Final Report
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HumRRO

Civil Helicopter Wire Strike Assessment Study

Volume I

by

Mr. Clyde H. Tuomela (Project Director) and
Mr. Mark F. Brennan

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by Clyde H. Tuomela and Mark F. Brennan

October 1980

Volume I. Findings and Recommendations

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PREFACE

This report covers work accomplished during the ten month period from December 1979 through October 1980.

Volume I presents summary findings and recommendations based on an analysis of 208 civil wire strike accidents in the ten-year period 1970 to 1979. Volume II, *Accident Analysis Briefs*, contains a description and analysis of each accident. Volume II distribution is limited. Copies may be requested from the NASA technical monitor.

The work outlined was performed under contract NAS2-10505, NASA - Ames Research Center. The technical monitor was Mr. William Snyder of the NASA - Ames Research Center, Mail Stop 237-3, Moffett Field, California 94035.

This project was conducted at the HumRRO office, Carmel, California under the supervision of Mr. William C. Osborn, Director, Military Training Research Division. Principal investigator was Capt. Clyde H. Tuomela, USN (Ret). Major contributors were Col. Mark F. Brennan, USA (Ret) and Dr. Elaine N. Taylor.

EXECUTIVE SUMMARY

NTSB and FAA reports of 208 civil helicopter wire strike accidents for a ten-year period 1970-1979 are analyzed. It was found that 83% of the wire strikes occurred during bright clear weather.

Analysis of the accidents is organized under pilot, environment, and machine factors. Methods to reduce the wire strike accident rate are discussed, including detection/warning devices, identification of wire locations prior to flight, wire cutting devices, and implementation of training programs.

The benefits to be gained by implementing accident avoidance methods are estimated to be fully justified by reduction in injury and death and reduction of aircraft damage and loss.

Major findings are these:

1. Out of 331 persons involved, 37 (11%) died, 52 (16%) were seriously hurt, and 85 (26%) received minor injuries.
2. Eighty-eight aircraft (42%) were destroyed and 120 (58%) suffered substantial damage.
3. Dollar cost of aircraft loss and damage was $11,108,000.
4. The primary cause for 130 of the 208 accidents was, in the determination of the NTSB, the pilot's failure to see and avoid objects and obstructions.
5. The average age of pilots experiencing wire strikes was over 34 years.
6. Pilot experience in helicopter and fixed wing aircraft combined averaged over 4,200 hours.
7. Pilot helicopter experience averaged over 2,200 hours.
8. Seventy-nine pilots (38%) were aware of wire location prior to impact; 100 (48%) were not.

9. Of 100 agricultural accidents, 93 occurred during chemical application of which 38 involved toxic chemicals. Only one pilot reported being affected by chemical exposure in flight.

10. Of 21 fatal accidents, only 10 pilots had autopsy and toxic level tests performed.

11. In 95% of accidents, the ceiling was greater than 1,000 feet and corresponding visibility was greater than 3 miles -- the visual flight rule minimums. Eighty-three percent occurred with clear skies and unlimited visibility.

12. Eighty-seven percent of the wire strikes occurred in rural areas; 62% occurred over level terrain.

13. The greatest percentage of wire strikes in Agriculture occurred during swath runs (54%); during cruise in Air Transportation (24%) and Public Service (31%).

14. The wires struck were power (68%), telephone (17%) and guy (5%).

15. Wire height above ground was 40 feet or less in 68% of the accidents. Fourteen percent of the wire strikes involved long span wires - over 150 feet between supporting poles.

16. In 22% of the accidents, initial impact was with the main rotor blades of the helicopter; the main rotor mast was initially struck in 20% of the cases; tail rotor 15%, canopy 15%, and skids and spray boom 15%.

17. Uncontrolled landings followed wire strikes on different parts of the helicopter with the following frequency: main rotor mast 84%, skid or spray boom 79%, tail rotor 68%, main rotor 65% and canopy 43%.

18. It is estimated that a pilot warning device would have been beneficial in 76% of the accidents.

19. It is estimated that a pilot training program would have been beneficial in avoiding 56% of the wire strikes.

20. It is estimated that wire cutters would have been effective in 49% of the wire strikes.

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INTRODUCTION

Helicopter wire strike accidents are a problem in both the civilian and military sectors. In a study of 197 civil helicopter aerial application accidents for the years 1975-1977, for example, 19% were found to be caused by collision with wires and poles, the most common causal factor* (ref. 1). In the Army during the period 1971 to 1977, 74% of 1,100 obstacle strike mishaps were tree and wire strikes (ref. 2). Furthermore, utilization of civil helicopters is growing. This is illustrated by the growth of aerial application in the U.S. from 1968 through 1977 (see Figure 1), and by the projected growth in agricultural helicopter fleet size from approximately 1,100 in 1979 to 3,600 by the year 2000 (ref. 3). Comparable growth may be expected in other mission categories.

In recognition of the growth in utilization of civil helicopters and of current military tactics calling for nap-of-the-earth and contour flying, a number of investigators have undertaken studies in attempts to reduce wire strike accidents. Their efforts have concentrated on two aspects of hardware design: (1) development of wire detection and location display devices and (2) development of designs to increase the tolerance of helicopters to wire/pole/tree strikes (ref. 4, 5, 6, 7, 8, 9, 10). These developments are discussed and assessed in this report. While some work has been carried out to identify causal factors in wire strike accidents for specific missions (ref. 1, 3), an exhaustive study of available data to provide a better understanding of such mishaps has not been undertaken previously.

In the present study, the 208 National Transportation Safety Board (NTSB) civil helicopter wire strike accident reports for the ten-year period 1970-1979 were reviewed.

*Engine failure was a close second, accounting for 18% of the accidents.

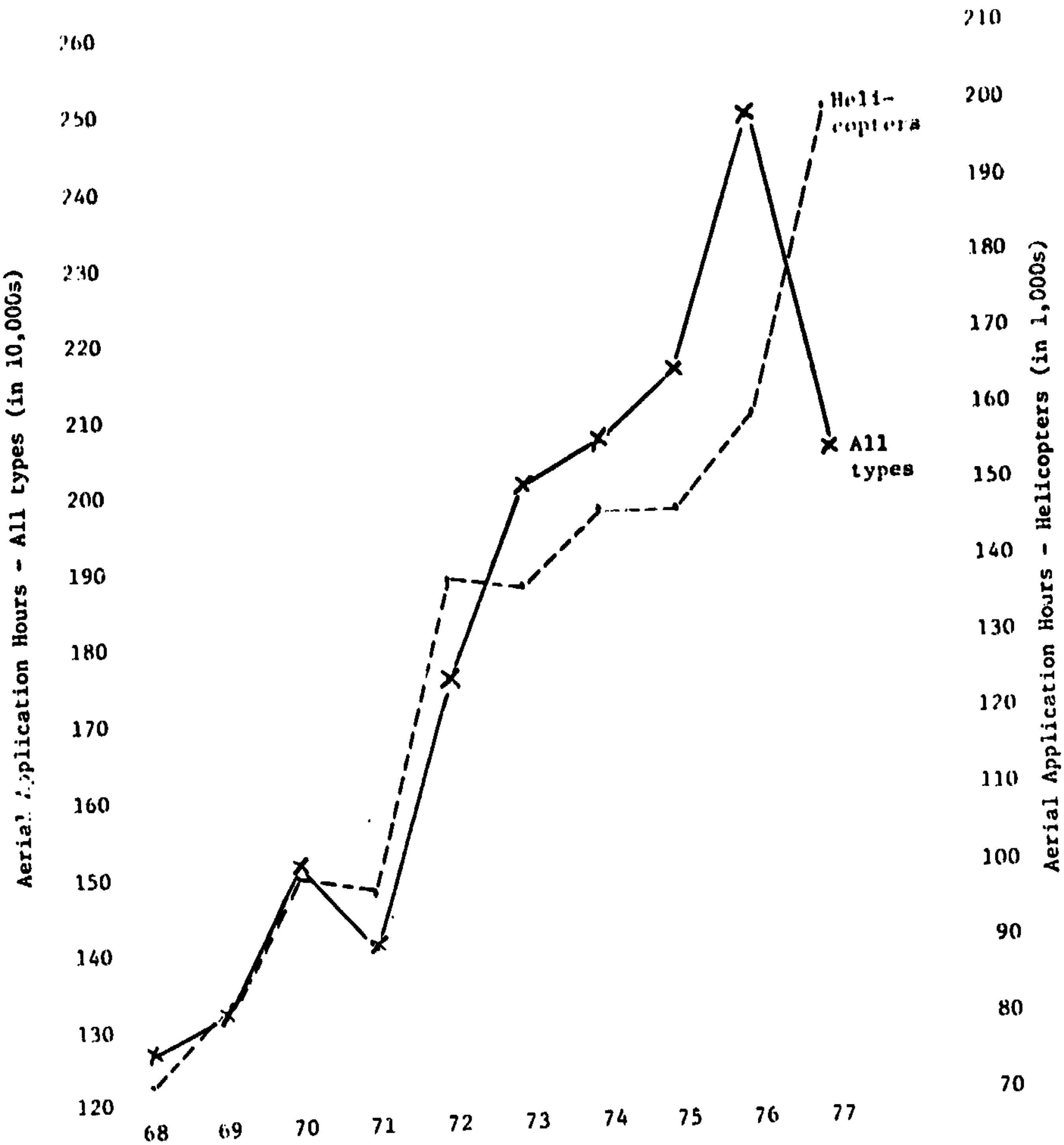

Figure 1. Utilization of Civil Helicopters in Aerial Application 1968-1977 (Based on data in Waters, 1979, p. 2)

The objectives of the project were

1. To identify factors, if any, that are common to the majority of wire strike accidents.

2. To assess the potential of existing technology and procedures, both military and civilian, for reducing civil wire strikes.

