The Benefits of a Safety Studies Program to Proactively Promote Aviation Safety

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Abstract

The U.S. National Transportation Safety Board's (NTSB) aviation safety interests go far beyond accident investigations. In fact, the NTSB's enabling legislation in Chapter 11, Title 49 of the United States Code mandates that it "carry out special studies and investigations about transportation safety." This mandate comprises a major element of the Board's proactive safety agenda. The Board's safety study program efficiently augments the conventional approaches of identifying safety issues and developing safety recommendations through accident investigation by conducting analysis of safety issues beyond the circumstances of a single event.

The benefits of a safety study program are demonstrated by discussion of selected studies of general aviation safety that have employed a variety of data collection procedures, analysis techniques, and study methodologies. These studies resulted in the issuance of 34 safety recommendations to the Federal Aviation Administration (FAA) and aviation industry groups. Examples discussed in this paper include risk factors associated with weather-related general aviation accidents using a case–control analysis; safety effects of the introduction of electronic flight displays (i.e., glass cockpit avionics) and of inflatable occupant restraint systems (i.e., airbags) into light aircraft using proactive assessments; and an examination of the safety of the experimental amateur-built aircraft using retrospective data analysis, targeted prospective data collection, and a large-scale voluntary survey.

Introduction

The National Transportation Safety Board (NTSB) employs safety studies as a complement to its accident investigation activity. Safety studies serve as a vital component of an effective safety management program and represent an inherently proactive approach to identifying, assessing, and mitigating safety risks. Studies complement traditional accident and incident investigations by expanding safety analysis beyond the circumstances of discrete events to include evidence of safety risks derived from aggregate analyses of existing information held in databases and prospective data collections.

Conventional wisdom regarding a proactive aviation safety management program includes data inputs such as near-miss events, voluntary safety reporting, and flight data monitoring that can potentially identify safety hazards before they cause a serious incident or accident. This conventional wisdom may suggest that the accident or incident investigation is merely a reactive response to a missed opportunity for prevention. The bridge between these efforts, however, is the safety study. Whereas accident and incident investigations provide the motivation and opportunity to identify and collect safety data, safety studies go beyond the investigation and recordation of accident circumstances to proactively pursue peripheral information and focus detailed attention to issues that may identify effective safety mitigations or previously unidentified safety hazards. Similarly, directed safety studies can collect and analyze comparison data from nominal operations to support truly predictive measures of safety risks.

NTSB safety studies differ from accident investigations in that they examine safety issues from an aggregate perspective. In most cases, the NTSB uses safety studies to gain a more thorough understanding of safety issues identified during the course of its accident and incident investigations. These issues are often best analyzed, and the resulting safety recommendations are most persuasive, when the power of numbers is put to work.

In some cases, the NTSB has used its safety studies to gain a new and unique perspective on persistent safety problems. One example, discussed later in this report, was the application of research techniques commonly used in the field of public health to the examination of weather-related general aviation accidents. By expanding its accident investigations to include the collection of information from non-accident flights, the study identified risk factors predictive of weather-related accidents.

The NTSB has also used its safety studies to assess new and emerging issues. Two examples described in this report are the NTSB's assessments of glass cockpit avionics and airbags in light aircraft. Using targeted prospective data collection protocols during its accident and incident investigations, the NTSB was able to proactively assess the real-world performance of these technologies—including the possibility of unanticipated negative safety effects.

Both approaches highlight an important characteristic of the NTSB's safety studies—their integration with the agency's investigations. When integrated with an effective safety studies program, investigations identify potential safety areas for further study; provide the fundamental data upon which these studies are based; and provide a vehicle for targeted data collection. The combination of studies and investigations is unique aspect of the NTSB's safety study program. Unlike other safety researchers who may be limited to archival data or research activities, independent investigation authorities typically have access to a wealth of detailed information regarding the circumstances surrounding safety management failures and hazardous events. This opportunity underscores the sometimes overlooked value of comprehensive accident investigations as an important aspect of proactive safety study programs.

