Autogenic Feedback Training Improves Pilot Performance During Emergency Flying Conditions

Emergencies in flight create stress factors that can seriously degrade pilot performance. A recent study examines how autogenic feedback training improves pilot performance during high-stress and emergency situations.

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by
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Studies have shown that autonomous mode behavior (AMB) is one cause of aircraft fatalities caused by pilot error. In AMB cases, the pilot is in a high state of psychological and physiological arousal and tends to focus on one problem, while ignoring more critical information.

The following study, conducted under the auspices of the U.S. National Aeronautics and Space Administration's (NASA) Ames Research Center, examined the effect of training in physiological self-recognition and regulation, as a means of improving crew cockpit performance. Seventeen pilots were assigned to the treatment and control groups matched for accumulated flight hours.

The treatment group comprised four pilots of HC-130 Hercules aircraft and four HH-65 Dolphin helicopter pilots; the control group comprised three Hercules pilots and six Dolphin helicopter pilots.

During an initial flight, physiological data were recorded for each crew member and individual crew performance was rated by an instructor pilot. Eight crew members were then taught to regulate their own physiological response levels using autogenic feedback training (AFT). The remaining pilots received no training.

During a second flight, treatment pilots showed significant improvement in performance, while control pilots did not improve. The results indicated that AFT management of high states of physiological arousal may improve pilot performance during emergency flying conditions.

Human Factors Gain Increasing Importance

Human error is the largest single cause of accidental mortality among aviators.[1] It is not surprising, then, that increased attention has been placed on the human factors associated with aircraft accidents. The U.S. Aviation Safety Research Act of 1988, for example, directed the U.S. Federal Aviation Administration (FAA) to expand research efforts examining the relationships between human factors and aviation safety.[2] A central human factors problem, human error has been identified as the leading cause of aviation mishaps.[3] Recent FAA reports reveal that human error is a causal factor in 66 percent of air carrier incidents and accidents, 79 percent of commuter and 88 percent of general aviation accidents.[2] Human errors account for a substantial number of military aviation accidents as well. It has been estimated that at least 50 to 70 percent of aviation mishaps across all branches of the armed forces are attributed to human error.[4,5]

Human error is the largest single cause of accidental mortality among aviators.

The Aviation Safety Commission[6, 8] narrowly defines the cause of accidents as pilot error only in those instances where the error appears "undeniable." This definition and the figures cited above can be misleading, however, as a result of the simplistic approach generally taken in the identification of human error as contributory or causal in aircraft incidents. These classifications do not adequately address the fact that human errors are the result of very complex processes. The term "pilot error" carries with it the implication that an aircraft commander was solely responsible for a given accident as a result of some discrete act of omission or commission. In fact, errors are only rarely attributable to a single cause[7] and culpability for accidents lies within the interaction between human and other factors. These factors typically include mission-demand characteristics, environmental considerations and equipment design. Another factor often involved is the abrupt onset of emergency conditions, where the impact on task performance has been demonstrated.[9]

Historically, attempts to decrease human errors in aviation have focused on the automation of tasks, leading increasingly to the pilot as a backup to the automated systems.[2] This approach, however, does not adequately address the full spectrum of human factors problems. As automation and complexity increase, so does the potential for human error.[10] Within automated systems, there is the expectation that humans will remain alert during boring periods and deftly assume control of the aircraft in the event of a critical situation. However, the complacency that accompanies prolonged reliance on automated systems may reduce the pilot's ability to respond effectively in emergency situations.[11] It is becoming increasingly recognized that efforts to reduce human error must be aimed more directly at the human element.

Crew resource management (CRM) is a relatively recent attempt to reduce human errors in the multicrew cockpit.[12] CRM addresses the human error issue by attempting to enhance communication and workload distribution, and it appears to be a fairly successful strategy. A primary assumption of CRM training is that crew coordination will become routine, thereby increasing the probability that it will be practiced during stressful situations. This assumption may be unrealistic because crew coordination and communication skills may become peripheral tasks during an in-flight emergency, because the pilot's central focus may well be with stick and rudder activities. Perhaps the primary value of CRM is as a preventive measure. This training may enhance crew effectiveness, thereby reducing the likelihood of errors caused by poor crew coordination.

CRM training alone does not sufficiently address the problem of human error incidents. Reasonable evidence exists to conclude that pilots may lose control of their aircraft as a direct result of reactive stress.[13-17] The condition in which a high state of physiological arousal is accompanied by a narrowing of the focus of attention can be referred to as autonomous mode behavior. This study examined the efficacy of physiological self-regulation training as a means of improving pilot performance during emergency flying conditions. A number of studies have produced evidence that this type of training effectively reduces physiological arousal which affects operational efficiency in student pilots.[16, 18] The specific method used in the present study was AFT, which was developed by Cowings et. al. as a potential treatment for space motion sickness of astronauts aboard the space shuttle.[19-21] This method has also been used successfully by the U.S. Air Force to control airsickness in military flight crews.[22, 23]

AFT has advantages over other methods for this particular application because it teaches individuals to regulate the levels of multiple physiological responses simultaneously, thus enabling a more systemwide reduction in reactivity to stressors. AFT was designed to be administered in a relatively short period of time (six hours) and can reliably produce the autonomic control necessary to reduce responses to severe environmental stressors (i.e., motion sickness stimuli); it has been demonstrated to be effective in a wide population of subjects under a variety of stimulus conditions.[19]

> ***Reasonable evidence exists to conclude that pilots may lose control of their aircraft as a direct result of reactive stress.***

All the pilots were active-duty U.S. Coast Guard personnel and received no additional compensation for their participation. Their informed consent was obtained prior to the initiation of the study. The research protocol was approved by the Clinical Investigation/Human Use Committee of Tripler Army Medical Center. The 17 pilots who served as subjects were volunteers from the U.S. Coast Guard Air Station, Barbers Point, Hawaii, U.S. These crew members consisted of seven men from fixed-wing aircraft (HC-130), and nine men and one woman from rotary-wing aircraft (HH-65). Following an initial flight, pilots were assigned to one of two groups (treatment or control) that were matched for accumulated flight hours. The treatment group comprised four pilots from fixed-wing aircraft and four rotary-wing pilots; the control group comprised three fixed-wing pilots and six rotary-wing pilots. No attempt was made to match groups by sex or type of aircraft.

Physiological responses monitored were respiration rate, with a pneumograph (PNG) placed around the subject's chest; heart rate (HR), with electrodes located at precordial sites; skin conductance level (SCL), with electrodes placed on the underside of the right wrist; skin temperature, using a thermistor placed on the lateral side of the right small finger; and muscle activity (EMG), with surface electrode placement bilaterally on the upper trapezius.

Electrode/transducer wires were secured to each subject and exited the flight suit at the collar opening; they were connected to a J&J I-330 data acquisition system mounted behind the subject's headrest. Cables connecting the modules to a laptop computer were taped to the deck of the aircraft. Neither motor movements or sensations of the subject or other crew members were inhibited by the instruments. In both aircraft and ground-based training sessions, these data were digitized and stored as 0.75-second averages on a laptop computer.

Initially, all the pilots participated in an intense emergency flying condition "check ride." Physiological monitoring and evaluation of performance commenced with the preflight checklist and continued throughout the flight scenario, terminating with the aircraft's return to the ramp. Allowing for the differences in flight parameters of the two types of aircraft flown and given the inherent limitations of conducting a field study, each flight scenario was very similar.

The airborne portion of this study took place on U.S. Coast Guard HC-130 and HH-65 aircraft. Actual aircraft (in contrast to simulators) were utilized for this study primarily because it is methodologically desirable to study, as much as possible, real-life situations with their inherent uncertainties. No modifications to the aircraft were made, and each flight carried its routine crew complement. These crew members performed their usual duties aboard the HH-65 and HC-130, with one exception on the HC-130 flights: The navigator, while on the aircraft, was not stationed at his table on the flight deck. As the scenario did not require his presence in the cockpit, his table was utilized as a work station for the physiologic data acquisition.

