# Introduction of Glass Cockpit Avionics into Light Aircraft


**Safety Study**

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National
Transportation
Safety Board

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490 L'Enfant Plaza, S.W.
Washington, D.C. 20594

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**Abstract:** This study used manufacturer records, aircraft investigation information, and a tailored subset of general aviation activity survey data to assess how the transition to electronic primary flight display (PFD) avionics has affected the safety of light aircraft. The study also evaluated the resources and requirements supporting the transition to this new technology. The results of this study suggest that, for the aircraft and time period studied, the introduction of glass cockpit PFDs has not yet resulted in the anticipated improvement in safety when compared to similar aircraft with conventional instruments. Advanced avionics and electronic displays can increase the safety potential of general aviation aircraft operations by providing pilots with more operational and safety-related information and functionality, but more effort is needed to ensure that pilots are prepared to realize that potential. The Federal Aviation Administration (FAA), manufacturers, aviation industry groups, and academia have an established history of collaboration through the FAA Industry Training Standards (FITS) program initiative for supporting aircraft model-specific and scenario-based training techniques that would teach pilots "higher-order thinking skills." However, the FAA has changed the focus of the FITS initiative and has to date relied on manufacturers and commercial vendors to deliver the equipment-specific training originally envisioned for FITS. Adoption of uniform equipment-specific training elements by the FAA to ensure pilots have adequate knowledge of aircraft equipment operation and malfunctions, as well as improved reporting of equipment malfunctions and service difficulties, is likely to improve the safety of general aviation operations beyond those involving aircraft with glass cockpit displays. However, such actions are particularly important in order to achieve the potential safety benefits associated with advanced cockpit technologies in light aircraft.

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# Abbreviated Terms

| | |
|---|---|
| **AC** | advisory circular |
| **ADAHRS** | Air Data Attitude Heading Reference System |
| **AERI** | Airmanship Education Research Initiative |
| **AFM** | aircraft flight manual |
| **AGATE** | Advanced General Aviation Transport Experiments |
| **AHRS** | attitude and heading reference system |
| **AOPA** | Aircraft Owners and Pilots Association |
| **ATP** | airline transport pilot |
| **CAB** | Civil Aeronautics Board |
| **CB** | circuit breaker |
| **CFR** | *Code of Federal Regulations* |
| **CPS** | certification process study |
| **CRT** | cathode ray tube |
| **FAA** | Federal Aviation Administration |
| **FITS** | FAA Industry Training Standards |
| **GA** | general aviation |
| **GAATAA** | *General Aviation and Air Taxi Activity and Avionics Survey* |
| **GAMA** | General Aviation Manufacturers Association |
| **GIFD** | Garmin Integrated Flight Display |
| **G-LOC** | G-induced loss of consciousness |
| **GPS** | global positioning system |
| **IFR** | instrument flight rules |
| **IMC** | instrument meteorological conditions |
| **MFD** | multifunction flight display |
| **NASA** | National Aeronautics and Space Administration |
| **nm** | nautical miles |
| **NTSB** | National Transportation Safety Board |

| | |
|---|---|
| **PFD** | primary flight display |
| **PTS** | Practical Test Standards |
| **SDR** | service difficulty report |
| **SFAR** | special federal aviation regulation |
| **TAA** | technically (also, technologically) advanced aircraft |
| **TSO** | technical standard order |
| **TSRV** | Transport Systems Research Vehicle |
| **VFR** | visual flight rules |
| **VMC** | visual meteorological conditions |

# Executive Summary

In a span of only a few years, the cockpits of new light aircraft have undergone a transition from conventional analog flight instruments to digital-based electronic displays commonly referred to as "glass cockpits." These new displays integrate aircraft control, autopilot, communication, navigation, and aircraft system monitoring functions, applying technology previously available only in transport-category aircraft. The enhanced function and information capabilities of glass cockpits represent a significant change and potential improvement in the way general aviation pilots monitor information needed to control their aircraft. The National Transportation Safety Board (NTSB) initiated this study to determine if the transition to glass cockpits in light aircraft has improved the safety record of those aircraft.

Three different approaches were used in this study. First, a retrospective statistical analysis of manufacturer records, aircraft investigation information, and activity survey data was conducted to compare the accident experience of recently manufactured light single-engine airplanes equipped and not equipped with glass cockpit displays. Second, an evaluation of glass cockpit training requirements and resources was conducted to characterize the training and to identify areas for potential safety improvement. Finally, accident cases were reviewed to identify emerging safety issues associated with the introduction of glass cockpit displays into this class of aircraft.

The statistical analysis found that for 2002–2008, light single-engine aircraft equipped with glass cockpit displays experienced lower total accident rates—but higher fatal accident rates—than the same type of aircraft equipped with conventional analog instrumentation. Accidents involving glass cockpit aircraft were more likely to be associated with personal/business flights, longer flights, instrument flight plans, and single-pilot operations, while accidents involving conventional analog cockpit aircraft were more likely to be associated with instructional flights, shorter flights, and two-pilot operations. Accident pilots flying glass cockpit equipped aircraft were found to have higher levels of pilot certification and more total flight experience than those flying conventional aircraft.

The evaluation of light aircraft glass cockpit training requirements found that the Federal Aviation Administration (FAA) has been updating training handbooks and test standards to incorporate generic information about electronic flight instrument displays. However, current airman knowledge written tests (such as private pilot, instrument rating, commercial pilot, and flight instructor certificates) do not assess pilots' knowledge of the functionality of glass cockpit displays. In addition, the FAA has no specific training requirements for pilots operating glass cockpit-equipped light aircraft. The lack of equipment-specific training requirements from the FAA results in a wide range of initial and recurrent training experiences among pilots of glass cockpit aircraft. With the exception of training provided by airframe manufacturers with the purchase of a new aircraft, pilots must currently seek out and obtain equipment-specific glass cockpit training on their own.

The review of accidents involving light aircraft equipped with glass cockpits found that pilots' experiences and training in conventional cockpits do not prepare them to safely operate the complex and varied glass cockpit systems being installed in light aircraft today. Further, the lack of information provided to pilots about glass cockpit systems may lead them to misunderstand or misinterpret system failures. As a result, there is a need for new training procedures and tools to ensure that pilots are adequately prepared to safely operate aircraft equipped with glass cockpit avionics.

The results of this study suggest that the introduction of glass cockpits has not resulted in a measurable improvement in safety when compared to similar aircraft with conventional instruments. The analyses conducted during the study identified safety issues in two areas:

- The need for pilots to have sufficient equipment-specific knowledge and proficiency to safely operate aircraft equipped with glass cockpit avionics.
- The need to capture maintenance and operational information in order to assess the reliability of glass cockpit avionics in light aircraft.

As a result of this safety study, the NTSB made six recommendations to the FAA: five address training requirements and one addresses reporting requirements.

# Chapter 1: Background

## Introduction of Glass Cockpit Displays into Light Aircraft

In a span of only a few years, the cockpits of light aircraft[1] have undergone a transition from conventional flight instruments to integrated, computerized displays commonly referred to as glass cockpits.[2] This change has occurred rapidly. Glass cockpit avionics first started to appear in light aircraft as noncertified systems installed in experimental and amateur-built aircraft. Cirrus Design Corporation began the transition to glass cockpits in Federal Aviation Administration (FAA)-certified light aircraft in 2003 when it started delivering single-engine piston airplanes with electronic primary flight displays (PFD). The new displays quickly became standard equipment in the company's SR20 and SR22 models. Cessna Aircraft Company, Piper Aircraft Incorporated, Mooney, and Hawker Beechcraft soon followed, and data from the General Aviation Manufacturers Association (GAMA) indicate that by 2006, more than 90 percent of new piston-powered, light airplanes were equipped with full glass cockpit displays.[3] In addition to flight instruments, the previously separate components for autopilot, communication, navigation, and aircraft systems have been integrated into glass cockpit displays to provide flight management, terrain and traffic avoidance, enhanced/synthetic vision displays, and upset recovery functions. Autopilots and global positioning systems (GPS) in particular have become standard components in the avionics systems of light aircraft. Several manufacturers of glass cockpit displays now produce displays with supplemental type certification for retrofit installation in existing aircraft, suggesting that the number of aircraft equipped with full glass cockpits will continue to grow.[4] The introduction of this advanced technology into light aircraft has brought with it a new set of potential safety concerns to the National Transportation Safety Board (NTSB), such as equipment design and operation; pilot performance and training; and new accident investigation techniques.

This study was designed to test the hypothesis that the transition to glass cockpit avionics in light aircraft will improve the safety of their operation. The study also sought to evaluate the resources and requirements supporting the transition to this new technology. To accomplish these goals, this study included three separate analyses, as described in this study report:

[1] The term "light aircraft" is used throughout this report in reference to aircraft with a maximum gross weight less than 12,500 pounds and certified under 14 *Code of Federal Regulations* Part 23. The statistical comparisons included in this study were limited to a specific group of light aircraft: the single-engine piston aircraft typically used in general aviation operations.

[2] The term "glass cockpit" refers to the use of computer screens rather than analog gauges.

[3] *General Aviation Airplane Shipment Report, End-of-Year 2006* (Washington, DC: General Aviation Manufacturers Association, 2007) indicates that 92 percent of the 2,540 piston airplanes delivered during 2006 were equipped with glass cockpit electronic flight displays.

[4] This study was limited to factory-installed cockpit displays and did not include any analyses of retrofit installations of glass cockpit equipment.

- A retrospective statistical analysis of accidents and activity data from two cohorts[5] of recently manufactured airplanes produced with and without electronic PFDs, conducted to identify any differences in activity, accident rates, or accident circumstances associated with glass cockpit displays.
- A qualitative review of FAA and industry training resources and requirements related to glass cockpit displays conducted to characterize the training and identify areas for potential safety improvement.
- A review of accident case studies conducted to identify emerging safety issues associated with the introduction of glass cockpit displays into this class of aircraft.

Changing from conventional instruments to glass cockpit displays has created new challenges for interface and display design with implications for the way pilots monitor information in the cockpit. However, the differences between conventional and glass cockpit displays extend beyond appearance (figures 1 and 2). Each of the conventional round-dial instruments relies on electromechanical, pneumatic, or pressure-sensitive components to generate and display specific aircraft performance and control parameters, such as airspeed, altitude, heading, pitch and bank attitude, rate of climb, and rate of turn. In contrast, glass cockpit displays rely on computerized systems that integrate multiple data inputs and controls. Glass cockpit displays can present more information in the space required for conventional instrument panels, but the increase in information places greater demands on pilot attention and creates a risk of overloading pilots with more information than they can effectively monitor and process. The complexity of the integrated computerized systems that drive glass cockpit displays may also limit pilots' understanding of the functionality of the underlying systems.

The typical light aircraft glass cockpit consists of at least two displays: a primary flight display, or PFD, and a multifunction flight display (MFD). A PFD replaces individual flight instruments to display the airspeed, altitude, attitude, and rate information that pilots use for aircraft control.[6] As the name "multifunction" suggests, a wide range of supplementary and status information can be selected for display on an MFD. Typical MFDs supplement or replace discrete navigation, communication, weather displays, and system status information, such as engine and fuel gauges. They can also display navigational charts, airport diagrams, and electronic checklists. For this study, a glass cockpit aircraft is defined as having at least a PFD.[7]

[5] The term "cohort" is used in statistics to refer to a group of subjects, in this case aircraft, that share similar characteristics. The aircraft cohorts in this study were all single-engine, piston-powered airplanes manufactured during the same 5-year period, with either glass or conventional cockpit instruments.

[6] Electronic PFDs replace pressure-sensitive mechanical instruments with an air data computer to process static and dynamic pressure values for airspeed, altitude, and associated rate information. Computerized PFDs also replace conventional mechanical gyroscopic flight instruments with an attitude and heading reference system (AHRS) that uses sensors in three axes to calculate heading, attitude, and yaw information. Integrated PFD processing subsystems are usually further integrated with aircraft autopilot and navigation systems.

[7] Some light aircraft with conventional flight instruments have been manufactured or retrofitted with MFDs and/or GPS equipment with moving map displays. In this study, the classification of a glass cockpit is based on the primary flight instrument display, consistent with the industry consensus definition of an integrated cockpit/flightdeck provided in *GAMA Publication 12 - Recommended Practices and Guidelines for an Integrated Cockpit/Flightdeck in a 14 CFR Part 23 Airplane:* "…at a minimum, an integrated cockpit/flightdeck must include electronic display and control of all primary airplane airspeed, altitude and attitude instruments, and all essential navigation and communication functions." See <http://www.gama.aero/files/gama_publication_12_p23cockpit_april_2005_pdf_498cadb978.pdf>.

**Figure 1.** Example of a light aircraft conventional cockpit.

**Figure 2.** Example of a light aircraft glass cockpit.

NTSB accident investigators now encounter glass cockpit-equipped aircraft more frequently than in the past, and the onboard data recording capabilities in many of these displays have enabled investigators to obtain detailed recordings that document specific actions, events, or equipment operations that would not be available with conventional instruments. However, not all manufacturers include recording capabilities in their equipment, so these records are not always available. Further, conventional analog instruments can be physically examined[8] for indications of preaccident operation, but the software-based systems that drive electronic displays leave no evidence to indicate how they were functioning before or during an accident unless data are intentionally recorded.[9]

## History of Advanced Cockpit Avionics

Electronic flight displays were first developed for military applications in the 1960s, and by the 1970s, computer-driven cathode ray tube (CRT) displays began replacing electromechanical instruments in commercial transport-category airplanes. The use of CRTs led to the moniker "glass cockpit," which is still commonly applied to aircraft that incorporate digital flight displays, even though lighter weight, liquid-crystal-display or light-emitting diode technologies have replaced CRTs.

In 1974, the National Aeronautics and Space Administration (NASA) started testing a full glass cockpit in a specially equipped Boeing 737 as part of the Transport Systems Research Vehicle (TSRV) project. The typical transport-category airplane cockpit at that time was crowded with more than 100 instruments and gauges. Integrated displays were developed in conjunction with increased automation as a means of reducing some crew tasks and combining aircraft control, position, and status information into a few space-saving displays.[10] Much of NASA's TSRV work made its way into the design of cockpits of civilian transport-category aircraft with the introduction of the Boeing 757/767.

Although the airframe and engine systems in light aircraft are not nearly as complex, the glass cockpit displays now being used in these aircraft share similarities with their transport-category predecessors, such as integrated flight management and autopilot functions, communications, and detailed navigation displays. The range of features offered in the cockpit displays that are now being introduced into light aircraft has moved ahead of many of their transport-category counterparts to include infrared imaging systems, synthetic vision, highway-in-the-sky navigation, and upset recovery capabilities.

### Advanced Avionics in General Aviation

Much of the research leading to the recent introduction of glass cockpit displays into light aircraft developed from the NASA-sponsored Advanced General Aviation Transport Experiments (AGATE) consortium. In response to decreasing general aviation activity and aircraft sales during the 1980s and 1990s, NASA, the FAA, the general aviation industry, and academia joined

[8] Such evidence includes rotational scoring on gyros or witness marks from needles hitting the face of instrument displays during impact.

[9] Chapter 6 of this report contains more discussion of data recording functions in electronic flight displays.

[10] L. E. Wallace, *Airborne Trailblazer: Two Decades with NASA Langley Boeing 737 Flying Laboratory*, NASA SP-4216 (Washington, DC: National Aeronautics and Space Administration, 1994).

to form AGATE as the first step in pursuit of a new transportation system based on light aircraft. The goal of AGATE was to develop new and affordable airframe and avionics technology, certification methods, and flight training systems for the next generation of light aircraft used in general aviation by adapting technology previously available only in transport-category aircraft operated by commercial airlines.[11] At the core of the initiative was the vision of replacing short-haul, intercity air carrier flights with personal flights in small aircraft that would be so easy to fly that almost anyone "could get in, select a destination, and go" with minimal training and expense.[12] AGATE-sponsored research resulted in new certification and design guidelines for affordable composite materials, cockpit displays, and avionics that are now used in such airplanes as the Cirrus Design Corporation SR20/22 series, the Diamond Aircraft DA40 series, and new models of very light jets.[13] The AGATE program ended in 2001 before the real-world effects of many of these changes could be assessed.

With the introduction of this new technology, the FAA and aircraft manufacturers anticipated a need to provide specific training for general aviation pilots transitioning from conventionally equipped aircraft to those with digital flight displays. To that end, the FAA worked with academic and industry partners like the Embry-Riddle Aeronautical University, the University of North Dakota, and participating manufacturers to develop the FAA Industry Training Standards (FITS) program. The original FITS program plan advocated aircraft type-specific training and the use of scenario-based techniques to teach pilots the "higher-order thinking skills" required to safely operate high performance aircraft with advanced automation capabilities. To date, several manufacturers and national training providers have developed FITS-accepted training courses. In addition, the FAA is incorporating FITS principles, such as scenario-based training, decision-making techniques, and learner-centered grading, into its training materials. Using a similar collaborative approach, the FAA has also worked closely with manufacturers and industry groups to produce new and/or updated manuals that discuss electronic flight displays. Such manuals include the *Advanced Avionics Handbook*,[14] *Instrument Flying Handbook*,[15] and *Pilot's Handbook of Aeronautical Knowledge*.[16]

## Previous Lessons Learned

The applicability of air carrier experience may be limited due to the diversity in general aviation equipment, operations, and pilot population. Nevertheless, the large body of research into human-machine interaction and aircraft control issues stemming from the increase in flight

[11] E. M. Bolen, president of the General Aviation Manufacturers Association, statement before the Subcommittee on Science, Technology, and Space, U.S. Senate Commerce Committee (April 24, 2001).

[12] "Affordable Alternative Transportation: AGATE – Revitalizing General Aviation," *NASA Facts*, July 2, 1996, FS-1996-07-02-LaRC (Hampton, Virginia: National Aeronautics and Space Administration, 1996), available at <http://www.nasa.gov/centers/langley/news/factsheets/AGATE.html> (accessed September 1, 2009).

[13] K. Gale, *The Advanced General Aviation Transport Experiments (AGATE) Alliance, AGATE Alliance Commercialization Impact Report, 1995-2000,* NASA AGATE-WP 12.0-120011-114 (San Francisco, California: STARnet, 2002).

[14] *Advanced Avionics Handbook*, FAA-H-8083-6 (Washington, DC: Federal Aviation Administration, 2009).

[15] *Instrument Flying Handbook*, FAA-H-8083-15A (Oklahoma City, Oklahoma: Federal Aviation Administration, AFS-600: 2008).

[16] *Pilot's Handbook of Aeronautical Knowledge*, FAA-H-8083-25A (Oklahoma City, Oklahoma: Federal Aviation Administration, AFS-600: 2008).

deck automation in transport-category aircraft during the 1980s and 1990s holds lessons for what can be expected in light aircraft. In general, advances in automated control systems have led to substantial improvements in equipment reliability and have increased the precision of complex aircraft control functions. Airlines quickly realized that glass cockpit avionics, and the automated control and flight management functions that accompanied them, would increase efficiency and decrease operating costs. New displays also provided crews with far more status and planning information. Further, glass cockpit displays are generally lighter and cheaper to maintain than the multiple systems they replaced, and the integration of automation with aircraft systems allowed aircraft to be certified for operation with a two-person crew.[17]

Flight crew response to the new technology was also for the most part positive. However, the overall effect of increased automation and system integration was to shift workload from task performance to the higher level cognitive tasks of planning and systems monitoring. The new technology generally reduced workload demands on the crew, but in some cases, the greatest reductions occurred during times when workload was already low. In addition, crews began reporting that glass cockpit equipment could actually increase workload during emergencies and times of high demand because they were often forced to reconfigure the navigation and flight management systems in flight to modify routing or approach information.[18] Pilot reports and observational research also identified crew difficulties when transitioning to glass cockpit aircraft[19] and occasional confusion with the operation of integrated systems, even among pilots who reported feeling as though they understood their systems well.[20]

Even before electronic displays became common, anecdotal reports from flight crews, as well as findings from accidents and research, revealed potential problems if pilots relied too heavily on automated systems or if they misunderstood automated system behavior.[21] In its findings of probable cause on the 1984 Scandinavian Airlines accident at John F. Kennedy Airport,[22] the NTSB identified the crew's over-reliance on the aircraft auto throttle system and issued the following recommendation to the FAA:

> Apply the findings of behavioral research programs and accident/incident investigations regarding degradation of pilot performance as a result of automation to modify pilot

[17] A presidential task force determined in 1981 that transport-category aircraft such as the MD80 and Boeing 757/767 could be safely flown with only a two-person crew because automation could be used to replace flight engineer duties. See J. L. McLucas, F. J. Drinkwater, and H. W. Leaf, *Report of the President's Task Force on Aircraft Crew Complement* (Washington, DC: 1981).

[18] E. L. Wiener, *Human Factors and Advanced Technology (Glass Cockpit) Transport Aircraft*, NASA-TR 177528 (NASA Ames Research Center: National Aeronautics and Space Administration, 1989).

[19] N. B. Sarter, D. D. Woods, and C. E. Billings, "Automation Surprises," G. Salvendy, ed., *Handbook of Human Factors and Ergonomics*, 2nd ed. (New York: Wiley, 1997).

[20] N. B. Sarter and D. D. Woods, "How in the World Did We Get Into That Mode? Mode Error and Awareness in Supervisory Control," *Human Factors*, vol. 37 (1995), pp. 5-19.

[21] For example, see E. L. Wiener and R. E. Curry, *Flight-Deck Automation Promises and Problems*, NASA-TM-81206 (NASA Ames Research Center: National Aeronautics and Space Administration, 1980).

[22] *Scandinavian Airlines System, Flight 90, McDonnell Douglas DC-10-30, John F. Kennedy International Airport, Jamaica, New York, February 28, 1984*, Aircraft Accident Report NTSB/AAR-84/15 (Washington, DC: National Transportation Safety Board, 1984).

training programs and flight procedures so as to take full advantage of the safety benefits of automation technology. (A-84-123)[23]

Subsequent fatal air carrier accidents, like the April 26, 1994, crash of a China Airlines Airbus 300-600 in Nagoya, Japan, and the December 20, 1995, American Airlines Boeing 757 crash near Cali, Colombia, drew further attention to the issues of human interaction with computerized aircraft systems, cockpit displays, and associated data input and communication functions. In response to these issues, the FAA commissioned a comprehensive review of crew interfaces with advanced flight deck systems. Among the findings were such vulnerabilities as the flight crews' inadequate understanding of complex flight deck systems and their occasionally inappropriate decisions about how and when to use automation.[24]

A 2001 study conducted by the U.S. Army Aeromedical Research Laboratory[25] examined how the Army's move to glass cockpits had affected safety in real-world flight operations. The study analyzed accident rates of four models of helicopters with conventional and glass cockpit configurations. Study results indicated a significantly higher accident rate for the glass cockpit configuration group than for the conventional cockpit group. The authors suggested that the findings provided reason for concern and discussed several possible reasons for the difference, including the possibility that concurrent mission and equipment changes rather than cockpit design alone contributed to higher accident rates. Subsequent survey research suggested that even though pilots preferred the glass cockpit design and believed it improved safety, they found learning to use the displays and maintaining their proficiency to be more difficult and reported issues of higher cognitive workload in glass cockpit aircraft than in those with a conventional design.[26]

## General Aviation Research to Date

Less research is available specific to the safety consequences of glass cockpit avionics in light aircraft, mostly due to their recent introduction and a general lack of available data. In 2003, a joint FAA and industry group published a study of technically advanced aircraft (TAA) issues[27] based on subject matter expert evaluations and reviews of case studies using the Human

[23] Closed in 1991, "Acceptable Alternate Action," based on several actions by the FAA that included (1) collaborating with NASA and aviation industry representatives in the development of a comprehensive *National Plan for Aviation Human Factors*; (2) issuing Advisory Circular (AC) 120-35B, *Line Operational Simulations: Line-Oriented Flight Training, Special Purpose Operational Training, Line Operational Evaluation*; and (3) issuing an advanced qualification program special federal aviation regulation (SFAR) establishing alternative methods of complying with training requirements of 14 CFR Parts 121 and 135 to incorporate advanced training methods and techniques.

[24] K. Abbott and others, *The Interface Between Flightcrews and Modern Flight Deck Systems*, Federal Aviation Administration Human Factors Team Report (Washington, DC: Federal Aviation Administration, 1996).

[25] C. Rash and others, *Accident Rates in Glass Cockpit Model U.S. Army Rotary-Wing Aircraft*, Army Aeromedical Research Laboratory Final Report (Fort Rucker, Alabama: U.S. Army Aeromedical Research Laboratory, 2001).

[26] C. Rash and others, *A Comparison of AH-64 Pilot Attitudes Toward Traditional and Glass Cockpit Crewstation Designs*, Army Aeromedical Research Laboratory Final Report (Fort Rucker, Alabama: U.S. Army Aeromedical Research Laboratory, 2002).

[27] *General Aviation Technically Advanced Aircraft, FAA-Industry Safety Study: Final Report of TAA Safety Study Team*, <http://www.faa.gov/training_testing/training/fits/research/media/TAA Final Report.pdf> (Washington, DC: Federal Aviation Administration, 2003). This report defines a TAA as follows: "A General Aviation aircraft that contains the following design features: Advanced automated cockpit such as MFD or PFD or other variations of a Glass Cockpit, or a traditional cockpit with GPS navigation capability, moving map display and autopilot."

Factors Analysis and Classification System (HFACS).[28] The study was prompted by an industry observation that accident numbers for TAAs were no better than for conventionally equipped aircraft—contrary to expectation. Most safety problems identified in the study were attributed to pilot judgment errors rather than issues associated with pilot-equipment interaction. Unfortunately, findings from the study are of limited applicability to the current generation of aircraft because none of the accident aircraft included in the study was equipped with a PFD.

A 2005 analysis by the Aircraft Owners and Pilots Association (AOPA) Air Safety Foundation[29] came to conclusions similar to those in the 2003 FAA report and concluded that the TAA accident record at the time was generally similar to that of legacy aircraft. Like the FAA's TAA study, the report attributed most accidents to faulty pilot judgment rather than problems with the avionics or the pilot-aircraft interface. In a 2007 followup study,[30] the AOPA Air Safety Foundation compared accidents involving TAAs to general aviation accidents from 2003 through 2006. This study suggested that the number of TAAs involved in accidents was smaller than would be expected, given the percentage of these aircraft in the overall population: while TAAs made up 2.8 percent of the aircraft fleet, they were involved in 1.5 percent of total accidents and 2.4 percent of fatal accidents. Additional results suggested that differences in aircraft usage might have contributed to the distribution of accidents. For example, the percentage of accidents involving weather was higher for TAAs, and the percentage of accidents during takeoff and climb was lower.[31] These findings would be expected if the TAAs were used for long distance, point-to-point flying rather than primary flight training. The AOPA studies were limited because comparisons were made to the diverse group of aircraft used in general aviation operations, and the flight-hour or usage data needed to determine differences in exposure or to verify the resulting conclusions were not available.

## General Aviation Safety Record

The annual number of general aviation accidents, fatal accidents, and fatalities occurring in the United States has been decreasing for many years. In 2008, U.S. general aviation experienced the lowest number of fatal accidents and its second-lowest number of total accidents since 1944.[32] As shown in figure 3, annual general aviation accident and fatal accident totals

[28] For an explanation of the HFACS classification, see S. A. Shappell and D. A. Wiegmann, *The Human Factors Analysis and Classification System—HFACS*, DOT/FAA/AM-00/7 (Washington, DC: Federal Aviation Administration, 2000).

[29] *Technically Advanced Aircraft: Safety and Training* (Frederick, Maryland: Aircraft Owners and Pilots Association, Air Safety Foundation, 2005).

[30] *Technically Advanced Aircraft: Safety and Training* (Frederick, Maryland: Aircraft Owners and Pilots Association, Air Safety Foundation, 2007).

[31] The AOPA Air Safety Foundation report was based on data extracted from the NTSB's aviation accident database; however, the reported accident categories are assigned by Air Safety Foundation analysts and may differ from the NTSB findings of probable cause.

[32] Based on data compiled from *Annual Review of U.S. General Aviation Accidents Occurring in Calendar Year 1968* (Washington, DC: National Transportation Safety Board, 1969); *Annual Review of Aircraft Accident Data, U.S. General Aviation Accidents Calendar Year 1979*, NTSB/ARG-81-1 (Washington, DC: National Transportation Safety Board, 1981); *Annual Review of Aircraft Accident Data, U.S. General Aviation Accidents Calendar Year 1989*, NTSB/ARG-93/01 (Washington, DC: National Transportation Safety Board, 1993); and National Transportation Safety Board, *Aviation Accident Statistics: Accidents, Fatalities, and Rates, 1989–2008, U.S. General Aviation* (available at <http://www.ntsb.gov/aviation/Table10.htm>).

declined from 1999 through 2008. Without any additional information, such as activity data, this trend might be interpreted as being due in part to the introduction of new, advanced aircraft technologies.

