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Further Improving General Aviation Flight Safety: Analysis of Aircraft Accidents During Takeoff

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Data from the National Transportation Safety Board (NTSB) reveal that general aviation (GA) accounted for 76% of total air transport related accidents and incidents in the U.S. between 2014 and 2019. The identification of causes is one of the most important tasks in aircraft accident investigation and a critical strategy for proactive aircraft accident prevention. Aircraft and flight crew perform differently in each phase of flight given the changes of aircraft configuration, flight operation environment and flight crew workload, therefore, the causes of aircraft accident may vary by phase of flight. Most accidents occur in the phases of final approach and landing have been investigated by many researchers from various perspectives. Few studies, however, have been published on flight safety for the phase of takeoff, which has the second-highest number of GA aircraft accidents and incidents. A good understanding of the causes of GA aircraft accidents during takeoff is crucial to develop more effective countermeasures for aircraft takeoff risk mitigation and accident prevention. The objective of this study is to understand the causes of GA aircraft takeoff accidents by analyzing aircraft accident investigation reports published by the NTSB. To better understand the causes of GA aircraft takeoff accidents, the following research design has been implemented. First, comparative analysis was applied to depict the statistical features of GA takeoff accidents compared to other air transport categories. Temporal change of GA takeoff accidents was analyzed using a linear-by-linear association test. Secondly, primary accident causes were identified by analyzing the NTSB investigation reports. Text mining techniques were applied to further explore contributing factors associated with the identified causes to enrich discovered knowledge. Finally, logistic regression analysis was applied to explore risk factors for fatal GA aircraft takeoff accidents. Lists of key causal and contributing factors were revealed and discussed from the analytical results. The identification of causal factors, contributing factors and risk factors for GA aircraft takeoff accidents are expected to be a valuable supplement to existing knowledge for aircraft accident prevention.

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Flight safety improvement has been one of the fundamental objectives for all aviation stakeholders for decades. A variety of flight safety enhancement measures have been undertaken globally to mitigate aviation risks. With continuous effort and collaboration among aviation stakeholders, the total number of aviation fatalities and the accident rate have decreased over the last decades. However, according to the General Aviation Manufacturers Association (GAMA), in the year of 2017 alone, the general aviation (GA) community operated more than 446,000 aircraft flying worldwide with 1,233 accidents in the U.S., which was around 5.67 accident per million flight hours (General Aviation Manufacturers Association [GAMA], 2018). National Transportation Safety Board's (NTSB) statistics show GA was accountable for around 76 percent of total air transport related accidents and incidents in the U.S. between 2014 and 2019 (National Transportation Safety Board [NTSB], 2019). Aircraft accident investigation is "a process conducted for the purpose of accident prevention which includes the gathering and analysis of information, the drawing of conclusions, including the determination of causes and, when appropriate, making of safety recommendations" (International Civil Aviation Organization [ICAO], 2016, p.13). With the purpose of preventing future accidents, aircraft accident investigation seeks to answer how and why accidents take place. Accurately identifying and understanding of the causes of aircraft accidents are critical for the development of practical safety recommendations for future accident prevention. Approximately 80 percent of aircraft accidents are due to human errors and the other 20 percent are caused by machine failures (Rankin, 2007). Reviewing aircraft accident statistics, investigation reports, and published aviation safety studies, a number of causal factors and occurrence categories were revealed in various accident scenarios for different types of operations. Loss of Control In-Flight (LOC-I), runway excursion, and Controlled Flight into Terrain (CFIT) are the three most common fatal accident categories in scheduled commercial jet airplanes, with primary contributing factors of safety management failure, adverse weather conditions, and flight crew errors of standard operating procedure (SOP) adherence during the years of 2014-2018 (Boeing, 2018; International Air Transport Association [IATA], 2019). For the GA operations – in addition to the CFIT and the LOC-I, system component failure – powerplant and unintended flight in Instrument Meteorological Conditions (IMC) are among top ten leading causes of fatal GA accidents during 2001 - 2016 identified by the Federal Aviation Administration (FAA) (2018).

Given the high accident rate and the diversity of the GA fleet and pilots, the FAA made the goal of reducing the general aviation accident rate one of its top priorities; and, set a goal of "no more than 1 fatal accident per 100,000 hours of flight by 2018" (FAA, n.d., p. 4). A number of studies on GA aircraft accident analysis and prevention have been published from a variety of important perspectives. The primary causal factors for GA aircraft accidents vary depending on the perspectives of the studies. Based on the GA accident and incident data between 1984 and 2004, the FAA (2005) published a high-level analysis of the major causal factors of GA accidents for various categories of aircraft. The study presented causal factors based on aircraft categories, which could be valuable for aircraft manufacturers for aircraft safety design improvement. However, the growing age of the GA fleet and slow replacement of aging GA aircraft make this study subject to validation using more recent data. Specifically considering the different flight profiles and performance characteristics, Boyd (2015) studied accidents of non-commercial twin piston engine GA aircraft. Results of Boyd's (2015) study revealed that most fatal accidents under visual weather conditions were attributed to: malfunction with a failure to follow single engine procedures, poor instrument approach procedures, and failure to maintain obstacle clearance with low visibility (or night). From the perspective of operational environment of mountainous and high elevation terrain (MEHET) for GA aircraft, Aguiar, Stolzer, and Boyd (2017) revealed that CFIT and wind gusts/shear were the most frequent accident causal factors. Taking pilot certification into account, the causes of fatal accidents were studied for instrument-certified and non-certified private pilots (Shao, Guindani, & Boyd, 2014).

