JOURNAL OF ACCIDENT INVESTIGATION

A biannual publication to promote transportation safety through science

Special Features

- *Combating Hardcore Drunk Driving*
- *Fighting Fatigue*
- *Safety and Security*

Research and Technical Reports

- *Applying Research Methods to Accident Investigations*
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About The Cover

The NTSB Academy moved into its new home in Sterling, Virginia, in September 2003. The Academy provides training for NTSB investigators and others from the transportation community to improve their practice of accident investigation techniques.

Editorial Policy

Research/Technical Articles

The NTSB Journal will publish research and technical articles on accident investigations that may be of interest to professionals in safety, accident investigation, engineering, and the behavioral sciences. Papers may be empirical or concerned with the development and use of accident investigation methods, techniques, or technologies. All papers should have a strong scientific or technical basis and be related to accident investigation or transportation safety analysis.

Organization of material for empirical investigations should follow standard reporting format: problem, method, results, discussion, and summary. Papers discussing accident investigation methods, techniques, or technologies should include a clear and concise description of the method, technique, or technology that uses accident data and information to illustrate the approach and a discussion of the added benefit the approach brings to accident investigation or transportation safety analysis.

Public Forums, Symposiums, and Public Hearings

The NTSB Journal will publish papers describing public forums, symposiums, and public hearings conducted by NTSB. The papers will describe the purpose of the event, the participants, and the topics covered by the event. The paper should include clear and concise statements of the areas of open discussion, topics identified for further analysis, conclusions reached, and any recommendations that were made as a result of the event.

Special Features

Articles that treat policy issues related to transportation safety will be accepted for consideration as special features of the Journal. These papers may be solicited from both internal and external sources. These articles should represent a balanced view of the various aspects of an important safety issue.

Business of the Academy

The Journal will include short reports of major developments, news, events, research efforts, and announcements of upcoming courses, forums, symposiums, and topical public hearings.

Editorial Board

The Editorial Board comprises the NTSB Managing Director or designee, the Director of the NTSB Academy, the Chief of the Safety Studies and Statistical Analysis Division, and the Director of Government and Industry Affairs. The Editorial Board may solicit critiques or counterpoints on matters open to debate. Unsolicited articles may be accepted subject to space availability. Special features may be edited for suitability and fit.

Guidelines for Submissions to the Journal

- Submissions to the NTSB Journal must be submitted as Word documents. Any documents submitted as PDF files will be returned to the author for reformatting.
- Graphics should be submitted in native format, preferably as high-resolution 300 dpi files in Jpeg or Tiff format.
- NTSB staff should ensure that text is edited to comply with the NTSB Style Guide prior to submission.
- Submissions must include a brief biography of all authors, including the following information: full professional name (initials are acceptable), professional titles (e.g., Ph.D., M.D.), education, and a brief description of professional experience specific to the subject of the article. Including an e-mail address or point of contact information is recommended but optional.

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Mission Statement

The Journal is an interdisciplinary publication that provides for the public exchange of ideas and information developed through accident investigations at the National Transportation Safety Board in all modes of transportation. The intended audience is professionals in safety, accident investigations, engineering, and the behavioral sciences.

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The NTSB Journal of Accident Investigation *Special Features* presents articles that treat policy issues related to transportation safety. These papers may be solicited from within the government or from public sources. These articles are intended to represent a balanced view of the various aspects of an important safety issue. They do not represent an official view of the Safety Board.

Special Features

Combating Hardcore Drunk Driving Innovative Funding Sources and Courtroom Strategies

Susan Molinari, Chairman of The Century Council

Since 1982, alcohol-related traffic fatalities have decreased 33 percent according to the National Highway Traffic Safety Administration (NHTSA). That decrease translates into lives saved and injuries prevented—and also demonstrates substantial progress.

However, in recent years the number of alcohol-related traffic fatalities has increased slightly with relatively no change last year. Preliminary estimates from NHTSA indicate that in 2003, 40% (17,401) of all traffic fatalities were alcohol-related, compared to 41% in 2002 (17,419).

The Century Council is a national not-for-profit organization, funded by America's leading distillers. The Council develops programs, strategies, and tactics to fight drunk driving and underage drinking.

Data show that hardcore drunk drivers cause the majority of alcohol-related traffic fatalities. Hardcore drunk drivers are individuals who drive with a blood alcohol concentration (BAC) of .15 or above, who do so repeatedly as demonstrated by more than one drunk driving arrest, and who are highly resistant to changing their behavior despite previous sanctions, treatment, or education efforts. Drivers at .15 BAC levels and above are responsible for 58% of all alcohol-related traffic fatalities and are at least 385 times more likely to be involved in a single-vehicle fatal crash than a non-drinking driver. Additionally, about one-third of all drivers arrested or convicted of driving while intoxicated (DWI) nationally have had a previous conviction within the past 3 years.

Recognizing the serious danger these drivers pose on our roadways, in 1997, The Century Council created the National Hardcore Drunk Driver Project. Under the umbrella of this project, The Council has worked with all sectors of the traffic safety and advocacy community in developing strategies and tactics to more effectively address hardcore drunk drivers and keep them off our nation's roads.

The National Hardcore Drunk Driver Project has developed a sourcebook, *Combating Hardcore Drunk Driving.* This single, comprehensive resource was developed to assist in reducing fatalities, injuries, and crashes caused by hardcore drunk drivers. It includes information on a broad range of policies, laws, sanctions, and treatment programs, culled from professionals in the fields of alcohol abuse, traffic safety, and research, and from surveys of U.S. territories, special jurisdictions, and every state. The Council updated this sourcebook in 2003 and distributed it nationwide. At the core of the project's work is a commitment to provide comprehensive solutions that include swift identification, certain punishment, and effective treatment of hardcore drunk drivers.

Recognizing the power of working collectively, The Council often works with other members of the traffic safety community to implement programs and enact effective state laws to address hardcore drunk driving. In 2000, The Council, along with the National Transportation Safety Board and Mothers Against Drunk Driving, formed the National Coalition to Prevent Hardcore Drunk Driving, which works to pass laws that provide for a comprehensive approach to preventing hardcore drunk driving. Significant progress has been made in numerous states including Illinois, Maryland, Massachusetts, Texas, and Virginia, to name a few.

These legislative victories are important achievements; however, recent statistics emphasize the need to reach beyond traditional solutions in search of innovative drunk driving countermeasures that will significantly reduce alcohol-related traffic crashes. The Century Council believes that innovative funding sources and judicial education, when added to ongoing comprehensive efforts to tackle the hardcore drunk driving problem, will make a substantial impact in the fight against drunk driving.

Self-Sustaining, Offender-Funded Systems — Additional funding is needed for effective local programs to combat the hardcore drunk driving problem, yet state budgets are stretched thin. Innovative funding sources to fight drunk driving are desperately needed. This funding shortfall can be effectively addressed through self-sustaining drunk driving prevention programs funded by offender fines.

The State of New York's STOP-DWI (Special Traffic Options Program for Driving While Intoxicated) is one of the most comprehensive, self-financed programs in the country and has been cited by NHTSA as a national model of excellence. STOP-DWI is based entirely on mandatory minimum fines and was established by state legislative statute in 1981, laying the foundation for the development of effective, locally based programs.

The law allows each county to establish a STOP-DWI program, develop a comprehensive plan, and appoint a coordinator. Counties receive all fines collected for alcohol and drug-related traffic offenses within their jurisdictions and have the flexibility to develop tailored local programs. Every county in New York has opted to participate in the program.

When the law was passed, the average DWI fine was $11. The legislature increased the mandatory fines to a minimum of $300 and a maximum of $500. Additionally, drivers who refused to submit to a BAC test were subject to a $100 fine (now $300).

STOP-DWI has been very successful and has generated $22 million each year along with a 39% reduction in alcohol-related traffic crashes, a 70% reduction in alcohol-related traffic crash deaths, and a 57% reduction in alcohol-related traffic crash injuries according to NHTSA.

The replication of New York's STOP-DWI will help move other states from reliance on federal funding to self-sustaining state programs while substantially reducing drunk driving crashes, deaths, and injuries. The Century Council encourages states to adopt self-sustaining, offender-funded systems and urges Congress to provide incentive grant funding to states that establish such systems that, over time, will reduce federal and state financial burdens while securing funding from the source of the drunk driving problem.

Judicial Education — All too often, hardcore drunk drivers who have slipped through the system on multiple occasions cause alcohol-related traffic deaths and injuries. Hardcore drunk drivers may be difficult to detect, difficult to prosecute, and difficult to properly sanction and treat. Because they go undetected, many are not reflected in statistics. Often those who are apprehended know how to manipulate the judicial system's weak spots and avoid appropriate sanctions and treatment.

The judiciary plays a pivotal role in the effort to reduce hardcore drunk driving. Of all types of criminal cases, drunk driving cases—especially hardcore drunk driving cases—are among the most complicated in terms of legal and evidentiary issues.

Drunk drivers vary greatly in how they respond to specific deterrent efforts. Judicial policies that increase the swiftness of adjudication and the certainty of punishment of convicted offenders can be very strong deterrents—even stronger than severity of punishment. However, there are often significant delays between the offense and the disposition of a DWI case. Plea-bargaining and pre-trial diversion programs can lead to a reduction in charges resulting in the possibility of avoiding a conviction for drunk driving and reduced sanctions. When hardcore drunk drivers receive a lenient sentence, rehabilitation can be impeded and recidivism often results. Judicial education is critical to substantially impacting the hardcore drunk driving problem.

This summer, The Century Council and the National Association of State Judicial Educators (NASJE) released its *Hardcore Drunk Driving Judicial Guide*. This resource outlines the issue of hardcore drunk driving, judicial challenges, effective strategies, and model programs. A national panel of judges and judicial educators from across the nation examined the judiciary's critical role in reducing hardcore drunk driving.

The *Judicial Guide* combines the panel's ideas and expertise with research in the field of hardcore drunk driving and highlights effective strategies, tactics, and programs that can be implemented across the nation to reduce this dangerous problem. It is designed to serve as a resource for judges and judicial educators as they address the complexities of reducing drunk driving in their courts. In addition to innovative programs and promising practices, the guide contains effective strategies for judges that include the following:

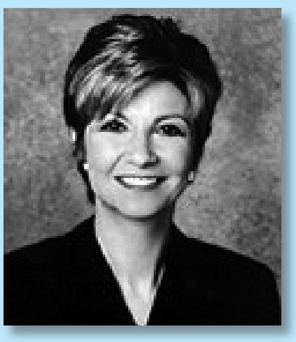
- Recognize high BAC as an indicator of hardcore drunk driving.
- Restrict plea-bargaining and diversion programs.
- Consider pre-trial intensive supervision programs.
- Mandate alcohol assessments or evaluations for all hardcore drunk drivers.
- Conduct pre-sentence investigations or interviews.
- Introduce measures for failure to appear.
- Impose meaningful fines.
- Employ the use of vehicle sanctions.
- Order the installation of offender-funded ignition interlocks.
- Place hardcore offenders on intensive monitoring, supervision, and probation.
- Consider staggered sentencing with intensive probation.
- Consider home confinement with electronic monitoring and sobriety testing.
- Utilize dedicated detention facilities.
- Supplement incarceration with treatment and aftercare.
- Avoid substituting community service for harsher sanctions.

The judicial community is uniquely positioned to lead the effort to reduce hardcore drunk driving through consistent sentencing and creative, comprehensive sanctions that not only punish the offender and protect the public, but also promote behavior change leading to reduced recidivism.

The *Hardcore Drunk Driver Judicial Guide* is a proactive means of providing critical information—as well as counteractive strategies and tactics—to address the issue of hardcore drunk driving.

The Century Council stands ready to work in partnership with national, state, and local government, as well as educators, the traffic safety community, and advocacy groups, to continue to identify and implement effective ways to eliminate drunk driving on our nation's roads. For more information about The Century Council's programs, visit www.centurycouncil.org.

THE AUTHOR



SUSAN MOLINARI is Chairman of The Century Council. A Member of Congress from 1990 to 1997, Molinari was a member of the Republican Majority Leadership and the House Leadership in 1996. Prior to Congress, Molinari was twice elected to the New York City Council, where she was Minority Leader. After leaving Congress to co-anchor *CBS News Saturday Morning*, she now represents a multitude of corporations and not-for-profits on various issues.

Safety and Security Vital To America's Transportation System

Rep. Don Young of Alaska
Chairman
House Committee on Transportation and Infrastructure

The National Transportation Safety Board, under the leadership of Chairman Ellen Engleman Conners, investigates a broad range of transportation accidents each year. Since 1967, the NTSB has investigated more than 115,000 aviation accidents and at least 10,000 accidents in other transportation modes. Obviously, NTSB's effectiveness is dependent upon timely accident reports and safety recommendations. I am told that, since the Board's inception in 1967, 82 percent of the NTSB's almost 12,000 safety recommendations in all modes of transportation have been adopted.

Despite its good record of working with other Federal agencies to ensure that its recommendations are implemented, some important ones have remained open for years. For example, the NTSB's recommendation to improve runway safety has been listed among their "Most Wanted" transportation safety improvements each year since 1990. And while we cannot expect instant results on such complicated issues, we cannot afford to wait 5 to 10 years or more to address important aviation safety problems.

To address this problem, the House Transportation and Infrastructure Committee passed legislation that President Bush signed into law last year. This law requires the Secretary of Transportation to submit an annual report to Congress and to the NTSB on the status of each recommendation that is included on NTSB's Most Wanted list of safety improvements.

I have seen the effectiveness of the NTSB firsthand. The number of aviation accidents in my home State of Alaska has decreased significantly. As we come to the end of this fiscal year, Alaska had just 79 accidents from October 2003 through September 2004. That's a 36% decrease compared to the total of 124 accidents in FY 2002 and 2003. The number of fatal accidents in Alaska dropped from 31 in FY 2003 to 18 in the last fiscal year. That's a 42% drop. This decrease is a direct result of our aviation community working closely with the FAA and the NTSB. I commend these agencies for their tireless efforts to improve transportation safety.

The terrorist attacks of September 11, 2001, highlighted the fact that the best aviation safety system must be accompanied by the best aviation security system. The Transportation

Committee has worked tirelessly since September 11 to overhaul all forms of transportation security and initiate a thorough reexamination of transportation security issues. The Committee has conducted approximately 50 public hearings in addition to multiple classified meetings and briefings, has worked with the Administration to make regulatory security improvements where possible, and has worked with the 9/11 Commission to implement expanded security programs.

Some major highlights include the following:

- Aviation and Transportation Security Act (ATSA) (P.L. 107-71), which created the Transportation Security Administration (TSA), federalized passenger and baggage screening functions, imposed stricter qualifications for screeners, required aviation employee background checks, mandated that cockpit doors be fortified, established a deadline for screening checked baggage, and instituted other security measures.
- Arming Pilots Against Terrorism Act (H.R. 4635), which established the Federal Flight Deck Officer Program, allowing for all trained and qualified pilots to carry firearms to combat terrorist attacks aboard commercial aircraft. This bill was incorporated into the Homeland Security Act of 2002 (P.L. 107-296).
- Vision 100 – Century of Aviation Reauthorization Act (P.L. 108-176), which authorized Federal aviation safety, security, and capacity enhancement programs, and airport improvement projects. This act includes requirements for a program for self-defense training for flight and cabin crewmembers, an aviation security program for charter air carriers, and regulations to strengthen security at foreign repair stations.
- Commercial Aviation MANPADS Defense Act (CAMDA) (H.R. 4056), which provides interim protections for commercial aircraft from shoulder-fired missiles and directs FAA to establish a process for conducting airworthiness and safety certification of missile defense systems used to defend commercial aircraft against Man-Portable Air Defense Systems (MANPADS).
- Aviation Biometric Technology Utilization Act (H.R. 4914), which requires establishment of biometric identification standards for use at airports, and use of biometrics for law enforcement identification credentials for police officers carrying weapons on board commercial aircraft.

Another major bill the Committee authored was the Maritime Transportation Security Act of 2002 (P.L. 107-295). This landmark legislation is designed to help protect America's maritime community against terrorism without adversely affecting the flow of U.S. commerce through our ports.

Legislation that compliments the maritime security bill is the Coast Guard and Maritime Transportation Authorization Act of 2004 (H.R. 2443). This legislation authorizes funding for the Coast Guard and accelerated acquisition of assets that allow the agency to combat terrorist threats (Deepwater Program).

In addition, the Pipeline Safety Improvement Act of 2002 (P.L. 107-355) authorizes programs to improve safety and security of pipelines and residents living near them, includes research and development funding that may be used to improve security, directs the Secretary of Transportation to develop rulemaking on security measures to protect pipes from terrorism, and provides funding for emergency responders to improve preparedness for incidents and response coordination.

Recently, the Committee introduced the Protecting Railroads against Enemy Efforts through Modernization, Planning, and Technology Act (PREEMPT) (H.R. 4604). This bill provides the resources to harden the nation's rail system against the possibility of terrorist attack and to improve our ability to recover from such an incident. The bill provides for comprehensive security plans, expanding the authority of the nation's existing railroad police force, developing new counter-terror technologies, and funding to improve the safety of critical rail tunnels used by Amtrak.

