Effective use of a helicopter with a Bambi bucket firefighting system in Bulgaria

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Abstract. The present paper studies the effectiveness of the use of the Mi-17 helicopter with a Bambi bucket firefighting system in operations against mountain and forest fires in the Republic of Bulgaria. It makes an analysis of the conditions under which it is used, on the basis of numerous publications about theoretical and experimental studies, including ones aimed at increasing the efficiency of using helicopters with other external hanging firefighting systems. The preparation and conduct of flying experiments with a Bambi bucket system have been made. They take into account the specifics of this system, the characteristics of the firefighting methods used in the Republic of Bulgaria, and the of country specific external factors. On the basis of the results of these studies, and by taking into consideration the flight safety requirements, recommendations have been made to improve the effectiveness of using a Bambi bucket firefighting system in Bulgaria.

1. Introduction

Forest fire is a violent spread of fire across the entire forest area, unmanageable by humans, and characterized by dense smoke and intense heat radiation. It reduces the protective characteristics of the forests, their water-conservation and other properties. It causes the destruction of trees and shrubs, fauna and, in some cases, impacts populated areas. Due to their social and economic costs scale, forest fires could grow to national disasters. Such an example are the fires in Greece last summer, which have been identified as the largest in Europe since the Second World War. Therefore, firefighting is a matter of national security, and all supporting means must be used, including aviation firefighting systems.

World practice shows that the extinguishing of complex combined (both low and peak) forest fires with water (currently the best extinguishing agent in the world used for this purpose) is possible only using helicopters. This is a multifarious, labour-intensive and costly process characterized with little efficiency and effectiveness. Unfortunately, there is no other fire extinguishing method for extinguishing fires in inaccessible, difficult to reach and remote areas, far from water basins.

Over the last few decades around the world, and since 2010 in our country as well, helicopters with a suspension fire extinguishing system (SFS) have been used for extinguishing mountain and forest fires. The most common firefighting method is to pour water from the system's external storage tank onto the place of fire or to create an enclosing lane. The advantages of the use of helicopters for forest fires are their operability in delivering water to the hearth, the great instantaneous efficiency of pouring a lot of water, airport independence, and the high level of safety for humans.
In Bulgaria, during the extinguish mountain and forest fires, the use of Mi-17 helicopters with Bambi bucket system was established. In order to make it safe and effective a number of theoretical and experimental studies [1, 2], including those aimed at increasing the efficiency of this use in compliance with the requirements of flight safety, have been completed in Russia and in Europe [3]. A problem with the application of the results of these studies in our country is the fact that in Russia the SFS is VSU-5, whose characteristics vary from those of the Bambi bucket (table 1). Thus, specific adaptation of the results of this research is required and conduction of surveys in our country in order to improve the overall performance in our current conditions and environments.

Table 1. Technical characteristics of SFS Bambi bucket and VSU-5A.

| Technical Characteristics          | Bambi bucket | VSU-5A  |
|-----------------------------------|--------------|---------|
| Maximum volume, m³                | 3.0          | 4.5     |
| Diameter of the top, mm           | 1400         | 2200    |
| Bottom diameter, mm               | 800          | 800     |
| Length of rope, m                 | 15           | 20-40   |
| Maximum helicopter speed with empty tank, km/h | 176       | 160     |
| Maximum helicopter velocity with full tank, km/h | 176       | 180     |
| Most advantageous helicopter speed, km/h | 80-100   | 80-100  |
| Efficient altitude for running water above the surface, m | 10-20 | 20-30  |
| Required time to pour water after pushing the pilot button, s | 4-5 | 6-8    |
| Average water consumption, l/s     | 800-1000     | 800-1000|
| Time to fill the system tank, s    | 75           | 60      |
| Closing time of the valve, s       | 1-2          | 1-2     |
| Mass of the empty system, kg       | 75           | 160     |

The present work analyses the conditions under which a Mi-17 helicopter with a Bambi bucket suspension system is used for extinguishing mountain and forest fires in Bulgaria. Descriptive and experimental materials are presented, taking into account the specifics of our conditions. The main conclusions and recommendations for providing higher firefighting efficiency in compliance with the requirements of the flight safety are formulated.

2. Fire extinguishing in Bulgaria

Helicopters could be used in different firefighting and emergency operations, performing the following tasks:

- search for and rescue victims in the case of wild fire;
- targeting and on site control of the ground fire and rescue forces;
- transport of rescue teams and fire-extinguishing means and their delivery by parachute, fast-rope and landing;
- victims’ evacuation from the disaster area;
- extinguishing of wild fires from the air with water or a flame-retardant solution in areas not accessible for ground firefighting teams;
- conducting aerial fire surveillance and monitoring;
- preventing fire evolution until the ground forces arrive, preventing the spread of fire;
- establishing enclosing lanes using water, foam and chemical solutions;
- communication between firefighting teams, search and rescue teams and the on-site decision-maker.