Based on the findings of relevant aircraft accident studies, safety recommendations were proposed by researchers from different perspectives. For example, turbo-charged-powered airplanes and flying under IFR were encouraged for operations with MEHET, additional training of twin-engine IFR night operations was recommended for twin-engine GA pilots, and regulatory oversight, safety management system, and SOP-checking were suggested to be reinforced for commercial air transportation (Aguiar, et al., 2017; Boyd, 2015; IATA, 2019). However, existing research publications on aviation accidents typically consider the factors of operational environment, types of operations, and types of aircraft. Moreover, the research results usually tend to cite generic causes such as: pilot errors, aircraft issues, and weather-related conditions. Unfortunately, the analyses of specific causal factors often fail to distinguish between phases of flight.

Purpose

Aircraft and flight crew perform differently during each phase of flight given the changes of aircraft configuration, operational environment, and flight crew workload. As a result, aircraft accidents distribute differently by phase of flight. According to NTSB (2019), the distribution of GA aircraft accidents by phase of flight is shown as Figure 1. Around 40 percent of GA aircraft accidents from January 2013 to January 2018 occurred during the landing phase, followed by the takeoff phase with nearly 24 percent of total accidents. Similar to GA, Boeing (2018) indicates that commercial jet aircraft fatal accidents and onboard fatalities are distributed with a similar pattern. Nearly half of worldwide commercial jet airplane fatal accidents from 2008 to 2017 occurred during the final approach or landing phase of flight. These accidents accounted for 1,003 on-board fatalities, or around 44 percent of total on-board fatalities, followed by the takeoff phase and initial climb with 14 percent of fatal accidents (Boeing, 2018).

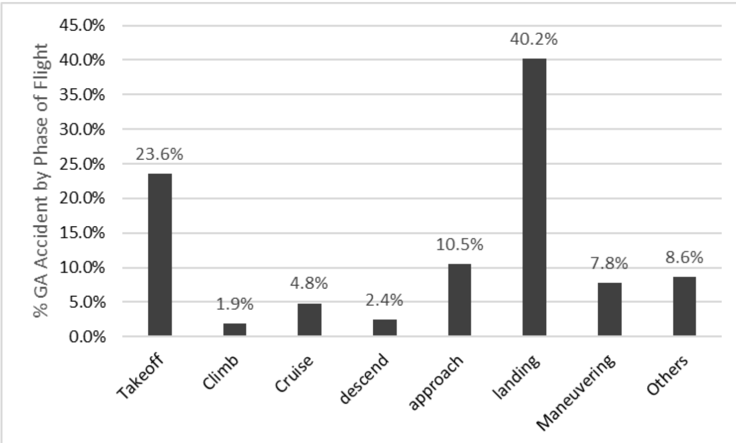


Figure 1. Distribution of GA aircraft accidents by phase of flight through January 2013 to January 2018 (NTSB, 2019).

Global aviation accident statistics show that final approach, landing, takeoff and initial climb are critical phases of flight for safety. During the phases of final approach and landing, aircraft are close to the ground with a more vulnerable configuration in preparation for landing. The crew operates with a high workload and decreased maneuver margins. Similarly, fatal accidents are also likely to occur during the takeoff and initial climb stage, given low flight altitude and limited aerodynamic capabilities. Because of the high accident rate, the final approach and landing phases have drawn more attention in aircraft accident studies in comparison to the takeoff and initial climb phases. Numerous studies have been published on GA aircraft accident prevention at final approach and landing phases of flight by analyzing and modeling operational flight data. For example, one of the early studies on the risk factors for pilot fatalities in GA aircraft crash landings suggested that the use of lap and shoulder restraints could reduce risk of death in GA crash landings (Rostykus, Cummings, & Mueller, 1998). Pilot performance, workload, and aircraft factors affecting pilot performance while executing final approach and landing were explored in different studies from the human factors standpoint (Boehm-Davis el al., 2007; Lee, 2010).

However, a review of the literature shows that few studies have been done to explore the causal factors of GA aircraft accidents during takeoff. Given the second highest GA accident rate occur during takeoff, it is critical to understand the primary causes for GA accidents occurring during this phase. With a better understanding, more effective and comprehensive aircraft accident prevention strategies could be developed and applied by pilots across different types of operations, aircraft, and operational environments. This paper presents research on the analyses of GA aircraft accidents during the takeoff phase of flight using historical aircraft accident information released by the NTSB.

In this research, the following research questions were studied:

1. Does the phase of takeoff pose a high risk for GA aircraft accidents?
2. What are the primary causes for GA aircraft takeoff accidents?
3. What are the contributing factors for GA aircraft takeoff accidents?
4. What are the risk factors for fatal GA aircraft takeoff accidents?

