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SPECIFIC RISKS OF HELICOPTER AERIAL WORKS AND THEIR ELIMINATION

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Abstract

Safety is the highest priority in all aspects of air transportation. This paper is focused on different hazards and risks that might be encountered by helicopters during different types of aerial works and offers ways to mitigate those risks. The introductory part lists companies who are currently licensed for helicopter aerial work in Slovakia and outlines different types of aerial works. The methodology process describes four steps, which are then executed in the central part of the paper. The main part was written as a result of combining two different approaches to hazard identification – reactive and proactive – which encompassed studying and analyzing reports from helicopter accidents and incidents, as well as brainstorming techniques with assistance from aviation professionals. The results provide different mitigating techniques to lower assessed risks to tolerable values, along with alternative proposals of risk mitigation to air operators

Keywords

safety, aerial works, helicopters, hazards, risks

1. INTRODUCTION

Helicopter aerial work is a process that possesses high risk due to its specific operating conditions. When combining complicated technology and a challenging task in a limited space, many situations arise that may have negative consequences. When performing aerial work, the specified minimum flight altitudes are often exceeded, as well as the safety distances from obstacles are reduced. The helicopter can often be in a dangerous situation and the ground staff is also exposed to various risks when handling the cargo, for example. The execution of such activities requires professional guidance and management of all persons involved in the process. This type of work can only be carried out safely through a thorough risk assessment, complete use of all risk mitigating options, careful selection of suitable work materials and staff, as well as extensive training of staff.

2. THEORETICAL INFORMATION

Currently, there are six companies that hold the license to operate helicopters for specialized activities (SPO) in Slovakia. The companies are:

- HELI COMPANY, s.r.o.
- Aerial East, s.r.o.
- AIR – TRANSPORT EUROPE
- AVE Fermo, s.r.o.
- TECH-MONT Helicopter company, s.r.o.
- UTair Europe, s.r.o. [1]

2.1. Aerial work

The Aviation Act of Slovak Republic (Act No. 143/1998 Coll.) defines aerial work as follows: "Aerial work are paid aviation activities performed in agriculture, forest industry and water management, construction, healthcare, advertising, photography, patrol, sightseeing flights and similar activities" [2]. The aircraft is usually specially equipped and the crew on board is familiar with the risks associated with the work.

2.1.1. Aerial advertising

Aerial advertising can be defined as operation of an aircraft for the purposes of displaying advertisements in the sky, pulling banners, displaying aeronautical signs, dropping leaflets, or making announcements from the aircraft.

2.1.2. Aerial construction activities

Helicopters are often used in the construction of masts, power lines or cableways in an inaccessible terrain, but also to increase the efficiency and safety of work performed at heights. They are also often used in densely populated areas, where it is often impossible to use cranes. Helicopters are used to transport parts of equipment, concrete, or other building materials. Other aeronautical construction activities include construction of power lines and telecommunication towers or masts. The advantage here is the process of cargo transportation, which is attached to the helicopter by an external load device, which practically does not limit the dimensions of the cargo. However, the limiting factor here is the weight of the cargo, which depends on the type of helicopter used.

2.1.3. Aerial firefighting

Airplanes and helicopters are an integral part of forest firefighting and often must be operated at low altitudes in a dangerous environment. They are often used to deliver

emergency equipment and supplies to hard-to-reach and dangerous places where they can apply fire suppressants quickly and effectively. Management of the forest fire extinguishing process includes operation of aircraft for fire detection and control purposes, as well as the discharge of a specific substances intended for firefighting and fire prevention. The process also includes transporting firefighters to fire affected areas. Helicopters have a certain advantage in such activities because they can fly at low speeds, require a relatively small take-off / landing area, and can quickly turn.

2.1.4. Aerial frost protection

Helicopters are also used in orchards, whereby creating air turbulence, warm air is being moved to a cooler surface, therefore protecting the fruit from frost and consequent damage. The optimal flight altitude for this job is very low, often under 100 feet with a flight speed of 8 to 40 km/h. The flights only stop when the air temperature rises above the critical temperature for the possible crop damage [3]. Helicopters are also used to dry cherries after storms, often being the fastest and the most effective way to save crops. Helicopter flies just above the treetops and creates turbulence that blows most of the rainwater away.

2.1.5. Aerial photography and filming

Aerial photography is operation of aircraft for the purpose of photographing or recording information using a camera or other measuring and recording equipment. Currently, aerial photography or filming can be performed from any flying device, from hot air balloons to fighter jets. However, helicopters are the most practical platform used by aerial photographers. The advantage over airplanes is the ability to fly with removed doors, so that the windscreens or parts of the wing do not interfere with the view. Other advantages include the ability of a slow flight and good maneuverability.

2.1.6. Aerial survey

Aerial survey can be defined as the operation of aircraft for the purpose of conducting aerial observations of objects and phenomena, wildlife, or other observations, as well as for the purpose of examining objects and phenomena by means of a camera or other measuring and recording devices. In agriculture, helicopters are used to monitor crops and survey livestock over large areas.

2.1.7. Aerial transport of external cargo

Wood is among the most frequently transported cargo by helicopter, mostly collected from hard-to-reach areas. Helicopters are also used to transport various types of materials, such as construction or assembly material. Other operational helicopter uses include supplying areas otherwise inaccessible or transporting large equipment, such as air conditioning, to the roofs of tall buildings.

