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**AEROMEDICAL FACTORS IN AVIATOR FATIGUE, CREW  
WORK/REST SCHEDULES AND EXTENDED FLIGHT  
OPERATIONS: AN ANNOTATED BIBLIOGRAPHY**

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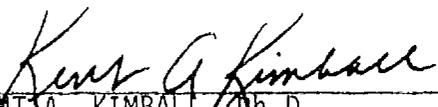
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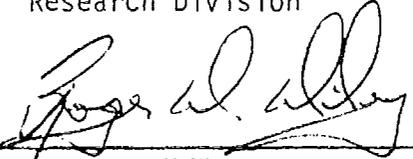
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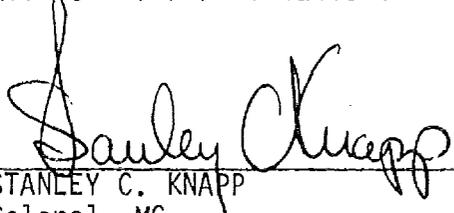
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<p>The influence of aviator fatigue on sustained flight operations is an important aeromedical topic. Available research data on the topic are either in short supply or are scattered throughout diverse printed sources and are difficult to tap when questions of their application to operational decisions are posed. This annotated bibliography lists 224 references containing research data, conceptual position papers and different methodological approaches to studying aviator fatigue, aviation crew work-rest schedules and extended flight operations. The bibliography contains an index which categorizes the references</p>		

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into such categories as: (1) circadian rhythms and jet lag; (2) psychological measurement of performance; (3) helicopter, transport, and civilian flight operations; (4) crew work-rest schedules; and (5) biochemical and physiological indices of fatigue. The basic period of coverage is 1940-1980.

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## INTRODUCTION

In preparation for the conduct of a series of experiments on the effects of fatigue on aviator performance, we began a comprehensive review of the scientific literature on the subject. Our primary interest was in the psychological literature on fatigue which might apply to the performance of military helicopter pilots during extensive flight missions. However, we quickly found ourselves gathering up and reading articles on fixed wing aviator fatigue, on automobile and truck driver performance during long road trips, and on continuous military operations in which other complex man-machine systems were being used. In addition, we found great interest in multidisciplinary articles which described different methodological approaches to studying not only the psychological, but the physiological, biochemical and ergonomic factors relating to pilot fatigue as well.

Eventually, we intend to produce a comprehensive review of the literature on the topics which relate directly to aviator fatigue. However, at this point, we have merely compiled all the references together into this annotated bibliographic listing in order to share their compilation with the rest of the aeromedical community.

The references cited within were obtained from diverse and widely scattered sources. Most of the references cited came directly from the authors; some were taken from the journal article; some were modified by us; and others were written by us as we compiled this bibliography. To us, all of them are in some way of interest to those who wish to do scientific research on fatigue and aviator and flight crew performance. Some of them can be categorized as reviews, overviews or conceptual descriptions of problem areas. Some offer alternative methodological approaches. Some offer fairly complete data while others offer only sketchy or incomplete data. For the sake of completeness, and because the ideas advocated in some paper listed here may one day spur more good research on the topic, we have included them all.

Predominately, we searched available resources printed in the English language, with a concentration on those readily available in North America. However, we have included several references from French, Spanish, Italian, Russian, and Japanese sources as well.

Users of this bibliography are encouraged to submit copies of additional applicable references to the Biomedical Applications Research Division of the US Army Aeromedical Research Laboratory for consideration in research and subsequent publications related to these topics.

# A

1. Adams, A. H., Huddleston, H. F., Robson, B. M., and Wilson, R. V. 1972. *Some effects of sleep loss on a simulated flying task*. Farnborough, England: Royal Aircraft Establishment. TR No. 72168, August 1972.

Twelve RAF pilots performed a simulated flying task. One group of 6 pilots performed after loss of a night's sleep. The second group of 6 pilots participated after loss of part of a night's sleep. Integrated tracking error scores showed no significant differences between the two groups. Peripheral light detection was significantly impaired by one night's sleep loss. Card-sorting and digit memory tasks showed no effects.

2. Adams, J. T. 1967. Fatigue in helicopter aircrews in combat. In: *Aeromedical aspects of helicopter operations in the tactical situation*: Aerospace Medical Panel Specialists' Meeting, 1967 May; Paris, France. London: Technical Editing and Reproduction Ltd. NATO/AGARD CP-24. AD 667-210.

It is generally felt by dual-rated pilots that a higher level of physical coordination and attention coupled with less opportunity to relax are required in helicopter as compared to fixed wing flying. This article deals with the newer roles that military helicopters are being cast in with emphasis on the requirements being placed on the aircrews. Material for discussion of combat related problems is largely being based on experience. Nevertheless, analogies exist and may be relied upon to lend a broader perspective where future problems are to be anticipated.

3. Adams, O. S., and Chiles, W. D. 1960. *Human performance as a function of the work-rest cycle*. Wright-Patterson Air Force Base, Ohio: Behavioral Sciences Laboratory. WADD TR 60-248, March 1960. AD 240-654.

This study was designed to investigate the effect on performance of four different work-rest period schedules (2 hours on duty and 2 hours off duty, 4 on and 4 off, 6 on and 6 off, and 8 on and 8

off) followed over a period of 96 consecutive hours. The subject sample consisted of 16 male college students with 4 subjects being assigned to each of the four work-rest period schedules. Performance was measured by means of a battery of psychomotor tasks involving arithmetic computation, pattern discrimination, monitoring, and vigilance. Additional data were obtained from information recorded in an experimenter's logbook and from responses to a subject questionnaire administered at the end of testing.

Although the performance tasks failed to differentiate among the four experimental groups, the observational evidence suggested that the subjects in the 2-hour and 4-hour groups achieved a more favorable adjustment than those in the other two groups.

4. Adams, O. S., and Chiles, W. D. 1961. *Human performance as a function of the work-rest ratio during prolonged confinement*. Wright-Patterson Air Force Base, Ohio: Aeronautical Systems Division. ASD TR 61-720, November 1961.

This study investigated the feasibility of using a 4-hours-on-duty and 2-hours-off-duty schedule in the operation of advanced aerospace systems. Two B-52 bomber combat-ready crews were confined for 15 days in a simulated advanced system crew compartment and were tested with a battery of five performance tasks and four psychophysiological measures. Data obtained during two 15-day testing periods are summarized in the main body of this report. Additional performance data obtained from five studies using college student subjects are presented in appended sections of this report. These results are based on four 96-hour investigations (two with a 4-on and 2-off schedule and two with a 6-on and 2-off schedule) and one 120-hour control group study (4 hours per day, 5 days per week, for 6 weeks). With proper control of selection and motivational factors, crews can work effectively for periods of at least two weeks and possibly longer using a 4-hours on and 2-hours off work-rest schedule.

5. Adamson, G. L. 1952. Fatigue. *Aviation Medicine*. 23:584-588.

The physiologist thinks of fatigue in terms of work and fuel and the accumulation of metabolites. These can be measured. However, the subjective experience (symptom) seems to have little connection with measurable physiological fatigue.

Flying fatigue is generally of two types: (1) that experienced in long, dull flights where there is no particular danger or need for constant alertness, although considerable tension may be involved, and (2) that encountered in flight at high speed, while under fire or wherever excessive watchfulness and quickness necessitates a

constant state of alertness. This second state introduces the element of stress beyond that involved merely in doing a "job."

Flight fatigue and skill failure involve (1) a breakdown in normal response to signals demanding action, (2) an impairment of skill as fatigue progresses because of increasing awareness of discomfort, and (3) a gradually decreasing ability to anticipate. Increases in airspeed and accompanying workload tend to pile up unacknowledged anxieties for aircrew members. Accumulated, unresolved anxiety is the most potent conditioning agency in air fatigue.

The avoidance of this state of affairs lies in acknowledging the importance of the problem and in combined executive and medical action.

6. Allnutt, M. F. 1970. Sleep at unusual hours, drugs and subsequent performance. In: Benson, A. J., *Rest and activity cycles for the maintenance of efficiency of personnel concerned with military flight operations*. Aerospace Medical Panel Specialists' Meeting, 1970 May; Oslo, Norway. London: Technical Editing and Reproduction Ltd. NATO/AGARD CP-74-70.

If a pilot has to get up early in the morning to fly a long and difficult sortie, should he be given drugs to aid his sleep?

This paper reports an experiment in which eight trainee pilots were sent to bed at 2000 hours, and then awakened at 0300 hours to spend the rest of the day carrying out performance tests.

There were four experimental conditions: (1) no drug, (2) placebo, (3) mogadon, and (4) seconal. Each subject spent two nights under each condition. During every alternate 24-hour period of the three weeks for which the experiment lasted, the subjects were off duty and free to sleep as they pleased. In addition to objective measures of performance and subjective measures of mood and sleep, continuous EEG recordings were made throughout each "experimental" night.

Although EEG records showed all subjects obtained an adequate night's sleep, subjects rated their sleep as being better under both drug conditions than under the no drug conditions. The drugs had no noticeable effect on a calculation task, and only slight effects on a vigilance task, these occurring in the later runs of the day, 16-20 hours after the drugs had been taken.

7. Allnutt, M. F., and O'Connor, P. J. 1971. Comparison of encephalographic, behavioral and subjective correlates of natural and drug-induced sleep at atypical hours. *Aerospace Medicine*. 42:1006-1010.

Eight trainee pilots retired to sleep under laboratory conditions from 2000 hours to 0300 when they were awakened to spend 8 hours performing 2 behavioral tests (calculation and vigilance). This regime was repeated on alternate nights in a 4 x 2 design. The four experimental conditions under which they slept were: (1) no drug, (2) placebo, (3) mogadon (5 mgs), and (4) seconal (100 mgs). Each subject spent 2 nights under each condition and during every alternate 24-hour period, they were off-duty and free to sleep as they pleased.

Continuous EEG recordings were made on each "experimental" night and subjective ratings of mood and quality of sleep were used to complement the behavioral measures. Under both the drug conditions there were changes in the EEG together with a slight decrement in vigilance performance in the later (1100-1500) runs of the day and an improvement in the rated quality of sleep.

8. Alluisi, E. A. 1967. Methodology in the use of synthetic tasks to assess complex performance. *Human Factors*. 9: 375-384.

The application of synthetic tasks to the assessment of complex performance is discussed in relation to the trade-offs involved in achieving adequate levels of face validity and in specifying the exact changes in psychological functions that may result from particular environmental manipulations. It is argued that the multiple-task performance battery approach can provide levels of face validity adequate to maintain the motivation of subjects while at the same time permitting the identification of changes in specific performance functions. The characteristics of this approach are discussed in relation to a program of research on the effects of confinement and demanding work-rest schedules on crew performance.

9. Alluisi, E. A. 1969. Sustained performance. In: Bilodeau, E. A., ed. *Principles of skill acquisition*. New York: Academic Press. 59-101.

The author presents the philosophy, techniques, and data of a program of research on the assessment of sustained performance on man's work behavior. The methodology developed employed a synthetic-work situation in which it is possible to measure and evaluate the performances of subjects or operators who are required to work at the time-shared tasks presented with a multiple-task performance (MTP) battery.

The tasks themselves were selected to measure certain behavioral functions that man is called upon to perform in a variety of work situations in the complex man-machine systems of today. Specific research studies have dealt with confinement in a volumetrically restrictive environment, sustained performance, work-rest scheduling, and diurnal rhythms in man, and with the behavioral effects of infectious diseases.

The general conclusions supported by the results of experimentation are as follows: (1) Crews consisting of as many as 10 men can be confined in a space as small as 1100 ft<sup>3</sup> for as long as 30 days or more without observable detriment. (2) Men apparently can follow a work-rest schedule of 4 hours on-duty and 4 hours off for very long periods without damage to their performances. (3) For shorter periods of 2 or possibly 4 weeks, selected men can follow a more demanding 4-2 work-rest schedule with reasonable maintenance of performance efficiency. (4) In following the more demanding schedule, man uses up his performance reserve and so is less able to meet the demands of emergency conditions such as those imposed by sleep loss. (5) The diurnal rhythm which is evidenced in physiological measures may also be evidenced in the performance, depending on the information given to, and the motivation of, the subjects, and depending also on the total workload. (6) Even where motivation is sufficiently high, the diurnal cycling of performance may be demonstrated when the operator is overloaded or stressed. (7) The average performance efficiency of a crew of men will drop between 25 and 33% during a period of illness with a febrile disease such as *typhoid*. (8) During such an illness, the average drop in performance efficiency is between about 6 and 8% per 1°F rise in rectal temperature, but (9) individual differences will be very great and may be expected to range from essentially no decrement to one of about 20% per degree.

In short, the synthetic-work methodology and its Multiple Task Performance (MTP) batteries appear to yield measures of sustained performance that are sensitive to the manipulation of both obvious and subtle experimental variables. They have provided a means for the conduct of experimental research on sustained performance or work behavior, and the data collected have led to inferences and conclusions like those listed in the preceding paragraph.

10. Alluisi, E. A., and Chiles, W. D. 1967. Sustained performance work-rest scheduling and diurnal rhythms in man. *Acta Psychologica*. 27:436-442. AD 644-152.

This paper summarizes a 10-year program of research that dealt with sustained performance, work-rest scheduling, and diurnal rhythms in man. The general conclusions reached are: (1) man can

probably follow an alternating 4 hours of work-4 hours of rest schedule for very long periods without detriment to his performance; (2) for shorter periods of 2 or possibly 4 weeks, selected men can follow a more demanding 4 hours of work-2 hours of rest schedule with reasonable maintenance of performance efficiency; (3) in following the more demanding schedule, man uses up his performance reserve and so is less able to meet the demands of emergency conditions such as those imposed by sleep loss; (4) the diurnal rhythm which is evidenced in physiological measures may also be evidenced in the performance depending on the information given to, and the motivation of the subjects, and depending also on the total workload; even where motivation is sufficiently high, the cycling may be demonstrated when the operator is overloaded; and (5) the methodology employed yielded measures that are sensitive to the manipulation of both obvious and subtle experimental variables.

11. Alluisi, E. A., Chiles, W. D., and Hall, T. J. 1964. *Combined effects of sleep loss and demanding work-rest schedules on crew performance*. Wright-Patterson Air Force Base, Ohio: US Air Force Aerospace Medical Research Laboratories. AMRL-TDR-64-63, June 1964.

Four 12-day confinement studies are reported. In each of two of these studies, subjects were organized into two 5-man crews who worked alternating shifts on a schedule of 4-hours on duty and 4-hours off for the entire 12-day confinement period. In each of the other two studies, six US Air Force pilots were confined for 12 days while following a schedule of 4-hours on duty and 2-hours off. The groups in each study were confined to a simulated advanced-system crew compartment. While on duty the operators were tested with a battery of six performance tasks, two of which required interactions among crewmembers in the form of exchanges of information, cooperation, and temporal coordination. During the middle two days of the 12-day confinement period, (on days six and seven), the crews following the 4-4 work-rest schedule were assigned extra work that resulted in each man's remaining awake for a 44-hour period. On the same days, the crews following the 4-2 schedule were assigned extra work that resulted in each man's remaining awake for a 40-hour period.

The data show that performance is generally inferior on the 4-2 schedule as compared to the 4-4 schedule and that the stress of a period of sleep loss results in generally greater performance decrements on the 4-2 than on the 4-4 schedule. The 4-2 schedule is not recommended if emergency periods involving sleep loss can be expected and a high level of performance is a critical requirement.

12. Alluisi, E. A., Chiles, W. D., Hall, T. J., and Hawkes, G. R. 1963. *Human group performance during confinement*. Wright-Patterson Air Force Base, Ohio: US Air Force Aerospace Medical Research Laboratory. AMRL-TDR-63-87, November 1963.

Six Air Force Academy cadets were confined for 15 days in a simulated advanced-system crew compartment while following a schedule of 4-hours on duty and 2-hours off, and two 5-man crews of US Air Force pilots were confined for 30 days while alternating shifts on a schedule of 4-hours on duty and 4-hours off. While on duty the operators were tested with a battery of 6 performance tasks, 2 of which required interactions among crewmembers in the form of exchanges of information, cooperation, and temporal coordination. In addition, the data of the present studies were compared with those of two previous 15-day tests of two crews who worked the 4-2 schedule while being tested with a battery of 5 individual-performance tasks.

The data suggest that with proper control of selection and motivational factors, crews can work effectively for periods of at least 2 weeks and probably longer using a schedule of 4-hours on duty and 2-hours off. Crews can work even more effectively for periods of at least a month and quite probably for 2 or 3 months using a schedule of 4-hours on duty and 4-hours off, and with this schedule less demanding controls of selection and motivational factors are required.

13. Anderson, D. B., and Chiou, W. C. 1977. *Physiological parameters associated with extended helicopter flight missions: An assessment of pupillographic data*. Fort Rucker, Alabama: US Army Aeromedical Research Laboratory. USAARL Report No. 77-21, September 1977.

Six Army aviators served as subjects in a study of various psychological and physiological parameters associated with extended helicopter flight missions. This report presents the results of pupillographic data collected in the study as well as the problems encountered and the recommended solutions. It was shown that the waveform characteristics of the pupillary reflex response to light were irregular. Furthermore, the blinking frequency increased and the pupillary amplitude varied as a function of loaded flight task. Results also revealed that the average pupillary diameter was smaller in the morning than in the evening. This report recommends the future use of pupillography in which an evaluation of pilot alertness is needed.

14. Aracil, A. S. 1977. Circadian rhythms in aerospace medicine (Ritmos circadianos en medicina aeronáutica). *Revista de Aeronáutica y Astronáutica*. 37:109-118. (In Spanish.) English translation NASA TM-75165, October 1977.

Literature on somatic and psychosomatic cyclic rhythms of more or less diurnal periodicity is critiqued for possible effects of nocturnal occupations on flight schedules; data on subjects kept in darkness for prolonged intervals are examined to describe whether the rhythms are predominantly endogeneous or imposed by repeated patterns and work habits. Literature on body temperature, hormonal function and secretions, kidney function, cardiovascular and hematological periodicities, psychic fatigue, intelligence and response times, and synchronization and coordination of functions is described. Physiological and social disequilibria engendered by work schedules out-of-phase with the surrounding population are considered. Problems for military personnel, airline personnel, and airline passengers are considered, and some palliative proposals are advanced.

We should see that military personnel who make night flight missions are in the optimal conditions for them. Hygienic measures should be accentuated the most. These include rest before a mission and the elimination of toxicants such as alcohol, tobacco and even coffee. Missions should be as far apart as possible and there should be a definite attempt to prevent any other factor from causing aviator fatigue.

Personnel selected for the civil airlines should be the most balanced and healthful possible, and the companies should separate flights as far as possible and break up routes and intermediate points by relief crews so that the time shifts will be less. In short, every kind of measure to care for this group of personnel whose social responsibility is extremely great should be taken.

The recommendation for transcontinental flight passengers is that they should try to follow the rhythm of their own clock with gradual adaptation to a new time system and nothing else, since in 8-10 days they will be completely adapted to the new time system. This and other cautions are particularly pertinent to diabetic patient passengers.

The recommendation for astronauts is to pre-establish a rhythm on the ground to be maintained during the flight. Both the Russians and the Americans follow a time rhythm in their capsules similar to that which they had on earth.

15. Atkinson, D. W., Borland, R. G., and Nicholson, A. N. 1968. *A study of the sleep rhythms in a double crew, five day continuous duty operation.* England: Flying Personnel Research Committee, Air Force Department, Ministry of Defence. FRPC Rep. No. 1282, December 1968. AD 859-428.

The sleep rhythms of aircrew, during a double crew continuous duty operation of approximately 110 hours duration, were studied in a "Belfast" heavy transport aircraft of the Royal Air Force. The study relates the subjective feelings of fatigue of the aircrew members to their sleep patterns and indicates possible patterns for duty during future flights of this duration. Also included is a list of recommendations for minimizing sleep disruption during long-haul transport operations.

16. Atkinson, D. W., Borland, R. G., and Nicholson, A. N. 1970. Double crew continuous flying operations: A study of aircrew sleep patterns. *Aerospace Medicine.* 41:1121-1126.

Continuous flying operations, in which crews sleep aboard the aircraft instead of sleeping at route stations, provide an operational capability independent of positioned crews. Such missions may lead to sleep difficulties and it is concluded from two missions operated by the Royal Air Force Air Support Command that the optimum duration is 48 hours. In the case of a fast strategic transport aircraft, this provides a worldwide capability.

17. Austin, F. H., Jr., Gallagher, T. J., Bricton, C. A., Polis, B. D., Furry, D. E., and Lewis, C. E., Jr. 1967. Aeromedical monitoring of naval aviators during aircraft carrier combat operation. *Aerospace Medicine.* 38:593-596.

A team of US Navy and NASA personnel monitored Navy carrier pilots flying high-risk attack combat missions in North Viet Nam during a 22-day line period near the end of a seven-month deployment. During the first 10 days, ECG, respiration and acceleration were recorded in flight on 32 pilots. Samples of pre- and post-flight blood and urine were collected for biochemical analysis for stress hormones and other fractions. Landing performance was recorded from radar tracking of carrier approaches. Results of the cardiorespiratory response are reported in a separate paper. The phosphatidyl glycerol fraction of the plasma phospholipids became elevated during the combat period, as did the phosphatidic acid, while the cardiolipin level remained relatively constant. These changes plotted against time in combat indicated a characteristic biochemical response pattern for combat flying stress. Statistical analysis of the designated phospholipid components showed significant concentration changes in the combat pilots in contrast to that previously found in other stress states and

in normal controls. Analysis of the landing data of the monitored pilots showed a mean performance for the group which compared closely to the performance of pilots flying similar aircraft.

18. Aviation Human Engineering Research Team. 1976. *Survey report of the sleep time on the Moscow route (Mosukuwa sen sumin jikan chosa hoboku)*. Aviation and Space Laboratory, Tokyo, Japan, October 1976. Trans: Scientific Translation Service. Washington, DC: National Aeronautics and Space Administration. NASA TT F-17, 530, May 1977.

A study was conducted over three months on 23 subjects concerning changes in sleep patterns and sleep amounts which develop as a consequence of the time differential and the long work periods on the Tokyo to Moscow route. The results were as follows:

(1) In both the three- and five-day patterns, an amount of sleep equivalent to one night's sleep was lost from the departure on the Moscow route to the return to Tokyo. In both cases, that developed during the eastward flight to Tokyo from Moscow on the final part of the duty, and it was quite difficult to adjust to this insufficiency during lay-over before the return flight.

(2) The amount of insufficiency increased after Moscow departure and reached a peak about six hours into the flight. The amount was eight to ten hours.

(3) Comparison of the five-day with the three-day pattern uncovered no significant difference in the cumulative amount of insufficiency, but the divergence from the activity time was greater in the five-day pattern and periods of insufficiency occurred periodically at four occasions so that the degree of fatigue was greater.

(4) Based on their life styles in Tokyo, the participants were classified into a standard group whose members had regular hours of activity and an adaptable group whose members did not conform to a standard hour for activities. The standard group had more hours of sleep on the average. While the adaptable group had fewer average hours of sleep, the effect was less if the hours of activity on Tokyo time were disrupted.

The characteristics of changes in the amounts of sleep and the sleep patterns which develop due to work on a long distance route were listed, but the survey itself had many imperfections.

## B

19. Balke, B. 1962. *Human tolerances*. Oklahoma City, Oklahoma: Federal Aviation Agency, Civil Aeromedical Research Center. FAA TR 62-6. AD 421-156.

The ultimate limitations in flight performance and in future civil air carrier equipment are the limitations imposed by what may be termed "human tolerances." This is particularly applicable to the matter of the supersonic transport. The discussion of man's maximum adaptive capacities for the majority of stresses potentially encountered in atmospheric and transatmospheric flights points to the weakest links in the man-machine complex of air and space transportation. An attempt is made to point out the means by which the human tolerances can be maximally adapted to the advanced technology.

20. Barreca, N. E. 1972. Flying fatigue. *US Army Aviation Digest*. 23:14-16.

This article discusses problems and preventive measures for military aircrew fatigue. Hypoxia, decompression sickness, acceleration, noise, and vibration are identified as environmental fatigue-producing stressors which must be recognized and controlled if skill fatigue is to be reduced. Other psychological and emotional stresses are also described. Symptoms of potentially dangerous fatigue such as crewmember acceptance of lower performance standards, loss of control smoothness, and neglect for peripheral tasks are described along with verbal responses a fatigued crewmember might exhibit. Specific advice is offered to aircrew commanders concerning fatigue prevention and implementation of provisions of US Army Regulation 95-1.

21. Bartlett, F. C. 1941. Fatigue following highly skilled work. *Proceedings of the Royal Society of London. Series B. Biological Sciences*. 131:247-257.

If the character and causation of fatigue following highly skilled work are to be understood, the first need is for the discovery of more relevant and experimentally controlled facts. Unfortunately, almost all the investigators who have attempted to study

fatigue of this type have adopted methods taken over with very slight change from those which have proved valuable in the study of simple muscular fatigue. They have chosen elementary operations usually considered to require some "mental" effort--such as easy calculations, work or color recognition and naming and the like--have repeated these operations over and over again for long periods, and have tried to express the resulting fatigue in terms of the diminution in quantity or quality of the work done. The skill fatigue of daily life is not set up under such conditions. Routine repetition of simple actions is not a characteristic of any highly skilled work, and least of all of work having a strong "mental" component. The operations involved here are marked by complex, coordinated and accurately timed activities. The stimuli in response to which these activities are set up are neither simple nor do they usually fall into an order of fixed succession. They have the character of a field, or a pattern, which has become very highly organized, and may retain its identity in spite of a great diversity of internal arrangement.

It is possible to develop fully controlled experimental situations in which these realistic considerations have full play. When this is done the picture of fatigue following highly skilled work which emerges has certain strongly marked characters.

In such fatigue the "standards" accepted and followed by the central nervous system unwittingly deteriorate. The operator tends to think that he is doing better work, because errors treated as significant all the time get wider and wider limits. Until a stage of great fatigue is reached, it is far more likely that the right actions will be performed at the wrong times than that the wrong actions will be performed. If accurate timing is insisted upon, gross mistakes of action may appear. The stimulus fields split up. Its pattern character alters. It becomes a collection of unconnected signals for action, with some of these predominant over all the others. Particularly, stimuli which are in the margin of the pattern, not closely organized with the central field, are ignored, "forgotten," and serious lapses of specific reactions occur. There is a marked change in the effect of certain "distracting," or additional stimuli. Sensations of bodily origin, in particular, become more pressing and insistent and affect the performance in ways peculiar to the tired operator. Side by side with all these changes go constant subjective symptoms. Verbal reports about any circumstances connected with known failure of performance become increasingly inaccurate, and errors are regularly projected upon objective conditions, or attributed to the interference of other people. There is a tremendous growth of irritability.

An attempt is made to discuss the light thrown by this picture upon the relation of high-level central nervous functions to simpler neuro-muscular mechanisms.

22. Bartlett, F. C. 1942. *Fatigue in the air pilot*. Cambridge, England: Psychological Laboratory, University of Cambridge. FRPC 488, August 1942. AD 138-651.

Muscular, mental and "skill" fatigue have to be distinguished from one another, and it is the third of these which is most important from the point of view of the pilot or other members of the aircrew. Fatigue is a normal and healthy effect of long repeated effort without rest, or of effort under unusual pressure. Until it becomes extreme most of its effects can be countermeasured without undue difficulty by anyone who is keen on his job and who knows something about the results that fatigue usually produces.

Fatigue is certain to occur even in the case of the fittest and most experienced members of aircrew in the later stages of any long operation. Most people are unaware that their behavior is showing signs of fatigue until a long time after these signs have begun to appear.

While there are considerable individual differences in resistance to fatigue, the evidence is that fit and experienced pilots are fairly likely to begin to show signs of tiredness after about 2 1/2 to 3 hours flying. Symptoms of fatigue are very likely after about 4 hours flying, and are almost certain to appear, unless special efforts are made to avoid them, near home after long flights, especially long and exciting flights.

The main demonstrated signs of pilot fatigue are:

(a) The control of steering column and rudder bar tends to become less smooth and accurate, and large errors - though generally made less often - take the place of smaller errors as fatigue develops.

(b) Timing of coordinated movements and of maneuvers becomes less accurate, rate of climb and dive, and control of direction especially being affected adversely.

(c) End deterioration is likely to be marked unless the pilot is particularly on his guard.

(d) While the fresh and trained pilot connects all the essential signs for action into a single whole, as he becomes tired his task and the signals for it both tend to split up, so that

he is apt to do one thing without much reference to other related things. This is especially noticeable in instrument flying.

(e) Instruments and actions that have to be attended to only occasionally are more and more likely to be forgotten as a pilot gets tired.

(f) Fatigue which is not recognized and controlled almost always gives rise to marked irritability.

(g) Bodily sensations usually attract a lot of attention, and may easily be wrongly interpreted.

