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Capabilities and Limitations of Military Helicopter Wire Strike Protection Systems

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Abstract:

The aim of this article is to identify the functional limits of wire cutters, which are an integral part of passive protection systems designed to protect certain civil and military helicopters from damage caused by wire strikes. These limits are not well-known and are not explicitly stated by the manufacturers. The primary result of the study is an annotated specification of the functional capabilities and limitations of wire cutters mounted on helicopter structures in relation to the type of wire to be cut, flight speed and other circumstances. A further finding is that the stated capabilities and limitations of these technical systems may not be known and available to flight crews in different countries around the world for various reasons.

Keywords:

helicopter, wire, cable, wire strike protection system (WSPS), Cable Cutter System

1 Introduction

Wires, i.e. in particular stranded steel wire ropes and electrical cables of various kinds, present a significant hazard to airplanes and helicopters that are sometimes operated at ground level. This danger can be particularly fatal for helicopters as they fly at even lower altitudes and usually at lower speeds than airplanes. Therefore, they have lower kinetic energy that could be exploited in the event of a wire strike. In the history of Czechoslovak and Czech military helicopter aviation, there have been instances where a collision with power line wires resulted in damage or even destruction of the helicopter, including the loss of the crew (see Section 2).

Despite this fact, military helicopters operated in Czechoslovakia, or the Czech Republic have never been equipped with any protective technical systems that could safeguard the helicopter structure or, at the very least, its most critical components

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(e.g., the main rotor) in the event of a wire strike. The initial implementation of passive protection systems incorporating wire cutters is observed in the currently introduced H-1 military helicopter family, specifically in the U.S.-manufactured Bell UH-1Y Venom and Bell AH-1Z Viper helicopters (see Fig. 1). These helicopters are equipped with a set of deflectors and wire cutters on both the upper and lower sides of the front fuselage, as indicated by the red circles in Fig. 1.

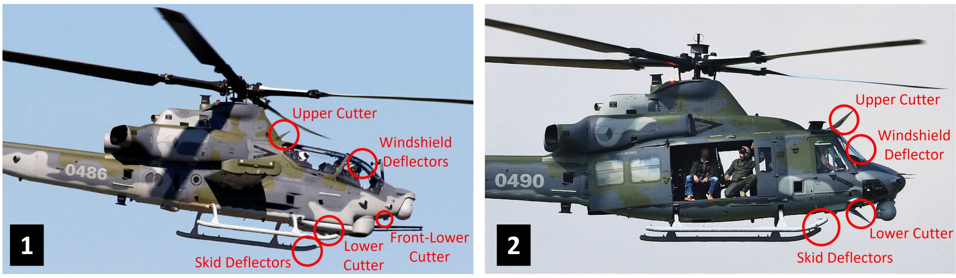

Fig. 1 Elements of the wire strike protection systems on H-1 military helicopters: (1) Bell AH-1Z Viper; (2) Bell UH-1Y Venom [1]

A recent aviation accident (hereinafter referred to as “AA”), classified as an air disaster, involving a Hungarian Airbus H-145M helicopter on 21 June 2023, has brought new insights to the issue at hand. The incident occurred in Croatia during an international military exercise, resulting in the deaths of three flight crew members [2]. The helicopter collided with two stranded steel wire ropes of a local zip-line while passing through a mountain canyon. Despite being equipped with a wire cutter system, the helicopter was literally cut through longitudinally and transversely and destroyed. In the course of investigating the disaster, attention was also directed towards the technical limitations of the wire cutter system that the helicopter was equipped with.

Given that a wide range of civilian and military helicopters are currently equipped with such systems, a comprehensive examination was conducted of the available information sources that can specify the limitations of the wire cutters in greater detail and thereby assist future flight crews in avoiding potential missteps stemming from a lack of knowledge.

2 Aviation Accidents of Czechoslovak and Czech Military Helicopters

A review of the history of Czechoslovak and later Czech military helicopter aviation (i.e. since 1956) revealed a total of 14 instances of AAs [3-5] involving a collision with power line wires (as defined in the military regulations Let-1-5 [6-13] and Všeob-P-10 [14] that were in force at the time, as well as in the currently effective “Flight Safety” Order of the Minister of Defense No. 13/2016 of the Journal of the Ministry of Defense [15]). This represents approximately 10 % of the 131 documented and traceable AAs of helicopters operated in the military aviation of Czechoslovakia and the Czech Republic between 1956 and 2023 (see Tab. 1 below) [16, 17]. The following paragraphs provide an explanation of the abbreviations and numerical codes (based on the formerly effective military regulation Všeob-P-10 [14]) used in Tab. 1, provided that the information was available in the investigation records. The use of abbreviations and short numerical codes is intentional to facilitate the consolidation of pertinent data within the Tab. 1.