2.1.8. Adventure flights and flights at air shows

Adventure or experience flights can be defined as operation of an aircraft for the purpose of providing passenger recreation. Flights usually start and end at the same airport. Air show flight means any flight activity intentionally performed for demonstration purposes or as an entertainment program for an air show or other public aviation event. Training demonstration flights and flights to and from the air show can also be considered as air show flights.

2.1.9. Agricultural flights

The use of aircraft in agriculture is mainly for treating crops against pests by releasing insecticides and other chemicals. Aerial spraying can be defined as the operation of aircraft to disperse products in agriculture, horticulture, forestry or in protection of public health. Aerial spraying activities are carried out by aircraft equipped with tanks for liquids or solids, which are discharged at low altitudes to ensure their optimal application.

2.1.10. Forest liming

Helicopters are the preferred means to use when liming forests due to its maneuverability, low flight speed and the ability of placing the limestone used for the operation directly in the desired location, as opposed to the airport. Special containers with a device that regulates the amount of applied lime are often used.

2.1.11. Patrol flights

Police support from the air plays a key role in tackling crime and protecting the public in the search for suspects or missing persons, giving support to law enforcement, surveying dangerous situations, or assisting in a vehicle chase. The advantage of helicopter use for patrol flights is the speed of search in large areas and reduction of the risk to the ground forces. Helicopter intelligence flights also provide information to the public in dangerous situations through real-time aerial shots when remote and hard-to-reach places can be reached quickly.

2.1.12. Power line / pipeline inspection flights

Inspections performed by helicopters usually include inspections of transit pipeline, inspection of oil pipeline system, protection zones, detection of possible leaks, and monitoring the condition and safety of the system. In addition, inspections of high voltage power lines are often performed by helicopters as well.

2.1.13. Rescue flights

This type of operation is mainly intended for the evacuation of people or animals from areas that are difficult to reach by land. Other irreplaceable services provided by helicopters are assistance in traffic accidents or mass accidents, provision of first aid in remote areas, transport of critically ill patients to hospitals, or transport of medical supplies.

3. METHODOLOGY

To ensure safety in the performance of any aerial work, it is necessary to assess the risks through the process of hazard identification and risk evaluation. To examine this process in detail, the methodology has been divided into four steps:

3.1. Definition of analysis process focus

In the first step, we determine on which area the risk analysis should focus on. In case of companies that operate helicopters, this may involve a risk assessment in terms of:

- risks related to workplace,
- risks related to persons,
- risks related to the area of operation, or
- risks related to the activity performed.

In the administrative or maintenance part of the helicopter operating company, we can talk about assessment of risks related to the workplace, i.e., specifically with the place where these administrative or maintenance activities are performed. In the operations department we talk mostly about the risks directly related to the activity performed, whether it is the performance of commercial air transport or aerial work. The objective and scope of the risk assessment process should also consider internal and external factors that affect safety of the performed activity.

3.2. Identification of hazards and risks

Hazard is a condition that can potentially cause damage or injury. Risk is defined as the possible outcome of a hazard, expressed by its probability and severity of consequences. However, the probability of risk occurrence is irrelevant in the identification phase; if there is even a small chance that a risk may appear, we must include it. Risks that may arise can be taken from many sources including reports, inspections, audits, brainstorming sessions, or expert reviews [4]. The aim is to identify hazards before accidents, incidents or other safety-threatening events occur. Furthermore, risks can be identified by studying investigation reports from accidents or incidents that happened to operators in the area. This method will be the main risk identification method used in this paper, which will be complemented by a brainstorming session and an external information research, sourced mainly from internet and aviation professionals.

3.3. Risk assessment

It is necessary to evaluate the risk to be able to identify appropriate corrective measures to increase occupational safety. The two main factors in assessing risks are the probability of their occurrence and the estimated extent of damage caused. The factors defining the probability of damage are:

- duration and frequency of exposure,
- probability of event occurrence,
- options to prevent or limit damage.

Regarding the extent of the damage, we can distinguish between minor and severe injuries, permanent health consequences, and even the death of persons. Estimating, or evaluating existing risk is a very subjective process. A decision process should be used for a proper evaluation. Companies operating in Slovakia are obliged to use the tables provided by the Transport Authority, which are specially adapted to a specific operator. The values of financial losses are determined according to the type of aircraft operated by the company. When assessing risks by their severity, it should be assessed by taking the worst-case scenario of the event into account. The severity of risk is determined according to the following table:

TABLE I. RISK SEVERITY ASSESSMENT

Severity	Persons	Environment	Material value and assets	Reputation	Value
Catastrophic	More casualties	Massive negative effects, pollution	Huge financial losses, >50,000€	International impact	**5**
Hazardous	Casualties	Effects are difficult to remove	Large financial losses, <50,000€	National impact	**4**
Major	Major injuries	Significant local negative effects	Significant financial losses, <20,000€	Major impact	**3**
Minor	Minor injuries	Small negative effects	Large financial losses with small damage, >1,000€	Limited impact	**2**
Negligible	Superficial to no injuries	Negligible or no negative effects	Financial losses with negligible effects, <1,000€	Little to no impact	**1**

To determine the probability of a risk, we should ask: "what is the probability that a risk will occur?" In addition to the probability, we can also talk about the number of situations where which the event occurred in the past. The risk probability is determined according to the following table:

TABLE II. RISK PROBABILITY ASSESSMENT

Probability	Definition	Value
Frequent	This accident happens, such an event has already occurred in the company, it often occurs in the history of aviation.	**5**
Occasional	Sometimes this accident can occur. It already happened in society.	**4**
Remote	Unlikely, but possible. The event is rare in history.	**3**
Improbable	Very unlikely, but it has already occurred in the history of aviation.	**2**
Extremely improbable	Extremely unlikely, almost unthinkable. Such an event has never occurred before.	**1**

