanha conhecidos pelas suas condições climatéricas adversas; como ventos fortes, chuva, nevoeiro e temperaturas frias, exigem que o VANT esteja equipado com um sistema de estabilização robusto para evitar a perda de controlo por parte do operador.

Nesta dissertação, serão ainda abordados alguns dos procedimentos atuais usados por equipas de busca e salvamento, e simultaneamente desenvolvida a proposta de um plano operacional que será validada através de ensaios de campo.

Objetos e Objetivos

Neste estudo, o objeto sob avaliação será o Unmanned Aircraft System (UAS) e os procedimentos operacionais atualmente utilizados, em missões de busca e salvamento, pelo Subagrupamento de Montanha-Grupo de Intervenção, Proteção e Socorro (GIPS)-Unidade de Intervenção (UI)-Guarda Nacional Republicana (GNR) na Serra da Estrela, referido de agora em diante como SAMONT-GNR.

O objetivo desta dissertação é avaliar se a aplicação de um UAS poderá trazer melhorias quando aplicado em missões de busca e salvamento, mais especificamente em ambiente de montanha. Será também desenvolvida uma proposta de plano operacional para aplicar a este tipo de aeronaves, de forma a introduzi-las nos procedimentos utilizados atualmente pelas equipas de busca e salvamento, sem causar limitações aos mesmos. Neste estudo será também realizada uma análise de alguns relatórios de missões de busca e salvamento; após esta análise, dois deles serão escolhidos para recriar no caso de estudo.

[8] Equals [25] in the references content
[9] Equals [25] in the references content

Serão tiradas conclusões através dos dados adquiridos experimentalmente durante a recriação dos cenários de busca e salvamento escolhidos, sendo auxiliadas por comparação com os dados obtidos de quando aconteceu o cenário real, e através das respostas obtidas ao inquérito aplicado.

Principais Conclusões

A aplicação de um UAS, em missões de busca e salvamento tem sido um recurso cada vez mais procurado pelas equipas de busca e salvamento, para melhorar a sua taxa de sucesso e evitar sempre que possível colocar a vida dos seus membros em risco.

A partir do caso de estudo, foi possível perceber a que nível operacional o uso de um UAS poderia ser uma melhoria, especialmente devido ao cenário real de busca e salvamento que foi recriado com a aplicação deste tipo de sistema. Também foi possível validar o plano operacional proposto. No final de cada ensaio de campo foi aplicado um inquérito a todos os participantes, cuja identificação não está especificada na dissertação, sendo apenas utilizada para identificação a tarefa que realizaram durante cada um dos ensaios.

Através do inquérito aplicado aos participantes dos ensaios de campo, percebemos que apenas para os operadores do UAS, que representam 3 dos 8 participantes, obtivemos valores expectáveis para o índice de carga de trabalho, tendo estes considerado a exigência mental o fator mais importante em missões de busca e salvamento. Para os restantes participantes, integrantes do pelotão de Busca e Resgate em Montanha (BRM), obtivemos valores diferentes do esperado tendo estes considerado o desempenho como o fator mais importante neste tipo de missões. A partir do inquérito, também foi possível perceber que quase todos os participantes apresentaram incoerências na atribuição das classificações a cada fator após a operação. Uma possível explicação para esta ocorrência deve-se ao facto de, apesar de considerarem um fator como sendo o mais importante, no decorrer da missão todos eles acabam por ser cruciais dado que está em jogo, na maioria das vezes, a vida de uma pessoa.

Todos os participantes dos ensaios de campo tinham muito experiência em missões de busca e salvamento permitindo concluir, especialmente para os membros do pelotão de BRM presentes nestes ensaios que nunca tinham utilizado o UAS como recurso neste tipo de missões, da enorme mais valia para avaliar se a proposta de plano operacional com a implementação deste tipo de sistema poderia vir a ser uma realidade. A recriação dos cenários originalmente escolhidos não foi realizada, devido às condições climatéricas agressivas que se fizeram sentir no dia agendado para tal, e acima de tudo permitiu verificar que a implementação deste tipo de sistema não é um recurso que possa ser aplicado em todas as situações.

A partir dos dados recolhidos durante os ensaios de campo, no período diurno, foi possível constatar que caso se tratasse de uma situação real o uso de um UAS poderia ser crucial em algumas partes da operação, tal como na monitorização do resgate. Porém, este cenário era fictício, não permitindo a comparação com outros dados, tendo sido difícil perceber se a aplicação do plano operacional proposto trouxe alguma melhoria aos procedimentos atualmente utilizados. No período noturno, como se tratava de uma recriação de um cenário de busca e salvamento real, foi possível comparar os dados de ambas as operações.

Uma das conclusões mais importantes desta dissertação é que o uso de um UAS pode fazer a diferença no desfecho de uma missão de busca e salvamento. Considerando todas as dificuldades apresentadas pelos membros da equipe do Grupo de Intervenção, Proteção e Socorro (GIPS), que estavam presentes quando o cenário real ocorreu, foi possível concluir que o uso deste sistema as conseguiu ultrapassar. A implementação da proposta de plano operacional trouxe melhorias no âmbito do estudo desenvolvido, especialmente no que diz respeito à duração da operação. A utilização deste tipo de sistema quando o cenário real aconteceu poderia ter feito a diferença entre a vida e a morte.

Perspetivas de Investigação Futuras

Ao longo do desenvolvimento desta dissertação, alguns tópicos foram reconhecidos como úteis para serem implementados em trabalhos futuros de pesquisa para que seja possível entender se a aplicação de uma UAS pode realmente trazer melhorias numa missão de busca e salvamento, bem como as medidas que devem ser tomadas para tornar esta aplicação possível. Reconheceu-se também que experiência dos membros das equipas de busca e salvamento é um fator crucial para garantir que a implementação deste tipo de sistema consiga realmente fazer a diferença. Posto isto, acredita-se que os próximos passos deste trabalho devem incluir as seguintes linhas de investigação:

- Adição de mais participantes nos ensaios de campo para uma avaliação mais precisa da carga de trabalho de cada um deles, assim como a sua opinião sobre as vantagens e limitações na aplicação de um UAS;
- Recriação de mais cenários de busca e salvamento reais, ou seja, que já tenham acontecido, para obter mais dados para comparação;
- Aplicação do plano operacional proposto numa missão de busca e salvamento real;
- Utilização de diferentes UAS para observar as diferenças no respetivo desempenho;
- Potenciação de um programa de treino para os operadores, de modo a que a sua carga de trabalho não comprometa o desenrolar da missão;
- Aperfeiçoamento de cenários de busca e salvamento padrão e realização de várias missões facilitando a recolha de dados que poderiam levar a futuras melhorias no UAS utilizado.

Table of Contents

List of Figures

List of Tables

List of Acronyms

ANAC	Autoridade Nacional da Aviação Civil
ATC	Air Traffic Control
ATS	Air Traffic Service
BRLOS	Beyond Radio Line-of-Sight
BRM	Busca e Resgate em Montanha
CINGOP	Centro Integrado Nacional de Gestão Operacional
CLN	Centro de Limpeza de Neve
CMA	Centro de Meios Aéreos
COS	Comandante das Operações de Socorro
CS	Control Station
CTER	Comando Territorial
EASA	European Aviation Safety Agency
EO	Electro-Optical
FLIR	Forward-Looking-Infrared
FOV	Field of View
FPV	First Person View
GCS	Ground Control Station
GIPS	Grupo de Intervenção, Proteção e Socorro
GNR	Guarda Nacional Republicana
GPS	Global Positioning System
HALE	High Altitude Long Endurance
HD	High Definition
HTOL	Horizontal Take-off and Landing
ICAO	International Civil Aviation Organization
ICNF	Instituto de Conservação da Natureza e das Florestas
IR	Infrared
LADAR	Laser Detection and Ranging
LIDAR	Light Detection and Ranging
LIPO	Lithium Polymer
LLL	Low-Light-Level
LOS	Line of Sight
MALE	Medium Altitude Long Endurance
MAV	Micro Air Vehicle
MSAR	Mountain Search and Rescue
MTOW	Maximum Take-off Weight
NAA	National Aviation Authority
NASA	National Aeronautics and Space Administration

NAV	Nano Air Vehicle
NOTAM	Notice to Airmen
PNSE	Parque Natural da Serra da Estrela
VANT	Veículo Aéreo Não Tripulado
RLOS	Radio Line-of-Sight
SAMONT	Subagrupamento de Montanha
SAR	Search and Rescue
TLX	Task Load Index
TO	Teatro de Operações
TUAV	Tactical Unmanned Air Vehicle
UA	Unmanned Aircraft
UAS	Unmanned Aircraft System
UAV	Unmanned Air Vehicle
UI	Unidade de Intervenção
VTOL	Vertical Take-off and Landing

Chapter 1 – Introduction

1.1. Motivation

In the latest years, the unmanned branch of aviation has been repeatedly associated with the different areas of our daily life. Unmanned Aerial Vehicles (UAVs), well known around the world as “Drones”, are certainly responsible for the most considerable development in modern aviation.

UAVs are high-tech assets with almost unlimited application potential (Figure 1). Abroad, this type of aircraft has already been applied to a wide range of purposes, Search and Rescue (SAR) missions have been one of these. During this dissertation, the focus was on the missions that occurred in a mountain environment. Although most of the missions in which this type of technology was used are a test to see if they would be helpful, they have already been applied in real situations, proving that they can make a difference [1].

Figure 1 - Example of UAVs in different application environments - Source: [2]

In some specific situations, UAVs can be transported in a patrol vehicle and being operated by someone with the correct knowledge and training, they can reach a specific location and analyze the area to find a person that went missing, for example. When this method is compared to the procedures that are used today in this type of situation, it is expected that with the use of the UAV the search for the missing person gets done faster [3].

This study started with the objective of understanding if the use of a UAV can be the next step to SAR missions in Portugal. The implementation of this type of aircraft can be a factor that contributes to improving the success rate of this kind of mission, without endangering the SAR team.

1.2. Object and Objectives

In this study, the object under evaluation will be the Unmanned Aircraft System (UAS) and the operational procedures, in SAR missions, used by the Subagrupamento de Montanha- Grupo de

Intervenção, Proteção e Socorro (GIPS)- Unidade de Intervenção (UI)- Guarda Nacional Republicana (GNR) in Serra da Estrela, referred from now on as SAMONT-GNR.

The objective of this dissertation is to evaluate if the application of a UAS could bring improvements when applied in SAR missions, more specifically in a mountain scenario. An operational plan proposal will also be developed to apply this type of aircraft in the current procedures used by SAR teams, without causing constraints to what is already used. In this study, the analysis of some SAR missions reports will be carried out. Following this analysis, two of them will be chosen to be recreated in the case study.

Conclusions will be drawn from comparing data acquired experimentally during the recreation of the chosen SAR scenarios and data obtained from real scenarios. A survey will be also applied to the participants in the case study with the objective of measuring the workload of each one of them. This survey will be explained in more detail in chapter 2 and will also be relevant to support some of the conclusions.

1.3. Methodology

The elaboration of this dissertation began with the literature review. In this phase, the main goal was to gather the relevant information, namely the different types of UAVs, their different classifications and respective elements, such as the application in SAR missions. Different sensors that could be used in this type of mission were also studied, as well as the current legislation regarding the operation of this type of aircraft in Portugal. In Figure 2, we can see the methodology flowchart. The flowchart is divided into 4 sections.

Section 1 of the flowchart corresponds to the analysis of the literature review, where each of the themes will be studied in more depth.

In section 2, the planning of the operation, that corresponds to the chapter of the operational procedures and SAR scenarios was developed. The objective was the analysis of the operational procedures used by the SAMONT-GNR and then the elaboration of an operational plan proposal for SAR missions, more specifically for the search phase, with the use of an UAS. Some real scenarios were mentioned and among them, two were selected for the case study.

Section 3 of the flowchart concerns the chapter of the case study. In this section all acquired data were presented over the field trials as well as the specifications of the UAS used. A survey was also applied to the participants in the field operation. In this chapter, why the initial scenarios were replaced by different ones will also be explained.

The last section of the flowchart concerns the chapter of the result analysis. All the data gathered and previously presented in the case study were analyzed and then discussed. During this section, the answers to the survey applied to the participants of the field trials were also analyzed.

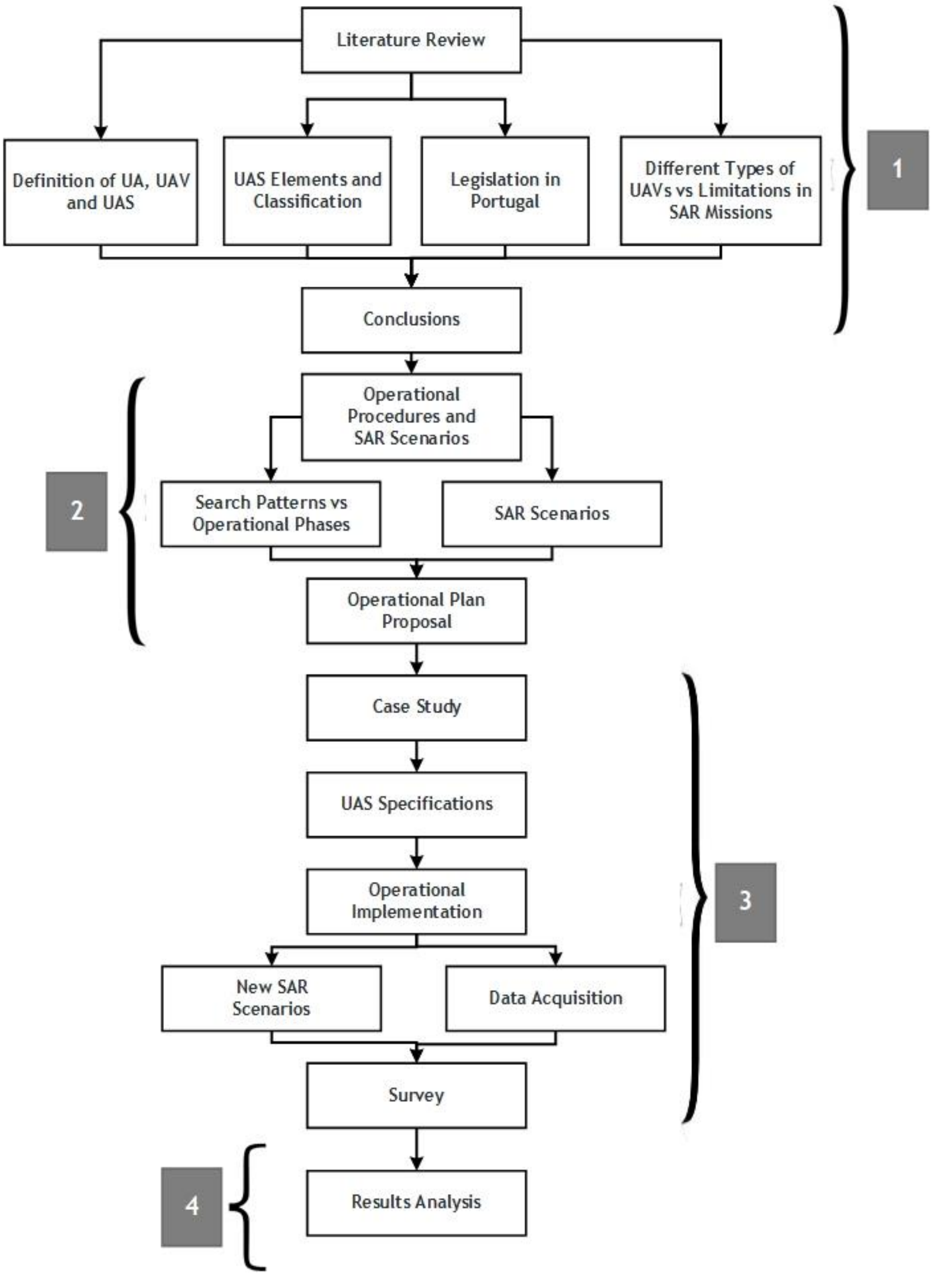

Figure 2 - Methodology Flowchart - Source: Own elaboration

1.4. Dissertation Structure

The first chapter of this dissertation is an introduction to this study and is divided into four subchapters: motivation, object and objectives, methodology and the dissertation structure.

The second chapter is the literature review, where the most relevant information for this study was collected. It contains seven subchapters being them: introduction, definition of UA, UAV and UAS, UAS elements, different types of UAVs vs limitations in SAR missions, UAS classification, legislation in Portugal and conclusion.