*Tab. 1. Aviation accidents of Czechoslovak and Czech military helicopters caused by wire strikes and aviation accidents in which wire strikes were the result of another in-flight emergency (marked with an asterisk *)* [3-5]

Type of AA	Date of AA	Helicopter type	Weather conditions	Cause factor / Main cause	Phase / Mode / Airspeed / Altitude (at striking wires)
Cr *	10 Aug 1961	Mi-1	NWCD	HF-fp / 04	7 / DES / 50 km/h / unk.
Cr *	10 Jul 1963	Mi-1	NWCD	HF-np / 19	7 / DES / unk. / unk.
Cr	16 Jul 1963	Mi-1	NWCD	HF-fp / 06	4 / LEV / 120 km/h / 40 m
Da	11 Sep 1964	Mi-4	NWCD	HF-fp / 06	4 / LEV / 120 km/h / 25−30 m
Cr	24 Feb 1965	Mi-4	NWCN	HF-np / 01	3 / CLM / 110 km/h / 30−40 m
Da	25 Jun 1965	Mi-4	NWCD	EF	4 / LEV / unk. / 10−15 m
Di	30 Mar 1967	Mi-1	NWCD	HF-fp / 06	4 / LEV / 120 km/h / 40 m
Da	12 Jul 1967	Mi-1U	NWCD	HF-fp / 04	3 / CLM / unk. / unk.
Di	20 May 1969	Mi-1M	NWCD	HF-fp / 06	4 / LEV / 120 km/h / 25 m
Da	20 May 1969	Mi-1M	NWCD	HF-fp / 06	4 / LEV / 120 km/h / 25 m
Di	22 Jun 1973	Mi-1M	NWCD	HF-fp / 06	4 / LEV / 120 km/h / 25 m
Di	17 May 1983	Mi-24D	NWCD	HF-fp / 03	4 / LEV / 220 km/h / 15−30 m
Da *	27 Feb 1990	Mi-8P	DWCD	HF-np / 09	4 / DES / unk. / unk.
Da	12 Aug 2021	En-480B	NWCD	HF-fp / 06	4 / LEV / 130 km/h / 8 m

* AAs in which the collision with the wires was not the cause but the effect.

Legend of abbreviations: Di (disaster), Cr (air crash), Da (damage); NWCD (normal weather conditions during the day - time: between dawn and dusk, cloud cover: 0/8-4/8, cloud base: above 1 500 ft, visibility: more than 5 000 m), DWCD (difficult weather conditions during the day - time: between dawn and dusk, cloud coverage: 5/8-8/8, cloud base: below 1 500 ft, visibility: less than 5 000 m), NWCN (normal weather conditions at night - time: between dusk and dawn, cloud coverage: 0/8–4/8, cloud base: above 1 500 ft, visibility: more than 5 000 m); HF-fp (human factors - flight personnel), HF-np (human factors - non-flight personnel), EF (environmental factors); Main cause codes (01 – Command and organization, 03 – air navigation services, 04 – Piloting, 06 – Crew non-compliance, 09 – Meteorological services, 19 – Poor quality of service work of the production or repair facility); Flight phase codes (3 – climb after take-off, 4 – flight task, 7 – landing); Flight mode (DES – descent, CLM – climbing, LEV – level-flight)

In total, there were 4 disasters, 4 air crashes and 6 damage-type accidents. Collision with power line wires was the cause in 11 of the 14 AAs. In the remaining three events (two crashes and one damage accident), the wire strike was a consequence of the development of another pre-existing in-flight emergency. The first documented instance of this type of AA occurred in 1961, involving a Mil Mi-1 helicopter. The most recent such incident, to date, occurred in 2021, involving an Enstrom En-480B helicopter. The 14 AAs presented occurred on a total of five helicopter types: the Soviet Mil Mi-1, Mil Mi-4, Mil Mi-8, Mil Mi-24, and the American En-480. The greatest number of AAs (8) occurred on Mil Mi-1 helicopters.

Of the 14 AAs, 12 of them occurred under “normal weather conditions during the day”; 1 AA occurred under “difficult weather conditions during the day” and 1 AA occurred under “normal weather conditions at night”.

In 13 of the 14 AAs, the causative factors were identified as “human factors”. In only one case was the influence of the “environmental factors” dominant. Among the HFs, “flight personnel” was the dominant factor in 10 AAs, while in only 3 AAs was the cause of the event related to “non-flight personnel”.

For flight crew, the most frequently represented main cause was “crew non-compliance”, i.e. various forms of flight indiscipline‑most frequently non-compliance with the prescribed minimum flight altitude (7 AAs). In 2 AAs, the main cause of the event was an error in “piloting”. Exceptionally, in 1 AA, there was also a deficiency in “air navigation services”, i.e. deficiencies in navigational preparation for the flight.