Existing protective measures are always considered when determining the probability and severity of a risk. After defining the severity and probability of risks, the company compiles a safety risk assessment matrix, which allows it to assess tolerability of the risks. Risks can be assigned into one of three categories:

- intolerable – if the risk is assessed as intolerable, the company's activities should be stopped immediately, and the operation should not continue until significant risk mitigation measures have been taken to minimize the risks as much as possible;
- tolerable – additional risk mitigation measures should be taken to lower the risk, while monitoring the severity and likelihood of their occurrence. However, if, even after these measures have been taken, the risk cannot be reduced to an acceptable level (e.g., due to high financial costs), the operation may be carried out after management approval;

- acceptable – in this case, the adverse consequences of the risk are not serious / unlikely to occur; there is no need to further reduce the risk. [4]

Based on the values in Tables 1 and 2 and their subsequent multiplication, the risk acceptance value is determined (see Table 3). An unacceptable level of risk is shown in red, an acceptable level in yellow and an acceptable level of risk is shown in green.

TABLE III. SAFETY RISK MATRIX

Risk probability	**Risk severity**				
	Catastrophic 5	Hazardous 4	Major 3	Minor 2	Negligible 1
Frequent 5	25	20	15	10	5
Occasional 4	20	16	12	8	4
Remote 3	15	12	9	6	3
mprobable 2	10	8	6	4	2
Extremely improbable 1	5	4	3	2	1

3.4. Specification of protective measures

The fourth step is a selection of measures to protect safety in aerial work operations after previous risk assessment. Economic aspects often play a key role in the selection of appropriate measures. Expensive investments can ultimately bring benefits, whether from an economic or safety point of view. In such cases it is necessary not only to look at the amount of the initial investment, but also at its effects spread over time. Another important aspect is the time aspect – how long it will take to implement the corrective action. The third aspect is the effectiveness or practicality of applied measures, how much the measures will reduce the risk and whether it is practical given the available technology, state legislation or the administrative and financial capabilities of the company. Another aspect of choosing the correct protective actions may be the enforceability of the measures and the ability of employees to accept and implement them. Lastly, possible additional security issues the measures may bring must also be considered. It is necessary that any measures taken and their effectiveness are subsequently verified.

4. RISK ANALYSIS

4.1. Hazard identification and risk specification

In aviation, hazard can be considered as a hidden possibility of damage / injury / loss of life that occurs in some form in the system or in the external environment. This possibility of damage can take various forms, such as natural or technical hazards. Hazards are part of all aviation activities, but their effects and possible consequences can be reduced through mitigation measures. In aviation, assessed potential for adverse consequences resulting from a hazard is called risk. The aim of mitigation measures is to reduce the likelihood that the hazard will result in a dangerous situation. Identifying these hazards is the first step in the safety risk management process. According to the ICAO Safety Management Manual, there are two main methods to identify hazards. These focus on the past – a reactive method that analyzes past accidents and serious incidents; and present – a proactive method that uses analysis of less dangerous situations and their frequency and determines whether hazard could lead to an accident. The manual also mentions a third method – predictive. [4]

The first step in obtaining safety information will be the use a reactive method of hazard identification. As an external source, we will use reports from accidents and serious incidents that occurred during helicopter operation in Slovakia and the Czech Republic. At the time of writing, final reports from 2009 to 2020 were available on the website of the Ministry of Transport and Construction of the Slovak Republic. According to the website of the Air Accidents Investigation Institute of Czech Republic, 38 accidents / serious incidents occurred from 2003 to 2021.

For the purposes of reactive hazard identification, general aviation flights were not included in the further investigation as these flights do not fall under companies subject to strict safety regulations. Another group excluded from the survey are training flights, thus giving us fourteen final reports to use for hazard and risk factor identification. To avoid the assumption of relationships between individual factors, we will not use the term "cause" of the accident.

Based on the conclusions of the accident / serious incident report analysis, hazards in Table 4 were identified, which can be divided into five groups. These groups are hazards associated with 1) pilots, such as insufficient experience or risky behavior, 2) technology, 3) work performed, 4) regulatory framework, which are external factors affecting the company, and 5) situational circumstances, such as weather or type of operation [5]. Some reports in the conclusions mentioned several factors contributing to the accident. The resulting factors were simplified and assigned to the appropriate subgroups after classification.

TABLE IV. RISK FACTORS FOUND IN ACCIDENT REPORTS

Hazard groups	**Risk factors**	**Number**
Human factors	Risky behaviors	2
	Violation of procedures	3
	Continuation of the task despite unfavorable conditions	1
	Lack of experience	4
Technology	Insufficient engine power under the circumstances	1
	Technical failure	4
	Specific helicopter behavior in certain flight modes	1
Performed work	Insufficient risk analysis	2
	Insufficient procedures	4
	Insufficient training	2
Regulatory framework	Insufficient rules	1
	Missing elements in helicopter pilot training	1
Situational factors	Low altitude	2
	Meteorological conditions	8
	Challenging terrain	5
	Errors of other persons involved	2
	Insufficient marking of obstacles	1

According to table 4, adverse meteorological conditions were the most frequently mentioned risk factor in the conclusions of the investigation reports, particularly reduced visibility due to fog, nighttime, turbulence or blinding by the setting sun. The second most common factor was operation in difficult mountain terrain. Furthermore, factors such as lack of pilot experience, technical failure of the helicopter or insufficient operational or

emergency procedures for the performed activity were often mentioned.

