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A HISTORICAL REVIEW OF PILOT INDUCED OSCILLATIONS (PIO) OCCURRENCE

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Abstract. *The increase in technology applied to aircraft control systems has enabled aviation to increasingly adopt the use of automatic flight controls, which means a leap in development, safety, and comfort in aircraft. However, it does not free this segment from old problems like the PIO (Pilot Induced Oscillation), present in the aeronautical environment since the first flights and object of research for some decades. This phenomenon is still far from being solved, since the occurrence of recent accidents with loss of aircraft and lives, being one of the obstacles to the development of new flight control tools and automatic flight control systems. A consistent investigation of this problem and its contributing factors could allow the development of new and safer systems. This work performed a thorough investigation of the bibliography on this subject, in order to build a historical panorama of occurrences of the phenomenon, investigating causes, types of occurrence, flight phase, among other parameters, to isolate patterns and trends in the occurrence for PIO, to map the main relevant ones to be attacked in the development of the future design of flight controls actuation. Due to the robustness of available data, and in order to have a valid sample, all accidents and incidents that occurred in the USA from 1986 to 2013 were mapped, isolating those with any relationship with the PIO phenomenon, in a total of 38 events. Thus, a more pronounced trend was found to occur in small aircraft, with propeller engines, and in the landing flight phase. In this way, the authors hope to demonstrate which factors can increase the proneness for PIO occurrence, contributing as a starting point in future developments, collaborating with aviation safety.*

Keywords: *Pilot Induced Oscillations, Historical Review, Flight Safety*

1. INTRODUCTION

Amongst various factors that make up Flight Quality, one is called “Pilot Induced Oscillation” (PIO) which's taken into careful consideration and has been studied since 1960. PIO can be defined as “non-sustained or non-controllable oscillations resulting from a pilot's direct action to control an aircraft” (Department of Defense Interface Standard, 1995). In other words, PIO is related to the pilot's difficulty in maintaining an aircraft's certain flight altitude, especially during emergency conditions, where the maneuver's gain is higher.

Figure 1 shows a PIO emergence condition obtained in a FAR 25 regional aircraft flight test where the green dash (Synthetic Task) indicates that the pilot should maintain the aircraft while the red dash is the commandeered attitude. This graphic clearly shows that the observed attitude presents a strong oscillation around the condition that should have been maintained by the aircraft.

Studies such as Powers (1982), Liang et al. (2007) or Lu & Jump (2014) show importance of projects that minimize the outcome of PIO in an aircraft without the use of automatic control systems. It is noteworthy that the three articles are from very different times, showing that it is a problem far from completely understood, despite being at stake for a long time.

Toader & Ursu (2014), Acosta et al. (2015), and Schroeder & Chung (2000) show results of an attempt to build a human pilot model, which tried to predict its susceptibility to PIO, while Anderson (1998) and Mitchell, Kish & Seo (1998) present case studies trying to investigate the cause of PIO in real aircraft.

Given the variation in approaches and dates in the cited works, it becomes evident that this phenomenon is still very present in aviation and that with each relevant change on flight command actuation systems this topic should be revisited.

Thus, for the approach to be adequate and the solutions to be more precise it is important to know the occurrences' origins and characteristics. There are countless examples of aeronautical phenomena that were solved or mitigated due to information from previous such occurrences.