To assess the subject's performance and physiologic response while experiencing a considerable stressor, a compounding emergency condition was simulated.

In the HC-130 emergency flight scenario, subsequent to the preflight, taxi and takeoff, the aircraft was flown to a cruising altitude designated by air traffic control (ATC). As a peak performance exercise, the pilot was instructed to return to the traffic pattern and execute a series of touch-and-go maneuvers (one systems-normal, one simulated No. 1 engine fire and one automatic direction finder instrument approach). Upon completion of these tasks the aircraft departed the pattern at an altitude assigned by ATC for a search-and-rescue (SAR) case in which there was ostensibly a downed A-4 pilot approximately 20 miles (32 kilometers) offshore.

To assess the subject's performance and physiologic response while experiencing a considerable stressor, a compounding emergency condition was simulated.

Once the search pattern had been established, the cargo door had been opened and secured, and the aircraft had descended to 200 feet (61 meters) above ground level (AGL), a turbine overheat of the No. 2 engine, followed by an uncontained turbine failure of that engine, was simulated. The pilot was then notified of a simulated airframe damage, a minor fuel leak from the No. 2 engine, and that a crew member had sustained injuries presumably resulting from shrapnel. This announcement was followed by left-hand and essential AC bus failure indicators. Moments later, an instructor pilot told the pilot that there was simulated smoke (without fire) emanating from under the flight deck, that there was charring on the nacelle paint in the vicinity of the No. 1 generator, and the master fire light T-handle and a visible confirmation revealed that the No. 1 engine was on fire. Upon stabilizing the aircraft, the pilot was directed to maintain a cruising altitude as instructed by ATC, return to base and make a two- engine full-stop landing. This was further complicated by a simulated landing gear malfunction which required a simulated manual extension of the landing gear.

In the HH-65 emergency flight scenario (following preflight and taxi to a hover-takeoff), the aircraft was flown to an ATC-designated altitude. The pilot was then instructed to execute a series of touch-and-go maneuvers (one standard no hover, one standard engine stall at takeoff and one simulated No. 1 engine stall to a running landing). Upon completion of these tasks, the aircraft departed the pattern at an altitude assigned by ATC for an SAR case in which there was ostensibly a distressed boat that would likely require removal of a crew member with unknown injuries. While proceeding to the vessel's position, the aircraft experienced an AC bus malfunction with a resulting loss of the gyro and pitch and roll controls. Upon stabilizing the aircraft and returning to systems normal flight, the pilot was directed to the position of the simulated craft and was instructed to prepare to hoist the injured party aboard. While in a hover at approximately 50 feet (15 meters) AGL, the pilot was given a servojam warning followed by a secondary hydraulic failure indicator, which resulted in the rudder pedals being locked. The pilot was then requested to enter a holding pattern and return to base and land the "impaired" aircraft as instructed by ATC. The pilot was then directed to fly the aircraft from the runway to the outer ramp (helo-pad). As the aircraft was on short-final approach, the instructor pilot simulated a stall of the No. 1 engine from which the pilot was to recover and land the aircraft as instructed.

Pilot performance measures involved subjective assessments of two instructor pilots who served as observers, with roughly equal numbers of treatment and control pilots assigned to each. The observers were not told the group assignments of individual pilots, and they graded the same individuals on both flights. Two types of observer ratings were obtained, both adapted from performance scales developed by Foushee et al.[24] The first type involved performance judgments made routinely by supervisory check pilots and were grouped by specific phases of the flight (i.e., checklist execution, taxi/takeoff, cruise, touch-and-go, cruise/SAR, emergency initiation, emergency return to base, and emergency approach and landing). Performance dimensions examined by this study were stress management; crew coordination and communication; aircraft handling; and planning and situational awareness. Each performance dimension was scored on a five-point Likert scale with the following anchors: 1 (below average performance); 2 (slightly below average); 3 (average); 4 (slightly above average); and 5 (above average). The observer was instructed to circle N/A (not applicable) should a dimension not apply for some reason.

As the aircraft was on short-final approach, the instructor pilot simulated a stall of the No. 1 engine from which the pilot was to recover and land the aircraft as instructed.

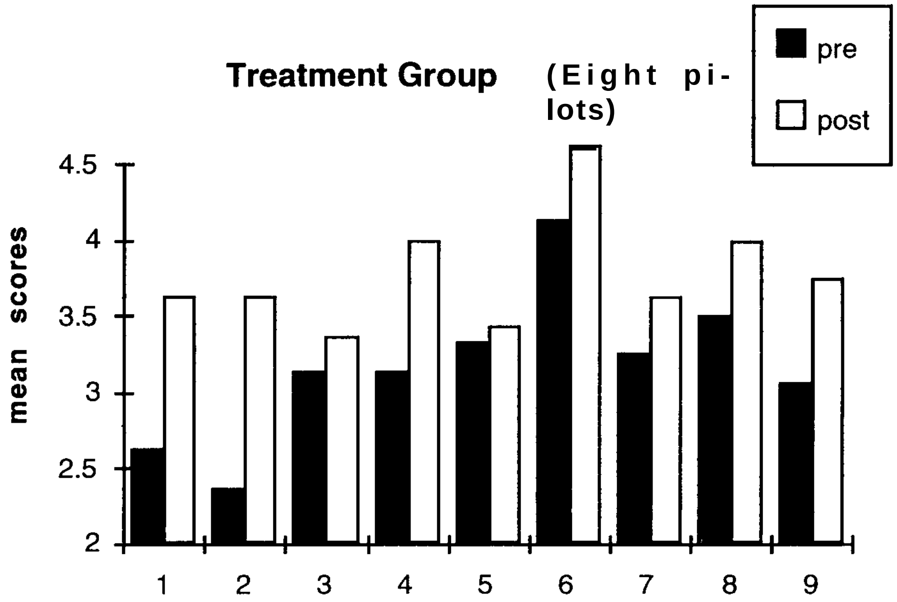
The second type of rating was designed to assess the observer's overall impression of performance throughout the flight,[24] and was done upon completion of each flight. All pilots were instructed not to discuss the specific aspects of their participation in the study with other crew members.

AFT consisted of 12 sessions of 45 minutes each using a regimen of AFT training based upon the protocol developed by Cowings.[19] This protocol included directed biofeedback, discrimination training and stress challenge training with and without feedback designed to increase pilot efficiency in maintaining appropriate psychophysiological control. With respect to the stress challenge condition, subjects were required to maintain physiologic control within identified parameters while actively involved in a video game challenge. The treatment group also utilized progressive daily relaxation exercises via audio tape. The control group received no treatment. This design was deemed appropriate because previous research by Toscano and Cowings[25] demonstrated that control group pilots given "sham training," with the same number of exposures to experimenters as treatment group subjects, had no advantage over a "no treatment" control group in improving their tolerance to environmental stress.

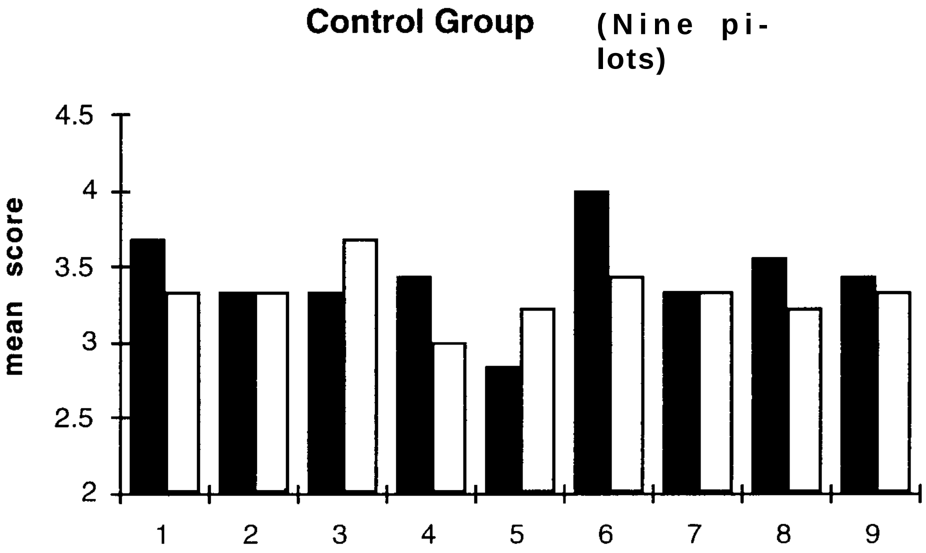
Following completion of the treatment condition, each pilot flew the simulated emergency scenario again at approximately the same time of day, and with the same rater as in the initial flight.

