THE ROLE OF FATIGUE IN PILOT PERFORMANCE

Prepared

by

National Research Council Committee on Selection and Training of Aircraft Pilots for the Civil Aeronautics Board at the request of the Division of Research, Civil Aeronautics Administration.

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National Research Council

Committee on Selection and Training of Aircraft Pilots

Executive Subcommittee

M. S. Viteles, Chairman

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LETTER OF TRANSMITTAL

NATIONAL RESEARCH COUNCIL

2101 Constitution Avenue, Washington, D. C.
Division of Anthropology and Psychology

Committee on Selection and Training of Aircraft Pilots

May 2, 1946

Dr. Dean R. Brimhall
Director of Research
Civil Aeronautics Administration
Washington 25, D. C.

Dear Dr. Brimhall:

Attached is a report entitled The Role of Fatigue in Pilot Performance, prepared by the Committee on Selection and Training of Aircraft Pilots. It is submitted by the Committee with the recommendation that it be included in the series of Technical Reports issued by the Division of Research, Civil Aeronautics Administration.

The report includes materials pertinent in considering the petition of TWA for a change in regulations pertaining to hours of scheduled flight by commercial airlines on long-range operation within the continental limits of the United States. In the section entitled "Foreword and Recommendations," the Committee has formulated certain tentative conclusions with respect to this problem. It has been found impossible to arrive at definitive recommendations because of the unavailability of crucial data applying specifically to commercial airline operations. The Committee strongly recommends that steps be taken to obtain such data through the use of scientific research methods applicable (a) in determining objectively attitudes of commercial pilots; (b) in analyzing operating data, including elapsed time of flight and distribution of schedules in relation to accident, overt signs of fatigue, etc.; and (c) in direct experimental studies of the type referred to in the attached report. I feel certain that the Committee on Selection and Training of Aircraft Pilots will be very willing to cooperate in planning the details of such investigations in association with the Division of Research, Civil Aeronautics Administration and other interested groups.

Cordially yours,

Morris S. Viteles, Chairman
Committee on Selection and
Training of Aircraft Pilots
National Research Council

MSV:rm

Second Edition
August 12, 1946

FOREWORD AND RECOMMENDATIONS

The report which follows has been prepared by the Committee on Selection and Training of Aircraft Pilots at the request of the Division of Research, Civil Aeronautics Administration, to provide information for use by the Civil Aeronautics Board in considering a request by Transcontinental & Western Air, Inc. (Appendix 1) for a change in regulations pertaining to hours of flight by commercial airline pilots. The petition requests that TWA be permitted to substitute compliance with the provisions of CAR Part 41, Paragraph 41.3041, for compliance with the provisions of CAR Part 61, Paragraph 61.518 in long-range operation within the continental limits of the United States with Lockheed Constellation type aircraft.

A basic question in considering this petition is whether 12 hours of long-range flight with one unscheduled stop is more or less fatiguing than 8 hours' scheduled flight time on domestic operations calling for a multiplicity of scheduled stops. It seemed appropriate that the literature of fatigue studies, particularly those involving aviation and related industries, be reviewed with a view to discovering information which might be pertinent in arriving at a decision with respect to the TWA petition.

The review which follows was prepared in the main, by Lt. Cdr. J. W. Macmillan, U.S.N.R., and Roland E. Johnston. A supplement, entitled Physiological Studies of Fatigue, prepared by Dr. A. C. Williams, Jr., Department of Psychology, University of Illinois, is attached to this report. The services of Lt. Cdr. Macmillan were made available to the Civil Aeronautics Administration by the Division of Aviation Medicine, Bureau of Medicine and Surgery, U. S. Navy. The Committee acknowledges its debt to this Bureau and to other units and personnel of the Army, Navy, Public Health Service, and other government organizations which contributed to the findings presented in this report. The services of Dr. Williams were provided through the courtesy of the Board of Trustees of the University of Illinois.

A striking feature of the survey is the paucity of experimental studies involving commercial airline pilots. The absence of data from such studies makes it impossible to arrive at definitive recommendations with respect to the problem posed in the communication from TWA. The situation is further complicated by the fact that nearly all experimental studies in the aviation field were made under conditions where the pilot had complete responsibility for doing all the work, and was not in a position to take advantage of the rest pauses and other avenues of relief available to the pilot on a commercial airline. Nevertheless, it does seem feasible, from a consideration of related studies, to make tentative suggestions as follows, with respect to the steps that might be taken in connection with the petition for the application of foreign regulations to domestic long-range operations.

