Safety in high-risk helicopter operations

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Safety in high-risk helicopter operations: The role of additional crew in accident prevention

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ABSTRACT

Objectives: To examine the causes associated with high risk helicopter operations, in particular external load and aerial application flight, and determine the role of crew management in accident mitigation strategies.

Methods: Data from the US National Transportation Safety Board online database were analyzed. Flight phases and types of rotor strike were added categories extracted from the narrative statements included in the accident reports.

Results and recommendations: Aerial application and external load accidents are characterized by high numbers of rollovers, rotor strikes and errors during preflight checks. Additional flight or ground crew may assist the pilot in maintaining a visual lookout. The number of accidents can be further reduced with adequate fuel management in which both pilot and ground crew can contribute. Although the ground crew can be both victim and cause of an accident, their supporting role has much to contribute to safety in high risk helicopter operations.

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1. Introduction

Helicopters are uniquely equipped for specialized operations such as forestry and fire-fighting, often categorized as external load operations, as well as operations at low altitude in confined areas, such as crop-spraying also known as aerial application. The environment in which these operations take place allow little room for error and the machine's performance is limited by the specialized loads. The risks of these operations are highlighted by accidents, reported in the United States by the National Transportation Safety Board (NTSB).

External-load and aerial application operations commonly employ highly experienced pilots and are one of few helicopter operations in which ground crews are added to assist the pilot. This study analyzes the causes and factors contributing to accidents in these operations and seeks to identify those elements in which the interaction between ground and flight crew can play a role in the mitigation of helicopter accidents.

Aviation accident research has given increased attention to the category of general aviation, constituting all unscheduled and non-military flights. Studies of general aviation accidents provide a generalized view across several categories of aircraft, mostly motorized planes and helicopters (Wiegmann, 2003; Li et al.,

1999; Billing and Reynard, 1984). A few studies examined accidents that involve one particular category of aircraft such as balloons (de Voogt and van Doorn, 2006; Frankenfield and Baker, 1994), gliders (van Doorn and de Voogt, 2007), ultra-lights (Pagán et al., 2006) and helicopters. These studies reveal that some causes and factors contributing to accidents are similar across aircraft such as pilot errors and the influence of weather conditions, while other accident factors are aircraft specific.

Previous studies on helicopter accidents (Conroy et al., 1992; de Voogt et al. 2007) provide a benchmark for a more detailed study of particular helicopter operations. Emergency medical services are one of few helicopter operations that received ample attention in this respect. It is noted that recommendations to the aviation industry are particularly beneficial when analyses are based on both operation and aircraft specific data.

1.1. External-loads and aerial application

One of few published studies on external-load helicopter operations, also known as sling-load operations, was presented by Manwaring et al. (1998) who described the causes and circumstances of accidents between 1980 and 1995. They linked their outcomes to studies of Alaskan wood-logging helicopter operations in which progress on safety had been made. It remains one of few published epidemiological studies on external-load operations and is used here as a primary reference point.

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Aerial application is an operation for which even fewer published analyses are known despite an average of more than 4000 aircraft per year that are active in this industry in the United States. Research on aerial application flights has concentrated on the danger of the applied chemicals rather than the danger of the flight operation (Gerry et al., 2005; Rice et al., 2005). From October 1996 through June 1997, the Professional Aerial Applicators Support System (PAASS, 2006) was introduced to reduce accidents with the aircraft and drift accidents with the chemicals. In addition, the aerial application industry has introduced turbo shaft or turbine engine helicopters, mainly for their favourable weight and power ratio (Spencer, 1979).

Aerial application and sling-load operations are characterized by experienced pilots, specialized loads and limited room for maneuvering in case of an emergency. This latter characteristic suggests a higher incidence of rotor-strikes with trees or wires. The operations have an added characteristic that they reload or even refuel on location, which often requires the presence of a ground crew. The particular dangers of these helicopter operations and the role of ground crew in preventing accidents are central to the analysis below.

2. Methods

2.1. Human factor taxonomies and analyses

Starting with the work of Rasmussen (1982), human factors in industry have been given wide attention from a psychology perspective (e.g. Zapf et al., 1992; Wagenaar et al., 1990). The analysis of such factors for the aviation industry was developed soon after by O'Hare et al. (1994), Ferrante et al. (2004), Thomas (2004) and notably by Shappell and Wiegmann (1997) to name a few. The taxonomy by the latter authors was implemented in a Human Factors Analysis and Classification System (HFACS) on which the NTSB database is partly modelled.

