Amphibious Airplane Accidents: An Exploratory Analysis

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Abstract: Causes and contributing factors of amphibious airplane accidents are examined by comparing the proportion of fatal accidents for different causes of accidents, with a focus on landings on water and low-level flying maneuvers. A set of 183 accidents involving amphibious planes from 2005 to 2020 was extracted from the National Transportation Safety Board’s online database. Amphibious airplane accidents are reported to be fatal in 34% of cases, which is higher than the average of 20% for general aviation. Logistic regression analysis shows that the maneuvering flight phase and decision-making factors are significantly more often associated with fatal accidents than other flight phases and causes. In addition, the number of accidents associated with decision-making factors significantly increased during the studied time period. Amphibious airplanes benefit from accident analysis despite the absence of denominator data and the limitations of most general aviation accident reports. Intentional low-level flying is shown to be a central area of concern that may be addressed at the operational as well as the training level. Landing accidents could be avoided by introducing additional warning systems and training regarding (retractable) landing gear as well as general awareness training of decision-making during landings on water.

Keywords: amphibian; accident analysis; aviation safety; maneuvering; decision making

1. Introduction

General aviation (GA) accidents account for 94% of all aviation fatalities in the United States [1], and approximately 20% of all GA accident prove fatal. Although weather and light conditions have been shown to constitute some of the main causes of fatality, understanding and mitigating fatal accidents is complicated by the diversity within this part of civilian aviation, which includes all operations apart from paid passenger transport [2].

Each type of aircraft, including balloons, gliders, and ultralights, is associated with different causes of accident and subsequent safety recommendations [3]. However, even within the larger categories of helicopters and fixed-wing airplanes, different operations and types of aircraft require different courses of action. For instance, sling-load, agricultural, instructional, and emergency medical service operations with helicopters each receive different safety recommendations [4,5], while twin- and single-engine helicopters also show different safety profiles [6]. The importance of distinguishing aircraft types and operations is equally salient for fixed-wing airplanes, which include agricultural operations [7] and instruction [8], in addition to aerobatics [9] and amateur-built aircraft [10]. Unlike in the case of helicopters, the number of engines often has a negative effect on fatal outcomes [11]. The subsequent fine-grained analyses have assisted in untangling variation in GA and have helped to prioritize future research. For instance, the low 2% proportion of fatal accidents in balloon operations in the United Kingdom [12] is in stark contrast with the 80% proportion of fatal accidents in flights with aerobatic maneuvers in the United States [9]. In
this context, the study of seaplanes has been noticeably absent for GA and for air taxi and commuter operations.

A recent study by the Aircraft Owners and Pilots Association highlighted the absence of seaplane activity data since 2015 from the Federal Aviation administration “due to unreliable reporting and analysis” [13]. Aircraft may switch out floats for other landing gear, depending on the season, which obfuscates accurate activity as well as accident analysis reporting. The study provides recommendations but it is limited by inconsistent data and an absence of analytical statistics.

In order to address the need for understanding this category of aircraft, the present study focused on amphibious planes, a subset of seaplanes. These aircraft do not present the same challenges for conducting accident analysis. Although denominator data, such as the total number of landings or flight movements per year, remain unavailable, the National Transportation Safety Board consistently records airplanes as being amphibious since, unlike other seaplanes, this type of aircraft can always land on either water or land without switching out their landing gear [13]. Subsequent analysis still needs to account for variation in the number of engines, the presence of home- or amateur-built aircraft, and instructional operations.

Out of 183 amphibious aircraft accidents selected from the National Transportation Safety Board’s (NTSB’s) online database for the period 2005–2020, 34% appeared fatal, confirming that this category of aircraft may benefit from further analysis in the interest of GA as well as operational safety. This is due to the fact that unfavorable weather and light conditions, the main causes for fatality in GA, are less often present in this dataset.

The nature of amphibious airplane operations is affected by the possibility of landing on water, which can be performed in a few ways. Water runways are typically unlit, which limits operations that intend to include water landings in daylight operations. In times of emergency, an amphibious airplane operator has the option of landing on water as with any other aircraft pilot but with the knowledge that both plane and occupants have a higher chance of remaining unharmed. When studying accidents with amphibious aircraft, it is useful, therefore, to determine whether the aircraft landed on water or not. Some aircraft end up in the water after they miss a runway but these events do not constitute a water landing. The category of accidents with water landings allows for a better understanding of accidents that may be typical for this type of aircraft.