Figure 1 (page 6) shows the average overall scores obtained from each group on the first and second emergency flights. Treatment group pilots show an improvement in all nine performance dimensions while control pilots show higher post-test scores on only two of the nine dimensions measured and actually decreased performance scores for five of these dimensions.

Changes in Overall Performance During Emergency Flight Scenarios



Treatment Group (Eight pilots)



Control Group (Nine pilots)

1 = knowledge of aircraft/procedures; 2 = technical proficiency; 3 = smoothness; 4 = crew coordination and communication; 5 = external communication; 6 = motivation; 7 = command ability; 8 = vigilance; 9 = overall performance and execution

Source: U.S. National Aeronautics and Space Administration

Figure 1

Data were analyzed with nonparametric statistics: Mann-Whitney U-tests and Wilcoxan Sign Ranks tests. Table 1 (page 7) and Table 2 (page 8) show the results of analyses that compared performance scores between and within groups during specific phases of the flights. There was no significant difference between groups on the first test, with the exception that control pilots scored significantly higher on aircraft handling during cruise search and rescue (Table 2). Treatment group pilots had improved their performance after training, and the two groups were no longer significantly different during the cruise search and rescue phase of the second flight. Following training, the performances of AFT pilots during specific phases of flight were significantly better than that of the controls for stress management, crew coordination and communication, as well as planning and situational awareness. There was no significant difference between groups in aircraft handling during any phases of the second flight.

Comparisons within groups revealed that AFT pilots showed significant improvements in specific phases of the flight for all performance categories, while control pilots showed no improvement. In fact, control pilots showed a significant decrease in crew coordination and communication during the touch-and-go phase of flight.

Table 1

Group Performance Dimensions by Phase of Flight: Mann-Whitney U-Test

Crew Coordination and Communication	Between Groups AFT vs. Controls		Within Groups Pre- vs. Post-tests	
	Pre-test	Post-test	AFT	Controls
Checklist Execution	—	p<0.05	p<0.05	—
Taxi/Takeoff	—	p<0.05	—	—
Initial Cruise	—	—	—	—
Touch-and-Go	—	—	—	p<005*
Cruise Search and Rescue	—	—	p<0.05	—
Emergency Initiation	—	p<0.005	p<0.01	—
Emergency Return to Base	—	—	—	—
Emergency Approach and Landing	—	—	—	—

Planning and Situational Awareness	Between Groups AFT vs. Controls		Within Groups Pre- vs. Post-tests	
	Pre-test	Post-test	AFT	Controls
Checklist Execution	—	—	—	—
Taxi/Takeoff	—	p<0.05	—	—
Initial Cruise	—	—	—	—
Touch-and-Go	—	p<0.05	—	—
Cruise Search and Rescue	—	—	—	—
Emergency Initiation	—	—	—	—
Emergency Return to Base	—	—	p<0.05	—
Emergency Approach and Landing	—	—	p<0.05	—

* Control subjects scored significantly lower during the second flight.

Source: U.S. National Aeronautics and Space Administration

Physiological data obtained during flight and training sessions were not analyzed.

Table 3 (page 9) shows the results of Wilcoxan Sign Ranks tests, which were performed to examine the performance category, crew coordination and communication, in detail. AFT pilots performed significantly better than controls in 10 of the 13 specific dimensions of this category.

The results support the proposition that AFT improves pilot performance during emergency flying conditions. Specifically, the data reveal that those pilots trained in AFT demonstrated improved overall knowledge of the aircraft and procedures, technical proficiency and performance through the flight scenario. Of particular importance is a demonstrated improvement in overall performance and execution of duties as well as crew coordination and communication during that segment of the flight when multiple compounding emergencies were experienced. This suggests that AFT may be effective as a countermeasure for pilot stress-related performance decrements.

The improved crew coordination and communication performance found in the AFT pilots is particularly noteworthy, as these factors are emphasized in CRM approaches

Table 2

Group Performance Dimensions by Phase of Flight: Mann-Whitney U-Test

Stress Management	Between Groups AFT vs. Controls		Within Groups Pre- vs. Post-tests	
	Pre-test	Post-test	AFT	Controls
Checklist Execution	—	—	—	—
Taxi/Takeoff	—	—	—	—
Initial Cruise	—	—	—	—
Touch-and-Go	—	p<0.05	p<0.05	—
Cruise Search and Rescue	—	—	—	—
Emergency Initiation	—	p<0.05	p<0.05	—
Emergency Return to Base	—	p<0.05	p<0.05	—
Emergency Approach and Landing	—	p<0.05	p<0.05	—

Aircraft Handling	Between Groups AFT vs. Controls		Within Groups Pre- vs. Post-tests	
	Pre-test	Post-test	AFT	Controls
Checklist Execution	—	—	—	—
Taxi/Takeoff	—	—	—	—
Initial Cruise	—	—	—	—
Touch-and-Go	—	—	p<0.05	—
Cruise Search and Rescue	p<0.05*	—	p<0.05	—
Emergency Initiation	—	—	p<0.05	—
Emergency Return to Base	—	—	—	—
Emergency Approach and Landing	—	—	p<0.05	—

* Control pilots scored significantly higher than AFT subjects during their first flight.

Source: U.S. National Aeronautics and Space Administration to the management of human error. AFT treatment effects were demonstrated in those dimensions involving communications with crew members, crew briefings, workload delegation, planning and overall technical proficiency. Because all of the pilots of this study had some form of CRM training, as well as comparable previous experience in emergency flying conditions, the demonstrated improvement of these measures by the treatment group suggests that AFT may aid in the successful utilization and expansion of these skills. It is hypothesized that this improvement occurred because AFT reduced individuals' physiologic reactivity during stress. As a result, crew coordination and communication factors were not reduced to the pilot's periphery. Given the current emphasis on crew coordination and communication skills in the reduction of human error in flight, identification and control of the physiologic mechanisms that enhance or inhibit these activities warrant further study.

The problems associated with AMB are manifest when the pilot becomes saturated with tasks requiring increased complex decision-making skills. When a major ingredient of this saturation includes the pilot's own physiology, the recognition of internal cues that precede this hypersympathetic arousal and initiation of appropriate corrective action become increasingly important. Utilizing the pilot's own physiology as an asset, rather than as an undesirable event to be ignored, the available resources to deal with an external problem are increased. It is suggested that by expanding the pool of available resources for dealing with in-flight emergencies, the pilot is better able to manage the endogenous and exogenous stressors being experienced.