The effects of fatigue on skill are cumulative, and may be masked and delayed for longer periods than are generally admitted, perhaps for 24-48 hours. A tired man's account of what happened during the fatiguing period is often extremely inaccurate. There are no known substances which can be relied upon safely to counteract the normal fatigue process.

Although all this is true, a normal fit and trained man does not need to have any apprehension about the difficulties incidental to fatigue, unless it is prolonged far beyond any ordinary operational demands. If he is on his guard he will have more than sufficient reserves to cope with any threatened trouble.

23. Bartlett, F. C. 1956. *Effects on human performance of various stress conditions*. Cambridge, England: Applied Psychology Research Unit. APRU TR FPRC 961, January 1956. AD 96-383.

The report summarizes important conclusions drawn from a large amount of work upon the effects of human performance of exposure to:

- (a) Noise.
- (b) Heat and humidity, and
- (c) Sleeplessness.

All three forms of stress may, unless special precautions are taken, seriously affect human behavior when great accuracy and speed are required. In all three cases, the main need is for further experimental work specially directed to two main points:

1. The further effects that may be produced when work has to be continued under these forms of stress for a relatively long period and under environmental conditions which are apt to change suddenly and unexpectedly.

2. The further effects which are almost certainly associated with sudden changes of stress conditions, such as a very rapid increase or decrease of noise, temperature, and humidity.

It was hoped to add something about these rapid changes, especially as regards temperature and humidity, but in 1956, nothing was known about their effects upon human performance with sufficient certainty to make it possible to put forward conclusions with confidence. It was also hoped to be able to deal similarly with the effects upon human performance of vibration, but again, existing knowledge was too uncertain to warrant anything definite being said.

24. Beck, R. A. 1964. Jet crew fatigue. *Combat Crew*. 15:4-7.

This article discusses salient factors and medical aspects that affect jet aircrew members in the performance of their duties. Two types of jet crew fatigue are identified: acute fatigue, which results from normal work and disappears with normal rest, and chronic fatigue which is a cumulative phenomenon resulting when physical and inertial recuperation between flights is incomplete. Jet crew fatigue is compared with piston engine aircrew fatigue with special emphasis given to the Juin Report. Diurnal rhythms and time zone shift are also identified as factors contributing to jet crew fatigue. The results of Air Force Operation Headstart, an extended flight study of B-52 bomber crews conducted in 1958, are briefly summarized.

25. Behar, I., Kimball, K. A., and Anderson, D. A. 1976. *Dynamic visual acuity in fatigued pilots*. Fort Rucker, Alabama: US Army Aeromedical Research Laboratory. USAARL Report No. 76-24, June 1976.

Six rotary wing aviators were subjects in a continuous operation regimen involving some 12 hours of flying and 3.5 hours sleep daily for five days. Estimates of performance on a dynamic visual acuity (DVA) task were obtained several times each day during the study using target velocities of 25° and 40°/sec. DVA performance varied significantly during the fatigue regimen when measurements were made with target velocities of 40°/sec; with lower velocity targets differences in DVA scores were not significant. This indicates the need to tax the oculomotor system to demonstrate fatigue effects. Fatigue effects were partially obscured by practice effects which are considerable in the DVA task. DVA scores correlated only modestly with subjective estimates of fatigue intensity and flying performance, and instructor pilot ratings of performance, but the cluster of correlations provided a consistent picture.

26. Benson, A. J., ed. 1970. *Rest and activity cycles for the maintenance of efficiency of personnel concerned with military flight operations*. Aerospace Medical Panel Specialists' Meeting, 1970 May; Oslo, Norway. London: Technical Editing and Reproduction Ltd. NATO/AGARD CP-74-70.

This volume contains the text, discussion and technical evaluation of ten papers presented at the AGARD Aerospace Medical Panel Specialists' Meeting which was held in Oslo, Norway in May 1970. The meeting was convened in response to a request from the Military Committee of NATO for advice on the influence of work and rest schedules on the operational efficiency of personnel concerned with flight operations. The papers presented fell into three main categories: (a) Laboratory investigations of normal and abnormal work-rest schedules, (b) inflight studies of aircrew operating long-haul transports, and (c) duty cycles in air traffic control tasks.

27. Berkhout, J. 1970. Simulated time-zone shifts and performance ability: Behavioral, electroencephalographic and endocrine effects of transient alterations in environmental phase. In: Benson, A. J., *Rest and activity cycles for the maintenance of efficiency of personnel concerned with military flight operations*: Aerospace Medical Panel Specialists' Meeting, 1970 May; Oslo, Norway. London: Technical Editing and Reproduction Ltd. NATO/AGARD CP-74-70.

Three subjects were maintained on an experimental sleep-activity time-line which simulated a flight assignment crossing ten time-zones eastbound and return within 72 hours. The subjects were required to operate an automobile and an array of electronic equipment during the simulated flights. Sleep periods were assigned during the simulated local night, involving a ten hour translation of normal habits, and occasioning two 12 hour epochs of sleep deprivation. Including baseline and recovery periods, the subjects were studied continuously for nine days.

Mental calculating ability, motor coordination and auditory perceptual acuity were determined several times per day throughout this period. Electroencephalograms were recorded during all assigned sleep periods and during the administration of behavioral tests. All urine produced during the experiment was collected, and volume, osmolarity, creatinine and 17-OHC levels were determined as a function of time-of-day.

The EEG recordings provided useful monitoring of the subjects' transient arousal status, and permitted the resolution of observed behavioral deficits into sleep-induced, stress-induced and

idiopathic classes. The urine chemistry determinations provided measures of circadian physiological fluctuations and their distortion following sleep-activity dislocations, and provided independent estimates of endocrine stress and energy expenditure.

Behavioral capability was observed to depend on several factors, including baseline circadian phase, time-since-waking (an approximation of local circadian phase), endocrine stress and subjective fatigue.

Conclusions are drawn concerning the optimum scheduling of crew assignments on extensive trans-meridional flights.

28. Berliner, D. S. 1975. Joint committee on aviation pathology: VIII. Crew rest and nap-of-the-earth flying. *Aviation, Space, and Environmental Medicine*. 46:1267-1270.

Nap-of-the-earth flying was conceived by the US Army to evade enemy detection of rotary wing aircraft, requiring the stressful technique of aircraft movement only inches above the ground terrain. The 101st Airborne Division (Airmobile), Fort Campbell, Kentucky, tested the nap-of-the-earth (NOE) concept from June 1973 to June 1974, flying 3267 hours in NOE training. Four aircraft incidents occurred during this training period, with three of these taking place prior to March 1974. At that point, after over 59% of the total hours had been flown, NOE pilot training was curtailed from 8 hours per day to 4 hours per day. Objective and subjective data infer that pilot (crew) rest and the length of the flying day are important factors in the safety of NOE flying.

29. Berry, C. A. 1970. Summary of medical experiences in the Apollo 7 through 11 manned spaceflights. *Aerospace Medicine*. 41:500-519.

The 3105 hours of exposing man to spaceflight during the Apollo program have added greatly to knowledge of man's response to space travel. The spacecraft cabin environment has been suitably maintained for the crew. The radiation environment has been benign, no solar flares occurring during the Apollo program missions. Crews have generally adapted well to weightlessness, and have learned to utilize it to their advantage. Improvements have been made in inflight food, with the addition of moisturized packs and such items as sandwiches and dried fruit. The body weight losses, which have continued to occur during space missions, are not entirely due to body fluids loss. Work-sleep cycles have been improved somewhat by having all crewmembers sleep at the same time, and by having cycles more closely related to those during training period. Cardiovascular deconditioning has been identified postflight with both lower body negative pressure and 90°

passive standing techniques. Microbiological studies have shown that organisms transfer between crewmembers. Moreover, the growth of opportunist organisms appears to be favored by these shifts. Extravehicular activities on the lunar surface during the Apollo 11 mission were conducted within expected energy costs, at an average of 1,200 BTU per hour. The liquid-cooled-garment-temperature method of energy cost estimation is the most suitable. It appears that lunar surface time can be expanded safely. The Apollo 11 quarantine was a demanding operation, conducted very successfully.

30. Billings, C. E., Chase, R. C., Eggspuehler, J. J., and Gerke, R. J. 1968. Studies of pilot performance: II. Evaluation of performance during low altitude flight in helicopters. *Aerospace Medicine*. 39:19-31.

Studies of the effects of stress in the flight environment have been difficult because of the lack of objective, quantitative indicators of performance. This experiment was designed to test such measures of pilot performance in rotary wing aircraft. Four rated helicopter pilots flew four 4-hour power line surveillance missions at extremely low altitude in a Hiller 12-E helicopter. The vehicle was instrumented for the recording of rotor RPM, cyclic and collective pitch control position and throttle position. These variables were recorded during pre-arranged geographic segments of each flight. The data were converted to digital format and analyzed on a computer. In the course of these missions, designed to produce fatigue, pilots tended to allow rotor RPM to vary within wider limits as flight time increased. Control movements of relatively large amplitude increased considerably during the later hours of flight. These changes were evident both during flight in immediate proximity to obstructions and during flight of a less stressful nature. Significant differences among pilots appeared positively correlated with previous helicopter flight experience. It is believed that techniques of performance assessment such as those studied in this experiment can be useful in providing further insight into biomedical changes observed under stress.

31. Bodrov, V. A. 1976. Medical problems of rationalizing in the work-rest regimen of astronauts (Meditsinskie problemy ratsionalizatsii rezhima truda i otdykha kosmonavtov). In: Lomov, B. F., Nikolaev, A. G., and Khachaturlants, L. S., eds. *Characteristics of cosmonaut activities during flight (Osobennosti deiatel'nosti kosmonavta v polete)*. Moscow: Izdatel'stov Mashinostroenie. 34-45. (In Russian.)

Experimental data are analyzed to reveal the impairment of physiological, psychological, and hormonal functions related to the circadian rhythm of astronauts during space flight. The reasons for

which it is impossible to adopt a ground-based circadian rhythm during space flight are the absence of biological rhythm time sensors in the spacecraft cabin (alternation of day and night, diurnal fluctuations of the environment, etc.), displacement of the diurnal cycle during flight, necessity of having someone on duty around the clock, restraint muscular activity, and other causes. The complexity of developing a rational work-rest regimen is discussed in terms of creating and maintaining a predetermined wakefulness-sleep rhythm with appropriate allocation of rest time in the spacecraft.

[NASA A78-47956 Abstract]

32. Boissin, J. P., and Abbas, L. 1975. Variations of certain ocular system parameters as a function of fatigue resulting from long-haul flights (Variations de certains paramètres du système oculaire en fonction de la fatigue lors des vols long-courriers). *Revue de Medecine Aeronautique et Spatiale*. 14: 65-67. (In French.)

Ocular tonus, types of phoria, ophthalmic arterial tension, punctum proximum of convergence and punctum proximum of accommodation, amplitude of fusion in convergence and divergence, and normal nyctohemeral rhythms (response to jet lag) were studied in crewmembers experiencing two ten-hour nonstop flights, with 9 hours jet lag in one direction, before and after rest periods. The time involved is found too short to affect ocular tonus. Ophthalmic arterial tension is not affected by flight fatigue per se, unless accompanied by a heavy workload or added stress. Variations in the punctum proximum for convergence were observed in some individuals, with some variations in the punctum proximum for accommodation in the case of presbyopic subjects.

[NASA A77-32352 Abstract]

33. Bond, J. S. 1978. Crew rest in reserve/guard components. *US Army Aviation Digest*. 24:38-39.

Pilot fatigue causes are related to the typical reserve/guard drill weekend. Special reserve/guard problems are discussed. A sample crew rest questionnaire, developed specifically for reserve/guard units, is presented.

34. Bricton, C. A. 1974. Pilot landing performance under high workload conditions. In: *Simulation and study of high workload operations*: Aerospace Medical Panel Specialists' Meeting, 1974 April; Oslo, Norway. London: Technical Editing and Reproduction Ltd. NATO/AGARD CP-146.

A longitudinal study of pilot carrier landing performance was conducted to describe the influence of prolonged operations on pilot performance. A landing performance criterion previously validated

in a fleet environment was used to measure and compare pilot and squadron performance variations over time. Three levels of cumulative workload were defined to evaluate concomitant changes in performance associated with each workload. Pilot landing performance improved over time with more improvement found in night performance than day. The influence of practice on carrier landings is discussed in relation to high cumulative workload. The performance criterion was used to identify potential night pilots on the basis of landing proficiency. High and low proficiency pilots also were identified and diagnostic training information provided. A statistically significant increase in night landing performance during high cumulative workload may be due to practice effects as well as workload.

35. Britson, C. A. 1975. *Prediction of carrier aviator performance during sustained operations at sea: Summary paper.* Presented at the American Psychological Association Convention; 1975 September; Chicago, Illinois.

The research summarized here stems from an initial interest by the Bureau of Medicine and Surgery in defining and describing the influence of environmentally related variables on overall aviation performance effectiveness. The specific environment studied was that of long term combat deployment.

Longitudinal measures of pilot performance under prolonged periods of stress and variable flight workloads were recorded. In addition, measures of blood biochemistry, sleep, mood and experience were collected to determine their potential for describing stressful environments and predicting variations in pilot performance.

Aviation performance effectiveness was defined and standardized for the combat environment by use of a previously validated Landing Performance Score (LPS) criterion. In the combat studies three basic measures were used to describe the pilot environment. First, measures of pilot landing performance were recorded during a nine-month combat deployment off the Viet Nam coast. Second, physiological measures of stress as indicated by blood biochemistry were obtained during four time periods of the combat cruise to describe pilot reactions to variations in flight workload. A third category of pilot-related variables was that of sleep, pilot emotionality and pilot experience data. Pilot mood (emotion) data were collected concurrent with biochemical data (four times); sleep data were obtained during one seven day cruise period; and pilot experience and biographical information were initially collected prior to the cruise to obtain baseline estimates of pilot background information. Those variables formed the basis of a measurement scheme designed to integrate performance, physiological, psychological, sleep and experience data into a comprehensive description of the influence of a combat environment on Navy fighter pilots.

Effect of prolonged operations at sea were summarized as follows:

Pilot performance can be predicted from experience, mood and biochemistry under different cumulative workload.

Adaptation to stress is facilitated by experience.

Experienced pilots maintain high levels of performance at a lower physiological and emotional cost than inexperienced pilots.

Inexperienced pilots gradually achieve high levels of performance but do not adapt biochemically and emotionally as quickly as experienced pilots.

Pilot adaptation to stress during prolonged flying may be accomplished in four phases: sleep adaptation, mood adaptation, biochemical adaptation, and performance adaptation.

Sleep appears to be a potentially sensitive measure of changes in pilot performance, biochemistry and mood.

Experienced pilots appear to anticipate performance demands by adjusting and pacing their sleep to the tempo of operations. They use cat naps as a tactic in meeting the demands of increased workload and stress.

Experienced pilots sleep less and have more fragmented sleep than inexperienced pilots.

36. Britson, C. A., McHugh, W., and Naitoh, P. 1974. Prediction of pilot performance: Biochemical and sleep-mood correlates under high workload conditions. In: *Simulation and study of high workload operations: Aerospace Medical Panel Specialists' Meeting, 1974 April; Oslo, Norway*. London: Technical Editing and Reproduction Ltd. NATO/AGARD CP-146.

A preliminary longitudinal study of the factors affecting the carrier landing performance of naval aviators under high workload conditions has been carried out. Using stepwise multiple regression techniques, a substantial portion of the variability in landing performance could be accounted for by six factors under zero cumulative workload conditions and by seven factors under moderate cumulative workload conditions. High cumulative workload conditions sharply reduced predictive ability. Although specific aircraft experience and total flight experience were important predictors of average landing

performance, blood biochemical levels and emotional states had significant predictive ability. Sleep patterns relate strongly to performance. The factors that determine landing performance change as cumulative workload increases. Suggestions for further research in this area are discussed.

37. Brown, W. K., Rogge, J. D., Meyer, J. F., Buckley, C. J., and Brown, C. A. 1969. Aeromedical aspects of the first nonstop transatlantic helicopter flight: II. Heart rate and ECG changes. *Aerospace Medicine*. 40:714-717.

Electrocardiographic data were recorded continuously on three crewmembers during a 30-hour transatlantic flight in an H-3 helicopter. Heart rate changes during the flight were compared with control heart rates during routine daily activities. Changes in heart rates during flight indicated that there were significant periods of rest. The marked increases in heart rate associated with obvious stressful events such as air refueling indicate that heart rate may be a good index of acute stress. However, the lack of change in mean heart rate over control values in two of the three crewmembers indicate that either the stress was less than expected or heart rate does not adequately reflect prolonged stress.

38. Bruener, H., Klein, K. E., Ruff, S., and Wegmann, H. M. 1965. Fatigue-studies on overseas flights. *Aerospace Medicine*. 36:552-553.

Studies were made on aircrew personnel during transatlantic flights from Frankfurt to New York and return. A "natural" depression of the circulatory parameters in the diurnal fluctuation was found during the night hours. It is probably caused by vagotonia. A depression found after long hours of mental work should have the same cause: a relative vagotonia, and should be an expression of a relative state of fatigue. This interpretation would best explain and also agree with the results obtained with other physiological parameters. However, the practical significance of this conclusion is not within the field of study of this report.

39. Buck, L. 1976. Psychomotor test performance and sleep patterns of aircrew flying transmeridional routes. *Aviation, Space, and Environmental Medicine*. 47:979-986.

Pilots and flight attendants flying scheduled services between Vancouver and Tokyo and between Toronto and Rome were tested on a tracking task before and after flights in each direction. Flights were included in schedules involving both 24-hours and 7-day layovers at the overseas station. During these periods, they recorded their

sleep patterns. The data showed that, following flight, subjects made an immediate attempt to adapt their behavior to local time and the changes in their performance scores could be interpreted on that basis. It was concluded that behavioural circadian rhythms adapt rapidly to a new time zone.

40. Buckley, C. J., and Hartman, B. O. 1961. Aeromedical aspects of the first nonstop transatlantic helicopter flight: I. General mission overview and subjective fatigue analyses. *Aerospace Medicine*. 40:710-713.

Effects of stress and fatigue on aircrew members participating in the first nonstop transatlantic helicopter flight were examined. A general mission narrative and observations of the flight surgeon crewmember are presented together with results of subjective fatigue rating and sleep pattern survey studies, continuous electrocardiographic recordings, and the analyses of altered excretion patterns of urinary constituents commonly affected by stress and/or fatigue. Results indicate that satisfactory aircrew performance can be maintained when helicopter crewmembers are exposed to the levels of stress and fatigue which were encountered on this record duration helicopter flight, but certain deficiencies in life support/crew comfort items available to the helicopter crewmember exist when this type aircraft is employed for missions in excess of six or eight hours duration.

41. Buley, L. E. 1970. Experience with a physiologically-based formula for determining rest periods on long distance air travel. *Aerospace Medicine*. 41:680-683.

The subjective effects of physiological cycle dysrhythmia due to rapid time-zone translocation have been quite well appreciated for forty years, but it was only the advent of large-scale turbojet transport operations a decade ago that focused scientific attention on the phenomenon. This decade has witnessed out-of-character behavior and inept decisions at high levels by victims of inadequate circadian cycle adaptation, and also extensive high-quality research on the problem.

Official long-distance air travel by staff members of the International Civil Aviation Organization (ICAO) on missions and home leave is considerable. Until 1966, rest periods en route or at destination before active duty were predicated on arbitrary rule-of-thumb "maximum journey times." This system was conducive neither to optimum physiological adjustment of staff on commencing duty at remote locations and on return to Headquarters, nor to optimum staff/administration relationships. A formula, based on significant, easily-quantifiable stress factors (but necessarily compromising between scientific

accuracy and administrative expediency) was therefore developed and has been applied to all official ICAO air travel since January 1967:

Rest period (in tenths of days) = Travel duration (in hours)/2 + time zone differential in excess of 4, + departure time coefficient, + arrival time coefficient. (Departure and arrival time coefficients, which are related to local time, are read from a table.)

The qualitative and quantitative rationale of the formula is described and ICAO's experience with it, in terms of efficiency and wellbeing of traveling staff and of administrative acceptability, is reviewed. Other organizations which have shown an interest in applying it to their diverse needs are mentioned.

42. Burton, R. R., Storm, W. F., Johnson, L. W., and Leverett, S. D., Jr. 1977. Stress responses of pilots flying high-performance aircraft during aerial combat maneuvers. *Aviation, Space, and Environmental Medicine*. 48:301-307.

In aerial combat maneuvers (ACMs), at Luke AFB, Arizona, eight fighter pilots flew their two F-15 aircraft against nine pilots in three F-106 aircraft. A total of nine flights, consisting of 23 ACMs, were accomplished in 5 successive days. The degrees of fatigue, stress, and sympathetic activity were quantified using both subjective analyses and the biochemical constituents in the urine of the pilots of the F-15 or F-106. Biochemical indicators, reported per 100 mg creatinine, included: epinephrine, norepinephrine, 17-OHCS, urea, inorganic phosphate, sodium, potassium, and sodium/potassium ratio. The F-106 pilots exerted more relative effort than did the F-15 pilots--effort which appeared to be associated with high-G experience. Both groups of pilots were equally fatigued following ACMs; however, only the fatigue of the F-106 pilots was directly correlated with the length of the ACM. Sympathetic and stress responses during the ACM--similar for both groups of pilots--showed postflight increases of 54% in epinephrine, 19% in norepinephrine, and 20% in 17-OHCS over pre-flight values, thus suggesting a moderate stress response. Resting levels of these same indicators, for days the pilots did not fly and for pre-ACM values, were similar but higher than control values previously reported for other stressful activities. By late afternoon, postflight values for these indicators had returned to near-preflight levels.

43. Byrne, D. 1964. What's being done about crew fatigue? *American Aviation*. 27:65-66.

This article outlines plans for upcoming research into jet flights across time zones and fatigue. Plans for an FAA Civil Aeromedical Research Institute study of jet crew fatigue on flights

from Oklahoma City, Oklahoma, to Frankfurt, Germany, and from Oklahoma City to Tokyo are discussed. Fatigue is also identified as a social problem among jet crews which results in increased irritability and decreased libido. The author predicts that new crew scheduling regulations will be instituted either by FAA regulation or by the airlines themselves as a result of fatigue experiments.

# C

44. Cameron, C. 1968. *A questionnaire study of fatigue in civil aircrew*. Victoria, Australia: Aeronautical Research Laboratories, Australian Defence Scientific Service, Department of Supply. Human Engineering Note 24.

A questionnaire designed to explore aspects of aircrew fatigue identified in an earlier study was circulated to over 600 pilots, navigators and engineers employed by Australian airlines on international operations. Completed questionnaires were returned by 79% of the group.

The following conclusions were drawn after analysis of the completed questionnaires.

1. The complaints of fatigue which gave rise to the investigation have a reasonable basis: the majority of flight crews report severe feelings of tiredness under operating conditions which are quite regularly experienced.

2. Fatigue, as recognized by aircrew, is associated with disturbed sleep, the causes of such disturbances being:

(a) an irregular pattern of night and day work, with insufficient opportunity for adaptation;

(b) variations in local time due to rapid traversing of time zone, again with insufficient opportunity for adaptation;

(c) a chronic stress reaction among aircrew, clinically of a relatively mild nature, but important as a determinant of sleeping difficulties.

3. The contribution of environmental factors to the fatigue problem is not in itself of great importance. Low relative humidity contributes to personal discomfort and there is some evidence of dehydration among members of flight crew.

4. Gastric symptoms of a type and severity to justify a diagnosis of functional dyspepsia were reported by 25% of the aircrew group. Less severe gastric symptoms were reported by an additional 29%. Disturbed sleep was reported by 87% of the group. These figures are interpreted as evidence of a chronic stress reaction in the aircrew group.

5. There is some evidence that renal disorders occur more frequently in aircrew than in a comparable segment of the general population. A mild degree of dehydration experienced repeatedly is suspected as a contributing factor.

6. No relationship has been found between severity of fatigue and total flying hours. Individual tolerance to the factors tending to disturb sleep appears to account for variations in the severity of fatigue reported, which are independent of total hours flown.

45. Cameron, C. 1971. Fatigue problems in modern industry. *Ergonomics*. 14:713-720.

A study of fatigue in civil aircrew is briefly described and a view of fatigue as a generalized response to stress is developed from the results. The factors associated with a fatigue reaction in aircrew are identified, and it is pointed out that they derive directly from technological advances in the airline industry. Similar advances in other branches of industry may be expected to bring similar problems, notably a progressively wider adoption of shift working. Solutions may be achieved by the application of human factors principles to the full range of human factors problems in industry, and by the determination of appropriate work-rest cycles for various kinds of work.

46. Cameron C. 1973. A theory of fatigue. *Ergonomics*. 16: 633-648.

Early research on fatigue in industry dealt almost exclusively with variation in productive output which resulted from prolonged work. Later research, typified by studies of pilot performance, developed methods of measurement which were more sensitive to time-correlated variations in performance and were applicable to tasks which involved little physical effort. Neither approach has been outstandingly successful in uncovering the nature of fatigue phenomena. Recent research has taken a broader view of fatigue as a generalized response to stress extending over a period of time, and has had some success in explaining the paradoxical results of earlier studies in terms of activation theory. This approach requires the time scale of

fatigue studies to be extended greatly, to allow for cumulative effects over periods of days, weeks or months and for the effects of disturbed sleep habits, which appear to be very important. Fatigue effects are closely related to the effects of sleep deprivation. The importance of such long term effects suggests that the time required for recovery may be a useful method of quantifying severity of fatigue.

47. Cantrell, G. K. 1968. *Trends in aircrew attitudes and job-satisfaction: Wives' report*. Brooks Air Force Base, Texas: US Air Force School of Aerospace Medicine. SAM-TR-68-67, June 1968.

Part of the Military Airlift Command Annual Aircrew Management Survey is a short questionnaire to be completed by wives on a voluntary basis. The surveys which were completed during 1966 were sorted and analyzed in four groups: (1) the first officer wives group (N = 454); (2) the first airman wives group (N = 435); (3) the second officer wives group (N = 410); and (4) the second airman wives group (N = 120). Data from the second groups were compared to those of the first groups to reveal potential trends in the problem areas covered in the survey. This comparison revealed that, for officer wives, the largest favorable change involved a reduction in the numbers of days husbands spent on temporary duty (TDY) away from the home station and resulting improvement in the living conditions. For airman wives, the largest favorable changes involved living conditions and cost-of-living, the average number of days husbands spent on TDY, and additional duties. The largest negative changes involved attitude toward husbands' flying duties, effects of husbands' absences on children, and greater difficulties experienced by husbands in relaxing. Descriptions of the model officer and enlisted aircrewman were derived.

48. Cantrell, G. K. 1969. *Trends in aircrew attitudes and job-satisfaction: A two-year study*. Brooks Air Force Base, Texas: US Air Force School of Aerospace Medicine. SAM-TR-69-17, April 1969.

Data from the third group of line aircrewmen (airmen and officers) in the Military Airlift Command (MAC) were compared with those from each of two earlier MAC groups to reveal the presence, direction, and magnitude of any trends in the problem areas represented by the survey items. The analyses of the data revealed that among aircrewmen (1) both officers and airmen were away from home fewer days per month even though they made more TDY trips; (2) airmen reported an increased ability to take planned days off; and (3) excessive ramp-pounding time is still a problem of major concern.

49. Cantrell, G. K., Trimble, R. W., and Hartman, B. O. 1971. *Long-term aircrew effectiveness (a literature survey)*. Brooks Air Force Base, Texas: US Air Force School of Aerospace Medicine. SAM-TR-71-4, April 1971. AD 722-417.

A wide range of factors related to long-term aircrew effectiveness are discussed in this review. The major categories are work environment factors, task factors, personal factors in screening, and personal factors in development. The review identifies such significant problems as gaps in the existing scientific literature and failure to consider interactions between the categories described.

50. Carey, R. E., and Quinlan, D. A. 1976. Frequent wind: Part three, execution. *Marine Corps Gazette*. 60:35-45.

This article describes in detail the helicopter evacuation of 6,968 persons from Saigon, Vietnam, on April 29 and 30, 1975. Special attention was given to the multi-deck operation procedures necessitated by such a large helicopter force. Helicopter operations were continuous from first light on 29 April until the operation was completed at 0835 hours on 30 April. Elapsed flight hours for the entire operation totaled 559.7 hours and signified 682 sorties. The high time aviator logged 18.3 flight hours and the average crew operated 13 hours. Of the 682 sorties flown during frequent wind, 360 were flown during hours of darkness. No aircraft damage was reported as a result of hostile fire; however, two aircraft were lost due to mechanical malfunctions.

51. Chastain, G. D., and Kubala, A. L. 1979. *Effects of fatigue from wearing the AN/PVS-5 night vision goggles on skills involved in helicopter operations*. Alexandria, Virginia: Human Resources Research Organization, and US Army Research Institute for the Behavioral and Social Sciences. TR-1217, July 1979.

