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Consensus Emerges From International Focus On Crew Alertness in Ultra-long-range Operations

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In This Issue

Flight Safety Foundation is an international membership organization dedicated to the continuous improvement of aviation safety. Nonprofit and independent, the Foundation was launched officially in 1947 in response to the aviation industry's need for a neutral clearinghouse to disseminate objective safety information, and for a credible and knowledgeable body that would identify threats to safety, analyze the problems and recommend practical solutions to them. Since its beginning, the Foundation has acted in the public interest to produce positive influence on aviation safety. Today, the Foundation provides leadership to more than 910 member organizations in more than 142 countries.

Consensus Emerges From International Focus on Crew Alertness in Ultra-long-range Operations

After two years of workshop discussions and follow-up meetings, recommendations have been issued for planning and approving flight-sector lengths greater than 16 hours between specific city pairs. Specialists at these meetings forged operational guidelines that will help the airline industry to expand the operational envelope while maintaining safety.

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FSF Editorial Staff

An international consensus on operational guidelines, regulatory requirements and supporting research requirements will help ensure that pilots maintain the required alertness and performance while at their duty stations during ultra-long-range (ULR) operations, which the airline industry expects to begin in late 2003. Principal tenets of this consensus are that airlines obtain approval for ULR operational plans from civil aviation authorities and that the operational plans be developed using a scientifically based method. This method can employ validated mathematical models of crew alertness (tools that predict outcomes of situations in the absence of data) to show how ULR operations can be conducted safely between specific city pairs. Recommendations also call for operational plans to incorporate the crew-operating pattern, in-flight monitoring of crew rest and crew performance under an independently defined validation plan, and the application of ongoing scientific research.

ULR operations will have planned flight-sector lengths (block times) greater than 16 hours[1] and flight-duty periods from 18 hours to 22 hours in scenarios envisioned by the 11-member ULR Crew Alertness Steering Committee, which has conducted three workshops through cosponsorship of Airbus, Boeing Commercial Airplanes and Flight Safety Foundation (FSF). Some aircraft currently in production are capable of flight-sector lengths up to 21 hours. For purposes of this initiative, current long-range operations comprise operations with planned flight-sector lengths between 12 hours and 16 hours.

During ULR flights, the overall flight-duty period requires, for individual pilots, one period or two periods at a duty station on the flight deck, and at least one period of sleep in a crew-rest facility equipped with a horizontal bunk. Time off duty and rest before reporting for flight duty also require active management, including monitoring factors such as the pilot's endogenous circadian rhythm (body clock) and sleep/wake cycle. These factors must be included in planning the pilot's duty schedule, scheduled in-flight sleep, local departure time, crossing of time zones and alertness/fatigue levels.

The steering committee began in late 2000 as an initiative of Boeing and the Foundation to provide a global forum to define the operational issues and the technological issues associated with assuring flight crew alertness during ULR flights, and to develop common methods to address these issues. The workshops included participants from 14 countries. The participants represented three airline associations, 16 airlines, two manufacturers, 12 pilot unions, three cabin crew unions, 14 scientific organizations and nine regulatory authorities invited by the steering committee. The following meetings were part of the initiative:

- The initial workshop June 12–14, 2001, in Washington, D.C., U.S., was attended by 76 participants. After a plenary session that provided the latest industry updates and scientific updates on related issues, participants focused on topics such as in-flight-rest rostering, crew complement, crew-operating pattern (trip scheduling), personal strategies and design of aircraft crew-rest facilities;

- A second workshop March 5–8, 2002, in Paris, France, was attended by 83 participants. After a plenary session that focused on the potential for using mathematical models as predictors of crew alertness, participants exchanged views on topics such as initial operational concepts, requirements for further research and development (e.g., specific methodologies to determine acceptable levels of alertness and factors that affect quality and quantity of in-flight sleep by pilots), operational validation and global regulatory strategy for crew alertness in ULR operations; and,

- Steering committee members and subgroups from these workshops drafted the following four summaries of the consensus positions: Operational Best Practices Subgroup Report (see Appendix A, page 9), Operational Validation Programs Subgroup Report (see Appendix B, page 11), Global Regulatory Approach Subgroup Report (see Appendix C, page 13) and Research and Development Subgroup Report (see Appendix D, page 15). The follow-up workshop to prepare the reports was conducted March 12–14, 2003, in Kuala Lumpur, Malaysia. The reports include the subgroup members, steering committee members and other participants in the initiative (see Appendix E, page 19).

All workshop participants were encouraged to join in comprehensive discussions and share international expertise as they debated ULR operational technical issues without the constraints of official processes or economic competition, said Robert Vandel, FSF executive vice president, and R. Curtis Graeber, Ph.D., chief engineer, human factors, Boeing Commercial Airplanes. Vandel and Graeber are the steering committee co-chairs.

"The pending expansion of flight-duty time up to 22 hours per ULR flight sector is a significant issue," Vandel said. "The Airbus A340-500, for example, will enter ULR revenue service in late 2003 when Singapore Airlines begins operating flights between Singapore Changi Airport and Los Angeles [California, U.S.] International Airport. Airlines must ensure that crew fatigue is minimized and that crew alertness is optimized during ULR operations. Our subgroup reports contain operational guidelines that are based on expert consensus about what we know now, recognizing that debates about some issues may continue. We are emphasizing safety monitoring and continued research during initial revenue service to enhance future ULR operations." Some additional issues will have to be resolved by airlines and civil aviation authorities during approval processes, he said.

The steering committee's initiative has included significant interaction with the Civil Aviation Authority of Singapore (CAAS) ULR Task Force (see "Singapore Issues Provisional Rules for Ultra-long-range Operations," page 3).[2] The task force studied scientific research, consulted other authorities, participated in three steering committee workshops, worked with the European Joint Aviation Authorities (JAA) on ULR city-pair modeling research[3] based on data from long-range operations by European airlines and collected data for model validation during long-range flights conducted by Singapore Airlines, CAAS said.

The ULR Crew Alertness Steering Committee's subgroup reports include suggested regulatory language; refine research efforts and define the corresponding field-validation process; and provide credible and practical guidance developed by diverse specialists, Graeber said.

"Our overall goal has been to ensure that ULR flights are conducted by airlines to safety standards equal to, or greater than, those of current long-range operations," he said. "Regulatory authorities currently see modeling — combined with validating data — as one way forward. Our operational guidelines help to define a road map for regulatory approval of ULR operations involving specific city pairs, chart a direction for further research, and advise operators and flight crews on how to accomplish ULR operations safely and efficiently."

Challenges Exceed Those of Long-range Operations

Preventing decrements in crew alertness and performance during ULR operations involves issues beyond management of fatigue as practiced in current long-range operations. Countermeasures to prevent excessive fatigue in long-range operations have included augmenting the crew, providing airplane crew-rest facilities and providing adequate rest facilities away from home base. Participating scientists cited 20 years of study of physiological factors in sleep, alertness and fatigue-risk management, Graeber said. For example, research shows that a pilot's body clock normally is entrained (synchronized) to the 24-hour day but becomes desynchronized by time-zone transitions. Study of the body's normal process of sleep and waking also shows that over time, sleep increases alertness and wakefulness decreases alertness. Moreover, research suggests that assigned periods for pilots to sleep away from their duty stations during ULR flights should include adequate time to transition from wakefulness to sleep and from sleep to full alertness.

Workshop participants discussed the significance of acclimatizing crewmembers to the time zone of the departure city before beginning any flight duty. Because of the critical importance of scientific methods in defining acceptable crew-alertness levels, they also discussed funding future research, disclosure of research findings, research methodology, objectives of further research and proposals for a research advisory body, he said.

By identifying the data required for case-by-case approval of ULR city pairs (which would be treated as variations to the airline's current flight-time limitations, duty-time limitations and crew rest requirements [FTL]) rather than pursuing broad approval of ULR operations, the steering committee has demonstrated how to reduce to a manageable level the complexity of addressing alertness and performance without relying on prescribed duty limits, Graeber said.

Proposed ULR operations also raise issues of crew complement (number of pilots) and crew composition (qualifications of pilots) that go beyond the fundamental aircraft-certification question of how many pilots are required to fly the airplane. Composition of the crew typically is a regulatory issue, involving captain/first officer qualifications, type rating,

Singapore Issues Provisional Rules for Ultra-long-range Operations

Singapore Airlines plans to begin ultra-long-range (ULR) flight operations in late 2003 under provisional regulations established by the Civil Aviation Authority of Singapore (CAAS). The provisional regulations were developed specifically to govern the airline's planned nonstop flights between Singapore and Los Angeles, California, U.S., and will require a four-pilot flight crew, including two crewmembers with pilot-in-command qualifications.[1]

CAAS also will require the flights to depart at specific times and that the aircraft have rest facilities conducive to sleep and an in-flight rest schedule that allows each flight crewmember to have two rest periods during each flight. Before beginning the flights, Singapore Airlines will be required to conduct ULR training programs and establish guidelines for flight crews on topics such as in-flight rest and sleep management, alertness management and fatigue countermeasures.

The provisional regulations are based on studies conducted by the CAAS ULR Task Force, which was established in 1998 and comprises representatives of CAAS, Singapore Airlines and the Air Line Pilots Association–Singapore. Several task force members participated in ULR Crew Alertness Steering Committee workshops cosponsored by Airbus, Boeing Commercial Airplanes and Flight Safety Foundation (see "Consensus Emerges From International Focus on Crew Alertness in Ultra-long-range Operations," page 1).

The CAAS studies included a review of the scientific basis for current flight-time limits and duty-time limits worldwide, and mathematical modeling of crew-alertness levels. The modeling, conducted by QinetiQ in cooperation with the European Joint Aviation Authorities (JAA), was based on assumed flight-duty periods of 18 hours and 10 minutes from Singapore to Los Angeles, and 20 hours and 25 minutes from Los Angeles to Singapore, with a layover of 48 hours or 72 hours between flights. A report on this modeling research has been posted for public access on the JAA Internet site.[2]

The task force collected data from Singapore Airlines flight crews during long-range flights (i.e., with planned flight-sector lengths [block times] between 12 hours and 16 hours). CAAS commissioned the European Committee for Aircrew Scheduling and Safety to study the data to validate the models with input from the Defence Medical Research Institute of Singapore, which has conducted research on sleep patterns of military pilots.[3]

Based on the findings of the task force studies, CAAS said that fatigue experienced by flight crews conducting ULR flights between Singapore and Los Angeles under the provisional regulations should not be a greater problem than the fatigue currently experienced by crews conducting long-range flights. Nevertheless, the task force will continue the study by monitoring the initial ULR flights conducted by Singapore Airlines to determine the accuracy of the findings about pilot-alertness levels and to validate the provisional regulations.♦

Notes

1. Singh, Jarnail. "Study of Pilot Alertness Highlights Feasibility of Ultra Long Range [ULR] Flight Operations." International Civil Aviation Organization *ICAO Journal* Volume 58 (January–February 2003): 14–15, 30. Dr. Singh is chairman of the Civil Aviation Medical Board of the Civil Aviation Authority of Singapore (CAAS) and chaired the CAAS ULR Task Force.

2. Spencer, Mick. "Modelling of Aircrew Alertness in Future Ultra Long-Range Schedules, Based on a City Pair." A report prepared by QinetiQ for the Joint Operations and Evaluation Board of the Joint Aviation Authorities. February 2002. <www.jaa.nl/operations/Public%20Area/QinetiQ.pdf>.

3. Robert Vandel, co-chair of the ULR Crew Alertness Steering Committee and executive vice president of Flight Safety Foundation, said that the steering committee for the initiative requested in May 2003 that CAAS release the full report and the data from the model-validation research in the interest of international peer review, research and operational validation purposes elsewhere. CAAS declined to release this report, citing commercial value of the data as the reason.

experience, recency of experience and qualification to conduct takeoffs and landings.

Some of the civil aviation authorities that will be responsible for ULR-approval decisions contributed informally to workshop discussions of these issues. The steering committee found that individual states typically have detailed regulations for FTL that vary by culture, work practices and industrial agreements; nevertheless, these regulations may be outdated if they have not been amended to reflect scientific advances of the past 10 years. The International Civil Aviation Organization (ICAO) will be assessing the steering committee's report while considering amendments to ICAO standards and recommended practices, Graeber said.[4] Although some characteristics of future city pairs might be unique, safety will be enhanced significantly if ICAO develops one set of internationally accepted principles for ULR operations, he said.

First ULR Operations May Set Precedents

As a first step, recognition of the validity of the proposed operational guidelines will be needed from ICAO, Graeber said. After the first city pair has been operational and monitored for three months to six months, ICAO, civil aviation authorities and airlines also should recognize that the steering committee's proposed methodology is suitable for approving other city pairs — and possibly clusters of city pairs (additional city pairs that have specified characteristics in common with a validated city pair), Graeber said. Airlines and pilot organizations then would have data-driven guidance to take responsible decisions about crew complement/composition for a city pair, in-flight rest and the other issues.

Klaus Koplin, chief executive of JAA, said that JAA has supported the steering committee's independent work.

"We in the JAA agree that crew alertness in future [ULR] operations beyond 16 hours flight time or 18 hours flight-duty period is an issue which needs to be understood in time for appropriate regulations to be put in place," Koplin said. "We also feel that it is important that the debate is not unduly influenced by present legacy systems, and can be dealt with objectively. We observe that the steering committee, on which there is a representative of the central JAA, and the associated group of workshop participants, is the only group currently examining these issues worldwide and is doing so in accordance with a rational approach where the final outcome is not predetermined. We eagerly await the group's findings and technical representations arising from sponsored workshops and to incorporating these in future regulatory efforts."

During the workshops, scientists presented facts about the relationship of objective measures of vigilance, attention, short-term memory and reaction time to subjective measures of pilots' higher cognitive functions (such as complex decision making and judgment). To analyze ULR operations, such measures have been integrated with others that are sensitive to effects of sleep loss, long number of continuous hours awake, fatigue and circadian rhythms (i.e., trying to be awake and functioning at an adverse time according to the body clock).

The scientists also presented studies of how measurable physiological variables such as microsleeps — brief episodes of sleep intrusions into wakefulness with loss of attention, typically between two seconds and 30 seconds — are important signs of decrements in neurocognitive functioning that could cause lapses in pilot performance during any phase of ULR operations. (Signs of microsleeps include a blank stare, head snapping, momentary "dozing" or prolonged eye closure that occur when a person is fatigued but tries to remain awake to perform a monotonous task. During microsleeps, the person will not be aware of warning lights and other events.)

The consensus of participating scientists was that in-flight sleep is the best solution to the problem of maintaining crew alertness and performance in ULR operations, Graeber said. For example, scheduling the landing crewmembers for sleep during their circadian low point (time of greatest sleepiness based on the body clock) would prevent the unsafe situation of conducting an approach and landing in a low-alertness condition and/or with an accumulated sleep debt (a condition in which the body requires restorative sleep to overcome the effects of a period of insufficient sleep).

Other workshop presenters discussed the application of current knowledge to fatigue-risk-management systems in the long-range operations of Air New Zealand and Qantas Airways.[5]

Participants also discussed the feasibility of some pilots intentionally reporting for ULR flight duty during a circadian low point to be ready to sleep early in the flight, enabling them to report later to their duty stations in a fully alert condition. No other known countermeasures — cockpit naps, caffeine, exercise, light exposure, etc. — would be as effective in reducing the risk of microsleeps and decrements in alertness and performance, Graeber said. In this context, the design of crew-rest facilities for ULR operations has major significance.

Airplane crew-rest facilities have evolved as the length of flight sectors has increased, and past experience and recent research are being applied to ULR-related designs. These designs attempt to provide private compartments that enable pilots to leave the flight deck with little contact with the passengers, enter a secure crew-rest area, change clothing and obtain the desired quantity and quality of restorative sleep in a comfortable bunk in an environment that is dark and quiet. Nevertheless, the consensus of participating scientists was that the quantity and quality of in-flight sleep for pilots typically will be inferior to what they obtain while sleeping at home or at a hotel (see "Pilots' Bunk Sleep Varies Significantly During Long Rest Periods," page 5).

Continued on page 6

Pilots' Bunk Sleep Varies Significantly During Long Rest Periods

The amount and quality of in-flight sleep that flight crews are able to obtain during scheduled rest periods is a critical issue for designing safe long-range operations (flight-sector lengths between 12 hours and 16 hours) and ultra-long-range (ULR) operations (flight-sector lengths greater than 16 hours).[1] This in-flight sleep will be influenced by both physiological factors (prior sleep history and the body's biological clock) and operational factors (flight-sector length, crew complement, the number and type of crew-rest facilities available, in-flight disturbances and the method of allocating rest periods, etc.). Currently, very few scientific data are available on the in-flight sleep that pilots are able to obtain — particularly during the long rest opportunities that might be available during ULR operations.

The main aim of this study[2] was to document the amount of sleep and the quality of sleep that individual pilots were able to obtain in the crew-rest facility of the Boeing 777-200ER when they were provided a single seven-hour sleep opportunity during a flight sector with an average length of approximately 15 hours. A total of six nonrevenue, airplane-delivery flights were conducted. A comparison also was made between the amount and quality of sleep obtained during the first half of the flight compared with the amount and quality of sleep obtained during the second half of the flight, and the researchers assessed the effect of this sleep on the alertness of crewmembers during the final 50 minutes that they were on duty.

This study extends previous research on in-flight sleep in that the flight times and the rest periods were the longest yet monitored. The findings of the study are strengthened by the methods that were used for recording in-flight sleep data and for measuring alertness during the last 50 minutes of duty. One method — called polysomnography — involves recording brain activity, eye movement and muscle tone using small electrodes that are attached to the head and to the face of the pilot.

Twenty-one pilots — 11 captains and 10 first officers who had experience in long-range flights for a commercial airline — were monitored before, during and after a round-trip operation between Singapore and Seattle, Washington, U.S., or between Kuala Lumpur, Malaysia, and Seattle. All of these crews positioned to Seattle, with most spending at least 72 hours there before conducting the return leg for delivery of a Boeing 777-200ER aircraft.

To enable researchers to estimate the sleep obtained across the study period, the crewmembers wore an Actiwatch for approximately nine days — three nights prior to departing from their home base for Seattle, during their time in the United States and for a further three nights after returning to their home base. (The Actiwatch — a small, lightweight device approximately the size of a wristwatch — measures and records the motion of the body; this research method is called actigraphy. Actigraphy devices have proven to be highly sensitive to sleep, and they are a useful means of objectively monitoring sleep over extended periods of time.)

During one night in Seattle, the sleep of each pilot was monitored using polysomnography. This was done to allow pilots to adapt to the equipment and to provide data for the study that could be compared to data from in-flight sleep. During each airplane-delivery flight, polysomnography was used to monitor and to record the crewmembers' in-flight sleep and their alertness at the end of the flight.

The study found that in the 72 hours leading up to the aircraft-delivery flight, crewmembers obtained less sleep than they believed was necessary to be fully rested (called sleep debt). Prior to the flight, crewmembers accumulated an average sleep debt of 4.3 hours. Nevertheless, there was considerable individual variability, with some having zero sleep debt or very little sleep debt and others having a sleep debt of nearly 10 hours. In the 24 hours before the flight, crewmembers averaged seven hours of sleep, which was, on average, 1.9 hours less sleep than they believed was necessary to be fully rested.

During the flight, crewmembers were asked to spend as much as possible of their seven-hour rest opportunity trying to sleep but, on average, they spent 4.7 hours in the bunk and obtained 3.3 hours of sleep. The quality of the in-flight sleep was poorer compared to sleep obtained in the hotel during the layover. Sleep efficiency (percentage of time asleep compared with the time elapsed while trying to sleep) dropped from 90 percent in the layover hotel to 70 percent in the bunk. In-flight sleep also was more disrupted (indicated by more awakenings and sleep disturbances called arousals, which are short-duration changes in sleep). Less than 1 percent of in-flight sleep was deep sleep, with no stage-4 sleep observed.[3]

Pilots who were provided the sleep opportunity during the first half of the flight spent less time trying to sleep than those who had the later sleep opportunity (average 4.0 hours versus 5.4 hours), and pilots who had their sleep opportunity during the first half of the flight also obtained less sleep (average 2.7 hours versus 3.9 hours) than the others. The quality of sleep was comparable in both sleep opportunities, however.

The data showed that the amount of bunk sleep and quality of bunk sleep were not related to the amount of sleep obtained in the 24 hours preceding the flight (as estimated by data from the Actiwatch). This suggests that the strategy of purposely restricting layover sleep to improve the pilot's in-flight sleep may not always be advisable.

The most consistent factor affecting the amount and quality of bunk sleep was the crewmember's age. Older crewmembers took longer for sleep onset, obtained less total sleep — with lower proportions of certain stages of sleep (light stage-2 sleep and dreaming, also called rapid-eye-movement sleep[4]) — and experienced sleep that was more disrupted than the sleep of younger crewmembers. These statistical differences persisted after accounting for the amount of prior sleep that crewmembers had obtained and for whether they had slept during the first half of the flight or the second half of the flight.

Pilots who slept during the second half of the flight were more alert during their final 50 minutes of duty than those who slept during the first half of the flight. The amount of bunk sleep, but not the quality of bunk sleep, also had a significant effect on alertness in the last 50 minutes of duty; more sleep was associated with greater alertness. The study supports the general principle that more sleep results in higher alertness at the end of the flight, regardless of the age of the crewmember.

In summary, as this study and others show, in-flight sleep obtained in an airplane crew-rest facility is generally of poorer quality than sleep obtained in a layover hotel. In this study, in-flight sleep in the crew-rest facility occurred under relatively ideal conditions because the possibility of sleep disturbances caused by passengers was absent on these nonrevenue flights. The pilots who slept during the second half of the flight obtained more sleep than the pilots who slept during the first half of the flight. This finding has been replicated in several other studies and is consistent with the well-established principle that the pressure for sleep (particularly for deep sleep) increases as the length of time awake increases.

Older crewmembers obtained less sleep regardless of when their sleep opportunity was provided. Other studies have suggested that older crewmembers also lose more sleep across trip patterns. These changes are consistent with well-established age-related changes in sleep, which begin at about the age of 50 years.

Taken together, these findings suggest that — on this type of flight — each crewmember should be provided with one long sleep opportunity per flight, and that, to maximize the alertness of the landing crew, the landing-crew pilots should be provided their sleep opportunity during the second half of the ULR flight sector. Given that very little deep sleep was observed in the crew-rest facilities, the feeling of grogginess and disorientation on waking (called sleep inertia) is probably not a serious concern. Nevertheless, adequate time must be allowed for the landing crew to become fully alert and to be suitably briefed to take control of the flight.

Moreover, the best pattern of in-flight rest for any given flight will depend on departure times, whether or not crewmembers are adapted to the departure time zone, and the amount and quality of sleep obtained during prior layovers.♦

— Leigh Signal, Ph.D., Philippa Gander, Ph.D., and Margo van den Berg

Notes

1. These definitions were used by the Ultra-long-range Crew Alertness Steering Committee, a safety initiative cosponsored by Airbus, Boeing Commercial Airplanes and Flight Safety Foundation.

2. This article is based on the technical report titled “Sleep During Ultra-Long Range Flights: A Study of Sleep on Board the [Boeing] 777-200ER During Rest Opportunities of 7 Hours” by Leigh Signal, Ph.D., Philippa Gander, Ph.D., and Margo van den Berg. The authors are researchers at the Sleep/Wake Research Centre, Massey University, Wellington, New Zealand. This study was funded by Boeing.

3. A typical night’s sleep normally involves four cycles or five cycles of brain activity (electrical waves) that include non-rapid-eye-movement (NREM) sleep followed by rapid-eye-movement (REM) sleep. Within NREM sleep, sleep stages can be identified by specific patterns in an electroencephalogram (a visual representation of brain-activity wave forms). Stage-1 sleep lasts for a few seconds to 10 minutes and a person awakened during this stage may not realize that the onset of sleep occurred. Stage-2 sleep is slightly deeper than stage-1 sleep and lasts between 10 minutes and 45 minutes. Stage-3 sleep and stage-4 sleep comprise the deepest sleep (also called slow-wave sleep), which has important restorative properties and growth-inducing properties involved in maintaining general health.

4. Almost all dreaming occurs during REM sleep, which is similar in depth to NREM stage-2 sleep. Although the body is nearly motionless during REM sleep (except for twitches), the brain is as active or more active than when the person is awake. REM sleep completes each sleep cycle and plays a major role in memory, learning, task performance and mental health.

ULR crew-rest facilities must be even more conducive to effective sleep than those used in current long-range operations; such facilities are intended to enable pilots to relax in a reclining seat before transitioning to sleep in a horizontal bunk, and provide for a comfortable transition to full alertness after waking from in-flight sleep. Design of ULR crew-rest facilities also considers the lavatory/washroom, communication system, alert system, ventilation, temperature/humidity control, light/noise control, minimum-equipment-list status, in-flight entertainment system and power for portable electronic devices. Security issues also were recognized as a major consideration, Graeber said.

During the Paris workshop, deliberations included assessing models of ULR operations. Models used a combination of real-world data and interpolated data representing validated assumptions about crew rest and crew alertness/performance. The Singapore–Los Angeles city pair was evaluated — as an example — by altering specific variables such as crew complement and rest periods, then predicting the effects.

Although methods of measurement, modeling and laboratory experiments initially seemed too isolated from actual flight operations to be suitable for safety decisions, a consensus was reached that such methods are appropriate for ULR city-pair evaluations and that predictions from models can be generalized among average pilots, Graeber said.[6] Presenters said that their models should be considered as tools to aid understanding of complex data and that predictions by models should not be accepted as a sole basis for approval decisions about ULR city pairs.

Results from models of the Singapore–Los Angeles city pair were presented by representatives of QinetiQ, Harvard Medical School and the University of South Australia. Despite slight differences in output data, all three models predicted that ULR operations using a crew complement of four pilots would enable all pilots to be sufficiently alert for safe performance at their duty stations, Graeber said. The scientists said then that they recognized the absence of reliable data about crewmember sleep in bunks for periods of six hours or longer. They also said that limitations in modeling capabilities must be addressed by validating all model-based predictions through comparison with data from actual ULR line operations for the same city pair.