1. The burden of evidence suggests that factors other than actual scheduled flight hours within the limits of 8 to 12 may be more important

than elapsed flight time in producing fatigue effects which are of significance in flying. Among the factors which may be considered more significant than the actual number of scheduled flying hours (within the range indicated) in producing adverse fatigue effects are:

a. Confidence of the pilot in the maintenance of equipment.

b. Automatic pilot and exchange of duties between pilot and co-pilot at periodic intervals.

c. The number of hours at intermediate altitude (5,000 to 12,000 ft.) without supplementary oxygen or pressurized cabin.

d. Rest pauses during flight.

e. The number of landings.

f. The frequency of long and unanticipated delays.

g. The need for formulating crucial decisions based upon changes of weather and other conditions related to non-scheduled as contrasted with scheduled stops.

h. The off-duty activities of the pilot and provisions for rest and relaxation.

i. The number and distribution of total flying hours throughout the month.

j. The design of equipment for comfort and safety.

2. The benefits achieved from scientific research on fatigue suggest the need for further investigations applying specifically to commercial airline operation. Such research should include investigations of:

a. The sources and effects of fatigue inherent in the direct on-duty task of flying the plane.

b. The sources and effects of fatigue induced by secondary on-duty situations such as delays, weather, disturbed schedules.

c. Off-duty activities of the pilot affecting his performance while on duty.

Research should also include continued investigations of the relationship between equipment design, methods of using such equipment, and fatigue.

Washington, D. C.
April 13, 1946

Morris S. Viteles, Chairman
Committee on Selection and
Training of Aircraft Pilots

CONTENTS

SUMMARY AND CONCLUSIONS

1. Definition of Fatigue. The definition of fatigue involves four aspects. Fatigue has a subjective component, the feeling of fatigue, or tiredness. Fatigue may be related to a physiological state, involving changes in organic functions and the formation of chemical products. Fatigue has an overt manifestation in the form of reduced output on the task, or impaired performance. Boredom, which may result from monotony, may bring about reduced output or impaired performance, and may be confused subjectively with fatigue.

2. Causes of Fatigue. The causes of fatigue as listed by several authorities are presented. Many of the factors mentioned are operative while an individual is out of the work situation, but influence the onset and course of fatigue while he is in the work situation. Some of these factors are operative throughout 24 hours a day. For presentation only, the factors influencing fatigue have been divided into those which operate away from work and those which operate during the time work is in progress. Among the former, worry, lack of sleep, predisposition toward neurotic involvement, lack of recreation and exercise, and the effects of alcohol and other drugs are important. Among the latter, fear, altitude, monotony, lack of rest periods, and seat discomfort are found most frequently mentioned.

The influences of many of these factors have never been quantitatively determined and are not readily amenable to exact quantification. Their existence is none the less real, however, and measures should be introduced into both the "on duty" and "off duty" periods to reduce the effect of these factors to a minimum in commercial airline pilots.

3. Adverse Effects of Fatigue. In this section the topics discussed are fatigue and accidents, fatigue and general efficiency, and the long-range effects of fatigue. Fatigue results in impaired performance and such impairment may be a factor in the causation of accidents. Aircraft accident statistics show that about one-half of all accidents are landing accidents, and that one-half of all accidents are due to personnel error. The fact that long-range operation reduces the number of landings is an important fact in considering fatigue effects.

Investigations, both in the United States and in Europe have shown that industrial accidents tend to increase with each successive hour of work, with a falling off of the accident rate at the end of the work spell. This falling off is explained as due to a lower production rate toward the end of the work period. Such accidents in the industrial situation are held to be caused -- at least in part -- by fatigue.

Fatigue in flyers has been found to be out of proportion to the physical exertion involved and is ascribed primarily to psychological factors such as emotional stress. These psychological factors are difficult to study objectively, but there is essential agreement that they result in a deterioration of skill. Fatigue results in a lowering of general efficiency. It is significant for the present problem that the pilot may be unaware of this general reduction in efficiency.