3. To recommend solutions that could substantially reduce the number of wire strike accidents.

4. To conduct a benefits assessment for each of the recommendations.

5. To study and list appropriate references on research and development in wire strike avoidance. References 1 through 18 are listed on pages 47-48 of this report.

6. To prepare a detailed analysis of each accident to include any recommendations for wire strike avoidance. Volume II of the report contains one-page briefs for 208 accidents.

This report contains Appendices A through D. They are:

Appendix A	—	208 Civil Aviation Helicopter Wire Strike Accidents by Type and Mission 1970-1979
Appendix B	—	Primary and Secondary Causes of Accidents
Appendix C	—	Synopsis of Helicopter Research and Development
Appendix D	—	Sample of Accident Analysis Briefs as contained in Volume II

FINDINGS

ACCIDENT RESULTS

The results of helicopter wire strike accidents illustrate the seriousness of the wire strike problem. The incidence of mishaps during the ten years studied is shown, by mission, in Table 1. Although Forestry was among the missions to be studied at the beginning of the project, no accident reports were received for that category. By NTSB definition (ref. 11), a reportable accident involves substantial aircraft damage, serious injury, or death. The data in this study, therefore, represent only part of the wire strike problem. While a quantitative assessment of the magnitude of civil helicopter wire strikes is not possible, a qualitative estimate is that the sample data reported here represent less than 10% of all wire strikes. As an example, in a briefing before the Airborne Law Enforcement Association, 19 May 1980, 110 helicopter pilots were asked about striking wires in flight. Twenty-two stated that they had struck wires, but no strike had resulted in an NTSB report.

TABLE 1

HELICOPTER WIRE STRIKE ACCIDENTS REPORTED TO NTSB
1970-1979

Agriculture	100
Air Transportation	87
Public Service	16
Construction	4
Cargo Handling (Off-Shore Oil Support)	1
Total Accidents	208

Because the incidence of Construction and Cargo Handling mishaps was so rare, these two missions will be combined into a Miscellaneous (MISC) category in following tables. MISC will be treated as the other categories, but findings for this category are extremely tentative, because of the small size of the sample.

Severity of injury to personnel is shown in Table 2. The percentage of persons injured is based on the total number of persons on board the helicopter, including passengers and crew members other than the pilot (see Table 3). When the Fatal and Serious categories are combined, the percentage of injuries is seen to be markedly higher in PS (60%) and MISC (83%) than in AG (15%) or AT (27%).

TABLE 2

SEVERITY OF INJURY

	Fatal	Serious	Minor	None	Number of Persons Involved
AG Agriculture (n=100 Accidents)	4 4%[a]	12 11%	28 27%	61 58%	105
AT Air Transportation (n=87 Accidents)	22 12%	28 15%	50 26%	40 47%	130
PS Public Service (n=16 Accidents)	11 37%	7 23%	6 20%	6 20%	30
MISC Miscellaneous (n=5 Accidents)		5 83%		1 17%	6
Total (n=208 Accidents)	37 11%	52 16%	85 26%	157 47%	331

[a]Percents are based on number of persons involved.

TABLE 3

NUMBER OF CREW MEMBERS AND PASSENGERS

	Crew Members Other than Pilot	Passengers
AG (n=100)	0	5
AT (n=87)	4	99
PS (n=16)	11	3
MISC (n=5)	0	1
Total (n=208)	15	108

The relation of fatalities and injuries to factors such as speed and mission will be discussed later in the report. However, it is significant to note that, although agricultural aviation requires the greatest exposure to wires, it has significantly fewer fatalities with wire strikes relative to other missions. While beyond the scope of this study, evaluation of the greater survivability of aviators in agricultural missions merits investigation.

The extent of aircraft damage is presented in Table 4. In our review of aircraft destroyed by fire, we noted that the aircraft generally caught fire after landing, and that wire strike damage itself might not have been extensive. In some cases the pilot was able to turn off all switches after crash landing. In other cases the pilot was too incapacitated to do so. Installation of an automatic fire suppression system on helicopters might do much toward cutting aircraft losses and fatalities caused by fire.

TABLE 4

EXTENT OF AIRCRAFT DAMAGE

	Substantial Damage	Destroyed (total)	Destroyed: Structural Damage	Destroyed: Destroyed by Fire
AG (n 100 Accidents)	58 58%	42 42%	26 26%	16 16%
AI (n 87 Accidents)	53 61%	34 39%	21 24%	13 15%
PS (n 16 Accidents)	8 50%	8 50%	3 19%	5 31%
MISC (n 5 Accidents)	1 20%	4 80%	1 20%	3 60%
(n 208 Accidents)	120 58%	88 42%	51 25%	37 18%

Costs of aircraft losses for the 208 accidents are presented in Table 5. These data were taken from the accident reports if recorded there. When costs were not recorded in the accident report, *The Helicopter Blue Book* for 1979 was used as a source (ref. 12). For a substantially damaged aircraft, two-thirds of the *Blue Book* figure was chosen as the loss figure. If the aircraft was destroyed, the replacement cost for the year of the accident was used. Thus, the cost data are a combination of NTSB-recorded costs and *Blue Book* costs. Apparently, the NTSB costs for destroyed aircraft are based on the original purchase price. Replacement costs during the year of the accident will usually be higher. Neither figure is the actual loss to the operator of the demolished aircraft. While much of this loss will be covered by insurance (usually 90%) the remainder is a direct loss to the operator.

It must be remembered that these are costs only of aircraft. Data on other costs, such as damage to property or persons on the ground, replacement of trained pilots, personal injury and death settlement costs, increased aircraft hull insurance, and law suit settlements, are not reported in the NTSB findings.

Over the ten-year period, there is a rising trend in cost of wire strike accidents, as would be expected in consideration of the rising costs of equipment in general for this period. Costs for the year 1978 are strongly influenced by two MISC accidents that involved two high-powered, relatively expensive aircraft (Hughes 500C and Sikorsky S-55T). These same two accidents exert a strong influence on the average cost of the five MISC accidents over the ten-year period. The make and model of all aircraft involved in the accidents are listed in Appendix A. The lower average cost of AG accidents and the fact that for eight of the ten years AG accident costs were lower than those of other groups is probably due to AG helicopters' being generally smaller, less expensive aircraft.

To recapitulate: for the 208 civil wire strike accidents in the ten-year period 1970-1979

1. Thirty-seven lives were lost.
2. Fifty-two people suffered serious injury.

TABLE 5

AVERAGE AIRCRAFT LOSS (M) AND TOTAL AIRCRAFT LOSSES (Σ)
1970 - 1979

		AG (n=100)	AT (n=87)	PS (n=16)	MISC (n=5)	Total 208)
1970	M	17,000	26,000	2,000	--	19,000
	Σ	116,800	127,500	2,000		246,300
1971	M	14,000	44,000	50,000	-	36,000
	Σ	70,000	397,000	149,000		616,000
1972	M	21,000	64,000		59,000	39,000
	Σ	210,200	382,000	--	117,500	709,700
1973	M	24,000	48,000	35,000		34,000
	Σ	289,100	383,400	104,600		777,100
1974	M	23,000	59,000	48,000		45,000
	Σ	116,500	469,500	95,000	--	681,000
1975	M	68,000	48,000	49,000		56,000
	Σ	612,100	476,500	146,000	--	1,234,600
1976	M	36,000	43,000	92,000	79,000	46,000
	Σ	392,870	690,500	274,500	79,000	1,436,870
1977	M	54,000	74,000	66,000		60,000
	Σ	919,132	515,600	66,000		1,500,732
1978	M	46,000	86,000		517,000	107,000
	Σ	410,300	1,118,900		1,033,000	2,562,200
1979	M	74,000	46,000			67,000
	Σ	1,115,500	228,000			1,343,500
Total	M	43,000	55,000	52,000	246,000	53,000
	Σ	4,252,502	4,788,900	837,100	1,229,500	11,108,002

3. Eighty eight aircraft were destroyed.

4. One hundred twenty aircraft were damaged substantially.

5. Over eleven million dollars in aircraft losses were incurred.

CAUSAL FACTORS

The primary and secondary causes of the wire strikes, as determined by the NTSB, are shown in Appendix B. These causes have been grouped into the five categories listed in Table 6. The most common cause of helicopter wire

TABLE 6

PRIMARY (P) AND SECONDARY (S) CAUSES OF ACCIDENTS[a]

	AG (92)		AT (84)		PS (16)		MISC (5)		Total (197)	
	P	S	P	S	P	S	P	S	P	S
Failure to see and avoid objects and obstructions	63	9	59	8	7	3	1		130	20
Inadequate Procedures	13	5	16	24	5	4	2	2	36	35
Errors in Judgment	11	3	5	3	1	1	1	2	18	9
Aircraft Failures	4	1	3	1	3	2			10	4
Miscellaneous	1	2	1	1			1	1	3	4

[a] Incomplete data. Eleven 1979 cases not yet received from NTSB as of 26 August 1980.

strikes is failure to see and avoid objects and obstructions. By mission category, "failure to see and avoid" is the primary cause in the following proportions of accidents: AG 68%, AT 70%, PS 44%, MISC 27%, overall average 66%. This report will place special emphasis on why the pilot fails to see and avoid objects and obstructions, and recommendations will concentrate o actions to correct that deficiency.