Directed studies allow for a range of data collection and analysis techniques. A comprehensive study methodology is usually based upon hazardous event reports and investigation data, augmented with other sources of information. Examples of additional sources used in NTSB safety studies include prospective supplemental data collection, focus groups, interviews, surveys, and records review. The opportunity and authority to access those data is typically based in the responsibility to conduct thorough safety investigations.

Frequently, safety studies include analysis techniques that may be described as “proactive” or “predictive.” Prospective data gathering and examination of emerging technologies are two such techniques that were employed in the studies described here. Prospective data gathering is a technique where screening and selection techniques are determined in advance to help identify and obtain specific data believed to be factors in a safety issue. Examination of emerging technologies is equally important and provides a validation (or nullification) of a supposed safety benefit. This attribute can identify any potential for unintended consequences from using the emerging technology.

The NTSB Safety Study Program

Safety studies are an important facet of the NTSB's safety mission. In fact, the NTSBs enabling legislation clearly states that among its accident investigation mission, the NTSB shall “carry out special studies and investigations about transportation safety…” These studies are typically equivalent in scope and stature to any of the Board’s major accident reports. Similar to accident reports, an NTSB safety study report and resulting conclusions and recommendations must be deliberated and adopted by the NTSB’s Board Members during a public Board meeting.

Currently, studies are conducted in the NTSB’s Office of Research and Engineering. This Office has recently reconstructed its safety study program to facilitate more timely and focused studies of issues in response to information uncovered through the NTSB’s accident investigations. When a topic is suggested for study, a formal assessment is conducted to examine the safety impact of the issue, the quantity and quality of published research in the area, the proposed methodologies to be used, and the likely safety outcomes (publication and advocacy, safety recommendations, etc.) If the assessment is positive, a formal proposal is sent to the Board, and if approved, the study is conducted. Approximately two studies per year are generated by this process. This represents roughly 10-percent of the major reports issued annually by the NTSB.

Safety studies are also a highly efficient tool for the NTSB to examine safety issues, and provide great safety value. A typical NTSB study may result in as many findings, conclusions and safety recommendations as any accident investigation. Yet, generating studies typically requires modest staffing levels and resources compared to accident investigations and other safety programs. By consolidating the rich data provided by past and current accident investigations, and through our stewardship of the US aviation accident database, our researchers can leverage the previous efforts and expenditures of others for the benefit of safety study.

The NTSB conducts safety studies of issues concerning all modes of transportation. However, just as the NTSB's investigative workload is dominated by aviation, so too is its safety study archive. NTSB studies of aviation safety issues have included topics such as, *Public Aircraft Safety* (1), *Emergency Evacuation of Commercial Airplanes* (2), *Aviation Safety in Alaska* (3), *and Commercial Emergency Medical Service Helicopter Operations* (4). In this paper, four recent NTSB studies of general aviation safety issues will be highlighted for discussion.

Selected Safety Studies of General Aviation Safety

Since 2005, the NTSB has conducted four studies examining general aviation safety in the United States. These four studies illustrate the range of study methodologies and analysis techniques that have been utilized on specific safety issues, as well as the proactive nature of safety studies in general. The topics covered by this group of NTSB reports also span the range of various safety issues and concerns best suited for directed safety studies. These studies developed from issues encountered in the course of NTSB investigations, but were not necessarily comprehensively analyzed because the issue was not central to the cause of the particular accident or incident at hand or could not be adequately assessed based on the investigation of a single event. Because the NTSB investigates over 1,500 general aviation accidents a year, the ability to delve deeply into any particular safety issue or to recognize the pervasiveness of an issue is difficult to address on a case-by-case basis. For this reason, safety studies and aggregate analysis of these safety issues were a natural and necessary complement to investigations in a comprehensive, proactive approach to NTSB's efforts concerning general aviation safety.

The following four safety study examples resulted in the NTSB issuing 34 safety recommendations to the FAA and aviation industry groups to improve the safety of general aviation. It is unlikely that individual accident investigations alone could have identified the range of safety issues or provided the evidence necessary to support these safety recommendations.