Methods

Data Collection

For this study, GA aircraft accident information was retrieved from the NTSB Aviation Accident Database & Synopses and Summary of U.S. Civil Aviation Accident updated in January 2018 (NTSB, 2019). Aircraft accident records for operations under Title 14 of the Code of Federal Regulation (CFR) Part 91 – General Aviation, occurring between January 2013 and January 2018, were queried. Additional accident data for 14 CFR Part 121 – Air Carrier and worldwide non-U.S. commercial aircraft and 14 CFR Part 135 – Air Taxi & Commuter during the same time span were also collected for comparative analysis. Because no fatal accidents were recorded from 14 CFR Part 121 operations in the U.S., data on worldwide, non-U.S. commercial operations were collected to reflect the features of Commercial Air Carriers' takeoff accidents. Considering different flight characteristics due to the diverse aircraft categories and purposes of flight, 14 CFR Part 91 aircraft accidents were limited to personal, business/corporate, and instructional flights; and, only non-amateur built airplanes were included in the data query. In addition, available final accident investigation reports were retrieved to supplement causal and contributing factor information. Fatal outcome, causes, and contributing factors were determined per the NTSB reports (NTSB, 2019). The total annual flight hours for the 14 CFR Part 91 operations for the selected flight purposes were obtained from the FAA survey to determine accident rate (FAA, 2019). Given above criteria, 3,939 14 CFR Part 91 aircraft accidents comprised of 826 takeoff accidents and 3,113 non-takeoff accidents were collected in this analysis. Given the NTSB preliminary accident reports do not present causal factors, 721 final reports for GA takeoff accidents were retrieved from the NTSB database for causal factor analysis. Each phase of flight was defined by ICAO Common Taxonomy (ICAO, 2013). The phase of flight for each accident was determined by the NTSB. Accident causes and causal factor categories used in analysis were identical to the NTSB final reports.

Analytical Procedure

Focusing on analyzing the causes, contributing factors, and risk factors of GA aircraft takeoff accidents, the following analytical work was conducted:

1. A comparative study of aircraft takeoff accidents in 14 CFR Part 91, 14 CFR Part 135, and 14 CFR Part 121 operations was presented employing descriptive statistics and Chi-square tests.
2. Focusing on Part 91 operation, the Chi-square linear-by-linear association output was used for trend assessment of GA aircraft takeoff accidents.
3. A list of primary causes for fatal GA accidents during takeoff was developed from the NTSB final accident investigation reports.
4. Based on the identified primary causes, the associated contributing factors were explored employing text mining techniques.
5. Logistic regression analysis was employed to identify risk factors for fatal GA takeoff accident based on 95% confidence intervals.

The data collected from the NTSB database consists of two categories: *structured data* from the Summary of U.S. Civil Aviation Accident and NTSB Aviation Accident Database & Synopses; and, *unstructured text information* from the NTSB aircraft accident investigation reports. The structured data were used for the first and second analytical tasks described above. The unstructured data were transformed into structured data for the third and fourth analytical tasks. The fifth analytical task was conducted by analyzing the fused structured and unstructured data.

Results and Discussion

Comparative Study of Aircraft Takeoff Accidents

The distribution of GA aircraft accidents by phase of flight (Figure 1) shows the takeoff phase of flight accounts for around 23.6 percent of total GA aircraft accidents. However, the fatal accident rate would more effectively reflect the significance of GA aircraft takeoff accidents by eliminating the portion of non-fatal accidents. The number of aircraft departures and passenger departures are two effective denominators for aircraft fatal accident and fatality rates, respectively. However, no statistics of the number of aircraft and passenger departures are available for GA operations. In addition, the number of *fatal accidents per hours flown* is not expected to be an appropriate measurement for aircraft takeoff accidents given the duration of takeoff only counts for a small portion of entire flight duration. In this study, the percentages of fatal takeoff accidents in the total number of takeoff accidents, and the takeoff fatalities in the total fatalities were employed to reflect the fatal accident rate and fatality rate of aircraft takeoff accidents. Figure 2 shows these two percentages for 14 CFR Part 91, Part 135, Part 121 and Non-U.S. commercial operations, respectively, according to the retrieved data from January 2013 to January 2018. Approximately 32 percent of GA aircraft takeoff accidents were fatal accidents comprising 22 percent of fatalities of all GA aircraft accidents during the studied timespan.

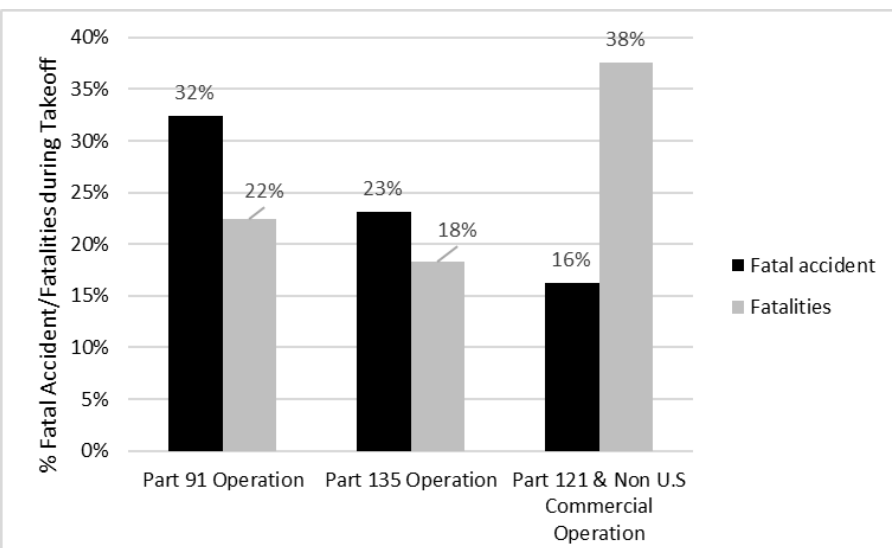


Figure 2. Percentages of fatal takeoff accidents and takeoff fatalities of GA aircraft accidents through January 2013 to January 2018.

