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RESEARCH REQUIREMENTS TO IMPROVE SAFETY OF CIVIL HELICOPTERS

By

Kenneth T. Waters

Prepared under Contract No. NAS1-13624
By
Boeing Vertol Company
Philadelphia, Pennsylvania

for

NASA
National Aeronautics and
Space Administration

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ABSTRACT

This report documents the basic research, applied development, and other changes required to achieve a dramatic improvement in civil helicopter safety. Helicopter and fixed-wing accident data is reviewed and major accident causal factors are established. The impact of accidents on insurance rates is examined and the differences in fixed-wing and helicopter accident costs are discussed. The state of the art in civil helicopter safety is compared to military helicopters and goals are established based on incorporation of known technology and achievable improvements that require development, as well as administrative-type changes such as the impact of improved operational planning, training, and human factors effects. Specific R&D recommendations are provided with an estimation of the payoffs, timing, and development costs.

FOREWORD

This report was prepared by the Boeing Vertol Company for the National Aeronautics and Space Administration, Langley Research Center, under NASA Contract NAS1-13624. William Snyder was NASA technical monitor for this work. The Boeing Vertol Project Manager was Wayne Wiesner.

SUMMARY

The purpose of this study was to identify safety improvements that require further research and development. These recommended programs are defined with estimated costs. Some of the recommended research is directed toward identifying other research and development programs that could not be defined within the scope of this report. Additional effort to define unsafe operational practices and aircraft features will require detailed analysis of accident investigation reports over the past 8 to 10 years. This study covered limited statistical trending and detailed analysis of U.S. civil helicopter accidents that occurred in 1975, which was considered to be representative.

In general, this study shows that there are many factors that affect civil helicopter safety and that an aggressive safety improvement program is required to reduce accidents and crash hazards to an acceptable level. Significant increases in numbers of helicopters and yearly flying hours are forecast in the next decade. A goal of a 62-percent reduction in accidents per 100,000 flying hours by 1985 was established and actions required to achieve this goal are identified. Many of the required actions are within existing technology and can be implemented immediately.

In our judgment the application of these existing technological safety improvements and recommended actions is more important than the longer-range research and development because of the immediate impact on safety and the effect on helicopter industry growth.

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1.0 INTRODUCTION

This study was conducted to define research and development needs to greatly improve civil helicopter safety in the next 8-year period. Included in the report are recommendations which will result in reduced crash injuries and fatalities. The report discusses the civil helicopter safety issues and their cost in terms of high insurance rates and other associated costs of accidents such as loss of revenue, delays, lack of public confidence, and the depression of helicopter industry growth.

Many data sources were surveyed including published reports, Boeing Vertol safety data bank, operators, accident investigators, insurance companies, NTSB, HAA, and the military. It was decided to use current statistics from accidents occurring in 1975 for general aviation and helicopters. 1975 is the latest source available and was similar to prior years. Accident rate trends are projected to 1985.

Changes needed for improving civil helicopter safety are defined, the state of the art is established, and technological gaps are identified. Specific programs for high-payoff future research are defined sufficiently for rough scheduling and cost-estimating purposes. An estimation of the probable impact of the recommended programs on reduced accident rate and reduced injuries and fatalities is included.

2.0 GOALS

Civil helicopter accident records show a significant improvement over the past 7 years (Figure 1). Fixed-wing rates have also improved, but less rapidly than helicopters. The dramatic reduction in helicopter accident rate in the 8-year period 1968 to 1976 (from 41 to 16 accidents/100,000 flight hours) can be attributed to several factors: more professionalism; increase in total flight hours; probably better flight hours reporting; a trend toward larger fleets with better pilot training and more planning and control of operations; improved component reliability; and increased use of turbine power.

A plot of U.S. Army accident rate trend data for FY 71-76 (Figure 1) is level at 6.5/100,000 flight hours (this data is dominated by the UH-1H). The better rate for Army operations, 6.5 compared to 16 for civil helicopters, is probably because of more stringent control of flight operations than in general aviation and the fact that nearly 50 percent of the flying hours in general aviation are in older reciprocating-engine-powered helicopters (Table 1), whereas Army helicopters are nearly all turbine-powered. Other factors affecting the rates are differences in accident definition and more hazardous operation in civil helicopter agricultural applications than in peacetime Army operations.

With the probable continued influx of newer turbine-powered helicopters (including twins) in general aviation, a substantial reduction in accident rate can be expected. For example, Table 1 shows that civil turbine-powered helicopters have a rate of 9/100,000 flying hours for 1976 compared to the overall rate of 16/100,000 flying hours. Given a continuing aggressive safety improvement program as outlined herein, a goal of 6.0 accidents/100,000 flying hours appears attainable by 1985.

This goal is based on Boeing Vertol experience with safety improvements achieved on military helicopters. Figure 2 depicts the cumulative accident rate trend of two generations of Boeing Vertol helicopters. This experience indicates that a 66-percent reduction in accident rate is attainable for subsequent generation helicopters. Since general aviation helicopters had a rate of 16/100,000 flight hours, a goal of 6/100,000 flight hours should be attainable, predicated on the fact that the present turbine-powered helicopters are at 9/100,000 flight hours.

If a rate of 6.0 is achieved the corresponding fatal-accident rate is expected to continue at about 1.5 percent of the overall accident rate (Figure 3) of 0.9/100,000 flying hours. A further reduction could be achieved by retrofitting crashworthy features, but since these will probably be introduced only in newer models, there will not be a significant impact by 1985.

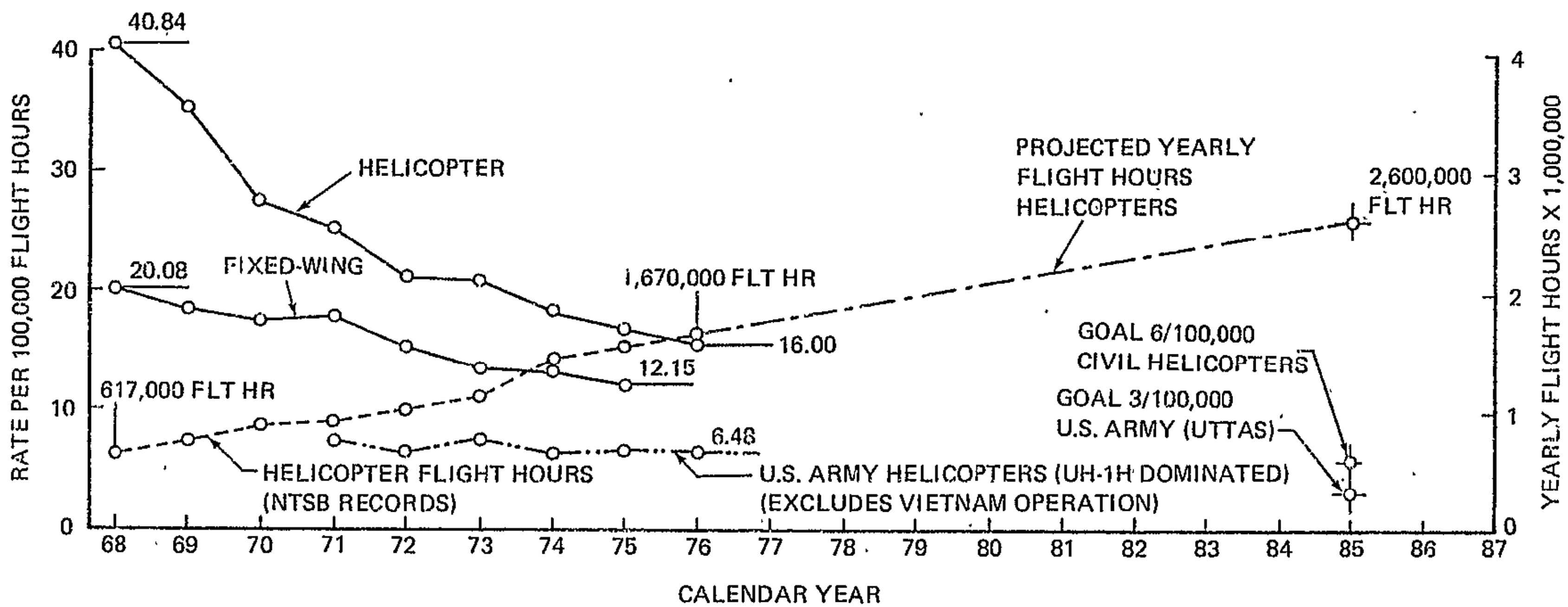


Figure 1. Trend of accidents with U.S. general aviation helicopters and fixed-wing aircraft

TABLE 1. U.S. GENERAL AVIATION ACCIDENTS IN 1975

Turbine-Powered Helicopters

Model	Flt Hr	No. of Accidents	Prime Causal Factors*: Matl	Maint	Pilot	Ops	Wea	Rate per 100,000 Flt Hr
Bell 206 (OH-58)	469,833	36	3	1	18	6	8	7.66
FH 1100	37,683	5	2	2	1			13.26
Bell 212 (Twin)	41,410	4	1	1	1	1		9.65
Bell 205 (UH-1)	46,453	2			1		1	4.30
Hughes 369 (OH-6)	91,701	20	6	2	11	1		21.81
Alouette III (SA316B,319)	10,894	2			1	1		18.35
Sud Avn SA341G	17,766	2		1	1			11.25
Aerospatiale SA315B	1,611	1	1					–
SNIAS SA318C	17,344	1			1			5.76
Sikorsky S-61 (Twin)	1,967	1				1		–
	736,662	74	13	7	35	10	9	10.04

*Selected by Boeing Vertol Co

	Flt Hr	No. of Accidents	Rate per 100,000 Flt Hr
No-Accident Models (Twin)	83,887	0	0
BV 107			
BO-105			
Sikorsky S-64			
Sikorsky S-58T			
Turbine-Powered Helicopters	820,549	74	9.02 (mostly single-eng)
Turbine-Powered Fixed-Wing	1,389,006	34	2.45 (mostly twin-eng)
Total Turbine-Powered	2,209,555	108	4.89
Recip-Engine Helicopters	735,526	219	29.77
Recip-Engine Fixed-Wing	31,062,000	3,910	12.59
Total Recip-Eng-Powered	31,797,526	4,129	12.99

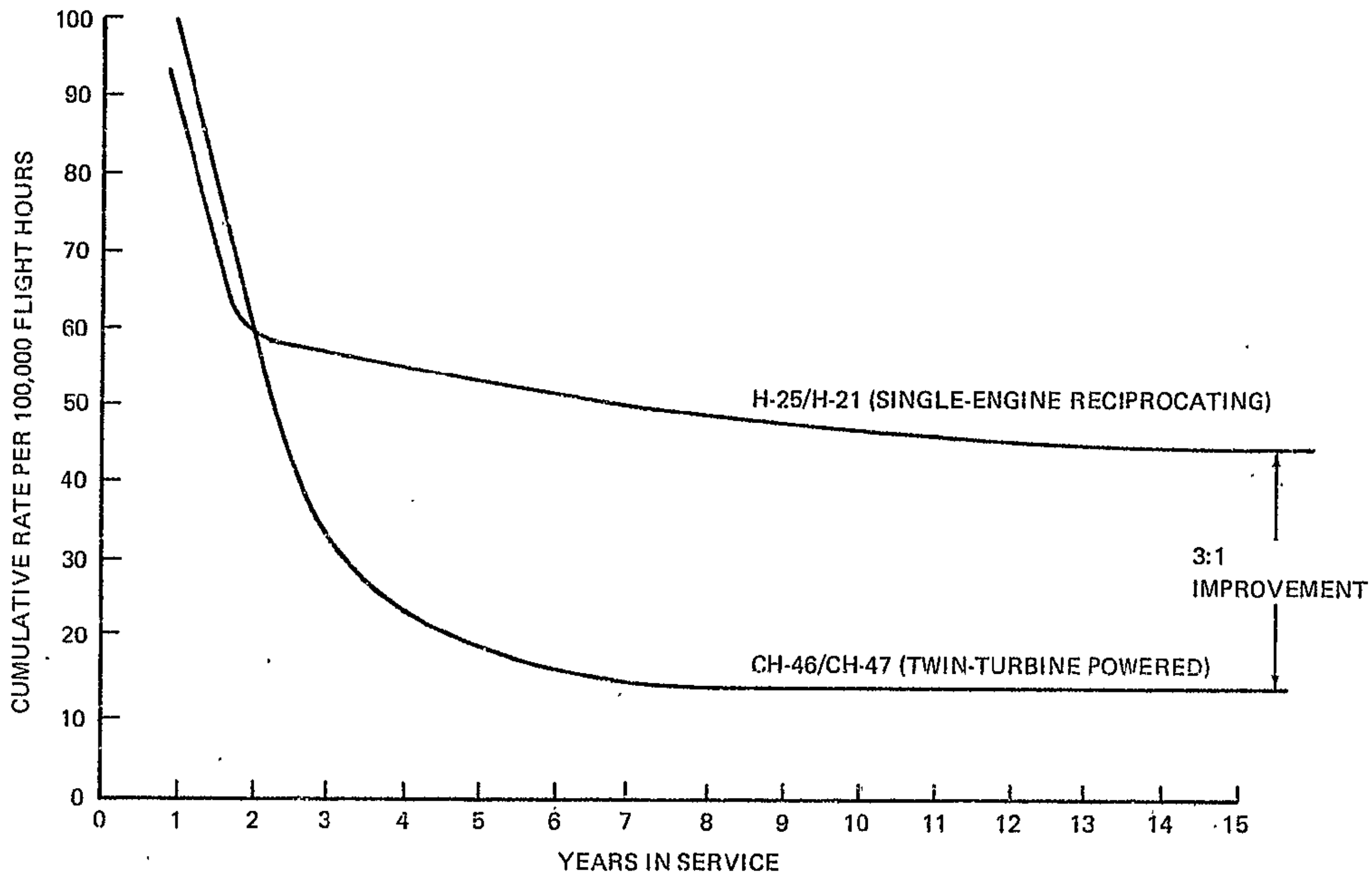


Figure 2. Rate trends of major accidents

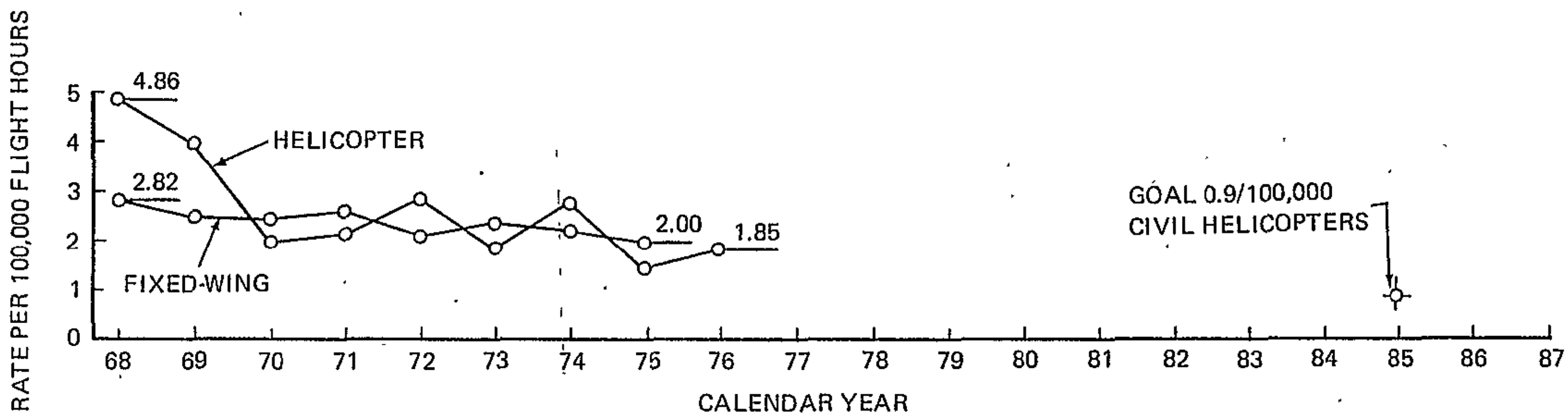


Figure 3. Trend of fatal accidents with U.S. general aviation helicopters and fixed-wing aircraft

3.0 MAJOR ACCIDENT STATISTICS AND CAUSAL FACTORS

3.1 General

U.S. general aviation accidents and fatal-accident trends are shown in Figures 1 and 3 for helicopters versus fixed-wing aircraft. U.S. Army helicopter trends are also shown for comparison. Figure 4 shows accidents and fatal accidents for 1975 broken down to show the rates for destroyed and substantial damage, comparing helicopters to fixed-wing aircraft. Examination of the graphs reveals no significant difference between civil helicopters and fixed-wing accidents in terms of "destroyed" to "substantial damage" ratios.