Safety Study NTSB/SS-05/01 - Risk Factors Associated with Weather-Related General Aviation Accidents

This first example illustrates the utility of safety studies as a means to proactively explore safety problems, and use sound methodology to identify predictive risk factors. This 2005 safety study by the NTSB examined weather-related general aviation accidents (5). Adverse weather has been a continuous hazard to general aviation. Yet, even with advances in forecasting, reporting, and training, weather-related accidents remain a significant safety concern. Although the role of adverse weather may be obvious in accidents, the underlying reasons why the accident flights and their pilots were different from those not involved in accidents were not as well understood.

The NTSB designed a prospective study of general aviation accidents occurring in weather conditions characterized by IMC or poor visibility, in which carefully selected accident cases were investigated in detail to form the basis of a case-control methodology commonly applied in public health research.

The case-control methodology applied in this study compared a group of accident flights to a matched group of non-accident flights flying in the same proximity to identify patterns of variables that distinguished the two groups from each other. NTSB investigators collected data from 72 general aviation accidents that occurred between August 2003 and April 2004. When accidents occurred, study managers used recorded radar data, flight plans, and weather to identify other general aviation flights that were operating in the vicinity at the time of the accident (see Figure 1). Non-accident pilots were contacted, and with voluntary consent, provided information about themselves, their aircraft, and their flight. A total of 135 non-accident flights were included in the study. Additionally, the FAA records were used to compare practical and written test results and previous accident/incident involvement.