To examine whether different types of operations have similar takeoff accident patterns, a Chi-square test was applied to compare the ratios of takeoff accidents versus non-takeoff accidents across Part 91, Part 135, and Part 121 & worldwide non-U.S. commercial operations. The *p*-value ($p = .004$, $\alpha < .05$) of the test indicates a rejection of null hypothesis, therefore the tested ratios of the three types of operations were statistically different from each other, as shown in Figure 3.

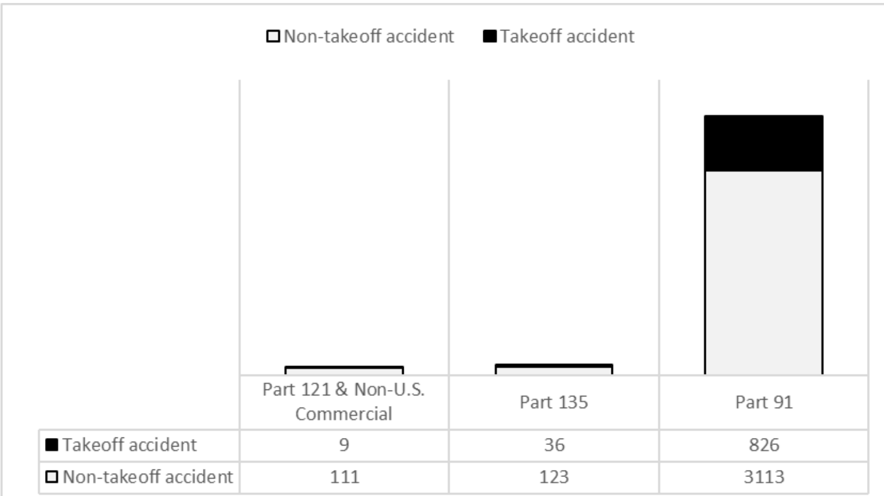
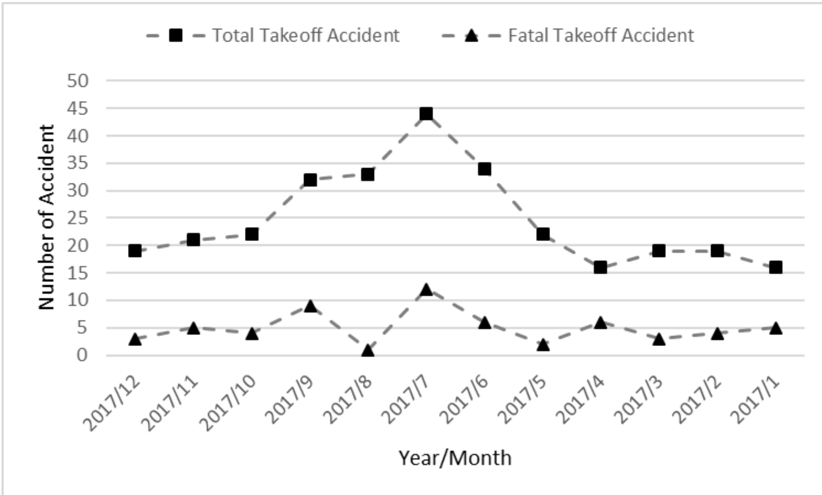


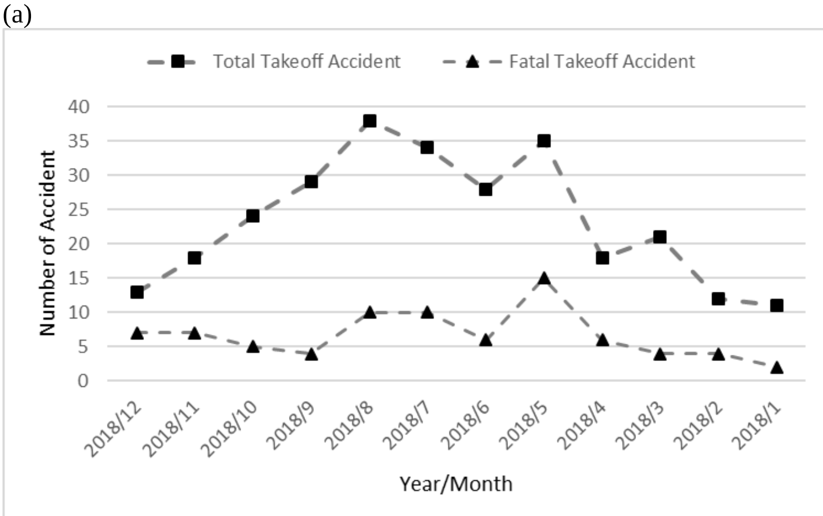
Figure 3. Ratio of takeoff accident versus non-takeoff accident, $p = .004$, $\alpha < .05$.

Temporal Trend of GA Aircraft Takeoff Accidents

Further exploration of the NTSB aviation accident statistics show that GA aircraft takeoff accidents occurred frequently in recent years. As shown in Figure 4, in 2017 and 2018, at least 10 GA aircraft takeoff accidents occurred every month in the U.S., and this number increased dramatically in the summer. The number of fatal takeoff accidents involving GA aircraft fluctuated accordingly. Analysis of the temporal trend of takeoff accidents provides better understanding of this particular type of aircraft accidents (Boyd, 2015). For a test of temporal trends of GA aircraft takeoff accident proportions across the studied timespan, a Chi-square linear-by-linear association value was used to determine the trend (Agresti, 2012; Boyd, 2015). In addition, Chi-square test was also used to determine if a difference in takeoff accidents comparing the initial time of 2013 and a subsequent period was statistically significant. The percentages of GA aircraft takeoff accidents in the total number of accidents for the corresponding time period are shown in Figure 5. The *p*-values indicate the statistical level relative to the takeoff accident percentage in 2013. The Chi-square linear-by-linear association is yielded $p = .285$, $\alpha < .05$, therefore, there was no statistically significant linear trend across all studied years. However, the *p*-value of Chi-square test comparing 2015 to 2013 ($p = .021$, $\alpha < .05$) shows a statistically significant increase of takeoff accidents in 2015.