Amphibious aircraft have fixed floats and either fixed wheels or retractable landing gear for use on land. Floats affect the aerodynamics of an airplane by causing additional drag, thereby limiting its maximum speed, and causing the aircraft to be more susceptible to an aerodynamic stall. Mistakes with the angle of attack, especially at low speeds, were identified by the AOPA report as a major concern for seaplanes [12].

The relative expense of amphibious aircraft, i.e., lower performance due to increased drag, and the skills necessary to land and take-off from water have made these aircraft less common than other fixed-wing aircraft for sightseeing, photography, and even instruction unless no cheaper alternative is available, or the environment requires otherwise. Amphibious aircraft are used especially in environments where landings and take-offs on land are limited compared to those on water. For this reason, both seaplanes and amphibious planes are most commonly found in environmentally challenging places, for instance those found in Alaska; Alaska is known for its challenging environmental conditions and higher accident rate [14]. The environmental conditions in which amphibious aircraft operate generally may affect their safety [12].

This study highlights the particulars of accidents that are specific to amphibious planes, a category of aircraft that has not been subjected to systematic accident analysis, even though its proportion of fatal accidents is higher than found in general aviation. We include analyses on cases where issues with the angle of attack, environmental conditions, or landings on water are mentioned by NTSB investigators. In addition, the analysis accounts for variation in aircraft design, such as the number of engines and those found
in home-built aircraft, following concerns in the existing literature on accident analysis in general aviation.

2. Materials and Methods
An aviation accident is defined by the NTSB as an occasion in which an aircraft was substantially damaged or destroyed and/or an occurrence in which its occupants or people on the ground were seriously or fatally injured. If only minor injuries and damage are reported, these events are defined as incidents and administrated by the Federal Aviation Administration (FAA).

All NTSB accident reports are made available online and may be searched using the CAROL (Case Analysis and Reporting OnLine) query tool. Each accident has a report that summarizes the findings of the NTSB investigator and determines the cause(s) and contributing factors of the accident. Each report includes a narrative statement, as well as data on the pilot, aircraft, airfield, and meteorological conditions. One of these causes is identified by the NTSB investigator as the defining event, and this information is also included in the analysis.

United States general aviation amphibious airplane accidents were extracted from the NTSB online database for the period from 2005 until the end of 2020. We excluded the years 2021 and 2022 to avoid the presence of incomplete accident reports in the dataset. Accidents were identified using the search term “amphibious” or “amphibian” and each case was assessed to determine if the report concerned an amphibious aircraft or merely mentioned amphibious planes in the narrative. Accidents were removed when they related to aircraft classified by the NTSB as ultralight or weight-shift aircraft, as well as one case that took place in Majuro, Marshall Islands, rather than in the United States.

The narrative text of each accident was used to determine whether the aircraft ended up in the water. Issues with the angle of attack, a low flying level or low flying speed, decision-making errors, and other elements of the flight were only included in the analysis if the NTSB investigator identified these factors as contributing to the accident. The year of the accident was dichotomized as “2010 or before” vs. “after 2010” for the statistical analysis.

The Federal Aviation Administration provides denominator data of different kinds, including those for different types of aircraft, but the movement and the number of seaplanes and amphibious planes in the United States is not recorded. Instead, we use the proportion of fatal accidents as an indication of safety, which is an approach that is often necessary in general aviation accident analyses [15,16].

In order to study the relationship between pairs of variables in the data, we run Fisher’s exact test of independence (using R, with a setting such that the p-value is calculated using Monte Carlo simulation if either variable contains more than two values). In comparison, we note that a χ²-test yields similar results, except for cases in which the χ²-test offers a poor approximation due to low expected cell counts. In addition, if two dichotomous variables are significantly correlated, we report the Pearson correlation coefficient as a measure of the size of the effect of the correlation.

Finally, we fit a logistic regression model with ‘fatal’ versus ‘non-fatal’ as the outcome variable and predictors identified using the individual test for independence.