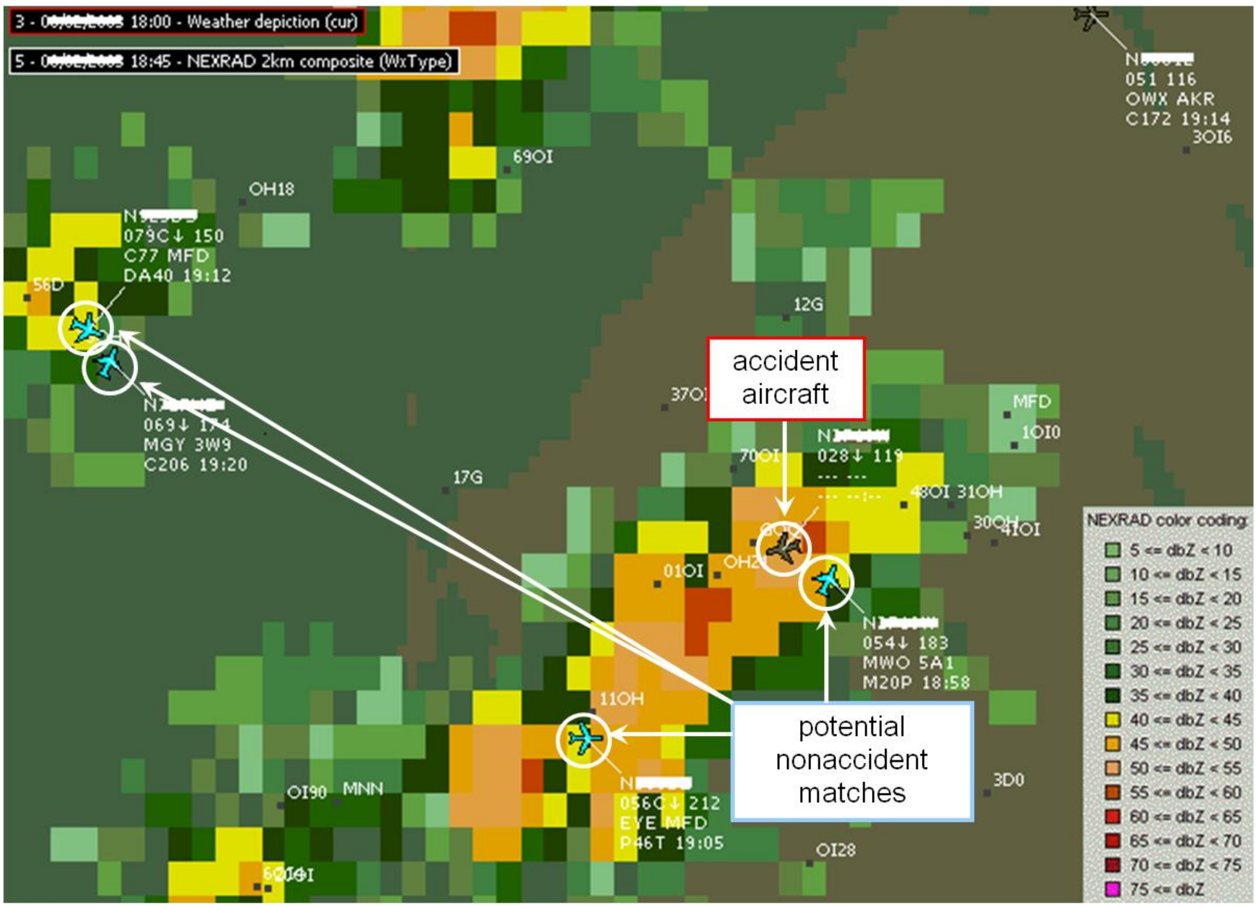

Figure 1 Example of study protocol for identifying non-accident flights for comparison with accident flights using recorded radar, weather, and aircraft flight plan data.

This study reached several conclusions that could only have been identified through systematic analyses of aggregate data. For instance, pilots who started flying earlier in life were found to be at lower risk of being involved in a weather-related general aviation accident than those who started flying when they are older, and this was a better predictor of future accident involvement than age at the time of flight. This finding is illustrative of the unexpected findings that can be indentified through proactive safety studies. In this case, there was no evidence that the observed connection between age and accident risk was due to aging issues, but rather to other factors associated with the age at which a person starts flight training, such as their motivation to pursue aviation, training environment, and other life demands.

Additionally, the study's review of pilot's training and testing history found that a history of knowledge and/or practical test failures were both associated with a higher risk of being involved in a weather-related general aviation accident. A history of accident or incident involvement was likewise found to be associated with a similar higher risk for involvement in weather-related general aviation accidents.

This study resulted in the NTSB issuing six recommendations to the FAA. Some of those recommendations were directed toward safety issue areas, such as weather reporting and regulatory requirements, that might be identified through investigations and voluntary safety reports. But the resulting ability to identify pilots of elevated risk for future accident involvement led the NTSB to issue a safety recommendation to the FAA to build on the predictive capability. The Board specifically recommended that the FAA,

> *Develop a means to identify pilots whose overall performance history indicates that they are at future risk of accident involvement, and develop a program to reduce risk for those pilots. (A-05-027)*

A finding like this, and the resulting safety recommendation, would not likely be reached through accident investigations, nor would it be reached using other data collection sources, like voluntary reporting programs, typically included in a proactive safety study program.

Safety Study NTSB/SS-10/01 - Introduction of Glass Cockpit Avionics into Light Aircraft

This second example demonstrates the use of a directed safety study to proactively seek out information to assess emerging issues and new technology when there is little real-world experience to draw from. In this case, the study focused on the introduction of glass cockpit avionics that represent a dramatic technological shift in light aircraft over the last decade (6). The study was motivated by the NTSB experience with GA accident investigations that involved rapidly increasing numbers of aircraft outfitted with advanced navigation and flight displays (i.e. glass cockpits). NTSB forensic evaluation of the data stored in their non-volatile memory has benefited the investigation process. However, NTSB staff observed several unusual events, raising the possibility that this emerging technology might not offer all the safety benefit possible.

The aircraft manufacturing information presented in figure 2 below illustrates how, during the very short time span from 2002 to 2006, the newly manufactured light aircraft fleet in the United States underwent a transition from conventional cockpit avionics to glass cockpit avionics. The change in technology started with newly manufactured aircraft, but avionics manufacturers quickly started developing and securing certification to retrofit aircraft with conventional cockpit avionics with glass cockpit avionics. The timing of the equipment change presented a remarkable opportunity for a "natural experiment" during which a carefully controlled comparison could be made between new conventionally equipped and new glass cockpit equipped aircraft of comparable capability.

