# Helicopter Logging in Alaska – Surveillance and Prevention of Crashes

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## BACKGROUND

To many logging companies, the helicopter represents a viable option for yarding and transporting timber recently felled in areas that are otherwise inaccessible and/or unfeasible for conventional logging (because of rugged terrain, steep mountain slopes, increasing environmental restrictions, and rising costs).[1, 2, 3] Because of their unique capabilities, the use of helicopters in hauling logs and recently felled trees ("helicopter logging," "helicopter long-line logging," "heli-logging," or "aerologging") has steadily increased in the logging industry. Unfortunately, helicopter logging in some areas, such as southeast Alaska, has been an extremely high risk operation, resulting in helicopter crashes with severe traumatic injury and death to pilots and loggers. A series of serious crashes in Alaska during 1992 and 1993 brought these operations to our attention. We believe that much can be learned from the Alaskan experience with this relatively recent technology. This book presents recent experience with these operations in Alaska, followed by a summary of the larger (U.S.) experience with this rapidly expanding industry, and recommendations for prevention of injuries.

## ALASKA INVESTIGATIVE FINDINGS

The National Transportation Safety Board (NTSB) investigated six helicopter crashes related to transport of logs by cable (long-line) that occurred in southeastern Alaska during January 1992-June 1993, and which resulted in nine worker fatalities (five loggers and four pilots) and 10 worker injuries (five loggers and five pilots) (Table 1). The following summarizes case investigations of these incidents:

**Incident 1.** On February 23, 1992, a helicopter crashed while transporting nine loggers. The copilot and five loggers were fatally injured; the pilot and four loggers were seriously injured. The NTSB investigation revealed that a long-line attached to the belly of the helicopter became entangled in the tail rotor during a landing approach, causing an in-flight separation of the tail section with subsequent crash.[4,5] Passenger flights with long-line and external attachments are illegal and violate industry safety standards.[6]

**Incident 2.** On March 6, 1992, a helicopter crashed while preparing to pick up a load of logs with a long-line while in a 200-foot hover. The pilot and copilot were seriously injured. According to the pilot and copilot, the engine failed, and the pilot immediately released the external log load and attempted autorotation.[4] NTSB investigation revealed a hole in the side of the rear section of the engine case, which had occurred when the engine failed.[4, 7] Further NTSB investigation revealed fatigue failure of the compressor assembly impeller, and inadequate quality control by the manufacturer. Inadequate routine maintenance by the operator was also cited in this incident.

**Incident 3.** On November 10, 1992, a helicopter crashed while attempting to land at a logging site, sustaining substantial damage. The solo pilot was not injured. NTSB investigation revealed that the helicopter's long-line had snagged on a tree stump during the landing. Further investigation revealed that the company had no documented training program.[4, 8] Thorough training in long-line lift-load techniques might have averted this occurrence.

Helicopter Logging Incidents, Alaska, 1992-1993

| Date | # Killed | # Injured | Type of Helicopter | Logging Company |
|---|---|---|---|---|
| 2/23/92 | 6 (co-pilot and 5 loggers) | 5 (pilot and 4 loggers) | Manufacturer A, type A Single-engine | Company A |
| 3/6/92 | 0 | 2 (pilot and co-pilot) | Manufacturer A, type A Single-engine | Company A |
| 11/10/92 | 0 | 0 | Manufacturer A, type B Single-engine | Company A |
| 2/19/93 | 2 (pilot and co-pilot) | 0 | Manufacturer A, type A Single-engine | Company B |
| 5/2/93 | 1 (solo pilot) | 1 (ground crew logger) | Manufacturer A, type C Single-engine | Company B |
| 5/8/93 | 0 | 2 (pilot and co-pilot) | Manufacturer A, type A Single engine | Company B |