3. Results
In the period from 2005 to the end of 2020, 183 accidents were reported that involved amphibious aircraft, of which 63 (34%) resulted in a fatality. The highest number of accidents was found in the state of Florida (n = 37), of which 11 were fatal, followed by Alaska (n = 34), of which 10 were fatal. The proportion of fatal accidents was not significantly different per state (p > 0.05).

A majority of the aircraft sustained substantial damage (n = 161, 88.0%), while the remainder was either destroyed (n = 20, 10.9%) or had only minor damage (n = 2, 1.1%). Destroyed aircraft were significantly more often associated with fatal accidents (p < 0.0001)
3.1. Operations

Only six accidents occurred during instructional flights and four during positional flights; most others occurred during personal flights flying under Part 91 flight rules. Fifteen flights were operated under Part 135 flight rules, providing non-scheduled air taxi or commuter services, of which six (40%) were fatal; one flight operated under Part 137 flight rules as an agricultural flight, which was not fatal. The number of fatal Part 135 flights was not significantly different from that of other types of operation ($p > 0.05$).

3.2. Aircraft

A total of 63 aircraft in our dataset were amateur-built, of which 22 (34.9%) were involved in a fatal accident, a similar proportion to that in the overall dataset. Five out of thirteen crashes (38.5%) involving twin-engine aircraft were fatal; however, this was not significantly different from accidents involving single-engine aircraft (34.1%, $p > 0.05$).

3.3. Pilot

Pilot age averaged at 58.8 years, with an average flight experience of 5956 h. Flight experience ranged from 0 h to 34,000 h, with seven unreported instances. With 37 pilots clocking more than 10,000 h of flight experience and only 10 pilots with less than 200 h of flight experience, most pilots in this dataset were experienced. Flight hours in the make and model of the amphibious airplane ranged from 0 h to 9050 h but was not reported in 40 cases, of which 32 were fatal; this partly explains the lack of flight-hour information. Pilots had less than 200 h flight experience in 82 cases, of which 17 accidents were fatal (20.7%). No significant relationship was found between the hours of flight experience and the number of fatal accidents ($p > 0.05$).

3.4. Phase of Flight

Overall, the phase of flight was significantly correlated with fatality ($p < 0.0005$). Specifically, out of 14 accidents that occurred during the maneuvering phase, 12 were fatal, which was a significantly higher proportion of fatal accidents than was found for other flight phases (85.7% vs. 30.2%, $p < 0.0001$). The NTSB defines maneuvering as either aerobatics or “intentional low-altitude flight not connected with a landing or take-off”. In addition, in the enroute or cruise phase, 12 out of 20 accidents were fatal, which, again, was a significantly higher proportion ($p = 0.0223$).

3.5. Environment

Nearly all accidents occurred under visual meteorological conditions (VMC) ($n = 175, 95.6\%$) with only eight accidents operating in instrument conditions (IMC), where six of which were fatal. The proportion of fatal accidents was significantly higher for flights operating in IMC than for flights operating in VMC (75.0% vs. 32/6%, $p = 0.0208$). Only two flights at night and one at dusk were reported, with both night flights being fatal.

3.6. Causes and Contributing Factors

The factor of “decision making” is combined with “disorientation” in the NTSB’s categories of causes. No disorientation-related accidents were identified in our dataset; however, in 13 cases the pilot either forgot to follow procedure during a task or took an incorrect action. In all other instances, the decision referred to the decision to depart, land, or continue a flight with problems known to the pilot in command. This category of cause is referred to as “decision making” in the remainder of this study and only refers to this cause when identified by an NTSB investigator as a contributing factor to the accident. In the set of 35 decision-making-related accidents, 18 were fatal (51.4%), which was a significantly higher proportion than in the set of accidents that were not related to decision-making (30.4%, $p = 0.0285$). Among water landing accidents, 26% of accidents had decision-making issues, which was significantly more frequent than among non-water landing accidents (11.2%, $p = 0.0218$).
In 26 cases, the defining event was an incorrect configuration of the landing gear, and 24 accidents happened while trying to land on water. This defining event was also more often associated with decision making \((p = 0.0134)\) and non-amateur-built aircraft \((p = 0.0362)\). In this case, decision-making exclusively referred to those causes where a pilot forgot something or made an incorrect action.