Chapter three consists of the current operational procedures used by the SAMONT-GNR and some examples of real scenarios. The proposal of an operational plan to apply during the search phase will also be introduced. This chapter is composed of six subchapters: introduction, Subagrupamento de Montanha-GIPS-UI-GNR, search patterns vs operational phases, SAR scenarios, operational plan proposal and conclusion.

In chapter four, the case study is detailed, and it is divided into four subchapters: introduction, UAS specifications, operational implementation, survey data and conclusion.

Chapter five contains the results and its analysis. This chapter is split into four subchapters: introduction, field trial results and analysis, survey analysis and conclusion.

Finally, in chapter six, conclusions and perspectives of future work are presented. It is composed of three subchapters: dissertation conclusions, concluding remarks and perspectives of future work.

Chapter 2 - Literature review

2.1. Introduction

Unmanned Aircraft (UA) are not recent, despite the opinion currently shared, and only emerged after manned aviation. Having first appeared around the time of the First World War in 1916, the first UA was presented in this same year and the first flight realized in 1917, having been given the name of Hewitt-Sperry Automatic Airplane, due to its two creators [4].

After the War, the funding was diverted from this type of technology that was not yet mature enough, to other interests that at the time were more relevant. Few people at the time saw any civilian application in this type of aircraft [5].

Early in 1951, Ryan Aeronautical Company developed and built what would become one of the most important UAVs of all time, known as “Ryan Firebees”. This UAV was used initially as a target drone but, due to some circumstances at the time, the Department of Defense (DoD) started thinking about surveillance [6]. It was also the first UAV to use a jet propulsion unit.

During 1970 the modern era of UAVs began. In some countries, such as the United States and Israel, some designers started using smaller, slower and cheaper aircraft. But of all these features, what stood out was the use of small video cameras that could send photos to the operator in real-time [7].

All the progress made over the last years has contributed to show how important and valuable this type of aircraft can be in different scenarios and applications. It was also possible to start thinking about the possibility of applying them in civil and commercial applications.

In recent years UAVs have been applied with very different purposes throughout the world and increasingly showing their utility. The use of UAVs in SAR missions, has been carried out for several years; according to the survey on reference [8], 88% of civilians accept their application in SAR.

UAVs can perform various tasks that humans can find "dirty, dull or dangerous" to them [9]. In several situations, people that integrate search and rescue teams, see their lives in jeopardy during the accomplishment of missions. With the application of this type of resource, the procedures may become faster and safer. When UAVs are used in SAR missions, a SAR team member is responsible for operating the aircraft, making it reach and sweep the desired areas and collect as much information as possible [10].

Over this chapter, it will be approached the most relevant topics concerning the different types of UAVs, as well as the sensors that could be used in SAR missions to achieve improved outcomes in this type of missions. It will also be discussed some relevant matters that emerge, when this type of aircraft is applied.

2.2. Definition of UA, UAV and UAS

According to the International Civil Aviation Organization (ICAO), the term UA is defined as "An Aircraft which is intended to operate with no pilot on board" [11][10].

The definition of UAV adopted by ICAO in "Global Air Traffic Management Operational Concept" [12][11] is that "An unmanned aerial vehicle is a pilotless aircraft, in the sense of Article 8 of the Convention on International Civil Aviation, which is flown without a pilot-in-command on-board and is either remotely and fully controlled from another place (ground, another aircraft, space) or programmed and fully autonomous". These vehicles are commonly known as "Drones".

When we use the expression UAS, we are not only talking about the UAV but also all the elements that are involved in the operation of this type of aircraft. Over this chapter, these types of elements will be addressed in more detail. UAS can be defined as "An aircraft and its associated elements which are operated with no pilot on board" [11][12].

2.3. UAS Elements

As was mentioned before the UAV is only one of the major subsystems that integrate the UAS. In the following subchapters, all the elements that integrate this system are explained in more detail. Figure 3 shows all the remaining elements.

[10] pp – 10 (Glossary)
[11] pp – 42 (Glossary B-6)
[12] pp – 10 (Glossary)

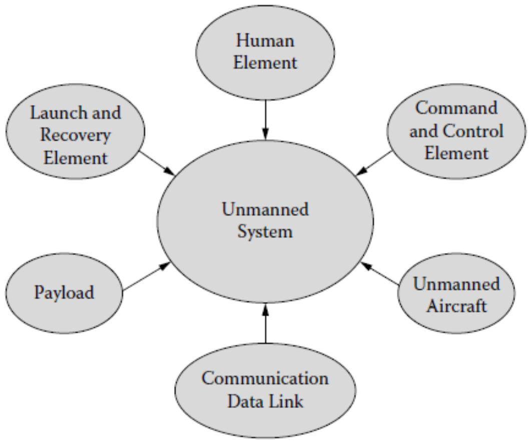

Figure 3 - Elements of an UAS – Source: [13]

2.3.1. Command and Control Element

A UAS can possess different levels of autonomy, that can vary from manually controlled to fully autonomous systems. In the case of manually controlled, the UAV is operated totally by remote control with the involvement of an operator. If the system is fully autonomous, no pilot intervention would be required and the aircraft is controlled from take-off to landing through the autopilot [13].

The Control Station (CS) is where the man-machine interface occurs, and it is responsible for the control of the UAV during its operation. This station is usually based on the ground designated by Ground Control Station (GCS) [14]. Although there may be other possible locations for the CS, the term GCS is used preferentially in this dissertation, because it is the most used configuration and the one that was adopted in the case study.

In the GCS we can usually find two stations, a pilot station, and a sensor station. The pilot station is projected to enable the pilot to control the aircraft and its main systems. The sensor station is used for operating and monitoring other UAV systems apart from flight control, for instance, radio communication or cameras [13]. These two stations can be combined in a single one when only one operator is able to control the entire UAV operation. Most of the time the UAV operation is planned in the GCS but can also be planned in a remote location and uploaded to the GCS.

When applied to SAR missions - the most suitable platforms are Mini UAVs not meaning that other type of platforms cannot be used - the GCS of these platforms is usually man-portable [15]. This characteristic increases the capability of the SAR team when they are moving the equipment from one place to another, for example in a patrol vehicle, not requiring a specific means of transportation.

According to reference [16], there are three key elements in the UAS, being them the GCS, Communications and finally the Launch and Recovery element. Besides these elements, the payload and the human element were also addressed because they play a fundamental role in the UAS used in the case study of this dissertation.

The operator responsible for manually controlling the UAV has two different ways of doing it. The first and most common way is through Line of Sight (LOS), requiring the observation of the platform during the entire flight. The First Person View (FPV) system is another way of controlling this type of aircraft, consisting of the radio transmission of the video image, obtained from an onboard camera to a display on the ground usually in the form of a screen or video goggles [17]. In Figure 4, a set of video goggles is presented.

Figure 4 - FPV with video goggles - Source: [17]

There are two types of FPV video links, the analogic and the digital. Analogue video does not require any kind of imaging processing; due to this fact, the image viewed by the operator has almost zero delay from the image captured by the camera. Another attribute of analog video is the presence of noise on the live video feed when the video link starts to fail due to range limitations. This failure happens when the operator reaches the limit of the radio range, encounters radio interference and also due to the presence of obstacles between the UAV and GCS, most of the time associated with the topography of the terrain [17].

Concerning the possible interferences that may occur, other sources of radio transmission can interfere with the main signal, especially when the interfering signal is within the same radio frequency band as the FPV transmitter. This problem can be overcome by selecting a different band of operation, far away as possible from the interfering frequency [17].

Interferences could also be minimized using a high gain directional antenna. Antennas with a narrow beam and high directional gain increase the received strength of the video signal transmitted from the UAV. These types of antennas can also be equipped with a UAV tracking system that automatically directs the antenna at the moving platform [17].

The advancement of technology in recent years has brought significant improvements in video transmission through FPV systems. Digital FPV systems can transmit video in High Definition (HD), but this feature has some disadvantages. Digital systems are more expensive and bulkier when compared to analogic systems. The increased equipment weight may be a problem when carried by ground personnel to deployment sites. The transmission range is also smaller within the most commercial offers.

2.3.2. Communication Data Link

In the communication system, the most critical task is making sure that it provides the data links between the UAV and the GCS in both ways (Figure 5).

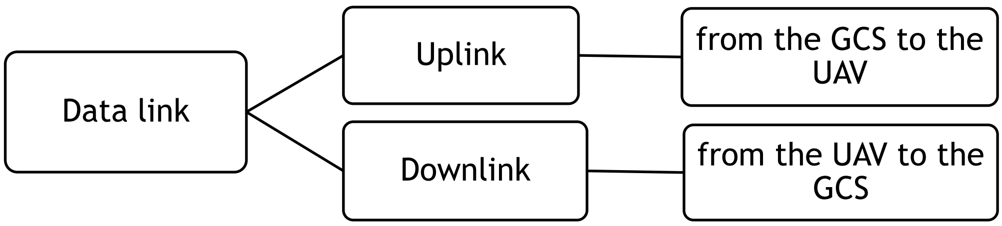

Figure 5 - Data link schematic - Source: Own elaboration based on [14].

Through the communication systems, the operator gives input commands to the aircraft, operates the payload if required, and also enables the aircraft to send information and images to the operator [14].

The transmission of the data between the UAV and the GCS is made in three different ways: by radio frequency, by laser and by optical fibers [14]. Although there is more than one way to establish the communication between these two elements, the radio frequency communication will be explained in more detail due to the fact of being the most relevant for the case study.

There are two different types of radio frequency operations, the Radio Line-of-Sight (RLOS) or Beyond Radio Line-of-Sight (BRLOS) [18].

In the case of an RLOS operation, the transmitter(s) and receiver(s) are within mutual radio link coverage and can communicate directly or through a land connection. When the transmitters and receivers are not in RLOS, it is called a BRLOS operation. This includes satellite systems and all other systems, in which the CS can communicate through a terrestrial network. The BRLOS operations have a greater communication delay when compared to the RLOS system.

2.3.3. Payload

The payload can vary a lot according to the operation of the UAV. The primary objective of this element is to be helpful in the accomplishment of the mission.

Due to the recent advances in technology, new developments in payloads can be expected with more frequency. These can be divided into basic types [14][13]:

- “sensors, cameras, etc. which remain with the aircraft; and
- dispensable loads such as armament for the military and crop-spray fluid or firefighting materials for civilian use. There may also be a future requirement for UAV to deliver mail or materials into difficult terrain”.

Time is one of the key elements that affect directly the success of a SAR scenario, which is a missing person being found alive. Victims at risk of exhaustion or hypothermia are a common situation in the mountain environment. So, it is of extreme importance that SAR resources are placed in the correct position as soon as possible [19].

During a SAR mission, the most critical and time-consuming phase is the search phase. This phase is critical to the person that is lost or injured if he/she has significant injuries or is exposed to aggressive weather conditions. Time can be the difference between a successful mission or a disaster [20].

In recent years, a lot of different payloads are usually applied to UAVs with the purpose of making them more useful for several applications. In the case of SAR missions, the choice of the required payload is crucial so that the platform can provide the best assistance to the actual procedures that are already used in this type of mission.

Almost all UAVs, when applied to emergency response situations, usually use sensors as payload. This type of sensors can be divided into two categories [15]:

- passive sensors; and
- active sensors.

The passive sensors category focuses mainly on the different types of imaging and cameras, more specifically [13]-[15]:

- Electro-Optical (EO) cameras, usually known as daylight or visible light camera. This type of cameras uses electronic tools to work in the properties of the image and

[13] pp – 128 (Chapter 8)

operate in the perceptible light spectrum and is used primarily during the day. Almost all the Mini UAVs is equipped with a camera of this kind;

- Low-Light-Level (LLL) cameras, which in terms of operation are very similar to the standard optical cameras but present a significant difference, this being the amplifier gain of the light sensor.
  Through the optical fiber, this gain is accumulated in the lens, allowing this type of camera to operate with only one-tenth of the light needed for the operation of standard cameras. Due to this type of characteristic, this sensor stands at a higher price level than the ones that are currently used. These cameras are usually used in night surveillance and recognition;
- Infrared (IR) or Forward-Looking-Infrared (FLIR) cameras generate an image using IR or heat radiation. The heat is emitted by the object, during the day and night, and is not reflected such as light, making these cameras an excellent option during the SAR mission that occurs during the night.
  The sensor that this type of camera possess is affected by rain and fog, but the great difficulty is that after a few hours the victim start to lose heat. However, the rain can be an asset to the search, because if this is tempestuous the FLIR image will highlight the hot spots more easily.
  This type of camera could be cooled or noncooled. The first type is usually more expensive and contributes with more weight to the UAV. In recent years, this type of sensor has been used in some civil applications.

The active sensors use laser devices for detection and ranging. In this category, terms like Light Detection and Ranging (LIDAR), Laser Detection and Ranging (LADAR), laser radar and laser range finder are commonly used. These types of sensors operate with a laser beam with the objective of measuring the distance to a particular object or performing target selection. When compared to passive sensors for example, they present a superior precision. Their use in military or civil applications is less common mainly due to the extra weight that they offer to the UAS, the higher battery consumption and its vulnerability to the changes of the weather conditions [13], [15].

The cameras can be fixed in the UAV, making the operator view limited. A solution to overcome this limitation is the application of a system called gimbal or turret (Figure 6), giving the camera a predetermined range of mobility and consequently improving the operator Field of View (FOV) [13]. The application of a dual camera (*EO and IR or EO and FLIR*) is other possible solution to overcome this limitation, both of these solutions were used in the case study of this dissertation during the field trials.

Figure 6 – Quadcopter UAV with an installed gimbal – Source: [21]

Payloads that can deliver images in the visible and near-infrared spectral ranges are usually the lightest and are common to almost all UAV applications. In a MUAV, the Maximum Take-off Weight (MTOW) is one of the most important aspects, because any unnecessary weight increase will be a challenge to the battery life of the system and consequently to the operation [22].

2.3.4. Launch and Recovery Element (LRE)

The LRE is the most hard-working and challenging aspect of the UAS operation. In this process, it is important to mention the type of equipment that is usually involved (Figure 7).

Launch equipment

- Used in aircraft that do not have the ability to fly verticaly or access to a suitable runway.
- Often used on a ramp along which the aircraft is accelerated on a trolley, by compressed air for example, until it has reached an airspeed that can sustain flight.

Recovery equipment

- Also required for aircraft without a vertical flight capability.
- Installed within the aircraft and usually takes the form of a parachute, being deployed at a suitable altitude over the landing zone.
- Alternatives like large nets are used in order to prevent damage at the time of impact.

Retrieval equipment

- If the aircraft is not light enough to be transported by a person, a way to transport the aircraft to the launcher is necessary.

Figure 7 - Launch and recovery equipment schematic - Source: Own elaboration based on [14]

2.3.5. Human Element

Of all the elements mentioned before, the human element is seen as the most important. This element is often mandatory in the UAS operation but depends on the complexity of the system that is used. If the aircraft is not fully autonomous, it requires an operator that is responsible for the safety of the operation and for controlling the platform. With the advances of technology, in the next years it is expected that the human element will gradually be replaced by fully autonomous systems [13].

In the case study, this element had a major role, because the UAS operators belonged to GIPS a specialized crew from GNR. This element was evaluated through a survey, that is detailed during the Subchapter 2.7. The UA element is described next.

2.4. Different Types of UAVs vs Limitations in SAR Missions

One of the major limitations of UAVs is flight time. As already discussed, many efforts have been made to overcome this problem. Additionally, different UAV configurations have different flight times, and it is not possible to claim that one performs better than other based only on the flight time. The best UAV configuration is chosen according to the type of mission it will perform.

According to wing configuration, the UAVs can be classified into the following categories [23]:

- Fixed-wing UAVs, also known as Horizontal Take-off and Landing (HTOL) UAVs. Usually, requires a runway to take-off and land, but in some specific cases, the flight can be initiated through catapult launching. The two main characteristics of this configuration are long endurance and high cruising speeds;
- Rotary-wing UAVs also referred to as Vertical Take-off and Landing (VTOL) UAVs, whose main advantages are hovering capabilities and high maneuverability. As for disadvantages, this type of vehicle has a lower cruising speed and shorter flight time when compared to a fixed-wing configuration.