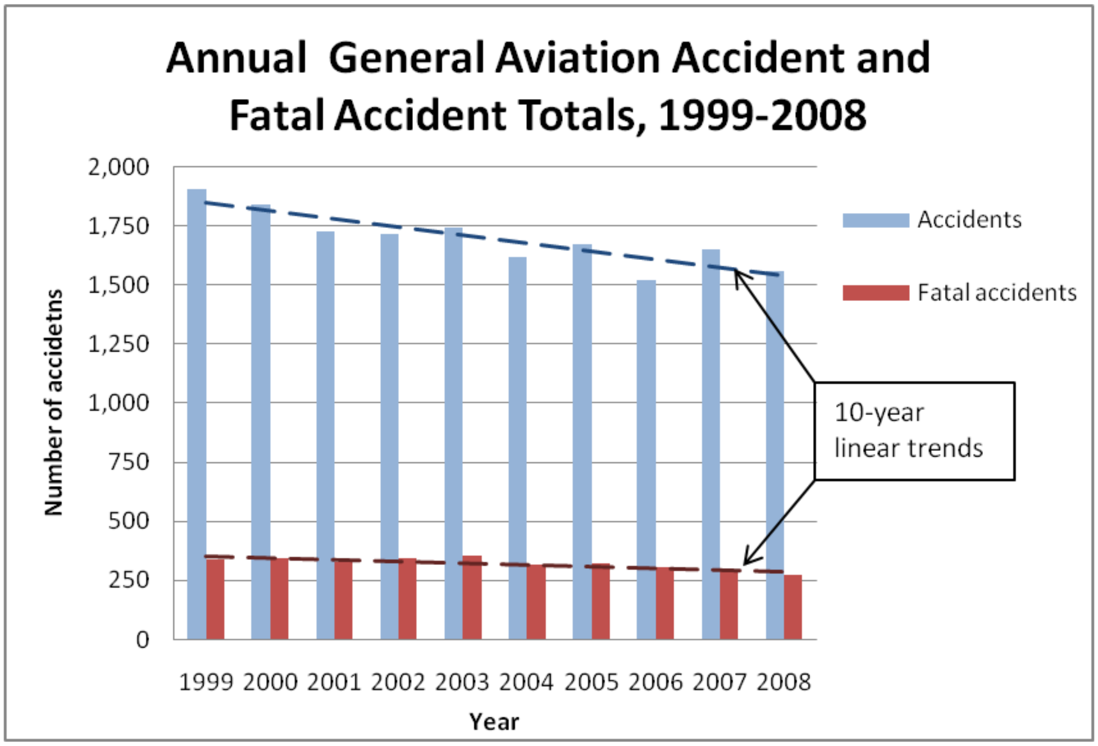



**Figure 3.** Annual general aviation accident and fatal accident totals, 1999–2008.

However, general aviation activity has also been decreasing. Normalizing the number of accidents by annual exposure data—in this case, the FAA's annual general aviation flight hour estimates—results in a rate that more accurately represents safety risk.[33] In contrast to annual accident totals, general aviation accident rates and fatal accident rates per 100,000 flight hours have remained relatively steady over the last decade. Annual accident rates and trends from 1999 through 2008 are presented in figure 4.

[33] See chapter 2, *Study Design and Methodology*, for a detailed discussion of the FAA's General Aviation and Air Taxi Activity and Avionics (GAATAA) Survey.

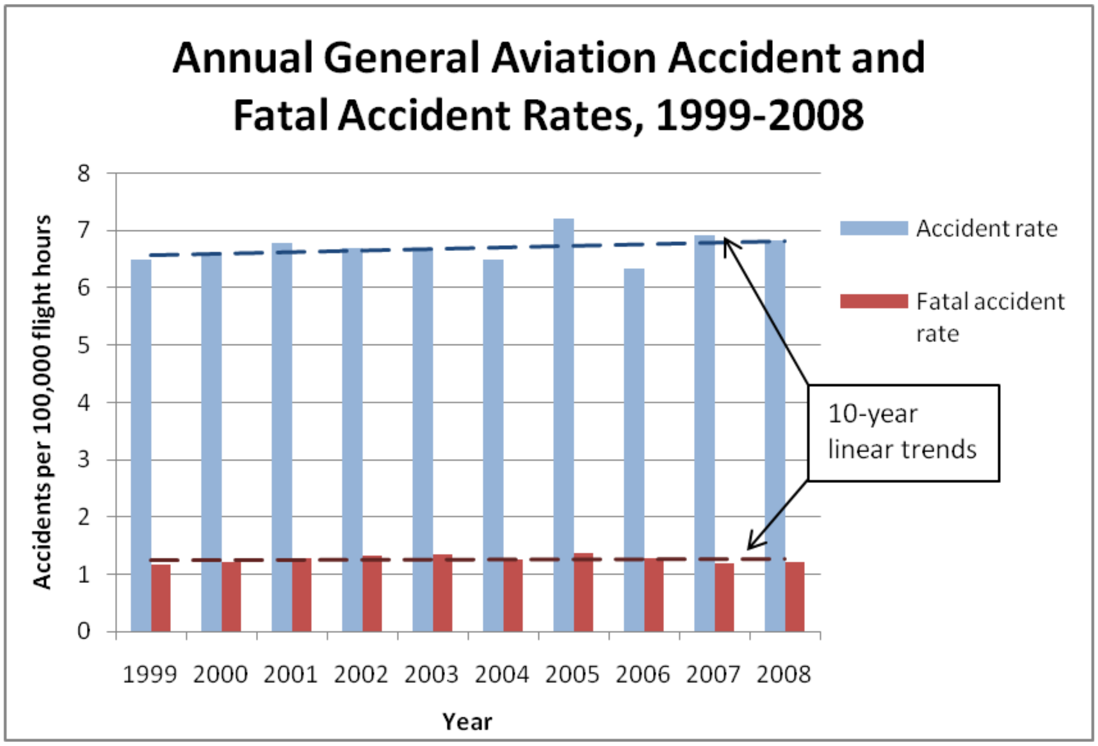



**Figure 4.** Annual general aviation accident and fatal accident rates, 1999–2008.

It should be noted that the diversity of aircraft, operations, and pilots comprising U.S. general aviation can easily mask localized safety issues and trends. Further, most analyses of aggregate activity and accident data lack the specificity and detail necessary to assess the effect of glass cockpits. Therefore, this study compared cohorts comprising conventional and glass cockpit aircraft of similar age and type, and a corresponding subset of activity data for both cohorts, to better assess how the introduction of glass cockpit display technology into light aircraft has affected the safe operation of those aircraft.

# Chapter 2: Study Design and Methodology

To determine how the introduction of glass cockpit avionics has affected the safe operation of light aircraft, the NTSB conducted both quantitative and qualitative assessments, as well as a case study review. The goals for the quantitative portion of this study were to identify any differences in the operational characteristics of conventional and glass cockpit aircraft and to determine how the introduction of glass cockpit avionics into light aircraft has affected safety. These goals were accomplished by comparing the accident records of two cohorts of airplanes produced during the 5 years from 2002 to 2006, as well as aircraft activity and usage data collected from 2 years of owner surveys. The cohorts selected had similar airframes, numbers of engines, and engine types but differed principally in their type of primary flight instrumentation: that is, one cohort comprised glass cockpit aircraft and the other included aircraft equipped with conventional displays.

For the qualitative assessment, which is discussed in chapter 4, the NTSB reviewed changes in training, resources, and requirements associated with the transition to glass cockpits. To that end, the NTSB reviewed FAA and manufacturer-provided training materials, visited aircraft manufacturers to observe factory transition training, and spoke with representatives of the aviation insurance industry about their requirements for owners and operators of glass cockpit aircraft. For the case study review, described in chapter 5, the NTSB reviewed the circumstances of accidents involving the glass cockpit cohort to identify safety issues unique to glass cockpit displays.

## Study Design Issues

An assessment of the safety consequences of a specific aircraft equipment change is easily confounded[34] if that change is associated with differences in aircraft use, pilot demographics, or additional equipment changes. For example, the average number of annual flight hours is known to decrease with aircraft age (see figure 5).[35] Comparisons of newly built aircraft with all aircraft or with older aircraft of similar type are therefore likely to mischaracterize risk exposure. New aircraft with new equipment capabilities may also attract a new demographic of pilots to general aviation who may use their aircraft differently than pilots flying older models.

[34] A statistical confound is a variable not accounted for in statistical comparisons but correlated to study variables in such a way that may result in misleading study findings. For example, a study may find that drownings increase when ice cream sales increase. Without additional study controls, one might erroneously conclude that there is a causal relationship between these variables. However, the confounding variable in this case is likely the time of year because ice cream sales and swimming activity both increase during the summer months.

[35] *General Aviation and Air Taxi Activity and Avionics Survey*, 2006 (Washington, DC: Federal Aviation Administration, 2007), <http://www.faa.gov/data_research/aviation_data_statistics/general_aviation/CY2006/>.

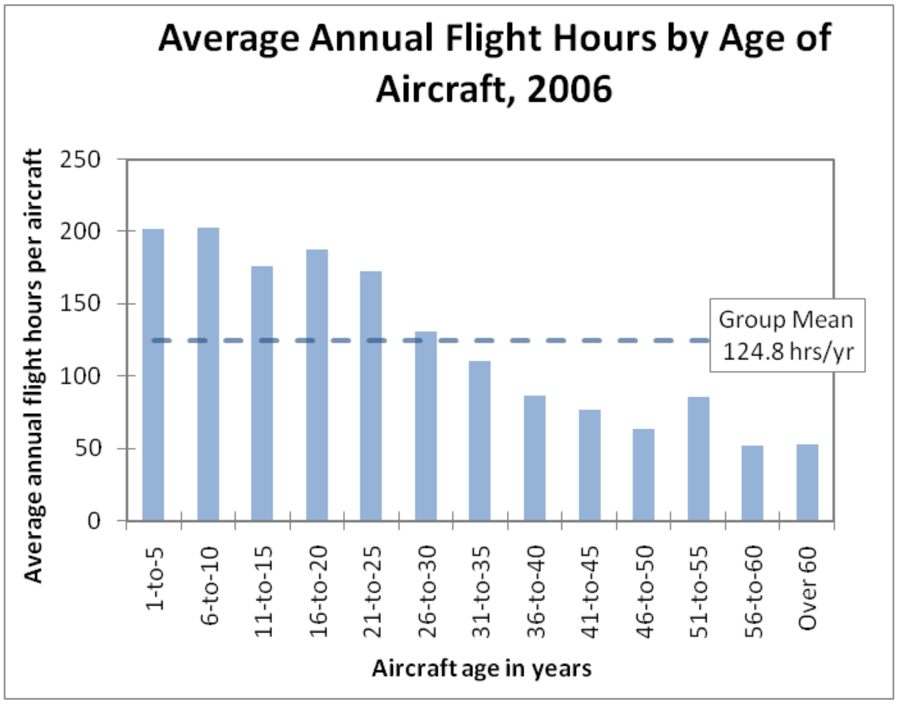



**Figure 5.** General aviation and on-demand Part 135 average annual flight hours by age of aircraft, 2006.

Potential confounds related to aircraft age, equipment, and usage were controlled for to the extent possible[36] in the present study by identifying groups of similar aircraft of similar age, with and without glass cockpits, and then gathering the information necessary to further identify any differences in use or user population.

## Methodology

Quantitative data analyses in the current study included (1) a comparison of specified aircraft models manufactured during the 5 years from 2002 through 2006, the years that spanned the transition of the fleet from conventional to glass cockpit displays, (2) statistical comparisons of retrospective accident data for the years 2002 through 2008 by display type, and (3) a comparison of aircraft and flight activity data obtained from the FAA aircraft registry and an analysis of GAATAA Survey data for the years 2006 and 2007.[37] Aircraft cockpit display configuration was determined using aircraft manufacturer records. All accident data were extracted from the NTSB Aviation Accident Database. Study analyses were limited to accidents involving U.S.-registered aircraft.

[36] The models of aircraft included in the study vary to some degree with regard to performance, range, and capability, but the study fleet represents a more homogenous group of aircraft than is typical of general aviation operations as a whole.

[37] The FAA conducts an annual survey of aircraft owners to generate information on general aviation and on-demand Part 135 aircraft use and activity. The stated purposes of the survey are to (1) anticipate and meet demand for National Airspace System facilities and services, (2) evaluate the impact of safety initiatives and regulatory changes, and (3) build more accurate measures of the safety of the general aviation community.

The NTSB worked with GAMA and individual manufacturers to identify the airplanes of interest manufactured from 2002 through 2006 and to classify the instrumentation of each airframe by serial number. Once this study fleet was identified, the NTSB worked with the FAA and its survey contractor to generate activity estimates from the survey responses collected from owners of those aircraft, grouped by type of cockpit display. The resulting activity estimates derived from the subset of GAATAA Survey data from 2006 and 2007 were used along with NTSB Aviation Accident Database records to develop accident rate measures by cockpit display type for those years.

The period of study represented a unique window of opportunity during which both the aircraft equipment information and activity records necessary to compare similar aircraft, both with and without glass cockpits, were available. Before the FAA changed its GAATAA Survey methodology in 2006, the activity data needed to compare newly manufactured aircraft were insufficient.[38] Similarly, such comparisons will become increasingly challenging in the future due to the growing number of glass cockpit retrofit options, which will make it difficult to readily identify aircraft equipped with this technology.

## Study Aircraft Fleet

The NTSB Aviation Accident Database does not contain sufficient detail to identify accident aircraft by both year of manufacture and cockpit equipment. The NTSB therefore used supplemental data available in the FAA aircraft registry, which includes build date information. Because some of these data are missing, the NTSB worked with GAMA and aircraft manufacturers to identify—by serial number—single-engine piston airplanes manufactured in the 5 years from 2002 through 2006 and the cockpit display configuration of each aircraft. In addition to being selected because they bridged the introduction of PFDs into this group of aircraft, the years 2002–2006 were selected because they were covered by an expanded sampling methodology introduced in the 2006 GAATAA Survey, which included contacting the owners of all aircraft manufactured during the preceding 5 years for participation in the survey.

Once the list of aircraft was compiled, that information was used to summarize the data and compare accident involvement by cockpit display type. Aircraft selected for the study included the following makes and models of airplanes manufactured between 2002 and 2006.

- Cessna Aircraft Corporation
    - 172
    - 182 series
    - 206 series

[38] Starting with the 2006 survey, the FAA modified its GAATAA Survey methodology to include a 100-percent sample of aircraft manufactured during the preceding 5 years. In comparison, the 2005 survey sampled only about 16 percent of single-engine piston airplanes. The final number of valid survey responses was still limited, however, by aircraft owners who declined to participate and aircraft that were subsequently exported, destroyed, or otherwise inactive. For specific details associated with the sampling methodology used in previous surveys, see the 2005 GAATAA Survey, appendix A, <http://www.faa.gov/data_research/aviation_data_statistics/general_aviation/CY2005/>. Washington, DC: Federal Aviation Administration, 2006.

- Cirrus Design Corporation
    - SR20
    - SR22
- Diamond Aircraft
    - DA40
- Lancair/Columbia Aircraft/Cessna Aircraft Company
    - 300/350[39] and 400
- Mooney
    - M20 series
- Piper Aircraft Inc.
    - PA-28-161
    - PA-28-181
    - PA-28-201
    - PA-32-301 series
    - PA-46-350P
- Hawker Beechcraft Corporation
    - 36 series

A total of 8,364 airplanes were identified from FAA registry records for inclusion in the study. Of those, 2,848 were identified for inclusion in the conventional cockpit display cohort, and 5,516 were included in the glass cockpit cohort.

## Activity Survey

As stated above, the FAA modified its GAATAA Survey methodology in 2006 by increasing its survey sample to include all aircraft manufactured during the preceding 5 years. The NTSB took advantage of this change to obtain the activity and usage data necessary to make statistical comparisons based on cockpit display type. Working with the FAA and the contractor responsible for conducting the survey,[40] the NTSB was able to obtain analyses of survey responses from the selected aircraft models manufactured from 2002 to 2006 that had undergone a change in standard equipment from conventional to glass PFD cockpit displays. Limiting the sample to a group of aircraft manufactured within a 5-year period also reduced the likelihood of confounding effects from changes known to occur as aircraft age, such as declining levels of flight hours. The study sample was further defined to include single-engine, piston-powered airplanes to allow direct comparisons between aircraft of relatively similar operational and performance capability.

[39] The Lancair 300 was only produced with conventional cockpit displays, but it is similar to the Columbia/Cessna 350 produced with glass cockpit displays.

[40] The FAA conducts the GAATAA Survey under a contract with PA Consulting Group, Madison, Wisconsin.

Because the 2006 survey included aircraft that were manufactured during 2006—and therefore had not experienced a full year of operation—activity estimates for those aircraft were also calculated from the 2007 GAATAA Survey responses. Due to the new survey sampling methodology, a total of 2,738 responses from the 2006 survey and 2,357 total responses from the 2007 survey were identified for inclusion in this study. The targeted aircraft activity and usage data obtained for the study were similar in format and content to the published GAATAA Survey results, with separate datasets for conventional aircraft and glass cockpit-equipped aircraft. The NTSB conducted several summary analyses of active aircraft, flight activity, and usage data from GAATAA Survey responses to identify any differences associated with the type of cockpit display.

### Accident Data

Data from the NTSB Aviation Accident Database were used, along with the registration and serial number information provided by manufacturers, to identify aircraft in each cohort that were involved in accidents between 2002 and 2008 and to capture the details of those accidents. NTSB accident data include details of the accident event, such as type of occurrence, phase of flight, and environmental conditions; pilot demographics and experience; and accident investigation findings.[41] These data were used to compare the accident experience of the two cohorts and to make statistical comparisons of the accidents each cohort experienced.

## Analyses

Summary statistics were calculated to compare the aircraft cohorts on variables such as the number of aircraft, hours flown, usage details, and accidents. For those aircraft in the study sample that had been involved in accidents,[42] univariate comparisons were made between the conventional and glass cockpit groups on the basis of data collected during the accident investigation, including accident occurrences and findings, weather and operational details, and accident pilot demographics and experience.[43] Because the study was targeted at a relatively small set of aircraft, the number of comparisons that could be made between glass cockpit and conventional aircraft as a function of operational and pilot characteristics was limited by the sample sizes (number of accident cases) for each comparison.

Statistical tests appropriate to the various accident-related variables were used to determine the extent to which the conventional and glass cockpit cohorts differed.

[41] See appendix for the list of accidents included in the study.

[42] Study accident analyses were limited to U.S.-registered aircraft.

[43] Univariate comparisons are those that compare differences between two groups based on one variable in isolation—for example, percentage of accidents resulting in fatality by cockpit type.

## Statistical Comparisons

Chi-square statistics[44] were used to compare the cohorts on categorical accident variables such as weather, time of day, and purpose of flight. Mann-Whitney U tests[45] were used to compare differences in continuous variables, including planned flight distance, pilot age, and flight experience. The following variables were selected for analysis:

Accident flight information

- Accident severity
- Planned length of flight
- Purpose of flight
- Day/night and visual meteorological conditions
- Visual/instrument meteorological conditions
- Instrument/visual flight rules flight plan
- Accident phase of flight and event details

Pilot information

- Number of pilots aboard accident aircraft
- Age at the time of the accident
- Highest certificate level
- Instrument rating
- Flight hours

[44] Chi-square is a statistical test that can be used to determine whether two or more groups differ significantly with respect to the proportional distribution of a given characteristic or quality. The chi-square statistic compares the observed counts of a categorical variable for one or more groups to those expected by the relative distribution of the groups. The chi-square test results in a measure of significance or probability that the observed distributions of a variable were similar for the study groups. A very low probability, such as 5 percent or less, indicates that the groups likely differed with regard to the variable of interest.

[45] Mann-Whitney U is a statistical test for assessing differences between two groups with regard to the distribution of a continuous variable. The test results in a measure of the probability that observations of a variable from both groups are similar, which is also an indication of whether observations of that variable are greater for one group than the other.

Accident rates were calculated for comparison with the applicable exposure data, such as number of aircraft or flight hours. Standard error values were included with GAATAA Survey results and calculated rate comparisons when appropriate.[46]

The following rate comparisons were calculated:

- Accidents and fatal accidents per active aircraft
- Accidents and fatal accidents per flight hour
- Accidents and fatal accidents by time of day
- Accidents and fatal accidents by weather condition
- Accidents and fatal accidents by purpose of flight

Accident records for the 2002–2008 period covered by this study provided enough data to make statistically reliable comparisons between the two study groups. While the activity data were limited to 2 years of FAA surveys, the similarities between the patterns of aircraft usage reported by survey respondents and the patterns in the accident data for the 7-year study period indicate that the accident rates derived from the activity data provide valid comparisons between the conventional and glass cockpit groups.

[46] Rate calculations, such as the number of accidents occurring annually per flight hour, are estimates of the "true" rate of an event based on historical occurrences of that event. Accident rates are subject to variability due to chance, particularly when the number of events and/or the size of the population of interest is small. The larger the population and/or number of events being studied, the more likely it is that the computed rate will be close to the true rate. The variability of a rate can be evaluated by computing a standard error that includes both the number of events and the size of the denominator (for example, registered aircraft, active aircraft, or flight hours) measured. In this report, standard error values are presented as a percentage of the associated value or rate. Rates based on small numbers are particularly unstable, which is reflected in a high percent of standard errors. Standard error values were either excluded for rates based on fewer than 10 events or noted as such. Note that most of the accident rates calculated from the 2006 and 2007 GAATAA Survey data are based on small numbers and that the resulting differences are therefore not statistically significant but are provided as possible further explanation of the differences in the 2002–2008 accident record for these aircraft.

# Chapter 3: Quantitative Analysis Results

## Description of Study Fleet

By comparing manufacturer aircraft serial number data with FAA aircraft registration records, the NTSB identified 2,848 single-engine piston airplanes for the conventional cockpit display cohort and 5,516 for the glass cockpit cohort, all manufactured between 2002 and 2006.[47] Figure 6 illustrates the rapidly changing distribution of the aircraft included in the study. Most aircraft in the conventional display cohort were manufactured between 2002 and 2004, while aircraft in the glass cockpit cohort first appeared on the FAA registry in 2003.

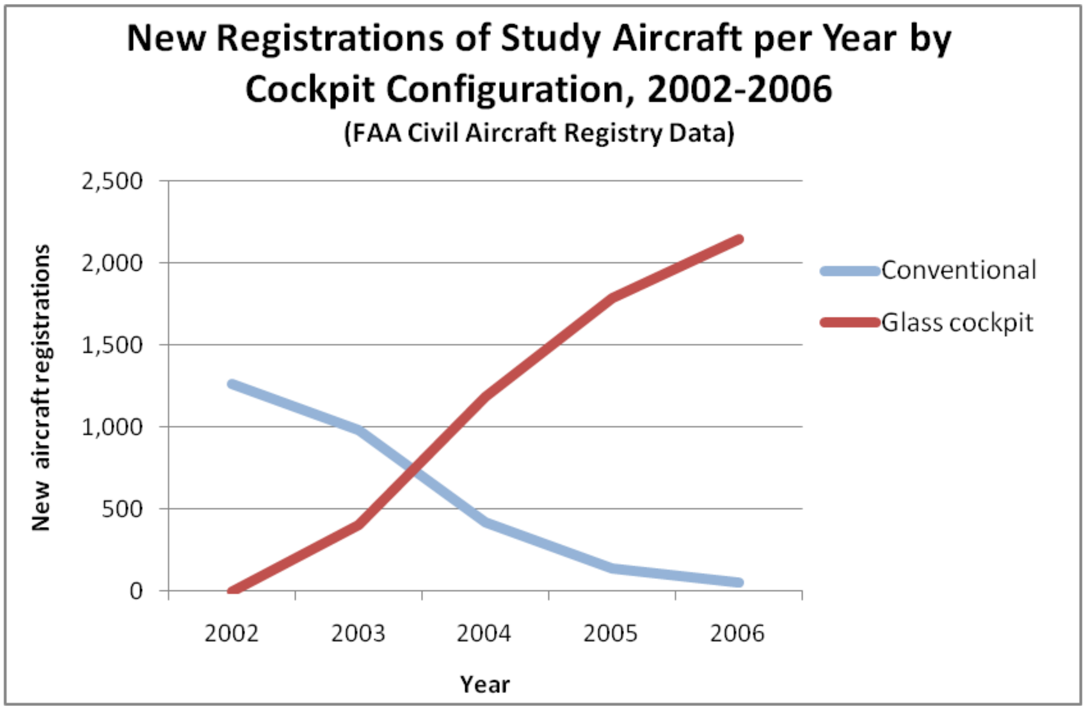



**Figure 6.** New registrations of aircraft study fleet by cockpit display configuration and year.

After 2004, the size of the conventional cohort remained relatively constant, while the size of the glass cockpit cohort increased rapidly, surpassing the conventional cohort in 2005 and nearly doubling it in 2006. Figure 7 shows the accumulated size of the study fleet for each year from 2002 through 2006 and the accumulated number of aircraft in the conventional and glass cockpit cohorts each year.

[47] The study aircraft fleet was identified by comparing the aircraft serial number and cockpit display data provided by manufacturers with FAA aircraft registry data. An aircraft was included in the study fleet if it ever appeared on the registry, regardless of whether it was subsequently deregistered or exported, or the registration later became inactive.

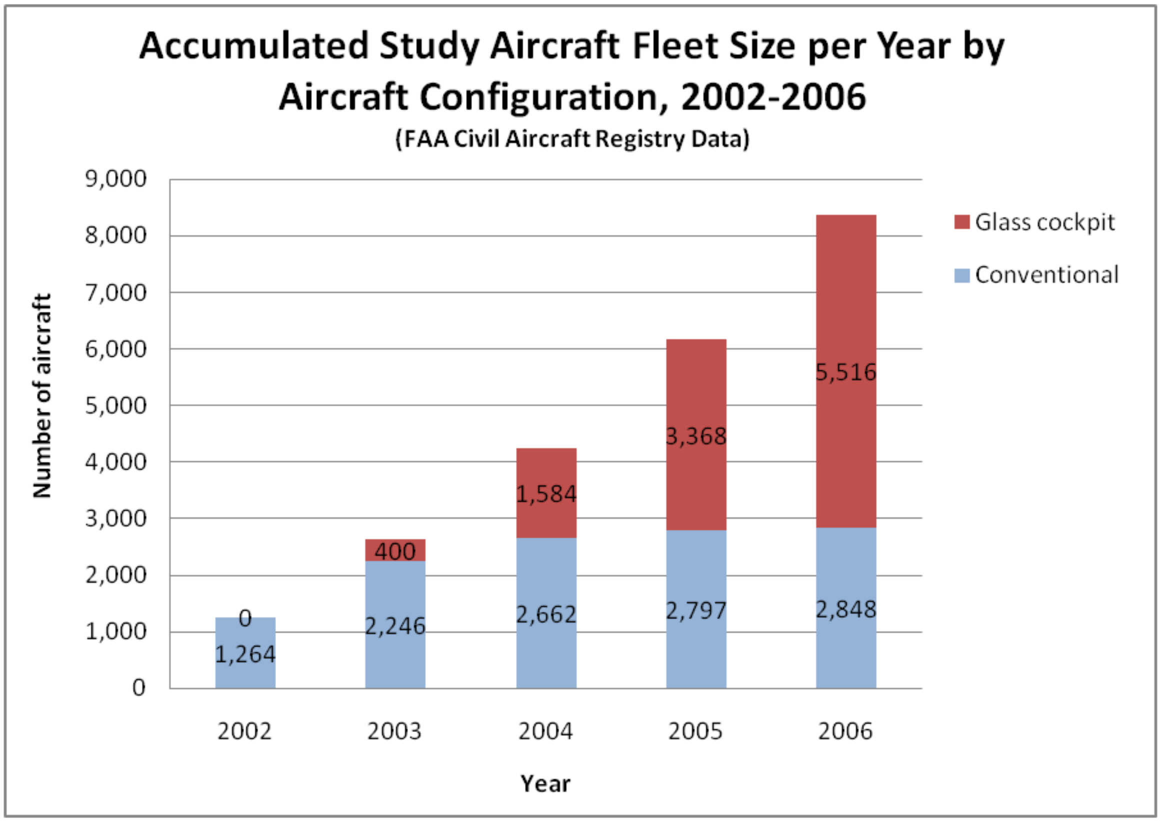



**Figure 7.** Accumulated study aircraft fleet size by cockpit configuration and year.

## Description of Study Accidents

Study analyses of accidents included the years from 2002 through 2008. The years of aircraft manufacture from 2002–2006 were selected to correspond with the 2006 GAATAA 100-percent sampling methodology for newly built aircraft. However, although the activity and accident data included aircraft manufactured throughout 2006, the number of study aircraft did not stabilize until the end of that year. Accident records for 2007 and 2008 were therefore included to represent 2 full years of accidents associated with the study aircraft, unaffected by the addition of newly manufactured aircraft.

## Accident Information

This section contains summary analyses of the relative accident occurrences and rates associated with the conventional and glass cockpit cohorts defined in this study. Comparisons of accident numbers are limited because aircraft can be used differently and in ways that expose one group of aircraft to more or less risk for severe accident outcomes than another. The validity of comparisons of accidents with aircraft manufacturing and registration records is likewise limited by the possibility that aircraft may be sold, exported, deregistered, or placed in storage.[48] Therefore, the accident data provided in this section should be considered within the context of corresponding activity data. Active aircraft information, flight activity, and aircraft usage data from the 2006 and 2007 GAATAA Surveys are presented throughout this section for comparison with FAA aircraft registry information and NTSB accident records from 2002 through 2008. Due to the unequal cohort sizes, the aircraft and accident data are presented as percentages of the respective cohort totals to facilitate interpretation. The complete list of study accidents is included in the appendix.