Normal tiredness or fatigue is relieved by normal sleep. When a person is fatigued day after day to the extent that normal sleep is not sufficient, then fatigue becomes cumulative and may result in a lowered state of efficiency frequently accompanied by chronic anxiety. However, the present problem is concerned more with the transient type of fatigue which is relieved by rest. Yet, the very fact that fatigue can be cumulative makes it desirable to raise the question if long-range operations will be more fatiguing than operations under existing regulations.

In this connection, it would be of interest to know how commercial pilots spend their off-duty periods, since unwise recreation can be as fatiguing as work itself. Would the long-range flight be more conducive to better utilization of off-duty time?

4. Study of Fatigue in Pilots. Studies made on pilots and on those in training to be pilots are here reviewed, especially a group of studies conducted by the British Air Ministry. Limited information, however, is available concerning flying hours and accidents. The conclusions to be drawn from the studies reviewed are:

a. Tired men unknowingly accept and are satisfied with a lower and lower standard of performance, but at the same time are sure that their work is being done as well or better than it was when they were fresh.

b. There is a disorganization of skilled performances with fatigue in the sense that timing of movements is erroneous, economy of movement breaks down, and the set task, instead of being a coordinated whole becomes a series of discrete unit tasks. The individual acts on a "stimulus-response" level without an intellectual grasp of the task to be performed.

c. Distractions in the form of increased perception of bodily discomfort may cause disturbance of skill and the carrying out of tasks in improper fashion.

d. Marginal reactions, or those which have to be performed only occasionally are likely to be forgotten.

e. Evidence given by tired men concerning happenings in their immediate surroundings become increasingly inaccurate with the development of fatigue.

f. The more a tired man is aware of the symptoms of fatigue, the less likely he is to display dangerous signs of fatigue.

g. There is evidence that the effects of fatigue may be far more delayed than is generally supposed.

These studies were made largely on the ground and with military pilots and to infer that the same findings would hold for pilots of commercial airplanes is not permissible unless and until it has been shown that the instruments and procedures used in the experiments correspond to those in the cockpit of a large aircraft in flight.

5. Studies from the Transportation Industry. This section includes studies of automobile driving, of accidents of motor vehicles, and the general problems of fatigue and hours of service of truck drivers.

An experimental study of the effects of about 11 hours of automobile driving revealed a loss of effectiveness of sensory discriminations, association processes, and motor reactions. Mean scores were lower and variability greater.

Studies of automobile and truck accidents occurring when the driver fell asleep indicated that these tend to happen after but a few hours at the wheel, but there is another upward trend after about 11 hours of driving. Fatigue accumulated prior to starting to drive is a factor in driver-asleep accidents.

A study made in France indicated again that for truck drivers working very long hours, fatigue results in lowered efficiency.

A study of fatigue and hours of service of interstate truck drivers indicated poorer scores on tests of speed of tapping, reaction coordination, body sway, reaction time, steadiness of hands, decrease in vigilance, decrease in ability to perceive flicker, and other psychomotor functions involved in driving, presumably due to fatigue.

Reports of the Interstate Commerce Commission contain other studies, and emphasize the high percentage of accidents of motor vehicles occurring after 10 hours of duty.

A report by the American Trucking Association finds no relation between accidents and hours of duty up to 16; that hours of rest and the time and duration of stops for rest bear no relation to accident frequency. This study proposes that some accidents may be caused by the driver being too rested. In the alert condition the driver does not need to give all of his attention to the task of driving. This matter is confused since alertness may be conducive to driving at higher speeds -- and this uncontrolled factor might be one of the many involved in the general problem.

These studies in transportation point to the importance of considering fatigue from all sources in relation to the decreased efficiency which increases accident liability. Hours on duty do not represent the sole consideration since many of the accidents occur after but a few hours at the wheel. These studies again suggest the desirability of exploring thoroughly the relation between off-duty activities and the incidence of fatigue during flights of long range. The off-duty factors might prove to be much more important in producing impaired performance than any difference in the fatiguing effect between eight hours of flight and the proposed long-range flight. There is a need for studies in commercial airlines of the problem of off-duty hours and the time and incidence of accidents, or other indices of impaired performance. A further problem is that of the degree of impairment in relation to the time since the last stop, where a number of landings are involved.