Once again, I would like to commend the dedicated staff at the NTSB for their exceptional work to make America's transportation system even safer. Their efforts to improve transportation safety, and those of other Federal agencies that are working to improve transportation security, puts us well on the way to providing the safest and most secure transportation system possible.

THE AUTHOR

U.S. REP. DON YOUNG (R-Alaska) was first elected to Congress in March 1973. He is currently serving his 15th term as Alaska's lone Member in Congress. He is now serving his second term as Chairman of the Transportation and Infrastructure Committee after serving six years as the Chairman of the Resources Committee. Originally from California, he moved to Alaska in 1960.

Fighting Fatigue

Rep. James L. Oberstar of Minnesota
Ranking Democratic Member
House Committee on Transportation and Infrastructure

We are very fortunate to have a great many Federal Government agencies for which the public gets the full value of its tax-dollar investment. But we get more than full value out of the National Transportation Safety Board. Its recommendations and its vigilance on safety issues result in improvements in the way we conduct the business of transportation in all modes. While pipelines and aviation get perhaps the greatest visibility for the NTSB when there is a tragedy, that should not overshadow nor cause anyone to forget the very significant and important work the agency performs in maritime, rail, truck, and automotive transportation.

Time and again, NTSB's recommendations for changes in safety oversight by agencies and safety practices by the private sector as well as by public entities result in saving lives, preventing property damage, and making transportation safer and more dependable throughout this vast land of ours.

NTSB's new Chair, Ellen Engleman Conners, came to this position from another safety responsibility as the head of the Research and Special Projects Administration (RSPA) of the U.S. Department of Transportation (DOT). There she had primary responsibility for pipeline safety and her agency was the subject of NTSB's recommendations for improvements in pipeline operations. Under her direction, the agency greatly improved on its long-standing poor track record of complying with NTSB recommendations and legislative mandates. Now at the NTSB, she brings the same dedication and vigor to her responsibilities as she did to the RSPA.

INVESTIGATIONS AND RECOMMENDATIONS

The unique role of the NTSB in its conduct of investigations of transportation accidents, after evaluating the evidence and making findings of fact, is then to make recommendations that are normative, not determined by cost-benefit analyses, not driven by one or another interest group, but based on what, in the best judgment of its seasoned safety professionals, is in the best public interest for safe operation in that particular mode.

In the last 5 years, there have been 8,124 accident investigations in aviation, 166 highway accidents, 82 railroad accidents, 41 pipeline accidents, 24 maritime accidents; and a total of 881 safety recommendations have been issued.

Unfortunately, not all of those recommendations have been implemented by the modal administrations of the DOT, and that is without regard to which party has been in charge of the executive branch. There is a very serious problem here. When our premier investigative agency looks at an accident, then relates it to a class or category of accidents and prescribes a remedy for it, the modal administrations ought to respond quickly.

Therefore, when Congress reauthorized the operation of the NTSB earlier this year, we included language to require an annual report to Congress from DOT on the status of regulations to implement each of the most significant safety recommendations from the NTSB, which is widely known as its "Most Wanted" list.

"MOST WANTED"

One of the usual suspects to appear regularly on the Most Wanted List is the issue of operator fatigue. Fatigue, brought on by working long hours on an irregular schedule, is a recognized occupational health and safety issue in all walks of life. It is also an especially serious issue in transportation, and one that cuts across all transportation modes.

The NTSB has been a leader in the effort to mitigate the impact of fatigue on pilots, truck drivers, and motorists, and to reduce fatigue-related accidents and their consequent injuries and fatalities. Unfortunately, the regulatory agencies responsible for making and enforcing the rules for these transportation modes have not been as responsive.

FATIGUE IN THE AIR

In aviation, fatigue is a constant challenge. In 1989, the Subcommittee on Aviation, under my chairmanship, held hearings on this issue. At that time, we were concerned that the Federal Aviation Administration had not issued rules regarding flight attendant duty limitations. About that same time, the NTSB called upon the DOT – including the FAA – to review its hours-of-service regulations to ensure that the latest scientific research on fatigue was incorporated. The FAA's response to this recommendation was woefully inadequate.

FAA proposed an overhaul to its pilot flight and duty regulations, but progress on the rule has been stymied for nearly 10 years. At the same time, flight attendants, who are on the front line of passenger safety and security in the air, are facing airline pressure to work longer hours and irregular shifts, and take shorter rest periods.

The FAA must be aggressive in its quest to resolve these very significant and complex flight and duty issues, using sound scientific principles as its guidepost.

PROGRESS ON THE GROUND

While the FAA has been lax in addressing the issue of fatigue in the air, a better effort has been made on the ground. When Congress created the Federal Motor Carrier Safety Administration (FMCSA) in 1999, we made it clear that safety was to be the FMCSA's highest priority, and expressly stated Congress's intent, encouragement, and dedication to the furtherance of the highest degree of safety in motor carrier transportation. Of particular importance was the expedited completion of rulemaking proceedings, including the driver's hours-of-service regulations.

On April 28, 2003, the FMCSA promulgated regulations to revise the hours-of-service requirements that were initially adopted by the Interstate Commerce Commission in 1937. (After 66 years of antiquated government policy on a matter of such importance, a new policy was long overdue!)

I did not agree with every provision of the new rules, but I believed that, on the whole, the regulations, properly enforced, could reduce the number of fatalities and injuries that occur each year because of fatigued commercial drivers.

By increasing the amount of required off-duty time from 8 to 10 hours and limiting the on-duty period to 14-hours, the new regulations promoted driver scheduling in closer alignment with the human body's 24-hour clock. There is general agreement on the positive safety effects of a 24-hour work/rest cycle and the scientific support for it. The "backward-rotating shifts" that occurred under the old rules intensified operator fatigue and made our highways less safe.

The increase in required off-duty time from 8 hours to 10 hours gave every driver the opportunity for 8 consecutive hours of uninterrupted sleep every day, the scientifically-determined amount of rest needed to promote alertness behind the wheel.

The new rules also provided drivers with adequate time off at the end of the work week to achieve restorative sleep. The 34-hour restart gave them time for two periods of uninterrupted recovery sleep before the beginning of the next work week.

On the other hand, I was concerned by the FMCSA's decision to increase allowable driving time from 10 hours to 11 hours each day. More time behind the wheel does not reduce fatigue or advance highway safety.

I was also concerned by the decision not to require the installation and use of electronic on-board recorders in commercial motor vehicles. My personal view is that such devices, recommended by the NTSB in 1990, are probably the single most effective way to ensure compliance with the hours-of-service regulations. In addition, I believe the recorders can be utilized in a manner that would address the legitimate privacy concerns of vehicle operators.

Safety regulations must also be vigorously enforced. The pending highway reauthorization bill–H.R. 3550, passed in different versions by the House and Senate–doubles the civil penalties for record keeping violations up to $1,000 for each day the offense continues, or up to $10,000 for an offense that conceals the fact that a non-record keeping violation occurred (such as a violation of the hours-of-service regulations). It is our hope that these higher penalties will reduce both the number of record keeping violations as well as the number of safety violations.

On July 16 of this year a federal court overturned the new hours-of-service rules, sending the FMCSA back to work on revising the outdated regulations. I would urge the agency to work quickly to bring forth new rules that will reduce fatigue and enhance highway safety by requiring adequate rest periods for commercial drivers, and to heed the court's admonition to ensure that safety and public health are the driving force behind the new regulations.

NEW TRAINING FOR INVESTIGATORS

One of the best initiatives undertaken by the NTSB in many years is the development of a training academy to teach state-of-the-art investigative techniques for transportation accidents. The Safety Board has always worked hard on training and improving the caliber and quality of its investigative personnel. This new training academy will be a huge benefit for the NTSB.

Among the courses offered by the academy is one that focuses specifically on investigating human fatigue factors in transportation accidents. Students learn the basis of fatigue in human physiology, study past NTSB investigations of accidents involving operator fatigue, and engage in interactive exercises based on actual accidents. This course will go a long way toward preparing investigators to look for signs of fatigue as a contributing factor in future accidents and enhance our knowledge of fatigue's role in transportation events resulting in property loss, injuries, and fatalities.

The NTSB serves as a model for civil investigative agencies throughout the world. Time and time again, the NTSB has been asked by other countries, especially those in the former Soviet bloc emerging after the Cold War, to help them establish their own transportation safety boards.

Again, the NTSB stands as the world standard for its honesty and integrity, the quality of its investigations, and for the quality of its recommendations for improving the safety of our nation's diverse, robust transportation systems.

THE AUTHOR

REP. JAMES L. OBERSTAR of Minnesota is the Ranking Democratic Member of the House Transportation and Infrastructure Committee. The committee has jurisdiction over America's surface transportation; freight and passenger rail; the inland waterway system, including the St. Lawrence Seaway; international maritime commerce; the Economic Development Administration; the U.S. Corps of Engineers' support of the nation's water resources; and the Federal clean water program. Elected to Congress in 1974, Rep. Oberstar has served on what is now the Transportation and Infrastructure Committee for the past 28 years, along the way chairing the Subcommittees on Economic Development, Investigations and Oversight, and Aviation.

Research and Technical Reports

Applying Research Methods to Accident Investigations

Joseph M. Kolly, National Transportation Safety Board
Thierry Blanchet, Rensselaer Polytechnic Institute

ABSTRACT

The National Transportation Safety Board uses both traditional investigation techniques and an alternate research methods approach in its technical accident investigations to determine the failure process of systems. A traditional investigation may be employed if the complete failure process can be identified with sufficient accuracy primarily through observation and examination of evidence and through full-scale demonstrations. The alternate approach uses research, testing, and analysis targeted to specific areas of insufficient or inadequate information. This approach is developed when the examination of evidence does not provide a complete understanding of the failure process, and full-scale demonstration tests are either impractical or unlikely to yield the necessary information. The amount and quality of available evidence, the existing knowledge base, and uncertainties about the factors that may have affected the failure process may influence the determination that an alternate approach using various research methods is necessary. This paper discusses the NTSB's successful use of research methods to investigate the failure of the jackscrew assembly in the Alaska Airlines flight 261 accident.

INTRODUCTION

Sound technical analysis serves as the cornerstone of many accident investigations concerned with determining why systems[1] fail. This determination is made, in large part, through discovery of the failure process. The failure process concerns the mechanisms by which the failure proceeded and the conditions and circumstances that affected the initiation and progression of the process. Several methods are available for determining the failure process.

[1] "Systems" in this context means any of the components or groups of components that make up the entire airplane.

Choosing the method that best suits a particular investigation depends on many circumstances regarding the availability of evidence and technical information, and knowledge of influencing factors.

TRADITIONAL INVESTIGATION TECHNIQUES

In many NTSB accident investigations, existing evidence and information are sufficient for using traditional techniques to determine why systems fail. These techniques rely primarily upon the detailed examination of evidence, supported by other sources of information, such as maintenance records, archival design and fabrication information, and witness interviews.

For example, by conducting a failure analysis investigation of the broken fan hub from a Pratt & Whitney JT8D engine,[2] the NTSB Materials Laboratory was able to determine from microscopic examination that fatigue cracking led to the fracture of the hub, that the fatigue cracking initiated from a cooling hole, and that the surface of the cooling hole was severely deformed and harder than the surrounding material. Investigators corroborated these findings by reviewing the hub's fabrication records from the time of manufacture, approximately 7 years earlier. The NTSB determined that problems during the hole drilling process were responsible for the conditions in the hole that led to initiation of the fatigue cracking. This example illustrates how a traditional approach based on physical evidence can be used to determine the entire failure process.

However, physical evidence and supporting information are not always sufficient to determine the circumstances of a failure process. Such information may never have been present, or, in the case of wreckage evidence, may have been compromised or destroyed in the accident. In such cases, full-scale demonstration tests may be conducted to test the validity of specific hypothesized failure scenarios when uncertainties about the failure process are limited to a few issues. Such tests may be as simple as operating a full-scale airplane system under certain predetermined conditions in an attempt to recreate the hypothesized failure process. Afterward, the system is examined and failure mechanisms observed or deduced. When properly applied, and under certain conditions, such full-scale demonstration testing can produce convincing results in a very efficient manner.

However, because flight-critical systems and components are part of the larger, complex airplane, which operates in a dynamic flight environment (see table 1), uncertainties affecting the failure process may not be limited to a few issues, and investigators may find it difficult to identify specific hypotheses to test.

Table 1. Examples of Variables that May Influence Flight System Failure Processes.

Potential Factors Influencing the Failure Process	Variables
Time Scales	• Failure can be instantaneous or can occur gradually over many flights • Failure can be a single event or a series of latent failures
Environmental Conditions	• May include the season, geographic location, weather, and flight profile - Temperature ranges of 200ºF+ - Pressure range of nearly 1 atmosphere - Relative humidity 0-100% - Contamination • Heating and vibration from neighboring systems
Operations	• Continuous (e.g., fuel pump) or intermittent (e.g., flap actuator) • High/low/variable speeds • Variable force, pressure loads, aerodynamic loads
Human Intervention/Activity	• Abuse/neglect • Maintenance procedures

[2] DCA96MA068, Pensacola, Florida, 7/16/1996, McDonnell Douglas MD-80.

Accordingly, deciding the degree of replication necessary for a valid test, and deciding which parameters to explore in the testing, may be problematic. These decisions and their uncertainty will affect the outcome of the tests. Additionally, because failures of flight-critical systems and components are extremely rare events, it may not be reasonable to expect that a failure can be replicated in a time-constrained laboratory test. When, for these reasons, neither examination of evidence nor full-scale demonstration testing can be used to resolve the failure process, research methods may be employed instead.

RESEARCH METHODS APPROACH

A research methods approach involves developing a program of experiments, tests, and analyses conducted in both a basic (generic) and specific (applied) fashion to systematically explore multiple factors believed to be important in the failure process. The tests and experiments are of a smaller scale and are highly controlled, so that a large number can be performed efficiently. This enables investigators to explore a wide variety of conditions believed to affect the failure process, while also allowing them to demonstrate experimental repeatability. The program should be designed to be flexible so that it can readily be adapted or changed as new information is uncovered by other sources within the overall accident investigation. Unlike demonstration tests, which usually focus on replicating and observing a failure event, the research methods approach enables investigators to develop auxiliary information outside of the binary results of a failure's occurrence or absence. This approach is therefore aimed less at observing or interpreting a specific failure process and more at determining a wider spectrum of knowledge concerning the conditions and circumstances of the failure process and other concerns related to the system's functions. By obtaining this broader understanding, NTSB investigators can examine and critique many aspects of the system's operation, maintenance, design, and certification and can develop safety recommendations to address any concerns.

CASE STUDY: THE TECHNICAL INVESTIGATION OF THE JACKSCREW FAILURE ONBOARD ALASKA AIRLINES FLIGHT 261

Background to the Accident

The Alaska Airlines flight 261 accident occurred off Point Magu, California, on January 30, 2000.[3] The NTSB concluded that the accident resulted from the failure of the MD-83 airplane's horizontal stabilizer jackscrew assembly (figure 1), which controls the motion of the horizontal stabilizer of the airplane. Examination of the jackscrew assembly recovered from the wreckage (figure 2) revealed that the assembly's aluminum bronze Acme nut threads were so severely worn that they were unable to carry the aerodynamic loads on the stabilizer during flight, resulting in a mechanical failure of the jackscrew assembly and loss of airplane pitch control.

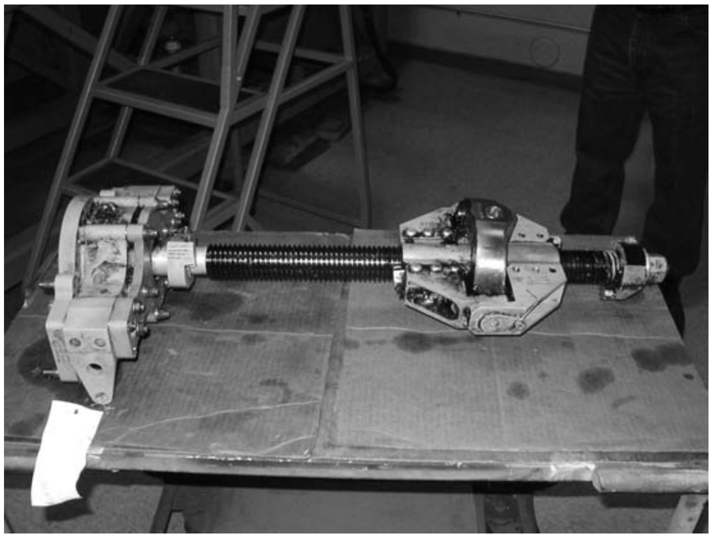


Figure 1. An Exemplar Jackscrew Assembly. The 23-inch-long steel screw is threaded through the aluminum bronze Acme nut (middle), which attaches to the airplane tail structure. The screw is driven by the gearbox (shown on the left), which is attached to the horizontal stabilizer. On the right end is the stop nut.