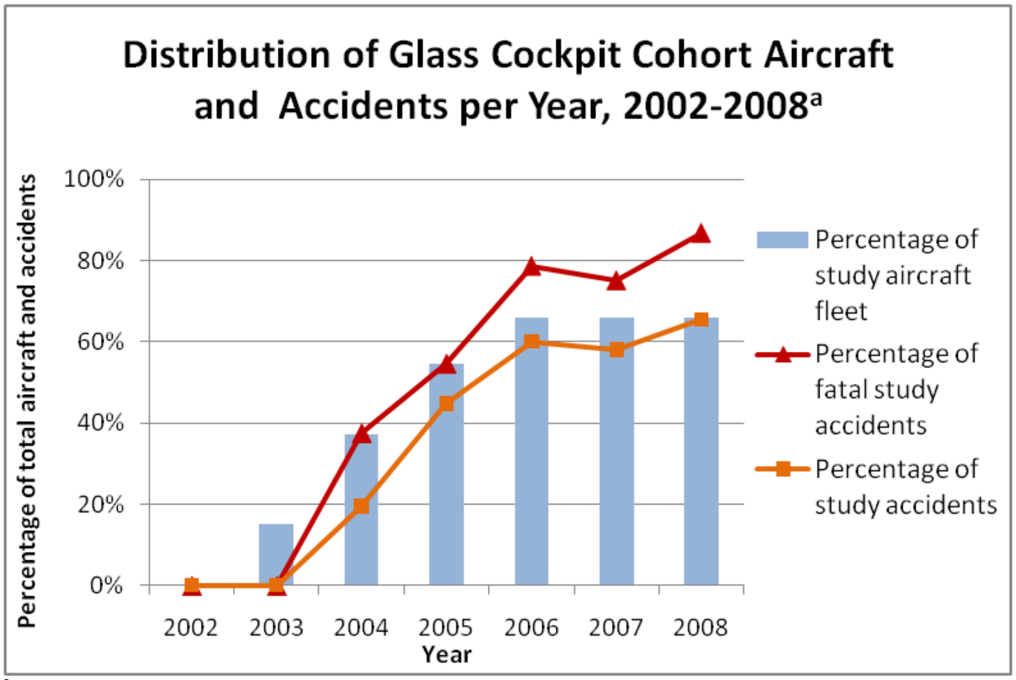
## Accident Involvement

A comparison of the list of study aircraft with NTSB records identified 266 total accidents involving study aircraft between 2002 and 2008, 62 of which resulted in one or more fatal injuries.[49] Of the 266 study accidents, 141 accidents—23 of them fatal—involved conventionally equipped aircraft. The remaining 125 total accidents and 39 fatal accidents involved glass cockpit aircraft. It is important to note that direct comparisons of the overall accident totals would be misleading in this case because of the changes in the sizes of the cohorts during the time period analyzed.

Comparisons of accident involvement from 2002 through 2006 must account for changes in the size of the study fleet due to the newly manufactured aircraft added to the fleet each year. The distribution of study aircraft and accidents associated with the glass cockpit cohort (as shown in figure 8) shows that the percentage of accidents involving glass cockpit aircraft was smaller than would be expected based on the percentage of the study fleet that those aircraft represented. During 2004 and 2005, fatal accidents for conventional and glass cockpit aircraft were proportional to the percentage of the study fleet they represented, but starting in 2006, the glass cockpit group began to experience proportionately more fatal accidents. Over the entire period from 2002 through 2008, aircraft in the glass cockpit cohort showed a disproportionately lower rate of total accidents per registered aircraft but a disproportionately higher rate of fatal accidents per registered aircraft than those in the conventional cohort.

[48] For example, data provided by GAMA indicate that approximately 30 percent of aircraft produced in 2007 and 2008 were exported. Similar data do not exist for 2002–2006, but the number of aircraft that remained active in U.S. civil aviation is likely well below the 8,354 total aircraft that had appeared on the FAA aircraft registry. Further support for this suggestion comes from the active aircraft estimate results of the 2006 and 2007 FAA GAATAA Survey cited in table 2 of the *Activity, Exposure Data, and Accident Rates* section later in this chapter.

[49] One accident (SEA03LA180) was excluded from study analyses because it occurred during the factory flight test.




[a] The study aircraft fleet included aircraft manufactured between 2002 and 2006; therefore, the distribution of glass cockpit aircraft in the study aircraft fleet remained constant from 2006 through 2008.

**Figure 8.** Distribution of glass cockpit cohort aircraft and accidents per year.

## Accident Severity

Statistical comparisons of the 2002 through 2008 accident data, independent of the registry or survey information, show similar differences in accident severity by cockpit display type. As shown in figure 9, the percentage of accidents resulting in fatality was about twice as high for the glass cockpit cohort as for the conventional cohort. Of the 266 accidents involving study aircraft between 2002 and 2008, accidents involving aircraft in the glass cockpit cohort were significantly more likely to be fatal: $\chi^2$ (1, $N$ = 266) = 8.216, $p$ = 0.004.[50]

[50] Throughout this report, the results of chi-square ($\chi^2$) statistical tests are included in the text using the following notation (degrees of freedom, $N$ = number of cases compared) = resulting chi-square value, $p$ = probability (that is, significance) of the result. The $p$ value can be interpreted as the percent likelihood that the observed value occurred by chance. Therefore, a difference that results in a small $p$ value is unlikely to have resulted from chance and is more likely the result of differences between the two groups. For the purposes of this study, $p$ values of 0.05 (5 percent) and less are considered statistically significant. Refer to table 7 at the end of this chapter for a summary of all study chi-square statistical test results.

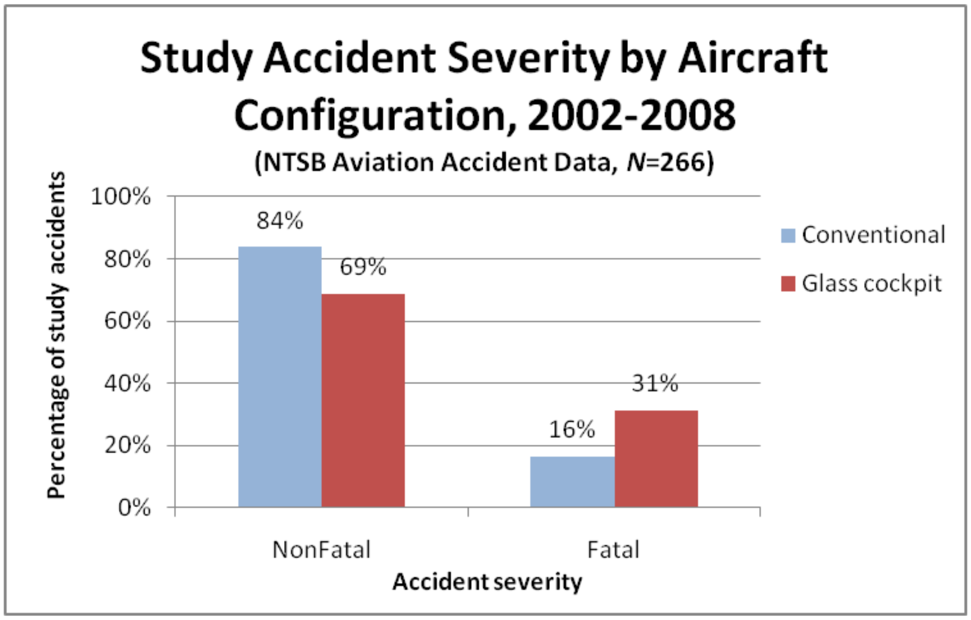



**Figure 9.** Comparison of study accidents by severity of outcome.

In addition to the statistical comparisons of accident data from 2002 through 2008, GAATAA Survey data were used to develop rates for the years 2006 and 2007 that represent accident risk by providing estimates of the number of aircraft actively operated, the number of hours flown, and specific characteristics of how those aircraft were operated. Rates based on flight activity provide a clearer indication of the relative safety of the conventional and glass cockpit configurations by identifying differences in the number of aircraft that were actively flying versus those that may have been sold or placed into storage, or that may have become inactive for other reasons. Differences between aircraft buyers who opted for a glass cockpit airplane can contribute to differences in accident risk, and pilots may use aircraft differently based on their avionics capabilities. The 2 years of available GAATAA Survey data were used to further explore these possibilities and provide evidence of activity and usage differences to aid interpretation of the aircraft's accident record to date.[51]

## Activity, Exposure Data, and Accident Rates

Of the 2,848 airplanes included in the conventional display cohort, 935 of the owners responded to the 2006 GAATAA Survey, and 472 responded to the 2007 survey. Of the 5,516 aircraft in the glass cockpit cohort, 1,803 owners responded to the 2006 GAATAA Survey, and 1,885 responded to the 2007 survey. These responses were used to calculate estimates of the number of active aircraft and total hours flown, as well as the number of hours flown by purpose of flight, day/night operations, and visual/instrument flight activity in accordance with the

[51] Note that the study includes statistical comparisons of all accidents involving the study aircraft fleet from 2002 and 2008. However, GAATAA Survey data were only available for the years 2006 and 2007. No attempt was made to apply the 2006 and 2007 survey results to the prior years 2002 through 2005.

normal GAATAA Survey methodology.[52] Results of the active aircraft and flight hour analyses are presented in table 1 below.

**Table 1.** GAATAA Survey analysis results.

| Year | Active Aircraft | | Flight Hours | |
|---|---|---|---|---|
| | Conventional | Glass Cockpit | Conventional | Glass Cockpit |
| 2006 | 2,412 | 4,203 | 593,853 | 805,152 |
| | (0.2% Std. Error) | (0.2% Std. Error) | (2.6% Std. Error) | (1.6% Std. Error) |
| 2007 | 1,738[a] | 4,205 | 565,370 | 838,573 |
| | (0.2% Std. Error) | (0.2% Std. Error) | (4.0% Std. Error) | (1.6% Std. Error) |

[a]The large drop in the estimated number of active conventional aircraft in 2007 was likely due in part to increased variability in survey estimates for this group because aircraft manufactured during 2002 were not included in the 100-percent 2007 survey sample. This subsequently resulted in fewer total responses for aircraft built during 2002, which were exclusively of the conventional cockpit design. The effect of this change is that the number of conventionally equipped aircraft and their associated activity were likely higher than the survey results indicate for 2007. The effect of this change is also evident in the higher standard error value associated with the flight hours for the conventional cohort in 2007.

Dividing the flight hours from the GAATAA Survey by the number of active aircraft provides an estimate of the average number of hours flown per aircraft. For the years 2006 and 2007, the average estimated hours flown per aircraft was 286 for the conventional cohort (246 hours/aircraft in 2006 and 325 hours/aircraft in 2007) and 195 for the glass cockpit cohort (192 hours/aircraft in 2006 and 199 hours/aircraft in 2007).

As illustrated in table 2, accident rates calculated from NTSB accident records and GAATAA Survey data indicate that the 2006 and 2007 accident rates per 1,000 active aircraft were higher for the conventional display cohort, but the fatal rates were higher for the glass cockpit cohort for both years.

Because the study cohorts included only a few thousand aircraft, and the numbers of total and fatal accidents within the cohorts were relatively small each year, the 2006 and 2007 activity and accident data were summed for comparisons of accident rates and specific accident details to provide more stable rate estimates and to reduce the potentially distorting effect of small numbers of events on rate calculations. Even when using this approach, the standard errors associated with the fatal rates are high due to the relatively small number of total events.

[52] Analyses of the subset of GAATAA Survey data were done by the contractor responsible for conducting the survey in accordance with the established survey methodology; however, this is the first published use of a subset of GAATAA Survey data for targeted analyses like those included in this report.

**Table 2.** Accident rates for 2006 and 2007 per 1,000 active aircraft, by aircraft cockpit configuration.

| Year | Accident Rate Per 1,000 Active Aircraft | | | |
|---|---|---|---|---|
| | Total | | Fatal | |
| | Conventional | Glass Cockpit | Conventional | Glass Cockpit |
| 2006 | 9.12 | 7.85 | 1.24* | 2.62 |
| 2007 | 12.08 | 6.9 | 1.15* | 1.43* |
| Combined 2006-2007 | 10.36<br>(15.3% Std. Error) | 7.37<br>(12.7% Std. Error) | 1.20*<br>(44.9% Std. Error) | 2.02<br>(24.3% Std. Error) |

*Rate based on fewer than 10 events.

As previously stated, comparisons of accident rates based on active aircraft provide a better indication of risk than those based on numbers of aircraft manufactured because they do not include aircraft that were subsequently exported, placed in storage, or not flown. However, accident rates based on owner-reported flight activity provide the best indication of risk because they include both the extent of operation and the way the aircraft was operated. Accident rates calculated from the survey responses regarding the number of hours flown annually are shown in table 3, along with comparison accident rates for all general aviation operations.[53]

Those results indicate that the total accident rate per 100,000 flight hours was higher for the glass cockpit cohort in 2006, but higher for the conventional cohort in 2007. The combined 2-year accident rates per 100,000 flight hours for 2006 and 2007 were similar for both the glass and conventional cohorts (3.77 and 3.71 respectively). The total accident rate for both cohorts was less than the 6.63 accidents per 100,000 flight hours for all general aviation operations for the same period, reflecting the wide range of aircraft and flight operations included in general aviation.

The fatal accident rate for the glass cockpit cohort exceeded the rate of fatal accidents per 100,000 hours for the conventional cohort for both years, and for all general aviation operations in 2006. Like the rates per active aircraft discussed previously, the fatal rates per 100,000 flight hours for both cohorts—especially the conventional cohort—have large standard errors due to the small number of events. The resulting rates, however, are consistent with the results of other study analyses, indicating that accidents involving the glass cockpit cohort were more likely to be fatal. The combined fatal accident rate for 2006 and 2007 was higher for the glass cockpit cohort (1.03) than for the conventional cohort (0.43). The combined 2006 and 2007 fatal rates for both study cohorts were less than the 1.24 fatal accidents per 100,000 hours for all general aviation operations for the same period.

[53] Includes all study accidents.

**Table 3.** 2006 and 2007 accident rates per 100,000 flight hours, by cockpit configuration.

| Year | Accident Rate Per 100,000 Flight Hours | | | | | |
|---|---|---|---|---|---|---|
| | Total | | | Fatal | | |
| | Conventional | Glass Cockpit | All General Aviation† | Conventional | Glass Cockpit | All General Aviation† |
| 2006 | 3.70 | 4.10 | 6.33 | 0.51* | 1.37 | 1.28 |
| 2007 | 3.71 | 3.46 | 6.92 | 0.35* | 0.72* | 1.20 |
| Combined 2006-2007 | 3.71 | 3.77 | 6.63 | 0.43* | 1.03 | 1.24 |
| | (15.3% Std. Error) | (12.7% Std. Error) | — | (44.2% Std. Error) | (19.2% Std. Error) | — |

*Rate based on fewer than 10 events.

†National Transportation Safety Board, *Aviation Accident Statistics: Accidents, Fatalities, and Rates, 1989 - 2008, U.S. General Aviation*. Available at: http://www.ntsb.gov/aviation/Table10.htm.

At the time of writing, targeted GAATAA Survey flight-hour data were not available to calculate 2008 accident rates for the study cohorts. If the hours flown for both cohorts during 2008 were similar to the averages in 2006 and 2007, the total accident rates for both the conventional and glass cockpit cohorts would again be less than the overall general aviation rate. However, with 13 fatal accidents during 2008, the fatal rate of aircraft in the glass cockpit cohort in this study would well exceed both the conventional cohort and the overall general aviation fatal rates for the year.[54]

## Flight Conditions

Accident details and survey responses associated with both cohorts were compared to identify any differences in accident circumstances, aircraft use, or pilots that could affect the severity of accident outcomes and explain the observed differences between the accident and fatal accident rates for the conventional and glass cockpit cohorts. For example, accidents that occur at night or in instrument meteorological conditions (IMC) have historically been more likely to result in fatality than those that occur during the day in good weather.[55]

### Time of Day

As illustrated in figure 10, the 2002 through 2008 accident data indicate that a higher percentage of accidents involving aircraft in the glass cockpit group occurred at night, but the difference was not statistically significant: $\chi^2$ (1, $N$ = 266) = 3.058, $p$ = 0.080.

[54] For example, if total flight hours were estimated for the study groups by averaging the 2006 and 2007 survey results, the 2008 fatal rate for the conventional group would be 0.35 fatal accidents per 100,000 flight hours, and the rate for the glass cockpit group would be 1.58, compared to the overall general aviation fatal rate of 1.20 in 2008.

[55] *Risk Factors Associated with Weather-Related General Aviation Accidents*, Safety Study NTSB/SS-05/01 (Washington, DC: National Transportation Safety Board, 2005).

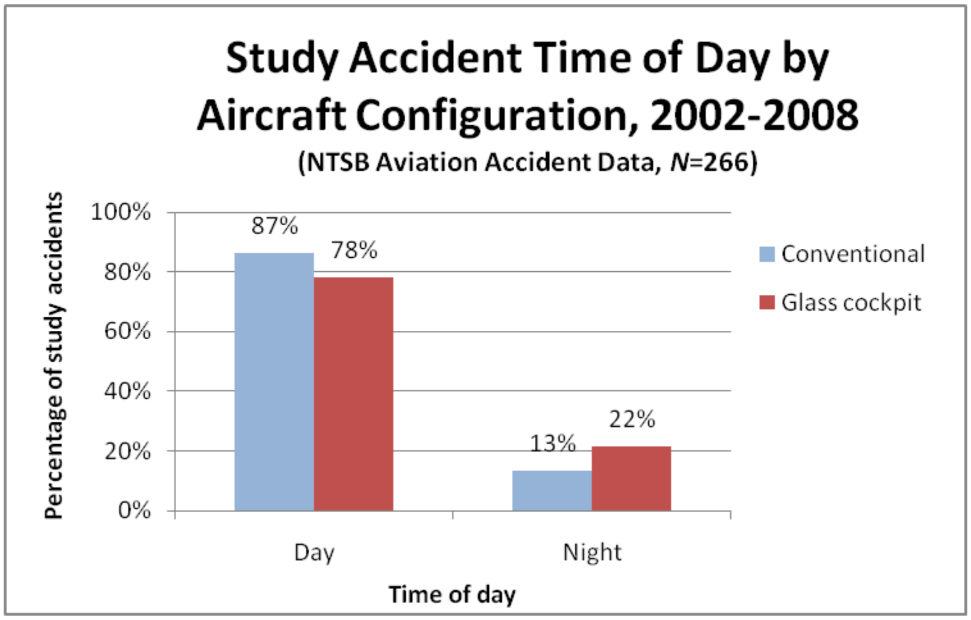



**Figure 10.** Comparison of study accidents by time of day.

As figure 11 shows, distribution of GAATAA Survey flight hour estimates by time of day for 2006 and 2007 was similar for both cohorts. However, when compared with the accident data for those years, the rates of total and fatal accidents per flight hour at night were higher for the glass cockpit cohort (see table 4).

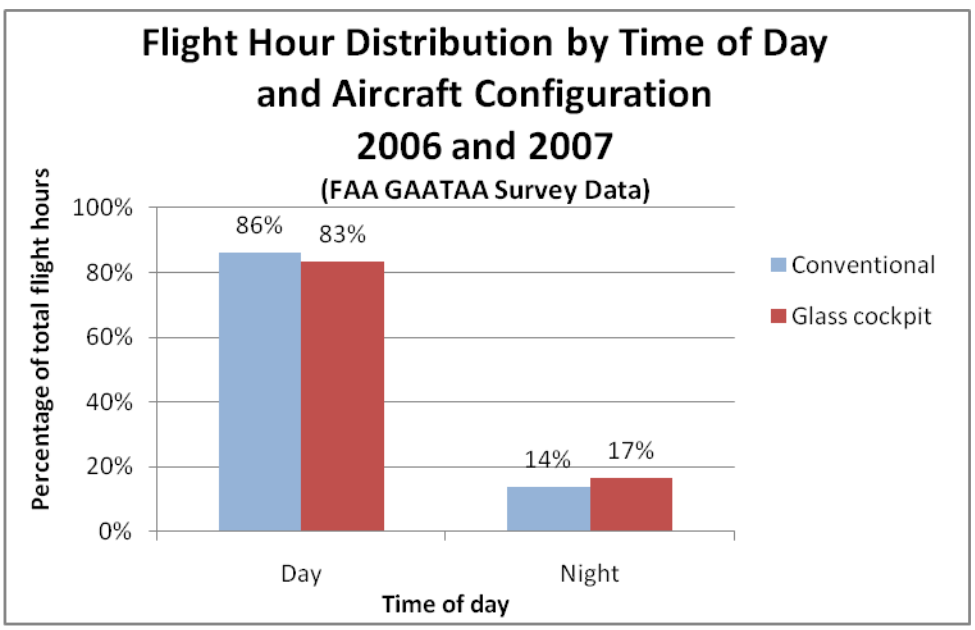



**Figure 11.** Combined 2006 and 2007 flight hour distribution by time of day and cockpit configuration.

**Table 4.** Combined 2006 and 2007 accident rates per 100,000 flight hours by time of day and cockpit configuration.

| | Total | | Fatal | |
|---|---|---|---|---|
| 2006-2007 | Conventional | Glass Cockpit | Conventional | Glass Cockpit |
| Day | 4.01 | 3.86 | 0.30 | 0.87 |
| Night | 1.85 | 3.31 | 1.23 | 1.84 |

## Weather Conditions

As shown in figure 12, the 2002 through 2008 accident data indicate that a higher percentage of glass cockpit accidents occurred in IMC. The difference in accident weather conditions was marginally significant: $\chi^2$ (1, $N$ = 264) = 3.639, $p$ = 0.056.

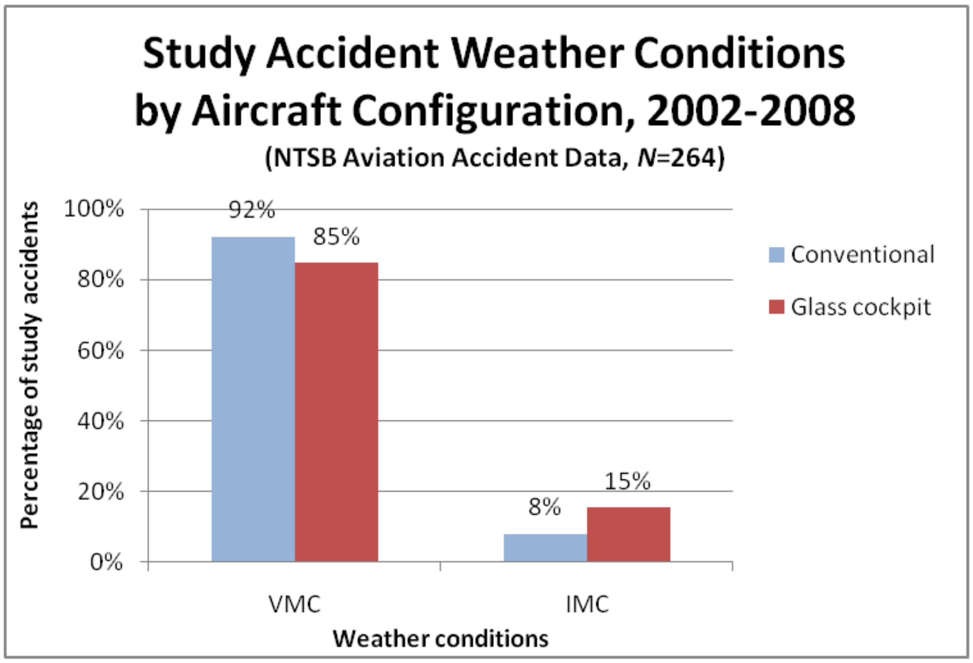



**Figure 12.** Comparison of study accidents by weather.

GAATAA Survey data regarding flight hours by weather conditions, shown in figure 13, indicate that glass cockpit aircraft owners reported a larger percentage of flight time in IMC. A comparison of accidents and flight hours during 2006 and 2007 (table 5) shows similar total accident rates for both groups in visual meteorological conditions (VMC) but higher total and fatal accident rates per flight hour in IMC for the glass cockpit cohort.

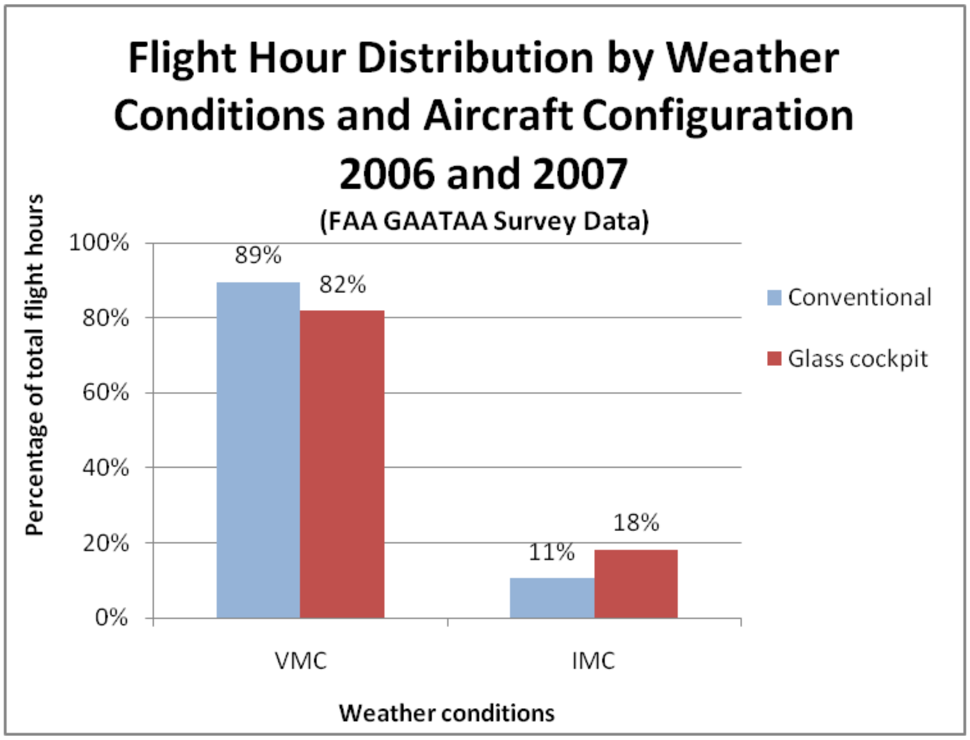



**Figure 13.** Combined 2006 and 2007 flight hour distribution by weather and cockpit configuration.

**Table 5.** Combined 2006 and 2007 accident rates per 100,000 flight hours by weather and cockpit configuration.

| | Total | | Fatal | |
|---|---|---|---|---|
| **2006-2007** | **Conventional** | **Glass Cockpit** | **Conventional** | **Glass Cockpit** |
| **IMC** | 1.63 | 2.68 | 1.63 | 2.34 |
| **VMC** | 3.86 | 3.94 | 0.29 | 0.67 |

## Flight Plan Filed

Consistent with the previous results showing that glass cockpit aircraft spent a higher percentage of flight hours in IMC, the aircraft cohorts also differed with regard to flight plan filed for the accident flight. Figure 14 shows that among those accidents during 2002 through 2008 with flight plan information available, pilots in the glass cockpit cohort were significantly more likely to have filed an instrument flight rules (IFR) flight plan for the accident flight: $\chi^2$ (1, $N$ = 250) = 11.718, $p$ = 0.001. GAATAA Survey data do not provide estimates of the number of hours flown by type of flight plan.

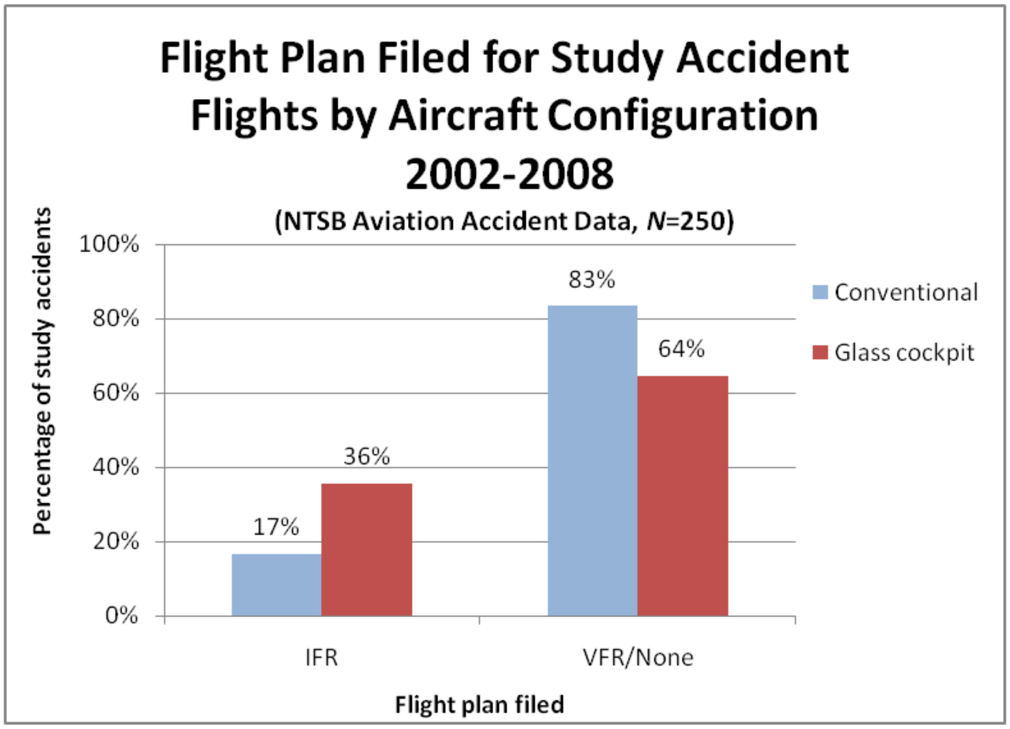



**Figure 14.** Comparison of study accidents by flight plan filed.

## Purpose of Flight

The study cohorts differed noticeably with regard to aircraft usage. Figure 15 shows that accident flights involving aircraft in the conventional cohort were almost equally split between instructional flights and personal/business flights, while glass cockpit accidents were significantly more likely to involve personal/business flights: $\chi^2$ (1, $N$ = 258) = 31.616, $p$ < 0.001.