"Modeling conducted so far has tended to concentrate on the lower limits of ULR — flight sectors of about 16 hours," Graeber said. "Validated predictions of fatigue and alertness levels out to 21-hour flight sectors would be of considerable value when ULR operations commence and new city pairs are proposed."

Discussions in Workshops Generate Consensus

Participants in the Washington workshop and the Paris workshop also exchanged information and opinions about the following issues:

- Required level of flight crew alertness and performance during each phase of flight, go/no-go guidance for captains, international standard measures (including a global validation committee) and collection of operational validation data derived from existing programs that monitor crew performance — such as flight operational quality assurance (FOQA)[7] and line operations safety audits (LOSA)[8] — and providing confidential systems that crewmembers can use to call attention to safety concerns;

- Crew complement (guidance on systems for determining the number of pilots in a flight crew), crew composition, advance scheduling and other mechanisms to ensure sufficient rest for standby crews, changes in crew demographics, assignment/transfer of command responsibility, ULR-flight training and qualifications, and maintenance of pilot proficiency;

- Preflight crew scheduling, including standby/reserve-pilot policies, minimum standby/reserve schedule-notification time, preflight synchronization of the body clock with the departure time zone, and deadheading/positioning flights;

- In-flight-rest scheduling (completed and communicated in advance to pilots, cabin crew and standby crews), including pilot-in-command authority for variations in this schedule, early/late departure-time windows, exercise breaks, rest periods and meals, and regulatory aspects and liability aspects of transferring command authority among pilots between rest periods;

- Crew-operating patterns (trip scheduling), including the frequency of ULR-flight assignments to individual pilots; procedures for departure delays, disruptions and diversions; minimum duration of layover periods to protect recovery sleep (sufficient rest before flight); change of crew bases; and the cumulative effects of ULR flights on pilots' health and flying proficiency; and,

- Specific educational guidance for pilots on individual responsibility for proper use of rest periods and personal strategies (preflight and in-flight), including sleep, naps, diet, exercise, stress management, crew resource management and managing alertness, such as when commuting before reporting for duty. Workshop participants also discussed similar educational guidance for management, schedulers and all other airline staff involved in ULR operations.

Preliminary results of a study of crewmember bunk sleep during delivery flights of the Boeing 777-200ER were presented at the final workshop.[9] In Kuala Lumpur, representatives from the previous workshops developed best-practice guidance for operators and crews; broadened how research efforts and modeling efforts could be conducted to address maximum flight-sector lengths; established technical recommendations for model validation; and identified opportunities to provide expertise to ULR-related rulemaking and approval processes.

Representatives of cabin crew unions participated as observers and made a presentation at the Paris workshop. They said that alertness issues and performance issues for cabin crew parallel those of pilots in most respects, requiring scientifically based provisions for adequate crew complement, in-flight rest and crew-operating patterns. Some cabin safety specialists anticipate exponentially greater passenger demands, disruptions and in-flight medical emergencies during ULR operations, they said. The steering committee developed a recommendation on augmented cabin crew because of the importance of adequate rest in ULR operations, but anticipates related issues to be addressed thoroughly in another forum, Vandel said.

The Foundation's interest in ULR operations evolved from an earlier initiative on safety issues — including crew flight-time periods and duty-time periods — that preceded the introduction of long-range corporate jet aircraft, he said. As in that initiative, the Foundation believes that additional work will be required to ensure that ULR operations have a scientifically sound basis, and that the scientific community has sufficient funding to continue basic research, apply evolving knowledge, model flights and monitor crew alertness and performance.♦

Notes

1. The Ultra-long-range (ULR) Crew Alertness Steering Committee has proposed that a ULR operation be defined as "an operation involving any sector between a specific city pair (A-B-A) in which the planned flight time exceeds 16 hours, taking into account mean wind and seasonal changes." Airplanes designed for ULR operations by airlines currently include the Airbus A380 and A340-500, and the Boeing 777-200ER, 777-200LR and 777-300ER.

2. Singh, Jarnail. Civil Aviation Authority of Singapore (CAAS). "Study of Pilot Alertness Highlights Feasibility of Ultra Long Range Flight Operations." *ICAO Journal* Volume 58 (January–February 2003): 14–15, 30. Dr. Singh is chairman of the Civil Aviation Medical Board of CAAS and chaired the CAAS ULR Task Force.

3. Spencer, Mick. QinetiQ. "Modelling of Crew Alertness in Future Ultra Long-range Schedules, Based on a City Pair." The QinetiQ modeling study was conducted by the European Committee for Aircrew Scheduling and Safety for the Airbus A340-500 Joint Operations and Evaluation Board of the European Joint Aviation Authorities.

4. On April 22, 2002, the ULR Crew Alertness Steering Committee submitted a working paper titled "Crew Alertness During Ultra-long-range Operations" to Operations Panel Working Group 1 of the International Civil Aviation Organization (ICAO OPSP WG 1). Amendments should be considered to the standards and recommended practices (SARPs) in ICAO Annex 6, *Operation of Aircraft*, Part 1, *International Commercial Air Transport–Aeroplanes*, and associated guidance (through ICAO Air Navigation Committee Task OPS-0010: "Limits for Flight Crew Time, Flight Duty Periods and Rest Periods" [FTL]), the steering committee said. The amendments should consider the current state of scientific knowledge relevant to the regulation of FTL and the aspects of ULR operations that will become common worldwide. "While it is acknowledged that it is impossible to expect that 'one size fits all' for today's FTL regulations, it is hoped that because of the similar nature of ULR operations, irrespective of where they originate, it should be feasible to develop a global regulatory approach to the problem," the steering committee said. "In view of the almost unique nature of such activity, the establishment of some form of global monitoring body that would undertake periodic reviews of actual ULR operations is also considered appropriate. … ULR regulations must include a requirement for operators to establish and maintain a system of continuous feedback from crews involved in such operations and … ULR operations must be subject to ongoing validation." New ICAO definitions of the following terms likely will be required to express ULR-specific concepts in SARPs and national regulations: crew operating pattern, duty flight crew, duty flight crew cycle, in-flight rest period, off-duty flight crew, off-duty flight crew cycle and ULR standby.

5. Fatigue-risk-management systems (FRMS) — as implemented by Air New Zealand in New Zealand and Qantas Airways in Australia — are designed to provide objective methods of ensuring acceptable levels of crew alertness. They are characterized by crew education and awareness, estimating and recording fatigue levels, determining acceptable fatigue levels, reporting unacceptable fatigue levels, schedule analysis, validation, auditing by the civil aviation authority and confidential crew reporting. FRMS was described in ICAO Document OPSP–WG/1–WP/8, Nov. 13, 2001.

6. Mallis, M.M.; Mejdal, S.H.; Nguyen, T.T.; Dinges, D.F. "Summary of Key Features of Seven Biomathematical Models of Human Fatigue and Performance. *Aviation, Space, and Environmental Medicine* 2003 (with supplement, in press). This article contains examples of current models.

7. Flight operational quality assurance (FOQA) is a program for obtaining and analyzing data recorded in flight operations to improve flight crew performance, air carrier training programs, operating procedures, air traffic control procedures, airport maintenance and design, and aircraft operations and design.

8. A line operations safety audit (LOSA) includes observation and collection of empirical data about flight crew performance and behavior during scheduled flights. Collected data on factors such as proficiency, decision making, crew resource management (CRM) and compliance with standard operating procedures are de-identified and remain confidential. LOSA also involves the recording of threats, such as adverse weather, aircraft malfunctions and crew errors — and the performance of crewmembers in managing the threats and errors.

9. Signal, Leigh; Gander, Philippa; Van den Berg, Margo. "Sleep During Ultra-Long Range Flights: A Study of Sleep on Board the [Boeing] 777-200ER During Rest Opportunities of 7 Hours." Boeing Commercial Airplanes, May 2003.

Appendix A
Ultra-long-range Crew Alertness Initiative
Operational Best Practices Subgroup Report

Facilitator:

Capt. Freddie Koh, Singapore Airlines

Participants:

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Capt. Harold H. Dahlmann, Civil Aviation Authority of Singapore

David Flower, M.D., Consultant (British Airways)

Capt. Gerard Gunter, Malaysian Airline System

Ian Hosegood, M.D., Emirates Medical Services

Capt. Kwok Him Yick, Civil Aviation Authority of Singapore

Capt. Chris Lawrence, Hong Kong Airline Pilots Association

Key Issues:

- Crew complement;
- Education;
- Delays and disruptions;
- Standby;
- In-flight environment;
- Rostering practices, including in-flight rest rostering;
- Go/no-go.

Recommendations — Guidelines for Best Industry Practice for ULR Operations:

Assumption: ULR operations consist of an out-and-back operation between an approved city pair using a specific aircraft type with a defined departure window.

- Crewing:
  - Flight crew complement:
    - For initial operations between a city pair, the number of flight crew required would need to be assessed using the best scientific means available at the time and industry operational experience. Following this assessment, if there is a discrepancy between the two recommendations, adopting the higher crew complement would represent best practice.
    - During the initial operations, a validation of the crew complement should be carried out. This validation should consist of a scientific assessment of crew alertness level, confidential crew reporting and any other evidence-based means available (e.g., flight operational quality assurance [FOQA], flight data monitoring [FDM], line operations safety audit [LOSA], etc.).
    - If the validation fails to support the original assessment, a review should be undertaken.
  - Flight crew qualifications:
    - Best practice suggests that ULR flight crews should have adequate operational experience, including previous long-range flights.
    - For ULR operations, the flight crew complement will not be less than four pilots, two of whom should hold pilot-in-command qualifications and four of whom should be qualified for the takeoff and landing phases of flight. A crewmember qualified as pilot-in-command should be at the controls at all times. Any assigned pilots who are not takeoff and landing qualified should be trained to support the command-qualified pilot in conducting landings and emergency procedures, including pilot incapacitation and emergency evacuation.
- Education:
  - Regulatory authorities should require the operator to provide appropriate education to ground and flying staff associated with ULR operations. This should include, but not be limited to, management, flight crew, cabin crew, scheduling and rostering staff, dispatchers (as appropriate), operational control staff, and airline medical service providers. Training should be tailored to the job description, as appropriate.
  - Curricula should include, but not be limited to, the following topics:

- Consequences of fatigue on aviation safety;
- Physiology of sleep;
- Circadian rhythms;
- Homeostatic process;
- Sleep and alertness strategies;
- Diet and hydration;
- Prescription and nonprescription medication;
- In-flight environment; and,
- Work scheduling.

- Delays and Disruptions:
  - The ULR approval should include a maximum departure delay after scheduled time of departure as a limit.
  - As part of the city-pair ULR approval, regulatory authorities should require operators to demonstrate plans to cope with delays and disruptions, including diversions.
  - The pilot-in-command has the final authority for any variation from the ULR scheduled duty. Following consultation with all operating crewmembers, the pilot-in-command should assess crew fatigue levels to determine whether the flight can be safely conducted.
- Standby:
  - Regulatory authorities should require the operator to demonstrate that its standby activation system will ensure that a crewmember assigned to ULR duty from standby status will have fulfilled the pre-ULR rest requirements.
  - ULR operations may require a dedicated standby system with crewmembers aware of the potential ULR assignment.
  - Early notification of in-flight rest allocation is desirable.
- In-flight Environment:
  - Rest:
    - Regulatory authorities should require the operator to demonstrate that the crew-rest facilities are sufficient to provide adequate rest opportunity in order to ensure that pilot alertness is maintained at an acceptable level. Preferably, these should include both an acceptable sleeping surface and the provision of a comfortable reclining seat for non-sleeping rest. Ideally, each resting pilot should have an individual sleeping compartment with facilities available to enable him or her to have a choice of a comfortable reclining seat or sleeping surface at all times. These facilities should be separated from the flight deck and not be positioned in the passenger cabin.
    - Comment: It is assumed that the design requirements for the rest facilities will be covered under a separate document (e.g., advisory circular). The following factors should be considered, as well as other sleep/rest related requirements:
      - Noise levels;
      - Space for changing into and out of uniform/sleep suit;
      - Reading lights;
      - Ventilation, temperature and humidity controls;
      - Alert systems and a communication system to the flight deck and passenger cabin; and,
      - In-flight entertainment and other passenger-cabin provisions.
  - Lavatories:
    - There should be a lavatory dedicated for flight crew use within a secure area and accessible from the flight deck.
  - Flight deck environment:
    - Due consideration should be given by operators to encourage manufacturers to continue improving flight deck ergonomic design aspects to assist in reducing stress and fatigue levels. Examples could include comfortable seating, suitable lighting, adequate provision of sunshades on all windows (to limit sunlight and heat), noise management, humidification and appropriate alert systems.
- Rostering Practices:
  - ULR operating pattern (including flights and layovers) — The build of a ULR pattern should:
    - Provide adequate preflight sleep opportunities so that it is possible for crewmembers to be fully rested;

    - Ensure that the layover provides an adequate sleep opportunity so the crewmembers are adequately rested for the return flight;

    - Provide adequate recovery time after the pattern to allow for physiological recovery from the trip;

    - Provide reasonable additional time off for normal social interaction; and,

    - The recovery time should not be used as pre-ULR rest requirements.

  – In-flight rest:

    - Regulators should ensure that operators have a responsible scheme for in-flight rest planning.

    - Operators should provide guidance to crew for in-flight rest planning.

    - This information should be tailored for the specific flight pattern.

    - Crews should be given adequate prior notification of their allocated in-flight rest period.

  – Scheduling of ULR trips:

    - Positioning is considered duty and may not be part of a pre-ULR rest period.

    - A ULR flight duty period may not be combined with other duties in a single duty period (e.g., simulator sessions, recovery days, office work or other flights).

- Go/No-go:

  – Operators should provide the crew with suitable go/no-go guidance material affecting crew performance with regard to crew alertness and/or rest facilities on:

    - Minimum equipment list (MEL) provisions;

    - Delays;

    - Disruptions;

    - Diversions; and,

    - Any other areas that may affect crew alertness.

Recommendation:

Because on-board crew sleep will be a critical factor in ULR operations, the quality of the crew-rest facility is of paramount importance. We recommend the development of guidance to ensure that crew-rest facilities are adequate for proposed ULR operations. The International Civil Aviation Organization (ICAO) should be encouraged to provide suitable specifications for rest facilities.♦

Appendix B
Ultra-long-range Crew Alertness Initiative
Operational Validation Programs Subgroup Report

Facilitator:

Capt. Richard Woodward, Australian and International Pilots Association, International Federation of Air Line Pilots' Associations

Participants:

Capt. Mike Davis, Hong Kong Civil Aviation Department

Capt. H.K. Leong, Singapore Airlines

Trevor Phillips, British Air Line Pilots Association

Leigh Signal, Ph.D., Sleep/Wake Research Centre, Massey University

Dr. Jarnail Singh, Civil Aviation Authority of Singapore

Capt. Othman bin Mat Taib, Department of Civil Aviation, Malaysia

Regine Vadrot, Airbus

Key Issues:

- Overview of the validation process (Figure 1, page 12):

  – Before initiation of ULR operations, a steering committee composed of representatives from the operator, pilots' group and regulators must be established and define the validation plan. The assistance of a subject matter expert (SME) may

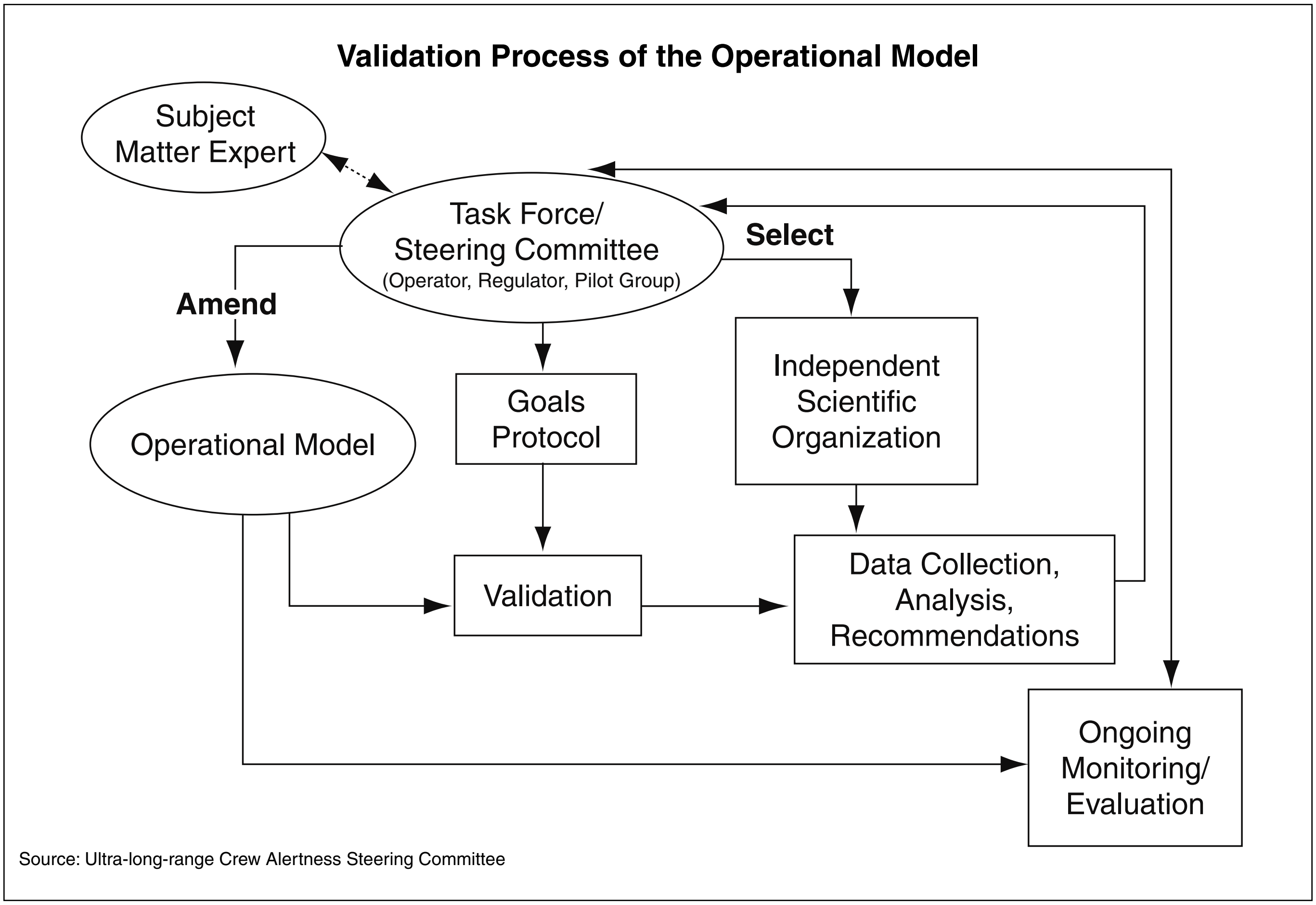

Figure 1

be required. The steering committee will select an "independent" scientific organization to assist in the data collection, analysis and recommendations. It is recommended that the SME should be from a different organization than the scientific group conducting the validation.

– Validation is required from the commencement of ULR flights and should be conducted in two phases: initial validation and ongoing monitoring. The initial validation should be sufficiently rigorous to ensure operational safety equivalent to, or better than, that in current long-range operations.

– As a result of initial validation, the operational model may then be adjusted as required, and ongoing monitoring will continue to take place.

- What do we validate?

  – We validate the ULR operational model to include validation of the agreed assumptions upon which the ULR approval is based. For example, this includes variables such as the city pairs, aircraft types, departure windows, routing, pre-ULR rest, post-ULR rest, crew complement, in-flight rest strategy, rest rostering in flight, etc.

  – The objective is to determine whether the level of flight crew performance/alertness and safety is equivalent to or better than that existing in current long-range operations.

- When validation should take place:

  – Initially, at launch of operations;

  – Continuous monitoring is required;

  – Specific validation may be required; and,

  – Any change to the ULR operational model.

  The recommendation is that the steering committee will in each case assess any change to the ULR operational model and decide whether some type of validation is needed for that particular change.

- Triggers for reassessment:

– The primary triggers requiring reassessment by the steering committee are changes to city pair, departure time window, time zone and aircraft type.

– These secondary triggers should also be considered:

- Crew demographic change (e.g., age distribution, gender distribution, etc.);
- Crew base change; and,
- Same city pairs, but route change.

- Validation metrics:

– Initial validation must include both subjective and objective measures, and we recommend the measures from the following toolbox.

– Toolbox:

- Sleep: sleep diaries (subjective), Actiwatches with diaries (objective), polysomnography (objective);
- Alertness: subjective rating scales, electroencephalography (EEG)/electrooculography (EOG) (objective);
- Performance: subjective rating scale, reaction time tests (objective), other cognitive tasks (objective).

– Ongoing monitoring may include some of the items from the toolbox in addition to normal processes as adopted by the operators (e.g., line operations safety audit (LOSA), flight operational quality assurance (FOQA), crew reports, air safety reports, etc.), regulatory feedback and/or confidential reporting.

Recommendations:

- International Civil Aviation Organization (ICAO) should incorporate standards and recommended practices (SARPS) for ULR operations in Annex 6 to the Convention on International Civil Aviation: Operation of Aircraft;
- The establishment of an SME group; and,
- The establishment of a standard recording procedure and database.♦

Appendix C
Ultra-long-range (ULR) Crew Alertness Initiative
Global Regulatory Approach Subgroup Final Report

Facilitator:

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Participants:

Francis R. John, Air Line Pilots Association – Singapore

James W. Johnson, Air Line Pilots Association, International

Capt. Ooi Teong Siew, Malaysia Airlines

Capt. Paul Ridley, Emirates

Capt. Philip Smith, General Civil Aviation Authority, United Arab Emirates

Capt. Phillip Walker, Cathay Pacific Airways

Richard Yates, Aviation Consultant

Key Issues:

- Definition of "ULR operation":

An operation involving any sector between a specific city pair (A–B–A) in which the planned flight time exceeds 16 hours, taking into account mean wind conditions and seasonal changes.

- Regulatory Requirements:

To be granted approval to conduct ULR operations, an operator must comply with the following minimum requirements:

– Submit to the applicable civil aviation authority an operational plan that has been developed using a scientifically based approach, or equivalent, to achieve an acceptable level of safety, taking into account at least the following:

- Departure time windows;
- Rostering arrangements for operating flight crew and cabin crew, and standby crewmembers;
- Proposed rest requirements:

– Preflight;

- In flight; and,
- Post flight;

- Crew complement (appropriately qualified flight crew [minimum of four] plus augmented cabin crew to enable adequate rest on board);
- Standby activation;
- Exceptional circumstances/commander's discretion; and,
- Proposed validation program.

  Note: It is not the intent of this document to preclude future flight schedules comprising more than two sectors, one of which is a ULR sector. However, any changes to the originally approved and validated city pair operation will require a revised operational plan. The ability of the industry to address such changes will be improved in the light of actual ULR experience.

– Propose a validation program that covers at least the following:

- Establishment of an operational steering committee comprising representatives of the company, the regulator and the pilots' association to define the validation plan and provide oversight;
- Standardized methodology for initial validation:
  - Sample size;
  - Sampling intervals;
  - Objective measures — operational and/or individual; and,
  - Subjective measures;
- Ongoing monitoring — all aspects (i.e., sleep achieved, performance, etc.):
  - Sample size;
  - Sampling intervals;
  - Objective measures — operational and/or individual; and,
  - Subjective measures;
- Occasions when revalidation is required; and,
- Feedback reporting system.

– Develop rest requirements that take into account both preparatory and recuperative rest that meets the modeled assumptions, or equivalent, covering:

- Preflight;
- In flight; and,
- Post flight;

  Note: It is intended that before a crew undertakes a ULR operation, crewmembers will be acclimatized to the initial point of departure both before a ULR operation and, following return from a ULR operation, before undertaking any other flight duty.

– Provide adequate rest facilities that enable horizontal rest for crewmembers resting in flight (e.g., Australian and International Pilots Association facility standard AIPA-RS 001-1998, toilet requirements, environment, etc.);

– Develop material to provide appropriate training and education for all staff involved in the operation; and,

– Develop material for the operations manual that addresses all of the above.

Note: Regulators may need to review/revise existing regulatory material in the light of ULR (e.g., where existing hard limits may be exceeded by ULR — 18 hours maximum flight duty period) and "grandfather rights."

- Approval process will require at least the following:
  - Initial approval:
    - Submission of the proposed operational plan;
    - Consideration of the proposed operational plan by the civil aviation authority. This should be an iterative process between the civil aviation authority and the operator;
    - Submission of operations manual amendments reflecting the proposed operational plan; and,
    - Initial approval by the civil aviation authority (e.g., operations specifications/variations/approval/interim approval).
  - Final approval and ongoing safety oversight by the civil aviation authority, which, based on the validation program, may require modification of the regulatory basis.

- City pairing — Once a city pair has been approved, additional destinations in the same "cluster" may be considered, taking into account the following to achieve an equivalent level of safety:
  - Time zone;
  - Departure time windows;
  - Acceptable increase in flight time;
  - Operational variables; and,
  - Risk levels.

Recommendations:

- Proposals should go to the International Civil Aviation Organization (ICAO) for consideration/inclusion in standards and recommended practices (SARPS) to cover ULR operations. The ULR Crew Alertness Steering Committee should recommend accordingly and include provision for operators to adopt a fatigue risk management approach as an alternative to prescription.

- A fatigue-risk-management system (FRMS) is a quality-assurance system that provides an objective method for ensuring that levels of crew alertness remain within acceptable limits and has the following characteristics:
  - Education and awareness training programs;
  - A means of estimating and recording fatigue levels based on duty hours;
  - A means of setting acceptable fatigue risk exposure levels for different activities;
  - A means of recording and reporting any exceedance of acceptable fatigue risk exposure levels (as determined by the state of the operator);
  - A means of recording and reporting incidents that are attributable, wholly or in part, to fatigue;
  - A means of analyzing a roster both prospectively and retrospectively for reasonableness and compliance;
  - A validation mechanism;
  - It is auditable by the regulatory authority;
  - It may use software validated for reliability and integrity; and,
  - Includes a confidential crew reporting mechanism with associated feedback.