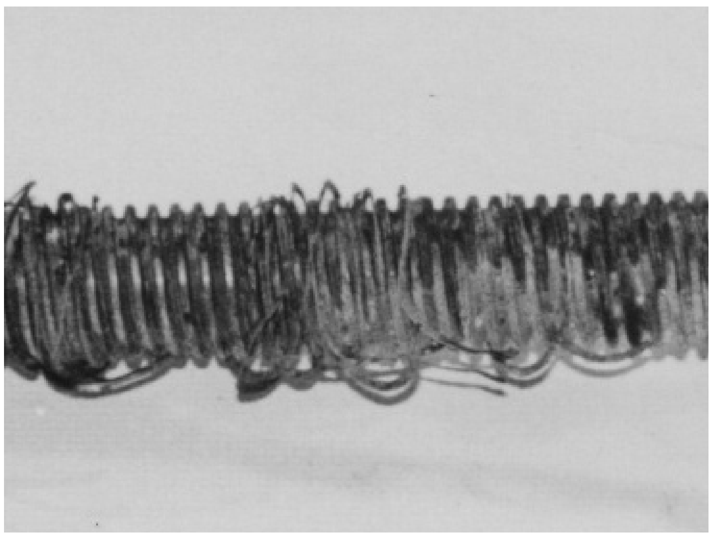


Figure 2. Close-up Photo of the Jackscrew Recovered from the Accident Wreckage. Note the remnants of the Acme nut threads wrapped around the steel screw. The threads had stripped free from the mating Acme nut during the accident flight. Also, note the absence of grease.

[3] See the accident docket at http://www.ntsb.gov.

Problem Statement

The NTSB reviewed the 30-year maintenance history of the entire DC-9/MD-80/MD-90 fleet and found a relatively consistent pattern of acceptably low rates of horizontal stabilizer jackscrew wear. This history was demonstrated across all airlines, with varying degrees of scheduled inspections and lubrication intervals. However, demonstration of such wear rates was limited to a few types of lubricating greases traditionally employed, with Mobilgrease 28 being the most common by far.

In the years prior to the accident, Alaska Airlines changed its maintenance procedures for lubricating the jackscrew and replaced Mobilgrease 28 with a relatively new brand of aviation grease, Aeroshell 33 (hereafter referred to as M28 and A33, respectively). For some undetermined length of time preceding the accident, the wear rate of the jackscrew had dramatically and unknowingly increased to several times its normal rate, leading to its failure during flight 261.

The NTSB needed to determine the cause of the excessive and rapid wear of the accident airplane's jackscrew Acme nut and in doing so, reveal the failure process. This required exploring the possibility that A33 was a less-effective lubricant than M28. Further, the NTSB wished to explore specific maintenance issues that may have influenced the failure process: the incompatibility of A33 grease when combined with M28 grease remaining from a previous lubrication interval (i.e., intermixing of greases); contamination of A33 grease by fluids such as water condensate or de-icing fluid; and inadequate grease application during maintenance.

Determining the Investigation Approach for the Jackscrew Failure Process

Metallurgical examination of the jackscrew components recovered from the wreckage revealed much information about the sequence of events experienced by the jackscrew during the failure process. Other traditional investigation methods (including record reviews, interviews, and examination of other airplanes), combined with mechanical engineering analysis of the wear patterns, indicated the stages of deformation experienced by the Acme nut threads during the failure process. Although this evidence was useful, it was not sufficient for investigators to determine the cause of the failure process or the conditions influencing that process: specifically, why the accelerated and excessive wear of the Acme nut occurred and what role the lubricating grease played in this failure process. Because no other sources of pertinent information were available,[4] the investigation sought ways to generate the necessary technical information.

Full-scale jackscrew demonstration tests were considered, in which jackscrews would be operated in a test fixture under simulated flight conditions and various means and conditions of lubrication. The objective would be to test various hypotheses and observe the failure process. However, during the exploratory phase of test development, many questions arose regarding the conditions and parameters to explore.

- How will the very large range of operating loads be simulated?
- Could grease intermixing or contamination have caused the grease to depart from the screw?
- What blends of the two different greases should be tested to determine if intermixing of greases was a causal factor?
- How can the possibilities of environmental contamination of the grease be explored?
- How can the effects of aging and weathering of the grease be accounted for?
- What role might corrosion play in the accelerated and excessive wear?
- What role did environmental temperature extremes have on wear rates?
- What confidence will we have in the results with respect to experimental repeatability?

These questions demonstrated the numerous unknowns regarding the failure process and reflected the complex operational environment on board the airplane that would need to be replicated. Because specific technical background information did not exist to provide a sound scientific basis to limit the parameters of proposed full-scale demonstration tests, the testing program would necessarily become extremely large, time-consuming, and expensive. Thus, it was apparent that any attempt to address all these concerns through full-scale demonstration tests would not be practical.

The NTSB therefore decided to use a research methods approach to understand the conditions and circumstances of the jackscrew failure process. A technical program was developed that considered a wide range of factors concerning the tribology[5] of jackscrew operation.

[4] Reviews of technical literature and inquiries with airplane and jackscrew designers and manufacturers yielded little, if any, information regarding wear behavior of grease-lubricated jackscrews that could be applied to this investigation.

[5] Tribology is the science of lubrication, friction, and wear.

Details of the Technical Program Used to Examine the Jackscrew Failure Process

The NTSB determined that the tribological issues of the failure process concerned three broad categories: physical behavior of grease, chemical behavior and interactions of grease, and wear behavior of grease-lubricated materials. Each of these areas was developed using a variety of testing, experimentation, and analysis.[6] Example studies from each area are described below.

Physical Behavior of Grease

A grease testing program was developed to examine the physical properties of the M28 and A33 greases, both separately and mixed, to explore potential reasons for (1) the excessive and accelerated wear of the airplane's Acme nut and (2) the absence of grease on the jackscrew when it was recovered from the wreckage. A battery of standardized American Society for Testing and Materials (ASTM) grease tests (over 50 tests using 5 methods) was conducted to examine a variety of grease characteristics, such as consistency and stability, relevant to jackscrew applications. These tests used standard equipment and test protocols and therefore could be conducted quickly and inexpensively. Modifications and/or supplementary analyses were often made to the tests to address the needs of the investigation more directly. These testing refinements proved enormously helpful in that investigators were not restricted to a conventional interpretation of results as put forth by the ASTM method, but were free to make other, more insightful interpretations of the results. For instance, results from the ASTM D-217 test method (figure 3) indicated that certain mixture ratios were incompatible.[7] However, detailed analysis of the results indicated that this incompatibility was not relevant to the excessive wear rates experienced by the jackscrew.

Overall, these tests revealed no significant differences in the physical behavior of the M28 and A33 greases that would indicate a significant difference in how well they lubricated the jackscrew Acme nut. In the same way, investigators determined that the effects of mixing greases were also insignificant and could not explain the absence of grease on the jackscrew recovered from the wreckage.

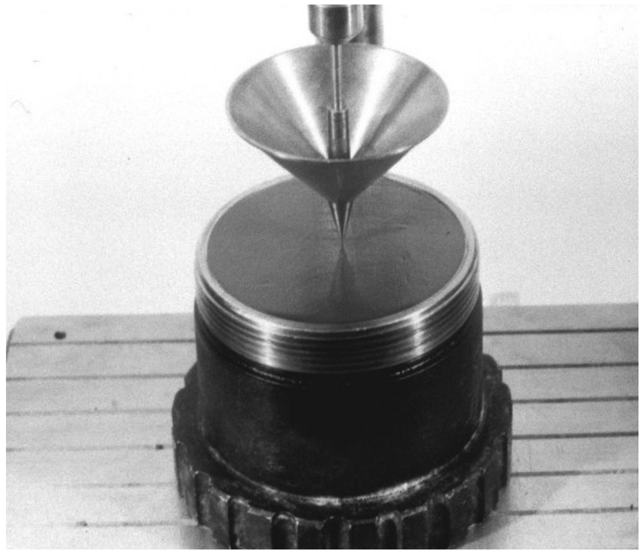


Figure 3. ASTM D-217 Cone Penetration Test Setup. A conical weight was lowered into a container of grease, and the depth of penetration of the cone was measured. This test indicated the firmness of the grease mixtures and was one of the tests used to determine grease compatibility.

Chemical Behavior and Interactions of Grease

An exposure-testing program was developed to examine the possibility that the grease corroded the jackscrew Acme nut material, prompting it to wear at a rapid rate. Although a standard test method, ASTM D-4048, is available for determining the corrosivity of grease to copper, the Acme nut was manufactured of aluminum bronze. Investigators therefore could not be certain that the standard test method would produce results that were either relevant or adequate to address corrosion issues concerning this investigation. Hence, the tests (figure 4) were run in a modified manner, as shown in table 2.

The standard tests for copper required a visual inspection of the metal test strip followed by comparison to a chart of standard corrosion images. A similar chart was not developed for use in the modified tests. Instead, a more rigorous surface chemistry analysis technique, XPS,[8] was performed. The XPS method is so sensitive that it is capable of detecting the slightest evidence of corrosion. This sensitivity ensured that an analysis of test specimens that were exposed for a relatively short time (2

[6] See the accident docket at http://www.ntsb.gov.

[7] "When greases made from different thickeners are mixed, the mixture may be poorer in service performance or physical properties than either of the component products. This lessening in performance is called incompatibility." National Lubrication Grease Institute (NLGI) Lubricating Grease Guide, fourth edition.

[8] The XPS technique, X-ray Photoelectron Spectroscopy, is also known as ESCA (Electron Spectroscopy for Chemical Analysis). The technique is widely used to measure the chemical composition of surfaces. Information is obtained from the first few atomic layers (~100 angstroms) regarding the chemical states of the existing elements and can be used to determine the presence of surface corrosion.

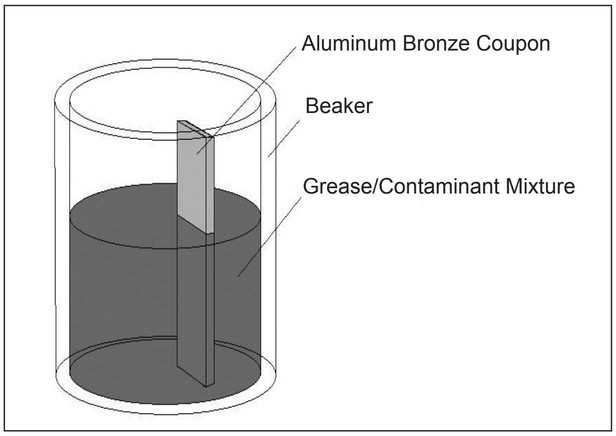


Figure 4. Exposure Test Setup. Aluminum bronze test specimens were partially submerged in a beaker filled with grease and contaminant fluids. Following exposure periods of 2 weeks at ambient or elevated temperatures, the submerged, interface, and unsubmerged regions were visually examined and chemically analyzed for indications of corrosion.

Table 2. Exposure Test Parameters. Over 30 individual exposure tests were run to cover the range and combination of parameters in the modified procedure.

Test Method	Standard ASTM D-4048 Test Method	Modified Test Method
Temperature	212º F	ambient (70º F) and elevated (150º F)
Duration	24 hours	2 weeks
Cuprous Metal	copper	aluminum bronze
Grease	neat (pure)	neat, mixture, and none
Contamination	none	water, de-icing fluids

weeks) could definitively establish the long-term susceptibility (several months) of the aluminum bronze Acme nut to exposures to grease and contamination on board the airplane.

Corrosion test results indicated that neither grease nor their mixtures, either pure or in combination with contaminants, would corrode the jackscrew's aluminum bronze Acme nut material.

Wear Behavior of Grease-Lubricated Materials

Upon establishing the physical and chemical characteristics of the M28 and A33 greases, the NTSB was able to explore the issues of wear behavior. It was highly beneficial to have established two key findings from the technical program prior to initiating the wear tests:

1. Variations in physical properties of the grease blends were roughly consistent with mixture ratios (i.e., greases were compatible); therefore, a 50/50 blend provided an acceptable surrogate for all blend ratio possibilities.
2. Corrosion was not an issue, eliminating the need to generate corroded test articles for wear tests.

These findings reduced the number of wear tests to be performed by more than half.

Subsequently, a wear test program was generated to directly answer the questions regarding the wear protection provided by M28 and A33 under a variety of conditions. These tests employed small-scale, generic geometry test articles, in a modified ASTM standard wear test.

A review of standard ASTM wear tests indicated that the "block-on-ring" apparatus would capture the important

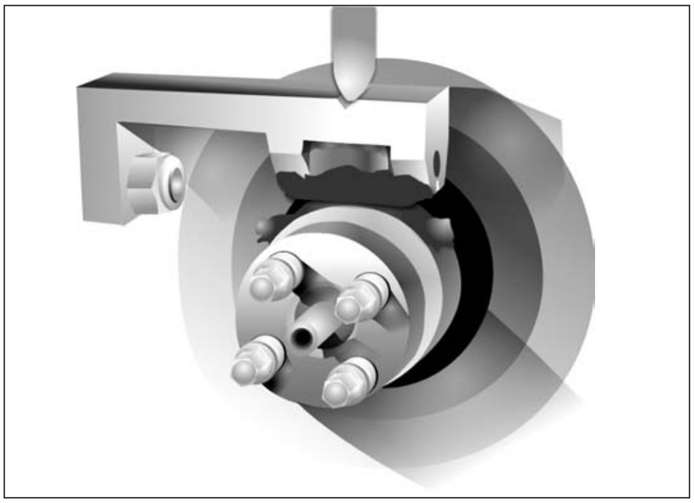


Figure 5. The Block-on-Ring Test Apparatus Configuration. A 1-3/8-inch-diameter steel ring was affixed to a spindle by a retaining nut and four bolts. The spindle rotated the ring in a reciprocating motion through 90 degrees of swing. The aluminum bronze test block, mounted in an armature, was held with force against the rotating ring. The contact area between the block and ring was lubricated with grease. The amount of wear of the aluminum bronze block was measured continuously throughout the test.

Table 3. Tribological Features of Actual and Test Configurations. All significant features identified were well matched.

	Actual Airplane Jackscrew	Block-on-Ring Test
Types of Material	aluminum bronze on steel	aluminum bronze on steel
Type of Motion	sliding, reciprocating	sliding, reciprocating
Speed of Motion	7.5 cm/sec = 3 inch/sec	8 cm/sec = 3.1 inch/sec
Type of Contact	finite area	finite area

tribological features of jackscrew operation (see figure 5). The apparatus produced a reciprocating, sliding motion similar to jackscrew operation and was run to match the speed of an operating jackscrew. The mating contact was over a finite area and, when several levels of load were tested, spanned the entire range of possible contact pressures generated by flight loads in the actual airplane. See table 3.

Because these smaller-scale wear tests required much less time and effort than full-scale tests, investigators could use them to explore many more parameters (table 4) and to demonstrate experimental repeatability. Thus, these test methods allowed the NTSB to obtain a valid and thorough simulation addressing all parameters relevant to jackscrew wear.

The results of these tests are summarized in figure 6. The chart shows the wear rates achieved by each type of grease under certain conditions. The horizontal blue line indicates the minimum level of wear rate that the accident airplane experienced. Thus, any factor responsible for the accelerated wear would have to meet or exceed this level.

From this representation, it is obvious that the A33 grease performed slightly better than M28, and its use could not be responsible for the accelerated wear of the jackscrew. Further, the only condition found to explain the severe wear experienced by the airplane was a lack of lubrication.

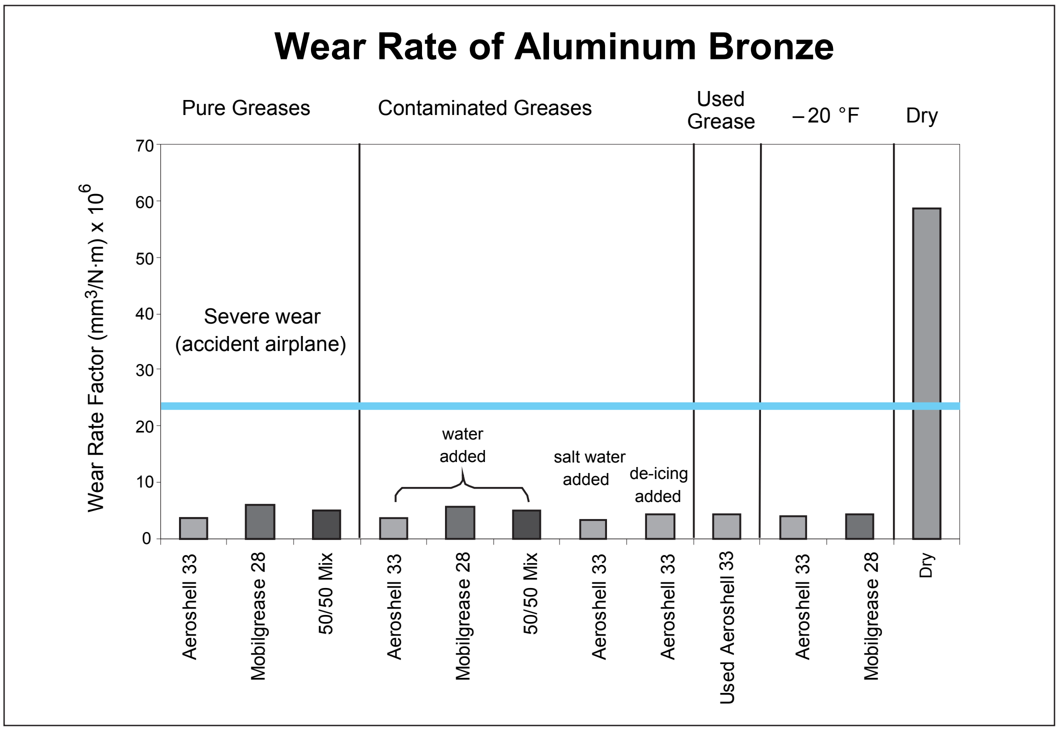
These findings were so convincing that the Safety Board issued the probable cause of the accident as follows:

[The Acme nut's] thread failure was caused by excessive wear resulting from Alaska Airlines' insufficient lubrication of the jackscrew assembly.