Based on the analysis of the above-mentioned accidents and incidents, following risks occurred during the execution of aerial work, helicopter rescue services and commercial air transport, which are later used in determining the specific risks for each type of aerial work:

- Transport of external cargo – steel rope contact with tail rotor, dropping of a foreign object from the cargo, destruction of the load during transport due to rotation and inadequate securing of the load.
- Photo flights – inappropriate management interventions, risk-taking in order to achieve the required photograph, technical failure over a built-up area, inability to reach emergency landing area.
- Measuring flights with an extended probe – contact of the probe with trees in a mountainous terrain, prescribed obstacle clearance exceeded.
- Adventure flights – technical failure during operation in difficult mountain terrain, inability of the pilot to respond to helicopter behavior in a specific flight mode.
- Pipeline inspection – pilot overload, forgetting to turn on carburetor heat resulting in engine failure.
- Rescue flights – sudden deterioration of meteorological conditions, blinding by the setting sun, contact with overhead power lines, contact with trees in mountainous terrain at night, continuing the mission despite deteriorating visibility conditions.

We can then divide the above-mentioned risks into risks that may be present in all types of aerial work and risks that are specific to individual tasks. General risks include a sudden deterioration of meteorological conditions, engine failure, or insufficient ability of the pilot to respond to an abnormal situation resulting from insufficient training or experience. This paper will only focus on risks we consider specific to each task.

The second way to identify risks is a proactive method. It focuses on potentially dangerous situations, which are identified, and based on them risks are assumed. One of the common ways is a brainstorming session and use of information from external sources, such as similarly oriented organizations, professional media, or aviation authorities. General data obtained from Heli Company, s.r.o. were used, which were expanded over a period of several weeks with risks obtained from brainstorming and professional literature. As a result of these activities, risks were defined, which are assessed later in this paper.

4.2. Risk analysis

For the purposes of this paper, only selected aerial works are evaluated.

4.2.1. Pipeline inspection flights

Helicopters are used primarily for visual inspections of large pipeline systems, identifying leaks and any interventions that threaten reliability of the distribution system. In some countries, aircraft sensors are being developed to identify leaks that cannot be found by visual inspections. To perform these tasks safely and efficiently, the crew should be composed of a pilot and an observer. The helicopter performing the patrols is operated in an environment full of obstacles and at low altitudes, which significantly increases the possibility of collision with the distribution system or terrain. At the low speed and altitude of the flight, it is necessary for the pilot and crew to be extremely focused, maintaining situational awareness, having knowledge of the area of operation, maintaining effective communication, and having established clear roles and responsibilities of individual members.

Based on the previous methods, risks have been identified, which are assessed in terms of their acceptability in Table 5. Mitigation measures are proposed in Chapter 4 of this paper, along with tables containing original and adjusted risk assessment values.

The FAA website was used to search for aviation incidents to determine the likelihood of their occurrence, which allows to search through the NTSB accident and incident report database. The database was used mainly due to a huge number of aviation accidents related to aerial work in the US and abroad, which gives us a more objective view of the occurrence of individual risks. The NTSB database contained 17 reports of accidents and incidents during pipeline inspections from 1984 to 2018 [6]. Degradation of helicopter performance was mentioned in seven cases. Incomplete planning, pilot occupancy or technical problems occurred in six reports. Entering an area of bad weather was mentioned in five reports, with weather information missing in three cases. Violation of the safety distance from obstacles and subsequent collision with the obstacle occurred in three cases and unintentional deviation from the planned route in one case.

4.2.2. High voltage power line inspection flights

Helicopter power line inspections provide an effective way of visually inspecting the structure of electrical networks, conductors and identifying elements that pose a threat to the reliability of the electrical systems. Together with pipeline inspections, when performing the task, the aircraft flies through a hazardous environment full of obstacles, which greatly increases possible collision with infrastructure or terrain. This type of aerial work also requires a crew of at least two people – an observer and a pilot – to perform the task in an efficient and safe manner. To reduce the risk of a collision, crew must identify potential hazards and take corrective action well in advance. Failing to do so, the pilot can only take very limited measures to avoid collision due to a very close distance to obstacles.

Risks have been identified and are assessed in Table 6. The main way to prevent a helicopter from colliding with power lines is crew understanding and knowledge of the characteristics of the system. This gives crew members an opportunity to anticipate locations of overhead lines, thus avoiding complete reliance on visual contact only. However, despite familiarizing themselves with the system, it is important for crew to remain vigilant throughout the mission.

The NTSB database contained 18 reports from 1983 to 2015 concerning power line inspections. Degradation of the helicopter's performance was mentioned in nine cases, mainly

due to improper maintenance, failure, fatigue of the helicopter's main and tail rotor systems, weather, or pilot human factor. Collision with an obstacle (especially with wires, poles, trees, or terrain) was mentioned eight times, which was caused by disorientation, insufficient training, technical failure, turbulence, pilot's reduced attention or a flight into unsuitable weather. Unfamiliarity with power line systems was mentioned five times, which was caused by poor planning, incorrect distance estimation or pilot inexperience. Lastly, emergency landing into terrain occurred in four reports.

