Social Acceptance of Increased Usage of the Ballistic Parachute System in a General Aviation Aircraft

Joseph Kirby

BACKGROUND: An airframe parachute ("Chute") available in certain aircraft is designed to lower the airplane safely to the ground for emergency situations that occur 500 ft (152 m) above ground level (AGL): the "Chute altitude envelope." This study will explore the change in Chute use before and after 2012 to better understand factors that increased usage and improved accident outcomes.

METHODS: Using the public National Transportation Safety Board (NTSB) accident database from January 1, 2001, through August 31, 2018, a regression model was developed to identify factors that may predict Chute use.

RESULTS: In accidents occurring after January 1, 2013, pilots were 5 times more likely to use the Chute, while 2.9 times less likely to use the Chute when the accident involved pilot-related causes. The presence of passengers did not predict Chute use. Injuries were likely to be more severe when the Chute was used outside the Chute altitude envelope.

DISCUSSION: In contrast to General Aviation (GA) overall, accidents outcomes in aircraft equipped with a Chute have seen great improvements between 2013 and 2018, with increased use of the Chute and improved injury outcomes. Results suggest that changes to pilot training in 2012 have increased the social acceptance of Chute use. Results highlight increased risk of injury outcomes for Chute use in accidents that occur outside the Chute altitude envelope.

KEYWORDS: airframe parachute, aeronautical decision making.

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In the United States, the general aviation (GA) accident rate (as measured by the number of accidents per 100,000 flight hours) in 2015 was 4.87 total and 0.92 fatal. Major causes of the 2015 accidents consist of Pilot-Related (73.8%), Mechanical (15.7%), and Unknown (10.4%).[7] GA accounts for 91% of all aviation accidents and 94% of all fatalities.[8] These results are consistent with prior research, which has shown that pilot-related issues represent the highest percentage of accidents and can be broken down into skill-based, decision-making, perceptual errors, and violations, with skill-based errors representing the highest share of accidents. Ongoing safety efforts within GA have only made modest improvements to GA accident rates.[10]

Cirrus Aircraft (Cirrus) designed their airplanes for the general aviation market with a focus on safety and performance and represents a new generation of advanced aircraft. Safety design elements in the Cirrus include the Chute, a cuffed wing design to reduce the chances of a stall, seats designed to a 26-G specification, a side-yoke, and harness seatbelt systems to increase safety in the case of impact or sudden stops. The combination of the cuffed wing design and the Chute allowed for Federal Aviation Administration certification with an Equivalent Level of Safety (ELOS), eliminating the need for spin recovery requirements; if a pilot enters a spin in a Cirrus, the Chute is the sole certified remedy available.[5]

The Chute represents a safety option designed to save lives in hazardous situations that emerge above 500 ft (152 m) above ground level (AGL) and at speeds less than 140 knots.[5] The system was based on the Ballistic Recovery Systems (BRS) originally designed for ultra-light aircraft. The Chute was intended to be used in life-threatening situations such as: loss of control, engine failure, pilot incapacitation, mid-air collision, and structural failures.[5]

From Creighton University, Omaha, NE, USA.

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Address correspondence to: Joseph Kirby, MBA, Heider College of Business, Creighton University, 602 N. 20th St., Omaha, NE 68102, USA; joekirby@creighton.edu.

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With all these safety features, it is interesting that a 2012 report comparing Cirrus accidents to that of general aviation overall found the Cirrus accident record is no better and, in some cases, worse than the industry.[3] Another study of aircraft certified under the latest dynamic crash rating requirements, under which Cirrus is grouped, found that while minor and serious injuries were lower in aircraft certified under the more stringent standards, the rate for fatal injuries was not lower.[4]

In 2012, Cirrus Aircraft and the Cirrus Owners and Pilots Association (COPA) worked together to modify training to consider the Chute as a primary safety mechanism rather than a last resort. Training and social media coverage[2,6] affected Chute usage after 2012.