6. Studies from other Industries. Studies in 12 American industrial plants have indicated that hours worked beyond 40 or 48 per week result in additional output, but at the price of continuous decreases in efficiency and marked increases in absenteeism as hours rise. In the absence of effective safety programs, work injuries tended to occur relatively more frequently under longer hours.

These studies indicate that fatigue results in a reduction of efficiency which is reflected in a falling off of production rate, an increase in the number of errors thus causing a greater spoilage of materials, unauthorized absenteeism, and an increase in the number of injuries and accidents. Sufficient motivation, as seen in wage incentive programs, promotes efficiency at a high level or even increases it.

If the proposed long-range flights mean more predictable schedules for the pilots, if they permit the pilots to spend more time at home, if they reduce the amount of time the pilots have to spend waiting for take-offs, then it may be considered if these factors are motivational to the extent that any possibly greater fatigue associated with the longer flight becomes of little significance.

Studies in Great Britain by the Industrial Health Research Board generally confirm the observation that fatigue is revealed in a lowering of the quantity and quality of work. These studies have shown that fatigue is productive of organic changes, sometimes expressed in some digestive disturbance, in eye strain, headache, and various minor disorders. There is diminution in the power of concentration, in memory, in ability to see the connection between ideas, all of which are important for efficiency.

While it is true that the hours of work obtaining in industrial plants differ considerably from those of commercial airline pilots, nevertheless they serve to point up the adverse effect of fatigue from whatever source upon human efficiency. These studies of fatigue in industry throw little light upon the very important question whether a long-range flight involving but two or three landings is more or less fatiguing than the flights under present regulations which often involve more landings -- considering the landing as the crucial aspect of the pilot's task, an aspect in which any effect of fatigue demands careful consideration.

7. Laboratory and Other Studies. Some investigators have felt that noise is one of the major contributing causes of fatigue in flying. Pilots

of heavy bombers, however, stated they had not noticed or been disturbed by noise. In general, noise is probably not a serious factor in view of the construction of modern commercial aircraft.

Studies regarding the effect of loss of sleep do not demonstrate conclusively that performance on short tests with sleep lack is increasingly worse with successive trials. However, the reports do state that the behavior of the subjects was vastly different from first to last trials.

A study of 13½ hours of continuous tracking showed a reduction in efficiency which was not counterbalanced by monetary motivation.

The evidence from laboratory experiments is conflicting and it becomes apparent that in order to determine whether additional hours of duty for pilots will produce a decrement in performance it will first be necessary to determine exactly what the pilot does, both on and off the job, and to what extent the job is fatiguing. Any general application of results of laboratory studies to the flying situation is dangerous because exact relationships between the performances measured in such studies and pilot performance in the air are largely unknown.

An extensive review of the literature on anoxia has led to the conclusion that flying at 10,000 feet without oxygen should not be permitted. Further work is needed to determine the maximum base altitude, especially where a pressurized cabin is employed. Most studies on chronic anoxia are either negative, equivocal, clinically insignificant, or difficult to interpret.

8. Design of Equipment and Fatigue. In this report there has been no attempt to cover thoroughly the problem of fatigue in relation to aircraft design. It has been suggested that there is room for a vast amount of research in this general area. This problem is mentioned in passing because the commercial airlines might well contribute to the definition of more specific problems by compiling lists of pilots' complaints and their suggestions regarding seats, controls, instruments, lighting, visibility, pressurization, temperature, ventilation, etc., and promote research activities. In doing so, the airlines could make a definite contribution toward the reduction of fatigue, and the solution of operating problems related to fatigue.

THE ROLE OF FATIGUE IN PILOT PERFORMANCE

I. DEFINITION OF FATIGUE

Although the literature upon the subject contains various approaches to the definition and the study of fatigue, the definitions proposed or implied in some way are related to the following four aspects.

1. Fatigue has a subjective component: a feeling of fatigue or tiredness.

2. Fatigue may be related to a physiological state, involving changes in organic functions and the formation of chemical products of fatigue.

3. Fatigue has an overt manifestation in the form of reduced output on the task, or impaired performance.

4. Boredom, which may result from monotony, may result in reduced output, or impaired performance, and may be confused subjectively with fatigue.

The problem with which this report deals may be considered in view of these four aspects of fatigue. While a complete analysis of the literature relating to definition is unnecessary for the present purpose, it may be well to discuss these definitions in detail and to review a few of the difficulties which obtain.