Table 3
Improvement in Specific Dimensions of Crew Coordination and Communications During the Second Flight Scenario: Wilcoxan Sign Ranks Test

	AFT vs. Control		
Dimension	**N**	**z**	**p<**
Briefing thorough, establishes open communication, addresses coordination, planning, team creation and anticipates problems	8	2.20	0.05
Communications timely, relevant, complete and verified	8	2.20	0.05
Inquiry/Questions practiced	8	1.69	0.05
Assertion/Advocacy practiced	8	1.82	0.05
Decisions communicated and acknowledged	8	1.57	—
Crew self-critique of decisions and actions	7	1.82	0.05
Concern for accomplishment of tasks at hand	8	0.91	—
Interpersonnel relationships/group climate	8	1.82	0.05
Overall vigilance	8	1.09	—
Preparation and planning for in-flight activities	8	2.20	0.05
Distractions avoided or prioritized	8	1.34	—
Workload distributed and communicated	8	2.20	0.05
Overall workload	8	0.91	—
Overall technical proficiency	8	2.02	0.05
Overall crew effectiveness	8	2.02	0.05

While the small pilot population in this study precluded fixed- vs. rotary-wing comparisons, airframe and related mission requirement influences are areas that necessitate further study. Future studies will determine if performance improvements are related to type of aircraft and if those pilots of multiple crew aircraft gain more value from training than those flying tactical (single- or dual-crew) aircraft.

Use of ambulatory monitoring equipment for recording physiological responses in flight would be less obtrusive than the instrumentation used in the present study and will provide objective indices of the effects of training on treatment group subjects.

More comprehensive examinations of AFT and its effect on pilot performance may reveal that training in recognition and regulation of one's own physiological reactions to environmental stress should become a portion of the standard curriculum of aerospace crews. ♦

Editor's Note: This article is a slightly edited version of NASA Technical Memorandum 104005*, an unedited report that was released in March 1993 "to quickly provide the research community with important information."*

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Aviation Community Loses a Voice

Editor's Note: The U.S. Federal Aviation Administration has ceased publication of its Aviation Safety Journal, *a four-color, quarterly magazine, because of budget reductions. This is an unfortunate loss of a valuable communication tool for the dissemination of safety information.*

Flight Safety Foundation's publications and Aviation Safety Journal *have shared information in the interest of aviation safety.* Aviation Safety Journal *has reprinted Foundation articles. More recently, Thomas J. Casadevall's presentation on volcanic ash at the 1992 International Air Safety Seminar in Long Beach, California, was printed in* Aviation Safety Journal; *the article was reprinted in an issue of* Flight Safety Digest.

Operations and Safety Statistics Updated for Worldwide Airlines Operating Large Jet Transport Aircraft Calendar Year 1992

by
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The *Air Carrier Aircraft Utilization and Propulsion Report*, published monthly by the U.S. Federal Aviation Administration (FAA), reports the daily use, monthly total fleet time and total engine time for all U.S. airline jet transports.

Similar data for jet transport aircraft used by non-U.S. airlines are not readily available. Therefore, the data for worldwide airlines are estimated based on information provided by aircraft manufacturers through an annual inquiry by the Flight Safety Foundation. This update does not contain information directly from airlines.

The number of aircraft in service in this update was reported as of December 1992. Note also that all operational data reported by the manufacturers was not in the same format and that there are discrepancies in data. Safety information for 1992 is also compiled from news media reports as well as from governmental publications.

Some manufacturers, for example, reported only the number of aircraft ordered and delivered as well as the total fleet time for the year. There is no breakdown of flight hours by military, commercial and general aviation uses. Thus, estimates of active airline jet transports have been adjusted based on information reported by news media, FAA publications and historical data used for estimates in previous years. The jet transport aircraft in this update include the following (Comet, VC-10, Convair 880 and Convair 990 are included in all historical data for presentation):

Four-engine: Boeing 747, B-707, B-720, DC-8, BAe-146;

Three-engine: B-727, McDonnell Douglas DC-10, Lockheed L-1011, Trident; and,

Two-engine: B-757, B-767, B-737, McDonnell Douglas DC-3, MD-80, MD-ll, F-28, F-100, A300, Lockheed Airbus A310, A320, BAC-111, SE-210.

In 1992, worldwide airlines operating these large jet transport aircraft recorded a total of 21,367,000 flight hours, an increase of about 9 percent more than 1991. This is the first annual increase of flight hours since 1989.

Table 1 shows the comparison of average number of aircraft in service as of December, and hours flown for calendar years 1991 and 1992. Table 2 shows the number of aircraft in service and hours flown of aircraft made by U.S. manufacturers and by manufacturers in western Europe (hereafter referred to as U.S. jets and non-U.S. jets). Table 2 also shows that for calendar year 1992, U.S. jets accounted for 83 percent of total jet transport aircraft and flew 85 percent of total jet hours. In average daily utilization, U.S. jets were used almost one hour longer than non-U.S. jets.

Table 1

Worldwide Airline Jet Transport Aircraft Number of Aircraft in Service and Hours Flown

Calendar Year 1991-1992

Year	Aircraft in Service As of Dec. 31	Annual Total Hours Flown	Daily Average Hours
1992	9,739	21,367,000	5.97
1991	9,299	19,618,000	5.78
Change +/-	+ 440	+ 1,749,000	+ 0.19

Source: U.S. Federal Aviation Administration

Table 2

Worldwide Airline Jet Transport Aircraft in Service and Hours Flown

Aircraft Made by U. S Manufacturers vs. Aircraft Made by Manufacturers in Western Europe

Calendar Year 1991-1992

Aircraft	Aircraft in Service		Hours Flown		Daily Average Hours
	1991	1992	1991	1992	
U.S.*	7,830	8,108	17,244	18,230	6.2
Non-U.S.**	1,469	1,631	2,374	3,137	5.3
Total	9,299	9,739	19,618	21,367	6.0 (Weighted Average)

* Includes B-707, B-727, B-737, B-747, B-757, B-767, DC-8, DC-9, DC-10, MD-80, MD-11, L-1011

** Includes A300, A310, A320, BAC-111, BAe-l46, SE-210, Trident, F-28, F-100

Source: U.S. Federal Aviation Administration

Table 3

Worldwide Airline Jet Transport Aircraft in Service and Hours Flown by Number of Engines of Aircraft

Calendar Year 1991-1992

Aircraft	Aircraft In Service		Hours Flown		Daily Average Hours	
	1991	1992	1991	1992	1991	1992
Two-engine	5,809	6,289	12,437	13,968	5.89	6.16
Three-engine	2,140	2,072	4,085	4,036	5.23	5.34
Four-engine	1,350	1,378	3,096	3,363	6.28	6.68
Total	9,299	9,739	19,618	21,367	5.78	6.01

Source: U.S. Federal Aviation Administration

Table 4

Fatal Accidents, Hull Losses and Rates Worldwide Airlines Operating Large Jet Transport Aircraft

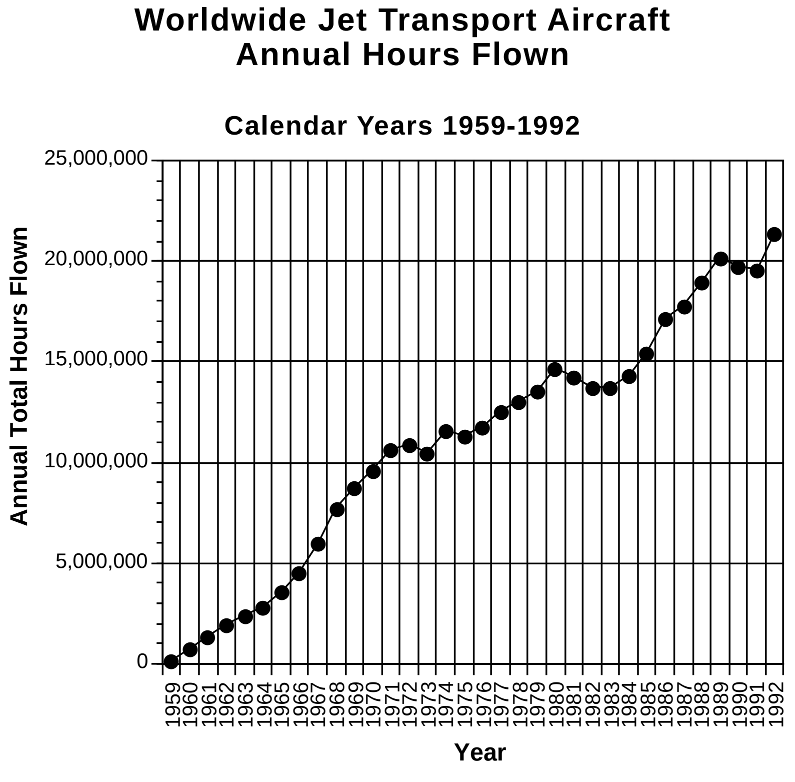
Calendar Year 1991-1992

Aircraft Type	Fatal Accidents		Rate per 100,000 Hours		Hull Losses		Rate per 100,000 Hours	
	1991	1992	1991	1992	1991	1992	1991	1992
Total	10	14	.051	.066	13	13	.066	.061
U.S.-made	8	10	.046	.056	11	9	.064	.049
Non-US-made	2	4	.084	.127	2	4	.084	.127
Two-engine Jet	7	9	.056	.064	8	7	.064	.050
Three-engine Jet	0	2	—	.049	0	2	—	.049
Four-engine Jet	3	3	.097	.089	5	4	.161	.119