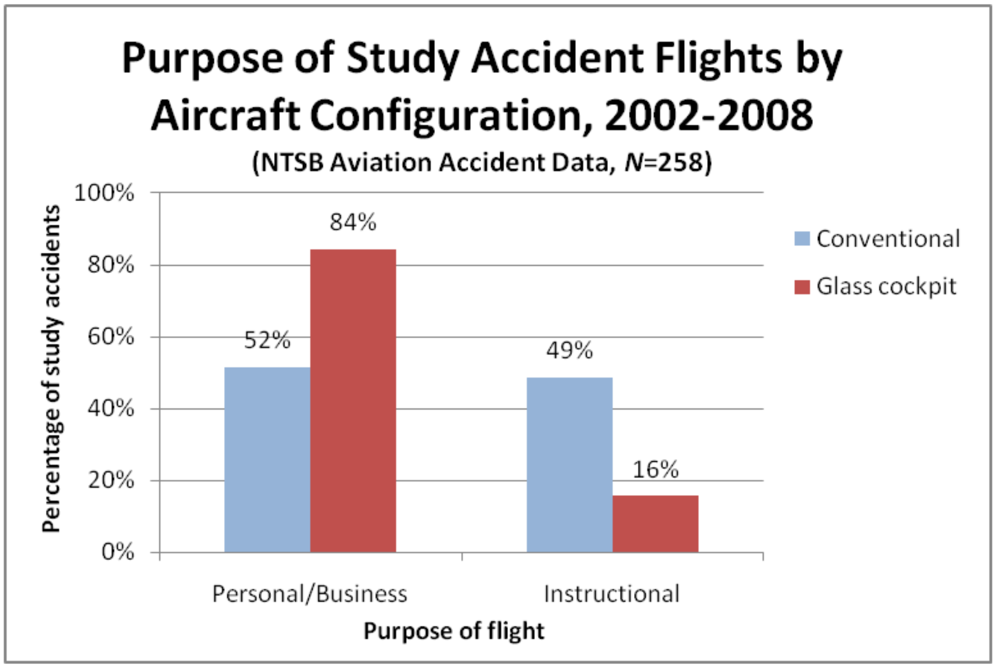



**Figure 15.** Comparison of study accidents by purpose of flight.

GAATAA Survey results regarding reported aircraft use indicated that a larger percentage of the conventional cohort's activity during 2006 and 2007 involved instructional flights, while the glass cockpit aircraft were more often used for personal and business flying (see figure 16). A comparison of accidents with reported aircraft use from 2006 through 2007, summarized in table 6, indicates that the conventional aircraft experienced higher total accident rates during both instructional and personal/business flying. Both cohorts experienced equally low fatal accident rates for instructional flights, but the glass cockpit cohort experienced a higher fatal accident rate during personal/business flights.

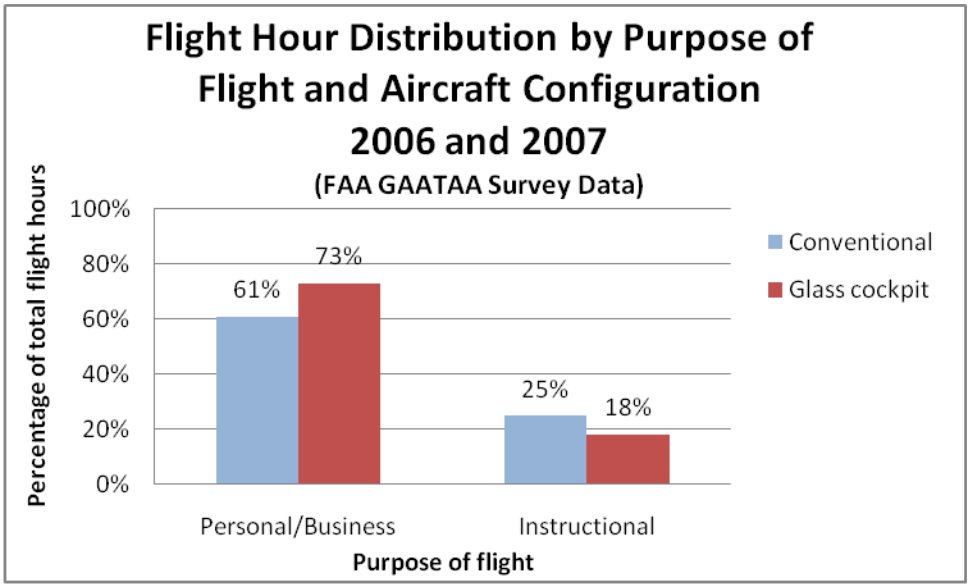



**Figure 16.** Combined 2006 and 2007 flight hour distribution by purpose of flight and cockpit configuration.

**Table 6.** Combined 2006 and 2007 accident rates per 100,000 flight hours by purpose of flight and cockpit configuration.

| | Total | | Fatal | |
|---|---|---|---|---|
| 2006-2007 | Conventional | Glass Cockpit | Conventional | Glass Cockpit |
| Instructional | 3.98 | 2.79 | 0.20 | 0.20 |
| Personal/Business | 6.62 | 5.05 | 1.26 | 1.65 |

### Planned Length of Flight

Among those accidents for which both point of departure and intended destination were known, the median planned length of accident flights associated with the glass cockpit cohort was 96 nautical miles (nm), compared to a median of 25 nm for conventional aircraft flights. Differences in the planned length of study flights for both cohorts were evaluated using the Mann-Whitney U test statistic. Results indicated that accident flights involving the glass cockpit cohort were significantly longer than those for aircraft in the conventional cockpit cohort (U = 5649.5, *N* (conventional) = 140, *N* (glass cockpit) = 122, $p < 0.001$).[56] Much of the

[56] Throughout this report, the results of Mann-Whitney U statistical tests are included in the text using the following notation (calculated value of the U statistic, $n_1$ and $n_2$ = number of cases in each study cohort, $p$ = probability, or significance of the result). Like the results of the chi-square test previously discussed, the $p$ value can be interpreted as the percent likelihood that the observed value occurred by chance. The Mann-Whitney test is calculated by ranking each of the observed values and summing the rank scores within the groups being compared. The sums of ranks are compared for both groups to identify the group with the higher result. In this case the sum of ranks for the conventional group is less than the sum of ranks for the glass cockpit group, so the significant U score can be attributed to accident flights involving glass cockpit aircraft being longer than those involving aircraft with conventional cockpit instruments. Refer to table 8 at the end of this chapter for a summary of all study Mann-Whitney U statistical test results.

difference in planned flight distance between the two cohorts can be attributed to the large percentage of conventional aircraft operating on local or very short flights, versus the percentage of glass cockpit aircraft, which were more likely to be operating on longer flights. Of the 140 conventional aircraft accidents with flight length information, 71 (51 percent) were conducting local flights that were planned to return to the departure airport or very short flights of less than 25 nm. Only 26 percent of glass cockpit accident flights were local—or less than 25 nm—but 42 percent of accident flights involving glass cockpit aircraft were planned for more than 150 nm versus only 16 percent of flights associated with conventional aircraft.

## Phase of Flight

In general, aircraft in the glass cockpit cohort were involved in a higher percentage of accidents during the in-flight phases from initial climb to approach, while conventional aircraft were involved in higher percentages of accidents during takeoff, landing, and "other," which include taxiing and standing (see figure 17).

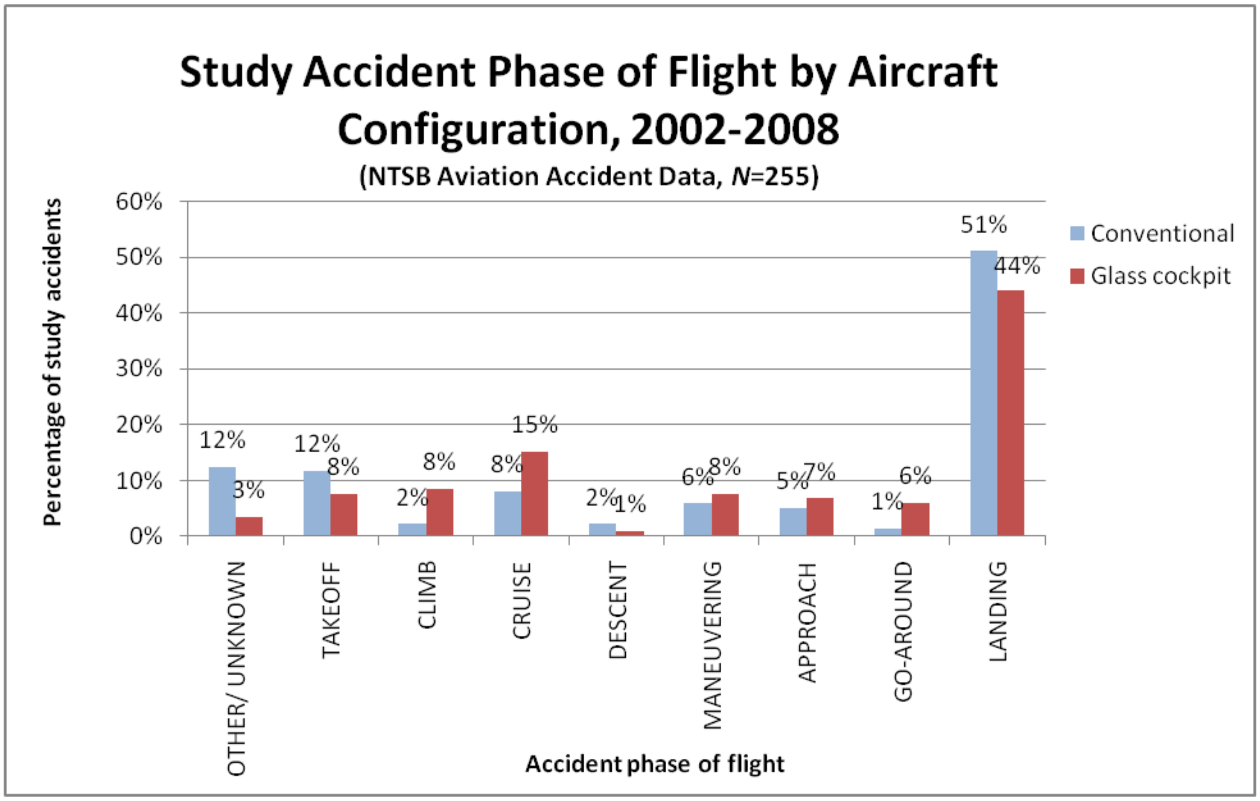



**Figure 17.** Comparison of study accidents by phase of flight. [57]

[57] Totals do not sum to 100 percent due to rounding.

### Accident Event Type

Glass cockpit aircraft were involved in higher percentages of loss-of-control in flight and collision-with-terrain events, and conventional aircraft were involved in more loss-of-control on ground and hard-landing events. This is consistent with the results of the previous comparison showing more glass cockpit accidents during in-flight phases and more takeoff and landing accidents for the conventional cohort. A summary comparison of accident event types is presented in figure 18.

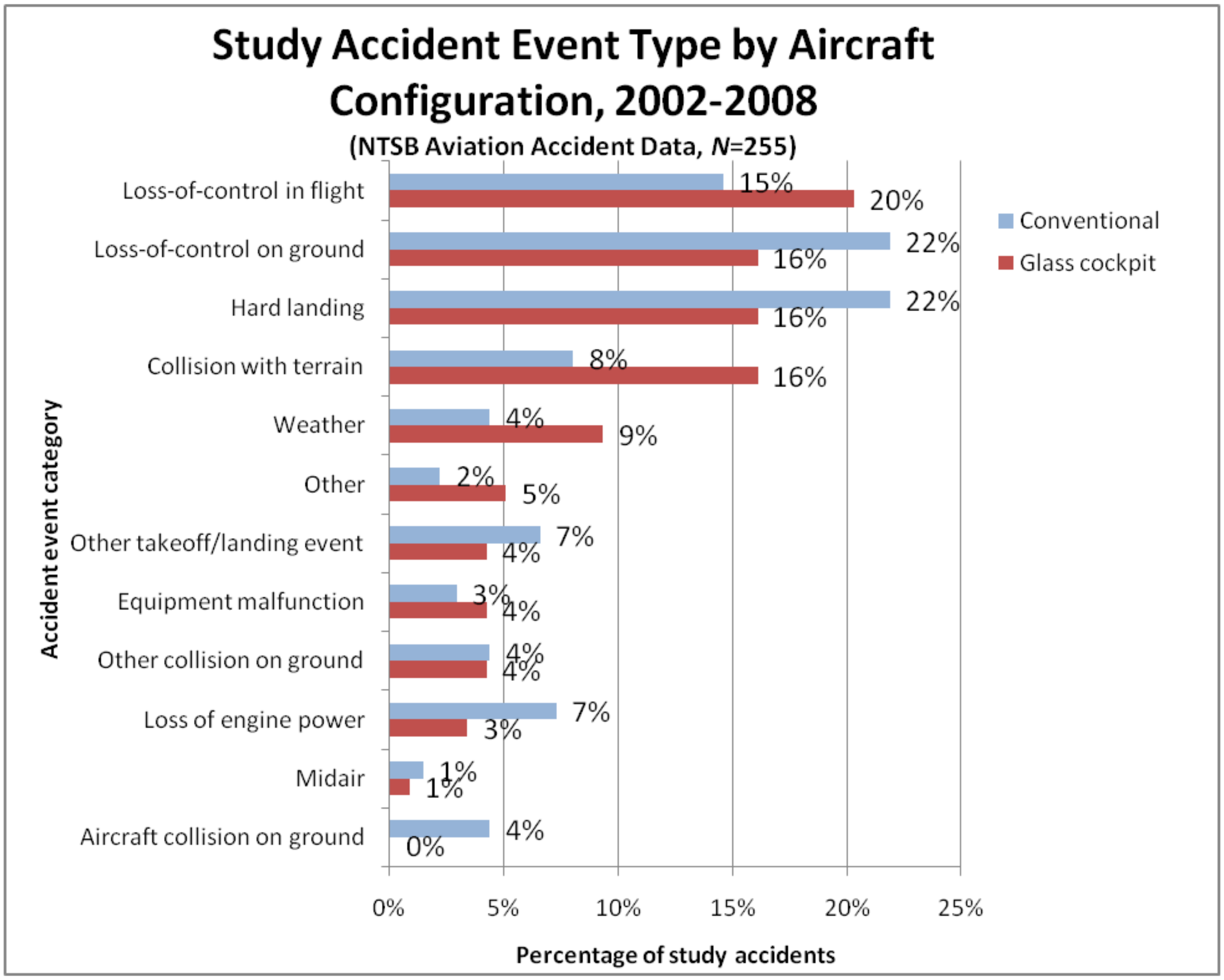



**Figure 18.** Comparison of study accidents by event type and aircraft configuration. [58]

The higher percentage of collisions with terrain versus all other events for the glass cockpit cohort was the only statistically significant difference between the two cohorts in accident events: $\chi^2$ (1, $N$ = 255) = 3.980, $p$ = 0.046.

[58] Totals do not sum to 100 percent due to rounding.

## Accident Pilot Information

Information regarding accident pilots was compared to identify differences that might have affected the safety record of study aircraft. For example, if one cohort was more likely to be flown by less experienced pilots, the accident record would likely be worse for those aircraft.

### Number of Pilots

As illustrated in figure 19, aircraft with conventional cockpits were more likely to have two flight crewmembers aboard than those with glass cockpits, which were more likely to be operated by a single pilot. The difference in the number of flight crew was statistically significant: $\chi^2$ (1, $N$ = 266) = 7.063, $p$ = 0.008. In approximately half of the conventional aircraft cases with two pilots, the second pilot was identified as a flight instructor, which is consistent with the previously presented results indicating that conventional aircraft were more likely to be used for instructional flights.

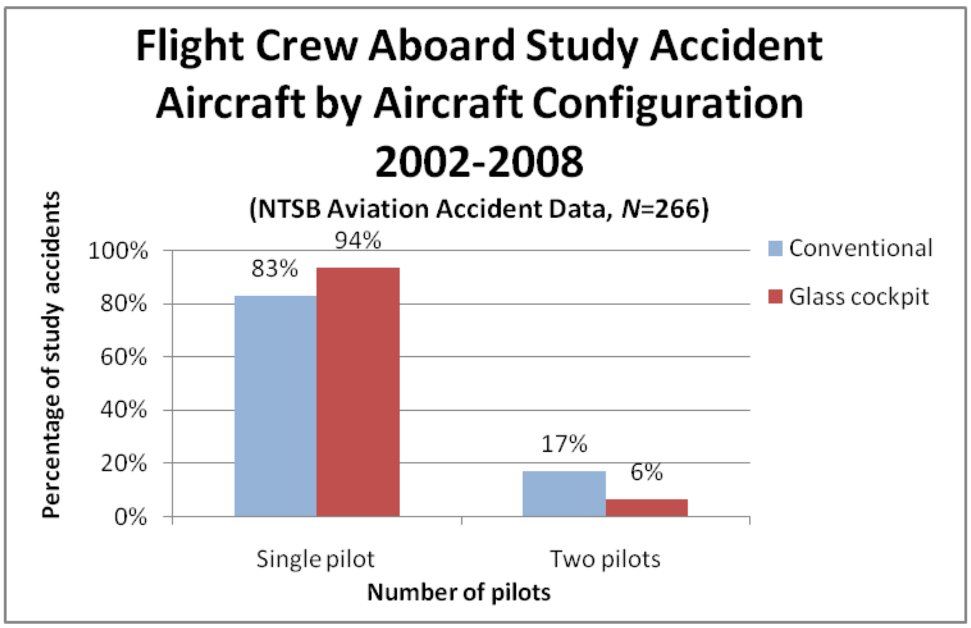



**Figure 19.** Comparison of number of pilots aboard study accident aircraft.

### Pilot Age

Age data were available for 257 of the 266 accident pilots considered in the study. Accident pilots in the glass cockpit cohort ranged in age from 18 to 76, with a median age of 47. Accident pilots in the conventional cohort ranged in age from 17 to 77, with a median age of 43. Accident pilots flying glass cockpit aircraft were significantly older than those flying conventional aircraft (U = 6736.5, $N$ (conventional) = 139, $N$ (glass cockpit) = 118, $p$ = 0.014). Much of the difference between the conventional and glass cockpit study cohorts with regard to age can be attributed to differences in the percentage of young pilots. Of the 139 accident pilots in the conventional aircraft cohort whose age was known, 38 (27 percent) were under 30 years old. In contrast, for the glass cockpit cohort, only 14 of the 118 accident pilots (12 percent) for whom age information was available were under 30 years old.

## Pilot Certificate Level

Of those accident pilots for whom certificate information was available, 26 percent held airline transport pilot (ATP) or commercial certificates, 50 percent held private pilot certificates, and 24 percent held student pilot certificates. As shown in figure 20, nearly equal proportions of the two cohorts held commercial or ATP certificates, but the two cohorts differed significantly with regard to student and private pilot certificates: $\chi^2$ (2, $N$ = 261) = 21.931, $p < 0.001$. In comparison, the data concerning the FAA's U.S. civil airman certificate for 2002 through 2008[59] indicate that an average of approximately 14 percent of active pilots held a student pilot certificate, 38 percent a private pilot certificate, and 43 percent a commercial pilot certificate or ATP.

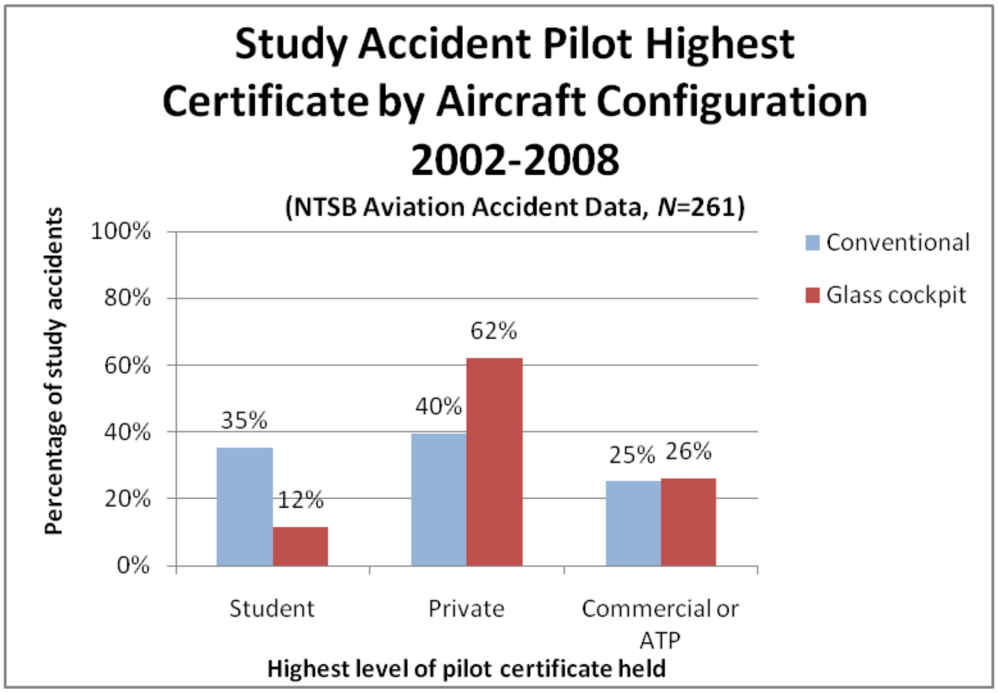



**Figure 20.** Comparison of study accident pilots by certificate level.

## Pilot Instrument Rating

As illustrated in figure 21, approximately 65 percent of accident pilots in the glass cockpit cohort were rated for instrument flight, compared to 37 percent of those in the

[59] See <http://www.faa.gov/data_research/aviation_data_statistics/civil_airmen_statistics/2008/>.

conventional cohort.[60] The difference in instrument rating between the aircraft cohorts was statistically significant: $\chi^2$ (1, $N$ = 257) = 20.828, $p < 0.001$. In comparison, the FAA's U.S. civil airman statistics indicate that, on average, 51 percent of the active pilot population from 2002 to 2008 held an instrument rating.

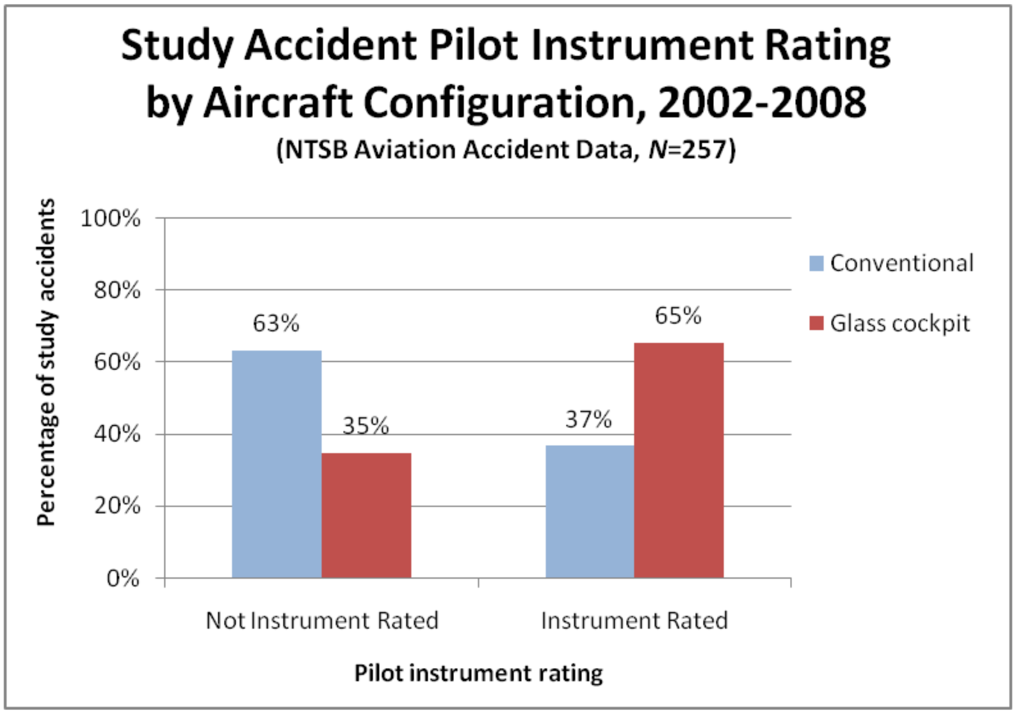



**Figure 21.** Comparison of study accident pilots by instrument rating.

### Pilot Flight Hours

The most commonly available measures of accident pilot flight experience were total flight hours in all aircraft and total time in the accident aircraft make and model. The total flight time of accident pilots in glass cockpit aircraft ranged from 22 to approximately 25,000 hours, while the total flight time for accident pilots in conventional aircraft ranged from 1 to 23,000 hours. The median number of total flight hours for glass cockpit pilots was higher than the median total flight hours for pilots of conventional aircraft (466 hours and 167 hours, respectively), and accident pilots in the glass cockpit cohort had significantly more total flight hours than those in the conventional cohort: U = 5503.0, $N$ (conventional) = 138, $N$ (glass cockpit) = 118, $p$ <0.001.

Flight experience in the accident aircraft make and model for pilots in glass cockpit aircraft ranged from 11 to approximately 1,430 hours and for accident pilots in conventional aircraft, from 1 to approximately 6,200 hours. Median flight experience in make and model for glass cockpit pilots was higher than for those flying conventional aircraft (99 hours and 70 hours,

[60] Insufficient data were available to compare instrument flight experience and currency at the time of the accident.

respectively). However, the overall distributions of flight time in the accident make/model were not significantly different: U = 6087.5, *N* (conventional) = 129, *N* (glass cockpit) = 106, $p= 0.148$. It is important to note that data concerning flight experience in aircraft make and model made no distinction in cockpit design, so some pilots may have been experienced in the aircraft type while having little experience with the particular cockpit display in the aircraft.

## Summary of Quantitative Analysis Results

Study comparisons of total and active aircraft, flight hours, and accidents showed similar patterns of accident rates for study aircraft. A comparison of the accidents from 2002 through 2008 involving the glass cockpit and conventional study cohorts with the number of registered aircraft indicates that the glass cockpit aircraft study cohort experienced a lower accident rate but a higher fatal accident rate. Analyses of the study-specific estimates obtained from the FAA's 2006 and 2007 GAATAA Surveys indicate that the 2-year, 2006 and 2007 accident rate per 100,000 flight hours was similar for both study groups, but the fatal accident rate per flight hour was higher for the glass cockpit cohort.

Statistical comparisons of accident characteristics identified several variables with distributions significantly different between the conventional and glass cockpit groups, including (1) accident severity, (2) purpose of accident flights, (3) planned length of accident flight, (4) number of pilots, (5) pilot age, (6) pilot certification level, (7) pilot total flight experience, and (8) pilot instrument rating. Accidents involving glass cockpit aircraft were more likely to be associated with personal/business flights, longer flights, and single-pilot operations, while conventional aircraft were more likely to be associated with instructional flights, shorter flights, and two-pilot operations. Accident pilots of glass cockpit-equipped aircraft were older, held higher levels of pilot certification, were more likely to hold an instrument rating, and had more flight hours than those flying aircraft with conventional instruments. The glass cockpit cohort was involved in more accidents in IMC, but the difference was only marginally significant.

These results are consistent with GAATAA Survey data indicating that the conventional cohort flew more instructional flight hours. A younger pilot group, two-pilot crews, and shorter flights are consistent with new pilots learning to fly. Aircraft in the conventional cockpit cohort were more likely to be involved in an accident but less likely to be involved in a fatal accident, which is also consistent with the conventional aircraft being used to conduct more instructional flights, which historically have had lower fatal accident rates than personal flying.[61]

Differences in accident rates between the study cohorts followed a similar pattern. The 2-year fatal accident rates for 2006 and 2007 were similarly low for both cohorts during instructional flights. The total accident rate was higher for conventional aircraft during both instructional and personal/business flying, but the fatal accident rate was highest for glass cockpit aircraft during personal/business flights.

