Cirrus Airframe Parachute System and Odds of a Fatal Accident in Cirrus Aircraft Crashes

Mustafa Alaziz; Adrienne Stolfi; Dean M. Olson

INTRODUCTION: General aviation (GA) accidents have continued to demonstrate high fatality rates. Recently, ballistic parachute recovery systems (BPRS) have been introduced as a safety feature in some GA aircraft. This study evaluates the effectiveness and associated factors of the Cirrus Airframe Parachute System (CAPS) at reducing the odds of a fatal accident in Cirrus aircraft crashes.

METHODS: Publicly available Cirrus aircraft crash reports were obtained from the National Transportation Safety Board (NTSB) database for the period of January 1, 2001–December 31, 2016. Accident metrics were evaluated through univariate and multivariate analyses regarding odds of a fatal accident and use of the parachute system.

RESULTS: Included in the study were 268 accidents. For CAPS nondeployed accidents, 82 of 211 (38.9%) were fatal as compared to 8 of 57 (14.0%) for CAPS deployed accidents. After controlling for all other factors, the adjusted odds ratio for a fatal accident when CAPS was not deployed was 13.1.

DISCUSSION: The substantial increased odds of a fatal accident when CAPS was not deployed demonstrated the effectiveness of CAPS at providing protection of occupants during an accident. Injuries were shifted from fatal to serious or minor with the use of CAPS and postcrash fires were significantly reduced. These results suggest that BPRS could play a significant role in the next major advance in improving GA accident survival.

KEYWORDS: ballistic parachute recovery system, Cirrus Airframe Parachute System, general aviation accidents, accident survival, post-crash fire.

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General aviation (GA) safety remains a challenging issue as evidenced by its continued high accident fatality rate.[15,20] In past studies, various factors have been linked to fatal outcomes, including phase of flight, meteorological conditions, terrain, and pilot characteristics.[15,21] Fatal accidents typically are high energy events due to flight speeds, impact forces, and impact angles. During a fatal crash, deceleration occurs upon ground impact, resulting in transmission of forces that are typically beyond human biomechanical tolerances. Research has shown that aircraft speed and impact angle at the time of impact affects survivability.[16] Efforts to reduce fatalities have concentrated on pilot education as well as reducing impact force transmission by implementing energy absorbing structures. These efforts have included Federal Aviation Administration (FAA) sanctioned pilot safety courses, crashworthy airframes, shoulder safety restraints, energy absorbing seats, and airbags.

More recently, ballistic parachute recovery systems (BPRS) have been incorporated in GA aircraft as a method to improve crash survival. Two major operational changes occur with a deployed BPRS: pilot control is no longer necessary for the aircraft to descend under canopy and the aircraft speed is reduced before impact occurs. Both changes are significant: pilot error has been associated with fatal accidents and the use of a BPRS provides aerodynamic braking, which allows the aircraft to decelerate to speeds below typical flight speeds. The desired result is a slowed descent with decreased ground impact forces. Based on the associated dynamics, an aircraft with a deployed BPRS should place the occupants in what has been considered a survivable envelope, as defined by the National Transportation Safety Board (NTSB).[16]

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Initial BPRS designs were introduced in the ultralight community in 1982 as an additional safety option. Since that time, advances in technology have allowed the manufacture of BPRS that are compatible with light sports aircraft and some GA aircraft. Cirrus Aircraft first tested the Cirrus Airframe Parachute System (CAPS) in 1998, and afterward CAPS (along with spin prevention) was certified by the FAA as the only approved method of stall/spin recovery in Cirrus aircraft. Since then Cirrus has included CAPS as a standard safety feature on their SR20, SR22, and SR22T models.

Although much controversy exists over the use and benefit of BPRS in the aviation community, a literature review revealed no previous studies on this topic. The purpose of this study was to evaluate the effectiveness and associated factors of CAPS at reducing the odds of a fatal accident in Cirrus aircraft crashes. Our hypothesis is the use of CAPS reduces the odds of a fatal accident.

METHODS

Data Sources

Publicly available Cirrus airplane accident and incident reports from the period of January 1, 2001–December 31, 2016, were obtained from the NTSB Aviation Accident Database, including preliminary, probable cause, and factual reports, and accident dockets.[14] All available resources for each accident were reviewed. The NTSB's Microsoft Access relational database, updated monthly, includes all reported civilian aviation accidents and incidents occurring in the United States from 1962–present, as well as some foreign accidents if the information is released by the jurisdiction to the NTSB. When possible, full reports for foreign accidents were obtained from the country of jurisdiction.