Source: U.S. Federal Aviation Administration

Table 3 shows a breakdown of active aircraft and hours flown by number of engines per aircraft. Although aircraft in service increased 4.5 percent from 1991 to 1992, the number of three-engine jets in service showed a slight decrease. This may be so because manufacturers stopped making three-engine jets in calendar year 1992 and the number of three-engine jets in service decreased because of aging. According to Boeing Commercial Airplane Group, as of December 1992 a total of 1,831 B-727 three-engine jets had been ordered and delivered, but it was estimated that only about 1,515 B-727s and only about 557 L-1011s, DC-10s and Tridents remained in service. Of the 2,072 three-engine jets in service, about 1,200 were operated by U.S. air carriers with an average of 5.6 hours daily utilization.

The aircraft daily utilization shown in all tables is a 365-day average. In fact, daily utilization of B-727, DC-10, Trident and L-1011 aircraft varied greatly. FAA statistics show that the daily utilization of three-engine (excluding Trident) and four-engine jets used by U.S. air carriers was as high as 13 to 14 hours a day; utilization of twin-engine jets 12 hours a day. Note that all aircraft must be idle for a period of days each year for maintenance/ repair.



Source: U.S. Federal Aviation Administration

Figure 1

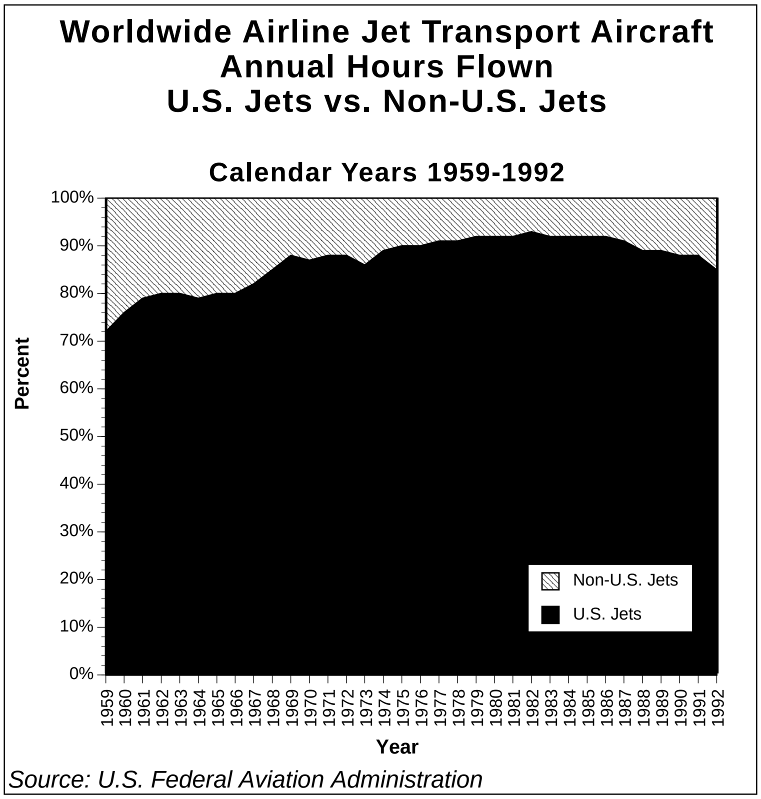
During calendar year 1992, large jet transports operated by worldwide airlines were involved in 14 fatal accidents and 13 hull losses, accounting for 805 fatalities, compared with 10 fatal accidents and 14 hull losses in 1991. A list of the fatal accidents and hull losses is presented in Appendix A (page 17).

The frequency of fatal accidents and hull losses as well as the rate per 100,000 aircraft hours by different aircraft types is shown in Table 4 (page 14). The worldwide airline fatal accident rate per 100,000 aircraft hours flown in 1992 was slightly higher, while the hull-loss rate was lower, than in 1991. A comparison of fatal accident rates and hull-loss rates between U.S. jets and non-U.S. jets revealed that rates for non-U.S. jets were still slightly higher, but their margins have been narrowing since 1989.

Figure 1 (page 14) shows that the annual jet transport aircraft hours flown have been increasing since 1959, reaching 20 million hours in 1989 and more than 21 million in 1992. (Jet transport hours flown as a percentage of total flight time of worldwide airlines operating all piston-engine, turboprop-engine and turbine-engine aircraft are not available.)

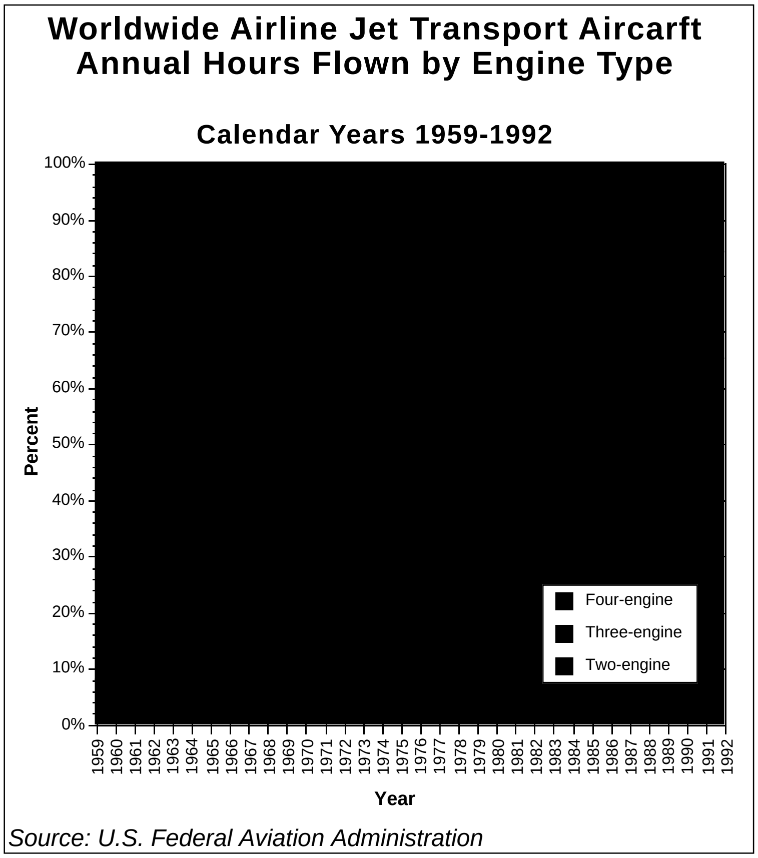
FAA reports show that in 1992, U.S. air carrier jet transport aircraft flight time accounted for approximately 78 percent of total flight time of all types of aircraft operated by U.S. air carriers, including major air carriers, regional air carriers and commuter air carriers.