Table 4. Block-on-Ring Test Parameters. Over 50 individual tests were run to cover the range and combination of parameters in the modified block-on-ring procedure.

Parameter	Range
Contact Pressure (during steady state wear)	low (10 to 20% maximum, nominal) medium (20 to 40% maximum, nominal) high (40 to 70% maximum, nominal) very high (70 to 100% maximum, nominal)
Grease Type	A33 M28 50/50 blend aged A33 none
Environmental Temperature	ambient -20ºF
Contamination Type	water de-icing fluid salt water

Figure 6. Wear Rates of Aluminum Bronze under Various Lubricant and Environmental Conditions. Shown from left to right are results for A33, M28, and their mixture in uncontaminated states; each contaminated with water to represent entrained condensation; A33 contaminated with salt water representing coastal atmosphere; A33 contaminated with de-icing fluid, representing inadvertent exposure during de-icing procedures; aged (used) A33; A33 and M28 at -20° F, representing temperatures at flight altitude; and an unlubricated condition.



CONCLUSIONS

Investigating the systems failure process can take several paths. Traditional investigative approaches can be quite effective when the evidence and background information available are sufficient. If this information is lacking, or if many unknowns factor into the failure process, the information can often be developed more effectively by employing research methods in the technical investigation.

Research methods were successfully used in the development of a test program for the technical investigation of the Alaska Airlines flight 261 accident. The jackscrew's Acme nut failure process was conclusively determined to have been caused by a lack of lubrication. The test program clearly and decisively showed that use of the newly adopted grease, A33, did not cause the excessive and accelerated wear of the jackscrew's Acme nut. Further, the NTSB was able to dismiss from causal consideration extraneous issues including grease mixing, contamination, aging, corrosion, and extreme temperatures. These conclusions could not have been reached through observation and examination of the wreckage, nor through any timely or practical application of full-scale testing. The entirety of the information developed in this technical program supported several safety recommendations to improve maintenance procedures and policies.

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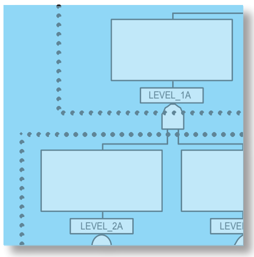

Information Management in Aviation Accident Investigations

Dana Schulze, Jana Price, National Transportation Safety Board,
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ABSTRACT

National Transportation Safety Board staff members are evaluating two new investigation approaches designed to address interacting system elements and to document the evidence-gathering process. The first approach employs accident fault trees, qualitative models depicting the events, conditions, and/or actions that are considered during an investigation as being potential contributors to the accident. The fault tree process is being used and evaluated in multiple ongoing NTSB aviation accident investigations. The second approach focuses on a Web-based tool, Investigation Organizer, which was developed by the National Aeronautics and Space Administration (NASA), Ames Research Center. Investigation Organizer was developed to facilitate the mishap investigation process for geographically dispersed teams by combining capabilities for storing, managing, and organizing information. NTSB staff members were initially exposed to Investigation Organizer while assisting NASA during the Columbia Accident Investigation and are currently evaluating the tool for its potential to support NTSB accident investigations.

INTRODUCTION

The National Transportation Safety Board regularly develops and evaluates new methods and technologies to enhance its existing accident investigation process and address emerging needs. This paper begins by identifying some existing and emerging challenges in aviation accident investigations. We then discuss the development of two new investigation approaches designed to address interacting system elements and to document the evidence-gathering process.

The first approach is the use of accident fault trees. Accident fault trees are qualitative models depicting the events, conditions, and/or actions that are considered during an investigation as being potential contributors to the accident. The objective of fault trees is to model potential contributing faults and failures across the entire aviation system, which consists of all equipment, personnel, and engineering/organizational controls in place in the accident environment. Unlike traditional fault trees used for quantitative risk assessment in aircraft certification, fault trees are not limited to failure conditions caused by random hardware failures. Instead, they consider all potential causes of failure conditions, including inadequate or improper maintenance, operation, or design. In addition to facilitating the development of causal models across multiple system factors, the resulting fault trees graphically convey both the structure and the deductive process behind evidence-gathering and evaluation. Currently, the NTSB is applying the accident fault tree process in multiple ongoing aviation accident investigations and is working to refine the approach further.

The second approach focuses on a Web-based tool, Investigation Organizer (IO), which was developed by the National Aeronautics and Space Administration (NASA), Ames Research Center. This tool was developed to facilitate the mishap investigation process for geographically dispersed teams by combining capabilities for storing, managing, and organizing information. Using a Web browser interface, investigators can use IO to visualize relationships and sequences between collected facts and potential causal factors. IO also facilitates secure distribution of investigative data to teams in different locations.

NASA has used IO in several investigations, including the crash of the Space Shuttle Columbia. While assisting the Columbia Accident Investigation Board on that investigation, NTSB staff members had the opportunity to work extensively with the IO tool. In doing so, staff recognized the potential for IO to help convey the relationship between causal factors in the accident fault tree and the conclusions drawn from multiple independent facts gathered over the course of an investigation. Accordingly, NTSB staff members are evaluating the IO tool for its potential to support NTSB accident investigations.

Before any new technology is adopted for use at the NTSB, it must be evaluated on many levels. First and foremost, it must support the NTSB's mission of determining the probable cause of transportation accidents and identifying safety improvements. Additionally, it should facilitate the investigative process and offer the potential to respond to future needs. Last, any new method or tool must provide sufficient value to enhance the existing investigative culture. Only if it meets these criteria will the new technology be perceived as usable and effective by the individual investigators who will use it.

CHALLENGES IN THE ACCIDENT INVESTIGATION PROCESS

Over the years, NTSB investigators have developed a standard approach to coordinating and executing a major accident investigation—a standard that has served as a model for many other organizations. When a major accident occurs, the NTSB gathers a large investigation team of experts from the government and from parties representing operators, manufacturers, and labor unions. During the early stages of an investigation, specialty groups consider relevant topics including maintenance, operations, vehicle design, and human performance. As dictated by NTSB needs, each group typically includes representatives from the parties to the investigation and is led by an NTSB investigator acting as group chairman. In addition to leading that group's portion of the investigation, the group chairman provides reports to the investigator-in-charge (IIC) and others about the group's progress in regard to collecting factual evidence. At each step of the investigation, the team faces a variety of challenges in managing investigative data, the first being to gather and document a large volume of factual evidence relevant to the accident.

Factual evidence is diverse, and it may include wreckage photos, interviews with operators and witnesses, maintenance records, toxicology reports, weather information, and training records. Sharing and evaluating factual evidence during the on-scene portion of an investigation is relatively straightforward because all group members are together, but once the on-scene phase is complete and group members have returned to their places of work, the process of gathering, distributing, and evaluating new factual data becomes more difficult.

The group chairman is responsible for keeping the geographically distributed team abreast of any new evidence as it becomes available and for communicating information about the status of the investigation as a whole. Currently, team members use mail, e-mail, electronic file sharing, teleconferences, and periodic follow-up meetings to share this information. Throughout the ongoing fact-finding phase, the group chairman must ensure that group members follow standard NTSB investigative procedures, including protocols for maintaining the security of information that is not yet releasable to the public.

In many cases, contributing factors unique to one area of expertise overlap, interact, or contribute to the factors unique to another area. Therefore, specialty groups must exchange information in order to fully explore and explain the range of failure conditions that may contribute to the accident. For example, an investigator may try to determine when and why a certain aircraft component failed during an accident sequence. One possible explanation could be a manufacturing defect while another explanation could suggest improper maintenance.

Group chairmen must therefore carefully coordinate with each other to share and thoroughly evaluate findings and to ensure that competing hypotheses are properly evaluated. Consolidating the resulting contributions from multiple group chairmen and compiling those contributions into a cohesive accident report—in a timely fashion—can be an especially difficult challenge.

Once an investigation is complete and the five-member Safety Board has determined the probable cause(s) and contributing factor(s), staff members face an additional challenge: documenting and preserving the findings so that they can be used to evaluate broader problems in the aviation system. Although information specific to a particular accident is captured in the final factual and analysis reports for that accident, these reports do not easily facilitate cross-accident analysis, sometimes referred to as trending. Board staff can perform a certain amount of analysis across multiple accidents using the Safety Board's Aviation Accident/Incident Database, which encodes numerous facts about the accident aircraft, flight crew, and environment. However, a large amount of investigative evidence is not available in either the report or the database but is maintained in the Safety Board's public docket. Although this information is stored in the NTSB's Docket Management System, classification and manipulation of docket information must be done manually and, despite careful concern for how the data are extracted, unintended bias can occur in such a manual process. This potential for bias poses a significant challenge for investigators performing broader studies that look across the aviation system.

One way to address this issue is to create a tangible link between each individual finding in an investigation and its supporting evidence in the docket. Accidents with findings that appear unrelated at first glance may have similar root causes that are revealed when supporting evidence is linked in this way. By using the accident fault trees to seek similar patterns of evidence present in multiple accidents, researchers may discover pervasive deficiencies in the aviation system's safety plan that might not be identified or understood by studying individual accidents.

NEW INVESTIGATIVE APPROACHES

The two investigative approaches described above, Accident Fault Trees and Investigation Organizer, are currently under review at NTSB. Fault trees are being used to construct and evaluate a causal representation of the accident. Correspondingly, IO is an electronic toolset that may support this process by facilitating the management, storage, and linking of evidence to the fault trees. The following sections summarize these approaches and describe how they may address existing investigative challenges.

Accident Fault Trees

Accident fault trees provide investigators with a framework for developing a deductive path that leads from a catastrophic consequence back to the most fundamental causes—the root causes—that lie at the heart of the accident. The strength and relevance of fault trees in accident investigation is in their ability to show how potential causal factors interact with each other. Showing such interaction is important in complex systems where human-machine coupling and management control failures may influence multiple system elements simultaneously. Fault trees are qualitative rather than quantitative models of the events, conditions, and/or actions being considered as contributors to the accident. Although useful for portraying known cause-effect relationships, fault trees are not intended to facilitate precise analysis of dynamic system characteristics such as feedback loops or nonlinear properties. Modeling and analysis of such relationships must be accomplished separately using other investigative methodologies including simulation, designed experimentation, or organizational analysis techniques. However, accident fault trees complement modeling and analysis by enabling investigators not only to translate the corresponding results into elemental failure conditions and potential causes but also to integrate these findings into the overall accident cause-effect hierarchy.

By using fault trees as an investigation unfolds, NTSB investigators can document the iterative steps of evidence-gathering and establish lines of inquiry as they develop. The investigation team starts with a description of the consequence or hazardous condition that is unique to the accident under investigation. This top event (shown in figure 1) is shaped by the specific facts of the case. Investigators then use the fault tree to consider and develop, in successive levels, the entire aviation system and identify all potential causes of the consequence or hazard, starting with the most immediate conditions and factors present in the operating time and space of the accident. As this analysis progresses, investigators move backwards through the sequence of accident events, asking why at each level, to eventually uncover potential root causes of the accident. Root causes address the most elemental events at the base of the fault tree hierarchy and include potential omissions, deficiencies, or compliance failures of the engineering and management safety controls designed into the system. For example, for an accident that involved a maintenance error as a contributing factor, the lowest events in the fault tree that address root cause could be events that include "failure of mechanic training program to properly address the skipping of maintenance procedure steps" or "failure of the operator's maintenance manual procedure to provide clear instruction on the steps required for successful rigging."

Figure 1 presents a general illustration of an accident fault tree.

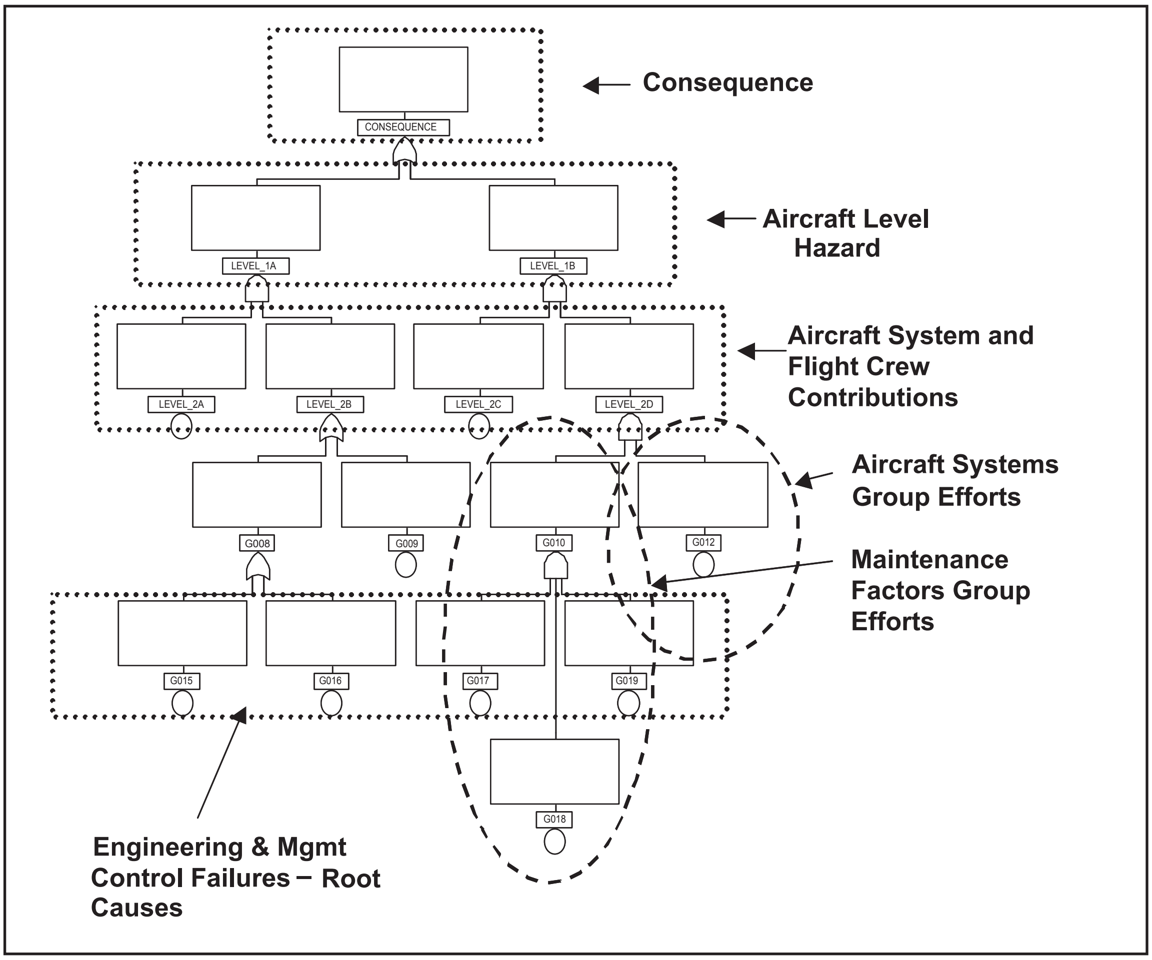

Figure 1. Illustration of Typical Accident Fault Tree

As the investigation unfolds, the many types of evidence collected and evaluated are used both to shape and to evaluate the potential causes outlined in the accident fault tree. Evidence can take many forms—data files, reports, videos, digital photographs, physical wreckage, and others. A Docket Management System, mentioned earlier, is available to catalog and store final reports and investigative materials. However, it does not provide a centralized vehicle to link developing evidence and information to potential causal factors under investigation. Such a link would allow the various groups involved in an investigation to access specific pieces of evidence that they might need to draw conclusions in their respective areas of concern. Having a common location for this information—and the ability to reflect the relationship between evidence and potential factors considered in the fault tree as the data become available—would assist the investigation team in gathering facts and drawing conclusions. This capability would also allow the IIC to check the status of the investigation more frequently and would facilitate the management of major aircraft accident investigations spanning a year or more. This is where the Investigation Organizer tool may provide value to the NTSB.

Investigation Organizer (IO)

Several features within NASA's IO tool may be of use in NTSB accident investigations. Two IO attributes specifically—its capacity for categorizing information and its ability to link evidence to fault trees—are described here as they relate to the accident fault tree process.

First, the IO tool allows investigators to upload accident fault tree models along with factual evidence and information to a secure, Web-accessible location. (See figure 2.) This feature is particularly well suited for fact gathering and analysis work in field locations, where most investigations start. With proper log-in authorization and Web access, NTSB investigators can visit the IO Web site remotely from laptops in the field and begin uploading pictures and information almost immediately. If necessary, individual NTSB investigators can block others from accessing this information until the evidence is ready for distribution, either internally to other members of the investigation team or externally to the parties. Likewise, critical information, such as flight data recorder (FDR) plots, can be uploaded to the Web site for real-time access by NTSB investigators in the field to help narrow their physical search of the accident wreckage. Within IO, various security levels can be established to control distribution of information. IO's Web accessibility and security feature could reduce the time and costs associated with transfer of information to the Safety Board via mail or express delivery service.