(a)



(b)

Figure 4. Total takeoff accident and fatal takeoff accident through (a) 2017 to (b) 2018.

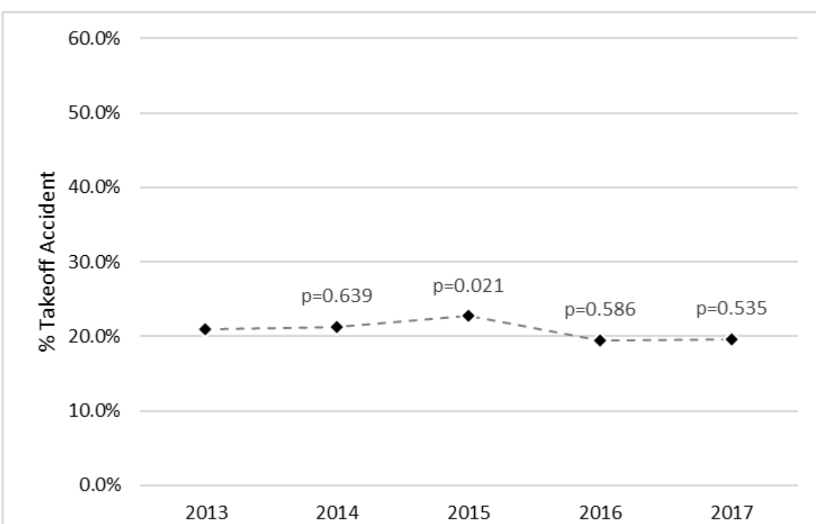


Figure 5. Temporal trend of GA aircraft takeoff accident percentage; *p*-values indicate the statistical level relative to the takeoff accident percentage in 2013.

Causes and Contributing Factors for GA Aircraft Takeoff Accidents

Each NTSB aircraft accident investigation report contains basic accident information (index), an analysis narrative, flight events, probable cause, findings, information about involved pilot(s), aircraft, meteorology, airport, wreckage and impact, and investigation administrative information. In the NTSB reports, accident causes and contributing factors were identified and categorized by aircraft issues, personnel issues, environmental issues, and organizational issues. Aircraft issues include aircraft mechanical problems or aircraft system related failures, personnel issues refer to related human errors, environmental issues include weather and all other flight operational environmental related factors, and organizational issues include all casual or contributing factors from organizational level.

Since the causes and contributing factors were presented in the form of unstructured data, text mining techniques were employed in this study to explore the patterns of text information to identify variables of primary causes of GA takeoff accidents. By analyzing the text file of aggregated NTSB reports in chronological order, four categories of causes were distributed (as shown in Figure 6). The horizontal axis divides the aggregated file into ten segments from 1 to 10, the tenth segment contains the most recent GA takeoff accidents. The vertical axis shows the relative frequencies for four categories of causes cited in the file with the total number of words as the denominator. According to this graph, aircraft issues are the most frequently cited causes during the studied time period, but there is evidence of a decreasing trend in recent years. Both personnel issues and environmental issues follow similar trends across the timespan. Organizational issues are the least frequently cited as GA takeoff accident causes, but more instances have been observed in recent years.

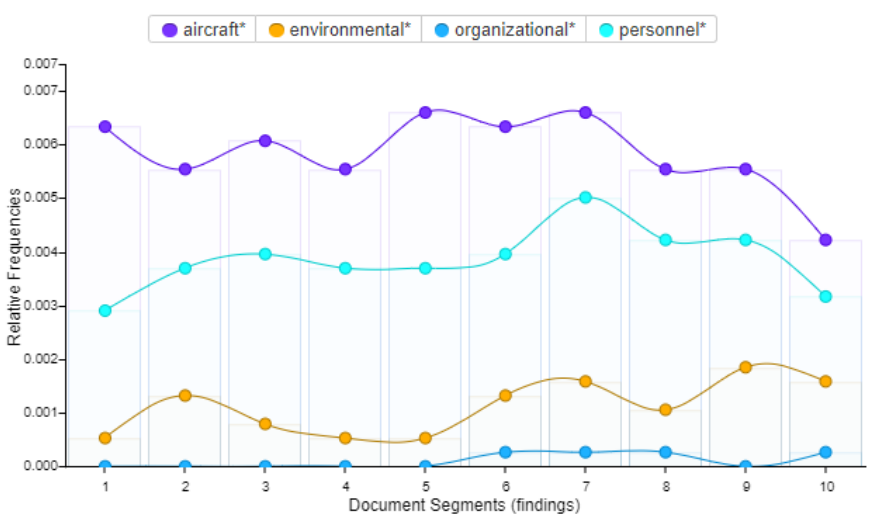


Figure 6. Distribution of four categories of causes in fatal GA takeoff accident reports

An aircraft accident is usually a consequence of multiple contributing factors (Reason, 1990; Hawkins & Orlady, 1993; ICAO, 2018). Most NTSB reports cite more than one accident cause or contributing factor from four categories discussed above. It is impractical to claim a single issue as the cause for an individual accident. Therefore, the percentage of each category being cited by accident reports was used to measure the significance of that category of causes. For instance, 77% of retrieved Part 91 aircraft takeoff accident reports cited aircraft issues as accident causal factors (see Figure 7). Figure 7 presents a latitudinal view of categorical causes for GA aircraft takeoff accidents in comparison with Part 135 and Part 121 & Non-U.S. commercial operations. It is noticeable that Part 91 aircraft takeoff accidents are more likely attributed to personnel issues and aircraft issues while Part 135 aircraft takeoff accidents cited more environmental issues and Part 121 & Non U.S. commercial aircraft takeoff accidents cited more organizational issues.

