NASA Technical Memorandum 104005

163055
P.12

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March 1993

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(NASA-TM-104005) AUTOGENIC-FEEDBACK TRAINING IMPROVES PILOT PERFORMANCE DURING EMERGENCY FLYING CONDITIONS (NASA) 12 p

N93-27076

Unclas

G3/03 0163055

National Aeronautics and Space Administration

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Michael A. Kellar and Raymond A. Folen, Tripler Army Medical Center, Honolulu, Hawaii
Patricia S. Cowings, Ames Research Center, Moffett Field, California
William B. Toscano, University of California at San Francisco
Glen L. Hisert, U.S. Coast Guard Station at Barbers Point, Hawaii

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Ames Research Center
Moffett Field, California 94035-1000

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MICHAEL A. KELLAR,* RAYMOND A. FOLEN,* PATRICIA S. COWINGS,
WILLIAM B. TOSCANO,** and GLEN L. HISERT†

Ames Research Center

Summary

Studies have shown that autonomous mode behavior is one cause of aircraft fatalities due to pilot error. In such 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. This study 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 pilots of HC-130s and six Dolphin helicopter pilots. During an initial flight, physiological data were recorded for each crewmember and individual crew performance was rated by an instructor pilot. Eight crewmembers were then taught to regulate their own physiological response levels using Autogenic-Feedback Training (AFT). The remaining subjects received no training. During a second flight, treatment subjects showed significant improvement in performance, while controls did not improve. The results indicate that AFT management of high states of physiological arousal may improve pilot performance during emergency flying conditions.

Introduction

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

The Aviation Safety Commission (refs. 6 and 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 HE as contributory or causal in aircraft incidents. These classifications do not adequately address the fact that HEs 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 point of fact, errors are only rarely attributable to a single cause (ref. 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 (ref. 9).

Historically, attempts to decrease HEs in aviation have focused on the automation of tasks leading increasingly to the pilot as a backup to the automated systems (ref. 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 HE (ref. 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 one's ability to respond effectively in emergency situations (ref. 11). It is becoming increasingly recognized that efforts to reduce HE must be aimed more directly at the human element.

*Tripler Army Medical Center, Honolulu, Hawaii.
**University of California at San Francisco.
†U.S. Coast Guard Station at Barbers Point, Hawaii.

Cockpit Resource Management (CRM) is a relatively recent attempt to reduce HEs in the multi-crew cockpit (ref. 12). CRM attempts to address the HE issue through enhanced communication and workload distribution and appears to have been a fairly successful strategy. A primary assumption of CRM training is that crew coordination will become overlearned, thereby increasing the probability that it will be utilized during stressful situations. This assumption may be unrealistic as these crew coordination and communication skills may become peripheral tasks during an inflight emergency, as the pilots central focus may well be with stick and rudder activities. Perhaps the primary value of CRM is as a preventive measure. That is, this training may produce enhanced crew effectiveness, thereby reducing the likelihood of those errors caused by crew coordination degradation.

But the problem of HE incidents are not addressed sufficiently by CRM training alone. Reasonable evidence exists to conclude that pilots may lose control of their aircraft as a direct result of reactive stress (refs. 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 (AMB). 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 physiolgical arousal with a resultant efficacious effect on operational efficiency in student pilots (refs. 16 and 18). The specific method used in the present study was Autogenic-Feedback Training (AFT), which was developed by Cowings et al as a potential treatment for space motion sickness of astronauts aboard the space shuttle (refs. 19–21). This method has also been used successfully by the U.S. Air Force to control airsickness in military flight crews (refs. 22 and 23).

AFT has advantages over other methods for this particular application because it enables training individuals to regulate the levels of multiple physiological responses simultaneously, thus enabling a more system-wide reduction in reactivity to stressors. AFT was designed to be administered in a relatively short period of time (6 hrs total), can reliably produce sufficient autonomic control necessary to reduce responses to severe environmental stressors (i.e., motion sickness stimuli); and has been demonstrated to be effective in a wide population of subjects under a variety of stimulus conditions (ref. 19).

Materials and Methods

Subjects

All subjects were active-duty 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 Coast Guard Air Station, Barbers Point, Hawaii. These crewmembers consisted of 7 men from fixed-wing aircraft (HC-130), and 9 men and one woman from rotary wing aircraft (HH-65). Following an initial flight, subjects were assigned to one of two groups (treatment or control), matched for accumulated flight hours. The treatment group comprised four pilots from fixed-wing aircraft and four helicopter pilots; the control group comprised three fixed-wing pilots and six helicopter pilots. No attempt was made to match groups for sex or type of aircraft.

Apparatus

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) 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 and connected to 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 crewmembers 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 lap-top computer.

Procedures

Initially, all subjects 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 essentially the same.

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.