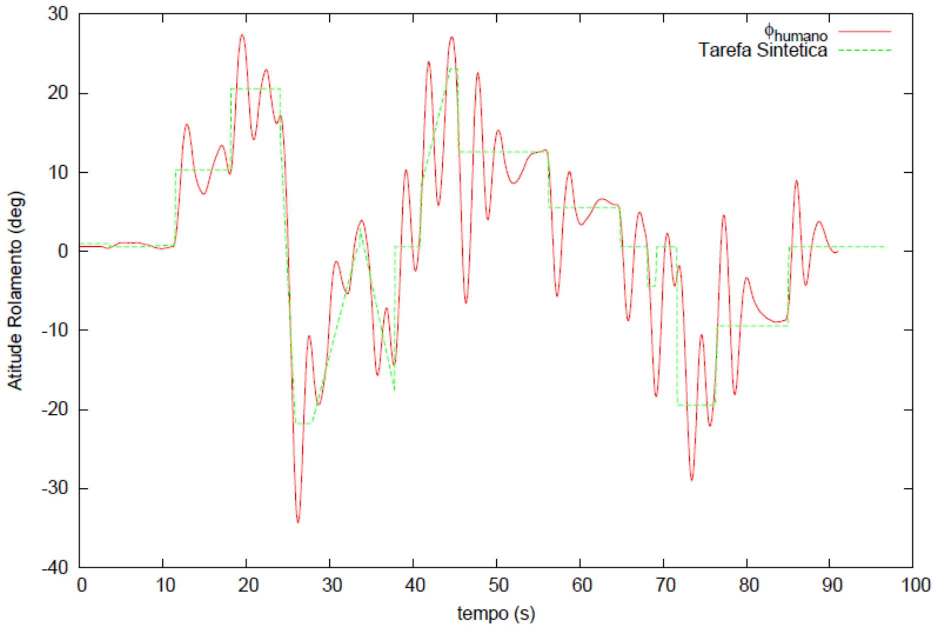


Figure 1. Demonstração de PIO. Celere (2008)

Therefore, this work proposes to investigate the PIO occurrences in recent official flight reports while raising basic information about each one of them such as type of aircraft, stage of flight, pilot experience, among other characteristics of the operation.

The idea is to look for patterns in the different occurrences in order to look for facts or characteristics that may be related to greater susceptibility or severity of PIO occurrences.

2. OBJECTIVES

Due to the wide variety of PIO occurrences, considering types of aircraft, pilots, or dates, this study seeks to survey the occurrences recorded in recent years in order to seek patterns in the different events, while attempting to identify facts that may facilitate these phenomena.

Once these facts are identified, it is expected that there will be greater understanding over such occurrences, leading to the possibility of safer projects less susceptible to this phenomenon, thus acting directly in favor of various aircraft categories' flight safety.

3. METHODOLOGY

The work methodology consists in the search for event reports involving Pilot Induced Oscillation raising some information deemed important for each of the occurrences, namely:

- Date
- Location
- Aircraft Manufacturer
- Pilot's Certificate
- Pilot's Experience
- Wing type
- Wing Configuration
- Engine Type
- Number of Engines
- Flight phase
- Meteorologic Conditions
- Damage
- Fatal Injuries
- Non-fatal Injuries
- Uninjured
- Purpose of flight

Aiming to build a regular and most reliable sample as possible, it was carefully collected data from the NTSB website (National Transportation Safety Board, 2020) using only reports from flights that took place in the United States. The analysis of a single country is due to homogenize the obtained data, and amongst the possible options, was selected the United States for having a denser air network with a lot of public documentation available. Other databases were consulted, but the lack of detailed information and searching options happened to preclude the data acquisition process.

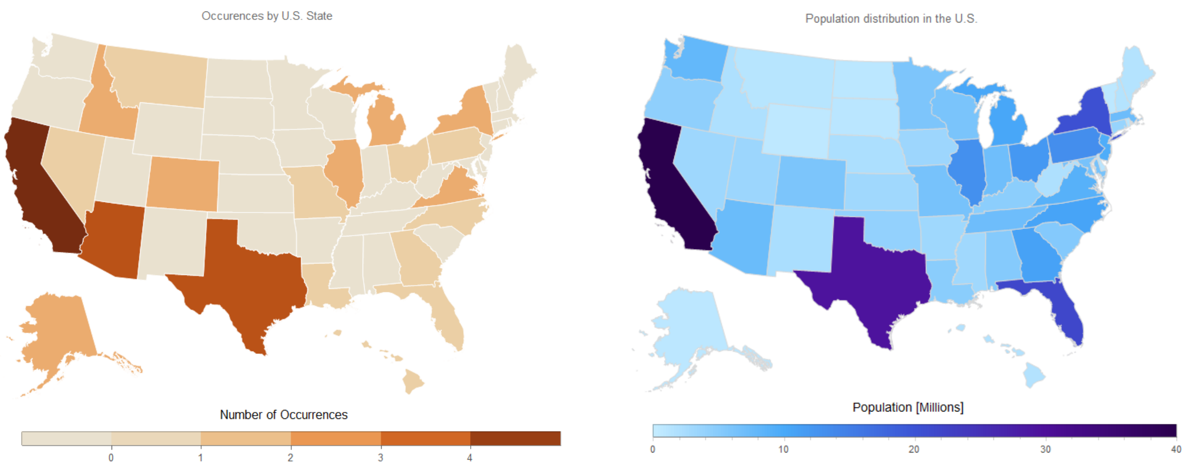
A dataset was then built from these selected reports, and thereafter it was sought to obtain patterns in these aforementioned occurrences in order to search for factors that could make the operation more susceptible to the PIO occurrence phenomenon.

