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HELICOPTER CRASHWORTHY FUEL SYSTEMS AND THEIR EFFECTIVENESS IN PREVENTING THERMAL INJURY (Reprint)

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20. ABSTRACT:

In 1968, the United States Army committed itself to a goal of eliminating postcrash fires in survivable helicopter accidents. New helicopters manufactured after 1970 were equipped with a crashworthy fuel system, and an extensive retrofit program of older aircraft was begun. This paper reviews all Army helicopter accidents during the period 1968-1976 and classifies them by survivability and whether or not the aircraft was equipped with a crashworthy fuel system. Accident associated fatalities and injuries were reclassified as to the primary injury involved and its relationship to the existence of any postcrash fire. The direct costs involved in the care of thermal fatalities and thermal injuries were calculated using the most conservative estimates. It is shown that the helicopter crashworthy fuel system essentially eliminated postcrash fatalities and injuries in accidents involving helicopters equipped with the new system.

HELICOPTER CRASHWORTHY FUEL SYSTEMS AND THEIR EFFECTIVENESS IN PREVENTING THERMAL INJURY

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SUMMARY

In 1968, the United States Army committed itself to a goal of eliminating postcrash fires in survivable helicopter accidents. New helicopters manufactured after 1970 were equipped with a crashworthy fuel system, and an extensive retrofit program of older aircraft was begun. This paper reviews all Army helicopter accidents during the period 1968-1976 and classifies them by survivability and whether or not the aircraft was equipped with a crashworthy fuel system. Accident associated fatalities and injuries were reclassified as to the primary injury involved and its relationship to the existence of any postcrash fire. The direct costs involved in the care of thermal fatalities and thermal injuries were calculated using the most conservative estimates. It is shown that the helicopter crashworthy fuel system essentially eliminated postcrash fatalities and injuries in accidents involving helicopters equipped with the new system.

INTRODUCTION

Aircraft postcrash fire injuries are emotionally hideous. The victims risk permanent disfigurement and are often socially crippled. Many never return to flying. Physical and emotional handicaps prevent, for some, any gainful employment. The clinical care of burn patients is expensive, long term, and logisitcally difficult. A social, occupational, financial, and medical responsibility is incurred. Employers, insurance underwriters, and a tax-burdened public carry this responsibility. Public money pays for most military or government service related injuries.

The prevention of aircraft postcrash fire related injury and death has been a long sought goal of physicians, airframe designers, manufacturers, and safety conscious management. Although crash impact forces have always been the primary etiologic factor in aircraft accident morbidity and mortality, postcrash fires create disproportionate suffering when associated with large fixed wing transport and rotary wing accidents. This is particularly true for accidents classified as survivable* or partially survivable.* Failure to escape or inability to escape because of momentary incapacitation, partial entrapment, or indecision are important secondary factors that contribute to thermal injury.

Ironically, large transport aircraft and helicopters greatly differ as to the nature of a postcrash fire, survival time, and usual cause of fire related death. Transports tend to slide away from the impact site and area of initial fuel spillage. Fuel is largely contained in wings that break apart or burn external to the main inhabited space. Large interior volumes allow time to egress of up to 90 seconds. Cause of death or primary incapacitation is smoke and toxic fuel inhalation from burning polymeric structures used in furnishings, insulation, wiring, and non-load bearing interior structures.

Helicopter crashes have a high vertical acceleration component that crush fuel cells located beneath the cockpit and passenger compartments. Misting of fuel in the cockpit is common. Rotor action causes the aircraft to roll over or beat itself apart structurally. Fire is immediate and rapid spreading. Small internal volumes surrounded by large areas of plexiglass that usually break open on impact dictate a maximum time to egress and be outside the fireball of 17 seconds.[1] Cause of death is flame contact and superheated air or flame inhalation.

The purpose of this paper is to report the operational effectiveness of the U. S. Army Crashworthy Fuel System (CWFS) for helicopters in eliminating helicopter postcrash fire mortality and reducing morbidity.

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*Survivability is a generic classification dependent on habitable postcrash cockpit structural space and/or crash acceleration forces at the floor under the seat that are within human tolerance irrespective of the influence of fire or water (drowning).[2,3]

BACKGROUND

In March of 1968, the Army Chief of Staff, General Harold K. Johnson, made a decision to allocate three million dollars in emergency research and development funds for the development of a crashworthy fuel system (CWFS) for Army helicopters. General Johnson's decision was based on a visit to Vietnam in early 1968, where Army field commanders expressed their concern for the increasing number of personnel being killed or injured from burns received in helicopter postcrash fires and who would have otherwise survived.