Causal factors are discussed in terms of the pilot, the environment, and the machine. Pilot factors examined include

- Age
- Experience
- Instrument qualification
- Health
- Prior knowledge of wire location
- Physiological factors (agriculture only)

Environmental factors examined include

- Weather: light conditions, cloud cover, visibility, and obstructions to vision
- Location and terrain
- Phase of flight
- Wire location, height, span, composition and visibility
- Wind and temperature

Machine factors investigated include

- Portions of the helicopter impacting wire
- Comparison of controlled *vs* uncontrolled landing following wire impact

Pilot

Age. Pilot's age by mission types is shown in Table 7. The distribution of ages is assumed to be representative of that of the overall helicopter pilot population. The average age of wire strike pilots was 34.7 years, an age at which aviation training, judgment, and physical condition are commonly regarded as optimal.

TABLE 7

PILOT AGE

	29 and under	30 to 39	40 to 49	50 and over	Not Reported	Average Age
AG (n=100)	40 40%	30 30%	24 24%	5 5%	1 1%	34.4
AT (n=87)	32 37%	27 31%	17 20%	10 11%	1 1%	35.5
PS (n=16)	4 25%	7 44%	4 25%		1 6%	34.0
MISC (n=5)	3 60%	1 20%	1 20%			30.0
Total (n=208)	79 38%	65 31%	46 22%	15 7%	3 1%	34.7

Experience. Pilot experience in all types of aircraft is shown in Table 8. A somewhat surprising finding is the large number of wire strike pilots with over 2,000 hours of total flight time. Overall, the average wire strike pilot had 4,207 hours of total flight time, certainly not a newcomer to aviation.

TABLE 8

PILOT EXPERIENCE
HELICOPTER AND FIXED WING COMBINED

	0-300 hours	301 to 1,000 hrs	1,000 to 2,000 hrs	Over 2,000	Not Reported	Average
AG (n=100)	2 2%	15 15%	10 10%	72 72%	1 1%	4,250
AT (n=87)	6 7%	10 11%	14 16%	57 66%		4,280
PS (n=16)		2 12%	4 25%	10 62%		3,373
MISC (n=5)				5 100%		4,748
Total (n=208)	8 4%	27 13%	28 13%	144 69%	1 .5%	4,207

Helicopter Experience. Helicopter experience is shown in Table 9. As with total flight experience, the number of wire strike pilots with over 2,000 helicopter hours is a large proportion of the total. Overall, the average wire strike pilot has 2,219 hours of helicopter time, clearly not a novice rotary wing aviator.

TABLE 9

PILOT EXPERIENCE
HELICOPTER

	0-300 hours	301 to 1,000 hrs	1,000 to 2,000 hrs	Over 2,000	Not Reported	Average
AG (n=100)	11 11%	23 23%	16 16%	49 49%	1 1%	2,345
AT (n=87)	24 28%	10 4%	16 18%	37 43%		1,976
PS (n=16)	1 6%	4 25%	4 25%	6 38%	1 6%	2,334
MISC (n=5)				5 100%		4,093
Total (n=208)	36 17%	37 18%	36 17%	97 47%	2 1%	2,219

Instrument Qualification. Table 10 illustrates the relation of instrument rating to accident outcome. It is concluded that the instrument rating of the pilots had no bearing on the seriousness of the accident, with respect either to damage or injury, since the differences in percentages of Not Rated and Rated pilots are relatively small.

TABLE 10

RELATIONSHIP OF INSTRUMENT RATING OF PILOT TO DAMAGE OF AIRCRAFT AND INJURIES

205 Accidents [a]

Aircraft Damage	Injuries [b]	Instrument Rating: Not Rated	Instrument Rating: Rated
Substantial	Fatal	1 1%	0 0%
	Serious	8 10%	5 12%
	None to Minor	70 89%	38 88%
	Subtotal	79 62%	43 55%
Destroyed	Fatal	13 27%	9 26%
	Serious	14 29%	11 31%
	None to Minor	21 44%	15 43%
	Subtotal	48 38%	35 45%
Total N		127	78

[a] Pilot rating was reported in only 205 of the 208 accidents.

[b] If a passenger was aboard, the data reported are for the most serious injury.

Pilot Health. All pilots are required to meet specific FAA physical standards to be authorized a medical certificate for flight. Pilot FAA medical classification is shown in Table 11. FAA Medical Categories, I, II and III are both time requirements between physical examinations and minimum requirements for qualification. The most stringent is Category I, the air transport pilot, requiring examination every 6 months, and the least stringent is Category III, the private pilot, requiring examination only every 24 months (ref. 13).

From the standpoint of this study, pilot vision is the most significant human factor consideration for the pilot's ability to see and avoid obstructions. FAA medical certification for pilot vision is basically the same for Category I and II pilots, with a lesser requirement for Category III. Flight with a Category III medical certificate (2% of the pilot records studied),

TABLE 11

PILOT HEALTH

	FAA Medical Category			Not Rep.	Waiver for glasses	Other Limitations
	I	II	III			
AG (n=100)	8 8%	92 92%			19 19%	
AT (n=87)	18 21%	63 72%	4 5%	2 2%	16 18%	3 3%
PS (n=16)	2 12%	13 81%		1 6%	1 6%	1 6%
MISC (n=5)		5 100%			2 40%	
Total (n=208)	28 13%	173 83%	4 2%	3 1%	41 20%	4 2%

however, does not necessarily imply a lesser vision capability. If carrying passengers for hire is not a mission requirement, a pilot with perfect vision might choose to retain only a Category III medical certificate for the convenience of the two-year interval between physical examinations.

The only valid indication of less than perfect vision that could be obtained from the accident reports is the requirement for the pilot to wear corrective lenses for flight. Of the 208 civil helicopter pilots involved in wire strikes, 41 (20%) required corrective lenses. This is considerably below the national average: according to the FAA Civil Aeromedical Institute (ref. 14), of 827,592 active pilots, 350,701 (42%) require vision correction.

Prior Knowledge of Wire Location. Pilot knowledge of wire location prior to the mishap is shown in Table 12. Of significance is the large number of

TABLE 12

PILOT'S PRIOR KNOWLEDGE OF WIRE

	Location of Wire Known	Location of Wire Not Known	Not Determined
AG (n=100)	50 50%	42 42%	8 8%
AT (n=87)	23 26%	50 57%	14 16%
PS (n=16)	3 19%	6 38%	7 44%
MISC (n=5)	3 60%	2 40%	
Total (n=208)	79 38%	100 48%	29 14%

agricultural pilots who knew where the wire hazard was located and flew into it nevertheless. Overall, wire strike pilots knew of the mishap wire location in 38% of the accidents.

A determination that the pilot had prior knowledge of wire location was made only if the NTSB accident report specifically stated so or it was clearly evident from the description of the accident. If anything, data in Table 12 are considered conservative.

The table highlights two areas of potential gain in wire avoidance: the ability of the pilot to see the wire and the ability to judge its distance and altitude. Note that 48% of pilots did not know the location of the wire prior to the wire strike - an indication that pilots need training in proper methods of wire reconnaissance if they have to fly low in wire areas. Misjudging distance to wires, or losing their location during flight - as suggested by the number of strikes that occurred when wire location was known - points up the need for training in wire avoidance procedures.

Physiological factors in agricultural missions. Agricultural aviation involves exposure to two hazards not normally experienced by other civil helicopter pilots: considerable low-level precision flight in the wire environment and exposure to chemicals. These aspects of AG flight raise the possibility of pilot fatigue and chemical effects as factors in AG wire strikes.

Figure 2 shows the hours flown on the calendar day of the accident, prior to the wire strike. While there is an increase in accidents in the fourth hour of flight over the third, these data are not by themselves sufficient to attribute the increase to fatigue.

Agricultural pilot exposure to chemicals as a result of wire strike accidents is shown in Table 13. There were three fatal accidents in Agriculture, with four fatalities. In all three accidents, the aircraft was carrying nontoxic chemicals. Autopsy and toxicity reports were negative.

