# Fixed-Wing Motorized Aircraft Accidents: Analysis of Injury Severity and Concomitant Factors (2000–2019)

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**BACKGROUND:** There is a paucity of research on general aviation accidents in Germany. The authorities investigate only a fraction of all national accidents. The current study analyzes existing accident reports and aims to identify injury severity in regard to concomitant risk factors.

**METHODS:** Data of flight accidents was analyzed for aircraft of <5700 kg maximum takeoff weight (MTOW) over a 20-yr period. Besides descriptive data, concomitant factors (type and category of aircraft, date, occupants and outcome, flight phase, etc.) were analyzed. Statistical analysis was performed using the Chi-squared test.

**RESULTS:** The authorities list 1595 aircraft accidents between 2000 and 2019, but only 17.9% of these were analyzed in detail. Accidents of aircraft of <2000 kg MTOW were over-represented between May and September and between Friday and Sunday. The fraction of fatal accidents was highest during cruise. During landing, significantly more mishaps of larger aircraft occurred. The number of seriously injured or deceased occupants was significantly higher for accidents involving private pilots. An occupancy rate of more than three persons on board correlated significantly with fewer number of deaths.

**CONCLUSIONS:** The annual count of aircraft accidents has almost halved during the previous 20 yr. Unfortunately, only a small number of mishaps were further investigated by authorities, which leads to a lack of evaluable data needed for in-depth investigations. The accumulation of larger aircraft mishaps in winter and the superior outcome of professional pilots in terms of safety, as well as the fewer number of mishaps in larger aircraft, should be further investigated.

**KEYWORDS:** flight accidents, general aviation, pilot license.

**Liebold F, Hippler C, Schmitz J, Yücetepe S, Rothschild M, Hinkelbein J. *Fixed-wing motorized aircraft accidents: analysis of injury severity and concomitant factors (2000–2019)*. Aerosp Med Hum Perform. 2022; 93(5):442–449.**

The German Federal Bureau of Aircraft Accident Investigation (Bundesstelle für Flugunfalluntersuchung, BFU) is a subdivision of the German Federal Ministry of Transport and is responsible for the investigation of civil aircraft accidents and serious incidents. The BFU publishes annual statistics about aircraft accidents and serious incidents within Germany that are defined in the high-risk category. According to the International Civil Aviation Organization, high-risk category events include:

- Loss of control in flight;
- Controlled flight into or toward terrain;
- Runway safety related events; and
- Midair collisions.[15]

Accidents are subdivided by the BFU based on the type of aircraft, injury severity, accident severity, incident severity, and maximum takeoff weight (MTOW). The weight classification follows national standards according to the Luftverkehrs Zulassungs Ordnung and considers the MTOW classes <2000 kg, 2000–5700 kg, and >5700 kg.[10] Alas, only a fraction of all accidents or incidents is further investigated by the BFU. The requirement for a full investigation is predicated on whether further knowledge will likely prevent future similar events. The

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This manuscript was received for review in July 2021. It was accepted for publication in January 2022.

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DOI: https://doi.org/10.3357/AMHP.5977.2022

compilation of accident reports is mandatory by law, whereby the determining factors are defined by the law relating to the Investigation into Accidents and Incidents Associated with the Operation of Civil Aircrafts (Flugunfall Untersuchungs Gesetz). In contrast, the investigation does not aim to determine culpability, liabilities, financial, or legal claims.

For improving aviation safety, it is of utmost importance to analyze the collected data to identify technical as well as human factors. To date, with the exception of a few perfunctory reports (3–5), no detailed systematic analysis of flight accident reports by the BFU in Germany has been undertaken and no trend data for a multiannual period of time is reported. The present study is an analysis of the BFU reports data over a 20-yr period with a focus on accidents involving fixed-wing motorized aircraft of less than 5700 kg MTOW.

## METHODS

The online BFU database (www.bfu-web.de) was queried for annual accident statistics as well as the detailed BFU accident reports. A detailed analysis of all brief accident reports was performed excluding all incidents. Definitions of "incidents" and "accidents" were per the Convention on International Civil Aviation, Annex 13: aircraft accident means "an occurrence associated with the operation of an aircraft which […] takes place between the time any person boards the aircraft with the intention of flight and all such persons have disembarked […] in which a person is fatally or seriously injured as a result of being in the aircraft, or direct contact with any part of the aircraft […], or the aircraft sustains damage or structural failure […]." Incidents means "an occurrence other than an accident, associated with the operation of an aircraft, which affects or could affect the safety of operation."[16] Events involving non-German registered aircrafts or accidents of German airplanes abroad were also excluded. Since the current study was a retrospective analysis of recently published accident reports in the public domain, no institutional review board or ethics commission approval was necessary.

