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The Human Factors Relating to Escape and Survival from Helicopters Ditching in Water

Brooks, CJ

LIST OF FIGURES

LIST OF TABLES

CHAPTER I:

INTRODUCTION

1.1. The Problem

When a helicopter ditches into water, it usually inverts and rapidly sinks. With water rushing in through cockpit windows, aircrew and passengers have to overcome inherent buoyancy to make their escape from a flooded compartment through cargo doors, access doors, windows or the windshield. They may even be thrown out through a split in the cabin if the impact is severe. Even if the crew and passengers are uninjured, escape is difficult with the loss of vision, the disorientation, the requirement to not breath under water in spite of the gasp reflex and the extreme terror created by the catastrophe (6, 8, 12, 13, 17, 24, 25, 41, 60, 63, 65, 66). Occupants whose passage is blocked by entanglement with debris, who cannot release their lap straps, or who are injured, commonly perish (24).

Although the problem of underwater escape has been present since the first aircraft flew over water, it was less severe in the early days, because aircraft were lightly constructed and usually floated. Aircrew and passengers had time to escape before complete submersion. Even World War II aircraft tended to float long enough for aircrew to escape (24). Immediately after the war, due to the greater water impact velocity of faster- flying aircraft, it became highly unlikely for the aircrew to escape following impact and rapid submersion. Consequently, ejection seats were introduced into fixed wing fighter aircraft, which improved the chance of survival where ejection was initiated before water impact.

The introduction of the helicopter has produced unique problems related to survival after impacts particularly under water escape for aircrew and passengers. Although helicopters tend to be lighter and more buoyant than fixed-winged aircraft, after ditching they either float upright (Figure 1), float inverted (Figure 2) or sink inverted. Unfortunately, unless there is a very calm sea state, the latter two situations occur more frequently and are more likely to result in loss of life. For instance, the Sikorski S61 is designed to stay afloat (if intact) up to conditions of Sea State 3; yet in the North Sea, where it is very commonly used, the sea state exceeds 3 for much of the year.

This chapter reviews worldwide statistics on both civilian and military helicopter accidents over water and the corresponding incidence of escape. The following chapters examine the causes of fatalities, discuss solutions and recommend research and development that is required to improve the survival rate. Criteria for categorizing accidents vary between nations so, for consistency, single-engined landings in water and semi – controlled ditchings are also considered as accidents/ditchings.

Figure 1. Typical helicopter accident where the helicopter barely floats upright.

Figure 2. Typical helicopter accident where the helicopter sinks and is rapidly inverted.

1.2. Statistics on Over Water Helicopter Accidents

1.2.1. Military Experience

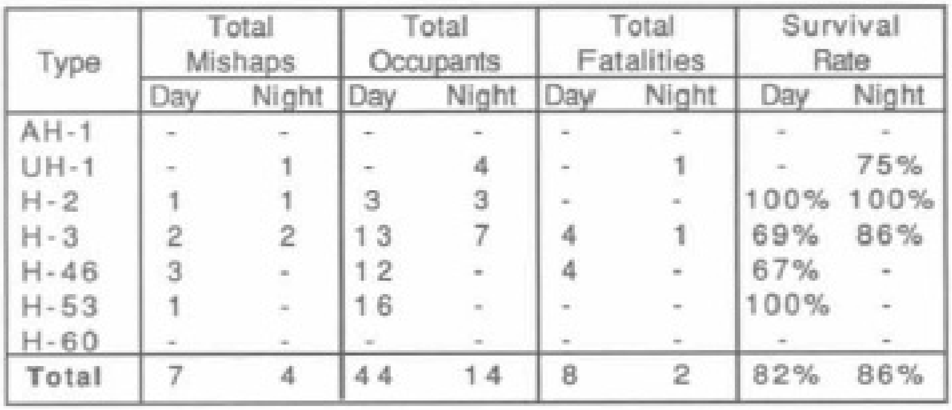
The United States Navy (USN) has so far published the largest study of over water helicopter accidents in three separate series of papers and one short article. The first study by Rice and Greear (60) examined accidents that occurred over a four-year period (1969-1972). They reported 78 accidents which involved the loss of 63 lives. Ten deaths were due to injuries while 25 were attributed to drowning; the remainders were categorized as "lost at sea". Twenty-one of those recovered, drowned, or lost at sea were last seen still in the aircraft. Ten of these 78 helicopters neither floated nor sank but rested on the bottom partially submerged in Shallow water, yet nine men still lost their lives. Five helicopters disintegrated on impact and 41 sank immediately, accounting for 26 fatalities. Twenty-five accidents resulted in fatalities. There were no survivors in five of these accidents; in the other 20, there were 72 survivors and 44 fatalities. Of the 44, death was attributed to drowning in 22, 15 more were lost at sea and never recovered, and the remaining seven suffered fatal injuries. The survivors of these accidents reported in-rushing water as the main problem in escaping from the aircraft. This, often coupled with disorientation and inability to either reach or open escape hatches, was reported by 36 (50%) of the survivors.

A second study is encompassing the Rice and Greear statistics was carried out by Cunningham (24) using the U.S. Navy Safety Centre statistics from July 1963 to February 1975. During this period, 234 helicopters with a total of 1, 093 occupants either crashed or were ditched at sea. The survival rate was 82%; 196 persons died in those accidents, of which 130 were listed as lost/unknown , 29 suffered either a fatal injury or an injury which caused drowning, and the remaining 37 were not injured but drowned nevertheless . Of 897 survivors, 437 (49%) egresses from underwater; they all encountered multiple problems, such as inrushing water, disorientation, panic, entanglement with debris, and unfamiliarity with existing release mechanisms. These will be discussed in Chapter Two.

In a paper on under water breathing apparatus (26), Eberwein referenced the above statistics and also updated the information with brief statistics on the frequency in which USN helicopters ditched at sea for the years 1978 -1983. In this time period, 72 helicopters were involved with 330 occupants. No survival rates were published.

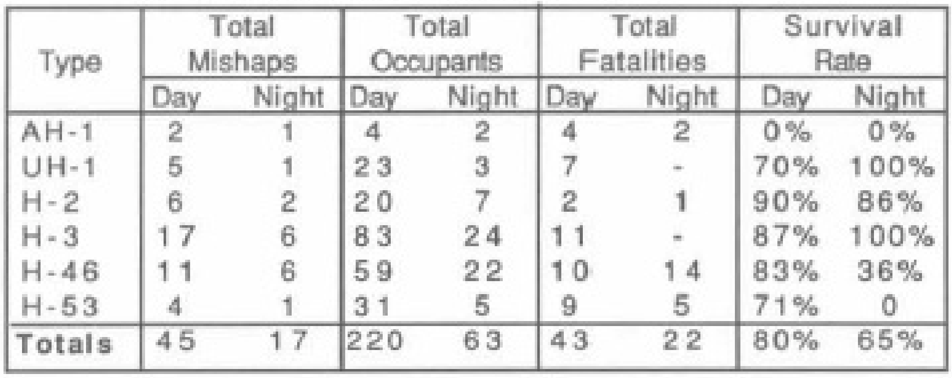
Since then, Thornton from the USN Safety Centre has compiled and will soon publish data for the period from 1984 through to 1986 (19). In this period, there have been 39 over water accidents involving a total of 219 occupants. There were 66 fatalities for an overall survival rate of 79% ; individual, yearly survival rates for 1984 , 1985 and 1986 were 77% , 52% and 81%, respectively . Of the 66 fatalities, 18 (27%) individuals drowned, five others probably drowned lost at sell, and 21 probably died from a fatal impact (also lost at sea) . Thornton’s preliminary figures for 1987 list an additional 28 cases in which personnel had to make an underwater escape. The latest U.S.N. statistics for Helicopter Water Escape in 1987 and cumulative figures for 1982 -1986 are presented in Table 1, 2 and 3, problem making an under water escape ; however he had to dive back into the cabin to release the pilot inverted underwater, hung up by his microphone cord . The third helicopter was an Alouette II which had an engine failure and crashed into the Atlantic Ocean. All four occupants had multiple bruises; one passenger had difficulty releasing the seat belt and another had difficulty releasing a foot trapped under the seat. The fourth and last accident was a Puma 330 that crashed into the Mediterranean Sea from approximately 2500 meters following a possible engine failure. The crash was unsurvivable and all six occupants were killed.

Table 1: U.S.N. Helicopter Water Escape CY 1987
(Courtesy of the U.S. Navy Safety Centre)



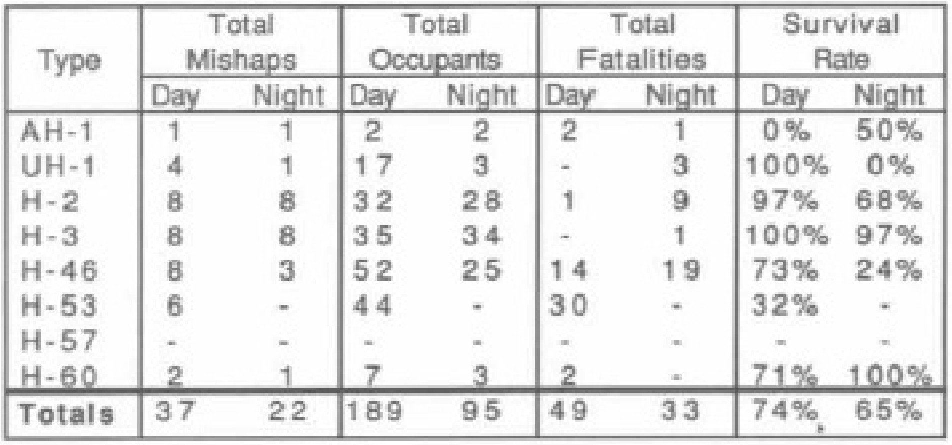
Type	Total Mishaps		Total Occupants		Total Fatalities		Survival Rate	
	Day	Night	Day	Night	Day	Night	Day	Night
AH-1	-	-	-	-	-	-	-	-
UH-1	-	1	-	4	-	1	-	75%
H-2	1	1	3	3	-	-	100%	100%
H-3	2	2	13	7	4	1	69%	86%
H-46	3	-	12	-	4	-	67%	-
H-53	1	-	16	-	-	-	100%	-
H-60	-	-	-	-	-	-	-	-
Total	7	4	44	14	8	2	82%	86%

Table 2. U.S.N. Helicopter Water Escape - Cumulative 1978 - 1982
(Courtesy U.S. Navy Safety Centre)



Type	Total Mishaps		Total Occupants		Total Fatalities		Survival Rate	
	Day	Night	Day	Night	Day	Night	Day	Night
AH-1	2	1	4	2	4	2	0%	0%
UH-1	5	1	23	3	7	-	70%	100%
H-2	6	2	20	7	2	1	90%	86%
H-3	17	6	83	24	11	-	87%	100%
H-46	11	6	59	22	10	14	83%	36%
H-53	4	1	31	5	9	5	71%	0
Totals	45	17	220	63	43	22	80%	65%

Table 3. U.S.N. Helicopter Water Escape - Cumulative 1982 - 1986
(Courtesy U.S. Navy Safety Centre)



Type	Total Mishaps		Total Occupants		Total Fatalities		Survival Rate	
	Day	Night	Day	Night	Day	Night	Day	Night
AH-1	1	1	2	2	2	1	0%	50%
UH-1	4	1	17	3	-	3	100%	0%
H-2	8	8	32	28	1	9	97%	68%
H-3	8	8	35	34	-	1	100%	97%
H-46	8	3	52	25	14	19	73%	24%
H-53	6	-	44	-	30	-	32%	-
H-57	-	-	-	-	-	-	-	-
H-60	2	1	7	3	2	-	71%	100%
Totals	37	22	189	95	49	33	74%	65%

1.2.2. Civilian Experience

The survival rate of helicopter ditchings into water for civilian operations is similar to that for military operations. For instance, in the North Sea, Anton (8) reported on seven civilian helicopters that ditched from January 1970 to November 1983. There was only one fatality in this series, although the condition of survivors in two of the seven accidents became marginal due to hypothermia. One passenger was originally thought to be badly shocked but was later diagnosed as seasick. Anton's findings indicated a correlation between sea state and probability of injury, structural damage and capsizing. In three of his seven cases, the helicopter capsized either immediately after striking the water, or very shortly afterwards. In a report by E&P Forum (75) in 1987, it was observed that there is, on average, one transport helicopter ditching per year in the North Sea. There were four ditchings from 1970 to 1977 and eight ditchings from 1981 to 1986. The most recent accident, in July 1988, was a Sikorsky S61 ditching following an engine fire -all 19 crew and passengers egresses successfully.

Elliot (50) made the following observations on 12 of these North Sea accidents occurring from 1970-1986, (information on the remaining four accidents is not yet available). The overall r ate of survival following ditching was 62%; six ditchings were controlled and six were crashes. NO fatalities occurred following a controlled ditching. Of the 108 people involved in the six crashes, only 21 survived, five of the helicopters sank, four floated upright and the other three floated inverted.

In 1984, the British Airworthiness Requests Board reviewed Helicopter Certification Standards and accident statistics (59); they concluded that:

a. helicopter accident rate s, either on a per hour or per flight basis, are significantly worse than those for modern jet transports, but are comparable to those for propeller turbine transports ;
b. the percentage of accidents that is due to airworthiness causes is greater for helicopters than for fixed-wing airplanes;
c. the percentage of accident with airworthiness causes and which prove fatal is significantly higher for helicopters than for fixed-wing airplanes; and
d. Helicopters which have had the benefit of military operations before entering civilian operations have a better accident record in their early years of service than the one helicopter which was never used in military operations, but sold directly to civilian operators.

The most up-to-date statistics for European over water civilian helicopter accidents has been recorded by Ferguson of Rotor and Wing International, Aberdeen (51). He has maintained records since 1969 on all helicopters that have ditched into the North Sea and off the coast of the British Isles. A complete list is presented in Table 4 grouped by country of origin, from 1969 until September 1987, there have been 28 ditchings. In 17 accidents, there were no fatalities but in the remaining II, there was a loss of 130 lives. The overall survival rate was 62%.

Of the 28 European accidents, 20 were in the British sector. 45 personnel were killed in one Chinook accident east of Sumburgh Airport following a gearbox failure. Twenty were killed in a Sikorski S6l accident after the crew became disoriented in fog and flew into the sea en-route Penzance to the Scilly Isles. Thirteen were killed in a Wessex accident off the Norfolk Coast, likely following a mechanical failure. There were nine fatalities in three Bell 212 helicopters -one fatality following pilot disorientation south of the Dunlin Field; six in an accident near the Murchison Field following a series of events, including bad weather and mechanical problems; and two northeast of the Humber River after the helicopter flew into the sea, likely as a result of mechanical problems.