Figure 2 shows annual jet transport aircraft hours flown by U.S. jets and non-U.S. jets. The total flight hours for non-U.S. jets accounted for about 25 percent of worldwide airline total flight time in the early 1960s but dropped to about 10 percent in the late 1970s and early 1980s. The trend turned upward again in 1983



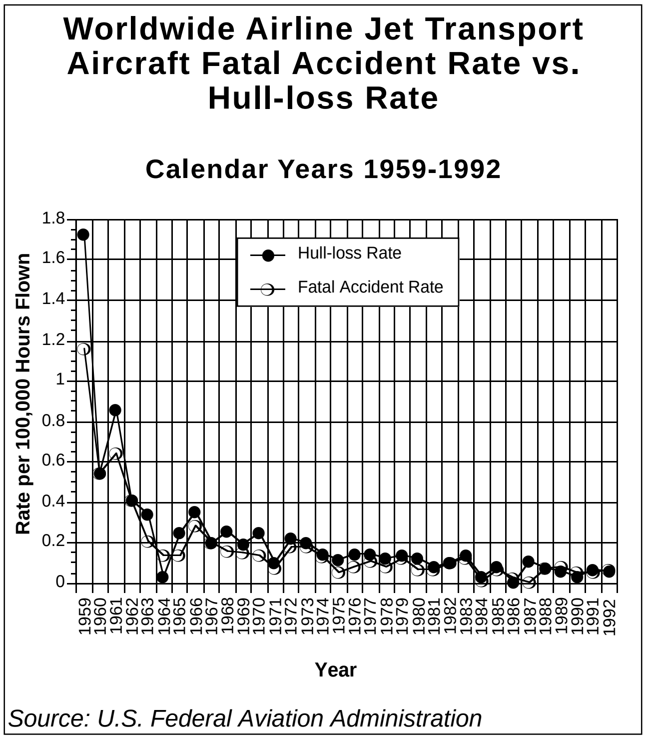
Source: U.S. Federal Aviation Administration

Figure 2



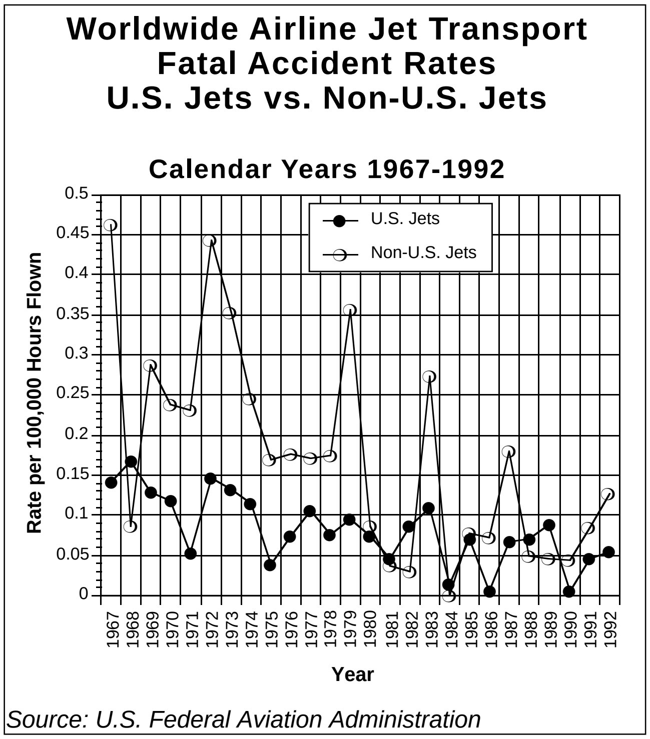
Source: U.S. Federal Aviation Administration

Figure 3



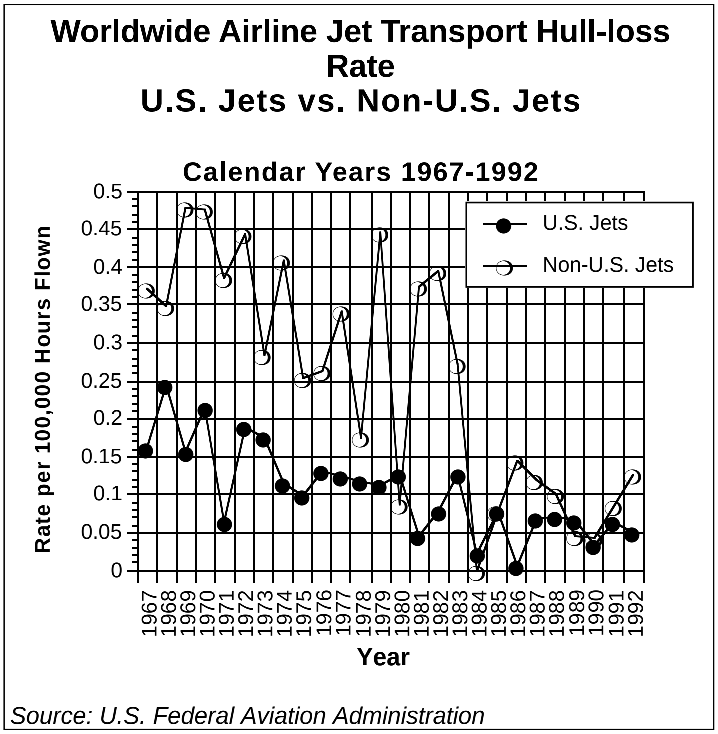
Source: U.S. Federal Aviation Administration

Figure 4



Source: U.S. Federal Aviation Administration

Figure 5



Source: U.S. Federal Aviation Administration

Figure 6

and increased to 15 percent of worldwide airline total flight time in 1992.

Figure 3 shows the trends of hours flown by twin-engine, three-engine and four-engine jets. In the early 1960s, four-engine jets accounted for almost 90 percent of all jet transport aircraft flight time, while twin-engine jets accounted for only 10 percent. In 1992, the total flight time recorded by twin-engine jets accounted for 65 percent, or almost two-thirds of worldwide airline total jet hours. In view of aircraft design advances and fuel economy, it appears that the demand of twin-engine jets will continue to grow.

Figure 4 shows fatal accident rates and hull-loss rate trends. In the early years, hull-loss rates generally were higher than the fatal accident rates. In the past 10 years, the gap between fatal accident rates and hull-loss rates has narrowed.

Figures 5 and 6 show fatal accident rates for U.S. jets and non-U.S. jets since 1967.

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Appendix A

Fatal Accidents and Hull Losses Involving Large Jet Transport Aircraft Operated by Worldwide Airlines

Calendar Year 1992

Date	Location	Aircraft Type	DMG	Fatalities	Phase of Operation	Remarks
1/20	Strasbourg, France	A320	D	87	Approach	Aircraft descended too low to recover.
2/15	Kano, Ghana	DC-8	D	None	Approach	Landed short of runway and crashed.
2/15	Toledo, Ohio, U.S.	DC-8	D	4	Approach	Landed short in fog during instrument landing system (ILS) approach.
3/22	New York, New York, U.S.	F-28	D	27	Takeoff	Aborted takeoff and overran into water in snowstorm.
3/24	Athens, Greece	B-707	D	7	Approach	Crashed during emergency landing.
4/3	Dayton,Ohio, U.S.	DC-9-32	None	1	Static	Mechanic killed by exploding wheel rim.
6/12	Sambu, Panama	B-737	D	39	Cruise	Broke up before crash in remote jungle area.
6/22	Moa River, Brazil	B-737	D	3	Approach	Crashed into jungle.
7/31	Katmandu, Nepal	A310	D	113	Approach	Crashed into mountain near airport.
9/28	Katmandu, Nepal	A300	D	167	Approach	Crashed near airport.
10/5	Amsterdam, Netherlands	B-747	D	4	Takeoff	On takeoff climb, crashed into apartment project. At least 250 persons on the ground were killed.
11/24	Guilin, China	B-737	D	141	Approach	Crashed into hillside.
12/6	New York, New York, U.S.	B-737	None	1	Static	Ground crewman struck by tug during pushback.
12/20	Faro, Portugal	DC-10	D	54	Landing	Aircraft lost control in a strong wind shear and crashed. Fire after impact.
12/22	Soukes-Sebt, Libya	B-727	D	157	En Route	Midair collision near Tripoli, Libya.