The phases of flight were as follows: takeoff/climb/departure, cruise/in flight, approach, and landing. With respect to injury severity and death, the Flugunfall Untersuchungs Gesetz defines detailed inclusion criteria that were presumably considered by the BFU. Thus, a fatal injury is defined as an injury that leads to the death of a person immediately or within 30 d post-event. Further, a serious injury is defined if the injury meets certain criteria such as damages to inner organs or second- or third-degree burns.[11]

Minor injuries are defined as any other than serious. Events involving two aircraft were considered as two separate accidents. Accident reports lacking certain information (e.g., pilot license) were excluded from the corresponding analysis (e.g., injury severity by pilot license), but included elsewhere if information content was sufficient. Consequently, the total number of cases included could differ slightly between analyses.

Data was collected in SPSS (IBM®, Armonk, NY, USA) regarding various factors of interest: date of accident, number of persons on board, pilot license, flight phase, MTOW, and injury severity or death. Statistical analysis was performed using Chi-squared tests (SPSS, IBM®) to determine if dichotomized parameters were correlated: e.g., injury severity and persons on board, injury severity and flight phase, number of accidents and flight phase, and between injury severity and pilot license. Further a Chi-squared test was performed to check for correlation between number of accidents, MTOW, month of the year, and weekday. A result was considered significant with a *P*-value less or equal to 0.05.

## RESULTS

Query of the BFU database indicated a total count of 1595 aircraft accidents between 2000 and 2019. In 129 (8%) cases, an accident was associated with serious injuries, whereas 211 (13.2%) accidents resulted in death of either aircraft occupants or uninvolved persons. All listed accidents accounted for 257 seriously injured individuals and 290 deaths, of which 110 (42.8%) were seriously injured and 285 (98.3%) deaths were further analyzed in an accident report. Contrary to the accident reports, annual statistics do not include the number of minor injuries. The total number of mishaps steadily declined over the years from 109 in 2000 to 61 in 2019.

For the present study, a total number of 285 flight accident reports (17.9%) were found (**Fig. 1**), of which 238 (83.6%) were referred to as MTOW category <2000 kg and 47 (16.5%) as MTOW category 2000–5700 kg. Aircraft in the latter category were powered predominately by boxer engines (40%), followed by turboprops (34%), turbofans (13%), radial engines (11%), and V-pistons (2%).

In the MTOW category of <2000 kg, 149 (62.6%) accidents occurred between May and September compared to 89 (37.4%) accidents between October and April. In the MTOW category of 2000–5700 kg, May to September accounted for 16 (34%) accidents compared to 31 (66%) accidents between October and April.

Comparing both weight categories, significantly more accidents involving <2000-kg airplanes occurred between May and September relative to aircraft in the 2000–5700 kg weight category. Conversely, significantly more accidents of aircraft in the weight category of 2000–5700 kg occurred between October and April ($P < 0.001$).

In the MTOW category of <2000 kg, 133 (55.9%) accidents occurred between Friday and Sunday compared to 105 (44.1%) accidents between Monday and Thursday. In the MTOW category of 2000–5700 kg, Friday to Sunday accounted for 14 (29.8%) accidents compared to 33 (70.2%) accidents between Monday and Thursday.

Comparing both weight categories, accidents involving aircraft in the <2000 kg weight category were over-represented in