The NTSB defines an accident as "an occurrence associated with the operation of an aircraft that takes place between the time any person boards the aircraft with the intention of flight and all such persons have disembarked, and in which any person suffers death or serious injury, or in which the aircraft receives substantial damage." An incident is an occurrence other than an accident that affects or could affect the safety of operations.[5] It was necessary to include incidents because some Cirrus events in which CAPS was deployed were classified by the NTSB as incidents if the only damage to the aircraft was due to the deployment itself. Inclusion criteria for the study were: 1) event (accident or incident) occurring in the United States, or if outside of the United States, involving U.S.-registered Cirrus aircraft; 2) Cirrus models SR20, SR22, or SR22T; and 3) CAPS deployment status known. All Cirrus aircraft in the study were equipped with CAPS.

Procedures

The primary outcome was whether or not at least one occupant of the Cirrus aircraft suffered a fatal injury. Secondary outcomes included total number of fatalities, and severe, minor, or no injuries to all Cirrus occupants as determined by the NTSB.[14] CAPS deployment was categorized as "yes" if it was intentional, or "no" if no deployment occurred, or it occurred due to impact. CAPS was the primary independent variable, but was also treated as the outcome in separate univariate analyses exploring factors that may be associated with CAPS deployment. In addition to accident location (within the United States or foreign) and Cirrus model (SR20, SR22, and SR22T), other independent variables obtained were meteorological conditions [visual (VMC) vs. instrument (IMC)], lighting conditions (day/dawn/dusk vs. night), terrain (categorized as within airport vs. not within airport due to sample sizes being too small for each of the different types of terrain), cause of accident (pilot related, not pilot related, or multiple/undetermined), and phase of flight.

Cause of accident was determined from the probable cause narrative field in the Access database, which includes a text summary statement of the probable cause findings included in the event investigation record. Cause was considered pilot related if it was due to: 1) loss of control caused by pilot error during any phase of flight; 2) pilot decision to fly into adverse weather conditions, or VMC-rated pilot flying into IMC conditions; 3) inadequate preflight inspection resulting in failure to detect mechanical problems; 4) spatial disorientation or loss of situational awareness; 5) health-related issues such as hypoxia or seizure; and 6) improper maintenance by the pilot. Phase of flight was determined from the Access database phase of flight field, a coded field that refers to the point in the flight in which the defining event occurred. For this study it was grouped into five levels: standing/taxiing/takeoff/landing (abbreviated STTL: grouped together due to the individual phases occurring outside of the CAPS deployment envelope), climb/initial climb, en route (cruise or descent), maneuvering, and approach/go around. Pilot demographics included age, sex, total flying hours, flying hours in the Cirrus make and model, and pilot's highest level of certification. Highest certification level was dichotomized into airline transport pilot/commercial pilot/certified flight instructor vs. private pilot/student pilot due to the small numbers of airline transport and student pilots. Whether a fire occurred in flight or on the ground was also documented, but was not included as a predictor variable in analyses of fatalities or CAPS deployments. Not all information was available from all accident reports.

Statistical Analysis

Descriptive statistics include frequencies (percents) for categorical variables, mean (SD) for age, which was normally distributed, and median (IQR) for total and Cirrus flying hours, which were right-skewed. Data were initially analyzed with univariate tests to assess the unadjusted association of each independent variable with accident fatality and CAPS deployment separately. Chi-square or Fisher's exact tests (when one or more expected cell frequencies was less than five) were used for analyses of categorical variables. Student *t*-tests were used for age comparisons and Wilcoxon rank sum tests for total and Cirrus flying hours. Variables significantly associated with fatal accidents were then entered into a multiple logistic regression model to determine the adjusted odds ratio (AOR) with 95% confidence interval (95% CI) for the effect of CAPS deployment on fatality after controlling for other significant independent variables. Due to small sample sizes for some of the levels of phase of flight, the climb/initial climb and approach/go around phases were combined in the logistic regression. For accident cause, pilot related was combined with multiple/undetermined because the multiple/undetermined category was small. Because odds ratios overestimate the risk of an outcome as prevalence of the outcome increases, modified Poisson regression models were used to estimate adjusted relative and attributable risks for the CAPS variable.

The same univariate analyses conducted for the fatality outcome were also conducted in separate analyses with CAPS deployment as the outcome. Multivariable analyses were not performed for the CAPS outcome due to the relatively small number of CAPS deployments. All data analyses were performed in SAS 9.4 for Windows (SAS Institute, Cary, NC). For all analyses, *P*-values less than 0.05 were considered statistically significant. The study was approved by the Wright State University Institutional Review Board.

RESULTS

A total of 304 accidents involving Cirrus aircraft from January 1, 2001–December 31, 2016, were retrieved from the NTSB database. There were 29 accidents excluded (27 non-U.S. accidents involving non-U.S. registered aircraft, 1 U.S. accident involving a non-U.S. registered aircraft, and 1 Cirrus model VK30). Of the remaining 275 accidents, 268 had information about whether CAPS was deployed and were included in the study. Of the 268 accidents, 6 involved a Cirrus aircraft and 1 other aircraft; 2 of these were near-miss on-ground collisions, 1 was an on-ground collision, and 3 were midair collisions. A seventh multiple aircraft accident was a midair collision involving a Cirrus and two other aircraft. CAPS was intentionally deployed in 57 (21.3%) accidents. The number of CAPS deployments among accidents, incidents, U.S., and foreign events are shown in **Fig. 1**.