Other outstanding items:

Method of ensuring flight crew proficiency: Resolving this issue is recognized as critical for assuring the safety of ULR operations; however, it was deemed outside the prescribed scope of crew alertness that governed our efforts. Another, more qualified group needs to consider flight crew proficiency for ULR operations and define the regulatory requirements necessary to achieve them.♦

Appendix D
Ultra-long-range Crew Alertness Initiative Research and Development Subgroup Report

Facilitator:

Philippa Gander, Ph.D., Sleep/Wake Research Centre, Massey University

Participants:

Phil Armitage, Qantas Airways

Capt. Greg Fallow, New Zealand Air Line Pilots' Association, International Federation of Air Line Pilots' Associations

Jim Lyons, Joint Aviation Authorities

Greg Roach, Ph.D., Centre for Sleep Research, University of South Australia

Key Issues:

- General principles:
  - Funding:
    - Availability of funds — who should fund?
    - Those that will benefit should fund — the stakeholders (e.g., manufacturers, operators, regulators, crew associations).
  - Conditions of funding:
    - Minimize proprietary information and maximize public availability.

- Incentives:
  - Worldwide improvement in safety;
  - Recognizing that the public interest could benefit the company interest (customer loyalty — the third bottom line); and,
  - Reduce duplication of effort.

- Disincentives to making information available:
  - Shareholder interests/profits; and,
  - Perceived loss of competitive advantage.
  - Visibility and accessibility of data and results: All research projects should include a full report to all stakeholders, peer-reviewed publications and feedback to the research advisory panel (for quality assurance).
  - Standardized methodology allows for comparability/sharing of data for research and operational validation purposes e.g., subjective and objective measures of sleep and alertness.

- Research That Needs to Be Done:

  The goal is to better understand and predict the impact of flight and duty schedules and rosters on crew performance and flight safety. There are some key research questions and issues that need to be addressed:

  - What are the relationships between objective and subjective measures of sleep quality/quantity? Use polysomnography, which is the current standard among objective measures and involves analysis of data showing brain-wave activity (electroencephalography), eye movement (electrooculography) and muscle tone (electromyography) to validate other methods that could be equally effective or more effective but cost less to implement than polysomnography.
    - Wherever possible, multiple measures should be used until these relationships are clearly established. This will enable advice to the operational community on which measures to use in which circumstances (could enable a tool kit to be created for validation of ULR operations and possibly other operations, and continuous improvement within an organization).
  - Establish the linkages between physiological alertness (electroencephalography), vigilance (psychomotor vigilance task) and flight crew performance (line operations safety audit [LOSA] and flight data monitoring).
    - Wherever possible, multiple measures should be used until these relationships are clearly established. This will enable advice to the operational community on which measures to use in which circumstances (could enable a tool kit to be created for validation of ULR operations and possibly other operations, and continuous improvement within an organization).
  - Continue the search for practical methods for monitoring circadian phase in field settings. The current standard markers for circadian phase are the evening rise of melatonin and body temperature low point. Melatonin cannot be sampled during sleep and is suppressed by light. Temperature is influenced by levels of physical activity, and monitoring is intrusive. There are several reasons why it would be useful to be able to predict circadian phase:
    - To know where the circadian low point is occurring (if in flight);
    - To optimize personal sleep strategies; and,
    - To determine the rate of re-adaptation and recovery at the conclusion of a flight pattern.
  - Research on the effects of aging on sleep (on-board, during layovers and between trips) and its impact on operational performance.
  - Research on the impact of ULR (and other) schedules on family and social life of crew. There are growing indications in shift-work research that life outside of work is an important intervening variable in an individual's ability to cope with work demands. This information can be valuable, for example, in education and training, and work force morale and retention.
  - Research on long-term health implications for crew of ULR and other schedules.

    Multi-variate analyses are recommended to take account of factors such as age, order in the bunk, crew rank, gender and individual variability.

- Mathematical Model Application Issues:

  Mathematical modeling is a tool that is based on known situations and may be used to predict outcomes in the absence of data.

  - No mathematical model captures all aspects of a situation.
  - The data set used to develop the mathematical model should be relevant to the situation being predicted (e.g.,

the characteristics of the population, the environment in which the data were collected, etc.).

- Different mathematical models use different inputs and provide different outputs. The inputs need to be able to be measured practically in the work environment (e.g., prior work history is easy, light exposure is more difficult). The outputs have to be tailored to the problem being addressed (e.g., to what degree are mathematical model predictions indicative of overall flight crew performance).

- Mathematical models should not be used in isolation. They are one tool that can be used to develop and assess ULR operations and are a support, but they are not a substitute for operational knowledge and standard regulatory processes.

• Improving Mathematical Models:

Mathematical modeling is an iterative process of data collection and model refinement. The following are suggestions for improving the process:

- Every effort should be made to share existing data for mathematical model validation. This could be facilitated by a central research advisory panel.

- Create and improve dialog between the operational community and mathematical modelers (integrate operational personnel into mathematical modeling teams).

- Encourage mathematical modelers to communicate and publish their efforts.

Mathematical models need to be strengthened in the following areas:

- Progressively address individual variability.

- Predictive mathematical models should be expanded to include measures of reliability/variability/confidence.

• Application of Research and Mathematical Modeling to Operational Validation Programs:

Develop an integrated approach to research, mathematical modeling and operational validation for continuous improvement of ULR operations (the iterative process).

- Build tools for the regulators and operators by standardizing:

  • Questionnaires and diaries/logs;

  • Data-collection protocols (e.g., duration of preflight and post-flight recording periods); and,

  • Actigraphy methodology (e.g., epoch length, sensitivity settings and event markers).

- Address the comparability of different performance and vigilance testing devices.

- Provide feedback to the research community of data collected for operational validation, as part of the continuous improvement process.

Recommended Actions:

• Creation of a research advisory panel.

We recommend the creation of a research advisory panel under the auspices of Flight Safety Foundation, the International Civil Aviation Organization (ICAO), etc. The aim is to provide a focal point for research in ULR operations.

Membership of this body should include specialists from the following types of organizations:

- Manufacturers;

- Operators;

- Regulators;

- Scientific researchers; and,

- Crew associations.

The objectives of this body are to:

- Provide a source of information/advice on ULR operations;

- Develop a register for past, present and proposed research projects, including data collection for operational validation;

- Develop a register of qualified and competent research teams; and,

- Develop standard data collection and analysis methods for operational validation.

The registration of research teams and projects, although voluntary, would be strongly encouraged. The research advisory panel will develop information templates for submitting details about mathematical model specification and use, research teams and projects.

– An example of a template for model specifications appears on this page.

– With regard to the research projects, the intention is that the research advisory panel will provide high-level descriptions of objectives, methods, datasets available and personnel to contact. Any more detailed exchange of information would be negotiated directly between the parties.

• Crew-rest facility.

Because on-board crew sleep will be a critical factor in ULR operations, the quality of the crew-rest facility is of paramount importance. We recommend the development of guidance to ensure that crew-rest facilities are adequate for proposed ULR operations.♦

Mathematical Model Specification Example

Model Name:	Fatigue Audit InterDyne (FAID) 1W13E
Modelers:	Drew Dawson, Adam Fletcher and Greg Roach
Point of Contact	
Name:	Greg Roach
Address:	P.O. Box 232 Woodville SA 5011, Australia
Phone:	int + 618 8222 6624
Fax:	int + 618 8222 6623
E-mail:	greg.roach@unisa.edu.au
Target Market:	Organizations that employ shiftworkers, industry regulators, accident investigators, fatigue research groups.
Current Users:	Australian Transport Safety Bureau, Civil Aviation Safety Authority, Qantas Airways (maintenance engineers), Queensland Rail, Australian Western Railroad.
Supporting Agencies:	Australian Research Council Fatigue Risk Management System Project (Civil Aviation Safety Authority, Qantas Airways, Australian and International Pilots Association) Australian Rail Industry Fatigue Management Consortium

Key References

Model Description:

1. Dawson D., Fletcher A. “A Quantitative Model of Work-related Fatigue: Background and Definition.” *Ergonomics*, 44(2): 144-163, 2001.
2. Fletcher A., Dawson D. “A Predictive Model of Work-related Fatigue Based on Hours of Work.” *Journal of Occupational Health and Safety-Australia and New Zealand*, 13(5): 471-485.

Model Application:

1. Fletcher A., Dawson D. “Field-based Validations of Work-related Fatigue Model Based on Hours of Work.” *Transportation Research* Part F, 4: 75-88, 2001.
2. Fletcher A., Dawson D. “A Quantitative Model of Work-related Fatigue: Empirical Evaluations.” *Ergonomics*, 44(5): 475-488, 2001.
3. Fletcher A., Dawson D. “A Work-related Fatigue Model Based on Hours-of-Work.” In L. Hartley (ed.) *Managing Fatigue in Transportation*, Oxford, Pergamon Press (pp. 189-208), 1998.

Mathematical Model Specification Example *(continued)*

Model Validation:	1. Fletcher A., Dawson D. "Field-based Validations of Work-related Fatigue Model Based on Hours of Work." *Transportation Research* Part F, 4: 75-88, 2001. 2. Fletcher A., Dawson D. "A Quantitative Model of Work-related Fatigue: Empirical Evaluations." *Ergonomics*, 44(5): 475-488, 2001. 3. Fletcher A., Roach G.D., Lamond N., Dawson D. "Laboratory Based Validations of a Work-related Fatigue Model Based on Hours of Work." In S. Hornberger, P. Knauth, G. Costa, S. Folkard (eds.) *Shiftwork in the 21st Century: Challenges for Research and Practice*, Frankfurt am Main, Germany, Peter Lang, 2000.
Real-time Update Capability:	The model's only required input is hours of work (i.e., start/end times of duty periods). The model can be linked to an organization's roster/schedule engine such that fatigue levels can be determined in real time for any past, present or future schedule of work.
Software Interface:	The model has three interfaces: Input, Analysis, Output
Conceptual Assumptions:	Fatigue level estimates are based on the notion that the work-related fatigue associated with a duty schedule represents the balance between two competing forces: those that produce fatigue during work periods; and those that reverse the effects of fatigue, i.e., produce recovery, during non-work periods. The fatigue value of work periods and recovery value of non-work periods are determined by their timing, duration and history over the previous seven days.
Technical Assumptions:	The previous seven-day work history is complete.
Range of Validity:	See references.
Adjustable Parameters:	1-day, 2-day, 7-day sleep targets. Threshold fatigue levels for various task risk levels (low, moderate, high, extreme).
Not predicted:	Sleep inertia Influence of pharmacological countermeasures Individual differences
Validation Assessments Performed:	Length of prior work history Length of work periods and breaks Time of day of work periods and breaks

Appendix E
Ultra-long-range Crew Alertness Initiative Steering Committee Members and Other Participants

Ultra-long-range Crew Alertness Steering Committee

Capt. Greg Fallow, New Zealand Air Line Pilots' Association, International Federation of Air Line Pilots' Associations

David Flower, M.D., Consultant (British Airways)

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Safety Benefits of the Wide Area Augmentation System During Instrument Approaches

Data-driven study by Flight Safety Foundation for the U.S. Federal Aviation Administration indicates that implementation of WAAS-based precision instrument approaches could prevent accidents and fatalities.

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Summary

The U.S. Federal Aviation Administration (FAA) *Aeronautical Information Manual* (*AIM*) defines the wide area augmentation system (WAAS) as "a satellite navigation system consisting of the equipment and software which augments the GPS [global positioning system] standard positioning service (SPS) [to provide] enhanced integrity, accuracy, availability and continuity."

The key benefit of WAAS is that it provides accurate and reliable navigation information in three dimensions. This means that pilots can receive accurate information about their position in the two-dimensional horizontal plane (i.e., latitude and longitude), as well as accurate information about their position in the vertical plane (i.e., altitude).

The general purpose of this study is to measure the degree of risk reduction that can be expected with the implementation of WAAS within the U.S. National Airspace System (NAS). Specifically, this study estimates the reduction in accidents and loss of life through the introduction of precision approach capability provided by WAAS to airports that currently have runways with nonprecision approaches. The study was limited to this very specific focus because it was a benefit that could be quantified and described.

The results indicate that approximately 141 accidents could be prevented over a 20-year period and that more than 250 lives could be saved through the introduction of WAAS-based instrument approaches. These are conservative estimates.

The safety improvements cited in this study would be greater if the overall growth rate for aviation exceeds the growth rate of 2 percent used in the study. If the growth rate averages 3 percent per year for the period 2001 through 2020, the estimated total number of accidents prevented would increase to approximately 175 and the number of lives saved would increase to approximately 315. Conversely, if the growth rate averages 1 percent per year during the period, the estimated accidents and deaths prevented would decrease to approximately 114 and 206, respectively.

Other benefits provided by WAAS also are reviewed and described. WAAS-based approaches will allow pilots to conduct stabilized instrument approaches in instrument meteorological conditions (IMC) and to maintain obstacle clearance at night, when terrain features are not visible, and in marginal visual flight rules (MVFR) conditions (usually considered as three statute miles to five statute miles [five kilometers to eight kilometers] visibility). These benefits likely would be most useful during single-pilot flight operations. Moving-map displays will help pilots maintain their situational awareness — a key component of

safe flight, especially in instrument conditions — and encourage direct point-to-point navigation, thereby reducing fuel use and improving air traffic control (ATC) routing flexibility.

Many airports that do not have instrument-approach capability will be able to implement precision-approach capability. This benefit also would be applicable to heliports at hospitals and at other locations. Precision-approach capability would improve the utility of these airports and heliports, reduce capacity demands on larger airports and improve safety because pilots will be able to fly instrument approaches to airports or heliports that are more convenient.

Introduction

The U.S. Department of Defense (DOD) began a research and development program in the early 1970s to develop an integrated navigation and position-determination system based on information transmitted from GPS satellites. GPS provides precise navigation signals anywhere satellite coverage is available. The first operational satellite was deployed in 1989. As of October 2001, 24 GPS satellites were deployed.

The FAA recognized that the type of guidance available from GPS would have large potential benefits for the civilian aviation community. The potential benefits include precise three-dimensional navigation (i.e., altitude guidance as well as lateral guidance), reduced separation standards for more efficient use of airspace, precision approach capability at many runways, lower avionics costs, reduced training costs, and significant cost savings from the eventual reduction of ground-based navigation systems. In addition to the economic benefits, there are potential safety benefits.

FAA has been developing a civilian aviation navigation system based on GPS. A key component of FAA's system is WAAS, which is designed to provide an accurate and reliable navigation signal for civilian aviation to support all phases of flight, including Category I precision approaches (typically, with minimums of 200 feet and 1/2-mile visibility).[1]

WAAS Description

The key benefit of WAAS is that it provides accurate and reliable navigation information in three dimensions. This means that pilots can receive accurate information on their position in the two-dimensional horizontal plane (i.e., latitude and longitude), as well as accurate information about their position in the vertical plane (i.e., altitude). This information is accurate to about seven meters (23 feet).

The type of information that will be available to pilots from WAAS will include precise en route navigation information, groundspeed, height above terrain and precision approach guidance. WAAS also will support moving-map displays in the cockpit that highlight the aircraft's position relative to fixed features such as terrain, navigation routes and runways. These benefits, and others, will prove helpful to pilots and likely will improve the safety of flight operations.

Research Goals

While many of the benefits of GPS, and specifically WAAS, have potential positive economic components, there also are many potential safety benefits from the introduction of the enhanced navigation capability provided by WAAS. The general purpose of this study is to measure the degree of risk reduction that can be expected with the implementation of WAAS within the NAS. Specifically, this study estimates the reduction in accidents and loss of life through the future addition of the precision approach capability provided by WAAS to airports that currently have runways with nonprecision approaches. The study is limited to the NAS and will rely on data from the past 18 years.

Objectives

There are two main objectives of this study. They are to:

- Quantify the safety benefits associated with implementation of WAAS in the NAS; and,
- Develop graphical depictions of the benefits of WAAS (as estimates of losses prevented).

Research Questions

The basic research questions to be answered by this project are:

- Will WAAS implementation reduce the risk of accidents?
- How much safety improvement will result from WAAS implementation?

Differences in Approach Types

The basic tenet of this study is that precision approaches provide additional safety benefits compared to nonprecision approaches.

Flight Safety Foundation defines precision approach, nonprecision approach and stabilized approach as follows:[2]

- Precision approach — An instrument approach with lateral guidance and vertical guidance from the final approach point (FAP) to the runway touchdown zone, with system accuracy, integrity and obstacle clearance guaranteed until the descent limit (decision altitude or decision height) is reached.

- Nonprecision approach — An instrument approach with lateral guidance from the final approach fix (FAF) to the runway environment. Descent limit is the minimum descent altitude (MDA), and obstacle clearance is guaranteed if the approach is discontinued at or before the missed approach point (MAP).

- Stabilized approach — An approach procedure along the extended runway centerline with a constant, in-flight-verifiable descent gradient from the final approach altitude to the runway touchdown zone. ILS (instrument landing system) procedures are inherently stabilized approach procedures (except in the rare case of an offset localizer). More information on stabilized approaches appears in Appendix B (page 38).

Generally speaking, precision approach guidance in the United States is provided by ILS equipment. An ILS includes two transmitters located near the runway that provide the electronic signals for vertical guidance (glideslope) and lateral guidance (localizer). An ILS usually is supplemented with specialized approach light systems. The most common ILS approach procedure is a Category I procedure, which provides for an approach to a height above touchdown of not less than 200 feet and with runway visual range (RVR) of not less than 1,800 feet (the typical visibility minimum is 1/2 statute mile). Category II approach procedures and Category III approach procedures have lower approach minimums but require special certification for the pilots, the aircraft and the ILS equipment, and typically are implemented only in areas where very low ceilings or visibilities are common. Precision approach guidance also is provided by precision approach radar (PAR), which is available at a few military facilities, and by microwave landing systems (MLS), available at a few civilian facilities. Installation and maintenance of precision approach systems are relatively complex and costly.

One of the key benefits of a precision approach is the obstacle clearance provided if the vertical guidance and horizontal guidance are adhered to. Precision approach procedures are more conducive than nonprecision approach procedures to stabilized approaches.

Nonprecision approaches do not provide electronic vertical guidance. Lateral guidance typically is less precise than that provided by an ILS. A variety of navigation transmitters provide lateral guidance for nonprecision approaches. The transmitters include very-high-frequency omnidirectional radios (VORs), nondirectional beacons (NDBs), localizers and GPS.

The differences between a precision approach and a nonprecision approach become more apparent when the general procedures used to fly the approaches are considered. (There are many variations to the general procedures described here.)

During an ILS approach, the pilot receives both vertical guidance and lateral guidance to a point in space from which a stabilized visual approach to the runway touchdown zone can be conducted. If the pilot cannot continue the approach visually from this point, a missed approach must be conducted.

The pilot's workload is higher during a nonprecision approach: The pilot typically receives lateral guidance and uses the barometric altimeter to position the aircraft vertically according to published minimum altitudes for various segments of the approach. During the final segment, the pilot must not descend below the MDA before reaching the MAP, which typically is identified by timing from the FAF, unless the pilot acquires the required visual references. If the approach cannot be continued visually from the MAP, the pilot must conduct a missed approach. The MAPs for many nonprecision approaches are at points in space from which a stabilized approach to the runway cannot be conducted (e.g., the MAP may be too high or too close to the approach end of the runway).

Previous Research and Accidents

There is a significant amount of research and accident data indicating that precise vertical guidance during an approach significantly reduces the risk of an accident. Flight Safety Foundation found that commercial aircraft operators worldwide were five times more likely to experience an accident during a nonprecision approach than during a Category I ILS approach.[3] Several other factors were evaluated by the Foundation in recognition that multiple factors influence the safe conduct of any flight, including the successful completion of an instrument approach.[4] Even when these factors were considered, the same overall pattern emerged of greater risk associated with nonprecision approaches.

A study conducted by the Foundation in 1998 found that three-fourths of all approach accidents involving turboprop airplanes and turbojet airplanes occurred without the guidance provided by precision approaches.[5]

There have been several air carrier accidents in which pilot procedure while flying a nonprecision instrument approach was a significant factor. One accident involved a U.S. Air Force CT-43A (Boeing 737-200) carrying U.S. Secretary of Commerce Ron Brown on approach to Cilipi Airport, Dubrovnik, Croatia.

On April 3, 1996, the crew of the CT-43A attempted to conduct an NDB approach in IMC to Runway 12 at Cilipi Airport. The aircraft struck a 2,300-foot mountain. The six crewmembers and 29 passengers aboard were killed in the accident. The Air Force Accident Investigation Board concluded that "the accident was caused by a failure of command, air crew error and improperly designed approach procedure." Reconstruction of the final approach profile indicated that the aircraft tracked a course of 110 degrees inbound to the NDB rather than 119 degrees.[6] This resulted in the aircraft flying left of course and impacting high terrain. If a precision approach had been available, the accident might not have occurred.

Another accident that might not have occurred if a precision instrument approach had been available was the controlled-flight-into-terrain (CFIT) accident involving Korean Air Flight 801, a Boeing 747-300 that struck terrain during final approach to Agana Airport, Guam, on Aug. 6, 1997. The flight crew expected to conduct an ILS approach to the airport in nighttime IMC conditions. ATC informed the flight crew, however, that the glideslope was out of service and told them to fly a localizer (nonprecision) approach. Analysis of the cockpit voice recorder (CVR) recording indicated that there was confusion about the glideslope status among the flight crew, but the crew correctly set the flight deck instruments for the localizer approach. The crew conducted the approach but did not initiate a missed approach quickly enough when they determined that the runway was not in sight. The airplane struck Nimitz Hill, which is three miles southwest of the airport. A total of 228 of the 254 people aboard the flight were killed. The U.S. National Transportation Safety Board (NTSB) determined that the probable cause of the accident was "the captain's failure to adequately brief and execute the nonprecision approach and the first officer's and flight engineer's failure to effectively monitor and cross-check the captain's execution of the approach."[7]

Benefits of Precision Approach Aids in IMC and Visual Meteorological Conditions

While the benefits of precision approaches primarily are associated with IMC, there are significant benefits associated with the use of precision approach guidance in other situations. For example, the guidance from a precision approach can be used as backup guidance for landing in visual meteorological conditions (VMC) and assist the crew in conducting a stabilized approach.

The benefits of WAAS must be considered for runways that do not have instrument approaches. While air carriers in the United States do not fly to airports that do not have instrument approaches, many general aviation operators do. Introducing instrument approach capability at airports that are limited to operations in VMC would improve access to the airports and relieve congestion at airports that currently service general aviation aircraft in IMC.

WAAS also should prove to be of great benefit to the helicopter community. Currently, most heliports in the United States, including more than 500 hospital heliports, do not have instrument approach capability. The introduction of WAAS will provide these heliports with a cost-effective precision approach capability. Such capability might also spark resurgence of the use of helicopters to transport passengers from city center to city center in busy areas such as the northeastern United States.

WAAS Characteristics

FAA plans to have WAAS precision approach capability fully implemented by fiscal year (FY) 2009; nevertheless, initial WAAS services will be available before 2009. The goal of the WAAS program is to provide precision approach capability for runways throughout the continental United States and portions of Alaska, Hawaii and the Caribbean.

WAAS will provide three levels of instrument approach service. The first level is basic lateral navigation (LNAV) guidance for nonprecision approaches with minimums of 400 feet to 600 feet (MDA) and one-half mile visibility for Category A aircraft and Category B aircraft, and one-mile visibility for Category C aircraft and Category D aircraft.[8] This service level will be superseded by WAAS-based precision approaches as described below.

The second level, called LNAV/VNAV (lateral navigation/vertical navigation), will reduce the landing minimums and provide vertical guidance. The minimums will include a decision height (DH) of 400 feet and one-half mile visibility for Category A aircraft, Category B aircraft and Category C aircraft, and one-mile visibility for Category D aircraft.

The third level of service, called GLS (global navigation satellite system landing system), will provide the lowest minimums available with WAAS. The GLS minimums will include a 200-foot DH and one-half-mile visibility for all aircraft. This is equivalent to the current Category I approach standard for ILS approaches.

Currently, there are 5,069 public-use airports in the United States. At these airports, there are approximately 561 ILS approaches and 1,500 nonprecision approaches (many airports have multiple instrument approaches). Many airports could benefit from the introduction of precision approach capability.

WAAS Implementation Schedule

FAA plans to have initial LNAV/VNAV capability available in FY 2004 and full LNAV/VNAV capability available by the beginning of FY 2008. GLS capability is scheduled to be introduced at the beginning of FY 2008 and to be fully available by the middle of FY 2009. Having WAAS capability available, however, does not guarantee that precision instrument approaches will be available for runways that have no approaches now or for runways that have nonprecision approaches. FAA also must ensure that all new WAAS approaches are safe to fly and meet applicable standards (as defined in FAA Order 8260.3B, *United States Standard for Terminal Instrument Procedures* [*TERPS*]). This will require obstacle-clearance review and installation of approach lighting. FAA plans to have all runways at airports serving air carrier traffic[9] approved for WAAS precision approaches by 2006. Runways that do not serve air carrier aircraft but are longer than 5,000 feet (1,525 meters) should be approved for WAAS approaches by 2010, and all other runways (as deemed appropriate) should be approved for WAAS-based approaches by the end of 2015.[10]

Another factor that must be considered is how quickly aircraft will be equipped to use WAAS for instrument approaches. Currently, GPS receivers with moving-map displays are available for about US$3,000.[11] FAA projects that about 80 percent of the civil fleet in the United States will be equipped with at least one WAAS-capable receiver and that 50 percent of the fleet will have a dual installation by 2010.[12]

Methods

General Method

The basic method used in this study was a retrospective evaluation of accidents that occurred during instrument approaches. Information from these accidents was used to estimate the safety benefits of WAAS implementation. The risks associated with precision approaches and with nonprecision approaches were calculated, normalized and compared. Factors that could be associated with increased risks such as low pilot experience or light condition also were evaluated. Once the risks of precision approaches and nonprecision approaches were quantified, the anticipated reduction in future accident risk (with the planned implementation of WAAS) was estimated.

Assumptions

Some basic assumptions were required to evaluate the benefits of the precision approach capability of WAAS. They were:

- Using precision approaches as a surrogate measure for the precision approach capability of WAAS is a valid assumption;
- The potential improvement in safety is measurable; and,
- Valid estimates for the terminal activity levels (primarily approaches) can be made.