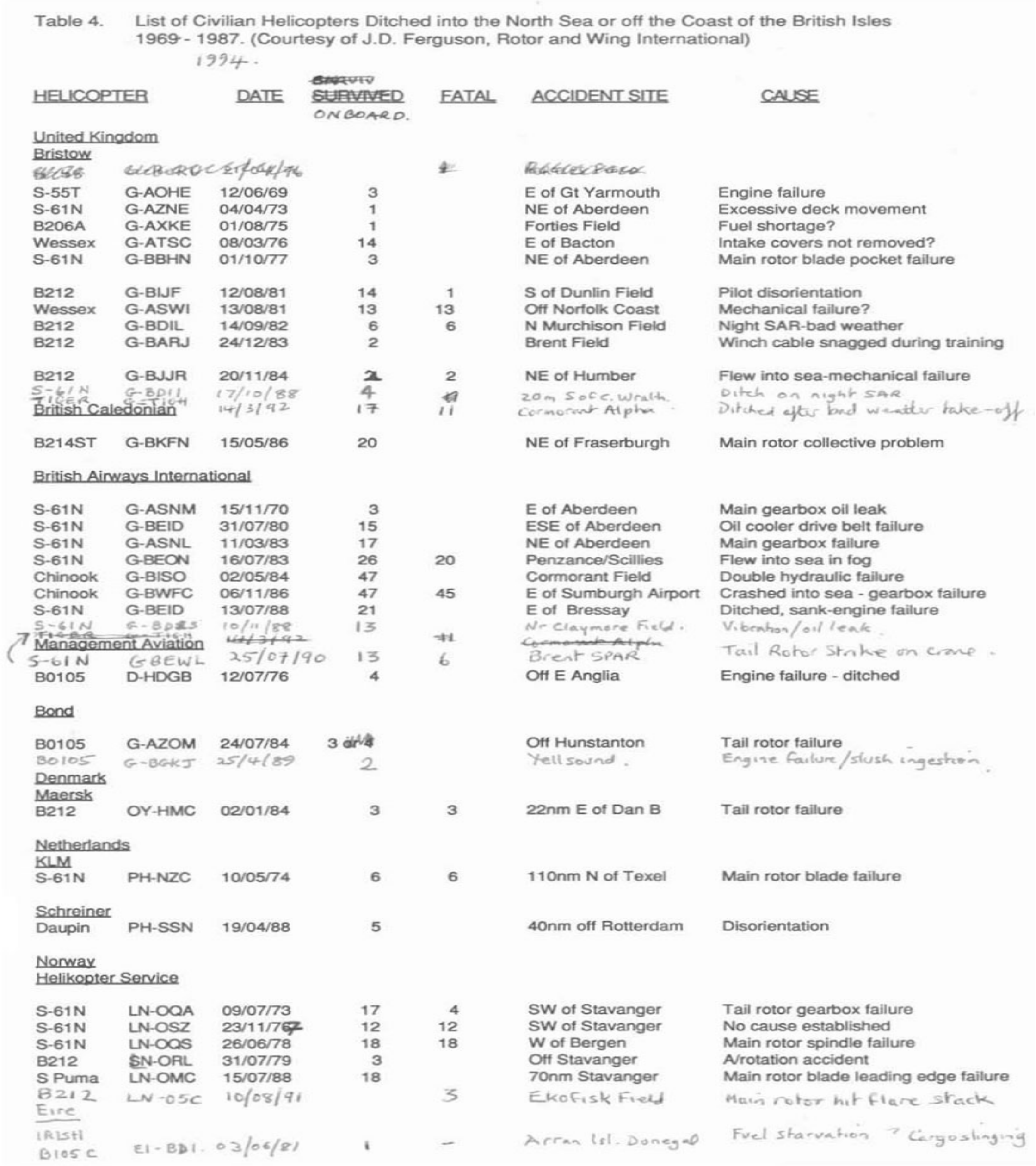


Table 4. List of Civilian Helicopters Ditched into the North Sea or off the Coast of the British Isles 1969 - 1987. (Courtesy of J.D. Ferguson, Rotor and Wing International)
1994.

HELICOPTER		DATE	~~SURVIVED~~ ONBOARD.	FATAL	ACCIDENT SITE	CAUSE
United Kingdom						
Bristow						
S-55T	G-AOHE	12/06/69	3		E of Gt Yarmouth	Engine failure
S-61N	G-AZNE	04/04/73	1		NE of Aberdeen	Excessive deck movement
B206A	G-AXKE	01/08/75	1		Forties Field	Fuel shortage?
Wessex	G-ATSC	08/03/76	14		E of Bacton	Intake covers not removed?
S-61N	G-BBHN	01/10/77	3		NE of Aberdeen	Main rotor blade pocket failure
B212	G-BIJF	12/08/81	14	1	S of Dunlin Field	Pilot disorientation
Wessex	G-ASWI	13/08/81	13	13	Off Norfolk Coast	Mechanical failure?
B212	G-BDIL	14/09/82	6	6	N Murchison Field	Night SAR-bad weather
B212	G-BARJ	24/12/83	2		Brent Field	Winch cable snagged during training
B212	G-BJJR	20/11/84	2	2	NE of Humber	Flew into sea-mechanical failure
S-61N	G-BDII	17/10/88	4	[illegible]	20m S of C. Wrath.	Ditch on night SAR
TIGER	G-TIGH	14/3/92	17	11	Cormorant Alpha.	Ditched after bad weather take-off
British Caledonian						
B214ST	G-BKFN	15/05/86	20		NE of Fraserburgh	Main rotor collective problem
British Airways International						
S-61N	G-ASNM	15/11/70	3		E of Aberdeen	Main gearbox oil leak
S-61N	G-BEID	31/07/80	15		ESE of Aberdeen	Oil cooler drive belt failure
S-61N	G-ASNL	11/03/83	17		NE of Aberdeen	Main gearbox failure
S-61N	G-BEON	16/07/83	26	20	Penzance/Scillies	Flew into sea in fog
Chinook	G-BISO	02/05/84	47		Cormorant Field	Double hydraulic failure
Chinook	G-BWFC	06/11/86	47	45	E of Sumburgh Airport	Crashed into sea - gearbox failure
S-61N	G-BEID	13/07/88	21		E of Bressay	Ditched, sank-engine failure
S-61N	G-BDES	10/11/88	13		Nr Claymore Field.	Vibration/oil leak.
~~TIGER~~	~~G-TIGH~~	~~14/3/92~~		~~11~~	~~Cormorant Alpha~~	
Management Aviation						
S-61N	GBEWL	25/07/90	13	6	Brent SPAR	Tail Rotor Strike on crane.
B0105	D-HDGB	12/07/76	4		Off E Anglia	Engine failure - ditched
Bond						
B0105	G-AZOM	24/07/84	3 or 4		Off Hunstanton	Tail rotor failure
B0105	G-BGKJ	25/4/89	2		Yell sound.	Engine failure/slush ingestion.
Denmark						
Maersk						
B212	OY-HMC	02/01/84	3	3	22nm E of Dan B	Tail rotor failure
Netherlands						
KLM						
S-61N	PH-NZC	10/05/74	6	6	110nm N of Texel	Main rotor blade failure
Schreiner						
Daupin	PH-SSN	19/04/88	5		40nm off Rotterdam	Disorientation
Norway						
Helikopter Service						
S-61N	LN-OQA	09/07/73	17	4	SW of Stavanger	Tail rotor gearbox failure
S-61N	LN-OSZ	23/11/76	12	12	SW of Stavanger	No cause established
S-61N	LN-OQS	26/06/78	18	18	W of Bergen	Main rotor spindle failure
B212	SN-ORL	31/07/79	3		Off Stavanger	A/rotation accident
S Puma	LN-OMC	15/07/88	18		70nm Stavanger	Main rotor blade leading edge failure
B212	LN-OSC	10/08/91		3	Ekofisk Field	Main rotor hit flare stack
Eire						
IRISH B105C	EI-BDI.	03/06/81	1	–	Arran Isl. Donegal	Fuel starvation ? Cargoslinging

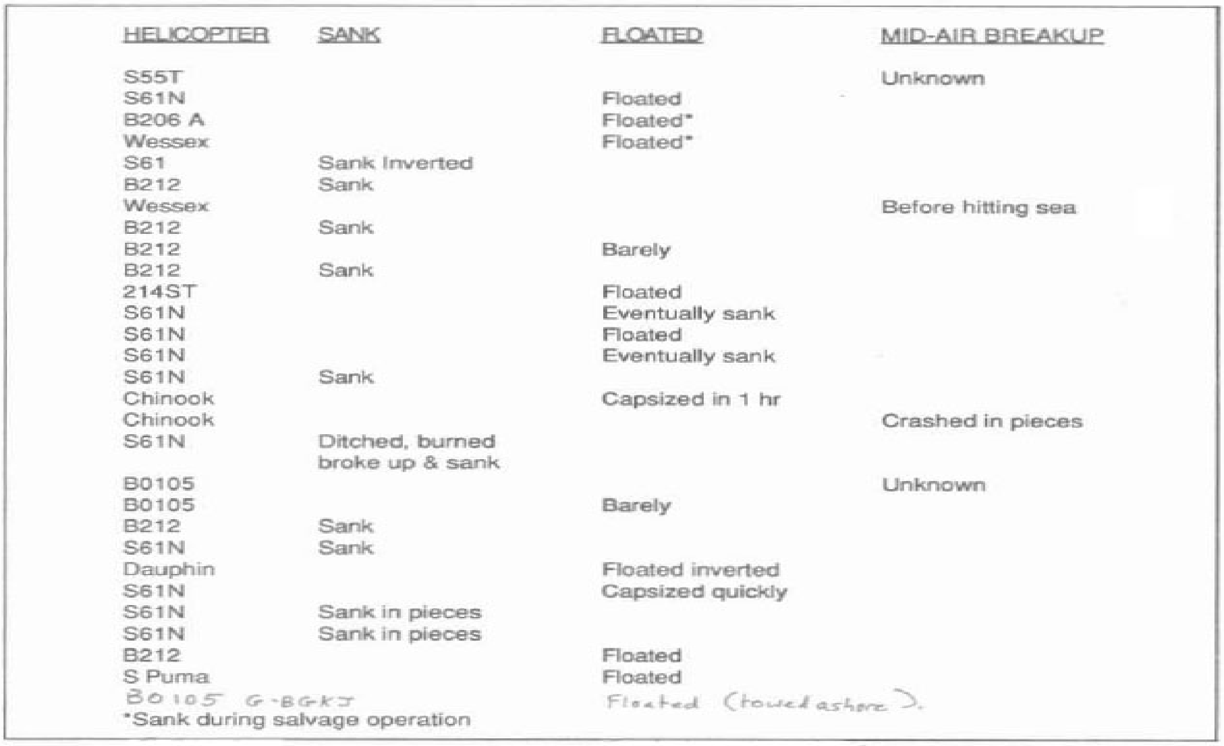
In the Norwegian sector, there have been five ditchings. Eighteen personnel were killed in a Sikorski S61 which sank in pieces southwest of Stavanger following a main rotor spindle failure. Twelve were killed in another Sikorski S61 which also sank in pieces southwest of Stavanger. The cause was not established. Four personnel were killed in a third Sikorski S61 southwest of Stavanger, following a tail rotor gear box failure. The helicopter floated for only a very short time, then capsized rapidly. The Norwegian Aircraft Accident Commission identified one additional sea water accident not in Ferguson's statistics -the case of a Hughes 369 which ran out of fuel and crashed into a fiord north of Trondheim with the loss of the single pilot occupant.

In the Danish sector, there has been only one accident, that of a Bell 212 caused by a tail rotor failure. The helicopter sank rapidly following impact 22 miles east of oil rig ‘Dan B’, killing three personnel.

In the Dutch sector, there have been two accidents; the first was a Sikorsky S61, with a main rotor blade failure. It sank on impact 110 miles north of Texel, and six personnel were killed. The second was an H65 Dauphin in which the pilot became disorientated on approach to landing a ship; the helicopter flew into the sea, but floated inverted, all five occupants esc aped from underwater.

In Ferguson's series (Table 5), only 14 helicopters (50%) floated, of which two barely floated, one floated inverted, one capsized "quickly", one capsized after an hour, two sank "eventually" (after some hours), and two sank during salvage operations. In the other 14 accidents, ten helicopters (37\ ) sank rapidly, one sank inverted and three sank with the fuselage broken into pieces. In two cases, the helicopter broke up in midair before hitting the sea and sinking. In two cases the condition of the helicopter at the time of impact with the sea could not be established.

Table 5. Condition of Civilian Helicopters ditched into the North Sea or off the coast of the British Isles 1969 - 1987
(Courtesy of J.D. Ferguson, Rotor and Wing International.)



HELICOPTER	SANK	FLOATED	MID-AIR BREAKUP
S55T			Unknown
S61N		Floated	
B206 A		Floated*	
Wessex		Floated*	
S61	Sank Inverted		
B212	Sank		
Wessex			Before hitting sea
B212	Sank		
B212		Barely	
B212	Sank		
214ST		Floated	
S61N		Eventually sank	
S61N		Floated	
S61N		Eventually sank	
S61N	Sank		
Chinook		Capsized in 1 hr	
Chinook			Crashed in pieces
S61N	Ditched, burned broke up & sank		
B0105			Unknown
B0105		Barely	
B212	Sank		
S61N	Sank		
Dauphin		Floated inverted	
S61N		Capsized quickly	
S61N	Sank in pieces		
S61N	Sank in pieces		
B212		Floated	
S Puma		Floated	
B0105 G-BGKJ		Floated (towed ashore).	

*Sank during salvage operation

Additional European statistics were submitted by the Swedish Board of Accident Investigation (Table 6). They have had silt helicopter accidents into water since 1976. Eighteen personnel were involved and there were three fatalities. The first helicopter was a Hughes 269 in which the pilot was checking the river for drifting timber when the helicopter hit a power line, somersaulted and sank immediately. Two passengers drowned probably knocked unconscious when hitting the water surface. The second was a Bell 47 in which the pilot on climb out suffered a partial power-loss at 40 meters altitude; landing could not be made at the shore line and the pilot continued out over the lake heading for a sight he knew was suitable. However, the power deteriorated further and the helicopter struck the water hard and sank immediately. The passengers were thrown clear, the pilot unbuckled his harness and stepped out, but unfortunately one passenger was knocked unconscious, sank and drowned before he could be rescued. The third helicopter was a Hughes 500 in which the pilot was emptying an under slung load of lime into a lake. The sack carrying the lime in a sling hit the tail rotor and the pilot being unable to control the helicopter made a successful emergency autorotation on to the lake surface, the helicopter later sank. The fourth was a Bell 205 in which the pilot was photographing a ferry leaving Trellborg Harbour; at 1500 meters, control of the helicopter was lost and the pilot made an emergency autorotation into the water. The helicopter floated upright and all three occupants success fully escaped with no difficulty. The fifth was a Bell 296A in which the pilot was also on a filming mission when the tail rotor hit a sea marker and the helicopter lost directional control. The pi lot inflated the emergency floats in preparation for autorotation and water landing; they were punctured most likely on water impact and rendered useless, the helicopter floated inverted. The cameraman was sitting in the open doorway with an extra safety belt tied across the door frame to minimize the risk of falling out when handling the camera. He was unable to release himself and drowned. Three other occupants escaped with ease, but a fourth required assistance by the pi lot to get out of the wreckage. The sixth and last helicopter was an Enstrom F28A in which the pi lot experienced deteriorating weather and attempted a precautionary landing on the beach, the pilot lost control at very low speed and height , the helicopter struck the water and sank, the three occupants successfully escaped with no difficulty.