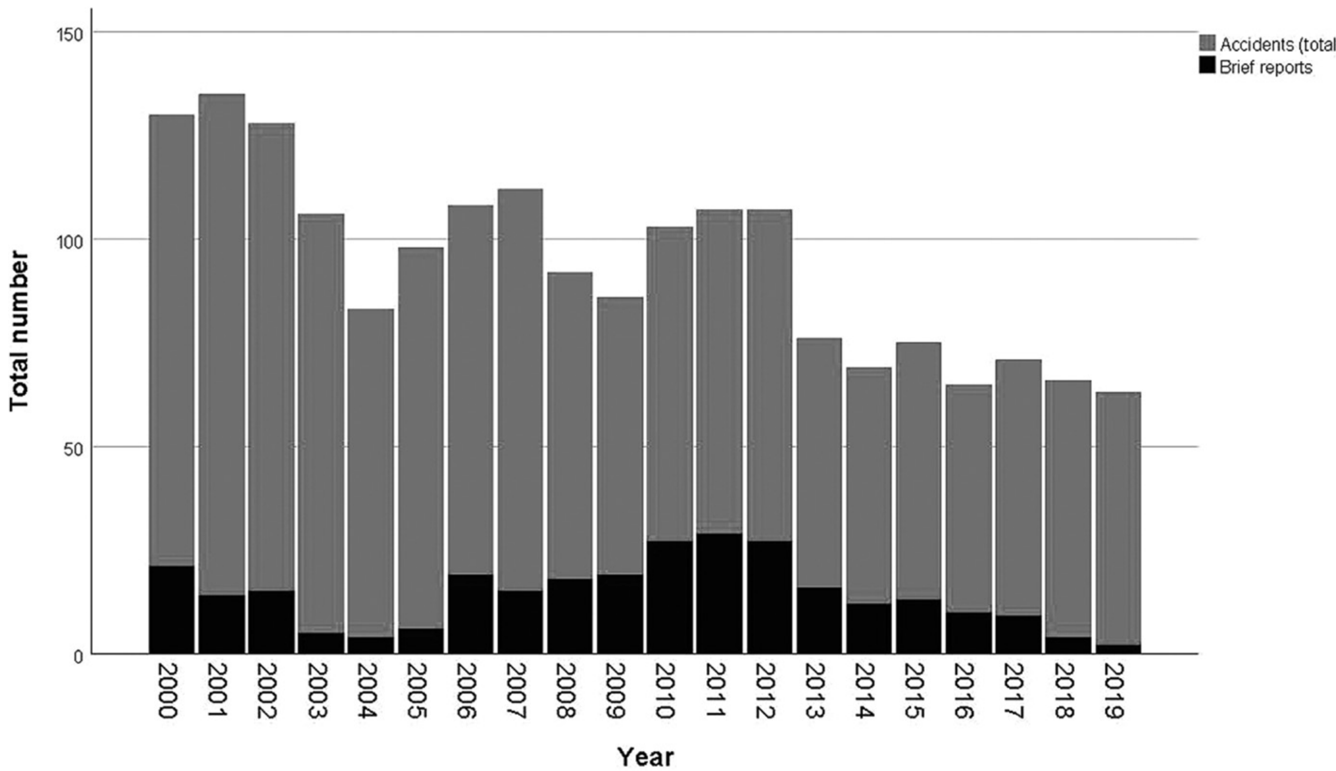


**Fig. 1.** Number of BFU accidents reported vs. number of BFU brief reports.

the Friday-Sunday period compared to mishaps of the 2000–5700 kg airplanes, which predominated during the week (Monday-Thursday). This difference was statistically significant ($P = 0.0011$).

Across the injury severity spectrum, minor injuries predominated during the landing phase (50%), whereas fatal injuries were most common during cruise (36.8%). The majority of serious injuries occurred during the takeoff phase (41.8%). Unharmed occupants could be found predominately during the landing phase (51.9%). Comparing injury severity level and flight phase, it can be stated that there were significantly more deaths that occurred during cruise as compared to other flight phases ($P < 0.001$).

The takeoff phase accounted for the most accidents in the MTOW category of <2000 kg (31.6%), whereas in this respect, the landing phase predominated in the MTOW category of 2000–5700 kg (51.1%) (**Fig. 2**). Comparing both weight categories there were significantly more accidents during landing in the weight category of 2000–5700 kg compared to aircraft of <2000 kg MTOW ($P < 0.001$).

The type of pilot license could be determined in 273 out of 285 accident reports. There were 5 (1.8%) pilots who were holding a sport or light aircraft pilot license (SPL or LAPL), 196 (71.8%) aircraft pilots who held a private pilot license (PPL), 55 (20.1%) pilots who were holding a commercial pilot license (CPL), and 17 (6.2%) pilots who were identified as pilots holding an airline pilot license (ATPL).

Fatal injuries accounted for the largest proportion of mishaps in each pilot license category (PPL: 43.5%; CPL: 42.7%; ATPL: 40%). Among accidents of private pilots, the fraction of unharmed occupants was lowest (18.7%) and the fraction of serious injuries was highest (20.1%) as compared to commercial licenses (**Fig. 3**).

Comparing injury severity for both private (PPL, SPL, LAPL) to that of professional (CPL, ATPL) licenses, the count of serious injuries/fatalities was disproportionate for the former aggregate ($P < 0.001$). Conversely, the same applies for the comparison of unharmed occupants between private and commercial pilot mishaps.

In this context, the distribution of injury severity within nine subgroups defined by the number of persons on board was investigated. Mishaps involving 1–3 persons on board showed the highest proportion of deaths (50.8%), whereas in accidents with 6–9 persons on board, unharmed occupants were predominantly represented (50.7%) (**Fig. 4**).