In Bulgaria, in the case of firefighting, an aviation fire system helicopter Mi-17 is used with external suspension Bambi bucket system. Mi-17 is a military version helicopter converted to use a Bambi bucket system. It is capable of delivering up to 4000 litres of water and discarding it with great precision at the place of the fire. It is also capable of transporting firefighting teams and special
equipment to the affected area. Up to now, over 14 000 units have been produced of various modifications, a world record for two-engine helicopters. These helicopters are operated in over 100 countries around the world and have a total of about 100 million flight hours.

The external fire extinguishing system is the Bambi bucket, produced by the SEI – Canadian Company, with a capacity of 3000 litres [4]. The main features of this system, compared to those of the Russian VSU-5A, are depicted in table 1.

For firefighting of mountain and forest fires by helicopters with SFS, two methods are applied – direct (active) and indirect (passive). In the direct extinguishing method, the fire is directly attacked by water or another fire-extinguishing agent. It is applied when the fire is flat and is in an early stage of development. The indirect method is used to create a restraining lane at a specific distance away from the fire. The end of these lanes must finish with natural or artificial fire barriers such as roads, rivers, and lakes or pre-prepared mineralized lanes.

The main stages of the firefighting flights are: take off; flight with SFS to the water basin to fill in the tank; hovering and filling the SFS with water; flight to the fire site; release of water into the fireplace.

Each stage of the flight is related to a threat for its safety. From the point of view of flight safety, the final stage is most dangerous due to the fact that complex air dynamic processes are developed over the fire site as result of combustion. There is a large difference in the temperature fields due to the different pyro-characteristics of solid combustible materials. This leads to the formation of winds different as speed and direction. Following the relief of the area, especially when mountain fires are extinguished, these winds create swirling and turbulent airflows. In many cases it is possible to form convective thermal pylons, the power of which is directly dependent on combustion intensity.

The intensity of combustion depends on the wind speed over the fire site, the type of the solid combustible materials and the height of the fire itself. Following the relief of the area, the flat fire can easily turn into a peak fire when the wind has a speed of over 20 m/s and the slope angle is 20-30°.

Helicopter flight over such convective pylons is especially dangerous because of the temperature of the elevated air. It could cause engine surge. It could happen when the air inlet temperature is above 70°C. Therefore, when flying over such areas, the limitations of maximum ambient air temperature limits must be taken into account. For example, using the methodology set out in [1] for high intensity fires (20000 kW/m) with diameter of 15 m, the following values of the ambient air temperature are observed at altitude $H$: 190°C at $H = 30$ m; 110°C at $H = 50$ m; 15°C at $H = 100$ m. Therefore, helicopter flight at an altitude of 30-70 m is dangerous because of the possibility of engine surge.

Turbulent flows in the area of fire also affect the work of the crew. They must constantly react to the external environment, which makes them tired much faster.

When the water from the water reservoir is released, rope backwards deflection is observed within the range of 45-60°. The angle of rope and SFS deviation is directly related to flight speed and the impact of the horizontal and vertical air masses. When the tank is full it has a streamlined shape and a low ballistic coefficient. After water is released, this coefficient increases, and the SFS creates a high drag. When moving the helicopter with an empty SFS over a vertical thermal pillar, it is possible for the airflow to impact the system for short period of time. From research [2] done so far it has been shown that even a vertical flow at 20-30 m/s cannot have a significant impact on the SFS and there is no danger of falling into the horizontal stabilizer and tail rotor.

Taking into account the conditions accompanying a fire (wind speed, high temperature, quivering) and the inability to operate the helicopter in a smoky environment due to the probability of engine surge, it should be assumed that fire extinguishing takes place at a forward speed. At high speeds and flight altitudes, the efficiency of falling water is reduced due to the fact that it covers a larger area and the amount of fallen water per 1 m² is less. At low speeds (less than 60 km/h), power demand is close to the available limit, and the helicopter operates in critical modes where flight safety is under threat.

The analysis of these conditions indicates that it is advisable to fly horizontally in the speed range of 80-100 km/h.
3. Firefighting efficiency

The effectiveness of fire extinguishing is the ratio of the water entering the fire site to the total amount of water discharged. This possible maximum is achieved by supplying a fire-extinguishing liquid in the fire site at the required concentration in accordance with the flight safety requirements.

