Survival from Canadian Seaplane Water Accidents: 1995 to 2019

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INTRODUCTION: Each year in Canada, there are a number of pilots and passengers who die in seaplane water accidents. A study examining the human factors and fatality rates associated with these accidents was conducted.

METHODS: Seaplane water accident investigations by the Transportation Safety Board of Canada (TSB) between 1995 and 2019 were reviewed.

RESULTS: There were 487 accidents involving 1144 occupants (487 pilots, 657 passengers). There were less than 15 s warning in 86% of cases. There were 60 pilots and 88 passengers who died—a survival rate of 87%. Drowning, trapped within the cabin was the principal cause of death (54%). Loss of control on landing, wheels down landings, and other landing problems (49%) were the principal causes of the accidents and 77% of the fatalities occurred in this group. These arose because the pilot(s) misjudged wind, waves, and glassy water. Over 50% of seaplanes inverted and 10% floated briefly then sank, resulting in the highest percentage of fatalities. Wearing the seat harness incorrectly, injury, in-rushing water, and inability to locate and operate exit mechanisms (including rescuers' inability to open the exits external to the fuselage) all contributed to the fatalities. Life jackets would have been of benefit in several cases. Of the accidents, 57% were private flights.

CONCLUSIONS: Passengers require a thorough preflight briefing, life jackets should be worn by all pilots and passengers, and private and commercial pilots should receive Underwater Egress Training.

KEYWORDS: seaplane, ditching, warning time, underwater escape.

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> *"During the takeoff, the a/c [aircraft] did not want to take off even after it had reached its takeoff speed. It then briefly bounced at the end of the lake and fell back into the water, striking the front tip of the right float. The a/c bounced left and right and tumbled upside down in the water. The pilot and front seat passenger left through the pilot window in the door. Seeing the rear passenger had not followed, the pilot dived in to try to rescue him. The rear passenger struggled with his seat belt and fought the actions of the pilot. Having no more breath, the pilot had to rise to the surface. The pilot and front seat passenger remained on the floats until rescue two and a half hours later. The pilot had not given safety instructions about the use of seat belts and opening of doors to the passengers."*
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> (Excerpt from a Transportation Safety Board of Canada Aviation Investigation Report.)

Published data for escape and survival from seaplane accidents in water is very sparse. In 1977, Davidson identified the fundamental human factors-related problems with escape from a NATO ditched fix wing jet fighter aircraft: 1) time to escape is limited; 2) escape can be made difficult or impossible by a variety of factors related to human performance and equipment design; 3) pilots may be incapable of logical thought or action because of panic (where realistic training is the best solution); and 4) postaccident cold water survival is also time and equipment dependent. At that time, much work was done trying to find a method to provide an emergency, supplemental air supply to the crew, but with little success. Significant emphasis was placed on canopy jettison

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systems and underwater egress training of aircrew to improve survivability.[8]

In 1994, the Transportation Safety Board of Canada (TSB) published an analysis of 1432 seaplane accidents that occurred between 1976 and 1990[17,18] [Transport Canada. Seaplane safety—an overview. Unpublished report; 2019]. This identified areas of seaplane operations where safety deficiencies might exist—the definition of a seaplane being a float plane, flying boat, or amphibious aircraft.

Of the 216 full reports that TSB analyzed, 103 (48%) terminated in water and involved 276 occupants; fewer than 10% of these occupants escaped unhampered, while 77% of crew and passengers died from a combination of incapacitation and/or drowning; approximately 50% of whom drowned while trapped in the cabin. Of accidents, 41% occurred during takeoff and 37% during landing. The aircraft "sometimes" flipped upside down, making it difficult to maintain situational awareness. The flaps, which are at least partially lowered on most aircraft during takeoffs and landings, prevented egress on some outward-opening exits. Disorientated occupants may have panicked as icy cold water rushed into the cabin in the seconds following impact. Some of the aircraft did not have a rear exit, making evacuation for the rear passengers difficult. In these cases, the only exit route for passengers would have been to crawl over the front seats and through the crew door(s).