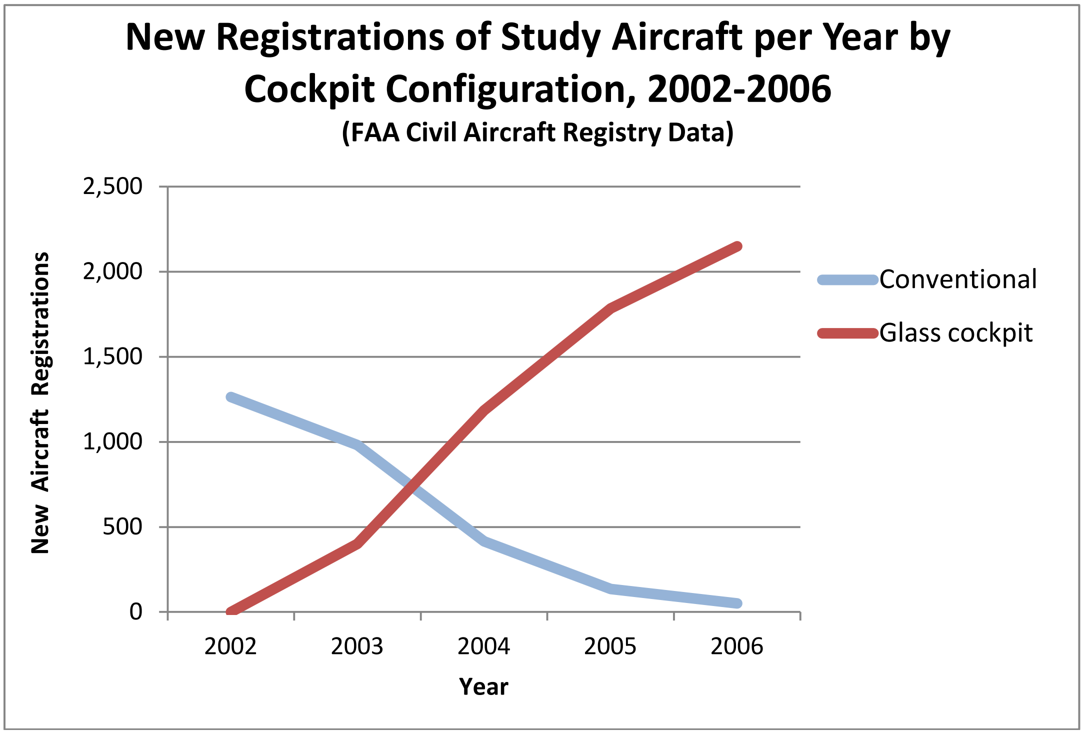

Figure 2 Comparison of new registrations of aircraft included in the NTSB study by cockpit display configuration and year of manufacture.

The goal of this study was to determine if the transition to glass cockpits in light aircraft has improved the safety record of aircraft equipped with this new and developing technology. 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 avionics. 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 avionics into this class of aircraft.

To ensure accurate comparisons, the study was limited to aircraft models that were manufactured in both conventional and glass cockpit versions. To eliminate confounding effects changing aircraft utilization that are known to occur with older aircraft, the study was also limited to airframes manufactured between 2002 and 2006 (7). By comparing manufacturer aircraft serial number data with FAA aircraft registration records, the NTSB identified 2,848 newly manufactured single-engine piston airplanes with conventional cockpit avionics for comparison with 5,516 aircraft with glass cockpit avionics.

The statistical analysis found that from 2002–2008, light single-engine aircraft equipped with glass cockpit avionics experienced lower total accident rates—but higher fatal accident rates—than the same type of aircraft equipped with conventional cockpit avionics.

The study identified important differences in the way aircraft equipped with these new technologies were being utilized. Counter to some previous assumptions, the comparison of accident rates suggested that the use of glass cockpit avionics had not resulted in a measurable improvement in safety when compared to similar aircraft with conventional cockpit avionics. By proactively seeking out the information to assess the safety effects of a new technology, the NTSB study was able to highlight the need for pilots to have sufficient equipment-specific knowledge and proficiency to safely operate aircraft equipped with glass cockpit avionics. The study also identified a similar need to capture maintenance and operational information to better assess the reliability of glass cockpit avionics in light aircraft.

