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The NASA Ames Fatigue Countermeasures Program: The Next Generation

Mark R. Rosekind[1], David F. Neri[1], Donna L. Miller[2], Kevin B. Gregory[2], Lissa L. Webbon[2], Ray L. Oyung[3]
[1]NASA Ames Research Center, [2]Sterling Software, [3]San Jose State University Foundation

Twenty-four hour, global aviation operations pose unique challenges to humans. Physiological requirements related to sleep, the internal circadian clock, and human fatigue are critical factors that are known to affect safety, performance, and productivity. Understanding the human operators' physiological capabilities—and limitations—will be important to address these issues as global demand for aviation activities continues to increase. In 1980, in response to a Congressional request, the National Aeronautics and Space Administration (NASA) Ames Research Center initiated a Fatigue/Jet Lag Program to examine the role of fatigue in flight operations. Originally established by Dr. John K. Lauber and Dr. Charles E. Billings, the Program was designed to address three objectives: 1) determine the extent of fatigue, sleep loss, and circadian disruption in flight operations; 2) determine how fatigue affected flight crew performance; and 3) develop strategies to maximize performance and alertness during flight operations.

The first ten years of the NASA Program were devoted to exploratory research, uniquely examining fatigue during regular flight operations. A large, diverse group of dedicated and talented individuals has participated in the NASA projects, from in-house scientists such as Dr. R. Curtis Graeber, Dr. H. Clayton Foushee, Linda J. Connell, William R. Reynard, and Dr. Donald Hudson, to collaborations with a worldwide group of airlines, pilots, other industry participants, such as the Federal Aviation Administration (FAA), and scientists. A series of field studies was conducted to evaluate fatigue, sleep loss, and circadian disruption in short-haul, long-haul, overnight cargo, and North Sea helicopter flight operations (1, 2, 3, 4, 5). These studies, and their findings, provided a critical foundation for understanding the role of human fatigue in these diverse flight environments. The science of sleep has been a research and medical focus for more than forty years. However, these NASA field studies and activities by other laboratories in the United States (e.g., Walter Reed Army Institute of Research, Armstrong Aeromedical Research Laboratory) and around the world (e.g., DLR in Germany, former Institute of Aviation Medicine in United Kingdom, Karolinska Institute in Sweden) have moved the study of these issues out of the laboratory and into real world operating environments.

In 1991, the NASA Fatigue/Jet Lag Program evolved into the Fatigue Countermeasures Program and added a new, fourth objective: to translate scientific findings into operational use. For the past six years, the NASA Ames Fatigue Countermeasures Program has addressed the complex issue of human fatigue through five major activity areas: 1) research activities; 2) equipment development; 3) education activities; 4) National Transportation Safety Board (NTSB) collaborations; and 5) policy support. A summary of each activity area will provide an overview of the significant progress made and for the management of fatigue in flight operations. Future directions for the Program also will be outlined.

1. Research activities. A NASA/FAA study of planned cockpit rest exemplified the transition from exploratory field studies to the evaluation of an operational fatigue countermeasure during regularly scheduled flights (6, 7). The results clearly demonstrated that a 40-minute planned inflight rest period significantly improved performance and physiological alertness in long-haul flight operations. This was the first NASA study to incorporate flight crew performance measures and continuous collection of brain and eye movement activity to physiologically determine sleep/wake state and alertness. The FAA is reviewing an Advisory Circular that would implement planned cockpit rest and about eight international carriers around the world have already instituted policies and procedures to use this effective fatigue countermeasure.

Two projects have been conducted to examine augmented long-haul flight operations, including the quantity and quality of sleep obtained using onboard crew rest facilities. First, three U.S. airlines participated in a survey to examine factors that promoted or interfered with sleep in onboard bunks (8). Results from over 1,400 international flight crewmembers indicated some difficulties sleeping in onboard bunks but that a reasonable amount and quality of sleep was obtained. This sleep was rated as significantly improving subsequent inflight performance and alertness. Factors were identified that promoted or interfered with sleep and which could be the basis for intervention strategies to promote optimal sleep in onboard crew rest facilities. The survey provided the initial data for a subsequent field study to examine these issues during actual flight operations. The second project involved a field study to collect physiological, performance, behavioral, environmental, and self-report measures to examine sleep quantity and quality in augmented long-haul flights with onboard bunk facilities (9). These measures were collected in several different types of international operations and aircraft, with two commercial airlines, and in one corporate/business aircraft. Physiological data confirmed that a good quantity and quality of sleep was obtained in onboard bunk facilities. Additional analysis is underway to determine the effectiveness of this sleep to maintain or enhance subsequent inflight performance and alertness.

