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Article

The Use and Management of Helicopters in Forest Fires-Fleet and Reserve

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Abstract

The use of aerial means in firefighting is undoubtedly a powerful tool that allows the use of speed, the ability to progress in areas without access, the capacity to extinguish in the direct attack, combined with extreme versatility and agility, especially in rotary-wing aerial means. The use of helicopters demands a very accurate management and the correct use of the assets. That is crucial to achieve a good performance, avoiding tasks that could be contrary to extinguishing the fire or even cause serious accidents. In the field of Civil Protection very limited studies present this, or similar type of analysis for the use of helicopters. This work appoints specific needs of aerial forest firefighting and the safety limitations of the aircraft envelope can be achieved through experience, but also by systematized knowledge, including operational failures that can be used as lessons learned to improve the management and use of these resources. In this article we make use of the real cases scenarios to study and identify failures in the use of these assets to improve the efficiency of combating forest fires, as well as improving the safe and the management of these resources. Therefore it is recommended that operators and management discuss the set reflection on the following topics, how firefighting maneuvers with helicopters should be managed when we have teams on the ground working nearby; Taking measures and caution when the fire's behavior can suddenly change due to internal or external factors, such as the indraft of air of an helicopter, the deployment and recovery of heli-transported teams; the use of helicopters in moop-up activities; and the use of devices on the aerial means that can interfere with operations including best way to attach them/ safely and the best way of performing the maintenance or of upgrading it. Finally an analysis of the availability time of the Helicopters of firefighting and management of maintenance in the fleet will be performed to anticipate the needs for maintenance services allowing to reduce serious breakdowns in service and increase the sustainability of the means.

Keywords: helicopters; aerial means; firefighting; physical assets management; sustainability

1. Introduction

The rapid advance of the fire can create problems for fire-suppression tactics and can even cause fire safety concerns [1,2].

Efficient maintenance management ensures the operational efficiency of the means and acceptable conditions for infrastructure [3]. Thus, maintenance is responsible for ensuring the safety of people and goods in companies, as well as their quality. Considering the mandatory requirements of the safety of people, goods and the environment [4].

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Aerial means are very important in firefighting activities. Although they are very affected by the thermal radiation, temperature, air density, the updraft in the forest fire, wind speed are the key factors affecting the safety of firefighting aircraft and so the safe altitude of flight is limited by the forest fire environment. Firefighting aerial means are often flying a few hundred feet above terrain, even in reduced visibility conditions, pilots must coordinate with ground crews, monitor fire behavior, manage multiple radio frequencies, and avoid interferences with the fire that will essence the fire and put the operational people in the ground and other aircrafts in danger.

Aerial firefighting appeared before the Second World War, especially in the US, and gradually increased in the 1950 and 1960s, using to a significant extent surplus military aircraft. From the 1970s specially designed amphibian water bombers. In 1970 and 1980s, helicopters started being widely used in aerial firefighting operations, but their role increased steeply as heavy helicopters found their way in the state fleets of aerial firefighting resources or became available for private contracting, especially in 1990s [5].

These rotary-wing aircraft (helicopters) are widely used in combat today due to their versatility and agility, especially in the initial attack. A rotary-wing aircraft known as Helicopters are aircrafts that can be fitted with a tank or carry a bucket with water or fire retardant. The tanks or buckets can be filled on the ground, drawing water from lakes, rivers or other water sources. They can also quickly send a firefighting team of nine to wherever they are needed, as well as fight fires with water/foam droplets.

Despite these many important advantages, it is well known that when many simultaneous fires escape initial attack, the number of air resources often proves inadequate, as they are often not used in an integrated way with ground teams but are expected to act as their substitutes.

Increasing attention is being paid to improving helicopter firefighting efficiency [6]. So it is today discussed accuracy and effectiveness looking for ways of improving the efficiency of combating forest fires, as well as improving the management of these resources [7], namely accuracy, reliability and safety. Nowadays, the main efficiency factors are the cost of water per litter and the cover water zone [8].

Also looking at factors that can be decisive such as, fire flame fronts and convection columns contain superheated gasses that can significantly reduce aircraft performance (and safety margin) while supporting fire suppression operations. Normal performance planning does not account for the drastic increase in density altitude associated with the increased temperatures [9]. Other issue is the use of shortline or longline, for launches, longlines are generally safer and versatility, while shortlines are used in specific situations where precision matters the most.[10] Also the presence of a second operator in the air to observe and give combat and safety indications to the pilot that improve the accuracy of the launch and safety. The use of pilot support elements that are often not properly adjusted, such as tablets, GPS, cameras and others, whose poor placement can lead to accidents.