Correlating injury severity to the number of persons on board, analysis showed that the number of deaths is significantly higher with flights having 1–3 persons on board compared to flights carrying 4–6 ($P < 0.001$) and 6–9 ($P < 0.001$) persons on board. The comparison of accidents involving 4–5 vs. 6–9 persons on board showed no significant difference regarding the proportion of deaths. Thus, there was a disproportionate count of occupants with fatal injuries for flights with three and fewer persons on board.

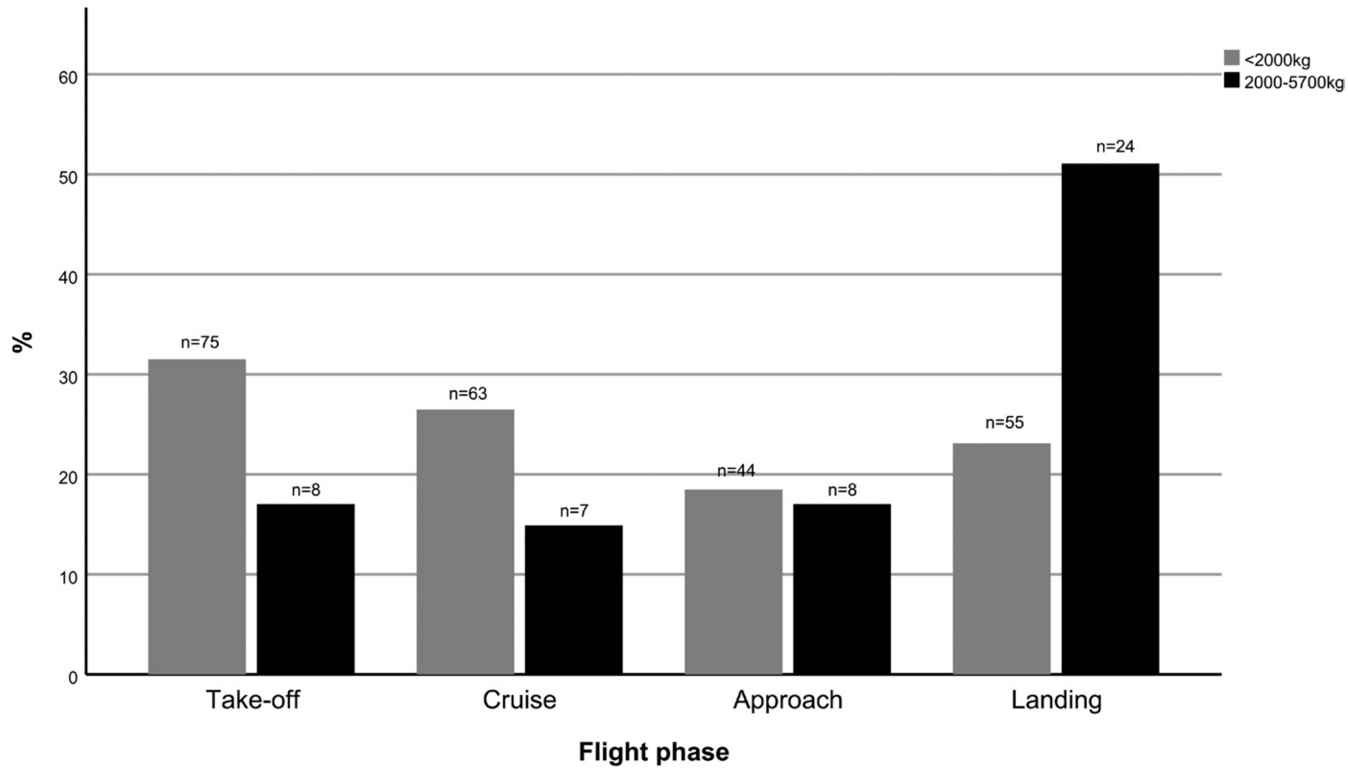


**Fig. 2.** Number of accidents (%) by flight phase and MTOW.

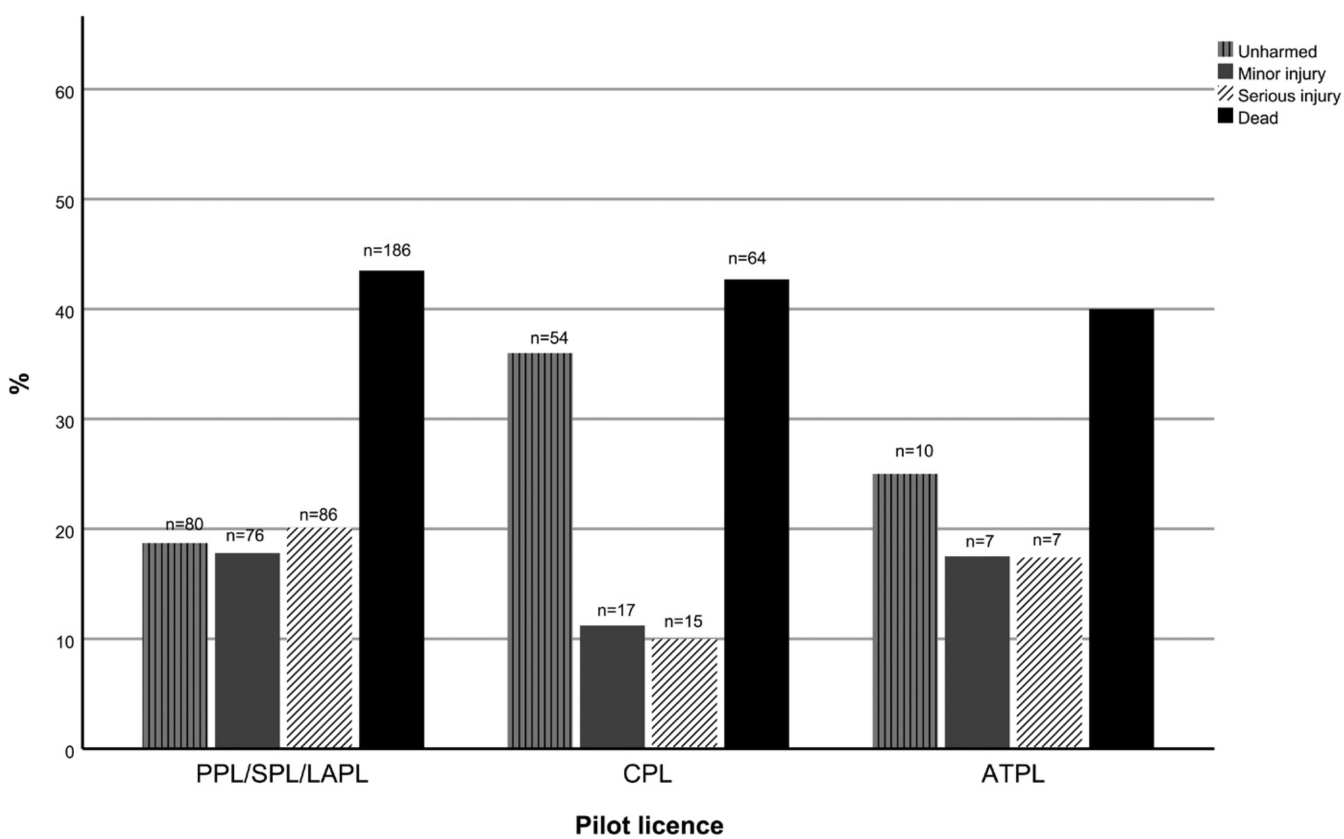


**Fig. 3.** Number of injured occupants (%) by pilot license and injury severity.

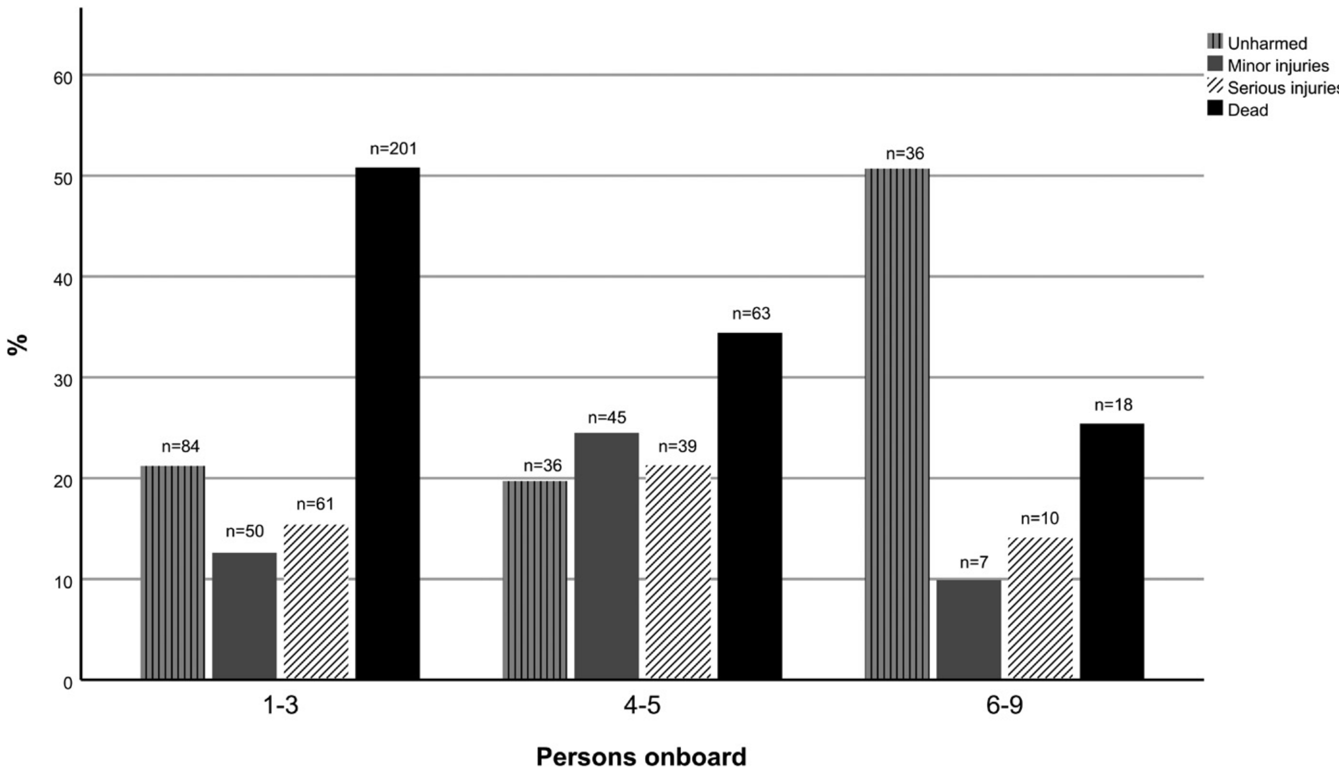


**Fig. 4.** Number of injured occupants (%) by injury severity and persons onboard.



## DISCUSSION

The present study is the first multiannual analysis of accident reports regarding fixed-wing motorized aircrafts of less than 5,700 kg MTOW in Germany. It contributes to the pre-existing literature by providing a detailed investigation of one particular aircraft subcategory, rather than focusing on the wider spectrum of general aviation (which, e.g., includes rotary wing aircraft). The study showed that accidents of smaller aircraft peak during the summer months and over the weekend. The flight phase landing showed the largest number of aircraft accidents, whereas the proportion