In 1989, Brooks summarized the human factors related to survival from a helicopter ditching.[1] In 2001, Cheung et al. demonstrated that helicopter occupants in many cases ran out of breath-holding ability before they managed to escape, particularly in cold water.[6] In 1996, Muir et al. described the problems of escape from the cabin.[13] In 1997, Brooks and Bohemier reported on the difficulty of jettisoning emergency exits in a flooded inverted helicopter fuselage.[3] In 2009, it took loss of life in an S-92 helicopter ditching off Newfoundland[19] for emergency breathing systems (EBSs) to be required in Canadian commercial maritime helicopters.[5] By 2013, this technology had evolved significantly[7] and is now in widespread use in military fixed wing and helicopter operations and required for civil helicopter operations in the North Sea. Following a series of Canadian seaplane accidents and fatalities between 2012 and 2019,[14] with the approval of Transport Canada (TC), it was decided to investigate the current accident statistics and to get a sense as to how much progress had been made regarding the safety of crew and passengers in seaplanes over the last 24 yr and make general comparisons to the literature noted above. This paper presents data from the TSB full reports and database.

METHODS

TSB publishes seaplane accident data in two ways. A full report is written for an accident when there is a high probability that the report can advance transportation safety and reduce risks to persons, property, or the environment. For other more minor occurrences, a record and short narrative is created in the air transportation occurrences database available to the public on its website. The narrative and quantitative data from these two data sources were extracted and loaded on Microsoft Excel®, reviewed by all three investigators, and transformed as required to support descriptive analysis. For example, when assessing environmental factors, the TSB narrative data was searched for a description of the wind and water conditions, the database was reviewed for quantitative wind velocity, wave height, and water surface condition data, and the accident environmental conditions were recorded in accordance with our classification system. An example of the output of this process is "SGW – Strong and/or gusty winds" associated as an environmental factor with 97 of the accidents in our study.

Table I. Type of Operation and Associated Fatality Rates.

TYPE OF OPERATION	*N* (% OF TOTAL)	# OCCUPANTS (MEAN OCCUPANTS PER FLIGHT)	# FATALITIES (% OF OCCUPANTS)
Private	278 (57%)	525 (1.9)	59 (11%)
Commercial	169 (35%)	547 (3.2)	83 (15%)
Training & Other	30 (6%)	59 (2.0)	3 (5%)
Government	8 (2%)	11 (1.4)	2 (18%)
Unknown	2 (< 1%)	2 (1.0)	1 (50%)
Grand Total	487	1144 (2.3)	148 (13%)

A survival event tree was created involving crew and passengers from flight planning, through embarking, water taxiing, takeoff, flight, and landing, to the safe return of the seaplane alongside the dock. The factors examined were: 1) preflight details; 2) factors at the point of impact; 3) postimpact factors; and 4) postescape factors.

We excluded occurrences where the seaplane landed long and ended up on the beach, or where after some minor incident, the pilot managed to taxi it to the dock and safely disembark the passengers directly on land. This type of occurrence was not evaluated due to the fact that there were few threats to occupant survival in these types of occurrences and virtually no injuries or fatalities.

For the majority of human factors reported, no specified classification system existed. Based on the authors experience in classifying water ditching,[4] combined with the natural groupings of many TSB classifications, the authors created classifications where they were either not specified by TSB (e.g., warning time), or where the broad array of classifications were too specific for the purposes of this study. For example, TSB classified, "Type of Operation", into 15 categories; these were reduced to the five aggregate categories listed in **Table I**.

The previous work by Brooks et al.[4] demonstrated that warning time was critical to surviving a helicopter ditching. Even though warning time was rarely noted in the TSB data, it was clear from many narratives that the accident occurred quickly and unexpectedly; as a result, most occupants received no indications of an impending crisis until the accident sequence began to unfold. In these cases, we estimated that the warning time was less than 15 s, which is, as noted above, a threshold previously used in maritime accident survivability research.[4]

RESULTS

General

A total of 984 seaplane accidents from 1995 to 2019 were reviewed, of which 487 (49%) terminated in water. A total of 1144 occupants were involved: 487 (43%) pilots and 657 (57%) passengers. On average, there were 2 occupants on board each flight, ranging from those involving a single pilot to one with 17 occupants on board. There were 178 (37%) accidents with no passengers on board. There were 148 (13%) fatalities, 47 (4%) serious injuries, and 220 (19%) minor injuries. Of the 148 fatalities, 60 (41%) were pilots and 88 (59%) were passengers. Of the full reports, 52 (11%), which included the most serious accidents, identified that 39% of the occupants in these occurrences were fatally injured. Conversely, the overall fatality rate for all 487 accidents was 13%. All but one accident occurred during daylight hours.