Regarding the theme of maintenance as factor that can be decisive to avoid accidents with the assets in study, the maintenance and its management its concept that will be presented and its management over time.

According to NP EN 13306:2021 [11], Maintenance is the "Combination of all technical, administrative and management actions, during the life cycle of an asset, intended to maintain or restore it to a state in which it can perform the required function".

The term "maintenance" has its remote origins in military vocabulary with the meaning of "keeping, in combat units, personnel and material at a constant level".

According to Farinha [12], the mechanization associated with the Industrial Revolution of the 19th Century highlighted the need to regularly repair machines; However, these interventions were left to the operators themselves. It was only after World War I that the industry was pressured to meet minimum production standards, leading to the formation of specialized teams to repair faults in the shortest possible time. These teams, however, were limited to carrying out corrective maintenance, remaining dependent on production.

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Unplanned maintenance corresponds to a policy in which interventions seek to recover the equipment so that it reaches a normal operating state, after the failure occurs.

The expansion of commercial aviation, from the 1940s onwards, brought new challenges to maintenance. On the one hand, it forced the development of preventive methods, since repairing damage during flight is rarely possible and, on the other hand, it accentuated the problem of the safety of people and property.

The advent of computers has led many companies to implement systematic preventive maintenance strategies. This approach, still dominant today, typically uses maintenance planning programs to control calendar-based maintenance activities to trigger work orders automatically.

The term conditional maintenance emerged in the 70s and 80s to designate a new approach to preventive maintenance, based on knowledge of the real state of machines, through the implementation of a condition control system.

This involves deciding when to intervene in equipment based on knowledge of its actual condition. In other words, instead of carrying out planned maintenance work at fixed intervals, as is the case with systematic maintenance, it is carried out at variable intervals, determined by the condition of the equipment. Conditional maintenance therefore affects equipment considered individually, replacing revisions at fixed intervals with inspections at fixed intervals. The economic advantages of conditional maintenance arise from gains in reduced production losses, due to increased equipment availability and gains in reduced maintenance costs. However, this methodology needs to be balanced taking into account the additional costs of data collection, whether manually or automatically.

There are a series of techniques for controlling the condition of machines and equipment with application in maintenance, the highlights being: vibration analysis; thermography; analysis of performance parameters; visual inspection; ultrasonic measurements; and analysis of service lubricants.

Predictive maintenance is often referred to as condition monitoring or condition-based maintenance, i.e., it assesses the actual condition of equipment using specific equipment, with the aim of adjusting preventive maintenance planning, detecting possible failures early, preventing the emergence of complex problems, and enabling decision-making based on real data.

The NP EN 13306:2021 [11] standard defines predictive maintenance as "conditional maintenance carried out in accordance with predictions extrapolated from the analysis and evaluation of significant equipment degradation parameters".

We present some studies on conditional and predictive maintenance and on the dimensioning of the reserve fleet, namely: [13–18]. We also present some studies and tools that can contribute to this line of research, such as: [19–21].

2. Methodology

In this work, we present and discuss a set of case studies. In this way, we will apply scientific methodology and use the inductive method, which takes as its starting point the observation of particular facts so that, through their association, we can establish generalizations that make it possible to formulate a law or theory [22]. The work will therefore consist of making observations and analysis of actual accidents. The observed data will then be coded and classified in order to identify characteristics consistently. Finally, based on the previously classified elements, general statements must be inferred from the initial observations, and these statements will be the theories to be developed. A list of best indicators will be presented. These will generate recommendations aimed at improving the safety and efficiency of the use of these means.

An analysis of the availability time of the Helicopters of firefighting and mangment of maintenance in the fleet will be performed to anticipate the needs for maintenance services allowing to reduce serious breakdowns in service. This will be made making use of concepts as the Fleet of Helicopters (m), Mean Technical Repair Time (MTTR), Mean Time Between Failure (MTBF), Availability (A) and Reserve Fleet (RF).

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2.1. Maintenance Versus Key Performance Indicators (KPIs)

The standard NP EN 15341:2019 [23], "Maintenance—Maintenance Performance Indicators (KPI)", in its introduction establishes maintenance performance indicators to support management, in order to achieve excellence in maintenance and use of fixed assets in a competitive manner. Most of these indicators apply to all industrial installations and services (helicopters, vehicles, equipment, buildings, infrastructure, transport, among others)".