Statistics from the Canadian Aviation Safety Program of Transport Canada (541 show that there were 852 Canadian registered helicopter accidents in and offshore Canada from 1976-1987. Of 741 accidents for which the type of terrain was reported, 98 cases (13%) were in water. The degree of difficulty of post-crash escape was -no problem 23 (24%) cases, with difficulty 20 (20%) cases, undetermined two (2%) cases, not applicable six (6%) cases, and not coded in the computer 47 (48%) cases. There were 245 personnel involved with 47 fatalities -a survival rate of 80%.

Finally, 3 Australian civilian helicopters (each with a single pilot only) have ditched into the sea between 1969 and 1987 (57). A SK58E with tail rotor gearbox failure, a Bell 47 with transmission failure and a Bell 206B in which improper procedures caused the accident. There were no fatalities in any accident.

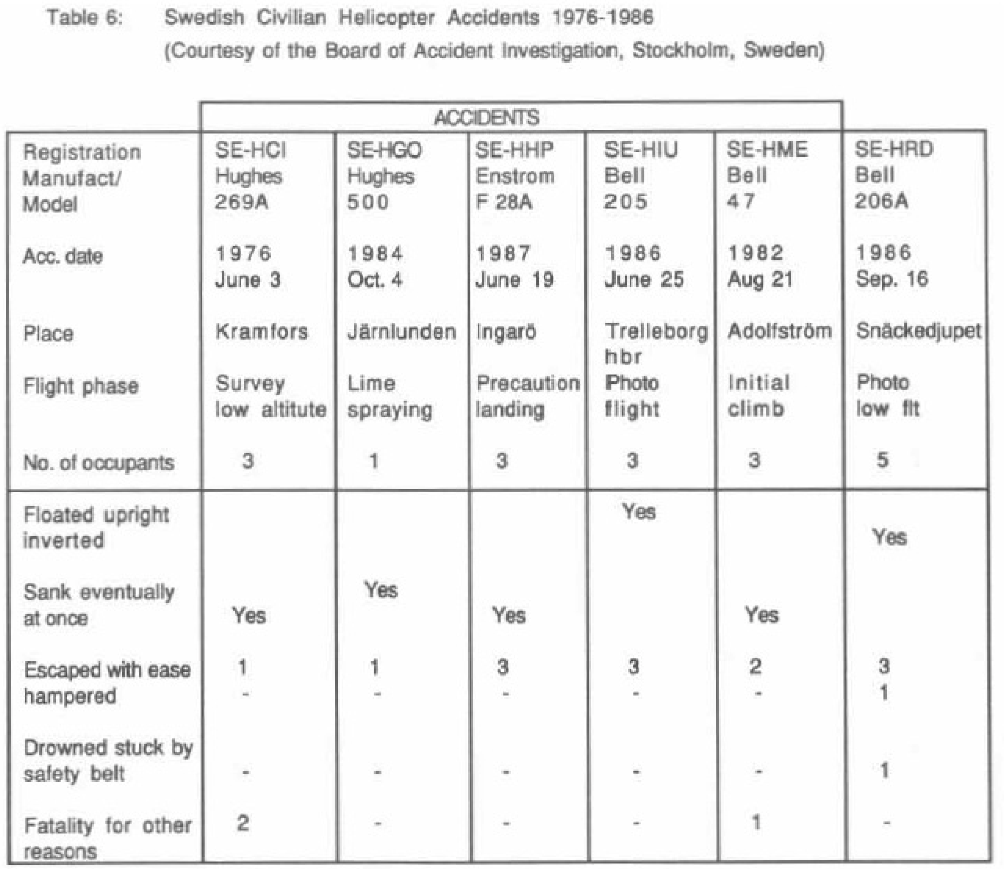


Table 6: Swedish Civilian Helicopter Accidents 1976-1986
(Courtesy of the Board of Accident Investigation, Stockholm, Sweden)

	ACCIDENTS					
Registration	SE-HCI	SE-HGO	SE-HHP	SE-HIU	SE-HME	SE-HRD
Manufact/ Model	Hughes 269A	Hughes 500	Enstrom F 28A	Bell 205	Bell 47	Bell 206A
Acc. date	1976 June 3	1984 Oct. 4	1987 June 19	1986 June 25	1982 Aug 21	1986 Sep. 16
Place	Kramfors	Järnlunden	Ingarö	Trelleborg hbr	Adolfström	Snäckedjupet
Flight phase	Survey low altitute	Lime spraying	Precaution landing	Photo flight	Initial climb	Photo low flt
No. of occupants	3	1	3	3	3	5
Floated upright				Yes		
inverted						Yes
Sank eventually		Yes				
at once	Yes		Yes		Yes	
Escaped with ease	1	1	3	3	2	3
hampered	-	-	-	-	-	1
Drowned stuck by safety belt	-	-	-	-	-	1
Fatality for other reasons	2	-	-	-	1	-

1.3. Summary

Five observations are clear from the data and associated reports. First, helicopters have had a greater accident rate than have fixed-wing aircraft. Second, helicopters ditching in water have a high fatality rate -in the range of 15-45%. Third, survivors will likely have to make an in or underwater escape because, on hitting the water even in the calmest sea, the helicopter is likely to flood and sink quickly, often rolling inverted. Fourth, approximately 35% of survivors have had great difficulty making their escape. And fifth, manufacturers have incorporated little current crashworthy technology into helicopters.

CHAPTER II:

SURVIVAL FACTORS

2.1. The Problem

The review of helicopter airworthiness (59) confirmed that the helicopter accident rates in the United Kingdom are significantly worse than for modern jet transport 2.0 vs. 0.4 per 100.000 flying hours. The rate is also greater for helicopters on a per flight basis. A principal reason for the differences is that conventional aircraft reliability has been developed over 80 years of evolution compared to about 45 years since the end of the Second World War for helicopters. Duplication or redundancy of many critical mechanisms of a helicopter cannot be achieved. For example, there can only be a single lifting system, even though there can be more than one engine. Helicopter rotor blade, rotor heads, engine mountings, controls and transmissions are particularly susceptible to fatigue. Disastrous results occur if the problem is not observed during maintenance, or if quality control of gearboxes is not of a high standard.

When an accident occurs, there is no systematic methodology applied to helicopters t o improve their crashworthiness and the survivability of occupants, in spite of the fact that technology is now readily available to achieve both goals.

There are many reasons why the survival rates for helicopters ditching into water are 75% on average worldwide. Boeing Vertol conducted a study of helicopter ditchings in 1976 (41). Although dates were not indicated, the accidents of 289 Navy Marine helicopters of seven different types were reviewed. The helicopters all reacted similarly on ditching -more than 50% sank in less than 1 minute, all non-amphibious craft capsized before or during submergence, and almost all that sank did so nose first. It was noted that the helicopters reacted violently as the turning rotor blade hit the water. The fuselage often rocked from side to side and the fuselage sometimes would spin on its vertical axis like an unwinding gyro. As rotor rpm decayed and aircraft control was lost, the helicopter typically rolled inverted left or right, breaking or bending the rotor blades. The cabin began to fill with water, usually from the nose direction, since nose windows are not designed to withstand severe water impact.

In contrast to this, the new H65 Dauphin II, made by Aerospatiale of France and just accepted into U.S. Coastguard service, has inflatable buoyancy bags built into the fuselage so that it will float tail up. There has only been one accident in moderate seas in which the performance of this system has been examined and details are available. A Dutch Schreiner Airways H65 Dauphin helicopter recently had an accident in which the pilot became disorientated at night on approach to a ship and flew into the sea at a low speed. The helicopter floated inverted and the two crew and three passengers escaped successfully. There has been scanty information of two other very recent H65 accidents, one off Goa and one off Gabon. Details are not available at present, except it would appear that all lives were lost in both accidents and the helicopters broke up on impacting the sea.

If a helicopter is forced to ditch into the sea, then it should be capable of floating for a sufficient time to allow occupants to escape into life rafts. The Civil Aviation Authority (CAA) postulated that ten minutes was an adequate time f or emergency egress, British Hovercraft (49) on behalf of the CAA conducted model tank experiments and concluded that the height of a breaking wave from crest to through that would overturn a floating helicopter was 1.75 meters. The CAA then asked the Institute of Oceanographic Sciences (105) to estimate the probability of a ditched helicopter encountering ~ breaking wave of greater than 1.75 meters in any 19 minute. The I0S study (22) of sea states off the coast of the 8ritish Isles and the North Sea showed that the probability ranged from 0.3% in the Celtic Sea (Daunt Light Vessel) to 11.9% in the Southern sector of the

North Sea (Scalloper Light Vessel). These theoretical calculations confirmed practical experience in that even helicopters ditching intact are very unstable in water and commonly capsize very soon after water landing.

Preventive measures taken which encompass the whole flight operation from training to strap-in to take-off and landing can reduce the fatalities for the typical scenario of a helicopter ditching into water. These are discussed below under six separate headings: 1) pre-flight briefing, 2) in-flight preparation.)) the unsurvivable accident, 4) the survivable accidents) equipment design and improvements, and 6) post-escape. Reference is made when possible to an accident narrative to help illustrate a point. Chapter 3 discusses a formal course training plan for a helicopter ditching course which reviews the six headings.

2.2. Pre-Flight Briefings

Before strapping into a helicopter, and certainly before take-off, it is important that the aircrew and passengers understand the hazards of over water operation and the remedies for survival. A good pre-flight briefing can mean the difference between survival and death. The following accident illustrates this point; no pre-flight briefing was given and the pilot was not even aware of the existence of the survival equipment onboard!

The civilian pilot of a Canadian registered Bell 285 helicopter and two passengers were on a VFR flight. As the helicopter neared the harbour, the visibility reduced in fog. The pilot, in order to remain in VFR, flew at airspeed of 10 to 20 mph, 75 to 100 feet from the shoreline and 30 feet above the water. Suddenly, the pilot lost visual contact with the shore and all visual references. He was unable to maintain control of the helicopter, and it struck the water and rolled upside down. The pilot and passengers exited the helicopter and climbed on to the inverted wreck. Two passengers were wearing immersion suits which contained flotation devices. One of them was able to swim to shore and then pull the helicopter in close to shore. The pilot was not wearing an immersion suit and suffered from hypothermia and shock. The helicopter emergency locator transmitter was tendered inoperative when it was immersed in the cold water. The survivors were rescued the following day by a local hunter. The pilot stated that he had not known about the existence of immersion suits before seeing his passengers' suit on this flight. He was not wearing a life vest, yet these were stored in the rear cabin section!

Space does not allow for a very comprehensive review; nevertheless, the following factors must be considered. Crew and passengers must be made fully aware that a system or mechanical failure is potentially always a hazard during a helicopter operation with or without fire. If any problems are going to occur, they tend to do so during the critical phases of flight (i.e. approach, missed approach, transit or the hover). Therefore, the passengers must be prepared to be particularly attentive to in-flight directions at these times . A classic example of this occurred when a Wessex 60 ditched in the North Sea after both engines stopped in rapid succession shortly after the helicopter had taken off from a gas platform. A successful alighting was carried out and the fourteen occupants were able to escape unhurt and boarded the life raft. After some twenty-five minutes they were picked up by a rig support vessel.

The pre-flight briefing should also include a short description of personal and aircraft safety equipment and its use , for example , the requirement for the immersion suit to be done up before ditching, so that it will be waterproof, activation of the life preserver , the method of deploying the life raft , and the operation of the headset or helmet .

The problems of underwater escape should be described, particularly the fact that water will rush in very rapidly, it will be cold and dark and that disorientation will occur. Survival techniques should be explained, such as adopting a good crash position and not undoing the harness until all motion has stopped. Emergency exits and methods for normal and emergency egress should be discussed to give some indication, especially to passengers who have not had a survival course, of how much force is required to operate emergency release handles, push out windows and open emergency doors.

The passengers must also be briefed that once they have escaped from the helicopter and are floating in the water; they should get out of the water and into a life raft as soon as possible.

Lastly, and most important, is the requirement for paying attention to aircrew instructions during all phases of a mishap.

Pre-flight briefings vary considerably in quality. They depend on the conscientiousness of the aircrew, their motivation to their service or company and, above all, their professional attitude towards their job.

2.3. In-Flight Preparation

This is where the importance of the pre-flight briefing is paramount . It is the main preparation of the occupants for a ditching possibility because commonly in flight there is little time for more than a few curt orders. Brooks (13) showed in 1984 that of 37 RCAF and CF water accidents (including fixed-wing aircraft) in the previous 20 years, the crew had less than one minute warning that water immersion was imminent in 34 cases (92\) and no practical warning at all(less than 15 seconds) in 29 cases (78%) . He also showed that t he Sea King Helicopter stood the highest risk for sudden water immersion without prior warning. This lack of warning had contributed to the death of crew members in two Sea King helicopter accidents. A later, more comprehensive study by Brooks (10) for the period 1952-1987, showed that there was less than 15 seconds warning in nine of ten Sea King ditchings, only two to three minutes in the other (tenth) .

The results are similar in Anton's review of UK Registered helicopter .ditchings in t he North Sea from January 1970 to November 1983 (8). The warning was less than one minute in two of seven helicopter accidents and less than five minutes in another two cases. This should be emphasized to helicopter crews and be t aught in their ditching training. This is the principal reason why a good pre-flight briefing is so essential, namely because it is unlikely that there will be any chance to explain anything during an emergency. for instance, in a recent Puma 330J accident the pilot experienced a tail rotor blade failure returning to shore from a rig off Western Australia (75); following the violent spin after an in-flight emergency in which the pilot lost his headset, it was impossible to brief the passengers for the impending ditching; thus they had not received a pre-flight briefing prior to take-off and they entered the water unprepared.

Once strapped in and in-flight, the objective should be for all crew members to have a thorough knowledge of their personal equipment, be knowledgeable of their emergency exits from the aircraft , the operation of their survival equipment and the preparatory procedures for a ditching. Due to the often cramped seating in the helicopter, the passengers must be aware of the difficulty of pulling on a survival suit hood, zipping up a suit and donning a life preserver. As a result, whenever possible, passengers should fly with constant-wear type life preservers and survival suits in the closed up position. Manufacturers of suits should be encouraged to spend more money and energy on making suits easier and simpler to close in such emergencies. Other simple instructions such as the importance of removing ear plugs before pulling on the hood can make the difference between hearing and not hearing vital aircrew instructions.

In order to obtain this knowledge, it is essential that all professional crew members and all passengers who earn their living offshore receive formal practical training in helicopter underwater escape.

2.4. The Unsurvivable Accident

An observation made by Elliot of Shell (UK) for 12 of the 16 helicopter ditchings in the North Sea was that six (or half) of the ditchings were controlled and six (or the other half) were crashes (50%). Furthermore, no fatalities occurred during the controlled ditchings and death on crash impacts accounted for 85% of fatalities.

Some accidents where the helicopter impacts the water at high velocity or disintegrates are virtually unsurvivable. The following narrative describes such an example and further emphasizes the point already discussed, namely that accidents tend to occur during one of the critical phases of flight previously mentioned.