3.2 Distribution of Causal Factors

A detailed analysis of all 293 helicopter accidents that occurred in 1975 was conducted to select prime causal factors. The results of this analysis are shown in Figure 5. Also shown in Figure 5 are the distributions by flight purpose and phase of flight. A similar breakout for accidents with fatalities and serious injuries is shown in Figure 6. From these charts it can be seen that operations and material failures are more predominant as causal factors in fatal and serious accidents than they are overall. Nevertheless, the pilot is listed as the prime accident causal factor in over 50 percent of the helicopter accidents, with nearly half of these being "commercial" and occurring in cruise flight. We quote from HAA (ref. 1) as follows:

> *"Pilot cause or factor accidents historically lead the list and this is the area that the greatest amount of accident prevention efforts must be expended. Management and supervision must share a large portion of the responsibility for these accidents which generally result from a lack of knowledge, training, or skills. Thorough and professional training will reduce pilot cause or factor accidents."*

Pilots have suggested that the design-related workload may be the real causal factor and that the average pilot cannot handle it. A study of helicopter pilot errors versus fixed-wing pilot errors would help to resolve this. A detailed breakout of causal factors is covered in appropriate sections of this report.

3.3 Fatal Accidents

Table 2 lists the distribution of fatalities and serious injuries by personnel categories, i.e., pilot, copilot, crew, passengers, etc, for helicopter accidents in 1975. In 23 fatal accidents there were 46 fatalities, 20 aircraft were destroyed, and 10 had fire after impact. No information was available in the published records as to the number of thermal injuries and fatalities. It is expected that U.S. Army experience with helicopters that did not have crashworthy fuel systems would offer guidance. In the Army case, a large percentage of the serious injuries and fatalities could be directly attributed to fire.

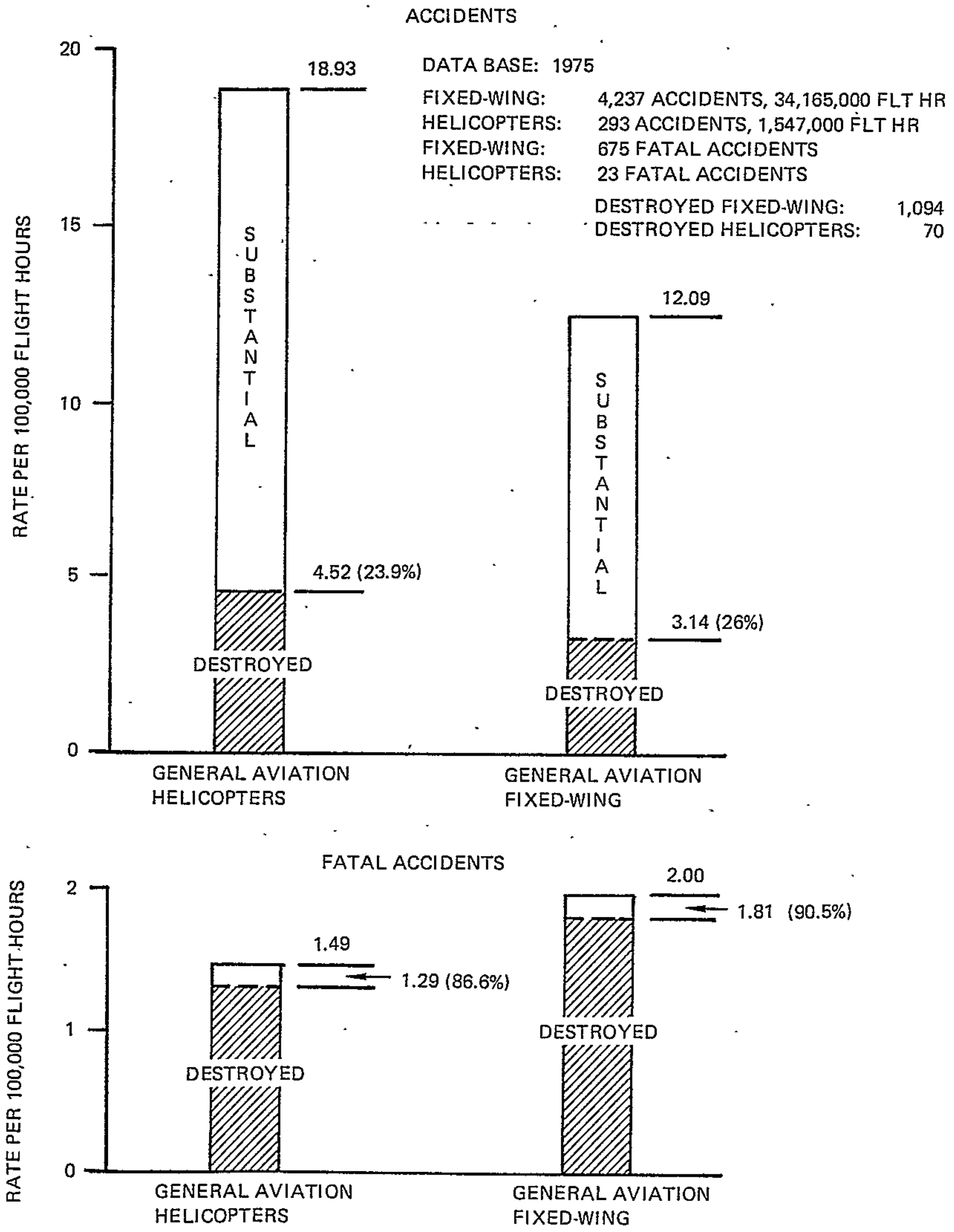


Figure 4. Comparison of accidents with helicopters and fixed-wing aircraft in 1975

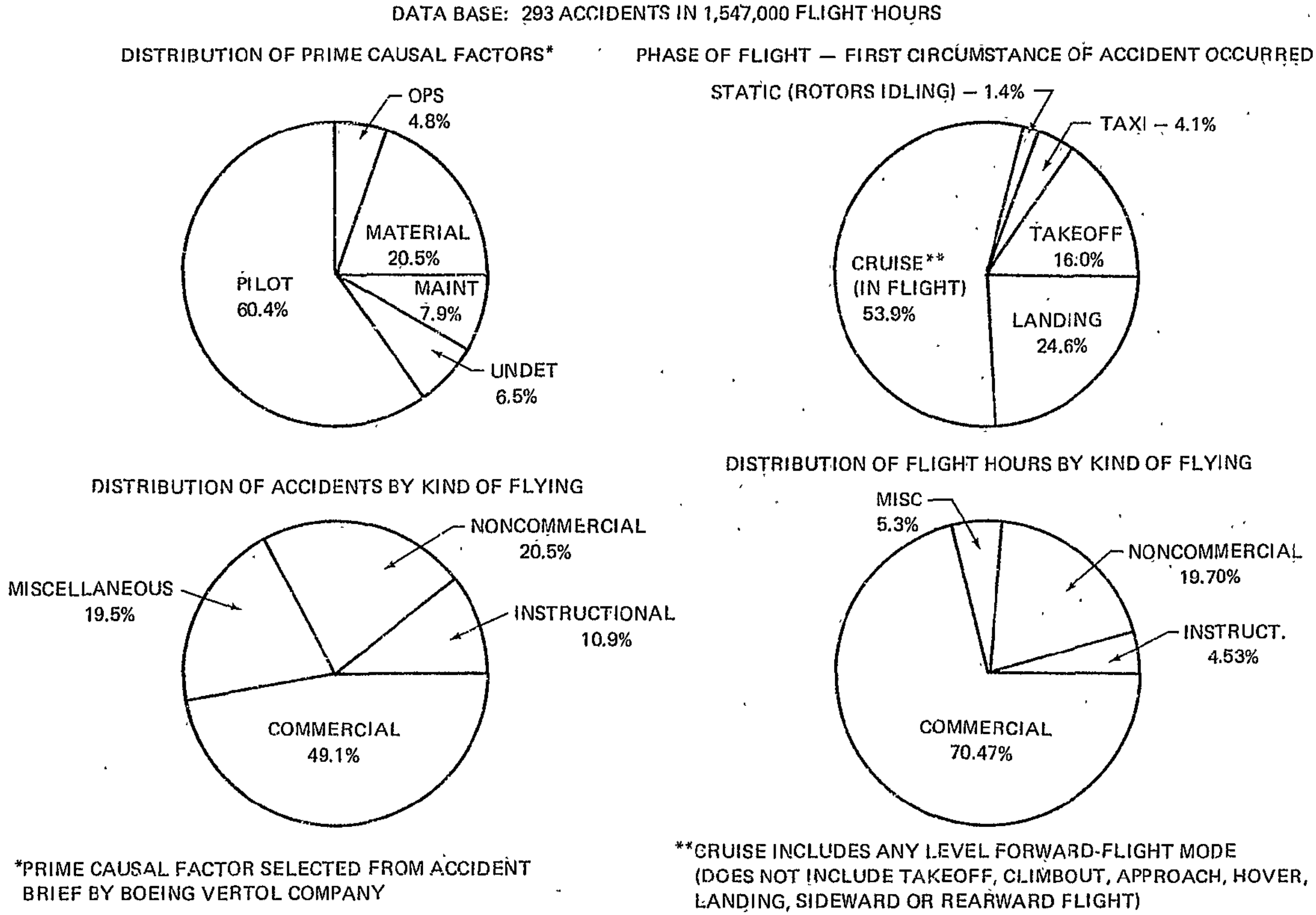
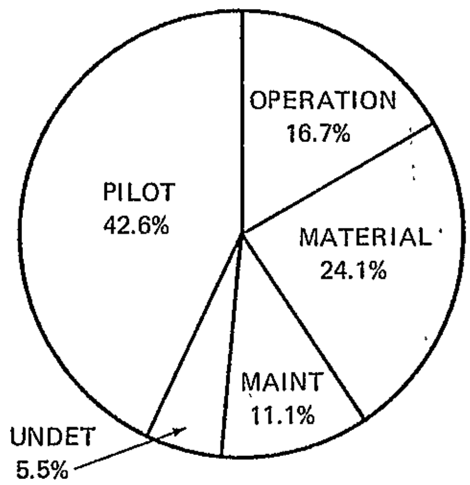


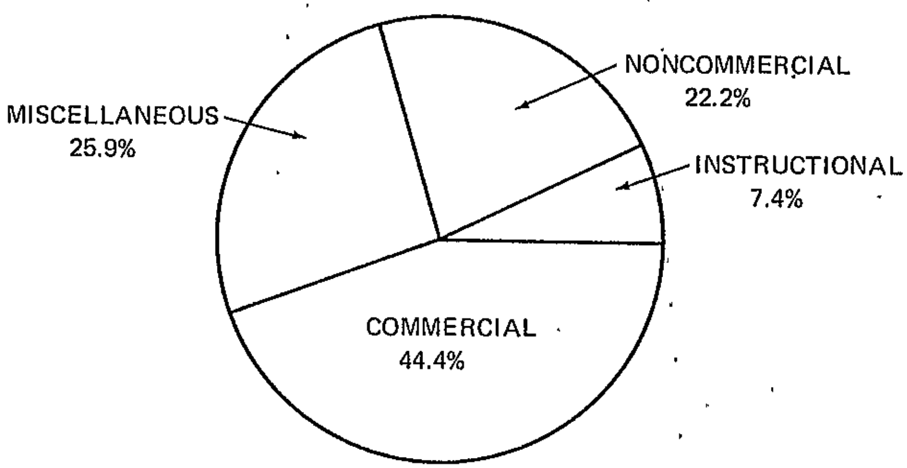
Figure 5. Causal factors of all helicopter accidents in 1975

DATA BASE: 54 ACCIDENTS WITH FATALITIES OR SERIOUS INJURIES IN 1,547,000 FLIGHT HOURS
(23 FATAL ACCIDENTS AND 31 ACCIDENTS WITH SERIOUS INJURY)

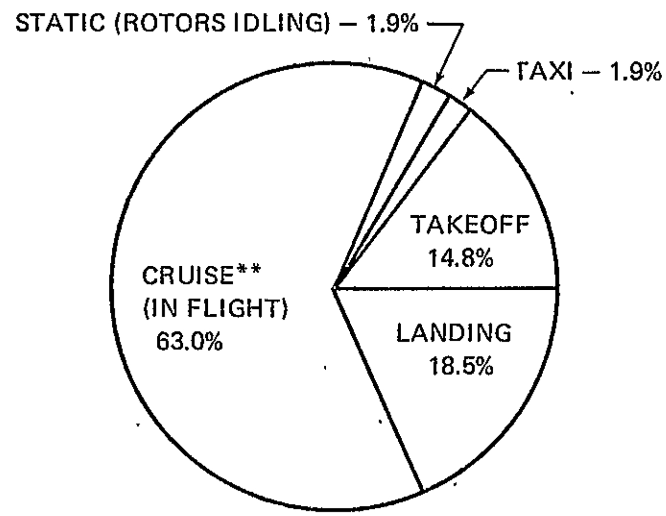
DISTRIBUTION OF PRIME CAUSAL FACTORS*



DISTRIBUTION OF ACCIDENTS WITH FATALITIES AND SERIOUS INJURIES BY KIND OF FLYING



PHASE OF FLIGHT — FIRST CIRCUMSTANCE OF ACCIDENT OCCURRED



**CRUISE INCLUDES ANY LEVEL FORWARD-FLIGHT MODE (DOES NOT INCLUDE TAKEOFF, CLIMBOUT, APPROACH, HOVER, LANDING, SIDEWARD OR REARWARD FLIGHT)

*PRIME CAUSAL FACTOR SELECTED FROM ACCIDENT BRIEF BY BOEING VERTOL COMPANY

Figure 6. Causal factors of helicopter accidents in 1975 involving fatalities and serious injuries

TABLE 2. ACCIDENTS AND INJURIES WITH U.S. GENERAL AVIATION HELICOPTERS IN 1975

	Injuries				
	Fatal	Serious	Minor	None	Total
Pilot	20	25	46	215	309
Copilot	1		2	3	6
Dual Student		3	2	19	24
Check Pilot			1		1
Flight Engineer					
Navigator					
Cabin Attendant					
Extra Crew	1	3	3	2	9
Passengers	24	19	43	161	247
Total	46	50*	97	400	Aboard 596

23 Fatal Accidents
20 Destroyed Helicopters
10 Fire After Impact

31 Accidents With Serious Injury
13 Destroyed Helicopters
5 Fire After Impact

*7 serious injuries in fatal accidents

In 31 serious-injury accidents, 43 occupants were seriously injured, 13 aircraft were destroyed, and 5 had fire after impact. There were also seven serious injuries in the fatal accidents.

Figure 7 shows a comparison of general aviation fixed-wing and helicopter cases of post-crash fire. Conclusions from Table 2 and Figure 7 are as follows:

1. Out of 54 accidents with fatalities or serious injury, 15 (28 percent) had fire.

2. Eleven additional accidents in 1975 had fire but had no fatalities or serious injuries.

3. In approximately 89 percent of accidents with fires, the aircraft was destroyed and 39 percent had fatalities. Fixed-wing aircraft had approximately the same percentage destroyed as helicopters but 65 percent had fatalities. Fire occurrence in helicopters is 1.6 times that of fixed-wing aircraft.

4. Some reduction in fatalities and serious injuries may be achieved by equipping civil helicopters with crashworthy fuel systems.

3.4 Twin- Versus Single-Engine Aircraft

The case for increased safety with twin-engined tactical aircraft is well-documented by the U.S. Navy Safety Center in reference 2, which states:

> *"Conclusions. 1. This survey shows that the twin-engined tactical aircraft has maintained a dramatic safety advantage over its single-engined counterpart. Of particular significance is the number of twin-engine aircraft considered as confirmed 'saves' attributable to the aircraft's redundant powerplants. The dollar savings directly attributable to the twin-engine configuration are considerable."*

The trend curves plotted in Figure 8 also show a dramatic difference in accident rates between single-engined versus multiengined civil fixed-wing aircraft. Admittedly, there are six times as many single-engined fixed-wing aircraft as there are multiengined, and multiengined aircraft fly twice as many hours per year, which probably means that longer missions at higher speeds are flown with fewer takeoffs and landings. The operational uses of single-engined civil airplanes may be more hazardous and pilot training is probably not as good as with the twin-engine airplane, which is more sophisticated. Normally, the multiengine rating is obtained only after having built up several hundred flying hours in single-engine airplanes. Nevertheless, the facts are that the multiengined aircraft has only 42 percent of the accident rate of the single-engined fixed-wing aircraft.

In the case of the helicopter, it is expected that pilot training for single and twin engines would be approximately the same, except where instrument ratings are involved.