Moreover, there are two more UAV categories: blimps and flapping-wing UAVs [23]. These two types of UAVs are not used as frequently, mainly due to the low cruising speed and low maneuverability in the case of blimps, and due to mechanical complexity and high price in the case of flapping-wing.

Regarding the fixed-wing UAVs, a new category with VTOL mechanism has emerged. Some manufactures has been developing some prototypes of this new hybrid system [24]. This system allows the combination of a rotary-wing flight and the traditional fixed-wing flight, offering the best of both aircraft types, namely the convenience of rotary-wing aircraft for take-off and land, with the efficiency, range and endurance of a fixed-wing aircraft.

Table 1- Strengths and Weaknesses of different UAV categories - Source: Own elaboration based on [25]

Characteristics	Rotary-wing	Fixed-wing
Maneuverability	✔	✖
Price	✔	✖
Size/Portability	✔	✖
Ease-of-use	✔	✖
Range	✖	✔
Stability	✖	✔
Payload Capacity	✔	✖
Safer Recovery from Motor Power Loss	✖	✔
Take-off/ Landing Area Required	✔	✖
Efficiency for Area Mapping	✔	✖

Table 1 provides a qualitative comparison among the aforementioned categories, in terms of strengths and weaknesses. It is important to mention that this comparison takes into account the price of the product.

The rotary-wing category, in comparison to the fixed-wing, allows the vehicle to become stationary in the air (hovering). This ability is essential when continuously monitoring the same area. In Table 1, the efficiency for area mapping is considered a strength of the rotary-wing configuration due to that capability. It does not require a runway or any kind of mechanism to be deployed [25]. This category comprises different types of configurations, such as helicopters and multicopters (quadcopters, hexacopters, and octacopters).

Regarding multicopters, which provide the highest maneuverability, quadcopters present the best balance between maximum payload weight and cost. This kind of design is often used because it can carry a significant amount of weight without raising the price of the product drastically. For instance, a hexacopter or an octacopter can carry heavier payloads but the price of the equipment is also higher [26].

In terms of safety of the operation, the hexacopter and octacopter are a more reliable choice due to the higher number of motors. If one of the motors fails, the others are still able to maintain the flight, allowing the operator to land the platform safely [26].

When applied to SAR missions, the UAVs also have limitations that need to be considered. As was previously mentioned, the flight time is one of the most important limitations in this type of mission. Mountain environments are well known by adverse weather conditions such as heavy winds, rain, fog, and cold temperatures. The presence of heavy winds requires the UAV to be equipped with a robust stabilization system to avoid loss of control by the operator.

Although UAVs can operate in rainy conditions, high levels of precipitation can cause short circuits in the electronic components and reduce the visibility of the operator. Weather conditions like humidity and fog can also have the same effect [27].

When the topic of discussion is the battery, it is important to have in mind that when carrying the maximum allowed payload, the battery consumption increases, leading to shorter flight time. The flight speed is also a factor that has a direct impact on flight time. Higher flight speeds increase energy consumption thus reduce the flight time.

Lithium Polymer (LIPO) batteries are the most used in nowadays applications, due to their high power to weight ratio.

The cold weather also affects the operator agility, thus requiring the use of special equipment such as gloves or hand warmers [28].

Cold temperatures present a major threat to battery life and consequently reduce the expected flight time. This phenomenon occurs due to the deceleration of chemical activity inside the battery. Some measures can be taken to improve flight time when the mission is performed under this circumstance [28], [29]:

- Monitoring the temperature of the environment before the operation. The discharge time of a fully charged battery is shorter in a temperature of -20ºC that in a 25ºC setting;
- Disconnecting the batteries when not in use and store them in a fireproof container, especially during indoor charging;
- Do not store batteries in extreme cold or heat, also avoid sunlight;
- Do not store individual batteries together. The terminals could touch and cause a short circuit;
- Pre-heat the batteries before flying up to a temperature around 25ºC. This measure should also be applied to spare batteries. Can be used battery heater or insulation stickers for this process. Some batteries come with internal temperature sensors that prevent them from providing power when the temperature is below a given safe value;
- Performing shorter flights to avoid a crash due to low battery condition;
- Before starting the flight, hover the platform around 30-45 seconds for warming up the batteries.

Other factors that difficult the correct and prompt identification of a human body are the environmental and weather conditions, such as the density of the vegetation and the low amount of light [19], [30].

Given that the field trials of this study have taken place in a mountain environment, only the most critical limitations associated with this environment were assessed.

2.5. UAS Classification

Although there are other forms of classification, the adopted classification was referenced by the author Reg Austin [14]. In this classification, an UAS is characterized based on their capacities like endurance and size of the UAV, which is one of the elements that integrate this system. The different classifications that are used may be:

High Altitude Long Endurance (HALE) – operations over 15 km of altitude and with more than 24 hours of endurance. They can carry out extremely long-range reconnaissance and surveillance missions and are increasingly able to carry weapons. The United States Air Force usually operates them from fixed bases.

Medium Altitude Long Endurance (MALE) – operations between 5 and 15 km altitude and 24 hours of endurance. Their roles are like the HALE systems but generally operate at shorter ranges and from fixed bases.

Medium Range or Tactical UAV (TUAV) – its range is between 100 and 300 km. These air vehicles are usually smaller and operated within simpler systems than are HALE or MALE and are operated also by land and naval forces.

Close-Range UAV – it is used by mobile army battle groups, for military/naval operations and diverse civilian purposes. They usually operate at ranges of 100 km and have probably the most prolific of uses in both fields.

Mini UAV – refers to a UAV below a certain mass still to be defined, but not as small as the Micro UAV (MAV). Capable of being hand-launched and with ranges up to 30 km. These are used by mobile battle groups and particularly for diverse civilian purposes.

Micro UAV - was initially defined as a UAV having a wing-span no greater than 150 mm. The MAV is principally used for operations in urban environments, particularly inside buildings and expected to be very vulnerable to atmospheric turbulence and rain.

Nano Air Vehicle (NAV) - These are proposed to be very small and used in swarms, for purposes such as radar confusion. If the camera, propulsion and control sub-systems can be made small enough, they can also be used for short-distance surveillance.

In the case study of this dissertation, according to the adopted classification, the platform that was used fits in the Mini UAV classification.

2.6. Portuguese Legislation

According to European Aviation Safety Aviation (EASA), operations with UAS fall into three categories, being them: open, specific and certificated category [31]. Each of these categories has specific regulations as can be seen in Figures 8-10.

Open category - it is a category that, considering the low risk involved, requires neither a prior authorization from the competent authority or a declaration from the UAS operator before the operation can be carried out.

UAS with a mass of less than 25 kg.

Flights below 120 meters (400 feet).

Line of sight (VLOS - Visual Line of Sight), night flights are possible, beign necessary identification lights.

Figure 8- Open category regulation schematic - Source: Own elaboration based on [31]

Specific category - Considering the risks involved, requires an authorization from the competent authority before the operation is carried out. Having in mind the mitigation measures identified in an operational risk assessment, except for certain standard scenarios for which a statement from the UAS operator is enough.

Operations of UAS considered as medium risk or aircraft with a maximum operational mass greater than 25 kg.

UAS operations in this category must be submitted to a prior operational risk assessment and the application of the identified mitigation measures.

Estabilish and maintain up-to-date, in a secure manner and acessible in real time to authorized people, one or more records of operational declarations.

Figure 9 - Specific category regulation schematic - Source: Own elaboration based on [31]

Certificated category - In this category, due to the high risk involved, a specific certification of UAS and operator is required.

UAS with a mass of more than 150 kg or considered to be complex.

Carry out operations beyond line of sight (BVLOS - Beyond Visual Line of Sight).

UAS used to transport of passengers and dangerous merchandise. Equivalent requirements to manned aircraft.

Figure 10 - Certificated category regulation schematic - Source: Own elaboration based on [31]

Autoridade Nacional de Aviação Civil (ANAC), in Portugal, has produced a regulation with the exclusive objective of establishing flight rules and the airspace use conditions by the manually controlled UAS, usually known as "Drones" [32]. This regulation is divided into general rules and specific rules regarding the operation conditions. In terms of specific rules, only the most important to this study will be presented.

Thus the general rules that should be fulfilled by operators, to guarantee the safety of the other airspace users and the people on the ground, must be [32]:

- It is allowed to fly by day up to a height of 120 m, without requiring the exceptional authorizations foreseen in the regulation (specific rules);
- Keep a safe distance from people and goods;
- Physical and mental state of the pilot (operator) suitable for the operation;
- Priority is given to manned aircraft. UAS have the obligation to step aside in their presence;
- Ensure good operational conditions of the aircraft and the system;
- If there are observers, they must maintain direct visual contact with the aircraft and be permanently in a position to establish bilateral communications;
- In LOS operations, no more than one aircraft can be operated simultaneously;
- Mandatory and permanent use of identification lights (day and night flights).

Within the specific rules of the previously mentioned regulation, the UAS is forbidden to fly in areas where protection and aid operations are in progress. Despite this rule, with the explicit authorization of the *Comandante das Operações de Socorro* (COS), UAS can fly over these areas and assist them if no manned aircraft is simultaneously flying in that area [32]. In the case of SAR missions, this rule is not applied but permission is also required, explained in detail on Subchapter 3.5. There are some operations that require authorization from ANAC, such as [32]:

- BVLOS flights;

- UAS with an operational maximum mass above 25 kg;
- Night flights;
- Flights above 120 m.

In the case study of this dissertation, the UAS used in the field trials does not fall within neither of the previously described categories but are mentioned in the *Article 1* in the regulation [32]. The UAS used in these trials belong to the GNR, and it is considered a State Aircraft as can be seen by the definition present in the *Article 2 - c) state aircraft - "aeronaves não tripuladas usadas nos serviços militares, aduaneiros e policiais"*.

According to the regulation mentioned above and considering that the UAS used is a State Aircraft, it is excluded from the fulfillment of this regulation. Despite this fact, the operators responsible for the UAS, must ensure whenever possible that the general rules are fulfilled.

2.7. Survey

As previously mentioned, all the participants involved in the field trials of this study were submitted to a survey. The main goal of this survey is to evaluate the workload of those who participate in the operation. It is also important to refer that the identities of the participants will not be revealed.

This survey was based on the Task Load Index (TLX) developed by the National Aeronautics and Space Administration (NASA). The TLX is a two-part evaluation procedure consisting of weights and ratings. The first requirement is for each individual to evaluate the importance of each factor (weight) to the workload of a specific task. There are 15 possible pairs of comparisons between the six factors that are being evaluated, as can be seen in Annex 1. Each of the possible comparisons is presented for the participant to choose which pair member contributed the most to the workload of the task. The number of times that each factor is selected is counted and then scored from 0 (not relevant) to 5 (more important than any other factor) [33].

The second requirement is to obtain numerical ratings for each scale that reflect the magnitude of that factor in a given task. The scales are presented on a rating sheet. Participants answer by marking each scale at the desired location. Ratings could be obtained either during a task, after task segments or following an entire task.

In order to obtain the overall workload score (workload index) for each participant, it is necessary to add the products of the multiplications from the weights assigned to each of the factors by the numerical rating obtained in Annex 2. For a better understanding of the described procedure, one can check TLX from NASA [33].

This survey evaluates the same factors as the TLX (Table 2). In the rating sheet, the scale ranges from 1 to 100, being 1 the lowest and 100 the highest, where the participants will attribute a percentage to each factor according to what they experienced during the task. An open question about the improvements and difficulties the participants encountered during the operation was also added; these answers will be presented in Chapter 4.

Table 2 – Factors Description - Source: Own elaboration based on [33]

Factors	Description
Mental Demand	How much mental and perceptual activity was required (deciding, remembering, looking, searching)? Was the task easy or demanding?
Physical Demand	How much physical activity was required (pushing, pulling, climbing)? Was the task easy or demanding?
Temporal Demand	How much time pressure did you feel due to the pace at which the task or tasks element(s) occurred?
Performance	How successfully do you think you were in accomplishing the goals of the task(s) that you performed during the operation? How satisfied were you with your performance in accomplishing this(ese) goal(s)?
Effort	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration Level	How insecure, discouraged, irritated, stressed and annoyed did you feel during the task?

2.8. Conclusion

From the literature review, it was realized that the most suitable UAV to apply in SAR missions belonged to the rotary-wing category. Within this category, there are different types of configurations, but a quadcopter was the selected one for the field trials of the case study. This type of platform has limitations, as already discussed, which will be considered over the dissertation.

The overall information gathered in this entire chapter, was crucial to understand all the elements within the UAS that will then be applied in the case study of this dissertation. Each of these elements has an essential role in the UAS operation, and consequently present abilities and limitations when applied in SAR missions. Regarding the legislation detailed in subchapter 2.6, allowed to acquire the proper knowledge for planning the field trials without causing any kind of constraint.

As mentioned previously, adverse weather conditions were the main limitations to the performance of the UAV during the field trials, so they must play a key role when designing an operational plan for SAR missions in any scenario.

Chapter 3 - Operational Procedures and SAR Scenarios

3.1. Introduction

In order to fulfill the objectives that were established in the beginning of this study, the operational procedures used by the SAMONT-GNR as well as a few reports from real SAR scenarios will be analyzed. The Severity and conditions associated to SAR missions are always different, usually influenced by the environment where it happens, obligating the members of this unit to elaborate a plan to follow and the most effective procedures to use for each mission.

After the analysis of all the information gathered during this chapter, and considering the conclusions arrived at the literature review, a proposal for an operational plan with the implementation of an UAS will be developed. Alongside with this proposal, the SAR scenarios recreated in the case study will be also explained and described, being the reasons that lead to their choice also pointed out.

In this chapter, unless stated otherwise, the information was provided by the SAMONT-GNR, more specifically, was obtained from internal manuals [34], [35].

3.2. Subagrupamento de Montanha-GIPS-UI-GNR

The GIPS was created on February 2, 2006, based on the Law-Decree nº 22 [36]. With the primary objective to respond to a long-felt need to have a highly specialized, motivated and capable national body in the state, with the ability to assist when necessary the entire national territory.

Mountain areas, like Serra da Estrela, have developed rapidly in the last years, leading to several changes. The appearance of new tourist infrastructures (Figure 11), and the development of many activities, mainly related to sports and leisure are examples of these changes. All the aforementioned factors plus the severe weather conditions felt in the mountain environment, have made ensuring the safety, protection, and aid of the citizens an increasing necessity [37].

Figure 11 - Evolution of hotel units and number of accommodations - Source: [37]

In 2003, GNR created for Serra da Estrela, a Special Mountain Group, composed by 12 military personnel, specially trained and prepared to carry out the GNR mission in adverse weather conditions, namely to help people in distress [37].

The Subagrupamento de Montanha was created, in 2009; this unit includes a Mountain Squad, constituted of Mountain Search and Rescue (MSAR) specialists, and a police component to perform the overall mission of GNR. Organically, it belongs to the GIPS, under UI command.

The MSAR squad is equipped with equipment and human resources with specific training and sharp experience in the field. This squad performs: security and policing at altitude; safety and support for events related to nature tourism activities; search for missing persons in hostile locations; mountain rescue in complicated places such as rivers (canyoning), caves, wells, cliffs; rescue in urban spaces and structures [37].

Technical and operational evolution over the years has contributed directly to an improvement in the safety, protection, and aid to the citizens, as is showed in Figure 12.

Figure 12 - Evolution in the security, protection, and aid of the citizen - Source: [37]

3.3. Search Patterns vs Operational phases

In terms of search operations, the most relevant are the following:

1. Primary search;
2. Extended/Secondary or General search;
3. Search and rescue.

For this study, the most relevant and approached type of search was the search and rescue. Search is an operation using personnel and means available to find people in distress; rescue is an operation to recover people in distress. The members of the MSAR squad, need to complete a three month mountain course given by GNR, that has the goal of preparing them for performing the tasks mentioned above. Below are present the operational phases that need to be fulfilled.

Operational phases:

- Alert;
- Search;
- Rescue;
- Recovery;
- Demobilization.

During the ***alert phase***, the tasks that must be fulfilled are:

- Detect potential alerts;
- Make sure the alert is correct; and
- Communicate the occurrence.

The alert can occur through self-reported, given by other people, or by the emergency call number 112. In most cases, the alert itself ends up providing a relevant amount of data for the search phase, for example, the clothes that the victim was wearing before disappearing.

It is important to take into consideration that the information given by the person communicating what occurred may not be accurate, mainly due to the anxiety, stress, and concern, ending up affecting the mission. There is always a military member from the SAMONT-GNR monitoring the possible incoming alerts. When received, this information is then immediately passed to the MSAR squad.