DMG=Damage D=Aircraft Destroyed

Source: Shung Huang

Publications Received at FSF Jerry Lederer Aviation Safety Library

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by
Editorial Staff

New Reference Materials

U.S. Federal Aviation Administration. Advisory Circular 25.773-1, *Pilot Compartment View Design Considerations*. January 1993. 6 p. Includes one page of illustrations.

This advisory circular (AC) outlines methods for demonstrating compliance with the airworthiness standards pertaining to pilot compartment view for transport category airplanes.

U.S. Federal Aviation Administration. Advisory Circular 25.1523-1, *Minimum Flightcrew*. February 1993. 9 p. Includes appendices.

This AC outlines methods of compliance with the requirements of Federal Aviation Regulation (FAR) 25.1523, which contains the certification requirements for minimum flight crew on transport category airplanes.

U.S. Federal Aviation Administration. Advisory Circular 90-92, *Guidelines for the Operational Use of Loran-C Navigation Systems Outside the U.S. National Airspace System (NAS)*. February 1993. vi, 20 and appendices.

This AC contains guidance material for the operational use of Loran-C navigation systems under visual flight rules (VFR) and instrument flight rules (IFR) while operating outside the United States National Airspace System (NAS) and beyond the coverage of the standard International Civil Aviation Organization (ICAO) navigation aids (NAVAIDs). These NAVAIDs include very high frequency omnidirectional range stations (VORs), with or without distance measuring equipment (DME) and nondirectional beacons (NDBs). This publication also contains guidance that is applicable for use over the Gulf of Mexico and other coastal waters. Includes an appendix of Loran-C oceanic and NAS coverage diagrams and a glossary.

U.S. Federal Aviation Administration. Advisory Circular 150/5220-21, *Guide Specification for Lifts Used to Board Airline Passengers with Mobility Impairments*. February 1993. 9 p.

This AC contains performance standards, specifications and recommendations for the design, construction and testing of lifts used to assist in the boarding of airline passengers with mobility impairments.

Reports

Mead, Kenneth M., director, Transportation Issues, Resources, Community and Economic Development Division, U.S. General Accounting Office (GAO). *FAA Budget: Important Challenges Affecting Aviation Safety, Capacity, and Efficiency*. Testimony before the Subcommittee on Transportation and Related Agencies, Committee on Appropriations, U.S. House of Representatives. 1993. 17 p. Includes bibliographical references. Available through the GAO**.

<u>Keywords</u>
1. United States — Federal Aviation Administration.

2. United States — Federal Aviation Administration — Appropriations and Expenditures.

Summary: This report presents testimony on the status of the Federal Aviation Administration's (FAA) programs and activities that make up the framework for its fiscal year 1994 budget request. At $9.2 billion, the FAA's budget request represents a 3.5 percent increase more than the fiscal year 1993 appropriation.

According to Mead's testimony, the FAA faces important challenges that affect the safety, capacity and efficiency of the aviation system in the areas of facilities and equipment (F&E), operations, grants-in-aid to airports and research, engineering and development (RE&D).

This report identifies these challenges and focuses on the status of FAA's air traffic control modernization program, work forces, airport development, and aviation security.

According to the report, the FAA must address three major challenges in the F&E area: delivering systems as promised, dealing with the budgetary impacts of facility consolidation and strengthening the acquisition process to enhance the aviation community's confidence in the agency's ability to manage the modernization program. In the operations area, the FAA continues to face problems in inadequate staffing standards, staffing imbalances at facilities and a lack of systems to direct resources to areas that pose the greatest safety risk. The report said the FAA must correct its staffing standards if it is to correct staffing disparities at air traffic control facilities.

In the RE&D area, technical problems affecting the performance of bomb-detection devices will preclude their being implemented at airports in the immediate future. In addition, the FAA has not yet determined how much new explosives detection devices will cost the airlines. The report said the FAA needs to determine the relationship and trade-offs between explosives detection and aircraft survivability. The report includes bibliographical references of related GAO publications.

Middleton, David B.; Srivatsan, Raghavachari; Person, Lee H. *Simulator Evaluation of Displays for a Revised Takeoff Performance Monitoring System (TOPMS)*, U.S. National Aeronautics and Space Administration (NASA) Technical Paper 3270. A special report prepared at the request of the NASA, Office of Management, Scientific and Technical Information Program. December 1992. 42 p. Includes bibliographical references.

Keywords
1. Flight Simulators.
2. Aviation — Training.

Summary: This report covers the evaluation of cockpit displays for a revised TOPMS used in flight simulators. New developments provide pilots with graphic and alphanumeric information pertinent to their decision to either continue or abort a takeoff.

The revised TOPMS includes an out-the-window projected head-up display (HUD) and a panel mounted head-down display (HDD) consisting of a runway graphic with status, situational and advisory information on the current position and airspeed, the predicted locations on the runway for reaching decision speed V_1 and rotating speed V_r, a ground-roll-limit line (GRLL) for reaching V_r, the predicted stop point (in the case of an abort), the engine-status flags, engine-pressure-ratio for each engine, and an overall situational advisory flag (SAF) that recommends either continuation or rejection of the takeoff.

In the study, 17 pilots evaluated the TOPMS displays in a real-time transport systems research vehicle simulator for the Boeing 737 airplane. The pilots rated the HDD as "good" and the HUD as "very good." The pilots reported that the HUD enhanced their situational awareness, even though they only focused on it for tracking airspeed or when some anomaly caused a sudden change in the display symbology (e.g., when an engine failed). Based on the comments and ratings of the evaluation pilots, it was con-

cluded that the TOPMS is a desirable and appropriate system for use by pilots during the takeoff roll. All the evaluation pilots expressed a desire to have at least a TOPMS HDD in their cockpits.

Wilcox, Bruce C., et. al. *Comparison of Portable Crewmember Protective Breathing Equipment (CPBE) Designs*, Report No. DOT/FAA/AM-93/6. A special report prepared for the Office of Aviation Medicine, U.S. Federal Aviation Administration. April 1993. 9 p.; ill. Includes bibliographical references. Available through the National Technical Information Service*.

Keywords
1. Aircraft — Oxygen Equipment — Evaluation.
2. Respirators — Evaluation.
3. Aircraft Survival Equipment — Evaluation.

Summary: This report provides the results of a study to evaluate the performance of three types of oxygen production systems used in crewmember protective breathing equipment (CPBE) certified for transport category aircraft.

Oxygen production was evaluated for CPBEs using chlorate candles, potassium superoxide and compressed oxygen to expose differences in levels of oxygen production and resulting by-products under different environmental conditions.

The evaluation employed human test subjects in measuring the total oxygen production, carbon dioxide concentration, internal temperature, moisture and breathing resistance for 15 minutes at ground level (1,300 feet [394 meters]) and cabin altitude (8,000 feet [2,424 meters]) while subjects exercised. Differences in internal temperature and humidity were found between the three systems: all CPBEs produced a mean oxygen level of at least 59 percent and maintained carbon dioxide below 5 percent at ground level. Performance at altitude generally paralleled these findings. Differences in the wearability of CPBEs, based on internal temperature, humidity and weight, were dependent on the type of CPBE oxygen production system.

Galaxy Scientific Corporation. *Human Factors in Aviation Maintenance: Phase Two, Progress Report*, Report No. DOT/FAA/AM-93/5. A special report prepared for the Office of Aviation Medicine, U.S. Federal Aviation Administration. April 1993. xi, 195 p.; ill. Includes bibliographical references. Available through the National Technical Information Service*.