Data Used for Analyses. Three types of data were used for this evaluation. Data on accidents that occurred during instrument approaches were obtained from NTSB. Information about airport activity and the number of instrument approaches flown was obtained from the FAA Office of Aviation Policy and Plans (APO). The NTSB data and APO data were used for the calculation of accident rates. In addition, activity projections were obtained from APO. This information was used as a frame of reference for understanding the potential reduction of future accidents with the planned implementation of WAAS. Specific steps associated with each of these data sources are described below.

NTSB Accident Records. The NTSB computerized accident database was queried to locate specific accidents that occurred in 1983 through 2000. The query was limited to accidents that occurred during instrument approaches in IMC and that occurred after the aircraft crossed the FAF. Accidents that occurred after aircraft touched down on the runway were not included.

The results of a database query conducted by NTSB were used to validate and verify the accidents obtained by the study group. NTSB briefs — typically, about 200-word summaries — were obtained for each accident; each brief provided key information such as date, location, weather, light conditions, type of aircraft, pilot qualifications and NTSB conclusions about the probable causes of the accident.

Each brief was reviewed separately by two experienced pilots/analysts to validate that the accident met the study criteria discussed above. Further, the accidents were reviewed to identify those that involved factors other than pilot error (such as mechanical failure and airframe icing). These accidents were removed because the focus of this part of the study was to estimate the risk associated with conducting precision vs. nonprecision approaches. The key assumption here was that the difference in risk, if any existed, would be associated with the actual conduct of the instrument approach, not extraneous factors such as mechanical failure or airframe icing. The results of the reviews by the two pilots/analysts were compared, and any differences were corrected by consensus of the analysts. The findings from review of the NTSB briefs were used to edit the computerized NTSB instrument approach database. These data then were analyzed with the aid of a statistical software program. Data for 2000 were eliminated because the data did not include all accidents that occurred that year. Information on the accidents used in this study appears in Appendix C (page 38).

Activity Data. Activity data — that is, the number of instrument approaches flown during the study period — were derived from the APO database, called the Air Traffic Activity Data System (ATADS). These data were used to calculate instrument approach accident rates (i.e., the number of accidents divided by the number of approaches flown). APO staff confirmed that the data derived from ATADS were the data required to calculate the accident rates.

The APO data included the number of instrument approaches flown, by airport, in 1994 through 1999. Data were not available for the previous 11 years, 1983 through 1993; therefore, interpolated activity estimates were needed for these years. Previous APO activity forecasts were reviewed to determine the average rate of aviation activity increases over the 11-year period. A 2 percent increase per year was found to be fairly uniform for the period. Using this adjustment, the estimated number of instrument approaches conducted in 1993 was calculated to be 98 percent of the number of instrument approaches conducted in 1994; the estimated number of instrument approaches in 1992 was 98 percent of the estimated number of instrument approaches in 1993; and so on.[13]

While the APO data provided a count of all instrument approaches flown, the data did not differentiate between precision approaches and nonprecision approaches.

Determination of the type of instrument approach flown at an airport was predicated on the type of runway markings at the airport. A runway served by a precision instrument approach is required to have markings that identify the runway as a precision-approach runway. Likewise, a runway served by a nonprecision approach is required to have markings that identify the runway as a nonprecision-approach runway.[14, 15]

The FAA Office of Airports collects data for the majority of airports in the United States. The data include the airport location, owners, runway configurations, runway markings and services available. These data are maintained in a database called the 5010 database (named after the form used to collect the data).

For this study, the runway-markings data were used to differentiate the APO activity data as either precision approaches or nonprecision approaches. If an airport had only precision approach markings on its runways, all instrument approaches to that airport reported by FAA were considered precision instrument approaches. If the airport had only nonprecision approach markings on its runways, all instrument approaches to that airport reported by the FAA were considered nonprecision instrument approaches. If an airport had runways with precision approach markings and with nonprecision approach markings, a weighting factor was applied to adjust the activity data for the distribution of precision approaches and nonprecision approaches for that airport. The underlying rationale is that a precision approach usually is preferred; this rationale is based on the experience of pilots involved in this study. The detailed procedures for the adjustment algorithms for airports with both precision approaches and nonprecision approaches are provided in Appendix A (page 37).

Historical Risk Determination

After the accident data and activity data were collected and verified, the following procedures were used to determine the risks associated with precision approaches and nonprecision approaches. The accident rates per million departures were calculated for precision approaches and nonprecision approaches, and were stratified by the type of operation being conducted — that is, whether the operation was conducted under U.S. Federal Aviation Regulations (FARs) Part 121 (air carrier operations), Part 135 (commuter and on-demand operations) or Part 91 (general operations). The underlying assumption is that there are significant differences in operating characteristics among these operators. The results from these analyses were used to calculate a risk ratio — that is, the accident rate associated with nonprecision approaches divided by the accident rate associated with precision approaches. The risk ratio provides a relative measure of the difference in risk between two different groups. For example, a risk ratio of two would indicate that one group encountered risk that was twice the risk of the comparison group.

Data Used for WAAS Benefit Projections

The accident-risk information was used to estimate the benefits of introducing WAAS precision approaches to the NAS. The projections were based on the risks associated with the period 1990 through 1999 rather than the risks calculated for the period 1983 through 1999 because the risks associated with the period 1983 through 1989 were much higher than the risks associated with the period 1990 through 1999 (although the patterns were similar). This was a more conservative approach because the projections would be based on more recent accident experience.

Estimates of future NAS activity were based on APO forecasts.[16, 17] The forecasts indicate steady growth of about 2 percent each year. Using this information and the information derived from historical risk evaluation, the expected numbers of precision-approach accidents and nonprecision-approach accidents without WAAS implementation were calculated. The expected number of fatalities was calculated based on past accident experience. The expected numbers of accidents and fatalities with the implementation of WAAS precision approaches then were calculated. As discussed earlier, WAAS precision-approach capabilities will be incremental because of the need for aircraft to be equipped with the appropriate receivers and because of the FAA's WAAS implementation schedule.

The anticipated benefits of WAAS begin in 2006 with the introduction of LNAV/VNAV capability. The following benefit schedule was applied for this analysis:

- 10 percent of benefit in 2006;
- 20 percent of benefit in 2007;
- 30 percent of benefit in 2008;
- 40 percent of benefit in 2009;
- 70 percent of benefit in 2010; and,
- 90 percent of benefit in 2011 through 2020.

The anticipated benefit remains constant at 90 percent from 2011 through 2020 because not all operators will use WAAS.

Limitations

The primary limitations of this study are the assumptions underlying the benefit projections. Every effort has been made to ensure that the underlying assumptions are conservative and defendable (conservative in this context means that the estimate erred toward showing no benefit). If conservative assumptions are applied and the results are robust and significant, then it can be assumed that the benefits are probably real.

As part of this conservative approach, only accidents that clearly were associated with the conduct of an instrument approach were included in this study. Two experienced pilots/analysts made this assessment. The goal was to ensure that only those accidents that occurred during instrument approaches were included.

Similarly, the benefit projections were predicated on the demonstrated risks associated with accidents during the period 1990 through 1999. As discussed earlier, the demonstrated risks for this period were lower and less variable than the risks for the period 1983 through 1989. Consequently, the period 1990 through 1999 was chosen as a more reliable frame of reference for risk projections.

The methods used to estimate past activity associated with instrument approaches may have introduced some systematic error. This error may have resulted in overestimation or underestimation of past activity. The impact of such error, if present, is likely minimized by the fact that the error should be equal for estimates of precision approach activity and nonprecision approach activity. The important metric for this evaluation is the relative difference in risk between precision approaches and nonprecision approaches; this type of error should not affect that metric.

Findings

Past Accident Experience

The NTSB accident database includes 46,979 accidents that occurred in 1983 through 1999. Of the total, 3,485 accidents (7.4 percent) occurred during the approach phase of flight. For this study, 404 approach accidents that occurred in IMC were analyzed (see "Methods," page 26). Table 1 shows the distribution by type of operation of the 3,485 approach accidents and the 404 IMC approach accidents.

As discussed earlier, the types of operation are defined by the sections of the FARs under which the accident flights were conducted, as indicated by NTSB. FARs Part 121 governs domestic, flag and supplemental air carrier operations. FARs Part 135 governs commuter and on-demand operations. (Before March 20, 1997, commuter operations under Part 135 were permitted in aircraft with 30 or fewer passenger seats and with a maximum payload capacity of 7,500 pounds [3,402 kilograms] or less. Since March 20, 1997, commuter operations under Part 135 have been permitted in non-turbojet airplanes with fewer than 10 passenger seats and in rotorcraft; scheduled service in turbojet airplanes and in other airplanes with 10 or more passenger seats have been governed by Part 121.) FARs Part 91 includes general operating and flight rules, which primarily govern general aviation operations.

Table 1
Distribution of Approach Accidents by Type of Operation, 1983–1999

Type of Operation	All Approach Accidents	IMC Approach Accidents
FARs Part 121	106	16
FARs Part 135	230	72
FARs Part 91	3,149	316
Total	**3,485**	**404**

IMC = Instrument meteorological conditions
FARs = U.S. Federal Aviation Regulations

Source: Robert Dodd, Ph.D., et al.

When the distribution of IMC approach accidents is evaluated by the type of approach being conducted at the time of the accident (i.e., precision approach or nonprecision approach), the distribution is roughly equal. Of the 404 IMC approach accidents, 203 accidents (50.2 percent) occurred during nonprecision approaches and 201 accidents (49.8 percent) occurred during precision approaches. Table 2 (page 29) shows the distribution of IMC approach accidents by year, type of approach and type of operation.

Based on the nearly equal numbers of IMC approach accidents that occurred during nonprecision approaches (203) and during precision approaches (201), one might assume that there is nearly equal risk involved in conducting nonprecision approaches and in conducting precision approaches. This would be an erroneous assumption because the data have not been adjusted for the underlying activity — that is, how often these types of approaches are conducted. For example, an estimated 32 million precision approaches and 4 million nonprecision approaches were conducted during the study period (see Appendix A). This represents roughly an eightfold difference. Consequently, one would expect a difference in the accident rates (a measure of actual risk) during nonprecision approaches and during precision approaches.

Figure 1 (page 29) shows IMC approach accident rates — that is, accidents per million precision approaches and accidents per million nonprecision approaches in 1983 through 1999.

The average nonprecision approach accident rate of 52.9 accidents per 1 million approaches is much greater than the average precision approach accident rate of 6.9 accidents per 1 million approaches — a 7.7-fold difference. This indicates that the risk of an accident during a nonprecision approach is much greater than the risk of an accident during a precision approach.

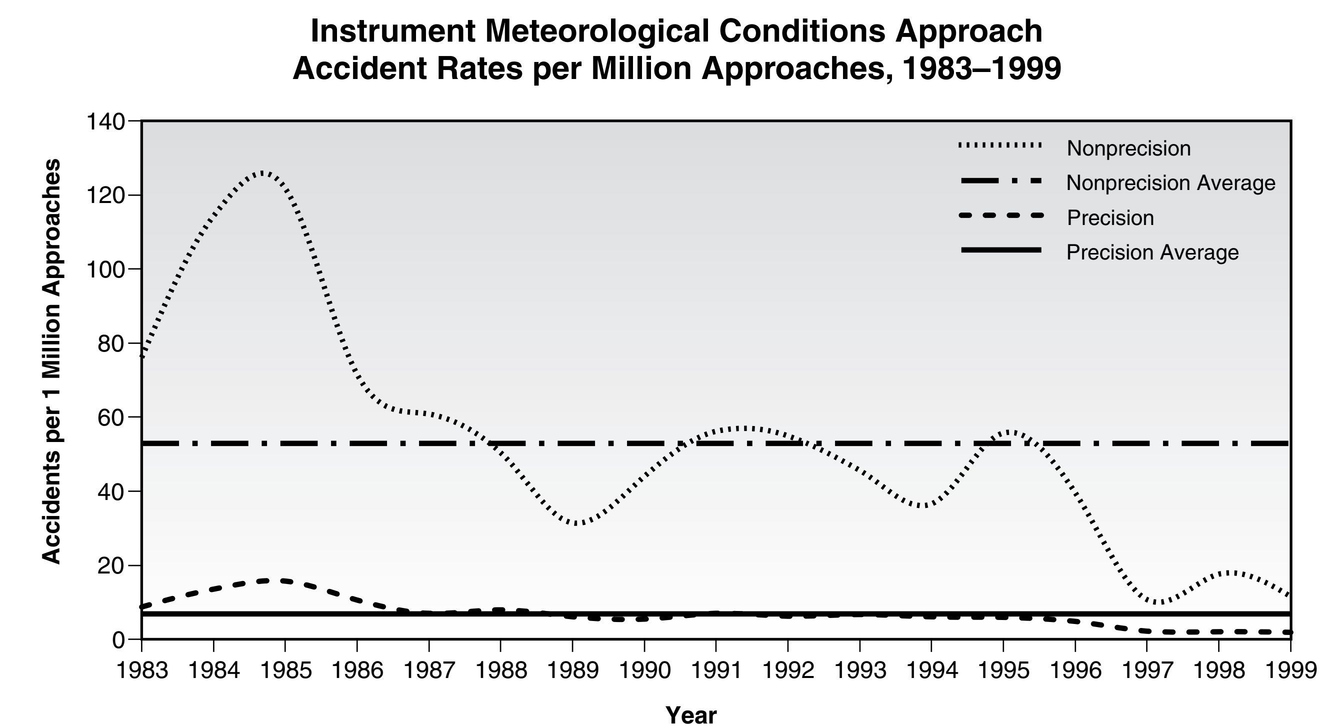
Among the issues that should be explored is the effect of factors such as the type of operation conducted, pilot experience and weather conditions on the difference between the accident rates for nonprecision approaches and for precision approaches.

Table 2
Instrument Meteorological Conditions Approach Accident Distribution, 1983–1999

	Nonprecision Approach Accidents			Precision Approach Accidents		
Year	**FARs Part 121**	**FARs Part 135**	**FARs Part 91**	**FARs Part 121**	**FARs Part 135**	**FARs Part 91**
1983	0	3	12	0	2	12
1984	0	4	20	2	0	16
1985	0	4	21	1	4	9
1986	0	1	14	1	3	25
1987	0	4	9	1	2	7
1988	0	2	9	1	4	16
1989	1	1	5	2	4	9
1990	1	3	6	0	4	7
1991	0	2	12	1	1	8
1992	0	3	10	0	2	11
1993	0	2	9	1	3	5
1994	0	0	9	1	2	2
1995	1	2	11	0	1	8
1996	1	1	9	0	2	6
1997	0	0	3	0	2	5
1998	0	2	3	1	1	3
1999	0	0	3	0	1	2
Total	**4**	**34**	**165**	**12**	**38**	**151**
Total for All Operations		**203**			**201**	

FARs = U.S. Federal Aviation Regulations

Source: Robert Dodd, Ph.D., et al.



Source: Robert Dodd, Ph.D., et al.

Figure 1

Another issue that should be explored is the marked decrease after 1997 in the accident rate for nonprecision approaches (and, to a lesser extent, the decrease after 1997 in the accident rate for precision approaches).

Regarding the type of operation conducted, FARs Part 121 operations typically are conducted in modern aircraft by two-pilot flight crews or three-pilot flight crews. One advantage of multi-pilot flight crews is the sharing of flight deck workload. Part 135 operations are conducted in modern aircraft as well as older-generation aircraft by multi-pilot flight crews and by single pilots. Part 91 operations include corporate/business flights typically conducted in turbine aircraft by professional pilots, but most general aviation operations are conducted in reciprocating-engine aircraft for pleasure or for personal transportation by private pilots.

Table 3 indicates that Part 121 operators have the lowest overall risk of accidents during IMC approaches, followed by Part 135 operators and Part 91 operators. The table also shows that the risk ratios (i.e., the nonprecision-approach-accident rates divided by the precision-approach-accident rates) are higher for Part 121 operators and for Part 135 operators than for Part 91 operators. The higher ratios result from the relatively low precision-approach-accident rates of Part 121 operators and Part 135 operators. Conversely, the risk ratio for Part 91 operators is lower than the risk ratios for Part 121 operators and Part 135 operators because the nonprecision-approach-accident rate and the precision-approach-accident rate for Part 91 operators are relatively high.

Table 3
Instrument Meteorological Conditions Approach Accident Rates Stratified by Type of Operation and Type of Approach, 1983–1999

Type of Operation	Precision Approach Accident Rate per 1 Million Approaches	Nonprecision Approach Accident Rate per 1 Million Approaches	Risk Ratio*
FARs Part 121	0.82	7.99	9.74
FARs Part 135	4.04	42.30	10.47
FARs Part 91	17.79	60.26	3.39

*Risk ratio is the nonprecision approach accident rate divided by the precision approach accident rate.

FARs = U.S. Federal Aviation Regulations

Source: Robert Dodd, Ph.D., et al.

Table 4 (page 31) shows the distribution of IMC approach accidents by type of operation, type of approach and prevailing light conditions. In Part 121 operations, twice as many precision approach accidents occurred in daytime (eight accidents) than in nighttime (four accidents). In Part 135 operations, more than 10 times as many precision approach accidents occurred in nighttime (35 accidents) than in daytime (three accidents). The distribution of nonprecision approach accidents in nighttime and in daytime was equal in Part 121 operations and nearly equal in Part 135 operations. In Part 91 operations, nighttime approach accidents were more numerous than daytime approach accidents for both precision approaches and nonprecision approaches.

Table 5 (page 31) shows the mean visibilities reported at the time of the accidents. The average visibilities for approach accidents during Part 121 operations were relatively low, as might be expected because Part 121 operations typically are conducted in most weather conditions. The relatively high average visibility for nonprecision approach accidents during Part 91 operations in nighttime provides some insight into the challenges of flying these approaches.

Fog was cited as the restriction to visibility in 78 percent of the NTSB accident reports. The actual visibility prevailing during an approach can be different than the visibility reported by the weather-reporting facility. Fog, for example, usually is a local phenomenon that not always is reported.

Table 6 (page 31) shows the average instrument flight hours accumulated by the pilots involved in IMC approach accidents. The values indicate that the accident pilots had substantial experience in instrument flying.

Table 7 (page 32) shows the percentages of fatalities among occupants of the aircraft involved in IMC approach accidents in 1983 through 1999. Approximately half of the occupants involved in accidents during Part 135 operations and during Part 91 operations were killed. The relatively low number of fatalities that occurred in accidents during Part 121 operations is due to the number of occurrences in which the aircraft was not destroyed during the accident sequence.

General Comments on Tables 3–7

Evaluation of the data in Table 3, Table 4, Table 5, Table 6 and Table 7 indicates that there are no other easily discovered factors associated with the increased risk of conducting nonprecision approaches. Other factors may be involved, but the data (at this level of analysis) do not identify these factors. The data show a difference in risk between precision approaches and nonprecision approaches; the data indicate that the difference in risk might be associated with the differences in the approach procedures.

The decrease in accident rates in 1997 through 1999 (Figure 1) is notable. The data show a marked decrease in both precision approach accident rates and nonprecision approach accident rates. While the rates decreased, the risk-ratio patterns remained constant (i.e., 4.7 in 1997, 8.75 in 1998 and 6.0 in 1999). The reason for the decrease in accident rates is unclear; it may be due to normal variation, the introduction of new technology or other factors. One method of exploring this anomaly is to

Table 4
Approach Accidents Stratified by Light Condition, Approach Type and Type of Operation, 1983–1999

Type of Operation	Number of Precision Approach Accidents		Number of Nonprecision Approach Accidents	
	Day	Night	Day	Night
FARs Part 121	8	4	2	2
FARs Part 135	3	35	18	16
FARs Part 91	46	104	67	99
Total	**57**	**143**	**87**	**117**

FARs = U.S. Federal Aviation Regulations

Source: Robert Dodd, Ph.D., et al.

Table 5
Mean Visibility Reported at Airport During Instrument Meteorological Conditions Approach Accidents, 1983–1999

Type of Operation	Average Visibility During Precision Approach Accidents (statute miles)		Average Visibility During Nonprecision Approach Accidents (statute miles)	
	Day	Night	Day	Night
FARs Part 121	0.6	0.5	1.0	1.7
FARs Part 135	2.4	2.4	2.4	2.3
FARs Part 91	1.4	1.9	2.3	2.7

FARs = U.S. Federal Aviation Regulations

Source: Robert Dodd, Ph.D., et al.

Table 6
Average Instrument Flight Time of Pilots Involved in Instrument Meteorological Conditions Approach Accidents, 1983–1999

Type of Operation	Average Instrument Flight Time of Pilots Involved in Precision Approach Accidents (hours)	Average Instrument Flight Time of Pilots Involved in Nonprecision Approach Accidents (hours)	Average Instrument Flight Time of Pilots Involved in Approach Accidents (hours)
FARs Part 121	806	1,000	907
FARs Part 135	475	604	535
FARs Part 91	449	394	520

FARs = U.S. Federal Aviation Regulations

Source: Robert Dodd, Ph.D., et al.

compare the accident rates for the period 1983 through 1989 with the accident rates for the period 1990 through 1999 (Figure 2 [page 32] and Figure 3 [page 33]).

Figure 2 shows that the average accident rates in 1983 through 1989 were 9.97 accidents per 1 million precision approaches and 75.23 accidents per 1 million nonprecision approaches; the resulting risk ratio is 7.5. Figure 3 shows that the average accident rates in 1990 through 1999 were 4.87 accidents per 1 million precision approaches and 37.25 accidents per 1 million nonprecision approaches; the resulting risk ratio is 7.6. While the overall accident rates decreased between the periods, the risk ratio remained constant.

Based on this review, accident rates from 1990 through 1999 were used as baseline measures for the projections of WAAS benefits.

WAAS Benefit Projections

As discussed in detail earlier, WAAS benefit projections for the period 2001 through 2020 involved determining average

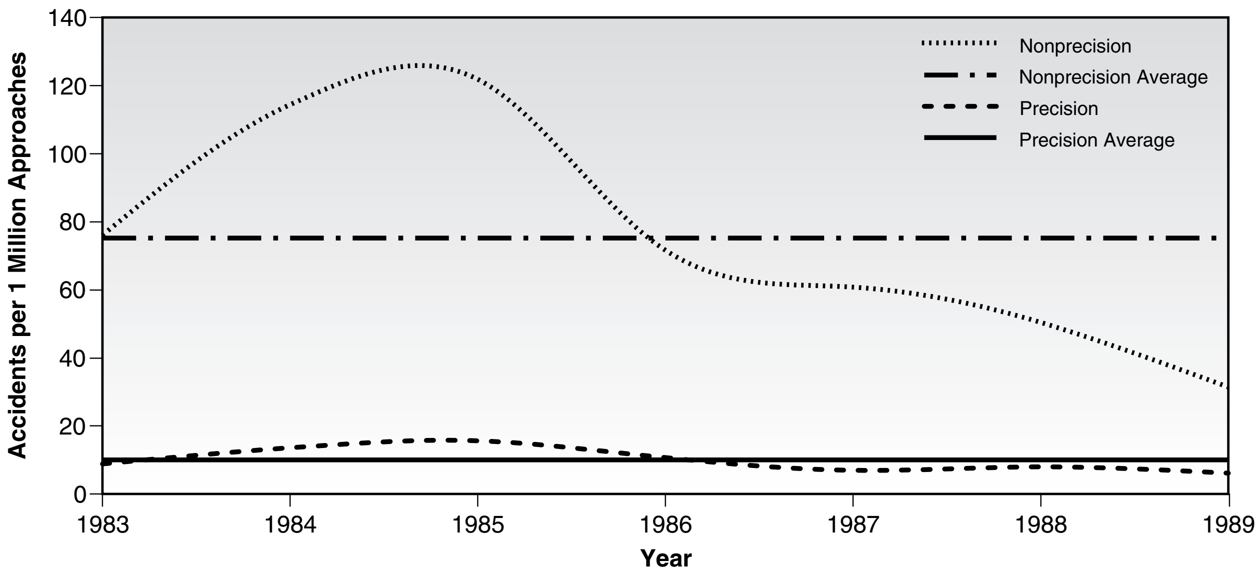
Table 7
Distribution of Fatalities by Type of Operation, Instrument Meteorological Conditions Approach Accidents, 1983–1999

Type of Operation	Fatalities	Total Number of Occupants	Number of Accidents	Fatalities Among Occupants
FARs Part 121	151	1,178	16	13%
FARs Part 135	135	247	72	55%
FARs Part 91	442	837	316	52%

FARs = U.S. Federal Aviation Regulations

Source: Robert Dodd, Ph.D., et al.

Instrument Meteorological Conditions Approach Accident Rates per Million Approaches, 1983–1989



Source: Robert Dodd, Ph.D., et al.

Figure 2

accident rates for precision approaches and nonprecision approaches in 1990 through 1999. The results were used to estimate future accident rates. Activity estimates were derived from FAA long-range forecasts, which showed that an average 2 percent increase in activity can be expected each year from 2001 through 2020. The projections reflected FAA's plans for gradual implementation of WAAS from 2006 through 2011.

For this study, WAAS is not considered as potentially 100 percent effective in eliminating IMC nonprecision approach risk because not all operators, especially general aviation operators, likely will abandon traditional nonprecision approach procedures.

Figure 4 (page 33) shows that approximately 10 to 14 nonprecision approach accidents are projected to occur each year from 2001 through 2020. Figure 5 (page 34) shows that approximately 141 approach accidents might be prevented by the introduction of WAAS during the period.

Figure 6 (page 34) shows that there are expected to be 11 to 16 fatalities per year associated with nonprecision approach accidents from 2001 through 2020. Figure 7 (page 35) shows the projected reduction of fatalities for the period is approximately 257.