Table 1

**Incident 4.** On February 19, 1993, a helicopter crashed from a 200-foot hover after transporting two logs to a log drop area. The pilot and copilot were fatally injured. NTSB investigation revealed an in-flight metal fatigue failure of a flight-control piston rod. Evidence indicated that log loads routinely carried by the helicopter exceeded the aircraft's weight and balance limitations. Laboratory examination of the flight-control hydraulic system revealed a degree of binding and wearing not consistent with normal wear.[4, 9]

**Incident 5.** On May 2, 1993, a helicopter crashed during an attempted emergency landing after using a long-line to lift a log to an altitude of 1,200 feet above ground level followed by rapid descent to a 75-foot hover. The solo pilot was killed, and a logger on the ground was injured. NTSB investigation revealed an in-flight separation of the tail rotor and tail rotor gear box from the helicopter. Investigative evidence indicated that log loads routinely carried by the aircraft exceeded its weight and balance limitations. Additionally, according to NTSB, on the day of the crash the company "...was reportedly using a procedure that would have heavily loaded the helicopter drive train, e.g., autorotating with a heavy external load from a point near the logging site to a drop point at a lower altitude where a full power recovery to a hover was executed before dropping the external load".[4] Further, records associated with the helicopter gear box showed that it had been purchased (by the company) as surplus from the U.S. Army, which had removed it from service in 1986 because of "excessive wear".[4, 10]

**Incident 6.** On May 8, 1993, a helicopter crashed after attempting to lift a log from a logging site with a long-line. The pilot and copilot sustained minor injuries, and the aircraft was substantially damaged. NTSB investigation revealed that company maintenance personnel had recently installed the engine and that the engine failed because machine (metal fastening) nuts had come loose from the engine or its housing and became caught in the engine. The helicopter crashed as the pilot attempted autorotation. Investigative evidence indicated that log load weights for flights over the preceding 2 weeks had substantially exceeded the maximum authorized gross weight of the helicopter. [4, 11]

## EPIDEMIOLOGIC ANALYSIS

Statewide occupational injury surveillance in Alaska through a federal-state collaboration was established in mid-1991, with 1992 being the first full year of comprehensive population-based occupational fatality surveillance for Alaska.

During the time these incidents occurred, an estimated 25 helicopters in Alaska were capable of conducting long-line logging operations; approximately 20 were single-engine models from one manufacturer (Federal Aviation Administration [FAA], unpublished data, 1993). Approximately 50 helicopter pilots were employed in heli-logging operations in southeastern Alaska (FAA and Alaska Department of Labor, unpublished data, 1993). Using these denominators, the events reported here were equivalent to an annual crash rate of 16% (6 crashes/25 helicopters/18 months), 0.24 deaths per long-line helicopter in service per year (9 deaths/25 helicopters/18 months), and an annual fatality rate for long-line logging helicopter pilots of approximately 5,000 deaths per 100,000 pilots, or 5% (4 pilot deaths/50 pilots/18 months).[12] In comparison, during 1980-1989, the U.S. fatality rate for all industries was 7.0 per 100,000 workers per year; Alaska had the highest overall occupational fatality rate of any state (34.8 per 100,000 per year) for the same period.[4]

According to NTSB investigations, all six crashes involved "...improper operational and/or maintenance practices that reflected a lack of FAA surveillance of logging operations (routine regulatory inspections of long-line helicopter logging) at remote sites in southeast Alaska".[4] NTSB further stated that, "The inadequate surveillance allowed unsafe operations and maintenance practices to continue until fatal accidents caused those practices to be detected".[4] In one-half of these incidents (numbers 4, 5, and 6 above) investigative evidence also indicated that log loads routinely exceeded weight and balance limits for the aircraft.

All of these severe incidents occurred among helicopters operated by two companies using single-engine aircraft (Table 1). To enable a more thoughtful approach to this analysis, proven and putative risk factors for these events have been arranged in a time-phase or Haddon’s matrix (Table 2). These events are often the result of the interaction of many different factors.