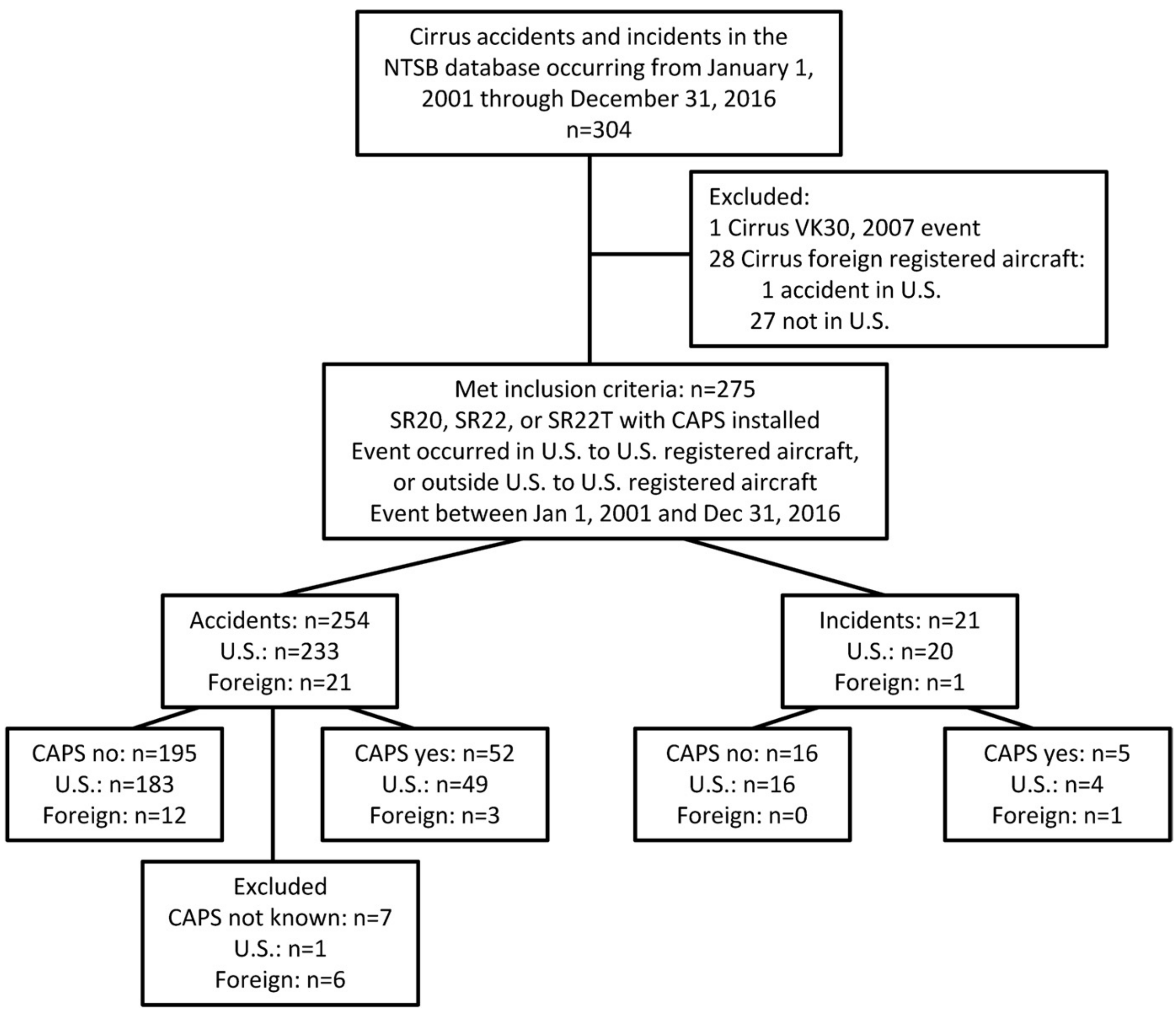

Fig. 1. Flow chart of inclusion and exclusion criteria for Cirrus aircraft accidents in the NTSB database.

There were 90 accidents (33.6%) which resulted in 1 or more fatalities among the Cirrus occupants, with 90.0% of fatal and 96.1% of nonfatal accidents occurring within the United States [$\chi^2(1) = 3.92$, $P = 0.048$]. Over the 16-yr period, the number of Cirrus accidents per year ranged from 4–27; fatal accidents per year ranged from 1–12 (11.8–50.0% of accidents), and CAPS deployments ranged from 0–8 per year (0.0–42.1% of accidents). **Fig. 2** shows the number of accidents by year, the number of accidents that were fatal, and the number with CAPS deployments. In both 2002 and 2003, 3/6 (50.0%) of accidents were fatal. The highest proportion of accidents with CAPS deployments occurred in 2015, when CAPS was deployed in 8/19 (42.1%) accidents.