[61] *Annual Review of U.S. General Aviation Accident Data, 2005,* Annual Review NTSB/ARG-09/01, "Focus on General Aviation Safety: Instructional Flight" (Washington, DC: National Transportation Safety Board, 2009).

Finally, accident and fatal accident rates were higher for the glass cockpit cohort in IMC and at night despite the aircraft being flown by pilots with higher levels of certification and more flight experience—and the additional capabilities of glass cockpit displays, which were intended to improve the safety of those flight operations. The tables that follow summarize the results of all statistical tests included in this study. Table 7 summarizes all comparisons of categorical accident variables in this chapter, with total numbers of cases included in each comparison, relative percentages, chi-square values, and significance.

**Table 7.** Summary of chi-square analyses.

| | Total Accidents | Conventional | | Glass cockpit | | $\chi^2$ | *p* |
|---|---|---|---|---|---|---|---|
| | | ***N*** | **% within cohort** | ***N*** | **% within cohort** | | |
| Accident Severity | 266 | - | - | - | - | 8.216 | 0.004 |
| Fatal | | 23 | 16% | 39 | 31% | | |
| NonFatal | | 118 | 84% | 86 | 69% | | |
| Total | | 141 | | 125 | | | |
| Light Condition | 266 | | | | | 3.058 | 0.080 |
| Day | | 122 | 87% | 98 | 78% | | |
| Night | | 19 | 13% | 27 | 22% | | |
| Total | | 141 | | 125 | | | |
| Weather | 264 | | | | | 3.639 | 0.056 |
| VMC | | 129 | 92% | 105 | 85% | | |
| IMC | | 11 | 8% | 19 | 15% | | |
| Total | | 140 | | 124 | | | |
| Flight Plan | 250 | - | - | - | - | 11.718 | 0.001 |
| VFR/None | | 110 | 83% | 76 | 64% | | |
| IFR | | 22 | 17% | 42 | 36% | | |
| Total | | 132 | | 118 | | | |
| Purpose of Flight | 258 | | | | | 31.616 | < 0.001 |
| Instructional | | 66 | 49% | 19 | 16% | | |
| Personal/Business | | 70 | 51% | 103 | 84% | | |
| Total | | 136 | | 122 | | | |
| Accident Event Type | 255 | - | - | - | - | 3.980 | 0.046 |
| Collision with Terrain | | 11 | 8% | 19 | 16% | | |
| Other | | 126 | 92% | 99 | 84% | | |
| Total | | 137 | | 118 | | | |
| Flight Crew Aboard | 266 | | | | | 7.063 | 0.008 |
| Single Pilot | | 117 | 83% | 117 | 94% | | |
| Two Pilots | | 24 | 17% | 8 | 6% | | |
| Total | | 141 | | 125 | | | |
| Highest Pilot Certificate | 261 | | | | | 21.931 | < 0.001 |
| Student | | 49 | 35% | 14 | 12% | | |
| Private | | 55 | 40% | 76 | 62% | | |
| Commercial or ATP | | 35 | 25% | 32 | 26% | | |
| Total | | 139 | | 122 | | | |
| Pilot Instrument Rating | 257 | - | - | - | - | 20.828 | < 0.001 |
| Not Instrument Rated | | 88 | 63% | 41 | 35% | | |
| Instrument Rated | | 51 | 37% | 77 | 65% | | |
| **Total** | | **139** | | **118** | | | |

Table 8 summarizes all comparisons of continuous accident variables in this chapter, with total numbers of cases included, median values, sums of ranks, Z-scores and Mann-Whitney U values, and significance.

**Table 8.** Summary of Mann-Whitney analyses.

| | *N* | Median | Sum of Ranks | *Z* | *U* | *p* |
|---|---|---|---|---|---|---|
| Pilot Age | - | | - | 2.467 | 6736.5 | 0.014 |
| Conventional | 139 | 43yrs | 16466.5 | | | |
| Glass Cockpit | 118 | 47yrs | 16686.5 | | | |
| Total | 257 | | | | | |
| Pilot Total Flight Time | | | | 4.469 | 5503.0 | <0.001 |
| Conventional | 138 | 167hrs | 15094.0 | | | |
| Glass Cockpit | 118 | 466hrs | 17802.0 | | | |
| Total | 256 | | | | | |
| Pilot Flight Time in Make/Model | | | | 1.445 | 6087.5 | 0.148 |
| Conventional | 129 | 70hrs | 14472.5 | | | |
| Glass Cockpit | 106 | 99hrs | 13257.5 | | | |
| Total | 235 | | | | | |
| Planned Flight Length | - | | - | 4.807 | 5649.5 | <0.001 |
| Conventional | 140 | 25nm | 15519.5 | | | |
| Glass Cockpit | 122 | 96nm | 18933.5 | | | |
| **Total** | **262** | | | | | |

# Chapter 4: Qualitative Assessment

In addition to conducting the retrospective data analyses included in this study, the NTSB reviewed FAA and manufacturer training materials and programs applicable to glass cockpit aircraft and visited aircraft manufacturers to observe factory training available to general aviation pilots transitioning to glass cockpit avionics. The NTSB also spoke with several representatives of the aviation insurance industry regarding experience and training requirements for coverage of glass cockpit-equipped light aircraft. This review enabled the NTSB to understand and assess the current state of training requirements and glass cockpit training available to general aviation pilots.

## FAA Requirements and Guidance Materials

The FAA has established minimum requirements for persons wishing to obtain initial or additional pilot certification and ratings. Pilot applicants must log a minimum number of flight hours, meet specified flight and ground training requirements, and pass a knowledge and/or practical test to receive a pilot certificate or additional qualifications, such as an instrument rating. Knowledge tests are designed to sample an applicant's understanding of the information necessary to exercise the privileges of a particular certificate or rating. Prospective pilots must pass the required knowledge test and obtain an instructor's endorsement to be eligible to take the practical test for a certificate or rating. The current pool of questions for FAA airman knowledge tests, such as private pilot, instrument rating, commercial pilot, and flight instructor certificates, do not assess pilots' knowledge of the functionality of glass cockpit displays.[62] However, most of the FAA's training handbooks and Practical Test Standards (PTS) have been updated to incorporate information about electronic flight instrument displays.

The FAA currently has no specific initial or recurrent training requirements for pilots of Part 23 certified[63] aircraft related to cockpit equipment or avionics. There are general requirements for all pilots to be knowledgeable about the operation and limitations of the aircraft they fly—including all aircraft systems—and to be proficient in the use of those systems. The FAA PTS requires that applicants be able to demonstrate proficiency with all equipment installed in their airplanes, and the FAA's most recent Instrument Rating[64] and Flight Instructor, Instrument[65] PTS mentions electronic flight displays with regard to knowledge of the operating characteristics of installed equipment and operating procedures such as preflight checks. The *Aircraft and Equipment*

[62] Based on the June 26, 2009, revision of FAA airman knowledge test banks, available online: <http://www.faa.gov/training_testing/testing/airmen/test_questions/>.

[63] Title 14 CFR Part 23 contains airworthiness standards for airplanes in the normal, utility, acrobatic, and commuter categories. The maximum takeoff weight of an airplane in the normal, utility, or acrobatic category cannot exceed 12,500 pounds, and the maximum takeoff weight of an airplane in the commuter category cannot exceed 19,000 pounds. In comparison, 14 CFR Part 25 contains airworthiness standards for airplanes in the transport category, which typically have a maximum gross weight of more than 12,500 pounds.

[64] FAA-S-8081-9C, available online: <http://www.faa.gov/training_testing/testing/airmen/test_standards/media/FAA-S-8081-9C.pdf>.

[65] FAA-S-8081-4E, available online: <http://www.faa.gov/training_testing/testing/airmen/test_standards/media/FAA-S-8081-4E.pdf>.

*Required for the Practical Test* section of the PTS also mentions electronic primary flight instrument and abnormal or emergency procedures for instrument failures.

The FAA Instrument Rating PTS specifically addresses electronic flight instruments in its guidance to pilot examiners regarding the evaluation of an applicant's response to instrument failures as follows:

> The loss of the primary electronic flight instrument display must be tailored to failures that would normally be encountered in the aircraft. If the aircraft is capable, total failure of the electronic flight instrument display, or a supporting component, with access only to the standby flight instruments or backup display shall be evaluated.

## Equipment-Specific Training

Even before it began updating its training materials and PTS, the FAA recognized a need to improve general aviation pilot training. The FAA developed its FITS initiative in anticipation of the increasing demands of managing advanced technology in general aviation cockpits. With a focus on scenario-based training techniques, the FITS initiative attempted to make pilot training more engaging and more relevant to real-world demands. Another element included in the initial FITS initiative was aircraft- and equipment-specific training.

Findings of the 2003 *General Aviation Technically Advanced Aircraft: FAA–Industry Safety Study* noted a divide between the potential safety benefits of increased use of technology and the realization of those benefits, as described below:

> TAAs provide increased "available safety," i.e., a potential for increased safety. However, to actually obtain this available safety, pilots must receive additional training in the specific TAA systems in their aircraft that will enable them to exploit the opportunities and operate within the limitations inherent in their TAA systems.[66]

and

> The template for securing this increased safety exists from the experiences with previous new technology introductions—the current aircraft model-specific training and insurance requirements applicable to high-performance single and multi engine small airplanes. However, the existing training infrastructure currently is not able to provide the needed training in TAAs.[67]

The FITS program plan,[68] published by the FAA in 2003, cited several intended product categories. In addition to general FITS training, the program sought to produce a "specific FITS

[66] Finding 4 of the FAA-Industry study.

[67] Finding 5 of the FAA-Industry study.

[68] *FAA-Industry Training Standards (FITS) Program Plan* (Washington, DC: Federal Aviation Administration, 2003).

program for a specific aircraft or technology." The FITS program plan described the intended product as follows:

> Specific standards will be initially developed in partnership with [manufacturers and training centers]. They will prototype and implement initial, transition, recurrent, and flight instructor training requirements of their customers and flight operations. Incentive mechanisms in these programs will include regulatory incentives within the current [*Code of Federal Regulations*] CFR (i.e. 141.57, Special curricula) as well as industry incentives such as insurance. Development will be in conjunction with certification under 14 CFR Part 142 and Part 141.

The description went on to suggest that similar specialized training was expected to be developed for individual avionics systems and displays and for pilots transitioning to upgraded equipment that was being retrofitted into existing aircraft.

The NTSB identified the need for pilots to receive specialized training for advanced aircraft equipment in a 1992 special investigation and analysis of several accidents involving the Piper Aircraft Corporation model PA-46 airplane.[69] The PA-46 included an autopilot and flight director system that was an advanced technology for single-engine light aircraft at that time. In response to the investigation of several accidents and one incident in which pilots misunderstood or misused that system, the NTSB issued the following recommendation to the FAA:

> Amend 14 CFR 61.31(f) to include integrated flight guidance and control systems as part of the ground and flight training requirements specified in subparagraphs (f) (1) (i) and (ii). (A-92-88)

The FAA did not establish the recommended training requirements, but in 1997, it enacted 14 CFR 61.31(h) requiring pilots to receive aircraft type-specific training and a logbook endorsement for aircraft identified by the Administrator as requiring such training.[70] On July 30, 1998, the NTSB noted that the FAA did not plan to make the recommended regulatory changes and classified Safety Recommendation A-92-88 "Closed—Unacceptable Action." One of the anticipated actions described in the FITS program plan was development of mandatory pilot training and qualification standards in accordance with 14 CFR 61.31(h). This approach would have created equipment-specific requirements akin to a type rating for a Part 23 aircraft. The program plan suggested that "Promulgation could be through an amendment to the aircraft flight manual, which refers to the FITS standard directory."

Since publication of the 2003 TAA report and FITS program plan, the FAA has shifted the focus of FITS away from equipment-specific training for advanced aircraft systems, as mentioned in the original program plan, and has focused instead on updating training manuals and promoting instructional techniques, such as scenario-based training and student-led performance reviews, for pilots of all aircraft. To date, the FAA has encouraged manufacturers

[69] *Piper Aircraft Corporation PA-46 Malibu/Mirage Accidents/Incident, May 31, 1989, to March 17, 1991*, Special Investigation Report NTSB/SIR-92/03 (Washington, DC: National Transportation Safety Board, 1992).

[70] The type-specific training requirement of 14 CFR 61.31(h) was never applied to the PA-46.

and training providers to develop specific training but has not incorporated equipment-specific elements into its training, testing, or currency requirements.

## Manufacturer Training Programs and Materials

The NTSB observed FITS-accepted training programs provided by two of the large manufacturers of aircraft included in this study and reviewed training materials provided by several glass cockpit display manufacturers.

### Aircraft Manufacturers

In general, aircraft manufacturers provide transition training for buyers of new aircraft, and most include training or require that pilots take a training course as part of the purchase contract. Manufacturer training includes several components. Written and electronic study materials, typically completed by the new owner before arriving at the factory to begin flight training, include several hours of familiarization study on aircraft systems, checklists, and operating procedures. Ground training and flight training, which generally occur at the factory, include 2 to 3 days of instruction, with the possibility of additional instruction if desired. Flight and ground training includes takeoffs/landings and flight maneuvers, normal and emergency procedures, and aircraft systems and equipment. Pilots who are instrument rated typically also practice instrument flying and instrument approaches. NTSB observations and anecdotal reports from pilots and instructors suggest that for many general aviation pilots, the transition to new avionics requires as much—or often more—effort than the transition to the new aircraft itself. Both manufacturers visited by the NTSB incorporated flight training devices and avionics simulators into their training to provide additional avionics instruction.

Typical factory training is designed as familiarization training or as a “checkout,” rather than as a proficiency evaluation. Persons who complete the course receive a certificate or proof of completion that insurance companies accept—and often require—and that can be credited toward the FAA’s WINGS pilot proficiency program.[71] Factory training typically does not result in an endorsement for a flight review or instrument proficiency check,[72] but manufacturers will provide the additional instruction necessary to complete a flight review or instrument proficiency check at additional owner expense. Manufacturers can also arrange to have a flight instructor accompany the owner on the flight home in the new aircraft, and most maintain networks of training centers and/or factory-trained instructors to provide additional and recurrent training throughout the country. Although aircraft manufacturers will provide training to anyone, free factory training programs almost exclusively target the original aircraft owner. Some new owners choose to allocate the transition training included with the purchase of a new aircraft to local flight instructors so that they can continue to receive factory-approved training after returning home. Buyers of used aircraft, or other pilots wishing to receive factory-approved training, can also purchase training at the factory, but they would typically receive training through the

[71] See <https://www.faasafety.gov/WINGS/pppinfo/default.aspx> for an explanation of the FAA Safety Team, WINGS pilot proficiency program.

[72] See 14 CFR 61.57 for the requirements of the flight review and instrument proficiency check.

distributed network of training centers or factory-approved instructors. Some aviation insurance providers require periodic factory-approved recurrent training or encourage such training through discount incentives.

In some cases, manufacturers and aviation insurance companies have collaborated with academic institutions to develop training programs and accident reduction initiatives. In addition to the FAA's FITS program and the training materials and programs currently in place, industry efforts are underway to identify new methods for reducing accidents.[73]

### Avionics Manufacturers

Most manufacturers of glass cockpit avionics produce training materials to support their products. A common training tool produced by some of the larger avionics manufacturers is a software simulator for use on a personal computer that allows pilots to interact with the display interface to become familiar with display operation and capabilities, menu organization, and control functions. These software simulators are not intended to replicate the functionality of an approved flight simulator or training device[74] but rather to serve as interactive procedural trainers that allow pilots to practice using glass cockpit avionics and experience various display system malfunctions and failures that may not be easily or safely replicated in the aircraft. Some avionics manufacturers provide free software simulators, while others charge a small fee but provide a free copy with purchase of the avionics equipment.

Some glass cockpit avionics manufacturers also produce training curricula and manuals. For example, Garmin produces a guide to its cockpit avionics for flight instructors and pilot examiners[75] that includes an overview of potential failure modes and operational scenarios that correspond to pilot knowledge and performance requirements of the FAA Instrument Rating PTS. Garmin also produces a pilot training guide and knowledge test, along with resource materials for flight instructors to train and evaluate pilots on the operation of its G1000 glass cockpit system.[76]

## Insurance Requirements

Although the FAA currently has no specific training requirements for pilots of light aircraft related to aircraft avionics and displays, aviation insurance providers often require pilots to complete training to receive and maintain coverage. The NTSB spoke with several aviation

[73] For example, the Airmanship Education Research Initiative (AERI) is a collaborative research effort by Cirrus Design Corporation, Avemco Insurance, and the University of Illinois Urbana-Champaign aimed at identifying methods for teaching improved decision-making techniques: <http://www.humanfactors.illinois.edu/news/news.aspx?29>.

[74] Title 14 CFR Part 60 and FAA Advisory Circular AC-61-136 provide guidance for the approval of flight simulators and training devices for pilot training and certification.

[75] Garmin International, Inc., *Integrated Flight Deck, Guide for Designated Pilot Examiners and Certificated Flight Instructors,* 190-00368-02 Revision C, May 2008. (Olathe, Kansas). Available online at: <http://www8.garmin.com/manuals/G1000:Non-AirframeSpecific_GuideforDPEsandCFIs.pdf>.

[76] Garmin International, Inc., *Integrated Flight Deck, Pilot's Training Guide, Instructor's Reference (-06).* 190-00368-06 Revision B, May 2008 (Olathe, Kansas). See <http://www8.garmin.com/manuals/G1000:Non-AirframeSpecific_PilotsTrainingGuide_InstructorsReference-06_.pdf>.

insurance company representatives and insurance underwriters to better assess the nonregulatory training requirements for pilots and owners of glass cockpit-equipped aircraft.

Actuarial data, including claims information and person-specific details, allow insurance companies to determine coverage costs and establish tailored training requirements for pilots transitioning to glass cockpit aircraft. Insurance companies consider each pilot's history and flight experience, as well as the pilot's record as a customer with a particular company, when establishing requirements for coverage. A private pilot with an instrument rating, 1,000 hours of flight time, and no history of major claims may be required to complete factory transition training, while a new private pilot who does not hold an instrument rating may be required to receive additional initial and/or recurrent factory-approved training beyond the basic transition course. Some providers suggested that they may decline coverage to pilots wanting to insure high-performance aircraft with glass cockpit avionics unless the pilots were previous customers with a good claims history. The exact details of insurance company requirements are tailored to individual pilots and vary from one company to the next. However, these requirements are often more rigorous than the regulatory requirements that the FAA has established for general aviation pilots based on other equipment-specific properties, such as high performance, complexity, or conventional landing gear.[77]

In some cases, however, insurance requirements are not particularly rigorous or do not establish additional requirements for pilots transitioning into aircraft with glass cockpit avionics. For example, the NTSB spoke with some insurance providers who suggested that they would not require additional training for an existing customer upgrading from an older aircraft with conventional instruments to a similar new aircraft with glass cockpit displays (for example, from a 1980 Cessna 172 to a 2006 Cessna 172), but that they would adjust coverage and premiums based on the value of the airframe. Other providers said they would require a one-time, equipment-specific checkout. With regard to new glass cockpit displays retrofitted to existing aircraft, insurance providers said that they typically would not be aware of the new equipment unless owners contacted them to increase their coverage, and that in that case, they would be unlikely to impose additional requirements for training. Manufacturers and insurance company representatives also mentioned that they are aware that in some cases, owners have chosen to "self-insure" their aircraft or forgo coverage and assume the responsibility for any problems they might encounter.

The lack of equipment-specific training requirements from the FAA and the variability of insurance company requirements result in a wide range of initial and recurrent training experiences among pilots of glass cockpit aircraft. With the exception of the training provided by manufacturers with the purchase of a new aircraft, pilots must currently seek out equipment-specific training.

[77] Title 14 CFR 61.31 details requirements for aircraft-specific training required to act as pilot-in-command.

# Chapter 5: Case Study Review

In addition to the data analyses and the assessment of training resources and requirements described above, the NTSB reviewed accident investigations involving glass cockpit-equipped aircraft to identify cases in which glass cockpit displays either malfunctioned or functioned in a manner that was different from a conventional display and/or pilot expectation. This chapter discusses those case studies and several issues identified in those reviews.

## Pilot Expectations Regarding Glass Cockpit Displays

On April 9, 2007, at 1159 mountain daylight time, a Cirrus Design Corporation SR22, N953CD, piloted by a private pilot, sustained substantial damage when it collided with trees 16 miles north of Luna, New Mexico, following a ballistic parachute deployment.[78] The personal flight was being conducted under the provisions of 14 CFR Part 91 on an IFR flight plan. The pilot was not injured. The cross-country flight originated at Tucson, Arizona, and was en route to Englewood, Colorado.

The pilot said he was climbing from 15,000 feet to 16,000 feet to avoid building thunderstorms and snow showers. The pilot reported that he was in IMC when the airspeed indication started to decrease and the airspeed and altimeter readouts on the PFD went to "hash marks" (an indication of system malfunction or data loss, which would have appeared on the display as red Xs). The pilot stated that he manually overrode the autopilot to initiate a descent and turned the pitot heat on. The pilot reported that shortly thereafter, the airspeed indication returned. The pilot sensed that he was in a descent and "pulled back" to slow the airplane down, and the attitude indicator went "haywire." The terrain warning system activated, and the pilot elected to activate the ballistic recovery parachute on the airplane. The airplane impacted trees and came to rest inverted at the top of several trees. The empennage separated from the airplane. The outboard portion of the right wing was crushed aft and had partially separated.

The pilot's written statement indicated that the airplane was "getting hit by snow pellets." He stated that he "turned the TKS [supplemental ice protection system] on to maximum and set the windshield defroster to its highest setting." The pilot contacted air traffic control and requested another altitude to "get out of the clouds," as he was "in light icing." The pilot wrote that when he completed a routing change, he noted that the numbers on the airspeed indicator were red.[79] The pilot stated that he "immediately pushed the nose down." Shortly thereafter, the airspeed indication went to "hash marks." He stated that the "altitude indicator also gave no indication of altitude and appeared to have completely failed." The pilot wrote that a cross-check of the backup airspeed indicator showed no readings, and in a followup telephone interview, he stated that the event happened so quickly that he did not initially look at the backup airspeed

[78] See DEN07LA082 <http://www.ntsb.gov/ntsb/GenPDF.asp?id=DEN07LA082&rpt=fa>.

[79] Numbers changing to red is consistent with the aircraft's approaching stall speed.

indicator, but when he did, it was at zero. The pilot also stated that he did not look at either the backup altimeter or backup attitude indicator.[80]

Data recovered from the aircraft PFD indicated that when the airspeed indication decreased to zero, internal validity checks in the PFD flagged the pitot data input as "invalid."[81] The extracted data further indicated that system logic checks identified the invalid airspeed value as an air data computer failure and subsequently flagged all air data parameters as invalid. According to the manufacturer, the result would be to replace all air data information on the display: airspeed, altitude, and vertical speed with red "X" indications, and outside temperature with dashed lines. The display operated as designed in this case, but the resulting behavior was different from that of conventional cockpit instruments. (If the pitot tube drain remains open, blockage of the pitot tube intake will typically result in a decreased or zero airspeed indication on a conventional airspeed indicator while the remaining instruments will continue to function normally.) In this case, the PFD displayed failure indications for all air data parameters,[82] which led the pilot to initially interpret a likely pitot tube intake blockage due to icing to be an air data computer failure.

During the investigation of an accident only a few months later, which involved a Piper Aircraft PA-46-500TP Meridian equipped with dual PFDs produced by the same avionics manufacturer as in the previous accident example, NTSB investigators found similar flagging of air data parameters in response to suspected pitot tube intake blockage due to airframe icing.[83] Data recovered from the accident aircraft indicated that the PFD software had also flagged as invalid the airspeed, altitude, and vertical speed information as the dynamic pressure sensed by the system decreased to zero. In that case, the pilot and copilot PFDs in the accident airplane were fed from separate pitot inputs, and the backup airspeed was fed from the pilot's side pitot input. According to the manufacturer,[84] blockage of both pitot tube intakes would have resulted in loss of all air data on both primary displays and a loss of usable information on the backup analog airspeed indicator. The flagged air data would also have resulted in the autopilot automatically disengaging with an audible warning.[85] The Piper Meridian was not equipped with a ballistic parachute as was the Cirrus involved in the earlier accident. The accident aircraft experienced a loss of control and subsequent in-flight breakup, resulting in fatal injuries to the pilot and two passengers.

Although the PFD displays in these accidents functioned differently than conventional displays would have under similar circumstances, they performed in accordance with the

[80] Refer to the document "Statements" in the NTSB Docket Management System records for accident case DEN07LA082.

[81] Refer to the flight data recorder group chairman's factual report in the NTSB Docket Management System records for accident case DEN07LA082.

[82] The other data parameters affected in this case included altitude and vertical speed.

[83] NTSB investigation number CHI07FA183, June 28, 2007. This accident is included here as an example of the PFD function, but it was not included in the statistical study analyses because it involved a turboprop-powered aircraft.

[84] Refer to manufacturer letter dated August 12, 2009, in the NTSB Docket Management System records for accident case CHI07FA183.

[85] For a complete discussion of system operation, see final accident report in the NTSB Aviation Accident Database at <http://www.ntsb.gov/ntsb/GenPDF.asp?id=CHI07FA183&rpt=fa>, as well as the manufacturer and FAA correspondence included in the official NTSB docket for this case.

intended design and software logic. Title 14 CFR 23.1309(b) requires that warning information be provided to alert pilots to unsafe operating conditions to enable them to take appropriate corrective action, and the requirements of 14 CFR 23.1581 state that an aircraft flight manual (AFM)—which must contain information about the safe operation of aircraft systems in the event of malfunction—must be furnished for each aircraft.

Given its concerns about pilots' need to understand complex aircraft system operation, which was established in its 1992 special investigation of several Piper Aircraft model PA-46 airplane accidents,[86] the NTSB issued the following recommendation to the FAA:

> Require the manufacturers of integrated flight guidance and control systems, for which supplements to the airplane flight manual and pilots operating handbook must be provided, to develop and make available to operators detailed training information that will enable pilots to diagnose system failures, understand pilot-induced flight control system problems, and use the system in a safe and proficient manner. (A-92-89)

In response to NTSB recommendation A-92-89, the FAA issued Change 1 to AC 23-8A, *Flight Test Guide for Certification of Part 23 Airplanes*, and AC 23.13091B, *Equipment, Systems, and Installations in Part 23 Airplanes*, emphasizing that complex integrated systems may dictate that cockpit warning indicators and/or detailed emergency procedures information be included in the FAA-approved AFM or AFM Supplement. Based on this action by the FAA, the NTSB classified Safety Recommendation A-92-89 "Closed—Acceptable Action" on June 28, 1996.

The AFM Supplement for the PFD installed in the Piper Aircraft Corporation Meridian included a full description of a loss of air data computer information, along with guidance to use the analog backup instruments in the event of failure. However, the manual did not provide specific information about system behavior in response to the loss of specific data inputs, such as a pitot tube intake blockage. In response to communication from NTSB investigators, the FAA and the avionics manufacturer reviewed this case and determined that flagging all air data parameter indications as invalid in response to a loss of pitot input was not ideal. The manufacturer agreed to change the functionality in future software revisions, and the FAA agreed that a revision would be added to the AFM to better inform pilots of the system functionality until the software could be changed.

## Equipment Design and Reliability

Like all aircraft systems and equipment installations, glass cockpit displays are subject to 14 CFR Part 23 requirements for reliability and safety assessment. The reliability of electronic PFDs is generally assumed by the FAA and the pilot community to exceed that of their conventional analog equivalents due to the mechanical reliability of solid-state systems and the additional redundancy often required for electronic systems. For example, guidance provided in 14 CFR 23.1311—and in the associated AC 23.1311-1B, *Installation of Electronic Display in*

[86] *Piper Aircraft Corporation PA-46 Malibu/Mirage Accidents/Incident, May 31, 1989, to March 17, 1991*, Special Investigation Report NTSB/SIR-92/03 (Washington, DC: National Transportation Safety Board, 1992).

*Part 23 Aircraft*—specifies that to satisfy the requirements of 14 CFR 23 for IFR flight, electronic displays of airspeed, attitude, and altitude information require either dedicated standby instruments or dual independent PFDs. Similar redundant instrumentation is not required for Part 23 aircraft in order to be certified for IFR flight with conventional analog instruments. The general principle guiding this and similar requirements for electronic displays is that the safety, workload, and operational consequences of a new technology should be at least as good as the equipment it replaces. Manufacturers must provide evidence that the operational reliability aspect of this requirement is met during initial certification. Following certification, manufacturers must report certain equipment failures to the FAA, and their manufacturing processes are subject to inspection by the FAA, but reliability information is generally not available outside the manufacturer.[87]

Human performance objectives of increasing pilot awareness while simultaneously reducing workload and error are more difficult to achieve and validate than equipment reliability. AC 23.1309-1D addresses this difficulty in section 19(a), *Flight Crew and Maintenance Task*, stating that "quantitative assessments of the probabilities of flight crew and maintenance errors are not considered reasonable." The qualitative standard is that crews should respond to equipment malfunctions in a timely manner without jeopardizing other safety-related tasks and that such a response should not require exceptional skill or strength.