1. <u>The Feeling of Fatigue.</u> The feeling of general tiredness may result from activity which is essentially physical, or from work which is largely mental. Bills (10) has discussed the feelings which are produced in these two kinds of activity.

> "There is some confusion in people's minds about how mental fatigue feels, because their early familiarity with the feelings accompanying physical exhaustion leads them to expect a similar set of subjective symptoms to accompany mental tiredness. When they fail to find these, they conclude that it is not real fatigue. But why should we expect to experience the same types of feelings when entirely different mechanisms suffer wear and tear? Physical fatigue consists of aches and soreness in the large muscles, accompanied by a feeling of impotence, increased awareness of the body's weight, and a strong desire to sit or lie down. The excitability of the sense organs is lessened, and the sensations of tonus are reduced because of the relaxed state of the muscles. Thoughts come rather sluggishly, and only by a special effort, rather than protruding upon the mind unbidden. Associations are restricted in range. Usually relaxation is easy and sleep comes quickly.

"Contrast with this the experiences that accompany overtired nerves and brain resulting from mental labor. The large muscles do not ache, although they may feel cramped because of having undergone too little rather than too much use. But, the small muscles of the face, eyes, neck, and throat may ache or feel sore, because they have been in a state of exaggerated tenseness. There is a restlessness of the whole body, the result of enforced restraint and of impulses to action that are unsatisfied. Sitting down or lying down only aggrevates it. If we try to sleep, thoughts keep crowding our consciousness, the anxious or annoying kinds of thoughts that increase our tenseness and keep us turning and tossing. The sense organs are not deadened as they are in physical exhaustion; they are more excitable than normally. Noises that ordinarily go unnoticed seem intolerable. Emotional irritability is enhanced; the temper is short. There is a sense of impotence, but not for physical exertion. It is rather an unwillingness to attempt any mental work or face any responsibilities."

It is quite apparent that seldom, if ever, will work be strictly dichotomized as physical or mental. Physical activities make demands upon the sensory apparatus and certain levels of the nervous system. On the other hand, mental activity will usually be accompanied by activity of the muscles. As Viteles (59) points out, the direct funtional impairment of nerve cells located at the higher levels can account for mental fatigue evident in work decrement and in the feeling of weariness experienced in purely mental operations such as silent reading, mental arithmetic, the solution of verbal intelligence problems, etc. However, mental fatigue may also be the result of the actual contraction of vocal muscles in the process of thinking or in other muscular activity in gesturing, in changes of facial expression, changes of body position, etc., associated with mental work. Viteles concluded that there appears to be little difference between so-called muscular and mental fatigue, at least in regard to practical effects.

It is of importance to consider the relationship between the feeling of fatigue on the one hand and the physiological condition of the organism and the ability to continue to work effectively on the other. According to Tiffin (54), for one speculating upon the subject of fatigue, it is a temptation to look upon these two aspects of the phenomenon -- the physiological and the psychological -- as different aspects of the same fundamental change. According to this point of view, feelings of boredom and tiredness occur in proportion as physiological changes in the muscle have taken place; and vice versa, actual changes in the physiological composition of the muscles have taken place to the extent that feelings of tiredness or boredom are experienced by the subject. If this simple relation were true, the problems of fatigue and its elimination would be greatly simplified. Unfortunately, numerous physiological and psychological experiments have shown that no such simple relation exists. This point is of importance to the present problem since it would be quite possible for pilot proficiency to suffer deterioration, although he may actually feel neither tired nor bored.

Braceland and Rome (17) have discussed the relationship between fatigue and anxiety. There is a reciprocal relationship between the degree of fatigue and the degree of anxiety experienced by the individual. The psychosomatic couplet which results is physiologically initiated in a normal person; fatigue, in this instance, functions as a catalyst to activate anxiety which is latent in all persons. Thoreau spoke of it as "that quiet desperation which rests in the heart of the great mass of men." On the other hand, in the frankly psychoneurotic personality this dynamic state of affairs is reversed and the patient's fatigue is not only proportional to his anxiety but is also induced by it. The dynamic interdependence which exists between the thresholds of anxiety and fatigue varies greatly in the same individual at different times as well as between individuals -- yet, there is a constancy in the relationship between the degree of fatigue and the height of the anxiety threshold. Then, too, within themselves these two phenomena vary independently in regard to a number of factors. Environmental conditions, both internal and external, have been recognized in recent years to exert important influences upon the degrees of fatigue and anxiety experienced. For instance, a deprivation of oxygen and an increase in the atmospheric pressure, both independently and in combination, bring about the rapid onset of fatigue in all of its characteristics, and this, in accordance with the individual's personality makeup, has a direct bearing upon his emotional state. Despite a very real physiological basis, the vulnerability of the individual to those effects is not necessarily a matter of constitutional predisposition. This is demonstrated by the variations in susceptibility to both anxiety and fatigue in the same individual at various times. Anxiety may be detrimental to the quality of performance.