For non-flight personnel, deficiencies in: flight “command and organization”, “meteorological services” and “poor quality of service work of the production or repair facility” were each represented by 1 AA. Most wire strikes (10 out of 14 AAs) occurred during the “flight task” phase of flight, in 2 AAs the wire strike occurred during the “climb after take-off” phase of flight and in 2 AAs the wire strike occurred during the “landing” phase of flight. The most frequently reported speed during the wire strike was in the range of 110–130 km/h (approx. 59–70 kt) during “level-flight” at an altitude of about 10–40 m above the ground (approx. 30–130 ft AGL). Wire strikes during the “descent” mode of flight were only the result of another in-flight emergency situations where the crew was unaware of the obstacle or was no longer able to avoid it. Wire strikes in “climbing” flight mode were recorded in only 2 AAs, one of which occurred at night.

The data on the AAs suggests that the pilots ventured close to ground, relying on favorable weather conditions, particularly good visibility. They counted on being able to discern potential obstacles in a timely manner. Unfortunately, this may not be the case with power line wires. There are several circumstances under which power line wires can be identified with the naked eye only at very short distances (i.e., a few tens of meters). In the event that a pilot is flying at a high speed in such conditions, there is effectively no time remaining for any form of reaction. This is particularly relevant in the context of helicopters, where the dynamics of almost all maneuvers are significantly constrained compared to most fixed-wing aircraft due to aerodynamic considerations (helicopters are usually less dynamically maneuverable than airplanes; i.e., they cannot be directed or altitudes changed as rapidly). Such conditions include rugged forested terrain, where power poles may be difficult to discern in time due to the presence of trees; dark backgrounds of rising terrain, where dark wires visually fade against a dark, non-contrasting backdrop; type of light, as varying light conditions can alter spatial perception and distance estimation; and glare from the sun, which can limit the pilot’s visual perception when flying into the sun. Furthermore, the specific ergonomics of different helicopter types and the often-limited view from cockpits contribute to a highly variable combination of factors that can impede the timely identification of obstacles in the field by the crew. As a precautionary measure, it is recommended that flights in the specific area be avoided at low altitudes, or, if unavoidable, that the airspeed be reduced to a point where an evasive action can be executed should an obstacle suddenly appear. It is regrettable that the majority of the crews involved in the aviation accidents in question did not take this into account, which resulted in significant difficulties.

The extent of the consequences of a wire strike (damage or destruction) for the helicopter and the crew typically depended on the weight of the helicopter, flight speed, rigidity of the helicopter airframe, type of wire (whether it was a stranded steel wire rope or an electric cable – see Section 3 below for details), and flight mode of the helicopter at the moment of impact. At the time, none of the five aforementioned helicopter types were equipped with any kind of wire cutter system.

Tab. 1 shows that the most prevalent AAs with the most severe consequences were associated with the Mil Mi-1 helicopter (see Fig. 2). There are several reasons for this. The Mil Mi-1 helicopter (maximum takeoff weight: 2 296 kg) was a light general-purpose utility helicopter that performed mostly reconnaissance and liaison tasks. The aircraft was not designed for direct combat, and thus its construction was not particularly resistant to mechanical damage. According to the available archival documents, the helicopters most frequently collided with high-voltage electrical wires. Given the diameter of the cables, their tensile strength is on the order of several tens of kN. Therefore, given the weight, flight speed, and structural rigidity of a light helicopter of the Mil Mi-1 type, it had virtually no chance of breaking the wire without suffering severe or fatal damage. The Mil Mi-4 helicopter (maximum takeoff weight: 7 800 kg) was a medium-heavy helicopter that was also designed for direct combat operations. As a result, the consequences of its collisions with wires were usually less severe compared to those of the Mil Mi-1 helicopter, a similar pattern being observed with the Mil Mi-8 helicopter (maximum takeoff weight: 12 000 kg).