Acting upon the decision of General Johnson, the U. S. Army Materiel Command awarded contracts to several companies for the development of a crashworthy fuel system for the UH-1 helicopter. The result of this developmental work was a fuel system designed to reduce fuel spillage by means of impact resistant fuel cells, fuel cells which were self-sealing (ballistic capability), and fuel lines including valves with break-away and non-leak features. Fig. 1 is a schematic of the UH-1D/H fuel system.

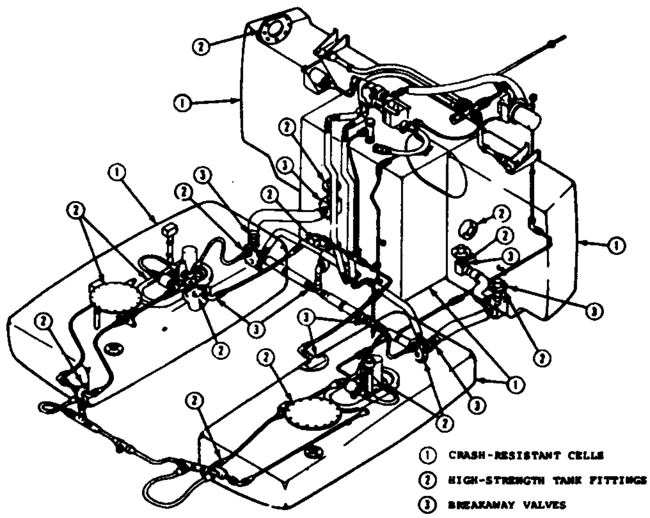

Fig. 1. Schematic of the Crashworthy Fuel System installed on the UH-1D/H helicopter fleet. The basic features are the same in systems installed in other aircraft types.

During the month of April 1970, following a period of intensive testing and evaluation, the first UH-1D equipped with a crashworthy fuel system came off the production line.

The original concept was to install the system only on new aircraft. Not all Army aircraft were to be outfitted. As early accident data from CWFS equipped aircraft were compiled by the U. S. Army Agency for Aviation Safety, a dramatic conclusion was evident. There were no thermal injuries in CWFS equipped aircraft. Decisions were rapidly made to incorporate the CWFS in other new Army helicopters during factory assembly. Human cost data by Zilioli and Bisgard[2] were used by the Army Safety Agency, Eustis Directorate, Army Air Mobility Laboratory, and the Army Aviation Systems Command to demonstrate that a systematic retrofit program in the Army's utility helicopter fleet could be cost effective from a human cost standpoint. A retrofit program was then instituted.

Table I outlines the rate at which the US Army has equipped its helicopters with the CWFS.

TABLE I
ARMY HELICOPTER CONVERSION RATE TO CRASHWORTHY FUEL SYSTEM

Aircraft	1971	1974	1975	1976
UH-1D/H	44%	93%	100%	100%
UH-1B/C/M	--	26%	76%	90%
AH-1G	--	66%	100%	100%
OH-58	--	70%	95%	99%
OH-6A	--	--	0	63%
CH-47A/B	--	--	0	5%
CH-47C	--	17%	100%	100%
CH-54		Conversion not planned		
UTTAS*		Will be CWFS equipped		
AAH**		Will be CWFS equipped		
ASH***		Will be CWFS equipped		

*Utility Tactical Transport Aircraft System
**Advanced Attack Helicopter
***Advanced Scout Helicopter

METHOD

To determine the operational effectiveness of the crashworthy fuel system, accident data compiled by the U. S. Army Agency for Aviation Safety were reviewed. Accidents occurring during two time periods were examined. The first, 1967-1969, represents an interval during which no crashworthy fuel systems were installed. Accident data prior to 1967 were not computerized and were considered statistically unreliable; thus, not used. The second interval studied began in 1970, coincident with the installation of the first crashworthy fuel system, and extended through 30 June 1976. No combat related accidents were included, primarily because of the incomplete nature of combat accident reporting.

All accidents were classified as survivable or nonsurvivable as defined by Army regulation[3] and the Army Crashworthiness Design Guide.[4] This classification does not consider effects of fire or drowning. Hence, a further classification was necessary to identify thermal and non-thermal crash events and their relationship to the primary cause of death or injury. It is possible under this classification for an individual to survive the impact of a nonsurvivable accident and die a thermal death. But the authors' analyses also identify those individuals who for some reason died from impact forces in survivable accidents and then were exposed to a postmortem fire.