While arguably difficult to validate, assessments of the interaction between equipment design and human performance could greatly improve safety, especially in light of the criticality of human/equipment interactions. In its 2006 *Safety Report on the Treatment of Safety-Critical Systems in Transport Airplanes*,[88] the NTSB expressed concern about the failure to consider guidance for human performance evaluation of Part 25 aircraft and issued the following recommendation to the FAA to consider human/airplane system interactions in the assessment of safety-critical systems in transport aircraft certification:

> Amend the advisory materials associated with 14 CFR 25.1309 to include consideration of structural failures and human/airplane system interaction failures in the assessment of safety-critical systems. (A-06-37)[89]

This recommendation was directed at Part 25 aircraft, but human/airplane system interaction failures are also a safety concern in Part 23 aircraft. At the time of writing, the FAA is reviewing the Part 23 certification process and related guidance. In addition, several FAA ACs that address avionics systems are currently open for comment, such as AC 23-17C, *Systems and Equipment Guide for Certification of Part 23 Airplanes and Airships*; AC 23.1309-1E, *System Safety Analysis and Assessment for Part 23 Airplanes*; and AC 23.1311-1C, *Installation of*

[87] Title 14 CFR 21.3 requires holders of TSO authorization to report certain equipment failures to the FAA, and 14 CFR 21.615 requires that each manufacturer of equipment under TSO authorization allow the FAA to inspect equipment, inspect manufacturing facilities, review technical data files, inspect the manufacturer's quality control system, and observe any equipment tests upon request of the Administrator. However, these activities are typically prompted by specific events rather than being part of a continuous review process.

[88] *Safety Report on the Treatment of Safety-Critical Systems in Transport Airplanes*, NTSB/SR-06/02. (Washington, DC: National Transportation Safety Board, 2006).

[89] As of November 2009, this recommendation was classified "Open—Acceptable Response."

*Electronic Display in Part 23 Airplanes*. In July 2009, the FAA released its *Part 23 - Small Airplane Certification Process Study* (CPS),[90] which included findings and recommendations from the FAA and industry groups, such as the AOPA, GAMA, the Experimental Aircraft Association, and the National Business Aviation Association. This report, which predicted that the introduction of new 14 CFR Part 23 technologies would continue to accelerate over the next two decades, went on to recognize increased responsibility on the part of the FAA: "This is good news for [general aviation], but it increases the FAA oversight burden. The FAA must develop new regulatory, policy and guidance materials to address such technologies."

One area identified in the CPS report as needing greater uniformity was the application of good human factors design principles to keep pace with the increasing capabilities and complexities of avionics systems. The aviation industry has attempted to develop design frameworks and voluntary guidance for the design of glass cockpit avionics,[91] and the FAA includes human performance considerations in its ACs[92] and Policy Statements[93] for certification. Nevertheless, design challenges persist due to the complexity and rapid development of display technology. FAA and industry representatives included a finding in the CPS report acknowledging the following:

> Avionics and aircraft systems in Part 23 airplanes are offering more features and integration of these features. There is a broad range of system complexities offered in Part 23; some intuitive and others non-intuitive for pilots.
>
> Not all airplane and avionics designers have considered the pilot-machine interface by using good human factors practices. General aviation needs airplanes that are intuitive to operate, requiring as little training as possible.[94]

Analyzing Part 23 certification requirements was not within the intended scope of this NTSB study, other than to highlight the historic emphasis on equipment reliability—despite an acknowledgment of human performance as a leading factor in aviation safety. The approach to certification of Part 23 aircraft equipment has implied that human error can be reduced with increased use of technology. This approach and the importance placed on avionics technology are summarized in AC 23.1309-1D:

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[90] U.S. Department of Transportation, Federal Aviation Administration, *Part 23 - Small Airplane Certification Process Study* (Washington, DC: Federal Aviation Administration, July 2009).

[91] See for example, *GAMA Publication 10 - Recommended Practices and Guidelines for Part 23 Cockpit/Flight Deck Design* (<http://www.gama.aero/files/gama_publication_10_hf_september_2000_pdf_498cad6edd.pdf>) and *GAMA Publication 12 - Recommended Practices and Guidelines for an Integrated Cockpit/Flightdeck in a 14 CFR Part 23 Airplane* <http://www.gama.aero/files/gama_publication_12_p23cockpit_april_2005_pdf_498cadb978.pdf>.

[92] FAA AC 23.1311-1B, available online at <http://rgl.faa.gov/Regulatory_and_Guidance_Library/rgAdvisoryCircular.nsf/0/48bc1051f079b741862570210063956c/$FILE/AC23.1311-1B.pdf>.

[93] FAA Policy Statement PS-ACE100-2001-004, available online at <http://rgl.faa.gov/Regulatory_and_Guidance_Library/rgPolicy.nsf/0/ad52dc6379f1e4e786256c40004a0128/$FILE/polmen.pdf>.

[94] Finding 5.2.

> For all airplanes, but particularly GA [general aviation] airplanes, pilot decision-making causes most accidents. Pilot decision-making accidents, the largest single cause, often are the result of a lack of situational awareness relative to terrain or weather, or to a loss of control due to excess workload. Correct pilot interventions and actions have prevented some of these accidents. An increase in avionics equipage rates that improved pilot situational awareness or simplify the task had a significant positive impact on the GA accident rate.

The text of the AC goes on to cite the AOPA Air Safety Foundation study of TAAs as evidence of that positive effect. However, the AC also acknowledges that increased aircraft technology must be accompanied by pilot training in that “technologically advanced aircraft has delivered multiple safety benefits to GA pilots, but pilot training tied to experience has to evolve with it.”

## Standardization of Instrument Design and Operation

Unlike glass cockpit displays, the design and operation of conventional flight instruments is similar regardless of aircraft or manufacturer. The six instruments that make up a conventional cockpit include three pitot/static and three attitude instruments. Pitot/static instruments use aneroid capsules, calibrated diaphragms that expand and contract in response to changes in static air pressure to provide information about altitude (altimeter and vertical speed indicator) and the differential between static and dynamic pressure associated with speed (airspeed indicator). The attitude instruments (attitude indicator, heading indicator, and rate-of-turn indictor) use vacuum-driven and/or electrically driven gyros to provide information about aircraft orientation.

Individual manufacturers may vary the design of their instruments or instrument display face slightly, but the basic operation is so similar for all Part 23 aircraft that instructional materials often explain instrument design and functionality using detailed cutaway views of the instruments. Not all pilots may share an equal understanding of the inner workings of analog instruments, but the information is readily available in training material. The following sample illustration of a conventional airspeed indicator (figure 22) is taken from the FAA’s most recent (2007) edition of the *Instrument Flying Handbook*.

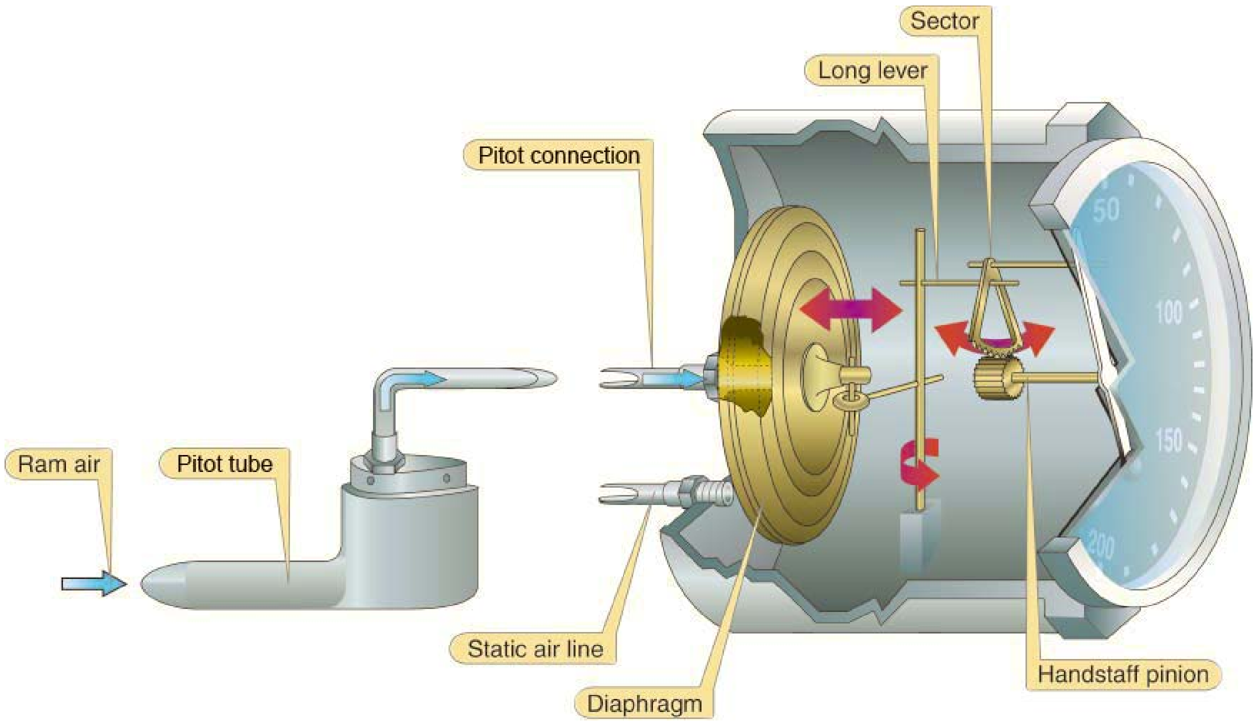


**Figure 22.** Illustration of a conventional airspeed indicator mechanism, adapted from the FAA *Instrument Flying Handbook*.

A similar example of instructional materials for analog instruments can be found in the FAA's newly revised *Pilot's Handbook of Aeronautical Knowledge.*[95] The illustrations in figure 23 were copied from chapter 7 of that handbook and show the operating and design principles at work in the instruments that display attitude and heading information. Like the altimeter, the basic design of the analog version of these instruments can be explained using cutaway images.

[95] Federal Aviation Administration, *Pilot's Handbook of Aeronautical Knowledge*, FAA-H-8083-25.

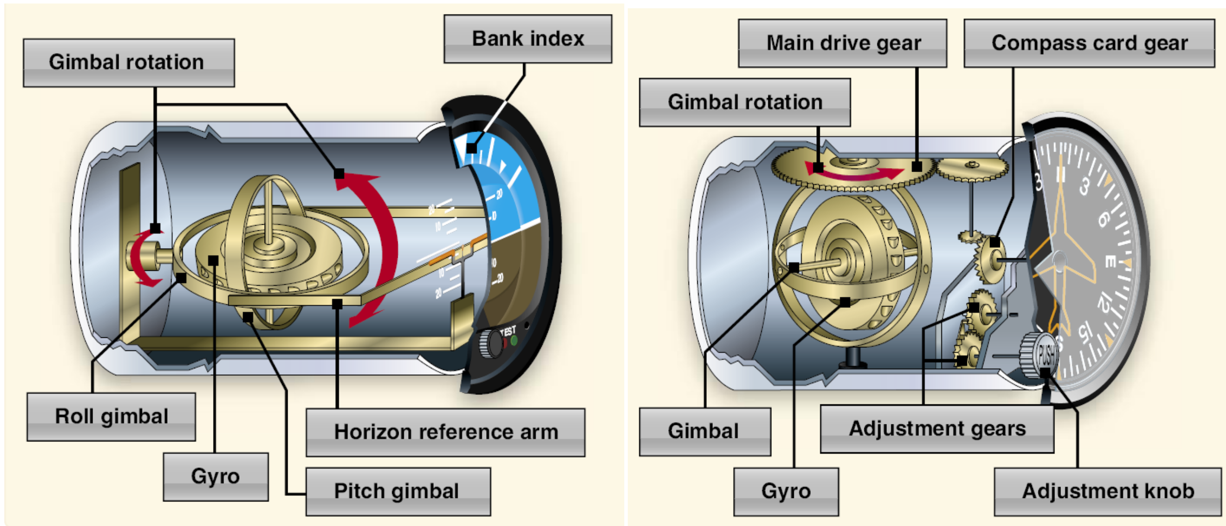


**Figure 23.** Illustrations of the internal mechanisms that drive analog attitude and heading indicator instruments, copied from the FAA *Pilot's Handbook of Aeronautical Knowledge*.

Unlike the relatively simple system of gyros and linkages that drives analog instruments, very little information is available to pilots about the glass cockpit display equivalent. The computerized systems at the heart of electronic PFDs are combinations of electronic components and software that are both unique to the manufacturer and equipment, and that are subject to change with any future system software revision. In contrast to the cutaway illustrations for analog instruments, illustrations of digital instruments do not lend themselves to the same amount of detail. Figure 24, for example, shows an AHRS, which drives the attitude and heading indicator displays of a PFD. As this illustration shows, the system is both figuratively and literally a "black box." Although the FAA *Pilot's Handbook of Aeronautical Knowledge* includes more than five pages of text and illustrations to describe the design and function of the analog gyroscopic instruments, it includes only four sentences describing the design of an AHRS. Rather than being indicative of an incomplete manual, this difference reflects the nature of the design of electronic display systems.


**Figure 24.** Illustration of an AHRS, copied from the FAA *Pilot's Handbook of Aeronautical Knowledge.*

The FAA summarizes the problem in its inspector handbook as part of the background information provided to inspectors regarding FITS acceptance of training courses or materials:

> In the past, displays, avionics, and navigation equipment all looked and functioned in a similar manner regardless of the manufacturer. This is not the case with today's advanced avionics systems and displays. Training in the operation of one manufacturer's GPS receiver may not give the pilot sufficient knowledge to safely operate another manufacturer's receiver. This is even more evident with full glass cockpits. Not only does the functionality of PFDs and MFDs vary between manufacturers, but also due to aircraft systems differences, the same avionics equipment in a different type aircraft may function differently.[96]

## Interpretation of Equipment Malfunctions

The wide variability in system design has implications for pilots' ability to identify and diagnose system malfunctions. For example, one of the fundamental skills required to fly an aircraft by reference to flight instruments is instrument cross-checking. Cross-checking, or scanning, refers to the task of comparing information from individual instruments and integrating that information into an overall understanding of the aircraft's orientation and performance. If information from one or more instruments does not agree with pilots' understanding of the aircraft attitude or performance, the pilots must rely on an understanding of instrument design and operation to reconcile discrepancies while ruling out the possibility of instrument malfunction. With conventional cockpit instruments, partially obstructed or blocked pitot tubes and static ports, vacuum pump failures, and gyro malfunctions exhibit characteristic symptoms

[96] FAA Order 8900.1, *Flight Standards Information Management System (FSIMS), Issue an FAA Industry Training Standards (FITS) Acceptance When Requested by a Flight School, Training Center, or Other Training Provider* (Vol. 5, Chapter 9, Sec. 5), 5-1669, CNG 0.

that can be identified by comparing information from all six instruments. Although these instruments use common sources of input, the independence between inputs and the redundancy among instrument displays are sufficient to enable pilots to diagnose common failure modes. Figure 25 is an example of a graphic referenced in questions from the FAA airman instrument rating knowledge test in which a pilot applicant must interpret an instrument failure identification. A typical knowledge test question associated with this type of graphic would ask the pilot applicant to identify the system that has failed and/or determine the corrective action necessary to return the airplane to straight-and-level flight. Similar graphics and questions are included in the knowledge test, requiring pilots to identify unusual aircraft attitudes and determine the corrective action necessary for recovery.

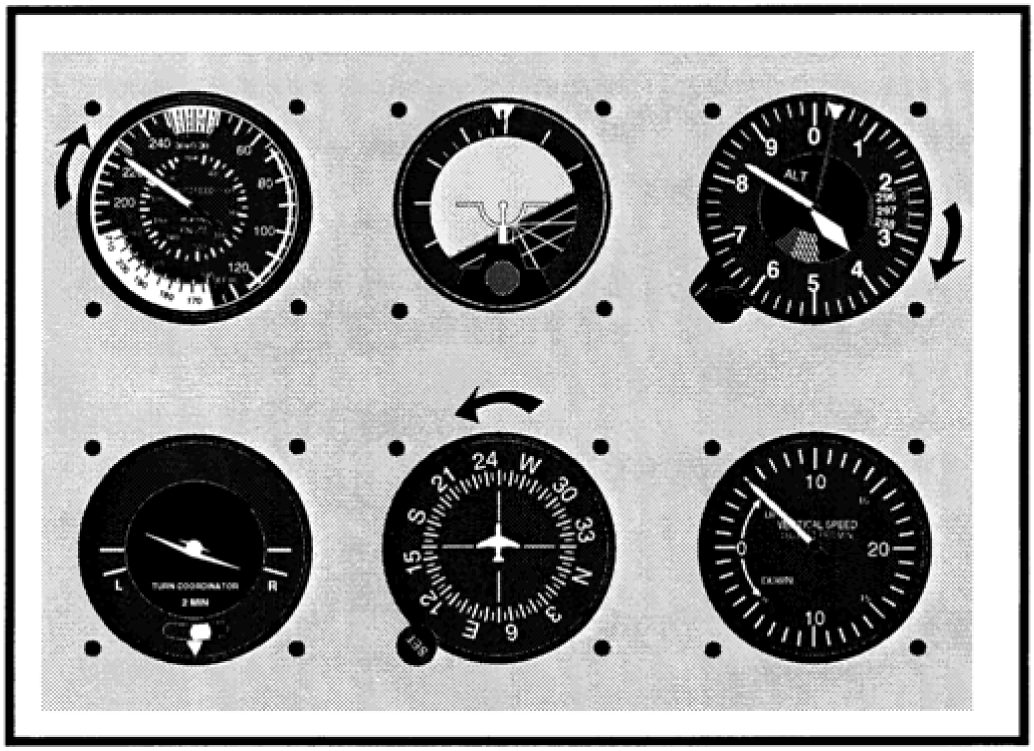


**Figure 25.** FAA instrument rating knowledge test sample: instrument malfunction interpretation (pitot tube intake and drain blockage).

As the pilot of the Luna, New Mexico, accident saw firsthand, however, the task of interpreting malfunctions and failures in glass cockpit displays is different than for conventional cockpit instruments. Different glass cockpit systems can also behave very differently from one another. For example, the pitot tube intake blockage in the system installed in the New Mexico accident aircraft resulted in the air data parameters being flagged as invalid. Further, some manufacturers of glass cockpit systems use designs that combine both the air data computer and

AHRS component functions so that a similar blockage could affect not only the airspeed and altitude displays but also the aircraft attitude display.[97]

Most of the current generation of light aircraft equipped with glass cockpit displays includes conventional airspeed, attitude, and altitude instruments as backup in the event of a PFD malfunction. These backup instruments typically share the same pitot and static inputs as the PFD. In some cases, a single small PFD-like electronic flight display is provided as a backup instead of conventional instruments. Due to differences in the design and operation of different electronic flight displays, it is possible that the backup display and the primary display will respond differently to a loss of data input, and that both will function differently than conventional instruments would under the same circumstances.

## Equipment-Specific Training

Problems associated with pilots learning to operate new and complex aircraft systems are by no means new, nor are they unique to glass cockpits. On February 3, 1959, a Beechcraft Bonanza, N3794N, crashed just after departure from Mason City Municipal Airport, Mason City, Iowa. The aircraft collided with terrain in an approximately 90-degree bank, nose-down pitch attitude, killing the pilot and three passengers: Charles Hardin, J. P. Richardson, and Richard Valenzuela, also known, respectively, as Buddy Holly, The Big Bopper, and Richie Valens.[98] The accident gained a level of notoriety in popular culture because of the celebrity of the passengers and subsequent movie and television depictions of the circumstances surrounding the accident. Less well known, however, are the findings of the accident investigation. In its final report on the accident, the Civil Aeronautics Board (CAB)—predecessor to the NTSB—found the probable cause of the accident to be the pilot's decision to depart into IFR flight conditions when he was not qualified to do so. In addition, the pilot's unfamiliarity with the attitude indicator, which provided a pitch display opposite that of the "artificial horizon" to which he was accustomed, was found to be a contributing factor to the accident.

The CAB considered the problem serious enough that it included as an attachment to the report a *Safety Message for Pilots*, stating the following in regard to flight instruments:

> The assumption may be that, providing one is aware of this difference, no difficulty should be experienced in utilizing either instrument. This assumption, however, is true only if the pilot has had sufficient training on both instruments.

The attachment went on to issue a warning to pilots:

---

[97] For example, the Airplane Flight Manual Supplement for the Aspen Avionics EFD1000 system (A-01-175-00 Rev. D) contains a warning that, "Because the EFD1000 uses pitot and static pressures as part of the ADAHRS [Air Data Attitude Heading Reference System] solution, loss or corruption of this data, such as from a line blockage, will impact the accuracy of data output by the ADAHRS. Affected parameters can include the airspeed, altitude and attitude information displayed by the EFD1000. If erroneous pitot or static inputs are detected by the EFD1000, the EFD1000 will present a 'CROSS CHECK ATTITUDE' annunciation."

[98] *Beech Bonanza, N3794N, Mason City, Iowa, February 3, 1959*, File No. 2-0001 (Aircraft Accident Report, Washington, DC: Civil Aeronautics Board, September 15, 1959).

KNOW YOUR AIRCRAFT EQUIPMENT, ITS CAPABILITIES AND LIMITATIONS. DO NOT RELY UPON ANY EQUIPMENT UNDER CIRCUMSTANCES REQUIRING ITS USE FOR THE SAFE CONDUCT OF THE FLIGHT UNTIL YOU HAVE ACQUIRED SUFFICIENT EXPERIENCE UNDER SIMULATED CONDITIONS TO INSURE YOUR ABILITY TO USE IT PROPERLY." (emphasis included in the original)

Pilots transitioning to glass cockpit-equipped aircraft face a situation similar to that of the Mason City accident pilot, but glass cockpit avionics present new and unique challenges for flight training that do not apply to conventional round-dial instruments. Rapidly changing equipment, the complexity of the systems, and the lack of standardization also increase the burden on flight instructors and pilot examiners to maintain their knowledge and proficiency with the variety of systems they may encounter when providing instruction.

The difficulty or inability to simulate various failure modes and functions can limit an instructor's or examiner's ability to train pilots and evaluate their ability to respond to various emergencies or equipment malfunctions. For example, the easiest type of equipment malfunction to simulate in a typical glass cockpit aircraft is the failure of a display screen or the associated backlighting. This is commonly simulated by decreasing screen brightness until it appears blank. In the event of an actual failure, a pilot would transfer functions to the remaining display and refer to backup instruments as necessary. It is also possible to simulate the discrete failure of the air data computer or AHRS components of some PFDs, depending on the system, by either switching off the unit or pulling a circuit breaker. However, a circuit breaker should not be used as a switch,[99] and pulling a circuit breaker is therefore not an appropriate method of simulating failures, even though some avionics manufacturer may suggest the practice.[100] In aircraft equipped with analog gauges, failure of an instrument can be simulated by covering that instrument, using static covers designed for the purpose or "sticky notes." However, the various flight data parameters of airspeed, attitude, heading, vertical speed, and altitude are combined on a PFD, making partial failures harder to simulate. Display manufacturers recommend against the use of sticky notes or static covers because they might harm expensive display screens. Some third-party vendors have developed full-screen overlays to simulate various failure modes.

[99] For example, FAA Advisory Circulars AC 23-17B and AC 120-80 include guidance stating that a circuit breaker (CB) should not be used as a switch. AC 120-80 (page 11-12) states, "Since CBs are designed to open an electrical circuit automatically at a predetermined overload of current, they should not be used for day-to-day operational functions because they would not be performing their intended function, which is protection against overloads. Circuit breakers, even those suitable for frequent operation, should not be used as a switch to turn protected items on or off."

[100] The "Recommendations for Failure Simulation" section (page 17) of Garmin International, Inc., *Integrated Flight Deck, Guide for Designated Pilot Examiners and Certificated Flight Instructors,* 190-00368-02, Revision C, May 2008 (Olathe, Kansas) includes instructions for two methods of simulating failures. The instructions state that the preferred method is to use the display dimming controls to simulate a display failure and that the other, less desirable, method is to pull various circuit breakers. However, the guide subsequently (page 19) notes that Cessna does not recommend this practice for its aircraft: "Cessna does not recommend pulling circuit breakers as a means of simulating failures on the GIFD [Garmin Integrated Flight Display]. Pulling circuit breakers—or using them as switches—has the potential to weaken the circuit breaker to a point at which it may not perform its intended function." The guide also acknowledges that pulling circuit breakers can interfere with the safe operation of other equipment.

In summary, accident records have demonstrated the importance of pilots understanding the capabilities and limitations of their aircraft. The nature and complexity of glass cockpit displays, and the variety of unique glass cockpit system designs, have created a need for new training procedures and tools to ensure that pilots have that understanding.

## Tracking Equipment Function and Reliability

The NTSB identified relatively few instrument failures in the set of study accidents that involved either conventional or glass cockpit aircraft,[101] and the information necessary to compare the reliability of conventional and glass displays was not available. In fact, one of the issues identified during the review of study accident reports was a lack of information being captured about system malfunctions and service difficulties, which could be used to research ways of preventing future accidents. One accident citing instrument malfunction in a glass cockpit aircraft occurred on January 15, 2005, when a Cirrus Design SR22, N889JB, was destroyed as the result of impact with a house and terrain following a loss of control in flight.[102] The certificated commercial pilot was fatally injured.

The pilot departed on an IFR flight plan in instrument meteorological flight conditions and shortly thereafter, misinterpreted a series of air traffic control instructions. Subsequent callouts and responses by the pilot indicated confusion, to the point at which he stated, "I gotta get my act together here." Less than 1 minute later, the pilot reported "avionics problems," and about 40 seconds after that, during his last transmission, he stated that he was "losin' it." The airplane subsequently descended nose-down, out of clouds, and impacted a house and terrain.

NTSB investigators were unable to determine the nature of the failure reported by the accident pilot due to the severity of impact damage. However, a review of the accident aircraft maintenance records identified a history involving several PFD issues. According to aircraft maintenance records, the PFD was replaced three times before the accident: first in response to an air data failure, then to fix a navigation course indicator failure, and finally in response to an AHRS data failure. During the third replacement, maintenance personnel found that the display had been replaced again previously—without logbook entry—due to damage to pitot and static fittings during installation of an air conditioning system.

The FAA maintains a service difficulty report (SDR) system to collect information about aircraft or equipment problems to accomplish the following:

> Provide assistance to aircraft owners, operators, maintenance organizations, manufacturers, and the Federal Aviation Administration (FAA) in identifying aircraft problems encountered during service. The Service Difficulty Program provides for the

[101] Of those cases with a probable cause published at the time of writing, two accidents in the glass cockpit cohort (NTSB case numbers IAD05FA032 and DEN07LA082), and one accident in the conventional cohort (NTSB case number MIA06FA050) included reported malfunctions or failures of flight instruments.

[102] NTSB case number IAD05FA032.

> collection, organization, analysis, and dissemination of aircraft service information to improve service reliability of aeronautical products.[103]

Title 14 CFR Parts 121 and 135 include requirements for air carriers to report certain aircraft and equipment malfunctions, failures, and maintenance difficulties.[104] Title 14 CFR Part 125 includes a similar requirement for reporting malfunctions or defects involving large aircraft not engaged in common carriage.[105] In addition to the list of specified failures, operators are required to report the following:

> Any other failure, malfunction, or defect in an aircraft that occurs or is detected at any time if, in its opinion, the failure, malfunction, or defect has endangered or may endanger the safe operation of the aircraft.

Although the SDR system was designed to collect information related to large aircraft, it also accepts malfunction and defect reports from light aircraft used in general aviation operations. The NTSB has previously identified the need to improve malfunction and defect reporting and service difficulty reporting for all aircraft, issuing the following recommendation to the FAA in 1993:

> Review the reporting items and establish standardized reporting formats for malfunction or defect reports and service difficulty reports that include the capability for electronic submission. Encourage all operations under 14 CFR Parts 21, 43, 91, 121, 125, 127, 135, and 145 to use electronic reporting methods for submission of service difficulty information. (A-93-61)[106]

The NTSB also issued the following recommendation to the FAA to improve malfunction and defect reporting for light aircraft and general aviation operations in particular:

> Encourage all persons or organizations that operate under 14 CFR Parts 43 and 91 to submit malfunction or defect reports and provide appropriate guidance to improve the quality and content of the general aviation service difficulty data base. (A-93-62)[107]

In response, the FAA published AC 20-109A, providing guidance for use of the SDR system by the general aviation community, but the reporting of malfunctions or defects is voluntary and not required for general aviation. A search of the FAA's SDR system found no records associated with any of the display failures or the installation damage event involving N889JB.

The FAA's Part 23 CPS report included a finding highlighting under-use of the SDR system by general aviation maintenance personnel as a continuing problem.[108] The report

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[103] FAA Advisory Circular 20-109A.

[104] Title 14 CFR 121.703 and 135.415, respectively.

[105] Part 125 applies to aircraft with a seating capacity of 20 or more passengers or maximum payload capacity of 6,000 pounds or more when common carriage is not involved.

[106] Closed in 2006, "Unacceptable Action."

[107] Closed in 1994, "Acceptable Action."