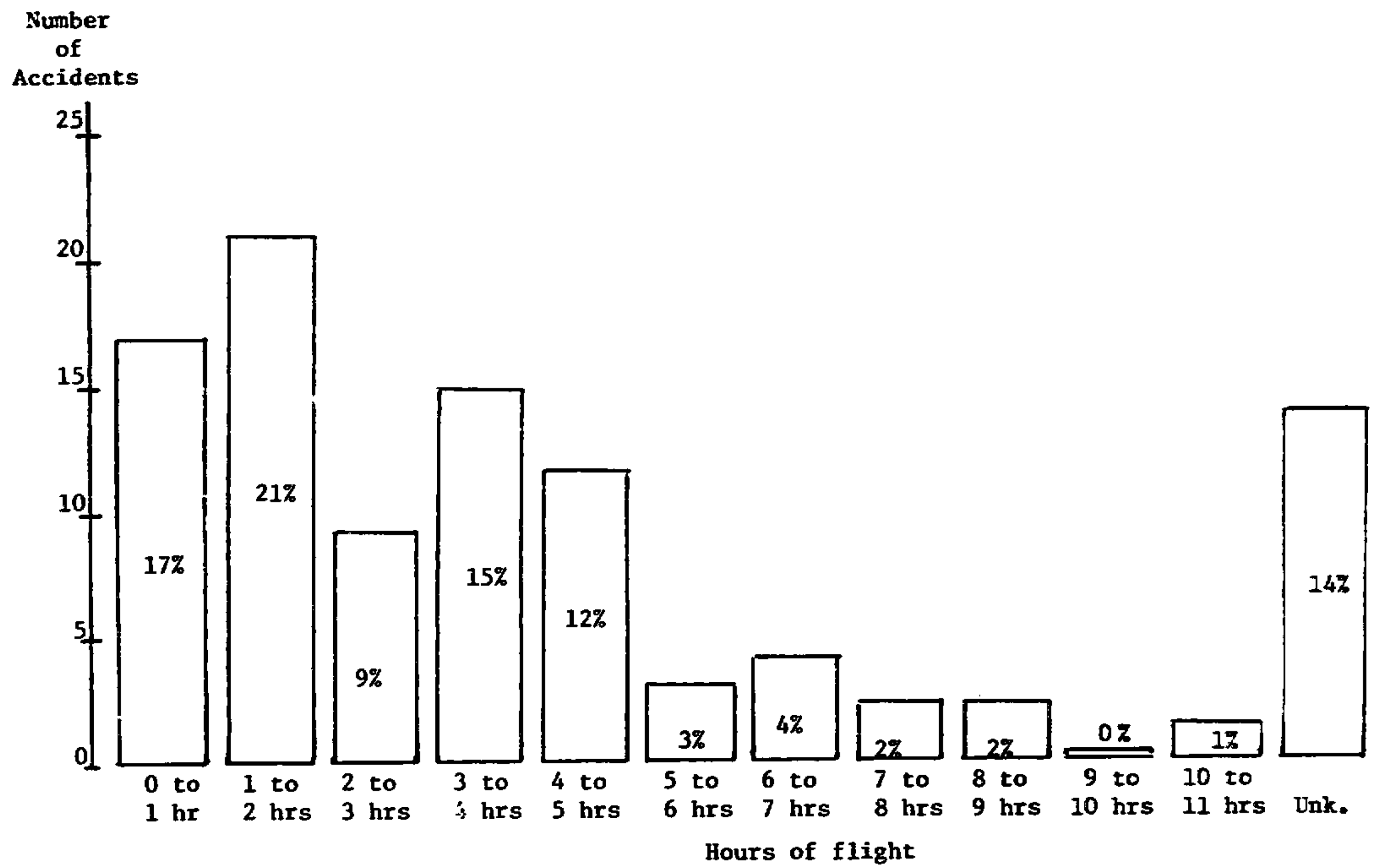

Figure 2. Flight hours on calendar day of accident - Agriculture only

(N = 100)

In three cases, pilots reported being affected by toxic chemicals. Two were affected on the ground, one in flight. Of the two affected on the ground, one had flown four hours that calendar day and reported being affected for five hours or less; the other had flown for two hours and was affected for 15 minutes or less. The pilot affected in flight had flown for 2 1/2 hours that day and reported being affected for 30 minutes or less. The small number of cases reported is insufficient to provide a basis for determining the influence on accident rates of pilot exposure to chemicals.

TABLE 13

PILOT EXPOSURE TO CHEMICALS
AGRICULTURE (AG)

Chemicals not used				7
Chemicals used:	Non-toxic chemicals		52	
	Toxic chemicals		38	
	Not reported		3	
		Subtotal	93	93
		Grand Total		100
Pilot exposure time to toxic chemicals:	15 minutes or less		11	
	15 to 30 minutes		2	
	30 minutes to one hour		2	
	2 to 4 hours		2	
	5 hours		1	
	Not reported		20	
		Total	38	
Pilot-reported effects of chemical exposure:	Not affected		87	
	Affected in flight		1	
	Affected on ground		2	
	No report		3	
		Total	93	

Table 14 shows pilot fatalities and whether autopsy and toxic level tests were performed on the pilot. Notable is that, out of 21 fatal accidents, only ten pilots had both autopsy and toxic level tests performed. The lack of autopsy and toxic level tests may well have a detrimental effect on determining accident cause. Such factors as the pilot's blood alcohol content, poisoning caused by exhaust carbon monoxide, heart attack, and strokes could go undetected. Although NTSB regulations require both an autopsy and a toxic level test to be performed on pilots involved in fatal accidents, the lack of agreement between various states and the federal government precludes a uniform policy for such action. In some states, the local coroner's assessment of the accident situation determines whether autopsy and toxic level tests will be performed. Such practical questions as who will pay for the autopsy also affect whether it will be performed. If accident victim autopsy and toxicity test results could be politically or socially embarrassing, tests might not be performed. A uniform national policy on performance of autopsy on fatal aircraft crash victims merits serious consideration. The performance of autopsy and toxic level tests in three out of three fatal agricultural accidents represents an administrative procedure that might be adopted for all helicopter missions.

TABLE 14

AUTOPSY AND TOXIC LEVEL TESTS
PERFORMED ON PILOTS IN FATAL ACCIDENTS

	Pilot Fatalities	Autopsy			Toxic Level Test		
		Yes	No	Not Reported	Yes	No	Not Reported
AG	3	3	0	0	3	0	0
AT	13	5	5	3	5	5	3
PS	5	2	2	1	3	1	1
MISC	0	0	0	0	0	0	0
Total	21	10	7	4	11	6	4

Environment

Weather. Examination of the data underlying Table 15 reveals that 197 of 208 wire strikes (95%) occurred when weather conditions were better than the visual flight rule (VFR) criteria of ceiling greater than 1,000 feet and corresponding visibility 3 miles or more. Eighty-three percent of the wire strikes occurred with clear skies and 88% with unlimited visibility.

Factors that might have impaired pilot vision were infrequently reported. The major restriction to pilot vision, haze or smoke, was present only in 9% of the 208 wire strikes. Another deterrent to vision, sunglare, was only present in 7% and rain, snow, or fog were mentioned as factors in only 4%.

Location and Terrain. Table 16 relates the incidence of wire strike to location and terrain. Overall, a high percentage of accidents occur in rural areas. This is not surprising in the case of agriculture pilots, since rural areas are the location of their work and airstrips. In other categories, it may be that pilots are more expectant of wires in the urban areas and exercise more caution in maneuvering there.

Also, the percentage of accidents taking place over level terrain is high. In the case of AG pilots who must fly close to the ground for proper application of chemical sprays and other products, the rate for level terrain (70%) can be understood. However, the percentage rates in the other categories may indicate the need for training pilots in the wire strike hazards of flying low over level terrain.

TABLE 15

WEATHER FACTORS

	Light Condition	Sky Condition: Ceiling ≤1000'	+1000'	Clear	Visibility < 3 mi.	3-5 mi.	Unlimited	Restrictions to Vision: Rain, snow or fog	Haze & Smoke	Sun-glare	Not Reported
AG (n=100)	Day (91)	1	9	81	1	9	81	1	8	9	
	Dawn/Dusk (6)	1	1	4	1		5	1		1	
	Night (3)	3					3				
AT (n=87)	Day (71)	3	10	55	2	4	62	2	8	4	3
	Dawn/Dusk (10)	1		9	1		9	1	1		
	Night (6)	1		5	1		5	1			
PS (n=16)	Day (8)		2	6			8	1	1		
	Dawn/Dusk (1)	1					1				
	Night (7)		2	5	1		6				
MISC (n=5)	Day (4)		1	3	1	1	2	1			
	Dawn/Dusk (1)			1			1				
	Night (0)										
Totals, each light condition (n=208)	Day (174)	4	22	145	4	14	153	5	17	13	3
	Dawn/Dusk (18)	3	1	14	2		16	2	1	1	
	Night (16)	1	2	13	2		14	1			
Total	208	8 4%	25 12%	172 83%	8 4%	14 7%	183 88%	8 4%	18 9%	14 7%	3 1%

TABLE 16

LOCATION AND TERRAIN

	Location			Terrain						
	Rural	Urban	Unk.	Level	Rolling	Hilly	Mountain-ous	Over Water	Over River/ Canyon	Unknown
AG (n=100)	100 100%			70 70%	18 18%	10 10%	2 2%			
AT (n=87)	66 76%	20 23%	1 1%	45 52%	6 7%	15 17%	11 13%	1 1%	3 3%	6 7%
PS (n=16)	10 63%	6 37%		11 69%	1 6%	1 6%	2 13%		1 6%	
MISC (n=5)	4 80%	1 20%		3 60%	1 20%		1 20%			
Total (n=208)	180 87%	27 13%	1 .5%	129 62%	26 12%	26 12%	16 8%	1 .5%	4 2%	6 3%

Phase of Flight. Table 17 shows, by mission, the phase of flight, estimated speed, and altitude at the time of the helicopter's impact with the wires. The phases of flight in which the Agriculture helicopters experienced the most wire strikes were the swath run, pull up from swath run, and in-flight turnaround. Air Transportation helicopters incurred the most accidents during the cruise, take-off, and low pass phases. Public Service helicopter wire strikes occurred most often during cruise, landing, and autorotation phases.

When the helicopter takes advantage of its vertical take-off and landing capabilities, it is inevitably exposed to the hazards of low-level flight. However, justifying helicopter *cruise* flight at wire-hazardous altitude (40 feet or less) is difficult. The percentage of wire strike accidents that occurred during the cruise phase of flight in the AT and PS categories at altitudes of 40 feet or less suggests a lack of pilot appreciation of wire hazards. Helicopter pilot wire strikes in cruise flight are a procedural error that could be avoided with wire hazard avoidance training.

Agriculture pilot wire strikes during the swath run are a more complex issue. The very nature of the agricultural aviation mission requires flying within a few feet of the ground. Under this condition, identifying field wire hazards and planning a flight path that will avoid wires is a demanding task. A more detailed analysis of Agriculture wire strikes by phase of flight is contained in Table 18.