In ten cases, the angle of attack was identified by the NTSB investigator as a contributing factor to the accident. Seven of these accidents were fatal (70%), which is a significantly higher proportion than seen in all the other accidents combined \((p = 0.0334)\).

An overview of the significant results in this study, which are sorted by the \(p\)-value of the Fisher’s exact test, are presented in Table 1. For comparison, we also report the \(\chi^2\)-test’s \(p\)-value and the Pearson correlation coefficient between the two variables.

**3.7. Logistic Regression**

We fitted a logistic regression model, with ‘fatal’ versus ‘non-fatal’ as the outcome variable and variables identified by the individual test for independence as predictors, using a total of \(n = 179\) data points (four accidents were omitted due to the presence of missing values). The model was fitted using R version 4.2.2 and the standard glm function from the base stats package. Results of the main effect model are reported in Table 2. In total, seven dichotomous predictors were used, such as “Destroyed aircraft”, which refers to whether the aircraft was destroyed during the accident, and “VMC”, which refers to whether the accident occurred under visual meteorological conditions. We determined that (at a 0.05 significance level) damage to the aircraft, decision-making-related issues, and the maneuvering flight phase were significantly more often associated with fatality while controlling for the other factors in the model. Specifically, when an aircraft was destroyed, we estimated that the probability of fatality increased by nearly 15-fold. With a few exceptions, destroyed aircraft were always significantly more often found in accidents with fatalities. The presence of decision-making issues increased the estimated probability of fatality by a factor of three, and being in the maneuvering phase of the flight increased the estimated probability of fatality by a factor of 15. In addition to the main effect model, we also fitted logistic regression models with pairwise interaction effects. No significant interactions were found.
Table 2. Coefficient estimates of logistic regression model with main effects. Probability ratio and its 95% confidence interval are also reported.

<table>
<thead>
<tr>
<th>Term</th>
<th>Estimate</th>
<th>Std Error</th>
<th>p-Value</th>
<th>Odds Ratio</th>
<th>CI 95 Lower</th>
<th>CI 95 Upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>−0.455</td>
<td>1.083</td>
<td>0.674</td>
<td>0.635</td>
<td>0.068</td>
<td>5.930</td>
</tr>
<tr>
<td>Destroyed aircraft</td>
<td>2.703</td>
<td>0.836</td>
<td>0.001</td>
<td>14.922</td>
<td>3.419</td>
<td>105.818</td>
</tr>
<tr>
<td>VMC</td>
<td>−0.644</td>
<td>1.086</td>
<td>0.553</td>
<td>0.525</td>
<td>0.055</td>
<td>4.740</td>
</tr>
<tr>
<td>Landing on water</td>
<td>−0.778</td>
<td>0.410</td>
<td>0.058</td>
<td>0.459</td>
<td>0.202</td>
<td>1.018</td>
</tr>
<tr>
<td>Decision-making</td>
<td>1.099</td>
<td>0.486</td>
<td>0.024</td>
<td>3.002</td>
<td>1.152</td>
<td>7.871</td>
</tr>
<tr>
<td>Maneuvering flight phase</td>
<td>2.711</td>
<td>0.825</td>
<td>0.001</td>
<td>15.040</td>
<td>3.527</td>
<td>104.746</td>
</tr>
<tr>
<td>Enroute flight phase</td>
<td>0.519</td>
<td>0.697</td>
<td>0.456</td>
<td>1.680</td>
<td>0.395</td>
<td>6.399</td>
</tr>
<tr>
<td>Angle of attack</td>
<td>1.288</td>
<td>0.769</td>
<td>0.094</td>
<td>3.626</td>
<td>0.834</td>
<td>18.872</td>
</tr>
</tbody>
</table>

The significant results relating to fatal and non-fatal outcomes are presented in Figure 1.