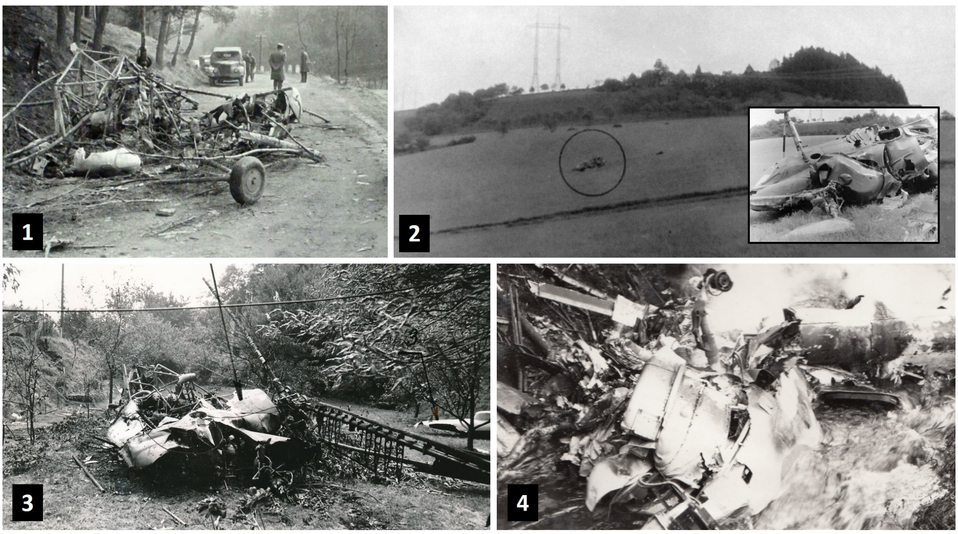

Fig. 2 Aviation disasters of Czechoslovak military helicopters due to wire strikes: (1) 30 March 1967, the Mi-1, pilot 1st Lt P. Joska; (2) 20 May 1969, the Mi-1M, pilot Maj Z. Bouška; (3) 22 June 1973, the Mi-1M, pilot Capt V. Kubeček; (4) 17 May 1983, the Mi-24D, pilot Capt B. Karkošiak [3, 4]

In regard of the unexpected severity of the consequences of a wire strike, the Mil Mi-24D and Enstrom En-480B helicopter accidents of 1983 and 2021, respectively, are of particular interest [3, 4].

The disaster of the Mil Mi-24D helicopter on 17 May 1983 was primarily attributable to a maneuver executed by the pilot in response to a report from the other crew member via the intercom of wires at a distance of only 60−100 m at a flight speed of 220 km/h at an altitude of 15−30 m above the terrain. From the vantage point of current understanding, the pilot cannot be faulted for his natural reaction. He would have had to undergo specialized training in order to react differently in a given situation of such high stress. However, at that time, such training was evidently not in place. The fundamental issue was that the pilot's intuitive response was to attempt to fly over the wires, rather than leveraging the kinetic energy and rigidity of the helicopter airframe to fly through them with a high probability of survival. Given the armored, very robust construction of the front fuselage and the high kinetic energy generated by the aircraft's weight and airspeed, it is probable that the helicopter would have been able to withstand the impact without sustaining significant damage. Instead, the pilot made an abrupt change in control inputs, rapidly and radically pulling up on the cyclic and collective. The helicopter did not ascend due to excessive longitudinal pitch; rather, it decelerated abruptly, resulting in a shudder caused by the change in airflow around the main rotor blades. The pilot therefore released the collective to the minimum angle of attack of the main rotor blades. This resulted in a collision with an electrical wire, which cut into the lower unarmored part of the fuselage. Concurrently, the main rotor blade wobble led to mechanical damage to the tail boom, as the blade became jammed in the boom, and then the tail section of the helicopter detached. Ultimately, the inevitable crash and fire of the helicopter occurred, with fatal consequences for the crew.

The Enstrom En-480B helicopter accident of 12 August 2021, which was separated from air disaster by an almost immeasurable chance, only resulted in damage. A power line wire impacted the front of the cockpit of the light multi-purpose helicopter (maximum takeoff weight: 1 361 kg) in a "fortuitous" location, where it cut through the composite fuselage skin and came into contact with the metal bracket of the flight instruments. At that moment, the bracket functioned as a wire cutter, severing the wire mechanically. The helicopter then continued to carry one section of the electrical wire wedged in the left side of the cabin for several seconds until the wire finally came loose and fell to the ground. Apart from the mechanical damage to the front of the cabin, the helicopter sustained no further damage. It should be noted that if the power line wire had struck any other point in the front of the fuselage (more than approximately 30 cm upwards or downwards), the consequences of the accident are likely to have been fatal.

It is evident that historical experience offers valuable insights into the issue of helicopter wire strikes. However, to gain a comprehensive understanding of this phenomenon, it is necessary to consider a few additional pieces of information. These are discussed in the following sections.

3 Steel Ropes vs. Electric Cables

The commonly used term "wires" encompasses more than just overhead electric power cables or electric power lines (see Fig. 3). It can also refer to high-performance stranded steel wire ropes.

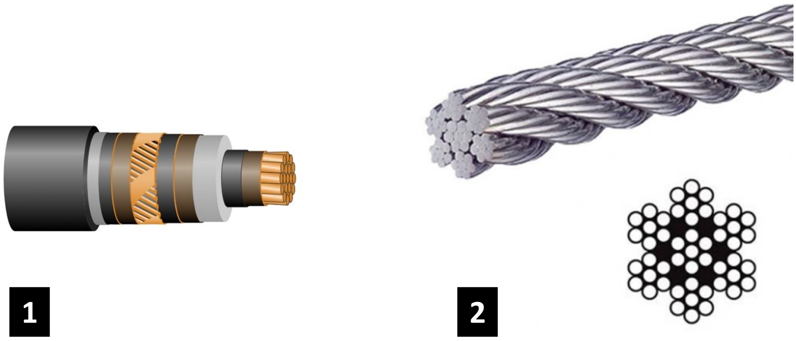

Fig. 3 Example of the difference in design between an electric power cable and a high-strength stranded steel wire rope: (1) electric power cable; (2) high-performance stranded steel wire rope [18]