## OVERVIEW OF HAZARDS OF HELICOPTERS AND SLING-LOAD LOGGING OPERATIONS

Helicopters are very complex machines with an inherent requirement for constant vigilance and input from the pilot during flight, and extraordinary maintenance requirements between flights. In contrast to conventional fixed-wing aircraft, helicopters can take off and land vertically, but are not self-trimming (i.e., able to maintain stable or level flight when control surfaces are in a neutral position), and cannot successfully move or hover without constant input to the controls by the pilot. The aerodynamics of these machines are fundamentally unforgiving, as they do not glide, and when the engine stops, free-fall commences immediately, and can only be arrested by successfully restarting the engine or by autorotation maneuvers. Autorotation allows a helicopter to make an unpowered descent by maximizing on the windmilling effect and orientation of the main rotor. Forward airspeed and altitude can be converted to rotor centrifugal energy to reduce the rate of descent. However, successful autorotation depends on helicopter airspeed and altitude when the maneuver is attempted (see Figure 1, Height-Velocity Curve [often referred to as the “Dead Man's Curve”] for Autorotation).[13] Most helicopter logging operations are conducted at an altitude of less than 500 feet while at a hover or very slow airspeed, which is dangerously within the height-velocity curve for single-engine helicopters, as illustrated. This chart also displays the location of the six previously mentioned crashes, all dangerously inside this curve.

Features of Alaska Helicopter Logging Injury Events (after Haddon)

| | Host/Human | Agent/Vehicle | Environment |
|---|---|---|---|
| Pre-event/ Pre-injury | Pilot<br>Training ,<br>Experience,<br>Fatigue,<br>Stress,<br>Rx, illegal drugs<br>Alcohol<br>Ground crew<br>Training<br>Experience | Helicopter design<br>Lift, durability;<br>Maintenance & repairs<br>Engines & controls<br>Ergonomics<br>Unstable work platform;<br>Surplus/improvised equipment | Terrain<br>Weather<br>Landing zones<br>Oversight<br>FAA (CFR pt 133)<br>industry |
| Event/Injury | Pilot<br>Reaction to emergency situation (i.e. autorotation),<br>Task overload<br>Ground crew<br>Reacting, avoiding | Helicopter<br>Autorotation performance:<br>deformation on impact;<br>Fires & explosions | Terrain<br>Weather |
| Post-event | Types of injury, severity | | Little assistance available<br>EMS not available |

Table 2

Even when successful autorotation is possible, suitable emergency landing sites in logging areas are rare. In short, such complex operations under these extreme and demanding circumstances, combined with frequent overloading of equipment (whether inadvertent or intentional), greatly increase the likelihood of both human error and machine failure.[14]

Helicopter flight is also comparatively dangerous overall: according to NTSB 1990 data, the rate of fatal crashes for unscheduled flights in helicopters is 14.5 per million hours flown, 18-fold that for fixed-wing aircraft, 0.82 per million miles flown.[15] Helicopter pilots have been well-documented to be an especially high-risk group for fatal occupational injuries.[16]

Helicopter logging operations place heavy demands on helicopter machinery and associated equipment. A typical logging helicopter carries an approximately 200-foot cable or long-line, which is attached by a hook to the belly of the helicopter.

A second hook is attached to the free end of the long-line, where a choker cable (a cable apparatus designed to cinch or "choke" around suspended logs) is connected to haul from one to four logs per load (a load may weigh from 6,000 to 10,000 pounds); the hook is opened and closed electronically by a hand control located in the helicopter cockpit.

A helicopter used in logging operations may complete up to 250 or 300 load/lift cycles, or "turns," each day; each turn takes one to three minutes to complete. These highly repetitive lift/transport/drop "turns" have been reportedly conducted at or beyond the maximum rated lift-load capacity for that aircraft, in remote areas where rugged forest terrain, extremely steep mountain slopes (as great as 70 degrees), and adverse weather conditions prevail. Under these conditions, and when combined with poor equipment maintenance, helicopter flight components and equipment have been known to fail with tragic regularity.[12, 17]