As a result of this study, the NTSB issued six recommendations to the FAA, including the need to take proactive steps to address new challenges of training pilots to safely operate aircraft with a much more diverse range of equipment, which continue to develop at a rapid pace, than ever before. For example, the NTSB recommended that the FAA incorporate equipment-specific training elements, and expand the use of simulators to train pilots on the unique characteristics of the avionics in the aircraft they fly.

> *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)*

Safety Study NTSB/SS-11/01 - Airbag Performance in General Aviation Restraint Systems

In another proactive examination of new and emerging technologies, the NTSB conducted a safety study assessing the performance of airbags in light aircraft (8). In 2003, airbags were first certificated for installation on general aviation aircraft. The NTSB was particularly interested in this development because of the potential to improve survivability and reduce occupant injuries during accidents and because of its experience with airbag technology during an NTSB safety study of restraint systems for children in automobiles in 1996 (9). In that study, the NTSB identified the unintended consequence of severe injury to children and infants during the deployment of automobile airbags. Therefore, the NTSB was interested in the potential benefits of this new technology, as well as understanding whether there was a risk for unintended deployments. Retrospective analysis of accident data clearly would provide the detail necessary to make these determinations. To conduct this study, NTSB researchers and investigators worked with the restraint manufacturer to develop a detailed prospective data collection protocol. The study protocol included a detail screening process for selecting accident and incidents for inclusion in the study.

Figure 3 depicts the classification protocol applied to the 145 event notifications involving airbag-equipped aircraft during the study period. Event notifications were assessed by whether they occurred in the United States, whether the event was survivable, by airbag deployment, and by occupant injury. This protocol included sending technical experts from the NTSB and restraint manufacturer to examine aircraft wreckage, conduct post-crash testing of the restraint system, and interview aircraft occupants. The response was conducted in coordination with the NTSB's accident investigation, but was equivalent to a separate investigation of the restraint system performance.

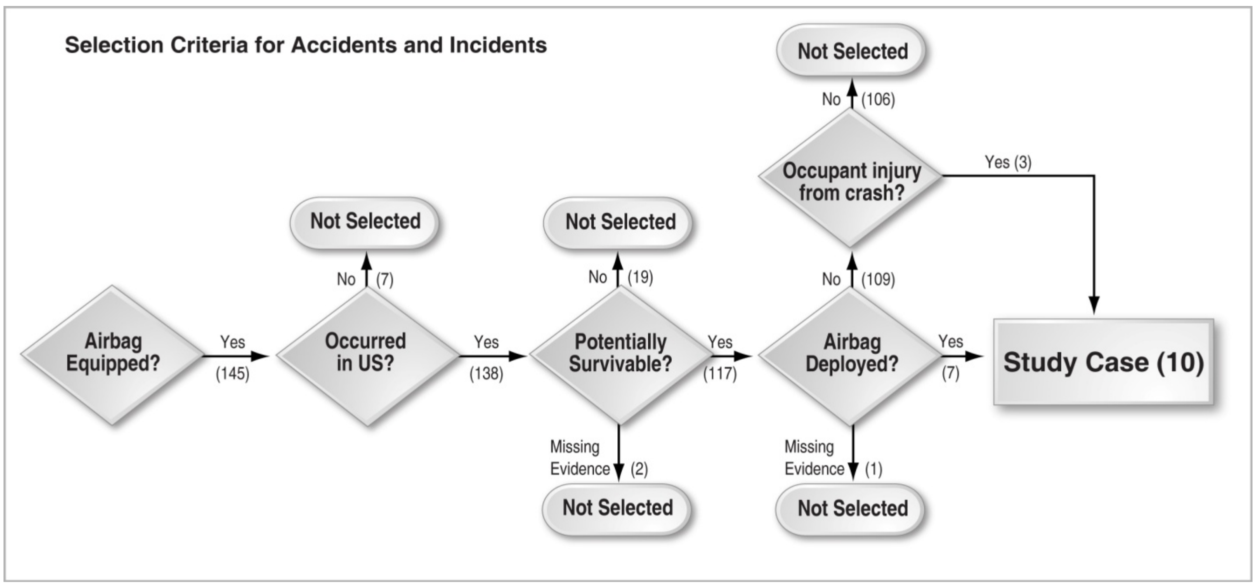

Figure 3 Chart depicting summary of the classification of all airbag-equipped airplane events tracked during the study period.