Following take-off from the ship carrying an external load of a truck, a USN H-S3 Sea Stallion helicopter began spinning and rolling to an almost inverted position with extensive breakup and disintegration occurring prior to water impact. The five-major sections then sank. All four crew died as a result of the mishap. The pilot's seat broke loose on impact but remained in the cockpit. His only major injury was a fractured jaw, but he died of asphyxia due to drowning. The co-pilot seat also tore loose from it s tracks and he was thrown through the windscreen and remained outside the cockpit, still strapped in the seat. He likely died from a combination of drowning and concussion. Both air crewmen were found outside the fuselage. The crew chief had sustained multiple extreme injuries when thrown from the aircraft and both had died from a combination of drowning, concussion and injuries.

Fortunately, accidents like this rarely occur, with all crewmembers killed, either in a combination of cabin break-up and impact, or by drowning shortly afterwards (because their injuries preclude them from making an escape). Yet during this phase of the abandonment, whether the helicopter has remained upright on the surface or has rapidly inverted and sunk. There is still a very high risk of death for individual crew members and passengers.

2.5. The Survivable Accident

A rapidly sinking helicopter is particularly perilous; the factors that contribute to the hazard are discussed next.

2.5.1. Sudden Immersion and Inversion

As stated above, aircrew and passengers usually receive little or no warning of a impending crash (8, 18, 2a). A ditched helicopter often rapidly sinks (8, 69, 63, 65, 77, and 78) and the immersion occurs after an in-flight emergency during one of the critical phases of the flight. The following accident is typical of sudden immersion:

A USN H-46 Sea Knight impacted the water after take-off from the ship. The helicopter was noted to never gain more than about 90 feet of altitude. It made an essentially wings -level descent into the water. The entire flight lasted but twelve seconds. The helicopter sank almost immediately, rolling to port as it did.

The pilot, crew chief and 13 passengers died. The co-pilot and one passenger suffered major injuries and the remaining two passengers no injuries. Impact forces ripped the cockpit section of the aircraft from the rest of the aircraft. The co-pilot, s till strapped in his seat, was thrown/carried to just aft of t he aircraft as it came to rest in approximately 53 feet of water. The co-pilot's seat slid from its rails, carrying him free of the aircraft structure. He inflated his life preserver and was carried to the surface. The survivors were rapidly retrieved from the water by a rescue boat.

This tragic accident clearly points out the necessity for a pre-flight briefing, for the crew and passengers to be aware of the possibility of sudden water immersion due to an in flight emergency during the critical phases of flight, and for all aircrew to be trained for underwater escape. It is also a typical example in which the forces involved in the ditching can literally split open the cabin and throw out the occupants (Figure 3).

Figure 3. Typical helicopter accident in which cabin has split open on water impact.

2.5.2. Injuries

In 1984, the British review of helicopter airworthiness (59) noted the fact that it was generally agreed among designers and operators that when helicopters crash they cause, in many cases, unavoidable injuries and often fatalities to the passengers and crew. However, lack of seat integrity, adequate se at restraint systems, and crashworthy cabin structures contribute to these injuries and fatalities. Methods to delethalize the cabins have been slowly applied to operational aircraft. The following accident is a typical case.

A USN UH-l Huey was conducting a transit from ship to shore when the aircrew heard a loud grinding/whirring noise in the transmission. The pilot elected to continue to the shore to land. Less than one minute from the intended emergency landing site, at 40-50 feet and 70 knots, complete loss of engine drive occurred. The helicopter impacted the sea and sank quickly in 30 feet of water. The pilot was knocked unconscious and subsequently drowned. The other three crew survived. The pilot's body was found tightly strapped in the cockpit. His visor was missing and his helmet had a deep abrasion on the right forward windshield quadrant corresponding to the autopsy evidence of a blow to the head in that area sufficient to cause unconsciousness. The co-pilot was rendered unconscious at impact. After impact his next awareness was that the cockpit was entirely under water. "Something was on top of me and I couldn't reach my seat belt release. Got right hand under whatever it was and pulled the release. Felt for the door, it wasn't there! Had to slide out of cockpit. Got hung up on something and I seemed attached to my survival vest. It was dark and I only saw jagged metal in front of me. Looked up, saw light, swallowed water, and thought I wouldn't last much longer. Got free, pulled toggles and floated to surface. Saw SAR helicopter. Pulled ring on day smoke flare, failed to ignite". At time of impact, the crew chief was securely strapped in. He placed his head in his lap and braced for impact. He was thrown forward into the hoist directly in front of him and temporarily rendered unconscious. On recovery he found that he was totally underwater with his right foot pinned under something. "Pulled about 15 times." Swallowing water "Thought I was gone". He gave one last try, his foot came loose and he surfaced. ~he second crewman had the door open prior to impact. He noted that the helicopter filled with water fast. He had difficulty releasing his seat belt because the helicopter rolled right, and he went out the left side. His helmet struck on something. He took it off and saw more clearly. He surfaced first, then saw co-pilot and crew chief come to surface.

Again, this accident points out the importance of training for underwater escape. The co-pilot may well not have survived had he not had the underwater escape course. It also illustrates the typical problems of equipment snagging during escape. The problem is still present -in the USN latest figures for 1987, there were three cases in which crewmen were hampered by equipment during escape from an H-46 Sea Knight and four cases in which crew equipment snagged something during escape (two in an H-l. and one each in an H-3 and an H-46).

The importance of designing good restraint systems for crashworthy seats and a cabin compartment devoid of jagged edges on which clothing or equipment can snagged must be re-emphasized. Shanahan (67) separates injuries into two categories -acceleration injuries and contact injuries. Acceleration injuries are those injuries which often occur some distance from the area of application. The injuries are due to the body's inertial response to the acceleration. A typical example is rupture of the aorta following a high sink rate crash. In this case the application of force occurs through the individual's thighs, buttocks and back in contact with the seat and the injury is due to the shearing forces acceleration of the body. Contact injuries occur when a localized portion of the b0dy comes into contact with a surface in such a manner that injury occurs at the site of the contact. A typical example is a skull fracture as a result of the head striking a bulkhead. Contact injuries may however also produce acceleration injuries at a site distant from the point of contact.

It is important to make a distinction between the two types of injury because prevention involves different strategies. Acceleration injuries are prevented by attenuating the energy of a crash before it can be transmitted to the individual (i.e. energy-attenuating landing gear and seats). Contact injuries are prevented by attempting to stop contact between an individual and a potentially injurious object (i.e. good restraint to prevent flailing of head, body and limbs plus padding of structures that cannot be moved).

Shanahan has demonstrated that contact injuries are about five times more common than acceleration injuries in helicopter accidents, and that they are preventable. Yet military agencies and civilian operators have done little to insist that manufacturers incorporate crashworthy technology into their aircraft.

2.5.3. In-rushing Water

In-rushing cold water is an extremely serious problem. In 1973, Rice and Greear (60) reported that it was the most frequent problem confronting survivors. They recorded that 43 survivors had experienced in-rushing water alone, 34 times in conjunction with difficulty in reaching the hatch, 26 times with confusion and disorientation and 12 times with darkness. More recently, in-rushing water was reported by the USN Safety Centre to be a problem in 57 cases of helicopter crews ditching in water during the years 1983 through 1985 Thornton's yet unpublished USN figures for 1987 describe an additional nine cases (56). One pilot that survived a ditching graphically described the sensation to be "like being hit in the chest by a fire hose".

Following a tail rotor failure, a USN H3 Sea King helicopter impacted the water and commenced rolling left. Both crewmen egresses through the cargo door before the aircraft became completely inverted. Both had difficulty due to in-rushing water.

The pilot unbuckled, reached for the window emergency release handle and was unable to exit through the open window, and became stuck 1/ 3 way through. He pulled himself back in t he helicopter, rotated body 50°· and pushed his body through the window.

In-rushing water has four serious effects, all of which may lead to drowning. The first effect is panic since the person is exposed to potential drowning, the second is uncontrolled hyperventilation and reduction in breath-holding ability (32, 33. 3B, 45, 46, 58, 691; and the third, is buffeting in the seat which may lead to intense disorientation. A fourth effect is an exaggeration of t he first two -that of immersion in cold water. If the water is below 10 C and the survivor is not wearing a protective suit , the chances of drowning is enhanced through a combination of events, panic, hyperventilation, reduced breath-holding ability, and the development of a cardiac arrest or arrhythmia.

Panic can only be prevented by good, repeated, realistic training. The reduction in breath-holding ability can be combated by supplying supplementary air. Arrhythmia can be prevented by providing good, comfortable, practical dry immersion suits. Disorientation can be ameliorated by having had practical escape training in an underwater escape trainer and by adopting a good crash position.

2.5.4. Disorientation

The rotation of the body underwater and loss of gravitational references makes disorientation inevitable for survivors prior to escape from an inverted sunken helicopter. In conjunction with .darkness, which contributes to disorientation, it is the second biggest problem, after in-rushing water. Confusion/panic/disorientation was reported in three cases for 1987 USN accidents and darkness was a problem in ten accidents .

The crew of a USN H-3 Sea King helicopter were conducting an automatic coupled approach to a sonar hover when the master caution light was illuminated, followed by a steady transmission oil press caution light. The helicopter made an emergency water landing, rolled, inverted and sank. Upon hitting water, the pilot released his lap belt and in-rushing water pushed him from his seat. He immediately became disoriented. He felt a seat, groped for a window, and exited thought the co-pilot’s window. The co-pilot had released his lap belt and exited feet first through his sliding window after removing his helmet. After all forward motion ceased , the crewman released himself and exited through the left sonar window just as the helicopter began t o roll. The report noted that the pilot and co-pilot had not had helicopter underwater escape training and also that the crewmen were treated for cold water immersion.

Only those who have experienced disorientation in a helicopter underwater trainer understand the problem and how to deal with it. Even experienced professional divers are surprised at the profound disorientation experienced when they first attempt the trainer. It cannot be taught entirely at a desk in a classroom· it must be practically demonstrated in a trainer. Ryack et a (64) note that, in spite of their lengthy experience, 16 o f '24 divers testing escape hatch illumination became seriously disoriented and needed assistance .

Helicopter underwater escape should be practically taught to all professional aircrew and passengers who must routinely travel over water. The benefits of training are clearly shown by Ryack et al (63) from the statistics of the US Navy Safety Centre from January 1969 to February 1975. During that time 424 men were involved in helicopter crashes into water. Less than 8% (13) of those who had received underwater escape training (179) died in the crashes, compared to more than 20% (54) who had not received training (254). The importance of adopting a good crash position is also essential and will be discussed in the next section.

2.5.5. Crash Position

(i) General

In survivable accidents, the most common reason why personnel die is injury before escape (69,67). Death is principally from contact injuries rather than acceleration injuries by a ratio of 5; 1. The adoption of a good crash position can increase the survival rate in five ways:

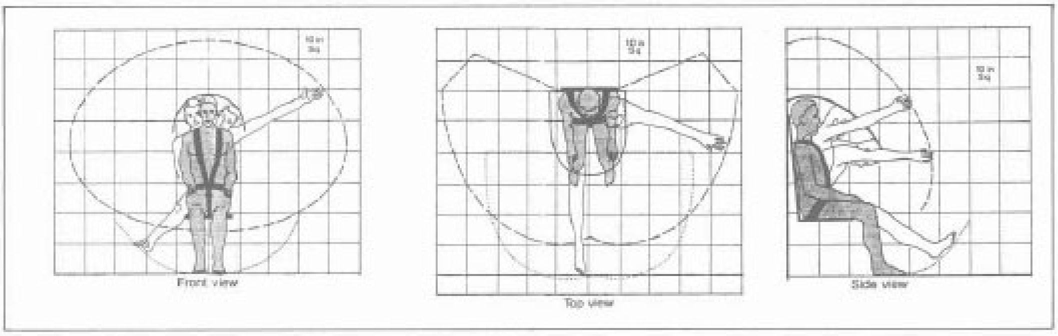
- By reducing the strike envelope of the arms, legs and head on the cabin contents. {The potential strike envelope for personnel with five point restraint and laps traps only is graphically illustrated in Figures 4 and 5 to demonstrate the seriousness of the problem (74) ;
- By stabilizing the survivor in the seat and minimizing the disorientation during and immediately post crash, particularly during an accident with smoke and/or fire, or with sudden in-rushing water or darkness in sinking helicopters;
- Specifically for underwater escape , by minimizing the profile of the body to the inrushing water, which further increases disorientation;
- By presenting a smaller human target area to flying debris;
- By providing the survivor with a good physical reference from which to rapidly re-orient and rationally consider what escape path to take.

Special considerations apply to helicopter crash positions compared to fixed-wing aircraft crash positions. A general review of the subject is well documented in the AGARD Conference Proceedings on Operational helicopter Aviation Medicine in 1978 (1). The crash dynamics for helicopters, particularly ditching in water, may be different than for fixed -wing aircraft. Helicopters tend to crash vertically or, under autorotation conditions, at more acute angles to the surface of the water or ground . The vertical component of the crash forces can be much greater than forward component. Disorientation is inevitable if the helicopter sinks and rolls and, as previously mentioned, is intensified by in-rushing water, which destabilizes the whole body in the seat.

Shanahan (67) describes two types of injury acceleration and contact. To prevent acceleration injuries, a method of attenuating the energy of a crash before it can be transmitted to the individual must be devised. Such devices as energy attenuating landing gear and seats can achieve this, as well as the controlled deformation of airframe structures; however as previously mentioned, little of this technology has been applied to helicopters presently flying offshore. Although there we r e no water accidents in his study, pertinent findings to this review are that 88% of all Army Class A helicopter accidents were considered survivable , while 32% of the fatalities and 96% of the disabling injuries occurred in survivable crashes. Better restraint removal of potentially injurious objects and adoption of a good low profile crash position are required to prevent contact injuries.

Most pilot seats are fitted with 4-point harnesses with or without headrests, but crewmen and passengers have simple lap straps, commonly with no headrests at all. Seating in helicopters is not always conventionally arranged in an all forward-facing configuration. Side-facing seats are structurally weaker because of asymmetrical loading. The preferred safe passenger seat position is rear-facing, followed by forward-facing and lastly, side-facing. Seats are often fitted in an ad hoc fashion to carry out the operational requirement of accepting cargo, fuel cells, and passengers in the same helicopter. With weight and space limitations, they are often fitted in a somewhat jig-saw fashion around these items. Before crash position advice can be given, each different aircrew and passenger position, with its type of harness and presence or absence of headrest, must be considered separately.

Figure 4. Potential strike envelope for personnel using a five-point harness.
(Courtesy U.S. Army Research and Technology Laboratory, Fort Eustis, Virginia).



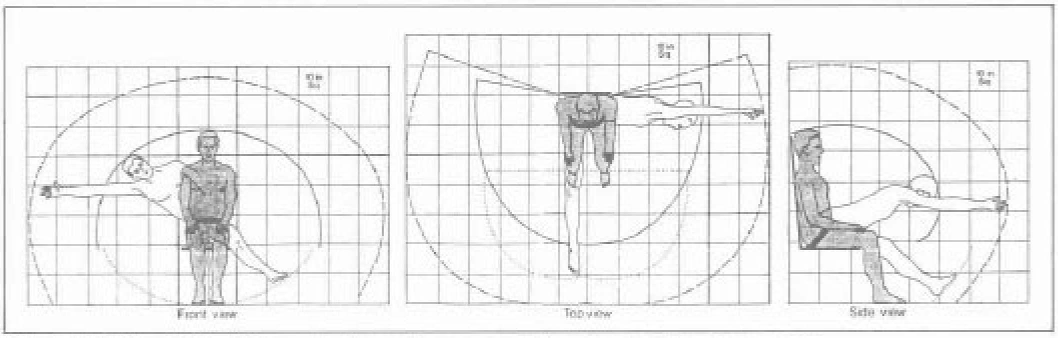


Figure 5. Potential strike envelope for personnel using a lap strap only.
(Courtesy U.S. Army Research and Technology Laboratory, Fort Eustis, Virginia).