3.8. Trends over the Years

With a Fisher’s exact test for independence, we found that the decision-making variable was significantly correlated with the time period variable (before and including 2010 vs. after 2010) \( p = 0.0030 \), which suggests a significant change over the years in the percentage of accidents where decision making was identified as a factor. We further found that the year variable (without dichotomizing) was significantly correlated with decision making \( p \)-values for both Fisher’s exact test using Monte Carlo simulation and \( \chi^2 \)-test were less than 0.0005. As displayed in Table 3 and Figure 2, the percentage of decision-making-related accidents showed a general increasing trend, with especially high percentages in 2017 and 2019. Further analysis showed that, in the first half of this time period, decision making was not found to be a contributing factor in non-fatal accidents, while in the second half the main part of the accidents where decision-making was identified as a factor consisted of non-fatal accidents.
Table 3. Number of total accidents and number and percentage of decision-making-related accidents by year.

<table>
<thead>
<tr>
<th>Year</th>
<th>Total</th>
<th>Decision-Making-Related</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>7</td>
<td>1</td>
<td>14.3%</td>
</tr>
<tr>
<td>2006</td>
<td>8</td>
<td>0</td>
<td>0.0%</td>
</tr>
<tr>
<td>2007</td>
<td>13</td>
<td>0</td>
<td>0.0%</td>
</tr>
<tr>
<td>2008</td>
<td>15</td>
<td>3</td>
<td>20%</td>
</tr>
<tr>
<td>2009</td>
<td>12</td>
<td>1</td>
<td>8.3%</td>
</tr>
<tr>
<td>2010</td>
<td>11</td>
<td>0</td>
<td>0.0%</td>
</tr>
<tr>
<td>2011</td>
<td>10</td>
<td>1</td>
<td>10%</td>
</tr>
<tr>
<td>2012</td>
<td>12</td>
<td>2</td>
<td>16.7%</td>
</tr>
<tr>
<td>2013</td>
<td>12</td>
<td>0</td>
<td>0.0%</td>
</tr>
<tr>
<td>2014</td>
<td>15</td>
<td>2</td>
<td>13.3%</td>
</tr>
<tr>
<td>2015</td>
<td>14</td>
<td>2</td>
<td>14.3%</td>
</tr>
<tr>
<td>2016</td>
<td>11</td>
<td>3</td>
<td>27.3%</td>
</tr>
<tr>
<td>2017</td>
<td>13</td>
<td>8</td>
<td>61.5%</td>
</tr>
<tr>
<td>2018</td>
<td>9</td>
<td>2</td>
<td>22.2%</td>
</tr>
<tr>
<td>2019</td>
<td>10</td>
<td>6</td>
<td>60%</td>
</tr>
<tr>
<td>2020</td>
<td>11</td>
<td>4</td>
<td>36.4%</td>
</tr>
</tbody>
</table>

Figure 2. Percentage of decision-making-related accidents by year. Among these accidents, the percentage of fatal vs. non-fatal accidents is also shown.

4. Discussion

The accidental analysis of amphibious planes in part follows the concerns of general aviation flights more broadly. Light and weather conditions proved disproportionately fatal, but, unlike in GA, only a small percentage of those conditions were present in the
dataset and in the logistic regression with other factors. The effect of weather conditions was no longer significant. However, fatal accidents appeared to be more common with amphibious planes, with 34% occurrence versus an average 20% in GA, which highlights the need for a better understanding of their underlying causes and contributing factors.

Several causes and contributing factors identified by the NTSB investigators were disproportionately present among fatal accidents and confirmed the results for seaplanes reported by the AOPA. Problems with the angle of attack that could lead to a stall were more often fatal but not significantly so. Instead, low-level flying or flying in the maneuvering phase, along with decision making, appeared significant factors. The latter also occurred more often when landings occurred on water, suggesting that the high incidence of fatal accidents could be partially attributed to a core element of flying amphibious planes, i.e., decision making during landing on water and general low-level flying.

It is noted that low-level flying was only noted for the maneuvering phase, a phase in which the aircraft is not engaged in a take-off or landing [17]. In other words, an aircraft in the maneuvering phase is flying at low levels for other reasons than take-off or landing, for instance, sightseeing or photography. Since this flight phase was significantly more often associated with fatal accidents, the decision to undertake low-level flights in amphibious aircraft should receive more scrutiny from aircraft operators.