Factors Associated with Fatal Accidents

In univariate analyses, CAPS deployment was associated with significantly fewer fatal accidents compared to no CAPS deployment. For the 57 accidents in which CAPS was deployed, 8 (14.0%) were fatal compared to 82/211 (38.9%) accidents where CAPS was not deployed. Other factors associated with fatal accidents were IMC, phases of flight, pilot related causes and terrain not within airport. Cirrus model, lighting, highest pilot certification level, and pilot sex were not associated with fatal accidents (**Table I**).

Pilot age, total flying time, and flying time in Cirrus model are shown in **Table II**. The mean ± SD age of pilots in fatal accidents was 52 ± 12 yr, which was significantly older than pilots of nonfatal accidents (48 ± 13 yr). There was no difference between pilots of fatal vs. nonfatal accidents for either total flying time or Cirrus model flying time.

Table III shows the AORs (95% CI) for the associations between factors that were significant in the univariate analyses and fatal accidents. After controlling for all other factors in the table, the AOR for a fatal accident when CAPS was not deployed was 13.14. IMC, phases of flight other than STTL, pilot related causes, and terrain outside of the airport remained significant, while pilot age did not. From the modified Poisson regression models, the adjusted relative risk was 2.99 (95% CI 1.54–5.79), and the attributable risk was 0.25 (95% CI 0.09–0.42) when CAPS was not deployed.

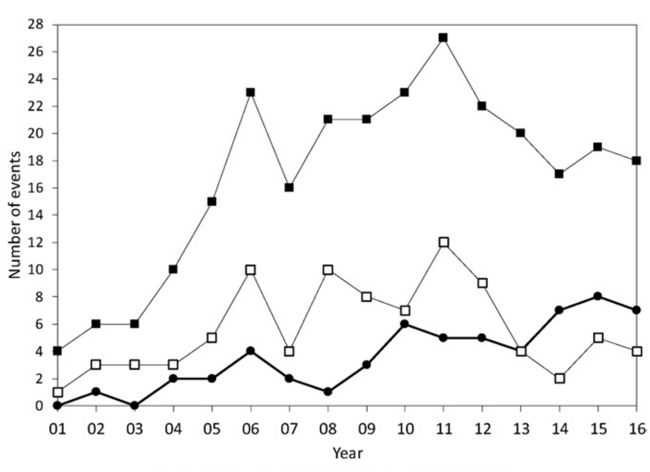

Fig. 2. Annual number of Cirrus accidents, accidents with CAPS deployment ($N = 57$), and accidents that were fatal ($N = 90$), 2001–2016.

Factors Associated with CAPS Deployment

Factors associated with CAPS deployment are shown in **Table IV**. Phase of flight, nonpilot related cause of accident, and terrain outside of the airport were associated with CAPS deployment. Pilot age was not associated; the mean ± SD age of pilots for CAPS deployment was 50 ± 13, $N = 56$, and for no CAPS deployment was 49 ± 13, $N = 208$ [$t(262) = 0.45$, $P = 0.653$]. Median (IQR) total flying hours was not associated ($P = 0.263$), but pilots who deployed CAPS had significantly more flying hours in a Cirrus aircraft compared to those who did not deploy CAPS [350 (508), $N = 48$ vs. 158 (332), $N = 176$, $P < 0.001$]. Cirrus model, meteorological and lighting conditions, highest pilot certification level, and pilot sex were not associated with CAPS deployment (Table IV).

Number of Fatalities and Injuries Among Cirrus Occupants

The total number of occupants in all 268 accidents was 561, and ranged from 1 to 5 per accident. There were 172 occupants who were fatally injured, 45 had serious injuries, 64 had minor injuries, and 280 were not injured. In 74/90 (82.2%) fatal accidents all Cirrus occupants were fatally injured. The proportions of accidents for which the highest injury level was fatal, serious, minor, or none for non-CAPS deployed vs. CAPS deployed accidents are shown in **Fig. 3**. The percent of accidents with fatal injuries was higher when CAPS was not deployed (38.9% vs. 14.0%), but when CAPS was deployed the percent of accidents with serious or minor injuries as the highest level were both increased (15.8% vs. 5.2% serious injuries, 26.3% vs. 7.1% for minor injuries). Since the percent of accidents with no injuries was similar for accidents with vs. without CAPS deployment (43.9% vs. 48.8%), this suggests a shift from fatal to serious or minor injuries with CAPS deployment [$\chi^2(3) = 30.00$, $P < 0.001$].