Conclusions

The study results indicate that the implementation of WAAS precision approach capability will introduce significant safety benefits. In this study, evaluation of these safety benefits

Continued on page 35

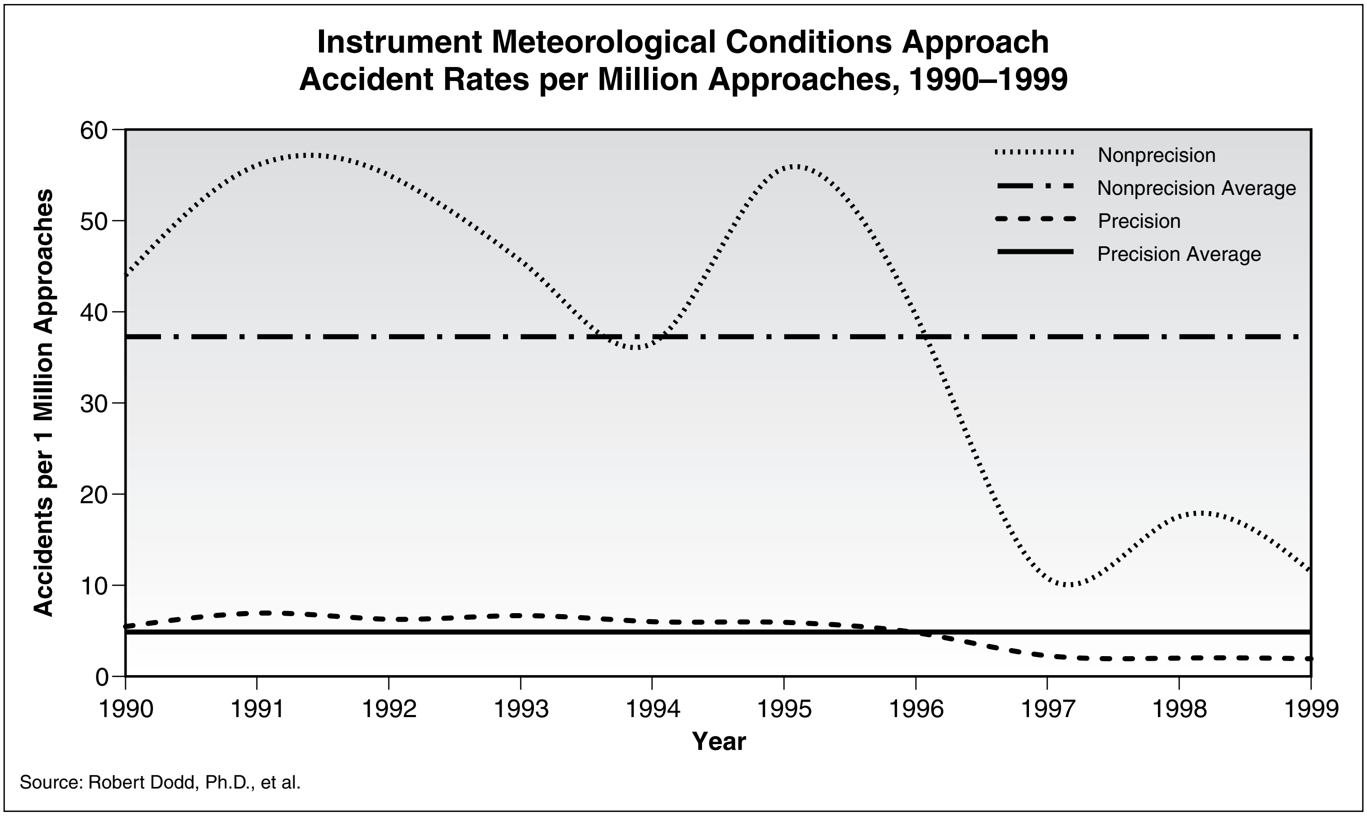


Figure 3

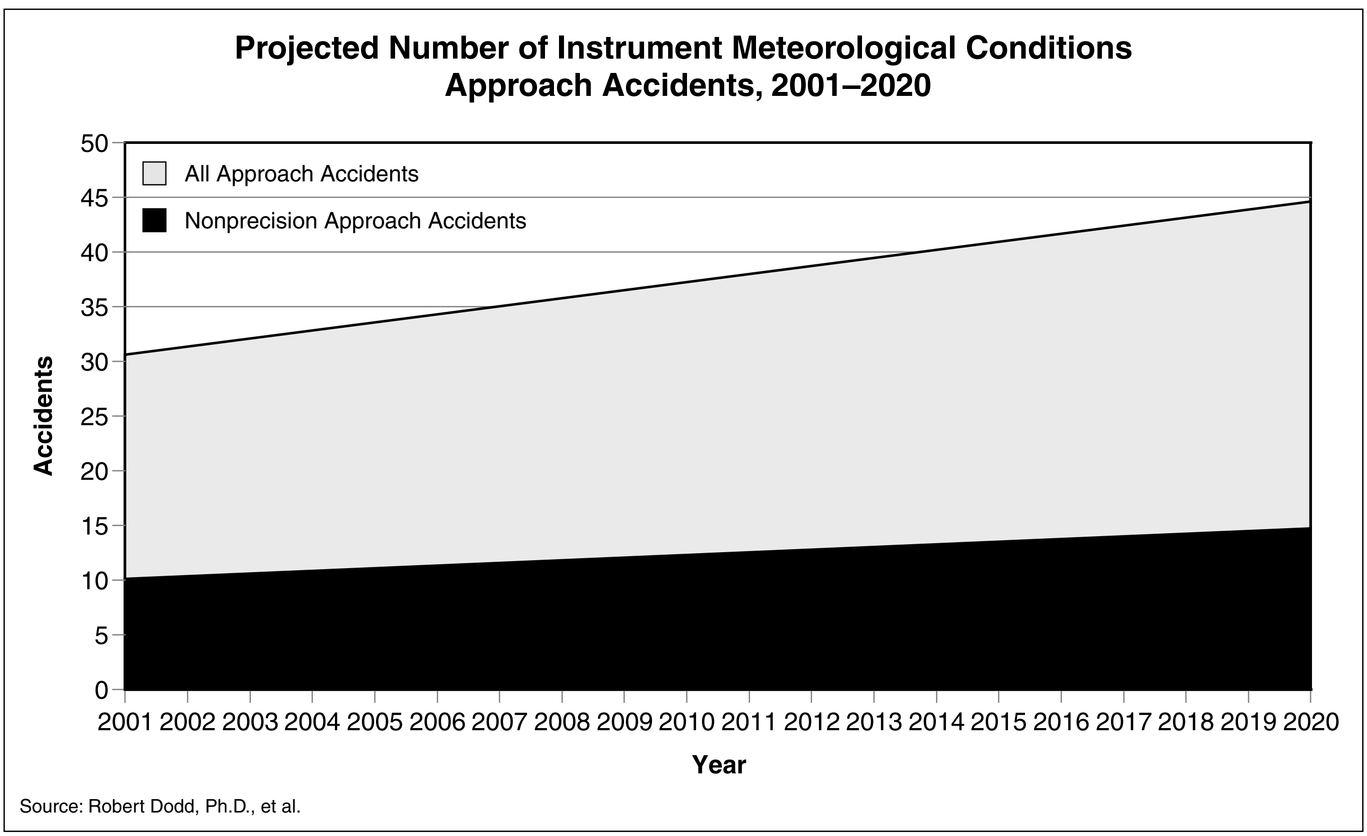
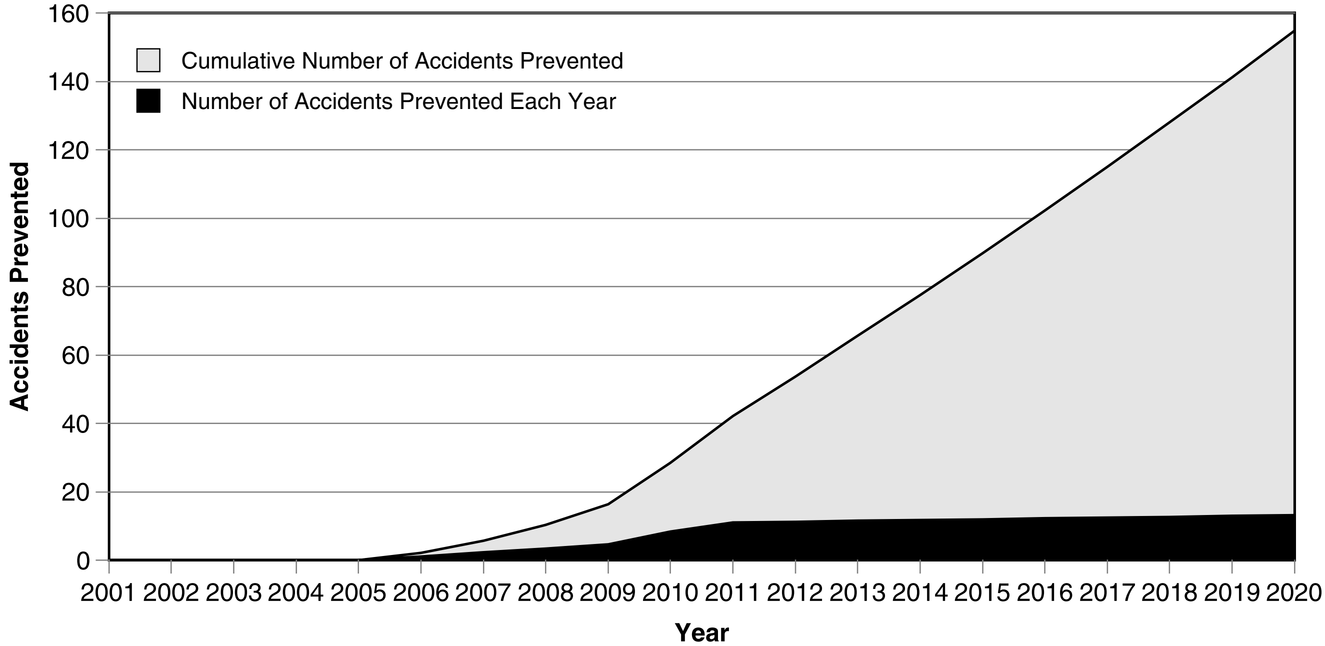


Figure 4

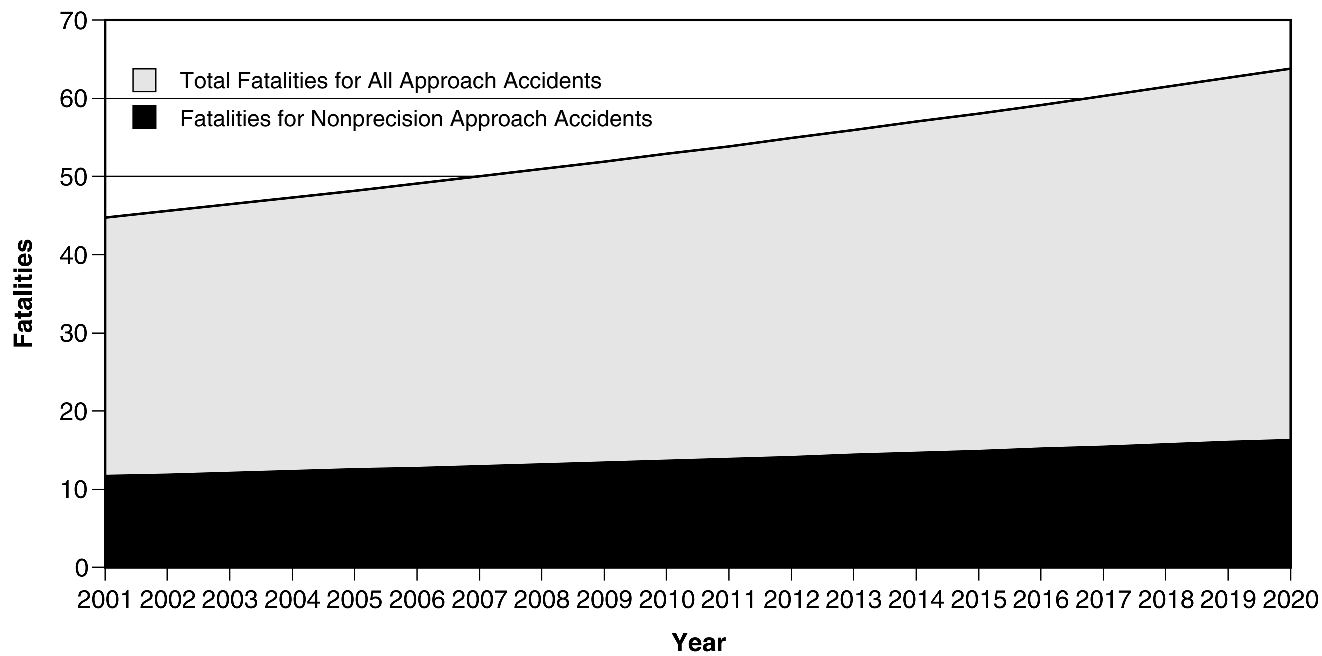
Projected Reduction of Nonprecision Approach Accidents With Introduction of Wide Area Augmentation System, 2001–2020



Source: Robert Dodd, Ph.D., et al.

Figure 5

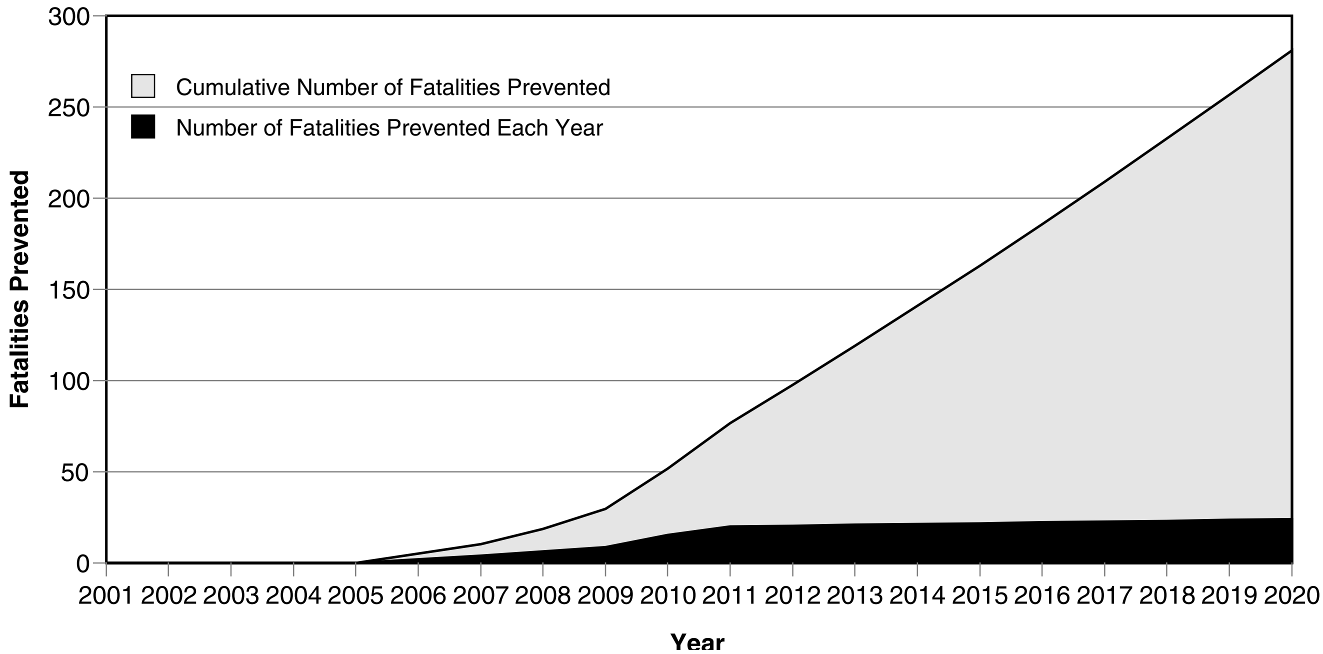
Projected Number of Instrument Meteorological Conditions Approach Related Fatalities, 2001–2020



Source: Robert Dodd, Ph.D., et al.

Figure 6

Projected Reduction of Fatalities Associated With Nonprecision Approach Accidents With Introduction of Wide Area Augmentation System, 2001–2020



Source: Robert Dodd, Ph.D., et al.

Figure 7

was limited to the reduction of accidents and fatalities associated with the decrease in reliance on nonprecision approaches. This evaluation was limited to this very specific focus because it was a benefit that could be quantified and described. The results indicate that approximately 141 accidents could be prevented and that approximately 257 lives could be saved from 2001 through 2020. These are conservative estimates.

Safety improvements may be greater if the overall growth rate for aviation exceeds the growth rate of 2 percent used in this analysis. If the growth rate averages 3 percent per year for the period 2001 through 2020, the total number of accidents prevented will increase to approximately 175 and the number of lives saved will increase to approximately 315. Conversely, if the growth rate averages only 1 percent per year during the period, the accidents and deaths prevented will be approximately 114 and 206, respectively.

Many other benefits may accrue from WAAS implementation. For example, pilots likely will use WAAS precision guidance while conducting approaches in VMC. WAAS precision guidance will help the pilots conduct stabilized approaches and will ensure obstacle clearance in nighttime and in MVFR conditions. These benefits most likely would be greatest for single-pilot flight operations.

WAAS implementation likely will improve safety during the en route phase of flight, as well as during approach. As mentioned earlier, WAAS provides three-dimensional navigation capability. This will enable pilots to accurately determine their position, altitude and groundspeed. Moving-map displays will help pilots maintain their situational awareness, a key component to safe flight, especially in IMC. Moving-map displays will facilitate point-to-point navigation, reducing fuel use and improving ATC routing flexibility. The cost of this capability, based on current GPS receiver costs, should be within the means of pilots who own their own aircraft.

WAAS ultimately will eliminate the need for a multitude of instrument approach systems throughout the country. This should significantly reduce, or eliminate, the cost of operating and maintaining these systems. Pilots will need to learn only one type of instrument approach procedure, in contrast to today's environment that requires knowledge and skill to fly a variety of precision approaches and nonprecision approaches.

WAAS implementation also will benefit many airports and heliports that currently do not have instrument approaches. This should improve the utility of these airports and heliports, reduce capacity demands on other airports and improve safety.

The introduction of WAAS will help achieve the goal of the U.S. White House Commission on Aviation Safety and Security for an 80 percent reduction in fatal accidents by 2008.[18]♦

[FSF editorial note: *Safety Benefits of the Wide Area Augmentation System During Instrument Approaches* is a report on a study performed for the U.S. Federal Aviation Administration and completed on Jan. 25, 2002, by Flight Safety Foundation. The 40-page report includes illustrations and appendixes. Some editorial changes were made by FSF staff for clarity and for style in this article.]

Notes

1. U.S. Federal Aviation Administration (FAA). <http://gps.faa.gov/GPSbasics/>.

2. Enders, John H., et al. "Airport Safety: A Study of Accidents and Available Approach-and-landing Aids." *Flight Safety Digest* Volume 15 (March 1996).

3. Enders et al.

4. The study factors included pilot experience, type of airplane, environmental conditions, presence of high terrain and presence of air traffic control radar.

5. Flight Safety Foundation (FSF). "Killers in Aviation: FSF Task Force Presents Facts About Approach-and-landing and Controlled-flight-into-terrain Accidents." *Flight Safety Digest* Volume 17 (November–December 1998) and Volume 18 (January–February 1999).

6. FSF Editorial Staff. "Dubrovnik-bound Flight Crew's Improperly Flown Nonprecision Instrument Approach Results in Controlled-flight-into-terrain Accident." *Flight Safety Digest* Volume 15 (July–August 1996).

7. U.S. National Transportation Safety Board. "Controlled Flight Into Terrain, Korean Air Flight 801, Boeing 747-300, HL7468." *Flight Safety Digest* Volume 19 (May–July 2000).

8. The FAA *Aeronautical Information Manual* defines approach categories as airspeed ranges based on 1.3 times the stall speed of an aircraft in landing configuration and at maximum gross landing weight. The airspeed ranges are: less than 91 knots for Category A aircraft; 91 knots to 120 knots for Category B aircraft; 121 knots to 140 knots for Category C aircraft; 141 knots to 165 knots for Category D aircraft; and more than 165 knots for Category E aircraft.

9. U.S. Federal Aviation Regulations Part 139, *Certification and Operations: Land Airports Serving Certain Air Carriers*.

10. Presentation by Pate, D., manager, Flight Procedure Standards Branch, U.S. Federal Aviation Administration (FAA) at the Eurocontrol RNAV Meeting, Luxembourg, Jan. 31, 2001.

11. Rogers, T. "The II Morrow GX55 Panel-Mount GPS." *Avionics Review*, <www.avweb.com/articles/gx55.html>.

12. FAA Office of Satellite Navigation. *FAA's Plan for Transition to GPS-Based Navigation and Landing Guidance*: 4.4.

13. FAA Office of Aviation Policy and Plans. FAA *Aviation Forecasts, 1995–2004*.

14. FAA Order 8260.3B, *United States Standard for Terminal Instrument Procedures*. Chapter 3.

15. FAA Advisory Circular 150/5340-1H, *Standards for Airport Markings*. Chapter 1.

16. FAA Office of Aviation Policy and Plans. *FAA Long Range Aerospace Forecast, Fiscal Years 2015, 2020, 2025*. FAA-APO-01-3, June 2001.

17. FAA Office of Aviation Policy and Plans. *FAA Fiscal Years Forecast 2001–2012*. Jan. 22, 2001.

18. Gore, Al, et al. *Final Report of the White House Commission on Aviation Safety and Security*. February 1997.

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Further Reading From FSF Publications

FSF Editorial Staff. "Sabreliner Strikes Mountain Ridge During Night Visual Approach." *Accident Prevention* Volume 60 (April 2003): 1–7.

FSF Editorial Staff. "Reduced Visibility, Mountainous Terrain Cited in Gulfstream III CFIT at Aspen." *Accident Prevention* Volume 59 (November 2002): 1–11.

FSF Editorial Staff. "Commuter Aircraft Strikes Terrain During Unstabilized, Homemade Approach." *Accident Prevention* Volume 59 (June 2002): 1–7.

FSF Editorial Staff. "Cargo Airplane Strikes Frozen Sea During Approach in Whiteout Conditions." *Accident Prevention* Volume 59 (January 2002): 1–7.

FSF Editorial Staff. "Descent Below Minimum Altitude Results in Tree Strike During Night, Nonprecision Approach." *Accident Prevention* Volume 58 (December 2001): 1–5.

Flight Safety Foundation. "Approach-and-landing Accident Reduction (ALAR) Briefing Notes." *Flight Safety Digest* Volume 19 (August–November 2000): 1–196.

Wilson, Dale R. "Darkness Increases Risks of Flight." *Human Factors & Aviation Medicine* Volume 46 (November–December 1999): 1–8.

FSF Editorial Staff. "B-757 Damaged by Ground Strike During Late Go-around From Visual Approach." *Accident Prevention* Volume 56 (May 1999): 1–8.

FSF Editorial Staff. "During Nonprecision Approach at Night, MD-83 Descends Below Minimum Descent Altitude and Contacts Trees, Resulting in Engine Flameout and Touchdown Short of Runway." *Accident Prevention* Volume 54 (April 1997): 1–15.

Koenig, Robert L. "FAA Outlines Transition Plan for Satellite-based Navigation and Approaches." *Airport Operations* Volume 22 (November–December 1996): 1–8.

FSF Editorial Staff. "Poorly Flown Approach in Fog Results in Collision With Terrain Short of Runway." *Accident Prevention* Volume 52 (August 1995): 1–7.

Appendix A
Activity Determination Procedures

Activity data — the number of instrument approaches flown during the study period — were derived from the U.S. Federal Aviation Administration (FAA) Office of Policy and Plans (APO) Air Traffic Activity Data System (ATADS). These data were used to calculate instrument approach accident rates (i.e., the number of accidents divided by the number of approaches flown). The APO staff responsible for ATADS confirmed that the data were suitable for calculating accident rates.

The ATADS data provided a count of instrument approaches flown, but the data did not differentiate between precision approaches and nonprecision approaches. Runway-marking information was used to categorize the ATADS activity data as precision approaches or nonprecision approaches. If an airport had only precision-approach markings on its runways, all instrument approaches to that airport reported by FAA were categorized as precision approaches. If the airport had only nonprecision-approach markings on its runways, all instrument approaches to that airport reported by FAA were categorized as nonprecision approaches. If an airport had runways with precision-approach markings and nonprecision-approach markings, a weighting factor was applied to adjust the activity data for the distribution of precision approaches and nonprecision approaches for that airport.

If an airport had an equal number of runways with precision-approach markings and nonprecision-approach markings (a 1-1 ratio), the activity measure was weighted as 80 percent precision approaches and 20 percent nonprecision approaches. The rationale was that an airport would install the precision approach on the runway that would be used for the majority of operations; the nonprecision approach would be used when the precision approach was not available or the winds dictated use of the nonprecision-approach runway.

For airports with a 2-1 ratio of runways with precision markings to runways with nonprecision markings, the weighting factor was 90 percent precision, 10 percent nonprecision.

For airports with a 3-1 ratio of runways with precision markings to runways with nonprecision markings, the weighting factor applied was 95 percent precision and 5 percent nonprecision.

At airports with more runways with nonprecision markings than runways with precision markings, similar weighting procedures were followed.

For airports with a 0.5-1 ratio of runways with precision markings to runways with nonprecision markings, the weighting factor applied was 70 percent precision and 30 percent nonprecision.

For airports with a 0.33-1 ratio of runways with precision markings to runways with nonprecision markings, the weighting factor applied was 60 percent precision and 40 percent nonprecision.♦

Appendix B
Stabilized Approach Considerations

The Flight Safety Foundation Approach-and-landing Accident Reduction (ALAR) Task Force has recommended the following elements of a stabilized approach. While this guidance was developed primarily for flight crews of turbine-powered airplanes, the basic concepts and tenets also are applicable to single-pilot operations in reciprocating-engine airplanes.[1]

- All flights must be stabilized by 1,000 feet above airport elevation in instrument meteorological conditions (IMC) and by 500 feet above airport elevation in visual meteorological conditions (VMC). An approach is stabilized when all the following criteria are met:
  - The aircraft is on the correct flight path;
  - Only small changes in heading/pitch are required to maintain the correct flight path;
  - The aircraft speed is not more than V_{REF} + 20 knots indicated airspeed and not less than V_{REF};
  - The aircraft is in the correct landing configuration;
  - Sink rate is not greater than 1,000 feet per minute; if an approach requires a sink rate greater than 1,000 feet per minute, a special briefing should be conducted;
  - Power setting is appropriate for the aircraft configuration and is not below the minimum power for approach as defined by the aircraft operating manual; and,
  - All briefings and checklists have been conducted;
- Specific types of approaches are stabilized if they also fulfill the following: instrument landing system (ILS) approaches must be flown within one dot of the glideslope and localizer; a Category II ILS approach or Category III ILS approach must be flown within the expanded localizer band; during a circling approach, wings should be level on final when the aircraft reaches 300 feet above airport elevation;
- Unique approach procedures or abnormal conditions requiring a deviation from the above elements of a stabilized approach require a special briefing; and,
- An approach that becomes unstabilized below 1,000 feet above airport elevation in IMC or below 500 feet above airport elevation in VMC requires an immediate go-around.♦

Note

1. Flight Safety Foundation. "Approach-and-landing Accident Reduction (ALAR) Briefing Notes." *Flight Safety Digest* Volume 19 (August–November 2000).