4. RESULTS

This research obtained data from 38 events from 1986 to 2014, all specified according to the parameters listed in section 3 of this text and presented in Table 1 (attached in the final pages).

Initially, it should be noted that data reporting does not follow an adequate standard which makes the proposed analyzes of this work burdensome. In addition, some information seems unreliable such as two same-day occurrences as well as the reported atmospheric conditions being in all cases classified as VMC.

Among the information that was possible to be analyzed, some of them that do not seem to present a defined pattern, e.g., the places of occurrence do not seem to show a reliable pattern since the states with the most occurrences (as can be seen in Figure 2(a)) are also the most populous in the US (displayed in Figure 2(b)), which would be an indication of greater air activity.



(a) (b)

Figure 2. PIO occurrences by state (a) and population by state (b) in the US

However, other parameters show recurring patterns that clearly stand out. Figure 3 shows the distribution of the flight purpose carried out amongst the considered occurrences. Noteworthy is the fact that the vast majority of flights were classified as Personal. This data is corroborated by the numbers presented in Figure 4 which show that the pilot's license is for Private Pilots or Students for the vast majority of the ones involved in incidents, highlighting a strong tendency for occurrences in operations with this purpose.

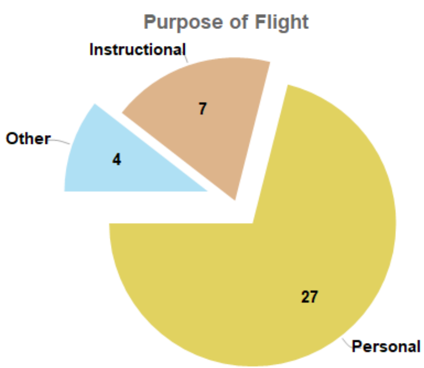


Figure 3. Flight purpuse distribution among PIO events considered

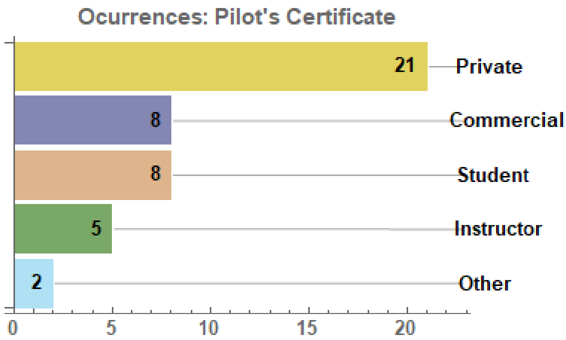


Figure 4. Pilot certificate distribution among PIO events considered

Aircraft with this mission type are mostly powered by a single reciprocating (piston) engine. Figure 5(a) shows this type's large motorization domain in combination with the data in Table 1 (at the end of the text) which presents a clear dominance of single-engine aircraft, thus confirming a greater propensity for PIO occurrence phenomena in airplanes of such category.

Figure 5(b) shows a reasonably equal distribution between High-wing and Low-wing aircraft which also leads to the conclusion that there is no strong correlation since both models are the most common aircraft in general, especially in the aforementioned categories.

