National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: February 1, 2011

In reply refer to: A-11-1 through -6

The Honorable J. Randolph Babbitt
Administrator
Federal Aviation Administration
Washington, D.C. 20591

The National Transportation Safety Board (NTSB) adopted the safety study *Airbag Performance in General Aviation Restraint Systems* on January 11, 2011.[1] As a result of this study, the NTSB is issuing six safety recommendations to the Federal Aviation Administration (FAA) to address issues concerning airbag restraint systems, shoulder harnesses, capturing and recording crash dynamics information relating to airbag deployment, and tracking aircraft safety equipment installations. Information supporting these recommendations is discussed in this letter and in the safety study.

Background

In 2003, airbags were first certificated for pilot and copilot seats on general aviation (GA) aircraft, and as of January 2011, they have been installed in nearly 19,000 seats in over 9,000 GA airplanes.[2] Airbags in GA aircraft are installed in the lap belt or shoulder harness portions of the restraint system and are designed to deploy outward from the pilot or occupant. Sled tests conducted under controlled conditions have suggested that aviation airbags may increase survivability and reduce injury in actual aviation accidents; however, no systematic evaluations had been conducted to evaluate their efficacy in real-world scenarios. Therefore, in 2006, the NTSB initiated an exploratory case series study to assess airbag performance in GA accidents. Two goals of the study were (1) to examine the effectiveness of airbags in mitigating occupant injury in GA accidents and (2) to identify any unintended consequences of airbag deployments.

During the 3-year data collection period, researchers tracked 145 notifications of events (including 88 accidents) involving airbag-equipped airplanes and conducted field investigations of 18 of those events. Ten airbag-equipped GA airplane accidents involving 25 occupants met the

[1] See *Airbag Performance in General Aviation Restraint Systems*, Safety Study NTSB/SS-11/01 (Washington, DC: National Transportation Safety Board, 2011) on the NTSB website at <http://ntsb.gov/publictn/2011/SS1101.pdf>.

[2] C. Soares, AmSafe, Inc., e-mail ("Airbag Installation for Part 23 & Part 25") to J. Price, National Transportation Safety Board, January 12, 2011.

study criteria and were subjected to a full review and analysis by a multidisciplinary team. The accidents represented a range of crash severities and included survivable accidents with and without airbag deployments. There were no unexpected deployments or unintended consequences identified during the study period. Overall, when occupants adjusted the restraint systems correctly, the deployment of the airbag systems did not result in any negative outcomes, and in certain cases, deployments mitigated the severity of occupant injuries.

Of the 88 accidents involving airbag-equipped airplanes that were identified during the study period, about two-thirds (66 percent) had no airbag deployment and no occupant injuries. An additional 22 percent had reductions in survivable space or crash forces that were not survivable. Therefore, airbags would only have been expected to yield a benefit in a relatively small (12 percent) proportion of accidents. Within that window of accident severity, the NTSB concludes that aviation airbags can mitigate occupant injuries in severe but survivable crashes in which the principal direction of force is longitudinal.

Four of the recommendations resulting from the study concern occupant safety issues associated with the use, adjustment, or design of restraint systems. Two additional recommendations concern the need to capture and store information relating to airbags, including precrash data, crash data, and airbag deployment data, and the need to track individual aircraft information about aircraft safety equipment.

Incorrect Usage or Adjustment of Restraint Systems

During the course of its investigations, the study team discovered two potential safety issues associated with the misuse or incorrect adjustment of restraint systems. One issue involves occupants reversing restraints in Cessna airplanes. After the February 27, 2007, Cessna T182T accident in Athens, Texas,[3] the accident pilot stated that at the beginning of the flight, the left front seat passenger had attempted to use the restraint for the right seat. In the Cessna T182T, both of the front seatbelts hang from the ceiling between the two seats. The pilot, who was also a certified flight instructor, noted that there had been other occasions when his students had inadvertently used the wrong restraint in either the Cessna 172 or Cessna 182.

The NTSB concludes that the 3-point restraint systems in certain Cessna airplanes can be reversed in such a way that the airbag and restraint systems are not used as designed and certified. For example, if a left-seated occupant fastened the right seat shoulder harness to his or her outboard buckle, the airbag system in the unused restraint would be active while the airbag in the buckled restraint would be inactive.