In this article the main technical indicators used are the following, as shown in Table 1: Mean Time Between Failures, Mean Time to Repair, Mean Waiting Time and Availability.

Table 1. Maintenance Performance Indicator Formulas (KPIs), adapted from [14].

Designation	Formulas	Variables
Availability (A)	$A = \frac{MTBF}{MTBF + MWT + MTTR}$	*MTBF Mean Time Between Failures* *MTTR Mean Time to Repair* *MWT Mean Waiting Time*
Mean Time Between Failures (MTBF)	$MTBF = \frac{\sum_{i=1}^{n} TBF_i}{n}$ $MTBF = \frac{MTTR}{\frac{(1-D)}{D}}$	*TBF Good Operating Time*
Mean Time to Repair (MTTR)	$MTTR = \frac{\sum_{i=1}^{n} TTR_i}{n}$ $MTTR = MTBF * \frac{(1-D)}{D}$	*TTR Technical Repair Time.*
Mean Waiting Time (MWT)	$MWT = \sum_{i=1}^{n} WT$	*WT Average Waiting Time*

2.2. Fleet and Reserve Fleet Dimensions

The total number of helicopters required for fire-fighting services is designated by fleet size (m), and corresponds to the sum of the helicopters required for the operation itself, normally determined by the needs in the period in question (depending on the time of year: summer, spring, autumn and winter, as well as the temperatures predicted by the meteorology for each month) with the reserve helicopters and those subject to maintenance operations.

Raposo et al. [24] considers that the reserve fleet (RF) is the number of vehicles ready to perform the service for which they are intended, that is, the vehicles would not be immobilized due to breakdown, nor undergoing preventive maintenance, thus providing the possibility of carrying out preventive maintenance on the remaining vehicles, increasing the availability and reliability of the operational fleet.

Civil protection always has a certain rate for booking emergency vehicles. A low reserve ratio is synonymous with high reliability, essentially based on the implementation of an efficient planned maintenance plan, which results in the application of new maintenance methodologies and techniques that lead to the assessment of the condition of the equipment and the decision to replace or renew the equipment.

Calculating and monitoring reservation rates continues to be an important management tool, especially in emergency services.

When making decisions regarding equipment management, maintenance costs, operating costs, overall cost of ownership, and accumulated costs must be considered. ([4,28])

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These indicators are essential factors to consider when sizing the reserve fleet. It can be stated that the Availability value is dependent on MTBF and MTTR and that these are clearly dependent on the maintenance policies used in companies and, consequently, have an influence on the sizing of the Reserve Fleet of Helicopters. The formulas presented in Table 2 represent this relationship.

Table 2. Reserve Fleet Formulas, adapted from [16].

Designation	Formulas	Variables
Reserve Fleet (RF)	$RF = \frac{m * MTTR}{k}$ $RF = \frac{m * MTBF * \frac{(1-A)}{A}}{k}$ $RF = \frac{m * \frac{\sum_{i=1}^{n} TTR_i}{n}}{k}$	*RF* *Reserve Fleet;* *m* *Number of vehicles that make up the fleet;* *MTBF* *Mean Time Between Failure;* *A* *Availability;* *TTR* *Technical Repair Time;* *i* *i=0,1,2,3…n* *k* *Number of days/years (365 days).*

3. Cases Studies

3.1. Trevim Fire

On July 11, 2020 at 6:26 p.m.: a team was sent to fight a "normal" fire. It was a bushfire in the Serra da Lousã."Nothing could have predicted its outcome", One firefighter died and two were seriously injured, two others with minor injuries [25]. On that day, three aerial means, light helicopters, tried to contain the flames before nightfall. Around 250 personnel and 64 vehicles from various fire departments in the districts of Coimbra and Leiria were on the scene. Among them was a team from the Miranda do Corvo extinguishing a small part of the fire on the right flank (João, Guiomar and the team leader, José Augusto). This team begins to make progress down the slope with hoses and water from the vehicles. Suddenly a low drop with a strong shot from the helicopter fills everything with smoke and the fire gains intensity Figure 1. Confusion set in among the team. At 7:19 p.m., the first communications "with distress calls" began to be heard. What happened was that the helicopter's discharge was too low and its downwash created projections below the firefighters' work zone. That's why it's presumed that there was a link between the discharge, the projections and the accident. On that day the team leader, Chief José Augusto died in the battle.