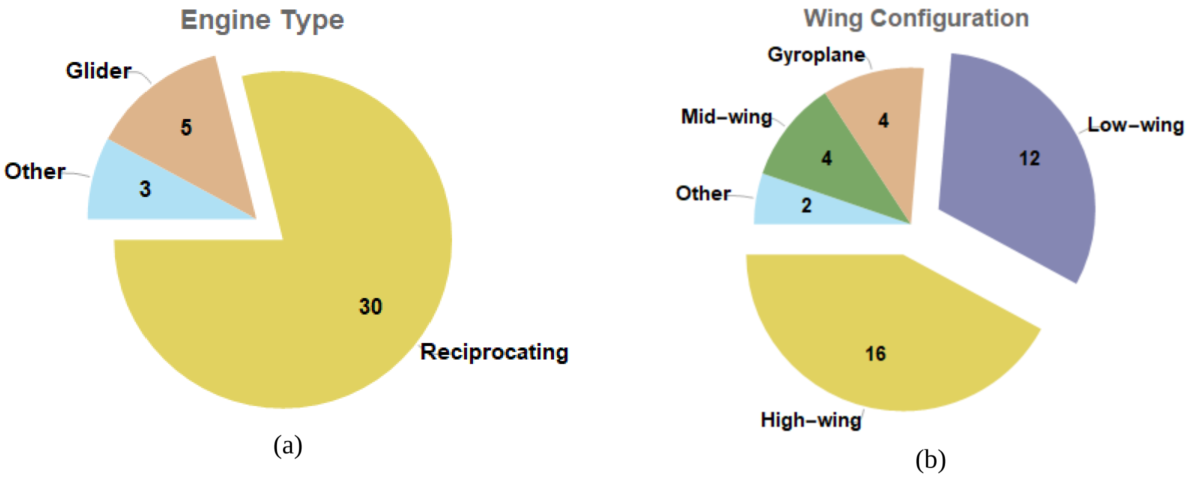


Figure 5. PIO occurrence distribution by Engine Type (a) and Wing Configuration (b) among considered events.

Figure 6, on other hand, shows the distribution of the occurrences by Flight Phase, enhancing the proclivity to happen at the landing phase, which holds almost three-quarters of the total number of occurrences.

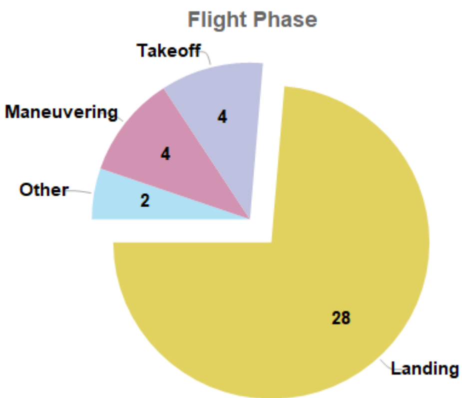


Figure 6. Occurrences' Flight phase distribution among events considered

Figure 7 in turn shows manufacturers' distribution by phenomenon's occurrences. The prevalence of aircraft manufactured by Cessna can be observed, although this fact does not lead to conclusions that compromise the company's products safety as this manufacturer dominates the recreational and instructional aircraft market in the United States. Thus, it is expected that a greater number of Cessna aircraft will end up being affected by a greater portion of such events.

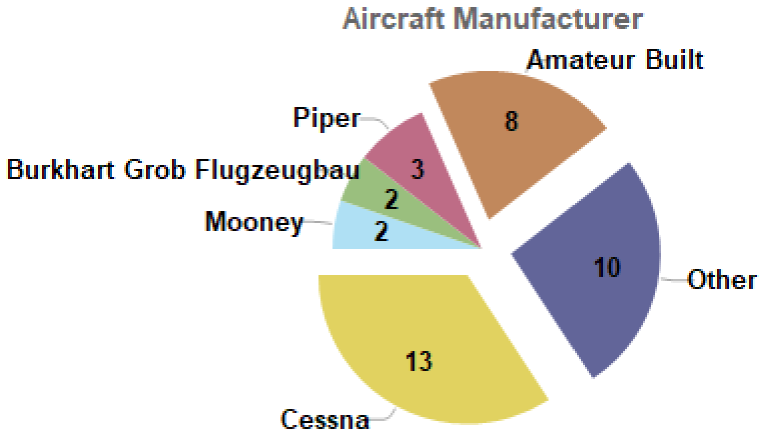


Figure 7. Aircraft manufacturer distribution among PIO events considered

Yet this same figure, alongside Table 1, brings another relevant information before: the unusually large Amateur-Built aircraft numbers involved in these accidents, demonstrating a tendency that should also be taken into account.

Therefore, Figures 5(b) and 7 draw attention to two categories that are less numerous in absolute number but present a worrying percentage in these statistics: Gyroplanes and Gliders, which represent a very small portion of the air network but have expressive numbers within these statistics.

Figure 8, for that matter, shows that the profile of these events changes when analyzing only the cases with crew or passengers injured as the outcome of the phenomenon. Even though it represents few cases, the recurring appearance of Amateur-Built aircraft, specially rotorcraft, in such severe cases is worrisome. Furthermore, the preponderance of Maneuvering and Takeoff phases, along with the previous observations and in opposing to figure 6, may indicate a susceptibility of homemade actuation and flight control systems to PIO, once these phases are critically dependent on those.