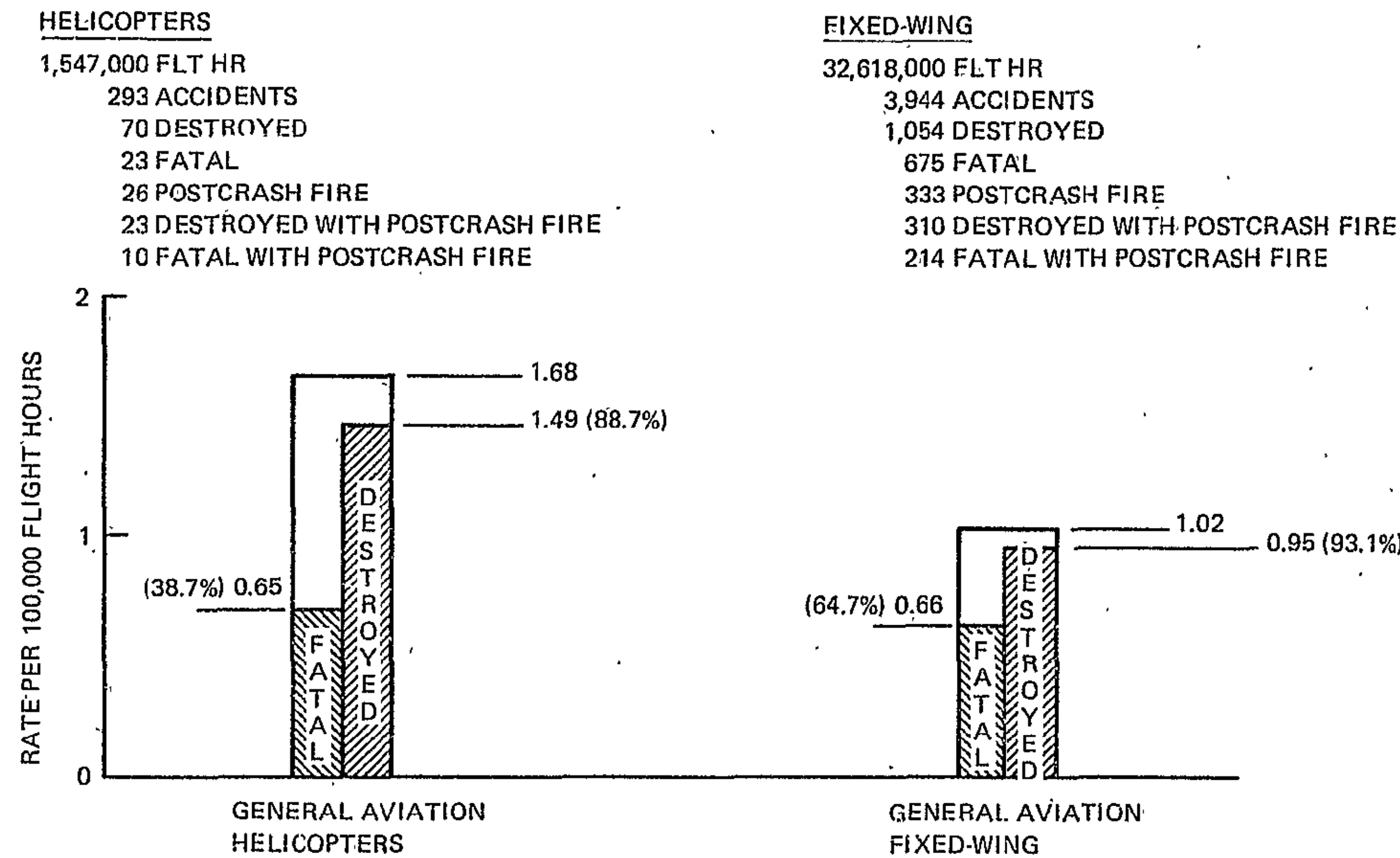
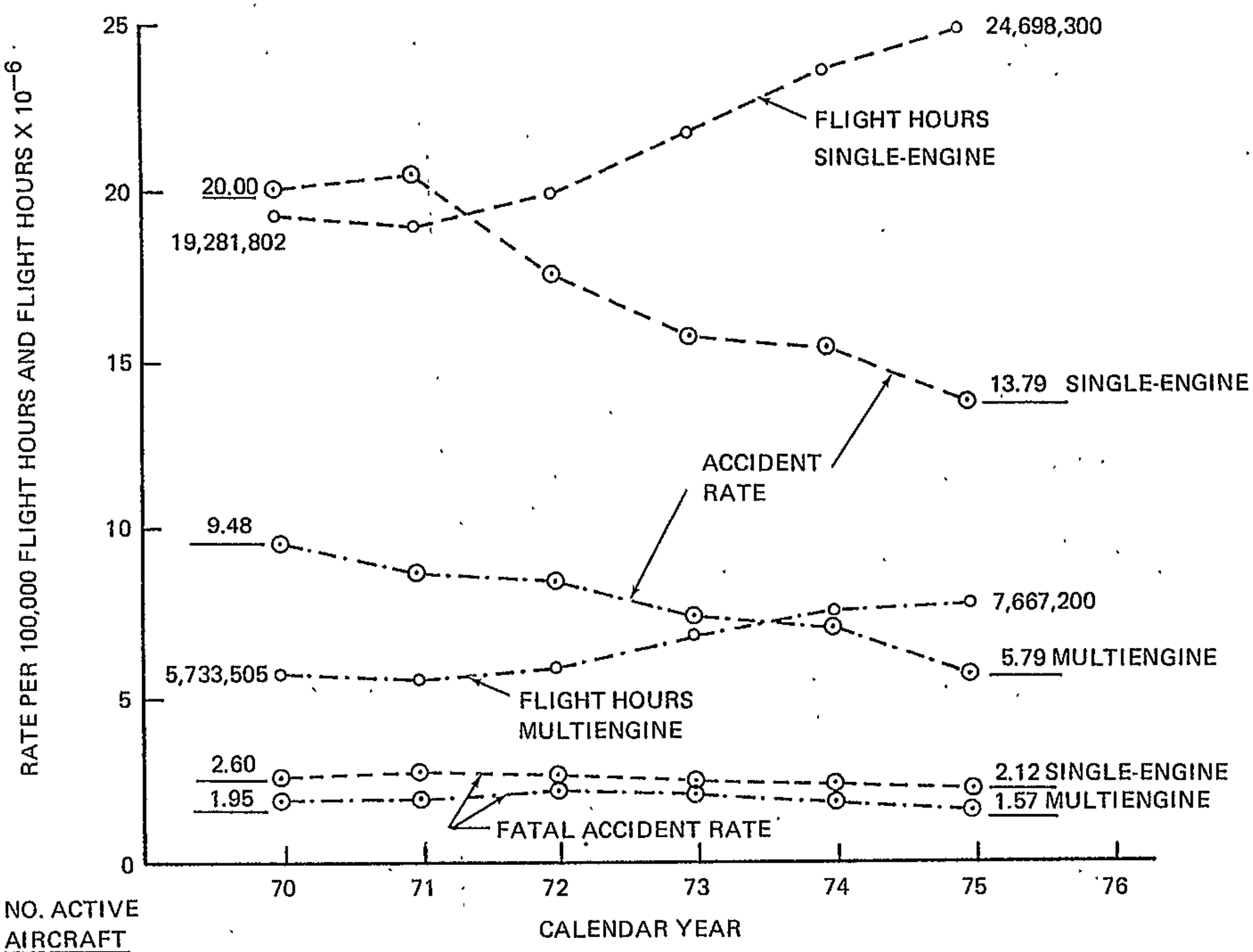


Figure 7. Comparison of 1975 accidents with helicopters and fixed-wing aircraft involving postcrash fire



NO. ACTIVE AIRCRAFT	70	71	72	73	74	75
SINGLE-ENG	109,647	109,257	120,451	126,217	131,932	137,011
MULTIENG	18,287	17,855	19,844	21,929	23,418	24,559

Figure 8. Comparison of accident rates with single-engine and multiengine fixed-wing aircraft

Although inconclusive because of the low number of flying hours, the five accidents in twin-engined civil helicopters for 1975 in 125,297 flying hours result in a rate of 4.07/100,000 flying hours.

From the fixed-wing aircraft and limited helicopter statistics, it is concluded that civil helicopter accident rates will be favorably impacted by increased use of twin engines.

3.5 Turbine-Powered Aircraft

The impact of turbine power on accident rates is shown in Tables 1 and 3 for 1975. Table 1 breaks out the turbine-powered helicopters and compares their rates with reciprocating engines. Table 3 shows similar comparative data for fatal accidents. This data shows that approximately 53 percent of the helicopter flying hours are with turbine power, with an accident rate of 9.02/100,000 flight hours, compared to 29.77/100,000 hours for reciprocating engines. Comparable data for fixed-wing aircraft is: 4.3 percent of the fixed-wing flying hours are with turbine power with an accident rate of 2.45/100,000 flying hours, compared to 12.59/100,000 flying hours for reciprocating engines.

Fatal accidents shown in Table 3 indicate that turbine-powered helicopters have a rate of 1.46/100,000 flying hours compared to reciprocating-engined helicopters at 1.49/100,000 hours. The comparable fixed-wing rates are 1.01/100,000 hours for turbine power and 2.05/100,000 hours for reciprocating-engine power.

In conclusion, turbine-powered helicopters have one-third the overall accident rate of reciprocating-engined helicopters but are nearly four times the fixed-wing aircraft rate. Fatal-accident rates are about the same for turbine- or reciprocating-engine-powered helicopters, while turbine-powered fixed-wing aircraft have half the fatal-accident rate of the reciprocating-engined fixed-wing aircraft. It is recognized that a major factor in these statistics is the difference in usage and accident hazards; therefore a more detailed analysis of causal factors is necessary.

3.6 Pilot Causal Factors

Table 4 is a breakout of the pilot causal factors as reported by the National Transportation Safety Board (NTSB) for 228 civil helicopter accidents in 1975. All pilot factors reported are ranked in terms of number of times reported. They are not necessarily prime causes, but frequently are contributing factors. For example, an autorotation because of fuel exhaustion may result in "failed to maintain rotor rpm," "mismanagement of fuel," and "inadequate preflight and planning" all being listed.

The most numerous single reason for pilot-caused accidents is "failed to maintain rotor rpm," which occurs predominantly in landings; but a significant number also occur in takeoff and hover with occasional occurrences in cruise. The next two highest factors are "misjudged speed and altitude" and "improper operation of controls," which frequently are listed along

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TABLE 3. FATAL ACCIDENTS IN U.S. GENERAL AVIATION IN 1975

Turbine-Powered Helicopters Model	Flt Hr	Number of Accidents	Number of Fatalities	Accident Rate/ 100,000 Flt Hr
Bell 206	469,833	7	15	1.48
FH 1100	37,683	1	2	2.65
Bell 212	41,410	2	10	4.82
Bell 205	46,453	1	1	2.15
Hughes 369	91,701	1	3	1.09
	687,080	12	31	1.75
Other Models (no fatal accidents)	133,469	0		0
Turbine-Powered Helicopters	820,549	12	31	1.46
Turbine-Powered Fixed-Wing	1,389,006	14	57	1.01
Total Turbine-Powered	2,209,555	26	88	1.18
Recip-Eng-Powered Helicopters	735,526	11	15	1.49
Recip-Eng Fixed-Wing	31,062,000	638	1,194	2.05
Total Recip-Eng-Powered	31,797,526	649	1,209	2.04

TABLE 4. PILOT CAUSAL FACTORS IN ACCIDENTS WITH U.S. GENERAL AVIATION HELICOPTERS IN 1975

		Percent (228 Accidents)
Failed to maintain adequate rotor rpm	61	26.8
Misjudged speed and altitude	46	20.2
Improper operation of flight controls	45	19.7
Inadequate preflight preparation/planning	43	18.8
Failed to see/avoid objects or obstructions	36	15.8
Misjudged altitude/clearance	22	9.6
Mismanagement of fuel	21	9.2
Lack of familiarity with aircraft	13	5.7
Diverted attention from operation of aircraft	12	5.3
Improper in-flight decision/planning	11	4.8
Failed to follow approved procedures/directives	10	4.4
Simulated conditions	10	4.4
Inadequate supervision of flight	10	4.4
Selected unsuitable terrain	9	4.0
Attempted operation beyond experience/ability level	9	4.0
Improper compensation for wind conditions	7	3.1
Improper level-off	7	3.1
Improper operation of powerplant and powerplant controls	6	2.6
Pilot fatigue	6	2.6
Exercised poor judgment	5	2.2
Poorly planned approach	5	2.2
Operation with known deficiencies in equipment	4	1.8
Continued VFR flight in adverse weather conditions	3	1.3
Initiated flight in adverse weather conditions	3	1.3
Lost/disoriented	2	0.8
Failed to attain/maintain flying speed	2	0.8
Misjudged speed, altitude, or clearance	2	0.8
Failed to maintain directional control	2	0.8
Spatial disorientation	1	0.4
Delayed initiating go-around	1	0.4
Delayed action in aborting takeoff	1	0.4

Note: Many accidents have more than one cause listed, therefore total percentage will exceed 100.

with "failed to maintain rotor rpm." Since these three factors are involved in most of the accidents involving autorotation, this area was studied as discussed below.

3.6.1 Autorotational landing accidents (1975). – Reasons for autorotation are:

29 reciprocating-engine failures
16 fuel exhaustion
6 fuel contamination
7 turbine-engine failures
3 other material failures
18 practice autorotation
79 total power-off autorotation accidents (27 percent of 293)

This data shows clearly that causes for unplanned autorotation are predominantly reciprocating-engine failures and fuel exhaustion or contamination.

Turbine power, and twin turbines in particular, would greatly reduce the unplanned power-off autorotation hazard. Means to prevent fuel exhaustion and fuel contamination would also be of substantial benefit.

Of the 79 accidents involving power-off autorotation, 66 had pilot causal factors as shown in Table 5. (Note that in some cases more than one factor was listed.) "Misjudged speed and altitude" (27), "failed to maintain adequate rotor rpm" (21), "improper operation of flight controls" (10), and "improper level-off" (5) account for a total of 62 entries listed for the pilot-causal-factor autorotational accidents.

This data shows the need for improved pilot qualification and understanding of low-speed aerodynamic characteristics when flaring to a power-off autorotative landing. Since unplanned autorotational landings are a fact of life and will continue to happen, improved training procedures appear to be necessary, together with design changes to make autorotational landings less hazardous and to reduce pilot workload. The fact that there were 18 practice autorotations and 61 unplanned autorotations that resulted in accidents in 1975 reinforces this conclusion. The development of flight simulators similar to those used by the U.S. Army at Fort Rucker, Alabama, to assist in pilot training for autorotation would appear to offer significant payoffs.

Reciprocating-engine failures (1975) – There were 29 reciprocating-engine failures that resulted in unplanned autorotational landing accidents in 1975 as listed below:

Engine-Failure Cause		Possible Contributing Factor
Unknown	12	Unknown
Connecting rod/bolts failure	6	Overspeed on startup/improper assembly, manufacturing, and quality control
Exhaust valve failure/sticking or poor seating	4	Improper fuel/fuel contamination/ improper mixture control/improper manufacturing and quality control

TABLE 5. PILOT CAUSAL FACTORS IN 66 AUTOROTATION ACCIDENTS WITH U.S. GENERAL AVIATION HELICOPTERS IN 1975

		Percent (66 Accidents)
Misjudged speed and altitude	27	45
Failed to maintain adequate rotor rpm	21	32
Inadequate preflight preparation or planning	21	32
Mismanagement of fuel	15	23
Improper operation of flight controls	10	15
Improper level-off	5	7.5
Inadequate supervision of flight	4	6
Lack of familiarity with aircraft	4	6
Improper operation of powerplant controls	3	4.5
Diverted attention from operation of aircraft	2	3
Selected unsuitable terrain	2	3
Misjudged altitude and clearance	2	3
Improper compensation for wind conditions	1	1.5
Improper in-flight decision/planning	1	1.5
Failed to follow approved procedures or directives	1	1.5
Failed to see and avoid objects and obstructions	1	1.5

Note: Some accidents have more than one cause listed, therefore total percentage will exceed 100.

Carb icing	2	Pilot error
Fouled plugs	1	Improper fuel/maintenance
Fuel pump failure	1	Material
Cracked distributor	1	Material
Oil exhaustion	1	Maintenance/operations
Valve rocker shaft retaining plate not installed	1	Quality control
	29	

Recommendations for reducing reciprocating-engine failures are discussed in paragraph 4.2.1.

3.6.2 Summary of pilot causal factors. – Exclusive of autorotation, the remainder of 40 cases of "failed to maintain rotor rpm," 19 cases of "misjudged speed and altitude," and 35 cases of "improper operation of flight controls" are generally related to inadequate training, inexperience, lack of understanding of helicopter power required to conduct safe power-on landings, and inability to safely control the helicopter under high rotor loading with low rotor inertia. The most critical case is in slowing up and flaring for a landing where power required increases substantially because of approach to hover. The increased sensitivity to wind shifts and inadequate consideration for density altitude (hot/high conditions) frequently result in marginal power and sloppy control when landing.

The related factors of "inadequate preflight preparation/planning," "failed to see/avoid objects or obstructions," "misjudged altitude/clearance," and several other pilot causal factors cited all reinforce the conclusion that the following are necessary:

1. Improve pilot training, qualifications, and professionalism

2. Improve flight operational planning and directives

3. Design changes to make helicopter more tolerant to hazardous environments–through improved stability and control

4. Provide the pilot with an advanced systems monitor to reduce workload

Table 6 shows pilot causal factors involved in accidents with fatalities and serious injuries. The same factors are involved as in Table 4, but "inadequate preparation and planning," "failed to see/avoid objects and obstructions," and "failed to maintain adequate rotor rpm" were the top three in order. The foregoing discussion and conclusions are applicable to data in Tables 4 and 6.