In this case, we can reflect on how firefighting maneuvers with helicopters should be managed when we have teams on the ground working nearby. To this end, the resources manager and the pilot should always consider the possibility of the helicopter's flow interacting with the fire. Ground crews should also give feedback on their position and exercise caution when penetrating mountainous terrain where the fire's behavior can suddenly change due to internal or external factors, as in this case.

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Figure 1. Copilot generated image of an helicopter passing very close to the flames with firefighters on the ground.

3.2. Case of the Serra da Estrela Fire

Once again in Portugal, it was the summer of 2022. The fire, which raged between August 6 and 23, was the sixth largest in Portugal since records began, Figure 2. With challenging conditions due to low humidity, mountainous terrain and strong winds. The fire was close to being resolved when the maneuvering of a helicopter to pick up its crew caused the fire to reactivate, carrying the flames to the opposite slope, causing an episode of eruptive behavior that caused the situation to lose control," says the report by the group of experts invited by the government to assess the major rural fires of 2022. The document concludes that it is possible that this maneuver, in addition to reviving the fire, caused secondary outbreaks on the opposite side of the slope [26].

The document, published on the website of the Agency for the Integrated Management of Rural Fires (AGIF), adds that the helicopter's maneuver should have taken place in a different area, further away from the perimeter of the fire, especially away from that area which was poorly consolidated and with a water line nearby. On the other hand, assuming that it wasn't possible to prevent the perimeter of the fire from getting so close to the waterline, this whole area should have been subjected to an increased consolidation effort since it was to be expected that the fire crossing the waterline would lead to a violent spread. And always avoid operating so low in the air near such a critical area.

In terms of operations management, this incident makes it possible to define conditions for the deployment and recovery of helitransport teams. As we have seen once again, there can easily be an interaction between the environment and the fire which, due to the need to land in order to recover the team, can intensify the fire and projections can occur due to the extreme proximity of the flow generator (aerial mean) and the fire. It is therefore recommended that the team be recovered in an area far enough away from the fire front.

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Figure 2. Serra da estrela Fire [26].

3.3. Semide 2017, Fire

It was already the second day of the fire, which had started on Friday afternoon, June 23, 2017. Early on Saturday morning, the fight began with an aftermath using aerial means. The two counter-rotating rotors eliminate the need for an anti-torque vertical rotor allowing all power to be used for lift and thrust to discharge the water. However, if on the one hand we have increased the amount of water released, on the other hand we have identified dangerous effects for the fire, such as the vertical runoff that is generated and which goes straight to the forest fire.

So in this case, as oxygenated and the entire area that was initially just smoldering was burning with flames. Clearly, the downwash effect of the passage of the aircraft ignited the firefront, worsening the situation and forcing the ground resources to once again take action to restore control of the situation.

This brings us a reflection on the use of physical assets of rotary-wing in mop-up activities. Mop-up operations are not the most suitable for this type of equipment, unless the site is otherwise inaccessible. Even then, due to the problems of reignition, excessive oxygenation of the still burning area and the possibility of generating projections, it is always possible for firefighters to act on the ground. Releasing this type of means for initial and extended attack situations.

3.4. Crash of a Poorly Fixed Element Boeing CH-47 Chinookum

An helicopter which was on a firefighting mission, crashed due to the fall of a poorly fixed element. The accident occurred with a Boeing CH-47 Chinook aircraft, of military origin, but operated by a civil company, to fight fires in the state of Idaho, USA in 2022.

The aircraft was refilling its water basket when it went into a tailspin and fell into the Salmon River, seriously injuring the two pilots who later died in hospital.

An iPad was found among the wreckage. A detailed analysis showed that the equipment was stuck between the aircraft's pedals.

tablets are quite often used in aviation today, they are used with apps that support multi-function navigation, with charts, maps, GPS, performance calculation features and other useful functions.

While in larger aircraft it is fixed to the cabin structure or to a suction cup attached to the windshield, in a helicopter, with a smaller cabin, spaces are limited. In this case, the pilots involved in the accident ended up leaving the device on their leg, according to investigators.

However, the belt that held the device ended up causing it to come loose and it to fall between the pedals on the copilot's side. The aviator could have even tried to reach the tablet, but due to the

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depth he was in, as well as the panel and helmet that prevented him from lowering himself any further, he was unable to reach it [27].