(ii) Pilots

As a general rule for pilots, it is essential in any accident scenario that the harness is tight and locked and that the buttocks are tightly pressed into the back of the seat. It is vital to reduce the strike envelope of the body extremities on the dashboard. The style of seat and whether or not the pilot is in control will dictate what position to adopt.

(iii) Pilot in Control Headrest Fitted (figure 6A)

It is unlikely that the pilot will be able to let go voluntarily of cyclic and collective controls or take his feet off the rudder pedals before impact. In fact, it is likely that he/she will grip them even harder during the last vital milliseconds before impact. Most training teaches that the pilot in control must continue flying the helicopter into the ground or water until it has stopped completely. Because the pilot will be in firm physical contact with the controls the crash forces will be transmitted through the limbs, resulting in possible fractures. Depending on the severity of forces involved, the limbs may flail, but there is little that can be done to prevent this. The head, however, is the most critical area to protect from the instrument panel. To reduce the strike envelope, it is recommended that pilots tuck their head and neck tightly into the root of their neck and chest, and force their head back into the headrest. If they have the opportunity at the last moment to let go of the controls, then they should follow the next procedure as described for the pilot not in control.

(iv) Pilot in Control Headrest Fitted (figure 6B)

The pilot should withdraw his feet from the pedals and place them firmly on the floor, but not wrapped around either front corner of the seat and squeeze the knees firmly together so that the legs form a triangulated shape, with the heels are on the cabin floor comfortably about 10-15 centimeters (4-6 inches) apart. This reduces the human profile and stabilizes the body against in-rushing water. The head should be again tucked firmly into the root of the neck and forced back into the headrest. To avoid the limbs flailing and striking the dashboard and/or extraneous cabin controls, the arms should be folded across each other in scissor fashion and the hands should grasp the opposite coat/coverall collar at the crown of the shoulder and, if possible, the shoulder harness. This will provide support for the chin and protection for the face.

(v) Pilot in Control Headrest Fitted (figure 6C)

There is no head support and it is likely that the head and neck will be injured by both acceleration and by direct impact. The only advice that can be given under these circumstances is that, if possible, the head should be tucked as tightly as possible into the root of the neck. If the hands can be released from the controls at the last second before impact, then the head should be protected in the same manner described below for the case of the pilot with no headrest and not in control. Lastly, again if possible, the feet should be withdrawn from the pedals and put on the floor in a triangulated position.

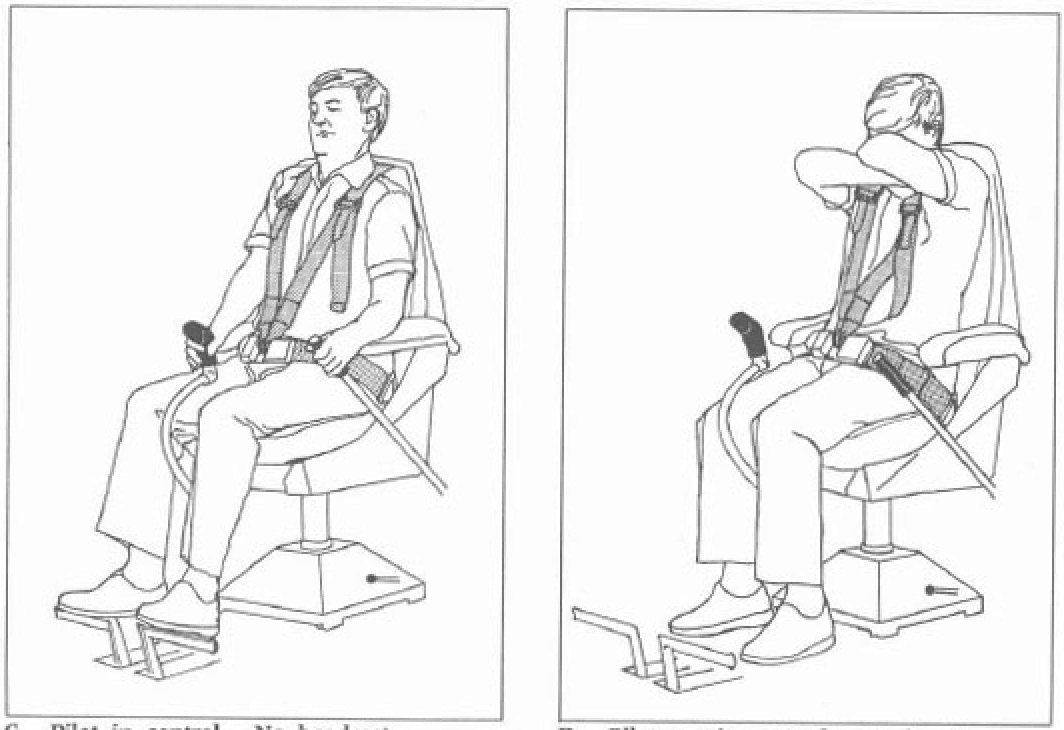
(vi) Pilot in Control Headrest Fitted (figure 6D)

The crash position of the feet and body should be exactly the same as in the situation with a headrest fitted. Without a headrest, however, the head and face are to the hand and elbow positioning. If it is at all possible, the hands should grip the collar of the flight coverall as far back as possible at about the point where the shoulder harness crosses the shoulder. This then protects the face in the crook of the elbow.

Figure 6. Recommended positions for pilots ditching helicopters in water using a 4 or 5 point restraint harness.

A. Pilot in control - Headrest

B. Pilot not in control - Headrest



C. Pilot in control - No headrest

D. Pilot not in control - No headrest

(vii) Crewmen and Passengers with Lap Strap Only (Figure 7)

Traditionally, there have been five types of crash positions advocated for passengers in fixed-wing aircraft wearing a lap strap. These positions have been transferred directly and adopted in the helicopter passenger scenario with little consideration for the fact that the majority of impacts have strong vertical force components with a high chance of contact injuries. No consideration been given to the profound disorientation effects of sudden immersion and inversion and the effects of in-rushing water. The only method to enhance escape is to adopt a crash position in which one hand always grips a part of the seat. This is called the manual physical reference point; only with this reference point will it be possible for the survivor to form a mental image of which way to proceed to an escape hatch after the accident. (Even this is not fool-proof if the fuselage has been seriously deranged.)

The following positions do not have manual physical reference points and are NOT recommended for use by helicopter personnel in seats with a lap strap prior to ditching into water. They are described and criticized as follows:

- Position 1(Figure 7A)

  The crossed hands/wrists are placed on the top edge of the seat in front and the head is buried into the wrists. The buttocks are pressed into the back of the seat and the knees and feet pressed firmly together on the floor. Unfortunately, this position is not satisfactory for various reasons. First, the strike envelope is extremely large. Second, the large body and limb surface area is prone to flail due to crash forces and in-rushing water, which in turn makes disorientation worse, whole body and limb stability, would be enhanced if the legs were positioned in the lower-body triangulated position described for pilots. Third, the seat in front is likely to fold forward during a vertical impact which will cause the head to strike either the base of that seat or the survivor's own knees. And fourth, after the impact there is no manual physical reference point with the seat for re-orientation to assist in determining direction of escape.

- Position 2(Figure 7B)

  The hands are folded across the chest grasping the front and/or sides of opposite knees, the buttocks are pressed firmly into the back of the seat, the back is flexed forwards and the head flexed forwards and buried into the crook of both elbows. The knees a r e placed together, and the feet are pressed firmly together on the floor. Although better than position I , there are still three important criticisms -flailing in the seat is likely due to inrushing water because of the lack of firm fixation t o seat to enhance the stability, the legs are not placed in the triangulated position, and there is no manual physical reference point for re-orientation.

- Position 3(Figure 7C)

  The third position is a variation of position 2. Instead of folded hands grasping the front and/or sides of the opposite knee, they grasp the outside of opposite thighs to keep the knees closed together. This is considered an improvement because the hands are in a more natural position and the legs naturally fall into the triangulated position. However, the position is still not satisfactory because there is a still no fixation to the seat and no manual physical reference; thus the occupant can still flail and have difficulty with re-orientation.

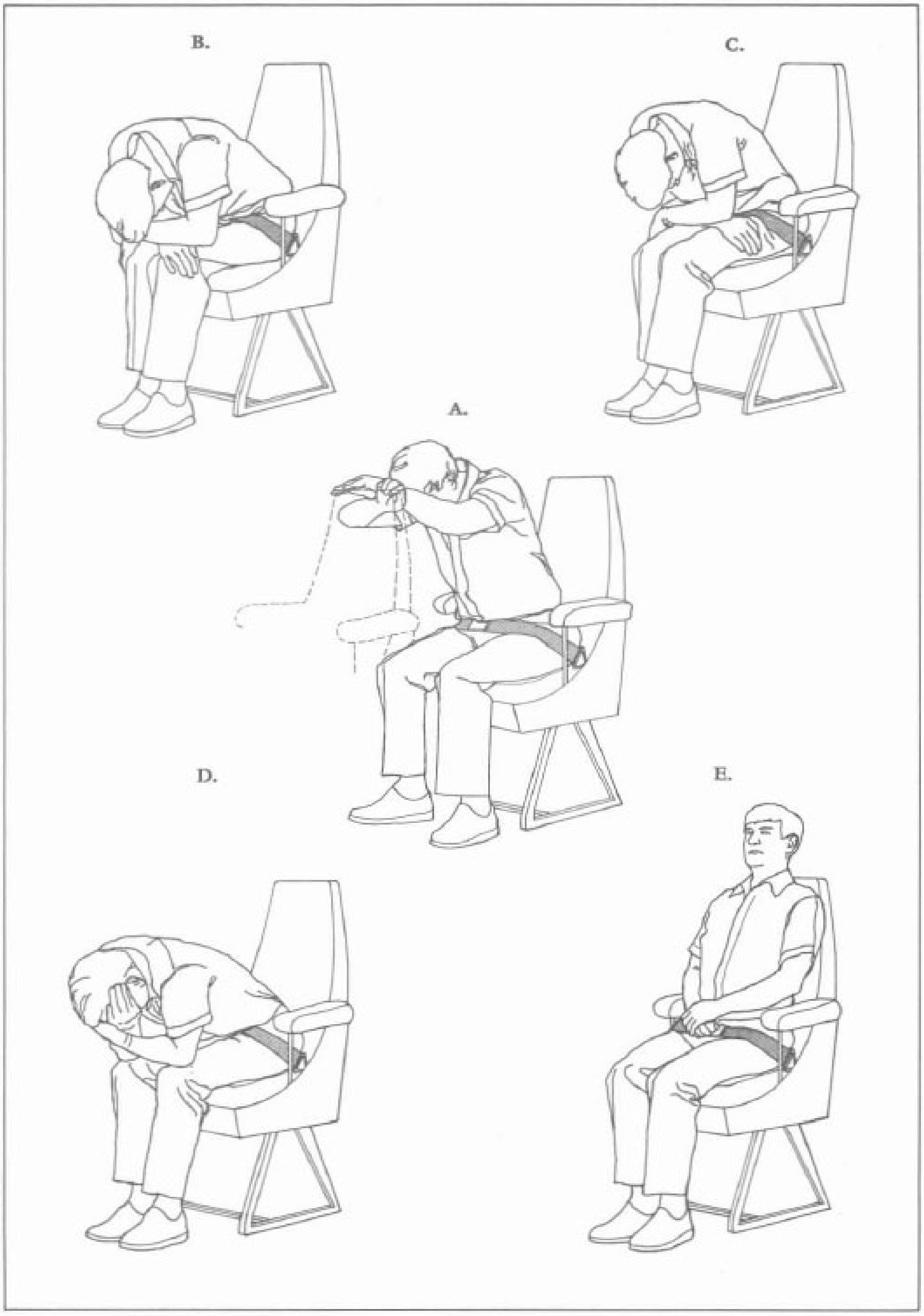
- Position 4(Figure 7D)

  The forearms are crossed at the wrists, and the elbows are placed on either knee. The buttocks are pressed firmly into the back of the seat and t he back is flexed so that the face is protected in the palms of the hands. The legs and knees are placed together, with the feet pressed firmly on the floor. This is a poor position because it is extremely vulnerable to head injury, because there is a large strike envelope. The seat occupant is extremely unstable and susceptible t o the effects o f in-rushing water because of the large profile. There is no manual physical reference t o the seat for re-orientation. And finally, the feet are not in a good stable triangular position.

- Position 5(Figure 7E)

  This position is the one advocated for rearward facing passengers. The person sits bolt-upright in the seat, buttocks firmly in the back of the seat, head pushed into the back of the seat, knees together, heels together and feet pressed firmly on the floor. The hands are held together in front of the pubic bone (Figure 7E). This position assumes that the majority of the force exerted on the passenger will be forward, whereas it is more likely to be vertical. This again is a poor position for under such conditions there is no protection for the face and the body presents a large strike area and will likely jack-knife on to the knees of the passenger in the facing seat. Resulting spinal, cranial and facial injuries could be fatal. It is an unstable position.

Figure 7. Five crash positions NOT advised for helicopter personnel using lap straps prior to ditching in water.



(viii) Recommended position for All Personnel with Laps traps (Figure 8A and 8B).