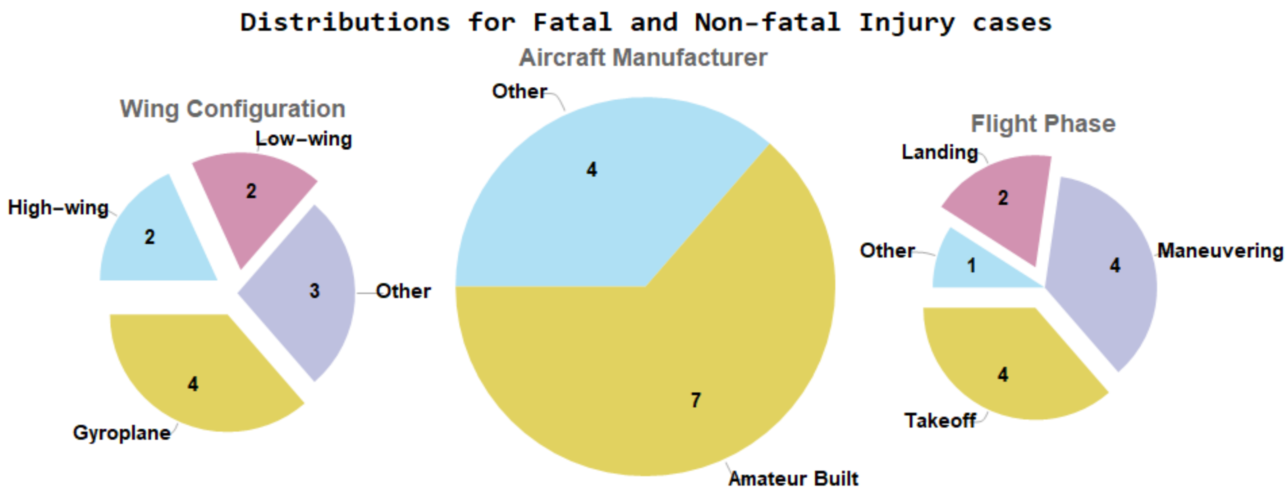


Figure 8. Wing Configuration, Aircraft Manufacturer and Flight Phase for injury outcome cases

Finally, it can be stated from Figure 9 that occurrences of the same outcome of the paragraph above happen more often among experienced pilots, despite a general profile of randomly distributed total Pilot’s Experience (in hours), also observed throughout cases with no harm to crew or passengers. These situations may be influenced by overconfidence, which could possibly be aggravated by the less effective systems mentioned previously.

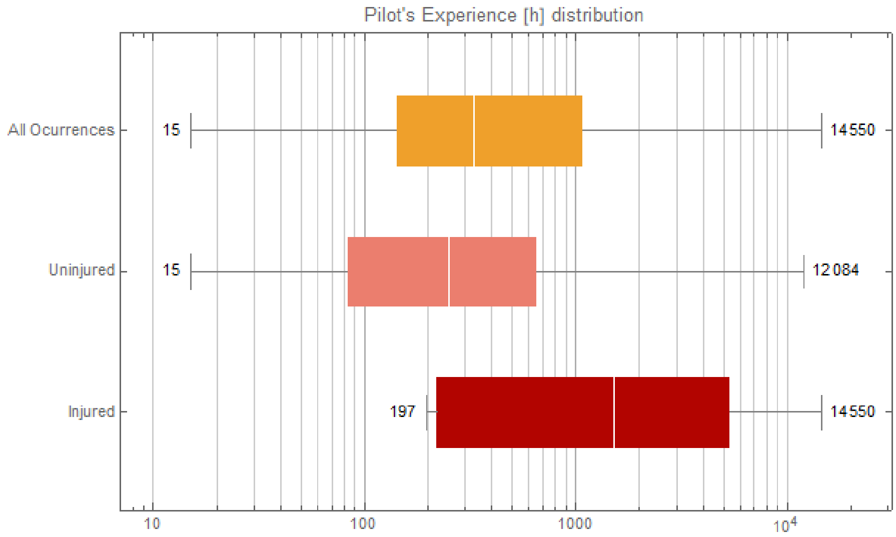


Figure 9. Distribution of Pilots' Experiences among occurrences, by event severity

5. CONCLUSIONS

The presented data reaches some important conclusions regarding the PIO phenomenon propensity based on its history of occurrences. Although data such as location and period of occurrence do not correlate with PIO propensity, they confirm that despite being a long time explored phenomenon, the Aeronautical Industry has not yet managed to solve it, as new technologies show new possible susceptibility sources.