Table 18 shows knowledge of wire location by phase of flight for Agriculture missions. When location of wires was known, the highest incidence of strikes occurred during swath runs (22%), pull up from swath runs (11%), and in-flight turnaround (11%). This may be attributed to misjudgment of distances to wires, loss of wire location in relation to pilot's placement over field, or attention to other mission requirements temporarily distracting the pilot from wire avoidance.

TABLE 17

PHASE OF FLIGHT, SPEED, AND ALTITUDE

	AG (n=100)	AT (n=87)	PS (n=16)	MISC (n=5)	Total (n=208)
Phase of Flight					
Take-off	4 4%	14 16%	2 12%	2 40%	22 11%
Climb	2 2%	8 9%			10 5%
Cruise		21 24%	5 31%	2 40%	28 13%
Low Pass		11 13%	1 6%		12 6%
Approach to Landing	2 2%	9 10%	1 6%		12 6%
Hover	1 1%	7 8%		1 20%	9 4%
Approach to Swath Run	7 7%				7 3%
Swath Run	57 57%				57 27%
Pull up from Swath Run	13 13%				13 6%
In-flight turnaround	13 13%	4 5%			17 8%
Landing		9 10%	4 25%		13 6%
Autorotation	1 1%	4 5%	3 19%		8 4%
Estimated Speed (Knots)					
30 and under	22 22%	45 52%	10 62%	4 80%	81 39%
Over 30	78 78%	42 48%	6 38%	1 20%	127 61%
Altitude (Feet)					
40 and under	87 87%	46 53%	9 56%	1 20%	143 69%
Over 40	10 10%	33 38%	5 31%	3 60%	51 25%
Not Reported	3 3%	8 9%	2 12%	1 20%	14 7%

The 30% of accidents that occurred during swath runs in which the pilot did not know the location of the wire can be attributed to improper or incomplete reconnaissance and hidden wires. The importance of thorough reconnaissance prior to swath runs must be emphasized in training. Location of all wires and selection of proper pull-up locations to avoid wires is essential if wire strikes in these areas are to be reduced.

TABLE 18

KNOWLEDGE OF WIRE LOCATION BY PHASE OF FLIGHT

Agriculture (n=100)

Phase of Flight	Location of Wire Known	Location of Wire Not Known	Not Determined
Take-off	2	2	
Climb		2	
Approach to Landing		1	1
Hover	1		
Approach to Swath Run	2	3	2
Swath Run	22	30	5
Pull up from Swath Run	11	2	
In flight Turnaround	11	2	
Autorotation	1		
Total	50	42	8

Wire Characteristics. Table 19 displays a variety of characteristics of the wires involved in the accidents. Power wires were involved in wire strikes more than twice as often as all other types of wire combined. Strikes occurred only half as often above 40 feet as at 40 feet or below.

The highest percentage of wire strikes occurred in the areas where wire density is light. Possibly pilots are more cautious about flying among wires in medium and heavy density areas or feel they have more maneuverability in the light density areas.

The number of strikes that occurred when poles were not visible, although less than 10%, is worthy of attention. It appears that pilots may see the wire, but, having no reference point on the ground such as a pole by which to judge the distance to the wire, hit it regardless.

The inability to judge distance to a wire is also highlighted in the number of long span wire strikes (over 150'). In a typical case, a pilot flew into long span power wires even though the supporting towers for the span were clearly visible on either side. If it is assumed that the human eye cannot accurately judge the location and distance to a long span wire, then the only safe course for a pilot would be to fly higher than the supporting towers themselves.

Wind and Temperature. Table 20 shows the incidence of accidents under various wind and temperature conditions. The higher percentage of mishaps in relatively calm air in Agriculture is undoubtedly due to the fact that AG pilots favor calm or very low wind conditions to avoid product drift. Seventy-eight percent of AG accidents took place with wind velocities under seven knots.

The table does not reveal any unusual relationships between temperature and incidence of wire strikes. Fifty-nine percent of the accidents took place in a temperature ranging from 33°F to 80°F, a range that may be considered within normal flight temperatures.

TABLE 19

WIRE CHARACTERISTICS

		Type[a]					Height above Ground			Number of Wires Struck			Density of Wires in area				Factors Affecting Wire Visibility				
		Power	Phone	Guy	Other	Not Rep.	40'& less	Over 40'	Not Rep.	2 or less	3 or more	Not Rep.	Light	Medium	Heavy	Not Reported	Blends with background	Pole(s) not visible	Wires hidden from view	IFR Conditions	Long Span Wire Strikes (over 150')
AG (n=100)	f	73	16	5	4	5	87	10	3	78	18	4	80	11	4	5	6	6	5	1	4
	%	73	16	5	4	5	87	10	3	78	18	4	80	11	4	5	6	6	5	1	4
AT (n=87)	f	57	17	4	4	5	46	33	8	69	9	9	53	14	11	9	3	12	2	2	22
	%	66	20	4	4	6	53	38	9	80	10	10	61	16	13	10	3	14	2	2	25
PS (n=16)	f	11	2	1		2	9	5	2	9	4	3	6	3	7			1			4
	%	69	12.5	6		12.5	56	31	12.5	56	25	19	38	19	44			6			25
MISC (n=5)	f	1	1	2	1		1	3	1	3	1	1	3	1	1				1		
	%	20	20	40	20		20	60	20	60	20	20	60	20	20				20		
Total (n=208)	f	142	36	12	9	12	143	51	14	159	32	17	142	29	23	14	9	19	8	3	30
	%	68	17	5	4	5	68	24	7	76	15	8	68	14	11	7	4	9	4	1	14

[a]Some strikes involve more than one type of wire.

TABLE 20

WIND VELOCITY AND TEMPERATURE

	Wind Velocity (Knots)						Temperature (Fahrenheit)					
	Calm	1-3	4-6	7-10	11-45	Not Reported	-32°	33-65°	66-80°	81-95°	96+°	Not Reported
AG (n=100)	26 26%	21 21%	31 31%	12 12%	1 1%	9 9%	2 2%	25 25%	40 40%	18 18%		15 15%
AT (n=87)	12 14%	10 11%	21 24%	19 22%	17 20%	8 9%	4 5%	28 32%	25 29%	14 16%	1 1%	15 17%
PS (n=16)	3 19%		3 19%	3 19%	6 38%	1 6%	3 19%	4 25%	1 6%	5 31%		3 19%
MISC (n=5)	2 40%			1 20%	2 40%		1 20%		1 20%	2 40%		1 20%
Total (n=208)	43 21%	31 15%	55 26%	35 17%	26 12%	18 9%	10 5%	57 27%	67 32%	39 19%	1 .5%	34 16%

Machine

This section of the report presents data regarding which portion of the helicopter impacted with wires and the direction of movement at the time of impact (Table 21) as well as the relation between impact location and whether landing was controlled or uncontrolled (Table 22). Wire strike aircraft manufacturer and model are contained in the individual accident summaries that supplement this report as well as in Appendix A.

Analysis of Table 21 does not reveal a high percentage of wire strikes on any one part of the helicopter; the chances of hitting one part are about equal to those of hitting another. Since most of the accidents occurred during forward motion, it may be that pilots are having difficulty detecting and judging distance to wires at all reference points in their span of vision: above, directly in front, and below.

In considering the type of landing following wire impact and the extent of damage (Table 22), it should be kept in mind that determining controlled or uncontrolled descent from a wire strike is difficult in many cases and that judgment was exercised in making the designation. Autorotations, which seemed to give the pilot some latitude in selection of a landing site, were considered controlled descents. In cases in which the aircraft landed right side up, the pilot was also given credit for a controlled descent. Even so, 67% of the landings following wire strikes were considered uncontrolled descents.

The most critical area for initial wire impact was the main rotor mast, probably due to the close proximity of main rotor blade control linkages. Eighty-four percent of the initial wire impacts with the main rotor mast resulted in an uncontrolled descent, with nine aircraft destroyed and seven damaged substantially. Mechanical wire cutters to protect the main rotor controls should receive design consideration. Also, future designs should include suitable shielding to protect main rotor control linkages.

TABLE 21

PART OF HELICOPTER STRIKING WIRES AND DIRECTION OF MOVEMENT

	Part of Helicopter Initially Impacting with Wires						Direction of Movement		
	Main Rotor Blades	Main Rotor Mast	Tail Rotor Blades or Tail Boom	Canopy	Skids or Spray Boom	Not Reported	Forward Motion	Tail Rotor Motion	Not Reported
AG (n=100)	20 20%	17 17%	10 10%	14 14%	22 22%	17 17%	85 85%	10 10%	5 2%
AT (n=87)	20 23%	18 21%	17 20%	14 16%	9 10%	9 10%	64 74%	16 18%	7 8%
PS (n=16)	4 25%	6 38%	3 19%		3 19%		13 81%	3 19%	
MISC (n=5)	2 40%	1 20%	1 20%			1 20%	2 40%	2 40%	1 20%
Total (n=208)	46 22%	42 20%	31 15%	31 15%	31 15%	27 13%	164 79%	31 15%	13 6%

TABLE 22

CONTROLLED *VS* UNCONTROLLED LANDING
FOLLOWING WIRE STRIKE

Initial Impact	Uncontrolled Landing	Controlled Landing	
Main Rotor/Rotor Head			
Substantial Damage	16	21	
Destroyed	28	3	
Total	44 65%	24 35%	68 Accidents
Tail Rotor/Tail Boom			
Substantial Damage	12	12	
Destroyed	14	–	
Total	26 68%	12 32%	38 Accidents
Bubble/Canopy			
Substantial Damage	3	16	
Destroyed	10	1	
Total	13 43%	17 57%	30 Accidents
Skid/Spray Boom			
Substantial Damage	12	6	
Destroyed	10	–	
Total	22 79%	6 21%	28 Accidents
Main Rotor Mast			
Substantial Damage	7	1	
Destroyed	9	2	
Total	16 84%	3 16%	19 Accidents
Initial Impact Undetermined			
Substantial Damage	5	7	
Destroyed	13	–	
Total	18 72%	7 28%	25 Accidents
All Wire Strikes			
Substantial Damage	55	63	
Destroyed	84	6	
Total	139 67%	69 33%	208 Accidents

Initial wire impact with the skids or spray boom was the second most likely impact to cause an uncontrolled descent. In many cases, upon initial wire engagement with skids, the pilot would attempt to break the wires with sheer aircraft power. The wire would stretch to the limit, then break, causing a sizable adverse increase to an already taxed flight control situation. The resultant instantaneous change in flight control loads usually resulted in an uncontrolled dive into the ground. It may be a more prudent course to reduce to minimum airspeed, stop, and disengage the skids or spray boom by reversing.