Keywords
1. Aviation Mechanics (Persons) — Psychology.
2. Airplanes — Maintenance and Repair.
3. Aeronautics — Human Factors.

Summary: In this report on the second phase of research on human factors in aviation maintenance, the emphasis is shifted from problem definition to development of demonstrations and prototypes. These demonstrations include a computer-based training simulation for troubleshooting an airliner environmental control system and a library software system to store and display documents. Chapters cover advanced technology for aviation training, emerging technologies for maintenance job aids, the FAA aviation maintenance human factors hypermedia system, human reliability in aircraft inspection, a human factors guide for aviation maintenance and the effects of crew resource management training in maintenance. References and appendices are also included.

Books

Robie, William. *For the Greatest Achievement: A History of the Aero Club of America and the National Aeronautic Association.* Foreword by Yeager, Chuck. Washington, D.C., United States: Smithsonian Institution Press, 1993. xix, 378 p., 16 p. of photographs. Includes index and bibliographical references.

Keywords

1. National Aeronautic Association (U.S.) — History.
2. Aeronautics — United States — Societies, etc. — History.
3. Aeronautics — United States — History.

Summary: This book chronicles the history of the Aero Club of America and its successor, the National Aeronautic Association (NAA). Founded in 1905, the NAA is the oldest national aviation organization in the United States. The NAA was formed to promote the safe, scientific development of aviation. The Aero Club certified pilots and issued flying licenses for more than 20 years before the U.S. government assumed this responsibility (an appendix documents the Aero club license holders, 1905-1919).

During the early 1920s, the leaders of the Aero Club brought together several national aviation organizations and in 1922 established the NAA, whose objective (among others) was to "aid and encourage the establishment and maintenance of a uniform and stable system of laws relating to the science of aeronautics and the art of aerial navigation and all allied and kindred sciences and arts." The history of the NAA parallels the history and development of aviation as a legal, military, research, commercial and recreational pastime in America. The book's appendices include lists of the recipients of the Robert J. Collier Trophy, the Gordon Bennett Cup for Gas Balloons, the Wright Trophy and the Brewer Trophy. Notes and an extensive bibliography are also included.

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**U.S. General Accounting Office (GAO)
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Updated Reference Materials (Advisory Circulars, U.S. FAA):

AC Number	Month/Year	Subject
183-32H	12/18/92	*FAA Designated Technical Personnel Examiner's Directory* (cancels AC 183-32G, dated March 24, 1988).
150-5220-18	10/15/92	*Buildings for Storage and Maintenance of Airport Snow and Ice Control Equipment and Materials* (cancels AC 150/5220-15, dated March 25, 1983).
20-109A	4/8/93	*Service Difficulty Program (General Aviation)* (cancels AC 20-109, dated Jan. 8, 1979).
20-126D	4/14/93	*Aircraft Certification Service Field Office Listing* (cancels AC 20-126C, dated Jan. 16, 1992).

Accident/Incident Briefs

by
Editorial Staff

This information provides an awareness of problem areas 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

Distractions Cause Premature Level Off

Boeing 737. No damage. No injuries.

The aircraft was cleared to FL280 (28,000 feet [8,485 meters]) and the clearance was correctly read back.

A few moments later, the captain leveled off at FL270 and the first officer called level at FL280. Radar Mode C indicated that the aircraft was at FL270, and the climb was continued to the assigned altitude.

The captain reported that at the time of the level off, the first officer was recording weather information and talking to operations. At the same time, a flight attendant was presenting the captain with refreshments.

Pressure Hull Damage Forces Turnback

Boeing 757. Minor damage. No injuries.

After takeoff at about 1,000 feet (303 meters) AGL (above ground level) and at a speed of 160 knots, the captain retracted the flaps and selected climb power.

Both pilots then heard a loud bang, which was followed by airframe vibration. The aircraft returned to the airport and the landing was uneventful.

A ground inspection determined that a cargo vehicle had damaged the pressure hull three feet (.9 meters) below the first officer's window.

Ramp Agent Struck by Nose Gear

Boeing 757. No damage. One serious injury.

The ramp agent was walking underneath the fuselage of the Boeing 757 during pushback when he was struck by the nose gear.

The gear ran over his right leg, crushing and severing it. The daylight accident occurred on the yellow taxi line in the gate area. The agent had just completed his annual ramp training.

Air Taxi
Commuter

Control System Failure Causes Uncommanded Climb

Fokker 28. No damage. No injuries.

While en route, the autopilot disengaged after the aircraft passed through light turbulence. There was a flight control system failure and the aircraft began a climb that could not be arrested even with full forward control pressure.

The ascent was finally stopped by moving passengers forward in the cabin, and by full control pressure applied by both pilots. The stall warning activated once and pre-stall aerodynamic buffer was felt. With physical assistance of one flight attendant, and by adjusting power and flap settings, the aircraft was flown to a safe landing. There were no injuries among the 49 passengers and four crew members aboard.

Flight Ends in Collision with Tree

McDonnell Douglas DC-3. Aircraft destroyed. Three fatalities. Fourteen injuries.

Shortly after the night takeoff, the aircraft began to drift off the 40-meter wide runway, and the right wing struck a tree.

The tree severed the wing and the aircraft crashed. The three crew members on board were killed. Fourteen passengers managed to escape with minor injuries.

Fuel Starvation Leads to Tragedy

De Havilland DHC-6 Twin Otter. Aircraft destroyed. Sixteen fatalities. Six serious injuries.

The aircraft was on a local parachute jumping flight when it crashed shortly after takeoff.

A preliminary investigation determined that the right engine was not producing power at impact. The investigation also found that the right-engine fuel system and fuel tank were contaminated by water. The two pilots and 14 passengers were killed in the daylight crash. Weather was not a factor.

Corporate
Executive

Weather Forces Twin Down

Cessna 402. Aircraft destroyed. Two fatalities.

During a night flight, the pilot contacted air traffic control (ATC) and advised that he was descending from 4,500 feet (1,364 meters) mean sea level (MSL) to 3,000 feet (909 meters) MSL to get beneath bad weather.

The aircraft disappeared from ATC radar at 3,000 feet MSL and radio contact was lost. The wreckage was found the next morning. An instrument flight rules (IFR) flight plan had been filed but not activated. The pilot and passenger were killed.

Engine Failure Dooms Light Twin

Cessna 310. Aircraft destroyed. Three fatalities.

After takeoff, the aircraft climbed to about 75 feet (23 meters) above ground level (AGL) and the landing gear was retracted.

The aircraft gained no additional altitude and descended suddenly about a mile from the departure end of the runway. According to an accident investigation report, a witness said, "It got real quiet and you could not hear the engines." The Cessna collided with trees and the ground and caught fire. The pilot and two passengers were killed in the crash.

Other General Aviation

Low Pass Claims Fatality

Swearingen Merlin III. Aircraft destroyed. One fatality. One serious injury.

The twin-engine, turboprop Merlin was flying low over the pilot's house when it struck trees.

The aircraft exploded and plunged to the ground. Witnesses reported that the engines "were running loud and clear." Weather was not a factor in the daylight crash.

Take-off Stall Ends in Death

Reims F172. Aircraft destroyed. One fatality. Three serious injuries.

The aircraft was observed in a near-stall during initial climb. The fully loaded single-engine aircraft reached less than 100 feet (30 meters) above ground level (AGL) before nosing down and crashing.

An investigation found no engine malfunctions. One passenger was killed and the pilot and two other passengers were seriously injured in the daylight crash.

Rotorcraft

Bell Plummets During Logging Operation

Bell 214-B1. Aircraft destroyed. Two fatalities.

The helicopter was attached to two logs when it began pitching and yawing while in hover at 200 feet (61 meters) above ground level (AGL).

Witnesses reported that the main rotor RPM reduced to a "slow turn" prior to impact. The pilot and copilot were killed in the crash. There was no fire.