TABLE 6. PILOT CAUSAL FACTORS IN ACCIDENTS WITH FATALITIES AND SERIOUS INJURIES WITH U.S. GENERAL AVIATION HELICOPTERS IN 1975

		Percent (54 Accidents)
Inadequate preparation and planning	13	24.1
Failed to see/avoid objects or obstructions	10	18.5
Failed to maintain adequate rotor rpm	6	11.1
Improper in-flight decision/planning	5	9.3
Misjudged altitude/clearance	5	9.3
Mismanagement of fuel	4	7.4
Operation with known deficiencies in equipment	3	5.6
Continued VFR flight in adverse weather conditions	3	5.6
Improper operation of flight controls	3	5.6
Attempted operation beyond experience/ability level	2	3.7
Diverted attention from operation of aircraft	2	3.7
Failed to follow approved procedures/directives	2	3.7
Initiated flight in adverse weather conditions	2	3.7
Poorly planned approach	2	3.7
Pilot fatigue	2	3.7
Misjudged speed, altitude, or clearance	1	1.9
Improper operation of powerplant controls	1	1.9
Improper level-off	1	1.9
Improper compensation for wind conditions	1	1.9
Exercised poor judgment	1	1.9
Misjudged speed and altitude	1	1.9
Spatial disorientation	1	1.9
Improper emergency procedure (autorotation)	1	1.9

Note: Some accidents have more than one cause listed, therefore total percentage will exceed 100.

3.7 Environmental Causal Factors

Table 7 is a breakout of environmental causal factors. In 54 accidents in 1975 "high obstructions" were hit, which was 18.4 percent of the accidents for that year. "Rough/uneven terrain" and "wet/soft ground" were causal factors in 32 accidents, or 11.1 percent. The significant point about "high obstructions" and "wet/soft ground" is that the majority of these accidents are associated with pilot causal factors also. There were 28 collisions with wires and 43 collisions with objects such as trees, poles, buildings, and crops, which is 24.2 percent of 293 total accidents. It is interesting to note that the obstacle-strike problems in U.S. Army helicopters also run about 25 percent of the accidents, and studies are in progress to determine means to alleviate this problem. The wire-strike problem is discussed in detail in section 4.2.10.

"Unfavorable wind conditions" and "sudden wind shift/turbulence" were involved in 20 accidents, or 6.8 percent. If we combine all weather conditions except "unfavorable wind conditions," that is, "fog, snow, low ceiling, conditions conducive to carburetor icing, and rain," only 19 accidents involved these factors, or 6.5 percent.

In summary, the major environmental causal factors are:

Obstacle strikes	54
Terrain conditions	32
Wind conditions	20
Weather (visibility and carburetor ice)	19

Major causal factors of accidents with fatalities and serious injuries are summarized as follows:

Obstacle strikes	17
Weather (visibility)	12
Wind conditions	4

3.8 Material and Maintenance Causal Factors

For the purposes of this study, only turbine-powered helicopter material and maintenance factors were studied in detail. These causal factors in reciprocating-engined helicopters should be analyzed to determine future R&D needs for improved safety.

Table 1 shows the turbine-powered helicopter accident record for 1975 by model of aircraft. Accident rates and general causal factor involvement are shown. Review of the material and maintenance factors for turbine-powered helicopters results in the following distribution of subsystem involvement:

TABLE 7. ENVIRONMENTAL FACTORS IN ACCIDENTS WITH U.S. GENERAL AVIATION HELICOPTERS IN 1975

		Percent (293 Accidents)
High obstructions	54	18.4
Rough/uneven terrain	19	6.5
Unfavorable wind conditions	16	5.4
Wet/soft ground	13	4.4
Downwind conditions	12	4.1
High density altitude	8	2.7
Fog	5	1.7
Snow	5	1.7
Snow-covered terrain	5	1.7
Evasive maneuver to avoid collision	5	1.7
Sun glare	5	1.7
Low ceiling	4	1.4
Conditions conducive to carburetor icing	4	1.4
Sudden windshift/turbulence	4	1.4
Foreign-object damage	4	1.4
Obstruction to vision	2	0.7
Rain	1	0.3

TABLE 8. ENVIRONMENTAL FACTORS IN ACCIDENTS WITH FATALITIES AND SERIOUS INJURIES WITH U.S. GENERAL AVIATION HELICOPTERS IN 1975

		Percent (54 Accidents)
High obstructions	17	31.5
Low ceiling	4	7.4
Fog	4	7.4
Snow	3	5.6
Unfavorable wind conditions	3	5.6
Rain	1	1.9
Sudden windshift/turbulence	1	1.9
High density altitude	1	1.9
Wet, soft ground	1	1.9
Downwind condition	1	1.9
Rough/uneven terrain	1	1.9
High vegetation	1	1.9
Snow-covered terrain	1	1.9

- Powerplant
  - Undetermined reasons 3
  - Compressor failure 1
  - Compressor blade failure 1
  - Power-turbine governor failure 1
  - Fuel pump failure 1

- Fuel systems
  - Ice in fuel – no deicer 1
  - Fuel contamination 1
  - Fuel gage malfunction 1

- Drive
  - Tail rotor drive shafting coupling failure 1

- Rotor
  - Tail rotor blade failure (corrosion) 1
  - Main rotor blade failure (corrosion) 1

- Flight controls
  - Main rotor pitch change clevis failure 1
  - Bolt came loose from controls 2

- Airframe
  - Engine cowling separated in flight 1
  - Tail rotor transmission cowling rubbing shaft 1

- Equipment
  - Hoist cable separated 1
  - Luggage rack separated 1

From the foregoing, it may be concluded that design improvements in the following areas are needed:

- Better understanding of turbine-engine failure causes so that redesign action can take place to improve engine reliability (ref. 3).

- Main and tail rotor blade corrosion control to prevent material failures in blade spars.

- Flight control positive-retention bolts to prevent disconnects because of improper maintenance such as leaving a nut off a bolt.

3.9 Ratio of Percentage of Accidents by Percentage of Inventory and Type of Flying

Figure 9 ranks the relative hazards by different types of civil helicopter flying. Where the ratio of percentage of accidents to percentage of inventory is above 1.0 (the average), this type of flying is more hazardous than the average. Other (police/fire, search and rescue, ferry, and miscellaneous) is the worst (2.18), with instruction/training (2.08), agricultural (1.7), personal (1.14), and air taxi (1.09) all above average.

Factors such as type of helicopter, reciprocating or turbine engines, matching causal factors to type of flying, and number of flying hours for each type of flying have not been broken out in this study. Therefore, it is difficult to draw specific conclusions. A more detailed study of the factors mentioned should be conducted to determine how the more hazardous operations could be improved to approach the records compiled by industrial (0.20), corporation/executive (0.22) and business flying (0.65); this is discussed further in section 5. Typical types of operation in these categories are:

- Industrial – logging, pipeline, photographic, powerline, and other construction – larger aircraft
- Corporation/executive – company aircraft, professional pilots
- Business – miscellaneous small companies, nonprofessional pilots
- Air taxi – transport of personnel and equipment for hire – professional pilots, offshore drilling, charter, etc

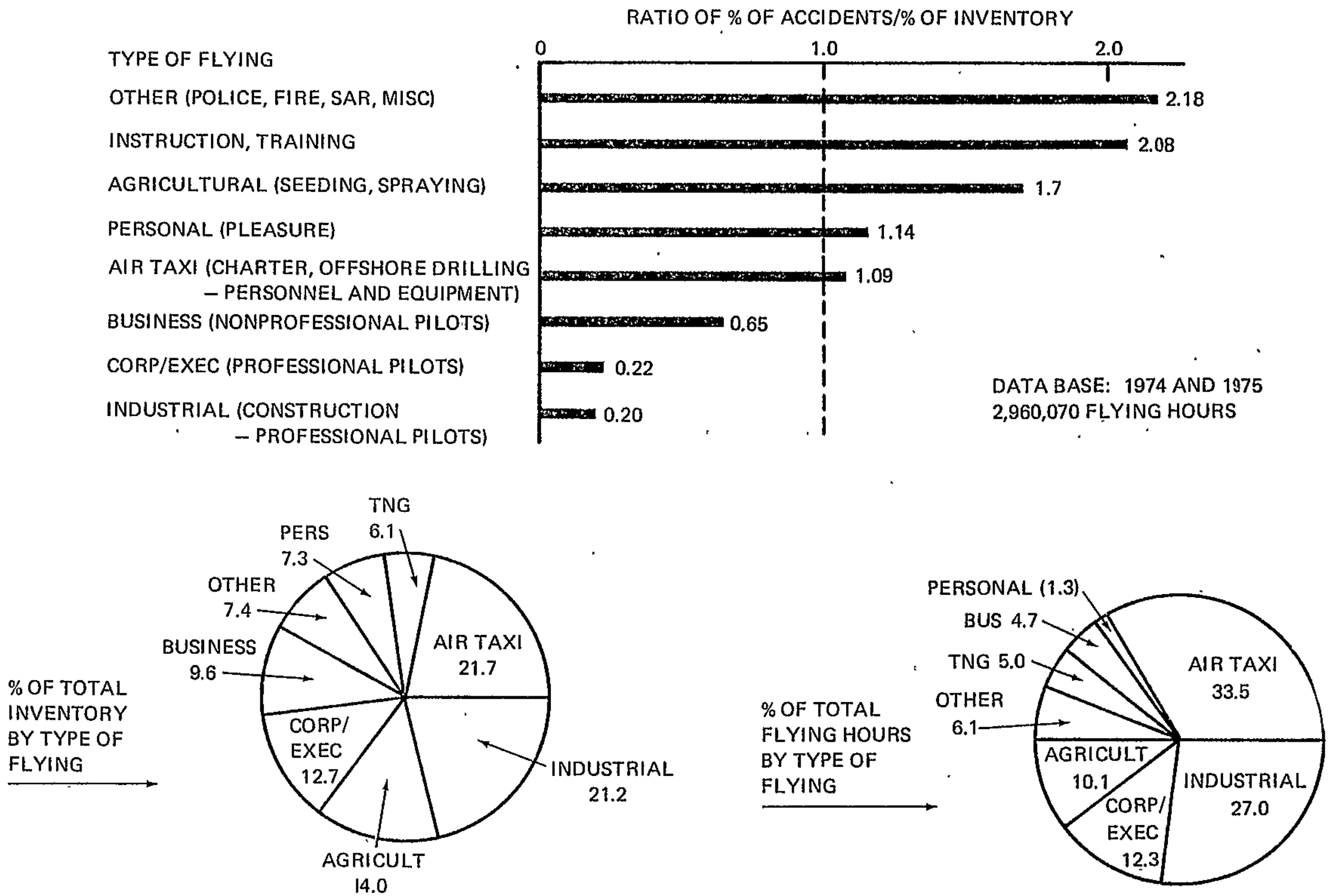

Figure 9. Percentages of helicopter inventory, flying hours, and accidents by type of flying

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4.0 TECHNOLOGY AND OPERATING CHARACTERISTICS FOR ACCIDENT PREVENTION

Major areas that impact civil helicopter safety are discussed in this section. The status of technology, gaps in technology, and needed advances are discussed and identified.

4.1 Operator Comments on Safety Hazards

A questionnaire was sent to over 200 civil helicopter operators covering the major types of operations encountered; to date, approximately 40 replies have been received. In addition, several large operators, pilots, accident investigators, insurance underwriters, and claims adjusters were interviewed for comments on helicopter safety. The following suggestions and problem areas were identified (note that no attempt at ranking has been made, but they are categorized).

4.1.1 Design considerations. – The following items were identified:

1. Crashworthy fuel system to prevent crash fires.
2. Design helicopters to withstand one blade damper failure without incident.
3. Pitot tubes get hit when in hangar.
4. Chin-height stabilizers hurt people.
5. Pilot on right side to protect from blade penetration into cabin during crash.
6. Tinted glass spoils wire vision in wet weather.
7. Civil helicopters are operated to limit on daily basis. Helicopters are put into the field without sufficient high-load testing to stand up under such usage. TBO's should reflect this kind of work.
8. Rotor clearance should be 14 feet (like Bell 205) to prevent contact with ground personnel or passengers.
9. Passenger loading and unloading and baggage compartments should not be near exhaust for noise and inhalation of fumes.
10. Make it easy for the pilot to identify which engine is failing (by proper warning light) so that there is no possibility of grabbing the wrong low-speed governor control.
11. Tail rotors should be high enough to clear brush and people (6.5 feet at bottom) and include a guard ring for people and obstacles.
12. Extended skid gear should be required for all helicopters operating in rough terrain to prevent rocks from penetrating the fuselage.

13. Improve cockpit crash survival features such as restraints, eliminate lethal protuberances, and require lightweight helmets.

14. Be sure that threaded fasteners are in such a direction as to not unscrew in operation.

15. Autostart system required for momentary power failure due to fuel, ice, FOD, etc.

4.1.2 Operational considerations. – These items were mentioned frequently:

1. Many accidents can be avoided by good planning of operation and good, clear debriefing; treat every mission as new and *not routine*.

2. Pilots do not have a good understanding of helicopter low-speed aerodynamics, particularly regarding landings under power-off autorotation or power-on high/hot marginal-power conditions.

3. Insure proper filtering and precautions to keep dirt and water out of fuel (main problem is in the truck).

4. Improve training and high-visibility marking to eliminate injuries from personnel walking into the tail rotor.

4.2 Accident Causes, Solutions, Recommendations, and R&D Needs

Table 9 presents a summary of accident causes, technical solutions, recommendations, and research and development needs to fill gaps. Where existing technology is considered to be adequate, even though it may require substantial nonrecurring and recurring dollars to implement in the civil fleet, the R&D-needed column states "None". Each item listed in the table is discussed in the following paragraphs; R&D needs are elaborated in section 5 of this report.

4.2.1 Reciprocating-engine failure. – Examination of reciprocating-engine failure modes and possible contributing factors indicates the following actions to alleviate the engine-failure problem:

- Improve quality control in engine manufacture and overhaul.
- Improve engine-failure analysis, reporting, and fixes as necessary to improve reliability.
- Improve pilot training:
  1. In engine starting to prevent overspeeds
  2. In use of correct fuel mixtures
  3. In use of carburetor heat in icing conditions.
- Insure proper fuel is used when available.

It is evident that there will be a continuing demand for reciprocating-engine power in new small helicopters because of cost. Some of the engines will be those now used in fixed-wing

TABLE 9. CAUSES OF CIVIL HELICOPTER ACCIDENTS AND REQUIREMENTS FOR SOLUTIONS, RECOMMENDATIONS, AND RESEARCH AND DEVELOPMENT

Accident Cause	Solution/Recommendation	R&D Needed
1. Reciprocating engine failure	a. Phase out older aircraft, improve operating procedures, and reduce engine overspeed	Study to determine what needs to be done such as improved bolt stretch and torqueing control
2. Turbine engine failure	a. Improve reliability of turbine engines; install health monitors to prevent in-flight failures	a. See Reference 3
3. Fuel contamination	a. Install filters/separators on hose near the nozzle to separate water	None
4. Twin-turbine OEI	a. Provide engine restart capability	a. Study to determine what could be done
	b. Provide HOEI contingency power	b. See Reference 4
	c. Provide failure warning so good engine will not be shut down inadvertently	None
5. Fuel exhaustion	a. Improve operational planning	None
	b. Improve fuel gaging/warning systems	None
6. Power-off autorotation (failed engine or practice autorotation to power-off landing)	a. Improve pilot knowledge of helicopter low-speed aerodynamic characteristics on landing	Develop an accurate omnidirectional low-airspeed system (such as LORAS) and improve accuracy in autorotation and put into production
	b. Improve practice autorotation procedures and pilot qualification	Develop an autorotation simulator to assist in pilot training, similar to those used by the U.S. Army at Fort Rucker, Alabama

TABLE 9 – Continued

Accident Cause	Solution/Recommendation	R&D Needed
6. Continued	c. Investigate potential changes to stability and control and rotor inertia to reduce hazard	c. Study helicopter characteristics by type and accident history to determine design criteria changes needed.
7. Power-on takeoff, landing, hover maneuvers, and cruise flight (pilot causal factors)	a. Improve pilot knowledge of helicopter low-speed aerodynamic characteristics and power required versus power available	a. Study the small operator versus large operator to define short-comings in operations, planning, and pilot qualifications and 6a above
	b. Phase out older aircraft, go to single and twin engines with better power match, and improve cockpits for reduced workload	b. Conduct cockpit human factors study for reduced workload and improved visibility; develop advanced systems monitor
	c. Investigate potential changes to stability and control and rotor inertia to reduce hazard	c. Same as 6c
8. High/hot operation	a. Install a power-remaining indicator (YUH-61A type)	None
	b. Provide HOGE contingency power	b. See Reference 4
9. Inadequate operational planning and controls	a. Improve planning and debriefings and avoid letting missions become routine; reduce complacency	a. Same as 7a

TABLE 9 – Continued

Accident Cause	Solution/Recommendation	R&D Needed
10. Wire strikes and obstacles such as trees, poles, buildings, and crops	a. Pilot training and awareness of wire-avoidance techniques	None
	b. Install wire cutters, deflectors, and detectors	b. Design and test wire cutters, deflectors, and detectors
	c. Reduce pilot complacency in maneuvering close to obstacles	c. None
11. Adverse terrain factors (pilot judgment)	a. Pilot training and experience	a. None
12. Adverse wind conditions	a. Improve operational planning and pilot awareness of aircraft limitations	a. None
	b. Increase control margin	b. Same as 6c
13. Weather – inadvertent entry into low visibility (fog, snow, rain, haze, and darkness)	a. Install limited IFR instruments and train pilots to use	a. Same as 6a, 6c, and 7b
	b. Trend is to increased IFR capability	b. Same as 6a, 6c, and 7b
14. Main rotor blade failure	a. Composite blades	a. None
	b. Corrosion control	b. None
	c. Install blade inspection equipment	c. None
	d. Blade retention assurance	d. None
	e. Failsafe blades (multiple spars)	e. None
15. Flight controls disconnects	a. Flight controls positive-retention bolts	a. None

TABLE 9 – Continued

Accident Cause		Solution/Recommendation		R&D Needed
16. Tail rotor failures	a.	Improve QC of tail rotor gearboxes	a.	None
	b.	Improve diagnostics to warn of impending failure	b.	Develop incipient failure detection equipment for production and field use, Reference 5
	c.	Composite blades and techniques to improve obstacle strike survivability	c.	Design and test new concepts
17. Postcrash fire	a.	Retrofit crashworthy fuel systems	a.	None
	b.	Design new helicopters with crashworthy fuel systems	b.	None
18. Crash injuries/fatalities in survivable crashes	a.	Crashworthy structure in all new helicopters	a.	None (change FAA criteria)
	b.	Energy-absorbing crew and passenger seating	b.	Complete development of energy-absorbing seats
	c.	Delethalize occupied space	c.	None
	d.	Provide pilots with lightweight crash helmets	d.	None
19. Inaccurate airspeed indication (pitot-static system plugged up)	a.	Maintenance to keep pitot-static system drained and clean	a.	None
	b.	Provide accurate omnidirectional low-airspeed system and improve airspeed position error accuracy for autorotation, slow climbout, etc	b.	Same as 6a

aircraft adapted for helicopter use. It is imperative that reciprocating-engine reliability be improved since the engine-failure accident rate for 1975 is 3.94/100,000 flying hours, compared with 0.96/100,000 flying hours for turbine-engine civil helicopters.