Pre-Flight Details

The majority of accidents occurred in Ontario [*N* = 163 (33%)], British Columbia [*N* = 118 (24%)], and Quebec [*N* = 97 (20%)]. The remaining provinces and territories reported no more than 35 (7%) accidents each.

The majority of the 148 fatalities occurred during private [*N* = 278 (57%)] and commercial operations [*N* = 169 (35%)]. Table I presents a breakdown of each type of operation and the associated fatalities.

Seaplane pilot flying experience was reported in 41 (79%) of the full reports. Experience ranged from a first flight by a student pilot, to a pilot with over 20,000 h of flying all types of aircraft, to a pilot with 8000 h specifically flying seaplanes. **Table II** presents pilot experience on seaplanes and the associated fatality rate.

The existence of previous underwater escape training (UET) was seldom documented. There were 14 occupants (1%) who had received the training and at least 2 attributed it to their survival. There were also two pilots (4%) who attributed their survival to informational flight safety leaflets published by TC. There was only one (2%) report where swimming ability was noted; in this case, the pilot drowned because he was a nonswimmer. Diving experience was only reported in four (8%) accidents. In one of these accidents, two divers were passengers and escaped from a partially submerged and inverted seaplane.

Table II. Pilot Seaplane Experience and Associated Fatality Rates (*N* = 52, Full TSB Reports).

SEAPLANE FLIGHT EXPERIENCE (HOURS)	*N* (% OF TOTAL)	# OCCUPANTS (MEAN OCCUPANTS PER FLIGHT)	# FATALITIES (% OF OCCUPANTS)
<1000	25 (48%)	83 (3.3)	39 (47%)
<10,000	16 (31%)	87 (5.4)	28 (32%)
Unknown	11 (21%)	36 (3.3)	13 (36%)
Grand Total	52	206 (4.0)	80 (39%)

The existence of a preflight briefing was documented in 18 (35%) full reports. In 12 (67%) of these cases, a briefing occurred, but reports indicated it was either poor, not in the language of the passengers, or did not demonstrate how to unlock the door or how to escape. In some instances, passengers were distracted and not paying attention. In six (33%) cases a preflight briefing was not provided.

Posted instructions for how to operate emergency exits were deficient in some cases. The following instructions were on a label on the inside of the forward leaf of a two-door cargo hatch: "Emergency Exit Operation. 1) Rotate forward cargo door handle full forward then full aft. 2) Open forward cargo door as far as possible. 3) Rotate red lever in rear cargo door forward. 4) Force rear cargo door full open."

Factors at the Point of Impact

In the entire series, the most frequent cause of accidents was landing problems, either loss of control in 159 (33%) cases and other landing problems in 77 (16%) cases, which included 33 (43%) emergency and 27 (35%) wheels-down landings. Loss of control on takeoff and stalling on takeoff accounted for 126 (26%) accidents. With the exception of accidents for which the cause was unknown, loss of control while in flight (*N* = 8) accounted for the greatest fatality rate. **Table III** groups the accidents by cause and reports the associated fatalities.

Table III. Cause of Accident and Associated Fatality Rates.

CAUSE OF ACCIDENT	*N* (% OF TOTAL)	# OCCUPANTS (MEAN OCCUPANTS PER FLIGHT)	# FATALITIES (% OF OCCUPANTS)
Landing - Loss of Control	159 (33%)	317 (2.0)	28 (9%)
Landing - Amphibious Floats Wheels Down	27 (6%)	56 (2.1)	5 (9%)
Landing - Stall on Approach	10 (2%)	29 (2.9)	14 (48%)
Landing - Controlled Flight into Water	7 (1%)	21 (3.0)	4 (19%)
Takeoff - Loss of Control	100 (21%)	240 (2.4)	19 (8%)
Takeoff - Stall on Departure	26 (5%)	68 (2.6)	15 (22%)
In Flight - Emergency Landing	33 (7%)	113 (3.4)	3 (3%)
In Flight - Loss of Control	8 (2%)	22 (2.8)	18 (82%)
Taxiing - Hit Obstruction	38 (8%)	93 (2.4)	3 (3%)
Taxiing - Upset or Capsize	30 (6%)	50 (1.7)	0 (0%)
Mechanical	29 (6%)	78 (2.7)	4 (5%)
Other	5 (1%)	21 (4.2)	4 (19%)
Unknown	15 (3%)	35 (2.3)	31 (89%)
Grand Total	487	1144 (2.3)	148 (13%)

Table IV. Primary Environmental Condition(s) and Associated Fatality Rates.