of deaths was highest during cruise. An occupancy rate of more than three persons on board and a professional pilot license correlated with fewer number of deaths. The majority of accidents occurred with smaller aircraft of less than 2000 kg MTOW probably because of the larger number of flight activities.

The number of mishaps showed a strong correlation to the season and the weekday. Dambier et al. observed a rise in the number of mishaps during the summer months across all weight classes in general aviation aircraft.[7] Presumably, the higher proportion of large aircraft mishaps in winter was not reproduced in their study due to the relatively low total number of large aircraft accidents. Aircraft below 2000 kg MTOW are mostly flown in the context of recreational aviation, culminating during the summer months and over the weekends. In contrast, larger aircraft are more likely to operate all year round due to their commercial deployment. The German Federal Statistical Office publishes flight traffic data of the 28 most trafficked airports in Germany. Accordingly, between 2011 and 2019, the mean number of takeoffs per month in the MTOW category below 2000 kg increased by 49% between May to September as compared to the time period between October and April (3811 vs. 2561). Similarly, the number of takeoffs per month increased by 23% in the summer months for aircraft of 2000–5700 kg MTOW (1797 vs. 1466).[12] However, the reason for the imbalance in the number of accidents of larger aircraft throughout the year remains unclear, but could be due to differences in expertise and routine for commercial pilots.

Due to the relatively small number of accidents of larger aircraft, takeoff was identified as the least safe flight phase considering aircraft of <5700 kg MTOW. Our findings disagree with other published data of the 2020 EASA Safety Review, which identified the landing phase as the most vulnerable flight phase in the respective weight category in general aviation.[8] On the other hand, our data differs only slightly from the study by Dambier et al.[7] For the latter study, a cumulative proportion of accidents during approach and landing of 53% was determined compared with 53.3% in the current study.[7] However, it is important to note that both prior referred studies do not differentiate between weight categories and include all aircraft of general aviation. Furthermore, the 2020 EASA Safety reports includes not only accidents but serious incidents as well. Besides, Hinkelbein et al. found that most accidents of emergency helicopters, which are included in general aviation, in Germany occurred during landing.[14] Thus, it seems that smaller motorized fixed-wing aircraft are more vulnerable to mishaps during takeoff. This might possibly be due to their single engine configuration that predisposes for mishaps in the initial stages of the flight, as additional engines cannot compensate for malfunctions.