Introduction of turbine engines can be expected to substantially reduce the accident rate simply through a reduction in engine failures which result in autorotational-landing accidents. Any available R&D funds are more likely to be used to improve turbines than reciprocating engines. One area that needs further understanding is the trend in helicopter use for crop-dusting and spraying. Turbine engines are susceptible to buildup of chemicals on compressor blades and therefore, as turbine-engine helicopters became operational for this use, it may be necessary to provide special inlet filters or separators.

The manufacturers of new reciprocating-powered helicopters such as the Enstrom 280 Shark, the Robinson R22, and the Hunt HS-180 Hunter must take steps to prevent engine failures from creating a bad accident record. This is especially true since the market for these aircraft will tend to be the small operator wanting the least-expensive helicopter and probably operating under the weakest FAA controls with minimal pilot qualifications. In fact, piloting will most likely be a secondary job in many cases. All of these factors tend to increase the possibility of high accident rates, in the opinion of the author.

4.2.2 Turbine-engine failure. – Turbine-engine reliability improvements to prevent in-flight failures are discussed in reference 3. There were seven turbine-engine failures that caused accidents in 1975: 3 undetermined, 1 compressor failure, 1 compressor blade failure, 1 power-turbine governor failure, and 1 fuel-pump failure. The fact that 43 percent of the causes were undetermined reveals a deficiency in the accident-investigation system. Powerplant failure history and determination of exact cause have historically been poor. Therefore, the data contained in the reliability report (reference 3) is helpful since it takes into account a larger sampling of failures, even though not all of the failures caused accidents. It is concluded that all powerplant and related fuel system component failures should be tracked and fixed. Where research and development is needed it is listed in reference 3.

4.2.3 Fuel contamination. – Engine failures because of fuel contamination can be prevented with existing technology. Fuel filters and separators should be installed on fuel trucks to prevent contaminants from entering the aircraft tank. Fuel filters are usually installed at the inlet to the engine fuel pump and, depending on the severity of the problem, an additional filter can be installed in the fuel line between the aircraft tank and the engine. The U.S. Marines found that both fuel supply truck filters and the additional fuel filter in the fuel line were necessary for operation in Vietnam. No R&D is necessary to apply this technology. It is reported by HAA representatives that fuel contamination problems have diminished in the past 2 years because of aggressive efforts to filter fuel in the civil fleets. Water in fuel is the only remaining problem of significance.

4.2.4 Twin-turbine one engine inoperative. – It has been suggested that engine restart capability be improved. There are several modes of engine failure or flameout that occur that may be amenable to engine restarting: deceleration compressor stall caused by blade erosion, flameout in heavy rain or snow, stator-vane trailing-edge damage from FOD, ice causing compressor stalling, and fuel-control malfunctions causing engine shutdown. Research and development to improve engine restart capability are discussed in section 5.

Research to provide hover with one engine inoperative (HOEI) was identified in reference 4. The recommendation was to provide a 2-1/2-minute contingency-power rating of double the 30-minute power rating by a combination of wet and dry augmentation. Dry augmentation increases engine speed up to 8 percent with up to a 20-percent absolute turbine-inlet-temperature increase. Wet augmentation requires the addition of a water-alcohol inlet-injection system to provide increased mass flow and power without further increase in engine speed or temperature.

It is recommended that twin-turbine helicopters be equipped with positive identification of the failed engine by a lighted condition-lever handle or equivalent so that the good engine will not be shut down inadvertently. For single-engine helicopters a failure-warning device would alert the pilot on landing approach where an engine failure would not affect rotor rpm or would not be easily detected by engine instruments until power is required for the landing flare. No new technology is involved.

4.2.5 Fuel exhaustion. – This problem is so obvious that it just seems as though pilot complacency is the whole issue. However, several possible reasons for fuel exhaustion are listed below to assist in determining what to do about it:

- Fuel gaging and warning light systems in small helicopters are typically prone to errors and inaccuracies.
- Not all helicopters have low-fuel warning lights.
- Pilots frequently operate with partial fuel so that maximum loads can be carried, particularly in agricultural work where both fuel and chemicals are replenished at the same time (maximum chemicals and minimum fuel).
- Improper estimates of fuel consumption in mountainous terrain or in headwind conditions.
- Maintenance personnel fuel inadequate quantity.
- Pilots in agricultural applications forget to watch fuel.

No new technology is necessary to solve the fuel exhaustion problem. The most obvious solution would appear to be more accurate low-level gaging and an audible warning at 5 minutes prior to empty. The standard warning light that is used in military aircraft for 20 minutes fuel remaining would also be helpful in many cases, but not in agricultural work where pilots are frequently in the 0 to 20 minutes of fuel range.

For helicopters with more sophisticated instrumentation such as the advanced systems monitor which involves microprocessors, a fuel-use-rate function could be added with voice warning to prevent fuel exhaustion.

4.2.6 Power-off autorotation. – Power-off autorotation landing accidents can be reduced considerably by increased engine reliability and updating to single and twin turbines. However, engine failures will always be with us and it is unlikely that all helicopters will have two engines. Therefore, the autorotational landing itself must be made safer by the following changes:

- Improve pilot training, qualifications, and understanding of helicopter low-speed aerodynamics. In the critical landing maneuver the pilot often misjudges speed, altitude, and rotor rpm and in consequence makes a hard landing, hits something, or lands on improper terrain because of lack of rotor-energy power margins to properly maneuver. More training and practice would help this situation.

- Reduce the hazard by designing a more forgiving helicopter. Helicopters having inadequate rotor inertia and stability and control must be improved. It is recommended that helicopter characteristics be studied and design criteria be changed for input into new helicopter designs. This is discussed further in section 5.

4.2.7 Power-on takeoff, landing, hover maneuvers, and cruise flight (pilot causal factors). – These types of accident frequently result from inadequate pilot qualifications, lack of understanding of the helicopter power-required curve, and lack of a low-airspeed indication system. Improved training and pilot manual explanations of power required, particularly in hover maneuvers, sideways flight, rearward flight, and landing transition flight, are necessary combined with development of an accurate, omnidirectional low-airspeed system.

As in power-off autorotational landings, it appears that the helicopter stability and control characteristics may be in need of change. It is recommended that these be studied and design changes made where appropriate.

Another area that needs attention is the cockpit arrangement, instrument layout, and specialized helicopter instruments to reduce pilot workload and improve visibility. As more helicopter IFR capability becomes available and more weather and night conditions are encountered, there will be increased hazards such as the disorientation phenomenon that is now predominantly a fixed-wing aircraft and Navy helicopter piloting problem (ref. 6, 7). An additional problem is that of getting IFR certification for helicopters. The stability and control requirements and low-speed measuring systems need to be related specifically to helicopters and should not be based on fixed-wing aircraft stability, as is now the case. At present, there is pressure to relax requirements for helicopter IFR because fixed-wing aircraft stability and control are so hard to achieve. This area needs level-headed study to prevent arbitrary relaxation which could lead to higher accident rates. In addition, the small operator versus the large operator situation and different uses of helicopters need to be input to insure that safe design criteria are established. This is discussed further in section 5.

4.2.8 High/hot operation. – The high/hot marginal power situation comes about because of poor anticipation of density altitude at destinations or remote landing sites. The pilot is frequently unaware that he is flying into a landing with inadequate power available for maneuvering, particularly in adverse wind conditions. A power-available indicator mounted on the instrument panel alongside the torquemeter would indicate when the aircraft was about to enter marginal power conditions; a typical installation is shown in Figure 10. Existing technology can be applied. A more advanced system could include engine parameters for input into the advanced systems monitor to provide power degradation information.

Providing contingency power as discussed in paragraph 4.2.4 and reference 4 would also help prevent the high/hot operational accidents.

4.2.9 Inadequate operational planning and controls. – Improved planning, good debriefings, avoiding letting missions become routine, reducing complacency, and planning for the average pilot's capability are all necessary to reduce this cause of accidents. This is one area where U.S. Army and Navy operations are generally superior to the civil operators and probably accounts for the better accident record. However, it is well-known that many of the larger civil operators are very meticulous in operations, planning, and pilot qualifications and consequently have a good accident record as evidenced by low insurance rates. Therefore, it is necessary to understand the differences between the large and small operator and also the type of helicopter and its use to determine shortcomings in operations, planning, and pilot qualifications. Many civil helicopter operations have more demanding tasks than the military and these need further study. This is discussed further in section 5.

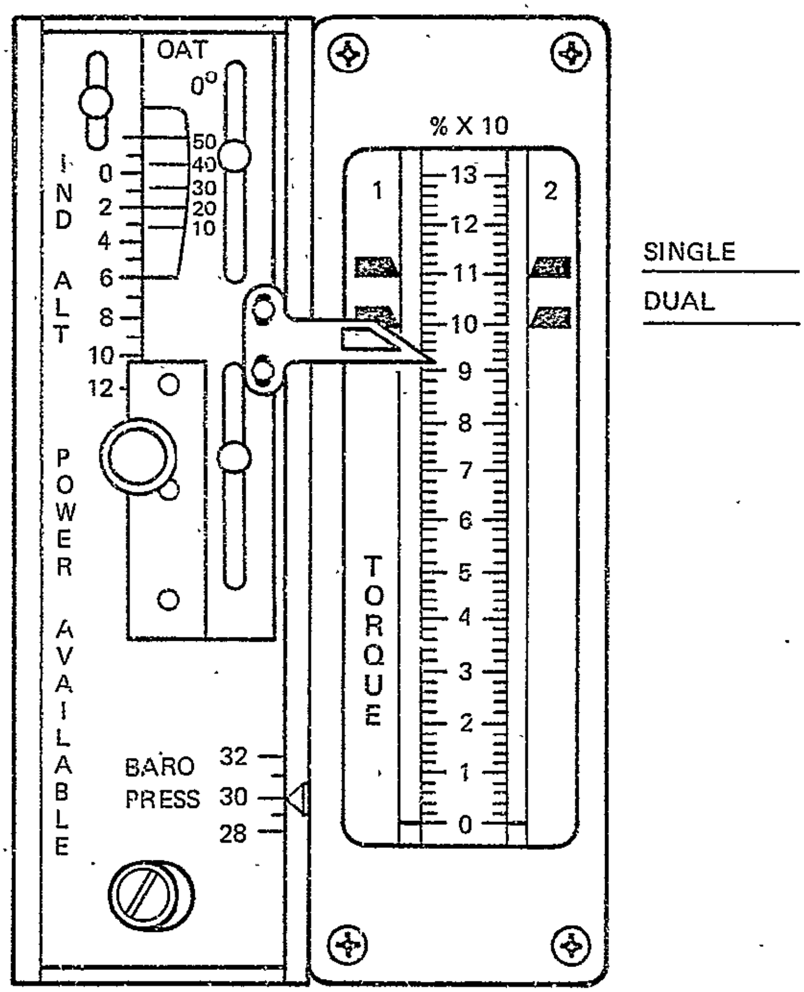
4.2.10 Wire strikes. – The current rate of wire strike accidents is 2.6 per 100,000 flying hours, 34 percent of which have fatalities or serious injuries and 30 percent of the aircraft are destroyed or have substantial damage. Reference 8 presents statistics which are reproduced in Tables 10 and 11. The following factors illustrate where the wire strike problem lies by types of operation:

- Agricultural 41 percent
- Business operations 25 percent
- Police and firefighting 17.5 percent

Approximately 50 percent of the wire strike accidents occur below 50 feet altitude. Many of these accidents occur because pilots are forced down to the deck by bad weather through lack of IFR capability.

Figure 11 illustrates the problems of wire strike. Wire avoidance is the most effective means for decreasing wire strike accidents and the following pertinent points are brought out:

- Fly high.
- Fly slow if low.



The power-available indicator is mounted on the pilot's instrument panel next to the torquemeter. It indicates maximum dual engine torque available, predicated on barometric pressure, altitude, and temperature. Setting the lower pressure knob or the upper altitude knob moves the pointer over the torquemeter scale up or down. The pointer then sets the dual engine torque limit for existing or predicted atmospheric conditions. Values set into this instrument are for a standard engine and would not account for engine degradation from environmental factors such as sand, dust, and corrosion.

Figure 10. Power-available indicator

TABLE 10. U.S. CIVILIAN HELICOPTER WIRE-STRIKE ACCIDENT STATISTICS

			1973	1974	1975	1976*
Total Accidents			251	258	293	267
Wire-Strike Accidents			29	26	25	28
Percent of Total			11.5	10.0	8.5	10.4
Damages:	a.	Destroyed	9	8	7	Not yet available
	b.	Substantial	20	18	18	
Injuries:	a.	Fatal	4	9	7	
	b.	Serious	11	3	3	
	c.	Minor	27	29	24	

Source: HAA and NTSB

* Preliminary

TABLE 11. HELICOPTER WIRE-STRIKE ACCIDENTS BY OPERATION

		1973	1974	1975	Total
FAR 135	(Air taxi, commercial)	2	5	1	8
FAR 137	(Agricultural)	15	8	10	33
FAR 91	(Business, pleasure)	7	8	10	25
	(Police)	3	3	2	8
	(Firefighter)	2	2	2	6
		29	26	25	80

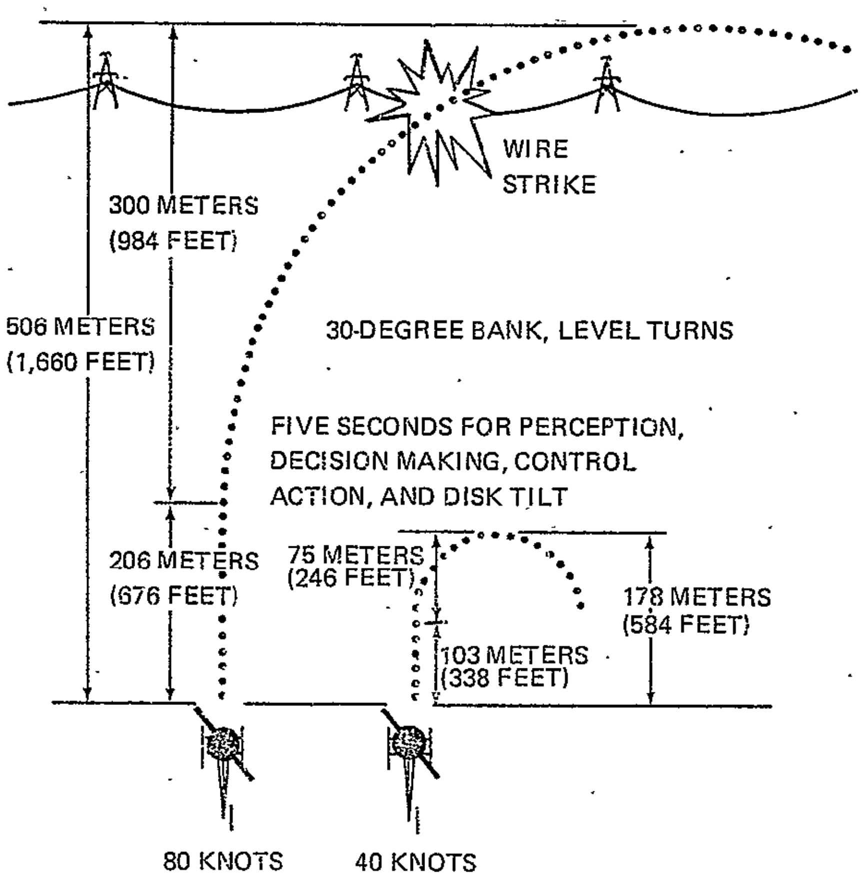


Figure 11. Slower is better when it comes to outmaneuvering wires

- Head-up scan.
- Diligent flight planning; avoid complacency.
- FAA regulations to require wire marking (conspicuity).
- Don't fly low in poor visibility.
- R&D on wire detectors.