Second, once information is uploaded, IO provides users with a means to link individual pieces of information to single or

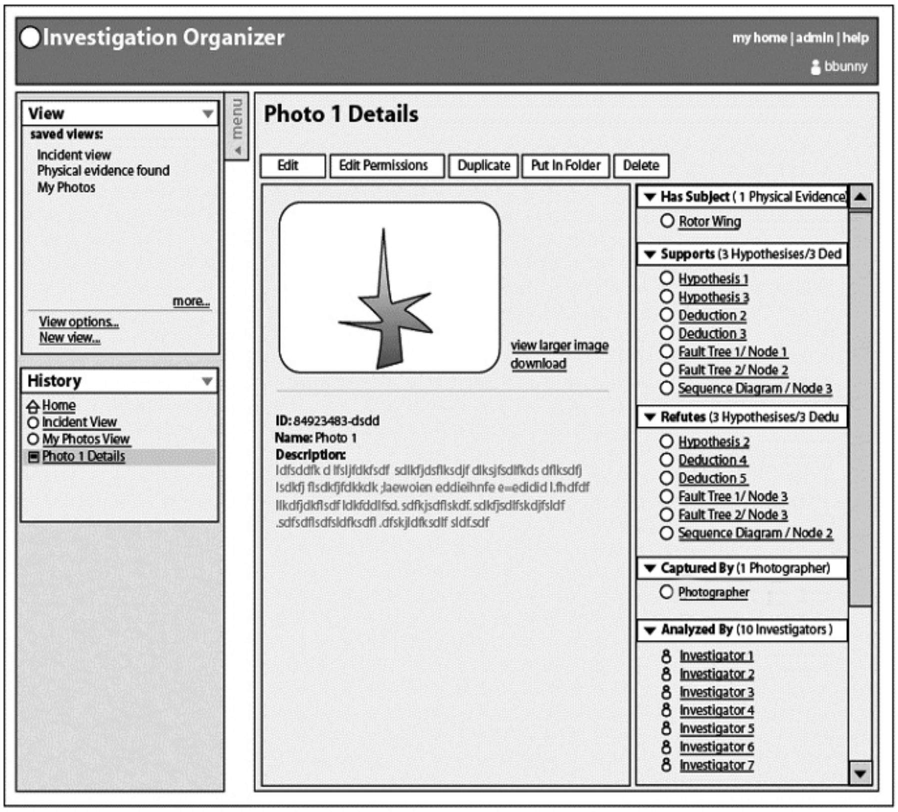

Figure 2. Screen-shot of Investigator Organizer

multiple events in the fault tree. This link is more than just a tie between a potential cause and supporting facts; it also conveys the relationship between the two entities. For example, if one potential contributing factor considered in the fault tree is the incorrect installation of a trim tab actuator on the accident aircraft, the investigator can use IO to link on-site photographs and functional test data for the actuators to this event in the fault tree. Then, when sufficient evidence exists to make a conclusion about the actuator installation on the accident aircraft, the investigator can use IO to establish another link that either rules out or confirms this condition as a potential contributor to the accident. Once these links are established, other NTSB investigators on the team and the IIC can use IO to determine the following quickly:

- How the trim actuator may have contributed to the unique aircraft level hazard or consequence pertaining to this accident (as depicted in the accident fault tree).
- The facts and information used to determine if the trim actuator played a role in the accident.
- The findings, rationale, and/or conclusions drawn regarding whether or not this factor played a role in the accident.
- A "big picture" overview of the multiple factors being considered (including the actuator itself), how the factors are being evaluated, and the evidence available at the time of the IO query for the entire accident investigation in question.

CONCLUSION

The NTSB's review of the accident fault tree process and IO tool is ongoing. These new approaches will continue to be evaluated for their potential in supporting the NTSB's primary mission of improving all modes of transportation safety. Accordingly, they must address the specific investigative challenges described in this paper, while accommodating an evolving investigative culture. Finally, before fault trees and IO can be integrated into the accident investigation process, investigators must find them to be usable and helpful in managing and analyzing the large number of complex facts that are gathered during the course of an accident investigation.

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Impact Resistance of Steel from Derailed Tank Cars in Minot, North Dakota

Frank Zakar, National Transportation Safety Board

ABSTRACT

On a freezing morning in January 2002, a freight train derailed in Minot, North Dakota, causing five tank cars that carried anhydrous ammonia to catastrophically rupture. The event led to immediate release of over 142,000 gallons of anhydrous ammonia, posing a great hazard to the local community. Charpy V-notch impact testing of samples removed from the shell portions of several catastrophically fractured tank cars showed that the impact resistance of the steel for each tank car varied greatly. The NTSB metallurgical investigation also determined that brittle fractures and low impact resistance of the steel contributed to the catastrophic fracture of the tank cars. The paper discusses the results of Charpy V-notch impact testing of selected samples from the catastrophically fractured tank cars and addresses options for improving the construction of future tank cars.

INTRODUCTION

On January 18, 2002, Canadian Pacific Railway freight train 292-16, traveling about 41 mph, derailed 31 cars, including 15 tank cars, about 1/2 mile west of the city limits of Minot, North Dakota. Each of the 15 tank cars was transporting about 29,000 gallons of anhydrous ammonia. The tank cars were loaded at Alberta, Canada, on January 15, and were destined for two locations in Iowa. The temperature of the anhydrous ammonia was 40°F when it was loaded into the tank cars, and the ambient temperature in Minot at the time of the accident was about minus 5° F. As a result of the accident, 11 people sustained serious injuries, one of whom eventually died, and 322 people, including the 2 train crewmembers, sustained minor injuries. Damages exceeded $2 million, and more than $8 million has been spent for environmental remediation. The National Transportation Safety Board found that the derailment was caused by cracked joint bars that completely fractured and led to the breaking of the rail at the joint [1]. The Safety Board's report on the Minot accident contains conclusions, a probable cause, and recommendations to various parties for improvements in the safety of tank cars.

The train consisted of 2 locomotives and 112 cars. The cars in the train were numbered in order, beginning with car number 1, directly behind the locomotives. The 15 anhydrous ammonia tank cars (18 through 32) were among the first cars to derail. Five of the anhydrous ammonia tank cars (19, 20, 22, 23, and 24) catastrophically ruptured and released all their contents. Six others (18, 21, 25, 26, 28, and 31) sustained minor damage and leaked for 5 days. The remaining four derailed anhydrous ammonia tank cars retained their contents. (Other cars being used to transport hazardous materials were located farther back in the train and were not involved in the derailment.)

The Safety Board Materials Laboratory devised a test plan to quantify the level of brittleness, or impact resistance, of the steel in the accident cars, which was not known. Accordingly, samples were removed from certain tank cars and subjected to Charpy V-notch impact testing at different temperatures. Additional samples were subjected to a normalizing heat treatment and subjected to Charpy testing for comparison.

On-site Evaluation of Catastrophically Fractured Tank Cars

On-site examination of the derailed train disclosed that the catastrophic fracture of the tank shells from four of the five failed tank cars (19, 22, 23, and 24) occurred as brittle fractures that propagated completely around the circumferences of the shells. The fracture sustained by car 20 propagated partially around the shell and through the head, causing the tank head to separate from the tank car. The head from car 20 also contained a ductile fracture that propagated from a brittle fracture in the shell portion. The shell from the fifth anhydrous ammonia tank car (19) showed "woody" features; follow-up metallurgical examination disclosed that the fracture toughness property of this shell material was highly anisotropic in that fractures would propagate much easier circumferentially around the shell compared to longitudinally along the shell.

Design and Construction

Anhydrous ammonia is transported as a liquefied compressed gas in pressurized rail tank cars like those that derailed in the Minot accident. Twelve of the anhydrous ammonia tank cars that derailed in this accident were DOT class 105 tank cars (cars 18, 19, 20, 21, 22, 23, 24, 26, 28, 28, 30, and 31), and three were class 112 tank cars (cars 25, 27, and 32). Each of these tank cars contained an outer jacket, and the portion between the outer jacket and shell contained thermal insulation. Each car had a capacity of approximately 33,000 gallons, and each was constructed of TC128 Grade B (TC128B) steel. Material standards for TC128B steel are specified in the Association of American Railroads (AAR) Specification M-1002 [2]. In accordance with this specification, the tank shells and heads of all pressure tank cars built after January 1, 1989, including class 105 and 112 tank cars, must be constructed of normalized steel.

However, the 12 class 105 tank cars involved in the Minot derailment, including the five with catastrophic shell failures, were originally built between 1976 and 1978, before AAR M-1002 required them to be constructed of normalized TC128B steel. Consequently, the shell portion of these 12 cars was built from non-normalized TC128B steel. For the period of time that the 12 cars were constructed, the tank heads were hot-formed at normalizing temperature. The hot forming process produced a steel plate that was characteristic of TC128 normalized steel. (Note that the determination that the tank cars involved in this accident were built of normalized or non-normalized steel was based on the dates of manufacture of those cars and their certificates of construction, not on actual testing of the shell material.) The three remaining anhydrous ammonia tank cars (25, 27, and 32) were DOT class 112J tank cars that were constructed in the late 1990s; as required, the heads and the shells of those cars were built of normalized TC128B steel.

Brittleness of Tank Car Steels

The ability of most steel alloys to resist fracturing changes with the temperature of the steel and its consequent loss of ductility. As the temperature drops, ductile steel becomes brittle and is more easily fractured, but the change occurs gradually, over a temperature range. The temperature at which steel changes from ductile to brittle is called the ductile-to-brittle transition temperature, or DBTT.

Ductile steel deforms before it fractures, and it fractures at an angle to the surface. Brittle steel shows no evidence of deformation before breaking, and its fracture is flat fracture. Less impact energy is required to break brittle steel than to break the same steel when it is ductile. The DBTT, and the amount of energy required to cause a fracture, are affected by three factors in the steel manufacturing process: the chemistry of the steel, its heat treatment, and the rolling process. A normalizing heat treatment is one method that is used to lower the DBTT of steel and increase its impact resistance. This heat treatment increases the level of energy absorbed as the steel fractures, thereby increasing the amount of energy required to fracture the steel.

Laboratory analysis of samples removed from the tank cars that fractured during the Minot accident showed that the chemical composition of the steel plates was within the range specified for TC128B steel. Although tensile testing showed that all of the shells and heads met the tensile strength requirements of AAR M-1002 for TC128B steel, tensile tests did not show and were not adequate to demonstrate the resistance of the steel to impact stresses, a characteristic of the steel that can be quantified through Charpy V-notch impact testing.

CHARPY V-NOTCH IMPACT TEST

Specification for TC128B Steel

AAR M-1002 contains standards for tank cars that are to be used for low-temperature service. Although the AAR specification does not define low-temperature service, the term typically applies to tank cars that transport products like carbon dioxide, vinyl fluoride, and hydrogen chloride, which are loaded at temperatures below -20° F. AAR M-1002 specifies that TC128B steel for low-temperature service is to be normalized and subjected to Charpy V-notch testing. However, AAR M-1002 does not specify Charpy testing for other uses such as transporting anhydrous ammonia. For low-temperature service, AAR M-1002 requires that the Charpy testing be performed at -50° F, and that, for the material to be acceptable, the average energy required to break three specimens at this temperature must be a minimum of 15 ft-lbs with no one specimen breaking below a minimum of 10 ft-lbs. The testing is to be performed with longitudinal specimens (length of the specimen oriented parallel to the direction of rolling) in accordance with ASTM 370 [3].

The Minot investigation disclosed that the 15 ammonia tank cars had not been specified for low-temperature service and therefore this shell material was not required to be Charpy-impact tested. Consequently, the impact resistance of the steel for the 15 tank cars was not known. To determine the impact resistance of the steel from the fractured tank cars, Safety Board investigators cut samples from the shells and heads of certain tank cars and subjected them to Charpy V-notch impact testing.

Sample Preparation

Coupons were cut from the shells of tank cars 19, 20, 22, and 24 and from the heads of tank cars 20 and 24. Charpy V-notch impact specimens were made from these coupons. Metallographic examination of the coupons from the tank cars revealed that the rolling direction of the steel plates for the shell portion was parallel to the circumference of the shell. Investigators tested longitudinal specimens (that is, those whose length was parallel to the direction that the steel was rolled during manufacture) and transverse specimens (that is, those whose length was perpendicular to the direction that the steel was rolled during manufacture). The transverse specimens were tested to demonstrate the energy required to propagate a fracture around the circumference of a tank shell because the shells were constructed with the direction of rolling of the material around (parallel to) the circumference.

Additional specimens from the shell of car 22 were subjected to a normalizing heat treatment and then prepared for Charpy V-notch testing to compare the effect of normalizing on impact resistance. Transverse and longitudinal specimens were prepared from blanks, which were subjected to a normalizing heat treatment in a furnace at 1,660° F, plus or minus 10° F, for 1 hour. The specimens were then cooled in still air on a firebrick.

Various test specimens were broken at specified temperatures between -150° F and 212° F, and a transition curve was plotted to determine the DBTT. The DBTT was defined as the temperature corresponding to the average of the energy of the upper and lower shelves.

Estimated Temperature of Tank Car Steel

The ambient temperature (minus 5° F) recorded at the time of the accident did not reflect the temperature of the anhydrous ammonia cargo or tank car steel at that time. However, the temperature of the tank car steel would have been, for the most part, the same as the temperature of the anhydrous ammonia cargo. As indicated earlier, the external shell of each tank car was insulated, and the anhydrous ammonia cargo did not significantly cool between the time it was loaded (January 15) and the time of derailment (January 18). Heat loss calculations performed by Trinity, the tank car manufacturer for the five tank cars that catastrophically fractured, showed that the temperature of the anhydrous ammonia and the tank car shells at the time of the accident was about 36° F for the class 105 tanks and 30° F for the class 112 tanks. This is consistent with on-scene measurements of approximately 55 psig internal pressure of the intact anhydrous ammonia tank cars (which converts to approximately 37° F). For the purpose of discussion, we will assume that the approximate temperature of a class 105 shell at the time of derailment was 36° F.

Results of Charpy Testing

Table 1. Average Energy Required to Break Charpy V-notch Specimen at 36 °F

Tank Car Number	Coupon Number	Location	Average Energy (ft-lb) at 36 °F				
			Arbitrary	Long	Transv	Norm Long	Norm Transv
19	19-3	Shell		52	18		
20	20-1	Shell		35	32		
20	20-3	Head	42				
22	22-3	Shell		28	20	51	36
24	24-1	Shell		13			
24	24-3	Head	54				

"Transv," "long," and "norm" are abbreviations for transverse, longitudinal, and normalizing heat treatment.
Blank spaces in the table indicate that no impact testing was performed for those specimen orientations.
Two specimens were tested for each orientation shown.

Table 2. Average Energy Required to Break Charpy V-notch Specimen at -50 °F

Tank Car Number	Coupon Number	Location	Average Energy (ft-lb) at -50 °F				
			Arbitrary	Long	Transv	Norm Long	Norm Transv
19	19-3	Shell		5	10		
20	20-1	Shell		8	8		
20	20-3	Head	35				
22	22-3	Shell		4	7	26	19
24	24-1	Shell		5			
24	24-3	Head	22				

Table 3. Ductile to Brittle Transition Temperature (°F) for Selected Coupons

Tank Car Number	Coupon Number	Location	DBTT (°F)				
			Arbitrary	Long	Transv	Norm Long	Norm Transv
19	19-3	Shell		-32	-35		
20	20-1	Shell		38	40		
20	20-3	Head	-80				
22	22-3	Shell		32	32	-48	-40
24	24-1	Shell		100			
24	24-3	Head	-18				

Tables 1 and 2 show the average energy that was required to fracture Charpy V-notch test specimens at 36° F and -50° F, respectively. Table 3 shows the calculated DBTT for selected coupons.

An arbitrary orientation was selected for coupons 20-3 and 24-3 (head portions) because metallographic examination showed no clear evidence of preferred orientation.

As table 1 shows, non-normalized longitudinal specimens withstood higher impact energies than did the non-normalized transverse specimens. Assuming that the tank car shells were at an approximate temperature of 36°F at the time of the accident, the average impact energy associated with a crack propagating along the length of the shell (longitudinal specimens) of tank car 22 was 28 ft-lbs, and the average impact energy associated with a crack propagating around the shell of the same tank car (transverse specimen) was 20 ft-lbs. At 36° F, the normalized specimens from the shell of tank car 22 fractured in a ductile manner with a significant increase in the impact energy required, up to nearly 50 ft-lbs for a longitudinal specimen and 36 ft-lbs for a transverse specimen.

In fact, the impact energies required to break specimens from nearly all of the normalized steel head specimens at 36° F were much higher than those required to break the non-normalized shell specimens. The higher impact energy required and the ductile fractures of the heads are typical characteristics of heads that are hot-formed at normalizing temperature.

As indicated earlier, the catastrophically fractured tank cars were not manufactured for low-temperature service. However, Charpy testing was performed at -50° F for comparison purposes. As shown in table 2, the average energy required to break tank head specimens from cars 20 and 24 and shell specimens that were subjected to a normalizing heat treatment (coupon 22) were much higher than the average energy values that were required to break non-normalized shell specimens. The energy required to break the normalized steel samples and head portions was greater than 15 ft-lb, the minimum energy values that were required for low-temperature service. The energy required to fracture non-normalized shell samples was less than 15 ft-lb.