Based on this finding, the NTSB recommends that the FAA require Cessna Aircraft Company and other manufacturers whose restraint system designs permit an occupant to use an inactive airbag restraint system not intended for use in his or her seat to modify their restraint system designs to eliminate that possibility, and require them to modify restraint systems in existing airplanes to eliminate the possibility of misuse.

[3] Additional information about this accident, NTSB case number DFW07LA078, can be found on the NTSB's website at <http://www.ntsb.gov/ntsb/query.asp>.

The second issue involves restraint- and airbag-related injuries that can result from occupants improperly adjusting restraint systems. In the February 14, 2009, Cirrus SR22 accident that occurred in Steamboat Springs, Colorado,[4] the right front occupant, a 5 foot tall, 97 pound female, suffered a bloody nose and chin bruises, likely due to contact with the airbag. The occupant also had bruises on her chest between her 3rd and 4th ribs near her sternum. The occupant reported that the bruise occurred in the location of the restraint buckle. The buckle of a properly adjusted 4-point restraint system should rest low on the pelvis, not at the sternum. In the accident, both rear seat restraints, which were not airbag-equipped, had load marks that suggested that they may also have been adjusted incorrectly because the load marks were inconsistent with the very small size and stature of the occupants. A subsequent interview with the front right seat occupant from this accident confirmed that she believed that the buckle was supposed to rest at the mid-chest region rather than at the pelvis.

Title 14 *Code of Federal Regulations* (CFR) 91.107 states that before each takeoff, the pilot must brief occupants on how to correctly fasten and unfasten their safety belts and, if installed, shoulder harnesses. Before moving the aircraft, pilots must also notify all occupants to fasten the restraints. Additionally, some manufacturers include guidance about proper use of restraint systems in their pilot operating handbook, or with a placard; however, this study found that in spite of the regulations and guidance, some occupants still used their restraints incorrectly.

The NTSB concludes that some GA occupants have misused or incorrectly adjusted their restraints in ways that could reduce the protection conveyed by the restraints or lead to injuries. Therefore, the NTSB recommends that the FAA revise the guidance and certification standards concerning restraint systems to recognize and prevent potential misuse scenarios, including those documented in this safety study. For example, the FAA should consider modifying the Technical Standard Order (TSO) C114, issued March 27, 1987, for restraints to include a usability evaluation component for any newly proposed designs.

Restraint Design Issues Affecting Nonnormative Populations

In the September 30, 2008, Cessna 172S accident that occurred in Fullerton, California,[5] the airbag embedded in the lap portion of the 3-point restraint system may have been out of optimal position because of the occupant's large waist size. If the size of an occupant causes the airbag to be positioned off to one side, the airbag may not provide full protection for the occupant's head and torso. Although it is unlikely that the offset airbag position would lead to any harmful outcomes in itself, it may reduce airbag effectiveness for large-sized individuals or pregnant women.

More than one-third of the occupants involved in the study accidents had body mass indices (BMIs) of 25 or higher and were classified as either overweight or obese.[6] In the

[4] Additional information about this accident, NTSB case number CEN09LA165, can be found on the NTSB's website at <http://www.ntsb.gov/ntsb/query.asp>.

[5] Additional information about this accident, NTSB case number LAX08FA301, can be found on the NTSB's website at <http://www.ntsb.gov/ntsb/query.asp>.

[6] Body mass index (BMI) classifications are based on guidelines from the World Health Organization. Information obtained from World Health Organization website <http://apps.who.int/bmi/index.jsp?introPage=intro_3.html> (accessed December 8, 2010).

introduction to the special conditions set by the FAA for the certification for airbag-equipped restraints, the following is noted:

> It is possible a wide range of occupants will use the inflatable restraint. Thus, the protection offered by this restraint should be effective for occupants that range from the fifth percentile female to the ninety-fifth percentile male.