Reviews of the literature on rotary wing flight and interviews with aviators were conducted to determine which helicopter tasks and maneuvers are performed most frequently and/or are the most critical. Those operations found to be most critical were analyzed into perceptual and psychomotor components, and a battery of perceptual and psychomotor tests was selected to measure these factors. Aviators were tested both before and after flying with the AN/PVS-5 goggles. Eye-hand coordination was marginally affected following flight, and reaction time to lights was significantly affected.

The results described in this report indicate that fatigue resulting from night vision goggle (NVG) wear affects performance

on tasks directly involved in helicopter operation. After lengthy NVG wear a general degradation in piloting ability would be expected. Efforts to limit the length of continuous use of the NVG seems prudent. The current findings should be useful in planning research designed to develop ways to reduce fatigue from NVG wear or to minimize the adverse effects of such fatigue.

52. Chiles, W. D., Alluisi, E. A., and Adams, P. S. 1968. Work schedules and performance during confinement. *Human Factors*. 10:143-196.

Thirteen investigations were carried out as a part of an 8-year program of research on the performance effects of various work/rest schedules during confinement to a simulated aerospace vehicle crew compartment. A total of 139 subjects were tested using a standard battery of performance tasks. The synthetic work approach used provided a reliable, face-valid, and sensitive technique for assessing complex operator performance.

It was found that a man can work 12 hours per day on a 4-hours work/4-hours rest schedule for periods of at least 30 days. For shorter periods, a man can work 16 hours per day on a 4/2 schedule but at a significant cost to his reserves for meeting emergencies such as sleep loss. Circadian periodicities are found in psycho-physiological functions paralleled by similar periodicities in performance functions, the latter being subject to modification by special motivational instructions.

53. Clark, D. 1979. Safety-fatigue. *Rotor Wing International*. 13:10-12.

Fatigue is not an uncommon accident causing factor--yet the US National Transportation Safety Board and the Federal Aviation Administration continue to disguise most accident reports that involve fatigue as "pilot error," "lack of judgment," or "pilot incapacitated."

There have been several studies and reports written in scientific language concerning fatigue. However, few have been written for the aviator or layman.

In 1974 aviation representatives from several of the member nations of NATO formed a study group which wrote a paper on helicopter aircrew fatigue. They developed a working definition of fatigue as "a change in bodily physiology, a decrease in work output (either in quality or quantity) and characteristic subjective feelings of tiredness or disinclination to work."

In 1975 the US Army published a letter that put in order of importance those tasks that involved aviator fatigue. Some of the top items are: instrument flying, exposure to hostile fire, limited visibility, sleep, duration of flying-duty pay, monotony of mission, etc. Federal Aviation Regulations and most company operation manuals prescribe minimum flight-time requirements and safety guidelines. Professional pilots should take the lead in aviator fatigue awareness.

Fatigue is a serious and costly problem. In 1976 there were 275 rotorcraft accidents involving 64 fatalities. Pilots were blamed as the cause of 70.8 percent of these mishaps. But how many were really victims of fatigue?

54. Collins, W. E. 1976. *Some effects of sleep deprivation on tracking performance in static and dynamic environments*. Oklahoma City, Oklahoma: Federal Aviation Administration, Civil Aeromedical Institute. FAA-AM-76-12, October 1976.

The influence of approximately 34 and 55 hours of sleep deprivation on performance scores derived from manually tracking the localizer needle on an aircraft instrument was assessed under both static (no motion) and dynamic (whole-body angular acceleration) laboratory conditions. In each of two experiments, 20 young men were equally divided into groups of control and sleep-deprived subjects. All tests were conducted in an enclosed Stille-Werner rotator in total darkness with the exception of the illuminated tracking display. In both experiments, significant decrements in dynamic tracking performance were uniformly obtained after 24 hours and more of sleep loss. Static tracking scores were also impaired but less consistently so.

In Experiment II, administration of d-amphetamine after 53 hours of sleep loss produced a sharp drop in error for both static and dynamic tracking. Although performance at both types of tasks remained poorer for sleep-deprived subjects, their static tracking scores did not differ significantly from control subjects 2 hours after drug ingestion. Thus, while the drug benefited performance, the benefits were only partial ones. Attentional lapses and inefficiency in perceptual-motor or information-processing mechanisms seem to account for the deleterious effects of sleep deprivation on performance. Thus, the study indicates clear declines in performance scores for an aviation-related task after a night without sleep. These negative effects become generally greater with increasing amounts of sleep loss and are more pervasive in motion environments.

55. Crane, J. E. 1972. Aeromedicine for business pilots: Pilots' fatigue and emotional problems. *Flight*. 61:44-46.

This article discusses acute and chronic fatigue on a general level. It describes the relation of emotional problems and tensions to fatigue and explains circadian physiological rhythms in terms of automatic conditioned responses. Eight recommendations of how to minimize aviator fatigue and pre- and post-flight checklists to enforce them are given.

56. Crane, J. E. 1977. Pernicious fatigue and pilot error. *Flight Operations*. 66:68-69.

Pernicious fatigue is a very special variety of weariness which is specific and cyclical in nature and occurs daily. Its cause has been established and its treatment is special and successful: The disease or symptom complex is a common psychological reaction to stress, which causes a chronic overactivity of the higher brain centers and the vagal-parasympathetic nervous system. Pernicious fatigue is extensive and pervading.

To diagnose this condition in the aviation environment we not only look for poor performance on an early morning flight, but also look for the second stage of pernicious fatigue which would occur in the afternoon about eight hours after waking up. Alterations in behavior due to fatigue can be responsible for the failure of the pilot to become aware of critical points in the flight.

Pernicious fatigue is treated by using the drug atropine sulfate in doses of 1/150th gram three to four times per day.

57. Creamer, L. R., Wheeler, D. E., and Gabriel, R. F. 1970. *Human error research and analysis program: Data analysis and fatigue studies*. Long Beach, California: Douglas Aircraft Company, McDonnell Douglas Corporation. TR MDC J0698/01, April 1970. AD 869-266.

Fatigue, while frequently cited as a contributing factor in accidents, remains an elusive element in terms of definition, recognition, measurement, prediction and alleviation.

Fatigue, defined as "The degradation in performance or affective state, resulting from previous work," was explored in 1968-1969 in a complex simulation experiment using an anti-submarine warfare flight trainer. Light workload over two hours and heavy workload over eight hours were imposed upon four professional crews. Each crew was in a controlled work environment 24-hours a day over a 2-week period.

Psychological, physiological, biochemical, and performance measures were taken for individual and crew as a group.

Some statistically significant effects in the physiological and blood chemistry measures were found. Bartlett's hypothesis in regard to increased variability of performance and perceptual break-up, and the activation pattern hypothesis were to some extent verified, although it was indicated that heavier or longer loads would be needed for greater significance.

In a second study in 1969-1970, a state of fatigue, induced by continuous performance of tasks over prolonged working time, was studied in a laboratory environment. The tasks were selected to resemble the airborne activities necessary to a prolonged anti-submarine warfare (ASW) mission.

Two loading conditions were imposed such that 12 subjects in a High Work Load (HWL) group worked without rest for approximately 18 hours and 12 different subjects in a Low Work Load (LWL) group worked for the same time span, but were permitted equal time on and off work, such that their workload was approximately one-half that of the HWL group. Psychological, physiological, biochemical, and performance measures were taken for each individual subject.

Performance decrement was obtained for the HWL reflecting at least moderate fatigue. A specially designed Discrete Tracking Task was the most sensitive index of fatigue. The task was moderately difficult with almost excessive temporal demands. The HWL group also made larger time estimation errors late in the session than the LWL group. No other psychological, biochemical, or physiological variable was correlated with performance decrement (Fatigue) in this study.

## D

58. Davis, D. R. (Psychology Laboratory, University of Cambridge). 1948. *Pilot error--Some laboratory experiments*. London: His Majesty's Stationery Office, Air Ministry. TR AP 3139A.

A large number of pilots carried out exercises in instrument flying in the Cambridge Cockpit, and it was supposed that the errors made in the tests were similar to those which are made in the air and which are responsible for accidents. The errors are described and their causes discussed.

Different parts of the task were differently affected, but in general, the number of errors increased in the first half hour of the test, were at a maximum in the second half hour, and then declined. The time for which errors persisted did not increase at first, but later, as the number of errors declined, their duration and size increased. As at first the number of errors increased, movements of the controls became excessive, and instrument deviations were overcorrected, these responses tending to be precipitate. The errors were termed errors of overaction and attributed to an overactivity reaction. As later the duration and size of errors increased, control movements were relatively large, since the size of deviations was large; otherwise, for a given size of error, they tended to be retarded and of relatively small range. The errors were termed errors of inattention and attributed to an inert reaction. Certain other kinds of error were observed: those due to a specific end effect, to preoccupation with one part of the task and neglect of others, and to perceptual disorganization. Another kind of effect was observed in the pilots who showed neither the overactivity nor inert reactions and who continued the test for more than two hours. This effect was not progressive, but intermittent, although in a group of subjects the incidence of errors increased with length of time.

Alcohol led to a marked deterioration of the performance. The effect of amphetamine was variable, but it tended to reduce deterioration caused by lack of sleep. The effects of noise of aircraft intensity were variable; noise did not adversely affect the accuracy of the performance, but there were large individual differences in its effects upon control movements.

The test performance was shown to be improved by special instructions describing the type of error to which pilots are liable.

The errors were explained as due to variations of anticipatory tension. Fatigue was not found to be a satisfactory explanation. An experiment is described in which errors of overaction were produced in the conditions predicted from the theory of anticipatory tension. The finding that the degree and type of deterioration in the test depended upon the grade and type of neurotic predisposition supported this theory.

59. De Hart, R. L. 1967. Work-rest cycle in aircrewmembers fatigue. *Aerospace Medicine*. 37:1174-1179.

The stresses acting upon military aircrewmembers are numerous and variable. These stresses are modified by such factors as morale, motivation and mission accomplishment. The interaction of stress and the individual may produce a subjective sense of weariness, with a concomitant objective deterioration in performance--an acceptable definition of fatigue.

This study was undertaken to more clearly delineate the subjective effects of fatigue in terms of the actual work-rest cycle. The subjects were highly motivated aircrewmembers in an operational squadron, performing a variety of aircraft systems tests. The missions were variable, from low level ground approach tests to high level photographic evaluations, from duration times of less than one hour, to over fifteen hours, and with a worldwide geographic spread.

A daily activity log, designed to cover a 24-hour period, was prepared by each subject. The log was divided into five major sections: Rest, Duty, Recreation, Nutrition, and Physiological Reactions. Twenty-four subjects completed the study, preparing the log for 30 consecutive days, thus providing a total of 24 man-months of subjective data for evaluation.

The daily logs were analyzed to establish trends and the influence of duty time and other factors on subjectively described symptoms of fatigue. The importance of modifying influences of such factors as job satisfaction and mission accomplishment on subjective fatigue are presented.

60. Dearnaley, E. J., and Warr, P. B., eds. 1979. *Aircrew stress in wartime operations*. London: Academic Press.

This is a book of important research papers in psychology and psychiatry. They were first published between 1940 and 1948, being

sponsored by the Flying Personnel Research Committee of the Ministry of Defence.

The papers describe eight research projects to examine the performance of aircrew during the second world war. The projects range from statistical investigations of accidents and effectiveness, through more clinical studies of personality and individual functioning, to the classic psychological experiments into fatigue and pilot error. The eight research reports are preceded by a specially written account of the historical background to the studies.

The book provides an insight into developments during a period when behavioral research achieved considerable advances. The flavor of the period and of research styles comes across vividly, and in this regard, the book is an important historical document and of vital interest to specialists in military studies as well as to those in aviation medicine, psychology, and psychiatry.

The articles contained include: (1) The Historical Background of Wartime Research in Psychology and Psychiatry in the Royal Air Force, (2) Clinical and Statistical Study of Neurosis Precipitated by Flying Duties, (3) The Influence of Psychological Disorder on Efficiency in Operational Flying, (4) Fluctuations in Navigator Performance during Operational Sorties, (5) Some Measures of the Effect of Operational Stress on Bomber Crews, (6) An Investigation of Landing Accidents in Relation to Fatigue, (7) The Psychological Aspects of Airsickness, (8) Experimental Study of Mental Fatigue, and (9) Pilot Error: Some Laboratory Experiments.

61. Del Vecchio, R. J. 1977. Fatigue. In: *Physiological aspects of flight*. Oakdale, New York: Dowling College Press. 97-101.

This chapter identifies three types of fatigue: physical, mental, and nervous fatigue. Physical fatigue, a result of muscular exertion, is eliminated by rest periods of as little as four hours. Mental fatigue is caused by expending mental effort and it, too, is eliminated by rest periods. However, an eight hour rest period is usually prescribed. Nervous fatigue, caused by tension, anxiety, boredom, or frustration is not alleviated by rest. On the contrary, physical activity is usually helpful in eliminating this type of fatigue. Fatigue in aviation activities is viewed using this three faceted model and general causes for each type are identified. Task learning is discussed as a method of fatigue reduction during alertness tasks.

62. Dempsey, C. A., Greiner, T. H., Burch, N. R., Chiles, D., and Steel, J. 1956. The human factors in long range flight. *Aviation Medicine*. 27:18-22.

The human factor problems of performance, personal maintenance and measurement of stress and fatigue were studied during 56 hours continuous confinement in a grounded F-84 aircraft cockpit. Performance deterioration was associated with changes in bio-electric measurements which objectively reflect state of consciousness.

Results showed that current jet aircraft cockpits are habitable for 56 hours without major physiological stress if limited protective equipment is employed.

63. Dhenin, G., ed. 1978. Aircrew schedules. In: *Aviation Medicine*. London: Tri-Med Books Limited.

Problems of commercial aircrew scheduling were discussed along with a history of scheduling regulations established in the United Kingdom. The American "Bidline" scheduling system and the British Airways "points system" were presented as possible solutions to scheduling problems. Some major physiological problem areas of airline operation were identified. Cockpit temperature, pressure, and humidity changes and aircrews obtaining less than adequate amounts of sleep were areas of major concern.

64. Domanski, T. J. 1957. The stress concept applied to flying. *Aviation Medicine*. 28:249-252.

Stress response is defined as the product of the interaction of a stress with a susceptible individual. Fatigue is treated as a stress response associated with the sheer duration of job performance (flying).

Applied to flying, eosinopenia appears to provide qualitative evidence of the occurrence of an emotional stress response in otherwise healthy individuals. The learning process, aircraft malfunction, accidents, and near accidents are classified as emotional stresses.

The blood eosinophil count has been used to provide information concerning two categories of flightline problems: (1) individual differences in the response to a given stress, and (2) the relative severity of a particular inflight stress or stress complex.

65. Dougherty, J. E. 1943. Effects of increased flying time on aviation instructors. *War Medicine*. 3:297-302. .

Twenty instructors selected at random from the first and the second training group at the Air Corps Basic Flying School were subjected to a fatigue study over a six week period, February 1, 1942 to March 17, 1942.

The average number of flying hours per person over this period was 118 hours, compared to an average of 81 hours for the same period in 1941 for another group of instructors. Including January flying time, the 20 instructors spent a total of 4,210 hours and 25 minutes, or an average of 210 hours per man. During the same period in 1941 the total was 2,760 hours, or an average of 138 hours per instructor, which is a total increase of 1,450 hours and an individual average increase of 72 hours.

The ages of the instructors ranged between 21 and 28 years, and the time spent as instructors ranged between one and sixteen months.

It is apparent that such an increase in flying hours should affect the instructors. This study was conducted to determine the effects, and the conclusions are as follows:

1. The younger instructors were slightly less affected than the older ones.
2. The periods of greatest stress occurred when day flying and night flying were necessary.
3. Seventeen of the 20 instructors required one to two hours' additional sleep.
4. Pilot fatigue was manifested subjectively in the 20 instructors by the following symptoms:
  - (a) A continuous sensation or feeling of tiredness.
  - (b) Late afternoon fatigue, usually pronounced.
  - (c) Increased irritability toward students, friends and wives.
  - (d) Less patience with students. Most of the instructors found it impossible to maintain patience; cadets were criticized severely for slowness and were frequently dismissed without sufficient instruction.

(e) Less concern with the progress of the students. All of the instructors stated that they tried at all times to keep an active interest in their students; however, some of the men found it impossible to maintain an interest because of the constant feeling of fatigue.

(f) Diminution in mental alertness and onset of mental fatigue. Ten of the 20 instructors reported this symptom on twenty occasions. However, when all 10 were requestioned carefully, they admitted that this symptom actually existed more often than stated; that on numerous occasions carelessness, especially late in the afternoon, was a common occurrence, and that they frequently discovered themselves in dangerous situations which under former conditions did not occur.

(g) Tinnitus aurium, loss of appetite and insomnia were relatively infrequent.

66. Dowd, P. J., Moore, E. W., and Cramer, R. L. 1975. Relationships of fatigue and motion sickness to vestibulo-ocular responses to coriolis stimulation. *Human Factors*. 17:98-105.

A Coriolis test on the USAFSAM biaxial stimulator was administered to 131 pilots. Two groups of pilots ("rested" and "fatigued") were tested twice. Some of the pilots in each group got motion sickness during the initial test period. A two-parameter analog, measuring the rates of decay and sensitivity coefficients of vertical nystagmic responses, was used to compare the effects of fatigue and induced motion sickness on the nystagmic responses induced by Coriolis accelerations.

Fatigue, in terms of moderate sleep deprivation of 24 to 30 hours, had significant deleterious effects on the vestibulo-ocular responses. Fatigue and induced motion sickness, simultaneously occurring, showed further deterioration of the vestibular system when compared with the nystagmic responses of rested and nonsick pilots. Such results indicate that fatigue and induced motion sickness make flying even more hazardous.

67. Drew, G. C. 1979. An experimental study of mental fatigue (FPRC Report 227, December 1940). In: Dearnaley, E. F., and Warr, P. B., eds. *Aircrew stress in wartime operations*. London: Academic Press.

The work reported in 1940 was an attempt to study the effects of mental fatigue on a simulated flight task. Special care is taken to separate mental from muscular fatigue because the two are

thought not to be entirely analogous. The experiments were conducted in a specially designed Spitfire fighter cockpit mockup in which instrument readings could be mechanically recorded. Subjects were instructed to perform a series of maneuvers such as climbing, diving, and turning. Each series was defined as a "course unit." Each subject performed seven "course units" separated by level flight segments, approximately two hours elapsed time, during the experiment. Error scores were calculated for airspeed, altitude, turn and slip, compass heading, climb and/or dive, and rate of climb. Performance deterioration resulted from subjective changes in the pilot's attitude which resulted in (a) pilot's lowering his own performance standards, (b) pilot's splitting the task up into small, seemingly unrelated, tasks, and (c) pilot's becoming preoccupied with physical discomforts. Some of the performance decrement is also attributed to the instrument panel lay-out. Some general design changes are discussed to remedy the instrument panel problems.

68. Duncan, C. E., Sanders, M. G., and Kimball, K. A. 1980. *Evaluation of Army aviator human factors (fatigue) in a high threat environment*. Fort Rucker, Alabama: US Army Aeromedical Research Laboratory. USAARL Report No. 80-8, September 1980.

Questionnaire data received from student and instructor pilots located at Fort Rucker, Alabama, indicate significant levels of fatigue when flying in different flight altitudes and profiles; the lower the altitude flown, the more rapidly pilots experience fatigue. These data suggest night standard flight is 1.4 times as fatiguing as day standard flight; day terrain flight is 1.3 times as fatiguing as day standard flight; night terrain flight, the most difficult flight profile examined, is 1.97 times as fatiguing as day standard flight. US Army Regulation 95-1, January 1980, sets a maximum of 140 hours per month per aviator of day flight in a combat environment. Existing doctrine emphasizes nap-of-the-earth (NOE) techniques, and if so accomplished for 140 hours, could possibly result in an unsafe and severely fatigued helicopter pilot. Using the guidelines presented in this report, field commanders may organize their crew work/rest schedules and more effectively continue their mission in Army aviation.

## E

69. Eberhard, J. W. (Matrix Corporation, Arlington, Virginia). 1966. *Sleep requirements and work-rest cycles for long term space missions*. Paper presented at Human Factors Society Convention; 1966 November; Anaheim, California.

This analysis tried to piece together data found in various industrial studies of the influence of sleep-wakefulness cycles on productivity, basic research studies applying physiological and psychological indices, results from space flight simulation studies, and finally, the data released from the long term American space flights that occurred to mid-1966. The review of the literature indicated: (a) There seems to be inadequate data relating the application of earth-oriented sleep/wakefulness cycles in long-term space missions; (b) the Gemini flights shift from a four-four schedule to one of eight hours tended to verify this for long-term missions; (c) the 14 day Gemini 7 flight seems to indicate that an extended flight gradually requires less sleep; (d) if mission oriented tasks require astronauts to perform on other than 8 hours consecutive sleep, consideration should be given to the effectiveness of different sleep periods from 2 angles: (1) selecting astronauts who require sufficiently less sleep, and (2) preconditioning the astronauts to use the different sleep/wakefulness cycle; (e) more definitive work should be done on the area of split sleep schedules if such schedules should be required for future long-term space missions; (f) more data is required on the influence of zero "g" on sleep requirements; and (g) consideration should be given to testing the period of wakefulness as related to the critical mission oriented tasks and astronaut performance of those mission oriented tasks to be performed upon sudden awakening.

70. Ellingstad, V. S., and Heimstra, N. W. 1970. Performance changes during the sustained operation of a complex psychomotor task. *Ergonomics*. 13:693-705.

Fifteen male subjects were exposed to a primary tracking task and a variety of subsidiary tasks for a total of 15 hours. Tracking performance was assessed through the use of two error measures: amount of time off the target track, and number of times off target.

Subsidiary performance tasks included: a vigilance task requiring subjects to respond to the deflection of the needle of a small meter; two reaction time tasks requiring response to the onset of one or the other of two lights; mental multiplication, which required the solution of simple multiplication problems; and digit span, in which the subject was required to repeat as rapidly and as accurately as possible a set of digits of either five, six or seven numbers in length. In addition, three physiological measures were obtained.

A significant decrement in tracking performance was obtained for both measures utilized. This decrement was not particularly abrupt in its occurrence but rather took place cumulatively over the entire course of the experiment.

There was no clearly established performance decrement on the subsidiary tasks utilized in this investigation. A marked variability in performance over the course of the experimental session was characteristic of performance on these tasks. Performance on the vigilance task, and one of the reaction time tasks improved during the 15-hour test session.

The 17-Ketosteroid and 17-Hydroxycorticoid values increased during the session but only in the case of the latter was the increase significant. The eosinophil count of subjects exposed to the test conditions decreased steadily throughout the experimental session. However, eosinophil measures obtained from control subjects increased during a similar time period.

71. Elliott, A. L., Mills, J. N., Minors, D. S., and Waterhouse, J. M. 1972. The effect of real and simulated time zone shifts upon the circadian rhythms of body temperature, plasma 11-hydroxycorticosteroids, and renal excretion in human subjects. *Journal of Physiology*. 221:227-257.

Observations were made upon five subjects who flew through 4 1/2-6 time zones, four of them returning later to their starting point, and upon 23 subjects experiencing simulated 6 or 8 hour time zone shifts in either direction in an isolation unit.

Measurements were made of plasma concentration of 11-hydroxycorticosteroids, of body temperature, and of urinary excretion of sodium, potassium and chloride. Their rhythm was defined, where possible, by fitting a sine curve of period 24 hours to each separate 24-hour stretch of data and computing the acrophase, or maximum predicted by the sine curve.

The adaptation of the plasma steroid rhythm was assessed by the presence of a sharp fall in concentration after the sample collected around 0800 hours. The time course of adaptation varied widely between individuals; it was usually largely complete by the fourth day after westward, and rather later after eastward, flights. After time shift the pattern often corresponded neither to an adapted nor to an unadapted one, and in a subject followed for many months after a real flight a normal amplitude only appeared 2-3 months after flight.

Temperature rhythm adapted by a movement of the acrophase, without change in amplitude, although on some days no rhythm could be observed. This movement was always substantial even on the first day, and was usually nearly complete by the fifth.

High nocturnal excretion of electrolyte was often seen in the early days after time shift, more notably after simulated westward flights. Adaptation of urinary electrolyte rhythms usually proceeded as with temperature, but the movement of the acrophase was slower, more variable between individuals, more erratic, and sometimes reversed after partial adaptation. On a few days there were two maxima corresponding to those expected on real and on experimental time.

Sodium excretion was much less regular than that of potassium, but adapted more rapidly to time shift, so that the two often became completely dissociated. Chloride behaved much as sodium.

The time course of adaptation of the plasma steroid and urinary potassium rhythms were sufficiently similar to suggest a causal connexion. The time course of adaptation of the temperature rhythm did not coincide with that of any other component considered here.

## F

72. Federation of American Societies for Experimental Biology (FASEB), Office of Biomedical Studies, Life Sciences Research Office. 1969. *A study of factors that affect the performance of Army flight crew personnel.* (Interim Report). Bethesda, Maryland: Federation of American Societies for Experimental Biology.

This technical report identifies and reviews the factors that influence the performance proficiency of Army flight crew personnel. There is a need to recognize the interdependence of the Army's requirements for human performance in the helicopter and the performance capacity of the man. The establishment of performance criteria for the former is considered necessary for understanding and recognition of the limitations of performance capacity of the man. Human parameters which affect performance, such as age, nutrition, sleep, socioeconomic factors, and use of drugs are reviewed. Rotary-winged aircraft characteristics and operational aspects such as noise, vibration, and cockpit environment are recognized as factors that are potentially detrimental to sustained adequate performance of the flight crew. The role of environment as it impinges on the performance of Army flight crew personnel is discussed. Establishment of performance norms and clarification of operational problems inherent in the Army's concept of helicopter utilization are urgent requirements. Additional biomedical research efforts are predicated on evolution of performance requirements and clarification of operational demands.

73. Fisher, K. D., and Carr, C. J. 1968. *An interim report on factors that affect the performance of Army flight crew personnel.* (Technical Report). Bethesda, Maryland: Federation of American Societies for Experimental Biology, Office of Biomedical Studies, Life Sciences Research Office.

This study was conducted as a portion of a comprehensive review of the biomedical aspects of human performance, to provide the Army Office of the Chief of Research and Development with the most current information on the performance of the soldier. This report identifies the need for performance requirements and reviews the factors

that influence the performance proficiency of Army flight crew personnel. There is a need to recognize the interdependence of the Army's requirements for performance in the helicopter and the performance capacity of the man. The establishment of performance criteria for the former is considered an essential prerequisite to investigation of the latter. Human parameters which affect performance, such as age, nutrition, sleep, socioeconomic factors, and use of drugs are reviewed. The design of the rotary-winged aircraft and operational aspects such as noise, vibration, and cockpit atmosphere are recognized as detrimental factors to sustained adequate performance. The role of environment as it impinges on the performance of Army flight crew personnel is discussed. Establishment of performance norms and clarification of operational problems inherent in the Army's concept of helicopter utilization are urgent requirements. Additional biomedical research efforts are predicated on evolution of performance requirements and clarification of operational demands.

Future studies will include both aspects of the performance of the soldier as well as factors which affect his performance. Reports will include relevant evaluative bibliographies.

74. Flight Safety Foundation, Inc. 1971. *Human factors in long distance flight*. Arlington, Virginia: Flight Safety Foundation, Inc.

This text was prepared in cooperation with the Flight Safety Foundation, the Federal Aviation Administration and the Aluminum Company of America with its intended purpose to provide an awareness and understanding of human factor safety considerations involved in the use of corporate and commercial aircraft for long distance flights at irregular hours.

The circadian rhythm is clearly defined. In simplified language, time-travel formulas as evolved by the International Civil Aviation Organization in order to minimize effects of circadian rhythm disruptions are described.

There are chapters on fatigue; flight-time limitations, including discussion of crew duty times; a section on alcohol; a section on high altitude flying with symptoms of hypoxia. There is a brief discussion of symptoms of hyperventilation and descriptions of other effects of atmospheric pressure changes including aerotitis; gastrointestinal distension; aerosinusitis; aerodontia; bends, air embolism and chokes; air turbulence is mentioned and other emergency and survival techniques including materials and procedures.

75. Fraser, D. C. 1957. *A study in fatigue in aircrew. IV. Overview of the problem.* Farnborough, England: Institute of Aviation Medicine, Royal Air Force., Flying Personnel Research Committee. TR FPRC 984, February 1957. AD 130-087.

This paper examines the evidence available from research on certain fatigue-inducing factors. Some of these factors include: the length of flight for both piston and jet powered aircraft, night versus day flying, and cumulative fatigue. On the basis of the research cited, several conclusions were drawn:

1. A significant fatigue effect occurs in subjects tested after flying continuously for more than ten hours in piston powered aircraft.
2. A significant fatigue effect occurs in subjects tested after three one-hour sorties in a jet fighter aircraft during the day, or two one-hour sorties at night.
3. The fatigue effect involved in night flying is greater than day flying of equivalent length.
4. Marked changes in performance can occur without any very extensive detectable physiological changes.