Tail rotor or tail boom impact was third most likely to cause an uncontrolled descent, accounting for 14 (37%) aircraft destroyed and 12 (32%) substantially damaged. In most cases, destruction of the tail rotor resulted in loss of directional control.

The high probability of an uncontrolled descent after a wire strike points up the urgent requirement for wire strike avoidance training and the need for hardware to avoid wire strike or prevent damage to flight control linkages or components.

RECOMMENDATIONS

Methods for avoiding wire strikes and for reducing their effects are discussed below. These include ways to detect wires in order to avoid them and ways to neutralize the effects of wire contact if it does occur. For each of the first three methods discussed, Table 23 presents estimates of whether the method would have been effective in the 208 accidents studied. In each case, the effectiveness was judged within the conditions existing at the time of the accident. For example, if during low speed take-off or landing in a confined area, the pilot could see and determine the distance to all the wires, the pilot warning device was judged as not being effective in preventing the accident. Also, identification of wires from a device or chart would be judged to be noneffective under similar circumstances, as the pilot's visual capabilities would be far more effective and reliable for wire avoidance. Wire cutters were judged as being effective only in those cases when the aircraft was moving at 30 knots or better and was estimated to have sufficient kinetic energy to cut the wire(s). An annotated bibliography pertaining to electronic warning devices, wire cutters, and rotor shields is presented as Appendix C.

PILOT WARNING DEVICE

A radar, laser, or other electronic device could provide an audio and/or visual indication of wires in the flight path and thus provide detection and warning beyond that provided by the human eye. Such a device would need to have sufficient selectivity to activate only for wires that are a hazard to flight. In areas with many wires, as sometimes experienced by the Agriculture pilot, the wire warning device would be useless if it activated on every wire in close proximity to the aircraft. The same is true of many Public Service missions. If such selectivity were possible in an electronic device, the device could be of great value. The estimates in Table 23 of the usefulness of a wire warning device have been made on the premise that development of such hardware is possible.

TABLE 23

RECOMMENDED PREVENTION DEVICES AND TECHNIQUE

	Device to warn pilot when within hazardous distance			Identification of wire location prior to flight			Wire Cutters		
	Recommended	Use Questionable	No Recommendation	Recommended	Use Questionable	No Recommendation	Recommended	Use Questionable	No Recommendation
AG (n=100)	81 81%	7 7%	12 12%	54 54%	3 3%	43 43%	65 65%	17 17%	18 18%
AT (n=87)	65 75%	4 5%	18 20%	53 61%	5 6%	29 33%	33 38%	14 16%	40 46%
PS (n=16)	10 62%	2 12%	4 25%	9 56%		7 44%	2 12%	1 6%	13 81%
MISC (n=5)	2 40%		3 60%	1 20%		4 80%	1 20%		4 80%
Total (n=208)	158 76%	13 6%	37 18%	117 56%	8 4%	83 40%	101 49%	32 15%	75 36%

The most impressive research and development for a warning device has been done by the U.S. Army (ref. 15). While the Army mission for nap-of-the-earth flight has application to civil helicopter wire avoidance, the civil helicopter weather requirements are not as demanding; 95% of wire strikes occurred during daylight visual flight rule (VFR) conditions, when a daylight warning device would have been adequate. The spectrum of available sensors broadens if a daylight-only, good-visibility-only device is required. A passive electronic sensor that uses daylight as an illuminating source would reduce weight and cost, thereby increasing the feasibility of such a device for acquisition by civil helicopter operators.

IDENTIFYING WIRE LOCATION

Methods of identifying wire location prior to or in flight could include visual or photographic aerial reconnaissance and techniques with maps or charts to survey areas for hazardous wires. All determinations in Table 23 of the effectiveness of wire location identification have been made on the premise that a procedural technique including suitable training and measurement of pilot performance is possible.

WIRE CUTTERS

Wire cutter effectiveness recommendations in Table 23 assume installation of wire cutters protecting the skids, canopy bubble, rotor mast and tail rotor against strikes in forward motion. Wire cutter effectiveness was determined from a combination of factors: speed of aircraft, direction of movement, size of wires, and degree of entanglement by tail rotor or main rotor blades. Some wire cutter effectiveness can be achieved at speeds as low as 10 knots, provided the angle of impact of the cutter to the wire is 90°. However, given varying angles of impact and different types of wire, a forward motion of 30 knots was the speed considered necessary for cutters to be effective. Wire cutters were judged to be not effective against very heavy steel long-span power wires. All determinations of wire cutter effectiveness have been made on the premise that, had such hardware been installed, it would have functioned reliably. There were no accidents reported involving helicopters with wire cutters installed. The table shows that wire cutters would have been of particular benefit in Agriculture (recommended in 65% of cases studied, as compared to Air Transportation - 38%, and Public Service - 12%).

Table 24 presents estimates of the potential effectiveness of wire cutters in the 23 accidents in which the pilot was a fatality. Of these, 19 hit power wires, 3 hit telephone wires and 1 hit a guy wire. In only eight accidents could the final cause factor be reasonably determined from primary or secondary wire impacts. In only one case could the cause factor be attributed to a secondary impact; this was with a tail boom after the main rotor had initially struck and broken other wires. Of the 23 fatal civil helicopter wire strikes investigated, it was determined that wire cutters could have been effective in 7 accidents, questionable in 5, and not effective in 11. If the first two categories are considered together, 12 out of 23 (52%) of the fatal wire strike accidents might have been avoided with effective wire cutters.

An example of a commercially available wire cutting device is the cutter/deflector system designed by Bristol Aerospace Limited (BAC) under contract to the Canadian National Defense Headquarters (ref. 16). The BAC Wire Strike Protection System (WSPS) has an upper cutter to protect the main rotor controls, a lower cutter to protect the skid gear, and a windscreen center post deflector with a serrated cutting edge insert to deflect wires to the upper cutter and to reinforce the center post structure.

Limited U.S. Army tests at NASA Langley Research Center Impact Dynamics Facility, Hampton, Virginia, in October 1979 (ref. 4), demonstrated the ability of the WSPS to cut 3/8-inch seven-strand messenger cable with a tensile strength in excess of 10,000 pounds at an impact speed of 39 knots. The Army concluded the WSPS was highly effective in protecting the test helicopter (OH-58) against the results of wire strikes. The WSPS weighs 16.3 pounds, requires approximately 40 man-hours to install, and is commercially available for approximately $4,000.

ROTOR PROTECTION

The Army has studied two methods of protecting the main rotors: pyrotechnic cutters and wire-strike-tolerant main rotor tips. The pyrotechnic

TABLE 24

ESTIMATE OF POTENTIAL FOR WIRE CUTTER USE
23 FATAL ACCIDENTS

Mission	Number of fatalities	Pilot knowledge of wire	Number of wires	Type of wire[a]	Height above ground (feet)	Long Span Wires	Initial Impact	Secondary Impact	Potential for wire cutter use[b]
AT	1	Unk	2	P	250	Yes	Rotor Head	Unknown	?
AT	1	Unk	3	P	150	Yes	Main Rotor	Unknown	Yes
AT	2	Unk	4	P	70	Yes	Wind Screen	Main Rotor	No
AT	1	Unk	16	T	170	Yes	Main Rotor	Unknown	No
AT	2	Unk	2	P	40	No	Main Rotor	Tail Rotor	No
AT	2	No	1	P	25	No	Between Rtr & Bubble	Main Rotor	Yes
AT	1	No	3	P	33	No	Main Rotor	Unknown	No
AT	1	Yes	2	P	40	No	Tail Rotor*	None	No
AT	1	Yes	1	G	65	No	Skid*	None	No
AT	1	No	2	P	20	No	Main Rotor	Tail Rotor	No
AT	3	Unk	2	P	40	No	Main Rotor*	Fuselage	?
AT	2	No	1	T	75	No	Canopy*	None	Yes
AT	1	Unk	2	T	25	Yes	Skid	Main Rotor Tail Rotor	Yes
AT	1	Unk	2	P	75	Yes	Bubble	Tail Rotor	Yes
AT	2	Unk	2	P	60	Yes	Bubble	Main Rotor	?
PS	1	Unk	3	P	200	Yes	Bubble	Unknown	Yes
PS	4	Unk	Unk	P	100	Yes	Main Rotor	Unknown	No
PS	2	Yes	1	P	225	Yes	Main Rotor*	None	?
PS	2	Unk	Unk	P	40	No	Main Rotor	Tail Rotor	No
PS	2	Unk	1	P	350	Yes	Main Rotor Shaft	Tail Boom	?
AG	2	Yes	2	P	80	Yes	Main Rotor	Tail Boom*	No
AG	1	Yes	1	P	70	No	Spray Boom*	Main Rotor	No
AG	1	Yes	3	P	100	Yes	Skid*	None	Yes

[a]P = Power T = Telephone G = Guy

[b]A Yes recommendation indicates that the aircraft was traveling at a minimum of 30 knots.