The ***search phase*** is the most crucial in SAR missions. The time that a SAR team takes to reach the victim has a significant impact on the success of the mission. In the initial phase of the mission, the objective is to verify the most likely location of the person or group in distress, so a search area close to this location must be established. In this phase, the search can be carried out by personnel on foot or in motor vehicles supported or not by aerial resources.

Only the initial and essential information is collected and analyzed, allowing the commander of the MSAR squad to determine who is missing, the equipment and the experience they possess in this type of activity. Using an operational data sheet, this information is gathered and registered:

- Who called?;
- How many people (if in group)?;
- If there are injuries and severity;
- Location if possible;
- The equipment they have;
- Starting point;
- Final objective;
- Ages;
- Experience/knowledge of survival techniques;
- Contacts;
- Route timings;
- Passage points, or other recognized;
- Recommendations.

In Annex 3, the current operational sheet used by the SAMONT-GNR (reserved) is presented, where the military member of the SAMONT-GNR who is on call registers all the initial operational information to be passed to the MSAR squad, before starting the mission.

The other ***remaining phases***, regarding the rescue and extraction of the victim, were not considered, since only the search phase was recreated in the case study.

As mentioned earlier, one of the most important measures in the search phase is to determine an area for the most likely location of the victim. To inspect this area, search patterns are used to cover the largest possible area at the same time and find the victim as fast as possible.

Line Search – This search pattern involves a line of people scattered across the missing group known itinerary, spaced a little less than twice the distance each person can visually cover. It can be done by one team in a limited area, or by multiple teams in different areas at the same time.

This type of technique can also be used by a group that is trying to find a cabin, tent or other shelters with reduced visibility and does not know the exact location. In this situation, as they get closer to the area of the search object, they spread out in a line, and sweep the zone.

Square Search - A square search is used systematically in an area around the last known position of the search target when the direction of the target is uncertain. It requires a compass and a watch.

Start at the last known position of the search target, then go in a random direction (for example south) and walk during a given time. After this turn 90 degrees east and walk again during the same time that was defined in the first direction. At least turn 90 degrees north and walk twice the time that was chosen for each one of the previous directions and then turn 90 degrees west and walk twice the time again. This process is repeated, as long as necessary.

Circle Search – It is a type of search that is made from the last known position and made clockwise, opening the circle line, stipulating the amplitude of the diameter immediately.

Despite the search patterns described above, often the victim's last position is not known, requiring the application of unorthodox search methods considering the weather and terrain conditions. These conditions do not always allow the implementation of the described operational procedures.

3.4. SAR Scenarios

Throughout this subchapter, the chosen scenarios from among those provided by the commander of the SAMONT-GNR will be described, where his experience and opinion were considered. The choice of scenarios was made according to the complexity of the operation and the difficulties encountered, so that the implementation of an UAS could eliminate some of the difficulties encountered and assist the procedures already used. It is also important to mention that the description of the scenarios chosen was not fully provided, due to the confidentiality agreement (Annex 4).

The main characteristics of A and B scenarios are described in Tables 3 and 4, respectively.

Table 3 - Characteristics of Scenario A – Source: Own elaboration

Type of search	Search and rescue
Location	Cântaro Magro
Victim	Male
Situation	Victim of climbing has fallen on the east face of the Cântaro Magro-Serra da Estrela, when he was ascending the eastern slope of the Cântaro through classical climbing. The victim was accompanied by someone else, but there was no contact with both. There was only the information that he was on the so-called “Cascata Musical”.
Difficulties encountered	• Lack of knowledge of the exact place where the victim was located; • Adverse weather conditions; • Terrain Orography; • Progression; • Need to transport a lot of equipment to the site.

In scenario A, the information that the MSAR squad had before going on mission is in the situation of Table 3. The alert call was received around 7 p.m.. The MSAR squad arrived at the site around 8 p.m., having committed the following means:

- 6 military members of the MSAR squad;
- 2 off-road vehicles containing the protection equipment for the SAR team to conduct the mission.

At the site, the weather conditions were adverse, strong winds, poor visibility and terrain with too much snow were the biggest obstacles for the MSAR squad. It was necessary to climb to a higher point and then descend through several places until finding the victim. The search phase began around 9 p.m. with the use of various mountaineering equipment to enable the progression on site. The MSAR squad, arrived at the victim's location around 2 a.m., found him with an exposed fracture of the lower limb and quite a few abrasions. Due to the situation of the victim, the use of a helicopter (which was only possible as soon as the visibility improved) was necessary to remove him from the site, and then transferred to the hospital in Covilhã, and the operation was successfully concluded.

Table 4 - Characteristics of Scenario B - Source: Own elaboration

Type of search	Search and rescue
Location	Garganta de Loriga
Victim	Female
Situation	The victim disappeared in Garganta de Loriga when she was ascending the northeastern slope of the Serra da Estrela (Loriga-Torre). The victim was accompanied by someone else, but there was no contact with both.
Difficulties encountered	• Lack of knowledge of the exact place where the victim was located; • Adverse weather conditions; • Terrain Orography; • Progression.

As in scenario A, the information that the MSAR squad had before going on mission is presented in the situation of Table 4. The alert call was received at approximately 8 p.m.. The MSAR squad arrived at the site around 10 p.m.. This delay was due to the snowfall which prevented access to the site, having been requested the support of the Centro de Limpeza de Neve (CLN) based in Piornos, for clearing the road. The following means were expedited:

- 8 military members of the MSAR squad;
- 2 off-road vehicles containing the necessary SAR team protection equipment to conduct the mission.

At the site, weather conditions were adverse, with the wind blowing close to 100 km/h, no visibility and the terrain full of snow. Around 10:30 p.m., the recognition of Garganta de Loriga (with an area of about 11 km) began, with the use of navigation by Global Positioning System (GPS), topographic chart and compass. The MSAR squad arrived at the location of the victim at about 4 a.m., who presented severe hypothermia, having provided the first health care on-site. The victim's evacuation and transfer protocols to the hospital in Covilhã were then activated, and the operation was successfully concluded.

3.5. Operational Plan Proposal

To develop this operational plan proposal, besides the information already mentioned, all the experience of the GIPS team that operated the UAS during the field trials was also taken into account. As can be seen in Figure 13, this plan is divided into three phases, each one detailed below.

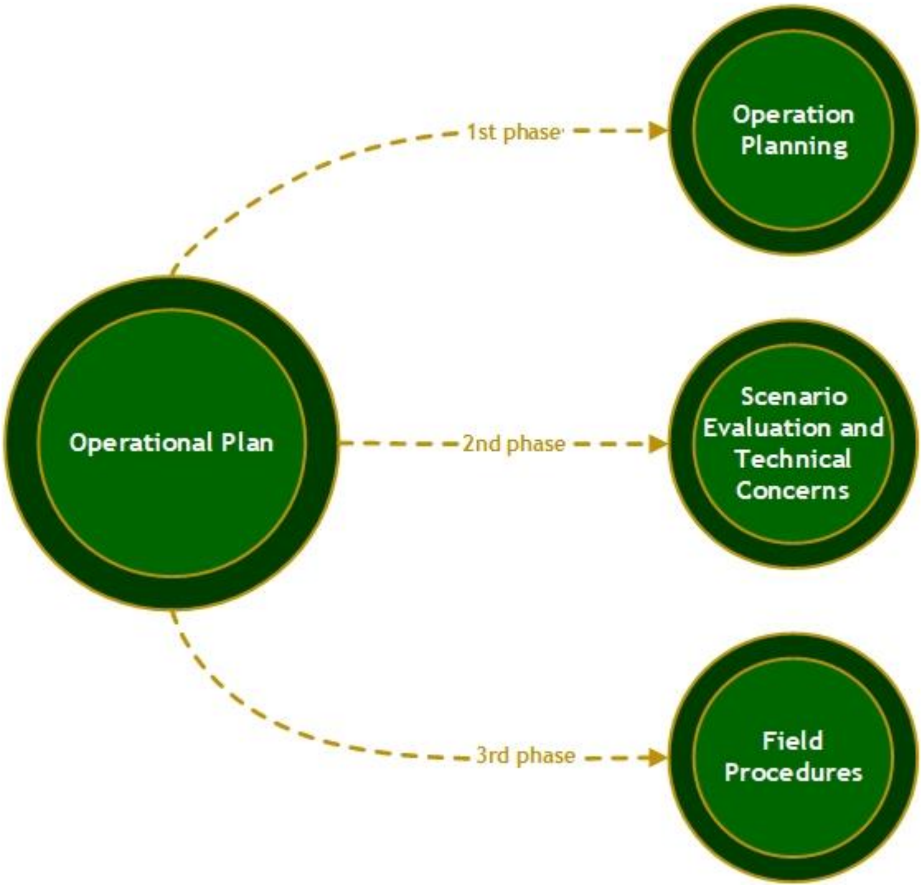

Figure 13 - Operational plan schematic – Source: Own elaboration

Over the following three phases, some key tasks must be performed by the UAS operator(s). It is typical of SAR missions that the aircraft is usually requested without previous notice of the Comando Territorial (CTER). An authorization of the Centro Integrado Nacional de Gestão Operacional (CINGOp) must be obtained. Then the CINGOp must communicate the order to the GIPS situation room. Only after these procedures, the commander of GIPS activates the team specialized in operating the UAS.

The first phase of the operational plan concerns the planning. This phase is usually performed before arrival on site. As a first task, the operator is advised to issue a Notice to Airmen (NOTAM) reporting the operation. This operational plan is conceived for state aircraft and its operators, so the accomplishment of this task is no longer mandatory, but it must be carried out whenever possible. Due to the unpredictable nature of SAR missions, this task is not accomplished in most cases. Still, the operator should check the updated and current information for the time of the flight in the Air Traffic Service (ATS) of NAV Portugal (national Air Traffic Control (ATC) service provider), at the NOTAM section, to avoid collisions or interferences.

If issuing a NOTAM is no longer possible it is recommended that the operator informs, ANAC as well as the National Aviation Authority (NAA), by other means, of the operation to be realized and its location. Simultaneously the operator should start analyzing weather forecasts for the site through specific tools. Then, within the available equipment and considering the requirements of the scenario, the operator can make its preliminary choice that will also depend on the information, concerning the victim and the location that the operator possesses.

The development of the second and third phases of this operational plan starts as soon as the operator arrives at the location where the SAR mission is taking place. The second phase of this plan includes the final selection of the UAS to be used (during the literature review some sensors and their characteristics were mentioned, which could be used as payload in SAR missions, and the different types of UAVs to be considered) and the respective care that should be taken with such type of aircraft.

In terms of technical concerns, these vary according to the limitations of the UAS or its operator. Some precautionary measures should be taken for any system, as mentioned in Subchapter 2.5 when the operation takes place in low-temperature environments. Regardless of the batteries used, it is crucial always to carry spare batteries. The number of spare batteries should be able to ensure a charge cycle of a discharged battery so that the time spent on the ground is as short as possible; thus, it is also essential to ensure a way of charging the discharged batteries on-site.

Arriving at the site, and after receiving all the information regarding the operational situation, the operator must then inspect the current weather conditions. At this point, the crucial decision of executing the mission must be taken, bearing in mind that the survival of a person may be at stake. If the weather conditions are not within the specification limits of the chosen UAS, the operator is strongly advised not to fly. However, the experience of the operator is a decisive factor in this choice, as he can feel capable of executing the flight. It is also crucial in this instance, to verify the existence of any kind of obstacles in the area of the flight.

Once all the tasks present in the two previous phases have been completed, then the last phase of this operational plan begins. Over this phase, some procedures are proposed, that must be taken into consideration in the application of the UAS during the SAR mission.

Before starting the flight, the UAV operator must gather all the information with the territorial team in charge of the operation, that is in command of the SAR mission. With the experience and knowledge of the area, by the territorial force, their opinion should be considered when the decision of how and where to start the search is made. Then, it is now time for deciding what would be the best search pattern to apply and define the search area for sweeping. The operator must realize, that the use of an UAS is for assisting the procedures that are already used by the SAR teams and it is important to try that the operation of this type of aircraft does not interfere in any way in the current procedures.

When the UAV and the ground team are sweeping the search area, it is crucial to make sure that the platform is inspecting a different zone within this area, especially to avoid false positives. In this operational plan, it is advised that the UAV sweeps the search area and requests the intervention of the military personnel on the field, whenever the operator detects a possible location of the victim.

If the search area is too extensive, the efforts of both teams should be combined in an organized manner to obtain the best possible outcome which in SAR missions is to find the victim as quickly as possible. Communication is definitely the key for UAS operators and the territorial force combine their efforts in the best possible way. There are some locations that the UAV is not capable of inspecting due to its limitations, or the sensors utilized cannot capture an image that is clear and leaves no doubt to the operator. In these specific situations, the military personnel on the field should be mobilized to these locations to inspect them, this is not necessary if the operators could identify without a doubt the image that they are receiving.

The number of operators that are involved in the operation of an UAS could vary according to the requirements of the mission and the type of system that is used. However, the use of 3 operators to carry out the following tasks is suggested based on the current practice of the GNR operators:

- Piloting the UAV (pilot station);
- Analyze the streamed content and operate the payload (sensor station);
- Monitor and ensure the safety of the operation (monitoring station).

At the first station, the operator in charge of piloting the UAV should be able to guarantee that the platform is within its operational limits. Simultaneously, it must be in communication with the remaining operators, and the commander of the territorial force for giving the information to the members in the field.

In the second station, the responsible operator must analyze the content streamed, and operate the payload, drawing attention always to what is detected that might be a possible location of the victim. The communication between the operator in charge of the sensor station and the responsible for the pilot station is absolutely crucial. If it is the case, the operator of this station must be able to transmit the content that is being streamed to another command post if needed.

Finally, the third operator oversees and ensures the safety of the operation. One of the most important tasks that must be performed by this operator, is gathering and analyzing the information related to the surrounding airspace and the terrain orography, while the operation is in progress. This operator needs to monitor the weather forecasts, during the operation, such as in the aeronautical radio frequency band, and report to the operator piloting the UAV any sudden change that could compromise the operation.

The monitoring station is crucial to assist, the pilot and sensor station; for example, if the requirements of the operation lead to a BVLOS flight, it is crucial to inform the pilot station what obstacles will be expected. The safety of the remaining operators, who lose the ability to pay attention to what is going on around them, becoming vulnerable, depends also on the operator responsible for this station.

Operators must be able to perform the tasks of each other, in the different control stations of the operation so that they can take over any of the stations. Achieving operator versatility will help to solve problems such as the identification and analysis of the image not being compromised due to saturation of the performed tasks.

3.6. Conclusion

Based on all the information provided by the MSAR squad, such as the operational procedures and the different phases that the SAR team have to fulfill during real SAR scenarios, it was possible to develop a proposal for a new operational plan with the use of an UAS. In this chapter the selected scenarios are also described, pointing out the major difficulties and procedures that the MSAR squad members performed until the search phase was successfully completed.

This plan approaches the tasks that should be fulfilled by the operator(s) to ensure the correct implementation of this kind of system, consequently, seizing advantage of their abilities and some procedures to deal with their limitations in SAR missions. It is also important not to forget that during the development of this plan, one of the major concerns was not to cause any kind of constraint to the procedures already used. For achieving this goal, the experience of the GNR members in the field was without a doubt essential.

After the conclusion of this operational plan proposal, it is now time of obtain their validation, to understand if it could really bring improvements in the success rate (find the victim alive int the shortest time possible) of SAR missions and take them to the next level. The next chapter concerns the case study, where this plan will be applied in the selected scenarios through field trials.

Chapter 4 - Case Study

4.1. Introduction

During this chapter the proposed operational plan, presented in the previous chapter, will be implemented and followed in the scheduled field trials. The elements of the UAS will be described and their specifications presented. Besides the implementation of this plan, the participants will be subjected to a survey, as referred to in Subchapter 2.7, and the related results will be presented below.

With the application of the developed operational plan, the main goal is to understand at what operational level the use of an UAS can assist the response in SAR missions and consequently reduce some of the difficulties encountered in the scenarios already described. New SAR scenarios, and the reasons that lead to the change from the ones originally selected will also be presented.

4.2. UAS Specifications

The UAS applied in the field trials was provided by the crew from GIPS that is specialized in the operation of this kind of aircraft in different situations. This selection was made within the available equipment, considering each scenario requirement.