Neither the introduction nor the special conditions explain how the restraint effectiveness should be evaluated for the range of occupants noted, and the range is not adequately defined. No testing is mandated, and no written guidance is provided for manufacturers to comply with the statement above. The average age of the GA accident-involved pilot in 2005 was 50; it was higher for pilots engaged in noncommercial operations.[7] The 95th percentile weight for 50 to 59 year old males in the United States is 260 pounds, and the 95th percentile waist circumference for that same group is 51 inches.[8] The NTSB questions whether the airbag-equipped restraints were designed or tested with this population in mind. The required emergency landing conditions testing in 14 CFR 23.562 was established in 1988. Anthropometric data gathered around that time indicated the average weight for adult males (of all ages) was just over 180 pounds, and the average waist circumference was 37.5 inches;[9] more recent data indicate that average weight and waist circumference for that population has increased to just under 195 pounds and more than 39.5 inches.[10] The testing in 14 CFR 23.562 refers only to a National Highway Traffic Safety Administration- or FAA-approved anthropomorphic test dummy with a nominal weight of 170 pounds. That weight is 20 pounds less than the average flight crewmember weight cited in the FAA Advisory Circular (AC) 120-27D, issued August 11, 2004, regarding aircraft weight and balance control, which derived its average from weights listed on all first and second class FAA medical certificates.[11]

The NTSB concludes that certain aviation airbag restraint configurations do not provide optimal protection for occupants whose anthropomorphic characteristics are substantially dissimilar to those of the anthropomorphic test dummy required for restraint testing. Given the lack of guidance in the special conditions, and the lack of a clear definition of the 5th percentile female and 95th percentile male referenced therein, the NTSB recommends that the FAA modify the special conditions for the installation of inflatable restraints on GA airplanes (at *Federal Register*, vol. 73, no. 217 [November 7, 2008], p. 66163) to provide specific guidance to manufacturers as to how they should demonstrate that the protection is effective for occupants

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[7] *Annual Review of Aircraft Accident Data: U.S. General Aviation, Calendar Year 2005*, Annual Review of U.S. General Aviation NTSB/ARG-09/01 (Washington, DC: National Transportation Safety Board) <http://www.ntsb.gov/publictn/2009/ARG0901.pdf>.

[8] M.A. McDowell and others, "Anthropometric Reference Data for Children and Adults: United States, 2003–2006," *National Health Statistics Reports*, October 22, no. 10 (2008) <http://www.cdc.gov/nchs/data/nhsr/nhsr010.pdf>.

[9] M.A. McDowell and others, "Anthropometric Reference Data for Children and Adults: United States, 1988–1994," *Vital and Health Statistics*, April, Series 11, no. 249 (2009) <http://www.cdc.gov/nchs/data/series/sr_11/sr11_249.pdf>.

[10] M.A. McDowell and others, "Anthropometric Reference Data for Children and Adults: United States, 2003–2006," *National Health Statistics Reports*, October 22, no. 10 (2008) <http://www.cdc.gov/nchs/data/nhsr/nhsr010.pdf>.

[11] GA pilots are only required to have a third class medical certificate.

that range from the 5th percentile female to the 95th percentile male. As part of that process, the FAA should consider gathering and evaluating the anthropometric data as a means to provide additional guidance to manufacturers about the anthropometric distribution of the GA occupant population.

Shoulder Harness Use

A large scale data analysis conducted as part of this safety study provides additional evidence that lap belt/shoulder harness use consistently reduces the risk of pilot fatal or serious injury when compared to lap belt use alone.[12] The analysis, which included over 37,000 single-engine airplane accidents that occurred between 1983 and 2008, determined that the risk of fatal or serious injury with a lap belt alone was nearly 50 percent higher than with a lap belt/shoulder harness combination. The results of this analysis provide definitive empirical support confirming previous NTSB conclusions issued during a GA crashworthiness study conducted in 1985 that involved detailed investigations of 535 accidents in which at least one occupant was fatally or seriously injured.[13]

Based on these findings, the NTSB concludes that lap belt/shoulder harness combinations provide significant protection beyond a lap belt alone, and fatalities and injuries would be reduced if lap belt/shoulder harness combinations were used in all GA airplanes.

In 1977, the NTSB recommended that the FAA require the installation of shoulder harnesses on aircraft manufactured before 1978;[14] however, the FAA never took steps to require retrofitting of aircraft not equipped with shoulder harnesses. In its final correspondence[15] to the FAA concerning the recommendation, the NTSB noted that the FAA had used, as its explanation for not requiring retrofits, the argument that there was insufficient justification to impose additional cost on owners of older aircraft. In response, the NTSB stated:

> Since the benefits of shoulder harnesses have been proven, the position that there is insufficient justification to impose the additional cost of modification on the owners of pre-1978 general aviation airplanes is unreasonable, and exposes the occupants of these airplanes to undue risk.
>
> We are aware that the FAA is preparing an Advisory Circular to discuss shoulder harness installation criteria and installation guidelines. Although this action may foster shoulder harness retrofit in some pre-1978 airplanes, it does not satisfy the intent of this old recommendation which we are now classifying in a "Closed—Unacceptable Action" status.