This position should be able to be maintained in at least a 4G impact and protects against the effects of in-rushing water. The recommended position to be adopted by all personnel in forward, rearward, or sideways-facing seats is as follows:

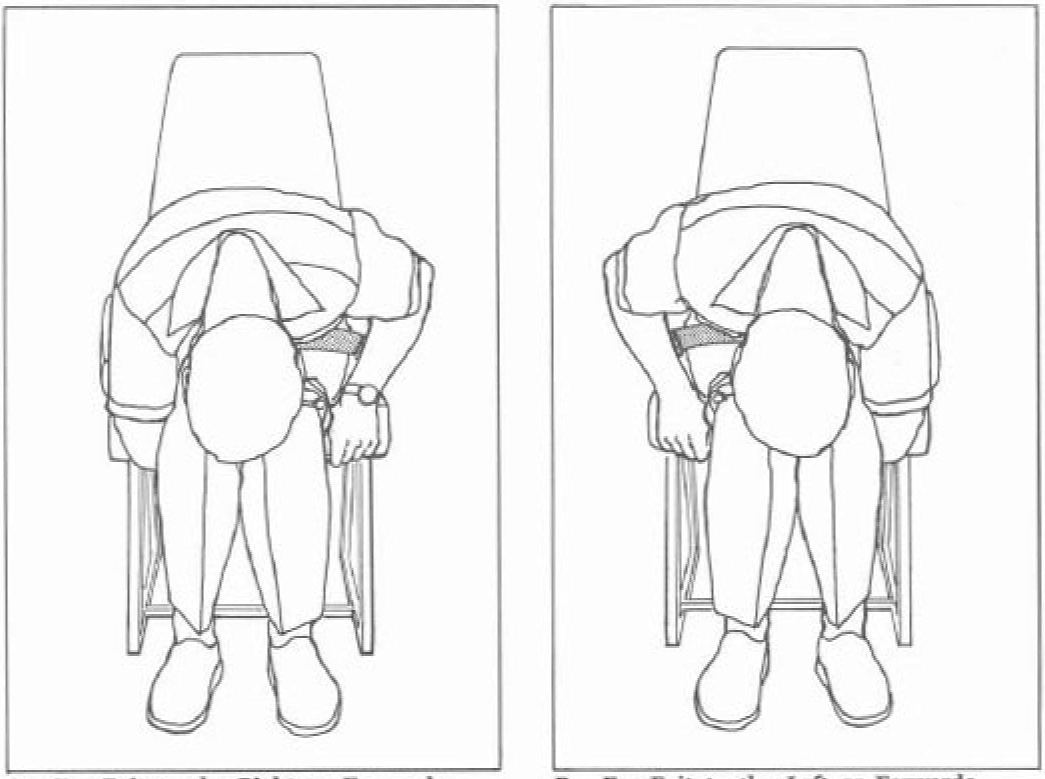
a. The lap strap should be cinched up tight and any excess length of strap distal to the buckle should be tucked inside the strap so that it does not float across the release buckle when underwater and obstruct release (commonly noted during underwater escape training).

b. The body profile and strike envelope should be reduced to a minimum by pushing the buttocks tightly into the back of the seat and bending forwards as tightly as possible so that the torso lies on top of the thighs and the head presses tightly on the knees.

c. The knees should be pressed and held firmly together by wrapping one arm underneath and around the thigh, gripping with the hand of that arm the underside of the opposite thigh or trouser leg. This hand is the first one to be released after the accident. The other hand should grip the edge of the seat at the mid-thigh level, close to the trouser seam. This is the hand that maintains stability in the seat and the one manual reference point for re-orientation once all motion and bubbles have stopped. This hand is to be released last before finally leaving the seat to escape. The hand that holds the seat should be the farthest from the escape exit, i.e., if the right hand IS closest to the ex t, then the left hand should hold the seat and the right arm and hand should hold the knees together. Once the turbulence has stopped, the right hand feels for the exit while the left hand still maintains seat reference.

d. The feet should be placed firmly on the floor, the heels comfortably approximately 4-6 inches apart. With the knees together, the legs adopt a slightly triangular position.

Figure 8. Recommended crash position for all personnel (crew and passengers) using lap straps.



A. For Exit to the Right or Forwards

B. For Exit to the Left or Forwards

(ix) Alternative position for Crewman or Passengers with Space or Anatomical Limitations (Figure 9)

Those passengers wearing lap straps, whose anatomical shapes do not allow them to adopt the standard position and by those passengers in a small cramped cabin where there is not enough room to do so, should adopt the following position. The leg position should remain the same triangulated position as in the standard position viii (d). One hand must grip the edge of the seat to maintain a reference point, as in viii(c). The other hand should be folded across the chest and grip the opposite coat collar beneath the ear, and the head should be buried as tightly as possible into the crook of the elbow. The spine should be bent forward to bring the face as close to the knees as is practical. The hand positions are interchangeable depending on direct ion of escape.

(x) Unrestrained Crewman

Those unrestrained or on a long tethered harness prior to impact, should if at all possible strap into the nearest seat and assume the position as recommended in 2.5.5. (viii) above. Otherwise they should immediately lie face down flat on the floor with their heads buried in the crook of their arms. In fact this is exactly what one USN crewman did recently and he was the only one, out of four crew, who did not suffer a compression fracture of the spine.

2.5.6 Visibility Effects of Darkness

Darkness compounds disorientation and has significant effect on survival rates. AS mentioned previously, in conjunction with in-rushing water, Rice and Greear(60) reported darkness to be a problem 12 times in 78 helicopter accidents between 1969 and 1972. The USN Safety Centre reported that cumulative survival rates for day and night helicopter water accidents from 1978 to 19 84 were, respectively 79% and 62%. And for the year 1987, the USN reported darkness to be a serious problem in three H-2 accidents, three H-3 accidents, and four H-46 accidents (18). In 1984, Brooks (17) reported two Canadian Sea King helicopter night accidents, in which only three of eight crew survived, concluding that darkness contributed to the cause of death. The following accident describes the problem of darkness and disorientation.

Following as system malfunction, a ISN H-2 Sea King helicopter, during flight at approximately 150 feet altitude, suddenly departed from controlled flight and impacted water. Despite bright daylight, moderate sea state and low impact forces all occupants (survivors) of the helicopter suddenly found themselves disoriented in a very dark-water-filled inverted cabin area. The pilot was unable to locate the window jettison handle, and in desperation, forced himself through the open pilot sliding window! Although his window jarred free on impact, the co-pilot became disoriented upon egress and swam down for a short time, which led to ingestion of water and fuel. The right-seated crewman found himself unable to exit through the right crewman's window (probable blocked by collapse sponsor or bent rotor blade and had extreme difficulty locating an alternate exit. He was underwater for a considerable length of time, finally exiting from the area of the cargo door, unsure whether he got out through the door or through a hole in the fuselage. The fact that none of the survivors remembers seeing any of the lost crewmembers after impact further attests to acute darkness/disorientation problem.

Although t raining can greatly reduce egress fatalities, it cannot entirely solve the problems of darkness, disorientation, and l ac k of visibility through bubbles and debris, due to the fact people often will not open their eyes underwater. In the last twenty year, considerable research on underwater lighting has taken place; yet there has been very little determination by operators and helicopter manufacturers t o implement the results.

2.5.7. Underwater Lighting

In 1962, the Royal Navy established a requirement to mark the escape hatches of their Wessex and Whirlwind helicopters with lights to facilitate escape at night (27). Initially, continuous tritium-activated gas light sources were considered, but at that time were not considered bright enough for underwater use. Consequently, in 1965, Wessex modification 737 and Whirlwind modification 1742 introduced systems powered by sea water cells. Although these systems supplied ample light, they were found to deteriorate rapidly in service use in the damp salty environment and were costly to replace. Furthermore, it was impossible to test the cells for serviceability and remaining capacity. In 1966 and 1969, with the advent of new technology, the Royal Navy re-evaluated a series of tritium gas sources, which worked on the principle that the gas emitted low energy beta-particles which, in turn, activated a zinc or cadmium phosphor. The color of the light emitted depended on the phosphor used. Any radiation given off was absorbed in the phosphor and or borosilicate glass which enclosed the complete system. They concluded that one of the tritium-activated green light sources, measuring approximately 1 inch in diameter and producing 6 candelas per square meter, was sufficient to mark each hatch for underwater escape purposes (27). They confirmed this conclusion in the underwater escape trainer at HHS Vernon and in the open ocean. The principal advantages of such lighting were that it was self-contained, easily fitted, and required no complicated installation, power supply, or emergency switches. Once fitted, it provided continuous light, it had a long maintenance-free life, and required no testing, since it could be seen at a glance if it was functioning correctly . The only drawback was that if the source broke, a small quantity of low-dose radioactivity would be released. Nevertheless, these lights were subsequently adopted in Royal Navy helicopters, Canadian Forces Sea King helicopters, and probably military helicopters of other countries. However, it now appears that beta lights (as they are now known) are not as effective as evidenced by the following accident:

In the hover at 40 feet a Royal Navy Sea King helicopter experienced severe vibration, probably from loss of a main rotor blade, and the aircraft was ditched. The blades struck the water and caused the helicopter to roll inverted and sink rapidly in the 4-8 foot swell. The co-pilot kicked at his window but was disoriented. The observer released his harness too early and was thrown around. The overall comment by the survivors after the escape was that the beta lights were not visible underwater.

In the united States, the first published work on emergency underwater exit lighting was by Clark for the US Coast Guard in 1969 (23). At that time, he tested five devices -one RF-excited fluorescent light from Dymo, two electroluminescent devices from Grimes and a ' Capsul ' light from Atkins and Herril , and lastly a new technology chemo luminescent system from the Remington Arms Company. Although no absolute conclusions were made, it appeared that the electroluminescent systems showed the best promise.

Ryack and Luria (43, 62, 63, 64) at the Naval Submarine Medical Research Laboratory continued with studies on the effects of escape hatch lighting . They emphasized the requirement that the lights should be visible underwater at a distance of 12 feet in turbid water at an angle of ±65°0 from direct view . They considered three types of lights -tritium, chemo luminescent and electroluminescent. Again the latter was found to be the most promising because the lights were flat and thin and could be contoured into any shape. They were also battery powered and easily waterproofed. Furthermore, the color was close to the optimum for underwater viewing.

Ryack used a team of professional USN divers to carry out a series of escapes from a simulated Sea King H-3 helicopter hull with and without hatch lighting (64). The escape times were significantly shorter when the hatches were illuminated and longer before the learning effect of the test had been established, (Figure la). Subjects' responses on the evaluation questionnaires showed strong support for the use of the lights, particularly at night. When asked to evaluate the difficulty of night escape on a scale of 1 (exceptionally easy) to 6 (exceptionally difficult), their mean rating was 1.5 with lights on and 4.6 with lights off. There were six recorded instances in which subjects became disoriented, lost, or entangled, five in the absence of illumination and one with lights. It was concluded that the lights were of demonstrated benefit and should be installed around hatches.

Optical characteristics of the lights were then studied by a team at Groton (68). They stated that the visibility of a light underwater depends primarily on intensity, viewing distance, water turbidity and dark adaptation of the observer. Nomo grams were established for estimating the threshold luminance of a light in the water for an observer without a facemask (Figure 11).

Luria et al in 1979 (44) then studied flashing lighting configuration, shape of lights around hatches, printed signs and viewing angle (43,44,63). Two steady lights, a high intensity collimated beam and a chemo luminescent light stick were tested and compared with a large and a small xenon strobe light with a flash rate of 1 flash/s. They showed quite conclusively that flashing lights around hatches were confusing and should not be used. The best configuration was found to be one in which the top and both sides of the hatch were illuminated; in an inverted U pattern (Figure 12). Short wide panels were more visible than long narrow panels of the same total area. It was concluded that, at night, the smallest back-lighted letter readable underwater is 3 inches high, that little information could be printed so that it would be legible underwater, and that it was not feasible to use printed instructions underwater. They also found that, as would expect, more light required for a less direct viewing angle. In less turbid water, the detection times do not increase very much until the viewing angle is quite oblique (62).

More recently light emitting diodes (LED) have been developed for underwater lighting. LEOs are used in the Helicopter Emergency Egress Lighting system (HEEL) manufactured by H. Koch' Sons in the United States (79) and in two types of EXIS lights that are sold by R.F. D. Limited in the United Kingdom.

Allan et al (41) evaluated such LEO devices to compare their underwater detect ability under varying conditions of water turbidity, ambient illumination, viewing distance and viewing angle. The most significant findings were, first, that none of the lights could be seen by any subject at 3.1 meters in turbid conditions regardless of ambient illumination, whether viewing was through a simulated face mask or simply immersed. Second, subjects immersed underwater had great difficulty detecting the lights at 1.54 meters viewing distance especially under bright and medium ambient illumination at 69 l ux. Even in the dark at 1.54 meters, some subjects failed to detect the light and the mean detection times were considered unacceptably long. The experiment confirmed the usefulness of goggles or face masks and, although the wearing of such items would not change the ability to see the LEDs at 3.1 meters, it would make a dramatic difference at 1.54 meters. Allan et al cautioned that designers of helicopter underwater escape lighting systems should understand that visibility over distances of greater than 1.5 meters is very unreliable and more than likely would be obscured due to luggage, debris, bubbles and even other passengers escaping. He recommended as the best form of lighting an illuminated guide bar which, by flashing , would direct escapees to the exit . A prototype has recently undergone preliminary evaluation at t he RAF Institute of Aviation Medicine and has shown great promise (J). Results showed that the escape times were reduced when the bar was operational. All the subjects considered that it made escape much easier, particularly in turbid water.

2.5.8. Optimum Colors for Marking Hatches, Etc

What are the best colors for marking escape hatches and escape routes? Work by Kinney et al (39) in 1967 determined which colors are most visible underwater, emphasizing that it was much more complex than making the same determination in air.

Using previous data from Oster (47), Hulbert (34, 35) and Jerlov {37) , they concluded that fluorescent orange is the most visible color for rivers, harbours, and other turbid bodies of water. Non-fluorescent colors of good visibility are White, yellow, orange and red. For coastal waters of mediocre clarity, fluorescent green and fluorescent orange are superior and white, yellow, and orange are the best non-fluorescent colors. For clear water, fluorescent greens and white are the best choices. As the clarity of water increases, with a consequent increase in viewing distance, the most visible color will change from yellow-green to green to blue-green. Fluorescent materials are superior to non-fluorescent materials of the same color in all bodies of water. White is the best non-fluorescent material in all bodies of water. The most difficult colors to see at the limits of visibility under natural illumination and a water background are grey and black. Other colors that have poor visibility are those whose major spectral components are absorbed by the water {i.e., orange and red in clear water and blue and green in murky water). Only a limited number of colors will not be confused with other colors underwater. To avoid confusion, if absolute identification is important , the following color combinations 5re suggested for escape hatches: green , orange and black; blue, green, orange and black in clear water; and green, yellow, red and black in murky water.

Figure 10. Mean times required to escape from submerged helicopter on three successive days through lighted (○) and unlighted (●) hatches. (24 subjects attempted each escape condition twice).
(Courtesy Ryack, Luria and Smith, USN Submarine Research Laboratory).

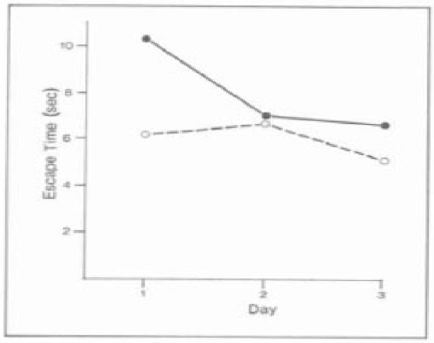


Figure 12. Recommended configuration for lighting around hatches.
(Courtesy Ryack, Luria & Smith, USN Submarine Research Laboratory).

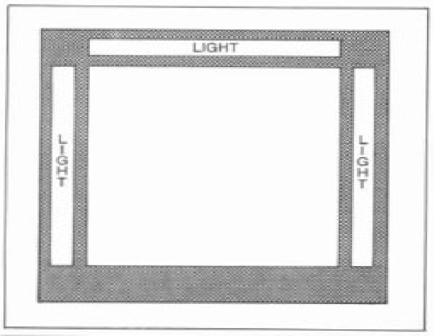


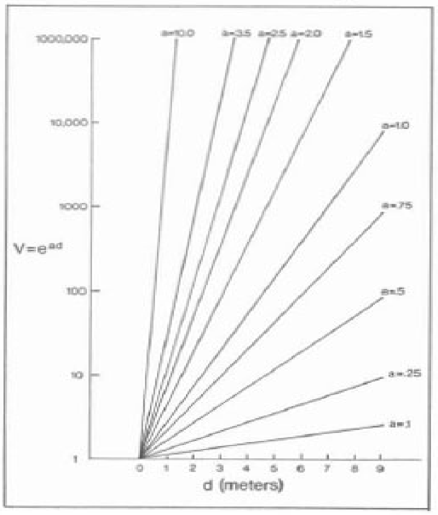
Figure 11. Nomograms for estimating the threshold luminance of a light in the water for an observer without a facemask.

v = degree of transmittance of the light through the water

d = distance the light must travel to the observer

a = turbidity of the water (an "a" of 0.1 indicates very pure water, whereas an "a" of 3.0 is characteristic of turbid harbour water.