2. <u>Physiological Fatigue.</u> Muscular activity and mental activity depend upon a transformation of energy, and the immediate source of energy for the muscle is the carbohydrate substance glycogen. In the process of energy release, glycogen is changed to lactic acid.

In recovery, lactic acid is reconverted to glycogen by the action of oxygen. This oxidation process is not a simple reaction, but its chemistry need not be considered here. The conversion of lactic acid to glycogen is anabolic, a process in which energy is stored. The energy to be stored in the newly produced glycogen is derived from the oxidation of approximately one-fifth of the lactic acid present to carbon dioxide and water. This process of recovery is aided by an increased heart rate and accelerated respiration. As lactic acid is formed, the demand for oxygen increases. This results in an accumulating <u>oxygen debt</u>, which is equated to the oxygen required for recovery.

Respiratory exchange has been found to be a valuable method of assessing the cost to the body of a given piece of manual work. Assuming that the individual is physically fit, the limiting factor in continued strenuous effort is the rate at which oxygen can be absorbed and utilized. He may gradually become fatigued, however, partly from the actual consumption of the energy producing substance. Chemical analysis of air expired when at rest compared with that of air expired during a given task, provides a method of determining the cost of the work to the body, expressed in terms of cubic contiuete. of oxygen used. Hence, the amount of the oxygen debt is determined as it is repaid. This method of determining the presence and extent of physiological fatigue was employed in certain of the experiments which will be cited below in reference to the problem of this report.

An acceleration of the circulatory function is a concomitant of fatigue. Pulse count and pulse pressure are increased. There may be an increase in the number of both red and white blood cells. Changes occur in blood pressure. The percentage of blood sugar may be higher. Changes occur in the chemical composition of the urine.

Fatigue of the nervous system is believed to be related to the excessive use of the synapses between the nerve cells in the spinal cord and the brain. Fatigue products at the motor nerve endings may account for the change in chronaxie, or in the strength and duration of the stimulus necessary to produce muscular response.

Fatigue, particularly that occurring in flying, may produce changes in the visual function. Borges Dias (12) found by means of phorometric examinations that heterophoria may be caused by visual fatigue due to prolonged flying in pilots with normal refraction. Heterophoria from visual fatigue is transient; it disappears by ceasing flying, rest, and physical and mental recreation.

The flicker-fusion frequency is decreased slightly with fatigue. However, Brozek and Keys (14) report that the test cannot be considered a sensitive indicator of general fatigue.

These changes in metabolism provide methods of detecting the presence of fatigue and serve in assessing the physiological cost of work. The experiments cited in later sections of this report employ such methods in answering questions which bear more directly upon the present problem.

3. Fatigue and Impaired Performance. The course of reduced productivity as a result of work can be illustrated in its simplest form through the use of the finger ergograph. This instrument permits the exercise of a single finger in lifting a weight tied to a string. The ergogram -- a graphic record of the movement of the lifted weight -- indicates a regular decrease in the amount of work from second to second. Less and less work is done by the finger, until in the course of a few minutes, a point is reached where, in spite of the desire of the subject, the weight can no longer be lifted.

Production records from many industries indicate a similar decrement, a decrease in the quantity and quality of work believed to be associated with fatigue. Figure 1 shows a typical daily production curve, from Viteles (59).