4.2.3. Aerial transport of external cargo

Various types of external cargo can be transported by helicopter, anything from building materials to harvested wood from forests. Helicopter logging is a method of removing felled and uprooted trees by helicopter. This external freight transport is a complex activity in which many events take place simultaneously or in quick succession. To ensure the safety of all involved and the efficient operation, it is necessary that all staff are well acquainted with the task, effective coordination of all activities and appropriate planning are in place.

The following risks have been identified when using helicopters in the forest industry:

- downwash / vertical airflow from the rotor can cause weak or damaged trees and other debris to fall and can create dusty conditions that reduce visibility for both ground staff and the pilot,
- transported material may come loose and fall to the ground if it is not properly secured. This may endanger people under the helicopter's flight path, or in the event of material falling and getting stuck on trees, it can become hazardous for people who will be in the area in the future.

The NTSB database contained 79 accidents and incidents that occurred during logging operations from 1983 to 2019. A technical failure resulting from insufficient maintenance or material fatigue and the subsequent forced landing in unsuitable terrain occurred in half of the cases. Inaccurate fuel calculations and insufficient flight preparation occurred in eight cases. Human factor such as inattention, mismanagement, or misestimation of obstacle location occurred in fifteen cases. Load and obstacle collision was identified in thirteen cases and disconnection of the rope / load dropping occurred three times. Third-party errors were mentioned three times and downwash and its consequences occurred in one report.

In addition, there were 31 accident reports from construction and assembly flights during 1983 and 2020 and 15 reports for flights with other external loads (1992-2020). The most common was a forced landing in unsuitable terrain, which was mainly caused by technological or human factor failure. The second most frequently mentioned risk factor was collision of the load-bearing rope / load with an obstacle, resp. fall of the burden. Other frequent risks included insufficient fixation or uncontrolled rotation of the load, falling parts or collision of the tow rope with tail rotor. Risks that have been identified are summarized in Table 7.

4.2.4. Photographic and film flights

According to NTSB reports, from 1988 to 2018, 27 accidents or incidents occurred during photographic or film flights. The most common factor in the accidents was the pilot's risky behavior to achieve the desired shot, whether by flying near the photographed objects, putting the helicopter in an inappropriate flight mode, or continuing the flight despite adverse weather conditions. Flights in excessive proximity to terrain, whether mountains or water, and resulting risks occurred as the second most frequent accident contributing factor. Improper arrangement of objects in the cabin, exceeding the weight and balance limits, or even accidentally dropping passengers during open door flights occurred in five cases. Landings in unsuitable terrain or forced landings in populated areas were mentioned four times. The risks are assessed in table 8.

4.2.5. Adventure flights

Adventure flights have recently become a popular activity offered on the internet. Offers include sightseeing flights, aerobatic flights or even offers for enthusiasts to try piloting the aircraft. The passenger is usually a layman who may have never experienced the forces of helicopter flight or has never flown even in an airliner. The passenger is also not subject to medical examination, which may result in the various risks listed in Table 9. 107 accidents and incidents from 1983 to 2021 related to adventure flights were found in the NTSB database. The most common risk factor was pilot's risky behavior to meet the often-inappropriate requirements of passengers. This usually involved flying outside the helicopter's flight envelope at a low altitude and near terrain or doing abrupt maneuvers. In several cases, kinetosis (motion sickness) also occurred in the pilots, which had serious consequences in two cases. Unintentional interference with controls by an unqualified passenger during difficult maneuvers may have catastrophic consequences, especially in cases when the pilot is unaware of such situation. However, none of the 107 accidents mentioned such event, so we can assess the probability of occurrence as unlikely.

4.2.6. Helicopter firefighting

Helicopters are mainly used to extinguish fires in inaccessible mountain and forest terrain, which poses many risks. Between 1996 and 2021, the NTSB database contained 39 reports of accidents and incidents that occurred during flights with a bambi bucket, which is used to bring water to the affected areas. According to the reports, the most common risk factor was a technical failure, which was caused not only by improper maintenance by corrosion or material fatigue, but also by the bag or helicopter colliding with trees, suction of tree parts and other foreign objects into the engine, failure of bucket rope system or tangling of rope to the undercarriage, which shifted the helicopter's center of gravity outside of set limits. Encounter with the water surface when filling the bucket was also mentioned, or a technical failure directly above the water surface. It is necessary to operate the helicopter with an external load within the permitted weight and balance values, considering the meteorological conditions in the area. The pilot must also not forget to maintain the safety distance of the main or tail rotor from obstacles in densely forested areas when trying to correctly place the water bucket between the trees. Reduced visibility due to smoke and consequent loss of spatial

orientation was a factor in ten cases, and the impact of high temperatures on the helicopter's performance was mentioned in 5 reports. Assessed risks can be found in Table 10.

5. MITIGATION MEASURES PROPOSAL

Risk mitigation measures are actions or changes, for example in the organization's operating procedures, equipment or infrastructure that reduce the likelihood and / or severity of the risk.

5.1. Pipeline inspection

In an event of time-related stress during pre-flight preparation and possible incomplete planning, the operator shall ensure that crew has sufficient time for pre-flight preparation. The operator shall ensure that no task is scheduled in which the maximum total mass of the helicopter is exceeded in relation to the altitude density at the mission location.

Pilot busy with other tasks, distracted from proper operation of the helicopter – the proposed measure is to assign a multi-member crew to the task, so that the pilot can focus on the proper operation of the helicopter.

Technical problems – the pilot will ensure that all maintenance irregularities are corrected before the flight and that the helicopter is airworthy. In a case of non-functional equipment, check that it is not included in the approved minimum equipment list.