[12] See section titled "Research Methods and NTSB Research" in Chapter 1 of the report.

[13] *General Aviation Crashworthiness Project: Phase Two—Impact Severity and Potential Injury Prevention in General Aviation Accidents*, Safety Report NTSB/SR-85/01 (Washington, DC: National Transportation Safety Board, 1985).

[14] See Safety Recommendation A-77-71.

[15] P.A. Goldman, National Transportation Safety Board, letter (regarding Safety Recommendation A-77-71) addressed to D.D. Engen, Federal Aviation Administration, July 1, 1986.

On June 4, 1993, the FAA issued Advisory Circular (AC) 21-34 to provide information and guidance for the "installation of shoulder harness and safety belt restraint systems at all seat locations on all previously type certificated aircraft." The advisory circular emphasizes the safety benefits associated with installing lap belt/shoulder harness combinations, stating that "they can prevent serious head, neck and upper torso injuries in what may be relatively minor accidents in terms of aircraft damage, and they can prevent irreversible or fatal injuries in more severe accidents."

Despite the guidance provided in the advisory circular and the FAA's promotion of shoulder harnesses,[16] there are a substantial number of GA airplanes flying today that have not been retrofitted with shoulder harnesses. A detailed review of NTSB pilot reports from accidents involving nonamateur built airplanes with single reciprocating engines for the calendar year 2008 revealed that 122 of 923 (13 percent) did not have shoulder harnesses installed. This proportion likely underestimates the total number of airplanes without shoulder harnesses installed because pilot reports were missing or incomplete in an additional 123 cases (13 percent). Therefore, the NTSB recommends that the FAA require the retrofitting of shoulder harnesses on all GA airplanes that are not currently equipped with such restraints in accordance with Advisory Circular (AC) 21-34, issued June 4, 1993.

Capturing and Recording Crash Dynamics and Airbag Deployment Criteria

Occupant safety in the automotive environment has benefited greatly from technology that captures and stores information such as precrash data, crash data, and airbag deployment data. As early as 1974, General Motors production vehicles equipped with airbags have had the ability to record airbag status and crash severity for deployment events.[17] More recent General Motors vehicles capture information both preceding and during a deployment or near-deployment event. By studying this real-world crash information alongside occupant injury data and other postcrash observations, automotive manufacturers have been able to improve many aspects of occupant safety, including airbag design, vehicle crashworthiness, and advanced restraint systems.

Like early automotive airbags, the GA airbag systems observed in this study employed a mechanical mass-spring-damper type sensor, a design that does not capture and record crash severity or airbag deployment information. However, having recorded airbag data in the aviation environment could not only provide detailed information about airbag performance, but could also lead to advances in GA occupant safety by enhancing our understanding of aircraft crash dynamics and survivability of aviation accidents in general.

As the GA fleet becomes increasingly equipped with airbag systems, future researchers should continue to track the efficacy of such systems, both through detailed investigations and through larger controlled studies. With respect to improving the detailed information that could be gathered in individual investigations, the NTSB concludes that the understanding of aircraft

[16] See, for example, the pamphlet titled *Seat Belts and Shoulder Harnesses: Smart Protection in Small Airplanes,* AM-400-91/2 (Oklahoma City, OK: U.S. Department of Transportation, Federal Aviation Administration, Aeromedical Education Division, 1991).

[17] A. Chidester and others, "Recording Automotive Crash Event Data," *International Symposium on Transportation Recorders*, National Transportation Safety Board, Arlington, Virginia, May 3–5, 1999.

crash dynamics and occupant safety would be improved if airbag-equipped aircraft recorded, at a minimum, data concerning crash dynamics and airbag deployment criteria. Although existing airbag system designs do not support this capability, the NTSB believes that such capability should be considered in future airbag designs to facilitate postcrash airbag evaluations. Therefore, the NTSB recommends that the FAA evaluate the potential safety benefits and feasibility of requiring airbag-equipped aircraft to have the capability to capture and record, at a minimum, data concerning crash dynamics and airbag deployment criteria that can be reviewed after a crash to determine whether the system performed as designed.