[108] Finding 4.4 of the FAA CPS Report.

included five recommendations to improve SDR reporting for 14 CFR Part 23 aircraft, covering issues such as improving maintenance personnel training requirements, communication with the aviation community about the SDR system, and the usability and functionality of the SDR database.

In addition to collecting voluntary failure, malfunction, or defect reports from operators, owners, and maintenance personnel, the FAA requires manufacturers to report certain types of equipment failures. In accordance with 14 CFR 21.3, holders of FAA type certificates, supplemental type certificates, parts manufacturer approvals, or technical standard order (TSO) authorizations are required to report to the FAA any failure, malfunction, or defect in any product, part, process, or article manufactured that may result in "failure or malfunction of more than one attitude, airspeed, or altitude instrument during a given operation of the aircraft." In a typical scenario, a pilot experiencing an equipment malfunction or failure would report the problem to a maintenance facility for repair. The manufacturer would then be notified of the problem through a warranty claim or an order for repair or replacement of the affected equipment. A manufacturer who determines that the problem involves a failure, malfunction, or defect outlined in 14 CFR 21.3 must notify the FAA through the appropriate Directorate Aircraft Certification Office. That report must include specific details of the aircraft and equipment involved and the nature of the failure. FAA Order 8150.1B regarding the TSO program explains that the Aircraft Certification Office will work with the manufacturer to determine the need for corrective action.

The failure, malfunction, and defect reporting requirements for manufacturers under 14 CFR 21.3 are limited to a specific set of circumstances, and problems similar to those experienced by N889JB prior to the January 15, 2005, accident would likely not result in a manufacturer's report to the FAA. An additional requirement under 14 CFR 21.3(e) states the following:

> Whenever the investigation of an accident or service difficulty report shows that an article manufactured under a TSO authorization is unsafe because of a manufacturing or design defect, the manufacturer shall, upon request of the Administrator, report to the Administrator the results of its investigation and any action taken or proposed by the manufacturer to correct that defect. If action is required to correct the defect in existing articles, the manufacturer shall submit the data necessary for the issuance of an appropriate airworthiness directive to the Manager of the Aircraft Certification Office for the geographic area of the FAA regional office in the region in which it is located.

In summary, NTSB accident investigations have identified cases in which system malfunctions and service difficulties with glass cockpit equipment were not captured in a systematic way prior to an accident. FAA requires equipment manufacturers to report specific failures and malfunctions and allows for voluntary reports to its SDR system of malfunctions and defects affecting light aircraft. However, the reported underutilization of the SDR system for reporting of problems associated with light aircraft leaves accident and incident investigation as the only publicly accessible means of identifying many types of equipment malfunctions and defects.

# Chapter 6: Data Recording in Glass Cockpit Avionics

One of the biggest changes associated with the introduction of glass cockpit displays in light aircraft is the capability for onboard recording of flight parameters and system information. The software-based systems that drive glass cockpit displays and their internal memory provide recording capabilities previously available only to large aircraft with dedicated flight data recorders.

On August 21, 2006, about 1341 eastern daylight time, a Cirrus SR22-GTS, N518SR, experienced an in-flight loss of aircraft control during cruise flight near McRae, Georgia. The personal flight was operated under the provisions of 14 CFR Part 91 under visual flight rules (VFR). Neither the private pilot nor the two passengers were injured, but the airplane was substantially damaged by aerodynamic forces.

The pilot stated that the aircraft "encountered clear air turbulence … bounced once, and then after losing altitude, hit a very hard bounce of severe turbulence." After stabilizing the airplane, the pilot noticed thin lines of paint missing from the top of the right wing. The pilot slowed the plane and landed at the nearest airport with no issues. The pilot contacted the manufacturer regarding the occurrence, and after examining the airplane, the manufacturer contacted the NTSB to report that the aircraft had sustained substantial damage.

This case initially generated interest because it involved a relatively new and popular airframe. Structural damage to the extent sustained by the accident aircraft would not be expected to result from a transient turbulence encounter. Had this event involved an aircraft equipped with a conventional cockpit, the investigation would have had to rely on analysis of the airframe structure and materials to estimate the forces encountered. However, the glass cockpit avionics in this aircraft provided additional information critical to understanding the event.

The Avidyne PFD installed in the accident aircraft contains flash memory that stores information processed by the unit to generate the various flight data displays. The PFD software includes a data logging function used by the manufacturer for maintenance and diagnostics. Working with the manufacturer, NTSB investigators were able to retrieve data recorded in the PFD from the AHRS, such as pitch, roll, heading, and accelerations, and by the air data computer, such as pressure altitude, indicated airspeed, and vertical speed recorded during the accident flight. The information recorded by the flight displays provided an entirely different description of the accident event than that described in the pilot's initial report.

Recorded data indicated that the airplane actually climbed to 15,400 feet above mean sea level, nearly 17,500 feet density altitude, which was the maximum operating altitude for the airplane. The airplane then slowed, stalled, and began a rapid descent, losing 13,000 feet of altitude in about 40 seconds before recovering. During the dive, the aircraft experienced several positive and negative pitch excursions (+50 to -80 degrees), rolled to the right about its longitudinal axis through two complete 360-degree revolutions, and started a third roll before recovering to straight-and-level flight. The airspeed increased from a low of 72 knots at the start of the dive to a maximum of about 336 knots indicated—135 knots (about 67 percent) above its published maximum limit.[109] During recovery, the airplane sustained a positive loading of at least 4.733 vertical Gs,[110] with an average of more than 4 Gs vertical loading for more than 20 seconds.[111]

During interviews with the NTSB investigator-in-charge of this accident, the pilot stated that he did not use oxygen during the flight. The NTSB's medical officer reviewed the circumstances of this event and determined that the sustained G-loading experienced by the pilot would likely have resulted in G-induced loss of consciousness (G-LOC) or near-loss of consciousness. The NTSB's medical officer determined further that the pilot's apparent failure to accurately recall the events of the flight most likely resulted from the confusion associated with hypoxia and the subsequent confusion and amnesia associated with G-LOC or near G-LOC.

Data recovered from PFDs and MFDs have significantly changed the understanding of other accident events. An example is the April 9, 2007, Cirrus accident near Luna, New Mexico, described in chapter 5 of this report. The pilot initially reported that the accident resulted from a PFD failure. Only after review of data recovered from the aircraft PFD and MFD was the mismatch between equipment function and pilot expectation understood.

Another example involved a Piper aircraft model PA-44-180 operated by the University of North Dakota on a VFR night cross-country flight.[112] On October 23, 2007, about 2212 central daylight time, the twin-engine PA-44-180, N327ND, was substantially damaged during an in-flight collision with terrain near Browerville, Minnesota. The accident pilot and flight instructor were fatally injured. With no additional information, this accident could well have been assumed to have been the result of crew disorientation or loss of control at night. However, data recovered from the aircraft PFD indicated that during cruise flight, the aircraft experienced an abrupt departure from controlled flight in both roll and pitch. Subsequent microscopic examination and DNA testing by forensic ornithologists identified material recovered from the wing skin section as remains of a Canada goose. As a result, investigators determined that a bird strike resulted in damage to the aircraft's left stabilator, causing the airplane to become uncontrollable. Based on the findings of this investigation, the University of North Dakota provided additional training to its pilots and instructors regarding bird strike hazards and recommended procedures for reducing the probability of bird strikes during night cross-country flights.

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[109] The aircraft pilot operating handbook specifies a maximum never exceed speed ($V_{ne}$) of 201 knots indicated airspeed.

[110] The PFD unit is limited to recording a vertical G-loading of 4.733 Gs even though the actual Gs loading may have been higher.

[111] For a detailed description of the recorded data, refer to *Specialist's Factual Report of Recorded Cockpit Display Data* for NTSB case ATL06LA134 in the NTSB Docket Management System.

[112] NTSB investigation number CHI08FA027: this accident is included here as an example of glass cockpit data recording, but it was not included in the statistical study analyses because it involved a twin-engine aircraft.

Prior to the advent of PFDs and the availability of recorded information, techniques used to collect information from flight instruments during general aviation accident investigations were often limited to analysis of witness marks from needles striking instrument faceplates and inspection of internal instrument components. Investigators were similarly limited to the analysis of physical evidence of ground scars, witness marks on flight instruments, postaccident engine tests, and aircraft wreckage when determining details of an aircraft accident or assessing aircraft performance prior to an accident. In contrast, software-driven systems typically leave no physical evidence of their performance but do allow for the recording of digital flight information that was previously limited to dedicated flight data recorders in large aircraft, enabling investigators to review aircraft and engine performance data from the flight.

# Chapter 7: Discussion

This study set out to assess the safety effect of advanced avionics capabilities on general aviation accident rates. To that end, the study compared the operational and accident history of two selected aircraft cohorts, one with conventional flight displays and the other with glass cockpit primary displays. Study analyses identified several differences in the activity and accident records of these two groups of aircraft.

## Accident Involvement and Accident Rates

Study analyses showed that glass cockpit-equipped aircraft experienced proportionately fewer total accidents than a comparable group of aircraft with conventional round-dial instruments. The 2007 AOPA report, *Technically Advanced Aircraft: Safety and Training*, included similar findings—that is, that fewer glass cockpit aircraft were involved in accidents than would be expected, given the percentage of the aircraft fleet they represent. However, unlike the NTSB analyses, which showed that glass cockpit aircraft had a proportionately higher number of fatal accidents than their numbers would indicate, the AOPA study found that glass cockpit aircraft experienced a proportionately lower number of fatal accidents. Differences in the results are due in part to differences in the methodologies of the two studies: while the AOPA study made comparisons throughout general aviation as a whole, the NTSB study limited its comparisons to a defined group of glass cockpit aircraft and a cohort of the same makes/models of aircraft with conventional instruments to reduce the potential for confounds associated with comparing aircraft of different age and capability. The NTSB study also used survey data to make additional comparisons between aircraft using activity-based accident rates that reflect accident risk.

The fact that the rate of total accidents observed for conventionally equipped aircraft was higher than that of the glass cockpit aircraft would suggest a safety benefit resulting from the new technology—if it were not for the glass cockpit cohort's significantly higher percentage of fatal accidents during the years 2002 through 2008 and the higher fatal accident rate observed for the cohort in 2006 and 2007. Activity and usage data from the FAA's GAATAA Survey confirmed that differences in the activity of the two cohort groups were likely to influence the type and severity of accidents involving the aircraft in each group.

When considered as a whole, the results describe two distinct aircraft operational profiles. Aircraft with conventional cockpit displays were more likely to be used for flight instruction. Accordingly, these aircraft were also found to have flown more hours per aircraft[113] although they were used for shorter flights[114] and flew less time in instrument conditions.[115] As a result, aircraft in the conventional group were involved in more accidents during takeoffs and landings,

[113] Based on 2006 and 2007 GAATAA Survey data.
[114] Based on statistical comparisons of accident flights.
[115] Based on 2006 and 2007 GAATAA Survey data and statistical comparisons of accident flights.

which often resulted in less severe outcomes, most likely due to the relatively low speeds during those phases and the resulting low impact forces.

Conversely, the operational profile of glass cockpit-equipped aircraft was found to involve fewer flight hours per year but longer trips. Consequently, the glass cockpit-equipped aircraft reportedly spent more time than conventional aircraft operating on instrument flight plans. The accident record is consistent with the way the aircraft were reportedly used. Glass cockpit aircraft experienced more accidents while on long trips and in IMC but also reported spending more time operating in instrument conditions.

Previous NTSB research has identified a higher risk of aircraft on longer flights being involved in weather-related accidents and has noted that accidents occurring in IMC are more likely to be fatal due to the event profiles and impact forces typically associated with such accidents.[116] The higher number of hours flown during long trips or in IMC results in increased exposure to the risks associated with those circumstances, but a comparison of activity-based accident rates would be expected to reveal similar rates for both cockpit configurations if the underlying accident risk were similar. The glass cockpit cohort instead experienced higher fatal accident rates and higher accident rates in IMC than the conventional aircraft—despite the fact that the pilots had higher levels of certification, were more likely to be instrument rated, had more total flight experience, and had more experience in the aircraft type.

Although the study analyses provided clear evidence of a difference in operational profiles, they did not reveal whether aircraft owners chose to purchase glass cockpit-equipped aircraft because they wanted the increased capabilities to support the type of flight operations they engaged in, or if the increased capabilities of their new aircraft encouraged them to conduct longer flights and/or fly in more adverse conditions. Pilot motivation and perception of the capabilities of their aircraft influence the risks they are willing to accept. Additional research is warranted to better understand how pilots of light aircraft perceive glass cockpit displays and how those perceptions influence safety. However, based on the pattern of study results, the NTSB concludes that study analyses of aircraft accident and activity data showed a decrease in total accident rates but an increase in fatal accident rates for the selected group of glass cockpit aircraft when compared to similar conventionally equipped aircraft during the study period. Overall, study analyses did not show a significant improvement in safety for the glass cockpit study group.

## Safety Issues

### Training Resources and Requirements

The study included reviews of training resources, requirements, and initiatives indicative of the FAA's efforts to address the needs of pilots transitioning to glass cockpit aircraft. Despite

[116] *Risk Factors Associated with Weather-Related General Aviation Accidents,* Aviation Safety Study NTSB/SS-05/01 (Washington, DC: National Transportation Safety Board, 2005.)

these efforts on the part of the FAA, the NTSB did identify several safety issues and areas for improvement during the course of the study.

A review of training resources and requirements showed that the FAA has been updating its training materials and PTS in response to the introduction of glass cockpit displays in Part 23 aircraft. However, FAA airman knowledge tests, such as those required for the Private Pilot Certificate, Commercial Pilot Certificate, and Instrument Rating, do not currently assess pilots' knowledge of glass cockpit displays. The NTSB concludes that pilots must be able to demonstrate a minimum knowledge of primary aircraft flight instruments and displays in order to be prepared to safely operate aircraft equipped with those systems, which is necessary for all aircraft but is not currently addressed by FAA knowledge tests for glass cockpit displays. Therefore, the NTSB recommends that the FAA revise airman knowledge tests to include questions regarding electronic flight and navigation displays, including normal operations, limitations, and the interpretation of malfunctions and aircraft attitudes.

A review of the FAA's training initiatives showed that the FAA worked with representatives from the general aviation industry and academia to develop its FITS initiative in response to a recognized need for improved training for advanced aircraft systems. Initial planning documents show that the FITS initiative intended to combine teaching techniques, such as scenario-based training, with requirements for equipment-specific training. The FAA is now incorporating scenario-based training and pilot decision-making tools, but to date it has not implemented the equipment-specific training requirements suggested in the original FITS program documents. Rather, the FAA has recognized several factory and national training provider programs as being "FITS accepted." This study relied on a retrospective review of accident records that did not allow for detailed comparisons of the training history of all accident pilots, but a review of manufacturer training programs suggests that they primarily benefit the first owner (purchaser) of a new aircraft or pilots who seek out such training. In some cases, insurance companies may require pilots to receive equipment-specific transition and/or recurrent training, but those requirements are neither uniformly nor universally applied. Further, some aircraft owners may avoid insurance requirements by choosing to self-insure their aircraft. The lack of FAA training requirements and the variability of nonregulatory training requirements and programs suggest that additional equipment-specific training requirements are necessary to ensure that all pilots of glass cockpit-equipped aircraft possess the knowledge and skill necessary to operate their aircraft safely.

## Providing Pilots with Information about Display Operation and Limitations

The study considered several accident case studies that highlighted the complexity and unique functionality of glass cockpit displays in comparison to conventional instruments, as well as potential safety-critical issues associated with the design and operation of software-based systems. The case studies illustrate the importance of pilots' receiving sufficient information about system operations and limitations so that they are prepared to identify and safely respond to system malfunctions and failures.

The functions of conventional instruments can be replicated in many ways using solid-state systems, and manufacturers have developed unique designs of pressure transducers, specially mounted gyros, accelerometers, and magnetometers controlled by proprietary software. The wide variety of complex glass cockpit equipment designs, and their proprietary technology, demands that any discussion of these displays be system-specific. Consequently, as electronic systems replace analog gauges, the expectation that average general aviation pilots will understand the inner workings of their cockpit instruments is no longer realistic. This problem is compounded by the fact that, unlike analog gauges, the functionality and capability of electronic display systems can continue to evolve after they are installed because of subsequent software revisions. The resulting increase in system complexity burdens pilots with the need to keep up with changes so that they can understand their avionics systems well enough to identify and troubleshoot any abnormal system operations or malfunctions that they might encounter in flight. An additional difficulty is that, in comparison to the detailed information included in FAA training handbooks about conventional flight instruments, the information about glass cockpits is currently limited to very general descriptions of system components and displays.

In addition, as the pilot of the Luna, New Mexico, accident aircraft found, glass cockpit displays may function differently than conventional displays under certain conditions. In that case, a blocked pitot tube intake that would have affected only the airspeed indicator of a conventional cockpit display resulted in loss of airspeed, altitude, and rate-of-climb information in a glass cockpit display. The information provided to the pilot indicated only that the air data computer had failed, with no indication of why it had failed or whether the situation could be safely corrected in flight. The NTSB concludes that pilots are not always provided all of the information necessary to adequately understand the unique operational and functional details of the primary flight displays in their airplanes. Therefore, the NTSB recommends that the FAA require all manufacturers of certified electronic PFDs to include information in their approved AFM and pilot's operating handbook supplements regarding abnormal equipment operation or malfunction due to subsystem and input malfunctions, including but not limited to pitot and/or static system blockages, magnetic sensor malfunctions, and attitude-heading reference system alignment failures.

## Equipment-Specific Training Requirements

Integrated electronic displays have the potential to increase the safety of general aviation aircraft operations by providing pilots with more operational and safety-related information and functionality. For that potential to be realized, however, the burden of responsibility falls on pilots to operate the equipment safely and efficiently. Any deficiencies or inefficiencies in equipment functionality and interface design must be addressed through superior pilot training and skill.

As aircraft equipment becomes more complex, the demands placed on pilots to manage and monitor equipment operation will continue to increase. FAA *Part 23 - Certification Process Study Report*[117] findings and comments included in pertinent draft FAA ACs suggest that the

[117] FAA, July 2009.

human-equipment interaction issues previously identified for Part 25 transport-category aircraft will become increasingly critical for Part 23 aircraft. In contrast to the generalized training traditionally required to operate the relatively simple systems in Part 23 aircraft, the complexity and variation of Part 25 aircraft systems have been addressed by requiring pilots to hold a type rating to act as pilot-in-command.[118] However, now that light aircraft are incorporating integrated glass cockpit avionics that rival in complexity those in Part 25 aircraft, generalized systems training may not be sufficient for pilots of these aircraft. Different system architectures require different operating techniques, and responses to failure and knowledge of one type of glass cockpit display are not likely to transfer to other systems. The NTSB concludes that generalized guidance and training are no longer sufficient to prepare pilots to safely operate glass cockpit avionics; effective pilot instruction and evaluation must be tailored to specific equipment. Therefore, the NTSB recommends that the FAA incorporate training elements regarding electronic PFDs into its training materials and aeronautical knowledge requirements for all pilots. The NTSB also recommends that the FAA incorporate training elements regarding electronic primary flight displays into its initial and recurrent flight proficiency requirements for pilots of 14 CFR Part 23 certified aircraft equipped with those systems that address variations in equipment design and operation of such displays.

## Equipment Malfunction Training

Although PFD screen failure is easy to simulate in a training environment, the accident case studies cited in this safety study suggest that screen failure may not be the most likely type of glass cockpit failure or abnormal operation that a pilot will encounter. That is, training pilots to fly by backup instruments when faced with a blank primary display may not adequately prepare them to respond to a partial failure in which they are likely to see a compelling display that is presenting erroneous or incomplete data. To be adequately prepared to respond to flight instrument system malfunctions and failures, pilots should be trained to identify and respond to all anticipated failure modes. However, in many cases, it is neither appropriate nor practical to train for all anticipated types of glass cockpit avionics failures and malfunctions in the aircraft. The NTSB concludes that simulators or procedural trainers are the most practical alternative means of training pilots to identify and respond to glass cockpit avionics failures and malfunctions that cannot be easily or safely replicated in light aircraft. Pilots who do not have ready access to approved flight simulators or training devices could benefit from equipment-specific training using software applications or procedural trainers that replicate glass cockpit displays. Therefore, the NTSB recommends that the FAA develop and publish guidance for the use of equipment-specific electronic avionics display simulators and procedural trainers that do not meet the definition of flight simulation training devices prescribed in 14 CFR Part 60 to support equipment-specific pilot training requirements.

[118] Title 14 CFR 61.31.

## Tracking Service Difficulties and Equipment Malfunctions

NTSB investigations have revealed multiple instances of glass cockpit avionics malfunctions that were not required to be reported to the FAA and that did not result in an SDR system report. Findings of the FAA *Part 23 - Small Airplane Certification Process Study* suggest a general difficulty with tracking Part 23 equipment performance due to SDR system underreporting for light aircraft. The NTSB concludes that identification and tracking of service difficulties, equipment malfunctions or failures, abnormal operations, and other safety issues will be increasingly important as light aircraft avionics systems and equipment continue to increase in complexity and variation of design, and current reporting to the FAA's SDR system does not adequately capture this information for 14 CFR Part 23 certified aircraft used in general aviation operations. The NTSB also concludes that the FAA's current review of the 14 CFR Part 23 certification process provides an opportunity to improve upon deficiencies in the reporting of equipment malfunctions and defects identified by the FAA and aviation industry representatives in the July 2009 *Part 23 - Small Airplane Certification Process Study*.

However, the review of 14 CFR Part 23 and resulting regulatory actions will likely require considerable time. Therefore, to improve the voluntary submissions to the FAA SDR system in the interim, the NTSB recommends that the FAA inform aircraft and avionics maintenance technicians about the critical role of voluntary SDR system reports involving malfunctions or defects associated with electronic primary flight, navigation, and control systems in 14 CFR Part 23 certified aircraft used in general aviation operations.

Despite the identified problems associated with tracking the function and reliability of glass cockpit displays in Part 23 aircraft, the technology has provided a new potential source of safety information. The NTSB concludes that some glass cockpit displays include recording capabilities that have significantly benefited accident investigations and provide the general aviation community with the ability to improve equipment reliability and the safety and efficiency of aircraft operations through data analyses.

# Summary

This study used manufacturer records, aircraft investigation information, and a tailored subset of general aviation activity survey data to assess how the transition to electronic PFD avionics has affected the safety of light aircraft. The study also evaluated the resources and requirements supporting the transition to this new technology. The results of this study suggest that, for the aircraft and time period studied, the introduction of glass cockpit PFDs has not yet resulted in the anticipated improvement in safety when compared to similar aircraft with conventional instruments. Advanced avionics and electronic displays can increase the safety potential of general aviation aircraft operations by providing pilots with more operational and safety-related information and functionality, but more effort is needed to ensure that pilots are prepared to realize that potential. The FAA, manufacturers, aviation industry groups, and academia have an established history of collaboration through the FITS program initiative for supporting aircraft model-specific and scenario-based training techniques that would teach pilots "higher-order thinking skills." However, the FAA has changed the focus of the FITS initiative and has to date relied on manufacturers and commercial vendors to deliver the equipment-specific training originally envisioned for FITS. Adoption of uniform equipment-specific training elements by the FAA to ensure pilots have adequate knowledge of aircraft equipment operation and malfunctions, as well as improved reporting of equipment malfunctions and service difficulties, is likely to improve the safety of general aviation operations beyond those involving aircraft with glass cockpit displays. However, such actions are particularly important in order to achieve the potential safety benefits associated with advanced cockpit technologies in light aircraft.

# Conclusions

## Findings

1. Study analyses of aircraft accident and activity data showed a decrease in total accident rates but an increase in fatal accident rates for the selected group of glass cockpit aircraft when compared to similar conventionally equipped aircraft during the study period. Overall, study analyses did not show a significant improvement in safety for the glass cockpit study group.

2. Pilots must be able to demonstrate a minimum knowledge of primary aircraft flight instruments and displays in order to be prepared to safely operate aircraft equipped with those systems, which is necessary for all aircraft but is not currently addressed by Federal Aviation Administration knowledge tests for glass cockpit displays.

3. Pilots are not always provided all of the information necessary to adequately understand the unique operational and functional details of the primary flight instruments in their airplanes.

4. Generalized guidance and training are no longer sufficient to prepare pilots to safely operate glass cockpit avionics; effective pilot instruction and evaluation must be tailored to specific equipment.

5. Simulators or procedural trainers are the most practical alternative means of training pilots to identify and respond to glass cockpit avionics failures and malfunctions that cannot be easily or safely replicated in light aircraft.

6. Identification and tracking of service difficulties, equipment malfunctions or failures, abnormal operations, and other safety issues will be increasingly important as light aircraft avionics systems and equipment continue to increase in complexity and variation of design, and current reporting to the Federal Aviation Administration's service difficulty reporting system does not adequately capture this information for 14 *Code of Federal Regulations* Part 23 certified aircraft used in general aviation operations.

7. The Federal Aviation Administration's current review of the 14 *Code of Federal Regulations* Part 23 certification process provides an opportunity to improve upon deficiencies in the reporting of equipment malfunctions and defects identified by the Federal Aviation Administration and aviation industry representatives in the July 2009 *Part 23 - Small Airplane Certification Process Study*.

8. Some glass cockpit displays include recording capabilities that have significantly benefited accident investigations and provide the general aviation community with the ability to improve equipment reliability and the safety and efficiency of aircraft operations through data analyses.