As argued by Beaubien and Baker (2002), Dekker (2003) and others, such coding systems are coarse, in particular for general aviation, and cannot overcome the absence of data on organizations or on near accidents that should give better insight in the causes of accidents and the measures to prevent them.

In this study, the codings provided by the NTSB are still used but refined, such as the number of flight phases, and placed in the context of the narrative text provided by the NTSB reports. The additional information used in this study was extracted from the text with the help of keywords, allowing little room for interpretation, and the information collection was supervised by an experienced helicopter pilot and researcher.

2.2. Data source

Data for our study came from the National Transportation Safety Board online database (2006), which contains probable cause statements and factual reports of Civil Aviation accidents in the United States since 1962. Accidents are reported if aircraft sustained substantial damage or were destroyed and/or if at least one of the occupants or ground crew suffered severe or fatal injuries.

Probable cause statements provide a summary of the accident as well as the causes and contributing factors determined by the NTSB examiner. The factual reports contain a narrative statement based on interviews with witnesses and pilot(s) as well as details about the aircraft, the pilot and the environment.

The database was used to organize the reports according to operation, aircraft type and date. Using the NTSB online database categories, we selected a set of 142 accidents of aerial application

flights with helicopters from the time period 1998 through 2005. The aerial application category as defined in the NTSB database contains flights in which aircraft administer fertilizer, pesticides or other sprayable products for agricultural purposes. Another set of 120 accidents of external load operations with helicopters was selected dating from the period 1995 through 2005. This set follows the earlier study by Manwaring et al. (1998) that analyzed accidents up to 1995.

The causes of accidents were divided into three groups partly based on human factor analysis models in aviation that distinguish operational and pilot errors in the analysis (Shappell and Wiegmann, 1997; Thomas, 2004). The first group consists of accidents related to technical aspects and maintenance, such as drive system failures. The cause of such an accident can sometimes be found with the maintenance department of a flight operation. We have split up the second group, which contains pilot errors, into those occurring during flight and those being made during the pre-flight phase. The pilot errors during flight include in particular wire and tree strikes, when a pilot was not able to maintain a visual lookout. Errors in pre-flight checks appear as fuel contamination problems, a skid trapped by a cable or a failure to remove a hose or tie. When helicopters refuel or reload, the responsibility of pre-flight checks may be deferred to ground crew. Both pilots and ground crew could be blamed for errors in pre-flight checks, but in nearly all cases, the pilot is ultimately held responsible.

The causes and factors are reported by the NTSB examiner and in most cases the flight phase in which the accident took place is specified as well. Flight phases are otherwise easily distilled from the narrative text and since no or rare occasions exist in which the data could not be scored before an interpretation of the situation, it was not deemed necessary to include multiple scorers and calculate inter-scorer reliability.

2.3. Statistical analysis

The data are presented using descriptive statistics. Some data, such as the flight phase and cause of accident, were categorized in more detail than the broader categories used by the NTSB. This detail was distilled from the narrative statements that accompany the data. The descriptive data are analyzed, using Pearson's χ^2 analysis to relate particular factors.

3. Results

3.1. Aerial application

A total of 142 accidents during agricultural helicopter flights were recorded from 1998 through 2005. All aircraft were either substantially damaged (80%) or destroyed (20%). Out of 142 pilots, 112 (78%) received no or minor injuries, 18 (13%) were severely injured and 12 (9%) received fatal injuries. No ground crew was injured during any of these accidents.

Pilots had an average of 10,476 h of total flight time with the lowest reporting 276, the highest 32,600 and for six pilots the total flight time was not recorded. The average age is calculated at 47 years, the oldest pilot being 70 and the youngest 23 years of age.

Out of 142 accidents, 63 (44%) are attributed to pilot error in flight, 32 (23%) were caused by mechanical failures, 30 (21%) were caused by errors during preflight and 17 (12%) accidents featured a problem of which the cause remained undetermined. Errors in pre-flight checks were all attributed to pilot error although in two cases it was ground personnel that, was to remove a hose or tie and the pilot merely omitted to check the completion of that task. Mechanical failures were caused by company or other maintenance personnel in 12 cases or 38% of all mechanical failures and

mentioned as a factor or finding in 7 (22%) other cases. Errors by fuel trucks and manufacturer caused another 3 (9%) accidents with a mechanical related problem.