Also, the pilots' experience does not have a great influence since there was a wide margin in these data amongst the considered events.

Meanwhile, flight purpose, pilot's license type, and motorization data show a strong propensity for the PIO occurrences in small recreational or instructional aircraft, which must be considered carefully in studies involving this phenomenon. The flight's phase must also be noted as the occurrences in the landing stage are much more common than in any other.

It is also worth drawing attention to the considerable PIO occurrences in Gyroplanes and Gliders whose participation in the air network is not large although they were seen with expressive frequency in the data.

Finally, it should also be emphasized that the quality of the obtained data regarding aeronautical accidents is not adequate, requiring standardization and greater care by the competent authorities in the handling and reporting of this important information.

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7. RESPONSIBILITY NOTICE

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Table 1. Experimental results for flexural properties of CFRC-4HS and CFRC-TWILL composites.

Date	**Location**	**Aircraft Manuf**	**Pilot**		**Wing**		**Engine**		**Flight Phase**	**Meteor Cond**	**Damage**	**Injures**			**Purpose of Flight**
			Certificate	**Experience (h)**	**Type**	**Config**	**Type**	**Number**				**Fatal**	**Non-fatal**	**None**	
Nov 30, 1986	Wurtsboro, NY	Schweizer	Private	41	Fixed	High-wing	Glider	0	Landing	VMC	Substantial	0	0	1	Personal
Aug 27, 1998	Opa Locka, FL	Piper	Private	337	Fixed	Low-wing	Reciprocating	1	Landing	VMC	Substantial	0	0	6	Personal
Oct 24, 1998	Saratoga Springs, NY	Burkhart Grob Flugzeugbau	Private	128	Fixed	Mid-wing	Glider	0	Landing	VMC	Substantial	0	0	2	Personal
Sep 2, 1989	Bellville, TX	Cessna	Student	20	Fixed	High-wing	Reciprocating	1	Landing	VMC	Substantial	0	0	1	Instructional
Jul 21, 1990	Hearne, TX	Amateur Built	Private	220	Rotary	Gyroplane	Reciprocating	1	Takeoff	VMC	Destroyed	1	0	0	Personal
Nov 4, 1994	Anchorage, AK	McDonnel Douglas	Commercial	12084	Fixed	Low-wing	Turbo Jet	3	Landing	VMC	Substantial	0	0	2	-
Apr 27, 1995	Washington, DC	Airbus	Commercial	4692	Fixed	Low-wing	Turbo Fan	2	Approach	VMC, w/ gusts	Missing	0	0	108	Commercial
Jul 13, 1998	GreatFalls, MT	Piper	Private	340	Fixed	Low-wing	Reciprocating	1	Landing	VMC, w/ gusts	Substantial	0	0	4	Personal
Oct 28, 1999	Cornelia, GA	Cessna	Student	68	Fixed	High-wing	Reciprocating	1	Landing	VMC	Substantial	0	0	1	Instructional
May 24, 2000	Waynesville, OH	Let	Private	250	Fixed	Mid-wing	Glider	0	Landing	VMC, w/ gusts	Substantial	0	0	1	Personal
Jun 29, 2002	Palmer, AK	Amateur Built	Private	204	Rotary	Gyroplane	Reciprocating	1	Takeoff	VMC	Substantial	1	0	0	Personal
Aug 10, 2002	Missing	Schempp-Hirth Flugzeugbau	Private	3084	Fixed	Mid-wing	Glider	0	Takeoff	VMC	Destroyed	1	0	0	Personal
Sep 13, 2002	Reno, NV	Amateur Built	Commercial	12000	Fixed	Low-wing	Reciprocating	1	Maneuver	VMC	Destroyed	1	0	0	Air Race