Tracking Individual Aircraft Information about Aircraft Safety Equipment

During the recent study, the NTSB relied on AmSafe, Inc., the airbag manufacturer, to provide lists of airbag-equipped aircraft. AmSafe similarly relies on individual airplane manufacturers to provide it with information, such as serial and registration numbers of airplanes that have airbag systems installed. When an owner decides to retrofit an airbag system to his or her aircraft, the installer is required to report the installation to the FAA; however, the NTSB is aware that this information is not always shared or recorded accurately. As new inflatable restraint manufacturers come into the market, it will become even more challenging to track which aircraft are equipped with such systems. Although the inability to track the installation of safety equipment on individual aircraft is unlikely to present a safety hazard, tracking such information may lead to a better understanding of the use and efficacy of such systems.

In the automotive industry, a unique identifier, known as the vehicle identification number (VIN), is given to each motor vehicle. The VIN is a code that provides information about the vehicle year of manufacture, manufacturer, model, and other vehicle attributes. Using this information and information from state and federal crash databases, researchers have been able to conduct studies about the relationship between certain automotive design features and the likelihood of crashes or crash outcomes. Such a database for aviation could greatly improve understanding of the effectiveness of emerging aviation safety features, particularly if it is linked to the FAA's existing aircraft registry database.

The NTSB is in the process of modifying its aviation accident/incident database to include data on whether an accident aircraft was equipped with airbags and whether the airbags deployed in the accident. The form that pilots fill out after an accident (NTSB Form 6120.1) is also being modified to elicit similar information about airbag systems. The NTSB concludes that future evaluations of the effectiveness of occupant protection features, such as restraint systems, airbags, and parachutes, would benefit from a system that provides information about what aircraft safety equipment is installed on individual aircraft. Therefore, the NTSB recommends that the FAA develop a system to track individual aircraft information about aircraft safety equipment, such as restraint systems, airbags, aircraft parachutes, and other specific aircraft equipment, designed to improve crash outcomes.

Therefore, the National Transportation Safety Board makes the following safety recommendations to the Federal Aviation Administration:

Require Cessna Aircraft Company and other manufacturers whose restraint system designs permit an occupant to use an inactive airbag restraint system not intended for use in his or her seat to modify their restraint system designs to eliminate that possibility, and require them to modify restraint systems in existing airplanes to eliminate the possibility of misuse. (A-11-1)

Revise the guidance and certification standards concerning restraint systems to recognize and prevent potential misuse scenarios, including those documented in this safety study. (A-11-2)

Modify the special conditions for the installation of inflatable restraints on general aviation airplanes (at *Federal Register*, vol. 73, no. 217 [November 7, 2008], p. 66163) to provide specific guidance to manufacturers as to how they should demonstrate that the protection is effective for occupants that range from the 5th percentile female to the 95th percentile male. (A-11-3)

Require the retrofitting of shoulder harnesses on all general aviation airplanes that are not currently equipped with such restraints in accordance with Advisory Circular (AC) 21-34, issued June 4, 1993. (A-11-4)

Evaluate the potential safety benefits and feasibility of requiring airbag-equipped aircraft to have the capability to capture and record, at a minimum, data concerning crash dynamics and airbag deployment criteria that can be reviewed after a crash to determine whether the system performed as designed. (A-11-5)

Develop a system to track individual aircraft information about aircraft safety equipment, such as restraint systems, airbags, aircraft parachutes, and other specific aircraft equipment, designed to improve crash outcomes. (A-11-6)

In response to the recommendations in this letter, please refer to Safety Recommendations A-11-1 through -6. If you would like to submit your response electronically rather than in hard copy, you may send it to the following e-mail address: correspondence@ntsb.gov. If your response includes attachments that exceed 5 megabytes, please e-mail us asking for instructions on how to use our secure mailbox. To avoid confusion, please use only one method of submission (that is, do not submit both an electronic copy and a hard copy of the same response letter).

Chairman HERSMAN, Vice Chairman HART, and Members SUMWALT, ROSEKIND, and WEENER concurred in these recommendations.

[Original Signed]

By: Deborah A.P. Hersman
Chairman