From 2001 through 2012, the Chute was used in 36.8% of Cirrus accidents; from 2013 forward, Chute usage increased to 77.1% of Cirrus accidents. In contrast with the modest safety improvements for GA overall, from 2012 to 2019 the Cirrus fatal accident rate fell from 1.5 to 0.84.[2,3]

According to the Cirrus Owners and Pilots Association safety pages, as of March 5, 2019, the Chute has been used 84 times, resulting in 172 saved lives and 1 fatality.[2] Further, use of the Chute by pilots is encouraged; insurance companies recognize the benefits of the Chute and incentives, such as waived deductibles, have been provided for accidents that involve a Chute deployment.[9] Successful deployments have been documented for accidents involving loss of control, pilot disorientation, and system failure.[1]

Prior research has demonstrated improved injury outcomes with Chute use. One study has shown the odds of fatal outcome were 13.1 times more likely when the Chute was not used.[1] While prior studies of Chute as a safety tool have looked at accidents in total, the present study offers a more fine-grained approach, adding Chute envelope as a predictor variable, segmenting data between accidents that fall within or outside of the Chute envelope, and exploring factors that influence a decision to use the Chute and explore accident outcomes in these scenarios.

METHODS

Data Sources

The research consisted of the analysis of Cirrus (SR-20 and SR-22) aircraft accidents from 2001 to 2018. Cirrus accident history was retrieved from the publicly available National Transportation Safety Board (NTSB) database (February 2019 release) from the NTSB website; no human subjects were involved in this study. The analysis included all accidents and incidents for which NTSB narratives existed and where flight phase and causal factors could be determined. A total of 370 accident reports resulted from the query, involving reported accidents from across the world. Only accidents within the United States for which sufficient data existed to properly code each accident were included, resulting in 290 records.

Procedure

Data from the NTSB tables were merged into an Excel worksheet with one record per accident; accident facts and narratives were reviewed for each accident and coded for analysis. Codes were assigned for Period, Chute Availability (within altitude envelope), Chute usage (deployment), Injury Level, Presence of Passengers, Phase of Flight, Causal Factor, Pilot Age, Pilot Total Hours, Pilot Gender, and Accident Location (country). **Table I** provides a breakdown of accident counts. Accidents were coded as either before or after January 1, 2013.

Accidents were coded as Chute Available when the accident aircraft was determined to be 500 ft (152 m) AGL. The narrative comments from the NTSB database or the full narrative of the accident were reviewed for each accident. Accidents were considered above 500 ft AGL when described as such in the narrative, in cruise flight or cruise climb, described as being in the flight pattern at an airport, or when the narrative mentioned the flight had reached Chute altitude. Accidents were coded as

Table I. All Cirrus Accidents Within the United States from NTSB Database Effective February 2019.

SUMMARY OF CIRRUS ACCIDENTS IN UNITED STATES				
	2001 THROUGH DECEMBER 2012		JANUARY 2013 FORWARD	
VARIABLES	*N*	% OF TOTAL	*N*	% OF TOTAL
Number of Accidents/Incidents	191	--	99	--
Chute Availability				
Outside Chute Envelope	123	64.4%	64	64.6%
Within Chute Envelope	68	35.6%	35	35.4%
Total	191	100.0%	99	100.0%
Chute Usage				
Activated outside Envelope	3	1.6%	5	5.1%
Activated within Envelope	25	13.1%	27	27.3%
Total Chute Usage	28	14.7%	32	32.3%
Chute Usage / Within Chute Envelope		36.8%		77.1%
Injury Outcomes				
None	96	50.3%	46	46.5%
Minor	17	8.9%	21	21.2%
Serious	13	6.8%	11	11.1%
Fatal	65	34.0%	21	21.2%
Total	191	100.0%	99	100.0%
Presence of Passengers				
Solo Flight	66	34.6%	28	28.3%
Additional Licensed Pilot	20	10.5%	8	8.1%
Non-Pilot Passengers	105	55.0%	63	63.6%
Total	191	100.0%	99	100.0%
Causal Factor				
Mechanical/Other	37	19.4%	28	28.3%
Pilot Related	154	80.6%	71	71.7%
Total	191	100.0%	99	100.0%

Chute Not Available when the accident involved ground operations, narrative indicated below 500 ft AGL, or the accident involved an impact with trees, low-level objects, or with terrain. For this study, the speed component of the Chute envelope was excluded as speed data is generally not present within the NTSB database.

A total of 187 accidents occurred outside the Chute altitude envelope and 103 occurred within the Chute altitude envelope. Two were excluded because pilot capacity could not be determined and another because the Chute safety pin had not been removed preflight, making the Chute unavailable during the flight.

Chute Usage was coded as either No Deployment or Deployed. An accident was coded as Deployed if the deployment occurred as a result of conscious pilot or passenger action. Some accidents referred to Chute deployment upon impact; these were coded as No Deployment. A total of 60 deployments occurred, with 8 occurrences of deployment outside of the Chute altitude envelope.