Degradation of helicopter performance, failure to ensure adequate power reserve, loss of control – to avoid failure to ensure adequate power reserve due to lack of pilot's attention, a multi-member crew assigned to the task should reduce this probability. Should performance degradation occur due to a sudden change in wind speed or direction, it is necessary to define the necessary power reserves for operators in different weather conditions. Operations should stop when wind gusts exceed the specified limit, or at lower values at pilot discretion. It is necessary to create a company environment in which pilots would not be afraid to end the task prematurely in the interest of safety. The customer must also be familiar with and understand the importance of maintaining safety.

Unintentional flight into bad weather – operation should cease when the cloud ceiling or visibility values are below the minimum specified values for the pilot performing the task, helicopter, or the company. To reduce the likelihood of terrain collision after entering IMC conditions, the company should consider installing radio altimeters to helicopters.

TABLE V. RESIDUAL RISK LEVEL DURING PIPELINE INSPECTIONS

Risk	Probability	Severity	Risk level	Adjusted probability	Severity	Residual risk level
Time stress, incomplete planning	Occasional	Hazardous	Intolerable	Remote	Hazardous	Tolerable
Pilot distracted from proper operation of helicopter	Occasional	Hazardous	Intolerable	Unlikely	Hazardous	Tolerable
Technical issues	Remote	Catastrophic	Intolerable	Unlikely	Catastrophic	Tolerable
Degradation of helicopter performance	Occasional	Catastrophic	Intolerable	Unlikely	Catastrophic	Tolerable
Unintentional entry into bad weather	Occasional	Hazardous	Intolerable	Remote	Hazardous	Tolerable
Inaccurate / missing weather information	Remote	Hazardous	Tolerable	Unlikely	Hazardous	Tolerable
Violation of safety distances	Remote	Catastrophic	Intolerable	Unlikely	Catastrophic	Tolerable
Unintentional deviation from route	Remote	Major	Tolerable	Unlikely	Major	Acceptable

Inaccurate / missing weather information – although the level of risk has been determined to be acceptable, it is necessary to ensure that pilots have all available weather data on the route and at the mission location during pre-flight preparation. The operator should ensure the availability of such data. However, weather forecast data is not always completely accurate, so the risk of inaccurate data cannot be eliminated completely.

Violation of safety distance from obstacles – the pilot should be familiar with the terrain characteristics of the pipeline area he surveys (rising terrain, etc.). Installing a radio altimeter in a helicopter can also be beneficial.

Unintentional deviation from the planned route – the level of risk was determined to be permissible, but to reduce the probability of an event, the flight path could be entered into the on-board navigation GPS system, if the helicopter has such a system. This would allow the pilot to be able to quickly check any deviation from the planned flight route.

5.2. High voltage power line inspection

Collision with obstacles – to mitigate the consequences, the use of a helmet with goggles, leather gloves, boots and fireproof clothing is proposed, as well as mandatory use of seat belts and other available protective equipment. To reduce the likelihood of an obstacle encounter occurrence, the pilot should inform all crew members to be vigilant and to monitor for any obstacles around the helicopter. A more expensive but beneficial measure could be to install a wire strike protection system.

Emergency landing into unsuitable terrain – the proposed measure to reduce the likelihood is active involvement of all crew members in emergency situations, such as vigilance and monitoring of any obstacles and objects that could endanger the safety of the crew.

Degradation of helicopter performance – proposed measures include the use of safety procedures, such as autorotation landings. To avoid degradation of performance due to pilot lack of attention or a sudden change in wind speed / direction, it is necessary to define the necessary power reserves that must be maintained. Operation will stop when wind gusts exceed the specified limit, or at lower value at pilot discretion. To prevent degradation due to a technical failure, the pilot must check that the helicopter has no maintenance irregularities before the flight.

Unfamiliarity with power lines being controlled – the proposed measure here is inclusion of power line maps in the pre-flight

preparation and pre-flight briefings with employees of the distribution company.

TABLE VI. RESIDUAL RISK LEVEL DURING POWER LINE INSPECTIONS

Risk	Probability	Severity	Risk level	Adjusted probability	Adjusted severity	Residual risk level
Collision with obstacles	Occasional	Catastrophic	Intolerable	Remote	Hazardous	Tolerable
Emergency landing into terrain	Occasional	Hazardous	Intolerable	Remote	Hazardous	Tolerable
Degradation of helicopter performance	Occasional	Catastrophic	Intolerable	Unlikely	Catastrophic	Tolerable
Unfamiliarity with power line systems	Occasional	Hazardous	Intolerable	Remote	Hazardous	Tolerable

5.3. Aerial transport of external cargo

Forced landing in unsuitable terrain – it is recommended to use a helmet and protective suit to mitigate the possible consequences. Another proposed action is to inform all crew members of emergency landing procedures and alert them to actively monitor any obstacles around the helicopter, such as trees, towers, or power lines. Before mission start, it is necessary to determine a suitable place for landing and a suitable area for possible dropping of external cargo in an event of emergency.

Downwash – the proposed measure here is alerting the ground crew of the event possibility, requiring wearing of protective clothing, helmets and goggles by ground personnel, and warning them to secure any loose objects in the area under the helicopter.

Electrostatic charge from the suspension – the employer should ensure that its employees adhere to safety principles and are regularly trained and encouraged to exercise caution when handling the suspension. Before lifting or unloading the cargo, the electrostatic charge must be discharged from the helicopter, load, or load lifting device by ensuring that the helicopter or load lifting device is in contact with the ground or that the load is gripped with a sufficiently grounded hook.