The AOPA report suggested additional training as one of the main mitigating strategies going forward. It is noted from this dataset that experience was not necessarily the problem, but that specific training for the types of issues most commonly reported in accidents should be most helpful. The risks of the maneuvering flight phase and decisions involved with water landings, especially the configuration of the landing gear, should be part of additional safety training.

One finding in our study did not support the AOPA results. Only 12 cases of abnormal runway contact were reported in our study, which were also not fatal as often; unlike the AOPA findings, this number did not appear to be of immediate concern.

The diverse types of aircraft, including single- and twin-engine aircraft as well as amateur or home-built machines, did not affect the proportion of fatal accidents, even though the overall proportion of amateur-built aircraft was high. Previous studies found that only 3% of GA flight hours pertained to home-built aircraft, while they made up 34.4% of this dataset. Their proportion of fatal accidents, however, was similar to that of other amphibious planes. This proportion, however, was higher than found in previous studies on home-built aircraft, where 26% proved fatal instead of 36.5% in our dataset. Landing gear configuration problems were disproportionally associated with amateur or home-built aircraft and should be highlighted in training manuals.

Finally, there was a surprising uptick in accidents, specifically in the years 2017 and 2019, that concerned problems of decision making. This factor was also found to be significantly associated with landing gear configuration and with landings on water, as well as fatality. Decision making was not found to be a contributing factor in non-fatal accidents for the first half of the studied period, and future research could determine whether this was specific for amphibious planes or was associated with a change in investigation practices via the NTSB more generally. Nevertheless, safety training and general awareness within the amphibious airplane community of the importance of decision-making skills in flying amphibious aircraft is not only important but increasingly urgent. Further research on current safety training protocols may assist in creating interventions that mitigate this factor.

5. Limitations

The NTSB accident reports give summaries of events but, particularly in the case of general aviation, rarely comment on the organization or the company operating the aircraft. In addition, the pilots are not interviewed regarding their knowledge or opinions related to safety, meaning that an overall understanding of safety climate and safety culture is generally unattainable. Therefore, accident analysis is limited to exploring the most common causes of accidents and how they compare to other types of aircraft.
or operations, and it is mostly silent on psychological and organizational factors unless explicitly mentioned by the NTSB investigators. In our study, decision-making was found to be an important cause of accidents, but the data did not explain to what extent safety culture in the organization was contributing to this problem.

The FAA commonly provides denominator data such as the number of flight movements, total number of aircraft in operation, or total number of hours flown. Unfortunately, in the case of amphibious aircraft, seaplanes in general, and in several other categories of general aviation, such information is not or is no longer available. Some have argued that this makes accident analysis of little use since risk assessments are largely impossible [15]. In lieu of abandoning accident analyses for an area of aviation where a disproportionate number of accidents are taking place, the proportion of fatal accidents has been used as a point of comparison and an indication of risk [16]. This remains merely an indicator, while risk calculations remain available for only some parts of general aviation.

In a recent study by AOPA, there was an added complication of identifying seaplanes in accidents, which affected all data collection. By concentrating on amphibious planes, this study endeavored to overcome this limitation but needed to limit its findings to a sub-category of seaplanes, i.e., amphibious aircraft.

Future studies investigating seaplanes and amphibious planes through interviews, site visits, and other comparisons could find the above study to be a useful point of departure, rather than a definitive study on amphibious aircraft safety.

6. Conclusions

Amphibious aircraft are involved in a high proportion of fatal accidents compared to general aviation as a whole. Fatalities are more often associated with maneuvering, low-level flying, and decision-making factors that refer to decisions regarding the start or continuation of a flight, as well as to forgetting necessary inputs in relation to the landing gear in particular. The number of cases in which the NTSB has identified “decision making” as a contributing factor to an accident has significantly increased over the last few years and further research could determine whether this is specific to amphibious aircraft operations. Training curricula should highlight the dangers of the maneuvering flight phase and the importance of decision-making for aircraft with the unique capabilities of an amphibious plane. Since most accidents concerned experienced pilots, such training may occur during flight reviews or proficiency checks. In addition, manufacturers and organizations such as AOPA could play an active role in communicating the main concerns.

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