Two surveys were initiated to examine known fatigue factors in operating environments not previously examined by the NASA Program. The first survey was conducted in Part 135 regional/commuter operations to examine factors unique to this flight environment. More than 1,400 surveys were collected from 26 small, medium, and large regional carriers throughout the U.S. The survey included questions about duty days, flight times, collateral workload activities, weather and mechanical delays, rest opportunities, and other fatigue-related factors. This project is exploratory and is intended to document self-reported perceptions of these factors from the operators. Analysis of the data is in progress and will result in a NASA Technical Memorandum. The second survey was conducted to examine fatigue factors in corporate/executive aviation operations (10). In collaboration with the Flight Safety Foundation and the National Business Aircraft Association (NBAA), almost 1,500 surveys were collected from those distributed to 2,100 NBAA member organizations. A significant number of respondents identified fatigue as a serious safety concern in corporate/executive aviation operations. Several findings demonstrated where these issues could be addressed, for example, in consistent and comprehensive flight and duty guidelines and through educational programs.

There have been several opportunities to examine fatigue-related issues in unique operational environments. One project examined the effects of shiftwork in the Missions Operations Directorate which supports space shuttle flight operations at the NASA Johnson Space Center (11). The issues examined in this operational environment are similar to other aspects of flight operations, such as maintenance and air traffic control. Another opportunity was a project to collect fatigue-related data during a record-breaking around-the-world jet-helicopter trip completed by Ron Bower and John Williams in 1996. This type of operational challenge that "pushes the envelope" by setting a new world's record provided a unique chance to obtain performance and sleep/wake schedule information during such an accomplishment.

Laboratory based research allows detailed examination of fatigue-related factors which can not be adequately controlled or measured in operational settings. Collaborative laboratory studies with academic colleagues are examining the effects of prolonged and restricted sleep loss with Dr. David F. Dinges (University of Pennsylvania), the effects of individual differences on sleep loss with Dr. Mary A. Carskadon (Brown University), and the effects of sleep loss compared to other performance-degrading conditions with Drs. Timothy Roehrs and Thomas Roth (Henry Ford Hospital).

2. Equipment development. The original Fatigue/Jet Lag Program field studies used self-report measures (e.g., background questionnaire, sleep/wake log) and one physiological measure of the internal circadian clock (i.e., core body temperature). The Fatigue Countermeasures Program has increased and improved the number of measures collected during field studies to include: background questionnaires; an electronic sleep/wake diary; self-report of sleepiness/alertness; performance; physiological measures of brain, eye, and muscle activity and oxygen saturation levels; vigilance and short-term memory performance; objective behavioral estimates of the 24-hour sleep/wake pattern continuously over a trip pattern; and environmental variables (e.g., noise, temperature, humidity). Measures are chosen to examine the specific questions addressed in a particular study.

One innovation developed and successfully implemented was the NASA AIRLOG (Ames Interactive Reporting Log), an electronic sleep/wake diary (12). Historically, a paper and pencil sleep/wake log was used to collect self-report data in the field, which was then entered into a database for analysis, sometimes taking five hours for transcription. The AIRLOG is an electronic organizer programmed with an extensive number of sleep/wake and duty questions which can be downloaded to a laboratory computer in about five minutes, including a preliminary analysis and summary report of variables. This information was subsequently added to a more comprehensive database for complete analysis. Operator acceptance is high and the AIRLOG already has been used successfully in one field study. Another innovation has been the development of AIRLAB. The AIRLAB (Airborne Instrument Research Lab) is composed of two carry-on bags that contains equipment and supplies allowing ambulatory measurement of up to four flight crew with the range of methods previously described. This provides a critical capability for the NASA Ames Fatigue Countermeasures Program to collect a wide range of measures during actual operations in diverse settings.

3. Education activities. One of the most direct methods to translate the scientific findings from research to operational use is through education and training activities. Education will provide a critical foundation for all other activities that address fatigue in flight operations. To meet this need, an education and training module entitled, "Alertness Management in Flight Operations" was developed (13). The module provides information on the physiological mechanisms underlying fatigue, some misconceptions, and fatigue countermeasures. The module was created as a 1-hour live presentation, to highlight interaction and address application questions, and is complemented by a NASA/FAA Technical Memorandum that includes the presentation materials and additional resources (14). To transfer this information to the aviation industry, a two-day "train-the-trainer" workshop is provided for interested parties. To date, 23 workshops have been conducted with 475 participants from 228 different organizations and 17 countries. Virtually all components of the aviation industry have been represented and involvement extends to many other 24-hour operational environments such as other modes of transportation, healthcare, the

petrochemical industry, nuclear energy, and law enforcement. Current estimates suggest that about 75 organizations are using the educational information to reach about 125,000 flight crews and others. Recently, participants from the Burlington Northern Santa Fe Railroad have committed to use the materials to train 45,000 employees.