The main factors affecting the effectiveness of helicopter usage and fire extinguishing capability are [1, 2]:

- prehistory of the flight until the moment of liquid release;
- altitude and speed of the flight when throwing the liquid;
- turbulence of the atmosphere and ascending flow from the fire site;
- induced flow of the main propeller;
- spatial position of the dropping points (the position and construction of the outlet of the SFS tank);
- initial drip rates (how the liquid is delivered to the SFS tank outlet);
- liquid flow rate per second.

These factors have been determined through the results of a number of theoretical and experimental studies [5-8]. These findings are of great importance for the development of aviation technologies and aeronautical fire extinguishing methods, which is a promising direction for achieving high firefighting performance.

When a helicopter with SFS is used, there is a loss of extinguishing liquid during transport, which reduces firefighting performance. Experiments show that up to 30% is lost due to evaporation of the low-dispersed part of the water, and about 20-30% of it remains on the branches and the tops of the trees.

In order to reduce losses and improve fire performance of liquid solutions, modern helicopters are equipped with chemical delivery systems - retarders, pigments, moisturizers or thickeners. Pure water can support fire extinguishing properties for only 5-15 minutes. Adding a moisturizing agent or retarder increases this ability for up to 2 hours. In general, special additives contribute to increasing cooling efficiency with liquid solution from 2 to 4 times.

It has been experimentally recognized and practically confirmed [9,10] that in order to achieve the necessary efficiency in fighting mountain and forest fires, it is necessary to provide the following water supply intensity $J$:

- in case of flat forest fire: $J = 0.1 - 0.15 \text{ l/m}^2 \text{ s}$, extinguishing time $t_f = 30 - 60 \text{ s}$;
- at peak forest fire: $J = 1.0 \text{ l/m}^2 \text{ s}$, $t_f = 30-60 \text{ s}$.

These data show that they are much higher than the intensity of fire extinguishing fluid supplied in fire in a residential building $J = 0.1 \text{ l/m}^2 \text{ s}$.

On releasing a fire-extinguishing liquid at the edge of the fire, the following results should be obtained:

- the edge of the fire can be extinguished when specific flow of water or other fire extinguishing solution $D_{sp}$ reaching the burning edge is not less than the specific flow $D_{need}$ required to extinguish the entire width and perimeter of the burning edge;
- the linear spread rate of the fire edge $V_f$ is reduced at least twice for a period of 15 minutes if the specific extinguishing rate of the fire extinguishing solution reaching the edge of the burning edge is not less than 0.5 l/m$^2$;
- for extinguishing the burning edge of a forest fire, the required specific water consumption should be $D_{need} = 5 \text{ l/m}^2$.

The values given for the specific water consumption are effective in extinguishing forest areas with a total density of not more than 0.5.

When setting an enclosing lane at the edge of the fire, it is necessary to provide the required specific consumption of fire-extinguishing solution or water along the entire length of the lane.

The necessary water consumption for laying an enclosing lane in the fight against forest fires, depending on the specifics of the forest vegetation, are given in table 2.
Table 2. The necessary water consumption for laying an enclosing lane depending on the specifics of the forest vegetation.

| Forest conditions                                                      | Necessary specific water consumption, l/m² |
|----------------------------------------------------------------------|------------------------------------------|
| Forests with a density of planting not less than 0.2                  | 0.7                                      |
| Forests of juniper with a density of 0.2 to 0.3 with a slight pronounced overlay | 1.3                                      |
| Forest juniper berries with a density of 0.4 to 0.5 with a moderately developed superior cover | 2.0                                      |
| High density forest plantations                                       | 2.6                                      |

When creating a locking barrier with water for a period of time between laying the strip and approaching the edge of the forest fire, part of the water evaporates. This can be limited by the use of fire extinguishing solutions containing special chemical additives (humectants, thickeners).

If the primary extinguishing site is larger than planned, it is necessary to use 2-3 helicopters depending on the extinguishing area. It should be taken into account that the relative efficiency of simultaneous fire extinguishing with 3-4 helicopters is less, as the area of simultaneous extinguishing and consequently water losses increases.

To achieve the required firefighting efficiency, it is necessary to release the water consistently over the extinguishing site (5-6 minutes).

In order to achieve it, the crew needs to have the necessary skills that can be developed through training. This skills and experience could be assessed by measuring the uniformity of water distribution on the fire area and the rate of water filling of the measuring vessels. This will allow the pilot to correctly assess the altitude of the flight at the moment of water release [11, 12].

The minimum safe flight altitude at which the highest firefighting performance is obtained is determined by the following condition (figure 1):

\[ H_{FL} = H_{TR} + H_{LR} + H_{SF}, \]  \hspace{1cm} (1)

where \( H_{TR} \) is the height of the trees; \( H_{LR} \) – the length of the rope; \( H_{SF} \) – the minimum safe distance between the tops of the trees and the SFS.

Figure 1. Minimum flight safety height for Bambi bucket usage.
In the case of open water basins, the helicopter approaches at the point of watering on a mid-slope glide. At the moment when the reservoir touches the water surface the forward speed does not exceed 5 km/h and the descent rate is about 0.5 m/s. After that, the pilot decreases the forward speed to zero and continues to decreasing the descent rate until the tank is full, then performs a hovering with a subsequent climb. This method of approach limits the generation of the vortex flow from the main rotor after SFS reservoir touches the water, which greatly facilitates the process and shortens the time of filling the tank with water.

Using the helicopter manoeuvrability higher effectiveness of the firefighting can be achieved while the required flight safety level is ensured.

To increase the fire extinguishing capability, a cycling technology is proposed in the fire area using a pair of helicopters [13]. One helicopter fills the SFS with water from the water basin, while the other delivers water to the site of the fire. The first one is then directed to pour the water on the fire and the second to the water basin.

The poor quality of interaction and coordination between ground and air forces adversely affects the effectiveness by not ensuring that the extinguishing agent is properly disposed of at the designated fire site.

4. Flight experiments

Taking into account the specific features of the Bambi bucket SFS in firefighting process in our country, and in order to increase the efficiency of its use while maintaining a high level of flight safety, flight experiments were conducted. They aim to determine the following parameters at certain flight speeds and altitudes:

- the groundwater concentration discharged from the SFS tank;
- the distribution of the water concentration in the area;
- deviation of the suspension SFS rope.

Table 3 presents theoretically determined data for the width and length of the lanes on which the experiments have been conducted to measure the fallen water from the SFS Bambi bucket. The selected speeds for the experimental study are in the range of 80-120 km/h.

| Speed (km/h) | 80  | 90  | 100 | 120 |
|-------------|-----|-----|-----|-----|
| Time to release the water, s | 4.0 | 3.43 | 3.6 | 3.7 |
| Lane width, m | 8.4 | 8.6 | 9.0 | 9.4 |
| Lane length, m | 89  | 86  | 100 | 123 |
| Rope deviation after release, ° | 52  | 55  | 58  | 60  |

Using calculations based on a mathematical model of the relationship between the specific water consumption, the volume of the ejected from the SFS water and the area of a fire [9], it was determined that by reducing the volume of the water in the tank from 2500 litres to 2000-2200 litres (which is done when extinguishing mountain and forest fires) the extinguishing area can be 60 m² and the radius of the dropped water is 4.5 m at hover mode. Taking these values into account, the time required is 333 s. Fire extinguishing using hovering can only be applied to small fires at an early stage of evolution.

Due to financial constraints, only 2 flight experiments (8 water-release legs) were conducted with a Mi-17 helicopter Bambi bucket. They were held at Krumovo Airport in helicopter hovering areas. The track size is 8m x 80m. On it plastic containers with a radius of 15 cm and a capacity of 12 l to measure the water falling from the SFS were situated. The step between containers is 4 m wide and 5 m in longitudinal direction. Additionally, entry and exit doors (indicated by red flags) are fixed and the flight direction corresponds to 322° (figure 2).
As a result of the conducted study, the concentration of the water fallen into the predetermined ground lane (in l/m²) is measured. The water concentration is highest at a speed $V_f$ of 80 km/h and an altitude $H_f$ of 50 m. The data for it is shown in figure 3. It can be seen that the average amount of fallen water between the thirty and sixty meters is 4.2 l/m². The covered area where the cessation of pyrolysis in hard combustible materials is possible [9, 10] is 240 m². For the complete termination of the fire spread on such an area, it is necessary to consecutively throw water from several helicopters within 5-10 minutes. Three helicopters can be used when the water source is up to 5 km away from the fire. For a distance of 10 km – 4 helicopters may be used.

5. Recommendations for efficiency enhancement
Mountain and forest fires fighting efficiency could be increased if these recommendations are followed:

- aerial intelligence by drones and determining the location and characteristics of the fire, water area and landing sites of helicopters;
- calculation of the fuel charge in advance by the helicopter crew taking into consideration the helicopter load with passengers and cargo and distance to the fire;
- performing a run-over flight to determine the fire characteristics, the location of ground crews and obstacles endangering flight safety in the area;
• accurate assessment of the fire type and selection of proper firefighting tactics by the crew;
• flights at low speed and minimum safe altitude are a prerequisite for delivering more liquid per m²;
• use of chemical additives in the water contributes to a faster extinguishing of the fire or to a greater resistance to the landing lanes;
• use of multiple helicopters for work on a single target together with ground crews is a prerequisite for rapid fire suppression.

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