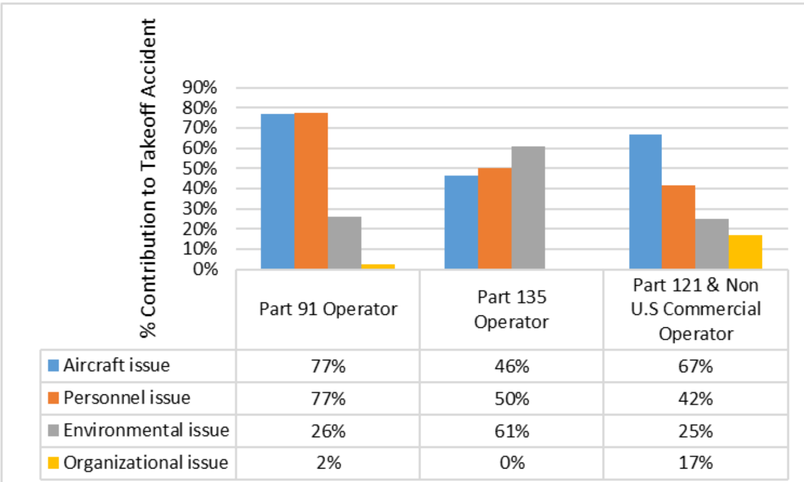


Figure 7. Contribution of categorical causes to fatal takeoff accident.

By parsing the aggregated text reports, the most commonly used phrases and causes identified by the NTSB reports are shown in Figure 8 and Figure 9. Most common phrases related to accident causes are shown in Figure 8. The five most common causes for GA aircraft takeoff accidents are listed in Figure 9: Aircraft Control Deficiency, Angle of Attack Exceeded, Airspeed not Attained/Maintained, Decision Making Mistake, and Fuel System Failure. The bar graph describes the number of accident reports by the type of cited cause. The line graph represents the cumulative percentage of reports by the type of cited cause. For example, Aircraft Control Deficiency was the most cited cause in 88 accident reports, which accounts for 38% of the GA aircraft accident final reports analyzed in this study.

Figure 8. Key phrases related to accident causes.

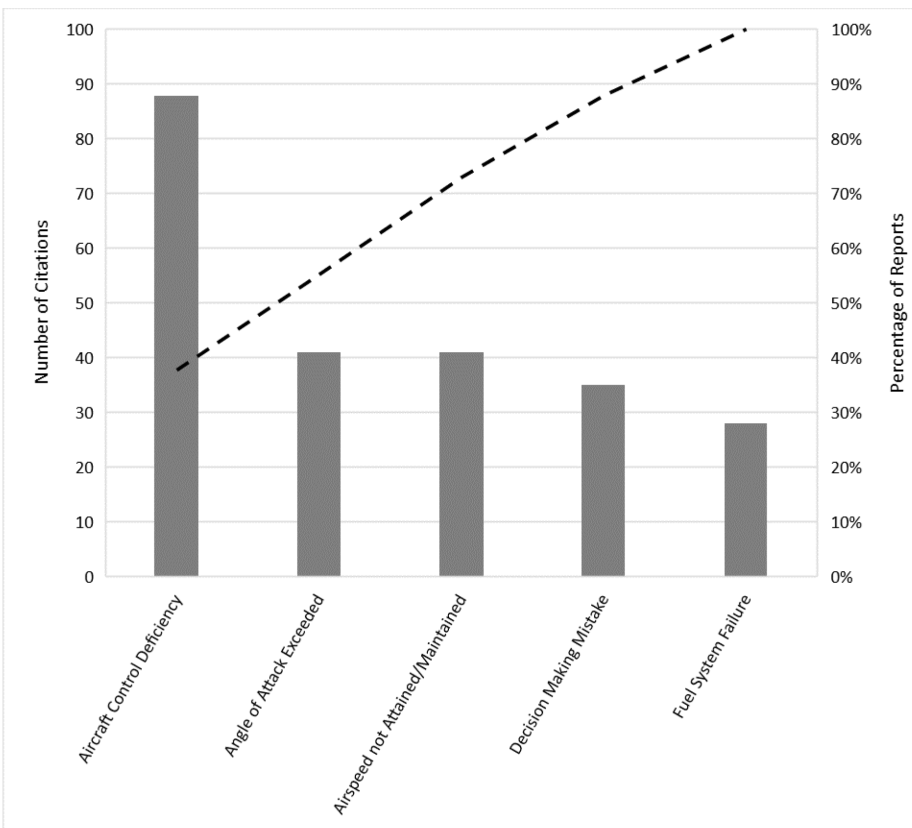


Figure 9. Primary causes cited by GA aircraft takeoff accident final reports.