ENVIRONMENTAL CONDITIONS	*N* (% OF TOTAL)	# OCCUPANTS (MEAN OCCUPANTS PER FLIGHT)	# FATALITIES (% OF OCCUPANTS)
Gusty wind	123 (25%)	283 (2.3)	25 (9%)
Glassy Water	38 (8%)	60 (1.6)	3 (5%)
Waves	19 (4%)	40 (2.1)	0 (0%)
Wind & Waves	11 (2%)	28 (2.5)	9 (32%)
Visual Obstruction	5 (1%)	20 (4.0)	4 (20%)
Unknown	291 (60%)	713 (2.5)	107 (15%)
Grand Total	487	1144 (2.3)	148 (13%)

Environmental conditions that contributed to the occurrences were unknown in 291 (60%) cases. Derived from the 196 (40%) cases where they were reported, gusty wind was found to have contributed to the majority of the accidents, with 123 (63%) cases. Where reported, the highest fatality rate (32%) was found to be associated with a combination of wind and waves. **Table IV** presents a breakdown of the contribution of environmental condition(s) to the accidents and the associated fatality rates. Estimated warning time was reported or assessed to be 15 s or less in 420 (86%) cases; this group had a fatality rate of 12% (114 of 949 occupants).

The use of restraint harnesses by pilots was unknown in 420 (86%) cases. Derived from the 67 cases where information was available, in 51 (76%) cases the harness system was correctly worn by the pilot, with an associated fatality rate of 14%. In the 15 (22%) cases where the harness system was incorrectly worn by the pilot, there was a 53% fatality rate. The same trend was observed for passengers, where the highest fatality rate was associated with incorrect wearing of the harness system. **Table V** presents pilot and passenger use of harnesses and the associated fatality rates.

Post-Impact Factors

After impact with the water, at least 20 seaplanes cartwheeled during the accident sequence before coming to rest. Once at rest, 153 (31%) floated on the surface, and 60 (12%) sank immediately, while 38 (8%) others sank after floating for some time. The final orientation of the fuselage in 254 (52%) cases was inverted. In only 48 (10%) of the accidents was the final position of the seaplane floating upright. **Table VI** presents the cross-tabulation of these final positions after impact and presents the associated fatality rates. With the exception of cases for which data was lacking, seaplanes that inverted and floated for some time, then sank, resulted in the highest fatality rate at 27% (10 fatalities out of 37 occupants). Inversion with the seaplane floating (*N* = 78) or followed by immediate sinking (*N* = 27) were only slightly less lethal, with a 21% fatality rate.

A common finding was that being hampered during escape was a combination of several problems: one difficulty precipitated a second and possibly a third. We have recorded the primary difficulty that was reported, which was an initial injury, followed by difficulty opening an exit, or being unable to navigate to a blocked exit. Pilot difficulty with egress during the postimpact phase was unknown in 420 (86%) cases. Derived from the 67 cases where information was available, in 21 (31%) cases the pilot had no difficulties with egress. Of the 14 (21%) cases where the pilot's injuries hampered their escape, there was an associated 79% fatality rate. For passengers, one of the highest fatality rates (86%) was associated with injuries sustained during impact and this was often associated with other factors, such as inability to undo the harness, or move to an exit, and blocked exits. **Table VII** presents pilot and passenger primary egress difficulty and the associated fatality rates.

Post-Escape Factors

Life jacket data was inconsistently recorded. Life jackets were worn in 52 (11%) cases. There were 6 accidents in which 14 survivors successfully swam ashore wearing them. In two accidents, during the swimming process, a victim slipped out of the jacket and drowned. In one accident, a victim decided to swim without a life jacket, became exhausted, and drowned. In the cold-water survival framework this type of fatality would be considered a swimming failure.[16] There were 13 accidents where 30 survivors successfully swam ashore, but no mention was made about life jackets. There was a case of two pilots wearing life jackets that snagged during otherwise successful escapes, and one case of a pilot who inflated his life jacket inside the cabin. There were 16 accidents where 57 survivors clung to some part of the fuselage/floats until rescue; it was not possible to determine whether they wore life jackets. In one of these, where four injured people clung to the floats, one of them died in the cold water. There were two other accidents where

Table V. Pilot and Passenger Use of Harnesses and Associated Fatality Rates.