During the 3-year data collection period, researchers tracked 145 notifications of events involving airbag-equipped airplanes and conducted in-depth field investigations of 18 of those events. Ten airbag-equipped general aviation airplane accidents involving 25 occupants met the study criteria and were subjected to a full review and analysis by the multidisciplinary team. This review included a detailed examination of the restraint performance by medical doctors and a team of experts in accident investigation, biomechanics, and survival factors.

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, the study determined that airbags could only be expected to yield a benefit in a relatively small (12 percent) proportion of accidents. Within that window of accident severity, the NTSB concluded that, when adjusted correctly, aviation airbags can mitigate occupant injuries in severe but survivable crashes in which the principal direction of force is longitudinal.

There were no unexpected deployments or unintended consequences identified during the study period.

During the course of the study, the study team observed previously unreported issues associated with the use, adjustment, or design of restraint systems that may compromise occupant safety. Because the safety issues were associated with occupants' lack of knowledge about the restraints, or misunderstanding of restraint usage, it is unlikely that these issues could have been identified through other proactive data collection methods like voluntary reporting programs.

This study identified steps that could be taken to address these safety issues and suggested future research directions in the area of general aviation occupant protection. As a result of this study, the NTSB issued six safety recommendations to the FAA. Examples of those recommendations include:

> *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)*

Safety Study NTSB/SS-12/01 - The Safety of Experimental Amateur-Built Aircraft

This fourth and final safety study example applied a combination of techniques to gather safety-relevant information beyond what is typically collected during accident investigations and compared that with information from the wider pilot population and aircraft fleet. A unique aspect of this study for the NTSB was the collaboration with an aviation industry group, the Experimental Aircraft Association (EAA), which provided important comparison information gathered through a survey of its membership. This study examined the safety of the increasingly popular experimental amateur-built (E-AB) aircraft in U.S. general aviation (10).

The NTSB undertook this study because of the popularity of E-AB aircraft, concerns over their safety record, and the absence of a contemporary and definitive analysis of E-AB aircraft safety. Although general aviation activity has decreased slightly over the past decade, one segment of general aviation activity that has seen marked growth is experimental amateur-built aircraft. Unfortunately, the proportion of general aviation accidents involving E-AB aircraft has also been increasing, and the fatal accident rates for this segment have averaged roughly four times higher than that of comparable general aviation aircraft and flight operations. No single E-AB accident investigation could adequately assess these safety differences. Therefore, a directed safety study was conducted to identify data-driven safety mitigations.

The study employed several different methods and data collection procedures to carefully examine this segment of U.S. civil aviation. This comprehensive approach resulted in a detailed characterization of the current E-AB aircraft fleet, pilot population, and associated accidents. Four sources of data formed the basis of this study. First, the NTSB performed a retrospective analysis of accident and activity data over the last decade to compare the accident experience of E-AB aircraft with that of similar non-E-AB aircraft used in similar general aviation flight operations. Second, the NTSB conducted a set of prospective, in-depth investigations of all E-AB aircraft accidents during 2011, which provided a case-series of accidents for more detailed analysis. Figure 4 below contains a map of all accidents involving experimental amateur-built aircraft that were included in the prospective data collection. Third, a broad survey of the community of aircraft owners and builders was conducted by the EAA, and the data were made available to the NTSB for analysis to understand the population of E-AB aircraft builders and owners. Finally, discussions with EAA representatives, FAA officials, E-AB aircraft builders and owners, kit manufacturers, and representatives of E-AB aircraft type clubs provided insights on E-AB aircraft safety issues and solutions.