The following design innovations have been suggested for increased survivability if a wire strike occurs:

- Wire cutters (blades, controls, and windshields).
- Wire deflectors (controls, windshields, landing gear, and tail rotor).

The U.S. Army Aviation Air Mobility Research and Development Laboratory has recently let a contract to Bell to study helicopter obstacle strikes which includes the wire strike problem. It is anticipated that solutions to the wire strike hazard will be developed for incorporation in Army helicopters and will eventually be installed on civil helicopters. However, until wire cutters and deflectors have been developed through analysis and test, it is believed that a significant improvement in civil helicopter safety can result from pilot training in wire avoidance and wire marking where appropriate.

A U.S. Army Agency for Aviation Safety (USAAAVS) article, reference 9, summarizes the solutions to the wire strike problems as follows:

> *"As for the future, recommendations are for the Army to examine the feasibility of using wirecutting and detecting devices as protective aids against wire hazards. Meanwhile, we should avoid complacency, continue to emphasize the hazards associated with wires, and maintain the effective supervision and controls presently in force. In addition, the following protective measures should be reviewed and followed:*
>
> - *Review unit SOPs and directives relative to low-level flying to make certain they reflect the safest procedures possible for the types of missions being flown.*
>
> - *Provide adequate supervision to ensure pilots adhere to established policies.*
>
> - *Limit the minimum altitude for required low-level flight training (outside the formal NOE program) to 150 feet above the terrain, or to lower altitudes over prescribed flight courses known to be free of wires.*
>
> - *When low-level flights are required, provide pilots with current maps that show wire obstacles, and make certain that crews receive thorough briefings.*

- *Where possible, mark all wires around takeoff and landing points on military reservations and airfields.*

- *Unless required by missions, avoid low-level flight over areas known to contain wires and over ranges where fine TOW (missile) wire can pose a potential threat.*

- *Use all crewmembers in searching for wire obstructions during all low-level flights and ensure maximum coordination between them.*

- *Keep in mind, the closer to the ground that low-level flight must be conducted, the slower the airspeed should be."*

Research and development recommendations are covered in section 5.

4.2.11 Adverse terrain factors (pilot judgment). – This type of accident involves landing on slopes, rocks, soft ground, and other adverse terrain conditions creating situations which cause accidents. Where no other contributing factors are involved, improved pilot training and mature judgment are probably the only solutions. When adverse terrain is encountered during marginal power situations or forced landings, the previously discussed power-available indicator, potential design criteria changes for improved stability and control, and cockpit human factors changes for improved visibility and reduced workload would apply. These are discussed in section 5.

4.2.12 Adverse wind conditions. – To combat this type of accident it is necessary to improve operational planning and pilot awareness of aircraft limitations in adverse wind conditions. In some helicopters there is probably a need for increased stability and control margins, which is covered in previous discussions and in section 5.

4.2.13 Weather and low visibility factor. – Inadvertent entry into low visibility conditions such as fog, snow, rain, haze, and darkness can cause loss of horizon with disorientation, becoming lost, and flying into obstacles either in cruise or in attempted landings. It is generally agreed that the trend is toward increased IFR capability through installation of avionics and instruments in helicopters and completion of the LORAN-C chains to cover all of the United States. IFR capability is necessary in order to maximize helicopter utilization and improve profits. If accompanied by pilot IFR qualifications, the helicopter safety record should be greatly improved. However, there still remains the problem of inadequate helicopter stability to meet FAA regulations for IFR certification in many helicopters. The general opinion is that subjecting the helicopter to fixed-wing aircraft stability and control criteria is too restricting and unnecessary. This area needs further study and definition, taking into account the special capabilities and uses of the helicopter, pilot qualification, and pushing the limits too far. Therefore, the IFR situation for the small, poorly equipped operator needs to be studied in more detail before accepting increased IFR capability as a panacea for weather flying accidents. This is discussed further in section 5.

4.2.14 Main rotor blade failure. – Metal rotor blade spars have a corrosion/fatigue failure history that continues to cause catastrophic accidents. Adhesive bond separation of blade boxes, particularly the root box, permits water to become trapped in the bond; this leads eventually to corrosion pitting of the spar with drastic loss of fatigue life. Corrosion control and blade inspection methods consisting of either pressurized or evacuated spars which provide a warning when a crack allows air to leak through it are an acceptable solution to this problem. More recently the introduction of composite rotor blades having no metal has greatly reduced the potential for blade spar failure. Most composite rotor blades have no need for blade inspection systems because failures are rare; the material is not susceptible to corrosion; the material is extremely damage tolerant; and the redundancy provided with numerous individual glass fibers acting as load paths make failure progression very slow and visually inspectable. No new technology is necessary and all active military helicopters are scheduled for eventual retrofit of composite blades. The introduction of composite blades into the civil fleet will be slower, but when it happens it will provide increased safety.

4.2.15 Flight controls disconnects. – This problem results from nuts backing off because they have not been safety-wired or cotter-pinned, or because mechanics forget to install nuts. In military helicopters most critical bolted connections in flight controls now have positive-retention bolts which feature spring-loaded mechanisms that prevent bolts from falling out even if the nut is not present. No new technology is required.

4.2.16 Tail rotor failures. – Failures of tail rotor gearboxes, rotor, and control components result in loss of directional control and usually cause a serious accident. If the tailboom and vertical and horizontal tailplanes remain intact, it is possible to make a safe landing. The usual case is that with the limited directional stability from the remaining vertical tail the landing maneuver is too demanding for most pilots. Therefore, preventive measures such as improved quality control of the tail rotor components, designing tail rotor drive systems to accept transient fatigue loads, designing tailbooms strong enough for fatigue loads, corrosion control on tailbooms, maintenance procedures to provide system integrity, tail rotor blade design for damage resistance/tolerance, and incipient failure detection are all needed.

Research and development are needed to apply a newly developed incipient failure detection (IFD) system for airborne monitoring of tail rotor gearboxes and other components. This equipment appears to be capable of providing a cockpit warning of incipient failures originating in tail rotor gearing and bearings so that precautionary landings can be made before catastrophic failure.

Improved tail rotor blades with greater damage tolerance and/or protective features need to be developed. New concepts should be designed and tested. Both IFD and improved tail rotor blades are discussed in section 5.

4.2.17 Crashworthiness and postcrash fire. — The Army's crashworthiness requirements are much more severe than those of the FAA. Furthermore, most of them are not readily accommodated unless included at the time of basic configuration layout (ref. 10).

The requirements contained in Military Standard 1290 (Table 12) are well-founded in extensive accident data studies and survivable crash impact analyses (Figure 12). Reference 11 is a crash survival design guide based on these studies and on crash testing. Where they have been applied, they have proven exceptionally successful; for example, the crashworthy-fuel-system retrofit to Army helicopters (Table 13) where there hasn't been a single thermal injury since introduction of the system.

4.2.18 Crash injuries and fatalities in survivable crashes. — The key features of the basic configuration necessary to accomplish such crash protection are shown in Figure 13. When accommodated from the beginning, the costs of this protection are minimal and, according to the U.S. Army, very cost-effective (Figure 14).

So, unless designed to these requirements from the beginning, it is difficult to imagine a civil helicopter being acceptable to the U.S. Army without major change.

Review of fatal accident records at the NTSB had limited value because autopsy reports were not available. However, the accidents all proved to be typical of those with military helicopters which have been extensively analyzed. Figures 15 and 16 identify the inadequacies in crashworthy features in potentially preventable injuries and fatalities in order of importance. Figure 17 shows a schematic of an energy-absorbing passenger seat being developed under NASA funding for fixed-wing aircraft which is predominantly for forward accelerations. Similar seats for helicopter passengers would have different kinematics to change the stroking and energy-absorbing characteristics, placing more emphasis on vertical accelerations.

In a study at the U.S. Army Agency for Aviation Safety in 1975 (reference 12), the following conclusions were reached:

> "a. *Crashworthy requirements, as outlined in Military Standard 1290 (5), are cost effective for the military UTTAS helicopter. The initial and recurring costs, as estimated in this report, are amortized in three to ten years.*
>
> b. *The most worthwhile crashworthy features which influence the prevention and/or reduction of occupant injuries and hardware damage are listed in an estimated order of priority according to their relative cost-effectiveness.*

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TABLE 12. CRASHWORTHINESS REQUIREMENTS OF MILITARY STANDARD 1290

Impact Condition	Requirements	
	Structural	Other
Longitudinal	20 fps into rigid wall; safe evacuation of crew 40 fps into rigid wall; troop-compartment reduction no more than 15% 60 fps at 10° nose down; reduction of cockpit or troop-compartment living space no more than 5%	95th-percentile seats; cockpit; 50 fps, MIL-S-58095 passenger: 50 fps
Vertical	42 fps; living space reduction no more than 15%	95th-percentile seats; cockpit and passenger: 42 fps
Lateral	30 fps; reduction in compartment living space no more than 15%	95th-percentile seats; 30 fps
Turnover Structure	Aircraft resting on ground; 4W perpendicular to WL; 4W longitudinally parallel to WL; 2W laterally Ground impact at 100 fps at 5° angle; passenger-occupied volume reduction no more than 15%	
Nose Plowing	Forward 25% fuselage uniformly loaded 10g up and 4 g aft (10g based on effective mass); preclude scooping	
Tail Bumper	MIL-A-003862A; 10-fps sink speed and pitch attitude corresponding to IGE hover in 60-knot tailwind	
Blade Strike	Rotor mast shall not fail; transmission shall not be displaced into occupiable section when main-rotor blades impact into a rigid 8-inch-diameter object in the outer 10% blade radius at operational rotor speed	
Mass-Item Retention	±20g longitudinal; 20/−10g vertical; ±18g lateral	
Postcrash Fire	—	Fluid containment; ignition sources; separation of fluids from occupants; shielding
Evacuation	—	30-second evacuation time (crew and passengers)

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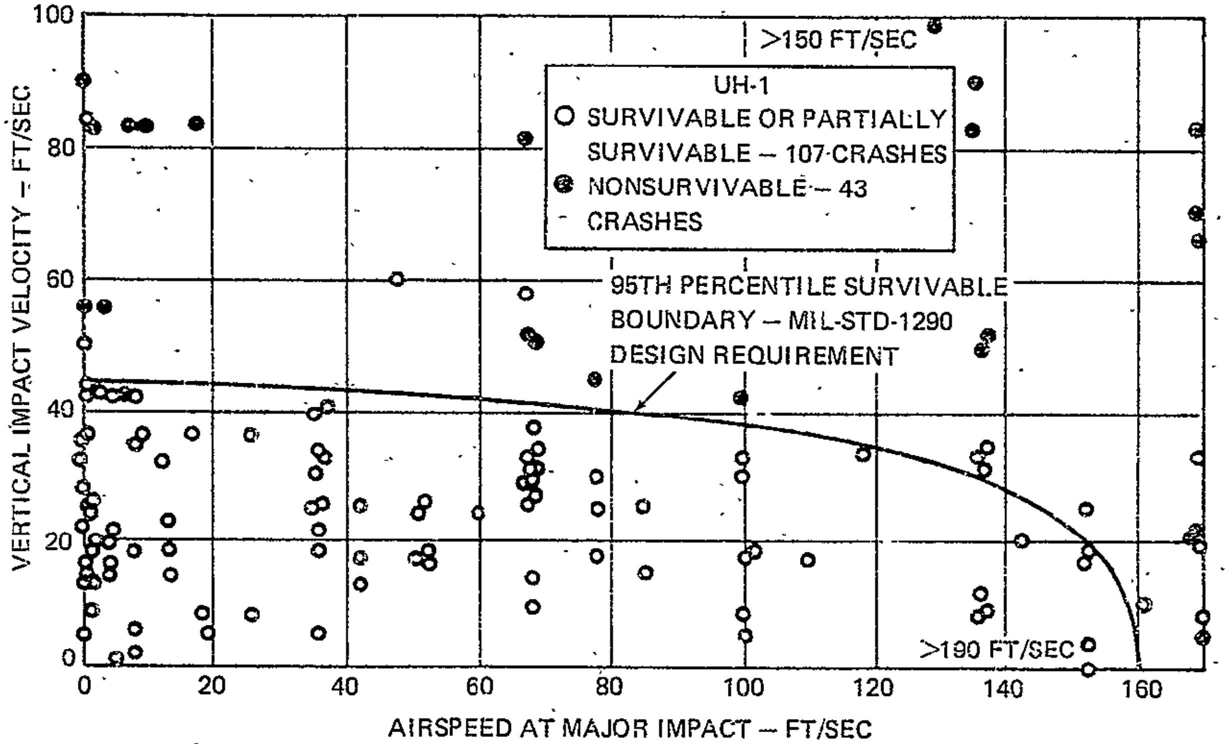

Figure 12. The relationship of survivability and speed at crash impact

TABLE 13. NO THERMAL INJURIES WITH CRASHWORTHY FUEL SYSTEMS

	Fatalities		Injuries	
	Thermal	Nonthermal	Thermal	Nonthermal
Without CWFS				
AH-1G	3	36	2	69
OH-58A	5	39	3	62
UH-1D	8	7	1	23
UH-1H	85	128	80	225
Total	101	210	86	379
With CWFS				
AH-1G	0	8	0	11
OH-58A	0	5	0	11
UH-1D	0	3	0	18
UH-1H	0	54	0	255
Total	0	70	0	295