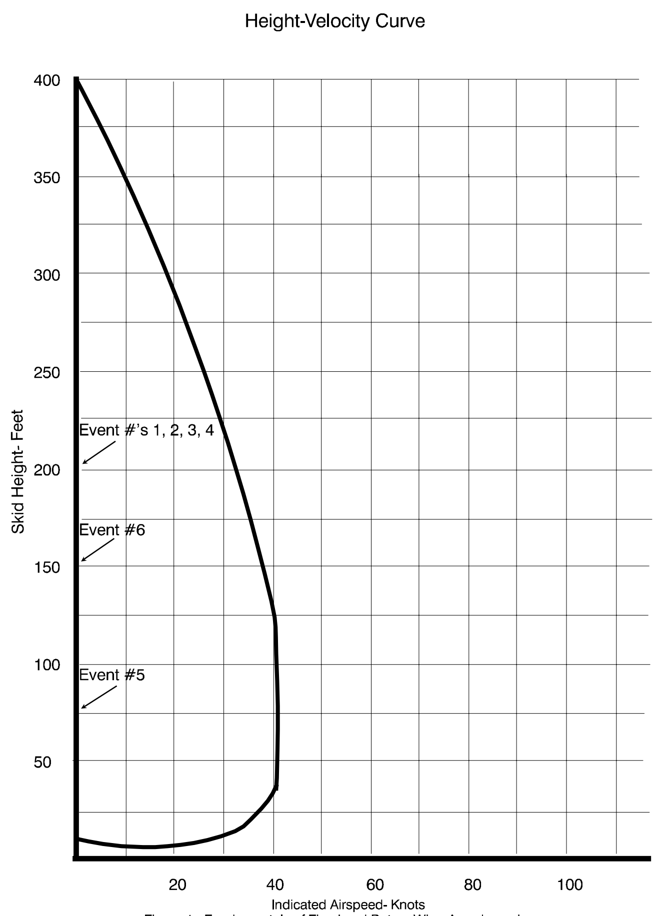


Figure 1: Fundamentals of Fixed and Rotary Wing Aerodynamics
Adapted from curve illustrated in Part I Fundamentals of Fixed and Rotary Wing Aerodynamics
by H.E. Roland, Jr. and J. F. Detweiler, University of Southern California, November 1967

The majority of experienced pilots we have interviewed reported having much greater confidence in multi-engine helicopters. One pilot with 20 years experience (and over 18,000 flight hours) in helicopter logging stated his concerns about heli-logging with single-engine helicopters and the need for redundant systems: To quote from Mr. Mark Lindamood, elsewhere in this volume: "Imagine accelerating your automobile engine from idle, to full throttle 320 times a day, six days a week, 52 weeks a year. Engines do quit, clutches fail, inputs fail, fuel pumps stop pumping, accessory drive shafts break, power plants do stop running, and most always at times when the pilot least expects it to happen. However, if he is flying a helicopter with two engines, things are a whole lot easier to handle....These helicopters have: (in addition to 2 engines), 2 servo systems, 2 electrical systems, 2 fuel systems, and 2 pilots!".[18]

Another human factors concern is the tremendous potential for task overload in solo pilots. The experienced heli-logging pilot quoted above also stated, "The small single-engine aircraft usually have only one pilot who flies all day long. He must divide his attention between the engine temps, pressures, power gauges, warning lights, fuel quantity, and weight cell, as well as watching his load to keep it clear of obstacles and ground personnel and his rotor blades out of the trees. While concentrating on all this, he very often lifts off too much weight and over grosses the aircraft before he realizes it."[12, 18] Under such complex operations, it is not uncommon for a helicopter long-line to suddenly snag on a tree, log, stump, or forest debris, occasionally with a disastrous outcome.