It is important for the reader to clearly understand this classification. The initial impression of lay persons or persons unfamiliar with postcrash accident analysis techniques when viewing the burned wreckage and victims of an accident is to make a wrong judgment that death was caused by fire. In fact, none of the victims may have died as a result of fire. Only a careful reconstruction of the accident sequence and a thorough autopsy examination of all deaths will assign cause of death and place the injuries seen in their proper sequence of occurrence.

It would be advantageous to assume that individuals involved in accidents classified as survivable without fire would all live. Unfortunately, the assumption is not valid. Factors such as time to rescue, drowning, cockpit intrusion, restraint failures, inadequate or absent protective equipment, and other unusual events contribute to fatalities in survivable accidents. These factors were not examined in this study. Only the event primarily responsible for the individual's death or injury was determined. A judgment was then made prior to final classification as to whether the individual would have survived or escaped injury had that event not occurred, be it fire or impact related.

RESULTS AND DISCUSSION

Table II presents fatalities and injuries from 68 nonsurvivable accidents classified as to their thermal and non-thermal etiologies. Data from accidents involving the three primary fleet helicopters being flown during the 1967-1969 time frame are presented. No aircraft were equipped with the crashworthy fuel system.

TABLE II
1967-1969 FATALITIES AND INJURIES IN NONSURVIVABLE ARMY HELICOPTER CRASHES*

	Fatalities		Injuries	
Aircraft	Thermal	Non-Thermal	Thermal	Non-Thermal
UH-1D	64	108	2	8
UH-1H	31	148	1	0
AH-1G	1	14	0	0
TOTAL	96	270	3	8

*68 accidents, no crashworthy fuel systems, 57 postcrash fires

Table III presents the same data on 1000 accidents classified as survivable. Elimination of fatalities and reduction of injury in survivable accidents are more realistic goals than trying to make nonsurvivable accidents survivable. It should be noted that postcrash fires occurred in 13.3 percent of survivable crashes and contributed 95 thermal injuries or 59.7 percent of the 159 fatalities produced in 1967-1969 by 1000 survivable accidents. Sixty-four thermal injuries account for 4.7 percent of the 1361 persons injured. These thermal injuries represent a fortunate group of aviators. Thermal protective flying suits were available but were still not universally used by all units. Considering all factors that can mitigate rapid egress from a crashed and burning helicopter, the 64 survivors with thermal injury are operationally significant. The senior author of this paper concluded from interviewing hospitalized postcrash fire survivors in 1971 that accident victims who survive the impact aspects of helicopter crashes and then encounter an ensuing postcrash fire (listed in order of decreasing frequency of occurrence) either do not know how they got outside the fireball, were thrown clear of the aircraft and/or fireball, or were rescued from the aircraft/fireball by other aircrew. Rarely is rescue accomplished by formal rescue techniques.

TABLE III
1967-1969 FATALITIES AND INJURIES IN SURVIVABLE ARMY HELICOPTER CRASHES*

	Fatalities		Injuries	
Aircraft	Thermal	Non-Thermal	Thermal	Non-Thermal
UH-1D	47	106	32	718
UH-1H	47	49	25	530
AH-1G	1	4	7	49
TOTAL	95	159	64	1297

*1000 accidents, no crashworthy fuel systems, 133 postcrash fires

A comparison of injuries and fatalities, both thermal and non-thermal, for survivable and nonsurvivable accidents during the 1970-1976 time frame is depicted in Table IV. There were 1160 survivable accidents involving aircraft not equipped with the crashworthy fuel system. Of these, 3.7 percent resulted in fire. This represents a 72 reduction in fire occurrence as compared to the 1967-1969 data. A major factor in this reduction was the rapid crashworthy fuel system retrofit program of fleet aircraft considered to be at highest risk. See Table I. Though the 1970-1976 reporting period is longer, the net yearly accident rate has been steadily declining. This has been especially true since the military "phase down" after the Southeast Asia withdrawal. There has been an overall reduction in all injuries and death regardless of etiology. Factors contributing to this reduction include introduction of better restraint systems, more crashworthy seats, Nomex® aramid flight clothing, the SPH-4 helmet, fewer old high-fire-risk aircraft (See Table I), and introduction of crashworthy airframe improvements.