As shown in table 3, the shell portion of tank car 24 (coupon 24-1) showed the highest DBTT, approximately 100° F. Not surprisingly, the longitudinal Charpy specimens for this coupon showed the lowest average impact energy (13 ft-lbs) relative to other longitudinal specimens (see table 1). A head portion (coupon 20-3) showed the lowest DBTT, minus 80° F. The DBTT of a shell from tank car 22 (coupon 22-3) in the transverse direction was 32° F. Normalized heat treatment of a sample from this coupon lowered the DBTT to minus 40° F. The normalized heat treatment lowered the DBTT of the shell by 72° F.

Other Charpy V-Notch Impact Tests

In September 1991, the National Institute of Standards and Technology (NIST) prepared report No. 24 (NIST IR 4660), *Mechanical Properties and Fracture Toughness of AAR TC128 Grade B Steel in the Normalized, and Normalized and Stress Relieved Conditions*, which described the properties of normalized TC128B steel [4]. The steel supplied for the NIST testing program was produced according to AAR M-1002, but with lower sulfur content (between 0.008 and 0.010 weight percent) than that of the tank cars that ruptured in the Minot accident (which were between 0.02 and 0.03 weight percent).

In the NIST testing, longitudinal NIST specimens required 120 ft-lbs to fracture at 36° F (the estimated temperature of the class 105 tank shells in the Minot accident), and the transverse NIST specimens required 55 ft-lbs. These impact values were even higher (by as much as 135 percent for the longitudinal specimens and 53 percent for the transverse specimens) than the impact values from the normalized test specimens from tank car 22. The DBTTs for NIST longitudinal and transverse specimens were approximately 10° and 20° F, respectively. These DBTT values also were below the temperature of the steel from the ruptured tank cars at the time of the Minot accident.

DISCUSSION OF CHARPY TESTING

Based on metallurgical examination and testing, Safety Board investigators found that the catastrophic fracture of the tank shells from four of the five failed tank cars (20, 22, 23, and 24) occurred as brittle fractures. The presence of these brittle fractures indicated that the steel shells of these four cars were below the DBTT at the time of the derailment, and therefore the steel's fracture toughness (its ability to resist fracture under static and/or dynamic loading) was lower than it would have been if the steel had been above the DBTT. As discussed previously, much less energy is required for any material to propagate cracks in a brittle manner rapidly and over longer distances than is required for ductile crack propagation. Thus, the low impact resistance of the brittle shell material of tank cars 20, 22, 23, and 24 led to early initiation and rapid, unarrested propagation of cracks. This resulted in the instantaneous release of the anhydrous ammonia and the rocketing of sections of the tank cars.

The fifth car, car 19, also completely fractured and separated. Fractographic examination of this car established that the shell material contained ductile dimple features that would normally be found in ductile material. The average energy required to fracture the longitudinal specimens in the shell of this tank car at 36° F was 52 ft-lbs, and the average energy for the transverse specimens was 18 ft-lbs. The large difference in energy values between the longitudinal and transverse Charpy specimens indicated that the shell of tank car 19 had highly anisotropic impact properties. The anisotropy was associated with manganese sulfide stringers that were more numerous and longer than those found in other coupons. Thus, the steel in the shell of car 19 was vulnerable to low-energy, ductile fracture propagation parallel to the rolling direction (circumferential direction in the tank shell) of the plate steel. Ductile fracture and a low DBTT are desirable features, but they must be accompanied by sufficient dynamic fracture toughness.

The transverse Charpy value for the tank car 19 shell was even lower than the transverse Charpy values for the brittle shell fractures from tank cars 20 and 22 (32 and 20 ft-lbs, respectively). Although the fracture face of the shell from tank car 19 exhibited ductile features compared to the brittle fracture features found in the shell of tank cars 20, 22, 23, and 24, the lower impact resistance of the transverse specimens in the steel of tank car 19 was due to extensive manganese sulfide stringers in the microstructure and processing of the steel plate. The fracture in tank car 19 extended with ease around the circumference of the shell (relative to other cars) because it connected the lengthy stringers.

The problem of brittle and low-energy fracture propagation was addressed in 1989 with AAR M-1002, which required that the shells of pressure tank cars be fabricated from normalized steel. The normalizing heat treatment process has been shown to reduce but not eliminate anisotropy and to significantly reduce the DBTT in steel plates. Further, the normalizing heat treatment increases the fracture toughness of steel plate at all operating temperatures.

Safety Board and NIST testing results clearly demonstrated the benefit of normalizing steel. The NIST tests showed that, with the proper combination of chemistry and processing, normalized TC128B steel can be manufactured with increased impact resistance energies. The impact resistance energy for the NIST transverse specimen was 53 percent greater than the corresponding energies obtained in the Safety Board's tests of normalized test coupons from car 22. For the NIST longitudinal specimen, the impact resistance was 135 percent greater. These improvements are a result of several factors, including smaller ferrite grains and lower amounts of sulfur in comparison with the steel used in the Safety Board experiments.

Given its testing results, the Safety Board concluded that the low fracture toughness of the non-normalized steels used for the tank shells of the five tank cars that catastrophically failed in the Minot accident contributed to the cars' complete fracture and separation.

The Safety Board also found that the instantaneous release of the 146,700 gallons of anhydrous ammonia within moments of the derailment in Minot produced a much larger and more concentrated plume of ammonia than would have occurred if the same quantity of ammonia were released more slowly, dissipating gradually into the atmosphere.

Further, the Safety Board determined that the complete fracture and fragmentation of tank cars and the rocketing of tank car sections, as occurred in the Minot derailment, can expose nearby residents to serious risks. Previous studies conducted by various tank car manufacturers and companies that transport anhydrous ammonia have not addressed the risk posed by immediate release of anhydrous ammonia, and these studies do not provide an adequate safety assessment of pressure tank cars built of non-normalized steel.

EVALUATION OF PRE-1989 PRESSURE TANK CARS

Of the top ten hazardous materials transported by tank car, five were liquefied compressed gases, categorized by the U.S. Department of Transportation (DOT) as class 2 hazardous materials. In 2000, these five DOT class 2 hazardous materials—liquefied petroleum gas (LPG), anhydrous ammonia, chlorine, propane, and vinyl chloride—accounted for more than 246,600 tank car shipments, or about 20 percent of all hazardous materials shipments by tank car.

Consequently, the Safety Board is concerned about the continued transportation of DOT class 2 hazardous materials in pre-1989 tank cars. Because of the high volume of liquefied gases transported in these tank cars and the cars' lengthy service lives, the Safety Board concluded in its Minot accident report that using these cars to transport DOT class 2 hazardous materials under current operating practices poses an unquantified but real risk to the public.

A comprehensive analysis to determine the impact resistance of the steel used for these tank car shells is needed in order to rank pre-1989 tank cars according to their risk level to the public. At a minimum, such an analysis should include data from Charpy V-notch or dynamic fracture toughness tests for the steels found in pre-1989 pressure tank cars. In the absence of such data, a statistically representative sampling of shells from pre-1989 tank cars should be tested.

To this end, the Safety Board recommended in its Minot accident report that the FRA conduct a comprehensive analysis to determine the impact resistance of the steels in the shells of pressure tank cars constructed before 1989. At a minimum, the Board recommended that the safety analysis include the results of dynamic fracture toughness tests and/or the results of nondestructive testing techniques that provide information on material ductility and fracture toughness and that the data should come from samples of steel from the tank shells from original manufacturing or from a statistically representative sampling of the shells of the pre-1989 pressure tank car fleet. The Safety Board also recommended that the FRA, based on the results of the tank car impact resistance analysis, establish a program to rank pressure tank cars built before 1989 according to their risk of catastrophic fracture and separation, and implement measures to eliminate or mitigate this risk. This ranking should take into consideration operating temperatures, pressures, and maximum train speeds.

IMPROVEMENT OF TANK CAR CRASHWORTHINESS

Although a normalizing heat treatment improves the impact resistance and reduces the DBTT of a given grade of steel, this treatment alone is not sufficient to ensure that tank cars have adequate impact resistance to prevent complete shell fractures. Means of improving the crashworthiness of pressure tank cars can be identified by evaluating alternative steels and tank car performance standards. The ultimate goal of this effort should be to construct railroad tank cars that have sufficient impact resistance to eliminate or reduce the risk of catastrophic brittle fractures under all operating conditions and in all environments. Such an endeavor will require evaluation of the dynamic forces and an integrated analysis of the response of the tank structure, as well as the response of the tank material, to these predicted dynamic loads.

An improved understanding of the dynamic forces imposed on tank cars under derailment conditions can be realized by developing predictive models and validating the models through comparison with experimental data. The validation must include the influence of stress and temperature in the tank. The validated models can then be used to reliably predict the survivability of tank cars in accident conditions. In 2004, the FRA, through the DOT Volpe National Transportation Systems Center, began developing a predictive methodology to define the forces acting on tank cars during accidents. This research is expected to take 2 to 3 years to complete. The engineering data from this research will contribute to the development of impact resistance criteria for tank cars.

Impact Resistance Criteria

The change to the AAR standard requiring that, starting in 1989, the tank shells of pressure tank cars be constructed of normalized TC128B steel was a significant step in reducing brittle fractures and improving the impact resistance of the steel used in these cars. However, a normalizing heat treatment does not guarantee a minimum material impact resistance. Other factors, such as the chemical composition and grain structure of the metal and the type of rolling process used to manufacture the steel, must also be controlled. Thus, the material impact resistance criteria should be based on a material fracture toughness requirement and be performance based for specific tank car designs so that manufacturers may choose the best combination of steel chemical composition, thermal treatment, rolling processes, and fabrication procedures to satisfy the criteria.

In general, the AAR and the FRA have not established adequate testing standards to measure the impact resistance of steels and other materials used in the construction of pressure tank cars. Several approaches are available for characterizing a material's resistance to dynamic fracture. The Charpy V-notch test is a comparatively simple and inexpensive procedure and is the most commonly used test. Because the Charpy values are dependent on specimen thickness, the standard developed must guarantee that the testing is consistent with the thickness of the tank car material. To some extent, the AAR and the DOT already require Charpy V-notch tests for certain pressure tank cars. For example, pressure tank cars used in low-temperature service, such as those used to transport specific hazardous materials like carbon dioxide, vinyl fluoride, and anhydrous hydrogen chloride, must have a minimum average Charpy value for longitudinal specimens of 15 ft-lbs. at -50° F. As shown by Safety Board tests, the samples taken from the non-normalized tank cars that catastrophically fractured in the Minot accident did not and were not required to meet this standard although test samples from the tank heads and samples that were subjected to normalizing heat treatment after the accident did meet this standard. However, the AAR standards and the DOT Hazardous Materials Regulations (HMR) do not recommend or require Charpy V-notch or other dynamic load testing of steels and metals used in pressure tank cars designed to move the most commonly transported class 2 materials, including anhydrous ammonia and LPG. [5]

Therefore, the Safety Board concluded in the Minot accident report that a materials standard to define the minimum level of dynamic fracture toughness, such as a minimum average Charpy value, for the material in all tank cars that transport class 2 hazardous materials, including those in low-temperature service, over the entire range of operating temperatures would provide greater assurance that tank car materials will perform in a safe manner in accident conditions.

Additionally, Charpy V-notch tests performed for the Safety Board Materials Laboratory on specimens from the same tank car but having different directional orientations (relative to the as-rolled direction of the steel) indicated significant differences in impact resistance. (In general, longitudinal specimens had greater impact resistance than transverse specimens of the same material.) AAR standards and the HMR specify Charpy V-notch testing for TC128B steel for low-temperature service. These tests are to be performed using longitudinal specimens (those with the greater impact resistance), rather than transverse specimens. But because the dynamic forces acting on a tank car in an accident develop stresses in all directions, the performance standard for fracture toughness of tank car materials must be determined for the direction with minimum impact-resistant properties.

Because such performance criteria do not exist, the Safety Board recommended in its Minot report that the FRA develop and implement tank car design-specific fracture toughness standards for steels and other materials of construction for pressure tank cars used for the transportation of DOT class 2 hazardous materials, including those in low-temperature service. The performance criteria must apply to the material orientation with the minimum impact resistance and take into account the entire range of operating temperatures of the tank car.

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Public Forums, Symposia, and Public Hearings

Driver Education and Training Forum

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ABSTRACT

In the United States, approximately 12.6 million drivers between the ages of 15 and 20 account for about 6.6 percent of the total number of drivers. Despite this relatively small percentage, these drivers were involved in about 14 percent of all traffic-accident-related fatal crashes in 2002. In addition, this age group had the highest fatality and injury rate per 100,000 population of any age group. More than 8,200 teens are involved in fatal crashes each year.[1]

On October 28-29, 2003, the National Transportation Safety Board hosted a Public Forum on Driver Education and Training. The purpose of the forum was to survey the current state of novice driver education and training, the extent to which it is used, and its quality and effectiveness. The forum also explored the shortcomings in driver education and training and what can be done to improve it. Thirty experts (see table) from around the world provided their opinions, which will help the Safety Board form recommendations to improve driver education and training aimed at reducing the number of teenage fatalities on the roads. This article describes the evolution of driver education and training, current graduated driver licensing (GDL) programs, programs initiated by various countries, States, and companies to develop and support driver education, and what some of the research shows.

HISTORY OF DRIVER EDUCATION IN THE UNITED STATES

Driver education safety materials and courses were first developed as early as 1916, but as the nation's road system developed and the number of vehicles expanded, the need for driver education became more apparent. National organizations like the American Automobile

[1] National Highway Traffic Safety Administration, *Traffic Safety Facts 2002: Young Drivers*, DOT HS 809 619 (Washington, DC).

Association (AAA) and the National Safety Council (NSC) were early advocates and providers of driver education programs. Both developed programs in the 1920s and 1930s to enhance traffic safety through driver education and to improve communications among the States on driver education issues.

From the late 1940s to the mid-1960s, driver education and training rapidly expanded. During the forum, Jim Nichols[2] noted that enrollment in high school driver education increased from about 200,000 students in 3,000 schools in 1947 to about 1.3 million students in 12,000 schools in 1964. With this expansion came an emphasis on course standardization, teacher qualifications, quality control, and the application of technology. It was during this period that the classic "30 and 6" program (30 hours of classroom and 6 hours of behind-the-wheel training) was developed and implemented throughout the nation.

Early studies of driver education indicated that it did achieve its original aim of training drivers who would have fewer crashes and violations than those who had not taken driver education. This early success resulted in widespread insurance premium discounts.

In the mid-1960s, congressional action spurred expansion of the federal government's role in setting driver education as a state priority program eligible for federal grant funds through the National Highway Traffic Safety Administration (NHTSA). At about the same time, several studies questioned not only the effectiveness of driver education in advancing driving safety but also the statistical rigor of older studies that had shown driver education to be effective. As a consequence, NHTSA embarked on a research and development program in DeKalb County, Georgia, to identify, demonstrate, and evaluate a state-of-the-art driver education program. The result was the Safe Performance Curriculum (SPC) and the Pre-Driver Licensing (PDL) Curriculum.

The SPC program encompassed the most rigorously operated and evaluated driver education conducted to date. Its design included random assignment of students to the SPC, PDL, and no-education control groups. After evaluating 16,000 students in the three groups, researchers were unable to identify a substantial safety benefit for those students enrolled in either of the education programs.

From 1980 to 2000, at least partially due to the DeKalb results, the number of driver education programs and students in public high schools declined precipitously. Information is less complete than for previous years, but 80 percent of eligible students were enrolled in driver education in 1976, 50 percent in 1990, and about 40 percent today. The numbers declined further when highway safety funding lost its priority program status at the same time that school budgets were cut and school curricula faced increasing time constraints.

GRADUATED DRIVER LICENSE

In the early 1990s, organizations like the Insurance Institute for Highway Safety (IIHS) and the Traffic Injury Research Foundation of Canada (TIRF) reported that novice drivers, especially those under the age of 20, have a higher crash rate than more experienced drivers. The American Association of Motor Vehicle Administrators and NHTSA recommended that states improve the driver entry system for young novice drivers and developed important characteristics for such a program.

After reviewing crashes involving novice drivers under the age of 21, and drawing from the proposed driver entry system for young novice drivers, the Safety Board recommended in 1993 that the 50 states and the District of Columbia implement graduated driver licensing systems. The Safety Board's recommendation for GDL included three phases: a learner's permit, an intermediate or provisional license, and finally, a full license. The Safety Board further recommended that GDL establish restrictions such that, until drivers have gained experience behind the wheel, they drive in less dangerous circumstances only. In 2002, the Safety Board revisited the teen driving issue and added a passenger restriction to its original GDL recommendation. Further, in 2003, the Safety Board concluded that states should prohibit holders of learner's permits and intermediate or provisional licenses from using interactive wireless communication devices while driving. Each of these restrictions would be lifted after successful completion of the learning and intermediate stages.