In 26 cases, an attempted autorotation landing, i.e. a procedure in which the pilot lands the helicopter with the engine off, was recorded for which no pilot fatality was recorded. Instead, fatal accidents resulted from a wire strike ($N=3$) and from a mid-air collision ($N=2$). Another two were caused by a system malfunction and one fatal accident was caused by a fuel problem and a subsequent loss of engine power. In four additional fatal cases the cause could not be determined by the NTSB examiner.

Seven phases of the operation were distinguished. The flights to and from the refueling or reloading area were taken as different phases. Table 1 illustrates the different flight phases in relation to maintenance related causes (1), pre-flight check related causes (2) and pilot error in flight (3).

The highest number of accidents appeared during the flight from the refueling or reloading station, often a truck with a landing platform. Flights from the platform were significantly more likely to have an accident related to preflight checks and maintenance as opposed to pilot error than flights to the platform ($\chi^2 = 4.85$, $df = 1$, $p < 0.05$). Causes related to pre-flight check errors contained at least 11 (37%) fuel-related problems and 6 (20%) instances in which a hose or tie was not removed before take-off.

There were 2 (1.4%) twin-engine helicopters in the data set, all other helicopters featured one engine only. Approximately 57% of the helicopters featured turbo shaft engines, 43% had reciprocating or piston engines. The causes relating to maintenance were not significantly different in comparison with other causes for the two engine types ($p > 0.05$). It was found that pilots above 40 years of age were significantly more likely to fly a turbo shaft engine than a reciprocated engine in comparison with pilots below 40 years of age ($\chi^2 = 4.45$, $df = 1$, $p < 0.05$).

3.2. External load

Out of 120 accidents with external load that occurred from 1995 through 2005, the aircraft were substantially damaged (74%), destroyed (22%) or without damage (4%). There were no cases where the aircraft suffered only minor damage. Out of 158 people involved in the accidents, which include injured ground crew and all passengers and flight crew, there were 27 fatalities, 37 severely injured and 94 people with minor or no injuries reported. Nine flights reported a second pilot and 14 helicopters carried passengers. Of the 27 fatalities, 20 (74% of all fatalities) were among the flight crew, 3 (11%) among the passenger crew and 4 (15%) among the ground crew.

In the four cases of ground crew fatalities, the cause of the accident was in two cases attributed to the ground crew when they entered an area before the necessary clearance or when they did not attach a load correctly. In one other case the pilot crashed the heli-

copter when a ground crew member was still on board. The last case involved a wire that struck a ground crew member, which was caused, according to the NTSB examiner, by inadequate management and ground crew coordination.

Out of the 120 accidents, 26 (22%) were caused by pilot error in flight, 48 (40%) by a mechanical failure, 35 (29%) by pre-flight related problems and 11 (9%) accidents showed a problem of which the cause remained undetermined. Pre-flight related problems included 4 accidents in which refueling or a fuel contamination problem was encountered. Dynamic rollovers were the result of 6 other pre-flight related problems.

In 9 (7.5%) external load accidents the helicopter was damaged by a dynamic rollover. Dynamic rollovers are caused by a tilting of the machine that cannot be stopped by a control input of the pilot. The skids may be entangled by the external load cable ($N=2$), passengers may imbalance the machine while entering or leaving the helicopter ($N=2$), loads that are too heavy may drag the helicopter to one side ($N=2$) or a skid that is snagged by matters on the ground can cause this rollover ($N=3$). Rollovers after hard landings are often found in helicopter accidents but dynamic rollovers as primary cause of the accident appear more prominent in external load operations than in helicopter accidents in general (cf. de Voogt and van Doorn, 2007). In comparison, aerial application accidents included only two (1.4%) dynamic rollovers, in both cases caused by a hose that was still attached to the helicopter during take-off.

In 16 cases, the accident was caused or had a contributing factor involving people other than the pilot crew. These included (combinations of) ground and other flight crew ($N=8$), company and other maintenance staff ($N=11$), but also manufacturers ($N=4$) and the Federal Aviation Authorities ($N=3$). The relative number of fatal accidents ($N=5$) and destroyed aircraft ($N=5$) is higher in this group than in the remainder of the data but this difference was not significant.