Associations Between Aircraft Fire, Fatal Accidents, and CAPS Deployment

For 264 of the 268 accidents, information was available for whether fire occurred after the crash. There were 60 accidents (22.7%) that involved fire either in flight ($N = 4$) or on the ground ($N = 56$). Fire occurred in 40/88 (45.5%) fatal accidents (3 in flight, 37 on the ground), and in 20/176 (11.4%) of nonfatal accidents (1 in flight, 19 on the ground) [$\chi^2(1) = 38.82$, $P < 0.001$]. It was not possible to determine from the available data whether the fatalities were due to the fire or the impact of the crash. Fire occurred in 57/207 (27.5%) accidents with no CAPS deployment (3 in flight) and 3/57 (5.3%) accidents with CAPS deployment [$\chi^2(1) = 12.63$, $P < 0.001$]. For the 3 accidents with CAPS deployment and fire, 1 was fatal and 2 were not, while 39/57 (68.4%) accidents with fire and no CAPS deployment were fatal.

Table I. Factors Associated with Nonfatal vs. Fatal Accidents in Univariate Analyses.

VARIABLE	ALL ACCIDENTS NO. (%)	NONFATAL NO. (%)	FATAL NO. (%)	χ^2	DF	*P*-VALUE
CAPS deployed				12.40	1	<0.001
No	211 (78.7)	129 (72.5)	82 (91.1)			
Yes	57 (21.3)	49 (27.5)	8 (8.9)			
Cirrus model				-	-	0.967
SR20	67 (25.0)	44 (24.7)	23 (25.6)			
SR22	192 (71.6)	128 (71.9)	64 (71.1)			
SR22T	9 (3.4)	6 (3.4)	3 (3.3)			
Meteorological conditions						
Visual	218 (81.6)	165 (92.7)	53 (59.6)	43.50	1	<0.001
Instrument	49 (18.4)	13 (7.3)	36 (40.4)			
	(*N* = 267)	(*N* = 178)	(*N* = 89)			
Lighting				2.75	1	0.097
Day/Dawn/Dusk	228 (85.1)	156 (87.6)	72 (80.0)			
Night	40 (14.9)	22 (12.4)	18 (20.0)			
Phase of flight				-	-	<0.001
Standing/taxiing	11 (4.1)	11 (6.2)	0 (0.0)			
Takeoff	27 (10.1)	22 (12.4)	5 (5.6)			
Climb/initial climb	17 (6.3)	8 (4.5)	9 (10.0)			
Enroute (cruise/descent)	72 (26.9)	45 (25.3)	27 (30.0)			
Maneuvering	27 (10.1)	7 (3.9)	20 (22.2)			
Approach/go around	58 (21.6)	31 (17.4)	27 (30.0)			
Landing	56 (20.9)	54 (30.3)	2 (2.2)			
Terrain				34.46	1	<0.001
Within airport	114 (42.7)	98 (55.4)	16 (17.8)			
Not within airport	153 (57.3)	79 (44.6)	74 (82.2			
	(*N* = 267)	(*N* = 177)	(*N* = 90)			
Cause				-	-	<0.001
Not pilot related	63 (24.0)	57 (32.6)	6 (6.8)			
Pilot related	190 (72.2)	116 (66.3)	74 (84.1)			
Multiple/undetermined	10 (3.8)	2 (1.1)	8 (9.1)			
	(*N* = 263)	(*N* = 175)	(*N* = 88)			
Pilot Sex				-	-	1.000
Male	204 (95.3)	138 (95.2)	66 (95.7)			
Female	10 (4.7)	7 (4.8)	3 (4.3)			
	(*N* = 214)	(*N* = 145)	(*N* = 69)			
Pilot highest certification				0.76	1	0.383
ATP/comm/CFI	75 (29.1)	53 (30.8)	22 (25.6)			
Private/student	183 (70.9)	119 (69.2)	64 (74.4)			
	(*N* = 258)	(*N* = 172)	(*N* = 86)			

Sample sizes are *N* = 178 for nonfatal accidents and *N* = 90 for fatal accidents unless otherwise indicated in the table. Comparisons with a dash in the Chi-squared and DF columns were made with Fisher's exact tests. ATP = air transport pilot; comm = commercial pilot; CFI = certified flight instructor.

DISCUSSION

The results of this study show a 13-fold reduction in the odds of a fatal accident with the use of CAPS. Typically, the major factor in occupant survival during an accident is the ability to provide protection from impact forces.[16] This is achieved through a combination of piloting skill, by attempting to safely land the aircraft, and through aircraft design, by reducing impact forces if the aircraft cannot be or is not landed safely. After CAPS deployment, piloting control input, as a positive or negative factor in protection from impact forces, has been removed from the accident sequence.

In this study, 72% of accidents were due to pilot related causes, which were associated with more than a fivefold increase in the odds of fatal outcomes. These results support historic data which have demonstrated that 85% of GA accidents can be attributed to pilot error.[12] Pilot's perception or knowledge of an error may play a significant role in the noted result. In this study, the unadjusted odds of deploying CAPS was 5.5 times higher if the cause of the accident was nonpilot related. Anecdotal information from the piloting community has suggested that some pilots are opposed to the use of a BPRS as a pilot would lose the ability to provide control input. The results of this study show, however, that not deploying the parachute resulted in significantly higher odds of a fatal accident.