Injury level was coded on a scale of 0 to 3, using the NTSB highest level of injury outcomes ranging from None, Minor, Serious, and Fatal. Presence of Passengers was coded into factors of Solo Flight, flights with an Additional Licensed Pilot, and flights with Nonpilot Passengers.

Phase of Flight was coded using the CAST/ICAO Common Taxonomy Team Phase of Flight definitions as a basis, then grouped for summarizing into categories of 01-Ground/TakeOff/Landing, 10-Initial Climb/Climb, 20-En Route, 30-Maneuvering, 40-Approach, and 90-Emergency Descent. Phase 01 involves operations below the 500-ft AGL where the opportunity for chute use does not exist; narratives for accidents in phases 10, 30, and 40 were reviewed to determine if the flight conditions were within the Chute altitude envelope.

Causal Factor was determined using the CAST/ICAO Common Taxonomy Team Occurrence definitions as a basis, then grouped for summarizing into categories for analysis. Multiple causes can exist for each accident. This study bifurcated the data into Pilot causes vs. Mechanical/Other. Accidents that involved causal factors of System Failure-Power, System Failure-Non-Power, and Wildlife Encounter were coded as Mechanical/Other; all other accidents were coded as Pilot causes.

Statistical Analysis

Data was read and analyzed using R-Script. Binomial logistic regression using R-Script was performed to develop a predictive model to assess factors that may influence Chute usage. The final model selected included independent variables of Period, Pilot causes, and the Presence of Nonpilot Passengers on board the flight. This model provided a predictive value on Chute usage for accidents within the Chute altitude envelope at 70%. Findings from this analysis are discussed below.

A Chi-squared test was performed using R-Script to compare accident outcomes for Chute use within the altitude envelope vs. outside the altitude envelope. Due to small cell counts for Chute usage outside the Chute altitude envelope, Fisher's exact test was used to validate results.

RESULTS

A total of 290 Cirrus SR20 and SR22 accidents within the USA were included in the study, with 191 that occurred prior to January 1, 2013, and 99 occurred after this date. The percentage of accidents that occurred within the Chute altitude envelope were consistent between periods at 35.6% and 35.4%, respectively. Chute deployments for accidents within the Chute altitude envelope increased from 36.8 to 77.1% between these periods and Chute deployments for accidents outside the Chute altitude envelope increased from 1.6 to 5.1% between these periods (Table I). A comprehensive breakdown of accident descriptive information by Period, Phase of Flight, Causal Factor, Accident Scenario of within or outside the Chute altitude envelope, Chute usage, as well as Pilot Age, Total Pilot Hours, and Gender is shown in Table I.

Factors influencing Chute usage are shown in **Table II**. A binomial logistic model was fit to predict Chute usage for accidents that occur within the Chute altitude envelope. This model reflects that for accidents occurring after January 1, 2013, pilots were five times more likely to use the Chute than compared to accidents prior to January 1, 2013 ($\beta = 1.609$, $P = 0.00094$). Additionally, while controlling for period, pilots were 2.9 times less likely to use the Chute if the accident scenario involved Pilot causes vs. Mechanical Failure ($\beta = -1.078$, $P = 0.01556$). Compared to pilots on a solo flight, the presence of a second pilot rated occupant or nonpilot rated passengers did not significantly predict Chute usage ($\beta = -0.839$, $P = 0.286$; and $\beta = -0.711$, $P = 0.156$, respectively). Additional testing included Pilot Total Hours or Pilot Age as predictor variables; both resulted in nonsignificant findings.

For accidents where the Chute was used, 26 resulted in no injuries, 17 resulted in minor injuries, 6 resulted in serious injuries, and 2 resulted in fatal injuries. For accidents where the Chute was not used, 15 resulted in no injuries, 3 resulted in minor injuries, 1 resulted in serious injuries, and 33 resulted in fatal injuries. **Fig. 1** shows the percentage of highest-level injury outcomes for accidents in which the Chute was not used vs. accidents for which the Chute was used for accidents within the Chute envelope. When the Chute was used for accidents within the Chute altitude envelope, the percentage of fatal outcomes was 3.9%, compared to 63.5% for accidents in which the Chute was not used. Chute use resulted in a higher percentage of serious injury outcomes (11.8% vs. 1.9%), as well as minor injury outcomes (33.3% vs.

Table II. Chute Usage.