Accidents related to the cruise phase of flight mostly resulted in the death of an occupant. This seems evident considering higher speeds and the midair height of fall compared to the takeoff and landing flight stages. Cullen et al. comprehensively explained the causes of mortality in plane crashes, outlining several mortality mechanisms derived from high impact crashes of aircraft.[6] In its analysis of 2015 stall and spin accidents between 2000 and 2014, the AOPA Air Safety Institute emphasizes that stall accidents account for almost 25% of all fatal injuries and are especially deadly during the in-flight phase.[1] Also in agreement with our findings is the annual review of aircraft accident data of U.S. general aviation from 2002. In its analysis, the National Transportation Safety Board declared landing as the phase accounting for the largest proportion of total accidents (29%) but least percentage of fatal occurrences (3%). Correspondingly, the largest proportion of fatal injuries occurred in flight (maneuvering, 29%), while only 14% of all accidents occurred during this phase.[20] However, the data of these two investigations also refer to general aviation, not fixed wing motorized aircraft only. The specific reasons for in-flight crashes are presumably to be found primarily in unsettled weather conditions and engine failures with a resulting impact between the aircraft and the ground. A precise analysis of the corresponding accident data in this regard must follow the work at hand.

This study also investigated a possible correlation between pilot license and injury severity. Accordingly, private licenses were more often associated with serious injuries or death compared to professional licenses. This fact is congruent with other studies. Baker et al. showed that, in the United States between 2000 and 2005, 87% of the persons who died in aircraft crashes were occupants of aircraft not categorized as commercial.[2] However, these figures should be treated with caution, as they do not consider the possibility of commercial licensed pilots flying private aircraft. The study further investigated that of all fatally injured victims, only 7% were occupants of commercial aircraft. Additionally, occupants of noncommercial aviation had only half as many hospital admissions as deaths. Again, Baker et al.'s investigation of the entirety of aviation-related injuries in the United States reduces comparability to the current study.[2]

As mentioned above, stall accidents account for a substantial proportion of all fatal accidents. Boyd investigated risk factors for fatal accidents in noncommercial single and twin-engine general aviation aircraft in two independent analyses. The mean difference between both studies was the pilot population, private pilots exclusively for single engine aircrafts, as opposed to a cohort of mostly commercial pilots in twin-engine aircraft. Comparing both inquiries, the author stated that fatal crashes due to aerodynamic stalls were higher in single engine as compared to twin-engine aircraft (14% vs. 22%). Boyd attributes this to the differences in license requirements that demand higher standards for commercial pilots in the United States.[3,22]

Thus, the answer to the imbalance in injury severity between private and professional pilots can presumably be found in differences of flight experience among pilots, the type of aircraft flown, and corresponding flight rules. A greater amount of flight experience (which can presumably be found in professional pilots rather than private pilots), including training on mishaps in simulator environments, can significantly increase the capability to handle unexpected situations and, therefore, help preventing serious accidents.[18,24] Furthermore, earlier studies emphasized that ATPL pilots in general aviation show reduced involvement in general aviation mishaps and pilot errors.[3,19,21]

In addition, the size of the aircraft correlates directly with the type of pilot license. In the present study, mainly private pilots flew smaller aircraft (82.2%), while larger aircraft were flown primarily by professional pilots (72.1%). In fact, the average aircraft MTOW in respect to private pilot licenses was 2187 kg compared to 4983 kg for professional pilot licenses. Thus, increased aircraft size might be a beneficial influencing factor in terms of injury severity.

However, this is in contradiction to a study by Neuhaus et al., who investigated the relative risk of sustaining a serious or fatal injury in aircraft in Germany between 1993 to 2007. According to this investigation, the probability of fatal injury per accident was 1.65 times higher in larger aircraft (2000–5700 kg MTOW) compared to smaller aircraft (<2000 kg MTOW). Regarding serious injuries, the earlier study found a lower relative risk for larger aircraft compared to smaller aircraft. The study group referred to the fact that off-airport landings can often be performed without harm by smaller aircraft while such maneuvers are not possible for larger aircraft or jets. Notwithstanding, a satisfying explanation for the discrepancy in figures between Neuhaus et al. and our study may require more detailed information about crew qualification, nature of flight, environmental factors, types of aircraft, etc.[13]

Lastly, the Joint Aviation Requirements differ between commercial passenger transports with less stringent operational rules for small, noncommercial aircrafts. It may be that these stricter regulations serve to diminish accident number and severity and can be considered a possible influencing factor.[4,5]

Accidents of aircraft with three persons or less on board are more likely to result in the death of an occupant compared to aircraft with four or more persons on board. The fundamental principles of crashworthiness are generally described using the CREEP criteria:

- Container (fuselage structure);
- Restraint (restraint system, seats, and attachments);
- Energy management (seats, restraints, fuselage, and engine mounts);
- Environment (items within the occupants' strike zone); and
- Post-crash factors (fuel system, fire, and egress).