All the equipment used was manufactured by DJI. The UAV used was a multicopter, more specifically the quadcopter Matrice 200 V1. This platform has a downward gimbal mount that allows the use of only one camera besides the FPV one already installed onboard.

Of all the UAV specifications available from the manufacturer, the most important are the following [38]:

- Mass – 6.14 kg;
- Number of batteries – 2;
- Mass with two standard batteries (TB50) – approximately 3.80 kg;
- Mass with two optional batteries (TB55) – approximately 4.53 kg;
- Maximum payload (TB50) – approximately 2.34 kg;
- Maximum payload (TB55) – approximately 1.61 kg;
- Maximum wind resistance – 43.2 km/h;
- Maximum speed (P Mode) – 61.2 km/h;
- Maximum flight time (no payload, with TB50) – 27 minutes;
- Maximum flight time (no payload, with TB55) – 38 minutes;

- Maximum flight time (full payload, with TB50) – 13 minutes;
- Maximum flight time (full payload, with TB55) – 24 minutes;
- Operating temperature – (-20ºC to 45ºC).

Regarding the maximum speed, there are three available modes that could be utilized for operating the platform: the ***S Mode*** where all the collision sensors are disabled but the flight speed is higher; the ***P Mode*** (used in the field trials) that is the most used and allows the operation with all the sensors activated with a loss in the flight speed; and finally the ***A Mode*** commonly used in autonomous flights. In the ***P*** and ***A Mode*** all the collision sensors are enabled.

Based on the specifications, it is possible to notice that this platform could fly with two different batteries. Being the flight time one of the major problems of the TB50, the selected batteries were the TB55, allowing an increase in the flight time, despite being heavy and thus reducing the payload capacity. Here are some of the specifications concerning these batteries that should be respected [38]:

- Operating temperature – (-20ºC to 45ºC);
- Storage temperature - less than 3 months: -20ºC to 45ºC/ more than 3 months: 22ºC to 28ºC;
- Charging temperature – (5ºC to 40ºC);
- Max charging power - 174.6 W.

The TB 55, also known as "intelligent flight batteries", has another characteristic that make them helpful in low-temperature environments, which is the use of an internal self-heating system. This heating function can be activated automatically or manually, and the management unit constantly monitors the battery status, making all information, including battery level and temperature, easily visible on the piloting interface (DJI Pilot).

During the operation of the UAV, the pilot can fly by LOS or through an FPV system, like it was explained before. In the field trials of this dissertation, a digital FPV system was used. The UAV used in the trials has a remote controller that operates within the 2.4 or 5.8 GHz frequency band, having a maximum transmitting distance (unobstructed, free of interference) of 7 km. This controller, when programmed, automatically changes the frequency band during the operation, using 2.4 GHz for flying and 5.8 GHz to record the streamed content received in the ground display [38].

As ground display, a CrystalSky monitor was used, which is an ultra-bright screen that is clearly visible in sunlight offering optimized video decoding in real-time. Due to limitations in software access on smartphones or tablets, video decoding in other smart devices is not ideal.

The operating temperature of this equipment should be respected and is between -20ºC to 40ºC [39].

The GCS used in the field trials was composed of the pilot station and the sensor station. The monitoring station is not within GCS, because the operator responsible for this station has no direct influence on the control of the UAV or its payload. The remaining operators responsible for the other two stations, had one remote controller connected by Universal Serial Bus (USB) to the CrystalSky monitor, as presented in Figure 14, both using the DJI Pilot interface. Only the operator responsible for the pilot station, who commands and controls the platform, decides when to give the control of the payload to the responsible for the sensor station.

Figure 14 - Remote controller with CrystalSky monitor - Source: Author

In Figure 15 it is possible to see the setup that was used in the field trials during the day period: the Zenmuse Z30 was the payload carried with a gimbal compatible with the UAV used. This camera weighs 556 g, and allows 30x optical zoom plus 6x digital zoom, making it an ideal tool for SAR missions. Its ability to zoom the image is crucial, especially when the operator has doubts about the image that he is watching and if the search area defined has locations that are difficult to access by the UAV. It is important to respect the operating temperatures of the equipment, that are [40]:

- Operating temperature – (-10ºC to 45ºC);
- Non-operating temperature – (-20ºC to 60ºC).

Figure 15 - Matrice 200 V1 with Zenmuse Z30 - Source: Author

During the field trial that occurred in the night period, a different setup was used with the Zenmuse XT2 [14] as payload. This camera combines the FLIR advanced thermal sensor with a high quality (4K) visual sensor. The number 1 in Figure 16 is the FPV onboard camera (that is not so perceptible in Figure 15), and the numbers 2 and 3 concern, respectively, the thermal and the visual camera.

Some of the abilities of the Zenmuse XT2 are the temperature check, which allows the selection of a point or area for temperature measurements, then a temperature range is defined and every point detected by the camera that is within this range produces a sound alert for warning the operator (the use of isotherms that focus on a specific temperature band helping to identify what is important); and finally the ability of adjust the color patterns applied to the thermal data with the objective of interpreting more easily what is really important [41]. This camera is a valuable device in SAR missions, especially the ones that take place during the night period; its abilities can help to overcome some of the difficulties experienced in extreme environments, like the lack of visibility due to the fog, or even the thick vegetation.

There is more than one type of lens model for the thermal camera, having a direct influence on the total weight of the XT2. The ones used are the 25 mm which leaves the total weight on 629 g. In terms of specifications, it is important to know, that the temperature range of the

[14] In 2018, this camera, operated by the same team present in the field trials of this study was the first to perform a detection of a victim alive in a real SAR mission.

thermal camera in high gain is between -25ºC to 135ºC and in low gain is between -40ºC to 550ºC [42]. The launch and recovery element were not used in the field trials of this study.

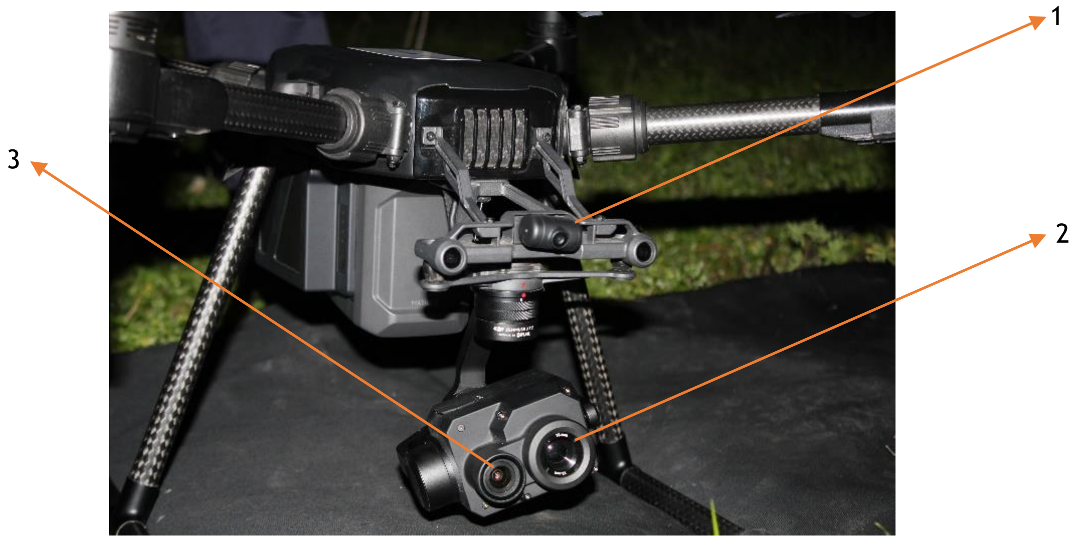

Figure 16 - Matrice 200 V1 with Zenmuse XT2 - Source: Author

4.3. Operational Implementation

To carry out the field trials of this study, it was necessary to obtain an authorization from the Instituto da Conservação da Natureza e das Florestas (ICNF), I.P., due to the locations of the scenarios being within the boundaries of the Parque Natural da Serra da Estrela (PNSE) which is a protected area (Annex 5).

The scenario A occurred during the night period, but it was decided to recreate this scenario during the day. The reason for this decision was to understand the different performance of the UAV and the participants involved in these two periods, as well as testing the capacities of all the payload used.

In Figure 17, it is possible to see the steps followed during the realization of the field trials. The first step is crucial to guarantee the independence of the results in these trials. In this step, a random member of the MSAR squad was asked to play the role of the victim and then positioned at the location where the victim was found in the real situation. The same steps were fulfilled during the day and night period.

During the description of the chosen scenarios, the location where the victim was found was not revealed, except for the commander of the SAMONT-GNR. The day before field trials, UAS operators only had access to the description of the scenarios presented above. Again, it was only the commander that knew the location of the chosen “victim”, but he did not take part in the realization of the trials.

While the recreations of the scenarios were being carried out, with a stopwatch, the time it took for each step to be performed was measured. During the second step, the time measured was until the UAV has been deployed. In the fourth step, when the territorial force (MSAR squad) arrives at the first detection site and confirms that it is the victim, the fifth step is no longer carried out. When the sixth step is realized, which concerns accounting for the total time of the operation, the first and seventh steps were not considered, as follows:

- The participants followed the proposed operational plan in the previous chapter, but as the accomplishment of these field trials was subject to prior planning, the first phase of the plan was not carried out on the day of the trials;
- The seventh step, as the first, was not considered for the total time of the operation because it occurred after the end of the trial and the accomplishment of this step was not part of the procedures presented over the operational plan proposal;
- The remaining phases were fulfilled on-site.

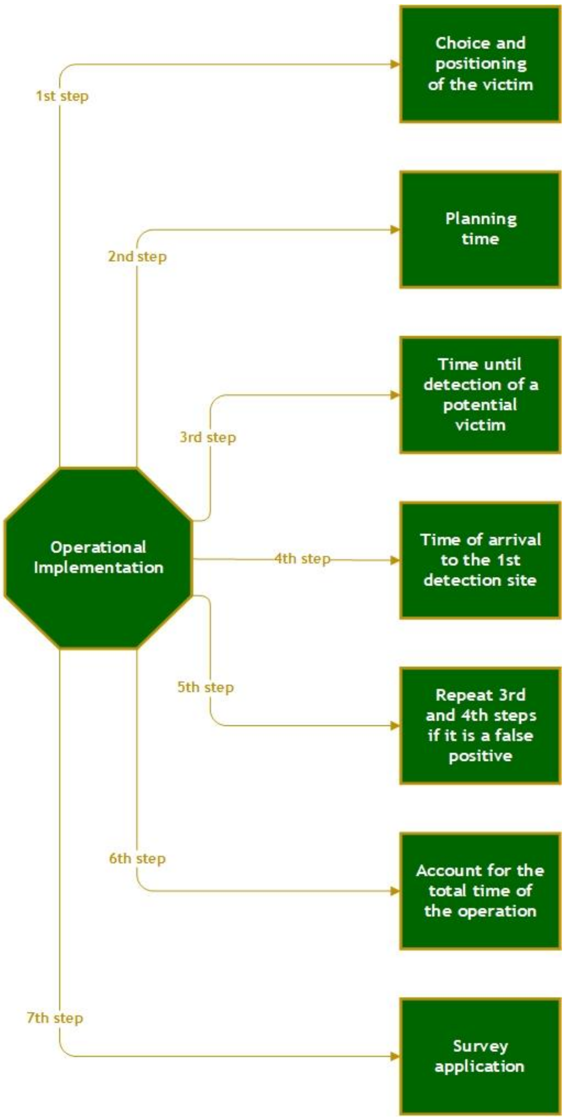

Figure 17 - Operational implementation schematic - Source: Own elaboration

After prior planning of the field trials, a day was scheduled with the members of the MSAR squad and the team of GIPS, who was responsible for operating the UAS, for conducting these trials.

The analysis of the weather forecast for this day was not favorable to what was found when we arrived at the location, where scenario A would take place. The weather conditions were extremely aggressive, with winds of approximately 100 km/h, heavy rain and a dense fog.

Due to these conditions, which by far exceed the limitations and most certainly could harm the capacities of the UAS used, the operators decided not to fly. So, the validation of the proposed operational plan did not occur, neither for scenario A or for scenario B. In order to validate this plan, it was discussed, decided and then scheduled a day for new trials, probably in new scenarios as the weather forecast for Serra da Estrela (in December 2019) was not favorable.

Indeed, the new scenarios are described below and all the data collected through the operational implementation described above are presented.

4.3.1. New SAR Scenarios

In the new field trials, only one scenario was recreated, the other was a fictitious one. These trials were conducted in Pombal, more precisely in Pousadas Vedras and Canhão dos Poios – Redinha, both belonging to the massif of the Serra de Sicó. This location was chosen with the purpose of maintaining the same environment where the first chosen scenarios occurred, that is, the mountain environment.

Scenario C is a fictitious scenario meaning that never happened in a real situation. The description of this scenario will focus only, on the information that was passed to the territorial force and the UAS operators, before the field trial started; this information is presented in Table 5.

Table 5 - Characteristics of scenario C - Source: Own elaboration

Type of search	Search and rescue
Location	Canhão dos Poios – Redinha
Victim	Male
Situation	The victim leaves his house at dawn to go climbing to the usual place. Due to the unusual long time he was taking to return home, his wife alerted the competent authorities. The location to which the victim went climbing, was the only information provided.
Difficulties encountered	• Lack of knowledge of the exact place where the victim was located; • Terrain orography.

Scenario D, described below, was provided by the GIPS team of the Centro de Meios Aéreos (CMA) of Pombal, and its main characteristics are described in Table 6. This scenario was a real scenario that happened, in 2012, and where the military personnel from GIPS who were involved recognized that the application of an UAS could have made the difference. Like it was mentioned above, the same operational implementation was followed, and the participants fulfilled the tasks presented in the operational plan proposal, except for the ones concerning the first phase of the plan as explained earlier.

Despite the change of location, the territorial force present in the field trials was the MSAR squad of the SAMONT-GNR, so these two scenarios were completely new to them as well as for the operators of the UAS, ensuring the independence of the results. The only ones that already knew the scenario D, were members of the GIPS team of the CMA of Pombal, who was present during the trials but did not participate, apart from one member that played the role of victim.

All the information, that the GIPS team of the CMA had access to before starting the search for the victim, is exposed in Table 5 plus the fact that the victim was elderly and medicated due to psychiatric pathologies. The victim also had severe problems in walking and needed to take insulin. The team constituted by 3 members was activated around 5 p.m..

Table 6 - Characteristics of scenario D - Source: Own elaboration

Type of search	Search and rescue
Location	Pousadas Vedras
Victim	Male
Situation	The victim disappeared after leaving his house to go check some of its proprieties on the outskirts of the village. Pieces of information like the name, age and the clothes he was wearing were provided.
Difficulties encountered	• Lack of knowledge of the exact place where the victim was located; • Almost no light (darkness); • A huge search area for the territorial force inspect on foot (1 km radius in a total of 314 Hectares).

The team started the search, walking the possible paths close to the properties of the victim, increasing the search area, during this process several decisions had to be made as the team was faced with what could be clues to the location of the missing person. These decisions were taken always having in mind the information received at first, that it would be easier for the victim to return home. The result of this search was unsuccessful, and the team returned to the CMA around midnight. The next day, as soon as it was possible, the team resumed the searches from where they had stopped and chose to follow different tracks from the previous day, having found the deceased victim.

4.3.2. Data Acquisition

As already mentioned, the field trials of this case study occurred in two different periods, scenario C during the day and scenario D at night. Only one member of the GIPS team from the CMA of Pombal participated in the field trials because of the reasons already explained above, to play the role of victim; to ensure his safety only one member of this team knew its location. The positioning of the victim was the first task to be performed in each one of the trials.

The fictitious scenario (scenario C) was the first to be carried out; in Figure 18 it is possible to see the MSAR squad and the team responsible for operating the UAS preparing themselves for the operation. Once the victim was positioned, both teams were gathered and briefed with the information presented in the description of scenario C. The teams were gathered in the Teatro de Operações (TO) of the location, where the briefing happened before the beginning of the operation, that happened around 3:30 p.m..

In both field trials, the teams participating in the operation used a frequency band, commonly known as direct, for all the communications between the field teams regarding the operation. A different frequency band was also used which belongs to the Sistema Integrado de Redes de

Emergência e Segurança de Portugal (SIRESP), that was requested especially for the realization of both operations.