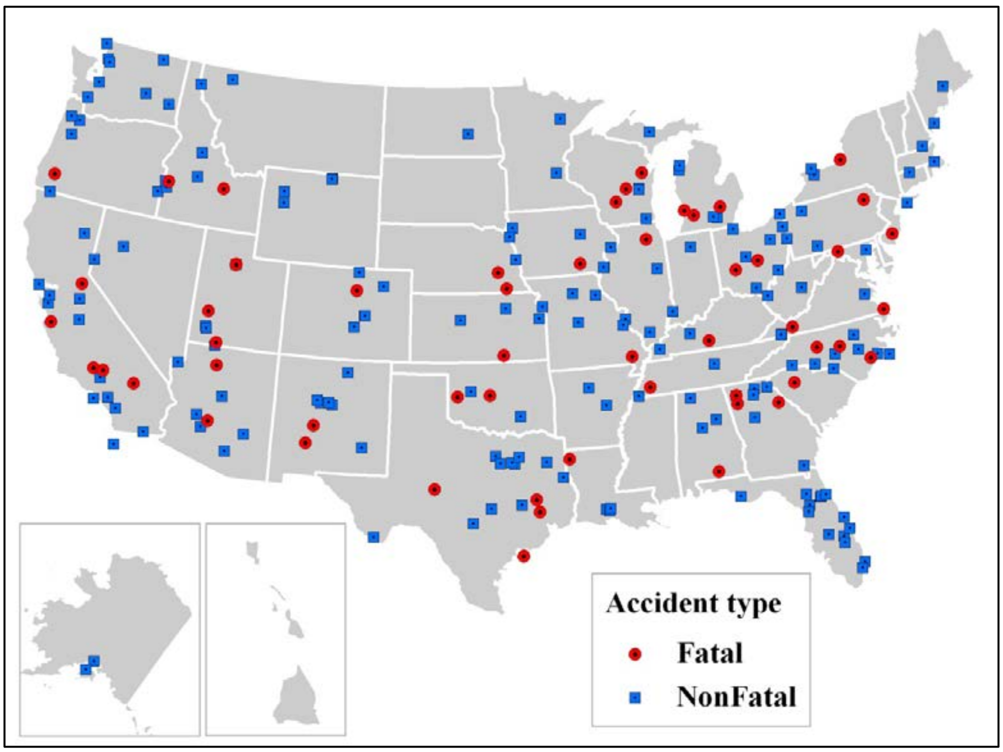

Figure 4 Map depicting the location of 224 experimental amateur-built aircraft accidents during 2011 that were included in the prospective data collection for the NTSB safety study.

Several study findings, and resulting safety recommendations, were identified as a result of the detailed prospective investigations. These included the need to improve documentation to support Phase I flight testing, improve pilots' access to transition training and supporting efforts to facilitate that training, encourage the use of recorded data during flight testing, ensure that buyers of used E-AB aircraft receive necessary performance documentation, and the need to improve aircraft identification in registry records.

In this case, the value of a proactive pursuit of safety information was illustrated by somewhat unexpected findings that more than half of E-AB accidents involved aircraft purchased used. Moreover, there were more accidents involving aircraft being flown for the first time by a new owner than there were during the first flight of newly built aircraft. The study also found that equipment issues were largely related to the actions of individual builders and that structural failures were rare.

Conclusions

The NTSB conducts safety studies as a proactive component to its overall safety mission. These studies have proven to be an efficient means to achieve a significant safety benefit. They are based firmly on accident investigation findings, but go beyond the single accident to include an aggregate analysis of operations and populations. In doing so, safety studies effectively bridge the gap of the safety analysis spectrum, lying between conventional accident investigation and predictive safety analysis techniques.

Through careful selection of study topics, and by employing a variety of research methodologies, studies can provide an effective tool for proactively identifying safety issues. The focus on emerging technologies in both the airbag and glass cockpit avionics studies served to proactively examine the presumed safety benefit and potential unintended consequences of these technologies early in their introduction and deployment. Prospective data collection provides another opportunity for safety studies to proactively seek out additional information from safety investigations, using expanded investigation protocols or selection criteria. Further, the use of supplemental data collections such as the case-control methodology employed in the study of weather-related accidents, and the voluntary survey of study populations used in the experimental amateur-built aircraft study, allow study findings to be applied to the wider population.

Safety studies will remain a vital component of the NTSB's safety mission, not solely because of a Congressional mandate, but because of the efficiency, effectiveness, and proactive impact they have on improving transportation safety.

Acknowledgments

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7. 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, exported, or the registration later became inactive.
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