*Final cause factor in crash

cutters consist of eight-inch linear-shaped explosive charges along the leading edge of the main rotor blades. When a wire is hit, a protective cover over the explosive charge is blown away, and the wire is cut. The structural integrity of the blade is not destroyed during detonation; new charges can be installed. While the leading edge explosive charge does appear effective in cutting wires, the impracticality of civil operators' handling the explosives and replacing them on rotor blades does not make this an attractive option.

Main rotor strike-tolerant blade tips crush with wire impact but remain with the rotor to avoid undesirable rotor imbalance. Crushable rotor tips could be replaced. While the crushable tip concept obviously has merit, field replacement of main rotor blade tips would have to be fast and economical for consideration by the civil operator.

A more attractive option to the commercial operator might be damage-resistant composite materials for main rotor construction. Its extremely high kinetic energy makes the main rotor blade itself a most effective wire cutter, provided that the blade can withstand wire impact. The use of fiberglass blade construction appears to be a promising way to increase wire strike tolerance (ref. 17). In the Agriculture missions studied, for example, 20% of initial impacts were with the main rotor and 10%, the tail rotor. With fiberglass blade usage, these wire strikes might not have resulted in accidents. The corrosion-resistant qualities of fiberglass also make it well suited to the corrosive environment of agricultural aviation that accompanies chemical use. In addition, the 10% lighter weight of fiberglass blades would permit greater payloads. Increased payload might compensate for higher fiberglass blade cost in agricultural aviation.

TAIL ROTOR PROTECTION

Shielding the tail rotor from wire strikes was determined by Army researchers to be a most promising area for increased wire strike tolerance. A practical, economical tail rotor shroud would enhance the wire strike tolerance of currently operating civil helicopters, and the fan-in-fin design is strongly suggested for future rotorcraft.

TRAINING

Analysis of the wire strike accidents indicates the need for pilot wire avoidance training to complement wire detection instruments and wire cutting devices. Successful helicopter operators' techniques and procedures might be used as the basis for industry-wide wire avoidance training. Such an effort could greatly reduce civil helicopter wire strikes. In all mission categories, pilots need to be aware of long span wire strike hazards when flying in stream beds and canyons with higher ridges on either side. Supporting poles are often hidden from a pilot's view; this hinders detection of wires. Cruise flight should always be above supporting poles and towers.

For pilots in the Agriculture category, training is needed in making the proper ground and aerial reconnaissance of ground obstacles. Marking these obstacles on plot charts and confirming their presence from the air should be routine. Aerial reconnaissance methods for determining pole lines, height of wires, and selection of pull up and turnaround areas should be part of flight procedures training for AG pilots.

In the Air Transportation, Public Service, and Miscellaneous categories, pilots are frequently required to land and take off from temporary or emergency landing sites. This is especially the case with Public Service helicopters responding to emergencies. Site conditions at temporary and emergency landing and take-off areas are seldom ideal, but criteria for selection and marking within reasonable safety margins are possible. Once practical site selection criteria are developed for temporary and emergency landing areas, they should be taught to ground personnel as well as pilots. Law enforcement, ambulance, forestry, construction personnel, etc., should know site selection and marking procedures.

HUMAN FACTORS STUDIES

The findings of this study raise the question: why are pilots unable to see and avoid wires under optimum ceiling and visibility conditions? Do the human visual and motor coordination systems have the ability to detect wires accurately and to take action to avoid them? Although physiological measurements to determine why pilots are unable dependably to see and avoid wires in low level flight were beyond the scope of this report, this question is certainly worthy of further study. Suggested areas for human factors research are these:

- Vibration effects on pilot vision. It is possible that helicopter vibration causes corresponding harmonic eyeball vibrations that could greatly reduce pilot visual acuity or cause blurred vision. If eye-critical helicopter vibration frequencies do exist and could be identified, future helicopter designs could avoid them.
- Relation of background visual clutter to wire detection.
- Relation of helicopter speed to visual and motor response to changing cues.
- Evaluation of helicopter blade diffusion of sunlight into the flicker phenomena.
- Wire strike flight simulation. Develop a helicopter wire strike simulator flight scenario from accident data that would duplicate actual flight conditions to quantitatively evaluate such human factors as pilot workload, cockpit design, effects of fatigue, etc. Development of a realistic wire strike flight simulation would be invaluable for development and assessment of future pilot wire warning device cockpit displays.

FLIGHT PROCEDURES

The following seven flight procedures are recommended for use by all helicopter pilots as a result of the findings of this report. In addition, formalized wire avoidance techniques for specific missions should be developed.

- Avoid flight in wire environment when not required by mission. Maintain altitude over 40 feet whenever possible.
- Fly over ridge heights.
- Fly over poles, not in between.
- Use extreme caution at unsurveyed sites.
- On wire hazard aerial survey, account for power/telephone poles and line runs prior to descending for landing.
- Use extreme caution when following ground observer's directions for wire avoidance.
- Never practice autorotations at other than surveyed sites.

SUMMARY OF RECOMMENDATIONS

The following are recommended for an effective helicopter wire strike reduction program:

1. Development of a wire detection/pilot warning device.

2. Development and dissemination of wire identification procedures.

3. Installation of mechanical wire cutters.

4. Use of fiberglass rotors.

5. Protection of the tail rotor by shroud or fan-in-fin design.

6. Development and test of a training program for pilots and ground personnel.

7. Conduct of human factors studies.

8. Adoption of wire-avoiding flight procedures by all helicopter pilots.

In considering hardware to increase helicopter tolerance to wire strikes, it is important to note that the study found no single area of the aircraft significantly more likely to incur an initial strike than any other area. The main rotors were struck initially about as many times as were the main rotor mast, canopy, and skids. This pattern implies that selection of only a single device is not advisable. Civil helicopters required to operate routinely in wire areas should incorporate mechanical wire cutters, a shielded tail rotor, and strike-tolerant rotor blades.

COSTS AND BENEFITS

This section discusses the cost of developing and testing needed components and training for helicopter wire strike prevention. The benefits are weighed against the cost of 37 fatalities and $11,000,000 in damaged and lost aircraft in the ten-year period.

PILOT WARNING DEVICE

The development of this device would require $100,000 for a project definition study over six months to identify sensors and displays. On completion, a $1,000,000 hardware development and testing program over 36 months is estimated. The study found that an effective pilot wire warning device could have prevented an estimated 76% of civil wire strike accidents in the ten-year study period and resulted in an estimated saving of 30 lives and $8,800,000.

STRIKE-TOLERANT DESIGN

Mechanical wire cutters are currently available. A commercial kit containing cutters for the top of the fuselage, windscreen, and areas below the fuselage for a Bell 206 helicopter can be purchased for $4,000. It is assumed that a similar kit for other helicopters would be available at comparable cost. Main and tail rotor blades manufactured with composite materials are in limited commercial use. They appear to hold promise for withstanding damage from wire strikes. A program to design wire cutters, deflectors, and structural reinforcement for a tail rotor shroud is estimated to cost $75,000 over 18 months. If wire cutting devices, composite main and tail rotor blades, and tail rotor shroud had been installed, it is estimated that 49% of the accidents could have been prevented, with a saving of 18 lives and $5,390,000.

TRAINING

Development of a civil helicopter wire avoidance training program requires the formulation of procedures including site selection and survey techniques for landing and take-off at other than established heliports. Pilot training would include instruction on human incapability of reliably seeing and avoiding wires and the required flying techniques and procedures for safe flight near wire hazards. Training of ground support personnel in site selection, survey, marking, and air-ground radio and visual procedures is also necessary.

A training program would require $250,000 to develop over an 18-month period. Had there been an effective training program for pilots, it is estimated that 56% of the accidents would have been prevented with a saving of 20 lives and $6,160,000.

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APPENDIX A

208 CIVIL AVIATION HELICOPTER WIRE STRIKE ACCIDENTS BY TYPE AND MISSION

1970 - 1979

APPENDIX A

208 CIVIL AVIATION HELICOPTER WIRE STRIKE ACCIDENTS BY TYPE AND MISSION

1970 - 1979

The make and model of the aircraft and engines involved in the 208 wire strikes studied are shown below. *These data do not support any conclusion concerning the accident rate of different aircraft, since neither the number of aircraft of each type in service during the study period nor the number of hours flown by each type is known.*

Type		Mission				
Civil Designation	Engine	AG	AT	PS	MISC	Total
Bell 47D-1	Franklin 6V4-200-C32	10	2			12
47G	Franklin VO-335	5	7			12
47G-2	Lycoming VO-435	20	1			21
47G-2A	Lycoming VO-435	4				4
47G-2A-1	Lycoming VO-435			1		1
47G-3	Franklin TVO-335	1	1			2
47G-3B	Lycoming TVO-25A	1				1
47G-3B-1	Lycoming TVO-435	4	4			8
47G-3B-1	Lycoming TVO-435-B1A	1	1	1		3
47G-3B-2	Lycoming TVO-435	1	2	1		4
47G-3B-2A	Lycoming TVO-435-F1A	3				3
47G-4	Lycoming VO-540	2	2			4
47G-4A	Lycoming VO-540-B1B-3	1	3	1	1	6
47G-5	Lycoming VO-435	3				3
47G-5A	Lycoming VO-435-B1A	1				1
47J	Lycoming VO-435		1	1	1	3
47J-2A	Lycoming VO-540		3	1		4
205A-1	Lycoming T53-13A	1				1

Helicopter Wire Strike Accidents by Type and Mission (cont.)