The primary causes identified by the NTSB could guide aviation stakeholders to a consensus about where GA aircraft takeoff risk mitigation work should concentrate. However, classic aviation accident analysis models and strategies, such as the "Swiss Cheese" model and accident causal chain, the SHELL model, and the Human Factor Analysis and Classification

System (HFACS), have recognized that aircraft accidents result from a series of unsafe events consisting of leading causes and contributing factors. A good understanding of associated contributing factors and the relationship between cause and contributing factor are expected to be important to discover effective means for aircraft accident prevention. Iterative text analysis was conducted for the identified five primary causes for the purpose of finding the most related contributing factors. Voyant Tools, an open-source text analysis software, was used for text mining (Sinclair, Rockwell, & Voyant Tools Team, 2012). The Pearson's correlation coefficient was used to explore the associated factors (Sinclair et al., 2012). The correlation coefficients were calculated by comparing the relative frequencies of identified causes and contributing factors. However, the use of Pearson's correlation coefficient was based on the assumption of normally distributed data. In addition, the relative frequencies of causal and contributing factors are relatively small given the same contributing factor could be expressed in different phrases of natural language. A relatively big confidence level of 80% was used as the cut-off value to select contributing factors. The results are shown in Table 1. The correlation analysis of text information was primarily used to explore associated contributing factors; further validation with a larger dataset might be necessary.

Table 1.
Associated contributing factors

Cause	Associated Contributing Factor	Correlation Coefficient	Significance (*p*)
Aircraft control deficiency	Directional control not attained/maintained	0.656	0.039**
	Recent experience	0.601	0.066*
	High density altitude takeoff	0.498	0.143
	Instructor/check pilot incorrect actions	0.492	0.148
Critical angle of attack exceeded	Elevator control failure	0.681	0.03**
	Lateral control failure	0.627	0.052*
Airspeed not attained/maintained	Flight control system malfunction	0.475	0.165
	Center of gravity exceeded capability	0.403	0.196
Decision making	Spatial disorientation	0.615	0.058*
	Drug effect	0.545	0.103
	Monitoring communications	0.483	0.158
	Instructor/check pilot incorrect actions	0.459	0.183
Fuel	Fuel distribution failure	0.908	0.001**
	Fuel selector valve damage	0.847	0.002**
	Fluid level incorrect	0.597	0.068*

Note. Associated contributing factors were selected with cut-off significance level of 20% (*p-value* < 0.2), ** indicates the coefficient is significant at 5% level, *indicates the coefficient is significant at 10% level.

For the five primary causes, *directional control not attained or maintained* was the contributing factor most highly correlated with aircraft control deficiency; *elevator control failure and lateral control failure* were believed to frequently contribute to the exceedance of critical angle of attack; *spatial disorientation* was a major contributing factor associated with decision making issues; *fuel distribution failure and fuel selector valve damage* were two significant factors resulting in fuel system related accidents. In addition, it is noticeable that some identified contributing factors are identical to other related publications, but some of them are unexpected. One of the unexpected results is that drug effect was recognized as a contributing factor for GA aircraft takeoff accidents, though the Federal Aviation Regulations (FARs) preclude flying while having a condition or taking a medication that might affect flight safety (14 C.F.R. § 91.17, 2006).

Risk Factors for Fatal Takeoff Accidents

Logistic regression analysis using 95% confidence intervals was adopted to identify risk factors for fatal GA aircraft accidents during takeoff, given its advantages over discriminant analysis. For instance, it is robust in the case of a violation of the normality assumption and does not require equal variances within independent variable group (Tabachnick & Fidell, 1996). According to the distribution of categorical causes to fatal takeoff accident (Figure 7) and findings from the literature review, pilot age (Bazargan & Guzhva, 2007), flight experience (Li & Baker, 1999; Bazargan & Guzhva, 2007), pilot certificate (Groff & Price, 2006), instrument rating (Bazargan & Guzhva, 2007; Boyd, 2015), weather condition (Li & Baker, 1999; Groff & Price, 2006; Bazargan & Guzhva, 2007; Boyd, 2015), number of engine (Bazargan & Guzhva, 2007), type of engine, and season of the year were selected as independent variables for logistic regression analysis. Table 2 presents selected variables with corresponding coding descriptions.

Table 2.
Variables for logistic regression analysis

Variable	***Coding***	***Description***
Type of Accident	0	Non-fatal takeoff accident
	1	Fatal takeoff accident
Pilot Age	Log(age)	Log transformation
Flight Experience by Hours Flown	Log(hours)	Log transformation
Pilot Certificate	0	Student pilot certificate
	1	Private pilot certificate
	2	Commercial pilot certificate
	3	Airline Transport Pilot certificate
Instrument Rating	0	No
	1	Yes
Weather Condition	0	Visual Meteorological Conditions (VMC)
	1	Instrumental Meteorological Conditions (IMC)
Number of Engine	0	Single engine
	1	Twin engine
Type of Engine	0	Reciprocating
	1	Turbo Prop
	2	Turbo Fan
Season of the Year	0	Spring (March to May)
	1	Summer (June to August)
	2	Fall (September to November)
	3	Winter (December to February)

The model is expressed as Equation (1).

$$Fatal_i = a_1 log(age) + a_2 \log(experience) + a_3 Certificate_i + a_4 Rating_i + a_5 Weather_i + a_6 EngineNum_i + a_7 EngineType_i + a_8 Season_i + b + e_i$$

Table 3 presents the parameter estimates from the logistic regression model. Wald Statistics is used to test the statistical significance of each coefficient in the model. Odds ratios are the probability of occurring over the probability of not occurring for an event. The regression results indicate that the model is able to correctly classify 80.1% of the cases into fatal or non-fatal takeoff accident with statistical reliability at 10% significance level (Chi Square $p = 0.098$). In addition, three coefficients are statistically significant at the 5% level: weather condition (IMC vs. VMC), number of engines (single engine vs. twin engine), and season of the year (spring, summer, fall, vs. winter). More specifically, IMC, twin engine, and season of the year were identified as risk factors for fatal GA aircraft takeoff accidents.