From a human factors standpoint there are other concerns. Helicopter logging, as well as other external load helicopter operations (which are regulated under the Code of Federal Regulations [CFR], Part 133) include (non-regulated) flight crew duty periods which can exceed ten hours per day for ten consecutive days, and flying much of the time under conditions which are unfavorable for successful autorotation of single engine helicopters in the event of engine failure or loss of power. This practice may lead to fatigue of sufficient magnitude to be hazardous. Recent analyses of NTSB data for fixed-wing aircraft show that U.S. pilots involved in repeat crash incidents ("accident-prone" pilots) were twice as likely to have crashed in Alaska as other pilots. [19] Decrements in aircrew function due to fatigue from overlong and repeat missions were also documented during the Desert Shield Operation. [20]

Ground operations also pose unique hazards in helicopter logging. Fallers and buckers must be especially cautious of downwash/rotorwash (air moved at high velocity by the helicopter's main rotor[s], which may also knock limbs and debris onto ground crew). The long-line cable is made of steel, and must be grounded prior to being handled, because of its high static electrical (shock) potential. Loads can be accidentally released in transit, and crush those below. Ground crewmen have also been killed by walking or falling into a moving main or tail rotor, as has been well-documented in military settings.[21] Rigorous attention to communications, procedures, and protective equipment can mitigate these risks.[22] Also, many loggers and ground crew are transported to their worksites by helicopters, with the attendant risk of such transport (see incident 1, above).

Lastly, major attention in private-sector helicopter design to adequate occupant restraint, crash attenuation, and fire prevention has been relatively recent.[23] Modest modifications in occupant restraint, such as headrests and chest harnesses, as well a G-absorbing or crash-attenuating seats and well-tested fire attenuation systems, when combined, could prevent up to an estimated 95 percent of all helicopter fatalities, and likely a substantial proportion of those associated with heli-logging.[24, 25, 26, 15]

## HAZARD REDUCTION AND INJURY PREVENTION: THE INTERAGENCY RESPONSE IN ALASKA

In response to the six Alaska logging helicopter crashes in 1992 and through May 1993, we convened a meeting in Anchorage on July 8, 1993, to discuss approaches for reducing the number of such crashes and ameliorating the outcome of crash injuries. The meeting was attended by representatives from the Alaska Interagency Working Group for the Prevention of Occupational Injuries (consisting of the Alaska Department of Health and Social Services, Alaska Department of Labor (AKDOL), FAA, NTSB, OSHA, U.S. Coast Guard, the U.S. Forest Service, and NIOSH). The Working Group noted that there were no formalized training programs or standards of performance required by the FAA for helicopter long-line logging operations.

Furthermore, crash investigation teams had previously observed that operating standards did not comply with manufacturers' recommendations.

Based on these and other findings, the following eight recommendations were made by the working group. [12, 27, 28]

- All helicopter logging pilots and ground crews should receive specific training in long-line logging operations.
- Companies should follow all manufacturers' recommendations for more frequent helicopter maintenance (because of intensity and use) and for limits on maximum allowable loads.
- Companies should establish and observe appropriate limits on helicopter crew flight time and duty periods.
- Companies should consider the additional safety factor of using multi-engine helicopters for long-line logging.
- Specific industry-wide operating standards and procedures should be developed.
- Companies should provide training in on-site emergency medical care for helicopter logging crews at all work locations.
- State, regional, and local agencies involved in emergency medical services education should make low-cost emergency medical training available to persons likely to work in a helicopter logging environment.
- All flights over water should include appropriate survival equipment for all crew, who should wear personal flotation devices at all times during flights over water.

When these preventive interventions are superimposed on the risk time-phase matrix for these events (Table 3), it becomes clear that the emphasis chosen by the Working Group was on pre-event factors.