Appendix C
Accident Reports Used in Study

Accident Date	Airport Identifier	Aircraft Registration Number	NTSB Report Identification Number	Airport Name	State
14-Jan-1983	GRB	N9916B	CHI83LA081	Austin Straubel	WI
23-Jan-1983	RFD	N61558	CHI83FA089	Rockford	IL
11-Feb-1983	3KM	N8981C	MKC83FA066	Col. James Jabara	KS
15-Feb-1983	FSD	N8478N	DEN83FTK03	Joe Foss Field	SD
23-Feb-1983	ESF	N4862G	FTW83FA126	Esler Regional	LA
24-Feb-1983	2A0	N123SM	ATL83LA120	Mark Anton	TN
16-Mar-1983	SSI	N8855V	ATL83FA176	Malcolm McKinnon	GA
27-Mar-1983	OCF	N123WK	MIA83LA105	Ocala	FL
03-Apr-1983	FRG	N8219L	NYC83FA085	Republic	NY
06-Apr-1983	IND	N3794W	CHI83FA160	Indianapolis	IN
14-Apr-1983	C29	N9215P	CHI83FA166	Morey	WI
15-Apr-1983	BLF	N7353S	ATL83FIJ02	Mercer County	WV
12-May-1983	IXD	N725M	MKC83FA108	Johnson County Industrial	KS
30-May-1983	FRG	N837E	NYC83FA126	Republic	NY
31-May-1983	PLB	N6207R	NYC83FA128	Clinton County	NY

Appendix C
Accident Reports Used in Study *(continued)*

Accident Date	Airport Identifier	Aircraft Registration Number	NTSB Report Identification Number	Airport Name	State
11-Nov-1983	MYF	N911SC	LAX84FA058	Montgomery Field	CA
27-Nov-1983	RMG	N3801N	ATL84AA053	Richard B. Russell	GA
02-Dec-1983	GPT	N36MP	ATL84FA059	Gulfport-Biloxi	MS
02-Dec-1983	RKR	N310JD	FTW84FA082	Robert S. Kerr	OK
05-Dec-1983	KCK	N704M	MKC84FA033	Fairfax	KA
12-Dec-1983	2M2	N66MZ	ATL84MA063	Lawrenceburg	TN
12-Dec-1983	40N	N3298D	NYC84FA047	Coatesville	PA
12-Dec-1983	SWF	N6774R	NYC84FA052	Stewart	NY
14-Dec-1983	BUF	N87291	NYC84FA054	Buffalo	NY
17-Dec-1983	LVK	N4513K	LAX84LA098	Livermore	CA
21-Dec-1983	DET	N90DF	CHI84LA065	Detroit City	MI
30-Dec-1983	PBI	N761HZ	MIA84FA053	Palm Beach	FL
05-Jan-1984	PVU	N3037T	DEN84FA065	Provo	UT
15-Jan-1984	—	N31844	ATL84FA083	(unknown)	AL
17-Jan-1984	GMU	N81717	ATL84FA084	Greenville	SC
24-Jan-1984	MEM	N46RS	ATL84FLT02	Memphis	TN
24-Jan-1984	GON	N900FE	NYC84FA074	Groton-New London	CT
26-Jan-1984	GRE	N76AP	CHI84LA094	Greenville	SC
10-Feb-1984	DRO	N6400E	DEN84FA089	Durango-La Plata	CO
17-Feb-1984	CHO	N9353Q	ATL84MA101	Charlottesville-Albemarle	VA
19-Feb-1984	HIO	N83382	SEA84FA058	Hillsboro	OR
25-Feb-1984	ITH	N6886D	NYC84FA092	Tompkins County	NY
26-Feb-1984	ELD	N33BP	MKC84FA084	Goodwin	LA
04-Mar-1984	POC	N60031	LAX84LA205	Brackett Field	CA
05-Mar-1984	3A1	N3291Q	ATL84MA114	Folsom Field	AL
05-Mar-1984	CBE	N6629L	NYC84MA102	Cumberland	MD
14-Mar-1984	GON	N5022S	NYC84FA108	Groton-New London	CT
16-Mar-1984	OWD	N8482N	NYC84LA111	Norwood	MA
19-Mar-1984	JLN	N6665X	MKC84FA106	Joplin	MO
31-Mar-1984	MLS	N743W	DEN84FA121	Frank Wiley	MT
04-Apr-1984	PTK	N3645T	CHI84FA148	Pontiac-Oakland	MI
05-Apr-1984	BGM	N511SC	NYC84LA133	Edwin A. Link Field	NY
15-Apr-1984	N44	N15VP	NYC84FA138	Air Park	NJ
18-Apr-1984	BED	N4467X	NYC84FA143	Hanscom Field	MA
07-May-1984	—	N6907L	NYC84FA163	(unknown)	PA
08-Jun-1984	UUK	N4206L	ANC84LA086	Kuparak	AK
13-Jun-1984	DTW	N964VJ	DCA84AA028	Detroit Metro	MI
30-Jun-1984	BOS	N120PB	NYC84FA227	Boston Logan	MA
31-Aug-1984	8A0	N55LP	ATL84FA274	Albertville	AL
31-Aug-1984	ILM	N5071R	ATL84FA275	New Hanover	NC
21-Sep-1984	MSO	N3736Q	DEN84FA300	Missoula	MT
23-Oct-1984	CYS	N1569T	DEN85FA017	Cheyenne	WY
04-Nov-1984	CEW	N9242S	MIA85FA023	Bob Sikes	FL
05-Nov-1984	GON	N62561	NYC85LA023	Groton-New London	CT
17-Nov-1984	IRK	N3955H	MKC85LA021	Kirksville	MO
19-Nov-1984	PPA	N54028	FTW85LA056	Perry Lefors	TX
30-Nov-1984	PIH	N37279	SEA85LA023	Pocatello	ID
04-Dec-1984	LBB	N4864A	FTW85LA068	Lubbock	TX

Appendix C
Accident Reports Used in Study *(continued)*

Accident Date	Airport Identifier	Aircraft Registration Number	NTSB Report Identification Number	Airport Name	State
19-Dec-1984	GLW	N6077H	ATL85FA061	Glasgow	KY
20-Dec-1984	ROG	N9229Y	MKC85FA037	Rodgers	AR
29-Dec-1984	DHN	N6527D	ATL85FA071	Dothan	AL
01-Jan-1985	LEB	N47364	NYC85FNC02	Lebanon	NH
04-Jan-1985	W97	N275MA	BFO85FA011	West Point	VA
19-Jan-1985	ABI	N735QN	FTW85LA098	Abilene	TX
04-Feb-1985	SXQ	N50NP	DCA85AA012	Soldotna	AK
13-Feb-1985	8G5	N2019U	NYC85FA064	St. Marys	PA
20-Feb-1985	HUT	N617CA	MKC85FCQ01	Hutchinson	KS
22-Feb-1985	UIZ	N100RN	CHI85FA120	Berz-Macomb	MI
06-Apr-1985	ACK	N68DD	NYC85FA099	Nantucket	MA
20-Apr-1985	ACY	N4972S	NYC85FA110	Atlantic City	NJ
17-May-1985	LBE	N66892	NYC85FA125	Westmoreland County	PA
21-May-1985	CRW	N8460M	ATL85FA171	Charleston	WV
21-May-1985	HRO	N10GE	MKC85FA110	Boone County	AR
18-Jul-1985	ACK	N8247A	NYC85LA184	Nantucket	MA
02-Aug-1985	DFW	N726DA	DCA85AA031	Dallas-Fort Worth	TX
25-Aug-1985	LEW	N300WP	DCA85AA035	Auburn-Lewiston	ME
16-Sep-1985	COQ	N8139P	CHI85FA379	Cloquet	MN
25-Sep-1985	HTS	N25Q	ATL85FA283	Tri-State	WV
04-Oct-1985	GAI	N2106X	BFO86FA002	Montgomery County	MD
22-Oct-1985	JNU	N456JA	SEA86MA018	Juneau	AK
30-Oct-1985	FZG	N8401E	ATL86FA014	Fitzgerald	GA
01-Nov-1985	ENW	N92302	CHI86LA022	Kenosha	WI
03-Nov-1985	GSP	N733KU	ATL86LA018	Greer	SC
09-Nov-1985	APA	N1909T	DEN86FA020	Centennial	CO
11-Nov-1985	LBE	N59MD	CHI86MA025	Westmoreland County	PA
12-Nov-1985	DTW	N6788Y	CHI86FA026	Wayne County	MI
12-Nov-1985	PPA	N6843Q	FTW86FA024	Perry Lefores Field	TX
12-Nov-1985	3KM	N3864P	MKC86FA026	Col. James Jabara	KS
13-Nov-1985	ELZ	N1400H	NYC86FA034	Wellsville	NY
14-Nov-1985	EDE	N735SS	ATL86FA025	Edenton	NC
16-Nov-1985	IDA	N124RS	SEA86LA024	Idaho Falls	ID
24-Nov-1985	FYV	N86JB	MKC86FA030	Fayetteville	AR
25-Nov-1985	DSM	N81589	MKC86MA031	Des Moines	IA
27-Nov-1985	PVD	N220F	ATL86FA032	T.F. Green State	RI
01-Dec-1985	17A	N9289J	ATL86FA034	Gwinnett County	GA
01-Dec-1985	MIV	N26FM	BFO86FA008	Millville	NJ
07-Dec-1985	IDA	N5635D	SEA86LA029	Idaho Falls	ID
11-Dec-1985	ELM	N7770Y	ATL86FA039	Elmira	NY
23-Dec-1985	CRR	N1494G	LAX86MA074	Buchanan Field	CA
29-Dec-1985	SLC	N2082S	DEN86FA056	Salt Lake City	UT
03-Jan-1986	HFD	N3349R	NYC86FA057	Hartford-Brainard	CT
04-Jan-1986	MSY	N9253Y	FTW86FA031	Moisant	LA
09-Jan-1986	JAX	N700CM	MIA86MA057	Jacksonville	FL
10-Jan-1986	SLC	N757ZE	DEN86FA060	Salt Lake City	UT
19-Jan-1986	FRG	N34069	NYC86LA064	Republic	NY
07-Feb-1986	LYH	N9477C	BFO86FA015	Lynchburg	VA

Appendix C
Accident Reports Used in Study *(continued)*

Accident Date	Airport Identifier	Aircraft Registration Number	NTSB Report Identification Number	Airport Name	State
18-Feb-1986	RST	N3940C	CHI86LA090	Rochester	MN
20-Feb-1986	3WE	N111MM	MKC86LA062	Weiss-Wilmington	DE
26-Feb-1986	SNA	N58SB	LAX86FA127	John Wayne	CA
13-Mar-1986	TOL	N3124P	ATL86FA092	Toledo	OH
13-Mar-1986	APN	N1356P	DCA86AA021	Phelps-Collins	MI
23-Mar-1986	BFA	N43769	CHI86FA108	Boyne Mountain	MI
15-Apr-1986	FOK	N4559X	NYC86LA105	Suffolk County	NY
02-May-1986	IAH	N69668	FTW86MA074	Houston	TX
07-May-1986	BIL	N577KA	DEN86FA128	Boston Logan	MT
07-Jun-1986	ENW	N1268Z	CHI86FA151	Kenosha	WI
23-Jun-1986	BFD	N4445D	NYC86FA158	Bradford	PA
01-Jul-1986	LYH	N133P	BFO86FA038	Lynchburg	VA
16-Jul-1986	MKG	N6857E	CHI86FA172	Muskegan County	MI
23-Jul-1986	MOB	N2952D	ATL86LA207	Bates Field	AL
28-Jul-1986	CKB	N96701	ATL86FA212	Benedum	WV
17-Aug-1986	MTN	N31AB	BFO86FA042	Martin State	MD
17-Sep-1986	UIN	N71650	CHI86LA224	Quincy	IL
19-Sep-1986	ISW	N4909F	CHI86FEP09	Alexander Field	WI
28-Sep-1986	W09	N6443Q	BFO86FA050	Leesburg	VA
20-Oct-1986	BNA	N5260F	ATL87FA007	Nashville	TN
26-Oct-1986	FDK	N4347X	BFO87FA004	Frederick	MD
05-Nov-1986	MYF	N399WM	LAX87LA033	Montgomery	CA
06-Nov-1986	CYS	N8216V	DEN87FA017	Cheyenne	WY
17-Nov-1986	ALN	N1631E	CHI87LA019	St. Louis Regional	IL
26-Nov-1986	INT	N9592Y	ATL87FA029	Smith Reynolds	NC
26-Nov-1986	IPT	N8130A	NYC87FA038	Williamsport	PA
02-Dec-1986	PIA	N9210M	CHI87FA040	Greater Peoria	IL
06-Dec-1986	TWF	N37561	SEA87LA020	Joslin Field	ID
10-Dec-1986	PSF	N65TD	ATL87MA041	Pittsfield	MA
15-Dec-1986	SLC	N164SW	SEA87FA036	Salt Lake City	UT
17-Dec-1986	BMG	N9603B	CHI87LA051	Monroe County	IN
22-Dec-1986	DPA	N1253R	CHI87FA054	DuPage	IL
23-Dec-1986	SAV	N4137Q	ATL87FA047	Savannah	GA
24-Dec-1986	OJC	N414LL	MKC87FA035	Olathe	KS
27-Dec-1986	TRI	N210M	ATL87FA051	Tri-City Regional	TN
27-Dec-1986	FLL	N84136	MIA87FA062	Fort Lauderdale	FL
07-Jan-1987	MLS	N57133	DEN87FA042	Frank Wiley Field	MT
28-Jan-1987	ANC	N7393U	ANC87FA028	St. Mary's	AK
18-Feb-1987	BNA	N31590	ATL87LA073	Nashville	TN
08-Mar-1987	AVL	N621M	ATL87FA082	Asheville	NC
20-Mar-1987	LWM	N200FD	NYC87LA113	Lawrence	MA
28-Mar-1987	GED	N2221E	ATL87FA100	Sussex County	DE
13-Apr-1987	MCI	N144SP	DCA87MA026	Kansas City	MO
17-Apr-1987	THV	N7987W	NYC87FA127	York-Thomasville	PA
28-Apr-1987	PWM	N13808	NYC87LA135	Portland	ME
20-May-1987	COD	N2336X	DEN87FA130	E.E. Faust Regional	WY
21-Jun-1987	MKE	N2678R	CHI87FA153	Gen. Mitchell Field	WI
26-Jun-1987	BOS	N33670	NYC87FA187	Boston-Logan	MA

Appendix C
Accident Reports Used in Study *(continued)*

Accident Date	Airport Identifier	Aircraft Registration Number	NTSB Report Identification Number	Airport Name	State
10-Sep-1987	S47	N9484R	SEA87FA185	Tillamook	OR
11-Sep-1987	6B6	N25223	NYC87FA251	Minute Man	MA
19-Sep-1987	FIT	N99151	NYC87LA261	Fitchburg	MA
30-Sep-1987	MMTJ	XAKOA	LAX87FA350	Tijuana, Mexico	CA
25-Oct-1987	MHE	N1257E	DEN88FA016	Mitchell	SD
03-Nov-1987	MCO	N888DJ	MIA88LA026	Orlando	FL
28-Nov-1987	ASG	N201CQ	MKC88LA022	Springdale	AR
14-Dec-1987	JLN	N331PX	MKC88FA027	Joplin	MO
18-Dec-1987	4R2	N33007	FTW88FA038	Horseshoe Bay	TX
07-Jan-1988	APC	N2938X	LAX88FA082	Napa County	CA
18-Jan-1988	MDH	N40265	CHI88FA046	Southern Illinois	IL
18-Jan-1988	HOU	XAKUT	FTW88MA048	Houston Hobby	TX
18-Jan-1988	STL	N200RS	MKC88FA041	Lambert-St. Louis	MO
19-Jan-1988	CLT	N996SA	ATL88LA083	Charlotte-Douglas	NC
19-Jan-1988	DRO	N68TC	DCA88MA017	Durango	CO
31-Jan-1988	PUB	N9393H	DEN88LA073	Pueblo	CO
01-Feb-1988	KTN	N3689D	SEA88LA043	Ketchikan	AK
03-Feb-1988	HLN	N517S	DEN88FA063	Helena Regional	MT
18-Feb-1988	LCH	N5701K	FTW88FA063	Lake Charles	LA
19-Feb-1988	ACY	N27400	NYC88FA087	Atlantic City	NJ
19-Feb-1988	BDR	N2469M	NYC88FA093	Igor Sikorsky Memorial	CT
20-Feb-1988	MMU	N5782E	NYC88LA088	Morristown	NJ
24-Mar-1988	AMN	N54848	CHI88FA082	Alma	MI
01-Apr-1988	UIN	N32076	CHI88FA090	Quincy	IL
01-Apr-1988	MKC	N989B	MKC88FA072	Kansas City Downtown	MO
08-Apr-1988	HLN	N8008M	DEN88FA093	Helena Regional	MT
31-Aug-1988	CRW	N15948	BFO88LA080	Charleston-Yeager	WV
23-Sep-1988	EUG	N234K	SEA88LA184	Mahlon Sweet	OR
12-Oct-1988	SMX	N6198H	LAX89FA013	Santa Maria	CA
19-Oct-1988	PRB	N739YS	LAX89FA021	Paso Robles	CA
21-Oct-1988	FDK	N8291Z	BFO89FA003	Frederick	MD
26-Oct-1988	L12	N79HW	LAX89FA025	Redlands	CA
02-Nov-1988	IAH	N60819	FTW89FA012	Houston	TX
18-Nov-1988	BVX	N308PS	MKC89FA027	Batesville Regional	AR
20-Nov-1988	OXC	N468CM	NYC89LA034	Waterbury-Oxford	CT
30-Nov-1988	MOD	N5852V	LAX89LA041	Modesto City	CA
02-Dec-1988	S88	N2706F	SEA89FA021	Arlington	WA
09-Dec-1988	TYS	N120G	ATL89FA054	McGhee Tyson	TN
22-Dec-1988	CWA	N427MQ	CHI89IA034	Central Wisconsin	WI
24-Dec-1988	IMS	N5121J	CHI89FA035	Madison	IN
24-Dec-1988	BDR	N262C	NYC89FA059	Igor Sikorsky Memorial	CT
01-Jan-1989	SPI	N2305U	CHI89FA038	Springfield	IL
02-Jan-1989	MFD	N500V	ATL89FA065	Mansfield	OH
09-Jan-1989	OAK	N1672T	LAX89FA081	Oakland	CA
11-Jan-1989	NC14	N9330B	ATL89FA071	Rockingham County	NC
22-Jan-1989	SLC	N712PC	DEN89IA067	Salt Lake City	UT
17-Mar-1989	GLS	N5280R	FTW89LA068	Scholes Field	LA
22-Mar-1989	JAX	N77BR	MIA89FA113	Jacksonville	FL

Appendix C
Accident Reports Used in Study *(continued)*

Accident Date	Airport Identifier	Aircraft Registration Number	NTSB Report Identification Number	Airport Name	State
08-Sep-1989	MCI	N283AU	DCA89IA071	Kansas City	MO
01-Oct-1989	TDF	N53CC	FTW90FA002	Person County	FL
01-Nov-1989	RSW	N50TR	MIA90FA022	Southwest Florida	FL
12-Nov-1989	CMA	N2723R	LAX90FA031	Camarillo	CA
15-Nov-1989	HPX	N55399	NYC90FA030	West Chester County	NY
22-Nov-1989	JST	N1028Q	NYC90LA032	Johnstown	PA
22-Nov-1989	PWT	N8918A	SEA90FA021	Bremerton	WA
27-Nov-1989	DMS	N919S	DEN90FA027	Des Moines	IA
02-Dec-1989	SRR	N9PU	DEN90FA030	Sierra Bianca	CA
08-Dec-1989	TLH	N404EA	MIA90IA038	Tallahassee	FL
10-Dec-1989	57A	N5417C	ATL90FA038	Rutherford County	NC
16-Dec-1989	APA	N477T	DEN90FA033	Centennial	CO
26-Dec-1989	PSC	N410UE	DCA90MA011	Tri-Cities	WA
15-Jan-1990	EKO	N2721M	DEN90FA042	Elko	NV
16-Jan-1990	ATW	N87163	CHI90FA065	Outagamie County	WI
16-Jan-1990	CWA	N4532Q	CHI90FA066	Central Wisconsin	WI
16-Jan-1990	BTV	N5115J	NYC90FA054	Burlington	VT
19-Jan-1990	LIT	N46TE	MKC90MA049	Adams Field	AR
19-Feb-1990	TLH	N7574Y	MIA90IA072	Tallahassee	FL
27-Feb-1990	DEN	N820FE	DEN90FA068	Stapleton	CO
19-Mar-1990	FUL	N2985E	LAX90FA123	Fullerton	CA
27-Mar-1990	UVA	N696JB	FTW90LA087	Garner Field	TX
04-May-1990	ILM	N418NE	ATL90FA108	New Hanover	NC
15-May-1990	DBQ	N111AY	MKC90LA108	Dubuque	IA
20-May-1990	CGF	N4859W	CHI90FA131	Cuyahoga County	OH
02-Jun-1990	UNK	N670MA	DCA90MA030	Unalakleet	AK
24-Aug-1990	B05	N85HB	NYC90FA199	Boston Logan	MA
19-Sep-1990	CBE	N8249J	BFO90FA076	Cumberland	WV
24-Sep-1990	SBP	N79DD	LAX90FA332	San Luis Obispo	CA
28-Sep-1990	ACK	N5289N	NYC90FA231	Nantucket	MA
20-Nov-1990	CVN	N22054	DEN91FA020	Clovis	NM
23-Nov-1990	ACY	N2693F	NYC91FA035	Atlantic City	NJ
25-Nov-1990	3KM	N6026G	CHI91FA033	Col. James Jabara	KS
01-Dec-1990	SEA	N437OZ	SEA91LA032	Seattle-Tacoma	WA
06-Jan-1991	RBL	N66SL	LAX91LA067	Red Bluff	OR
19-Jan-1991	114	N4827W	ATL91FA040	Starkville	MS
30-Jan-1991	JST	N30SE	NYC91LA068	Johnstown	PA
06-Feb-1991	CGI	N3966X	CHI91FA091	Cape Girardeau	MO
13-Feb-1991	ASE	N535PC	DEN91FA043	Sardy Field	CO
12-Mar-1991	OGA	N6687U	CHI91LA106	Lincoln	NE
14-Mar-1991	BLF	N3529Y	BFO91FA031	Mercer County	WV
17-Mar-1991	TVF	N8290Y	CHI91FA108	Thief River	MN
29-Mar-1991	CEZ	N3851C	DEN91FA056	Cortez	CO
09-Apr-1991	EAU	N8012T	CHI91FA126	Eau Clair	WI
15-May-1991	BNA	N882AA	ATL91IA094	Nashville	TN
07-Jul-1991	5BD	N43ER	NYC91FA174	Windham	CT
10-Jul-1991	BHM	N7217L	DCA91MA042	Birmingham	AL
06-Aug-1991	OTM	N61568	CHI91FA254	Ottumwa	IA

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Accident Reports Used in Study *(continued)*

Accident Date	Airport Identifier	Aircraft Registration Number	NTSB Report Identification Number	Airport Name	State
22-Nov-1991	D98	N24169	CHI92FA032	Romeo	MI
02-Dec-1991	MNZ	N6890T	FTW92LA032	Hamilton	TX
08-Dec-1991	SGF	N8411A	CHI92LA043	Springfield	MO
20-Dec-1991	FLG	N766BA	LAX92FA065	Flagstaff	AZ
26-Dec-1991	MSO	N6408P	SEA92LA031	Missoula	MT
03-Jan-1992	SLK	N55000	DCA92MA016	Adirondack	NY
11-Feb-1992	LAL	N66LM	MIA92FA085	Lakeland	FL
13-Feb-1992	MCN	N89071	ATL92LA044	Lewis B. Wilson	GA
18-Feb-1992	RDU	N33464	ATL92FA047	Raleigh-Durham	NC
24-Feb-1992	UNV	N6928L	NYC92FA067	University Park	PA
06-Mar-1992	FDK	N8104G	BFO92FA031	Frederick	MD
07-Mar-1992	EKM	N105A	CHI92LA106	Elkhart	IN
19-Mar-1992	DCA	N65737	BFO92FA044	Washington National	MD
04-Apr-1992	OTZ	N3555C	ANC92LA058	Kotzebue	AK
09-Apr-1992	TLH	N105FL	MIA92GA107	Tallahassee	FL
08-Jun-1992	ANB	N118GP	ATL92MA118	Anniston	AL
24-Aug-1992	MQT	N738HM	CHI92FA254	Marquette County	MI
05-Sep-1992	GED	N3647T	BFO92FA125	Sussex County	DE
18-Sep-1992	MVY	N102SR	BFO92FA151	Martha’s Vineyard	MA
18-Oct-1992	FUL	N9SQ	LAX93FA014	Fullerton	CA
19-Oct-1992	ORH	N1ZB	NYC93FA026	Worcester	MA
30-Oct-1992	UCY	N101KH	ATL93LA019	Everett-Stewart	TN
09-Nov-1992	BOI	N7381U	SEA93FA020	Boise	ID
30-Nov-1992	C18	N244JH	CHI93LA047	Frankfort	IL
11-Dec-1992	TWF	N856M	SEA93LA036	Hailey	ID
13-Dec-1992	CID	N17CH	CHI93LA052	Cedar Rapids	IA
13-Dec-1992	W04	N7285R	SEA93FA039	Ocean Shores	WA
21-Dec-1992	CSG	N9319C	ATL93FA039	Columbus	GA
26-Dec-1992	X41	N5343T	MIA93FA036	Tampa Bay Executive	FL
28-Dec-1992	TUL	N3809Q	FTW93FA061	Tulsa	OK
07-Jan-1993	MYZ	N8016M	CHI93LA066	Marysville	MO
22-Jan-1993	CGF	N2890A	NYC93LA054	Cuyahoga County	OH
29-Jan-1993	MRF	N363N	FTW93LA077	Marfa	TX
27-Feb-1993	ERW	N88KH	FTW93FA092	Kerrville	TX
15-Mar-1993	THA	N4341P	FTW93LA106	Tullahoma	TN
06-Apr-1993	CPR	N96JP	SEA93FA088	Natrona County	WY
04-May-1993	LNR	N80CB	CHI93FA158	Tri-County	WI
07-Aug-1993	AGS	N90BP	ATL93FA143	Bush Field	GA
18-Aug-1993	MGW	N3552R	NYC93LA161	Morgantown	WV
08-Oct-1993	BVY	N6AP	NYC94FA007	Beverly	MA
12-Oct-1993	ALI	N6198A	FTW94LA016	Alice	TX
31-Oct-1993	I77	N252G	NYC94FA025	Cincinnati-Blue Ash	OH
28-Nov-1993	BTP	N707JS	BFO94FA021	Butler County	PA
01-Dec-1993	HIB	N334PX	DCA94MA022	Chisholm-Hibbing	MN
02-Dec-1993	1M8	N39595	NYC94LA030	Hopkinsville-Christian	KY
04-Dec-1993	HVN	N1488X	NYC94FA033	Tweed-New Haven	CT
05-Dec-1993	DBQ	N9684X	CHI94LA045	Dubuque	IA
08-Dec-1993	DFW	N166AW	FTW94IA046	Dallas-Fort Worth	TX