HC-130 emergency flight scenario– Subsequent to the pre-flight and taxi and take off, subjects climbed to a cruising altitude as designated by the air traffic controller (ATC). As a peak performance exercise, the subject was instructed to return to the traffic pattern and execute a series of touch and go maneuvers (one systems-normal, one simulated number one engine fire, and one automatic direction finder instrument approach). Upon completion of these tasks the subject departed the pattern at an altitude assigned by the ATC for a search and rescue (SAR) case in which there was ostensibly a downed A-4 pilot approximately 20 miles off shore. In order 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 opened and secured, and the aircraft had descended to 200 feet above ground level (AGL), a turbine overheat of the number two engine followed by an uncontained turbine failure of that engine was simulated. The subject was then notified by a confederate of simulated airframe damage, a minor fuel leak from the number two engine, and that a crew member had sustained injuries resulting presumably from shrapnel. This announcement was followed by left hand and Essential AC bus failure indicators. Moments later, the instructor pilot communicated to the subject that there was simulated smoke (without fire) emanating from under the flightdeck, there was charring in the vicinity of the number one generator on the nacelle paint, and the master fire light, T-handle, and a visible confirmation revealed that the number one engine was on fire. Upon stabilizing the aircraft, the subject was directed to maintain a cruising altitude as instructed by the 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.

HH-65 emergency flight scenario– Following pre-flight and taxi to a hover-take off, the subject climbed to the ATC designated altitude. The subject 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 number one engine stall to a running landing). Upon completion of these tasks the subject departed the pattern at an altitude assigned by the ATC for a 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 subject was directed to the position of the simulated craft and instructed to prepare to hoist the injured party aboard. While in a hover at approximately 50 feet AGL, the subject was given a servo-jam warning followed by a secondary hydraulic failure indicator which resulted in the rudder pedals being fixed. The subject was then requested to enter a holding pattern and return to base and land the "impaired" aircraft as instructed by the ATC. The subject was then directed to fly from the runway to the outer ramp (helo-pad). As the subject was on short-final approach, the instructor pilot simulated a stall of the number one engine from which the subject was to recover and land the aircraft as instructed.

Performance evaluation– Pilot performance measures involved subjective assessments of two instructor pilots who served as observers, with roughly equal numbers of treatment and control subjects 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. (ref. 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 managment; 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.

The second type of rating was designed to assess the observer's overall impression of performance throughout the flight (ref. 24), and was done upon completion of each flight. All subjects were instructed not to discuss the specific aspects of their participation in the study with other crewmembers.

Autogenic-feedback training– The treatment condition consisted of twelve 45 minute sessions utilizing a regimen of AFT training based upon the protocol developed by Cowings (ref. 19). This protocol included directed biofeedback, discrimination training and stress challenge training with and without feedback designed to increase subject 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 daily progressive relaxation exercises via audio tape. The control group received no treatment. This design was deemed appropriate because previous research by Toscano and Cowings (ref. 25), demonstrated that control group subjects 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 again flew the simulated emergency scenario at the same approximate time of day, and with the same rater as in their initial flight.

Results

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

Performance data were analyzed with nonparametric statistics: Mann-Whitney -U tests and Wilcoxan Sign-Ranks tests. Tables 1a and b show the results of analyses which 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 subjects scored significantly higher on Aircraft Handling during Cruise Search and Rescue (table 1b). Treatment group subjects had improved their performance after training and the two groups were no longer significantly different during the Cruise Search and Resuce phase of the second flight. Following training, the performance of AFT subjects during specific phases of flight were significantly better than that of the controls for stress managment, 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 subjects showed significant improvements in specific phases of the flight for all performance categories, while Control subjects showed no improvement. In fact, Control subjects showed a significant decrease in crew coordination and communication during the touch and go phase of flight.