76. Funsch, H. F. 1965. Bewitched, bothered, and bewildered-- Love or fatigue? *The MATS Flyer*. 12:3.

This short article attempts to alert crewmembers to the causes and symptoms of fatigue. Acute and chronic fatigue are identified and differentiated. Aircrew members are asked to objectively determine whether they are suffering from fatigue by recognizing the following symptoms: getting stale on the job, not refreshed after a night's sleep, increased irritability, boredom, more intolerant with subordinates and family, increased drinking amount and frequency, sighing, yawning, and inattention. Aircrew members suffering from some of these symptoms are asked to consult their flight surgeons for possible corrective action.

# G

77. Gartner, W. B., and Murphy, M. R. 1976. *Pilot workload and fatigue: A critical survey of concepts and assessment techniques*. Moffett Field, California: NASA Ames Research Center. NASA TN-D-8365, November 1976.

This study addresses the principal unresolved issues in conceptualizing and measuring pilot workload and fatigue. These issues are seen as limiting the development of more useful working concepts and techniques and their application to systems engineering and management activities. A conceptual analysis of pilot workload and fatigue, and a discussion of current trends in the management of unwanted workload and fatigue effects are presented. Refinements and innovations in assessment methods are recommended for enhancing the practical significance of workload and fatigue studies.

78. Gartner, W. B., and Murphy, M. R. 1979. Concepts of fatigue. In: Hartman, B. O., and McKenzie, R. E., eds., *Survey of methods to assess workload*. London: Technical Editing and Reproduction Ltd. NATO/AGARDograph-AG-246.

Much of the difficulty involved in studying fatigue is agreeing on a definition of the term. This paper presents several concepts of the term "fatigue" along with comments and observations by some of the most notable researchers in the field. These conceptualizations include:

1. Fatigue as a feeling of weariness or tiredness.
2. Fatigue as a clinical syndrome.
3. Fatigue as a performance decrement or skill impairment.
4. Fatigue as a neurophysical condition or state.
5. Fatigue as a level of energy output.

75. Goerres, H. P. 1977. Subjective stress assessment. A new, simple method to determine pilot workload. *Aviation, Space, and Environmental Medicine*. 48:558-564.

Charged with the preparation of an expert opinion concerning psychophysical workload on pilots, the Aviation Psychology Branch of the German Air Force Institute of Aviation Medicine studied the "Subjective Stress Assessment" in which 217 Army, Air Force and Navy pilots filled in a standardized questionnaire. This questionnaire included 170 items to force the pilots into rating their on- and off-duty life; the answers of these people (117 jet, 41 multiple-prop, 14 single-engine, and 45 helicopter pilots) were evaluated quantitatively and qualitatively. It may be said--with all reservations towards subjectivity of pilots' opinions--that the pilots' image certainly requires some corrections, in particular as it relates to the ideal and material assessment of the activities of the separate groups of jet, helicopter, and prop pilots. It was the purpose of the study to show that the evaluation of pilots' workload by means of subjective interviews is a valuable method, aside from the assessment of difficulty of tasks by experts, aside from registration and evaluation of certain physiological parameters, and aside from the application of the Second-Task-Method-Registration.

80. Grandjean, E. P. 1968. Fatigue: Its physiological and psychological significance. *Ergonomics*. 11:427-436.

Physiologists very often consider fatigue simply as a decrease in physical performance. Psychologists try to consider it as a condition affecting the whole organism, including factors such as subjective feelings of fatigue, motivation, and, of course, the resulting deterioration of mental and physical activities.

The term "fatigue" is thus often used with different meanings and is applied in such a diversity of contexts that it has led to a confusion of ideas. This paper attempts to give, in the light of neurophysiological knowledge, a clearer notion of what could be defined and understood by "fatigue." It does not, however, deal with muscular fatigue, but with what is usually called general fatigue.

81. Grandjean, E. P. 1970. Fatigue. *American Industrial Hygiene Association Journal*. 31:11.

In the light of present neurophysiological knowledge we may consider fatigue as a state of the central nervous system controlled by the antagonistic activity of the inhibitory and activating system of the brain stem. The regulating systems in turn are susceptible to reaction to stimuli from the surrounding world, to stimuli from the conscious part of the brain, and to humoral factors originating within the

organism and having obviously the task of regulating recovery and wakefulness.

Recent investigations on human beings gave results matching well this neurophysiological concept of fatigue. Significant correlations were found between characteristic changes of the EEG and psycho-physiological changes, and between psychophysiological performances and subjective feelings of fatigue.

We may conclude therefore that these procedures are adequate for measuring fatigue related to workload and to monotony.

82. Graybiel, A., Lilienthal, J. L., Jr., and Horwitz, O. 1943. Flicker fusion tests as a measure of fatigue in aviators. *Aviation Medicine*. 14:356-359.

Flicker fusion frequency was determined repeatedly in thirty-two pilot instructors before and after a working day. No significant correlation was discovered between the alteration in flicker fusion frequency and the state of fatigue.

In this study, the flicker fusion test offered no promise as an objective measure of fatigue in aviation.

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83. Hale, H. B., Anderson, C. A., Williams, E. W., and Tanne, E. 1968. Endocrine-metabolic effects of unusually long or frequent flying missions in C-130E or C-135B aircraft. *Aerospace Medicine*. 39:561-570.

Flight-stress appraisal was made by means of a battery of urinary determinations (epinephrine, norepinephrine, 17-OHCS, urea, uric acid, phosphorus, magnesium, sodium, and potassium) for flyers who participated in (a) 20-hour missions in C-130E aircraft (flights from New Zealand to Antarctica, and back), (b) 6-day missions in C-135B aircraft (earth-circling missions), or (c) 7-week missions in C-135B aircraft (over-frequent transoceanic and transcontinental flying). The adrenal medulla (judging by urinary epinephrine) consistently showed flight-sensitivity, but other endocrine-metabolic functions varied in ways indicative of adaptation. With flight circumstances standardized (particularly with respect to time of day), flight effects tended to be reproducible. With crew rest limited to 2 days, recovery from flight-stress tended to be incomplete. Sleep-deprivation and crew position were shown to be factors which modify flight-stress reactions. Eastbound and westbound earth-circling missions did not induce different degrees of flight-stress, as judged by these endocrine-metabolic indices.

84. Hale, H. B., Ellis, J. P., Jr., and Williams, E. W. 1965. Endocrine and metabolic changes during a 12-hour simulated flight. *Aerospace Medicine*. 36:717-719.

Forty-eight young men were studied by means of serial urinary determinations while working in flight simulators for 12 hours. The "flights" began at 0700 hours and ended at 1900 hours. Post-flight values obtained at 2100 hours were compared with control values obtained at 2100 hours on the day before the test. Creatinine excretion did not show statistically significant variation with time. All other urinary constituents were expressed as ratios with creatinine. Simulated flight induced statistically significant elevations in urine volume, urea, uric acid, phosphorus, sodium, the Na/K ratio, 17-hydroxycorticosteroids, epinephrine and norepinephrine. The NE/E ratio fell significantly.

85. Hale, H. B., Hartman, B. O., Harris, D. A., Miranda, R. E., and Williams, E. W. 1973. Physiologic cost of prolonged double-crew flights in C-5 aircraft. *Aerospace Medicine*. 44:999-1008.

One double crew was studied during four standardized transoceanic flying missions in C-5 aircraft during the first year of its use by the USAF Military Airlift Command. All four flights went from Delaware, U.S.A., to South Vietnam and back, and each included short stops in Alaska, Japan, and Okinawa. Urine specimens collected at 4-hour intervals were analyzed for epinephrine, norepinephrine, 17-hydroxycorticosteroids, potassium, sodium, urea, and creatinine. In general, the results confirm and extend the findings for a double crew which flew long-duration missions in C-141 aircraft, indicating that physiologic entrainment remains at all times the principal determinant of endocrine-metabolic responsiveness to factors in the flying environment, including the work itself. Recovery from these long missions (average duration = 65 hours) involved differential reversal among the flight-affected endocrine-metabolic functions. Extrapolations of post-flight data suggest that the time for complete recovery exceeded the flight time.

86. Hale, H. B., Hartman, B. O., Harris, D. A., Williams, E. W., Miranda, R. E., Hosenfeld, J. M., and Smith, B. N. 1972. Physiologic stress during 50-hour double-crew missions in C-141 aircraft. *Aerospace Medicine*. 43:293-299.

By use of a battery of urinary techniques, the physiologic cost (stress) of prolonged C-141 flying operations (either staged or nearly continuous) was shown to be mild-to-moderate in degree. Staged missions lasting 5 to 7 days tended to be less stressful than double-crew nearly continuous 50-hour missions. In the latter type of mission, two extremely different work/rest schedules, namely 4/4 and 16/16 hours, induced similar degrees of physiologic stress. Anticipatory stress which was detected prior to double-crew flights tended to be higher than the flight stress that followed. Crew position was a contributory factor, slightly modifying flight and postflight trends. Pre-existing circadian periodicity persisted, although flight had modifying influence. Times of day that represented night at home were the times of highest sensitivity to flight. Recovery from prolonged, nearly continuous flying operations appears to require 4-5 days, and it appears to be a multiphasic process, with endocrine-metabolic depression appearing first, after which there was oscillation and final settling at the control level. In one double-crew mission, when extraordinary fatigue was noted, there had been a 12-hour pattern of change in the physiologic stress index that suggested an "overload" reaction.

87. Hale, H. B., Hartman, B. O., Harris, D. A., Williams, E. W., Miranda, R. E., and Hosenfeld, J. M. 1972. Time zone entrainment and flight stressors as interactants. *Aerospace Medicine*. 43:1089-1094.

Physiologic responsiveness to flying was studied, using the members of a double-crew of a C-141 aircraft during six flights, each of which lasted 54 hours and involved bi- or tri-directional trans-meridian flying. Responsiveness was quantified by means of endocrine-metabolic indices (urinary epinephrine, norepinephrine, 17-hydroxy-corticosteroids, urea, sodium and potassium), using urine specimens which were collected at 4-hour intervals during the flights. Physiologic entrainment was shown to be a factor contributing to responsiveness, for there was rhythmic variability which related to time of day at the crews' home base. The waveforms, amplitudes, time relations and overall levels, however, did not agree with those of unstressed persons. Preflight factors had carryover influence, acting as intensifiers of flight induced elevations at first, but gradually becoming less influential. As judged by epinephrine, norepinephrine and 17-OHCS, refractoriness toward flight stressors consistently developed at 2200 hours (Eastern Standard Time), even after the crew had crossed many time zones (flying either eastward or westward). These hormones indicated hyper-responsiveness regularly at 0600 hours EST; at other times responsiveness was shown (by these same indices) to be moderate in grade. Potassium, on the first day, indicated low responsiveness at 2200 hours and transient hyper-responsiveness at 0200 hours. On the second day, in association with sustained subjective fatigue of moderate degree, potassium indicated persistent noncyclic hyper-responsiveness. At the same time 17-OHCS indicated persistent hyper-responsiveness, although the factor of entrainment had modifying influence. Urinary sodium indicated cyclic change in responsiveness to flight, as did urea, but these two metabolic indices were out of phase with the hormones and potassium.

88. Hale, H. B., Kratochvil, C. H., Ellis, J. P., Jr., and Williams, E. W. 1958. Plasma corticosteroid levels in aircrewmen after long flights. *The Journal of Clinical Endocrinology and Metabolism*. 18:1440-1443.

Sweat's fluorescence method was used for the determination of hydrocortisone and a corticosterone-like fraction in blood in an attempt to evaluate flying fatigue in a group of 44 aircrewmen participating in flying activities in military aircraft. Mean pre-flight values for each of the two steroid fractions agreed with those reported by Sweat for normal male subjects, but significant increases in both fractions were noted after flights of nine to twelve hours' duration. This change was not of the nature of a diurnal variation.

89. Hale, H. B., Storm, W. F., Goldzieher, J. W., Hartman, B. O., Miranda, R. E., and Hosenfeld, J. M. 1973. Physiological cost in 36- and 48-hour simulated flights. *Aerospace Medicine*. 44:871-881.

Groups of young healthy men were studied during 36- and 48-hour simulated flights in which they performed on psychomotor measuring devices, using a 2-hour work/rest schedule. Physiologic cost was assessed by use of a battery of urinary techniques, including potassium, sodium, urea, 17-OHCS, and, in some cases, individual 17-ketosteroids. Comparison was made of responses to (a) uncomplicated flight, (b) flight complicated by environmental dryness, (c) flight complicated by 8,000-ft. pressure altitude, and (d) flight complicated by dryness and altitude. The prolonged psychomotor effort (and attendant sleep deprivation) acted as a nonspecific stressor. Altitude had intensifying influence, but dryness tended to counteract some phases of the stress response. In combination, altitude and dryness in certain physiologic respects acted in a depressant manner. Completed recovery from such prolonged effort required more than 2 days.

90. Hale, H. B., Williams, E. W., and Buckley, C. J. 1969. Aero-medical aspects of the first nonstop transatlantic helicopter flight: III. Endocrine-metabolic effects. *Aerospace Medicine*. 40:718-723.

Endocrine-metabolic appraisal was made by means of urinalysis for all participants (2 crews of 5 men each) in the first nonstop, transatlantic helicopter flight. Serial urine specimens were analyzed for epinephrine, norepinephrine, 17-hydrocorticosteroids (17-OHCS), urea, creatinine, phosphorus, magnesium, potassium and sodium. Nonspecific stress was evident, as flight caused a 143 percent gain in epinephrine, a 25 percent gain in urea and a 51 percent reduction in the norepinephrine/epinephrine ratio. It also modified the circadian trends for 17-OHCS and phosphorus. The interindividual endocrine-metabolic variability was high.

91. Harris, D. A., Hale, H. B., Hartman, B. O., and Martinez, J. A. 1970. Oral temperature in relation to in-flight work-rest schedules. *Aerospace Medicine*. 41:723-727.

Six experimental flying missions (each of 54 hours duration) were flown in a C-141 aircraft. Two crews took turns flying the aircraft during each mission. The same two crews flew all six missions. In three of the missions the work/rest schedule was 4/4 hours; in the remaining missions it was 16/16 hours. Oral temperatures of 9 of the crewmembers (2 aircraft commanders, 2 co-pilots, 2 flight engineers, 2 navigators and 1 loadmaster) were measured at 4-hour intervals during the flight periods and also during 54-hour postflight periods, with the

testing schedule standardized with respect to time of day. The oral temperature rhythm during flight periods, although remaining entrained to the time at the home base, was lower in amplitude than that during postflight periods. The 4/4 work-rest schedule had more depressant influence on oral temperature than the 16/16 schedule. The individuals occupying key positions had the lowest oral temperature during flight periods as well as during postflight periods.

92. Harris, D. A., Pegram, G. V., and Hartman, B. O. 1971. Performance and fatigue in experimental double-crew missions. *Aerospace Medicine*. 42:980-986.

Six experimental transport missions using a double crew were flown in a C-141 on routes generating various combinations of long and short legs. Crews followed a 4/4 or 16/16 work/rest schedule within operational constraints. On-board crew-rest facilities were provided so that the plane could fly through the airlift system without crew changes or crew delays. The missions required approximately 55-60 hours to complete. The flying time averaged around 43 hours. Crew performance was evaluated by ratings made by an on-board flight examiner. There were no significant differences in flight examiner ratings. Subjective fatigue was measured by a rating scale. There were no significant differences related to work/rest cycles. There were significant differences related to mission profile and crew position. Sleep EEG's were recorded on the two navigators and were supplemented by self-reports from all crewmembers. There was a marked reduction in total sleep as well as Stage 1-REM and deep sleep. Findings are discussed in relation to the demands of flying transport missions.

93. Harris, W., and O'Hanlon, J. F. 1972. *A study of recovery functions in man*. Aberdeen Proving Ground, Maryland: US Army Human Engineering Laboratories. TR No. HEL TM 10-72, April 1972. AD 741-828.

Concepts of sustained and continuous military operations were examined with respect to relevant literature. In particular, the objectives were to predict behavioral and biological impairments which might result in those operations; and to determine whether the period necessary for recovery following a sustained operation can be ascertained from the literature. It was concluded that those objectives could not be met due to inadequate information. Nonetheless, the literature did provide data which suggest that certain severe impairments may be experienced by soldiers engaging in sustained and continuous operations. It also provided guidelines for the design of studies to collect the required information. Finally, this review led to a call for serious re-evaluation of the current concepts of continuous operations.

94. Hartman, B. O. 1965. *Fatigue effects in 24-hour simulated transport flight--changes in pilot proficiency*. Brooks Air Force Base, Texas: US Air Force School of Aerospace Medicine. SAM-TR-65-16, April 1965.

Each of four pilots completed a 24-hour simulator flight broken into eleven 2-hour legs terminated by an Instrument Landing System (ILS) landing. Two kinds of performance measures are presented: (a) 20-second time-lapse photographs recorded airspeed, altitude, and rate of climb (or compass heading) through cruise portions of each leg; and (b) the ground-track record of the ILS approach was photographed after each landing.

The cruise portions of each leg showed an increasing variability in performance, but this change did not significantly reduce overall system efficiency. Instrument approaches were carried out at a high level of proficiency for approximately 20 hours, at which point there was a precipitous drop in performance.

Simultaneously recorded physiologic measures were reported separately elsewhere.

95. Hartman, B. O. 1967. Psychological factors in flying fatigue. *International Psychiatric Clinics*. 4:185-196.

This review is a brief summary of the controversies and problems found in the study of aircrew fatigue concentrating on the facts useful to practicing flight surgeons and physicians. Definitional aspects are avoided while the role of such factors as changes in work efficiency and subjective changes are discussed. These factors are determined by a host of forcing functions which are subdivided into three main groups: environmental, situation and personal factors. These factors are discussed with regard to the type of fatigue occurring (acute, cumulative and chronic), and the effectiveness of the crewman during normal and extended flights.

96. Hartman, B. O. 1971. Field study of transport aircrew workload and rest. *Aerospace Medicine*. 42:817-821.

Selected transport crewmembers flying 100 logistics missions maintained a log on work and rest on an around-the-clock basis starting 12 hours prior to the mission and ending after 3 days of post-mission rest. Ninety missions were flown to Southeast Asia and 10 to Europe. The average mission time was 6.7 days, during which the crew flew 44.5 hours. The full cycle, including pre-departure and post-mission crew rest, was 9.1 days. Logged work on the average mission accounted for 44.5% of mission time. The remainder was spent in an "off-duty" status. In the analyses, special attention was given to

self-reports on sleep. Crewmen slept somewhat more while out on a mission than during pre-departure (7.3 hours versus 6.8). During the post-mission crew rest, they slept considerably more (9.9 hours on day 1; 9.2 hours on day 2; 8.9 hours on day 3). This finding on sleep is discussed in relation to fatigue and sleep disturbances.

97. Hartman, B. O., and Cantrell, G. K. 1967. *MOL: Crew performance on demanding work-rest schedules compounded by sleep deprivation*. Brooks Air Force Base, Texas: US Air Force School of Aerospace Medicine. SAM-TR-67-99, November 1967.

Thirteen subjects took part in a series of 12-day runs in an experiment on the effects of demanding work/rest schedules (4/2, 4/4, or 16/8 hours). On days 8, 9 and 10, subjects were deprived of sleep and worked continuously. No significant work/rest effects were seen until subjects were sleep-deprived. In general, subjects on the 16/8 schedule tolerated sleep deprivation better and recovered faster, as evidenced by psychomotor test scores and sleep reports.

98. Hartman, B. O., and Cantrell, G. K. 1967. Sustained pilot performance requires more than skill. *Aerospace Medicine*. 38:801-803. AD 661-165; NATO/AGARD CP No. 14.

The impact of factors such as management, job satisfaction and workload was clearly demonstrated in research during World War II. A study of crew workload in the C-141 provided data which could be used to study living and working schedules during extended missions. A model mission was empirically derived and demonstrated major disruptions in the daily patterns of eating, sleeping and working. Situational factors associated with flying through several time zones appeared to have a primary effect. Actual reports from the field supported these findings. While it is reasonable to hypothesize that these and similar factors should reduce the aircrewman's physical and psychological fitness for sustained flying proficiency during demanding missions, the crucial studies remain to be done.

99. Hartman, B. O., and McKenzie, R. E. 1966. Hangover effect of secobarbital on simulated pilotage performance. *Aerospace Medicine*. 37:1121-1124.

A previous research study by one of the authors reported performance decrement in a simulated piloting task as a residual effect of secobarbital. This is a followup study to evaluate both the dose levels and the "hangover" effect without the complications of an extended "mission" and another drug (d-amphetamine) used in the previous design.

The results on 64 subjects performing a simulated flying task for 4 hours under one of 4 treatment conditions (3.0 gr. of secobarbital, 1.5 gr. of secobarbital, placebo, or control) indicated that 3.0 gr. of secobarbital administered the previous evening 10 hours prior to the "flight" produced degraded performance with associated subjective reports of a "hangover" effect. No degradation of performance was obtained with a dose level of 1.5 gr.

100. Hartman, B. O., Cantrell, G. K., and Sims, L. S. 1966. *An exploratory study of factors affecting aircrew morale.* Brooks Air Force Base, Texas: US Air Force School of Aerospace Medicine. SAM-TR-66-62, July 1966.

Aircrew morale was studied in 176 Military Airlift Command aircrewmembers. In interviews and questionnaires, nine problem areas were identified. The primary problem reported by the aircrewmembers was lack of planned free time. This factor had a negative effect both on duty and off duty. The remaining eight factors were more specific to the working environment. Several were a function of the mission of the command but some were accessible to local modification. In the face of these problems, aircrewmembers maintained good motivation, probably because of the satisfactions obtained from flying and from other aspects of their Air Force careers.

101. Hartman, B. O., Cantrell, G. K., and Sims, L. S., Jr. 1966. *A second study of factors affecting aircrew morale.* Brooks Air Force Base, Texas: US Air Force School of Aerospace Medicine. SAM-TR-66-91, November 1966.

A questionnaire concerning aircrew morale and job satisfaction was completed by 283 officers and 138 enlisted aircrewmembers in three Military Airlift Command Navy squadrons. The stability and predictability of off-duty time, with emphasis on scheduled time off-duty and elimination of wasted time on-duty, were areas of major concern to the Navy aircrewmembers. Officers and enlisted men expressed essentially the same attitudes. Responses were generally more moderate than in an earlier study with Air Force aircrewmembers. Satisfactions derived from flying apparently attenuated negative feelings to a considerable extent.

102. Hartman, B. O., Hale, H. B., and Johnson, W. A. 1974. Fatigue in FB-111 crewmembers. *Aerospace Medicine.* 45:1026-1029.

Fifteen biomedically dedicated missions of 8 hours duration were flown in the FB-111 fighter aircraft as part of its initial operational evaluation. Each two-man crew provided data on subjective fatigue, discomfort, efficiency, and pre- and post-mission sleep. In

addition, urine samples obtained from one crew on an unusually demanding mission were analyzed for epinephrine, norepinephrine, 17-hydroxycorticosteroids, sodium, potassium, and urea. The data showed that the crews experienced moderate fatigue and stress, aggravated by physical discomfort, from which they recovered after one night of sleep.

103. Hartman, B. O., Hale, H. B., Harris, D. A., and Sanford, J. F., III. 1974. Psychobiologic aspects of double-crew long-duration missions in C-5 aircraft. *Aerospace Medicine*. 45:1149-1154.

Subjective fatigue and oral temperature were used as biomedical indices in a study in which two C-5 jet transport crews alternately operated the aircraft. Data collected at 4-hour intervals during and following four 66-hour missions (each a roundtrip intercontinental flight) clearly established that (a) these dissimilar functions were rhythmic, and (b) flight factors exerted modifying influence on both rhythms. Particularly significant was the finding that subjective fatigue on the average showed (a) initial latency, (b) an intensification phase, and (c) a reversal endocrinometabolic and sympathetic nervous system hyperactivity (compensation). Oral temperature and subjective fatigue responses to prolonged flight tended to run parallel courses. Recovery rates for subjective fatigue and oral temperature tended to be similar, and at least 3 days were needed for elimination of residual flight effects.

104. Hartman, B. O., Storm, W. F., Vanderveen, J. E., Vanderveen, E., Hale, H. B., and Bollinger, R. R. 1974. *Operational aspects of variations in alertness*. London: Technical Editing and Reproduction Ltd. NATO/AGARDograph No. 189. AD 786-123.

Variations in alertness undoubtedly affect operator performance, sometimes to a degree which significantly degrades operational effectiveness. Alertness is a biological state with behavioral, neurophysiological and biochemical elements. Related states are vigilance, attention, and arousal. This monograph summarizes the literature on these topics, as well as the influence of various environments on alertness levels, spontaneous fluctuations in alertness, and effects of such variation on operator performance. The environments under consideration include long-duration flights, flights at night, monotonous tasks, solitude, mild hypoxia, and variations in thermal conditions in a flight compartment.

105. Hauty, G. T., and Adams, T. 1965. *Phase shifts of the human circadian system and performance deficit during the periods of transition: I. East-West flight.* Oklahoma City, Oklahoma: Civil Aeromedical Institute, Federal Aviation Administration. FAA-AM-65-28, December 1965.

At periodic intervals throughout the biological day, biomedical assessments were made for a week prior to jet flight from Oklahoma City to Manila, for 8 days of layover at Manila, and for a week following return. The rapid translocation effected primary phase shifts as follows: for rectal temperature and heart rate, 4 days; for palmar evaporative water loss, 8 days. The return flight effected a 1-day phase shift. Behavioral integrity was degraded, although to a lesser extent after return. Duration of behavioral impairment was much shorter than the lag time of physiological phase shifts.

106. Hauty, G. T., and Adams, T. 1965. *Phase shifts of the human circadian system and performance deficit during the periods of transition: II. West-East flight.* Oklahoma City, Oklahoma: Civil Aeromedical Institute, Federal Aviation Administration. FAA-AM-65-29, December 1965.

At periodic intervals throughout the biological day, biomedical assessments were made for a week prior to jet flight to Rome, for 12 days at Rome, and for a week following return to Oklahoma City. A primary shift of circadian periodicity was manifested by physiological functions--rectal temperature, heart rate, etc. Increase in fatigue occurred during the primary period of transition and following return, but psychological performance was not impaired during either period. Duration of the fatigue was shorter than the time lag of the physiological phase shifts.

107. Hauty, G. T., and Adams, T. 1965. *Phase shifts of the human circadian system and performance deficit during the periods of transition: III. North-South flight.* Oklahoma City, Oklahoma: Civil Aeromedical Institute, Federal Aviation Administration. FAA-AM-65-30, December 1965.

At periodic intervals throughout the biological day, biomedical assessments were made for a week prior to jet flight to Santiago, Chile, for 12 days at Santiago, and for a week following return to Washington, D. C. Although previous East-West and West-East flights effected a primary shift of circadian periodicity, as manifested by physiological functions, the North-South flight did not. There was, however, a significant increase of subjective fatigue, as in the other flights. The significant impairment of psychological performance produced by the East-West but not the West-East flight was not shown by the North-South flight.

108. Hauty, G. T., and Adams, T. 1965. *Pilot fatigue: Intercontinental jet flight 1. Oklahoma City <----> Tokyo*. Oklahoma City, Oklahoma: Civil Aeromedical Institute, Federal Aviation Administration. FAA-AM-65-16, March 1965. AD 621-433.

Following 3 consecutive days of biomedical assessment in Oklahoma City, six healthy subjects were transported to Tokyo, where assessments were made on alternate days throughout a period of 10 days, and were then transported back to Oklahoma City, where assessments were made for 3 consecutive days. Based upon the single parameter of rectal temperatures, the mean values of all subjects revealed that biological time had apparently shifted from Oklahoma City to Tokyo time within 3 days and from Tokyo back to Oklahoma City time within 1 day. Individual rectal temperature curves of the different subjects, however, revealed a profound range of individual differences. The mean proficiency with which the subjects executed basic task functions was adversely affected to a substantial extent during the first day in Tokyo and, to a lesser extent, the first day of return to Oklahoma City.

109. Higgins, E. A., Chiles, W. D., McKenzie, J. M., Funkhouser, G. E., Burr, M. J., Jennings, A. E., and Vaughan, J. A. 1976. *Physiological, biochemical and multiple-task-performance responses to different alterations of the wake-sleep cycle*. Oklahoma City, Oklahoma: Civil Aeromedical Institute, Federal Aviation Administration. FAA-AM-76-11, November 1976.

Three groups, each comprising five healthy, male, paid volunteers (ages 21 to 30), were studied for 11 days. Baseline data were collected for 3 days, during which subjects adhered to a day/night routine, i.e., sleeping from 2230 to 0600. On the fourth day each group took a "flight" in the altitude chamber. Following the flight day, subjects in the first group (Group I) slept from only 0230 to 0600 and then returned to the baseline routine; subjects in the next group (Group II) had their day extended by 6 hours and began a new routine of sleeping from 0430 to 1200 for the remainder of the study; subjects in the third group (Group III) had their day compressed by 6 hours and slept from 2030 to 2400 only that fourth night and then began a new routine of sleeping from 1630 to 2400 for the final 7 days of the study. According to the physiological and biochemical measurements, there was little difference between the two 6-hour-change groups (Groups II and III), both of which required longer rephasal times than did the group that experienced sleep loss but no time change (Group I). The psychomotor performance test indicated the greatest change in the group whose day was shortened by 6 hours (Group III). The Multiple Task Performance Battery (MTPB) indicated the greatest deficit in performance for Group III and the best postshift performance for Group II. Therefore, if performance of the type represented by the MTPB is the most important consideration, then travel from west to east (or "quick turn-arounds" for

shift workers) appears to be more deleterious than changes in the opposite direction. However, this effect cannot be predicted on the basis of the physiological and biochemical determinations made in this study.

110. Higgins, E. A., Chiles, W. D., McKenzie, J. M., Iampietro, P. F., Winget, C. M., Funkhouser, G. E., Burr, M. J., Vaughan, J. A., and Jennings, A. E. 1975. *The effects of a 12-hour shift in the wake-sleep cycle on physiological and biochemical responses and on multiple task performance.* Oklahoma City, Oklahoma: Civil Aeromedical Institute, Federal Aviation Administration. FAA-AM-75-10, October 1975.

Fifteen male paid volunteers (ages 20 to 28) were studied in three groups of five each. The first 4 days of the experiment they slept nights (2230 to 0600) and worked days. On the fifth night, they slept only 3 hours (2100 to 2400) before starting a 10-day period in which the sleep survey, the total quantity and quality of sleep did not change significantly when the cycle was altered. According to the subjective fatigue index, the total fatigue for the awake periods was not significantly changed; however, the times within days for greatest fatigue were altered and 9 days were required for a complete reversal of the daily pattern. Of the physiological parameters measured, those making the most rapid response to stress rephased in the shortest period of time after the shift. From shortest to longest mean rephasal times, these were: heart rate, norepinephrine, epinephrine, potassium, sodium, internal body temperature, and 17-ketogenic steroids.

Performance data based on the Civil Aeromedical Institute Multiple Task Performance Battery suggest the following: (1) There was evidence of diurnal variation during the preshift period. (2) There were decrements on the day of the shift following the short sleep period. (3) Performance during the first 3 days following the shift was relatively high for most of the day but was relatively poor in the final session of the day. (4) Performance on the fourth through sixth postshift days was average or above average for the experiment with relatively small variations among the five test sessions per day. (5) Performance on the seventh through ninth postshift days was below average for the experiment and showed some evidence of a return to a diurnal cycling pattern with a new peak period of performance that reflected the 12-hour shift in the wake-sleep schedule.

111. Hill, A. B., and Williams, G. O. 1979. An investigation of landing accidents in relation to fatigue. In: Dearnaley, E. J., and Warr, P. B., eds., *Aircrew stress in wartime operations.* London: Academic Press. 89-108.

In this 1943 work, landing accident rates after sorties of different durations, from roughly 1 hour to 10 hours, were calculated

for aircraft of Bomber Command returning from operational sorties during two years April 1940 to March 1942 (excluding accidents due to forced landings or attributed to the results of enemy action).

A detailed analysis of the data by duration of sortie indicated a rather high accident rate for very short sorties of under 2 hours and for very long sorties of 10 hours or more. The former is held to be due, at least in part, to the fact that such short sorties include a number in which the aircraft returned or was recalled owing to the development of some special difficulties (bad weather, technical failures, etc.), which would naturally add to the risks of landing. In the latter, fatigue of the pilot may have been a contributory factor. On the other hand over the relatively long period of time 2 to 10 hours, which includes the vast majority of sorties made, there is no evidence of increasing fatigue in the pilot having led to any increase in the landing accident rate. Within the range of sorties usually flown at this period, it seems that pilots have been able to overcome the fatigue consequent upon long sorties sufficiently, at least, to avert its effects as measured by reportable accidents on landing.

112. Howitt, J. S., Hay, A. E., Shergold, G. R., and Ferrer, H. M. 1978. Workload and fatigue--in-flight EEG changes. *Aviation, Space, and Environmental Medicine*. 49:1197-1202.

Continuous recordings were made of the EEG and ECG of one pilot during a series of instrument flights in a feeder-type transport aircraft. The flights were arranged to contain epochs of distinctly differing levels of workload. In addition, some flights were made after a night of sleep deprivation and others were made as the second and third flights of the day. Subjectively, there appeared to be marked differences in performance between the two types of tired flight. The EEG analyses showed changes that correlated well with differences in workload. In the highest workload areas during fresh flights, EEG activity increased by approximately a factor of 4 over that of the pre-flight resting values. This large increase did not occur in the tired flights. Further experiments are planned using flights in aircraft and in simulators using several subjects.

113. Huether, R. A. 1977. Fatigue--A consideration in mission planning. *US Army Aviation Digest*. 23:40-43.

This article deals with pilot-fatigue, words which are often used as catch-all terms. Fatigue must be recognized as the involvement of a group of quite distinguishable elements of the total situation. The elements are distractions, disorganization, discomfort, work decrement and those situational factors which cause fatigue itself. Some of the ways to prevent, or at least minimize, pilot fatigue are to: (1) adhere to established limitations on day flying and working

hours; (2) avoid scheduling the same pilots to all stressful missions; (3) avoid assigning stressful missions to a pilot who may be showing signs of fatigue; and, (4) give all pilots the opportunity for adequate rest and natural sleep.

114. Innes, L. G. 1968. *Aspects of fatigue in aviation*. Toronto, Ontario: Canadian Forces Institute of Aviation Medicine. TR No. 68-RD-6, September 1968. AD 844-132.

There are three main areas of research into fatigue effects in aviation. The first, and most widely studied, is the physiological and biochemical concomitants of fatigue, but this is not covered in this paper. The study of experiential fatigue by subjective reports, and of the relation of this subjective fatigue to behavioral measures of performance are reviewed. The use of several objective tests of fatigue is reviewed and some questionnaire evaluations are considered. Poor human engineering practices which contribute to in-flight fatigue are briefly discussed.

115. Innes, L. G. 1970. A subjective assessment of fatigue in transport aircrew. In: Benson, A. J., ed., *Rest and activity cycles for the maintenance of efficiency of personnel concerned with military flight operations*: Aerospace Medical Panel Specialists' Meeting, 1970 May; Oslo, Norway. London: Technical Editing and Reproduction Ltd. NATO/AGARD CP-74-70.

Two questionnaire studies were carried out on fatigue reactions of transport aircrew on transatlantic flights of approximately 12 hours duration. The first questionnaire assessed exhaustion fatigue due to the flight for all crew positions, and identified crewmembers having unusually high ratings. The second questionnaire study assessed nervous fatigue in the same type of operation, and again two crew positions only were identified as being of concern. There was no relationship between fatigue ratings and sleep patterns, nor with easterly or westerly direction of flight. Analysis of the use of questionnaire items showed that frequency of check marks against "fatigue" statements did not correspond well with fatigue rating.

116. Innes, L. G. 1970. *Exhaustion fatigue in long range aircraft crews*. Toronto, Ontario: Canadian Forces Institute of Environmental Medicine. TR No. 70-RD-1, January 1970.

A questionnaire study of fatigue reactions was carried out on transport aircrew on transatlantic flights in both the Yukon and Hercules aircraft. Questionnaire items were designed to assess physical tiredness aspects of subjective fatigue, and assessments were made before every flight, halfway through the flight and after landing. The average ratings for the crews showed an increase in fatigue feelings consistently through the flight, but the positions showing the strongest reaction were the Hercules Navigator and Flight Engineers. Loadmasters on both aircraft showed quite a high degree of subjective exhaustion fatigue. No relationship could be shown between self-rating on the questionnaire and sleep patterns, nor was there a relationship between unusually high or low ratings and eastbound or westbound flights.

## J

117. Jackson, K. F. 1956. *Aircrew fatigue in long-range maritime reconnaissance-pilot performance*. Farnborough, England: Institute of Aviation Medicine, Royal Air Force. TR No. FPRC 907-2, August 1956.

The performance of ten pilots was investigated by making continuous records of the altitude and heading of their aircraft at chosen times during a series in which each pilot undertook four 15-hour flights. The records, which concerned straight and level flying only, were examined--a 10-minute section at a time--for both extent and variability of error, thus providing four measures for each 10-minute record. Turbulence was recorded in terms of vertical accelerations, and certain personal factors were also observed. When the records were grouped in various ways and the average values of the measures were compared along the groups, the following information was obtained.

Performance in maintaining a constant heading deteriorated during 40 minutes of continuous work. Performance in both heading and altitude deteriorated during the first three of pilots' watches and partially recovered in the fourth.

In their first two watches, pilots tended to fly more accurately and consistently in rough air than in calm air, but in the last two watches they were adversely affected by turbulent conditions. Performance did not change appreciably from flight to flight during a week in which four 15-hour flights were made on alternate nights. The deteriorations which were observed could not be accounted for by increased turbulence.

118. Johnson, L. C. 1974. *Sleep loss and sleep deprivation as an operational problem*. San Diego, California: Naval Health Research Center. TR No. 74-45. AD A015-640.

Effects of total sleep loss, partial sleep loss, and sleep stage deprivation are reviewed with particular attention to performance decrement and operational consequences. Within the 36-48 hour range of total sleep loss most likely to be experienced by aircrew personnel, no consistent or uniform performance decrement has been found

in operational studies even though laboratory studies have found decrement on certain types of tasks, but marked increase in fatigue is a common problem. Sleep loss, both total and partial, tends to potentiate the circadian influence on performance and interact with other stressors to enhance the stress-induced physiological responses. Deprivation of sleep stage REM or sleep stage 4 produces no behavioral changes of operational consequence.

119. Johnson, L. C., and Naitoh, P. 1974. *The operational consequences of sleep deprivation and sleep deficit*. London: Technical Editing and Reproduction Ltd. NATO/AGARDograph No. 193.

Effects of total sleep loss, partial sleep loss, and sleep stage deprivation are reviewed with particular attention to performance decrement and operational consequences. Within the 36-48 hour range of total sleep loss most likely to be experienced by aircrew personnel, no consistent or uniform performance decrement has been found in operational studies even though laboratory studies have found decrement on certain types of tasks. Of major importance are the type of task, the setting in which the task is to be performed, and the individual. Physiological changes are minimal during moderate sleep loss, but mood changes are clearly noticeable. The most likely sleep problems for aircrew members are those associated with disruption of sleep-wakefulness cycles and partial sleep loss. Consistent performance decrement is difficult to find, but marked increase in fatigue is a common problem. Sleep loss, both total and partial, tends to potentiate the circadian influence on performance and interact with other stressors to enhance the stress-induced physiological responses. Deprivation of sleep stage REM or sleep stage 4 produces no behavioral changes supportive of earlier beliefs that these two stages, especially stage REM, were necessary for effective waking behavior.

120. Johnson, L. F., Jr. 1967. Sleep requirements during manned space flight. In: *Behavioral problems in aerospace medicine: Aerospace Medical Panel Specialists' Meeting, 1967 October; Rhode-Saint-Genèse, Belgium*. London: Technical Editing and Reproduction Ltd. NATO/AGARD CP No. 25.

In planning bioastronautics support for manned space flight, thought must be given to the human needs of the astronauts in order to keep them in good physical and mental condition. One question of great importance is what are sleep requirements of astronauts in outer space. A survey of research literature on this subject indicates that consideration must be given to the quality as well as the quantity of sleep. The conclusion of this survey indicates that: (1) If possible, astronauts on prolonged space flights should have 8 hours of continuous sleep, at the normal depth of sleep, out of each 24 hours. (2)

If conclusion 1 is not operationally practicable, a different wakefulness/rest ratio must be used, for example, 12 hours work/6 hours rest plus another 2 hours rest period in each 24 hour period. (3) Further experimental work is necessary to study the quality or depth of sleep as affected by differential cycling of the 24 hour time period.

121. Johnson, P. C., Carpentier, W. R., Driscoll, T. B., La Pinta, C. K., Rummel, J. A., and Sawin, C. F. 1972. Passenger fluid volumes measured before and after a prolonged commercial jet flight. *Aerospace Medicine*. 43:6-7.

Interstitial and intracellular fluid volumes were calculated from measured plasma volume, extracellular volume and total body water of six subjects before and after a 24-hour commercial overseas flight. No change occurred in these spaces or in peripheral hematocrit or total serum protein concentration. The subjective feeling of dehydration and the actual swelling of the lower extremities characteristically found among passengers at the end of a long trip of this type seems to represent a shift in body fluids to the dependent portions of the body rather than water retention or a decrease in the intravascular water volume.

122. Jones, G. M. (Department of Physiology, McGill University, Montreal, Canada). 1971. *Some aviation medical aspects of flight crew fatigue*. (Vol. I, 1964-1968). Ottawa, Canada: Department of National Defence, Defence Research Board. TR No. DR-208, May 1971.

This review article attempts to outline some of the negative effects of fatigue in flight crew personnel for researchers, aircraft designers, and legislators. Stressors associated with instrument flight and their effect on the pilot's vestibular system are examined in depth. Fatigue is also defined and the need for objective, as opposed to subjective, measurement of its effects on performance are discussed. A description of the "Cambridge Cockpit Experiments," conducted by D. R. Davis during World War II, and a summary of the conclusions based on those experiments, are presented. The author discusses the need for new legislation, based on scientific study, to help control flight crew fatigue problems.

123. Juin, G., and Pineau, P. 1962. Basis, protocol, and results of a medical inquiry on the fatigue of flying crews on Boeing 707 commercial planes (Bases, protocole et résultats d'une enquête médicale sur la fatigue des équipages volant a bord des Boeing 707 commerciaux). *Revue de Médecine Aéronautique*. 2:7-10. (In French.)

Because of the noticeable increase in fatigue seen and described among commercial aviation crewmembers since the start of

intercontinental, four-engine jet service, the authors, together with a team of specialists from the hospitals in Paris, undertook a medical inquiry for the purpose of rendering this abnormal fatigue, in personnel aboard these four-engine jet planes, more objective, more quantitative, and more precise. The authors describe this investigation which delves into the clinical, biological, physiological, and ophthalmological areas. The authors report on the general results of investigations made on blood pressure. They show the variations in blood pressure recorded on 11 crews of jet aircraft and on 2 crews of conventional aircraft, or a total of 136 subjects. Three hundred and sixteen pressure measurements have been taken on jet-propelled planes, 42 on the conventional type. Although for the latter no significant variations are present, in jet planes there appears a decrease in maximum pressure and an increase in minimum pressure. This assumes particular importance when considered with the biological, bio-hormonal, and ophthalmological changes also recorded.

The authors also report the results of the ophthalmological studies bearing on the variations in heterophorias during jet flights and comparing them with changes brought about in conventional planes. They point out the condition and variations in strength of convergence and divergence in crewmen of the same aircraft. In addition, they report the results obtained during the same study which deal with the endocrine and metabolic conditions, carried out in jet aircraft as well as in the conventional type.

In conclusion, during these concise analyses, the authors try to formulate a policy as to the supervision of crew personnel and to locate sources of difficulty in commercial jet aircraft. This medical investigation seems to be the only one of its type up until 1962 in commercial aviation.

# K

124. Karney, D. H. 1976. Flight limits and crew rest. *US Army Aviation Digest*. 22:38-39.

The United States Army Agency for Aviation Safety has recommended that Army Regulation 95-1 (Army Aviation: General Provisions and Flight Regulations), Section II, Flight Limits and Crew Rest, be changed. This article contains some suggested revisions of Army Regulation 95-1 and attempts to assist units in developing standard operating procedures concerning flight limits and crew rest. The individual crewmember's responsibility for properly utilizing off-duty hours is also discussed.

125. Karney, D. H., and Thompson, P. 1976. Fatigue. *US Army Aviation Digest*. 22:28-34.

Fatigue is a significant hazard in Army aviation. It reduces crewmember efficiency and contributes to reduced performance, poor coordination, faulty memory, slower reaction time and a decline in perceptual abilities. Few people actually appreciate the full extent and consequences of the effects of fatigue on aircrew performance. Also, many units fail to establish maximum flight time and crew rest limitations in accordance with Army Regulation 95-1. Crewmembers have to cope with numerous fatigue-producing stresses, such as those imposed by aircraft factors, flight operation factors, duration of work and rest in the duty day, scheduling of work and rest cycles, social, emotional and self-imposed factors and morale. To determine which factors in the aviation environment have the most bearing on fatigue, a survey of 500 experienced helicopter pilots was conducted by NATO/AGARD. Their ratings are listed in the article. Also included in the article is a Comparison of Actual Flying Hours/Rest Period Standards in Various Worldwide Military Aviation Agencies for Rotary Wing Aircraft.

126. Kendricks, E. J. 1951. Practical problems in aviation medicine. *Journal of the American Medical Association*. 147: 1024-1026.

This short paper points out that the problems of aviation medicine and of the flight surgeon enter into the fields of science and

engineering, particularly in connection with long-range bombardment aircraft. Aeromedical research problems associated with the development of new aircraft are described. Special attention is given to fatigue on long aerial missions. The author identifies four types of fatigue: (1) Physiological fatigue occurs as a result of anoxia, extremes of heat and cold, or motion sickness; (2) Psychological fatigue is often the result of poorly designed flight controls and instruments; it causes misinterpretations of flight instrument readings, landing and takeoff failures, etc.; (3) Physical fatigue is associated with poor health, lack of sleep, hunger and lack of comfort in the aircraft; and (4) Psychiatric fatigue results from a fear for one's survival while flying over snow, water, jungle, desert or enemy territory; from fear of the aircraft that all engineering factors are not completely resolved; from fear of night conditions or combat. Methods for reducing or preventing these four types of fatigue are discussed.

127. Kimball, K. A., and Anderson, D. B. 1975. Aviator performance: Biochemical, physiological, and psychological assessment of pilots during extended helicopter flight. In: Fuchs, H. S., Perdriel, G., and Gubernale, A., eds., *The role of the clinical laboratory in aerospace medicine: Aerospace Medical Panel Specialists' Meeting, 1975 October*; Ankara, Turkey. London: Technical Editing and Reproduction Ltd. NATO/AGARD CP-180.

This investigation was conducted to provide information on the physiological, psychological and performance effects of extended helicopter flight. Measurements of biochemical, physiological and psychological parameters were obtained and compared with inflight performance measures obtained by the US Army Aeromedical Research Laboratory Helicopter Inflight Monitoring System. Six rotary wing aviators performed extended daily flight missions for a period of five days. In addition, when not flying, various psychological tests were administered. Physiological and biochemical monitoring were conducted throughout the five day period. Subjects were on a controlled diet and slept approximately three hours each night. This paper presents preliminary findings with regard to performance, biochemical, physiological and psychological parameters.

128. Kirschner, L. J. 1976. *Fatigue and the flier: Case history of an aircraft disaster*. Paper presented at the 7th Annual Scientific Meeting, Aerospace Medical Association, May 10-13, 1976, Bal Harbour, Florida.

A United States Air Force transport aircraft attempting to make a 61 hour round robin trip from its home base to an overseas

location ended in the death of 24 of the 25 persons onboard. The crash occurred on the return leg when the aircrew was attempting to refuel 50 hours and 30 minutes into the mission. The primary cause of the accident was pilot error allowing the aircraft to descend below the proper altitude which would have insured proper terrain clearance. The major contributing factor was the aircrew's failure to obtain adequate rest during their 23 hours of ground time, thus inducing crew fatigue.

129. Klein, K. E., Bruner, H., Holtmann, H., Rehme, H., Stolze, J., Steinhoff, W. D., and Wegmann, H. M. 1970. Circadian rhythm of pilots' efficiency and effects of multiple time zone travel. *Aerospace Medicine*. 41:125-132.

When a standard instrument flight in a supersonic simulator was repeated in intervals of 2 hours the average performance of 12 pilots revealed a sinusoid circadian rhythm curve with the temporal position of peak and trough between 2-3 p.m. and 4-5 a.m., respectively. The amplitude of the diurnal oscillation came to an average of  $\pm 25$  (12-49) % of the 24-hours total average as against  $\pm 12\%$  found on average in the same subjects for the simple reaction time. After rapid transportation from Europe to the United States and back with a sojourn of 17 days (time shift: 8 hours), the duration of resynchronization was about 5 days on average for both directions with a rate of phase adjustment of approximately 1.5 (1-2) hours/day. The change in the performance level following transit, in dependence of the coincidence of old and new clock time, was unequal during the course of the day, but in general the level was significantly decreased (up to 40%) at daytime and increased during the late night hours. A performance decrement seen for the 24-hours total average, in comparison to the pre-flight control, was significant only after the eastward (-8.5%) but not after the westward (-3.3%) flight. The reason for this difference is mainly seen in a greater fatigue due to an unfavourable flight schedule and the more severe sleep loss connected with eastward travelling.

130. Klein, K. E., Wegmann, H. M., and Bruner, H. 1968. Circadian rhythm in indices of human performance, physical fitness and stress resistance. *Aerospace Medicine*. 39:512-518. AD 692-748.

In order to estimate the existence and magnitude of rhythmic day-night variations in human performance, physical fitness and stress resistance, the following variables were measured every three hours over a full day-night cycle: The reaction time and its individual constancy, the maximal psychomotor coordination ability, the Schneider index, the predicted  $\dot{V}O_2$  max, the cardiovascular responses to tilting, and the "time of useful consciousness" at simulated altitude. The twenty-four hours were divided into two experimental sessions so that limited sedentary activity could be maintained between

the tests. All parameters (including body temperature, blood eosinophils, plasma-protein, aldolase and 17-OHCS) revealed relative rhythmic oscillations of the circadian type, the ranges of which varied for the group average between 1.4 percent (temperature) and 68 percent (17-OHCS) from the total twenty-four hour average. Negative extreme values were shown during the night hours for all cardiovascular parameters; consequently, the Schneider index and the  $\text{VO}_2$  max predicted from the heart rate level during submaximal exercise had their positive peaks or best values at this time of the day. This phenomenon seems to be an "artificial" effect of the method determining physical fitness and probably is not identical with the course of "fitness" itself. However, "true" positive night peaks were found for the altitude tolerance. The significance of the results for the applicability of functional tests and human efficiency during stress is discussed.

131. Klein, K. E., Wegmann, H. M., and Hunt, B. I. 1972. Desynchronization of body temperature and performance circadian rhythms as a result of outgoing and homegoing transmeridian flights. *Aerospace Medicine*. 43:119-132.

Rectal temperature and performance were studied and urine samples taken in a group of eight United States residents before and after flights between the U. S. A. and Germany. Measurements were performed nine times per day "round the clock" at three-hour intervals on three days before the outgoing flight and on days 1, 3, 5, 8 and 13 following the flights in each direction; temperature measurement and urine collections were also made on the postflight days 2, 4, and 6. The difference in local time was in hours; the duration of stay in Germany was 18 days. Using the multiple regression technique, mode and duration of resynchronization were evaluated for phase, amplitude and 24-hour mean. After fitting a quadratic equation to the derived set of phase angles it was found that it took 14-15 days following the eastbound and 11-12 days after the westbound flight for the phase of the temperature rhythm to readjust completely. For the more complex (psychomotor) performance task the corresponding figures were 12 and 10 days; for the simple ones, including visual reaction time, they were nine and six days, respectively. Minor depressions of the 24-hour mean on the first day after travel--for temperature about  $0.1^\circ\text{C}$ , for performance between 2.1-3.2% (eastbound) and 1.1-2.4% (westbound)--were not statistically significant. Phase shift, amplitude reduction and decrease of the 24-hour mean together resulted in a depression of temperature significant on both first postflight days. This depression occurred mainly at 1200 and 1500 hours after eastbound travel and at 2100 and 2400 hours after westbound travel. At the same time postflight temperature was significantly elevated for five days between 2400 and 0600 hours after eastbound travel and for three days between 0600 and 0900 hours after westbound travel. Performance revealed depressions and elevations of 6-10%

at similar clock hours of the day; these were significant in some instances. The more pronounced and longer lasting effect of eastbound travel is in concordance with the earlier results obtained from studies done with German residents. It is concluded that the relative flight direction, i.e., in relation to the traveller's permanent home, is no major factor affecting de- and resynchronization of human circadian rhythm.

132. Klein, K. E., Wegmann, H. M., Anthanassenas, G., Hohlweck, H., and Kuklinski, P. 1976. Air operations and circadian performance rhythms. *Aviation, Space, and Environmental Medicine*. 47:221-230.

This paper reviews experimental results and pertinent data from the literature on circadian behavioral rhythms and their modifications through various factors. It relates them to the operation of aircrews "round the clock" and on transmeridian routes and discusses some possibilities of an appropriate scheduling.

133. Knapp, S. C. 1970. Asleep at the controls. *US Army Aviation Digest*. 16:18-19.

The author recounts an incident in which a student pilot fell asleep at the controls after having taken an off-the-shelf "cold remedy." The dangers of "cold tablets," particularly drowsiness attributable to antihistamines, and other non-prescription medications in the flying environment are discussed.

134. Knapp, S. C. 1970. *Problems of adaptation to long range large scale aerial troop deployments*. Fort Rucker, Alabama: US Army Aeromedical Research Laboratory. USAARL Rep. No. 71-10, September 1970.

This paper discusses the demonstrated stresses and adaptation problems during large scale, long range, rapid reaction time, aerial troop deployments. NATO Exercise, REFORGER I, January 1969, and other large scale aerial troop deployments are discussed.

Long range aerial troop transport and deployment is a technological achievement of the 1960's that influenced and shaped international political thinking and military strategy. "Super transport aircraft," capable of around-the-world troop lifts, became a reality in the military inventory. Careful consideration must be given to the aircrews that operate these aircraft. It is necessary to carefully assess the position, role, and regard for the individual soldier, the "passenger," whom all of this aviation technology and engineering supports.

Historically, soldiers have proven to be flexible, well-motivated, and capable of great personal and group ingenuity and adaptation in the face of stress. These factors create fighting forces that are able to go almost anywhere, at any time, by any means, and remain efficient and effective.

Certain human factors and parameters of personal adjustment and adaptation, however, are relatively fixed or slow. Among them are requirements for sleep, food, fluids, exercise, warmth, shelter, sensory stimulation, recreation, periods of quiet, and physical and psychological support. Man has proven biological or circadian rhythms that are essentially unalterable over prolonged periods of stress, let alone abrupt exposure. Man does not immediately adapt to sudden environmental changes, i.e., sea level to mountainous, arctic to equatorial, tropical to arid, or pastoral to aquatic.

Man's response to these changes or deprivations, until he accommodates, covers a wide physiologic and psychological spectrum. The individual's response from obscure biochemical alterations to physical and mental degradation are understood to some extent. A good many are predictable and quantifiable. All have the same titratable and point-reduced effectiveness and efficiency.

The individual soldier recognizes these changes as undefinable fatigue, malaise, and loss of physical and mental ability and endurance. The troop commander finds decisions difficult, comprehension elusive, and his troops less than anticipated as a fighting force. The medical officer is met with a plethora of minor physical injuries, somatic complaints, specific subjective symptoms, and objective findings, to which the etiologies remain all too obscure--unless there is an understanding of the stresses to which the patient has been subjected.

There is, however, a paucity of medical concern, knowledge, forethought, and industry in meeting and bridging the interface between advancing engineering technology and our most valuable commodity--the man, specifically our soldiers. With this insight, the observations and recommendations generated by this unusual study and presented in this paper can serve to sharpen appreciation for some of the less known problems of adaptation and acclimatization in aerospace medicine.

135. Koch, C., and Monesi, F. 1978. Evaluation of aircrew fatigue during operational helicopter flight mission. In: Knapp, S. C., ed., *Operational helicopter aviation medicine: Aerospace Medical Panel Specialists' Meeting*, 1978 May 1-5; Fort Rucker, Alabama. London: Technical Editing and Reproduction Ltd. NATO/AGARD CP No. 255.

Monitoring of physiological parameters is meant to be of value for the assessment of workload in laboratory and also field studies. In-flight recordings of ECG, breathing rate and amplitude, EMG, EEG, EOG and Gz were transmitted telemetrically from the helicopter crew station to the ground receiving station.

The investigators were provided with some objective data on the increase in biological cost for an Agusta/Bell 204 helicopter pilot trying to maintain a given level of performance. In fact, the same task was performed by the pilot in two successive phases of an operational flight mission, the latter being more demanding. However, it still remains that the attempt to assess aircrew's acute fatigue calls first for the solution of the methodological problem of the identification of parameters proving to be best adapted to encompass the biological impairment and weariness sometimes associated with flight profiles.

136. Kramer, E. F., Hale, H. B., and Williams, E. W. 1966. Physiological effects of an 18-hour flight in F-4C aircraft. *Aerospace Medicine*. 37:1095-1098.

Physiological assessment was performed by means of post-flight urinalysis for 8 pilots who flew F-4C aircraft for 18 hours. Flight effects were neither numerous nor of large magnitude, nor were the pilots unduly fatigued. The flight-induced, physiological changes included: (1) increased 17-hydroxycorticosteroid excretion, which implies adrenocortical stimulation, and (2) decreased excretion of uric acid, potassium, and urine, which suggests metabolic depression.