One other major concern was discussed during the July '93 Working Group meeting: According to CFR, Part 133, regardless of where helicopter logging operations are conducted, the jurisdictional responsibility for inspection currently resides with the FAA office nearest the main or registered corporate office for the helicopter logging company, no matter how distant the FAA office may be from the actual helicopter logging site. In the six Alaska cases in this report, these FAA offices were in Salt Lake City, Utah, and Riverside, California (this necessitates travel of great distances to conduct helicopter logging inspections, and therefore remote operations, such as encountered in southeastern Alaska may not be inspected for long periods). According to the NTSB, in the six Alaska heli-logging accidents, one operator had not received a prior onsite FAA inspection for two years, and the other operator had never received an onsite FAA inspection.[4] The NTSB has therefore recommended that operational and maintenance oversight responsibilities for remote heli-logging sites be assigned to the nearest FAA office.[4]

Alaska Helicopter Logging Injury Recommended Countermeasures
(From Alaska Interagency Working Group for the Prevention of
Occupational Injuries, July, 1993)

| | Host/Human | Agent/Vehicle | Environment |
|---|---|---|---|
| Pre-event/ Pre-injury | Increased training for pilots and ground crew<br>Improved work/ rest cycles | Maintenance per manufacturer's recommendations,<br>Impact (g)- resistant seats<br>NTSB- to prohibit surplus equipment | Improved interagency communication,<br>Increased FAA oversight |
| Event/Injury | Practical training in autorotation | | Emergency (backup) landing zones |
| Post-event | | | |

Table 3

During the summer of 1993, the FAA and AKDOL collaboratively increased their inspectional oversight of flight and ground operations at helicopter logging sites. Also, during this same period of time, two of the helicopter logging companies with the most operating problems, and who each accounted for three of these serious crashes, closed down their Alaska operations. Fortunately, there are other helicopter logging companies in southeast Alaska with outstanding safety records, that had already implemented the safety recommendations made by the Working Group. As a result, there were no further helicopter crashes or injuries in Alaska from May, 1993 until an isolated incident with one fatality in mid-1996, as shown in Figure 2 ("Crashes, Fatalities, and Non-fatal Injuries in Alaska Helicopter Logging Operations, 1989 -- 1996). Some have expressed a view that this decrease has been due to a decline in industry activity in Alaska since 1993. This question is a reasonable one, as the two companies accounting for most of the serious events withdrew from Alaska following the stepped-up oversight efforts by the FAA and AKDOL in mid-1993.

Overall timber harvest for lumber has remained relatively stable during this period (U.S. Department of Commerce data; 1999 is last year available):

Alaska Softwood Log Exports in Million Board Feet (MBF), 1991-1999

| 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|
| 517 MBF | 537 MBF | 500 MBF | 519 MBF | 543 MBF | 551 MBF | 586 MBF | 373 MBF | 416 MBF |

There has been a slight downward trend in Alaska employment patterns during the same period of time, mostly due to the closure of the lumber mill in Ketchikan (Alaska Department of Labor and USDA Forest Service, Region 10, Ecosystem Planning and Budget; 1999 is last year available):

Employment in the Wood Products Industry, Southeast Alaska, 1991-1999*

| 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|
| 3,069 | 2,863 | 2,650 | 2,225 | 2,002 | 1,911 | 1,551 | 1,269 | 1,190 |

*Total Direct Industry Employment

We have also surveyed the major current heli-logging operators in Alaska for their production levels over the same period of time:

Helicopter Logging, Southeast Alaska in Million Board Feet, 1991-1999

| 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|
| 23 MBF | 44 MBF | 78 MBF | 120 MBF | 183 MBF | 107 MBF | 137 MBF | 63 MBF | 52 MBF |

By 1995, over 180 MBF, or 38% of all of Alaska's raw lumber, was being harvested by helicopter, a huge increase over the 4% to 5% estimated for 1991. In the immense Tongass National Forest (the primary setting for Alaskan logging), the percent of acreage in timber sales requiring helicopter logging has increased from 5% in 1986 to 31% in 1997. This parallels an increase in the fraction of logging accomplished by helicopter in temperate and tropical rain forests worldwide. This transition is being largely driven by environmental pressures, as heli-logging permits selective logging without the construction of roads.

Thus, the sharp decrease in helicopter crashes and resultant fatalities observed since mid-1993 is much more likely the result of concerted efforts by industry (via adoption of voluntary standards), jurisdictional (via increased oversight and enforcement of regulations), and research/prevention efforts (including our own use of surveillance data to persuade the other parties toward action), than changes in industry patterns.