Neither pilot age nor experience (total flight time) were associated with the use of CAPS or with the fatal accident rate. Although prior studies have shown age[8,11,12] and experience[7,12,13] not to be associated with accident rates, older[1,9] and more experienced[7] pilots have been shown more likely to be involved in fatal accidents. In this study, pilots in fatal accidents were older in the univariate analysis, but the adjusted odds ratio was not statistically significant. Of note, pilots in this study who deployed CAPS had significantly more flight time in a Cirrus aircraft compared to pilots who did not deploy CAPS. This may imply that pilot experience in Cirrus aircraft helped to

Table II. Pilot Age, Total Flying Time, and Flying Time in Cirrus Aircraft for Nonfatal vs. Fatal Accidents.

VARIABLE	ALL ACCIDENTS	NONFATAL	FATAL	TEST STATISTIC*	DF	*P*-VALUE
Age (years), Mean ± SD.	49 ± 13	48 ± 13	52 ± 12	−2.21	262	0.027
Range	20–77	20–77	23–75			
	(*N* = 264)	(*N* = 174)	(*N* = 90)			
Total flying time (hours)				−0.973	-	0.331
Median (IQR)	714 (1347)	657 (1584)	799 (1104)			
Range	29–32,000	29–32,000	72–18,700			
	(*N* = 246)	(*N* = 162)	(*N* = 84)			
Cirrus flying time (hours)				−0.402	-	0.688
Median (IQR)	187 (378)	174 (433)	200 (306)			
Range	6–3505	6–3505	12–1114			
	(*N* = 224)	(*N* = 160)	(*N* = 64)			

* Test statistic = *t* for age, and *z* for total flying time and Cirrus flying time.

minimize fatal outcomes through the use of CAPS; however, further study is required to determine if an association exists.

Cirrus has identified IMC weather conditions as a possible scenario for the use of CAPS during an emergency situation. The results of this study show a similar exposure to and fatality rate in IMC conditions as other study populations.[7,9,18] Univariate analysis of meteorological conditions showed no association with the use of CAPS. This indicates that, although Cirrus has encouraged the use of CAPS in IMC related emergencies, pilots have not been using CAPS more in these conditions. IMC weather was associated with fatal accidents, suggesting that despite the possible benefits of CAPS, fatal accidents in IMC conditions remain significantly elevated in Cirrus aircraft.

Equally important, night conditions have been associated with increased fatality.[7] The results of this study did not support prior research: night conditions did not demonstrate an association with use of CAPS or fatal accidents. When looking at fatalities, however, 45% of night accidents were fatal compared to 32% of daytime accidents, whereas CAPS use between night and daytime lighting conditions was virtually the same (21% and 23%, respectively). Similar to meteorological conditions, this indicates that pilots have not been using CAPS more in night conditions despite recommendations by Cirrus.[3]

Table III. Adjusted Odds Ratios (95% Confidence Intervals) for Factors Associated with Fatal Accidents.

VARIABLES	AOR	95% CI	*P*-VALUE
CAPS deployment			
Deployed	1.00	-	
Not deployed	13.14	4.50–38.33	< 0.001
Meteorological conditions			
Visual	1.00	-	
Instrument	5.32	2.01–14.06	0.001
Phase of flight			
Standing/taxiing/takeoff/landing	1.00	-	
Climb/initial climb/approach/ go around	9.97	3.48–28.58	< 0.001
Enroute (cruise/descent)	9.05	2.50–32.74	0.001
Maneuvering	17.58	4.32–71.52	< 0.001
Cause			
Not pilot related	1.00	-	
Pilot related/multiple/undetermined	5.82	1.85–18.31	0.003
Terrain			
Within airport	1.00	-	
Not within airport	2.97	1.19–7.39	0.020
Age (years)	1.02	0.99–1.05	0.321

Sample size is 258 due to missing data for some variables. *N* = 171 for nonfatal accidents; *N* = 87 for fatal accidents. AORs are adjusted for all other variables in the table. At the default probability cutoff of 0.50 for fatal accidents, the model correctly classifies 87.7% of nonfatal accidents and 73.6% of fatal accidents. Nagelkerke pseudo R square = 0.567, Hosmer-Lemeshow goodness of fit *P*-value = 0.07.

Terrain has also been identified as a factor in accident survival,[9,17,19] with off-airport crashes demonstrating a ninefold increase in the odds of fatality.[9] Despite a relationship shown between off-airport accidents and CAPS use, this study supports prior research results showing a significant association between fatal outcomes and off-airport accidents.