This accident leads us to the observation that nowadays many physical assets are used and added to aircraft to support the operation of the aircraft. It is therefore recommended that operators and management discuss the use of these auxiliary devices with the maintenance teams and mechanics, so that the pros and cons of their use are discussed, as well as the best way and place to attach them safely.

3.5. Crash of the FireHawk Helicopter in Florida

In 2021 the crash of a FireHawk helicopter, on May 25 at Leesburg, Florida. The helicopter was conducting fire water drop exercises and lost control of the bucket causing the rotor section to separate, crashed in a wooded area, and caught on fire. The report of the incident says that violent swinging of a snorkel hose attached to a newly installed water tank caused the accident. All four on board were killed. The operator affirmed that a new water tank and snorkel were installed on the helicopter to facilitate firefighting operations. After the ground testing and calibration, they passed to the first flight after the new system was installed. Witnesses reported that the helicopter made six uneventful passes in front of the operator's hangar and dropped water that was picked up from a lake adjacent to the airport. On the seventh pass, an employee of the operator noticed the snorkel swinging and after the violent swing that caused the accident. [28] Maintenance operations, whether corrective, preventive or upgrading, on this type of aircraft always require very high levels of reliability and traceability, as it is possible for non-conformities to appear after they have been carried out. Test procedures and test flights must be strongly analyzed and validated at every step so as to reduce the possibility of an incident or accident as much as possible.

3.6. Crash of the Helicopter in Douro, 2024

On August 30, 2024, the Armamar aerial resources centre received a mission order to fight a fire in the Baião area, district of Porto. At 11:20 am, the pilot and a team of five members of the Emergency Protection and Rescue Unit (UEPS) of the GNR, took off aboard an AS350B3+ helicopter. At 11:30 they decided to return the aircraft to its base [29].

On the return flight the aircraft began a steady descent, where it flew over the left bank (south) of the Douro River towards the city of Peso da Régua. During the descent, according to the pilot's statements, he saw a medium-sized bird at the same altitude and on the helicopter's trajectory, which forced him to change course to the right, resuming the route thereafter. But not a contact happens, that seams that the incident was not due to the bird. At 11:32 while descending towards the river in a left-hand turn, the helicopter collided with the surface of the water at a speed of around 100 knots (185 km/h) for reasons to be determined. From the violent collision with the water, the helicopter suffered a deformation of the cabin incompatible with the survivability of its occupants. The collision resulted in fatal injuries to the 5 members of the UEPS and serious injuries to the pilot, who managed to surface and was rescued by bystanders.

This accident leads us to the conclusion that many factors were involved, starting with the human factor. But for sure we observe a case of poor maintenance and the failure of some control system that could explained the total loss of control of the aircraft. We must also consider the lack of training that should be offered to the pilots and crew of these aircraft, both for the specific exercise of firefighting activity and for safety issues. For example, in this case, must be mandatory the *Emergency and Evacuation Training* (ex. *Helicopter Underwater Escape Training* (HUET)) with practical simulations of evacuation in different scenarios, also *Maintenance and Fault Diagnosis Training* to identify and correct technical failures before they become critical. *CRM (Crew Resource Management)* to give to the crew resource management to improve communication and decision-making under pressure. And among others the *Aerial Firefighting Training* with specific simulations for pilots and crew to handle unexpected situations during firefighting operations.

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4. Analysis of the Availability Time of the Helicopters of Firefighting and Maintenance Fleet Management

In this chapter we will present a case study for a fleet of helicopters belonging to and managed by the Civil Protection of the Portuguese State [30].

4.1. Helicopter Operational Fleet Management

To calculate the availability, effectiveness and cost of light helicopters (HEBL) supplied to the Portuguese State, we took into account the following Table 3 of needs, for the year 2024 [30].

Table 3. HEBL Needs along the year of 2024.

	Period			
Helicopters	Rest of the Year	15/05—31/05	01/06—15/10	16/10—31/10
Total HEBL	10	14	26	14

It can be seen, through the analysis of Table 3, that the Helicopter Fleet varies according to critical periods, namely it can be seen that the critical period painted in red is the period between June 1st and October 15th, operational fleet of 26 helicopters.

In this sequence, Table 4 shows the radar map (Figure 3) showing the Availability versus Production Need (helicopters needed to perform the service) of the organization under study, throughout the year.