137. Kratochvil, C. H. 1967. Circadian rhythms and military man. In: *Behavioural problems in aerospace medicine: Aerospace Medical Panel Specialists' Meeting*, 1967 October 25-27; Rhode-Saint-Genèse, Belgium. London: Technical Editing and Reproduction Ltd. NATO/AGARD CP No. 25. AD 669-417.

This study reviews the effect of rapid east or westbound movement, such as via supersonic aircraft, and the resulting circadian rhythm shift, on performance and reaches the following conclusions:

(1) Supersonic or even subsonic transport of large numbers of troops will magnify the problems of adjusting to new time zones.

(2) It is predicted that this will be a factor of major operational importance.

(3) Central to this problem is the issue of altering basic metabolic patterns to provide adequate REM sleep and slow sleep in the correct phase.

(4) Present drug therapy is inadequate and possibly harmful.

(5) The only present solution is to pre-position manpower or pre-adapt them at their home station.

(6) More investigations specifically directed to the alternative of these rhythms are needed.

138. Krueger, G. P., and Jones, Y. F. 1978. *U.S. Army aviation fatigue-related accidents, 1971-1977*. Fort Rucker, Alabama: US Army Aeromedical Research Laboratory. USAARL Rep. No. 79-1, October 1978.

An accident data survey was made to determine how frequently aviator crew fatigue may have contributed to US Army aviation accidents from 1971 to 1977. All accident reports in the US Army Agency for Aviation Safety (USAAVS) data base were reviewed. Aviator fatigue was deemed to be a contributing factor in 42 rotary wing accidents which resulted in a total of 51 fatalities and 63 personnel injuries. Fatigue contributed to 10 fixed wing accidents, resulting in 3 fatalities and 5 injuries. This paper categorizes these fatigue-related accidents by aircraft and mission type and by time of day and day of week of the accident. It also tabulates pilot activities prior to the accidents which promote the likelihood of pilot fatigue contributions. The personnel and equipment costs of these accidents to the Army are estimated, and the relative importance of such accidents to the total US Army aviation accident picture is assessed.

139. Krueger, G. P., Armstrong, R. N., and Cisco, R. R. 1980. Aviator performance in week-long extended flight operations in a helicopter simulator. In: Auffret, R., ed., *Session A: Aircrew safety and survivability conference proceedings: Aerospace Medical Panel Specialists' Meeting*, 1980 May; Bodo, Norway. London: Technical Editing and Reproduction Ltd. NATO/AGARD CP-286, May 1980.

In the second experiment in a series of studies on near continuous operations, psychological, physiological and biochemical correlates of aviator crew performance, stress and fatigue were measured in a week-long flight schedule in a helicopter simulator. Three 2-man crews of rotary wing aviators performed 14 hours of precision instrument flight in a simulator on each of five successive work days. Missions included repetitions of routine 2-hour standardized day and night instrument flight profiles which were occasionally interrupted by simulated flight emergency situations. Aviator flight performance was measured. Parameters assessed included: meeting airspeed, altitude, headings, turn rates, navigation ability, etc. In addition, measures of fatigue, stress and bodily state were collected throughout the study. These latter measures included physiological (cardiovascular monitoring and body temperature), psychological (behavioral, short term memory, oculomotor performance and subjective ratings), and biochemical (urine and isoprene) parameters. When not flying, pilots participated in laboratory tests of pursuit rotary tracking skill and visual search strategies. They were also examined by flight surgeons daily. The pilots ate three regularly scheduled meals and slept approximately four hours each night. Baseline data were collected prior to, and recovery data after the extended flight schedule.

This paper presents a description of the study and summarizes preliminary findings of portions of the data. The findings of this research should be useful to operational flight surgeons, aviation safety officers and unit personnel strength planners.

# L

140. Lafontaine, E., Lavernhe, J., Courillon, J., Medvedeff, M., and Ghata, J. 1967. Influence of air travel east-west and vice versa on circadian rhythms of urinary elimination of potassium and 17-hydroxycorticosteroids. *Aerospace Medicine*. 38:944-947; NATO/AGARD CP-74-70.

The influence of air travel east-west and vice versa on circadian rhythms of urinary potassium and 17-hydroxycorticosteroids was measured on flights between Paris to Anchorage and Anchorage to Paris. The urinary potassium and 17-hydroxycorticosteroids which, taking the average of the subjects involved, show the lowest standard deviation and the clearest circadian variation, seem particularly interesting for studying the biological effects of time-zone changes. After a quick round-trip with a 20-hour exposure to a negative time-zone change of 11 hours, the circadian eliminatory rhythm of potassium and 17-hydroxycorticosteroids immediately becomes concordant with the pre-existing reference rhythm again. During a journey with a 5-day exposure to a negative time-zone change of 11 hours, the circadian eliminatory rhythm of these same elements begins to adapt itself to local time on the third day; this adaptation is complete on the fifth day, the excretive rhythms then being in opposition to the pre-established reference rhythms.

141. Lees, M. A., Kimball, K. A., and Stone, L. W. 1977. The assessment of rotary wing aviator precision performance during extended helicopter flights. In: Auffret, R., ed., *Studies on pilot workload: Aerospace Medical Panel Specialists' Meeting, 1977 April 18-22; Koln, Germany*. London: Technical Editing and Reproduction Ltd. NATO/AGARD CP-217.

To insure the most effective utilization of his aviation resources, the rotary wing flight commander requires information which describes how extended flight time affects the operational capability of his flight crews. In response to this requirement, the US Army Aeromedical Research Laboratory has conducted an investigation of the man-helicopter system performance during five days of extended flight. This report describes the changes in pilot performance and aircraft

stability on one of the maneuvers performed during the large scale fatigue investigation: the stabilized three-foot precision hover. In addition, this report describes changes in subjective ratings of fatigue and flight performance, and changes in the measurement of auditory reaction time.

The results obtained during this examination strongly suggest the occurrence of a learning effect across the first day of extended flight. The most stable hover performance was observed during the second flight day. By the third flight day, pilots attempted to maintain high quality precision hovers through an increase in the number of control inputs. Results obtained on the fourth day of flight suggest that the pilots have shifted their control technique from active control of the helicopter to a more passive strategy of responding to observed error.

Results from the subjective rating scales clearly demonstrate a progressive increase in the rated levels of fatigue between and within flight days. This increase in the level of fatigue corresponds to a general decrease in the ratings of flight performance.

142. Lees, M. A., Simmons, R. R., Stone, L. W., and Kimball, K. A. 1978. Changes in the rotary wing aviator's ability to perform an uncommon low altitude rearward hover maneuver as a function of extended flight requirements and aviator fatigue. In: Knapp, S. C., ed., *Operational helicopter aviation medicine: Aerospace Medical Panel Specialists' Meeting, 1978 May 1-5; Fort Rucker, Alabama*. London: Technical Editing and Reproduction Ltd. NATO/AGARD CP-255.

Changes in man-helicopter system performance for a variety of flight maneuvers were examined. The system performance changes in the rearward hover maneuver across five days of an extended flight schedule are described. System performance is categorized into measures of the pilot's control performance, measures of the aircraft's stability, and combined measures of total system performance for each primary aircraft control channel. System performance changes across the five flight days and within the flight days were examined using multivariate analysis. Significant changes in each aircraft control channel are presented and the overall changes in system performance are discussed.

143. Lees, M. A., Stone, L. W., Jones, H. D., Kimball, K. A., and Anderson, D. B. 1979. *The measurement of man-helicopter performance as a function of extended flight requirements and aviator fatigue*. Fort Rucker, Alabama: US Army Aeromedical Research Laboratory. USAARL Rep. No. 79-12, July 1979.

Field commanders have long been concerned about the impact of fatigue on aviator effectiveness, especially where aviators are called upon to fly numerous successive stress-related missions, e.g., combat and/or rescue work. At present there is little specific information upon which the commander can base his crew rest decisions. The US Army Aeromedical Research Laboratory sought to answer this need by observing pilots in an actual flight situation. In this study six pilots flew a helicopter for 11 1/2 hours per day for 5 days with 3.5 hours of sleep per night. Data collection included biochemical, visual, psychological and in-flight measurements. This report includes a critical literature review and describes the methodology of the study. It is intended to serve as a detailed background for the analyses to follow.

144. Lindbergh, C. A. 1953. *Spirit of St. Louis*. New York: Charles Scribner's Sons.

This book contains a detailed account of Lindbergh's flight from New York to Paris in 1927. It contains Lindbergh's own graphic description of an aviator's attempt to fight off the onset of fatigue in a lengthy transatlantic flight. The book also contains the story of his boyhood and youth and his experiences as a pilot of mail planes.

145. Littell, D. E., and Joy, R. J. T. 1969. Energy cost of piloting fixed- and rotary-wing aircraft. *Journal of Applied Physiology*. 26:282-283.

The energy cost of piloting three US Army helicopters (light, utility, and medium) and one utility fixed wing aircraft was investigated. Energy expenditure was calculated from expired minute volume and expired air oxygen content measured during the basal state and in normal flight conditions. Data were collected on a total of 16 pilots, 5 of whom flew all three helicopters. All of the helicopter pilots were experienced test pilots. The data indicate that, for these pilots, and flying conditions studied (level flight in good weather) and aircraft, the energy cost must be classed as very light work, averaging 1.79 kcal/min. The energy cost of flying the fixed wing aircraft by less experienced pilots was similar to previously reported energy expenditures for such aircraft. The data were segregated to separate measurements made at altitude from those made during flight in close proximity to the ground (takeoff, hover, etc.). In three of the four

aircraft, the pilot's energy expenditure was greater when ground contact was possible.

146. Lodessen, M., and Crane, J. E. 1963. Tired jet pilots. *Flying*. 72:33 and 52.

This article discusses some of the fatigue problems brought about by the advent of commercial jet aviation. Chronic and acute fatigue are differentiated and symptoms of each are identified. Results of a questionnaire study by Dr. J. E. Crane are presented. Dr. Crane administered his questionnaire, designed to reveal nervous tension both directly (such as irritability and insomnia) and indirectly (such as weight loss or gain), to 100 wives of jet pilots and a control group of wives of piston-engine aircraft pilots. Only 16% of the respondents indicated there had been little or no change in their husbands since they began flying jets. Also included is Crane's "Minimum-Fatigue Check List" to tell pilots how to minimize fatigue in flight activities.

# M

147. Marchbanks, V. H. 1960. Flying stress and urinary 17-hydroxycorticosteroid levels during twenty-hour missions. *Aerospace Medicine*. 31:639-643.

Stress evaluations were conducted on fourteen B-52 crew members and the author. Three of the subjects were involved in an original study (1957) of a single 22.5-hour mission. The mean increase in urinary steroids for all personnel was 38 per cent during the first study and 48 per cent during the present study.

The time of the mission in relation to the normal rest period influenced the 17-OHCS output. The highest increase occurred during missions flown furthest from the normal sleep cycle.

The findings indicate that urinary excretion of 17-OHCS served as a favorable index for evaluation of stress in flying personnel.

The experimental results reported herein are in agreement with similar findings in studies on oarsmen before and immediately after performance.

148. Marchbanks, V. H., Jr., Hale, H. B., and Ellis, J. P., Jr. 1963. Stress responses of pilots flying 6-hour overwater missions in F-100 and F-104 aircraft. *Aerospace Medicine*. 34:15-18.

Postflight urine and blood samples for pilots flying 6-hour overwater missions in F-100 and F-104 aircraft were employed in an attempt to appraise flying stresses. Comparison was made with a third group of pilots on an off-duty day. Urinary determinations included epinephrine, norepinephrine, corticosteroids (17-OHCS), sodium, potassium, inorganic phosphate, urea, uric acid, and creatinine. Blood determinations included free and conjugated hydrocortisone and corticosterone-like fractions. Flying raised corticosteroid levels in plasma but not in urine. Levels for the F-100 group were higher than for the F-104. Urinary epinephrine and norepinephrine values for the fly-

ing groups were significantly above those for the control values for the F-104 exceeding those for the F-100 group. Differences in flying groups appear to relate to aircraft characteristics, weather conditions, and flying experience. Both flying groups showed high urinary excretion of urea and uric acid, but only in the F-104 group was sodium and potassium excretion elevated. Flying induced no variation in urinary phosphate. Singly and collectively, these determinations are basic to future studies on flight stress.

149. McFarland, R. A. 1974. Influence of changing time zones on air crews and passengers. *Aerospace Medicine*. 45:648-658.

The introduction of jet aircraft into general use has resulted in a technological revolution for both air crews and passengers. Although safe and comfortable, they have introduced a physiological stress for passengers flying east or west, known as the problem of "circadian rhythm," which is essentially induced by the rapid time changes over four or more time zones. Certain intrinsic physiological mechanisms, cyclic in nature, and regulated by stimuli from the day-night cycle of the environment, appear to be disturbed. In the first part of the paper a brief analysis is presented of the basic physiological rhythms of the body in both man and animals. The findings are then related to air crews and passengers. The specialized studies simulating air transport schedules are then discussed from the point of view of suggested solutions. An example is "Project Pegasus," a study of the effects of air travel across nine time zones. Emphasis is then placed on various factors which may influence or accentuate the effects of rapid flights across time zones. The application of in-flight studies is reviewed and recommendations are made for air crews and passengers.

150. McFarland, R. A. 1975. Air travel across time zones. *American Scientist*. 63:23-30.

This article discusses physiological problems that occur as a result of rapid travel, east or westbound, across time zones. The paper attempts to highlight some of the more than 200 recent studies that throw light on some of these problems. Desynchronization of circadian rhythms appears to be the cause of many of the physiological and psychological problems known as "fatigue." Other factors influencing these physiological and psychological functions, such as cabin pressure and humidity, are also discussed. Numerous experimental studies are cited and referenced in the text. Some practical suggestions are also given to the air traveler on ways to lessen the severity and readjustment time of circadian desynchronization.

151. McGrath, S. D., Wittkower, E. D., and Cleghorn, R. A. 1954. Some observations on aircrew fatigue in the RCAF-Tokyo Air-lift. *Aviation Medicine*. 25:23-37.

The men studied were members of a transport squadron which, at the time of the investigation, were engaged in the Tokyo air-lift. They flew approximately 100 hours per month. The natural history of the fatigue process forming a composite picture of an average trip is described in the paper. The factors which the men considered relevant to "transient fatigue" may be divided into three main groups: (A) Factors common to transport flying in general: (1) length of flight; (2) delayed flights and false starts; (3) details prior to take-off; (4) reliability of radio communication and navigational aids; (5) bad weather and anticipation of bad weather; (6) monotony and boredom on familiar routes; (7) the number of intermediate stops; (8) drinking the night before; (B) Factors relating specifically to the operating condition of the squadron: (1) problems particular to their aircraft (DC-6); (2) problems particular to this route: (a) conditions after the flight; (b) recreation at stop-over points; (c) irregular hours; and (C) Personal factors: (1) inexperience; (2) tension among the crew; (3) responsibility; (4) relationships to the higher authorities; (5) domestic worries; (6) personality.

152. McIntosh, B. E., Milton, J. L., and Cole, E. L. 1952. *Pilot performance during extended periods of instrument flight*. Wright-Patterson Air Force Base, Ohio: Wright Air Development Center. USAF TR 6725. RDO No. 694-34.

The purpose of this investigation was to collect exploratory data on pilot performance during extended instrument flights. Each of three pilots flew a C-47 aircraft for ten, fifteen and seventeen hours, respectively. Equipment installed in the aircraft permitted recording of (1) amount of time flight indicators were kept within tolerance limits, and (2) continuous variation of flight indicators and control positions. Pilots' introspections and observations by a safety pilot were also obtained after each flight. To supplement the above measures, addition, illusion, and reading comprehension tests were given before, during and after the ten hour flight, pilot reaction time to a signal light was taken during the fifteen hour flight and an alertness indicator was operated during the seventeen hour flight.

The time within tolerance results indicate that the pilots kept the flight indicators within the specified tolerance limits for both precision maneuvers and straight and level flight as well after ten, fifteen and seventeen hours of instrument flight as they did during the first hours of these flights. The results of the graphic records also gave indications that performance, as measured, was not a function of time, since no decrement appeared between the first and last portions

of the flight. The introspections of the pilots indicate that they became preoccupied with their physical discomfort but they believed they could cope with a critical situation had it appeared. The constant level of their performance indicates they were coping satisfactorily with the flight requirements.

153. McKenzie, R. E., and Elliott, L. L. 1965. Effects of secobarbital and d-amphetamine on performance during a simulated air mission. *Aerospace Medicine*. 36:774-779.

The operational deployment of high performance fighter aircraft on extended missions poses some significant problems related to the effects of drugs upon pilot proficiency. This study was designed to simulate a pre-mission crew-conditioning program and 12-hour flight. The research goal was to determine the performance effects of secobarbital taken the night before and of d-amphetamine taken during the mission.

The results of 48 subjects indicated that performance decrement, unpredictable by selected psychologic test scores and not related to gross physiologic measures, occurred as a residual effect of secobarbital using a Multidimensional Pursuit Test as the measure of proficiency. Individuals receiving a hypnotic dose (200 mg) of secobarbital at bedtime demonstrated a performance decrement 10 hours later at the start of their simulated "flight" and continued to demonstrate degraded performance at the completion of their mission 12 hours later. Those subjects who received 5 mg of d-amphetamine "in flight" showed the often-documented enhancement of performance, but those who received secobarbital at bedtime and d-amphetamine "in flight" showed an altered performance response curve in terms of increased latency and lower peak performance.

154. Melton, C. E., and Wicks, M. 1969. *Binocular fusion time in sleep-deprived subjects*. Oklahoma City, Oklahoma: Civil Aeromedical Institute, Federal Aviation Administration. TR No. AM-69-1, January 1969. AD 688-426.

The attainment of binocular single vision when the distance of gaze is changed is a component of total reaction time and may be critical in flight when the gaze is changed from the instrument panel to the outside or from the outside to the instrument panel. This report deals with the effect of fatigue induced by sleep deprivation on the binocular fusion reflex. Binocular fusion times were measured morning and evening in six subjects during 86 hours of sleep deprivation and in six control subjects. The binocular fusion reflex under the experimental conditions employed appeared to be resistant to fatigue incident to sleep deprivation.

155. Metersky, M. L. 1967. *A study of simulated ASW crew performance in relation to selected fatigue factors*. Warminster, Pennsylvania: Naval Air Development Center. TR No. NADC-SY-6709, December 1967.

Air crew fatigue experiments were performed in conjunction with the Royal Canadian Navy, Shearwater, Nova Scotia, and the Royal Canadian Air Force, Greenwood, Nova Scotia. The intent of the study was to determine the operational endurance of airborne Anti-Submarine Warfare (ASW) crews. In so doing, aircraft endurance could be matched to the fatigue limit of the aircrew. The data obtained indicated a correlation between crew performance and operational exposure, but was not statistically uniform or consistent enough to define quantitative endurance limits.

To a certain extent the results of the study demonstrated the following functional relationship between the two fatigue factors manipulated in the experiment, i.e., time and type of activity, and crew performance:

1. In the Shearwater phase, one out of the twelve measures that were tested, i.e., number of radar sweeps for detection, revealed a significant difference as a function of the experimental fatigue factor.

2. Three measures, calibration error, flight path error, and climb performance affected the experimental fatigue factor in the Shearwater tests. The Alpha error (probability of rejecting a true hypothesis) for these measures was greater than 5 percent.

3. In the Greenwood phase, two out of the twenty-one measures tested, i.e., number of PDC's dropped and the number of sonobuoys within the range of the day, indicated performance differences as a function of the fatigue factor.

4. At Greenwood, flight measures influenced the fatigue factor at an Alpha error of greater than 5 percent. These were:

ECM classification error,  
RADAR sweeps per detection,  
RADAR range error,  
Number of calibration opportunities,  
Total of calibration error,  
ECM bearing error,  
Number of double echoes, and  
Total range error.

Significant differences in crew performance as a function of the level of problem difficulty or crew skill level were indicated in some isolated instances.

156. Miller, M. L. 1944. Aftermath of operational fatigue in combat aircrews. *American Journal of Psychiatry*. 101: 325-330.

The causes and aftermath of operational fatigue in combat aircrews was discussed. Three major causative factors were identified: (1) hardships, excessive combat experience and unusually harrowing events; (2) previous psychoneurosis; and (3) depression associated with the death of a friend. Typical symptoms such as restlessness, insomnia, and excessive drinking were also outlined. These observations were supported by several case studies. Several psychosomatic symptoms of operational fatigue, such as gastro-intestinal disorders, hyperactivity, and headaches were also identified.

157. Miller, W. H. 1936. Fatigue--Some special effects and tests. *Aviation Medicine*. 7:161-168.

Fatigue is a state of the body characterized by physiological, histological and chemical change. Regardless of the causes of fatigue the basic phenomena are the same: (1) decreased brain conductivity; (2) loss of muscle tone; (3) changes in circulation, (4) intra-cellular changes in brain, adrenals, and liver, and (5) changes in adaptive metabolism. Each of these are discussed in the article.

The author's premise is that flight fatigue is mainly the result of emotional conflict or stress and may be influenced by anoxemia, autonomy, irregularities and exposure to extremes. Greater piloting ability is demanded as aircraft advancements are made. Since we cannot alter the human pilot very much, flight surgeons should study and note the effects of flying conditions so that we may adapt them to the pilot when flight reaches the upper limits of human capabilities.

As for tests and indications of aviator fatigue, the Schneider index is of little aid in evaluating the effects of hypotension and observations of gross autonomic nervous disturbance do not give a correct index of fatigue. Introspective behavioristic psychology does not serve the purpose in estimating psychic factors of fatigue because of the economic factor in connection with the pilot's dependence on his employment and the disruption of operating regime occasioned by enforced relief of pilot personnel due to physical cause. There is a need for greater research and more open mindedness in the consideration of physiological and biochemical factors in the production of fatigue.

158. Mohler, S. R. 1966. Fatigue in aviation activities. *Aerospace Medicine*. 37:722-732. AD 620-022; TR No. FAA-AM-65-13.

This paper provides a survey of work in the field of aviation fatigue. Early work and studies in progress are included. The nature of fatigue itself is discussed along with possible factors that contribute to both physical and mental fatigue. Topics covered include flight-time limitations, indicators of excessive fatigue, new developments related to intercontinental flights and Forest Service flights.

159. Mohler, S. R., Dille, J. R., and Gibbons, H. L. 1968. Circadian rhythms and the effects of long-distance flights. *Airline Pilot*. 37:15-17. FAA-AM-68-8, April 1968.

Air travelers crossing four or more time zones experience significant desynchronization of certain daily biologic rhythms. Until rephasing of the rhythms occurs relative to the solar cycle at the destination, some subjective discomfort and disruption of psychophysiological responses can occur. This paper reviews research on diurnal rhythms, discusses the implications for aircrew and passengers, and makes recommendations for reducing the effects of time zone displacements.

160. Morgan, B. B. 1974. Effects of continuous work and sleep loss in the reduction and recovery of work efficiency. *American Industrial Hygiene Association Journal*. 35:13-20.

The synthetic-work technique has been employed in a series of investigations designed to determine (a) the extent to which performance efficiency is degraded during extended periods of continuous work, and (b) the amount of sleep necessary for the recovery of performance from the effects of continuous work and sleep loss. The results of these studies indicate that 36, 44, and 48 hours of continuous work and sleep loss result in decrements in over-all work efficiency of approximately 15, 20, and 35%, respectively. Following 36 hours of continuous work, it was found that 12 hours of sleep is sufficient for complete (100%) recovery of performance, but complete recovery is not provided by 2 (58% recovery), 3 (53% recovery), or 4 (73% recovery) hours of sleep. The time course of recovery is different following different durations of continuous work and subsequent sleep.

161. Morgan, B. B., Brown, B. R., and Alluisi, E. A. 1974. Effects on sustained performance of 48 hours of continuous work and sleep loss. *Human Factors*. 16:406-414.

The work efficiency of 10 subjects during a 48-hour period of continuous work and sleep loss was assessed using the synthetic work technique. Performance during the period of stress was

found to be significantly influenced by the circadian rhythm. Decrements first occurred after approximately 18 hours of continuous work, and performance decreased to an average of 82% of baseline during the early morning hours of the first night. Performance improved to about 90% of baseline during the daytime of the second day but decreased to approximately 67% during that night. All measures of performance recovered to baseline levels following a 24-hour period of rest and recovery.

162. Morgan, B. B., Jr., Coates, G. D., Brown, B. R., and Alluisi, E. A. 1963. *Effects of continuous work and sleep loss on the recovery of sustained performance*. Aberdeen Proving Ground, Maryland: US Army Human Engineering Laboratory. HEL TM 14-73, July 1963.

A synthetic-work methodology was employed in a series of eight studies conducted to provide definitive information concerning the time course of performance recovery from the detrimental effects of 36 and 44 hours of continuous work and sleep loss. Two crews of five subjects served in each of four continuous-work/recovery conditions in a partially counterbalanced order, namely: (a) 44 hours of continuous work followed by 4 hours of rest and recovery (sleep), (b) 36 hours continuous-work/4 hours rest and recovery, (c) 36/3, and (d) 36/2.

The results indicated that both the degree and pattern of performance recovery were related to the length of the continuous-work period as well as to the amount of subsequent sleep provided. The 36-hour continuous-work period was associated with decrements of 14-18% in performance efficiency while the 44-hour period resulted in a decrement of about 22%. Following 36 hours of continuous work, 2, 3, and 4 hours of sleep yielded an immediate recovery in performance of about 76%, 56%, and 75%, respectively, whereas 4 hours of sleep following 44 hours of continuous work produced only 39% immediate recovery. It is suggested that 6-8 hours is the minimum amount of sleep required for the recovery of performance from the effects of 36 hours of continuous work and sleep loss.

163. Morgan, T. R., and Cooke, J. P. 1976. Reduction of flight fatigue by a pulsating seat cushion. *SAFE Journal*. 6:18-22.

A pulsating-type seat cushion may reduce fatigue during 3-hour periods of physical inactivity for suited subjects seated in an ejection-type seat at a pressure equivalent to a cabin altitude of 25,000 feet (7,620 m). The feet were not moved during the test, simulating confinement in a small cockpit. Ultrasonic measurement of blood flow velocity showed a large reduction in flow velocity without the cushion. This finding agrees with subjective evaluation that the cushion reduced fatigue.

## N

164. Naitoh, P., and Townsend, R. E. 1970. The role of sleep deprivation research in human factors. *Human Factors*. 12: 575-585.

Sleep loss is a ubiquitous phenomenon that occurs on many long-term field missions. The effects of sleep loss are, in general, detrimental to efficient functioning of man-machine systems. To illustrate the effect of sleep loss on task performance, data from four independent research institutes are reviewed. Data are presented relating to the prevention of sleep loss, and to the detection and minimization of sleep loss effects when they occur.

165. National Research Council Committee on Selection and Training of Aircraft Pilots. 1946. *Role of fatigue in pilot performance*. Washington, D. C.: Civil Aeronautics Administration. Report No. 61.

This report provides information for use in considering Transcontinental and Western Air's 1946 request for a change in regulations pertaining to hours of flight by commercial airline pilots. The basic question was whether 12 hours of long-range flight with one unscheduled stop is more or less fatiguing than 8 hours of scheduled flight time on domestic operations calling for a multiplicity of scheduled stops. The literature of fatigue studies, particularly those involving aviation and related industries was reviewed for information pertinent to the TWA petition.

166. Neel, S. 1961. Flying is fatiguing. *Army Aviation Digest*. 7:31-32.

Fatigue is a significant problem in Army aviation. It reduces pilot efficiency and contributes to reduced performance and aircraft accidents. The characteristics of fatigue are listed in a pilot's checklist for fatigue (presented in this article) and should be familiar to both aviators and their supervisors. Fatigue can be minimized by proper hygiene, good physical conditioning, adequate rest

between missions, reduction in nonflying duty assignments, and judicious rotation of missions among aviators. The establishing of flying hour ceilings is not enough. Application of leadership and personnel management techniques is required, and are worth the effort.

167. Neel, S. 1973. Aviation medicine. In: *Medical support of the US Army in Vietnam 1965-1970*. Washington, D. C.: Department of the Army. p. 99-107.

This chapter reviews the medical care given to US Army aviators in Vietnam from 1965 to 1970. The duties of the flight surgeons assigned to aviation companies are reviewed. Along with a description of the flight care program instituted in Vietnam, attention is given to the problem of flyer fatigue. Several methods used to combat fatigue are reviewed. The author concludes that total flight hour limits are somewhat less than effective in limiting fatigue in a combat environment, but cites the "goal directed" flying hour schedule used by the 269th Aviation Company as being both workable and effective. This system would schedule a pilot for 5 to 6 days of flight operations and then schedule a day free from all duties. Also, problems of fatigue for enlisted crewmembers and flight support personnel are addressed.