Because of the previous Alaskan experience, a rising concern for heli-logging safety nationwide, and a projected increase in heli-logging due to environmental restrictions and economic factors, the Alaska Interagency Working Group for the Prevention of Occupational Injuries and NIOSH sponsored the first Helicopter Logging Safety Workshop in Ketchikan, Alaska, on March 1-2, 1995. The objectives of the Workshop were to: describe and analyze the risks of helicopter logging; share new aerologging technology; foster safety research in aerologging operations and technology; review current regulations governing helicopter logging; consider helicopter logging safety training opportunities and options; and draft consensus safety recommendations for helicopter logging.

The 65 workshop participants, representing 12 helicopter logging companies, four helicopter manufacturers, four industry associations, five federal agencies, two state agencies, six logging companies, one university, and a representative from the Helicopter Association of Canada, used a consensus-building group process to determine possible root causes, countermeasures, and action plans. Workshop participants drafted the safety recommendations for injury prevention in heli-logging, attached as Appendix A of this volume:[29] Subsequent developments and recommendations are detailed elsewhere in this volume.

## SUMMARY

Helicopter logging is an expanding industry in the U.S. and abroad. Helicopter pilots and ground crews involved in long-line logging operations face an extremely high risk for severe traumatic injuries resulting from helicopter crashes. Inadequate or inappropriate equipment, improper operational and/or maintenance practices, and the lack of adequate inspectional surveillance of helicopter long-line logging operations in Alaska have been frequently cited as the factors most strongly associated with the risk of crashes. The risks for fatal and serious injuries in this industry should and can be reduced by scrupulous attention to the needs of pilots, flight and ground crew, and equipment. To minimize these hazards, pilots and flight and ground crew need more rest and better training; helicopters and equipment need more frequent and intensive maintenance; and operators must adhere not only to existing regulations, but also to manufacturer recommendations for load, lift cycle, and other appropriate applications. The Alaska experience has shown that helicopter logging can be extremely hazardous. However, the most recent experience in Alaska also shows that careful attention to identifying and minimizing the risks and hazards can make it safer.


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### REFERENCES


1. Proctor, P.: “Ecological Benefits Boost Heli-logging”, Aviation Week and Space Technology, 140:65, May 9, 1994.

2. Stehle TC: “Helicopter Logging of Valuable Furniture Timber from Natural Rain Forest in the Southern Cape” South African Forestry Journal #155:51-53.

3. Georgia Forestry Commission, "Harvest By Helicopter - A New Way of Logging." Georgia Forestry, September 1986.

4. National Transportation Safety Board. "NTSB Safety Recommendation A-93-78 through -80." Washington, DC: National Transportation Safety Board, June 17, 1993.

5. National Transportation Safety Board, Final Report, Aviation, NTSB Accident/Incident Number: ANC92FA040, 1992-93, Washington, D.C.

6. Federal Aviation Administration. Code of Federal Regulations, Volume 14. Part 133 - Rotorcraft external load operations. Washington, DC: U.S. Government Printing Office, January 1992.

7. National Transportation Safety Board, Final Report, Aviation, NTSB Accident/Incident Number: ANC92LA044, 1992-93, Washington, D.C.

8. National Transportation Safety Board, Final Report, Aviation, NTSB Accident/Incident Number: ANC93LA015, 1992-93, Washington, D.C.

9. National Transportation Safety Board, Final Report, Aviation, NTSB Accident/Incident Number: ANC93FA033, 1992-93, Washington, D.C.

10. National Transportation Safety Board, Final Report, Aviation, NTSB Accident/Incident Number: ANC93FA056, Government Printing Office, 1992-93, Washington, D.C.

11. National Transportation Safety Board, Final Report, Aviation, NTSB Accident/Incident Number: ANC93FA061, 1992-93, Washington, D.C.