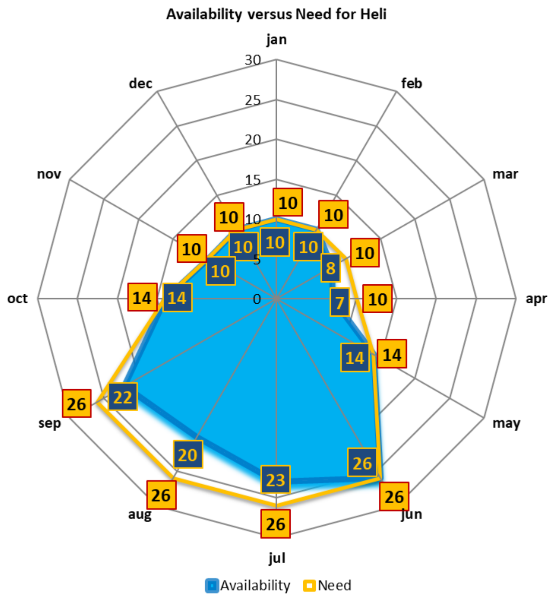

Figure 3. Availability versus Need the year of 2024.

Table 4. Availability versus Need the yaer of 2024.

2024				
Months	Availability	Need	Maintenance	Reserve Fleet
jan	10	10	0	12
feb	10	10	0	12
mar	8	10	-2	12
apr	7	10	-3	12

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may	14	14	0	17
jun	26	26	0	32
jul	23	26	-3	32
aug	20	26	-6	32
sep	22	26	-4	32
oct	14	14	0	17
nov	10	10	0	12
dec	10	10	0	12

4.2. Maintenance Versus Reserve Fleet Helicopters

Figures 4 and 5 show that when MTTR decreases, equipment availability increases. While this conclusion may seem obvious, these KPIs are strategic. Thus, the decision maker can decide on the maintenance policy, i.e., condition monitoring of helicopters.

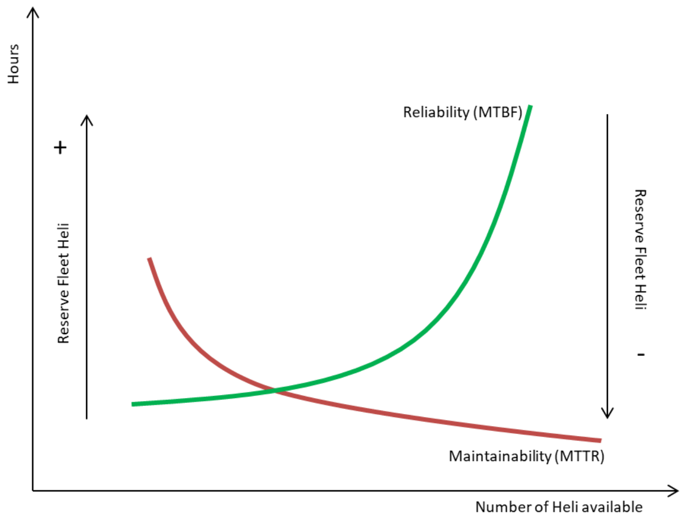

Figure 4. MTTR and MTBF versus Reserve Fleet Heli.

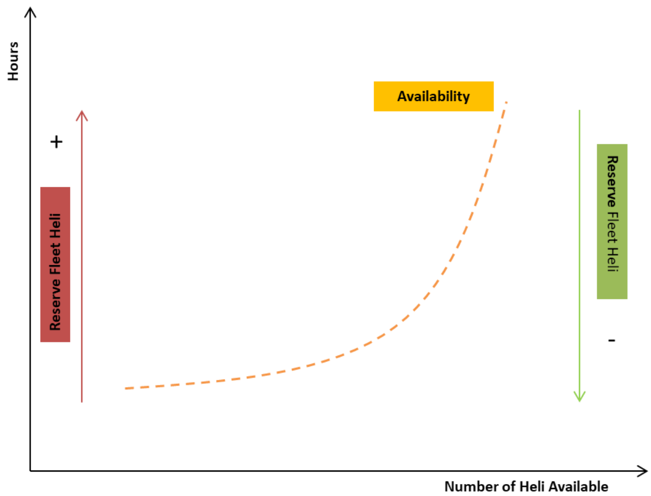

Figure 5. Availability versus Reserve Fleeto f Helicopters.

Figure 4 illustrates how an increase in MTBF and a decrease in MTTR increases helicopter availability, namely through a maintenance policy.