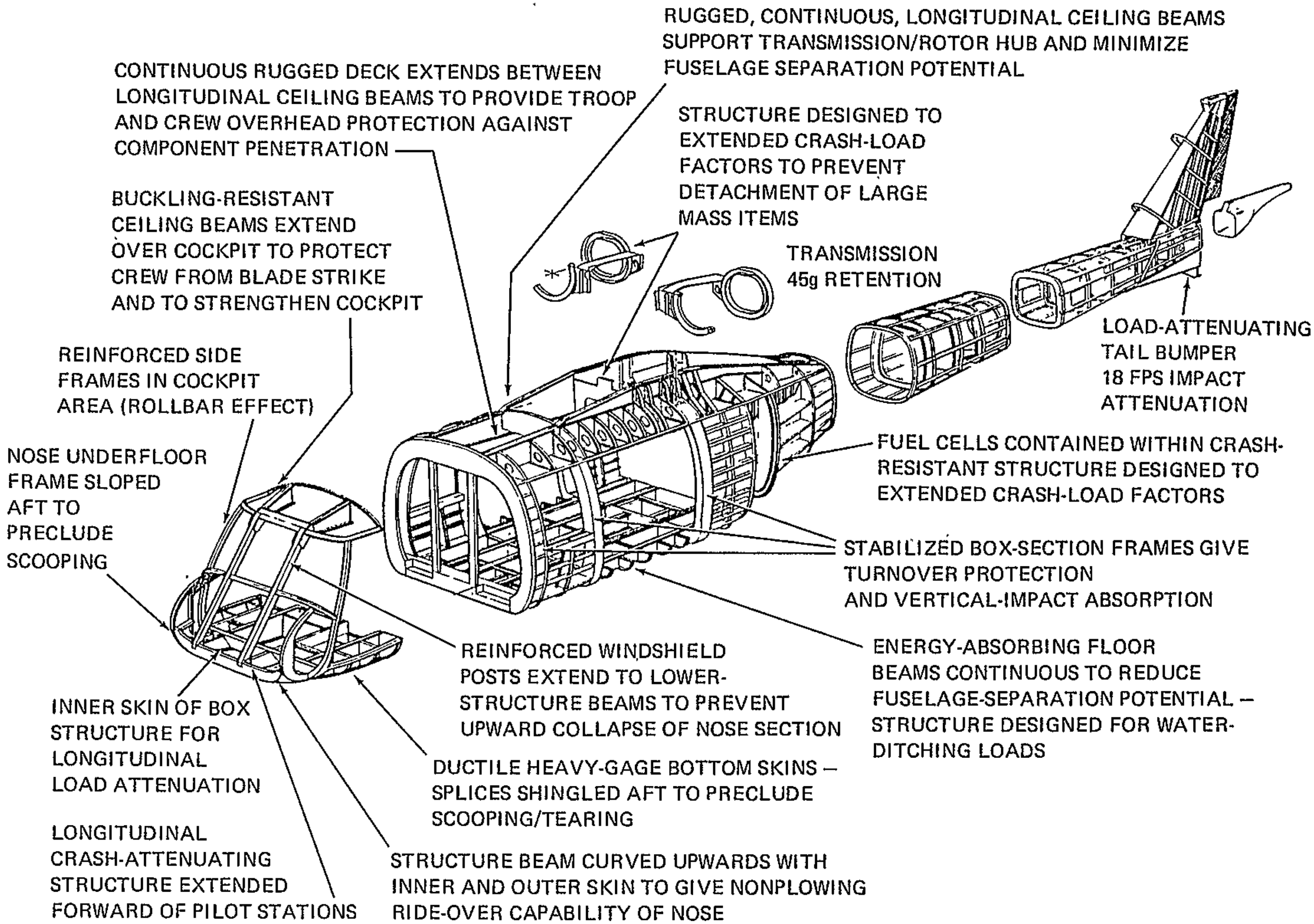

Figure 13. Principal crashworthiness features of the UH-61A structure

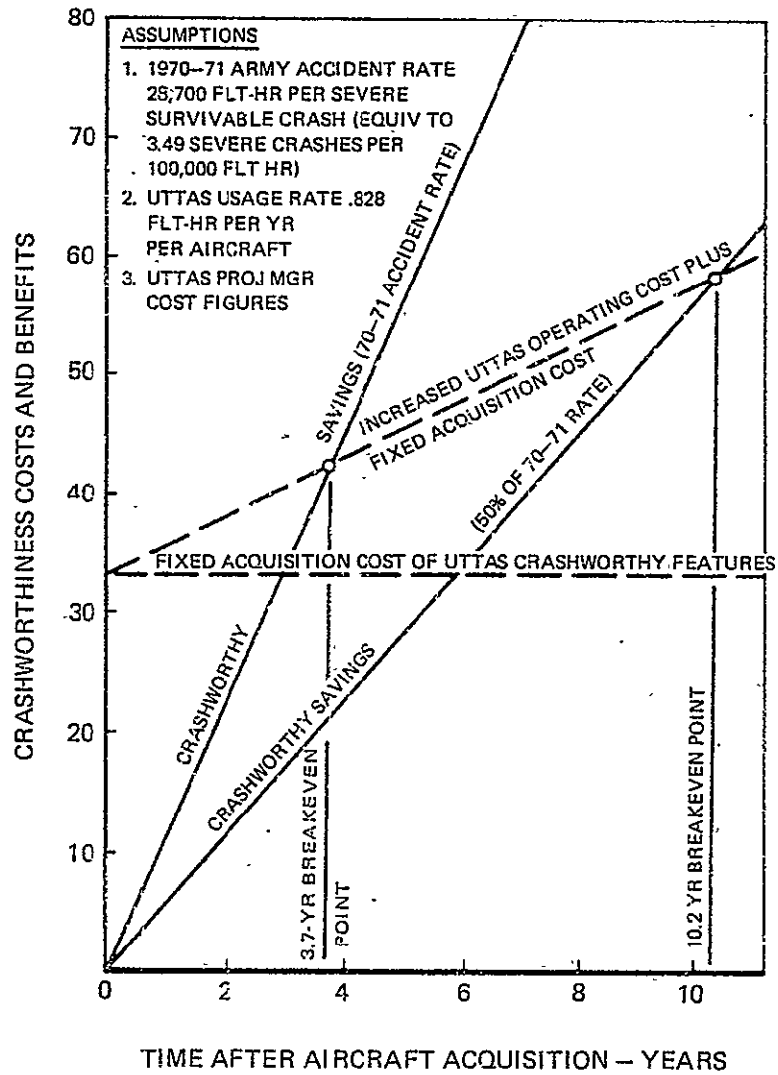

Figure 14. UTTAS crashworthiness investment saves the army money as well as lives

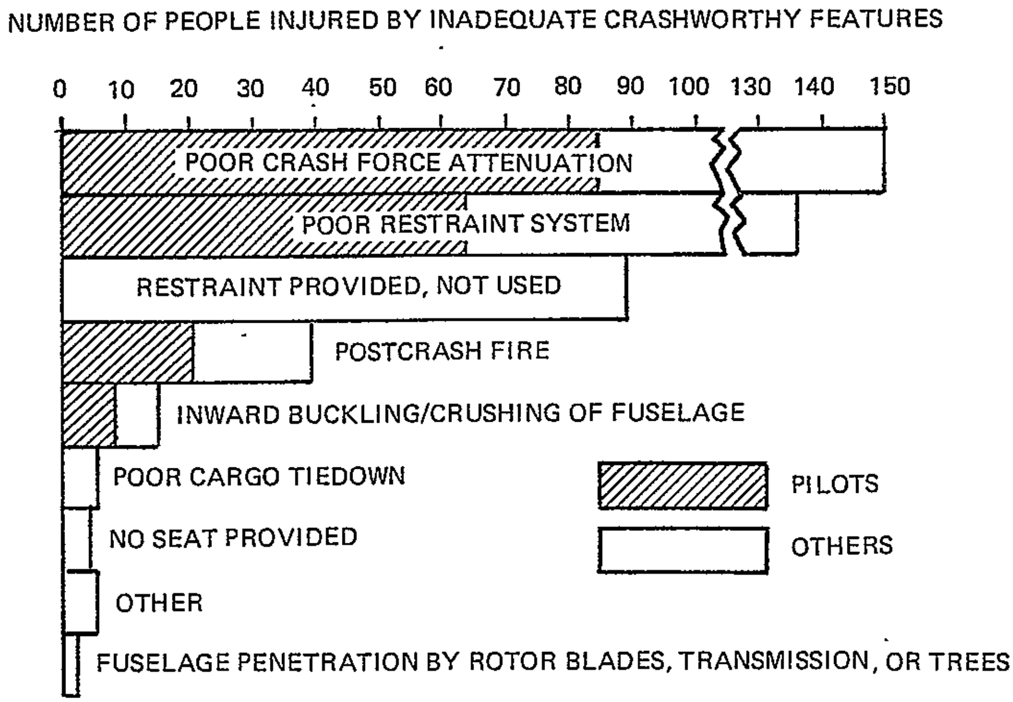

Figure 15. Identity of hardware deficiencies causing 356 potentially preventable injuries (1970 and 1971, from reference 8)

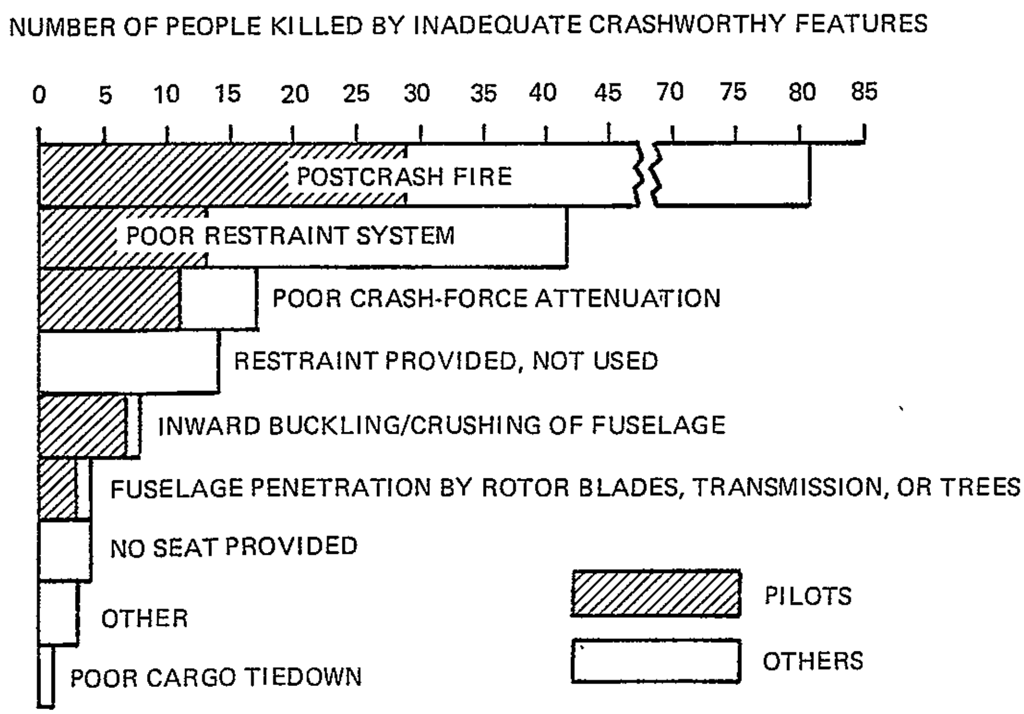

Figure 16. Identity of hardware deficiencies causing 160 potentially preventable fatalities (1970 and 1971, from reference 8)

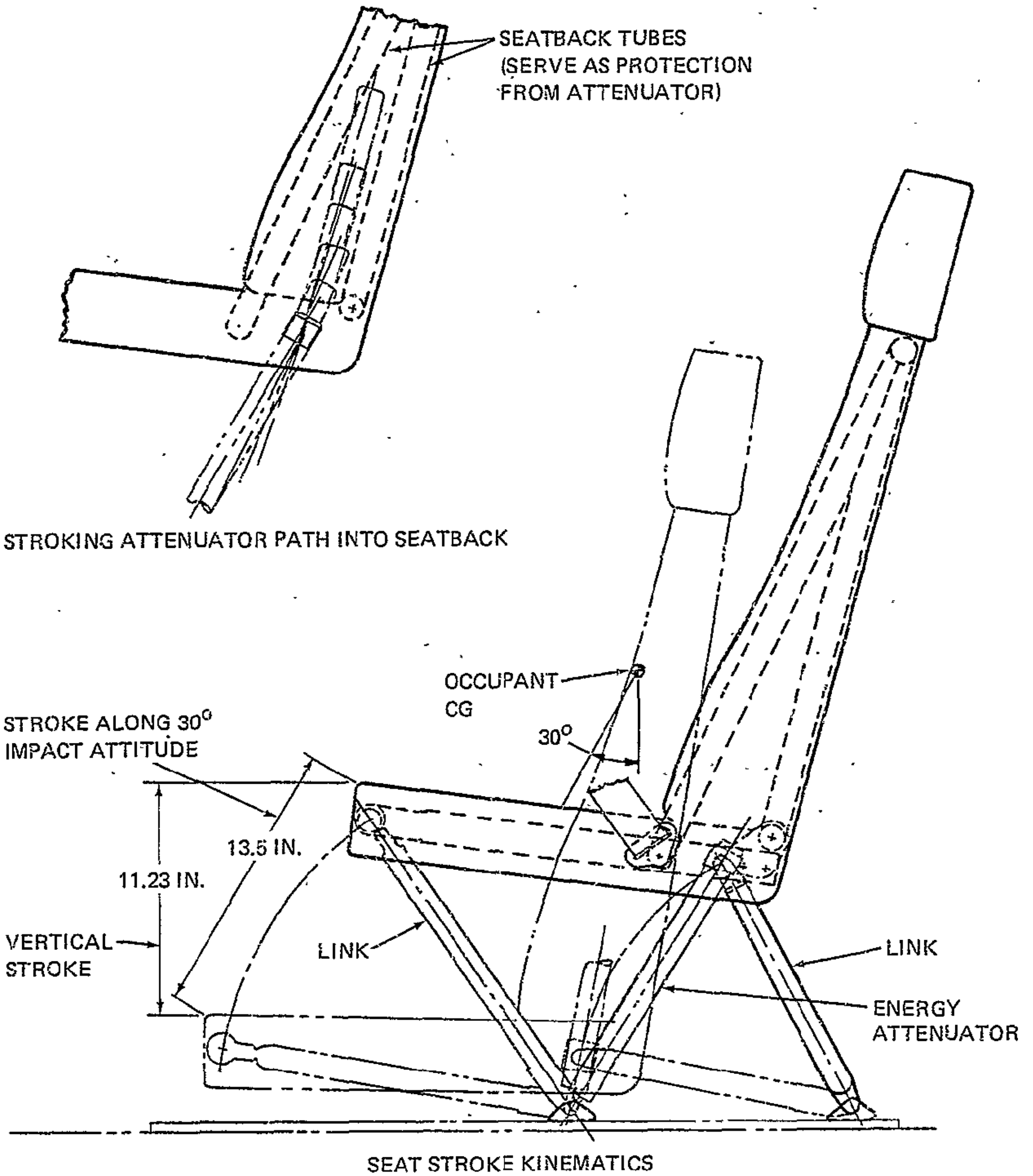

Figure 17. Crashworthy seat for passengers in fixed-wing aircraft

Reduction of Occupant Injury	*Reduction of Hardware Damage*
1. Improved occupant restraint, especially upper torso, to prevent flailing injuries.	*1. Protected tail rotor with impact tolerant blades.*
2. Fuselage rollover capability without collapse.	*2. Improved landing gear to prevent rollover, as well as greater absorption of sink speed energy.*
3. Improved landing gear to prevent snagging/gouging and resultant rollover, as well as greater absorption of sink speed energy.	*3. Impact-tolerant main rotor blade tips and transmission integrity to sustain unbalanced loads from bent/broken/missing tips.*
4. Increased 'load-limiting' capacity of seats and fuselage structure to prevent back injury.	*4. Crashworthy fuel system.*
5. Crashworthy fuel system."	

4.2.19 Inaccurate airspeed indication. – Although this problem does not stand out in accident causal statistics, HAA representatives have found numerous cases of inaccurate airspeed indication because of improper cleaning and draining of the pitot-static system. Pitot tubes are susceptible to plugging with dirt and water, which generally results in an erratic reading. This means that (1) autorotational speeds are frequently high with a higher than necessary rate of descent; and (2) V_{ne}'s are exceeded resulting in potential fatigue damage to rotor components or high-speed rotor instabilities, depending on what dictated the V_{ne} limit. Good maintenance practices should prevent these inaccuracies and reduce accidents.

4.2.20 Advanced systems monitor. – With the introduction of more complex helicopters and terrain flight profiles, additional demands are placed on the flight crew in terms of their anticipatory and decision-making capabilities. It is now possible with state-of-the-art display and computer systems to provide the crew with properly processed information to enhance their performance and reduce workload.

The Advanced Systems Monitor (ASM) is a general purpose, time-shared, electro-optical display driven by an on-board computer. The ASM has the potential to replace conventional subsystem instruments and annunciator panels and permits the crew increased outside-the-cockpit attentiveness.

The ASM would not be considered a primary flight display and would not be flight-safety critical in a first-failure condition.

All subsystems, excluding navigation-communication and flight displays, would be included. A generic listing using existing helicopters would include analysis of the following subsystems:

- Fuel system quantity and use rate
- Hydraulic system
- Electrical system
- APU system
- Engines
- Transmissions
- Annunciator displays
- Flight manual normal and emergency checklists
- Battery system
- Flight manual performance data
- Incipient failure detection (IFD) of critical systems
- Collision avoidance
- Primary display backup
- Navigation

A study is recommended to define ASM requirements and potential benefits in the various civil helicopter types and to define a developmental program.

5.0 RESEARCH REQUIRED TO IMPROVE SAFETY

Accident statistics and causal factors for general aviation helicopters were reviewed in section 3.0. Section 4.0 covered the status of technology needed to improve civil helicopter safety and to achieve the goals established in section 2.0. Gaps in technology that require research and development to provide solutions for improved safety are discussed here.

5.1 Turbine-Engine Reliability, Contingency Power, and Diagnostics

The following areas need R&D to reduce turbine-engine power failure accidents.

5.1.1 Improve reliability to greatly reduce in-flight engine failures which usually result in accidents. Reference 3 covers this subject and makes specific recommendations for R&D. Some of the more significant actions are: (1) to require more detailed reporting on cause of failure in the M or D reporting system at engine overhaul facilities; for example, the causes of four out of the eight turbine-engine failures (accidents) in 1975 were undetermined; and (2) introduction of an aggressive failure analysis and fix program with engine manufacturers.

5.1.2 A 2-1/2-minute contingency-power rating of two times the 30-minute power rating is achievable with a combination of wet and dry augmentation. This R&D program is outlined in reference 4. Estimated nonrecurring costs for the program are:

• Engine emergency power by wet and dry augmentation	$3 million	18 months
• Associated helicopter development	$2.5 million	24 months

5.1.3 Develop lightweight, low-cost, engine health-monitoring systems that will diagnose impending failures in time to prevent occurrence in flight. The newer turbine engines (such as the GE T700) have health-monitoring diagnostic systems but there is still a need for refinement and adaptation to the other turbine engines used in civil helicopters. The most practical solution is to provide an on-board minicomputer with multiplexing and memory storage for trending of critical parameters. The engine health parameters would only be a portion of the data input and therefore costs for the on-board computer would be shared with sensor inputs from the dynamic system, flight controls, stability augmentation systems, and data that would be helpful in crash investigations. Preliminary cost estimates indicate that a user cost of $10,000 per aircraft for a complete system should be achievable with a weight penalty of 20 pounds. Such a system would not only greatly reduce accident potential but offer substantial savings in maintenance fault analysis and reduced repetitive maintenance throughout the aircraft. Estimated nonrecurring costs are:

• Lightweight on-board diagnostics package (engine portion only)	$250,000	18 months

5.1.4 Improved in-flight restart capability has been listed as an R&D need because current turbine engines have airstart shortcomings. Technology for this is not well understood; therefore it is recommended that an engine manufacturer be given a study contract to determine what could be done and the probable cost benefits. Estimated cost is:

• Study-improved turbine-engine in-flight restart	$100,000	12 months

5.2 Tail Rotor Damage Tolerance

Several areas for improvement need R&D funding as discussed below.