TABLE IV
1970-1976 ARMY HELICOPTER CRASH FATALITIES AND INJURIES

	Survivable		Nonsurvivable	
Classification	w/o CWFS	with CWFS	w/o CWFS	with CWFS
Thermal Injuries	20	5	5	0
Non-Thermal Injuries	529	386	13	28
Thermal Fatalities	34	0	31	1
Non-Thermal Fatalities	120	44	229	85
Accidents	1160	1258	61	32
Postcrash fires	43	16	42	18

Table IV also shows that during the period 1970-1976, 1258 survivable accidents occurred involving aircraft equipped with a crashworthy fuel system. Sixteen fires occurred and resulted in five thermal injuries, but no thermal fatalities. This represents a 75 percent reduction in thermal injuries and elimination of thermal fatalities when compared to survivable accidents during the same period in aircraft not equipped with the crashworthy fuel system.

Table V shows the sources of flammable fluid spill causing postcrash fires in crashworthy fuel system equipped aircraft accidents.

TABLE V
SOURCES OF FLAMMABLE FLUID SPILL CAUSING POSTCRASH FIRE, 1970-1976

Source	Survivable Accident*	Nonsurvivable Accident*	Other
Ruptured fuel cell or lines	10	12	---
Hydraulic fluid	1	1	---
Transmission fluid	1	1	---
Fuel vent	9	0	---
Auxiliary tank	0	1	---
Engine	0	0	1
Unknown	1	1	---
TOTAL	22	16	1

*Accidents involving CWFS equipped aircraft

The system is not crash proof. It is only crashworthy. Fuel vent leakage can be indicated in nine survivable accidents. The fuel vent does not have crashworthy or non-leak characteristics and may be expected to cause fires in roll over accidents. Ruptured fuel cells and fuel lines contributed another 10 fires. Though the fuel lines are coiled or looped to allow considerable deformation before rupture, line fracture does occur. If fuel boost pumps are running at the time of line fracture, raw fuel can be pumped onto hot engine surfaces or exposed to sparks. Some retrograde flow can also occur, especially if all one-way valves fail to function properly. It is nearly impossible to reconstruct the exact sequence of events from the study of an aircraft consumed by fire. Tank rupture can occur secondary to intrusion by cargo hooks, tree trunks, or other objects external to the airframe. Fig. 2 depicts an unburned crashed aircraft classified as partially survivable that has literally torn itself apart from roll over during fuselage deceleration after impact with the ground. The intact and non-leaking main fuel cell can be seen in the foreground where it was found by the accident investigation team.

Fig. 2. This UH-1H crashed at night in instrument meteorological conditions (IMC). The pilot and copilot survived with injuries. The crashworthy fuel system functioned as designed. Note the right forward fuel cell in the foreground, which tore loose from the aircraft and prevented fuel spillage. There was no postcrash fire.

It should be noted that one thermal fatality listed in Table IV occurred in a nonsurvivable accident. The individual may have survived had there not been a fire. Non-lethal facial injury possibly rendered the individual unconscious and thus unable to egress. Severe fire enveloped the aircraft postcrash and before any rescue could be attempted.

Tables VI and VII break down injuries and fatalities respectfully by aircraft type for the 1970-1976 reporting period. The majority of deaths and injury occurs in UH-1H accidents. The UH-1H is not necessarily less crashworthy. It is the workhorse of the Army helicopter fleet and the most flown aircraft; thus, exposing it to the greatest accident risk.

TABLE VI
1970-1976 INJURIES BY AIRCRAFT TYPE

Aircraft	Thermal		Non-Thermal	
	w/o CWFS*	with CWFS**	w/o CWFS*	with CWFS**
UH-1D	1	0	39	26
UH-1H	18	5	352	345
AH-1G	3	0	75	17
OH-58A	3	0	76	26
TOTAL	25	5	542	414

*1221 accidents, without CWFS, and 85 postcrash fires
**1290 accidents, with CWFS, and 34 postcrash fires

TABLE VII
1970-1976 FATALITIES BY AIRCRAFT TYPE

Aircraft	Thermal w/o CWFS*	Thermal with CWFS**	Non-Thermal w/o CWFS*	Non-Thermal with CWFS**
UH-1D	8	0	10	5
UH-1H	49	1	263	107
AH-1G	3	0	36	12
OH-58A	5	0	40	5
TOTAL	65	1	349	129

*1221 accidents, without CWFS, and 85 postcrash fires
**1290 accidents, with CWFS, and 34 postcrash fires

With this review of the fatalities and injuries caused by postcrash fires, it is of value to examine the human costs of these fires. Table VIII depicts fatality and injury costs. These figures are very conservative in that they are based on military medical facility care and not civilian facility care. These figures represent direct costs to the Army and do not include Veteran's Administration benefits, Social Security benefits, or other factors. They include a pro rata estimation of medical evacuation costs and average all active duty Army burn injury or fatality expenses. They do not reflect costs of retraining. They do not take into consideration grade, rank, or seniority. These figures do not reflect the intangible but considerable costs associated with personal and family suffering, alterations in life style, and home care. The significantly higher figure for thermal fatalities probably is derived from the fact that so many thermal fatalities are preceded by extended hospital care involving heroic measures.