Based on the Safety Board's investigations and recommendations since 1993, the Board encourages states to enact GDL programs with the following elements:

- A minimum 6-month holding period for the learner's permit, during which a licensed driver who is at least 21 years old supervises the permit holder.
- At least 50 hours of supervised driving practice with the supervising licensed driver.
- A minimum period of 6 months without at-fault crashes or traffic violations (and accelerated penalties if the driver has an at-fault crash or traffic violation) before proceeding to the intermediate or provisional license.

[2] Retired from NHTSA, where he specialized in driver education.

- A minimum 6-month holding period for the intermediate or provisional license.
- A nighttime driving restriction, which prohibits the intermediate or provisional license holder from driving unsupervised at night, particularly between the hours of midnight and 6:00 a.m.
- A passenger restriction, which allows no more than one other passenger in the vehicle, unless accompanied by a supervising adult at least 21 years old.
- A minimum period of 6 months without at-fault crashes or traffic violations (and accelerated penalties if the driver has an at-fault crash or traffic violation) before proceeding to the full license.
- At each stage, prohibition of the use of alcohol and interactive wireless communication devices and mandated seat belt use.

Although GDL has reduced the number of teen fatalities,[3] highway accidents continue to be the leading cause of death for this age group.[4] An effective driver education and training program, in conjunction with GDL, could help reduce the number of fatalities further. Numerous programs currently exist, but no comprehensive, validated education program used throughout the United States has proven effective in reducing the number of teen fatalities.

DRIVER EDUCATION AND TRAINING IN THE UNITED STATES

Federal Perspective

In the United States, the federal government has a limited role in driver education and training through NHTSA. In the 1960s and 1970s, driver education reached its zenith when 14,000 schools offered programs for about 70 percent of students. The federal government offered highway safety program grant funds to states to improve and evaluate their driver education programs. However, states used the funds primarily to expand the programs and reach more students, not to improve or evaluate the programs, or to train the trainers. When the federally-funded DeKalb study did not show a decrease in crashes for those who took driver education—a finding the DOT did not expect—funding to the states was halted. Currently, no federal standards exist for driver education, and no funding is available to states to offer, improve, or evaluate driver education.

However, NHTSA is funding development of a teacher credentialing program and a standardized driver education curriculum. NHTSA is also studying the development of a two-phase driver education curriculum and is providing public information and education materials on what driver education is and what students should be prepared for. NHTSA also provides technical assistance for state GDL programs, including a parent-teen guide. Further, NHTSA has proposed development of a model non-commercial driving test. NHTSA is also evaluating Michigan's two-phase driver education and Texas's parent-taught curriculum.

State and Teacher Perspectives

Driver education representatives from Montana, Oregon, Idaho, Michigan, and Vermont, as well as a representative from the Governors Highway Safety Association, were asked to describe their roles in educating the novice driver, their views of the strengths and weaknesses of driver education, and suggestions for how to improve it.

In general, state panelists agreed that novice drivers must first learn the basics: the mechanics of accelerating and braking, proper placement of the hands on the steering wheel, how to back and park, and how to use mirrors and restraints. Novice drivers must also become familiar with the rules of the road and the accepted courtesies of sharing the highways with other drivers. The panelists concurred that the best way to accomplish these tasks is through formal driver education courses, taught by trained driver educators.

However, all panelists indicated that driver education must reach beyond the mechanics of operating a vehicle to encompass the maturity level of novice drivers, their tendency to take risks, and the influence of peers both inside and outside the vehicle. Given the short amount of time and the high expectations to which driver education is held, most educators on the panel stated that meaningful behavior modification cannot be accomplished with the time and resources currently available. They stated further that time and practice are the most effective tools for developing safe driving practices.

Many panelists criticized the curricula currently used by many states, which involve the accepted practice of 30 hours of classroom learning and 6 hours of behind-the-wheel training. They said that this level of instruction was inadequate to achieve the goals of affecting student driver driving mechanics, behavior, and decision-making. Some states—Michigan, for example—have implemented a multi-tiered licensing program that includes an initial period of formal classroom instruction,

[3] See http://www.nhtsa.dot.gov/people/injury/newdriver/SaveTeens/sect4.html.

[4] NHTSA, *Traffic Safety Facts 2002: Young Drivers*.

followed by behind-the-wheel instruction, driving with the parent(s) as part of the GDL program, and, prior to full licensure, additional formal instruction. This combination has been found to provide student drivers with the skills and decision-making criteria they need to become safe drivers, and has reduced the number of teen fatalities in Michigan.

The effectiveness of driver education is difficult to evaluate, and the choice of criteria and standards often influences the outcome of any evaluation. Traditionally, the yardstick of reducing traffic collisions and traffic violation convictions has been used to determine the effectiveness of a driver education program. However, panelists indicated that this might not be the best evaluation tool. No other subject matter in the educational curriculum is held to such a stringent standard.

According to the panelists, driver instructor qualifications are crucial to the success of any driver education program. Traditionally, public school driver education is a part-time or additional task assigned to teachers who teach other subjects primarily. These instructors do not receive specialized and specific training on how to adequately teach safe driving practices. However, some states, like Idaho, Oregon, and Vermont, offer extensive training for driver education instructors although other states, like Illinois, have reduced the amount of training offered as funding gets tighter.

Another concern of the panelists was that after NHTSA's withdrawal of driver education funds, many public schools closed or sharply reduced their programs, relegating driver education courses to before- or after-school, non-curriculum activities. Although some states still provide a subsidy for driver education programs, which often does not cover the entire cost of the program, many states do not cover any costs. These costs have shifted to the parents for instruction at either public schools or private commercial driver training schools.

The consensus of the state panelists was that an effective driver education program needs to (1) be relevant, (2) be flexible, (3) make use of current technology, and (4) instill the desired behavior modification necessary to create lifelong safe driving habits. To this end, the panelists proposed the following:

- Create a national, performance-based curriculum, with a minimum of 50 to 60 hours of formal instruction, that makes maximum use of available technology.
- Standardize driver-trainer (instructor) educational minimums.
- Make traffic safety a component of the curriculum for grades K through 12.
- Develop a program of accountability through a multi-tiered state licensing program.
- Re-establish driver education as a national priority and allocate adequate public funding (through NHTSA grants) to provide affordable and available driver education to the student driver.

Student Perspectives

Two students were invited to participate in the forum; both were representatives of the National Student Safety Program and freshmen in college. They were asked to give their impressions of the driver education programs in which they had participated.

Both students stated that the driver education course at their school was beneficial and necessary for obtaining a driver's license, but did not fully teach them to drive safely. Both commented that they enjoyed the program but found faults with the basic structure and approach to student driver training. Their comments included such statements as the following:

- I learned more about my teacher than I did about driving a car.
- I had to learn many of the basic driving techniques later that I should have learned in school.
- The material presented in class was out of date.
- The teacher minimized important aspects of the driving tasks.
- The teacher assumed the students knew certain material, which they did not, and only touched on that material.
- Most students went to class to learn enough to get a license – that's all they cared about.

The panelists said that student driver habits had to be changed for them to become safe drivers and that driver education must overcome many misconceptions such as, "It (accidents, injuries, and fatalities) will never happen to me."

These students also had some comments on how to improve driver education. They endorsed more behind-the-wheel time and instruction; increased parental participation, both during the formal instructional phase (coordinated with the instructor) and during the GDL phase; improvement and participation in defensive driving exercises; raised standards for a passing grade; and instructor accountability for what they teach.

Associations

Various associations described their efforts and suggestions for improving young driver safety.

The American Automobile Association, a federation of auto clubs throughout the United States and Canada, is devoted to making the highways safer and providing people with the education and skills to be safe drivers. In 1997, AAA launched its "National Young Novice Driver Safety Initiative," undertaken to raise awareness of the young novice driver crash problem as a public health issue and to change the way young people are licensed in the U.S. through graduated driver licensing. In addition, the AAA's "License to Learn" program is being implemented to train novice drivers in the skills needed to avoid crashes. The program will standardize course content, implement instructor qualifications, and mandate more behind-the-wheel driving experience, with classroom and on-the-road instruction offered concurrently. "Teaching Your Teens to Drive," another AAA initiative, provides parents with guidance on what skills they should teach their teens and provides a checklist for monitoring young drivers' performance. Further, to help drivers select a quality driving school, AAA publishes a brochure titled "Choosing a Driving School." The AAA is also pilot-testing a program of approved driving schools that offer AAA's driver education programs.

The AAA Foundation, the research affiliate of AAA, identifies traffic safety problems, fosters research that seeks solutions, and develops appropriate educational products that are disseminated to the widest possible audience. The AAA Foundation published the "Novice Driver Education Model Curriculum" outline in 1995. The curriculum, which proposed performance objectives and methods for achieving effective driver education, was an attempt to reinvent driver education to reduce crashes. This effort led to the release in 1997 of the "DriverZed Interactive Risk Management Training Tool." This PC-based, interactive training program focuses on giving novice drivers experience in risk identification, evaluation, and avoidance and is intended to complement and supplement driver education programs. Other projects undertaken by the AAA Foundation include a research initiative to examine why teens crash; an evaluation of a Canadian incentive program that provides insurance premium discounts to teens who are violation- and crash-free for a specified period; and the development of guidelines for the evaluation of driver education programs, including technical protocols and guidance.

The American Driver and Traffic Safety Education Association (ADTSEA) represents traffic safety educators in the United States and abroad. ADTSEA, in cooperation with other organizations, has developed a set of curriculum standards that specify what students should know and be able to do. The curriculum includes 40 to 50 hours of instruction, instead of the traditional 30 hours classroom and 6 hours behind the wheel. Several state representatives said that they use the curriculum in their classrooms. To complement the standards, curriculum content was drafted for classroom and in-vehicle instruction, emphasizing topics directly related to the driving task—specifically, visual perceptual skills and good decision-making skills. The curriculum is currently available on the ADTSEA website. ADTSEA has also created a model teacher certification and credentialing program to ensure teachers are well-prepared and equipped to teach driver education, and has efforts underway to improve professional development opportunities.

The Driving School Association of the Americas (DSAA), which represents more than 4,000 driver education and traffic safety companies in North America, aims to establish the highest standard of education while promoting traffic safety. DSAA has an accredited school and student certification system to improve driver safety and professional ethics.

The Governors Highway Safety Association represents all State highway offices. In 2003, the Association, in partnership with Ford Motor Company, launched the "Real World Driver Program." This program focuses on four driving skills: hazard recognition, vehicle handling, space management, and speed management. The program is designed to educate teens and parents through kits that have been sent to 20,000 high schools, reaching over 4 million students and parents. The Real World Driving Program is not intended to be a driver education program, but its goal is to raise awareness of driver training issues and to encourage national discussion about how best to teach teens to drive safely.

The National Safety Council, which is dedicated to reducing preventable deaths and injuries, is working with DaimlerChrysler to develop the "Road Ready Teens Program." Road Ready Teens provides parents with tips and tools to ease teenagers into driving, so that they can gain experience and maturity before driving on their own. The program includes a videogame that illustrates the risks teens face on the road and why they must gain experience to be safe drivers.

The association panelists agreed that driver education, as it currently exists, has not been effective in reducing the number of teen crashes and fatalities. However, as new programs are developed, there must be meaningful ways to evaluate these programs and assess their efficacy. The consensus was that, although driver education necessarily addresses basic driving skills, it must also address attitudes, emotions, lifestyles, and judgment—aspects of safe driving that are much harder to teach. Although the age at which teens should begin driving is debatable, particularly due to social pressures to get a license early, the first 2 years of driving are the most dangerous time for young drivers, no matter when they start. To date, experience and maturity have proved to be the most effective means of becoming a safer driver, and that's what GDL attempts to provide to teen drivers—experience under protected conditions (that is, limited night driving, driving with parents, driving without peers). The panelists believed that complementing GDL with better driver education is a step that needs to be taken. Further, the panelists agreed that young drivers need better support from parents and that by learning the risks associated with driving, parents can convey those risks to their teens.

Private Companies

Several private companies have developed driver education programs that are used throughout the country. A common theme among these programs is to teach concepts in the classroom and to demonstrate those concepts shortly thereafter in the car.

The National Driver Training Institute has developed a parent-taught course that incorporates education with graduated driver licensing. The course comprises seven phases of training with concurrent classroom and behind-the-wheel sections, each of which builds on the previous one. The program guides parents through each step of training and provides information on the psychological makeup of young drivers, including early warnings of common errors. Each level of training includes an objective evaluation standard that helps teens take an introspective view of their own skills. The course includes an entire section for parents in how to instruct their teenage children.

Several states are currently using a curriculum developed by the National Institute of Driver Behavior (NIDB) for behind-the-wheel training. The curriculum was developed using recent research into how the brain develops during the educational process and seeks to provide students with a "lifelong risk prevention education." The curriculum develops the individual behaviors that comprise safe driving and then builds upon those behaviors. NIDB offers instructor training to develop risk prevention managers, not just driver education instructors.

Adept, Inc., has developed a science-based curriculum, "TeenSmart," for use during GDL to reduce crash rates. The curriculum uses behind-the-wheel driving, computer-based training, and video shorts for students and parents to watch. The developers identified the causes of crashes and focused on six areas that could have an impact in reducing crashes. Initial findings show increased knowledge and skills as well as behavioral changes for teens taking the TeenSmart curriculum. Further, compared with teens in other driver education programs, those in TeenSmart have had a 30-percent lower accident rate. Larger studies are underway.

RESEARCH

Several researchers discussed studies of driver education and training. The Texas Transportation Institute is studying novice-driver crash rates, particularly when coupled with parental involvement and training. More reliable data are needed to determine if the Texas programs are effective and what changes need to be made. The Centers for Disease Control and Prevention, working with Systems Technology, Inc., are reviewing student-driving records after licensure to determine the effectiveness of simulators in driver education. More studies are needed on the transfer of training from simulators to driving and the best use of simulators in driver education. Unfortunately, where the study is taking place, few schools offer driver education, and as a result, fewer opportunities are available to conduct such studies. Southern Illinois University, Carbondale, conducted a survey of driver education courses to determine what teachers were teaching, what students were learning, and how to refine driver education content. Based on the results, the study recommended increasing driver education courses to at least 45 hours in the classroom and 10 hours behind the wheel. The study authors also recommended placing more focus on driving, not just the rules of the road.

The panelist from the University of Michigan suggested that driver education be approached from a public health perspective that addresses behaviors, not just education. This approach would identify the problem, consider several behavioral theories, and identify and apply interventions. Driver education and safety would be taught at all grade levels, starting in kindergarten, as part of health education. Further, she stated that driver education currently affects knowledge and competence, but could also affect experience, attitudes, and risk perception, depending on content and teaching methods.

SUMMARY

Overall, participants in the forum believed that novice driver education and training must be improved. The consensus was that, although it does a good job teaching students the basics of driving, it does not teach them how to drive safely. Driver education programs should complement GDL to help our teenagers survive their early years of driving. Further, the public needs to become more aware of teen driving problems and what this country needs to do to reduce the number of teen fatalities that occur every day. As the above summary shows, numerous programs are available to teach young drivers. NHTSA said they need a call from states to take a more active role in driver education and most participants suggested that a national program to guide the development and implementation of effective driver education is needed.

The Safety Board will be issuing recommendations to improve novice driver education and training this fall.

Table. Participants in the Driver Education and Training Forum

History and Research	
Jim Nichols	NHTSA, retired
Allen Robinson	American Driver and Traffic Safety Education Association
U.S. and International Programs	
Sean McLaurin	United States (National Highway Traffic Safety Administration)
Larry Lonero	Canada (Northport Associates)
Stefan Siegrist	Europe (Swiss Council for Accident Prevention)
State Programs	
Elizabeth Weaver	Idaho Department of Education
Greg Lantzy	Michigan Department of Education
David Huff	Montana Office of Public Instruction
John Harvey	Oregon Department of Transportation
Barry Ford	Vermont Department of Education
Driver Education Teacher and Student Perspectives	
Debbie Cottonware	Teacher of the Year, American Driver and Traffic Safety Education Association
Steve Cebulka	Colonial School District, New Castle County, Delaware
Kayla Craddick	National Student Safety Program
Brad Wells	National Student Safety Program
Associations Panel I	
Randy Thiel	American Driver and Traffic Safety Education Association
D. Keith Russell	Driving School Association of the Americas
Wayne Tully	National Driver Training Institute
Frederik Mottola	National Institute of Driver Behavior
Dr. Richard Harkness	Adept, Inc.
Associations Panel II	
Troy Costalas	Governors' Highway Safety Association
Charles Butler	American Automobile Association
Allan Williams	Insurance Institute for Highway Safety
Chuck Hurley	National Safety Council
Peter Kissinger	AAA Foundation for Traffic Safety
Gerald Donaldson	Advocates for Highway and Auto Safety
Current Research	
Bimal Aponso	Systems Technology, Inc.
Dale Ritzel	Southern Illinois University
Terry Kline	Eastern Kentucky University Traffic Safety Institute
Jean Shope	University of Michigan Transportation Research Institute

THE AUTHORS

JENNIFER H. BISHOP is a Senior Project Manager in the Office of Highway Safety and was the coordinator for the Forum on Driver Education and Training. In her 7 years with the Safety Board, Mrs. Bishop has worked on such projects as Intelligent Transportation Systems, 15-passenger van safety, school transportation safety, grade crossing safety, and truck parking areas. Prior to coming to the Safety Board, Mrs. Bishop worked for a contractor developing an intersection collision warning system and worked for the government as an intelligence analyst. She has a bachelor's degree in aerospace engineering from the University of Virginia and a master's degree in human factors engineering from Texas A&M University. Mrs. Bishop is active on several Intelligent Transportation Society of America committees and is a member of the Society of Automotive Engineers.