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Accident Reports Used in Study *(continued)*

Accident Date	Airport Identifier	Aircraft Registration Number	NTSB Report Identification Number	Airport Name	State
01-Jan-1994	81J	N243KW	MIA94FA044	Destin-Fort Walton Beach	FL
07-Jan-1994	CMH	N304UE	DCA94MA027	Port Columbus	OH
20-Feb-1994	3GV	N58325	CHI94FA089	East Kansas City	MO
03-Mar-1994	FOK	N512SK	NYC94FA052	Suffolk County	NY
11-Apr-1994	SUS	N9187M	CHI94LA130	Spirit of St. Louis	MO
13-May-1994	H21	N4226B	CHI94FA157	Camdenton	MO
18-Jun-1994	JYO	N6679U	BFO94LA106	Leesburg	VA
18-Jun-1994	IAD	XABBA	DCA94MA061	Washington Dulles	VA
20-Oct-1994	JVY	N40509	CHI95FA018	Clark County	IN
18-Nov-1994	HYA	N402BK	NYC95FA030	Barnstable	MA
18-Nov-1994	6B6	N14315	NYC95LA029	Minute Man	MA
21-Nov-1994	N88	N2949Q	NYC95FA033	Doylestown	PA
27-Nov-1994	GSP	N6556M	ATL95LA020	Greenville-Spartanburg	SC
08-Dec-1994	MCI	N5647D	CHI95LA053	Kansas City	MO
18-Jan-1995	JAC	N5603S	SEA95FA038	Jackson Hole	WY
21-Jan-1995	LGD	N36PB	SEA95LA039	La Grande	OR
02-Mar-1995	TUL	N9448B	FTW95FA129	Tulsa	OK
03-Mar-1995	GVL	N227DM	ATL95FA057	Lee Gilmer	GA
22-Mar-1995	RNO	N9417B	LAX95FA141	Reno-Cannon	NV
09-May-1995	OLY	N81TS	NYC95FA105	Olney Noble	IL
02-Jun-1995	VPZ	N8447T	CHI95LA166	Porter County	IN
05-Jul-1995	RDU	N15743	ATL95FA128	Raleigh-Durham	NC
18-Sep-1995	CNO	N693PG	LAX95FA338	Chino	CA
27-Sep-1995	CAE	N2160E	ATL95FA174	Columbia	SC
04-Oct-1995	ELM	N9461E	NYC96FA002	Elmira-Corning	NY
27-Oct-1995	LGB	N2167F	LAX96LA024	Daugherty Field	CA
10-Nov-1995	RPB	N9894R	CHI96LA031	Belleville	KS
12-Nov-1995	BDL	N566AA	DCA96MA008	Bradley	CT
20-Nov-1995	FUL	N888JK	LAX96FA050	Fullerton	CA
25-Nov-1995	BZN	N3729T	SEA96FA024	Gallatin Field	MT
03-Dec-1995	2G9	N8775W	CHI96FA045	Somerset County	PA
19-Dec-1995	EQY	N4219T	ATL96LA024	Monroe	NC
19-Dec-1995	SPS	N8349Z	MIA96FA048	Wichita Falls	TX
22-Dec-1995	FCM	N222RB	CHI96LA057	Flying Clould	MN
30-Dec-1995	EGV	N991PC	CHI96FA067	Eagle River Union	WI
30-Dec-1995	DLO	N7337R	LAX96FA086	Delano	CA
31-Dec-1995	MKY	N91MJ	MIA96FA051	Marco Island	FL
08-Jan-1996	GEG	N117AC	SEA96FA040	Spokane	WA
16-Jan-1996	FFC	N9210F	ATL96FA036	Falcon Field	GA
22-Feb-1996	PLD	N5024J	CHI96FA095	Portland	IN
01-Mar-1996	GNV	N2456U	MIA96FA089	Gainesville	FL
18-Mar-1996	LNP	N54839	IAD96FA050	Wise	VA
08-May-1996	UGN	N225BA	CHI96FA152	Waukegan	IL
09-May-1996	OLE	N65792	NYC96LA102	Cattaraugus County-Olean	NY
07-Jun-1996	SBA	N4303X	LAX96FA226	Santa Barbara	CA
03-Jul-1996	ISO	N23806	MIA96LA174	Kinston	NC
30-Nov-1996	MFD	N9129N	IAD97FA025	Mansfield	OH
11-Dec-1996	ELZ	N3424N	IAD97LA031	Wellsville	NY

Appendix C
Accident Reports Used in Study *(continued)*

Accident Date	Airport Identifier	Aircraft Registration Number	NTSB Report Identification Number	Airport Name	State
16-Dec-1996	ISP	N425EW	NYC97FA030	MacArthur Field	NY
24-Dec-1996	LEB	N388LS	NYC97FA194	Lebanon	NH
21-Jan-1997	STP	N1160G	CHI97FA058	St. Paul Downtown	MN
14-Feb-1997	KCVG	N922FE	NYC97LA054	Cincinnati	KY
02-Mar-1997	SLC	N117WM	SEA97FA067	Salt Lake City	UT
27-Apr-1997	JYO	N885JC	NYC97FA080	Leesburg	VA
02-Jun-1997	FWA	N171DB	CHI97LA154	Fort Wayne	IN
14-Aug-1997	DNN	N74EJ	MIA97FA232	Dalton	GA
19-Sep-1997	ACK	N6879Y	NYC97LA183	Nantucket	MA
28-Nov-1997	OYM	N6923	NYC98FA035	St. Marys	PA
29-Nov-1997	SPW	N22NC	CHI98LA050	Spencer	IA
10-Dec-1997	CLT	N30SA	ATL98FA023	Charlotte	NC
13-Jan-1998	IAH	N627WS	FTW98MA096	Houston	TX
09-Feb-1998	ORD	N845AA	DCA98MA023	Chicago O'Hare	IL
01-Mar-1998	PQI	N777HM	NYC98FA071	Presque Isle	ME
07-Apr-1998	BIS	N868FE	CHI98FA119	Bismarck	ND
16-Jun-1998	HLN	N446JR	SEA98FA100	Helena Regional	MT
07-Jul-1998	PBV	N501FS	ANC98FA091	St. George	AK
17-Oct-1998	BRD	N138BA	CHI99LA008	Hartford Brainard	MN
28-Oct-1998	HDN	N35533	DEN99FA016	Hayden	CO
03-Dec-1998	PIZ	N3542H	ANC99LA014	Point Lay LRRS	AK
04-Dec-1998	PTK	N59902	CHI99FA047	Pontiac	MI
08-Jan-1999	PDX	N141LC	SEA99FA028	Portland	OR
29-Jan-1999	HOT	N260LH	FTW99FA074	Memorial Field	AR
11-Feb-1999	KSM	N31240	ANC99FA028	Anchorage	AK
15-Apr-1999	MYF	N7706R	LAX99FA150	Montgomery Field	CA
21-Sep-1999	CCO	N27343	MIA99FA263	Newnan-Coweta County	GA
09-Dec-1999	PLK	N525KL	CHI00FA040	M. Graham Clark	MO
17-Jan-2000	LBL	N12654	CHI00LA058	Liberal	KS
21-Feb-2000	OTZ	N219CS	ANC00LA029	Ralph Wein Memorial	AK
23-Sep-2000	3B1	N590TA	NYC00LA265	Greenville	ME

U.S. Scheduled Air Carriers Had No Fatal Accidents in 2002

The accident rate for U.S. Federal Aviation Regulations Part 121 scheduled air carriers was lower than the rate for Part 135 scheduled air carriers. The accident rate for Part 121 nonscheduled air carriers was higher than the rates for scheduled air carriers operating under Part 121 or Part 135.

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FSF Editorial Staff

There were no fatal accidents in 2002 involving scheduled U.S. air carriers operating under U.S. Federal Aviation Regulations (FARs) Part 121 or Part 135. It was the first year since 1998 that there were no fatalities in scheduled U.S. airline operations.

The 34 accidents in scheduled Part 121 operations represented a preliminary rate of 0.337 accidents per 100,000 departures. For scheduled Part 135 air carriers, the corresponding rate was 1.575 accidents per 100,000 departures. Nonscheduled (charter) Part 121 operations resulted in 2.333 accidents per 100,000 departures (Table 1, page 48). (Departure data for nonscheduled Part 135 operations were not available.)

Air carriers operating under Part 121 flew 18.012 million hours in 2002 compared with 17.752 million flight hours in 2001 (Table 2, page 49). Major accidents[1] declined from five in 2001 to one in 2002. There was one serious accident[2] in 2002, the same number as in 2001, and 14 injury accidents[3] occurred in 2002 compared with 18 in 2001. The number of damage accidents[4] rose from 21 in 2001 to 25 in 2002.

The preliminary rate of major accidents per million flight hours for Part 121 air carriers, 0.056, was the lowest since 1998, and the rate of injury accidents, 0.777, was lower than in any of the years in the 1997–2001 period. (Since March 20, 1997, aircraft with 10 or more passenger seats have been operated under Part 121, so the post-1996 data in Table 1 are not comparable to those for 1996 and earlier.) The rate of damage accidents, 1.388 per million flight hours, was greater than the rate of 1.183 for 2001.

The scheduled Part 121 air carrier accident preliminary rate of 0.337 per 100,000 departures was lower than 0.379 for 2001 and 0.453 for 2000 (Table 3, page 50). (The Sept. 11, 2001, airliner hijackings were excluded in calculating the 2001 rate.) The 34 accidents in these operations were fewer than the 41 in 2001 (which included the four hijackings) and the 50 in 2000.

Table 1
Accidents, Fatalities and Rates, U.S. Air Carrier Operations Under FARs Part 121 and Part 135, 2002

	Accidents		Fatalities				Accidents Per 100,000 Flight Hours		Accidents Per 100,000 Departures	
	All	Fatal	Total	Aboard	Flight Hours	Departures	All	Fatal	All	Fatal
U.S. air carriers operating under FARs Part 121										
Scheduled	34	—	—	—	17,395,000	10,100,000	0.195	—	0.337	—
Nonscheduled	7	—	—	—	616,700	300,000	1.135	—	2.333	—
U.S. air carriers operating under FARs Part 135										
Scheduled	8	—	—	—	308,300	508,000	2.595	—	1.575	—
Nonscheduled	58	17	33	33	3,051,000	—	1.900	0.56	—	—

Notes: All data are preliminary. Flight hours and departures are compiled and estimated by the U.S. Federal Aviation Administration. Departure information for nonscheduled Part 135 operations is not available.

FARs = U.S. Federal Aviation Regulations

Source: U.S. National Transportation Safety Board

The accident rate for nonscheduled Part 121 air carriers of 2.333 per 100,000 departures was an increase from the 2001 rate of 1.248 and was the highest rate in the 1983–2002 period (Table 4, page 51). The seven accidents in the category exceeded the four in 2001 and the six in 2000.

Scheduled Part 135 small-aircraft commuter operations — involving aircraft with fewer than 10 passenger seats and a maximum payload capacity of 7,500 pounds (3,405 kilograms) — resulted in eight accidents in 2002, compared with seven in 2001 and 12 in 2000 (Table 5, page 52). The preliminary accident rate of 1.575 accidents per 100,000 departures for these operators increased compared with 1.251 in 2001, although the rate represented a decrease from those in 1999 and 2000.

There were 58 accidents in nonscheduled (on-demand or air taxi) Part 135 operations in 2002, the lowest annual total in the 1983–2002 period (Table 6, page 53) and a decrease from 72 in 2001. The preliminary 2002 accident rate per 100,000 flight hours (1.90) was the lowest in the 1983–2002 period as well.

Caution should be used in inferring trends from year-to-year changes in numbers of accidents because of the small numbers involved and the variation in exposure (number of departures or number of flight hours).♦

[FSF editorial note: The U.S. National Transportation Safety Board (NTSB) compiled the data used for this article. Data for 2002 are "preliminary," NTSB said.]

Notes

1. *Major* accident was defined as an accident in which a Part 121 aircraft was destroyed, or there were multiple fatalities or there was one fatality and a Part 121 aircraft was substantially damaged.

2. *Serious* accident was defined as an accident in which there was one fatality without substantial damage to a Part 121 aircraft, or there was at least one serious injury and a Part 121 aircraft was substantially damaged.

3. *Injury* accident was defined as a nonfatal accident with at least one serious injury and without substantial damage to a Part 121 aircraft.

4. *Damage* accident was defined as an accident in which no person was killed or seriously injured, but in which any aircraft was substantially damaged.

5. *Total fatalities* were greater than *fatalities aboard* when people other than aircraft occupants were killed in an accident.

Table 2
Accidents and Accident Rates, 1983–2002, for U.S. Air Carriers Operating Under FARs Part 121

Year	Accidents				Aircraft Hours Flown (millions)	Accidents per Million Hours Flown			
	Major[1]	Serious[2]	Injury[3]	Damage[4]		Major[1]	Serious[2]	Injury[3]	Damage[4]
1983	4	2	9	8	7.299	0.548	0.274	1.233	1.096
1984	2	2	6	6	8.165	0.245	0.245	0.735	0.735
1985	8	2	5	6	8.710	0.918	0.230	0.574	0.689
1986	4	0	13	7	9.976	0.401	0.000	1.303	0.702
1987	5	1	12	16	10.645	0.470	0.094	1.127	1.503
1988	4	2	13	11	11.141	0.359	0.180	1.167	0.987
1989	8	4	6	10	11.275	0.710	0.355	0.532	0.887
1990	4	3	10	7	12.150	0.329	0.247	0.823	0.576
1991	5	2	10	9	11.781	0.424	0.170	0.849	0.764
1992	3	3	10	2	12.360	0.243	0.243	0.809	0.162
1993	1	2	12	8	12.706	0.079	0.157	0.944	0.630
1994	4	0	12	7	13.124	0.305	0.000	0.914	0.533
1995	3	2	14	17	13.505	0.222	0.148	1.037	1.259
1996	6	0	18	13	13.746	0.436	0.000	1.309	0.946
1997	2	4	24	19	15.838	0.126	0.253	1.515	1.200
1998	0	3	21	26	16.817	0.000	0.178	1.249	1.546
1999	2	2	20	27	17.555	0.114	0.114	1.139	1.538
2000	3	3	20	30	18.299	0.109	0.109	1.093	1.475
2001	5	1	18	21	17.752	0.282	0.056	1.014	1.183
2002	1	1	14	25	18.012	0.056	0.056	0.777	1.388

Note: Since March 20, 1997, aircraft with 10 or more seats used in scheduled passenger service have been operated under FARs Part 121.

[1] *Major* accident was defined as an accident in which a Part 121 aircraft was destroyed, or there were multiple fatalities or there was one fatality and a Part 121 aircraft was substantially damaged.

[2] *Serious* accident was defined as an accident in which there was one fatality without substantial damage to a Part 121 aircraft, or there was at least one serious injury and a Part 121 aircraft was substantially damaged.

[3] *Injury* accident was defined as a nonfatal accident with at least one serious injury and without substantial damage to a Part 121 aircraft.

[4] *Damage* accident was defined as an accident in which no person was killed or seriously injured, but in which any aircraft was substantially damaged.

FARs = U.S. Federal Aviation Regulations

Source: U.S. National Transportation Safety Board

Table 3
Accidents, Fatalities and Rates, 1983–2002, for U.S. Air Carriers Operating Under FARs Part 121, Scheduled Service

	Accidents		Fatalities[1]					Accidents Per 100,000 Flight Hours		Accidents Per 1,000,000 Miles Flown		Accidents Per 100,000 Departures	
Year	All	Fatal	Total	Aboard	Flight Hours	Miles Flown	Departures	All	Fatal	All	Fatal	All	Fatal
1983	22	4	15	14	6,914,969	2,920,909,000	5,235,262	0.318	0.058	0.0075	0.0014	0.420	0.076
1984	13	1	4	4	7,736,037	3,258,910,000	5,666,076	0.168	0.013	0.0040	0.0003	0.229	0.018
1985	17	4	197	196	8,265,332	3,452,753,000	6,068,893	0.206	0.048	0.0049	0.0012	0.280	0.066
1986 *	21	2	5	4	9,495,158	3,829,129,000	6,928,103	0.211	0.011	0.0052	0.0003	0.289	0.014
1987 *	32	4	231	229	10,115,407	4,125,874,000	7,293,025	0.306	0.030	0.0075	0.0007	0.425	0.041
1988 *	29	3	285	274	10,521,052	4,260,785,000	7,347,575	0.266	0.019	0.0066	0.0005	0.381	0.027
1989	24	8	131	130	10,597,922	4,337,234,000	7,267,341	0.226	0.075	0.0055	0.0018	0.330	0.110
1990	22	6	39	12	11,524,726	4,689,287,000	7,795,761	0.191	0.052	0.0047	0.0013	0.282	0.077
1991	25	4	62	49	11,139,166	4,558,537,000	7,503,873	0.224	0.036	0.0055	0.0009	0.333	0.053
1992	16	4	33	31	11,732,026	4,767,344,000	7,515,373	0.136	0.034	0.0034	0.0008	0.213	0.053
1993	22	1	1	0	11,981,347	4,936,067,000	7,721,870	0.184	0.008	0.0045	0.0002	0.285	0.013
1994 *	19	4	239	237	12,292,356	5,112,633,000	7,824,802	0.146	0.033	0.0035	0.0008	0.230	0.051
1995	34	2	166	160	12,776,679	5,328,969,000	8,105,570	0.266	0.016	0.0064	0.0004	0.419	0.025
1996	32	3	342	342	12,971,676	5,449,997,000	7,851,298	0.247	0.023	0.0059	0.0006	0.408	0.038
1997	44	3	3	2	15,061,662	6,339,432,000	9,925,058	0.292	0.020	0.0069	0.0005	0.443	0.030
1998	43	1	1	0	15,921,447	6,343,690,000	10,535,196	0.270	0.006	0.0068	0.0002	0.408	0.009
1999	46	2	12	11	16,693,365	6,689,327,000	10,860,692	0.276	0.012	0.0069	0.0003	0.424	0.018
2000	50	3	92	92	17,478,519	7,152,260,112	11,043,409	0.286	0.017	0.0070	0.0004	0.453	0.027
2001 *	41	6	531	525	17,098,510	6,919,437,497	9,761,387	0.216	0.012	0.0053	0.0003	0.379	0.020
2002	34	0	0	0	17,395,000	7,150,000,000	10,100,000	0.195	—	0.0048	—	0.337	—

Notes: 2002 data are preliminary. Flight hours, miles and departures are compiled by the U.S. Federal Aviation Administration.

Since March 20, 1997, aircraft with 10 or more seats used in scheduled passenger service have been operated under FARs Part 121.

Years marked with * are those in which an illegal act was responsible for an occurrence in this category. These acts, such as suicide and sabotage, are included in the totals for accidents and fatalities but are excluded for the purpose of accident rate computation. Other than the persons aboard aircraft who were killed, fatalities resulting from the Sept. 11, 2001, terrorist acts are excluded from this table.

[1]Total fatalities were greater than fatalities aboard when people other than aircraft occupants were killed in an accident.

FARs = U.S. Federal Aviation Regulations

Source: U.S. National Transportation Safety Board

Table 4
Accidents, Fatalities and Rates, 1983–2002, for U.S. Air Carriers Operating Under FARs Part 121, Nonscheduled Service

	Accidents		Fatalities[1]					Accidents Per 100,000 Flight Hours		Accidents Per 1,000,000 Miles Flown		Accidents Per 100,000 Departures	
Year	All	Fatal	Total	Aboard	Flight Hours	Miles Flown	Departures	All	Fatal	All	Fatal	All	Fatal
1983	1	0	0	0	383,830	148,409,000	209,112	0.261	—	0.0067	—	0.478	—
1984	3	0	0	0	429,087	169,153,000	232,776	0.699	—	0.0177	—	1.289	—
1985	4	3	329	329	444,562	178,264,000	237,866	0.900	0.675	0.0224	0.0168	1.682	1.261
1986	3	1	3	3	480,946	188,497,000	273,924	0.624	0.208	0.0159	0.0053	1.095	0.365
1987	2	1	1	1	529,785	234,647,000	308,348	0.378	0.189	0.0085	0.0043	0.649	0.324
1988	1	0	0	0	619,496	242,641,000	368,486	0.161	—	0.0041	—	0.271	—
1989	4	3	147	146	676,621	267,849,000	378,153	0.591	0.443	0.0149	0.0112	1.058	0.793
1990	2	0	0	0	625,390	258,545,000	296,545	0.320	—	0.0077	—	0.674	—
1991	1	0	0	0	641,444	266,287,000	311,002	0.156	—	0.0038	—	0.322	—
1992	2	0	0	0	627,689	272,091,000	365,334	0.319	—	0.0074	—	0.547	—
1993	1	0	0	0	724,859	313,402,000	351,303	0.138	—	0.0032	—	0.285	—
1994	4	0	0	0	831,959	365,485,000	413,504	0.481	—	0.0109	—	0.967	—
1995	2	1	2	2	728,578	325,100,000	351,895	0.275	0.137	0.0062	0.0031	0.568	0.284
1996	5	2	38	8	774,436	423,111,000	377,512	0.646	0.258	0.0118	0.0047	1.324	0.530
1997	5	1	5	4	776,447	357,206,000	393,325	0.644	0.129	0.0140	0.0028	1.271	0.254
1998	7	0	0	0	895,108	392,853,000	444,566	0.782	—	0.0178	—	1.575	—
1999	5	0	0	0	861,843	411,987,000	448,070	0.580	—	0.0121	—	1.116	—
2000	6	0	0	0	820,738	371,767,000	414,403	0.731	—	0.0161	—	1.448	—
2001	4	0	0	0	653,937	299,439,000	320,636	0.612	—	0.0134	—	1.248	—
2002	7	0	0	0	616,700	288,900,000	300,000	1.135	—	0.0242	—	2.333	—

Notes: 2002 data are preliminary. Flight hours, miles and departures are compiled by the U.S. Federal Aviation Administration.

[1]Total fatalities were greater than fatalities aboard when people other than aircraft occupants were killed in an accident.

FARs = U.S. Federal Aviation Regulations

Source: U.S. National Transportation Safety Board

Table 5
Accidents, Fatalities and Rates, 1983–2002, for U.S. Air Carriers Operating Under FARs Part 135, Scheduled Service

	Accidents		Fatalities[1]					Accidents Per 100,000 Flight Hours		Accidents Per 1,000,000 Miles Flown		Accidents Per 100,000 Departures	
Year	All	Fatal	Total	Aboard	Flight Hours	Miles Flown	Departures	All	Fatal	All	Fatal	All	Fatal
1983	16	2	11	10	1,510,908	253,572,000	2,328,430	1.059	0.132	0.0631	0.0079	0.687	0.086
1984	22	7	48	46	1,745,762	291,460,000	2,676,590	1.260	0.401	0.0755	0.0240	0.822	0.262
1985	18	7	37	36	1,737,106	300,817,000	2,561,463	1.036	0.403	0.0598	0.0233	0.703	0.273
1986	14	2	4	4	1,724,586	307,393,000	2,798,811	0.812	0.116	0.0455	0.0065	0.500	0.071
1987	33	10	59	57	1,946,349	350,879,000	2,809,918	1.695	0.514	0.0940	0.0285	1.174	0.356
1988	18	2	21	21	2,092,689	380,237,000	2,909,005	0.860	0.096	0.0473	0.0053	0.619	0.069
1989	19	5	31	31	2,240,555	393,619,000	2,818,520	0.848	0.223	0.0483	0.0127	0.674	0.177
1990	15	3	6	4	2,341,760	450,133,000	3,160,089	0.641	0.128	0.0333	0.0067	0.475	0.095
1991	23	8	99	77	2,291,581	433,900,000	2,820,440	1.004	0.349	0.0530	0.0184	0.815	0.284
1992 *	23	7	21	21	2,335,349	507,985,000	3,114,932	0.942	0.300	0.0433	0.0138	0.706	0.225
1993	16	4	24	23	2,638,347	554,549,000	3,601,902	0.606	0.152	0.0289	0.0072	0.444	0.111
1994	10	3	25	25	2,784,129	594,134,000	3,581,189	0.359	0.108	0.0168	0.0050	0.279	0.084
1995	12	2	9	9	2,627,866	550,377,000	3,220,262	0.457	0.076	0.0218	0.0036	0.373	0.062
1996	11	1	14	12	2,756,755	590,727,000	3,515,040	0.399	0.036	0.0186	0.0017	0.313	0.028
1997	16	5	46	46	982,764	246,029,000	1,394,096	1.628	0.509	0.0650	0.0203	1.148	0.359
1998	8	0	0	0	353,670	50,773,000	707,071	2.262	—	0.1576	—	1.131	—
1999	13	5	12	12	342,731	52,403,000	672,278	3.793	1.459	0.2481	0.0954	1.934	0.744
2000	12	1	5	5	369,535	44,944,000	610,661	3.247	0.271	0.2670	0.0222	1.965	0.164
2001	7	2	13	13	300,432	43,099,000	559,402	2.330	0.666	0.1624	0.0464	1.251	0.358
2002	8	0	0	0	308,300	41,254,000	508,000	2.595	—	0.1939	—	1.575	—

Notes: 2002 data are preliminary. Flight hours, miles and departures are compiled by the U.S. Federal Aviation Administration.