168. Nicholson, A. N. 1970. Influence of duty hours on sleep patterns in aircrew operating in the long haul transport role. A study of single crew operations and double crew continuous flying operations. In: Benson, A. J., ed., *Rest and activity cycles for the maintenance of efficiency of personnel concerned with military flight operations*: Aerospace Medical Panel Specialists' Meeting, 1970 May; Oslo, Norway. London: Technical Editing and Reproduction Ltd. NATO/AGARD CP-74-70.

Military aircrew operating in the strategic long haul role experience repeated time zone changes and irregular and often long hours of duty. A satisfactory sleep pattern is of prime importance in maintaining their well-being and operational efficiency. The normal regular nightly period of sleep during non-flying duty at base is replaced by a complex sleep pattern while operating world-wide east-west routes. However, the sleep obtained over three days preceding each duty period is usually similar in duration to that obtained over three day periods while on non-flying duty and the ability of the pilot to obtain a similar amount of sleep appears to be an essential factor in preventing subjective fatigue.

There is a cumulative effect of repeated adaptation to time zones and irregular hours of duty. Aircrew find it increasingly difficult to maintain an acceptable sleep pattern as the number of days route flying increases. It would appear that the workload (average

hours duty/day) compatible with an acceptable sleep pattern diminishes in a logarithmic manner with the number of duty days. This implies restrictions to the deployment of aircrew if serious sleep disturbances are to be avoided.

To increase the effectiveness of a strategic transport force in the absence of positioned crews, double crew continuous flying operations have been studied. In these missions the off duty crew rests within the aircraft. The success of such operations depends to a large extent on the crew which operates during the period in which they are normally accustomed to sleep.

It is considered from experience within the Royal Air Force Air Support Command that the optimum duration of such a mission is about 48 hours. Beyond this period serious sleep disturbances appear. An operation of 48 hours using a fast strategic transport provides a world-wide capability and during this time the aircraft can circumnavigate the world.

169. Nicholson, A. N. 1970. Military implications of sleep patterns in transport aircrew. *Proceedings of the Royal Society of Medicine.* 63:570-572.

The Royal Air Force Institute of Aviation Medicine and the Board of Trade Civil Aviation Medical Department conducted studies of flight deck environment of both military and civil transport operations. These studies have reported that operating long haul routes can grossly affect aircrew sleep/work cycles. These studies have helped to formulate the manner in which aircrew sleep is modified and to define the workload compatible with a sleep pattern which approximates in some respects to that experienced during nonflying duty.

170. Nicholson, A. N. 1970. Sleep patterns of an airline pilot operating world-wide east-west routes. *Aerospace Medicine.* 41:626-632.

The sleep patterns of an airline pilot operating long haul east-west routes have been observed over a period of eighteen months. The normal sleep pattern was modified by irregular duty periods and by adaptation to time zone change. It is considered that sleep disturbance rather than sleep deprivation is the main problem in such aircrew. The physiological significance of the sleep patterns experienced during route flying is not understood, but it would appear possible that complex adjustments of intrasleep cycles and short periods of sleep (naps) may provide an adequate sleep pattern.

171. Nicholson, A. N. 1972. Duty hours and sleep patterns in air-crew operating world-wide routes. *Aerospace Medicine*. 43: 138-141.

Sleep patterns of an airline pilot operating world-wide, east-west routes have been related to duty hours. It is suggested that duty hours compatible with an acceptable sleep pattern may be related in a logarithmic manner with the number of days of the schedule. It would appear that the most critical consideration in preserving a control sleep pattern may involve the relation between total duty hours and duration of schedule.

172. Nicholson, A. N. 1972. Rest and activity patterns for prolonged extraterrestrial missions. *Aerospace Medicine*. 43: 253-257.

Difficulties in obtaining satisfactory sleep have been encountered during many space missions and it is generally recognized that an appropriate rest and activity pattern is essential to maintain the well-being and operational effectiveness of spacecrews. During earth orbital flights and lunar explorations satisfactory sleep is more likely if the crews maintain a reasonable relation with their normal terrestrial rhythm but many missions have required unusual patterns of activity. In the future prolonged extraterrestrial flights may also demand that the sequence of work and rest be subordinated to operational requirements and under these circumstances work and rest regimes developed under earth conditions may be of little use.

Irregular duty periods superimposed upon daily cycles of varying duration are experienced by long haul transport aircrew and an analysis of these schedules has suggested that irregular patterns of rest are compatible with a satisfactory sleep pattern as long as the workload is limited. It is considered that a similar relationship could be established for prolonged spaceflights and in this context the sleep patterns of an airline pilot operating worldwide schedules have been examined and relevant recent work on modified sleep regimes discussed.

173. Nicholson, A. N. 1978. Irregular work and rest. In: Dhenin, G., ed. *Aviation Medicine Vol. 1: Physiology and Human Factors*. London: Tri-Med Books Limited. 1:494-503.

This textbook chapter provides a brief review of the problems of disturbed sleep and circadian function in air operations and attempts to outline current approaches to the many important issues involved in the management of irregular rest and activity. A comparison of sleep patterns of long-haul and short-haul aircrews reveals that

long-haul crews typically make use of short "naps" to obtain adequate amounts of sleep while short-haul crews choose instead to prolong some regular sleep periods to compensate for sleep deprivation. Shifts in circadian activity and their effects on performance are outlined. Also, a function for determining optimum and maximum duty hours is presented to assist the flight crew's doctor in determining adequate and excessive workload schedules. The use of hypnotics to aid in inducing sleep in pilots is discussed.



174. O'Donnell, R. D., Bollinger, R., and Hartman, B. O. 1974. *The effects of extended missions on the performance on airborne command and control teams: A field survey.* Wright-Patterson Air Force Base, Ohio: Aerospace Medical Research Laboratory. AMRL-TR-74-20, July 1974. AD A011-549.

This report covers the effects of extended mission lengths on the performance of airborne command and control teams, wherein complex "cognitive" components consisting primarily of information collection, interpretation, and communication constitute the bulk of the workload. The survey centers on investigating general categories of performance-related factors, such as overall fatigue, rather than specific task performances such as long-term memory, sensory motor reaction time, or information processing.

# P

175. Patrol ASW Development Group. 1970. *Problems of fatigue in patrol aircrewmembers during extended flight operations*. Norfolk, Virginia: US Naval Air Station. ASW TR No. 33, June 1970. AD 509-163L.

During a forty day period in 1969, a patrol squadron equipped with P-3 aircraft was exercised with the various demands of an extended Anti-Submarine Warfare exercise in passively tracking an assigned nuclear submarine target. The purpose of this portion of the project was to obtain information from the flight personnel regarding the fatigue they may have experienced during this extended exercise. The five crews which had the most overall flight time were selected for this study. A questionnaire was given to all crewmembers. The squadron commander, executive officer and flight surgeon at the time of the operation were interviewed as well as one officer from each of the five crews. The areas studied included brief/debrief times, activity during transit periods, workload prior to and during the flight, tactical effectiveness, safety, quality of operating bases, rest and sleep, illness, boredom/monotony, superior's interest, motivation and morale throughout the exercise. Conclusions were drawn relating the above areas to the occurrence of fatigue. Recommendations were made in the areas of flight hours, augmentation of maintenance and ground support personnel, crew work/rest schedules, and cross-training.

176. Pegram, V., Storm, W., Hartman, B. O., Harris, D. A., and Hale, H. B. 1970. Evaluation of sleep, performance and physiological responses to prolonged double crew flights: C-5 operation cold shoulder, a preliminary report. In: Benson, A. J., ed., *Rest and activity cycles for the maintenance of efficiency of personnel concerned with military flight operations*: Aerospace Medical Panel Specialists' Meeting, 1970 May; Oslo, Norway. London: Technical Editing and Reproduction Ltd. NATO/AGARD CP-74-70.

"Cold Shoulder" was a real-world experiment designed to determine the effects on aircrewmembers of marrying two crews to a jet transport and flying operational missions. Two basic crews were flown

in a C-141 cargo aircraft, utilizing either a 4/4 or 16/16 hours work/rest cycle. A battery of measures were conducted on each crew: (a) oral temperature, (b) endocrine-metabolic trends, (c) electroencephalogram (EEG) for determining sleep, and (d) crew performance evaluations. The oral temperature data showed that flight per se induced a low-grade hypothermia which was more pronounced in individuals occupying key crew positions. The endocrinometabolic data tentatively suggested that the Aircraft Commanders, as a group, experienced more stress than the other crewmembers. The sleep EEG analysis showed that both human and primate subjects suffer a significant reduction in deep sleep and dream sleep when exposed to actual or simulated flight conditions. When combined with the sleep and physiological changes, the performance data from both humans and primates suggests caution in the application of in-flight double crews.

177. Perelli, L. P. 1980. *Effects of fatigue stressors on flying performance, information processing, subjective fatigue, and physiological cost indices during simulated, long-duration flight*. Washington, DC: The Catholic University of America; *Dissertation Abstracts*, 1980.

The purpose of this study was to assist in the development of flight duration parameters for scheduling aircrew work-rest cycles. This was achieved using objective measures of flying performance, subjective reports of fatigue and sleepiness, and three physiological indicators: Heart Rate (HR), Heart Rate Variability (HRV), and Rectal Temperature. An additional purpose was to demonstrate the correlation among these measures and relate them to a Discrete Information Processing Test (DIPT) developed for eventual use in the actual flight environment. The DIPT is a computer-controlled, five-choice reaction time task which adapts its stimulus presentation rate to the subject's response accuracy and continuity, up to a point where the subject can no longer keep pace. Through an iterative process, the subject's threshold of information processing speed can be determined.

A literature review provides an historical perspective for various concepts of fatigue, and evaluates past research concerning performance decrement accompanying sleep deprivation, physiological cost indices of fatigue, circadian rhythm changes, and flying skill assessment. The unique requirements for a device to assess performance in the field are discussed and presented as the rationale for the development of the DIPT. The DIPT is described within the framework of adaptive technology.

It was hypothesized that each dependent measure would change significantly in the presence of three fatigue stressors experienced during simulated flight: (a) time awake prior to flying (1 versus 12 hours), (b) daily flight duration (9 hours), and (c) total

mission duration (4 days). HR and HRV were predicted to be significantly related to the arousal value of each task based on its complexity and fatigue level. Disrupted circadian rhythm was predicted to be more detrimental to flight performance than cumulative fatigue.

Twenty-four airmen each received an intensive 7-day flight training program in Link Fixed Wing Flight Trainers. Then, 12 subjects were randomly assigned to a schedule that regularly alternated 12-hour duty days with 12-hour crew rest periods for 4 days. The remaining subjects followed a schedule with duty days of 12, 24, 24, and 12 hours, each separated by a 12-hour crew rest period. During each duty day, all subjects flew two 4.5-hour simulated flights, separated by a 1-hour rest. Flying performance was evaluated by a time-on target tracking score derived from heading, altitude, airspeed, turn rate, turn coordination, and vertical velocity errors. A PDP-12 computer administered and scored both a simple straight and level test, a complex flight maneuver test, and the DIPT, each flight hour. Continuous HR and Rectal Temperature, subjective fatigue and sleepiness reports, and sleep logs were collected throughout each mission.

All measures demonstrated significant fatigue effect. HR increased with flight task complexity only during extreme fatigue. HRV decreased with increasing task complexity for both groups, for all three performance measures. Performance on the less complex flight task declined most during extreme fatigue. Disrupted circadian rhythm during night flights seemed to cause greater performance decrement than cumulative fatigue. Performance measures, subjective fatigue, and sleepiness reports were significantly correlated with each other and to changes in Rectal Temperature. Subjects recovered from the intense fatigue effects by the fourth flight day.

178. Perry, I. C., ed. 1974. *Helicopter aircrew fatigue*. London: Technical Editing and Reproduction Ltd. NATO/AGARD TR No. 69, May 1974. AD 780-606/OGA.

The studies by the Aerospace Medical Panel have shown that aviator fatigue is generally agreed to be an important problem in helicopter operation. Apart from the effects that such a condition has on efficiency, fatigue has also been found to be an important contributory factor in helicopter accidents, both in peace time operations and in the combat environment. Many of the major causes of fatigue result from inadequate training on the part of those responsible for the well-being of aircrew; such training in the causes and effects of fatigue would of themselves lead to the changes of organization and procedures which would minimize the occurrence of fatigue. It has been found that the Army helicopter aviator throughout the NATO nations, continues to be treated and to work under the same conditions as the ground soldier. Whilst such a policy may have been desirable in the past, it

can now be argued that because of the increasing complexity and expense of the aircraft used, the aviator should be considered as more of an integral part of the man-machine complex rather than as a ground soldier. He should therefore be managed and maintained more like the aircrew of the Air Forces and Navies of NATO.

The report contains a rank order listing of items which 500 helicopter aircrew members rated as being important contributors to pilot fatigue. A comparison of actual flying hours and rest period standards for helicopter pilots in NATO nations is also presented.

179. Petersen, P. B. 1972. *Fatigue in sustained tactical operations*. San Antonio, Texas: Medical Service Agency, US Army Combat Developments Command. (Technical Report). AD 746-643.

Concepts for future US tactical operations envision man's capabilities as encompassing rapid acclimation, fatigue reduction, changed wake-sleep cycles, and changes to the circadian cycle under sustained and continuous operational requirements. Our forces must be able to compete with and win against an enemy who may have these capabilities. No evidence can be found of any current coordinated effort to collect, evaluate or recommend measures that can be used in the study subareas. This study focuses on concepts for the reduction of fatigue in its various stages in sustained tactical operations. There are a number of concepts applicable for this subject, yet, fatigue reduction by chemical and electronic methods are assumed not be politically and socially feasible and hence are not dealt with in this paper. Methods for the reduction of fatigue focus specifically on techniques of leadership and on measures to prevent fatigue as well as measures taken to reduce the effects of fatigue, once it is evident. In addition, other subject areas within the scope of fatigue reduction are isolated in terms of areas that need to be identified for further research in order that factual conclusive information can be recommended for use in tactical training.

180. Pincus, G., and Hoagland, H. 1943. Steroid excretion and the stress of flying. *Aviation Medicine*. 14:173-192.

The urine volume output and 17-ketosteroid excretion is reported for control and "flight" specimens taken from (1) seven college students who performed sixty-seven runs upon the Steven's serial coordination meter, (2) three subjects in twenty-seven experiments on the Hoagland-Werthessen pursuit meter at various oxygen tensions, (3) seven Pratt and Whitney pilots who performed fifty-six test flights, and (4) sixteen U.S. Army instructor-pilots in 152 routine instruction

flights. In all groups the operations performed caused a ketosteroiduria and diuresis. The diureses and excess 17-ketosteroid excretion are directly proportional to the per cent of flying time in both groups of pilots, but quantitatively greater in the test pilots. The diuresis and ketosteroiduria of the Hoagland-Werthessen pursuit meter subjects increased with increasing "altitude" and with the poorer performance accompanying reduced oxygen tension. In the Steven's meter subjects the poorer performers tended to exhibit the greatest ketosteroiduria and diuresis. An independent rating of the Army fliers' fatigability (made by their squadron commander) correlated significantly with the degree of ketosteroiduria and diuresis exhibited by the fliers. The most fatigable fliers tend to excrete dilute urines during flight, the least fatigable somewhat concentrated urines. These data are interpreted to indicate that the simulated and actual stress of the flying studied induces adrenal steroid hormone hypersecretion that is reflected in the 17-ketosteroid output; this hypersecretion either causes or is accompanied by diuresis.

181. Preston, F. S. 1967. Measurement of pilot fatigue. *Transactions of the Society of Occupational Medicine*. 17:52-56.

The subject of fatigue in airline pilots is discussed with particular regard to the operational problems of the industry. So far no reliable means of assessing pilot fatigue in quantitative terms has been found, although much work has been carried out by researchers in many countries. There is no short-cut to safety in aviation and the assessment of pilot fatigue and the prevention of errors in flight by pilots can only be achieved by study of all the factors affecting skill and mental performance. The reduction of flying accidents due to human error in the air and on the ground can only be achieved by the utilization of knowledge from the biological and engineering sciences and further active research programmes.

182. Preston, F. S. 1970. Time zone disruption and sleep patterns in pilots. *Transactions of the Society of Occupational Medicine*. 20:77-86.

This study investigated sleep patterns in BOAC pilots by having them keep a log of sleep time and subjective feelings of tiredness or freshness on retiring to bed. The following conclusions were presented. Much more research is required in this field--the control of plasma cortisol levels being possibly the most promising. In addition, the control of external cues such as illumination/darkness could also be investigated in the transport field. This could probably be accomplished by removing aircraft windows and transporting the unfortunate passengers in total darkness. This would not be a popular airline.

In the case of airline operating crews, the problem is more acute. The economic pressures on airlines to operate their aircraft throughout the twenty-four hour period are immense. One way of tackling the problem would be to base crews down the routes (as was done in the past in BOAC). By so doing the pilots would operate over set routes with small time-zone changes, but the costs involved in overseas bases are considerable and although popular with individual pilots and their families, the system has led in the past to trade union disagreements.

An alternative method, which is used in some long-haul U. S. airlines, is to send the crew round the world at a much faster rate, i.e., 6-8 days. In this way, by keeping stop-overs between 14-24 hours, pilots manage to remain on their home time throughout the trip, e.g., Eastern Standard Time if operating out of New York and Pacific time if operating out of San Francisco. Such a regime, while rigid, is based on good physiological principles and pilots get their tours over and return to their homes with a minimum of delay. To achieve such a regime, of course, demands a highly professional outlook by the pilots backed by good hotels which can provide the sort of service described in this article.

183. Preston, F. S. 1973. Further sleep problems in airline pilots on worldwide schedules. *Aerospace Medicine*. 44:775-782.

This study follows previous work carried out on airline pilots operating long-haul transmeridian routes with particular respect to the sleep patterns obtained at slip stations en route. The author accompanied a B-707 crew on a long transmeridian tour when all members kept careful sleep logs for a period of 1 month and the data obtained show clear evidence of sleep deficit occurring in tours of this nature with some evidence of age variation in individuals. The practical problems in scheduling crews in such operations are discussed in some detail in relation to performance, the use of hypnotics, and difficulties surrounding pilots in bidding for successive tours which may result in sleep deprivation.

184. Preston, F. S. 1978. Aircrew schedules. In: Dhenin, G., ed. *Aviation medicine Vol 2: Health and clinical aspects*. London: Tri-Books Limited. 2:37-47.

This textbook chapter discusses aircrew scheduling practices and the major obstacles to proper scheduling procedures. The author feels that aircrew schedules are still formed using utility and economy as guidelines rather than physiological and scientific data. A brief history of aircrew scheduling regulations enacted in the United Kingdom is presented. The "Bid-line" scheduling procedure practiced

by many long-haul commercial airlines is examined in detail. Also, the "Points" system used by British Airways European Division is presented as a method for scheduling short-haul routes where workload and stressors are more concentrated than long-haul routes. Special physiological problems associated with the flight environment, such as heat and humidity, are related to possible crew fatigue.

185. Preston, F. S., and Bateman, S. C. 1970. Effect of the time zone changes on the sleep patterns of BOAC B.707 crews on worldwide schedules. *Aerospace Medicine*. 41:1409-1415.

The paper discusses a study of sleep patterns carried out on pilots of the Boeing 707 fleet of British Overseas Airways Corporation on worldwide schedules. Rapid transit of multiple time zones produces disruption of normal sleep patterns which, in itself, is probably one of the greatest problems facing airline pilots.

The nature of sleep is examined and the practical problems surrounding the use of hypnotics are noted.

186. Preston, F. S., and Cussen, D. J. 1973. Sleep patterns in a lone global pilot. *Aerospace Medicine*. 44:669-674.

A considerable amount of work has been carried out on the sleep disruption engendered on flying across time zones in airline pilots. This paper is concerned with the sleep patterns of a lone woman record-breaking pilot involved in a global flight and discusses the problems facing those engaged in such flights and in the planning of them. No measurements were made on psychomotor performance by the authors as this was carried out by other agencies and the results of these studies are yet to be published. Adequate sleep, however, is essential in the record-breaking pilot if he or she is to maintain the necessary stamina and willpower to complete such a demanding task. The record-breaking pilot is subjected to many extraneous pressures such as personally conducting flight planning, supervising refueling and aircraft maintenance, and dealing successfully with the news media which may cause stress and distraction themselves and so load the main task.

187. Preston, F. S., Bateman, S. C., Short, R. V., and Wilkinson, R. T. 1973. Effects of flying and of time changes on menstrual cycle length and on performance in airline stewardesses. *Aerospace Medicine*. 44:438-443.

The paper describes a study on the effects of transmeridian flights on the menstrual cycle lengths of 29 airline stewardesses. From this group, eight stewardesses were selected for further study in

an isolation unit at the University of Manchester. Four subjects spent four days as a control group and were not subjected to time-zone changes. The second group of four were subjected to three time-zone changes, of eight hours, each representing long easterly flights. Both groups were required to complete a similar battery of workload tasks during isolation. These tests included Addition, Reaction Time, Short-term Memory, Vigilance and Visual Search. Only one subject of the time-zoned group showed any change in menstrual cycle length, but there was a significant impairment in efficiency of this group both over the performance tasks as a whole and in particular in the ability to react quickly, memorize and search.

188. Preston, F. S., Ruffell-Smith, H. P., and Sutton-Mattocks, V. M. 1973. Sleep loss in air cabin crew. *Aerospace Medicine*. 44:931-935.

In recent years there have been a number of studies of the changes in circadian rhythms and their effect on the sleep of pilots. Little definitive work has been carried out on this aspect as it affects air cabin crews. As part of a cabin crew workload study in BOAC the sleep patterns of 12 stewards and 12 stewardesses were studied for periods of about 14 weeks. Attempts were made to correlate sleep loss with variables such as time zone change, days away on tour and rest days during any given integration. In this particular group, sleep loss seemed to be related to the number of night flights, at local time, per tour and not to time zone changes.

## R

189. Rassvetayev, V. V., Ivanov, A. V., Kolosov, V. A., Kuznetsov, V. N., and Mikhaylik, N. F. 1978. Dynamic medical monitoring of flight crews in the course of long-term flights. *Space Biology and Aerospace Medicine*. 12:16-19.

Results of monitoring flight crews during long-term flights establish two types of reactions of the main physiological systems during flights: reactions of functional systems in response to brief complication of professional work (emotional and motivational factors are the triggering mechanism of such reactions) and reactions resulting from the combined effect of tense work and adverse flight factors (these reactions are based on developing fatigue and relative exhaustion of body systems).

190. Ray, F. T., Martin, O. E., and Alluisi, E. A. 1961. *Human performance as a function of the work-rest cycle: A review of selected studies*. Washington, D. C.: National Academy of Sciences, National Research Council. NRC Pub. No. 882. AD 256-313.

Studies relating to the effects of different work-rest cycles on man's performance are reviewed in this report. Included are only those studies in which (a) observations of performance extend for 24 hours or longer, and (b) results pertain to the general problem of optimizing performance through the scheduling of work and rest periods.

While several specific conclusions are supported by the studies reviewed, the number of generalizations relating to optimal work-rest scheduling are limited. It is not yet possible to describe accurately the complex relations among performance variables, work-rest cycles, sleep-wakefulness cycles, and the durations of the work, rest, and sleep periods. The need for additional long-term experimentation is evident.

191. Robson, B. M., Huddleston, H. F., and Adams, A. H. 1974. *Some effects of disturbed sleep on a simulated flying task.* Farnborough, England: Royal Aircraft Establishment. RAE-TR-74057, June 1974. AD 923-598L.

Data are reported for 12 Royal Air Force pilots required to perform a series of 30-minute runs in a simple flight task simulator. Six pilots knew they were to return to bed immediately after a 0300 (or 0330) hour run, and six knew they were to remain awake and work. Pilots aroused for a single early morning task showed degraded height control performance, scored significantly higher on a subjective fatigue check list, and recorded a larger number of fast reaction times to peripheral lights.

192. Rotondo, G. 1969. Experimental contribution to preventive and therapeutic treatment of flight fatigue. *Revista Di Medicina Aeronautica E Spaziale.* 32:231-268. (In Italian.)

The author frames nosologically flight fatigue syndrome through its definition, the study of its pathogenesis, diagnostic methods, symptomatology and traditional therapy. Results of experimental research are summarized. Investigations were carried out to test the possible effectiveness of a few cortical hormones, as dehydroisoandrosterone as well as of association of metabolic drugs, as adenosine triphosphoric, and cocarbossilasis, and acetyl aspartic acids and citrulline in preventive and therapeutic treatment of this syndrome.

For each substance studied the author surveys possible physiofarmacologic mechanisms of its favorable action in therapy and prevention of operational fatigue. This survey is carried out mainly in light of the modern concepts on etiopathogenesis of this syndrome.

The author states that the favorable results obtained with the tested drugs, mainly with dehydroisoandrosterone in manifest flight fatigue, and with acetyl aspartic acid-citrulline association in mild and initial syndrome, are such as to encourage further and larger clinical experimentation. This proposed study would be possibly useful in view of flight safety and flight accident prevention, as well as of prompt recovery of eventually fatigued flight personnel, and of preserving conditions of perfect physiopsychological efficiency.

193. Rotondo, G. 1978. Workload and operational fatigue in helicopter pilots. *Aviation, Space, and Environmental Medicine.* 49:430-436. (In English.); *Revista Di Medicina Aeronautica E Spaziale.* 1976. 39:91-116. (In Italian.); NATO/AGARD CP-217.

In light of the modern etiopathogenic views, a brief review was made concerning possible causes of operational fatigue to which

flying personnel in general are exposed in the exercise of flying activity. The author then describes and analyzes the meaning and importance of the various stressing factors that constitute the physical and psychic workload to which the helicopter pilot is subjected in performing his professional activities. Also analyzed are the influences exercised, both separately and jointly, on the genesis of flight fatigue in helicopter pilots by stressing and fatiguing effects of vibrations, noise, and psycho-emotional and psycho-sensorial factors related to the variety and danger of utilization of this modern aircraft. Such an analytical investigation enables the author to conclude that one must admit that helicopter piloting involves a psycho-physical workload certainly no less than that required by more powerful and faster aircraft.

## S

194. Schreuder, D. B. 1966. Medical aspects of aircraft pilot fatigue with special reference to the commercial jet pilot. *Aerospace Medicine*. 37(4):1-43.

This review article attempts to analyze the various ramifications of pilot fatigue in an endeavor to come to some conclusion as to the severity of the problem. The body of the article is divided into three chapters. Chapter One presents a review of literature on fatigue and includes lay articles and questionnaire studies. The physiological, psychological, and pathological aspects of stress and fatigue are examined. Chapter Two describes both the operational aspects of fatigue, such as the flight environment, and non-operational aspects of fatigue such as the physical condition of the pilot and his off-duty activities. Chapter Three is concerned with pilot health and fatigue prevention. It is emphasized that pilot fatigue is a very complex problem, however, the occurrence of pilot fatigue, as defined in the article, is stated not to be a common occurrence in the airline pilot.

195. Siegel, P. V., Gerathewohl, S. J., and Mohler, S. R. 1969. Time-zone effects: Disruption of circadian rhythms poses a stress on the long-distance air traveler. *Science*. 164: 1249-1255.

The scientific literature of many countries reports circadian rhythms which influence the behavior of biological systems. In the modern aviation environment man is exposed rather abruptly to disruptions of these rhythms, particularly during long east-to-west and west-to-east flights. It is still an open question whether eastward or westward flights from the point of origin pose a higher stress on the air traveler.

Experimental evidence obtained on animals and man is still inconclusive. In the case of man, the individual differences between "early risers" and "early sleepers" may mask to some extent the trans-meridional time-shift effect. As to the latitudinal displacements, the flight experiments conducted so far did not last long enough to determine whether pronounced shifts of the light-dark ratio would affect the

circadian oscillator. In any case, the methods of lessening the effects of desynchronization of circadian periodicities are similar to those that are used for crew members and travelers on long-distance flights. They specifically include the following:

(1) Keeping the clock time and the environmental factors at the destination the "same" as those at the point of origin through simulation (this approach is often not practical).

(2) Scheduling flight time and rest time according to a formula that takes into account the number of time zones traversed, departure time, state of rest at time of departure, and arrival time, so that there is as much rephasing of the critical circadian rhythms as is felt necessary in the light of demands made on the individual before, during, and after the trip.

(3) Pacing activities during the initial period of rephasing so that superimposed stresses (in particular, heavy eating and drinking) are kept to a minimum.

(4) To avoid the necessity of taking traditional hypnotics, with consequent loss of REM sleep, inducing sleep by moderate exercise and a warm bath.

196. Simonson, E., ed. 1971. *Physiology of work capacity and fatigue*. Springfield, Illinois: C. C. Thomas.

This volume is a comprehensive review of the physiological aspects of fatigue. The author has concentrated on fundamental problems and mechanisms of fatigue with representative references for the various problems discussed. These problems include cardiovascular, respiratory, metabolic, biochemical, and physiochemical functions and their relationship to fatigue. The information given provides the basis for practical applications in athletics, military situations, occupational work, extreme environment (temperature and high altitude), and medicine. However, the applications are not spelled out in detail. No systematic differentiation between fatigue and exhaustion is made.