The dominant flight phase in external load operations is the hover. A hover out-of-ground effect that is at a height or in conditions where the downwash of the rotors do not provide a so-called ground cushion, occurred in 41% of the accidents with an additional 6% in a hover near the ground. High hovers complicate autorotations that require an optimal height and velocity ratio (see Manwaring et al., 1998 for a discussion). In our data, hover-related accidents showed a smaller number of pilot errors in flight, most probably since rotor strikes are more common during maneuvering than in a hover. The number of fatalities and the number of particular causes was, however, not significantly different when compared with the non-hover related accidents, nor were the number of twin engine helicopters more or less prominent in the hover phase.

Pilots had an average of 10,336 h of total flight time with the lowest reporting 492 and the highest 29,325 h. The accident involving the pilot with relatively few hours was partly attributed to a lack of experience. Compared to Manwaring et al. (1998) the average age went from 40 years average in the period 1980–1995 to 46 for the period 1995–2005. Pilots who had less than 10,000 h of total flight time were significantly more often part of in-flight or pre-flight related accidents as opposed to mechanical failures compared to pilots with 10,000 or more hours of total flight time ($\chi^2 = 14.42$, $df = 1$, $p < 0.01$). Those pilots with less experience were also significantly more likely to be part of fatal accidents as opposed to non-fatal accidents ($\chi^2 = 11.53$, $df = 1$, $p < 0.01$). No such relations were found in aerial application operations.

Out of 120 aircraft involved in the accidents, 105 had only one engine, the rest, 15 of them, had two. In only one case, the engine type was reciprocating; the remaining helicopters featured a turbo shaft engine.

In low-altitude operations, helicopters have an increased risk of colliding with trees, transmission wires, power lines or other high

Table 1

Flight phase in relation to the cause of aerial application accident expressed in number of accidents.

Cause/flight phase	Maintenance	Pre-flight	In-flight	Unknown	Total
1. Airport to site	1	0	0	1	2
2. Truck/platform to field	9	15	16	3	43
3. Field to truck/platform	1	3	11	4	19
4. Straight swath over field	7	4	10	4	25
5. Maneuvering on the field	9	4	21	2	36
6. From one field to another	2	1	0	0	3
7. From site to airport	0	0	0	1	1
8. Unknown flight phase	3	3	5	2	13
Total	32	30	63	17	142

Table 2

Rotor strikes in external load and aerial application operations.

	Trees	Wires	Structures	Load cable	All accidents
External load	18 (15%)	3 (2.5%)	1 (0.8%, tower)	17 (14.2%)	120 (100%) total
Aerial application	8 (5.6%)	25 (17.6%)	1 (0.7%, pole)	0	142 (100%) total

structures. In external load and aerial application accidents they make up 18% and 24% of all accidents, respectively. While external load operations feature 15% collisions with trees and 3.3% with wires or other structures, the distribution is opposite in aerial application where only 5.6% record trees and 18.3% show collisions with wires (see Table 2).

External load operations show fewer rotor strikes, but another 14% of accidents is made up of load lines or cables extending from the helicopter that collide with the tailrotor of the helicopter. In 10 accidents the tail rotor or the tail in its entirety was destroyed by the external load cable or in one case a banner, resulting in a grand total of 32.5% rotor strikes.

4. Discussion and recommendations

Manwaring et al. (1998) suggested a long list of possible improvements for external load operations, which could for an important part also be applied to the aerial application industry. They include the introduction of twin and turbo shaft engines, the enforcement of FAA rules and regulations, the setting and enforcement of policies at the company level for maintenance and safety in general, as well as improved training and equipment. The following conclusions partly relate to the suggestions made by Manwaring et al. (1998) but focus on the possible assuaging effects of additional crew.

The suggestion of introducing twin engines for these high risk operations does not seem to have had a following. The prohibitive costs of twin engine helicopters partly explains that only 12.5% of the helicopters reported in external load operation accidents and only 1.4% of helicopters in aerial applications accidents reported twin engines. In addition, accidents caused by fuel exhaustion, tail or main rotor strikes, and external cable entanglements appear frequent but cannot be remedied by a second engine. The high number of autorotations in the data set suggests that some advantage of twin-engine helicopters is to be expected but this is true for only those cases where a mechanical failure is identified that affects just one engine.