(Courtesy Smith & Luria, USN Submarine Research Laboratory).



2.5.9. Visibility Without a Facemask

Lauria and Kinney made the observation (42) that almost no attention has been paid to the measurement of the visual processes o f diver s in water without face masks, yet there have been many occasions in which an escaping submariner or helicopter crewman ditching in water needed to see underwater in order to be able t o escape . They concluded that only stereo acuity is markedly degraded underwater and that, despite a great decrease in range of visibility, distance estimates are reasonably accurate. Size estimation tended to be too small, and those subjects with refractive errors did no t appear t o be more hampered than those with normal vision.

Allen and Ward in the United Kingdom (6) and Brooks in Canada (11) quite independently observed that under water vision during simulated escape is greatly aided by wearing a simple pair of swimming goggles and that these should be included as part of the safety equipment provided to everyone (crew and passengers alike) in helicopters flying over water. Personal observation over a span of 22 years of occupational submarine and diving medicine has shown, perhaps not surprisingly, that many people are terrified to open their eyes under water. It is presumed that a significant number of fatalities have occurred because the survivors have literally been too frightened to open their eyes underwater and therefore could not make the appropriate escape response.

Practical training, of course, can only solve some of this problem. In the next generation of helicopters, this fact should be taken into consideration. Manufacturers and designers must be encouraged to develop escape routes which are achievable in complete darkness, irrespective of whether underwater lighting is available; in effect, it might be like an underwater Braille system. Some years ago, an attempt to do this was made by the Royal Navy in their Wessex helicopter. A series of cones were fitted on a bar which leads to the escape hatch. No report could be found as to their usefulness in aiding underwater escape. The French Navy has a similar idea in their Alouette II helicopters; there is a tape with plastic knobs on it to guide personnel in the back of the helicopter to the escape hatch.

2.5.10. Excess Buoyancy

Added to the effects of in – rushing water, disorientation, and darkness are the effects of buoyancy once the harness buckle is released. Except for those who are very agile, comfortable underwater and practiced at escape, the buoyancy may indeed be of such a high value that it slows down or even prevents the survivor making an escape. The following accident is such a case:

The Tactical Observer of a Canadian CH124 Sea King helicopter was standing in the stern of the helicopter at 50 feet in the hover, when it suddenly lost power, plunged into the water, inverted and rapidly sank. Due to the fact that his regular constant wear immersion suit was under repair, he was wearing a very bulky, loose fitting quick don suit which contained large volumes of trapped air. Completely disoriented and pinned to the floor of the helicopter by the additional buoyancy, he described floating helplessly around like a zeppelin within the cabin. He could not see the beta light to guide him to an escape hatch. Only by the greatest stroke of luck, when he thought he had met his demise, did he spot a glimmer of light and managed to haul himself out through an escape window (66).

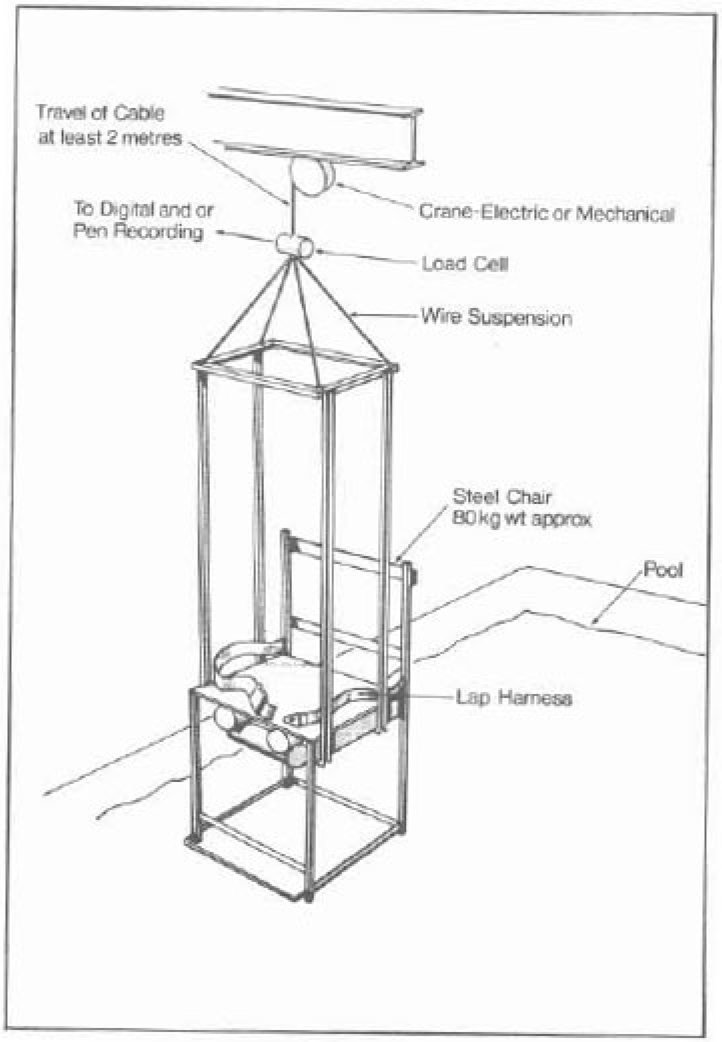


Figure 13. Simple chair designed to measure the buoyancy of immersion suits worn by humans when completely immersed in water. (Courtesy Canadian General Standards Board. 65.17-M86)

In 1982, the Ocean Ranger oil rig disaster occurred off the coast of Newfoundland. As a result, the Canadian General Standards Board (CGSB) identified a requirement to establish a helicopter passenger immersion suit standard. One question asked was how much inherent buoyancy could an immersion suit have without impairing escape from an inverted helicopter? At that time, a literature search by Brooks failed to identify any previous work in this area.

In 1984, to establish a preliminary standard, Brooks et al (17) conducted two sets of experiments simulating a helicopter escape, first in a closed flooded diving chamber using clearance divers, and second in an open pool using native swimmers. They concluded that the shell of the immersion suit alone should not add more than 89 Newtons(N) or 20 Ibs buoyancy, and it was recommended that this figure be confirmed in the dynamic situation using a Helicopter Underwater Escape Trainer (HUET).

The original experiments by Brooks et al (17) indicated that the maximum inherent buoyancy for the total suit system must be less than 177 Newtons (40 lbs). The definition of inherent buoyancy of a suit system is the total amount of buoyancy of the user of the suit and liner materials, and of any trapped air (between the skin, linings and outer shell and in the suit pockets), after total immersion in a seated position for 15 seconds. It was recommended that the suit shell buoyancy not exceed 89 Newtons (20 Ibs) since the insulating layer, shirt, trousers, liner, etc., would add an estimated 44- 89 Newtons (10 – 20 lbs) to this value. The underclothing worn would depend upon weather conditions and personal preference.

It then became apparent that measuring the buoyancy of just the shell of a suit did not take in to account the true dynamic effects of trapped air in the whole suit system during a ditching. Therefore, the Canadian Offshore Research and Development Group of Nova Scotia (CORD) (71) developed a simple underwater weighing chair (Figure 13) connected to an electronic scale and load cell. This was found to give reliable repeatable measurements of the additional buoyancy of a suit system when worn by a human. Moreover, because it completely immersed the subject in the simulated crash position, it represents a condition close to that which would be experienced by a survivor in a true water ditching situation.

An observation of particular interest, which had not been previously noted, was that trapped air in all commercially- available suits, liners, and underclothing which potentially could vent off would do so in less than 19 seconds after total immersion. This is a benefit because it is a factor in reducing the inherent buoyancy of the suit system just prior to escape. Thus, an upright or vertical I5-second dunked buoyancy reading was considered to be a good measurement of the suit system buoyancy. These readings were later validated when these at was transferred to the inside of the Helicopter Underwater Escape Trainer (HUET). Subjects were weighed underwater, upside down, 15 seconds after immersion in a standard helicopter ditching procedure. The suits recorded, by and large, the same buoyancies in the inverted dynamic conditions of the HUET as in the upright or vertical chair condition. The only discrepancies were data for those suits which were poorly fitted and/or poorly designer. These suit systems leaked badly under both conditions, but worse in the HUET because it is a much more aggressive test and can break water tightness of zips and neck and wrist seals. Hence, in the HUET, these suits became relatively heavy. The air in the lining was displaced with water and therefore buoyancy was less than under similar circumstances in the vertical dunked buoyancy measurement. Normally, in the process of commercial acceptance tests on such suits, the suits would have failed because they would not pass the thermal test due to the gross leakage, so these discrepancies were not significant.

Once a simple method of measuring a suit system buoyancy had been established, it was possible to measure the buoyancy of the then current commercially -available suit systems being used by the crews and passengers of helicopters flying off the Eastern sea board of Canada, and used in survival training in the HUET by Survival Systems Limited of Dartmouth, Nova Scotia.

Purely by coincidence, Bohemier et.al(14) at Survival Systems Limited, Nova Scotia had noted that students using two types of these suits in the HUET occasionally got into trouble while making escapes . They were observed to be just too buoyant and the subjects had to be assisted out by one of the safety divers. With the new technique for buoyancy measurement, these suit systems measured 155N (37 Ib) and 169N (38 lb).
Brooks et al (16) reported a preliminary study with four test subjects (three male, one female) to assess their escape capability using these two suits. The conclusion was that the suit system buoyancy must be less than 155N (37 Ib). For the suits to meet the thermal requirement, it was considered that the suit system could not be constructed with less than about 146 N (35 Ib), particularly for the large sizes. A further group of subjects (six males, four females) were evaluated during a relatively complex underwater escape wearing exactly 146N (35Ib) off added buoyancy. All escaped successfully, and the CGSB were advised that this should be the maximum allowable inherent buoyancy for the Canadian-approved passenger helicopter Immersion suits (71). This value now has been incorporated into the CGSS Helicopter Passenger Transportation Suit System Standard (21), and the technique for measuring the buoyancy of a suit system has been made an Air Standardization Coordination Committee Air Standard (2).

It is therefore important to ensure that the buoyancy is kept to the minimum. Passengers must know not to inflate their life preservers before making their escape, another reason for a good preflight briefing. Practical underwater escape training should demonstrate the profound effect of being pinned to the inverted floor of the submerged helicopter.

2.5.11. Harness Release

While undoing the buckle of the lap strap in air is a simple task strapped in an aircraft seat sitting normally up righted, it can be extremely difficult to do upside down when completely submerged in water. Rice et al had recommended water-actuated time-controlled release of lap belts in 1973 (60), yet no such device is fitted to any helicopter fifteen years later. The U.S. Navy Safety Center reported 14 cases of difficulty releasing the restraint system in the three years 1983-1985. Moreover, if the general anatomical structure of the seat and surroundings has been disarranged by the accident, the problem is compounded by sharp edges which can cause serious entanglement. For the same period, the U.S. Navy reported 31 cases in which the crews were hampered by equipment. Preliminary results for 1987 compiled by Thornton (19), indicated a further three cases, in H-46 Sea Knight accidents. The problem of harness release Is very well demonstrated in the following narrative to an accident in which one passenger was lost at sea and one suffered hand injuries.

Engine malfunction in a USN H-46 Sea Knight helicopter in flight led to an unsuccessful attempt at a single engine landing aboard the flight deck of a ship. Ditching was elected when it appeared that a successful landing could not be accomplished. Seven passenger’s egresses underwater through openings created where the aft section broke just aft of the stub wings. Four of seven passengers had difficult releasing their seat belts. Two passengers had to add more air to their life preserver, one passenger foot got caught in the seat during egress , and one passengers web seat collapsed on impact with water due to the locking rod under him not being secure . The co-pilot egresses underwater through the right escape hatch.

He had forgotten to disconnect his communication cord. The lobe of the pilot's life vest caught during his egress from left escape hatch. The two crewmen egressed underwater through upper hatches of the passenger doors. Hatches slid shut on both of them. The first crewman pulled the hatch back and tried to egress again. The rotor blade bent down pinning his head against the fuselage as the helicopter continued to roll. He got free and proceeded hand over hand to pop out of a hatch on the port side. He surfaced, inflated his life preserver, and turned on his radio. The helicopter rolled over seconds after he egressed. The pilot had climbed on to the fuselage upon egress As the helicopter continued to roll, he fell backward into water. He swam a few feet away and inflated his life preserver, put his radio on emergency beacon and strobe light on his helmet. Rescue was completed within 25 minutes. The co-pilot had difficulty climbing the cargo net when boarding ship.

In the pre-flight briefing and particularly in the Helicopter Underwater Training Course , it is essential to stress the importance of remaining in the seat until all motion has stopped , and only then releasing the harness ; otherwise the only physical reference that the survivor had is lost. It is also important to emphasize the necessity y to tuck. the "tail" of the lap strap inside the tightened lap belt. This prevents the flap from interfering with efforts to locate the buckle. Although, by and large, the pilot and co- pilot will tend not to have too much difficulty in escaping , providing they are not injured , passengers with as little as four meters (approximately 12 feet) of distance to the nearest exit may indeed perish, particularly if their escape route is blocked by a panicking survivor , debris from the wreckage or personal equipment. Escape routes must be well lit. Manufacturers should be encouraged to design escape routes that are minimal in distance and that can be followed with eyes closed. Ideally there should be a push-out window adjacent to every seat or row of seats .

2.5.12. Escape Hatches

It is essential that an escape aperture is adequate for the survivor to be able to squeeze through it . The single and multi-seat life rafts must also fit through exits and hatches. Chapter G4-3 of the British Civil Air worthiness Requirements describes the four types of passenger emergency exits (I-IV), the smallest type IV dimensions being 483 mm (19 inches) wide by 669 mm (26 inches) high . The number of each type of exit is laid down in relation to passenger seating capacity. In addition to the standard requirements, the Super Puma helicopter has fitted also secondary escape hatches 432 mm (17 inches) wide by 483 mm (19 inches) high to enhance escape from a submerged cabin . A recent study was conducted by Allen and Ward at RAF IAM to investigate whether this smaller aperture is large enough to pass through while wearing a commercially –available life preserver and immersion suit (6). It was concluded that underwater escape for subjects up to the 95th percentile bi-deltoid breadth would have no problem escaping under water from such a window aperture . Exits down to the size of 432 mm (17 inches) by 356 mm (14 inches) were also compatible with escape for all but the exceptionally large persons. A second important observation from their experiment for consideration by the designers of safety equipment was that protrusions or snags over the back of the passenger pose a greater risk to escape than those over the abdomen.