5.2.1 A program is recommended to design and test improved fiberglass tail rotor blades to: (1) be capable of impacting a 1-inch-diameter hardwood dowel without damage; (2) be capable of losing a blade without tearing the tail rotor gearbox out of the aircraft; or (3) possibly providing a shear pin to let the blade pivot to prevent loss in case of impact. The program would include design, analysis, and impact testing of several concepts to determine the best means to combat the tail rotor damage problems. A full-scale tail rotor assembly would be instrumented to measure impact loads and gearbox mounting loads under blade loss conditions. Estimated cost for this program is:

• Tail rotor impact testing	$300,000	18 months

5.2.2 A tail rotor blade guard to protect against strikes on objects and wires and to protect personnel is required. Helicopters vary from no guards to half rings to full rings. Design criteria must be established to reduce this hazard and should be combined with the blade impact program defined in 5.2.1 and wire strike protection in 5.3.1. Estimated cost of this study is:

• Tail rotor guard design criteria	$50,000	18 months

5.3 Design and Test Wire Cutters, Deflectors, and Detectors

5.3.1 The recommended program is to develop wire cutters, deflectors, and structural reinforcements through analyses, design, and wire strike testing as follows:

1. Review wire strike accidents and designs of cutters and deflectors.
2. Analyze typical helicopter types for dynamic response when impacting various sizes and numbers of wires.
3. Design concepts to provide structural guards, wire deflectors, or wire cutters as appropriate. Typical areas that must be considered are windshields, hub and upper controls, rotor blades, landing gear, antennas, and tail rotor.
4. Fabricate test hardware and devise a test setup to simulate wire strikes and prove the best concepts. A scrapped helicopter could be used for this testing.

Estimated cost is:

•	Design/test wire cutters/deflectors	$400,000	18 months

5.3.2 Wire detector research has been conducted at U.S. Army ECOM for several years and at present has not been developed to a practical production model. Continuing R&D is needed. Estimated costs to determine what needs to be done are:

•	Study to define needs	$15,000	4 months

5.4 Analyze Small Versus Large Operator Accidents and Types of Flying

Figure 9 indicates the relative hazards of various types of flying but it is difficult to draw conclusions from the present state of the analysis. Therefore, it is recommended that further studies be conducted to determine why the statistics are as they are and what operational practices are affecting both bad and good accident rates. Rate trends should be studied for the past 8 years by kinds of flying, type of helicopters being flown, reciprocating or turbine engines, size of the operation, standard operating procedures, type of pilot training and experience level, and other factors that may be influencing the rates. It is anticipated that this study would reveal several areas for improving safety in addition to those contained herein. Estimated cost is:

•	Analyze small versus large helicopter operators versus kinds of flying	$50,000	10 months

5.5 Stability and Control Design Criteria (VFR/IFR/Autorotation)

Helicopter types have a large variation in rotor inertia and stability and control characteristics. Some are easy to fly and others are hazardous, particularly when entering marginal conditions such as power-off emergency or practice landings or power-on landings, takeoffs, and hover maneuvering in adverse winds, at high gross weights, or at high/hot conditions. Pilot error is often cited as the primary cause or a contributing cause of accidents under these conditions. The question is whether or not the average pilot is given a machine that is safe when pushed to the limits of his capability. Design criteria need to be examined in light of the trend toward more IFR flying and increased use of helicopters in the borderline operations with marginally experienced pilots. Estimated cost for this program is:

•	Study stability and control criteria and requirements (VFR/IFR/autorotation)	$100,000	12 months

5.6 Cockpit Layout, Visibility, Workload, and Crash Survivability

Cockpit and instrument layouts will need attention to minimize pilot workload, improve instrument presentations, and reduce glare, rotor flicker, anticollision light reflections, and other phenomena that cause disorientation. An improved low-airspeed system is discussed in paragraph 5.9.

A system analysis approach addressing civil operations should be initiated to provide criteria for improved cockpit design and reduced pilot workload. Better definition of civil operating parameters is needed. Analysis of historical data, evaluation of present usage, and prediction of future utility should be included in such a study. Further classification of helicopter type capability is necessary to assure that each design is properly certified to a more definitive operating category.

The program would involve mockups to assist in pilot evaluations of improved cockpit environment and advanced systems monitoring concepts.

With improved cockpits it is also necessary to consider the crash safety problems of delethalization of the interior and energy-absorbing seat stroking requirements. There should also be a consideration of pilot comfort and how to combat the high-temperature, high-humidity fatigue problem. Estimated cost of this study program is:

• Cockpit layout/visibility/workload/ crash survivability	\$250,000	18 months

5.7 Dynamic System Diagnostics and Incipient Failure Detection (IFD)

For dynamic systems positive airborne incipient failure detection (IFD) is needed to prevent accidents (reference 5). IFD can be applied to any rotating machinery and can detect impending failure of gears and bearings. Application would include the main transmission, intermediate gearbox, tail rotor gearbox, swashplate bearing, and tail rotor drive shaft hanger bearings. The capability of this equipment in laboratory applications has been demonstrated. The program recommended here is as follows:

1. Conduct spall failure progression testing of bearings.
2. Develop lightweight airborne monitoring equipment using the IFD demodulated resonance principle.
3. Conduct implant testing of failed components in gear test stands. Adjust thresholds and conduct false warning testing.
4. Demonstrate reliability in test helicopters.
5. Define how to combine with other diagnostic equipment in the on-board computer box discussed in paragraph 5.1.3.

Estimated cost of this program is:

• Dynamic systems airborne IFD	\$200,000	18 months

5.8 Energy-Absorbing Crew and Passenger Seating

Current NASA contracts are in process to define fixed-wing aircraft seat configurations. Follow-on design, fabrication, and dynamic testing of several seat configurations for helicopter application are required to complete development. Estimated cost is:

• Energy-absorbing crew and passenger seat development testing	$200,000	18 months

5.9 Study Reciprocating-Engine Failures

As discussed earlier, reciprocating engines fail because of improper operations such as overspeed on starting, improper fuel, fuel contamination, improper mixture control, running out of oil, and improper assembly and maintenance practices. A detailed analysis of all types of engines and causes for failure is beyond the scope of this study. Since reciprocating engines will continue to be used in helicopters in the foreseeable future and failures of reciprocating engines will continue to cause high accident rates, a high priority must be assigned to failure prevention. A survey of operators and engine manufacturers and a detailed study of NTSB accident records and FAA M or D reports for the past 7 years is recommended. Estimated cost is:

• Study reciprocating-engine failures	$50,000	10 months

5.10 Develop Omnidirectional Airspeed System and Improve Existing System Accuracy

There is a definite need for an accurate omnidirectional low-airspeed system for helicopters. Many systems have been evaluated over the years in helicopter flight testing with limited success. One system, the Low-Range Omnidirectional Airspeed System (LORAS), has demonstrated that it will do the job but needs further research to make it suitable for low-cost production.

Existing airspeed systems must also be improved in flight modes such as autorotation and low-speed high rate of climb where substantial errors are introduced because of directional changes in airflow and errors from pitot tube location. At present, there is no requirement for calibration of the airspeed system under the unusual flight modes. A study of this problem to assess what could be done is recommended. Estimated cost for such a study is:

• Study low-airspeed systems and improve existing systems	$15,000	4 months

5.11 Develop Advanced Systems Monitor

It is recommended that a design and analysis program be conducted to include concept formulation, selection, and evaluation of an Advanced Systems Monitor (ASM) to reduce crew workload and eliminate numerous subsystem instruments. The concepts identified shall be capable of practical application toward existing and future helicopters. Additional details are discussed in paragraph 4.2.20. Estimated cost is:

• Define ASM needs and cost benefits	$80,000	12 months

5.12 Develop an Autorotation Simulator

It is recommended that a study and design analysis be conducted to define an autorotation simulator for pilot training and proficiency checks. The simulator would be capable of reproducing various helicopter characteristics and the hazards involved in a power-off approach and landing. This study would compare and relate similar requirements for civil operations to those incorporated in CH-47 and UH-1 simulators now in use by the U.S. Army at Fort Rucker, Alabama.

• Study needs and define simulator requirements	$50,000	10 months

6.0 IMPACT OF SAFETY IMPROVEMENTS ON SIZE, CONFIGURATION, AND MISSION APPLICABILITY

Table 14 is a summary of the research and development recommended for increased safety, including an estimation of the impact on size, configuration, and mission applicability.

TABLE 14. SUMMARY OF RECOMMENDED R&D FOR INCREASED SAFETY

No.	Research Item or Area	Priority	Size Applicability	Payoff
1.	Turbine engine reliability/ contingency power diagnostics	High	All	High
2.	Tail rotor damage tolerance	High	All	High
3.	Design/test wire cutters, deflectors, and detectors	High	All	High
4.	Analyze small versus large operator accidents (kinds of flying)	High	All	High
5.	Stability and control design criteria (VFR/IFR/autorotation)	High	All	High
6.	Cockpit layout/visibility/workload/ crash survivability	High	All	High
7.	Dynamic system diagnostic incipient failure detection (IFD)	High	All	High
8.	Energy-absorbing crew and passenger seating	High	All	High
9.	Study reciprocating engine failures to determine what R&D needs are	High	Small, under 5,000 lb	High
10.	Develop omnidirectional low-airspeed system and improve system for autorotation and low-speed high rate of climb	High	All	High
11.	Develop advanced systems monitor for reduced pilot workload	High	All	High
12.	Develop an autorotation simulator	High	Small, medium	High

7.0 IMPACT OF SAFETY IMPROVEMENTS ON LIFE-CYCLE COSTS AND INTERACTING TECHNOLOGY REQUIREMENTS

The costs of a high accident rate in civil helicopters are generally reflected in high hull insurance rates, which are discussed below. Other associated costs of accidents such as loss of revenue, costs of delays, investigations, and lack of public confidence in helicopters are substantial and have the effect of depressing helicopter industry growth. Therefore, effort spent in continuing the downtrend in accident rate can be traded for lower operating costs and increased demand for services. A good safety record is mandatory for continued growth and maturity in the civil helicopter marketplace.

Accident Rate Trends and Insurance

As shown in Figure 1, the accident rates for 1969 through 1976 are decreasing for both rotary-wing and fixed-wing aircraft in general aviation. The fact that helicopter accident rates are approximately 1.6 times the fixed-wing aircraft rate as shown in Figure 4 has a direct effect on hull insurance rates. The opinion of insurance underwriters, brokers, and claims adjusters is that the current rates of rotary-wing hull insurance are now too low and a downward trend in accidents must continue for hull insurance to remain at present levels. Note that hull insurance rates vary with type of helicopter, type of operation, accident record of aircraft and operator, pilot experience, availability of repair parts, and fleet size. For example, for a helicopter that has a good record with replacement parts readily available in a large fleet used for corporate air taxi with well-trained, experienced pilots with good records, the hull insurance rate can be as low as 4 percent of the selling price per year. Conversely, factors that increase the probability of accidents such as crop dusting with a small, poorly maintained fleet and poorly trained pilots with low flying hours, can push the rate as high as 20 percent and, in some cases, no one wants to insure the operator. This leads to the conclusion that the most effective methods for preventing accidents today are better operations and planning and better pilot and maintenance crew training, i.e., more professionalism. However, in the long run, many other actions must be taken to effect a 62-percent reduction in the accident rate by 1985. These are discussed elsewhere in this report.

The safety record for civil helicopters is reflected in part by the insurance rates. The hull insurance rate has decreased from about 15 to 20 percent in 1969 to 4 to 8 percent in 1977. This reduction was brought about by the following:

- A reduction in U.S. civil helicopter accident rates from 41/100,000 flying hours in 1968 to 16/100,000 flying hours in 1976.
- Entry of U.S. insurance companies into the market offering lower rates than those in the U.K. consortium. At present about 25 percent of the helicopter insurance is written by five U.S. companies.

- Increased professionalism among operators, maintenance personnel, and pilots which promotes safer operations.
- Increase in use of turbine-powered helicopters.
- Greater use of twin-turbine-powered helicopters.
- Increase in fleet size and better scheduling and planning.

In general, when a helicopter has a hard landing or uncontrolled touchdown in either normal operation or in an emergency situation, it frequently rolls over and disintegrates because of the energy in the whirling rotor blades. The result is major damage which may be beyond repair. A similar situation in a fixed-wing aircraft usually results in much less damage that is quickly repairable. The impact on hull insurance rates is that the helicopter rate may be several times that of the fixed-wing aircraft in similar operations (air taxi, for example), even though the accident rates may only be slightly higher for the helicopters.

Liability insurance has remained about the same as for fixed-wing aircraft in equivalent operations in spite of the higher accident rate of helicopters. This reflects the fact that fewer people are killed or injured in helicopter accidents than in fixed-wing aircraft because helicopters are as survivable as fixed-wing aircraft in major crashes and fewer people are carried in helicopters. The fatal accident rates of helicopters and fixed-wing aircraft are approximately the same at two per 100,000 flying hours. Even though minor accidents in helicopters frequently result in major hull damage, the crew and passengers may not be severely injured because they are located near the center of rotation of the blades, and centrifugal force throws parts outward away from occupants.

8.0 CONCLUDING REMARKS

The limited analysis of accident statistics and causal factors, operator surveys, and response from operator questionnaires conducted in this study has shown that there are many areas for work in reducing accidents in civil helicopters. Twenty-one areas that are within existing technology and therefore are available for immediate action are summarized below:

1. Phase out older aircraft and go to single and twin turbines with better power match.

2. Improve reliability of reciprocating and turbine engines with an aggressive failure analysis and fix program with engine manufacturers.

3. Install fuel filters in fuel truck hoses near nozzle to prevent engine failures caused by fuel contamination and water in fuel.

4. On twin-engine helicopters, provide failed engine warning so good engine will not be shut down. On single-engine helicopters, provide failed engine warning so that pilots will not be surprised when making descents to find no power on descent termination.

5. Improve operational planning and fuel gage accuracy and provide 5-minute fuel warning to prevent fuel exhaustion.

6. Train pilots to understand helicopter low-speed aerodynamics for high gross weights and autorotation, combined with improved low-airspeed indication (see item 13 under R&D below).

7. Improve practice autorotation and pilot qualifications for autorotation and improve aircraft stability and control.

8. Install power-remaining indicators in all helicopters.

9. Improve operational planning, have good debriefings. avoid letting missions become routine, and reduce complacency.

10. Train pilots in wire-avoidance techniques and provide IFR capability in helicopters to reduce flying in wire environments.

11. Reduce pilot complacency in maneuvers close to obstacles.

12. Improve pilot awareness of adverse terrain factors and aircraft capabilities in adverse winds.

13. Install limited IFR instruments, and sufficient helicopter stability to use them, and train pilots in their use.

14. Improve metal main rotor blade corrosion control, blade fatigue crack inspection, and blade retention assurance.

15. Retrofit composite main rotor blades.

16. Install positive-retention bolts in critical flight controls.

17. Improve quality control of tail rotor gearboxes.

18. Retrofit crashworthy fuel systems and design into new helicopters.

19. Improve crashworthy structure concepts in all new helicopter designs.

20. Provide pilots with lightweight crash helmets.

21. Improve maintenance to keep pitot-static system drained and clear for accurate airspeed indication.

The following additional areas for safety improvement are recommended for R&D funding:

1. Specific turbine-engine reliability improvements (ref. 3).

2. Develop a lightweight, low-cost turbine-engine health-monitoring system.

3. Engine contingency power by wet and dry augmentation (ref. 4).

4. Improve turbine-engine in-flight restart capability.

5. Improve tail rotor damage tolerance and develop tail rotor guard design criteria.

6. Design and test wire cutters and deflectors and develop wire detectors.

7. Analyze small versus large operator accidents and kinds of flying.

8. Review stability and control design criteria (VFR/IFR/autorotation).

9. Cockpit layout/visibility/workload/crash survivability – study and mockups.

10. Dynamic systems airborne incipient failure detection (IFD) (ref. 5).

11. Energy-absorbing crew and passenger seating development and testing.

12. Study reciprocating-engine helicopters, engines, and related drive system components to determine where research is required to prevent engine failures.

13. Improve airspeed systems for accurate omnidirectional low-airspeed indication and develop improved accuracy for autorotation and low-speed high rate of climb.

14. Develop Advanced Systems Monitoring to combine engine health (power available), systems status, failure warning devices, and improved cockpit presentation for greatly reduced pilot workload.

15. Develop an autorotation simulator.

Action on most of these recommendations will be necessary to achieve the goal of less than 6.0 accidents/100,000 flying hours and less than 0.9 fatal accident/100,000 for the U.S. civil helicopter fleet by 1985. The cost of a bad accident record in restraining growth of the helicopter industry and losses of equipment and lives far outweighs the cost of an aggressive safety campaign.

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