	CHUTE USAGE	
	ESTIMATE	***P***
Period: After 2013	1.609**	0.00094
Pilot causes	−1.078*	0.016
Presence of 2nd pilot	−0.839	0.286
Presence of nonpilot passenger	−0.711	0.156
Constant	0.549	0.235
Observations	103	--
Log likelihood	−59.954	--
Akaike Inf. Crit.	129.907	--

* $P < 0.05$; ** $P < 0.01$.

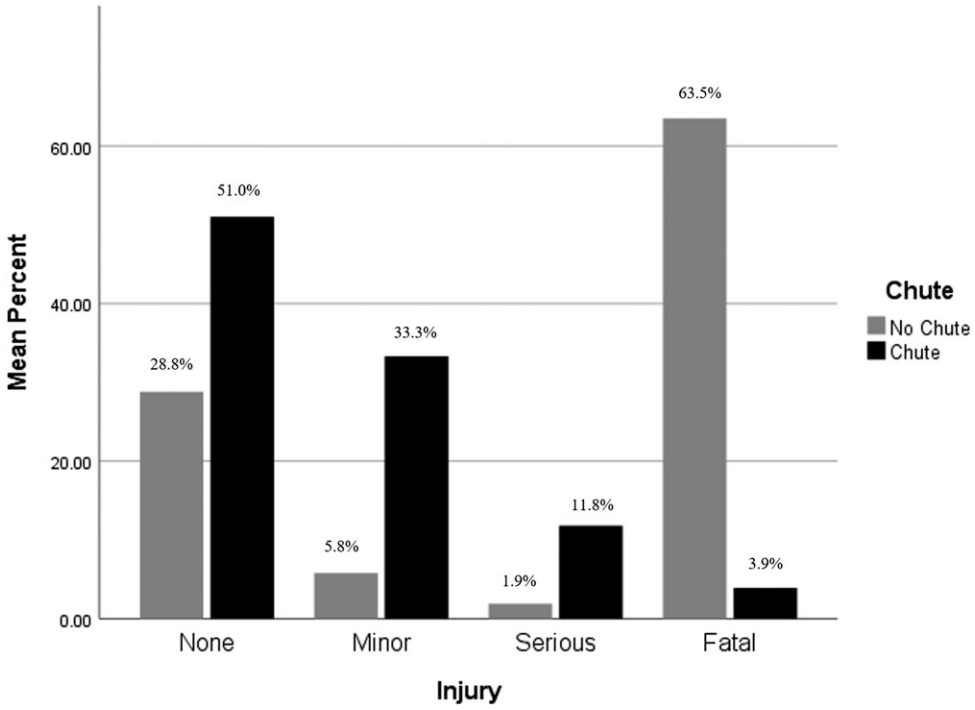

Fig. 1. Injury outcomes for accidents within the Chute envelope.

5.8%), and resulted in more outcomes with no injury (51.0% vs. 28.8%). These results demonstrate the benefits of Chute use for accidents within the Chute altitude envelope [$\chi^2(3) = 43.75$, $P < 0.0001$)]. Chi-squared results were validated with the Fisher exact test due to low cell counts, with Fisher exact $P < 0.001$.

The total number of accidents occurring outside the Chute altitude envelope for this study was 187, with the Chute being used in 8 accidents and not used in 179 accidents. For accidents where the Chute was used, 0 resulted in no injuries, 2 resulted in minor injuries, 2 resulted in serious injuries, and 5 resulted in fatal injuries. For accidents where the Chute was not used, 101 resulted in no injuries, 16 resulted in minor injuries, 15 resulted in serious injuries, and 46 resulted in fatal injuries. **Fig. 2** shows the percentage of highest-level injury outcomes for accidents in which the Chute was not used vs. accidents for which the Chute was used outside the Chute envelope. When the Chute was used for accidents outside the Chute altitude envelope, the percentage of fatal outcomes was 55.6%, compared to 25.8% for accidents in which the Chute was not used. Chute use resulted in a higher percentage of serious injury outcomes (22.2% vs. 8.4%), as well as minor injury outcomes (22.2% vs. 9.0%) and resulted in zero outcomes with no injury (0.0% vs. 56.7%). These results suggest negative outcomes of Chute use for accidents outside the Chute altitude envelope; however, these results may also reflect the fact that pilots did not use the Chute as a first consideration, but rather a last resort [$\chi^2(3) = 11.23$, $P = 0.012$]. Chi-squared results were validated with the Fisher exact test due to low cell counts, with Fisher exact $P = 0.011$.