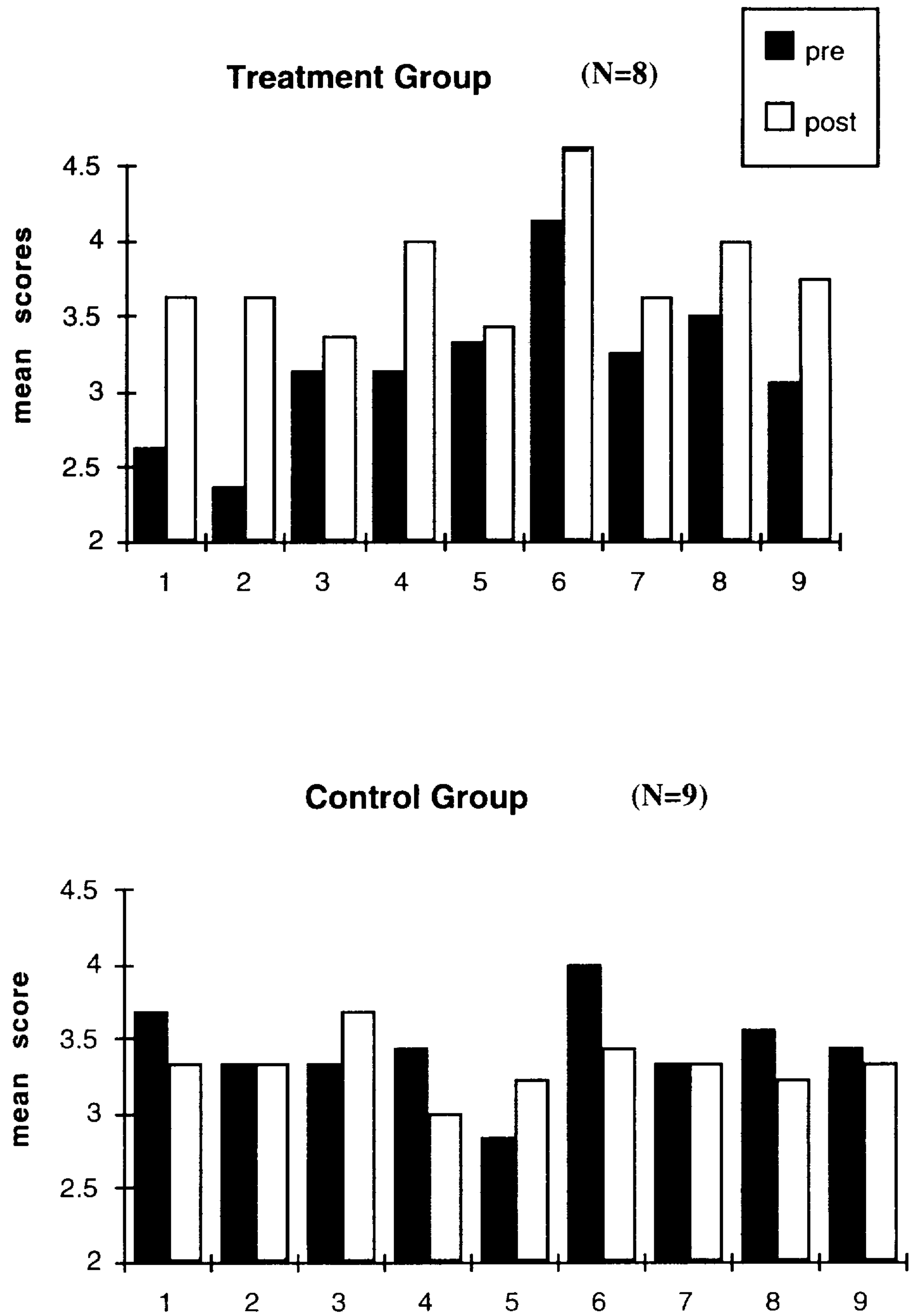
Physiological data obtained during flight and training sessions were not analyzed and will be presented in another paper.

Table 2 shows the results of Wilcoxan Signs-Ranks tests which was performed to examine the performance category, Crew Coordination and Communication, in detail. AFT subjects performed significantly better than Controls in 10 of the 13 specific dimensions of this category.

Discussion

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 where 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 subjects is particularly noteworthy, as these factors are emphasized in CRM approaches 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. As all of the subjects of this study have 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



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

Figure 1. Changes in overall performance during emergency flight scenarios.

Table 1a. 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 & Go	–	–	–	$p < 0.05$*
Cruise Search and Rescue	–	–	$p < 0.05$	–
Emergency Initiation	–	$p < 0.005$	$p < 0.01$	–
Emergency Return to Base	–	–	–	–
Emergency Approach and Landing	–	–	–	–

Planing 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 & 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.

Table 1b. 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 & 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 & 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 subjects scored significantly higher than AFT subjects during their first flight.

Table 2. Improvement in specific dimensions of crew coordination and communications during the second flight scenario: Wilcoxan Sign-ranks test

Dimension	AFT vs. Control		
	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

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 one's 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.

While the small subject population in this study precluded fixed vs. rotary wing comparisons, air frame 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 it's 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.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
March 1993

3. REPORT TYPE AND DATES COVERED
Technical Memorandum

4. TITLE AND SUBTITLE
Autogenic-Feedback Training Improves Pilot Performance During Emergency Flying Conditions

5. FUNDING NUMBERS
199-70-12-14

6. AUTHOR(S)
Michael A. Kellar,* Raymond A. Folen,* Patricia S. Cowings, William B. Toscano,** and Glen L. Hisert†

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Ames Research Center
Moffett Field, CA 94035-1000

8. PERFORMING ORGANIZATION REPORT NUMBER
A-93046

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA TM-104005

11. SUPPLEMENTARY NOTES
Point of Contact: Patricia S. Cowings, Ames Research Center, MS 239A-2, Moffett Field, CA 94035-1000; (415) 604-5724
*Tripler Army Medical Center, Honolulu, Hawaii; **University of California at San Francisco; †U. S. Coast Guard Station at Barbers Point, Hawaii

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified — Unlimited
Subject Category 03

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

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14. SUBJECT TERMS
Biofeedback, Cockpit resource management (CRM), Pilot error

15. NUMBER OF PAGES
12

16. PRICE CODE
A02

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified		