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The Efficiency of Aerial Firefighting in Varying Flying Conditions

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Abstract—**This paper investigates and describes an aerial firefighting process by the use of helicopters equipped with the Bambi Bucket. An experimental airplane, in the flight simulator of the Mi-17 Moder/Tv-17, was utilized here as one to evaluate the effectiveness of the aerial firefighting process. One of simulator´s modules named „Fire Extinguishing" was used to evaluate dimensions of a terrain covered by an extinguishing substance and also a volume of the extinguishing substance remained on the surface unit which was released from the Bambi Bucket after a helicopter overflight. The experimental flights with variables like helicopter speed and flight height, became the basis for the research of firefighting effectiveness and also a source of various recommendations for daily practice.**

Keywords - firefighting; wildfire; helicopter; flight simulator; the Bambi Bucket

I. INTRODUCTION

Early days of the aerial firefighting start in 1924. This was in Canada, where for the first time in history, a new system of the wildfire alarm service was launched. DHC-2 Beaver airplanes were used to transport necessary material and staff to those remote alarm service sites. And also, very this airplane was used for the first attempts at aerial firefighting or so called water bombing. Various leather bags full of water were dropped off airplanes onto the terrain stroke by fire [1]. Currently, most aerial firefighting services are used in the extinction of fires outside of inhabited areas like forests and grasslands. The reasons why we use aerial firefighting are time pressure and hindered terrain accessibility for any of ground firefighting mechanisms. Aerial technology is predominately used in a direct firefighting, material transport, staff and casualties transport (rope and non-rope procedures; parachute dropping), terrain monitoring and firefighter divisions management too [2-6].

This paper deals with the issue of wildfire aerial firefighting in the Slovak Republic. The paper describes the utilization of large Bambi Bucket water (or other type of fire extinguishers) bags. The bags are mounted on the helicopter´s under-belly devices what allows for water being released directly down onto a fire affected area. Nowadays, in the Slovak Republic, this firefighting process is being served by Mi-17 helicopters, operated by the Slovak Air Force [7] and Mi-171 helicopters, operated by the Ministry of Interior of the Slovak Republic.

Some private operators´ helicopters like Mi-8, Mi-171 and airplanes like Z-37, Z-37T are also used in the aerial firefighting services. A success and effectiveness of such extinguishing depend on many important factors like a type of fire (surface, underground, roots, …), sort, height and the water absorbability of burning vegetation, terrain surface, speed and direction of wind, smoke clouds height and direction, fire brigade experience, firefighting tactics (e.g. height and speed of an overflight) and others. Nevertheless, an environmental protection is very important as well. A choice of effective extinguishing substances with an immediate fire-stopping impact and as little as possible environmental damage, are essential criteria as well [8, 9]. Aforementioned provisions are significant not only for their firefighting efficiency, but also for flight safety, which, of course, is the primary interest of any operator.

The Aviation Fighting Fire Experience are very important part of the Knowledge Alliance of Aviation Education based on the know-how, past and present aviation experience, the results of the theoretical work and the scientific and research activities in the field of :

- Academic subjects,
- Simulation and modelling of Security issues, as in [10],
- Technical Sciences, as in [11],
- Military/Air Force management, education and training etc., as in [12].

The educational resources for more detailed study are available at the university library or on-line open access / e-learning modules, MOOC Massive Open Online Courses. The perspective Expert Database of Civil and Military Aviation Experience is still in progress.

II. METHODS

Flight conditions like the flight height and speed can affect final results of the fire extinction with a use of the Bambi Bucket. The extinction success was evaluated upon an outcome how effectively the fire was put out. The metric unit, for this research, was agreed as a fire spot covered by the extinguishing agent after its releasing from the Bambi Bucket on the burning area during helicopter overflights and the actual amount of the extinguishing agent released onto the defined terrain unit. Those two mentioned coefficients became the basis for a calculation of the fire extinguished area, and formulated in percentage. The flight simulator the Mi-17 Moder/Tv-17

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including its module „Firefighting", were used for these experiments. And also for the purpose of this research, 2000 liters Bambi Bucket filled with water, in this case as the extinguishing agent, was used here. This research, performed a demonstration of a surface fire on 75 meters long quadrate shape and with a pitch of 45° (the overflight was controlled in a diagonal course). Software module for extinguishing provides only this square shape of fire. It is possible to change the shape of the fire only by intervention from the manufacturer of the flight simulator for adequate financial remuneration (for example circle or ellipse). Therefore, the square shape of the fire was chosen for research purposes as fully satisfactory. The center of the fire spot was positioned into the middle of Prešov LZPW military heliport at an altitude of 315 meters above sea level. This fire location had an advantage of easy multiple reposition after each overflight. Also, this positioning guaranteed sufficient number of landing points for pilots and simulator administrators perform flight circuits and as an indicator mark where to initiate the water release from the Bambi Bucket.

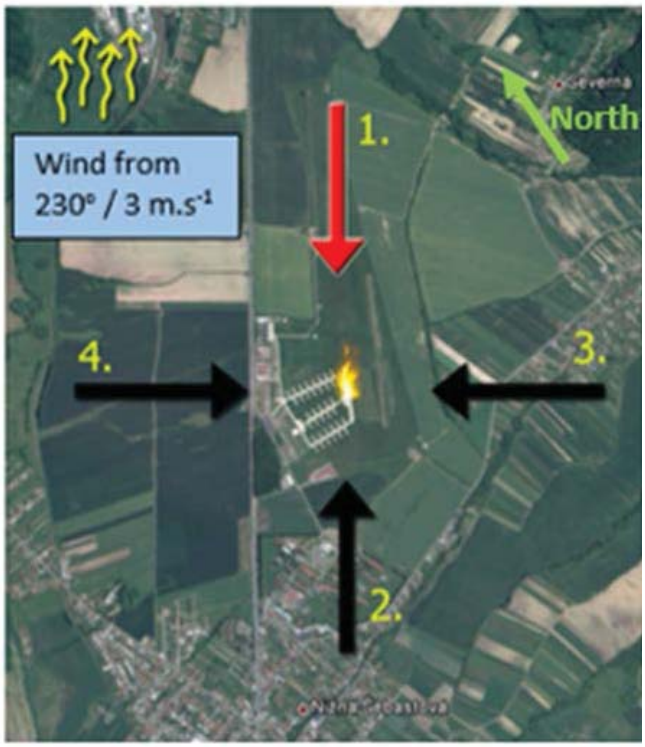

Figure 1. Prešov Airport – The directions of firefighting overflights [Source: Gromovský, P., Mi-17 Moder/TV-17, flight simulator maps]

A pilot set 230° flight angle and the helicopters´s course against the wind upon approaching to the fire spot. You see the flight courses number 2, 3 and 4 in Fig. 1 which are discussed further in the chapter „Discussion". The initial point of water release was defined as an experimental one only and always allocated during the test helicopter approaching by the speed of 50, 60, 80 and 100 km.h^{-1}. There was a specific requirement on the initial point of water release, the point must have been situated in front of the the boarders of the fire spot. This limit led to the provision that the water flow must have copied the ballistic curve as a result of helicopter horizontal velocity. The horizontal speed always equaled to the helicopter speed. Single helicopter operations were performed as circles. The Bambi Bucket was water filled when the flight was performed in the wind direction. The flight course used to be adapted to a required level. Then followed by 180° turn maneuver, this time against the wind, and the helicopter flew into the center of the fire spot. Finally, the pilot modified the flight speed and released water as soon as reached allocated the water release initial point. After the water had been released the pilot performed a turn of 180° and the whole experiment lapse was repeated, but in this case the flight altitude and helicopter speed were modified. The extinguishing process was carried out from the heights of 60, 90 and 120 meters over the terrain. Three flights, all in the speed of 50, 60, 80 and 100 km.h^{-1} were performed in each agreed height. It means that there were 36 flights performed in total. The flight height and speed were decided by the pilots, according their practical aerial firefighting experiences [13, 14]. Within this framework, the water feature has also been taken into account, which with its increasing dropout rate and with the increasing speed of the flight, changes its state from the liquid to the fine water nebula. As a consequence, the impact on the fire will lose its sequential extinguishing effect. The lower the water drain height and the flight speed, the greater the water's extinguishing effect.

Figure 2. Administrator´s and pilot´s view on a firefighting overflight in the simulator environment. [Source: Gromovský, P. – Mi-17 Moder/Tv-17]

III. RESULTS

The rate of successful attacks of fire extinguishing was defined in percent for every single flight (at a defined flight height and speed). The results are summarized in Tab. I. Following the recorded data, we see that the defined height and speed of a flight proved 35 % of fire put out as the most successful rate and this was achieved by the flying speed of 50 km.h^{-1} and in the height of 60 meters over the wildfire spot. Following the records, the flying speed of 100 km.h^{-1} and in the height of 120 meters over the spot proved that only 20 % of burning field was put out, and also this rate was found as the most unsuccessful.

TABLE I. EFFICIENCY OF AERIAL FIREFIGHTING [%] VS. FLYING HEIGHT AND SPEED

Flying conditions	Height 60 meters	Height 80 meters	Height 120 meters
speed 50 km.h^{-1}			
overflight 1	35	27	26
overflight 2	35	27	26
overflight 3	34	24	24
speed 60 km.h^{-1}			
overflight 1	32	30	26
overflight 2	32	30	24
overflight 3	33	29	24
speed 80 km.h^{-1}			
overflight 1	31	28	23
overflight 2	30	26	24
overflight 3	29	27	21
speed 100 km.h^{-1}			
overflight 1	30	29	20
overflight 2	29	28	22
overflight 3	29	29	20

IV. DISCUSSION

The term of Fire Extinguishing Effectiveness, specifically for this experiment, was defined as a surface of the wildfire terrain covered by the extinguishing agent after being released from the Bambi Bucket during helicopter flight over, to a volume of the extinguishing agent practically reached the defined terrain unit.

A. REVIEW OF THE FLIGHT SPEED

2000 liters of water can drain off the Bambi Bucket approximately in 5 seconds ± 0,5 seconds. By the flight speed of 50 km.h^{-1}, the helicopter can fly the distance of 70 meters in 5 seconds. By the flight speed of 60 km.h^{-1}, the helicopter can fly the distance of 83 meters. By the flight speed of 80 km.h^{-1}, the helicopter can fly the distance of 111 meters and finally by the speed of 100 km.h^{-1}, the helicopter can fly the distance of 139 meters. Our fire spot was designed in a quadrate shape, with 75 meters long sides and diagonal of 105 meters long. The flights were performed copying the diagonal indicator of the quadrant. We explored results that all released water volumes hit the target by the speed ranges from 50 to 60 km.h^{-1}. But the operation performed by the speed ranges from 80 to 100 km.h^{-1} proved, that some water volume must have missed the fire spot. The higher helicopter speed used for the operations, the more mistakes occurred to keep the flight course into the center of the fire spot (a pilot disposes with less time to make flight adjustments and also with less time to allocate the assigned initial point of the water release). The lower speed helicopters fly, the bigger volume of water can attack the terrain affected. The research proved that the most optimal flight speed for the helicopter Mi-17 used for firefighting with installed the Bambi Bucket is 50 km.h^{-1}. On the other hand, low speed flights require more effort from a pilot to control the whole helicopter. It could be alleged that a wildfire spot over 100 meters, allows for higher speed for helicopters during the firefighting process, and also this fact contributes to acceptable helicopter control.

B. REVIEW OF THE FLIGHT HEIGHT

The flight height of the helicopters using the Bambi Bucket mainly effects an allocation of the initial point of the water release and accuracy of the overflight onto this point. The higher height helicopter flies, the accuracy of the initial point allocation becomes more difficult, and certainly, lower heights are easier to allocate such point. Following the research achieved results, the most effective extinguishing performance arrived when the helicopter flew in the height of 60 meters, but the terrain specifications and meteorological conditions must be observed here as well. A flat terrain allows for the firefighting helicopter fly in lower heights. But it is always very important to secure a minimum safe distance between the Bambi Bucket and a terrain. It is recommended for helicopters flying in low speed to keep the distance about 10 meters between the water bag and the terrain. In the case of operations above a broken terrain, it is also recommended to safe some extra meters for extraordinary events which might occur during operations (engine failure, engine depression, opposite wind, and etc.).