197. Simonson, E., and Weiser, P. L., eds. 1976. *Psychological aspects and physiological correlates of work and fatigue*. Springfield, Illinois: C. C. Thomas.

This volume is meant to be mutually supplemental to Simonson's *Physiology of Work Capacity and Fatigue*. Due to the fact that the separation of physiological and psychological aspects of fatigue is somewhat arbitrary the first part of the volume contains chapters with primarily a physiological orientation followed by chapters with primarily a psychological orientation. The book is broken down

into six sections, the first of which is physiological background. Sections two, three, and four cover motor, sensory, and central processing aspects of fatigue. Sections five and six deal with aging and introspective aspects of work and fatigue, respectively.

198. Staack, K. 1970. Differences between military and commercial aircrews' rest and activity cycles. In: Benson, A. J., ed., *Rest and activity cycles for the maintenance and efficiency of personnel concerned with military flight operations: Aerospace Medical Panel Specialists' Meeting, 1970 May; Oslo, Norway*. London: Technical Editing and Reproduction Ltd. NATO/AGARD CP-74-70.

During the past years considerable experience on fatigue during long distance flights has been gained under conditions of disturbed diurnal rhythm. The object of this investigation was to find out, whether - in addition to the duration of flight and the diurnal rhythm factor - there exist any other factors contributing to the difficulties arising in connection with the rest and activity cycles. For this purpose, aircrew members of the FMOD Air Transport Wing flying the Boeing 707 have been interviewed with respect to their flying duty, ground duty and duty-free time.

The results of these interviews show that the difficulties arising are not so much caused by the duration of flights and even less by the disturbed diurnal rhythm, but very much more by certain administrative procedures, by prolonged layover times and, most of all, by the ground duty times. In this respect, there is a marked difference between military aircrews and aircrews of commercial airlines. Good leadership and team spirit as well as an effective organization are of great importance.

199. Stamper, D. A., Leibrecht, B. C., and Lloyd, A. J. 1978. *Honest 1: Personality heart rate, urinary catecholamine, and subjective fatigue measures related to night nap-of-the-earth flying*. Presidio of San Francisco, California: Letterman Army Institute of Research. Inst. Rep. No. 51, January 1978.

Personality, subjective fatigue, urine catecholamine, and heart rate measures of helicopter pilots that participated in a night nap-of-the-earth training exercise were evaluated. These selected variables provided estimates of normal personality function, subjective feeling states, and biochemical and physiological changes. According to the hypothesis, these variables are related to night nap-of-the-earth flying. Scores on the Self-acceptance and Achievement via Independence scales of the California Psychological Inventory (CPI) were significantly above the mean for pilots rated as above average ability. Additionally,

the CPI scales of Self Control and Good Impression were significantly related to urine catecholamine levels. Heart rate levels were significantly related to epinephrine, but not to norepinephrine. Despite the significant increases in epinephrine within flights and norepinephrine across flights, there were no significant increases in perceived anxiety, as measured by the State-Trait Anxiety Inventory. The lack of increase in perceived anxiety may be explained by the processes of dissociation and the general adaptation syndrome.

200. Stanbridge, R. H. 1951. Fatigue in aircrew: Observations in the Berlin airlift. *The Lancet*. 2:6671-6674.

This is a precis of two papers written in 1948 and 1949 on a field investigation into fatigue in aircrew. The main objects of the investigations were to enable action to be taken to prevent fatigue; to indicate means of preventing it in future operations; and to make some contribution to the general problem of fatigue. As to the last objective it is suggested that while in World War II fatigue was not shown to be a prominent cause of psychological disorders and pilot error, the causes of fatigue in this operation would be present in war and would play an important part in preparing the way for psychological disorders and flying accidents.

201. Stave, A. M. 1977. The effects of cockpit environment on long-term pilot performance. *Human Factors*. 19:503-514.

A fixed-base helicopter simulator was used to examine pilot performance as influenced by noise, vibration, and fatigue. Subjects flew the simulator for periods ranging between three and eight hours while exposed to vibrations (at 17 Hz) ranging from 0.1 to 0.3 g, and noise stimuli varying between 74 (ambient) and 100 dB. Despite reports of extreme fatigue on these long flights, subject performance did not degrade. Within the limits of this study, performance tended to improve as environmental stress increased. However, subjects did suffer from lapses resulting in abnormally poor performance. These lapses are probably of short duration (seconds) and occur at unpredictable times. If such lapses occur in actual flight, they could provide an explanation for many so-called "pilot error" accidents.

202. Stolze, H. J. 1971. *Circadian rhythms of pilots' performance in a flight simulator*. Bonn, West Germany: Deutsche Forschungs und Versuchsanstalt Fuerluft and Raumfahrt. TR No. DLR-FB-71-14, February 1971. AD 855-740.

In order to investigate variations in pilots' performance, possibly existing in dependency on daytime, 18 pilots had to perform a standardized instrument flight in a simulator. Their deviations from

the preset flight task were measured and their responses to flight incidents were evaluated. The results showed an almost constantly high performance plateau during the late afternoon and a trough during the night hours between 3 and 6 a.m. The range of oscillation in performance parameters, amounting to 28.1% of the 24-hour mean was considerably larger than that of the reaction time with 8.1%, which was measured at the same time for reasons of comparison. From the results it can be concluded that, considering the nightly trough in performance, pilots on night flight duty may be subjected to a substantial stress. It is suggested that a possible safety risk can be reduced by a sufficiently long rest period prior to the night flight duty and by limiting the duration of the night shift.

203. Storm, W. F., and Hapenny, J. D. 1976. *Mission-crew fatigue during RIVET JOINT operations*. Brooks Air Force Base, Texas: School of Aerospace Medicine. SAM-TR-76-36, September 1976. AD A032-437.

Subjective fatigue and sleep data were collected from a US Air Force Security Service airborne mission team before and during an airborne mission. The primary purpose of the test was to refine the procedures and analytical techniques in preparation for an upcoming demonstration/evaluation of a new and modernized system of electronic surveillance equipment. Results indicated that only minor changes in procedures and techniques were necessary. The data also provide unique baseline information for future comparison and evaluation of similar subjective fatigue rating scores data from the flights planned with the modernized system.

204. Storm, W. F., Hartman, B. O., and Makalous, D. L. 1977. Aircrew fatigue on nonstop, transoceanic tactical deployments. In: Auffret, R., ed., *Studies on pilot workload*: Aerospace Medical Panel Specialists' Meeting, 1977 April; Koln, Germany. London: Technical Editing and Reproduction Ltd. NATO/AGARD CP-217.

The central issue addressed by this study was operational effectiveness following long-range deployment. Stress and fatigue were evaluated in F-4D crews before and after flying nonstop, transoceanic deployments from New Mexico to Germany and return. The measurement battery consisted of subjective fatigue ratings, self ratings of fitness to fly, sleep logs, and biochemical analyses of urine samples for norepinephrine, epinephrine, 17-hydroxycorticosteroids, urea, sodium, and potassium. The magnitude and the consistency of behavioral and physiological changes indicated the occurrence of mild fatigue immediately after both flights. The fatigue was acute and was ameliorated by one uninterrupted sleep period.

205. Strasser, H., Klinger, K. P., Mueller-Limmroth, W., and Brillling, G. 1973. *Comparative experiments on performance and fatigue effects on pilots using tracking tests and physiological measurement parameters*. Presented at the 21st International Congress on Aviation and Space Medicine; 1973 September 17-21; Munich, Germany.

Trials on a pursuit tracking test with simple position control and four reference inputs were carried out initially on ten male industrial employees aged between 40 and 65. Physiological parameters were also measured during testing, namely heart beat frequency, a measure of irregular heart beat, and evoked potentials. Performance was evaluated in terms of the number of errors per unit time. Expected learning curves were produced, but during the adaptive tests the rate of learning increased with time. Runs of the same tests with the same physiological parameters being measured were then performed by a group of nine Navy pilots aged 25 to 36, run 1 without alcohol, run 2 with 0.6 deg/infinity alcohol. They showed quicker adaptation and faster reactions than the older industrial subjects. The pulse rates of the pilots were higher than those of the group of older subjects. Both groups showed a drop in the evoked potentials during testing caused by tiredness. A lowering of vigilance level caused by small quantities of alcohol could be detected.

[NASA N79-14774 Abstract]

206. Strickland, B. A., Jr. 1961. Aircrew maintenance. In: Armstrong, H. G., ed. *Aerospace Medicine*. Baltimore, Maryland: Williams and Wilkins Co. 507-529.

This chapter, aimed primarily at flight surgeons, outlines the elements of an effective aircrew maintenance program. Medical examinations given to flight personnel are discussed and a list of essential medical tests and a list of special medical problems encountered by crewmen are presented. Aircrew members' diets are discussed and their special requirements are outlined. Work-rest schedules and the aircrew members' need for sleep are given special attention. Primary responsibility for insuring that flight crew personnel obtain proper rest periods is given to the flight surgeon. Also, the flyer's need for periodic vacation is emphasized. The chapter concludes with a description of the general activities and responsibilities of the squadron flight surgeon.

207. Strughold, H. 1952. Physiological day-night cycle in global flights. *Journal of Aviation Medicine*. 23:464-473.

The physiological diurnal cycle, synchronized with the physical or astronomical periodicity of day and night, is discussed. Emphasis is made on the persistence of the physiological cycle. This

persistence leads to a phase shift of the physical and physiological day-night cycle following long distance flights in east-west or west-east directions. The implications of this phase shift during the incomplete cycle adaptation of the first few days, involving the individual's efficiency, is discussed at some length.

208. Stupnitskii, V. P., Pozniakov, V. V., Trofimov, V. N., Bogdashevskii, R. B., and Kuznetsov, O. N. 1976. Operator activity in a state of continuous wakefulness (Operatorskaia deiatel'nost' v usloviakh nepreryvnogo boдрstvovaniia). In: Lomov, B. F., Nikolaev, A. G., and Khachatur'iants, L. S., eds. *Characteristics of cosmonaut activities during flight (Osobennosti deiatel'nosti kosmonavta v polete)*. Moscow: Izdatel'stov Mashinostroenie. 121-127. (In Russian.)

Astronauts in space flight may encounter situations where they would be forced to perform control and monitoring operations for prolonged periods of wakefulness. The paper describes an experiment performed in an isolation chamber to evaluate the effects of prolonged wakefulness - up to 74 hours - on the performance of operators in reading and processing information from various sensors. A block diagram of a setup for monitoring the sensorimotor functions of operators during prolonged wakefulness is presented and curves indicating operator performance with progressing wakefulness are given.

[NASA A78-47969 Abstract]

# T

209. Tasker, D. I., Kinel, S. G., and Tredici, T. J. 1975. Use of the ERG and EOG in evaluating the effect of sleep deprivation on visual function in flying personnel. *Aviation, Space, and Environmental Medicine*. 46:943-945. AD A019-896.

The electroretinogram (ERG) and electrooculogram (EOG) are electrophysiological tests employed in ophthalmology to diagnose degeneration of injury to the outer half of the retina, including the rods and cones of the visual system. This pilot study was undertaken to determine if sleep deprivation of more than 24 hours in rated flying personnel may show an abnormality in retinal function as measured by the ERG and/or EOG. This may give insight to the visual function in flying personnel on deployment or other long missions where uninterrupted sleep may be a problem. The results of this study showed that some subjects deprived of sleep exhibited a statistically significant variance in their EOG ratios as compared to a nondeprived control group. No significant changes in ERG were detected. Principles and theory of electrophysiological testing in ophthalmology are presented.

210. Trumbull, R. 1966. Diurnal cycles and work-rest scheduling in unusual environments. *Human Factors*. 8:385-398.

The extension of man's working environment and its control have led to a new consideration of his "normal" neuro-physiological and psychological rhythms. There are some fifty such patterns of fluctuating functions within man which have various degrees of influence upon his level of performance and ability to maintain performance. Data are provided from physiological and psychological research in an attempt to provide perspective for selection of appropriate personnel and establishment of work/rest or duty cycles in deference to these influences. Discussion includes application to aircrew schedules.

## U

211. US Army Aeromedical Center. 1976. Stress and fatigue in flying operations. In: *Army flight surgeon's manual*. Fort Rucker, Alabama: US Army Aeromedical Center. Special Text ST1-105-8, C15.

This chapter discusses stress definitions and measurements, stress concepts and etiologies, factors influencing or determining reactions to stress, fatigue diagnosis and classification, the prevention of fatigue, and the treatment and disposition of fatigue cases. Stress is identified as the major cause of fatigue and stresses present in the aviation environment are examined in detail. They include extreme environments, poor weather, hypoxia, human factors inadequacies in equipment design, and insufficient rest. Factors which determine reactions to stress, such as temperament, morale, discipline, and leadership are also examined. Fatigue is described in two major classifications: acute skill fatigue, which can be cured by a good nights rest, and chronic fatigue, which requires more extensive treatment. Fatigue management can be accomplished by: maintaining physical fitness, minimizing self-imposed stress, obtaining adequate rest, and having pre-scheduled rest and recreation periods.

212. US Department of the Air Force. 1954. *Fatigue in aircraft operations*. Washington, DC: Department of the Air Force. US Air Force Manual 160-5, 173-182.

This article, aimed at flight surgeons, is divided into two sections. The first deals with fatigue in general while the second discusses management and prevention of fatigue related problems in aviation activities.

Section one attempts to define the term "fatigue" in both a physiological and psychological context. The conceptual evolution of the term is traced from a simple concept of muscular contractile decrement to a concept which recognizes fatigue as having two distinct processes: subjective feelings and performance decrement. The concept of "skill fatigue" developed by Bartlett during the "Cambridge Cockpit" experiments is also described.

Section two discusses techniques flight surgeons can employ to treat fatigue in aircrew members. Perhaps the greatest service a flight surgeon can render is to discuss fatigue symptomatology thoroughly and frankly with all persons in his charge. Another recommendation involves added emphasis on providing crewmembers with rewards and privileges available within the natural setting of the operation to allay the onset of disabling fatigue episodes by providing additional motivation for successful task completion. The flight surgeon should also ensure proper rest and relaxation periods are utilized as part of pre-flight preparations.

213. US Department of the Air Force. 1968. *Fatigue in aerospace operations*. Washington, DC: Department of the Air Force. US Air Force Pamphlet 161-18, C12.

This chapter is a revision of coverage of similar material in the 1954 US Air Force Manual 160-5. The first half of this article defines fatigue, for the flight surgeon, as "that condition characterized by a detrimental alteration or decrement of skilled performance related to duration or repetitive use of various skills. Physical, physiological, and psychological stress may singly or in combination accentuate the fatigue state." Skill fatigue and chronic fatigue are defined and causes are identified for each.

The second half of the article discusses management of fatigue by the flight surgeon. Emphasis is placed on recognition and prevention of excessive fatigue in crewmembers. A table of factors that have been identified in previous research as having positive or negative effects on fatigue levels is presented. Flight surgeons are also given the responsibility for identifying individual crewmembers who are fatigued to the point where their performance is likely to be unsafe. This requires the flight surgeon to have detailed knowledge of how each crewmember normally behaves. The flight surgeon is also directed to "employ every means available to him to consider human factors and their relationship to safe and efficient job performance." The prescription of fatigue reducing drugs such as caffeine and dextro-amphetamines are discussed.

214. US Department of the Army. 1979. Stress and fatigue in flying operations. In: *Aeromedical training for flight personnel*. Washington, DC: Department of the Army. US Army Training Circular 1-20, C3.

This chapter identifies stress as a leading cause of fatigue. Therefore, in order to manage fatigue, stress must be combated. Stressors present for the aviator, such as extreme environments, poor weather, hypoxia, human factors design inadequacies, and insufficient sleep, are examined in detail.

Other factors which can determine aircrew's reaction or response to stressors are identified. Some of these factors include morale, leadership, and crewmember temperament. The prevention and/or reduction in aviator fatigue can be accomplished by following these guidelines: staying physically fit, minimizing self-imposed stresses, obtaining adequate rest, and having pre-scheduled rest and recreation periods.

215. US Department of the Army. 1980. Safety: Crew rest scheduling guide. In: *Army aviation: General provisions and flight regulations*. Washington, DC: Department of the Army. Army Regulation 95-1, C5.

This chapter of Army Regulation 95-1 outlines Army aviation safety procedures. Paragraph nine is specifically concerned with aircrew rest scheduling and gives commanders the responsibility for developing workable and effective schedules. To assist the commander, this chapter contains a table of suggested maximum duty hours, day flight, night flight, and combination day-night flight hours for specific duty periods of 24, 48, 72, 168 and 720 hours.

216. US Department of the Navy. 1978. Fatigue. In: *US Naval flight surgeon's manual*. Washington, DC: Office of Naval Research, Department of the Navy, C20.

This chapter identifies three types of fatigue for the flight surgeon. Chronic fatigue is produced by boredom and/or progressive anxiety and is cumulative in effect. Acute fatigue is produced by brief but very tiring work output. Task oriented fatigue, which is produced by long hours of work in a taxing environment, is of most consequence to the flight surgeon. The operational problems associated with task oriented fatigue are discussed in detail using accident reports and research findings. The need for some type of objective fatigue test, which can be used in the field within a short period of time, is outlined. However, until this type of test is developed, flight surgeons are instructed to look for fatigue correlates in crew members to aid in their diagnosis of fatigue. A list of fatigue correlates is provided for this purpose. Flight surgeons are also instructed to bring the need for appropriate work-rest schedules to the attention of command personnel. To facilitate this a brief summary of acceptable schedules is presented.

# W

217. Welford, A. T., Brown, R. A., and Gabb, J. E. 1950. Two experiments on fatigue as affecting skilled performance in civilian air crew. *British Journal of Psychology*. 40:195-211.

The two experiments described here were carried out at the B.O.A.C. Flying Boat Base at Southampton, in an attempt to secure objective measures of changes in the performance of air crew as a result of flying fatigue. Measures of performance by crew members, both before and after flights, at realistic complex tasks, were taken and the authors tried to analyze these into components which would indicate the nature of the changes taking place.

a. It would appear that if changes of performance occur with flying fatigue, they are more likely to be shown by tasks at least as complex as those with which the crew concerned normally deal, than by tasks which are considerably simpler, and

b. The complexity of the compensatory mechanisms of human behavior is such that even if significant effects could be shown on very simple sensory and motor functions studied in relative isolation, the effects of these changes when acting in a larger whole are not, in the present state of knowledge, predictable with any certainty.

Experiments carried out on civilian air crew with a view to studying the effects on complex skilled performances of fatigue resulting from flying gave the following results:

1. Electrical problems:

a. Radio Officers tested on return from a trip took longer and required more data to solve the problems than did those tested after a stand-down of at least 8 days.

b. When the trip had been a "hard" one, their solutions were markedly less accurate than when the trip had been an "easy" one.

2. Plotting task:

a. Radio Officers and Stewards tested on return from a hard trip showed a performance which was no less accurate but markedly slower than that of subjects tested after stand-down.

b. Similar impairment of performance was not found in the case of Radio Officers tested on return from an easy trip.

c. Stewards tested on return from an easy trip showed a performance intermediate between that of Stewards tested after a hard trip and those tested after stand-down.

3. Performances when tested a second time:

a. The impairment of performance shown in subjects tested first after a trip appeared also when they were retested after at least 8 days' stand-down.

b. Conversely, subjects initially tested after stand-down showed no impairment of performance when subsequently retested after a trip.

It appears, therefore, that measurable impairment of performance is likely to occur at tasks met for the first time when fatigued, but that little or no impairment occurs when the tasks have been met previously in a non-fatigued state.

The extent of the impairment appears to vary somewhat from one function to another, and the way in which impairment manifests itself appears to depend in part upon the demands made by the task upon the performer.

Suggestions are made for further research.

218. West, V., and Parker, J. F. 1975. *A review of recent literature: Measurement and prediction of operational fatigue.* (Final Report). Arlington, Virginia: Office of Naval Research. NR 201-067, February 1975. AD A008-405.

This report presents an overview, and selected bibliography, of research dealing with the measurement and prediction of fatigue and stress. The impetus for this review is the need by military medical personnel for procedures which might be used to evaluate "operational fatigue" during periods of sustained operations. Of most

interest are those techniques which can ultimately be easily implemented in a field setting. Two broad lines of investigation are being followed in current stress research. Investigators are generally attempting to identify either neurosensory or biochemical correlates of fatigue. Fatigue studies have failed to demonstrate conclusively a high positive correlation between subjective fatigue and work decrement. Performance can be maintained, within certain limits, in spite of limited sleep and high subjective fatigue.

While urinary excretion of proteins, electrolytes, and hormones seems to be related to fatigue, the relationship does not appear to be consistently demonstrable, principally because of individual variability in the magnitude and direction of response, and because of difficulty in controlling variables not under study such as circadian rhythms, climatic conditions, and food and fluid intake. It has been suggested that a fruitful area of research might be to seek other metabolites in the urine originating from tissue catabolism which would reflect more specifically stresses of various origins and fatigue in various stages. Some success may be in the offing in identification of neurosensory correlates of fatigue. Factor analysis of critical flicker fusion can distinguish meaningful phases of a long-term variation of cortical activity, and blink measurement may be a reliable index. Blink value, an indicator of autonomic system function, decreases with accumulation of fatigue. Moreover, these decreases follow trends similar to those shown by urinary excretion of total 17-hydroscorticosteroids. The blink technique is easily implemented, and evaluations can be performed with a high degree of accuracy within thirty seconds.

219. Wever, R. 1970. Circadian rhythms of some psychological functions under different conditions. In: Benson, A. J., ed., *Rest and activity cycles for the maintenance of efficiency of personnel concerned with military flight operations*: Aerospace Medical Panel Specialists' Meeting, 1970 May; Oslo, Norway. London: Technical Editing and Reproduction Ltd. NATO/AGARD CP-74-70.

Just as nearly all physiological functions, most measurable psychological functions show clear circadian rhythms. Their measurement requires, in contrast to that of physiological functions like rectal temperature, the wakefulness of the subjects. Therefore, measurements during night time can only be obtained, either when the subjects become awakened several times from sleep, or when they are continuously awake. In the first case, there are clear circadian rhythms, for instance in reaction time, with high performance during day time and low performance during night time. In the second case, the circadian amplitude of several functions decreases, coming from an approximation of the night values to the day values. This means: performance during night time is higher when subjects are continuously awake than when they

are awakened from sleep at the same time, and this difference seems to be the greater the more performance depends on decisions. This may be of interest with regard to alert readiness.

Furthermore, it would be advantageous with regard to a continuous readiness if circadian rhythms of parts of a crew could be shifted, in order to have available at any time of the day a part of this crew at its maximum of efficiency. It has been proved, on the one hand, that, in strong isolation from the environment and under the influence of an artificial Zeitgeber being strong enough, human circadian rhythms can be shifted to any phase in relation to local time. But on the other hand, in shift workers which are under the influence of a reversed work-rest schedule, circadian rhythms remain unshifted; the reason is that they cannot avoid social contacts with unshifted people. Shifts against local time are only possible, (1) if personnel do not perceive the shift, (2) if personnel have no direct contacts with unshifted people, and (3) if the shifted Zeitgeber is strong enough. In order to have available two groups of a crew with circadian rhythms being reversed against each other, it is proposed to try to shift both groups for each 6 hours but into opposite directions, instead of shifting only one group for 12 hours.

220. Whitehurst, L. R., and Schopper, A. W. 1980. *Aeromedical aspects of CH-47C helicopter self-deployment (Operation Northern Leap)*. Fort Rucker, Alabama: US Army Aeromedical Research Laboratory. USAARL Rep. No. 80-1, March 1980.

In August 1979, the US Army accomplished its first transatlantic helicopter flight. Four CH-47C cargo helicopters departed Fort Carson, Colorado, and landed in Heidelberg, Germany, with intermediate stops in Iowa, Pennsylvania, Maine, Canada, Greenland, Iceland and England. A flight surgeon accompanied the mission to provide medical support and assess aircrew workload, stress and fatigue. Direct observation, interviews and questionnaires were used to gather data.

Respiratory infections were experienced by approximately 50% of the mission crew during the 14-day journey. These were attributed to wide climate variations and inadequate crew rest during the first half of the mission. Daily pre-flight questionnaires showed highest levels of stress occurred at the start of the mission and decreased to a constant level once the mission was underway. Daily post-flight data demonstrated that cockpit workload increased appreciably with deterioration of weather during the latter part of the mission. Time at the flight controls and mission conditions during flight were found to be the greatest contributors to pilot fatigue; whereas, crew chiefs reported frequent time zone changes and poor facilities at stop-over points to be their greatest causes of fatigue.

The results demonstrated the feasibility of self-deployment and the need for medical support of such missions.

221. Whiteside, T. C. D. 1966. Sleep rhythms in transatlantic civil flying. In: *Assessment of skill and performance in flying*: Aerospace Medical Panel Specialists' Meeting, 1966 September 7; Toronto, Canada. London: Technical Editing and Reproduction Ltd. NATO/AGARD CP-14.

A number of east-west and west-east flights have been carried out in civil aircraft (Boeing 707 and Super VC10). These flights have been to New York, Bermuda, Singapore and Boston-Detroit. The parameters recorded and made use of in the investigation were pulse rate from take off to landing, with some short breaks in recording when the Captain who was being investigated, had to go aft for natural or for social purposes. A log was kept of activities on the flight deck and of the periods of sleep during the slip period.

The amount of sleep taken seems to be reflected in the changes in heart rate recorded at various periods of the flight. If the Captain has to fly during a period in which he would normally be sleeping, then, obviously, he must either have a sound and full night's sleep to whatever is the number of hours he usually requires, or he must in addition "bank" some sleep by sleeping in the middle of the day. To do this "banking" in an environment which is not conducive to sleep, introduces difficulties. For these reasons, it seems that a Captain is more liable to be fatigued by westerly flight in which the take-off time is in early evening as opposed to one in which the take-off time is in the late morning.

An attempt has been made to relate the degree of tiredness resultant from this sleep loss together with the fatigue produced by the flying task itself, to the pattern of cardiac activity during flight period.

A fatigue check list modified from one designed by the United States Air Force was employed in this investigation.

222. Wood, W. C. 1978. Implementation of a divisional aviation program to decrease flight crew fatigue. In: Knapp, S. C., ed., *Operational helicopter aviation medicine*: Aerospace Medical Panel Specialists' Meeting, 1978 May 1-5; Fort Rucker, Alabama. London: Technical Editing and Reproduction Ltd. NATO/AGARD CP-255.

Pilot error remains the leading cause of aircraft accidents. Pilot fatigue due to multiple stresses is a primary cause of pilot error. A vigorous and continuing program to recognize aviator

fatigue has been implemented in the U. S. First Armored Division in Europe. Aviators are given lectures which review the various stresses inherent in aviation. The two types of aviator fatigue, acute skill fatigue and chronic skill fatigue, are discussed in detail. The emphasis is on recognition by the aviators themselves of symptoms and signs of fatigue. Flight hour limitation is an important part of a crew rest program, but does not replace the other elements as presented in this paper. Prevention of fatigue and recognition of fatigue which has developed is an essential component of an aviation safety program. Prevention of aircraft accidents will result in the saving of lives and increased combat readiness of aviation units.

223. Woodward, D. P., and Nelson, P. D. 1974. *A user oriented review of the literature on the effects of sleep loss, work-rest schedules, and recovery on performance.* Washington, DC: Office of Naval Research. TR No. ACR 206, December 1974. AD A009-778.

This review provides a brief systematically organized account of the information from the scientific literature on the effects of sleep loss and work-rest schedules on performance. The orientation is practical, but consistent with the available data. A brief narrative description and a series of summary statements about the effects of sleep loss and work-rest schedules on human performance as they apply to operational settings is presented. Recovery from sleep loss effects as well as costs related to sleep loss effects are discussed briefly. Suggestions for future research are presented.

## Y

224. Yoss, R. E., Moyer, N. J., Carter, E. T., and Evans, W. E. 1970. Commercial airline pilot and his ability to remain alert. *Aerospace Medicine*. 41:1339-1346.

Fifty commercial airline pilots were studied, by means of infrared pupillography, as to the ability of each to remain alert while sitting in darkness for 15 minutes. The pupils of those who remained alert were large and stable; if drowsiness developed the pupils became smaller and pupillary waves appeared, with ptosis or eyelid closures. The performance of each subject was placed in one of four categories: superior, average, marginal, or unsatisfactory. Of the 32 pilots who were regarded as well rested, 28 performed in either a superior or an average manner; the performance of 3 was marginal; and 1 gave an unsatisfactory performance. Pilots with inadequate rest did less satisfactorily in their tests, as a group. It is recommended that testing of this type be studied further, since the ability to remain alert at present is not included in the assessment of pilots for medical certification by the Federal Aviation Administration.

## REFERENCE INDEX

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