As has already been clearly demonstrated, helicopters ditching in water commonly invert and sink; it is surprising, therefore , that no helicopter designer has considered the idea of extending the windows designated for escape right down to the floor of the helicopter in order to reduce the problem of over coming inherent buoyancy when inverted. As early as 1973, Rice and Greear (60) recommended that more hatches be provided both overhead and in the deck , and that water pressure activated charges be fitted to remove the hatches automatically in the event that the crew could not release them normally. The U.S. Navy, in the three year period 1983-1985 , reported 33 cases in which personnel had difficulty or found it impossible to open the escape hatch. Little progress appears to have taken place since Rice and Greear's recommendations.

The design of escape hatch emergency jettison levers is simply abysmal. This was apparent in a recent midwinter flight from Tuktoyuktuk in Northern Canada offshore to a rig in the Beaufort Sea. It was observed that, to release the passenger door/window of the Bell 214 helicopter in an emergency, it is first necessary to remove a small blanking plate which covers the handle. This cannot be done with a gloved hand because it requires a small diameter finger to be inserted through a hole in the cap. Then gripping with the finger and thumb, it is supposed to be pulled off to access the release handle. But the mechanism underneath was impossible to identify and the technique, force and direction to initiate door/window jettison was also not indicated or obvious! Lastly, with four large adults sitting line abreast on the bench seat in the helicopter, it would have been quite impossible to get one's elbow and arm anywhere near the release mechanism!

2.5.13. Underwater Breathing Apparatus

Once the potential survivor, in darkness, upside down and completely submerged in freezing water, has released the restraint harness, become untangled from the head set, analyzed which escape path to take, and struggled across debris, broken seats, brief cases and disoriented passengers, he/she likely has run out of air and is panicking. This may have been a factor in the death of one member of a USN H-3 Sea King crew in the accident described below.

While in a night ASW sonar hover, the pilot of a Sea King experienced total gyro failure. The crew conducted an emergency freestream with the helicopter impacting water after sonar recovery. It impacted the water under forward speed in a nose high, left yaw attitude with water immediately entering from the right side and the air craft rolling right to the inverted position. One crewmember was lost at sea. All rescued crewmembers exited the air craft underwater as it was flooded and became inverted. The pilot egresses through left window, co-pilot through right window, and third crewman through port window across from the left sonar seat. The second crewman braced himself with his arms at impact to avoid injury. He punched out his window immediately. He attempted to exit via the window, but because stuck half way out. Needing air badly he inflated his vest which pulled him out of the window and to the surface.

In order to make a successful underwater escape, it is essential that the survivor be able to hold his/her breath for a period of time. Tansey, in his review (7a) of Medical Aspects of Cold Water Immersion, concluded that a subject immersed in cold water at the end of an expiratory phase of breathing risks the likelihood of uncontrolled aspiration of a large volume of water. Moreover, current research indicates that there is a direct correlation between immersion in decreasing water temperature (TN) and duration of breath-holding ability (BHD) (24).

This first became apparent between 1977 and 1979 when the US Coast Guard (USCG) lost a utility boat and two helicopters in cold water. In the first incident, eight crewmen were trapped in a large air pocket in the capsized utility boat. Only a relatively short swim was required; yet the survivors found it difficult to hold their breath in the 7°C water and most survivors had to make repeated attempts before they succeeded. Two of the crewmen perished because they couldn't hold their breath long enough.

Of the two helicopter ditchings, only three of the nine crewmen escaped from the inverted flooded cabins. In water temperatures of 13°C and 14°C, effects on breath holding ability were implicated as one of the possibilities for the drowning. Sterba and Lundgren (69) studied breath-holding duration (BHD) in subjects immersed in 15-35°C water. They found that at I5°C, the BHD was 30% of non- immersed values. Hayward (32, 58) showed a 25-50% reduction in adult breath-holding ability in 0-15°C water compared to relatively warm water, and he suggested a dependence (TW) according to the equation BHD = 15.01 + 0.92 TW. For adults in a group of 87 subjects aged from 4-13 years. This problem of a reduced breath-holding ability is exaggerated by the increase in respiratory drive, or ' gasp reflex ' as it has become known. Keatinge and MCCance (38) observed that cold water immersion caused stimulation of coetaneous cord receptors in humans, producing sudden deep inspiration. Both Martin and Cooper (45) and Hayward and Eckerson (33) noted a four-fold increase in ventilation during head-out immersions; the latter also noted a doubling of frequency and a tripling of tidal volume. This was reconfirmed by Mekjavic et.al (46) during recent tests of immersion suits. Expressed in a more practical way, this means that helicopter crews would only have between 12 and 17 seconds at 9°C to hold their breath, hardly long enough to make a simple escape , never mind a complex one!

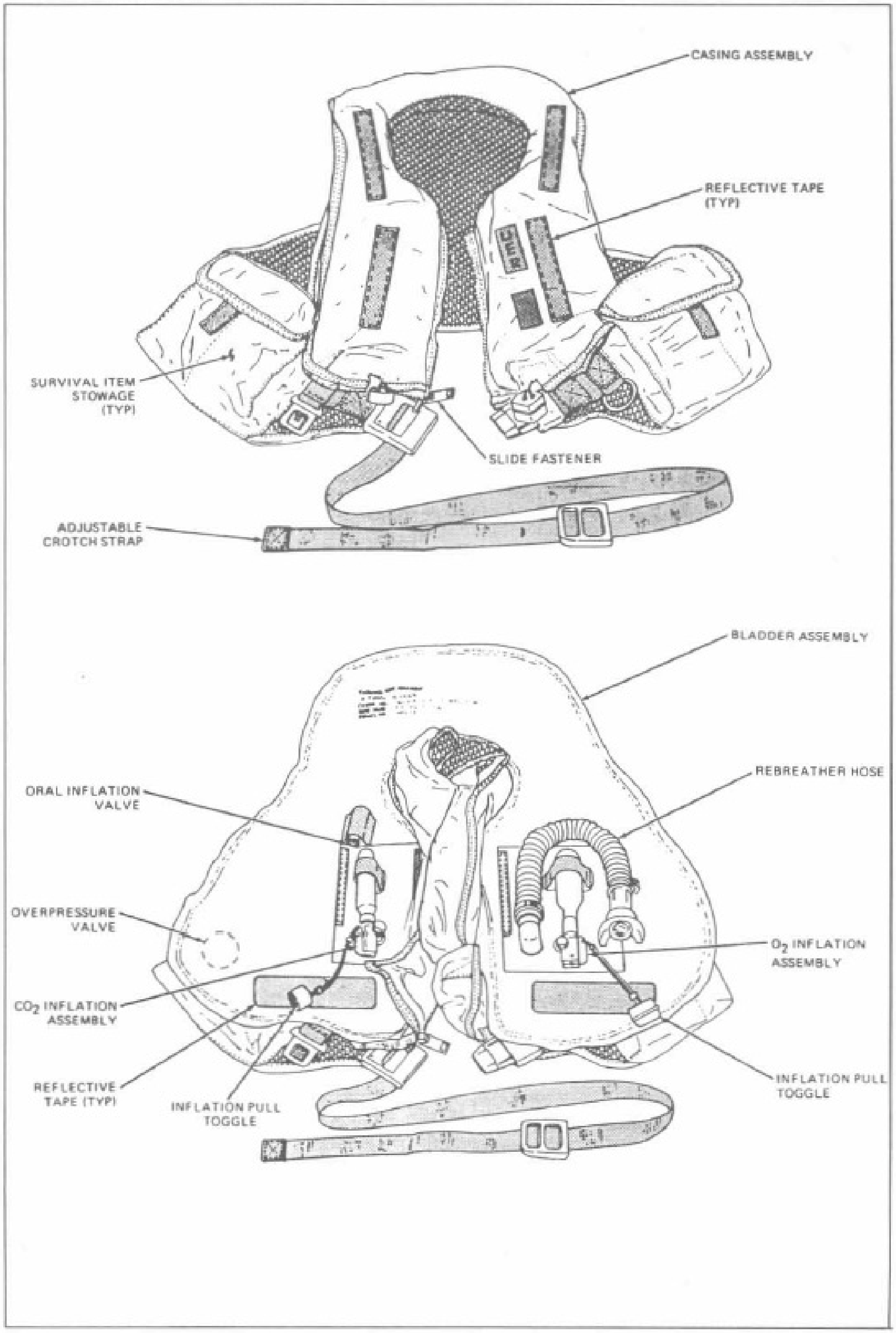
The first work on underwater breathing systems for helicopters was done by the Royal Navy. In September 1974 (72) the Flag Officer Naval Air Command stated it was desirable that under water emergency breathing equipment be developed to assist troops / passengers to escape from sunken helicopters . From original ideas from Prince, Miners and Bartholomew, helicopter emergency breathing equipment (HEBE) device was constructed and tested in June 1975 by the Royal Naval Survival Equipment School (61). They recommended that HEBE be introduced into service. To date the Royal Naval Air Command had not implemented the recommendation.

In 1977, Ryack et.al (64) tested a prototype SCUBA apparatus manufactured by Robertshaw Controls of Anaheim, California. The investigators were testing the effectiveness of escape hatch illumination and had issued each subject with the breathing device to assist in escape if they became disoriented. The short report described how six subjects became disoriented and/or entanqled within the helicopter. In four cases, the subjects used the breathing device to assist them out of difficulty, with good results. The availability of a breathing device was strongly recommended by the subjects and the investigators.

As a result of a 1979 H-3 U.S. Coast guard Sea King helicopter accident off Cape Cod , in which four of the five aircrew drowned while attempting under water escape , the USCG decided to develop their own underwater escape breathing system. The prototype system consisted of a modified dual -cell life preserver. One cell of the preserver contained an oral inflation tube and 28 gram $C0_2$ cartridge; the other cell, had a mouthpiece with breathing tube and a l2-litre compressed oxygen cartridge (Figure 14). Upon immersion, the oxygen cartridge was manually activated by a pull toggle and inflated the left cell of the preserver with 100% oxygen. The system was combined into a prototype life preserver/survival vest combination in 1981.

There-breather system was physiologically evaluated by the USN Experimental Diving Unit early in 1981 (31). The primary criticism of the system was the significant suppression of the hypoxic drive and a tendency toward the development of hypercapnia and loss of consciousness while breathing 100% oxygen underwater. “Removing the hypoxic drive caused the subjects to continue re-breathing well beyond the point where their mental state would be adequate for helicopter egress·. It was therefore recommended that the 100% oxygen be replaced with a 60:40 nitrogen / oxygen mixture to create sufficient dyspnea to warn of impending $C0_2$ intoxication and blackout. However, in retrospect, it does appear that the USN misunderstood that this was designed specifically as a shallow water escape device that would commonly be used for 30 seconds and never for more than two minutes. Therefore, despite their recommendation, the USCG proceeded with re-breather development using 100% oxygen, rather than with either air or 40% oxygen, because of the significantly longer breathing times. The product, Model No. 81349/81 UER 108-1, is now in service. It is made by Soniform Incorporated, El Cajon, California. To date, there has not been an accident in which a USCG pilot or crew member has needed the apparatus.

Figure 14. The U.S. Coastguard LPU-25/P Survival Vest Assembly/Underwater Escape Rebreather.



In 1979, the Defence & Civil Institute of Environmental Medicine (DCIEM) in Toronto decided to proceed with the investigation of alternate compressed gas systems too. The system originally developed and tested in prototype form by Ryack et.al (67) was now commercially available from Robertshaw and was acquired for DClEM evaluation (Figure 15A) . It consisted of a coiled stainless steel tube reservoir containing 130 liters of air compressed to 5000 psi. From the reservoir, a 22-inch hose within-line quick-disconnect fitting connected to a miniature demand regulator mouthpiece. The air supply was initiated by a pull-to-start ring at the base of the unit. Underwater evaluations by the Diving Division at DCIEM during 1981 revealed that during a moderate workload of 75 watts at 10 and 30 fsw, the average breathing times were 3 and 2.5 minutes, respectively. In addition, it was found that the regulator mouthpiece occasionally filled with water, requiring excessive purging to clear, thus depleting the air supply quickly. The leakage was thought to arise from inadequately designed flapper valves on the regulator mouthpiece exhaust port, or from some design deficiency in the regulator itself. Consultation with the manufacturer revealed that re-design would result in the price per unit becoming prohibitive. As a result, this design was abandoned.

In the latter half of 1982, another commercially available emergency breathing system (EBS) was identified (Figure 15B). This was designed specifically as an emergency supply for divers. It was thought that it could have potential as an underwater escape system for aviators. Manufactured by Submersible Systems incorporated (SSI), Huntington Beach, California, it consists of a I5-inch long, 2- inch diameter "mono block" aluminum cylinder containing 56 liters (2 cu. ft.) of air pressurized to 1800 psi. A single-stage demand regulator incorporating a twist-turn on/off knob, rubber mouthpiece, purge button, pin-type pressure gauge, and refuel port was attached directly to the cylinder head. The cylinder itself had been approved by the Canadian Ministry of Transport and could be repeatedly re-filled without inspection. Over pressurization during refill was prevented by the incorporation of a frangible brass disc designed to burst at 2700 psi. The cylinder itself is designed with a minimum burst pressure of 6000 psi. The EBS is available in single or dual cylinder configurations (Figure 15C).

Operation of this system is simple. The rubber mouthpiece is placed in the mouth either before or after the knob is rotated counterclockwise to open the bottle , and the user either exhales or depresses the PURGE button momentarily to clear the regulator of water, and then breathes normally through the demand regulator.

In 1983, 16 test dives at 10 and 30 fsw were carried out with these units. Respective breathing duration times averaged 96 seconds and 78 seconds for a single cylinder. It was recommended that a number of these units be procured for user trials and flight evaluations (36).

A user trial was undertaken by the Sea King pilots at CFB Shearwater, Nova Scotia. They were satisfied with the apparatus, in principle, provided consideration was given to placing the unit in the survival backpack. Thus, the manufacturer was requested to modify several EBS units to a Mark II design by inserting a 24-inch high-pressure hose between the bottle head and the mouthpiece regulator (Figure ISD). This modification is now complete and has been tested. The first two EBS training courses were completed in August 1988 and it will go into service shortly.

At the same time that the Canadian Forces were evaluating the latter SSI/EBS system, the USN was conducting an evaluation of both systems the USCG and SSI/EBS systems, designated by them as Helicopter Emergency Egress Devices (HEEDS) 1 and 2, respectively. Formal operational evaluations commenced in March 1985. Although the USCG system (HEEDS I) was able to provide a required two-minute breathing supply at 20 fsw and 55°F, the buoyancy of the inflated oxygen cell was found to interfere with a test subject's ability to locate and manoeuvre out of emergency escape hatches. As a res ult, Naval Air Systems Command terminated testing of the system. The SSI/EBS (HEEDS 2) was successfully tested and approved for production. Hardware deliveries to the US Fleet began in September 1986.

The HEEDS 2, also designated the SRU-36P, is now in service with the USN and, as recently as August 1987, the first units proved their worth. The extensive narrative below illustrates the role of the HEEDS and egress training played following the crash of an H-46 helicopter at sea on 27 August 1987.

This was the first reported accident in which an aircrew used HEEDS to escape from a sinking aircraft; two air crewmen's lives were saved. Prior to deployment, all aircrew on the detachment received HEEDS training through an accelerated training program provided by the NAS Miramar Aviation Water Survival Program (NAWSTP). Also, all four crewmember's escape was directly attributed to the underwater egress training in the helicopter underwater escape trainers at/or NAS Miramar and NAS Pensacole (95D).