Figure 18 - MSAR squad and operators of the UAS in preparation - Source: Author

After all these procedures were completed the second step of the operational implementation regarding the measurement of the planning time began. During this step the operators of the UAS and the territorial force decided to position themselves closer to the climbing wall, as is presented in Figure 19, then the setup for the first operation was assembled and calibrated.

Figure 19 - Deployment site - Source: Author

It was also discussed by both teams what would be the best way to start the search phase, being decided to start by inspecting the climbing wall and then if no detection was made start increasing the search area. When the UAS was in the air, the measurement of the time concerning the second step of the operational implementation stopped.

The operators responsible for the pilot and sensor station, connected the CrystalSky monitor to the internet, to obtain the map of the area and ensuring better navigation. If this location was a “no-fly zone” an internet connection would be required to unlock the UAV. Both commands are connected to each other and it is necessary to ensure that there is no obstacle between the operators with them, otherwise, the operator responsible for the sensor station is no longer able to view the streamed content, endangering the payload operation.

Besides the team of 3 operators responsible for the UAS operation, 5 members of the MSAR squad participated in both field trials. During both trials, despite what is recommended in the operational plan proposal, one member of the MSAR squad stayed with the operators of the UAS, with the objective of helping the interpretation of the streamed content and also mobilize the territorial force rapidly to the possible detection sites.

Regarding the daily operation, the UAS was able to detect the victim during its first flight; the time until this detection concerns the third step of the operational implementation. After this detection the territorial force was then mobilized to the location to confirm, the time that they took to arrive at the location concerns the fourth step of the operational implementation. In Figure 20 the image that was seen through the FPV onboard camera is presented and below (Figure 21) the image with the zoom provided by the Zenmuse Z30 camera.

Figure 20 - First detection with FPV onboard camera - Source: Author

Figure 21 - First detection with Zenmuse Z30 camera - Source: Author

After the MSAR squad arrived at the victim location and gave the confirmation, the field trial was successfully completed. The MSAR squad performed the extraction of the victim (Figure 22) under the monitoring of the UAS and then the survey was applied to all the participants.

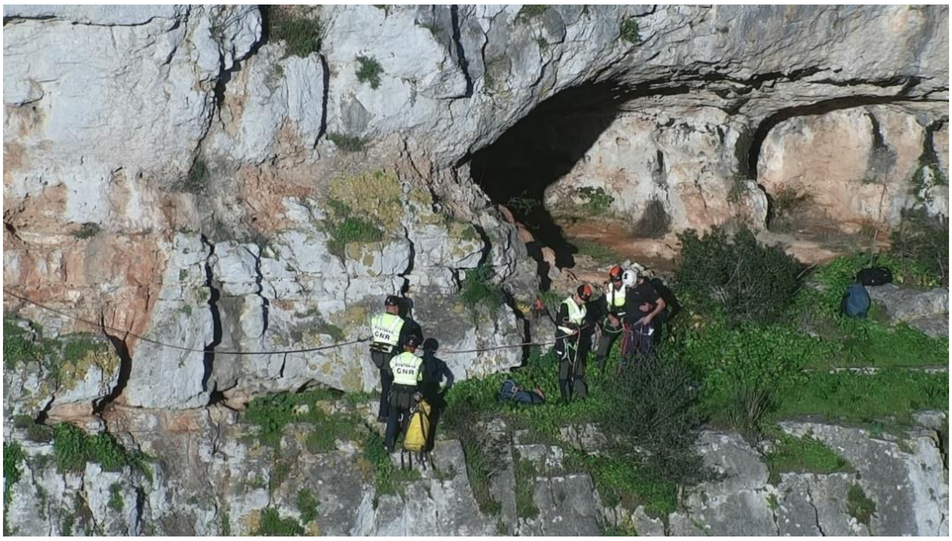

Figure 22 - MSAR squad performing the rescue - Source: Author

All the procedures that were realized for the first operation, and the time measurements for each step, were also repeated for the operation that would be realized in the night period.

Both teams were gathered in the TO for the briefing with the information concerning scenario D, the next, before the beginning of the operation. One difference from what happened during the field trial performed in the day period, was the connection of the CrystalSky belonging to the operator responsible for the sensor station to a TV set, as is showed in Figure 23.

During the planning phase, the operators and the members of the MSAR squad decided to start by inspecting the possible paths that the victim could have gone to see his properties on the outskirts of the village, as they were informed in the briefing, before the beginning of the operation. All the pathologies and the walking difficulties that the victim had were also considered. So, the operators of the UAS started inspecting these paths increasing the search area and mobilizing the territorial force to a possible detection site, when necessary.

Figure 23 - Sensor station in the night operation - Source: Author

Unlike what happened in the daily operation, the detection of the victim only occurred during the fourth flight of the UAS, and some false positives were registered. When the members of the MSAR squad confirmed one of the victim possible locations that were detected, the field trial was successfully completed. Figure 24 presents the image of a false positive, with a red circle marking what would be the potential victim. The image of the location where the victim was found is presented below, being the victim identified with a white circle and the members of the MSAR squad with a yellow circle (Figure 25).

Figure 24 – Detection of a potential victim with Zenmuse XT2 camera – Source: Author

Figure 25 – Detection of the location where the victim was found with Zenmuse XT2 camera - Source: Author

In Figure 24 the false positive presented is from a stone, that absorbed the heat was felt during the day and was still releasing this heat overnight, being detected by the thermal camera. The weather conditions present in both field trials were within the operational limits of the UAV and its payload, the wind during the day trial was around 18 km/h having risen to 25 km/h overnight.

Apart from the batteries used for the first flight, the operators took 16 spare batteries and a generator to be able to charge them between flights. Also, the operators between operations were responsible for different stations, apart from the operator responsible for the monitoring station due to the lack of flight hours, to achieve versatility among them as was proposed in the operational plan.

The times measured for the day and night operation are presented respectively, in Tables 7 and 8. Green color means a positive confirmation was obtained by the territorial force, when arrived at the possible detection site; in the case of a false positive this time is marked in red. All the data presented in both Tables will be analyzed in Chapter 5.

Table 7 - Data collected during the field trial performed in the day period - Source: Own elaboration

Steps	Time measured [hh:mm:ss]	Cumulative time [hh:mm:ss]
Planning time	00:22:25	00:22:25
First detection of a potential victim	00:09:16	00:31:41
Time of arrival until the first detection site	00:27:09	00:58:50
Total time of the operation	00:58:50	

Table 8 - Data collected during the field trial performed in the night period - Source: Own elaboration

Steps	Time measured [hh:mm:ss]	Cumulative time [hh:mm:ss]
Planning time	00:22:39	00:22:39
Flight time until first landing for battery exchange	00:11:58	00:34:37
Time for exchange batteries	00:02:00	00:36:37
First detection of a potential victim	00:14:24	00:51:01
Time of arrival until the first detection site	00:06:28	00:57:29
Second flight time until landing for battery exchange	00:16:03	01:13:32
Time for exchange batteries	00:06:02	01:19:34
Second detection of a potential victim	00:12:30	01:32:04
Time of arrival until the second detection site	00:05:15	01:37:19
Third flight time until landing for battery exchange	00:15:06	01:52:25
Time for exchange batteries	00:01:45	01:54:10
Third detection of a potential victim	00:05:45	01:59:55
Time of arrival until the third detection site	00:03:20	02:03:15
Total time of the operation	02:03:15	

4.4. Survey Data

Throughout this subchapter, data gathered with the application of the survey to each participant is presented. The data is divided into two tables to enable a better understanding. The weights will be considered the same for the different scenarios evaluated; as was asked in the first part of the survey. It was requested each participant to consider the entire SAR mission instead of a specific task. Under each table (9-24), if it is the case, will be presented the answers given by the participants to the open question mentioned in Subchapter 2.7.

Task(s): Responsible for the pilot station

Table 9 – Workload index of participant 1 in the day operation – Source: Own elaboration

Factors	Weights		Ratings [%]	Workload index [%]
	Number of selections	[%]		
Mental Demand	5	33	50	17
Physical Demand	2	13	20	03
Temporal Demand	2	13	20	03
Performance	4	27	20	05
Effort	1	07	20	01
Frustration Level	1	07	10	01
Total	15	100		30

Task(s): Responsible for the sensor station

Table 10 - Workload index of participant 1 in the night operation - Source: Own elaboration

Factors	Weights		Ratings [%]	Workload index [%]
	Number of selections	[%]		
Mental Demand	5	33	70	23
Physical Demand	2	13	20	03
Temporal Demand	2	13	70	09
Performance	4	27	85	23
Effort	1	07	20	01
Frustration Level	1	07	60	04
Total	15	100		63

Task(s): Responsible for the sensor station

Table 11 - Workload index of participant 2 in the day operation - Source: Own elaboration

Factors	Weights		Ratings [%]	Workload index [%]
	Number of selections	[%]		
Mental Demand	5	33	80	26
Physical Demand	3	20	40	08
Temporal Demand	1	07	70	05
Performance	4	27	90	24
Effort	2	13	40	05
Frustration Level	0	00	30	00
Total	15	100		68

"There were no difficulties to report"

Task(s): Responsible for the pilot station

Table 12 - Workload index of participant 2 in the night operation - Source Own elaboration

"*The biggest difficulty felt was the lack of autonomy provided by the batteries, as well as the presence of high-voltage lines in the area"*

Task(s): Member of the MSAR squad

Table 13 - Workload index of participant 3 in the day operation - Source: Own elaboration

"*Lack of knowledge about the equipment and its capabilities, and [instructions about its use] under the right conditions could be a major help"*

Task(s): Member of the MSAR squad

Table 14 - Workload index of participant 3 in the night operation - Source: Own elaboration

Factors	**Weights**		**Ratings [%]**	**Workload index [%]**
	Number of selections	**[%]**		
Mental Demand	4	27	100	27
Physical Demand	3	20	100	20
Temporal Demand	2	13	100	13
Performance	5	33	100	33
Effort	1	07	100	07
Frustration Level	0	00	1	00
Total	15	100		

Task(s): Member of the MSAR squad

Table 15 - Workload index of participant 4 in the day operation - Source: Own elaboration

"*There were no difficulties to report*"

Task(s): Member of the MSAR squad

Table 16

Task(s): Member of the MSAR squad

Table 18 - Workload index of participant 5 in the night operation – Source: Own elaboration

Factors	Weights		Ratings [%]	Workload index [%]
	Number of selections	[%]		
Mental Demand	5	33	100	33
Physical Demand	4	27	100	27
Temporal Demand	1	07	100	07
Performance	3	20	100	20
Effort	2	13	100	13
Frustration Level	0	00	10	00
Total	15	100		100

Task(s): Member of the MSAR squad

Table 19 - Workload index of participant 6 in the day operation - Source: Own elaboration

Factors	Weights		Ratings [%]	Workload index [%]
	Number of selections	[%]		
Mental Demand	3	20	90	18
Physical Demand	2	13	90	12
Temporal Demand	1	07	90	06
Performance	5	33	100	33
Effort	4	27	100	27
Frustration Level	0	00	10	00
Total	15	100		96

Task(s): Member of the MSAR squad

Table 20 - Workload index of participant 6 in the night operation - Source: Own elaboration

Factors	Weights		Ratings [%]	Workload index [%]
	Number of selections	[%]		
Mental Demand	3	20	90	18
Physical Demand	2	13	90	12
Temporal Demand	1	07	90	06
Performance	5	33	100	33
Effort	4	27	100	27
Frustration Level	0	00	10	00
Total	15	100		96

Task(s): Responsible for the monitoring station

Table 21 - Workload index of participant 7 in the day period - Source: Own elaboration

Factors	Weights		Ratings [%]	Workload index [%]
	Number of selections	[%]		
Mental Demand	5	33	90	30
Physical Demand	4	27	80	22
Temporal Demand	2	13	70	09
Performance	0	00	80	00
Effort	3	20	90	18
Frustration Level	1	07	70	05
Total	15	100		84

Task(s): Responsible for the monitoring station

Table 22 - Workload index of participant 7 in the night period - Source: Own elaboration

Factors	Weights		Ratings [%]	Workload index [%]
	Number of selections	[%]		
Mental Demand	5	33	90	30
Physical Demand	4	27	80	22
Temporal Demand	2	13	70	09
Performance	0	00	80	00
Effort	3	20	90	18
Frustration Level	1	07	70	05
Total	15	100		84

Task(s): Member of the MSAR squad - coordination of the operation

Table 23 - Workload index of participant 8 in the day period - Source: Own elaboration

Factors	Weights		Ratings [%]	Workload index [%]
	Number of selections	[%]		
Mental Demand	4	27	100	27
Physical Demand	2	13	1	00
Temporal Demand	1	07	90	06
Performance	5	33	100	33
Effort	3	20	50	10
Frustration Level	0	00	100	00
Total	15	100		76

"The difficulties felt concern the limitations of the equipment"

Task(s): Member of the MSAR squad – coordination of the operation

Table 24 - Workload index of participant 8 in the night operation - Source: Own elaboration

Factors	Weights		Ratings [%]	Workload index [%]
	Number of selections	[%]		
Mental Demand	4	27	100	27
Physical Demand	2	13	1	00
Temporal Demand	1	07	90	06
Performance	5	33	100	33
Effort	3	20	50	10
Frustration Level	0	00	100	00
Total	15	100		76

"The difficulties felt concern the endurance of the equipment and also the dependence on it throughout the operation"

4.5. Conclusion

With the data collected during the field trials, through the operational implementation of the proposed operational plan and the applied survey, and considering the information provided about scenario D (real SAR scenario), it was possible to draw some conclusions. This data shows that UAS can make the difference when applied in SAR missions specifically in terms of duration of the operation, but also the limitations that were felt in these trials.

The operational plan proposal, which was followed during these trials, contemplates the tasks that needed to be fulfilled to ensure the safety of the operation, the coordination between both teams and above all the best possible outcome. The data obtained from the survey applied, particularly the answers to the open question, were of extreme importance to understand if the application of the UAS did not cause any constraint to the standard procedures which the SAR teams were used to.

Chapter 5 - Result Analysis

5.1. Introduction

In this chapter, the results obtained through the implementation of the proposed operational plan as well as the answers obtained to the survey, which were displayed in the previous chapter will be analyzed and discussed. Nevertheless, only the results that were considered relevant to reach the objectives of this study will be analyzed and discussed in this chapter.

5.2. Field Trials Results and Analysis

In the field trials, where the scenarios C and D were carried out, the time to reach the operation site was not measured because it was a previously planned operation. This means that the teams involved did not have to move to a certain location without prior notice, as usual in most SAR missions, due to its unpredictable nature. There are other factors that should be considered regarding this time; like it was possible to see in the description of scenario B, the MSAR squad took 2 hours to reach the location due to weather conditions that no one can control.

As mentioned in the previous chapter, during both field trials two different frequencies were used, the direct and the one that belongs to the SIRESP. The first one was used by the participants only to communicate with each other about all relevant matters to the coordination of the operation, due to its limited range. Regarding the second one, a channel was requested with the objective of not interfering in the channel used in the field.

These frequencies (direct and SIRESP) plus the aeronautical frequency were monitored during the operation by the responsible for the monitoring station as was advised in the operational plan proposal. Despite what was recommended in this plan, one of the members of the MSAR squad stayed with the UAS operators, more specifically with the operator in charge of the sensor station, during the realization of both field trials. This member performed the task of helping to interpret the streamed content and then mobilizing the rest of his team to possible detection sites, if agreed by all the operators.

As observed in the data presented in the case study of this dissertation, the total time of the operation realized in the day period (Scenario C) was 58 minutes and 50 seconds. With the capacities of the camera used, it took 9 minutes and 16 seconds to, without a doubt, get the first detection of the victim, as can be seen in Figure 21 at Subchapter 4.3.2. After the MSAR squad arrived at the detection site, the trial was successfully concluded as was already mentioned but it was then decided to perform the extraction of the victim to the ground level.

Although only the first two batteries were used for the first flight of the UAS, where the detection of the victim took place, a total of 4 batteries were used to monitor the extraction of the victim. Due to the presence of some people that were climbing the wall, where the victim was found, the monitoring of the rescue allowed to ensure the safety of those people and also to inform the members of the MSAR squad of any unpredictable situation that might occur, such as a landslide for example. Although this was a fictitious scenario, in a real situation this task could be crucial.