	PILOTS		PASSENGERS (PAX)		
USE OF HARNESSES	*N* / # PILOTS	# FATALITIES (% OF PILOTS)	*N*	# PAX (MEAN PAX PER FLIGHT)	# FATALITIES (% OF PAX)
All Correctly Worn	51	7 (14%)	33	64 (1.9)	24 (38%)
All or Some Incorrectly Worn	15	8 (53%)	13	41 (3.2)	17 (41%)
None Worn	1	0 (0%)	1	1 (1.0)	0 (0%)
Unknown	420	45 (11%)	262	551 (2.1)	47 (9%)
Grand Total	487	60 (12%)	309	657 (1.3)	88 (13%)

Table VI. Frequency of Seaplane Final Position and Associated Fatality Rates.

# FINAL POSITION (% FATALITIES)	FLOATED	SANK IMMEDIATELY	FLOATED, THEN SANK	RESTED ON BOTTOM / SHOAL	UNKNOWN	GRAND TOTAL
Inverted	78 (21%)	27 (21%)	13 (27%)	12 (14%)	124 (7%)	254 (15%)
Upright	48 (0%)	5 (17%)	13 (2%)	7 (0%)	10 (13%)	83 (2%)
Nose Down	4 (0%)	4 (0%)	1 (0%)	3 (0%)	3 (20%)	15 (7%)
On Side	1 (0%)	0 (0%)	2 (0%)	1 (0%)	5 (0%)	9 (0%)
Unknown	22 (4%)	24 (29%)	9 (36%)	13 (21%)	58 (18%)	126 (20%)
Grand Total	153 (10%)	60 (23%)	38 (20%)	36 (11%)	200 (11%)	487 (13%)

a survivor was found floating by the side of the fuselage with no comment about life jackets or water temperature. The highest fatality rate (39%) was associated with cases where no life jackets were worn. **Table VIII** presents the use of life jackets and the associated fatality rate.

In the 229 cases where rescue details were reported, the majority of rescues (137 cases, 60%) were attributed to local boaters or residents. Other methods included self-rescue (49 cases, 21%), others (24 cases, 10%), and government Search and Rescue, which in Canada is a combination of the Department of National Defense and the Canadian Coast Guard (19 cases, 8%).

Much like the scant data above on flying experience, the cause of death was only reported for 72 (90%) of the 80 fatalities that are discussed in the full TSB reports—very little information about cause of death was reported for the other (*N* = 435) accidents. The majority of victims drowned while still trapped in the cabin. Of these, 31 were uninjured (7 pilots and 24 passengers); in 2 of these cases the investigator noted there was dark frigid water. The second highest cause of death was drowning associated with injuries in the cabin (6 pilots and 7 passengers); and the third was fatal injuries in the cabin (10 pilots and 15 passengers). **Table IX** presents the causes of death overall.

Rescue time for victims was not stated in 313 cases and in 32 cases they were not rescued. Where known, 97 survivors were rescued within 1 h; 35 were rescued within 24 h; 9 were rescued within 48 h; and 1 was rescued after 2 d in the bush following escape. There were two accidents in which rescuers arrived on the scene very quickly, but there was no way of opening the exits from outside the fuselage. As a result, the occupants died.

DISCUSSION

Davidson[8] identified the four fundamental problems with escape from a ditched fixed wing aircraft as noted in the introduction. He did not attach any specific details or statistics to these problems. The TSB reports[17,18] [Transport Canada. Seaplane safety—an overview. Unpublished report; 2019] confirm that these factors also apply to seaplanes and assign more detail and numbers to the problems, as do the several papers published in surviving a helicopter ditching cited in the Brooks summary.[2]

Davidson[8] provided no survival rates. The TSB reported on 103 fatal water accidents with a survival rate of 39%.[17] In our study, 31% of all water accidents resulted in fatalities and 87% of occupants survived. The difference likely being due to the fact that TSB chose only to examine fatal accident reports and not the entire series of water accidents where there were no fatalities. In all three sets of studies (Davidson, TSB, and Brooks) the majority of deaths occurred in the cabin due to drowning.[2,8,17]

Table VII. Pilot and Passenger Primary Egress Difficulty and Associated Fatality Rates.