KEVIN E. QUINLAN is the Chief of the Safety Advocacy Division. Mr. Quinlan has been with the Safety Board for 15 years serving as the Alcohol and Drug Program Coordinator and Chief of the Safety Recommendations Division. He is currently responsible for promoting State action on Safety Board recommendations to reduce fatalities, injuries, and crashes in all modes of transportation. Mr. Quinlan is the author of five major studies for the Board. Prior to coming to the Safety Board, Mr. Quinlan served in the U.S. Army for 29 years, receiving the Legion of Merit and Meritorious Service Medal. He has an undergraduate degree from Boston University and graduate degrees from William and Mary, the U.S. Army Command and General Staff College, and the U.S. Air Force Air War College.

DANIELLE E. ROEBER is the Alcohol Safety and Occupant Protection Coordinator. In her position, Ms. Roeber advocates for and tracks the implementation of the Safety Board's highway safety recommendations issued to State legislatures and Governors and that address the areas of impaired driving, seat belts, and child occupant protection. Her work includes providing technical expertise to Board Members, State officials, and local advocates; drafting advocacy letters; preparing remarks for press events and speeches; writing testimony; and giving presentations on highway safety. Since starting at the Safety Board in October 2001, Ms. Roeber has testified before legislative committees in Connecticut, Kansas, Ohio, Pennsylvania, Tennessee, and Virginia. Ms. Roeber participated in the 2003 Child Passenger Safety Summit and is a member of the Transportation Research Board's Committee on Alcohol, Other Drugs, and Transportation.

GARY VAN ETTEN is a senior Transportation Safety Specialist, specializing in commercial vehicle issues, and Investigator in Charge in the Office of Highway Safety. He has been with the Safety Board for 12 years. Prior to the Safety Board, Mr. Van Etten was a Deputy Sheriff with the Los Angeles County Sheriff's Department for 21 years. He has also been an instructor for the Los Angeles and Riverside County Sheriff's Departments, the Institute of Police Technology and Management, University of California, Riverside, and the U.S. Department of Transportation. Mr. Van Etten is a member of the Commercial Vehicle Safety Alliance, Driver Committee, the Southwest Technical Accident Investigators Association, and the National Association of Accident Professionals. He received his master's degree in religion from Biola University, his bachelor's degree in political science from California State University in Los Angeles, and his associate's degree in education from East Los Angeles Community College.

Air Cargo Safety Forum

Joseph M. Sedor, National Transportation Safety Board

ABSTRACT

The Air Cargo Safety Forum brought together more than 160 representatives from cargo and airline operators, government agencies, and pilot associations to discuss air cargo safety and share ideas that would help advance the important work currently being done in this area. Sixteen papers from government and industry experts addressed the current state of the cargo industry, operational issues, human factors, and regulatory issues.

BACKGROUND

Although cargo-only flights make up less than 10 percent of U.S. domestic air carrier operations, the cargo accident rate is at least twice the equivalent accident rate of passenger flights. In addition, air cargo tonnage is expected to increase by about 80 percent in the next 10 years. Accordingly, the NTSB held the Air Cargo Safety Forum on March 30 and 31, 2004, at the Academy to spur industry stakeholders to address relevant safety issues in an effort to prevent the accident rate from increasing. Chairman Ellen Engleman Conners initiated the forum "to augment and support industry-government dialogue on air cargo safety and to help advance the important work currently being done in this area." The forum was attended by more than 160 participants from cargo and airline operators, government agencies, and pilot associations.[1]

The forum was a collaborative effort between the NTSB and many industry associations, including the Air Line Pilots Association (ALPA), Air Transport Association (ATA), Cargo Airline Association (CAA), Federal Aviation Administration (FAA), Flight Safety Foundation (FSF), National Air Carrier Association (NACA), and Regional Airline Association (RAA).

[1] The forum was broadcast on the NTSB Web site, and the proceedings were posted on the Web site at (http://www.ntsb.gov/events/symp_air_cargo/symp_air_cargo.htm) for participant and public access.

After obtaining input from industry associations regarding the topics that should be covered at the forum, the NTSB selected 16 papers for the forum from the more than 30 abstracts submitted. The papers were grouped into four sessions: Current State of the Cargo Industry, Operational Issues, Human Factors, and Regulatory Issues.[2]

In her opening remarks, Chairman Engleman Conners welcomed the participants to the "open, communicative, and cooperative public debate" among all parties in the air cargo industry. Afterward, Vice Chairman Mark Rosenker and Member Richard Healing presented their remarks.

SESSION 1: CURRENT STATE OF THE CARGO INDUSTRY

The FAA began with an overview of some of the safety initiatives currently being pursued by two of its industry-government working groups: the Aircraft Certification Service Cargo Strategic Action Plan and the Flight Standards Service Air Cargo System Safety Implementation Plan (ACIP). These groups are working to develop and issue an advisory circular that will provide cargo operators with consistent and concise guidance on air cargo operations and to develop guidance for FAA inspectors who oversee these operators. FAA and industry representatives also summarized the ongoing work of the industry-government Commercial Aviation Safety Team (CAST), which was formed to prioritize safety enhancements to reduce the rate of fatal commercial aviation accidents. This portion of the first session closed with presentations showing the perspectives of small cargo operators, large all-cargo air carriers, and pilots on the safety issues currently confronting the industry.

Empire Airlines, representing small cargo operators, discussed how the nature and size of its operations allowed it to build in an extra margin of safety. Empire cautioned that the economy-of-scale that helps small cargo operators engineer safety into their business might be nullified by a "one size fits all" regulation. Large all-cargo air carriers were represented by the CAA, which presented examples of the industry's current safety initiatives. These initiatives included the industry-government Safe Flight 21 program, which was formed to introduce new technology and procedures to increase safety and capacity. ALPA presented the pilot's perspective, focusing on the safety and regulatory differences between cargo and passenger operations, such as certification of cargo preparation and loading personnel, night-oriented operating schedules, and remote airport operations.

SESSION 2: OPERATIONAL ISSUES

NACA began the session by discussing the upcoming FAA advisory circular covering cargo operations. NACA reiterated that the goal of current industry-government working groups was to provide guidance to all cargo operators to increase safety and provide needed standardization among air carriers and others in the air cargo industry. ALPA followed with a presentation on the need for greater standardization of procedures and practices in the air cargo industry. In its presentation, ALPA outlined some of the current problems it sees in the industry involving handling, loading, and securing cargo; calculating weight and balance; moving cargo between carriers; and loading international versus domestic flights.

The next two presentations in the second session addressed specific operational issues: tracking dangerous goods and preventing cargo from shifting during flight. FedEx Express described the development and implementation of its dangerous goods tracking system, AutoDG. FedEx also described several safety issues involving shipping and tracking of dangerous goods and the ways in which the company has overcome some of those difficulties. Hawaiian Airlines presented its findings that several suspected load shifts aboard its Boeing 767-300ER airplanes were the result of mixed combinations of unit load devices. As a result of its investigation, Hawaiian Airlines modified its training program for load agents, loadmasters, and supervisory personnel and designed a job aid card to choose an optimum restraint configuration.

The first day of the forum concluded with a presentation from the Safety Board's Transportation Disaster Assistance office regarding the responsibilities of all parties in an air cargo accident.

SESSION 3: HUMAN FACTORS

FSF began the second day of the forum with a presentation about its ongoing work to reduce the number of approach and landing accidents (ALA) and controlled flight into terrain (CFIT) accidents in commercial aviation. The data presented by FSF showed that cargo operations have demonstrated a higher risk for both ALA and CFIT. Because such accidents continue to be one of the primary challenges in aviation, FSF has continued to produce and distribute an ALA/CFIT training aid to help educate pilots.

The next two presentations focused on the physiological problems with night flying and flight duty time. Dr. Mark

[2] Each of the four sessions was followed by a question and answer session. Many questions could not be answered in the allotted time for each session, and were instead included in the forum proceedings.

Rosekind from Alertness Solutions discussed the physiological challenges associated with night cargo operations and stated that the problems will be solved only with a comprehensive approach that involves all stakeholders (companies, pilots, and regulators). ALPA then gave a presentation on flight and duty time issues in the cargo industry. ALPA's presentation included a discussion of the need to unify the passenger, cargo, and domestic and international flight time/duty time regulations to provide "one level of safety."

SESSION 4: REGULATORY ISSUES

The presentations in this session outlined regulatory differences between Part 121 flag (passenger) carriers and Part 121 supplemental all-cargo carriers. The Independent Pilots Association (IPA) explained the differences in the airport rescue and fire fighting (ARFF) requirements between cargo and passenger flights. IPA stated that FAA regulations concerning ARFF requirements are solely based on the number of seats in the airplane and not on its size or weight. IPA pointed out that International Civil Aviation Organization rules indicate that ARFF requirements be based on the size/weight of the airplane and not the number of passenger seats.

The Airline Professional Association Teamsters Local 1224 (Local 1224) then made a presentation on the lack of regulations covering personnel who are directly involved in cargo preparation. Local 1224 stated that the cargo loadmasters and loading personnel should be licensed and monitored by the FAA to ensure that cargo loading activities are accomplished safely. ALPA finished the session by highlighting several other differences between the regulations for cargo and passenger operations, including the less stringent requirements for cargo operations regarding weather reporting; alternate airport designations; and critical safety equipment, such as escape slides. ALPA stressed that these regulatory differences must be modified to provide one level of safety throughout the U.S. commercial air transportation industry.

Chairman Engleman Conners closed the forum with a challenge to all of participants to continue the dialogue established at the forum to improve air cargo safety. Chairman Engleman Conners has since reiterated the importance that the NTSB places on air cargo safety by stating at the 2004 ALPA Air Safety Forum that "the families [of crews aboard cargo carriers] waiting at home deserve the same expectation of safety [as crews aboard passenger carriers]."

NTSB AIR CARGO SAFETY FORUM AGENDA

The Current State of the Cargo Industry

- *Aircraft Certification Service Cargo Strategic Action Plan (CSAP) and Flight Standards Service Air Cargo System Safety Implementation Plan (ACIP)*, presented by Mr. David Cann, Manager of the FAA Aircraft Maintenance Division, and Mr. Ali Bahrami, Acting Manager of the FAA Aircraft Transportation Directorate
- *A Regional Cargo Airlines Perspective,* presented by Mr. Richard Mills, Director of Safety and Compliance for Empire Airlines
- *A Transport Category Perspective,* presented by Mr. Stephen Alterman, President of the Cargo Airline Association
- *An ALPA Perspective,* presented by Captain Terry McVenes, Vice-Chairman of the Air Line Pilots Association Executive Air Safety Committee
- *The Commercial Aviation Safety Team,* presented by Mr. Jay Pardee, Manager of the FAA Engine and Propeller Directorate, and Dr. Michael Romanowski, Assistant Vice President of Civil Aviation at the Aerospace Industries Association

Operational Issues

- *FAA and Industry Collaborative Safety Effort,* presented by Mr. Jack Hagenmayer from the National Air Carrier Association
- *The Need for Greater Standardization of Cargo Handling Procedures,* presented by Captain Ken Young, Chairman of the ALPA DHL/ASTAR Air Cargo Airline Central Air Safety Committee
- *Improvements in Air Cargo Dangerous Goods Safety,* presented by Mr. Patrick Oppenheimer, Manager of the Dangerous Goods Administration at FedEx Express, and Mr. Scott Mugno, Managing Director of Corporate Safety at FedEx Express
- *B767-300ER Variant Lower Lobe Cargo ULD Restraint System,* presented by Mr. Marc Kup, Senior Director of Performance Engineering, and Mr. Mont Smith, Senior Director of Safety and Compliance, Hawaiian Airlines
- *NTSB Transportation Disaster Assistance,* presented by Ms. Sharon Bryson, Director of the NTSB Office of Transportation Disaster Assistance

Human Factors

- *The CFIT/ALA Challenge: Attacking the Killers in Cargo Aviation,* presented by Mr. Jim Burin, Director of Technical Programs at the Flight Safety Foundation
- *Managing the Physiological and Safety Challenges of Night Flying: A Shared Responsibility,* presented by Dr. Mark Rosekind, President and Chief Scientist at Alertness Solutions
- *Flight Time and Duty Time Issues in Air Cargo Operations,* presented by Captain Dave Wells, Chairman, ALPA FedEx Central Air Safety Committee

Regulatory Issues

- *Double Standards in Cargo Safety Aircraft Rescue and Fire Fighting,* presented by Captain Shannon Jipsen, Chairman of the Independent Pilots Association Accident Investigation Committee
- *Qualification of Load Master and Third-Party Contract Loading,* presented by Mr. Gregory Feith, representing the Airline Professional Association Teamsters Local 1224
- *Safety Implications of Regulatory Differences in Operating, Equipment and Certification Rules*, presented by Captain Bruce Brielmaier, Vice Chairman of the ALPA ASTAR Air Cargo Central Safety Committee

THE AUTHOR

JOSEPH M. SEDOR is a Senior Air Safety Investigator (Investigator in Charge) in the Major Investigations Division of the NTSB Office of Aviation Safety. Mr. Sedor was the coordinator for the Air Cargo Safety Forum and has been with the NTSB for 6 years. Prior to joining the Safety Board, he worked for Cessna Aircraft Company as a flight test engineer/pilot. Mr. Sedor has a bachelor's degree in aerospace engineering from the University of Michigan and a master's degree in flight test engineering from the University of Tennessee Space Institute. Mr. Sedor is an Investigator in Charge on domestic air carrier accidents and acts as a United States Accredited Representative on international air carrier accidents.

NTSB ACADEMY

The Academy

Julie Beal, National Transportation Safety Board

With the opening of the Academy last August, NTSB stepped up to its role as the worldwide leader in transportation accident investigation. The aviation accident investigation community has always looked to the NTSB for guidance and training in accident investigation management and techniques, but with the expanded facilities available at the Academy, that role has been extended to encompass training, research, and public forums in both aviation and surface accident investigation and transportation safety. In addition, the increased classroom space has enabled us to make our classes available to a larger number of students than before. In its first year of operation, the Academy delivered 15 courses and 2 symposia attended by over 1000 people, including 65 students from 35 foreign countries.

The 72,000-square-foot building accommodates a variety of training activities with five classrooms; a 30,000-square-foot, five-story laboratory; two additional 2,400-square-foot, temperature-controlled laboratories; an outdoor simulation/staging court; and meeting rooms. All classrooms and meeting rooms have state-of-the-art audiovisual capabilities and Internet connections for each attendee. Approximately 25 percent of the large laboratory space is used to house the three-dimensional, 93-foot-long reconstruction of the forward portion of the fuselage from the TWA flight 800 aircraft, a Boeing-747. This reconstruction, the largest of its kind in the world, is of immense value in demonstrating how investigators piece together wreckage in their quest to identify an accident's cause.

The laboratories also provide hands-on experience for Academy students taking courses at the Academy. For example, investigators studying structural and material failure mechanisms are able to conduct demonstration tests in the mechanical testing laboratory to observe the influence of geometric and material variables on failure characteristics often observed in wreckage. In addition to being used for training, the two smaller laboratories greatly enhance NTSB's research capabilities, both in support of specific accident investigations and in investigating broader technical and scientific issues pertinent to transportation safety. Several resaearch initiatives that will use laboratory capabilities are under development.

Although accident investigation techniques are the primary focus of courses offered at the Academy, others developed by the NTSB Office of Transportation Disaster Assistance have demonstrated that lessons learned from major accident investigations are of value to disciplines beyond accident investigation. The events of September 11 demonstrated how the NTSB, with its decades of experience in managing chaotic, traumatic, and technically challenging events, provides both security and law enforcement agencies with extremely valuable first-hand lessons in preparing for the worst. Over the past year, the Academy has trained participants from more than 25 state and local first-responder and law enforcement organizations. The Department of Homeland Security, Federal Bureau of Investigation, National Aeronautics and Space Administration, U.S. Coast Guard, Department of Defense, and many other federal government agencies have attended classes to gain—and share—valuable knowledge that will help us all work together on-scene.

The Academy has also provided an effective venue for convening experts in transportation safety to share ideas and information to promote a higher safety consciousness in the community. One week after the Academy opened, the International Society of Air Safety Investigators held a meeting here, hosting more than 100 participants—the most ever to attend that organization's annual tutorial. In addition, the NTSB hosted public forums on driver education, air cargo safety, and personal flotation devices in recreational boating. Attendance at these public meetings exceeded our expectations. One need only look at our safety recommendations to see the numerous possibilities that exist in promoting transportation safety concepts through such programs.

Building relationships throughout the transportation accident investigation community is a vital component of the Academy's success. This year, staff members have worked to establish partnerships with organizations and institutions to promote shared interests in safety. Working with our partners, we can reach even greater numbers in the community to promote the safety dialogue and expand our knowledge base.

We are off to a great start. We will continue to move forward, doing our part to keep the American traveling public safe here and abroad—not just through our accident investigations, but also through training, educational programs, and the development of relationships throughout the accident investigation community.

NTSB *ACADEMY*

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