Load contact with obstacles, load falling, cargo damage – PIC should carefully examine the maps and / or conduct a flight survey of the area at safe altitude during pre-flight preparation to identify all obstacles and possible flight hazards. The pilot must also ensure that the rope is long enough to maintain a safety distance from obstacles when attaching / disconnecting the load.

Rope contact with tail rotor – this event can occur if the rope is unloaded and towed behind the helicopter. Setting the maximum permitted helicopter speed when flying with an unloaded rope is proposed, so that at high speed no excessive drag on the rope is created, which would reduce the distance between the rope and the tail rotor. In addition to the speed of the helicopter, the direction and strength of the wind should be considered, so that the the operation with an unloaded rope is safe.

Dangerous external cargo spinning – some loads tend to rotate during the flight, which can lead to damage to the rope and excessive stress on the primary hook or its attachment to the helicopter. This can lead to unintentional release of the load. The proposed measure is the installation of a rotating device in the helicopter suspension system for loads that are known to tend to rotate during flight, and for all loads whose flight characteristics are not known.

Falling fragments, danger to third parties – all persons working near the helicopter must wear hearing protection in addition to protective clothing, and it is also appropriate to wear a vest or high visibility clothing. The pilot shall ensure that the aircraft is operated at an altitude which, in the event of a failure of the critical helicopter system, will allow an emergency landing without undue danger to persons or property on ground. If cargo is damaged during transport and debris falls from the cargo, the cargo must be disconnected at a suitable place immediately.

Insufficient load securing – the ground staff employer should be checked by the customer to ensure that only the appropriate material and procedures are used to secure the cargo. The aerial work provider should appoint a person to oversee the appropriate securing of cargo from the ground. The load capacity of the attachment device must correspond to the weight of the load.

Before starting the task, the pilot will make sure that the appropriate type of helicopter and carrying ropes, hooks or other special equipment are used for the task. Prior to take-off, the pilot shall ensure that the hooks and ropes are properly attached and secured to the helicopter and that the rope is not accidentally tangled in any part of the landing gear. During the pre-flight briefing, the pilot shall inform the ground staff of the emergency procedures, communications, and measures to be taken by the staff in an event of an emergency.

TABLE VII. RESIDUAL RISK LEVEL DURING EXTERNAL CARGO TRANSPORT

Risk	Probability	Severity	Risk level	Adjusted probability	Adjusted severity	Residual risk level
Emergency landing into terrain	Frequent	Catastrophic	Intolerable	Remote	Hazardous	Tolerable
Downwash	Occasional	Major	Intolerable	Remote	Major	Tolerable
Electrostatic discharge from suspension	Remote	Major	Tolerable	Remote	Major	Tolerable
Load contact with obstacles / load falling	Frequent	Hazardous	Intolerable	Remote	Hazardous	Tolerable
Load-bearing rope collision with obstacles	Frequent	Hazardous	Intolerable	Remote	Hazardous	Tolerable
Contact of rope with tail rotor	Occasional	Hazardous	Intolerable	Remote	Hazardous	Tolerable
External cargo spinning	Occasional	Hazardous	Intolerable	Unlikely	Hazardous	Tolerable
External load damage	Occasional	Major	Intolerable	Remote	Major	Tolerable
Falling fragments, danger to third parties	Occasional	Hazardous	Intolerable	Remote	Hazardous	Tolerable
Insufficient load securing	Occasional	Hazardous	Intolerable	Unlikely	Hazardous	Tolerable

5.4. Photographic and film flights

Take-offs and landings on uneven terrain – the PIC will check that there are no hazards such as power lines or other obstacles

near the approach or departure routes of the landing / take-off area.

Flights in excessive proximity to terrain obstacles – in all circumstances, the safe height above the terrain and obstacles must be maintained and the pilot must take care to maintain an adequate power reserve. Installing a radio altimeter could help prevent the helicopter from descending below a set level. To mitigate the effects of an accident in mountainous terrain, all crew members should wear a helmet, be properly bucked up and have survival equipment and an ELT emergency transmitter on board.

Inadequate demands from filming personnel, inappropriate helicopter operation and risk-taking to achieve a desired shot – during pre-flight training, pilots shall inform photographers / filmmakers of the importance of safe helicopter operation. The film staff and the pilot must agree on the activities they plan to take and the shots they plan to achieve before the flight. Prior to assigning the task, the pilot must be checked by the operator that none of the contributing factors in his previous incidents was incorrect decision-making or excessive self-confidence. If it is the case, another pilot must be assigned to the task.

Improper arrangement of objects in the cabin, the possibility of objects falling out during flight without doors – proposed measure is a mandatory securing of all loose objects or film equipment inside the helicopter. All internal cargo must be secured in the cabin so that crew members and other passengers cannot be endangered or injured during normal flight operations or emergency landings. Any object taken into the helicopter cabin must be adequately secured against unintentional movement. The position of the center of gravity with the load on board and the calculations of the fastening forces must be calculated according to the requirements of the helicopter flight manual and must allow safe operation. During doors-off flights, the door must be properly secured or removed. Flying with the door open is only permitted if described in the flight manual.

Technical failure during flights above populated areas – the pilot will ensure that all maintenance irregularities are corrected before the flight and that the aircraft is airworthy. Pilot will also check that the required equipment is in working order and that any non-functional equipment is not included in the minimum equipment list. The pilot shall ensure that he / she always flies at a sufficient height above the populated areas in order to be able to land the helicopter safely if any failure should occur.