	PILOTS		PASSENGERS (PAX)		
TYPE OF PRIMARY EGRESS DIFFICULTY	*N* / # PILOTS	# FATALITIES (% OF PILOTS)	*N*	# PAX (MEAN PAX PER FLIGHT)	# FATALITIES (% OF PAX)
No Difficulty	21	0 (0%)	11	34 (3.1)	0 (0%)
Injuries	14	11 (79%)	6	14 (2.3)	12 (86%)
Opening Exit	10	3 (30%)	6	17 (2.8)	7 (41%)
Exit Blocked	6	2 (33%)	1	8 (8.0)	0 (0%)
Undo Harness	3	0 (0%)	6	16 (2.7)	7 (44%)
Navigate to the Exit	1	0 (0%)	1	1 (1.0)	1 (100%)
Breath Hold	1	1 (100%)	1	6 (6.0)	2 (33%)
Locate Exit	1	0 (0%)	2	10 (5.0)	1 (10%)
Multiple Factors	1	0 (0%)	1	7 (7.0)	6 (86%)
Other (e.g., life jacket snag)	3	2 (50%)	4	9 (2.3)	1 (11%)
Inrushing water	6	0 (0%)	5	11 (2.2)	3 (27%)
Unknown	420	41 (10%)	265	524 (2.0)	48 (9%)
Grand Total	487	60 (12%)	309	657 (1.3)	88 (13%)

Table VIII. Use of Life Jackets and Associated Fatality Rates.

USE OF LIFE JACKETS	*N* (% OF TOTAL)	# OCCUPANTS (MEAN OCCUPANTS PER FLIGHT)	# FATALITIES (% OF OCCUPANTS)
All Worn	52 (11%)	117 (2.3)	3 (3%)
None Worn	37 (8%)	131 (3.5)	51 (39%)
Some Worn, Some Not Worn	3 (1%)	21 (7.0)	0 (0%)
Unknown	395 (81%)	875 (2.2)	94 (11%)
Grand Total	487	1144 (2.3)	148 (13%)

The overall causes of death were linked to a combination of one or more factors such as no preflight briefings, lack of use of shoulder restraint harnesses, in-rushing cold water, disorientation, tortuous escape routes, blocked exits, complicated exit mechanisms, access to life jackets, and the deadliest of all, rapid inversion and sinking of the fuselage. The TSB reports[17] noted that 'sometimes the aircraft flipped' and Brooks noted that in the helicopter ditching data that 30–100% of helicopters inverted.[2] In 254 (52%) cases of our study, the final orientation of the fuselage was inverted. In 60 (12%) cases the aircraft sank immediately. In only 48 (10%) accidents, the final position of the seaplane was floating upright. Except for cases which were unknown, seaplanes that floated inverted for some time, then sank, resulted in the highest fatality rate at 27%. Inversion with the aircraft floating ($N = 78$) or followed by immediate sinking ($N = 27$) were only slightly less lethal, with a 21% fatality rate. We noted rescuers could not activate emergency exits from outside the fuselage.

Lack of warning is common in helicopter ditchings.[4] Previously unreported in seaplane accidents, we estimated that in 87% of cases there were less than 15 s warning for the crew and passengers to take a deep breath or make other preparations to prepare for escape. Of the fatalities, 77% occurred in this group. This lack of warning time is the first compelling reason a thorough preflight briefing should be made mandatory. Enhancement of the briefings has been under consideration since recommended in 1988 by the Canadian Aviation Safety Board, the predecessor to the TSB, but this has never been actioned.[17] Survival begins before the point of impact. To understand why this is so important, it is helpful to understand the way the brain functions when facing extreme danger.