Phase of flight is important when considering the use and effectiveness of CAPS. Considering CAPS, there is an altitude (500 ft AGL) above which CAPS is considered "available" for use during the initial climb.[3] This renders CAPS inappropriate and likely ineffective for phases occurring at lower altitudes such as the STTL phase and the lower portions of the approach and climb phases of flight. Fatal outcomes typically have been associated with phases of flight that are away from the airport, possibly due to high altitudes and faster airspeeds.[18] This study demonstrated a significant difference for fatal accidents between the STTL phase of flight and the other phases of flight, when controlling for other factors. As one would expect, the majority of CAPS deployments occurred in the non-STTL phases; however, the results indicate that there is room for improved safety. More research is needed to determine if CAPS could provide additional safety improvement.

Although CAPS has demonstrated improved accident survival, in this study Cirrus aircraft have demonstrated a relatively high fatal accident rate. When looking for a trend by comparing annual percent use of CAPS against annual percent fatal accidents, the data showed the percentage of CAPS use to have increased in the years 2014–2016 to a use rate of 40–42% of accidents. The fatal accident rate during these years dropped to 12%, 26%, and 22%, respectively. Overall, the range of 20–40% annual use of CAPS appeared to be a transition range where the annual percent fatal accident rate began to approach levels consistent with overall GA operations. Similarly, Fig. 3 demonstrates a significantly lower percent of fatal accidents when CAPS was deployed. This would suggest that, in some of the

Table IV. Factors Associated with CAPS Deployment in Univariate Analyses.

VARIABLE	NO CAPS NO. (%)	CAPS NO. (%)	χ^2	DF	*P*-VALUE
Cirrus model			-	-	0.175
SR20	55 (26.1)	12 (21.1)			
SR22	151 (71.6)	41 (71.9)			
SR22T	5 (2.4)	4 (7.0)			
Meteorological conditions			1.87	1	0.172
Visual	175 (83.3)	43 (75.4)			
Instrument	35 (16.7)	14 (24.6)			
	(*N* = 210)	(*N* = 57)			
Lighting			0.04	1	0.837
Day/Dawn/Dusk	180 (85.3)	48 (84.2)			
Night	31 (14.7)	9 (15.8)			
Phase of flight			-	-	<0.001
Standing/taxiing	11 (5.2)	0 (0.0)			
Takeoff	27 (12.8)	0 (0.0)			
Climb/initial climb	8 (3.8)	9 (15.8)			
Enroute (cruise/descent)	40 (19.0)	32 (56.1)			
Maneuvering	23 (10.9)	4 (7.0)			
Approach/go around	47 (22.3)	11 (19.3)			
Landing	55 (26.1)	1 (1.8)			
Terrain			33.02	1	<0.001
Within airport	109 (51.7)	5 (8.9)			
Not within airport	102 (48.3)	51 (91.1)			
	(*N* = 211)	(*N* = 56)			
Cause			-	-	<0.001
Not pilot related	34 (16.4)	29 (51.8)			
Pilot related	163 (78.7)	27 (48.2)			
Multiple/undetermined	10 (4.8)	0 (0.0)			
	(*N* = 207)	(*N* = 56)			
Pilot Sex			-	-	1.000
Male	162 (95.3)	42 (95.5)			
Female	8 (4.7)	2 (4.5)			
	(*N* = 170)	(*N* = 44)			
Pilot highest certification			-	-	0.827
ATP/comm/CFI	58 (28.4)	17 (31.5)			
Private/student	146 (71.6)	37 (68.5)			
	(*N* = 204)	(*N* = 54)			

Sample sizes are *N* = 211 for no CAPS and *N* = 57 for CAPS unless otherwise indicated in the table.
Comparisons with a dash in the chi-square and DF columns were made with Fisher's exact tests.
ATP = Air transport pilot; comm = Commercial pilot; CFI = Certified flight instructor.

accidents, the use of CAPS changed the accident outcome from fatal to one involving lesser injuries.

In the same light, pilot training and education may play a role in the use and effectiveness of CAPS. Simply put, the parachute will not be effective if it is not used. There are potentially many reasons for the noted increased CAPS use in 2014–2016; however, it does coincide with a recent effort by Cirrus to improve pilot training and education, which includes recurrency training regarding the use of CAPS.[3] Although a temporal relationship between pilot training and increased use of CAPS may exist, more research is necessary before any relationship can be determined.

Ultimately, the protective effect of CAPS likely comes from a reduction of crash impact force. Prior studies have demonstrated that increased impact forces during an accident increase pilot fatality[9,16] and, therefore, reduction of these forces is an important safety strategy.[16,20] In an ideal deployment, a BPRS will reduce aircraft speed and, therefore, decrease the impact force during a crash. Although impact force data was not available from the NTSB records, Cirrus Aircraft has published a descent speed of 17 kn with an impact equivalent of a 10-ft drop for a fully stabilized CAPS-deployed impact.[2,4] Based on prior research as well as the survival rates demonstrated in this study, the resultant impact force is likely within biomechanical human tolerances.[6]

As further indication for improved survival through impact force reduction, one can plot the speed and impact angle of a CAPS deployed accident (17 kn at 90°) on the NTSB survival envelope curve for GA aircraft. In the CAPS deployed configuration, the aircraft impact reaches only 37% of the upper limit of the survival envelop speed of 45 kn. This places the CAPS deployed configuration well within survival limits, as shown in **Fig. 4**.