Regarding the field trial realized during the night period (Scenario D), the operators and the members of the MSAR squad encountered more difficulties. The total time of the operation performed was 2 hours 3 minute and 15 seconds. It is important to explain that the time needed to identify a possible detection site, starts counting when the responsible for the pilot station begins the lift off in each different flight.

The operators decided to land the UAS in the deployment site whenever the battery level was below 30%; this data is provided by the pilot interface used during both operations (DJI Pilot). In the data collected during the night operation, it is possible to see that the second battery exchange when compared to the others took more time, this fact can be explained due to some technical issues that have arisen.

Considering the maximum flight time that the chosen battery is capable of providing to the UAS and since in both field trials the maximum payload was not exceeded or matched, it was expected to obtain a flight time around 30 minutes. Through the analysis of the data collected, on the night operation, it is possible to see that in all the flights performed the duration was not even close to what was expected to obtain. During this operation, there were some key factors that need to be analyzed due to its contribution to the reduction of the battery level. Over the literature review, it was explained that factors like wind speed, flight speed, and the payload weight had a direct influence on the battery life, consequently in the flight time of the UAS.

In the night period, all the factors mentioned above have increased, when compared to the operation performed during the day. The flight velocity increased due to the size of the search area, as was presented in the description of scenario D, to allow the inspection of all areas as quickly as possible. The altitude of the flight also increases to allow the operators to analyze a bigger area.

Only in the operation realized during the night was not possible to fulfill the general rules regarding the UAS application, mentioned in the Subchapter 2.6: the characteristic of scenario D required the performance of a BVLOS flight, and an altitude exceeding the allowed for daytime flights.

Although all the aforementioned factors lead to shorter flight time, the camera used in the night operation, in particular the thermal camera with the FLIR thermal sensor, decreases quickly the battery level. The capacities of this camera, already explained in Subchapter 4.2, can make a difference in operations performed under the same conditions but can be a huge threat to the battery life. Another factor that also contributes to the reduction of the flight time is the activation of the recording function, so during both operations only the essential was recorded.

Despite the recommendations in the operational plan proposal, related to the charging of the batteries in the field, it was chosen not to charge all of them with the generator. This decision was due to the fact that the generator could harm the battery capacity (the batteries used need to be charged with a specific charger or could lose capacity according to the manufacturer); allied to this factor and since this was a field trial and not a real operation, it was not reasonable to put the equipment used at risk. In a real SAR mission, charging should be carried out immediately after the mission, or even between flights as explained in this operational plan, to avoid the lack of batteries, but above all, it should be carried out with a charger suitable for this purpose.

From the four flights performed during the night operation, it is possible to conclude that the first flight was the one with the shortest duration. This flight had the purpose to adjust and reach an agreement between the responsible for the pilot and sensor station, in which the best color band (isotherm) would be to apply in the thermal camera to improve the interpretation of the streamed content. The chosen one is presented in Figure 24 in Subchapter 4.3.2. A temperature range was also defined, being changed throughout the operation, to activate the alert temperature function explained above. The duration of this flight shows how the capabilities of the thermal camera affect battery life drastically.

The first detection of a possible location of the victim happened only on the second UAS flight. When the first detection occurred, the operator responsible for the sensor station and in agreement with the operator piloting the UAS, decided to mobilize the territorial force for this first detection site, as established in the proposed operational plan. This difficulty in interpreting the streamed content was due to the dense vegetation that covered a large part of the search area. Once in the field, the MSAR squad was able to get to other possible detection site detected during the operation more quickly, as can be seen from the data previously presented in Table 8 in Subchapter 4.3.2.

After being in the field, and even though the operators were aware of this fact, the number of false positives increased and were often detected members of the MSAR squad. These detections end up having a negative impact, especially in the time of the operation, since in some cases it was necessary through radio communication to understand where the territorial force was to perceive if the heat alert detected could belong to the victim.

The time that was needed to perform the third detection of what could be the victim (around 5 minutes and 45 seconds), which would be the correct location, was due to the fact that during the third UAS flight this location had already been detected. The MSAR squad, already in the field, were mobilized to the site through indications received by one of its members who was close to the responsible for the sensor station, as already explained. Due to the UAS battery level being at the previously defined value for landing, the team stopped receiving indications and could not reach the desired location. After a quick change of batteries, the operators returned to the same place and then it was possible to guide the members of the MSAR squad to this location.

Concerning the difficulties that were felt by the members of the GIPS team of the CMA, that were involved in the real mission, the use of the UAS allowed overcoming these difficulties. Besides these difficulties, the dense vegetation was a problem that was not mentioned by the territorial force present in the real mission, but during the trials complicated the UAS operation. In the field trial, it was also possible to reduce significantly the time that took to find the victim, due to the capabilities that the equipment used can offer as was already explained.

Based on the information provided by the GIPS team involved, concerning scenario D, it is possible to see that the search phase took around 7 hours until the search was interrupted without success. The exact time that the operation took was not provided by this team. During the recreation of this scenario, with the implementation of the UAS, the operation took around 2 hours having been reached a successful outcome, it is important to mention that during the field trial all the conditions were the same as in the real mission. It is possible to conclude that there has been an improvement of about 70%.

5.3. Survey Analysis

The applied survey obtained a universe of 8 answers, given by those who participated in the field trials. This survey was divided into two parts, as explained in Subchapter 2.7. In the first part regarding the importance (weights) that the participants attributed to the evaluated factors, 6 of them considered the frustration level the less important factor in SAR missions. It was expected that this factor would have bigger importance for the participants, due to the nature of these missions and given that the outcome is not always positive.

In Figure 26, it is possible to see that the factors that were considered the most important in SAR missions by all the participants were the mental demand and performance. Participants 1, 2 and 7 represent the UAS operators, and the remaining participants are the MSAR squad members.

For the UAS operators, the mental demand was considered the most important factor - this result was expected due to the high level of focus that they need to maintain during all operations. Regarding the members of the MSAR squad, the performance was considered the most important factor, except for one member. This result is justified by the type of tasks that these participants need to perform in the field. They always give their absolute best to guarantee the success of the mission - “failure is not an option”; so, for these members, the performance is crucial as they elected in the first part of the survey.

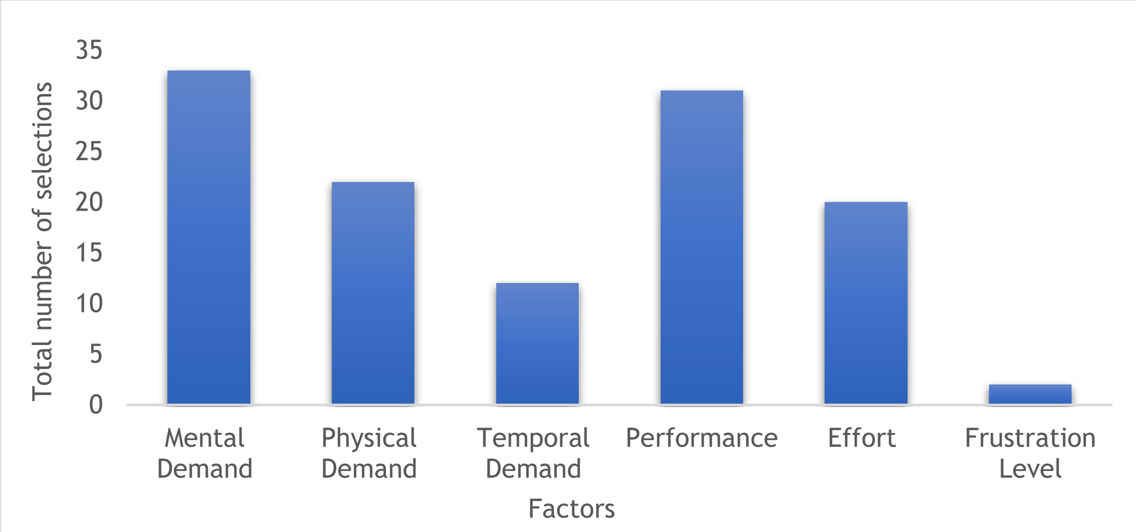

Figure 26 - Total number of selections of the evaluated factors - Source: Own elaboration

Based on all the responses presented in Subchapter 4.4, it is possible to understand that in the second part of the survey, the ratings given by the participants in the field trials either in the day and night periods were not consistent with the importance given in the first part. Participant 8, for example, considered the frustration level the less important factor in SAR missions and gave this factor a rating of 100% after each one of the field trials. With the other participants, this inconsistency in the attribution of ratings also happens, especially with the members of the MSAR squad.

It was expected that the ratings given by the participants would be higher in the operation performed during the night when compared with the operation realized during the day. In Figure 27, the workload index of each one of the UAS operators is presented and below the workload index of each one of the MSAR squad members (Figure 28). In Figure 27, as expected, the workload index of participants 1 and 2 is different between both operations and higher during the operation performed in the night period. Participant 7 presents the same workload during the day and night period, which can be explained by the fact that this operator has performed the same task in both operations.

The rating inconsistency already mentioned above can be seen in Figure 28 through the values of the workload index obtained. Despite what was expected, only participant 4 presented a different workload between the two different periods, pointing a higher value for the operation realized during the day period. This value can be explained due to the rescue of the victim that was performed during the day, leading to a higher workload. Although it was expected that the members of the MSAR squad presented a higher workload in the night period, and not the same value for both periods, due to the lack of light, the difficulty in moving through the terrain for reaching the detection sites and understanding the indications that they were receiving in the field during the operation.

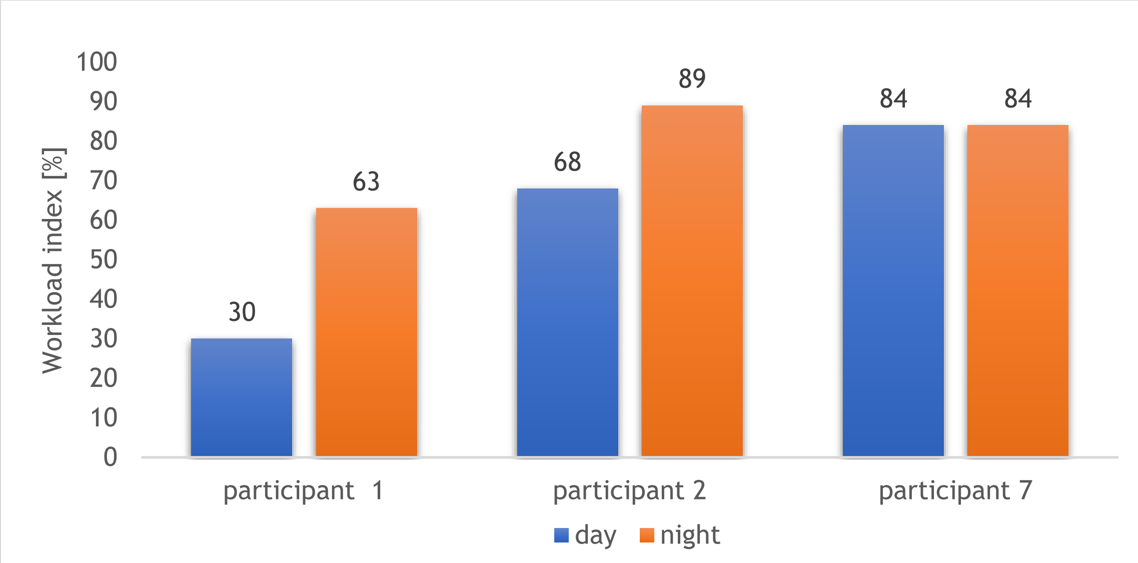

Figure 27 - Workload index of the UAS operators - Source: Own elaboration

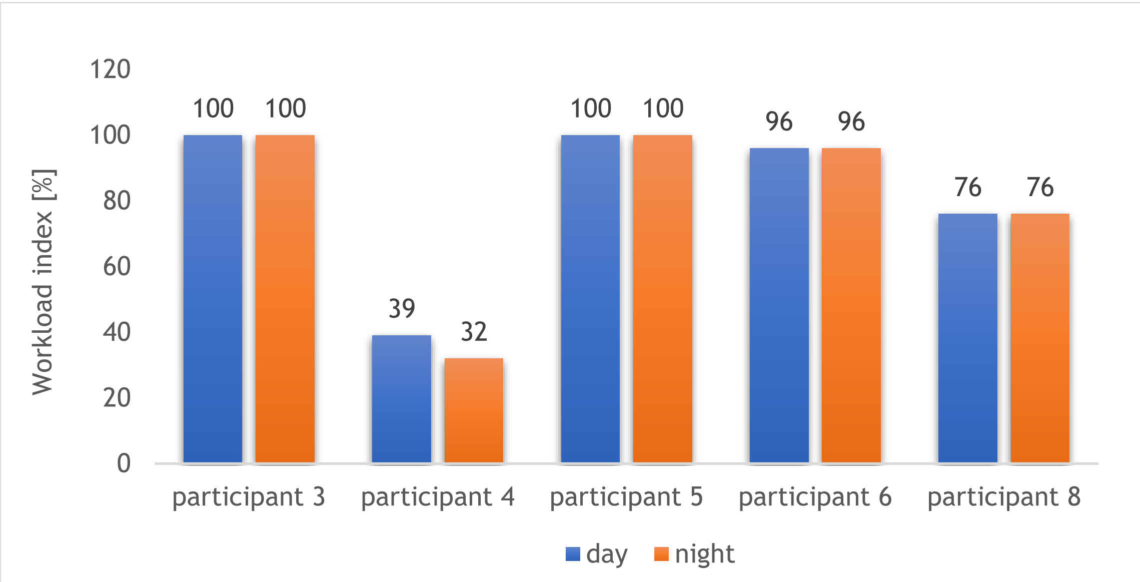

Figure 28 - Workload index of the MSAR squad members - Source: Own elaboration

Regarding the answers obtained to the open question added to the survey, it is possible to verify that the respondents did not feel difficulties in the implementation of the UAS in the operation, except from participant 8 which pointed out as difficulties the limitations of the system and the lack of endurance. This lack of endurance, that is seen by the short duration of the flight during the field trials, is also mentioned by participant 2. The reasons that lead to this fact were also explained previously but, it is indeed a problem, already identified in this dissertation.

The dependence of the UAS was also mentioned as a difficulty in the operation and help us to understand some changes that could be made to the operational plan proposal in order to achieve a better coordination between the UAS and the members of the territorial force. Another difficulty mentioned was the lack of knowledge about the equipment in use. This can be solved if the members of the MSAR squad had more explanations/workshops about this resource and its capabilities. The presence of the high-voltage lines in the search area of the night operation, as mentioned, only affected the quality of the streamed content during a limited period of time, when the system was flying nearby.

5.4. Conclusion

Regarding the results collected in the field trials (Scenario C and D), scenario C despite fictitious, allow to identify some improvements brought with the application of the UAS. The opportunity to recreate scenario D was, without a doubt, a “game changer” to this study because through comparison of the data about the real scenario and the ones collected over the trial was clear that the UAS application made a huge difference in overcoming the difficulties experienced, and consequently in the outcome of the mission.

The results withdrawn from the survey, were crucial to this study thanks to the professionalism and commitment revealed by the participants. These results allowed to analyze and then describe the difference in the workload between the different periods (day and night) where the field trials occurred as well as the possible reasons that lead to this difference. Although only a few answers obtained to the open question, which could be more with a larger number of participants, it was of extreme importance to understand possible failures in the proposed operational plan. Maybe those identified troubles can serve as guidance to find the best way to make the UAS intervention in SAR missions a nearby reality.

Chapter 6 - Conclusion

6.1. Dissertation Conclusions

At the beginning of this dissertation, a study was made to understand what the most suitable UAV and the best payload would be to apply in SAR missions for overcoming the difficulties usually felt by SAR teams and improve the outcomes in currently used procedures. With this study, we concluded that the best configuration to use was the VTOL, as showed in Subchapter 2.5. Then it was established that the objective of this dissertation would be to understand if the application of an UAS could bring improvements to the currently used procedures without being an operational constraint. It was also established that a proposed operational plan would be elaborated and validated through the realization of field trials.

After these objectives were established, the current procedures used by the MSAR squad were studied for understanding the reality of a SAR mission. With this information and the experience of members from this squad an operational plan proposal was elaborated. The knowledge of the UAS operators and their experience was also crucial for the elaboration of this plan. Reports from real SAR scenarios were also analyzed to choose the most suitable for recreation.