Turbine engines appear in over half of the aerial application accidents in the studied period, not unlike most helicopter operations, but they dominate external load operations where only one accident with a reciprocating engine was reported. Although turbine helicopters were more often found with experienced pilots, the absence of denominator data about the distribution of experienced pilots between piston and turbine engines prevents us from drawing conclusions from this finding. The distribution of accidents over flight phase and causes appeared not significantly related to the type of engine.

Pilots in high-risk helicopter operations are experienced and well-trained. In external load operations, more experienced pilots showed fewer fatal accidents and fewer in-flight or pre-flight related problems in the accidents, but this difference was found only after 10,000 h of flight experience. When such a pilot is part of an accident in which a visual lookout is not maintained or in which fuel starvation stopped the engine, it is rarely a lack of understanding and experience that causes the accident. Rather, the specialized

nature of the operation may require so much of a pilot that even tens of thousands of flight hours cannot compensate for the high demands put on the pilot. In high risk helicopter operations in general, a trained ground crew or an extended flight crew should mitigate future mishaps and reduce the risks of fatality and in-flight or pre-flight related accidents.

It is surprising and disconcerting that in only 7.5% of the flights that had an accident in external load operations, a second pilot was present. No dual pilot configurations were reported in aerial application. In the latter case, the presence of a second flight crew member seriously diminishes the maximum loads carried by the relatively small aircraft, mostly Bell 47 helicopters, used for crop-spraying. In both operations the presence of ground crew during maneuvering has not always been reported in or refuted by the NTSB reports, but could compensate for the absence of a second pilot.

The role of ground crew is limited to situations where the pilot and crew may cooperate. In external load operations this pertains to the hover flight phase, while in aerial application operations the crew is mostly present during reloading and refueling on a platform. It is these two situations that require particular attention.

In external load operations the pilot hovers at heights that are frequently on the edge of the safety envelope, where a specific height and velocity ratio is needed to ensure a safe recovery in case of an emergency landing (Manwaring et al., 1998). The external load and the terrain leave little room for a proper landing and in some cases the external load cannot be dropped due to the presence of ground personnel. This makes the emergency landing procedure particularly dangerous in these operations, which explains the large percentage of accidents in the hover phase. Ground personnel may even increase the risk of an accident by its presence underneath the helicopter, but is otherwise essential, since pre-flight check related accidents are most prominent in this flight phase.

Helicopters may refuel or reload on site, a procedure that is not always possible for airplanes. On site refueling is particularly common in aerial application flights. The cause of accident that is related to pre-flight checks shows that problems with fuel management lead to engine failure during flight in 37% of aerial application accidents. With the added risk of in-flight collisions, the flight phase directly after leaving an on-site truck or platform showed the highest instance of accidents. It is the one stage in which ground crews can effectively contribute to safety; they could have removed a hose or line, made sure refueling took place or checked for water contamination. The pilot is held responsible for preflight checks and fuel management, but it is clear that much is to be gained in overall accident mitigation if attention was paid to the role of ground crews in the refueling and reloading process during aerial application.

The demanding tasks of external loads and aerial application are illustrated by the high number of accidents during crucial stages of the operation. High hover and confined area maneuvers have led to collisions with trees and wires, while most dynamic rollovers appeared when leaving the loading area. The presence of wires in agricultural areas and trees in wood-logging operations shows that both suffer from the risk of rotor strikes. It is also in these situations that ground crew or additional flight crew can assist the pilot to maintain an adequate visual lookout.

Although the arguments for adding ground crew are numerous, their presence also adds risk. They can cause or become part of an accident or they may obstruct a safe landing area of a helicopter in trouble. No ground crew accidents occurred in aerial application, but external load operations reported 4 ground crew fatalities, which is 3.3% of all fatalities and thereby twice the percentage reported by Manwaring et al. (1998) for earlier years. It shows that ground crew safety management in high risk helicopter operations is essential for the benefit of the companies, the pilot and the ground crew itself.

The introduction of twin-engine helicopters or an additional pilot is complicated by cost and weight restraints in the above operations. The experience of the pilot leaves little to be desired but an evaluation of the responsibilities and training of the (ground) crew requires further study. The role of ground crew in high-risk helicopter operations shows a paradox of safety since ground crews can be cause of, victim or a mitigating factor in accidents. The presence of ground crews is, however, the most promising asset to the safety of high-risk helicopter operations, but only if their training and responsibilities are managed with a similar care and experience as found among the pilots.

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