An interesting result from univariate analysis in this study showed that CAPS deployment was significantly associated with fewer postcrash fires. In CAPS deployment accidents, postcrash fire only occurred in three cases. The first involved a midair collision, the second involved CAPS deployment after the aircraft hit high voltage power lines, and in the third the aircraft contacted power lines while descending under canopy.

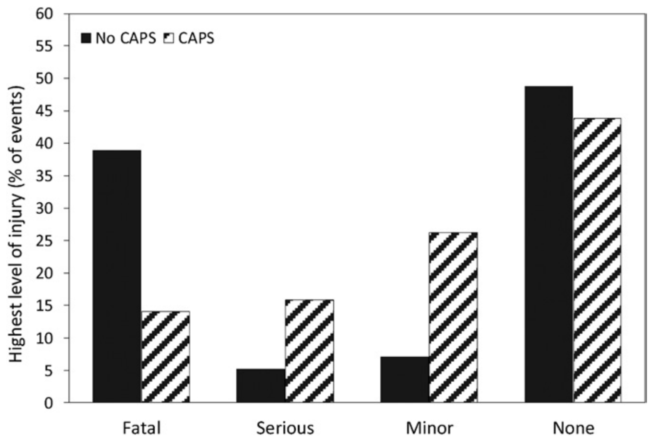

Fig. 3. Highest injury level for accidents with no CAPS deployment ($N = 211$) compared to CAPS deployment ($N = 57$).

As in this study, prior evidence has shown that postcrash fires were associated with pilot fatalities in more than two-thirds of cases.[9] Of equal importance, postcrash fire has been shown to typically occur at or after impact in aircraft crashes.[10] Although this does not demonstrate cause and effect, the reduction in postcrash fire with the use of CAPS likely had an effect on occupant survival.

Finally, when reviewing the eight fatal accidents that involved CAPS activation: six appeared to involve low altitude activation of CAPS, outside the operational envelope of the system, resulting in partial deployment of the parachute; one accident was concluded by the manufacturer to involve a CAPS deployment above the operational limit of 133 kn; and the final accident involved a midair collision with subsequent in-flight fire while under a deployed CAPS parachute.

Our study had several limitations: first, data were limited or missing in some of the accident reports, especially in reports regarding accidents that occurred outside the United States; second, at the time this study was completed, several of the reports were preliminary and the full investigation process had not been completed; third, despite the study period spanning 16 yr, the study population resulted in a small sample size, which did not allow for inclusion of interactions in the logistic regression for fatal accidents; fourth, every in-flight emergency had its own set of unique variables that made it difficult to establish a direct comparison between individual fatal and nonfatal accidents with regard to use of CAPS; and finally, the data collection method used by the NTSB in nonfatal accidents relied on self-reporting methods by those pilots regarding pilot characteristics, introducing a potential reporting bias that caused these data to not be used in this study. Despite these limitations, the statistical results clearly showed a considerable benefit when CAPS was used in emergency situations.

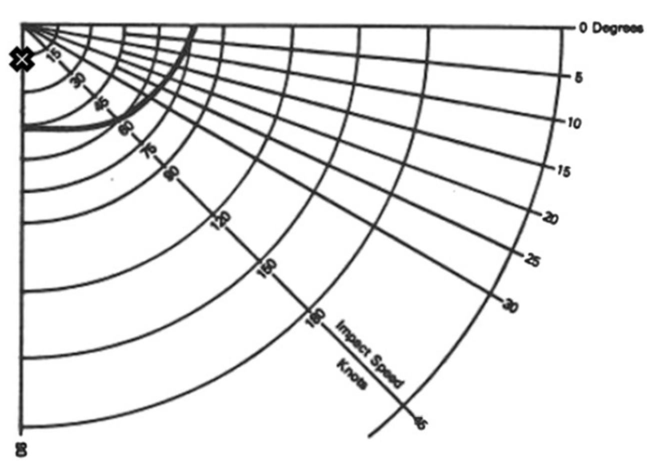

Fig. 4. Comparison of impact of Cirrus SR20 G3 while under fully deployed CAPS parachute (outlined "X") and 1985 NTSB defined GA accident survival envelope (black line). Original radial graph from NTSB 1985 safety report.[16]

In this study, the effectiveness of CAPS was quite significant at reducing the odds of a fatal accident in Cirrus aircraft accidents. Additionally, CAPS was associated with significantly fewer incidents of postcrash fire. Although not directly evaluated in this study, the benefits likely come from a reduction in crash impact forces. The potential significance of BPRS as a safety measure in general aviation must be considered. With GA occupant survival at the forefront of research efforts, the results of this study indicate that BPRS could play a significant role in the next major advance in GA safety.

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