Our case study was conducted through the realization of field trials, with the recreation of a real SAR scenario, as well as the realization of a fictitious one. The results of this case study allow us to understand at what operational level the use of an UAS could be an improvement, especially due to the real SAR scenario, recreated with the use of an UAS validating the operational plan proposal. At the end of each field trial an anonymous survey was applied to all the participants, identifying every task they performed.

From this survey, we realize that only the UAS operators, that represent 3 of the 8 participants, obtained expected values for the workload index, and considered the mental demand the most important factor in SAR missions. The remaining participants that are members of the MSAR squad obtained different values from what was expected, and for them, the performance was the most important factor in SAR mission. From the survey, it was also possible to notice that almost all the members of the MSAR squad were inconsistent in the attribution of the ratings to each factor after the operation. This fact can be explained by the level of commitment and dedication that the members of this squad put in their tasks, so for them each factor deserves the rating of 100%.

All field trials participants had a lot of experience in SAR missions which made possible to understand, especially for the members of the MSAR squad, if the proposed operational plan with the implementation of the UAS could become a reality. The recreation of the original chosen scenarios was not accomplished, due to the aggressive weather conditions, and that allowed us to understand that the implementation of this type of system is not yet a solution to apply in all SAR missions.

From the data collected during the field trials, in the day period, it was possible to see that the use of an UAS could be crucial in some parts of a real operation, like monitoring the rescue, for example. This scenario was fictitious, so it was not possible to see if the application of the proposed operational plan brought any improvement to currently utilized procedures. In the night period, since it was a recreation of a real SAR scenario, it was possible to compare the data of both operations. It was also seen that under aggressive weather conditions, typical of the mountain environment, the application of this system was not possible.

A very important conclusion of this dissertation is that the use of an UAS can make a difference in the outcome of a SAR mission. Considering all the difficulties presented by the members of the GIPS team at the time the real scenario took place; it was possible to conclude that the use of this system overcomes these difficulties. The implementation of the proposed operational plan brought improvement, especially in the duration of the operation. The use of this resource when the real scenario happened could possibly have made the difference between life and death.

6.2. Concluding Remarks

The objectives of this dissertation previously established at the beginning of this work were fulfilled since it was possible to perceive that the implementation of the proposed operational plan with the use of an UAS could bring improvements to the currently used procedures. The differences between the UAS operation during the day and night period were also studied to perceive the changes between them. If it was possible to recreate more scenarios that already have happened, it would have been more perceptible to verify if the implementation of an UAS can really be the next step in SAR missions, and it would be possible to make more conclusive affirmations. Regarding the survey, if the number of participants had been higher it would be possible to interpret the results in a most accurate manner.

Although the objectives of this work have been fulfilled, the path that led to this achievement was not always easy. During the development of this work, a lot of difficulties were encountered but always overcome with the help of several people and the persistence needed, that in the end allowed its success.

After the conclusion of this work, an operational manual was prepared with the collaboration of GNR regarding the implementation of the UAS in real SAR missions, as well as the procedures and technical concerns that must be considered in the field (Annex 6). This manual will be submitted to the Comando da Doutrina e Formação (CDF) for approval.

6.3. Prospects of Future Work

Throughout the development of this dissertation, some topics have been recognized as useful to implement in future research work, to start using UAS in a regular basis in the assistance of SAR missions. It was also recognized that the experience of the SAR team members is crucial to guarantee that the implementation of this system makes a difference. Therefore, the next steps should include the following lines of investigation:

- To add more participants in the field trials for a more accurate evaluation of the workload of each one of them, as well as their opinion regarding the advantages and limitations of the UAS application;
- To recreate more real SAR scenarios, this means, that already have happened to obtain more data for comparison;
- To apply the proposed operational plan in a real SAR mission;
- To use different UAS to observe the differences in the performance;
- To perfect a training program for operators so that their workload doesn't compromise the mission;
- To improve standard SAR scenarios and repeat missions to collect data that could lead to future improvements of the UAS used;
- To evaluate the costs/resources between a standard mission and a mission with the UAS application.

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Annex 1 – Comparison Sheet (Weights)

Workload Evaluation - Part 1

Comparison Sheet (Weights)

Please, from the options presented in each line, select the factor that you consider to be the most important in the success of the tasks performed during the SAR Missions.

Effort	or	Performance
Temporal Demand	or	Frustration
Mental Demand	or	Frustration
Temporal Demand	or	Effort
Physical Demand	or	Frustration
Performance	or	Frustration
Physical Demand	or	Temporal Demand
Physical Demand	or	Performance
Temporal Demand	or	Mental Demand
Frustration	or	Effort
Performance	or	Mental Demand
Performance	or	Temporal Demand
Mental Demand	or	Effort
Mental Demand	or	Physical Demand
Effort	or	Physical Demand

1/2

Annex 2 – Operational Rating Sheet

Workload Evaluation - Part 2

Operational Rating Sheet

Please fill in the line below with the task(s) that you performed during the mission. Then evaluate with a percentage, between 1 and 100, 1 being the lowest value and 100 the highest, each of the following factors according to what you felt in the accomplishment of your task(s).

Day Period

Task(s) ID: ____

Mental Demand	
Physical Demand	
Temporal Demand	
Performance	
Effort	
Frustration Level	

Observations of the difficulties and improvements experienced during the operation:

____

____

____

Night Period

Task(s) ID: ____

Mental Demand	
Physical Demand	
Temporal Demand	
Performance	
Effort	
Frustration Level	

Observations of the difficulties and improvements experienced during the operation:

____

____

____

2/2

Annex 3 – Operational Sheet used in Real SAR Scenarios by SAMONT-GNR

GUARDA NACIONAL REPUBLICANA

UNIDADE DE EMERGENCIA PROTEÇÃO E SOCORRO

SUBAGRUPAMENTO DE MONTANHA

FICHA DE INFORMAÇÃO OPERACIONAL

O MILITAR DE ATENDIMENTO

Annex 4 – Confidentiality Agreement

GNR
GUARDA NACIONAL REPUBLICANA

Anexo B à Circular 001/CDF/DF/2009

DADOS DE IDENTIFICAÇÃO

TÍTULO DO ESTUDO/INVESTIGAÇÃO (a preencher quando se trata de solicitação em nome individual)
ESTUDO DA VIABILIDADE OPERACIONAL E ECONÓMICA NA UTILIZAÇÃO DE UMA AERONAVE NÃO TRIPULADA NUMA MISSÃO DE BUSCA E SALVAMENTO EM AMBIENTE DE MONTANHA.

NOME DO ALUNO/INVESTIGADOR
LUÍS EDUARDO DA COSTA SANTOS

INSTITUIÇÃO PROPONENTE (a preencher quando se trata de solicitação em nome institucional/colectivo)

ORIENTADOR DO ESTUDO/INVESTIGAÇÃO *(se aplicável)*
NOME - JORGE MIGUEL DOS REIS SILVA
TÍTULO – PROFESSOR (PHD)

DECLARAÇÃO DE CONFIDENCIALIDADE

Considerando que a instituição GNR, nas áreas que opera, é detentora de informação crítica que, pela sua relevância é obrigada a manter a confidencialidade, obrigação essa que é extensível a todo o seu pessoal (militar e civil) ou outras pessoas que, de algum modo, possam a ela ter acesso.

LUÍS EDUARDO DA COSTA SANTOS

Declara ter conhecimento do supra referido e consequentemente DECLARA e ACEITA, sob compromisso de honra, que:

1. Não divulgará nem fará uso, de qualquer tipo e por qualquer meio, de qualquer informação a que venha ter acesso, salvo e na medida em tal seja necessário para a realização do estudo/investigação com autorização expressa do Comandante da Doutrina e Formação.

2. Manterá sigilo sobre informações, materiais e toda a documentação técnica que façam parte do *know how* da instituição ou que lhe tenham sido concedidos por terceiros, e que não fará deles qualquer tipo de utilização salvo para fins de desenvolvimento do estudo/investigação.

3. Não fará cópias não autorizadas, quer em formato físico ou electrónico, de manuais, livros, relatórios técnicos, dados, que a instituição GNR seja proprietária.

| 1/ 2 |

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Anexo B à Circular 001/CDF/DF/2009

4. Garante o anonimato dos indivíduos alvo de observação bem como das respectivas Unidades objecto de análise.

5. Não procurará aceder a informação existente quer nas instalações da GNR quer nos seus sistemas informáticos, cujo acesso não lhe tenha sido expressamente concedido.

6. A não observância das obrigações estabelecidas nesta declaração determinará a imediata cessação de colaboração entre a GNR e o aluno/investigador, não obstante poderem ser accionados os procedimentos civis e criminais.

O ALUNO/INVESTIGADOR

Luís Eduardo da Costa Santos

O/A ORIENTADOR/A *(se aplicável)*

Jorge Miguel dos Reis Silva

Local e Data
Covilhã, 05/06/2019

CDF
COMANDO DA DOUTRINA E FORMAÇÃO

| 2/ 2 |

Annex 5 – ICNF,I.P., Authorization

ICNF
Instituto da Conservação da Natureza e das Florestas

ICNP, IP	SAÍDA
DATA 19/11/2019	
N.º 53402	

Ao

Núcleo de Investigação em Transportes

Departamento de Ciências Aeroespaciais

Universidade da Beira Interior

Att. Luís Eduardo da Costa Santos

luis96t@gmail.com

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SUA REFERÊNCIA	SUA COMUNICAÇÃO DE	NOSSA REFERÊNCIA
		53402/2019/DRCNFC_DRCNB_DCAP

ASSUNTO TRABALHO DE INVESTIGAÇÃO CIENTÍFICA - VANTS / PNSE

Na sequência da solicitação de parecer sobre o assunto em epígrafe, e após análise da informação remetida, tem o ICNF, I.P. a informar o seguinte:

Por requerimento registado no Instituto da Conservação da Natureza e das Florestas, I.P. (entrada n.º 79012/2019/ICNF, IP de 02/10), o senhor Luís Eduardo da Costa Santos, aluno de Mestrado em Engenharia Aeronáutica, e o Senhor Prof. Jorge Miguel dos Reis Silva, orientador científico, do Núcleo de Investigação em Transportes do Departamento de Ciências Aeroespaciais da Universidade da Beira Interior, solicitaram a emissão de parecer para a **utilização de VANTS** (veículos aéreos não tripulados), no interior do **Parque Natural da Serra da Estrela**, nos dias 20 e 21 de novembro de 2019.

I. ENQUADRAMENTO

1. A atividade prevista, no âmbito do trabalho de investigação científica, pretende monitorizar e avaliar procedimentos de busca e salvamento em ambiente de montanha, com a utilização de VANTS – *quadcopter* de cerca de 5 Kg de peso, com altura máxima de voo permitida pela ANAC e raio de 4 a 6 Km.
2. A atividade será acompanhada pela Guarda Nacional Republicana – Subagrupamento de Montanha do Grupo de Intervenção, Proteção e Socorro.
3. As áreas a sobrevoar definidas para os testes serão o Vale Glaciar (Covão D´Ametade), a meio da tarde, e a Garganta de Loriga, ao início da noite do dia 20/11/2019. Caso não sejam completados os testes no dia 20, serão prolongados para a noite do dia 21 de novembro.
4. Aquelas áreas situam-se no interior dos limites do **Parque Natural da Serra da Estrela** (PNSE), conforme Anexo I do Decreto Regulamentar n.º 83/2007 de 10 de outubro, e do **Sítio de Importância Comunitária Serra da Estrela**, no âmbito da Rede Natura 2000 (PTCON0014; conforme a Resolução do Conselho de Ministros n.º 76/2000, de 5 de julho).

Direção Regional da Conservação da Natureza e Florestas do Centro
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5. As localizações indicadas inserem-se, também, nos **Perímetros Florestais** de **Manteigas** e da **Serra da Estrela – Núcleo de Seia**, que são áreas sujeitas ao Regime Florestal (Decreto de 24 de dezembro de 1901; Decreto de 24 de dezembro de 1903 e legislação complementar).

II. ANÁLISE

1. A recolha de imagens no **PNSE** com recurso a aeronaves, e que se desenvolvem abaixo dos 1000 pés de altura, em **áreas sujeitas a regimes de proteção**, está sujeita a **parecer** do **ICNF, I.P.** em conformidade com o regulamento do respetivo Plano de Ordenamento (POPNSE; Resolução do Conselho de Ministros n.º 83/2009, de 9 de setembro, alínea *i)* do n.º 1 do artigo 8.º).
2. Os locais indicados para a recolha de imagens integram áreas sujeitas a regime de proteção, delimitadas no POPNSE como **Áreas de Proteção Parcial dos Tipos I** e **II**.
3. Fora da época de nidificação da avifauna (15 de março a 15 de julho), e após análise de cartografia em função do POPNSE, conclui-se que a realização da pretensão é possível, no pressuposto de que os requerentes garantam total respeito pelos valores naturais da Área Protegida.

III. PRONÚNCIA

O **Instituto da Conservação da Natureza e das Florestas, I.P.** emite **parecer favorável** à utilização de VANTS – veículos aéreos não tripulados no **Covão D´Ametade** e na **Garganta de Loriga**, no interior do **Parque Natural da Serra da Estrela** e do **Sítio de Importância Comunitária Serra da Estrela**, no âmbito de um trabalho de investigação científica do Núcleo de Investigação em Transportes do Departamento de Ciências Aeroespaciais da **Universidade da Beira Interior**, nos dias 20 e 21 de novembro de 2019, nos termos do disposto na alínea *i)* do n.º 1 do artigo 8.º da Resolução do Conselho de Ministros n.º 83/2009, de 9 de setembro, **condicionado** ao cumprimento das disposições enunciadas a seguir.

1. Deverá ser cumprido o estipulado no Código de Conduta estabelecido na Portaria n.º 651/2009, de 12 de junho (http://www2.icnf.pt/portal/turnatur/resource/docs/ap/codigos/codig-condut).
2. O voo dos VANTS não pode perturbar a fauna e a flora. Caso se verifique a existência de aves em voo nas imediações da área de sobrevoo, deve cessar a sua atividade.
3. Caso se verifiquem danos em edifícios, antenas ou fios elétricos, decorrentes da utilização dos VANTS, será responsabilidade do utilizador a reparação e/ou indeminização a que houver lugar.
4. Não devem ser causados danos à vegetação e à fauna, nomeadamente pelo estacionamento de viaturas em locais indevidos.
5. Todos os resíduos produzidos devem ser recolhidos e depositados em local apropriado, preferencialmente de recolha seletiva.
6. A versão ou versões do(s) filme(s) produzido(s), que sejam objeto de divulgação pública, devem incluir nos créditos a seguinte menção "Agradece-se ao Instituto de Conservação da Natureza e das Florestas, I.P. a autorização para a recolha de imagens no Parque Natural da Serra da Estrela.".

Acresce ainda informar que:

A. O **parecer** do **ICNF, I.P.** não dispensa nem exime o requerente do cumprimento das disposições do Regulamento n.º 1093/2016, de 14 de dezembro, da **Autoridade Nacional de Aviação Civil**;

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B. O Instituto de Conservação da Natureza e das Florestas, I.P. declina quaisquer responsabilidades sobre eventuais acidentes ocorridos, resultantes realização da atividade;

C. A autorização do ICNF, I.P. fica ainda condicionada ao cumprimento da demais legislação aplicável;

D. No decorrer da atividade, o ICNF poderá fazer, de acordo com a disponibilidade das equipas de vigilância, o acompanhamento julgado necessário, procedimento que repetirá finda a mesma, de forma a analisar o rigoroso cumprimento dos requisitos inerentes à efetiva salvaguarda dos espaços naturais.

Os condicionalismos expressos no presente ofício devem ser divulgados pelos requerentes a todos os participantes na atividade.

A atividade objeto de parecer não está sujeita ao pagamento de taxa devida pelo acesso e visita a áreas integradas no Sistema Nacional de Áreas Classificadas, em conformidade com as disposições do Decreto-Lei n.º 142/2008, de 24 de julho, na redação dada no Decreto-Lei n.º 242/2015, de 15 de outubro, da Portaria nº 122/2014, de 16 de junho, alterada pela Portaria n.º 110/2015, de 21 de abril, e do Despacho n.º 13350/2014, de 4 de novembro.

Com os melhores cumprimentos,

A Diretora Regional da Conservação da Natureza e Florestas do Centro,

Teresa Fidélis

Annex 6 – Operational Manual

UAS Application in Search and Rescue Missions
Procedures and Technical Concerns

COMANDO DA DOUTRINA E FORMAÇÃO