C. REVIEW OF OVERFLIGHTS DIRECTION

Upon the firefighting flight course planning, a few parameters must be considered, like a terrain relief, vertical and horizontal wind and smoke direction over the spot. It is recommended for helicopters not to fly into high smoke density areas because higher air temperatures (lower air density) might significantly affect the helicopter engines run. Smoke is characteristic for a low air oxygen and this can result in negative engines run too. The radiating heat from a terrain seems to be the most dangerous one for helicopters. This heat can produce a high temperate without any visible smoke. In case a helicopter operates under these conditions, here again, it is recommended to avoid a tail wind and low flying height.

A decision about a flight course could be limited by the wind direction during the firefighting actions onto a small spot fire and small flat terrain fire (our test fire spot was of 75x75 meters as demonstrated in Fig. 1), and also it is determined by the smoke dispersion over the terrain.

In case the smoke does not ascend to the altitude of the safe distance between the Bambi Bucket and the terrain, then it is recommended, as the most beneficial, to perform flights straight against the wind (Fig. 1, the flight course number 1). It is very contributing for helicopter´s performance to fly against the wind. In this case helicopter speed is reduced by the opposite wind (this has a favorable effect for an allocation of the water release initial point) and a pilot need not consider any side wind.

In case of the presence of a smoke in the flight level appropriate for firefighting and in a combination with the tail wind, it is recommended to perform side overflights onto the spot. Considering helicopter main rotor rotation and positioning of the tail rotor, it is recommended to control the helicopter in the left side wind mode (illustrated in Fig. 1, the Overflight number 4). The side wind helicopter operations mean for a pilot to put an extra effort for eliminating this side wind and thus the helicopter control is more challenging.

On the other hand, helicopter firefighting in the wind direction or tail wind (illustrated in Fig. 1, the Overflight number 2) is inconvenient due increased helicopter speed against the terrain (there is a risk to miss the initial point of water release) and subsequently fly into the smoked area It is also disadvantageous due to reduced performance and difficult flight control.

Side wind and right side wind helicopter operations (illustrated in Fig. 1, Overflight number 3) are inconvenient for helicopters Mi-17 (Mi-8, Mi-171) due reduced performance and difficult flight control.

V. CONCLUSION

For safe and satisfactory operations of the helicopter Mi-17 (Mi-8, Mi-171) with installed the Bambi Buckets used for firefighting, we must adapt flight direction, flight height and flight speed to the terrain characteristics, meteorological conditions (wind speed and direction, wind gust, ascending and descending air blasts, altitude and outside air temperatures) and horizontal and vertical smoke expansion out of the fire spot.

Figure 3. Mi-17 helicopter with the Bambi Buckets, operated by the Slovak Air Force [Source: Gromovský, P.]

The successful helicopter firefighting operations could be achieved by flying slow speed and at low heights. The experimental flying in the simulator environment brought out some basic recommendations for the helicopter Mi-17 (Mi-8, Mi-171) with installed the Bambi Buckets. In case the terrain surface and meteorological conditions allow, the helicopter should perform the firefighting flight against the wind or left side wind and by speed ranges from 50 to 60 $km.h^{-1}$ and at the height of 60 meters over the fire spot. In case there are some terrain obstacles in the surrounding area and the flight cannot be performed at the height of 60 meters, it is recommended to ascend to the height maximum of 120 meters over the terrain and remain with flight speed ranges from 50 to 60 $km.h^{-1}$ (The flight speed could be modified to the range from 80 to 100 $km.h^{-1}$ for firefighting a very extensive wildfire). A final decision about the methods of helicopter firefighting processes with installed the Bambi Buckets lies with a pilot, who is actually responsible for the flight safety too. That should be very beneficial to train pilot operations in a rugged terrain simulation and severe meteorological conditions. Nevertheless, the simulations of flight course modifications, height and speed changes will be a big value for future pilots too.

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