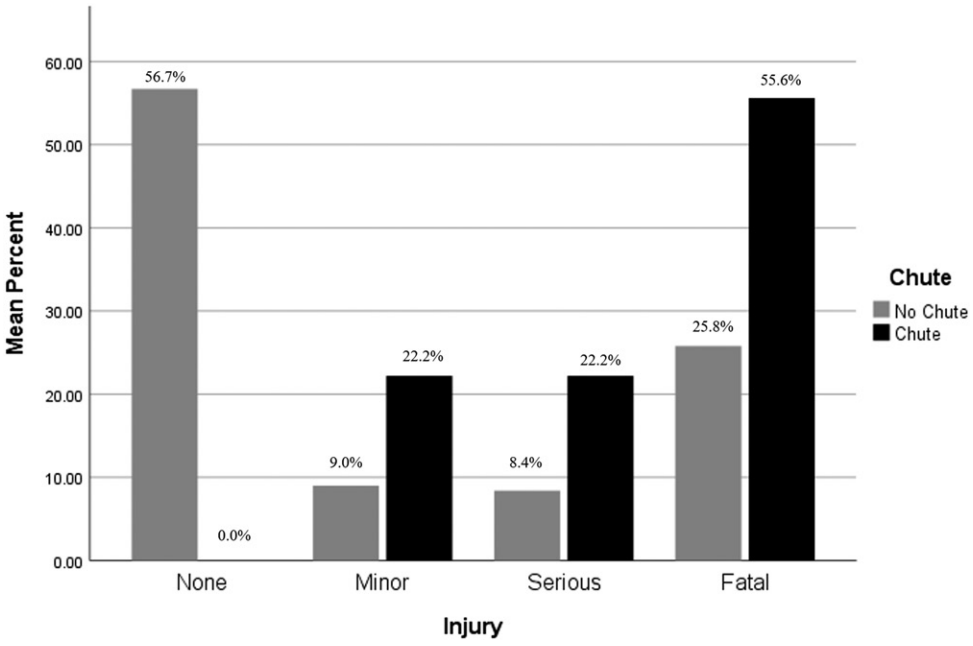

Fig. 2. Injury outcomes for accidents outside of the Chute envelope.

DISCUSSION

The results of this study highlight the significant increase in use of the Chute by pilots after 2013, offset by a lower likelihood of Chute use when the accident scenario involves pilot causes; the presence of passengers on the flight was not a significant predictor of Chute use. Further, this study determined that Chute usage outside the altitude envelope resulted in more fatalities than when the Chute was not used.

As a safety device, the Chute is not intended to be used in all accident scenarios and analysis of accident outcomes should include the Chute altitude envelope as a factor. Previous studies of Chute use have found that Chute use results in lower odds of fatal outcomes. The current study confirmed these results when assessing all accidents, but found more fatalities were reported

with Chute use in accident scenarios that fall outside of the Chute altitude envelope.

The significant finding of increased Chute use after January 1, 2013, may be the result of the changes in training brought about by COPA and Cirrus Aircraft. A change in Cirrus training encouraged pilots to consider the Chute as a primary safety tool vs. the prior view of the Chute as a tool of last resort, adding credibility to the Chute and changing pilot's perceptions, increasing the social acceptance of Chute use. Accidents with pilot-related issues showed a lower use of the Chute, which suggests that further training may be required to enable pilots to recognize when they have entered a dangerous emergency scenario for which Chute usage is merited.

Further, the findings that fatal accident outcomes are more common in Chute use for accident scenarios that do not fall within the Chute altitude envelope suggest that further training of Cirrus pilots may be required to encourage pilots to recognize scenarios where the Chute needs to be used before they lose so much altitude that they are outside of the Chute altitude envelope, or recognize when the accident scenario begins outside the Chute altitude envelope.

There are limitations to this study that must be considered. The analysis included only accidents within the United States for which narrative details existed in the NTSB accident database. The number of accidents for Chute use outside the Chute altitude envelope resulted in small cell counts; Fisher's exact test was used to confirm the significance of Chi-squared test results. The assessment of whether an accident fell within the Chute altitude envelope was made based on narratives that do not mention speed, resulting in the Chute envelope only being defined by the altitude component.

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Author and affiliation: Joseph Kirby, MBA, BSBA, Creighton University, Omaha, NE.

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