4. NTSB collaborations. The NTSB has examined a variety of human performance factors in their many investigative and safety activities and made related recommendations. The NASA Ames Fatigue Countermeasures Program has provided analysis of fatigue factors to support several NTSB investigations (e.g., 15, 16). In the investigation of a 1993 DC-8 accident at Guantanamo Bay, Cuba, the NASA Ames Fatigue Countermeasures Program provided a structured approach to examine fatigue factors in the accident and conducted an analysis of the fatigue-related data. Based on the results regarding the fatigue factors and their relation to the performance contributing to the accident, the NTSB cited fatigue as a probable cause of the accident. This was the first time in a major U.S. aviation accident that the NTSB had cited fatigue as a probable cause. NTSB recommendations were made to revise flight/duty/rest regulations to include the latest scientific information and provide educational material on fatigue to flight crews. In another collaboration, the Honorable James Hall, current Chairman of the NTSB, attended a NASA education workshop and saw the opportunity to provide the information to other modes of transportation. In November, 1995, a NTSB/NASA Ames symposium entitled, "Managing human fatigue in transportation: Promoting safety and productivity," was held in the Washington, D.C. area. The symposium drew 600 participants from 16 countries and involved presentations on operationally relevant scientific information and organized working groups that addressed issues specific to particular modes of transportation. The proceedings from the symposium included reports of the scientific presentations and the outcomes of the modal working groups (17).

5. Policy support. Diverse groups, from regulatory authorities to individual flight departments, have been interested in the policy implications and applications of the scientific findings related to fatigue in flight operations. The FAA initiated a rulemaking activity to examine current flight/duty/rest regulations. As part of this activity, the FAA requested that NASA provide

input on the scientific research relevant to these issues. In response to this request, an International Scientific Working Group was organized that included Drs. David F. Dinges, R. Curtis Graeber, Mark R. Rosekind, Alex Samel, and Hans Wegmann. This group developed an operational document, a NASA Technical Memorandum entitled, "Principles and Guidelines for Duty and Rest Scheduling in Commercial Aviation," that provides an approach to manage fatigue issues in the context of flight/duty/rest requirements (18). The Principles section of the document provides the significant scientific considerations, and the Guidelines section provides one approach to their application. The FAA has published a Notice for Proposed Rulemaking (NPRM) on flight/duty/rest and cites the NASA report as one source for their proposed regulations. Flight/duty/rest issues are perhaps some of the most contentious and complex in aviation as well as other operational settings. The FAA provided an extended comment period for the NPRM and is currently reviewing the many comments received. The same issues are being addressed by regulatory authorities all over the world, including the Joint Aviation Authority in Europe, Transport Canada, and New Zealand Civil Aviation Authority. The International Civil Aviation Organization has an opportunity to provide leadership and guidance to approach these complex issues from a global perspective and support some level of harmonization across regulatory authorities.

The Flight Safety Foundation formed a working group to address fatigue in corporate/executive flight operations. This group, in collaboration with the NASA Ames Fatigue Countermeasures Program, used the Principles and Guidelines document as a foundation to develop recommendations for corporate aviation. The Flight Safety Foundation is publishing a document entitled, "Principles and Guidelines for Duty and Rest Scheduling in Corporate/Executive Aviation," that provides an approach and specific recommendations for addressing these issues in the corporate environment (19).

Based on the NASA Ames Fatigue Countermeasures Program's education and training module, the FAA has formed a working group to develop an Advisory Circular on fatigue countermeasures for distribution throughout all segments of the aviation industry.

Future Directions. These activities are indicative of the significant progress made to address the issue of human fatigue in flight operations. There are many other contributions by research and operational groups all over the world that have made significant changes in how this issue is approached. There is much more to be done. First, many of the activities and products cited here need to be incorporated more extensively throughout the industry. Education about fatigue must become commonplace and accepted as an ongoing component of all training curricula. The NASA Ames Fatigue Countermeasures Program continues to pursue relevant and operationally useful activities to maintain progress in this area. The Program is involved in the development and evaluation of other potential countermeasures, such as bright light, melatonin, caffeine, and exercise. Another activity is exploring how an individual airline could establish its own internal program to address fatigue issues empirically. When making scheduling or reserve decisions, information could be collected to add quantitative data to the considerations. Transfer of current information to other operational settings also is underway. For example, scheduling recommendations for space shuttle operations, using the AIRLOG to collect ongoing sleep/wake data from space shuttle astronauts, and providing strategies to support military operations. Research also must continue to examine new operating environments and challenges and support the translation of the latest scientific findings to operational use.

Since evolving into the NASA Ames Fatigue Countermeasures Program in 1991, many more individuals are to be acknowledged for their significant contributions to the Program and aviation safety. Some of these individuals include Dr. J. Victor Lebacqz, Dr. Philippa H. Gander, Dr. David F. Dinges, Roy M. Smith, Elizabeth L. Co, and Barbara T. Sweet. To obtain information on study results and other publications, write directly to: Fatigue Countermeasures Program, NASA Ames Research Center, MS 262-4, Moffett Field, CA 94035-1000, U.S.; fax a request to 415-604-2177 or visit on the Internet at http://olias.arc.nasa.gov/zteam.

Human operators remain a central element in safe and efficient aviation operations. Physiological considerations, along with other performance factors, are critical to understanding the capabilities and limitations of these human operators. Optimal performance, alertness, and safety will be dependent on the successful management of fatigue-related factors in operational settings. The projected increase in 24-hour global aviation activities indicates that these issues will only become more significant and prevalent. The progress cited here demonstrates that there are specific and effective approaches available to successfully manage alertness and performance in aviation operations. Many challenges remain and the global aviation industry has tools that can address these issues now and in the years ahead.

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