The distinction between them is in their respective tensile strengths at a given diameter, which is a consequence of the dissimilarities in their construction. In general, high-performance stranded steel wire ropes exhibit a higher tensile strength than electric power cables while maintaining the same diameter (i.e., a greater force is required to break them). This is due to the fact that electric power cables are typically composed of multiple layers of diverse materials, with only one layer specifically designed to provide tensile strength. Typically, a central steel core is situated in the center of the cross-section of such a cable, comprising a strand of steel wires that ensures the cable's requisite tensile strength. A conductive sheath surrounds the core, comprising a strand of wires, typically aluminum, to ensure optimal electrical conductivity. Externally, multiple insulating and protective layers are present, offering resilience against external factors, particularly weather conditions. In contrast, high-performance stranded steel wire ropes are constituted exclusively of bundles of steel wires braided in diverse configurations, primarily intended to impart tensile strength.

Therefore, in consideration of the anticipated consequences of a collision, stranded steel wire ropes present a greater risk for helicopters. Such rope can be found particularly in a variety of ropeways, used for the transportation of materials or passengers, with typical diameters ranging from 16 to 300 mm. They are also utilized in zip-lines for individual transportation, with diameters of steel ropes often below 16 mm. Additionally, they are employed in high and extra high voltage electricity pylons, where they are situated in the uppermost position and serve as a grounding wire. In such pylons, the highest-positioned "wire" (steel rope) is therefore the strongest one and, consequently, the most dangerous in terms of potential collision.

More detailed information on the design and technical parameters of electric power wires can be found, for example, in reference [19] and on the design and technical parameters of high-performance stranded steel wire ropes in reference [20].

It is also noteworthy that the electric power transmission systems (i.e., power lines, electricity pylons, and voltages) can vary considerably from one country to another and from one continent to another. It is therefore advisable to pay close attention, with a special focus on wires, to the study of mapping data and field surveys when planning flight operations, particularly in foreign countries.

4 Helicopter Wire Strike Protection Systems

4.1 Brief History of the Patent

The impetus for the development of systems to safeguard helicopters from wire strikes emerged in response to the elevated incidence of helicopter accidents in the United States in the 1970s. As detailed in the final report of a safety study [21], a total of 208 AAs involving civilian helicopters were caused by wire strikes in the United States between 1970 and 1979. A total of 88 helicopters were destroyed in these accidents (with irreparable damage) and the remaining 120 helicopters were damaged. A total of 331 individuals were involved in the AAs, of which 37 were killed and another 52 sustained serious injuries.

The fundamental concept underlying the wire protection system originated in 1976 and is attributed to Major André Seguin (at the time commander of the Canadian 444 Combat Support Squadron operating in West Germany). He formulated his concept of wire cutters in response to an accident involving a Bell OH-58 Kiowa helicopter that occurred on 16 May 1976 near Avasinis, Italy. The OH-58A-BF 71-20900 helicopter of the 444 Combat Support Squadron was on a reconnaissance flight to the area affected by an earthquake, with the objective of determining the extent of the damage. While navigating a valley, at an altitude of approximately 60 m above the ground (200 ft AGL) at approximately 110 km/h (60 kt), the aircraft collided with a wire that slid up the windshield and damaged the main rotor head control rods. The helicopter was rendered uncontrollable and crashed. The aircraft captain was killed, and the remaining crew members were injured [22].

The concept was subsequently developed and technically implemented in 1979 by the Canadian company Bristol Aerospace (since 1997 part of the still-existing company Magellan Aerospace [23]). In 1980, the final product was granted a patent in Canada (patent no.: CA1079182A, dated 10 June 1980) [24] and then in the U.S. (patent no.: US4215833A, dated 5 August 1980) [25] under the designation “Cable-Cutting Device”.

A total of five companies worldwide have been found to produce these systems under different brand names: Magellan Aerospace (Canada) [23], DART Aerospace (Canada) [26], MD Helicopters (U.S.) [27], Bell Textron Inc. (U.S.) [28] and Airbus Helicopters SAS (the helicopter division of the French-German-British company Airbus S.A.S.) [29].

These systems are most typically designated under the trade names “Wire Strike Protection System” (WSPS) [23] or “Cable Cutter System” [26].

4.2 Description of System Parts

In accordance with the patent documentation [24] and [25], the “Cable-Cutting Device” is comprised of two groups of components (see Fig. 4):

- deflectors (of landing skids, landing gear wheels, wipers, windscreen, etc.),
- wire cutters (upper, lower, landing gear, etc.).

Deflectors and wire cutters can be of different dimensions, placement and technical designs (see Fig. 5). However, the principle of operation is common to all of them. All types of deflectors serve to direct the wire away from any part of the helicopter structure (especially away from the main rotor head and landing gear) or into one of the wire cutters that are designed to sever the wire.

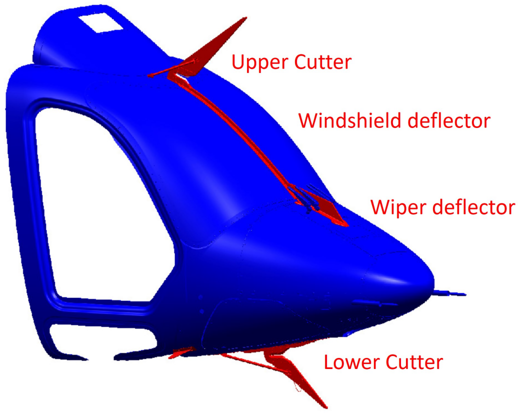

Fig. 4 Example of the configuration of the principal components of the "Cable-Cutting Device" [23]

Failure to do so may result in mechanical damage to the helicopter structure (in particular damage to parts of the main rotor head, resulting in a possible loss of control, can be fatal), entanglement of the wire on any of the rotors (especially with thin wires – again resulting in the rotor being rendered inoperative), or entrapment of the helicopter in the wires without the crew being able to control its further movement (usually followed by an uncontrolled crash of the helicopter).

Interestingly, the cutting edges of the cutters can be coated with a thin layer of suitable rubber material at the manufacturing facility to minimize the risk of accidental injury to personnel. At first glance, the cutters may appear to be dull and coated in camouflage paint. Nevertheless, upon contact with the wire, the coating is expected to disintegrate rapidly under pressure, thereby exposing the sharp edges of the cutters. The coating should demonstrate resistance to the effects of aviation fuels, oil, water, and weathering. The most appropriate materials for this purpose are Buna-N rubber and polysulfide coating compounds [25].

It is, unfortunately, not always feasible to provide total protection for the helicopter's front hemisphere from wire strikes. This is particularly so when additional equipment or weapon systems are installed on the forward fuselage, which can disrupt the smooth shape characteristics or create narrow slots where wires may become trapped.

4.3 Large-Scale Tests

The functional limits of the helicopter wire strike protection system (especially of the wire cutters) are presented in the patent documentation of June and August 1980 [24] and [25], based on calculations and partial tests. Large-scale tests were conducted in 1980 for the purposes of the patent proceedings, followed later (in 1982) by further tests. The helicopters subjected to testing were (see Fig. 5) the Bell OH-58A Kiowa (in June 1980) [30], the Bell UH-1H Iroquois (in November 1982) [31], and the Bell AH-1S Cobra (in December 1982) [32].

Fig. 5 Helicopters tested in large-scale tests in 1980 and 1982: (1) the Bell OH-58A Kiowa, (2) the Bell UH-1H Iroquois, and (3) the Bell AH-1S Cobra [30-32]

All large-scale tests were performed on a swing test facility with actual helicopters at 1:1 scale.

The initial trials were conducted in June 1980 on a Bell OH-58A Kiowa helicopter (see Fig. 6), which was partially stripped of its equipment for this purpose, with a remanent weight of 2 610 lbm (approx. 1 183 kg). A seven-strand steel wire rope with an overall diameter of 3/8 inch (9.525 mm) was used for the tests. It carried a section of 50-pair 0.85-inch (21.59 mm) communications cable comprising 100 copper wires. The carrier rope used had a tensile strength of 11 500 lbf (approx. 5 216 kg). The helicopter's impact speed with the wire was determined to be 40 kt (approx. 74 km/h). The tests demonstrated that no thicker or stronger wires could be cut than the type and diameter tested. However, a potential problem may emerge if multiple wires are placed in a row, as their tensile strengths add up. Conversely, a strike and subsequent successful wire cut should not impair helicopter control, nor cause excessive (dangerous) main rotor blade vibrations [30].

A second series of tests was conducted in November 1982 on a Bell UH-1H Iroquois helicopter, which was also partially stripped of its equipment for this purpose, with a remanent weight of 5 027 lbm (approx. 2 280 kg). The same type of wire was utilized for the tests as previously with the Bell OH-58A Kiowa helicopter. The helicopter's impact speed with the cable was also determined to be 40 kt (approx. 74 km/h). These tests corroborated previous findings that no thicker or stronger wires could be cut than the type and diameter tested. Moreover, it was demonstrated that the efficacy of all cutters declines significantly when the angle of contact with the wire is greater than 30° from perpendicular. It was also found that there is an unsafe speed limit, theoretically set at 90 kt (approx. 167 km/h), beyond which there is a risk of exceeding the structural strength limit of the helicopter cabin columns on which the cutting device is mounted (see possible consequences as in the case of the Hungarian Airbus H-145M helicopter mentioned above in Section 1) [31].

A third series of tests was conducted in December 1982 on the Bell AH-1S Cobra helicopter (see Fig. 6), which was also stripped of equipment for this purpose, with a remanent weight of 6 044 lbm (approx. 2 740 kg). The same type of cable was utilized for the tests as previously with both the Bell OH-58A Kiowa and Bell UH-1H Iroquois helicopters. The helicopter speeds at cable impact were set this time at 40 kt (approx. 74 km/h) and 18 kt (approx. 33 km/h). These tests validated prior experience and reaffirmed the hypothesis that at elevated flight speeds the wire has the potential to cut through the helicopter airframe. Another significant outcome was the realization that, due to the configuration of armament and equipment on the Bell AH-1S Cobra helicopters, comprehensive protection of all parts of the helicopter could not be attained. Therefore, the effectiveness of the helicopter's wire strike protection system is likely to be less than that of the previous types tested (Bell OH-58A Kiowa and Bell UH-1H Iroquois) [32].

Fig. 6 Large-scale tests on a swing test facility (Ford Eustis, Virginia, U.S.) in 1980 and 1982: (1) the Bell OH-58A Kiowa, (2) the Bell AH-1S Cobra, and (3) close-up view of the cutter cutting the wire [30-32]

5 Helicopter Wire Protection Options

In general, helicopter-wire collisions can be either prevented or, if necessary, countered. Accordingly, the means of prevention and protection can be classified into three groups:

- I. Wire map databases (for wire strike prevention),
- II. Safety devices (for wire strike prevention),
- III. Protective equipment (to protect the helicopter in case of a wire strike).

Group I includes all map databases that are accessible within a given country or geographic region and contain pertinent information regarding the location and characteristics of electric power transmission lines.

Group II can be principally divided into equipment located "on board" the helicopter and that located "on the ground", in particular on structures. "On-board" equipment may include: Powerline Detection System (PDS), Terrain Awareness and Warning System (TAWS), Obstacle Avoidance and Warning System (OAWS) or Electronic Flight Bag (EFB). "On the ground", an Obstacle Collision Avoidance System (OCAS) may be installed on selected objects (potential high obstacles in the terrain) or wire markers may be placed on selected sections of long-distance electric transmission lines.

Group III can be further subdivided into two categories: "passive" and "active" means. The "passive" devices (without moving parts) include Wire Strike Protection Systems (WSPS) and Cable Cutter Systems. The "active" devices (with moving parts) are represented by active wire cutters. Regrettably, their large-scale production and pervasive implementation have yet to materialize.

Further details regarding the aforementioned systems and devices can be found, for example, in reference [33].

6 Factors Affecting the Course and Outcome of a Helicopter Wire Strike

In general, the efficiency of the helicopter wire strike protection system is contingent upon approximately six input conditions:

- Wire diameter and tensile strength
  The larger the diameter of the wire and especially its tensile strength, the more difficult it is to cut until the limit of the given type of cutter is reached, at which point cutting is no longer possible.
- Angle of approach of the helicopter to the wires
  The greater the deviation from the perpendicular to the wire axis, the more difficult the cutting and the greater the loss of the helicopter's kinetic energy.

There is also a greater risk of the helicopter falling from the wires or coming to rest in a highly unusual position.

- Helicopter speed
  The higher the airspeed, the greater the energy for cutting, unless the strength limits of the cutter and its attachment to the helicopter structure are reached.
- Helicopter weight
  The higher the weight of the helicopter, the greater the inertia, which theoretically allows for cutting several wires in a row.
- The rigidity and robustness of the helicopter structure
  The greater the rigidity and robustness of the airframe – especially that of the front fuselage, the greater the resistance to wires.
- Type of cutter
  Each cutter has a limit in terms of wire diameter and tensile strength; beyond this limit, a successful cut is not possible and may destroy the cutter and the structure to which it is attached.

7 Recommendations for Helicopter Flight Safety

The following recommendations for helicopter pilots have been developed based on a detailed analysis of Czechoslovak and later Czech military helicopter AAs (see Section 2) and consultations with flight crews:

- **Never underestimate the risk of a wire strike.**
  As the speed and altitude of a helicopter decrease, the probability of collision with any obstacle increases. Additionally, the smaller (thinner) the obstacle, the less conspicuous it is to the human eye at a given distance. It can be reasonably deduced that, due to the nature of their operational use, military helicopters, especially attack helicopters, which often operate at a mere few meters above the ground, are at an elevated risk of a wire strike. Civilian aircraft typically operate at altitudes exceeding the height of even the tallest electricity pylons in the area (the tallest electricity pylons in the Czech Republic are 75 meters).
- **Never underestimate navigational preparation for flight.**
  The accessibility and quality of cartographic materials can vary significantly across different countries. Furthermore, despite the potential risks to air traffic, various devices (such as zip-lines) are being constructed without the inclusion of such information on maps, unless explicitly required by local legislation. For these reasons, it is generally safer to conduct a survey of any potentially hazardous sections of planned flight paths from the ground or from the air by means of reconnaissance flights in a safe flight configuration prior to the commencement of selected military exercises, and to supplement the map documentation.
- **Observe technical limitations of wire cutters.**
  Technical limitations of wire cutters concern in particular:
  - wire strength, or the *force corresponding to the "ultimate tensile strength" for a given cross-section of wire made of a given material* (currently, the value given for most cutters 62 275 N),
  - *wire diameter* (currently approx. 11 mm, which is determined by the distance between the cutting edges of the cutter),
  - *angle at which the wires are brought into contact* (a deviation of more than 30º from the perpendicular to the direction of the wire means a sig-

nificant reduction in the effectiveness of the cutter; the cutter is most effective when it is perpendicular to the wire),
    - *flight speed* (during large-scale tests it was established that the speed of the tested helicopters should be in the range of 40‑90 kt, i.e. 74‑167 km/h; outside this speed range there is a risk of passive cutter malfunction or, on the contrary, its mechanical destruction together with the part of the fuselage structure to which it is attached). However, helicopters with different fuselage structures may have a different upper speed limit (higher or lower).

- **Avoid places and conditions that impair the visibility of the wires.**
  The combination of inadequate or rapidly changing lighting conditions and low contrast ‑ especially dark ‑ backgrounds in a rugged terrain may result in delayed detection of the presence of wires by the crew.
- **If these places and conditions cannot be avoided, adjust airspeed and flight task execution.**
  The circumstances that may compromise the visibility of wires have already been described in more detail in Section 2 above. It should be noted that in the event that these conditions arise during flight and the helicopter is not equipped with additional technical systems for wire strike prediction (see Section 5 above), consideration must be given as to whether the risk is acceptable for the execution of the planned mission. In the event that the helicopter crew encounters such conditions unplanned, it is imperative that they adjust the airspeed to align with the technical limits of their onboard wire cutters (see point 3 above). As a second step, the helicopter should promptly depart from the danger zone, ensuring that the associated risks are no longer unmanaged.
- **Train the pilot's response to unexpected visual contact with wires at short distances in the flight axis.**
  In accordance with the natural self-preservation instinct, individuals tend to avoid obstacles. This is a natural reflex that is supported by the fundamental principles of flight training. However, there are instances when it may be advisable to suppress this reflex in a controlled manner (see, for example, the Mil Mi-24D helicopter crash on 17 May 1983 referenced in Section 2 above). In fact, if the helicopter is of a greater weight category and has a more robust and rigid (reinforced) structure, which predisposes it to slower maneuvering (but high inertia in motion), it may prove advantageous to utilize the available kinetic energy to break through the obstacle (wire) with a frontal impact. It is, therefore, paradoxical that attempting an evasive action for which there may no longer be sufficient time or space can result in a more detrimental outcome than remaining in a straight flight path. This is because it will result in a loss of kinetic energy of the helicopter, potentially leading to an aerodynamic stall during a sharp maneuver (flight outside the flight envelope) or exposing less resilient parts of the structure (e.g., flight deck floor, tail fuselage beam, or tail rotor) to a collision with an obstacle. Therefore, for some types of helicopters, it is useful to assess the potential consequences of a wire strike in advance and choose the appropriate method and corresponding pilot response training to maximize the likelihood of survival in a given scenario.

8 Conclusion

This article summarizes the issue of helicopter protection against wire strikes. As the above fact overview shows, to gain insight into this issue, one must consider a multitude of disciplines, including but not limited to aerodynamics, flight mechanics, power engineering, elasticity and strength of structures, as well as human factors. It has been found that the available information on wire cutters can be traced, but this tracing is often not straightforward, nor is the analysis, synthesis, and especially the interpretation of the available information for current flight safety.

An overview of the existing systems and technical elements employed in helicopter protection against wire strikes was successfully created. The historical experiences (military aviation accidents) with potential wire strike consequences were also analyzed. In addition, the working principles and limitations of the WSPS or the Cable Cutter System were traced. Based on the analyses performed, recommendations for pilots were also formulated to improve the level of flight safety.

A comparison of the original manufacturers' technical documentation and the above overview shows that there may be discrepancies between the two. It is unfortunate that the potential absence of certain information may ultimately increase the probability of erroneous decisions by flight crews in the context of flight planning or in the event of an in-flight emergency. Therefore, it is practical to additionally request from the manufacturer, or to search independently, information regarding any unpublished technical details on limitations of the technical systems used in order to increase the level of flight safety of the type of aircraft operated. The safety of flight crews performing flight tasks should always be a priority.

In closing, the author would like to pay tribute to the work and memory of the flight crews killed or injured in the above-analyzed aviation accidents, from whose lessons learned, and often dearly paid, we have the opportunity to learn for the future of flying and flight safety.

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