Table 3.
Logistic regression parameter estimates and odd ratios

Variable	***Coefficient***	***Wald Sig.***	***Odds ratio***	***95% CI in odds***	
				Lower	***Upper***
Pilot Age	0.003	0.715	1.003	0.989	1.017
Flight Experience	0.000	0.272	1.000	1.000	1.000
Pilot Certificate	0.291	0.144	1.338	0.905	1.977
Instrument Rating	-0.122	0.666	0.885	0.509	1.539
Weather Condition	2.344	0.000*	0.096	0.034	0.269
Number of Engines	1.053	0.004*	2.969	1.417	6.219
Type of Engine	0.585	0.153	1.795	0.804	4.008
Season of the Year	-0.258	0.019*	0.772	0.622	0.959
Constant	0.717	0.309	2.047		

Note, * indicates statistical significance at the level of 5%; *CI* – Confidence Intervals.

Conclusion

Despite accounting for the second most number of fatal GA accidents, the literature largely ignores accidents occurring during the takeoff phase of flight. In response, this study verified the assumption of high risk of GA flight operations during the phase of takeoff, analyzed the causes and contributing factors for GA aircraft takeoff accidents, and explored risk factors for fatal GA takeoff accidents using available aircraft accident information from the NTSB database from January 2013 to January 2018.

In comparison with aircraft accident in Part 121 and Part 135 operations, GA operations show higher ratios of takeoff accidents vs. non-takeoff accidents and fatal takeoff accidents vs. non-fatal takeoff accidents. The results indicate that takeoff accidents are statistically more frequent and risky for GA compared to Part 135 and Part 121 operations, and no temporal change of GA takeoff accidents was observed statistically across the studied years. The findings of descriptive analyses of aircraft accident data support the author’s assumption and motivation on this study topic: GA operations face significant risk during the takeoff phase of flight which may result in fatal accidents.

Unlike Part 135 and Part 121 operations, aircraft and personnel related issues were more often cited as causes by accident reports for GA takeoff accidents. The difference might be explained by the limited resources that GA operators allocate to aircraft maintenance, the large number of old GA aircraft, and the diverse background and experience of GA pilots. In general, aircraft control deficiency, angle of attack exceeded, airspeed not attained/maintained, decision making mistake, and fuel system failure were identified as primary leading causes for GA aircraft takeoff accidents.

In addition, a list of 15 contributing factors associated with the primary causes was identified by text mining the final accident investigation reports. Due to the characteristics of natural language used in the NTSB accident reports, a confidence level of 80% was employed as the cut-off value to explore a bigger scope of associated contributing factors for each leading cause. Directional control deficiency, elevator control failure, fuel distribution failure, and fuel selector value damage were identified as contributing factors at 5% significant level; recent experience, lateral control failure, spatial disorientation, and incorrect fluid level were identified at 10% significant level. Surprisingly, drug effect was marginally significant at 10% level though FARs prohibit flying while having a condition or taking a medication that might affect flight safety. However, other identified contributing factors at lower confidence level might also be considered in GA aircraft takeoff accident prevention.

The results of logistic regression analysis present weather conditions, number of engines, and the season of the year as risk factors for fatal GA aircraft takeoff accident. In addition, the analysis results show that IMC and twin engine aircraft increase the likelihood of a GA aircraft takeoff accident to be fatal. GA aircraft takeoff accidents happening in spring and summer are more likely to be fatal than those happening in fall and winter. The weather condition of IMC means that the aircraft was taking off in low visibility or an adverse operational environment, which intuitively explains the high likelihood of fatal takeoff accidents. The finding that twin engine aircraft takeoff accidents are more likely to be fatal stays in line with the narratives in corresponding NTSB accident reports. Pilots encounter serious directional control difficulties while having engine failure of twin engine aircraft during takeoff. There could be many other reasons making the season of year a possible risk factor, but generally, the relatively lower air density and higher air temperature in summer and spring could reduce the aircraft takeoff performance during takeoff.

In conclusion, this study emphasizes the importance and necessity of additional accident prevention strategies for takeoff phase of flight in GA operations. The findings of this study inform GA operators as to the causes of takeoff accidents and where the training should be focused on. For example, improvement of aircraft control proficiency during takeoff in spring and summer, as well as in an adverse weather condition is expected to be beneficial, proficient execution of twin engine aircraft takeoff procedures upon loss of power in one engine should be reinforced in an adverse weather condition. Additionally, findings of this study could be helpful for better identifying possible gaps between current flight training techniques and pilot proficiency standards. In this study, the available aircraft takeoff accident data from the NTSB were categorized by broad phases of flight: Standing, Taxiing, Takeoff, Climb, Cruise, Descend, Approach, Landing, Go-around, Maneuvering, and Others. There was no information explaining whether the aircraft accidents during the phase of climb-out were categorized as part of takeoff accidents or climb accidents. Further research is necessary to verify the accuracy of this study by eliminating data errors because of above reasons.

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