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The operational availability of helicopters generally varies between 70% and 80%, depending on the efficiency of maintenance and logistics, implying different MTTR times [31].

The fleet reserve refers to helicopters that are available for operations and cannot be considered assets that are not available due to maintenance, repairs or other reasons.

In this sequence, it is now possible to calculate the reserve fleet indexed to the MTTR values. The following table and graph show the variation in the size of the reserve fleet according to this indicator.

Thus, calculating the number of repair hours for our helicopters, based on the MTTR based on the data in Table 5, we can arrive at the value of our reserve fleet Figure 6 Reserve Fleet for an MTTR of 250 hours.

Table 5. MTTR versus Reserve Fleet.

MTTR [Hours]	Heli Fleet [m]	Reserve Fleet [RF]	Interval [RF]
8	26	0	[1,1]
15	26	0	[1,1]
23	26	1	[1,2]
39	26	1	[1,2]
83	26	2	[2,3]
132	26	3	[3,4]
188	26	5	[4,5]
250	26	7	[6,7]
300	26	8	[7,8]

From Table 5, the Equation (1) can be drawn up to determine the size of the reserve fleet [14–17]:

$$\mathbf{RF} = \frac{\mathbf{m} * \mathbf{MTTR}}{\mathbf{k}} \quad (1)$$

where,

RF Reserve Fleet;
m Number of helicopters that make up the fleet;
MTTR Mean Time to Repair;
k Number of hours/years.

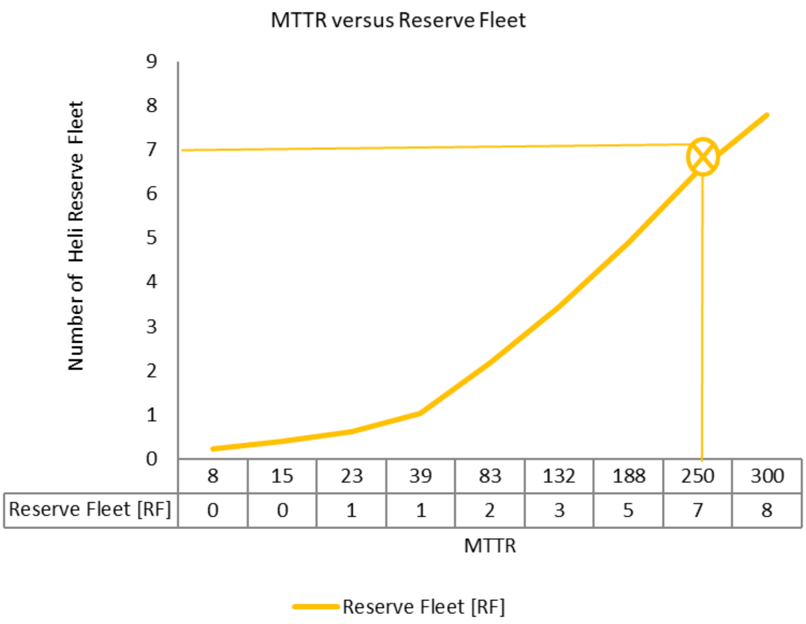

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Figure 6. Fleet Heli versus Reserve Fleet Heli.

For a MTTR of 250 Hours, in a fleet of 26 helicopters, a value of 7 units is obtained for the size of the reserve fleet.

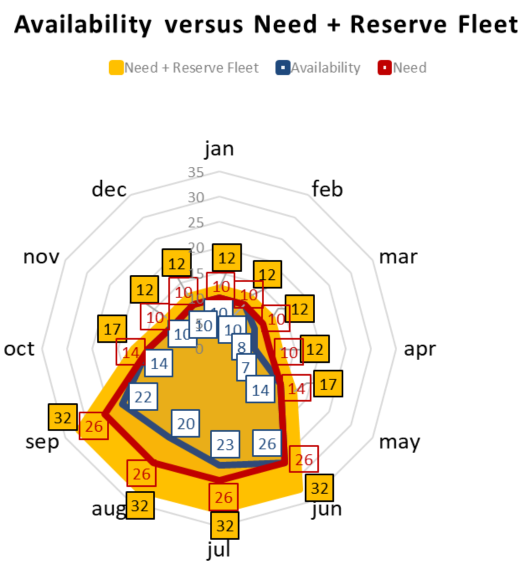

Figure 7. Radar Map Availability vs. Need + Reserve Fleet.