# Recommendations

As a result of this safety study, the National Transportation Safety Board makes the following recommendations to the Federal Aviation Administration:

> Revise airman knowledge tests to include questions regarding electronic flight and navigation displays, including normal operations, limitations, and the interpretation of malfunctions and aircraft attitudes. (A-10-36)

> Require all manufacturers of certified electronic primary flight displays to include information in their approved aircraft flight manual and pilot's operating handbook supplements regarding abnormal equipment operation or malfunction due to subsystem and input malfunctions, including but not limited to pitot and/or static system blockages, magnetic sensor malfunctions, and attitude-heading reference system alignment failures. (A-10-37)

> Incorporate training elements regarding electronic primary flight displays into your training materials and aeronautical knowledge requirements for all pilots. (A-10-38)

> Incorporate training elements regarding electronic primary flight displays into your initial and recurrent flight proficiency requirements for pilots of 14 *Code of Regulations* Part 23 certified aircraft equipped with those systems that address variations in equipment design and operation of such displays. (A-10-39)

> Develop and publish guidance for the use of equipment-specific electronic avionics display simulators and procedural trainers that do not meet the definition of flight simulation training devices prescribed in 14 *Code of Federal Regulations* Part 60 to support equipment-specific pilot training requirements. (A-10-40)

> Inform aircraft and avionics maintenance technicians about the critical role of voluntary service difficulty reporting system reports involving malfunctions or defects associated with electronic primary flight, navigation, and control systems in 14 *Code of Federal Regulations* Part 23 certified aircraft used in general aviation operations. (A-10-41)

## BY THE NATIONAL TRANSPORTATION SAFETY BOARD

**DEBORAH A.P. HERSMAN**
Chairman

**ROBERT L. SUMWALT**
Member

**CHRISTOPHER A. HART**
Vice Chairman

**Adopted: March 9, 2010**

# Appendix: Study Accidents

| ntsb_no | ev_date | Registration | Make | Model | Glass | Severity |
|---|---|---|---|---|---|---|
| ANC06CA036 | 24-Mar-06 | N514ER | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| ANC06CA114 | 12-Aug-06 | N2469U | Cessna Aircraft Company | 172 | Glass cockpit | NonFatal |
| ATL03LA022 | 3-Dec-02 | N289HG | Piper Aircraft, Inc. | PA-28-161 | Conventional | NonFatal |
| ATL03LA034 | 11-Jan-03 | N5199H | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| ATL04FA096 | 19-Apr-04 | N8157J | Cirrus Design Corporation | SR20 | Glass cockpit | Fatal |
| ATL04LA060 | 27-Dec-03 | N742CD | Cirrus Design Corporation | SR22 | Conventional | NonFatal |
| ATL04LA140 | 24-Jun-04 | N2116P | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| ATL04LA143 | 20-Jul-04 | N2069S | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| ATL04WA042 | 12-Oct-03 | N100BR | Cirrus Design Corporation | SR22 | Conventional | Fatal |
| ATL05CA153 | 24-Aug-05 | N21670 | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| ATL05CA160 | 10-Sep-05 | N1251C | Cessna Aircraft Company | 182 | Glass cockpit | NonFatal |
| ATL05FA034 | 9-Dec-04 | N42SE | Diamond Aircraft | DA40 | Conventional | Fatal |
| ATL05LA105 | 20-Jun-05 | N53538 | Cessna Aircraft Company | 182 | Conventional | Fatal |
| ATL05LA156 | 31-Aug-05 | N5213M | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| ATL06CA068 | 16-Apr-06 | N21527 | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| ATL06CA089 | 6-Jun-06 | N1046P | Mooney | M20 | Glass cockpit | NonFatal |
| ATL06CA117 | 3-Aug-06 | N124CK | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| ATL06FA029 | 29-Dec-05 | N799TM | Cirrus Design Corporation | SR22 | Glass cockpit | Fatal |
| ATL06LA035 | 13-Jan-06 | N87HK | Cirrus Design Corporation | SR22 | Conventional | NonFatal |
| ATL06LA058 | 31-Mar-06 | N2157V | Cessna Aircraft Company | 182 | Conventional | NonFatal |
| ATL06LA134 | 21-Aug-06 | N518SR | Cirrus Design Corporation | SR22 | Glass cockpit | NonFatal |
| ATL07CA035 | 28-Jan-07 | N221GW | Cirrus Design Corporation | SR22 | Conventional | NonFatal |
| ATL07CA047 | 5-Mar-07 | N2145T | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| ATL07CA049 | 11-Mar-07 | N313L | Cirrus Design Corporation | SR22 | Glass cockpit | NonFatal |
| ATL07CA093 | 15-Jun-07 | N2228L | Cessna Aircraft Company | 172 | Glass cockpit | NonFatal |
| ATL07CA105 | 15-Jul-07 | N13151 | Cessna Aircraft Company | 172 | Glass cockpit | NonFatal |
| ATL07FA010 | 22-Oct-06 | N2135L | Cessna Aircraft Company | 182 | Glass cockpit | Fatal |
| ATL07LA041 | 9-Feb-07 | N315P | Hawker Beechcraft | 36 | Conventional | NonFatal |
| ATL07LA115 | 17-Aug-07 | N869CD | Cirrus Design Corporation | SR20 | Glass cockpit | NonFatal |
| CEN09CA002 | 3-Oct-08 | N5172J | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| CEN09CA020 | 11-Oct-08 | N764C | Piper Aircraft, Inc. | PA-28-181 | Conventional | NonFatal |
| CEN09CA049 | 3-Nov-08 | N558SR | Cirrus Design Corporation | SR22 | Glass cockpit | NonFatal |
| CEN09FA083 | 6-Dec-08 | N6053B | Cessna Aircraft Company | 206 | Glass cockpit | Fatal |
| CEN09WA033 | 22-Oct-08 | N467BD | Cirrus Design Corporation | SR22 | Glass cockpit | Fatal |
| CHI02FA231 | 4-Aug-02 | N316PM | Piper Aircraft, Inc. | PA-46-350 | Conventional | Fatal |
| CHI02LA258 | 17-Aug-02 | N336CB | Hawker Beechcraft | 36 | Conventional | NonFatal |
| CHI03FA057 | 18-Jan-03 | N9523P | Cirrus Design Corporation | SR22 | Conventional | Fatal |
| CHI03FA284A | 22-Aug-03 | N53033 | Cessna Aircraft Company | 172 | Conventional | Fatal |
| CHI03LA061 | 31-Jan-03 | N670CS | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| CHI04CA251 | 9-Sep-04 | N379BF | Cessna Aircraft Company | 182 | Glass cockpit | NonFatal |
| CHI04FA257 | 12-Sep-04 | N843MC | Cessna Aircraft Company | 182 | Conventional | Fatal |
| CHI05CA007 | 16-Oct-04 | N555MN | Cirrus Design Corporation | SR22 | Glass cockpit | NonFatal |
| CHI05CA027 | 31-Oct-04 | N814FA | Cessna Aircraft Company | 182 | Conventional | NonFatal |
| CHI05CA035 | 21-Nov-04 | N967SA | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| CHI05CA085 | 2-Apr-05 | N8150F | Cirrus Design Corporation | SR22 | Glass cockpit | NonFatal |

| ntsb_no | ev_date | Registration | Make | Model | Glass | Severity |
|---|---|---|---|---|---|---|
| CHI05FA042 | 9-Dec-04 | N587C | Piper Aircraft, Inc. | PA-32-301 | Conventional | Fatal |
| CHI05LA223 | 10-Aug-05 | N795WW | Cirrus Design Corporation | SR20 | Glass cockpit | NonFatal |
| CHI05LA227 | 11-Aug-05 | N632FA | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| CHI06CA122 | 28-Apr-06 | N1129P | Cessna Aircraft Company | 182 | Glass cockpit | NonFatal |
| CHI06CA133 | 20-May-06 | N814SN | Cirrus Design Corporation | SR22 | Conventional | NonFatal |
| CHI06CA135 | 23-May-06 | N409TA | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| CHI06CA183 | 8-Jul-06 | N335SP | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| CHI06CA189 | 13-Jul-06 | N918TA | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| CHI06CA197 | 22-Jul-06 | N52728 | Cessna Aircraft Company | 206 | Conventional | NonFatal |
| CHI06CA267 | 15-Sep-06 | N6500V | Lancair/Columbia Aircraft/Cessna Aircraft Company | 350 | Glass cockpit | NonFatal |
| CHI06CA276 | 6-Sep-06 | N2430A | Cessna Aircraft Company | 206 | Glass cockpit | NonFatal |
| CHI06FA043 | 11-Dec-05 | N621PH | Cirrus Design Corporation | SR22 | Glass cockpit | Fatal |
| CHI06FA186 | 11-Jul-06 | N8163Q | Cirrus Design Corporation | SR22 | Glass cockpit | Fatal |
| CHI06FA218 | 5-Aug-06 | N658CD | Cirrus Design Corporation | SR22 | Glass cockpit | NonFatal |
| CHI06FA245 | 28-Aug-06 | N91MB | Cirrus Design Corporation | SR22 | Glass cockpit | Fatal |
| CHI07CA308 | 29-Sep-07 | N2327J | Cessna Aircraft Company | 172 | Glass cockpit | NonFatal |
| CHI07LA164 | 7-May-07 | N51827 | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| CHI08CA002 | 3-Oct-07 | N437ND | Piper Aircraft, Inc. | PA-28-161 | Conventional | NonFatal |
| CHI08CA029 | 29-Oct-07 | N77LU | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| CHI08CA091 | 17-Mar-08 | N53417 | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| CHI08CA138 | 21-May-08 | N1387C | Lancair/Columbia Aircraft/Cessna Aircraft Company | 400 | Glass cockpit | NonFatal |
| CHI08CA263 | 25-Aug-08 | N1281 | Cirrus Design Corporation | SR20 | Glass cockpit | NonFatal |
| DCA07MA003 | 11-Oct-06 | N929CD | Cirrus Design Corporation | SR20 | Conventional | Fatal |
| DCA07WA024 | 2-Feb-07 | N901SR | Cirrus Design Corporation | SR20 | Glass cockpit | Fatal |
| DEN03LA017 | 20-Nov-02 | N850FS | Piper Aircraft, Inc. | PA-28-201 | Conventional | NonFatal |
| DEN04CA137 | 29-Aug-04 | N2099J | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| DEN04FA087 | 7-Jun-04 | N6162E | Hawker Beechcraft | 36 | Conventional | Fatal |
| DEN04LA053A | 26-Mar-04 | N5345G | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| DEN05LA022 | 29-Oct-04 | N203RF | Cirrus Design Corporation | SR22 | Glass cockpit | NonFatal |
| DEN06CA022 | 10-Dec-05 | N1053X | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| DEN06FA023 | 13-Dec-05 | N1257Z | Cessna Aircraft Company | 172 | Conventional | Fatal |
| DEN06FA114 | 15-Aug-06 | N8127J | Cirrus Design Corporation | SR20 | Glass cockpit | NonFatal |
| DEN06FA131 | 15-Sep-06 | N787SL | Cirrus Design Corporation | SR20 | Glass cockpit | Fatal |
| DEN07CA128 | 26-Jul-07 | N1049V | Cessna Aircraft Company | 182 | Glass cockpit | NonFatal |
| DEN07CA154 | 13-Aug-07 | N249FS | Cessna Aircraft Company | 172 | Glass cockpit | NonFatal |
| DEN07LA082 | 9-Apr-07 | N953CD | Cirrus Design Corporation | SR22 | Glass cockpit | NonFatal |
| DEN07LA119 | 11-Jul-07 | N97PP | Cessna Aircraft Company | 206 | Glass cockpit | NonFatal |
| DEN07LA137 | 14-Aug-07 | N395MR | Mooney | M20 | Glass cockpit | NonFatal |
| DEN07WA005 | 8-Oct-06 | N147SR | Cirrus Design Corporation | SR22 | Glass cockpit | NonFatal |
| DEN08CA051 | 17-Jan-08 | N819C | Piper Aircraft, Inc. | PA-32-301 | Glass cockpit | NonFatal |
| DEN08FA141 | 15-Aug-08 | N487TC | Cessna Aircraft Company | 182 | Glass cockpit | Fatal |
| DEN08LA111 | 21-Jun-08 | N5178Y | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| DFW05CA077 | 21-Jan-05 | N832TC | Cessna Aircraft Company | 182 | Conventional | NonFatal |
| DFW05CA253 | 29-Sep-05 | N5343U | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| DFW06CA098 | 9-Apr-06 | N358TW | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| DFW06LA038 | 9-Dec-05 | N302BY | Cirrus Design Corporation | SR22 | Glass cockpit | NonFatal |
| DFW06LA101 | 7-Apr-06 | N142SF | Cirrus Design Corporation | SR20 | Glass cockpit | NonFatal |
| DFW07CA012 | 15-Oct-06 | N1013Y | Cessna Aircraft Company | 182 | Glass cockpit | NonFatal |

| ntsb_no | ev_date | Registration | Make | Model | Glass | Severity |
|---|---|---|---|---|---|---|
| DFW07CA210 | 28-Sep-07 | N364GW | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| DFW07FA019 | 5-Nov-06 | N53443 | Cessna Aircraft Company | 172 | Conventional | Fatal |
| DFW07LA021 | 31-Oct-06 | N506C | Piper Aircraft, Inc. | PA-32-301 | Glass cockpit | NonFatal |
| DFW07LA207 | 25-Sep-07 | N22237 | Cessna Aircraft Company | 172 | Glass cockpit | NonFatal |
| DFW08CA021 | 26-Oct-07 | N5181A | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| DFW08FA060 | 2-Feb-08 | N824BJ | Cirrus Design Corporation | SR22 | Glass cockpit | Fatal |
| DFW08FA111 | 22-Apr-08 | N729SR | Cirrus Design Corporation | SR22 | Glass cockpit | Fatal |
| DFW08FA204 | 10-Aug-08 | N214MT | Cessna Aircraft Company | 182 | Conventional | Fatal |
| ERA09CA007 | 7-Oct-08 | N889LD | Cirrus Design Corporation | SR20 | Glass cockpit | NonFatal |
| ERA09CA016 | 6-Oct-08 | N22AS | Cessna Aircraft Company | 182 | Glass cockpit | NonFatal |
| ERA09CA017 | 7-Oct-08 | N771CP | Cessna Aircraft Company | 182 | Glass cockpit | NonFatal |
| ERA09CA035 | 1-Nov-08 | N2055R | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| ERA09CA041 | 6-Nov-08 | N1242C | Cessna Aircraft Company | 172 | Glass cockpit | NonFatal |
| ERA09CA110 | 27-Dec-08 | N178AF | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| ERA09FA053 | 13-Nov-08 | N827GM | Cirrus Design Corporation | SR22 | Conventional | Fatal |
| FTW02CA249 | 4-Sep-02 | N9855S | Piper Aircraft, Inc. | PA-28-161 | Conventional | NonFatal |
| FTW04CA163 | 16-Jun-04 | N2101M | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| FTW04LA072 | 7-Feb-04 | N2124Z | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| FTW04LA123A | 9-May-04 | N89SE | Diamond Aircraft | DA40 | Conventional | NonFatal |
| FTW04LA178 | 24-Jun-04 | N810SA | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| IAD03FA039 | 20-Mar-03 | N1005P | Mooney | M20 | Conventional | Fatal |
| IAD04CA009 | 5-Feb-04 | N5165M | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| IAD05CA014 | 19-Nov-04 | N2120M | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| IAD05CA056 | 16-Apr-05 | N127X | Diamond Aircraft | DA40 | Glass cockpit | NonFatal |
| IAD05CA131 | 5-Sep-05 | N209SL | Cirrus Design Corporation | SR22 | Glass cockpit | NonFatal |
| IAD05FA032 | 15-Jan-05 | N889JB | Cirrus Design Corporation | SR22 | Glass cockpit | Fatal |
| IAD05LA043B | 9-Mar-05 | N3513F | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| IAD05LA111 | 20-Jul-05 | N1328N | Cessna Aircraft Company | 182 | Glass cockpit | NonFatal |
| LAX02LA192 | 8-Jun-02 | N480DW | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| LAX03LA170 | 29-May-03 | N5329L | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| LAX03LA186 | 8-Jun-03 | N519ER | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| LAX03LA228 | 7-Jul-03 | N288PA | Piper Aircraft, Inc. | PA-28-181 | Conventional | NonFatal |
| LAX03LA231 | 12-Jul-03 | N5327G | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| LAX03LA273 | 31-Aug-03 | N280KT | Piper Aircraft, Inc. | PA-46-350 | Conventional | NonFatal |
| LAX04CA130 | 14-Feb-04 | N262TA | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| LAX04CA288 | 8-Aug-04 | N5327G | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| LAX04LA060 | 6-Dec-03 | N396TA | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| LAX04LA211 | 14-May-04 | N5341G | Cessna Aircraft Company | 182 | Conventional | NonFatal |
| LAX04LA324 | 19-Sep-04 | N931CD | Cirrus Design Corporation | SR22 | Conventional | NonFatal |
| LAX05CA028 | 5-Nov-04 | N20519 | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| LAX05CA299 | 4-Sep-05 | N53056 | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| LAX05FA032 | 10-Nov-04 | N803ZG | Piper Aircraft, Inc. | PA-32-301 | Glass cockpit | Fatal |
| LAX05FA088 | 6-Feb-05 | N286CD | Cirrus Design Corporation | SR22 | Glass cockpit | Fatal |
| LAX05LA073 | 18-Jan-05 | N2157H | Cessna Aircraft Company | 172 | Conventional | Fatal |
| LAX05LA109 | 7-Mar-05 | N517SW | Cirrus Design Corporation | SR22 | Glass cockpit | NonFatal |
| LAX05LA118 | 22-Mar-05 | N562AB | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| LAX05LA210 | 18-Jun-05 | N626Z | Cirrus Design Corporation | SR22 | Glass cockpit | NonFatal |
| LAX06CA039 | 30-Oct-05 | N51732 | Cessna Aircraft Company | 182 | Conventional | NonFatal |

| ntsb_no | ev_date | Registration | Make | Model | Glass | Severity |
|---|---|---|---|---|---|---|
| LAX06CA128 | 9-Mar-06 | N8141L | Cirrus Design Corporation | SR22 | Glass cockpit | NonFatal |
| LAX06CA173 | 28-Apr-06 | N1488C | Cirrus Design Corporation | SR20 | Conventional | NonFatal |
| LAX06CA218 | 27-Jun-06 | N562H | Cessna Aircraft Company | 206 | Glass cockpit | NonFatal |
| LAX06FA014 | 17-Oct-05 | N285JB | Lancair/Columbia Aircraft/Cessna Aircraft Company | 400 | Glass cockpit | Fatal |
| LAX06FA087 | 9-Jan-06 | N526CD | Cirrus Design Corporation | SR20 | Glass cockpit | Fatal |
| LAX06FA186 | 27-May-06 | N451JE | Cessna Aircraft Company | 182 | Glass cockpit | Fatal |
| LAX06FA243 | 23-Jul-06 | N241JL | Hawker Beechcraft | 36 | Glass cockpit | Fatal |
| LAX07CA092 | 14-Feb-07 | N289SP | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| LAX07CA101 | 3-Mar-07 | N526ER | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| LAX07CA139 | 28-Apr-07 | N1273E | Cessna Aircraft Company | 206 | Glass cockpit | NonFatal |
| LAX07CA171 | 7-May-07 | N533ER | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| LAX07CA185 | 2-Jun-07 | N65755 | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| LAX07CA193 | 24-Jun-07 | N567DD | Cessna Aircraft Company | 172 | Glass cockpit | NonFatal |
| LAX07CA199 | 1-Jul-07 | N214GZ | Cessna Aircraft Company | 172 | Glass cockpit | NonFatal |
| LAX07CA202 | 3-Jul-07 | N619TH | Cessna Aircraft Company | 172 | Glass cockpit | NonFatal |
| LAX07CA213 | 9-Jul-07 | N747PZ | Diamond Aircraft | DA40 | Glass cockpit | NonFatal |
| LAX07FA021 | 25-Oct-06 | N121LD | Cirrus Design Corporation | SR22 | Glass cockpit | Fatal |
| LAX07FA062 | 18-Dec-06 | N457S | Cirrus Design Corporation | SR22 | Glass cockpit | Fatal |
| LAX07FA160 | 11-May-07 | N512DS | Diamond Aircraft | DA40 | Glass cockpit | Fatal |
| LAX08CA084 | 22-Mar-08 | N3105Q | Piper Aircraft, Inc. | PA-32-301 | Glass cockpit | NonFatal |
| LAX08CA102 | 13-Apr-08 | N21705 | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| LAX08CA124 | 7-Apr-08 | N65630 | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| LAX08CA158 | 28-May-08 | N2252Z | Cessna Aircraft Company | 182 | Glass cockpit | NonFatal |
| LAX08CA189 | 24-Jun-08 | N877CM | Cirrus Design Corporation | SR22 | Glass cockpit | NonFatal |
| LAX08FA023 | 28-Oct-07 | N21101 | Cessna Aircraft Company | 172 | Conventional | Fatal |
| LAX08FA261 | 7-Aug-08 | N15963 | Cessna Aircraft Company | 172 | Glass cockpit | Fatal |
| LAX08FA265B | 10-Aug-08 | N8341 | Cirrus Design Corporation | SR22 | Glass cockpit | Fatal |
| LAX08LA179 | 12-Jun-08 | N233GW | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| LAX08LA191 | 22-Jun-08 | N2436F | Cessna Aircraft Company | 172 | Glass cockpit | Fatal |
| LAX08LA217 | 6-Jul-08 | N2544W | Lancair/Columbia Aircraft/Cessna Aircraft Company | 400 | Glass cockpit | NonFatal |
| LAX08LA283 | 30-Jul-08 | N5329L | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| MIA03CA125 | 18-Jun-03 | N53352 | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| MIA03LA096 | 12-Apr-03 | N52903 | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| MIA03LA144B | 18-Jul-03 | N431ER | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| MIA04CA028 | 21-Nov-03 | N378FA | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| MIA04CA077 | 17-Apr-04 | N5280D | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| MIA04CA106 | 17-Jul-04 | N315PA | Piper Aircraft, Inc. | PA-28-181 | Conventional | NonFatal |
| MIA04CA109 | 12-Aug-04 | N21063 | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| MIA04FA045 | 19-Jan-04 | N298PA | Piper Aircraft, Inc. | PA-28-181 | Conventional | Fatal |
| MIA05CA121 | 2-May-05 | N66113 | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| MIA05CA156 | 13-Sep-05 | N513JG | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| MIA05FA140 | 30-Jul-05 | N65982 | Cessna Aircraft Company | 172 | Conventional | Fatal |
| MIA05LA042A | 6-Dec-04 | N294PA | Piper Aircraft, Inc. | PA-28-181 | Conventional | NonFatal |
| MIA05LA043 | 17-Dec-04 | N375LP | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| MIA05LA083 | 28-Mar-05 | N53589 | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| MIA05LA129 | 2-Jul-05 | N53269 | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| MIA05LA143 | 4-Aug-05 | N513CD | Cirrus Design Corporation | SR22 | Glass cockpit | NonFatal |
| MIA06CA021 | 18-Nov-05 | N5182Z | Cessna Aircraft Company | 172 | Conventional | NonFatal |

| ntsb_no | ev_date | Registration | Make | Model | Glass | Severity |
|---|---|---|---|---|---|---|
| MIA06CA072 | 26-Mar-06 | N326XT | Piper Aircraft, Inc. | PA-32-301 | Conventional | NonFatal |
| MIA06CA079 | 5-Apr-06 | N4654M | Mooney | M20 | Glass cockpit | NonFatal |
| MIA06FA050 | 4-Feb-06 | N667WP | Cirrus Design Corporation | SR22 | Conventional | Fatal |
| MIA06LA067 | 18-Mar-06 | N777YM | Cirrus Design Corporation | SR20 | Glass cockpit | NonFatal |
| MIA07CA008 | 21-Oct-06 | N401ER | Cessna Aircraft Company | 172 | Glass cockpit | NonFatal |
| MIA07CA019 | 19-Nov-06 | N53095 | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| MIA07CA045 | 27-Jan-07 | N20956 | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| MIA07CA101 | 24-May-07 | N904MM | Mooney | M20 | Glass cockpit | NonFatal |
| MIA07CA115 | 1-Jul-07 | N321MD | Mooney | M20 | Glass cockpit | NonFatal |
| MIA08CA056 | 15-Feb-08 | N618VT | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| MIA08CA068 | 26-Jan-08 | N65329 | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| MIA08CA073 | 6-Mar-08 | N213LP | Cessna Aircraft Company | 182 | Glass cockpit | NonFatal |
| MIA08CA092 | 20-Apr-08 | N375LP | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| MIA08CA112 | 5-Jun-08 | N300PB | Cirrus Design Corporation | SR22 | Glass cockpit | NonFatal |
| MIA08CA124 | 20-Jun-08 | N65357 | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| MIA08CA165 | 9-Aug-08 | N1600U | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| MIA08CA192 | 11-Sep-08 | N710ND | Hawker Beechcraft | 36 | Glass cockpit | NonFatal |
| MIA08FA081 | 20-Mar-08 | N615WM | Cirrus Design Corporation | SR22 | Glass cockpit | Fatal |
| MIA08FA115 | 7-Jun-08 | N206GG | Cessna Aircraft Company | 206 | Glass cockpit | Fatal |
| MIA08LA132 | 14-Jun-08 | N166DS | Lancair/Columbia Aircraft/Cessna Aircraft Company | 350 | Glass cockpit | NonFatal |
| NYC02FA089 | 24-Apr-02 | N837CD | Cirrus Design Corporation | SR22 | Conventional | Fatal |
| NYC04CA085 | 10-Mar-04 | N316MA | Diamond Aircraft | DA40 | Conventional | NonFatal |
| NYC04CA094 | 25-Mar-04 | N340PA | Piper Aircraft, Inc. | PA-28-181 | Conventional | NonFatal |
| NYC04CA164 | 30-Jun-04 | N421RW | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| NYC04LA061 | 22-Jan-04 | N344CD | Cirrus Design Corporation | SR22 | Conventional | NonFatal |
| NYC04LA209 | 11-Sep-04 | N579AL | Cirrus Design Corporation | SR22 | Glass cockpit | NonFatal |
| NYC05LA024 | 21-Nov-04 | N5294W | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| NYC05LA040 | 22-Dec-04 | N714KL | Piper Aircraft, Inc. | PA-46-350 | Conventional | NonFatal |
| NYC05LA110 | 30-Jun-05 | N3452L | Cirrus Design Corporation | SR22 | Glass cockpit | NonFatal |
| NYC05LA131 | 7-Aug-05 | N915DJ | Cirrus Design Corporation | SR20 | Conventional | NonFatal |
| NYC06CA058 | 22-Jan-06 | N285MG | Cirrus Design Corporation | SR22 | Glass cockpit | NonFatal |
| NYC06CA116 | 14-May-06 | N642KM | Cessna Aircraft Company | 172 | Glass cockpit | NonFatal |
| NYC06CA232 | 30-Sep-06 | N61WT | Cessna Aircraft Company | 172 | Glass cockpit | NonFatal |
| NYC06FA072 | 22-Feb-06 | N400WX | Lancair/Columbia Aircraft/Cessna Aircraft Company | 400 | Glass cockpit | Fatal |
| NYC06WA203 | 12-Aug-06 | N357MV | Cirrus Design Corporation | SR22 | Conventional | NonFatal |
| NYC07CA010 | 19-Oct-06 | N246MT | Cirrus Design Corporation | SR22 | Glass cockpit | NonFatal |
| NYC07CA074 | 9-Mar-07 | N323RW | Mooney | M20 | Conventional | NonFatal |
| NYC07CA112 | 4-May-07 | N462ER | Cessna Aircraft Company | 172 | Glass cockpit | NonFatal |
| NYC07CA116 | 9-May-07 | N924LP | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| NYC07CA131 | 2-Jun-07 | N2298W | Cessna Aircraft Company | 172 | Glass cockpit | NonFatal |
| NYC07FA037 | 30-Nov-06 | N665CD | Cirrus Design Corporation | SR22 | Glass cockpit | Fatal |
| NYC07FA083 | 24-Mar-07 | N324ST | Piper Aircraft, Inc. | PA-32-301 | Glass cockpit | Fatal |
| NYC07FA126 | 26-May-07 | N2537A | Lancair/Columbia Aircraft/Cessna Aircraft Company | 350 | Glass cockpit | Fatal |
| NYC07LA032 | 17-Nov-06 | N1442E | Lancair/Columbia Aircraft/Cessna Aircraft Company | 400 | Glass cockpit | NonFatal |
| NYC07LA134 | 8-Jun-07 | N729P | Hawker Beechcraft | 36 | Conventional | NonFatal |
| NYC08CA179 | 10-May-08 | N65433 | Cessna Aircraft Company | 182 | Glass cockpit | NonFatal |
| NYC08CA187 | 7-May-08 | N513JG | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| NYC08CA214 | 13-Jun-08 | N65939 | Cessna Aircraft Company | 172 | Conventional | NonFatal |

| ntsb_no | ev_date | Registration | Make | Model | Glass | Severity |
|---|---|---|---|---|---|---|
| NYC08CA233 | 29-Jun-08 | N357TG | Cessna Aircraft Company | 182 | Glass cockpit | NonFatal |
| NYC08CA282 | 10-Aug-08 | N5210A | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| NYC08FA041 | 21-Nov-07 | N108GD | Cirrus Design Corporation | SR20 | Conventional | Fatal |
| NYC08FA138 | 14-Mar-08 | N141SR | Cirrus Design Corporation | SR22 | Glass cockpit | Fatal |
| NYC08LA004 | 5-Oct-07 | N5205X | Cirrus Design Corporation | SR22 | Conventional | NonFatal |
| SEA04LA040 | 10-Feb-04 | N6503C | Lancair/Columbia Aircraft/Cessna Aircraft Company | 350 | Glass cockpit | NonFatal |
| SEA05FA023 | 4-Dec-04 | N1159C | Cirrus Design Corporation | SR22 | Glass cockpit | Fatal |
| SEA05FA038 | 20-Jan-05 | N6057M | Cirrus Design Corporation | SR22 | Glass cockpit | Fatal |
| SEA05FA075 | 12-Apr-05 | N448T | Hawker Beechcraft | 36 | Conventional | Fatal |
| SEA06CA187 | 22-Sep-06 | N320CP | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| SEA06TA118 | 30-May-06 | N8210G | Cessna Aircraft Company | 206 | Conventional | NonFatal |
| SEA07CA003 | 5-Oct-06 | N134GW | Cessna Aircraft Company | 182 | Conventional | NonFatal |
| SEA07CA064 | 24-Feb-07 | N224MT | Cirrus Design Corporation | SR22 | Glass cockpit | NonFatal |
| SEA07CA089 | 31-Mar-07 | N65067 | Cessna Aircraft Company | 206 | Glass cockpit | NonFatal |
| SEA07CA207 | 18-Jul-07 | N907JW | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| SEA07FA247 | 31-Aug-07 | N2520P | Lancair/Columbia Aircraft/Cessna Aircraft Company | 400 | Glass cockpit | Fatal |
| SEA07LA013 | 31-Oct-06 | N2097G | Cessna Aircraft Company | 172 | Conventional | NonFatal |
| SEA08CA052 | 26-Dec-07 | N13974 | Cessna Aircraft Company | 172 | Glass cockpit | NonFatal |
| SEA08CA131 | 10-May-08 | N196DC | Diamond Aircraft | DA40 | Glass cockpit | NonFatal |
| SEA08CA205 | 19-Sep-08 | N420FP | Diamond Aircraft | DA40 | Glass cockpit | NonFatal |
| SEA08FA023 | 8-Nov-07 | N881CP | Cessna Aircraft Company | 182 | Glass cockpit | Fatal |
| SEA08FA078 | 16-Feb-08 | N621ER | Lancair/Columbia Aircraft/Cessna Aircraft Company | 400 | Glass cockpit | Fatal |
| SEA08FA108 | 8-Apr-08 | N868PC | Cirrus Design Corporation | SR22 | Glass cockpit | Fatal |
| SEA08LA015A | 30-Oct-07 | N309PA | Piper Aircraft, Inc. | PA-28-181 | Conventional | NonFatal |
| SEA08LA095 | 25-Mar-08 | N432RM | Piper Aircraft, Inc. | PA-28-181 | Glass cockpit | NonFatal |
| WPR09CA007 | 9-Oct-08 | N206TT | Cessna Aircraft Company | 206 | Glass cockpit | NonFatal |
| WPR09CA066 | 21-Dec-08 | N379P | Piper Aircraft, Inc. | PA-46-350 | Glass cockpit | NonFatal |
| WPR09CA273 | 5-Oct-08 | N6048Z | Cessna Aircraft Company | 172 | Glass cockpit | NonFatal |
| WPR09LA049 | 27-Nov-08 | N936EW | Hawker Beechcraft | 36 | Glass cockpit | NonFatal |