Oct 12, 2002	Rexburg, ID	Mooney	Private	266	Fixed	Low-wing	Reciprocating	1	Landing	VMC	Substantial	0	0	4	Personal
Jan 1, 2003	Lansing, IL	Amateur Built	-	-	Rotary	Gyroplane	Reciprocating	1	Maneuver	VMC	Destroyed	1	0	0	Personal
Jul 10, 2003	Phoenix, AZ	Cessna	Student	88	Fixed	High-wing	Reciprocating	1	Landing	VMC	Substantial	0	0	1	Instructional
Jul 20, 2003	Tehachapi, CA	Amateur Built	Private	500	Fixed	Tandem	Reciprocating	1	Takeoff	VMC	Destroyed	1	0	0	Personal
Jul 20, 2003	Livermore, CA	Cessna	Private	374	Fixed	High-wing	Reciprocating	1	Landing	VMC	Substantial	0	0	1	Personal
Jul 26, 2003	Page, AZ	Amateur Built	Private	715	Fixed	Low-wing	Reciprocating	1	Landing	VMC	Substantial	0	0	1	Personal
Aug 24, 2003	Brownsville, TX	Cessna	Private	750	Fixed	High-wing	Reciprocating	1	Landing	VMC	Substantial	0	2	0	Personal
Nov 16, 2003	Nelsonia, VA	Amateur Built	Instructor, Commercial	14550	Rotary	Gyroplane	Reciprocating	1	Maneuver	VMC	Destroyed	1	0	0	Personal
Aug 27,2004	Nampa, ID	Luscombe	Instructor, Commercial	4511	Fixed	High-wing	Reciprocating	1	Landing	VMC	Substantial	0	0	2	Personal
Aug 29, 2004	Erie, CO	Cessna	Private	198	Fixed	High-wing	Reciprocating	1	Landing	VMC	Substantial	0	0	1	Personal
Apr 10, 2006	Sanford, NC	Cessna	Private	146	Fixed	High-wing	Reciprocating	1	Landing	VMC	Substantial	0	0	1	Personal
Apr 28, 2006	Honolulu, HI	Cessna	Student	81	Fixed	High-wing	Reciprocating	1	Landing	VMC	Substantial	0	0	1	Instructional
Apr 28, 2006	Willows, CA	Cirrus	Student	72	Fixed	Low-wing	Reciprocating	1	Landing	VMC	Substantial	0	0	1	Instructional
Jun 3, 2006	Llano, TX	Burkhart Grob Flugzeugbau	Student	40	Fixed	Mid-wing	Glider	0	Landing	VMC	Substantial	0	0	1	Instructional
Jun 8, 2006	Fresno, CA	Mooney	Private	695	Fixed	Low-wing	Reciprocating	1	Landing	VMC	Substantial	0	0	1	Personal
Jun 10, 2006	Flagstaff, AZ	Cessna	Private	724	Fixed	High-wing	Reciprocating	1	Landing	VMC	Substantial	0	0	2	Personal
Sep 29, 2006	Pontiac, MI	Beechcraft	Private	331	Fixed	Low-wing	Reciprocating	1	Landing	VMC	Substantial	0	0	2	Personal
Oct 8, 2006	Saint Charles, MO	Cessna	Private	226	Fixed	High-wing	Reciprocating	1	Landing	VMC	Substantial	0	0	2	Personal
Apr 11, 2007	Charlotte, MI	Cessna	Instructor, Commercial	4100	Fixed	High-wing	Reciprocating	1	Landing	VMC, w/ gusts	Substantial	0	0	1	Missing
Apr 28, 2007	Grand Canyon Village, AZ	Cessna	Private	547	Fixed	High-wing	Reciprocating	1	Landing	VMC, w/ gusts	Substantial	0	0	2	Personal

Aug 25, 2007	Manassas, VA	Cessna	Student	15	Fixed	High-wing	Reciprocating	1	Landing	VMC	Substantial	0	0	1	Instructional
Apr 20, 2009	Slaughter, LA	Amateur Built	Student	197	Fixed	High-wing	Reciprocating	1	Landing	VMC	Destroyed	1	0	0	Personal
Jul 6, 2012	New Douglas, IL	Hoffmann Flugzeugbau	Private	184	Fixed	Low-wing	Reciprocating	1	Landing	VMC	Substantial	0	0	1	Personal
Jul 16, 2013	Dove Creek, CO	Bell	Instructor, Commercial	5000	Rotary	Helicopter	Turbo shaft	1	Maneuver	VMC	Substantial	1	0	0	Personal
Sep 6, 2014	San Diego, CA	Piper	Instructor, Commercial	5307	Fixed	Low-wing	Reciprocating	1	Climbing	VMC	Substantial	0	1	0	Personal