Leach explains that the prefrontal cortex is associated with the Supervisory Attentional System in the basal ganglia. This is designed to cope with technically difficult and dangerous situations.[11] It can easily be disabled and overwhelmed under threat and is inadequate in a typical seaplane accident with less than 15 s warning.[12,15]

The surge of stress hormones and neurotransmitters in an emergency reduce functioning in the prefrontal cerebral cortex. This part of the brain is very resource intensive, very slow in functioning, and concerned with processing future matters such as planning, thinking, and higher order decision making. When facing danger, the present moment becomes paramount, so the prefrontal cortex becomes an expensive luxury and is effectively taken offline. Instead, the hormones and neurotransmitters boost the function of the basal ganglion and subcortical structures which handle moment by moment interaction with the environment.

In the precious seconds before impact with 15 s or less of warning, higher order mental processing cannot take place, all the person can do is respond. An effective preflight briefing prepares the passenger for this emergency as the response is already packaged as a mental schema but must be absorbed and retained to be useful.[10]

In order to make human information processing more efficient, the brain has developed a system of using schemas. These are cognitive frameworks or concepts that help organize and interpret information. Schemas are very useful because they allow us to take short-cuts in interpreting vast amounts of information. The concept of schemas can also help us to understand why one specific type of seaplane accident—wheels-down landing in water—is so hazardous. The landplane pilot's schema is to lower the gear for landing and is well established from repetitive practice in every landplane pilot. Almost every seaplane pilot has previously been trained as a landplane pilot. This can have fatal consequences when an amphibious seaplane flown by a pilot who commonly flies landplanes or has taken off from land on the accident flight is landed wheels-down on water. There were 27 (6%) wheels-down landings which occurred, exposing the occupants to several of the risk factors identified in this report.

Table IX. Pilot and Passenger Causes of Death ($N = 52$, Full TSB Reports).

CAUSE OF DEATH	# FATALITIES (% OF TOTAL) ALL OCCUPANTS	PILOTS	PASSENGERS
In-Cabin, Drowning*	31 (38%)	7 (25%)	24 (44%)
In-Cabin, Drowning w/Multiple Injury	13 (16%)	6 (21%)	7 (13%)
In-Cabin, Multiple and/or Fatal Injury	25 (30%)	10 (36%)	15 (28%)
Out-of-Cabin, Post-Escape Drowning	3 (4%)	2 (7%)	1 (2%)
Unknown	8 (10%)	2 (7%)	6 (11%)
Grand Total	80	27	53

*It should be noted that in one case (A04P0041) the pilot had a history of cardiac problems, which were likely to have rendered him incapacitated, leading to the accident.

The principle of creating survival schemas as part of the survival strategy for passengers (and indeed for pilots) must take place immediately when they step into the seaplane, noting the general layout of the cabin. Once strapped in, they must receive a thorough briefing. Thorough preflight briefings were rarely reported in this series of accidents.

The majority of accidents and deaths occurred during two critical phases of flight: landing (49%) and takeoff (26%); this is a reversal from the original TSB data (41% takeoff and 37% landing). No reason could be found for this. In the cases of loss of control, stalling, and the 27 wheels-down water landings, the accidents were caused by some form of skill-based/perceptual or decision dilemma experienced by the pilot.

Seaplane operations present unique challenges and risks. Consider taxiing for takeoff, a phase of operations that might be considered safe and routine on land. Faure,[9] who wrote one of the most respected books about flying on floats stated: *"Remember you are driving a machine that has no brakes, no reverse gear, and somewhat vague steering. As soon as you untie, it's at the mercy of the wind."* Piloting a seaplane requires very special skills, knowledge, and a lot of practice.

The operating environment bears heavily on seaplane safety. The previous TSB studies and this study show that it is a riskier task to take off and/or land in windy conditions (123 accidents), on glassy water (38 accidents) or in wind and waves (30 accidents), and in the wake of another vessel. Moreover, a tiny error of judgement or distraction by the pilot that would have minimal safety risk when landing on a solid airfield can result in a fatal accident in a seaplane. Two pilots attributed their survival to UET; two others found the TSB and aviation safety literature useful.

Many of the seaplanes involved were designed over 60 yr ago and are mostly commercial or recreational aircraft converted to floats (e.g., the Piper PA 11 has not been produced since 1949; the DHC-2 and -3 since 1967, and the Cessna 180 since 1981). No thought was given in the original designs to underwater escape because the aircraft were primarily land based and the emergency exits were not designed for that. Actuating a door-opening mechanism can become an almost impossible task when faced with all the life-threatening factors described above. The mechanism of some doors is not so simple, with more than one handle or lever to actuate and there is minimal standardization of exit design. This is a common theme that runs through the TSB data and was first noted by Davidson.[8] We cannot see that there has been any improvement or amelioration of this situation in seaplanes. The regulatory requirements and guidance information for certifying small fixed-wing aircraft did not and still do not contain any requirements specific to underwater egress.