TABLE VIII
FATALITY AND INJURY COSTS*

	Estimated cost for each
Thermal fatality	$155,000
Thermal injury	15,000

*DA Circular 385-48, 1974

Table IX depicts the human costs for accidents involving noncrashworthy fuel system equipped aircraft for the period 1967-1969. It is to remember that these figures are considered conservative, and they take into consideration only those injuries and fatalities directly related to fire. If the primary cause of death was impact injury with associated thermal injury, the statistic would not appear in Table IX. It is interesting to note that the total number of individuals involved and their associated fatality costs for both survivable and nonsurvivable accidents were approximately the same. However, for those accidents classified as survivable, the number of individuals who sustained thermal injuries but apparently escaped some of the effects of the postcrash fire is 20 times the number of thermal injuries reported for nonsurvivable accidents. This difference may be attributable to the severity of the accident and not the severity of the fire.

TABLE IX
HUMAN COSTS* FOR NON-CWFS ACCIDENTS, 1967-1969

	Survivable		Nonsurvivable	
	Individuals	Cost	Individuals	Cost
Thermal fatality	95	$14,725,000	96	$14,880,000
Thermal injury	64	992,000	3	46,500
Total	159	$15,717,000	99	$14,926,500

*Calculated using data Tables II, III, and IV.

Table X depicts thermal injury and thermal fatality costs associated with noncrashworthy fuel system helicopter accidents for the period0-1976. The significant reduction in the number of individuals involved in both survivable and nonsurvivable accidents over the period 1967-1969 is attributable to the gradual attrition of older high-fire-risk aircraft (See Table I) and the introduction of effective fire resistant clothing.

TABLE X
HUMAN COSTS* FOR NON-CWFS ACCIDENTS,** 1970-1976

	Survivable		Nonsurvivable	
	Individuals	Cost	Individuals	Cost
Thermal fatality	34	$5,270,000	31	$4,705,000
Thermal injury	20	310,000	5	77,500
Total	54	$5,580,000	36	$4,782,500

*Calculated using data Tables IV, VI, and VII.
**1,221 accidents.

Table XI represents the direct human costs for thermal injuries and fatalities in survivable and nonsurvivable accidents involving Army helicopters equipped with a CWFS for the period 1970-1976. The reduction is dramatic.

TABLE XI
HUMAN COSTS* FOR CWFS ACCIDENTS,** 1970-1976

	Survivable		Nonsurvivable	
	Individuals	Cost	Individuals	Cost
Thermal fatality	0	0	1	$155,000
Thermal injury	5	$77,500	0	0

*Calculated using data Tables VI and VII.
**1,290 accidents.

The introduction of any safety device, especially if it means modification to an aircraft, involves trade offs of payload, fuel consumption, power, weight, and a host of others. These trade offs involve real dollars and perceived or actual reduction in operational capability. Table XII reviews the operational penalties and cost factors for installation of the helicopter CWFS in new and retrofitted aircraft.

TABLE XII
CRASHWORTHY FUEL SYSTEM OPERATIONAL PENALTIES AND COST FACTORS

Aircraft	Added weight pounds	Fuel penalty gallons	Development costs dollars	Hardware costs dollars	Aircraft modified	Aircraft net cost dollars
UH-1D/H	160	11	362,000	7,400	3,077	7,517
UH-IB/C/M	93	18	214,000	9,500	900	9,737
AH-1G	130	6	250,000	4,600	769	4,925
OH-58A	67	1.5	320,000	4,200	2,065	4,354
OH-6A	70	6	631,000	6,900	244	9,486
CH-47A/B/C	610	54	2,215,000	20,000	426	25,200

CONCLUSION

The introduction of the helicopter CWFS into the United States Army helicopter fleet as an integral part of a long-range program to eliminate crash fatalities and reduce crash injury has been shown to be a highly successful and operationally effective mechanism. As more aircraft are retrofitted with the CWFS and improvements are made in crashworthiness design for hydraulic systems and other potential sources of postcrash fire, the goal of eliminating postcrash fire as a significant hazard in survivable accidents seems to be within our grasp.

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