Summary and some considerations:

- Helicopters Available will change from 10 to 26 helicopters depending on the periods of the year , depending also from maintenance and from the need due to the danger of fire.
- Firefighting helicopter repair times can vary depending on the type of maintenance required. Here are some examples: Line/Baseline Inspections: These inspections are typically quick and can be completed in a few hours to a day.
- Preventative Maintenance: Includes regular checks and replacement of worn parts, which can take from a few days to a week.
- Component Repairs: When major components such as engines or hydraulic systems need to be replaced or repaired, repair times can range from one to several weeks.
- Biennial Inspections: Full inspections, such as those performed, can take approximately 10 weeks to complete.
- Parts Availability: How quickly replacement parts can be obtained can significantly impact repair time.
- Problem Complexity: More complex problems or extensive damage may require more time to resolve.
- Workshop Capacity: The capacity and efficiency of the maintenance workshop also influences the time required to complete repairs.
- These times are estimates and may vary depending on the specific circumstances of each repair.

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- Operating costs may vary, but based on previous contracts we can make an estimate. For example, HeliBravo [31] supplied four light helicopters for 350 000 euros for 25 flight hours per aircraft. If we apply this cost to the 26 helicopters:
  - 350 thousand euros / 4 helicopters = 87.5 thousand euros per helicopter
  - 87.5 thousand euros x 7 helicopters = 612,5 thousand euros for 25 flight hours for each of the 10 helicopters
  - 87.5 thousand euros x 11 helicopters = 962,5 thousand euros for 25 flight hours for each of the 10 helicopters
  - 87.5 thousand euros x 26 helicopters = 2.275 million euros for 25 flight hours for each of the 26 helicopters.
- These values are estimates and may vary depending on specific operating and maintenance conditions.

5. Conclusions

In this work we analyzed the use of Helicopters in firefighting, and we conclude that they require very precise management and correct use of resources. This is essential to achieve good performance, avoiding tasks that could be contrary to extinguishing the fire or even cause serious accidents. The set of cases analyzed allows us to reflect on the following conclusions, that are also summarized in Table 6.

Reflect on how firefighting maneuvers with helicopters should be managed when we have teams on the ground working nearby. Taking measures and caution when the fire's behavior can suddenly change due to internal or external factors, such as the indraft of air of a helicopter

In terms of operations management, it was possible to define conditions for the deployment and recovery of heli-transported teams, avoiding interaction between the fire and the aerial means. So, it is recommended that the team be recovered in an area far enough away from the fire front.

The next reflection was about the use of rotary-wing aircraft in moop-up activities, and it is reinforced the idea that these operations are not the most suitable for this type of physical assets.

Another issue is related with the training offered to the pilots and crew for the specific exercise of firefighting activity and for safety issues. More comprehensive and standard training must be offered to the teams.

The physical assets that are incorporated in the helicopters like auxiliary devices of main extinguisher devices. Therefore, it is recommended that operators and management discuss the use of these devices with the maintenance teams and mechanics to discuss the best way and place to attach them safely and the best way of performing the maintenance corrective, preventive or of upgrading. Test procedures and test flights must be strongly analyzed and validated at every step to reduce the possibility of an incident or accident as much as possible.

In the Table 6 is shown the summary of the conclusions.

Table 6. Type of issue and guide suggestion.

Type	Guide suggestion
Deployment of heli-transported teams	Caution! The indraft of air of the helicopter. Do not fly in way to interact with the fire behavior which can affect the teams in the ground. it is recommended that the team be recovered in an area far enough away from the fire front.

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Helicopters in moop-up	Warning! These operations are not the suitable for this type of machines.
Equipment that is incorporated in the helicopters	Attention! It is recommended that operators and management discuss the use of these devices with the maintenance teams and mechanics to discuss the best way and place to attach them safely and the best way of performing the maintenance
Training	Consider the lack of training offered to the pilots and crew for the specific exercise of firefighting activity and for safety issues.
Availability versus maintenance	Helicopters Available will change depending on the periods of the year due to maintenance and from the need demanded by the danger of fire.
	Firefighting helicopter repair times can vary depending on the type of maintenance required.
	When major components such as engines or hydraulic systems need to be replaced or repaired, repair times can range from one to several weeks and this will demand larger RF.
	RF (fleet reserve) refers to helicopters that are available for operations and cannot be considered assets.

As future work detailed information from time lap records of the incidents and of missions can be analised to extract data about the hours of use of these physical assets and compare with its effectiveness, among many other valuable data.

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