There is no robust solution to maritime-unfriendly designs in the short term. This is a second compelling reason for a thorough, mandatory preflight briefing. In the longer term, TC should insist on improved escape paths and universally simple exits in newly certified seaplanes. These must be operable both from within and outside the fuselage.

TSB referenced a previous Canadian Aviation Safety Board study conducted in 1988.[17] Here, eight occupants had drowned while attempting to swim to shore. It also noted that data on how many life jackets were worn, how many were stowed, who drowned as a result of either wearing or not wearing one was inconsistently reported and mostly missing. These were precisely our findings too. With so little warning time and limited breath holding, unless the pilot and passengers are wearing life jackets at the time of impact, it is not the time to search for a lifejacket or attempt to don one. Two victims drowned following a successful escape after falling out of their life jackets, while a third became exhausted and died from swimming failure after making a conscious decision to swim ashore without one. We can only postulate that they would have been of benefit to the 57 survivors who clung to the floats until rescue, one of whom died likely due to hypothermia.[16] Under consideration since 1994, TC should mandate the wearing of life jackets at all times for crew and passengers no matter the size of the seaplane.

Two other factors that contributed to death or near death were the incorrect use (or nonuse) of the restraint harness and the dangers of sudden unexpected immersion, unprotected, in cold water. Regarding harnesses, the TSB report[17] noted that reporting on the use or nonuse of the shoulder harnesses was inconsistent or missing, but where available showed that the fatality rate was 17% for those not wearing the harness compared to 10% where it was worn. Our study finds the same inconsistencies. The fatality rate was 27% when all occupants were correctly wearing the available harnesses, while it was 43% when this was not the case. Regulatory changes to specifically require wearing of shoulder harnesses for takeoff and landing have been under consideration since 1995, but to date have not been acted upon. Regarding cold water survival factors, there were 15 occurrences where the aircraft (and in most cases the occupants) were never located; we have little detail for these occurrences, but it is quite plausible that cold shock, swimming failure, or hypothermia could have caused or contributed to the deaths of the 35 crew and passengers who were the victims of these accidents. Space does not allow us to go into depth on these factors, but in UET, pilots should be reminded that lakes and rivers in Canada do not warm up until the late summer. Immersion in water below 15°C runs the risk of cold shock, swimming failure, hypothermia, and post-rescue collapse.[16] Hence, pilots should dress accordingly.

There is one weakness in our study: the TSB only issued 52 full reports on the accidents. The remainder were described in as little as five lines of narrative in some cases. There was no consistency to the questions that were asked or data recorded in any of the 487 accidents. Nevertheless, with such information, it was possible to identify the key factors that contributed to loss of life in Canadian seaplane water accidents.

Conclusions and Recommendations

The current overall survival rate for Canadian seaplane accidents for the last 25 yr in water is 87%. The human factors that appear to be influential in the survival of seaplane crew and passengers are discussed above. While not identical, these factors are in general agreement with those identified by Davidson, the TSB, and in the ditched helicopters reports.[2,8,17] As with that earlier research, it was apparent that many of the fatalities in the current study were preventable. As the regulatory authority with jurisdiction, we recommend that Transport Canada should immediately consider requiring enhanced preflight briefing for all passengers.

As soon as practically possible, crew and passengers must be compelled to wear life jackets on all seaplane flights, not just on smaller commercial flights. Commercial pilots should be trained and equipped with EBS.

All pilots should be required to wear the shoulder harnesses if they are available and encouraged to retrofit with highly functional harnesses to replace those that inhibit pilot function. Accident investigators should be provided with a standard check list to follow for all seaplane accidents in water.[2]

For future considerations, all private seaplane pilots on renewal or issue of their first license should be required to undergo training in underwater escape and use of the EBS. National and international aviation authorities should look at standardization of the exit jettison mechanisms and primary and secondary escape routes so that they can be externally jettisoned/opened externally.

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