Type: Civil Designation	Type: Engine	Mission: AG	Mission: AT	Mission: PS	Mission: MISC	Total
Bell 206A	Allison 350-C18		3	1		4
206B	Allison 250-C20	2	14			16
206B	Allison 250-C208		1			1
206L-1	Allison C28		1			1
Brantly-Hynes B-28	Lycoming TVO-360-A1A	1				1
Enstrom F28A	Lycoming 0-360-C1A		6			6
280-C	Lycoming 0-260-E1AD		1			1
Fairchild FH-1100	Allison 250-C18		1	1		2
Hiller UH 12-A	Franklin 6V-335	1	3			4
UH 12-B	Franklin 335-6D	1	1			2
UH 12-C	Franklin 6V4-200-C33	1				1
UH 12-D	Lycoming 0-435-23C	2	1			3
UH 12-L4	Lycoming TV10-540		1			1
12-E	Lycoming VO-540	8	2		1	11
12-E4	Lycoming VO-540	1				1
12-E-J3	Allison 250-C20	2	1			3
Hughes 269A	Lycoming H10-360-B1A	6	5	1		12
300 (269B)	Lycoming H10-360-A1A	6	6			12
300 (269C)	Lycoming H10-360-C1A	7	6	5		18
500D (369D)	Allison 250-C-20B		2			2
500S (369HS)	Allison 250-C-18A		3	1		4
500C/500MC (369HS/369HM)	Allison 250-C-20	1			1	2
Sikorsky S-55A	Wright R-1300	1	2			3
S-55B	Wright Cyclone 898C9 HE-2			1		1
S-55C	P&W R-1340	1				1
S-55T	P&W ACL PT6T-3/6				1	1
Kaman K 600	P&W 1340 48A	1				1
	Total	100	87	16	5	208

APPENDIX B

PRIMARY AND SECONDARY CAUSES OF ACCIDENTS

Table B lists the primary and secondary causes of accidents as determined by the NTSB. The first cause listed in the NTSB print-out report was recorded as the primary cause. Other causes listed were recorded as secondary. The listing is in order of number of occurrences.

PRIMARY (P) AND SECONDARY (S) CAUSES OF ACCIDENTS[a]

	AG		AT		PS		MISC		Total	
	P	S	P	S	P	S	P	S	P	S
Failure to See and Avoid Objects or Obstructions[b]										
Failed to see and avoid objects or obstructions	63	9	59	6	7	3	1		130	18
Precautionary landing-suspected/known damage				1						1
High obstructions				1						1
Inadequate Procedures										
Inadequate preflight preparation and/or planning	6	1	6	1	2		1		15	2
Diverted attention from operation of aircraft	4	1	2	4	1	1		1	7	7
Improper in-flight decision or planning	1		3	2	1	1			5	3
Failed to maintain adequate main rotor RPM	1		2	2	1				4	2
Failed to follow approved procedures/directions				2			1		1	2
Operated carelessly	1	1							1	1
Improper operation of flight controls			1	1					1	1
Improper compensation for wind			1	1					1	1
Selected unsuitable terrain			1						1	
Unwarranted low flying				5				1		6
Improperly loaded aircraft		2		2		1				5
Mismanagement of fuel				2						2
Inadequate supervision of flight				1						1
Disregard of good operating practice						1				1
Poorly planned approach				1						1
Errors in Judgment										
Misjudged clearance	11	2	4	3	1	1	1	2	17	8
Poor judgment			1						1	
Misjudged speed and altitude		1								1
Aircraft Failures										
Mech. malfunction-engine structure-cylinder assy.	3		2		3				8	
Material failure			1	1		2			1	3
Transmission rotor drive system	1								1	
Tail rotor drive shaft assembly		1								1
Miscellaneous										
Error of ground signalman	1								1	
Powerline static cable fell on aircraft			1						1	
Sunglare		2		1						3
Pilot fatigue						1				1
Not determined							1		1	

[a]Incomplete data. Eleven 1979 cases not received from NTSB as of 26 August 1980.

[b]NTSB causes have been grouped into five categories for the purpose of this study.

APPENDIX C

SYNOPSIS OF HELICOPTER
RESEARCH AND DEVELOPMENT

APPENDIX C

The following is a brief synopsis of helicopter research and development in hazard avoidance and aircraft survivability in the low altitude flight regime. This limited analysis addresses two of the proposed solutions to the civil helicopter wire avoidance problem: pilot's electronic warning devices and wire cutters and shields.

Kleehammer, R; Hunt, J.; Kleider, A. *Wire Obstacle Warning System (WOWS): A Real-time Airborne Sensor for Automatic Detection and Recognition of Wire-Like Objects*, U.S. Army Aviation R & D Activity, DAAB07-77-C-2167, January 1967.

This report describes a sensor designed by Fairchild Camera to provide real-time detection and recognition of 3mm wires at a range of 300 meters during nighttime helicopter flight operations. Wire or wire-like objects are electro-optically detected, then recognized by a pattern recognition technique within 50 msec of the first wire detection indication.

Kleider, A. *An Experimental Evaluation of Gated Low Light Level (GL^3TV) for Wire Obstacle Detection.* U.S. Army Electronics Command ECOMTR 4-321, May 1975.

This report presents a detailed examination of the utilization of a Gated low level light TV. Results indicate that this technique is applicable to the problem of wire detection provided means can be found to implement automatic acquisition and pattern recognition within a realistic cost.

Del Boca, R.L. and Mongeon, R. J. "Heterodyning CO_2 Laser Radar for Airborne Applications," paper reprinted from Conference Proceedings No. 258, NATO Advisory Group for Aerospace Research & Development.

This paper discusses design considerations, hardware configuration, and test results of flyable breadboard models that have demonstrated the feasibility of employing CO_2 scanning laser systems for wire detection, precision hover, Doppler navigation, and terrain following.

Burrows, L. T.; Brunken, J. E.; Gupta, B. P. *Helicopter Obstacle Strike Tolerance.* Paper presented at 35th Annual National Forum of the American Helicopter Society. May 1979.

This paper reports the results of Army R&D Contract DAAJ02-77-C-0049, conducted by Bell Helicopter for ATL, AVRADCOM. It defines the obstacle strike problem, suggests design concepts for increasing helicopter surivability, and proposes strike-tolerance design criteria that may be applied to future systems.

Gupta, B. T. *Helicopter Obstacle Strike Tolerance Concepts Analysis*, USARTL-TR-78-46. ATL AVRADCOM. April 1979.

In this report, helicopter obstacle strike tolerance designs for rotors, fuselage, and controls are analyzed, and the most promising concepts are selected for both existing and future helicopter systems.

Waters, K. T. *Identification of High Payoff Applicator Helicopters in Agriculture and Forestry*, NASA NAS2-10040. May 1979.

This report identifies R&D needs to make helicopters more productive and to reduct costs of aerial application in agriculture and forestry. The report also discusses existing designs that should be built into agriculture helicopters for safety, higher productivity, and reliability.

Kleider, A. "Applications of the Charge Coupled Device Sensor for Nap-of-the-Earth Helicopter Operations," paper reprinted from Conference Proceedings No. 230, NATO Advisory Group for Aerospace Research & Development.

This report examines the use of a charge couple device (CCD) in the Wire Obstacle Warning System (WOWS) that consistitutes a conceptual breakthrough in the wire detect-recognize-avoid (DRA) environment and holds promise of providing a solution to the wire strike problem. It has the desirable properties of being lighter, smaller, cheaper, and reliable. In this system, video information is logically processed to provide a symbolic display of the range and location of the wire obstacle relative to the aircraft heading.

APPENDIX D

SAMPLE OF ACCIDENT ANALYSIS BRIEFS
AS CONTAINED IN VOLUME II

APPENDIX D

PUBLIC SERVICE

Police Patrol

3-0608 3/16/77 Nr.Honolulu, HI   Hughes 269C 2 Fatal   Destroyed - $66,000

NTSB Accident Cause:

Pilot Error: Failed to see and avoid obstructions

Factors: Pilot fatigue - Pilot had flown 12 hours in last 24
Black-gray painted wires masked against foliage.

The Accident: A high time aerial law enforcement pilot (10,149 hrs) struck one strand of a 7 wire electrical high tension power line, about 225 feet above the ground. The pilot was engaged in a routine police patrol operation and had just taken off from a power pumping station prior to wire engagement. Total time of the flight was one hour and 51 minutes. The pilot had knowledge of wire location in that he had flown over the wires on departure from the last landing site and had gone 500 yards beyond, when he reversed direction and flew back into the wires.

The weather was scattered clouds with 25 miles visibility. At the time of the accident, 1521, the sun was high and not considered a contributing factor.

Upon initial impact with one wire at an estimated speed of 30 knots, the main rotor was sheared off and the aircraft crashed to the ground, fatally injuring both pilot and crewman.

The Honolulu police attribute the power lines being painted black to "satisfy environmental group" as a cause factor.

Conclusion: The pilot's failure to see and avoid the wires caused the crash. Pilot fatigue is regarded as a contributing factor in the crash.

Recommendations: A pilot warning device identifying wire location would have been beneficial in wire avoidance.

Forward speed of 30 knots could possibly have provided sufficient kinetic energy for effective use of wire cutters, had they been installed. However, main rotor engagement of the wires, rather than cockpit contact, makes use of external wire cutters questionable.