Since March 20, 1997, aircraft with 10 or more seats used in scheduled passenger service have been operated under FARs Part 121.

Years followed by the symbol * are those in which an illegal act was responsible for an occurrence in this category. These acts, such as suicide, sabotage and terrorism, are included in the totals for accidents and fatalities but are excluded for the purpose of accident rate computation.

Based on a February 2002 FAA legal interpretation provided to the U.S. National Transportation Safety Board, any FARs Part 135 operation conducted with no revenue passengers aboard will be considered a nonscheduled flight operation. This interpretation has been applied to accidents that occurred in 2002. It has not been retroactively applied to 36 accidents, nine of them fatal, that occurred during the period 1983–2001.

[1]Total fatalities were greater than fatalities aboard when people other than aircraft occupants were killed in an accident.

FARs = U.S. Federal Aviation Regulations

Source: U.S. National Transportation Safety Board

Table 6
Accidents, Fatalities and Rates, 1983–2002, for U.S. Air Carriers Operating Under FARs Part 135, Nonscheduled Service

Year	Accidents		Fatalities[1]		Flight Hours	Accidents per 100,000 Flight Hours	
	All	Fatal	Total	Aboard		All	Fatal
1983	142	27	62	57	2,378,000	5.97	1.14
1984	146	23	52	52	2,843,000	5.14	0.81
1985	157	35	76	75	2,570,000	6.11	1.36
1986	118	31	65	61	2,690,000	4.39	1.15
1987	96	30	65	63	2,657,000	3.61	1.13
1988	102	28	59	55	2,632,000	3.88	1.06
1989	110	25	83	81	3,020,000	3.64	0.83
1990	107	29	51	49	2,249,000	4.76	1.29
1991	88	28	78	74	2,241,000	3.93	1.25
1992	76	24	68	65	2,844,000*	2.67	0.84
1993	69	19	42	42	2,324,000*	2.97	0.82
1994	85	26	63	62	2,465,000*	3.45	1.05
1995	75	24	52	52	2,486,000*	3.02	0.97
1996	90	29	63	63	3,220,000*	2.80	0.90
1997	82	15	39	39	3,098,000*	2.65	0.48
1998	77	17	45	41	3,802,000*	2.03	0.45
1999	73	12	38	38	3,298,000*	2.21	0.36
2000	80	22	71	68	3,553,000*	2.25	0.62
2001	72	18	60	59	3,176,000	2.27	0.57
2002	58	17	33	33	3,051,000	1.90	0.56

Notes: 2002 data are preliminary. Flight hours are estimated by the U.S. Federal Aviation Administration (FAA). Miles flown and departure information for nonscheduled Part 135 operations are not available.

In February 2002, FAA changed the methodology used to estimate air taxi activity. The revision was retroactively applied to the years 1992 to present, resulting in substantial revisions to flight hours marked with *.

[1]Total fatalities were greater than fatalities aboard when people other than aircraft occupants were killed in an accident.

FARs = U.S. Federal Aviation Regulations

Source: U.S. National Transportation Safety Board

Publications Received at FSF Jerry Lederer Aviation Safety Library

Schiphol Must Upgrade Capability to Meet Expected Demand, Report Says

Dutch agency suggests that changes in the use of regional airspace, including that of neighboring countries, must be included in the Schiphol capacity expansion.

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FSF Library Staff

Reports

Future Use of Airspace: A New Approach to the Increasing Demand for Air Transport at Schiphol. Netherlands Agency for Aerospace Programmes (NIVR). October 2002. 76 pp. Figures, tables, supplements, references. Available from NIVR.*

This report, the last in a four-part series, presents NIVR's vision for "the Netherlands' agenda for balanced growth of air traffic" with particular emphasis on Schiphol (Amsterdam) Airport. According to the report, if predictions that worldwide air transport will double over the next decade are correct, there will be heavy demand on air traffic management systems. The pressure will be experienced strongly at Schiphol, the nation's only major international airport, the report said.

"Clear actions have to be taken in order to sustain the long-term economic benefits of Schiphol by accommodating the growth in air traffic," said the report. "Restrictive regulations and prevailing weather conditions, combined with a specific runway configuration, mean that Schiphol is at a disadvantage compared to other European [major airports]. So without any change, the airport will not be able to accommodate the growing demand for air transport and Schiphol will be downgraded to a European regional airport. Hence, capacity demand can only be met by introducing new technologies to optimize the use of the current runway configuration, while redesign of the runway configuration of itself also seems inevitable."

The report recommends that the Dutch government "stimulate initiatives for improvement of airspace for departing and approaching traffic around Schiphol by means of cooperation and bilateral agreements with neighboring countries. An unconventional approach must not be shunned, such as restructuring the lower airspace for departing and approaching traffic at Schiphol, outside the Dutch national borders if necessary." Technological innovations to counter certain inherent disadvantages of the airport, which include visibility restrictions and high crosswinds, also should be pursued, the report said.

Books

Investigating Human Error: Incidents, Accidents, and Complex Systems. Strauch, Barry. Aldershot, England: Ashgate Publishing, 2002. 308 pp. Figures, tables, references.

According to the publisher, "In this book the author applies contemporary error theory to the needs of investigators and of anyone attempting to understand why someone made a critical error, how that error led to an incident or accident, and how to prevent such errors in the future."

The first section defines concepts and discusses contemporary error theories and the changes in viewpoints over time. The second section focuses on antecedents to error — the role of equipment, such as display features and control features; behavioral factors and physiological factors; operator or company influences, such as operational procedures; the role of regulators; maintenance and inspection environments; and the influence of national cultures and corporate cultures.

The third section examines types and quality of data and data sources, and discusses different types of data analysis and their relationship to human error. The fourth section addresses situational awareness and decision making, with discussions on factors that influence situational awareness; the relationship of situational awareness to decision making; decision-making models; and automation.

The fifth section reviews the major principles of human-performance investigation that were previously discussed and applies them to a study of the ValuJet McDonnell Douglas DC-9 accident that occurred May 11, 1996. [The aircraft had just departed Miami (Florida, U.S.) International Airport when an intense fire erupted in the forward cargo compartment. The fire burned through the airplane's control cables and control was lost. The airplane struck terrain 17 miles (27.4 kilometers) northwest of the airport. The two pilots, three flight attendants and all 105 passengers were killed in the accident. The accident investigation determined that the fire had originated from unexpended chemical oxygen generators in the airplane's cargo compartment.]

Chapters were written to be read individually, as well as consecutively, without losing their meaning. Intended readership includes students in engineering programs and psychology programs, accident investigators in industry and government, airline pilots, airline management, and training personnel in transportation and other high-risk industries.

Safety First! Twenty Years of Safety Messages. Helicopter Association International (HAI); United States Aircraft Insurance Group (USAIG); U.S. Federal Aviation Administration (FAA). December 2002. 92 pp. Illustrations. Available from HAI.**

For many years, HAI has partnered with USAIG in the Safety Poster Program to create helicopter safety posters, copies of which were distributed to HAI membership. HAI, FAA and USAIG collected 80 posters from a 20-year period, 1983–2002, and reproduced them in this large-format book.

Posters in the collection use a combination of impressive graphics, headlines involving word play and concise safety-awareness slogans (e.g., "Plan ahead: Your body shouldn't go where your mind hasn't been").

Regulatory Materials

Aviation Safety Action Program (ASAP). U.S. Federal Aviation Administration (FAA) Advisory Circular (AC) 120-66B. Nov. 15, 2002. 32 pp. Appendixes, index. Available from GPO.***

This AC provides guidance for establishing a self-reporting safety program within an air carrier or repair station. The goal of such programs is to encourage employees to voluntarily report safety information that may identify potential precursors to accidents. Under an ASAP, safety issues are resolved through corrective action, rather than through disciplinary action or legal-enforcement action. ASAP reports are collected, analyzed and stored to identify risks, and then to develop and implement actions to reduce the potential for a recurrence of events that could compromise safety. Stored data also can be used to measure or benchmark aviation-system safety.

The previous edition of the AC was published in 2000. "Based on the lessons learned from [more than] two dozen programs established since that date, the present AC contains revised guidance to facilitate achievement of ASAP's safety goals, as well as to encourage wider participation in the program," the AC said.

[This AC cancels AC 120-66A, Aviation Safety Action Program (ASAP), dated March 17, 2000.]

Operations of Aircraft at Altitudes Above 25,000 Feet MSL and/or Mach Numbers (M_{mo}) Greater Than .75. U.S. Federal Aviation Administration (FAA) Advisory Circular (AC) 61-107A. Jan. 2, 2003. 30 pp. Tables. Available from GPO.***

This AC provides guidance to pilots who are transitioning to aircraft capable of high-altitude, high-speed flight. Its goal is to familiarize those pilots with the special physiological issues and aerodynamic considerations.

Subjects discussed include the high-altitude flight environment, weather, flight planning and navigation, physiological training, high-altitude systems and equipment, aerodynamics and performance factors, and emergencies and irregularities at high altitudes.

[This AC cancels AC 61-107, Operations of Aircraft at Altitudes Above 25,000 Feet MSL and/or Mach Numbers (M_{mo}) Greater than .75, dated Jan. 23, 1991.]♦

Sources

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Kluyverweg 1
2629 HT Delft
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** Helicopter Association International (HAI)
1635 Prince St.
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*** Superintendent of Documents
U.S. Government Printing Office (GPO)
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Unstabilized Approach Cited in Tail Strike

The accident report said that the first officer, who was scheduled for a check ride the following week, had planned to fly the night visual approach without the autopilot and autothrottles.

FSF Editorial Staff

The following information provides an awareness of problems through which such occurrences may be prevented in the future. Accident/incident briefs are based on preliminary information from government agencies, aviation organizations, press information and other sources. This information may not be entirely accurate.

Air Carrier

Crew Disengaged Flight Director On Final Approach

Airbus A321. Minor damage. No injuries.

Visual meteorological conditions prevailed as the airplane was flown on a night visual approach to an airport in England, with instrument landing system (ILS) data and without engaging the flight director, the autopilot and autothrottles. The airplane initially was flown above the glideslope, and the flight crew reduced power to return the airplane to the correct approach path.

The report said, "On regaining the glideslope, insufficient power was restored, and the speed decayed during the final part of the approach to five knots below V_{REF} [landing reference speed] at touchdown. As a result, the pitch attitude was higher than normal at touchdown. An appropriate rate of forward sidestick application on touchdown was not applied, and the pitch-up moment caused by the spoiler deployment — combined with an already high pitch angle — increased the latter sufficiently to cause a tail strike."

An investigation revealed that the first officer, who was scheduled for a check ride the following week, had decided to fly the approach using the flight directors but with the autopilot and autothrottles disengaged. The report said that, in preparing for the approach, the crew "overlooked the need to arm the flight director approach mode (i.e., the ILS localizer and glide path). … It was not until the aircraft had flown through the [glideslope] … that the omission was announced by the [captain]."

The crew then turned off the flight director, set the azimuth and pitch-attitude references on the primary flight displays to display the airplane's track and flight-path angle, reduced engine thrust to near idle and began a descent. About 580 feet above ground level (AGL), the airspeed began to decrease from the target approach speed of 143 knots; at 70 feet AGL, the airspeed was 134 knots, and first officer called out that the airspeed was low. He advanced the throttle levers, but the airspeed continued to decrease, and at touchdown, the airspeed was 130 knots. The low airspeed and the reduction in the rate of descent resulted in an increase in pitch attitude, which was 10.2 degrees nose-up when the spoilers were deployed after touchdown.

The report said that the "root cause of the accident was the [first officer's] desire (and perhaps need) to practice an instrument approach technique shortly before his ability to perform it satisfactorily was assessed in the simulator. He had not intended to fly the ILS approach without the benefit of the flight director, but once he had allowed the aircraft to fly through the [glideslope] at relatively close range to touchdown (about five nautical miles [nine kilometers]), if he wished to retain the use of the flight director, he had little choice other than to discard that approach and attempt another. Thus, the earlier oversight of omitting to arm the approach mode of the flight director subsequently robbed him of its value in reducing workload, and he never succeeded in regaining a properly stabilized approach.

"The direct cause of the accident was the decision to continue the approach when it was not properly stabilized. The [first officer's] call regarding low airspeed at 70 feet AGL was the flight crew's final chance to extricate themselves from the deteriorating situation by performing a go-around."

Incident Prompts Change in Pushback Procedures

Boeing 737. No damage. No injuries.

The airplane was being pushed back from the gate for a late afternoon departure from an airport in Australia when a ground crewmember used an interphone to tell the flight crew to park the aircraft brakes. The crew responded, "brakes parked, clear to disconnect." The tow bar was disconnected, and the crew began taxiing the airplane before the ground interphone was disconnected. The crewmember who was operating the interphone came near the right engine as the airplane began moving.

At the same time, the crew of an arriving aircraft was told to taxi their airplane onto the domestic-operations apron and, as soon as the B-737 had been moved forward from the tow-bar-disconnect point, to continue taxiing to a nearby gate.

When the air traffic controller told the B-737 crew to taxi to the tow-bar-disconnect point, the crew said that the tow-bar-disconnect procedure had been completed and that they could continue to taxi beyond the disconnect point.

The two ground crewmembers later said that they had been distracted by the arriving aircraft, and the crewmember operating the interphone said that he recalled that the flight crew had confirmed that the brakes were parked but could not remember hearing instructions to "clear to disconnect."

The report said, "The other [crewmember], who was standing at the nose of the aircraft, subsequently reported that he realized the aircraft had begun to move forward when he felt a 'bump' on the back of his head as it was contacted by the aircraft radome. He immediately turned, and realizing that the other [crewmember] had not noticed that [the B-737] had begun to move, ran aft and dragged the other [crewmember] clear of the vicinity of the right engine. The crew of [the B-737] realized that the disconnect procedure had not been completed and stopped the aircraft."

As a result of the incident, the operator changed its push-back procedures to require that a chock be placed in front of the nosewheel while the tow bar is disconnected. After the disconnect procedure is completed, the ground crewmembers disconnect the interphone, close the interphone panel door, remove the chock and position themselves clear of the airplane and in view of the flight crew.

Section of Rudder Missing After Flight

BAE Systems/EADS (European Aeronautic Defense and Space Co.) Concorde. Substantial damage. No injuries.

As the airplane was flown to cruise altitude during a flight from England to the United States, the fight crew felt a "bump," a preliminary report said. The flight instruments revealed nothing unusual, and the flight crew continued with the flight.

After the crew landed the airplane at the destination airport and began to taxi the airplane to the gate, the pilot of another airplane said that part of the rudder was missing. The crew stopped the airplane, which was towed to the gate, where passengers deplaned using the jetway.

Examination of the airplane revealed that the lower half of the lower rudder was missing. The investigation was continuing.

Air Taxi Commuter

Airplane Departs Runway After Tail-wind Landing

Reims-Cessna F406. Substantial damage. No injuries.

The airplane was being flown on a morning charter flight to transport hunters and supplies to a hunting camp in Tanzania. A passenger said that the pilot conducted the approach to Runway 32, a 1,200-meter (3,937-foot) dirt-and-grass runway, at the correct speed of 110 knots.

A preliminary report said, "However, on reaching the runway, the aircraft was too high and the pilot had to lower the nose for descent to flaring height. When the aircraft was finally flared, it gained speed and floated for much of the way down the runway. After covering about two-thirds of the runway length, the brakes became effective, and the aircraft swerved to the right."

The airplane crossed the right edge of the runway and collided with trees and tree stumps before the nose landing gear collapsed and the airplane stopped.

An investigation revealed tire marks on the soft-soil runway surface. The tire marks showed that the pilot had begun a heavy application of brakes about two-thirds of the way down the runway. The right brake was applied more heavily than the left.

The report said that an examination of the braking system revealed "nothing untoward."

Runway 32 was used for all landings because of a large bush that "had started growing into the runway" about one-third of the way from the threshold of Runway 14, the report said. When the accident occurred, there was a tail wind estimated at five knots to 10 knots; the report did not include other details about wind direction. The report said that there was a slight downhill gradient on the last half of Runway 32.

Compressed Oleo Strut Cited in Landing Gear's Failure to Extend

Piper PA-31-310 Navajo. Minor damage. No injuries.

The airplane was being flown on an early morning cargo flight in New Zealand. As the pilot turned the airplane onto final approach for a visual approach to the runway, he moved the landing-gear lever down, and the right-main landing gear failed to extend.

The report said that the pilot continued his approach and "made a touch-and-go landing to check the undercarriage in contact with the tarmac." When the pilot observed that the airplane's right wing was lower than usual, he flew the airplane away from the airport and retracted the landing gear.

The pilot flew the airplane low so that a pilot on the ground could observe the landing gear; the pilot on the ground said that the right-main landing-gear door was open but the right-main landing gear was not extended. Airport fire service personnel provided a similar assessment. The pilot tried to manually extend the landing gear and complied with instructions from maintenance personnel to try to lower the landing gear by conducting various flight maneuvers. After daybreak, the pilot conducted a landing in the grass adjacent to a runway, with the nose landing gear and the left-main landing gear extended.

An investigation revealed that the right-main landing gear had not extended because the uplock hook did not release the landing-gear leg. The uplock hook had failed because a flat oleo strut became compressed. The report said that there was no record of any similar landing-gear failure.

Airplane Strikes Ground During Dark-night Visual Approach

Beech E90 King Air. Substantial damage. Three minor injuries.

Night visual meteorological conditions prevailed for the emergency medical services flight in the United States. The pilot canceled an instrument flight rules flight plan as the airplane neared the destination airport.

After the pilot flew the airplane onto the downwind leg in the traffic pattern at the destination airport, he could see the airport but not the nearby terrain. The report said that the pilot suddenly saw the ground, and the airplane struck terrain at the snow-covered edge of a mountain ridge at 8,489 feet.

Corporate Business

Airplane Strikes Terrain During Approach in Low Visibility

Socata TBM 700. Substantial damage. Three fatalities.

Instrument meteorological conditions prevailed and an instrument flight rules (IFR) flight plan had been filed for the afternoon flight in the United States. The pilot received radar vectors from an air traffic controller to intercept the localizer course for a localizer approach and acknowledged the controller's instructions to fly the airplane at 3,000 feet until established on the localizer.

Weather reported at the airport 25 minutes before the accident included visibility of 1.0 statute mile (1.6 kilometers) and a ceiling of 500 feet. Five minutes before the accident, the ceiling was 300 feet. Published weather minimums for the localizer approach included a 400-foot ceiling and visibility of one statute mile.

Radar data showed that an IFR aircraft had approached the airport from the northwest, turned south to intercept the localizer course about nine nautical miles (17 kilometers) north of the runway and "made five [turns] to six turns across the localizer course, left and right, as it proceeded toward the airport."

A preliminary report said that one witness, a general aviation pilot, was driving a truck when the airplane "appeared out of the fog, about 300 [feet] to 400 feet above the ground." The airplane was in a 10-degree to 15-degree left bank with a 20-degree to 25-degree nose-down attitude. The witness said that the airplane then leveled and pitched up, and the power increased.

"The witness thought that the pilot realized he was low and was trying to 'get of out there,'" the report said.

The airplane then descended, with a nose-high attitude, toward a wooded area and disappeared from sight behind trees. The wreckage was found in the backyard of a residence about 2.0 nautical miles (3.7 kilometers) north of the airport at 395 feet.

Loose Connector Found After Collapse of Nose Landing Gear

Learjet 60. Minor damage. No injuries.

After landing at an airport in Canada, the airplane's nosewheel collapsed.

A preliminary inspection revealed no problems with the airplane's hydraulic landing gear system. Nevertheless, one connector at the nose-landing-gear-actuator down switch was loose and unlocked. A preliminary report said that the loose connector "was considered as a factor, but the system safety is provided with internal locking of the actuator, verified by the down lock switch and hydraulic pressure. The loss of both conditions [has] not been explained."

The investigation was continuing.

Baggage-compartment Fire Indicator Prompts Diversion of Flight

Dassault-Breguet Falcon 50. No damage. No injuries.

The airplane was being flown in cruise flight from Canada to Ireland when the baggage-compartment fire-indication light illuminated. The flight crew activated the fire-extinguisher bottle for the baggage compartment, but the light remained illuminated.

The crew declared pan-pan, an urgent condition, and diverted the airplane to another airport in Canada, where they landed the airplane one hour later.

An inspection of the airplane revealed no smoke or fire in the baggage compartment. The report said that the baggage compartment fire-indication light had illuminated because of a burned-out light bulb in the baggage-compartment smoke detector. The light bulb and the fire-extinguisher bottle were replaced, and the airplane was returned to service.

Other General Aviation

Landing-gear Axle Breaks During Landing

Bellanca 7GCBC Citabria. Minor damage. No injuries.

The ski-equipped airplane was being landed at a private snow-covered landing strip in Canada after a pipeline-patrol flight. Near the end of the landing roll, the right-main landing-gear axle broke, and the airplane entered a ground loop. The loose ski moved upward and damaged the window and door on the right side of the airplane and dented a strut at the back of the wing.

A preliminary investigation revealed that the same airplane had been involved in a similar incident two years earlier in which the left-main landing-gear axle broke during a landing rollout. The report said that both incidents involved axles that had been purchased recently from the manufacturer and that both failures occurred between the bolt holes that fastened the axle to the landing-gear leg. Neither incident involved a hard landing.

Chips of Fuel-tank Material Suspected of Blocking Fuel Flow

Rans S-12XL. Substantial damage. No injuries.

The kit-built airplane was the first of its type to fly in the United Kingdom and had been flown for about 15 hours of test flights when the owner/builder conducted several takeoffs and landings at an airport in England.

The pilot flew several circuits with no apparent problems and then landed the airplane. Soon afterward, he conducted another preflight check and conducted another takeoff. He said that the takeoff was normal, but when the airplane was about 150 feet above ground level (AGL) to 200 feet AGL at the appropriate climb speed of 50 miles per hour, "engine power suddenly reduced to approximately one-third of maximum."

The pilot landed the airplane on the ground next to the runway; the engine continued to operate but did not recover any additional power. The report said that as the airplane touched down, the nose landing gear dug into the ground and the airplane pitched forward.

The report said that the owner's examination of the airplane found no apparent anomalies. A small amount of plastic debris, resembling the material from which the fuel tank was manufactured, was found on the fuel-filter element, but the amount would not have caused a significant obstruction. The report said that chips of material produced during drilling of the fuel tanks might have lodged in the fuel-feed line and might have restricted fuel flow.

Microorganisms in Glue Cited in Loss-of-control Accident

De Havilland DH-82A Tiger Moth. Destroyed. Two fatalities.

As the pilot was conducting a takeoff from a grassy area next to a runway at an airport in Australia, the airplane's right wheel struck two taxiway lights. The pilot continued the takeoff and flew the airplane for about 50 minutes, then entered the traffic pattern at another airport. The report said that soon afterward, the airplane "departed controlled flight" and struck the ground.

An investigation did not determine why the loss of control of the airplane occurred or whether any part of the aircraft structure or the propeller had failed. The report said that the right wheel was not damaged during the takeoff in any way that would have contributed to the accident.

Examination of laminated components of three wings revealed microorganisms in the glue in several areas. The laminated components and the propeller "failed at the glue line, rather than in the wood," the report said.

Rotorcraft

Disbonding of Rotor-blade Skin Cited in Loss-of-control Accident

Robinson R44. Substantial damage. Two minor injuries.

The helicopter was being flown in cruise flight at 1,000 feet and 95 knots on a midday charter flight in Australia when the pilot heard "an unusual noise associated with the main-rotor blades," the report said.

"The pilot reported that the noise sounded as though a potato-chip packet had been caught in the blades, and a violent vibration occurred in conjunction with the unusual noise."

The vibration prevented the pilot from observing the aircraft instruments and from controlling main-rotor speed. The pilot conducted an autorotative landing in a pasture.

Later, the pilot said that the helicopter had been difficult to control during the descent and that he had been unable to turn the helicopter. As a result, he was unable to maneuver the helicopter to avoid power lines.

An investigation revealed main-rotor skin disbonding from a point 60 millimeters (two inches) from the tip of one main-rotor blade to another point 1,070 millimeters (42 inches) inboard. The investigation also revealed "the beginning of skin disbonding" on the other blade, the report said.

As a result of the investigation, the Civil Aviation Safety Authority of Australia issued an airworthiness directive requiring operators of Robinson R44 helicopters to visually inspect and test the upper and lower skin-to-spar seams on main-rotor blades "for evidence of disbonding of the laminate structure" and to remove from service any blades that showed indications of disbonding.

Faulty Retaining Pin Found After Loss of Collective Control

Enstrom F-28C. Minor damage. No injuries.

The helicopter was being flown on an afternoon training flight from an airport in England. Both the flight instructor and the student pilot had flown the helicopter for a total of 45 minutes when the flight instructor took the controls to demonstrate a simulated engine-out landing.

The instructor began a run-on landing, and after a normal flare, he had difficulty raising the collective control lever. The helicopter landed in a nose-high attitude with a greater-than-normal descent rate.

An investigation revealed that the retaining pin that holds the right collective lever in the proper position was bent and that the locating holes in the lever were distorted, allowing the retaining pin and its locking lever to rotate freely. The accident report said that, in a similar helicopter, an undamaged retaining pin could not be rotated easily and that the pin rested atop a thin plate surrounding the cutout in the floor for the collective lever.

In the incident helicopter, the plate was distorted in a manner that was "consistent with the locking lever having been trapped between the seat floor and the plate," the report said.♦

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