TABLE VIII. RESIDUAL RISK LEVEL DURING PHOTOGRAPHIC FLIGHTS

Risk	Probability	Severity	Risk level	Adjusted probability	Adjusted severity	Residual risk level
Take-offs and landings on uneven terrain	Occasional	Hazardous	Intolerable	Remote	Hazardous	Tolerable
Excessive proximity to obstacles	Occasional	Catastrophic	Intolerable	Remote	Hazardous	Tolerable
Inadequate filming demands and risk-taking	Frequent	Hazardous	Intolerable	Remote	Hazardous	Tolerable
Improper cabin object arrangement, objects falling out	Occasional	Major	Intolerable	Remote	Major	Tolerable
Technical failure above populated areas	Occasional	Catastrophic	Intolerable	Unlikely	Catastrophic	Tolerable

5.5. Adventure flights

In an event of pilot kinetosis, the operator shall ensure that the pilot performing the task is in a satisfactory physical condition and has not experienced nausea during maneuver performing in the past.

Danger to third parties on the ground (possibility of damage to health or property) – when performing aerobatic maneuvers, it is necessary to select a suitable area under the helicopter, where no people or property on the ground that could be damaged are present should the helicopter become uncontrolled. Only a pilot who has sufficient experience with the maneuvers should be assigned to the task by the operator.

Unintentional interference to flight controls from an unskilled passenger during difficult maneuvers – for helicopters with dual control, it is necessary to explain the principles of controls during pre-flight briefing with passengers and emphasize dangers of potential interference of the passenger. For helicopters with more passenger seats, it is recommended to seat passengers primarily at the rear of the aircraft.

Risky pilot behavior to meet inadequate passenger requirements – the operator shall ensure that the pilot selected for the task has not had an incident in the past, where the risk factor was poor decision-making, excessive confidence or risk-taking.

TABLE IX. RESIDUAL RISK LEVEL DURING ADVENTURE FLIGHTS

Risk	Probability	Severity	Risk level	Adjusted probability	Severity	Residual risk level
Pilot kinetosis	Occasional	Major	Intolerable	Unlikely	Major	Acceptable
Passenger kinetosis, fear of flying and heights	Remote	Negligible	Acceptable	Remote	Negligible	Acceptable
Danger to third parties	Occasional	Major	Intolerable	Remote	Major	Tolerable
Interference of unqualified passenger	Unlikely	Catastrophic	Tolerable	Extremely unlikely	Catastrophic	Tolerable
Risky pilot behavior	Occasional	Catastrophic	Intolerable	Unlikely	Catastrophic	Tolerable

5.6. Helicopter firefighting

Technical failure during flight over the affected area – before the flight, the pilot must check that the helicopter has no maintenance irregularities, and all the necessary equipment is in working order. To mitigate the consequences of risk, the pilot must wear a protective suit with fire-resistant material, a helmet and leather gloves. If any possible problems are observed with the handling of the bambi bucket, they should be reported to the pilot by radio immediately. The crew must identify safety zones and potential escape routes near the fire or the burned area. However, special care must be taken when landing in burned areas to avoid exposure to excessive heat and the possibility of fuel ignition.

Reduced visibility due to smoke – the pilot must ensure maximum co-operation of the crew in observing and reporting any obstacles, such as trees or power lines. Before approaching the fire area, it is necessary to check the airspace for other aircraft. Before descending to a low altitude, it is recommended to conduct a survey flight at a higher altitude above the obstacles to identify possible dangers.

High temperatures due to fire – the pilot must have altitude and temperature data at the point of intervention before the flight to ensure that the payload is within the allowable values and does not exceed the weight limits.

TABLE X. RESIDUAL RISK LEVEL DURING AERIAL FIREFIGHTING

Risk	Probability	Severity	Risk level	Adjusted probability	Adjusted severity	Residual risk level
Technical failure above affected areas	Frequent	Catastrophic	Intolerable	Remote	Hazardous	Tolerable
Reduced visibility due to smoke	Occasional	Hazardous	Intolerable	Remote	Hazardous	Tolerable
High temperatures due to fire	Remote	Hazardous	Tolerable	Remote	Major	Tolerable

6. CONCLUSION

The aim of the paper was to identify hazards and determine risks that could occur during aerial work performed by helicopters, to evaluate the risks and propose measures to bring them to an acceptable level. This paper dealt with six different types of aerial work in which different risks were found. Subsequently, corrective measures were proposed for situations with an unacceptable level of risk to bring them to the minimum acceptable level of risk, which was successful for each defined event.

Tens or even hundreds of risks could be potentially found for individual types of work, but only a few of them were identified for each type. Estimation or evaluation of probability or severity of the risk involved may depend on the personal experience and sensitivity of the assessor. Therefore, due to lack of experience, the probability of occurrence was based on the NTSB accident database, but it also has its limits. For some activities, only a few accident reports were available, but dozens or hundreds for others, which significantly distorted the probability of occurrence. However, some helicopter aviation activities are more widespread than others. The probability could be better determined if, for example, the numbers of flights performing the activities were available and they could then be compared with the number of incidents and accidents. Additional measures could be proposed when proposing mitigation measures, but these would require more experience in the field and would be more time consuming. Findings suggest that a complete risk elimination is not possible. The human factor remains the most common risk factor in air accidents and incidents, but human cannot be completely removed from the process. A more suitable term in this case is mitigation.

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