It can be assumed that larger commercial aircraft provide improved protection of their occupants due to a more stringent implementation of crashworthy components. Influencing factors such as resistance of the fuel system components to rupture, sufficient emergency exits, or adequate materials of seats and cushions increase survivability in case of fire and are usually more strictly regulated in professional aircraft.[23] Furthermore, Li et al., in their analysis of crash risks in general aviation, indicated that in recent decades, major airlines have invested in, e.g., improved seat strengths or more fire-retardant materials, while little improvement has been done in general aviation aircraft. In fact, modernization of general aviation aircraft is often slow acting and comprehensive implementation of new technologies can be delayed by many years compared to commercial aircraft.[17] On the other hand, larger airplanes in a controlled crash will be landing faster due to higher stall speeds and more energy has to be dissipated compared with a smaller plane with a lower stall speed. This presumably reduces the advantage of superior aircraft architecture.

According to the BFU, the number of aircraft accidents has decreased by 44% between 2000 and 2019. The German Federal Statistical Office has collected national air traffic data by MTOW since 2011. Accordingly, air traffic in respect of aircraft with less than 5700 kg MTOW decreased by 22% between 2011 and 2019.[12] The total number of general aviation aircraft accidents reported by the BFU decreased by 21% within the same period. It can therefore be presumed that the decreasing number of accidents is due to a lower fleet activity.

The current study investigates BFU data of 285 flights representing 17.9% of all accidents listed by the BFU. This reflects the fact that while systematic accident investigations are performed comprehensively for scheduled air services (commercial and airline aviation, rescue helicopters),[13] such analyses are not routinely undertaken for general aviation and nonscheduled air services accidents.

In its study about "approaches and collisions of aircraft in German airspace 2010–2015", the BFU identified timely traffic warnings from air traffic control or from onboard collision warning devices and a resulting "See and Avoid" as the main reasons for classifying an event as "not worth further investigation." In cases of flight accidents, the "EU Regulation on the investigation and prevention of accidents and incidents in civil aviation"[9] could provide clarification of why the number of accident reports significantly lag behind the total number of accidents. Thus, "the extent of safety investigations […] and the procedure to be followed in conducting […] safety investigations shall be determined by the safety investigation authority, taking into account the lessons it expects to draw from such investigations for the improvement of aviation safety […]."[9] It appears that the BFU provided the indication for conducting an accident report considerably less frequently since 2013. The reasons for this remain unclear and should be analyzed in cooperation with the BFU in the future. Nonetheless, underlying casual connections of aircraft accidents are multifactorial. The relatively small percentage of accident reports measured against the total number of accidents reflects deficiencies in the recording of civil aircraft usage and impact data. Detailed information about the entirety of incidents and accidents should be acquired and made available to safety researchers.

The current analysis is based on data extracted from the BFU accident reports. This inclusion criterion determines a selection bias toward those investigated comprehensively. On the one hand, the study data lacks all accidents that did not result in a mishap report and were cited in annual statistics only. On the other hand, the BFU selection criteria of whether to investigate a mishap or not could possibly reduce the representativity of the investigated results. Consequently, comparability to other studies on the topic is limited. In addition, accidents of the two weight categories differ in total number, which also reduces comparability between the two cohorts. Besides, the analysis relies on the accuracy of the data collected by the BFU. Finally, the lack of a denominator (fleet exposure) which is not collected by the BFU or some other data by any other institution (e.g., number of aircraft operating per weekday) means that accident rates cannot be calculated and reduced mishaps may simply reflect less flying.

The annual count of aircraft accidents has almost halved during the previous 20 yr. Analysis of the seasonal distribution of accidents finds an accumulation of larger aircraft mishaps in winter, raising the question of possible underlying factors such as icing, deficient runway conditions, or lack of pilot experience under challenging weather conditions.

Furthermore, there seems to be disagreement about the vulnerability of each flight phase. According to the current study, the challenge in preventing mishaps of smaller aircraft during takeoff is underestimated in the literature due to a general lack of differentiation between MTOW classes and type of aircraft. Generally, operating an aircraft appears safer for professional pilots. This raises the issue whether this is due to superior pilot training, more stringent flight rules for professional operations, or the type of aircraft that presumably increases in size concomitant to higher licenses. This matter should be further investigated.

## ACKNOWLEDGMENTS

We would like to thank Prof. Douglas Boyd (Embry Riddle Aeronautical University, Daytona Beach, FL, United States) for his extremely helpful comments for analysis as well as for the language edits of the manuscript.

*Financial Disclosure Statement:* The authors have no competing interests to declare.

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