12. Centers For Disease Control and Prevention. "Risk for Traumatic Injuries from Helicopter Crashes During Logging Operations -- Southeastern Alaska, January 1992-June 1993." Morbidity and Mortality Weekly Report, July 8, 1994.

13. Roland HE Jr., Detwiler JF. Fundamentals of Fixed and Rotary Wing Aerodynamics, Part I. Los Angeles: University of Southern California, November 1967.

14. University of Southern California, Institute of Safety and Systems Management. Aircraft Accident Investigation Manual. Los Angeles: December 1992.

15. Bertoldo, R.: "Operational and Aircrew Factors in Helicopter Application", in Klatt, M., Hudson, D., and Conway, G.A. (Eds.): Proceedings of the Helicopter Logging Safety Workshop, March 1-2, 1995, Ketchikan, Alaska, Alaska Interagency Working Group for the Prevention of Occupational Injuries, Anchorage, Alaska, 1996, pp. 76-81.

16. Conroy C, Russell JC, Crouse WE, Bender TR, Holl JA: "Fatal occupational injury related to helicopters U.S. 1980-1985. Aviat. Space Environ. Med. 1992; 63:67-71.

17. Transportation Safety Board of Canada (TSB): "Aviation Occurrence Report: Hydra Management Ltd. Aerospatiale 332c Super Puma (Helicopter) C-GQRL, Quatam River, British Columbia, 03 October 1987" TSB, 1991.

18. Lindamood, M.: "Helicopter Logging from a Pilot's Perspective", in Klatt, M., Hudson, D., and Conway, G.A. (Eds.): Proceedings of the Helicopter Logging Safety Workshop, March 1-2, 1995, Ketchikan, Alaska, Alaska Interagency Working Group for the Prevention of Occupational Injuries, Anchorage, Alaska, 1996, pp. 76-81.

19. Baker, S.P., Li, G., Lamb, M.W., and Warner, M.: "Pilots Involved in Multiple Crashes: 'Accident Proneness' Revisited", Aviation, Space, and Environmental Medicine, 1995; 66:6-10.

20. Bisson, R.U., Lyons, T.J., Hatsel, C.: "Aircrew Fatigue During Desert Shield C-5 Transport Operations"Aviation, Space, and Environmental Medicine, 1993; 64: 848-53.

21. Crowley JS, Geyer SL. "Helicopter rotor blade injury: a persistent safety hazard in the U.S. Army" Aviat. Space Environ, Med. 1993;64:854-8.

22. Workers Compensation Board of British Columbia, Helicopter Operations in the Forest Industry, a Manual of Standard Practices. Richmond, British Columbia, November, 1990.

23. Vyrnwy-Jones P. " A review of Army Air Corps helicopter accidents 1971-1982." Aviat. Space Environ. Med. 1985; 56:403-9.

24. Krebs MB, Li G, Baker SP " Factors related to pilot survival in helicopter commuter and air taxi crashes." Aviat. Space Environ. Med.; 66: 99-103.

25. Glatz JD: "Energy Attenuation for crashworthy seating systems: past, present, and possible future development " Naval Air Development Center, Warminster, PA .

26. Springate CS, McMeekin RR, Ruehle CJ: “Fire deaths in aircraft without the crashworthy fuel system” Aviat. Space Environ, Med. 1989; 60 (10, Suppl.):B35-8.

27. Alaska Department of Health and Social Services, Division of Public Health, Section of Epidemiology, "Helicopter Logging: Alaska's Most Dangerous Occupation?" State of Alaska Epidemiology Bulletin. August 16, 1993, Bulletin #32.

28. Alaska Department of Health & Social Services, Alaska EMS Goals Document. Juneau, January 1993.

29. Klatt, M., Hudson, D., and Conway, G.A. (Eds.): Proceedings of the Helicopter Logging Safety Workshop, March 1-2, 1995, Ketchikan, Alaska, Alaska Interagency Working Group for the Prevention of Occupational Injuries, Anchorage, Alaska, 1996.