During the first part of the morning there is an increase in production due to a "warming up," or incitement. Fatigue produces a falling off of production in the later part of the morning. The luncheon period is

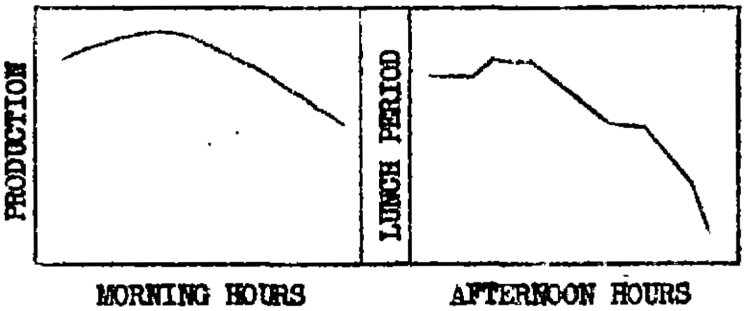


FIGURE 1

TYPICAL DAILY PRODUCTION CURVE
(From Viteles, after Burtt)

followed by an increase in relation to the end of the morning period, but the afternoon does not reach the maximum occurring during the morning. The late afternoon brings on another serious impairment. This impairment is considered to be an overt manifestation of fatigue.

Manzer (39) has investigated the effect of fatigue upon variability of output in muscular work. The data consisted of work performed by 27 men (college students), each of whom performed 11 periods of work or a total of 297 work periods. The muscles used were the flexors of the middle finger. In each work period, work was continued to exhaustion; a rest of 5 minutes was interspersed between successive work periods; the load was a 10-pound weight. He found that in work done with unfatigued muscles, the work done in the later periods of the series is significantly more variable than that done in the earlier periods. A comparison of the work done in the first 10 contractions of each work period with that done in the last 10 contractions shows that the mean output of work done with fatigued muscles is one-fifth (21 per cent) of that done with unfatigued muscles. The relative variability of work done with fatigued muscles is 3 times (309 per cent) the variability of the work done with unfatigued muscles.

It is recognized that mental work does not require energy in amounts comparable to that required in manual labor. Yet, as indicated above, mental work does reqire energy and it usually involves considerable physical activity as well.

Bills (11) has cited experiments which show that under certain conditions impairment is transferred. "The theory that sensory and motor fatigue contribute much of the decrement to mental work was tested by the transfer method. Lucien Cohen tested 120 subjects. In Experiment I, the decrement in speed, accuracy, etc., from 15 minutes of manual color responding, using one eye, was compared with the subsequent recovery when a shift was made to the unused eye. The entire decrement transferred. In Experiment II, the shift was from one hand to the other. Again, the transfer was 100 per cent. But, in Experiment III, only 25 per cent of the decrement from responding to color stimuli transferred to colored form stimuli, or vice versa. These experiments show that the decrement was neither sensory nor motor, but specific to the meaningful aspect of the stimuli reacted to. Therefore, fatigue is mainly central."

Although later sections of this report will deal more fully with the impairment of performance in various types of industrial work, examples will be presented here as a matter of illustration. Smith (50) has summarized the studies made by the Industrial Health Research Board, in Great Britain. Vernon (55) recorded for 3 shifts the time in minutes required for each charge and the actual hours when each occurred in the heavy work of charging blast furnaces by hand. The results showed that (with the exception of the brief spell from 6 A.M. to 8 A.M.) the rate of charging fell off during the last period of each spell, showing an average decline of 14 per cent; also that this effect became exaggerated during the morning and afternoon shifts of Sunday when the men worked a continuous shift of 16 hours (6 A.M. to 10 P.M.) in order to allow the shifts to change over. If the hourly output is represented by a graph, there is low output to begin with, followed by a rise leading to a fall. The interpretation given is that the fall is due to the effect of fatigue.

Although accidents have several causes, yet there is evidence that a state of fatigue due to too long hours and insufficient rest causes an increase in the number of accidents. Vernon (56) reports that during a period of 1914-1918 war when a 12-hour day (75-hour week) was being worked, the accidents incurred by women workers were 2½ times more numerous than in the subsequent period when the daily hours were reduced to 10.

4. Monotony and Boredom. The chief characteristic of monotonous work is the unpleasant feeling that the task arouses in the individual. A feeling of boredom and an increasing feeling of tension as the work progresses represent the subjective characteristics of monotonous work. Objectively, this feeling of monotony is characterized by restlessness, indicated in a frequent shift of position, by yawning, and by verbal expressions of dissatisfaction with the work on the part of the worker (59).

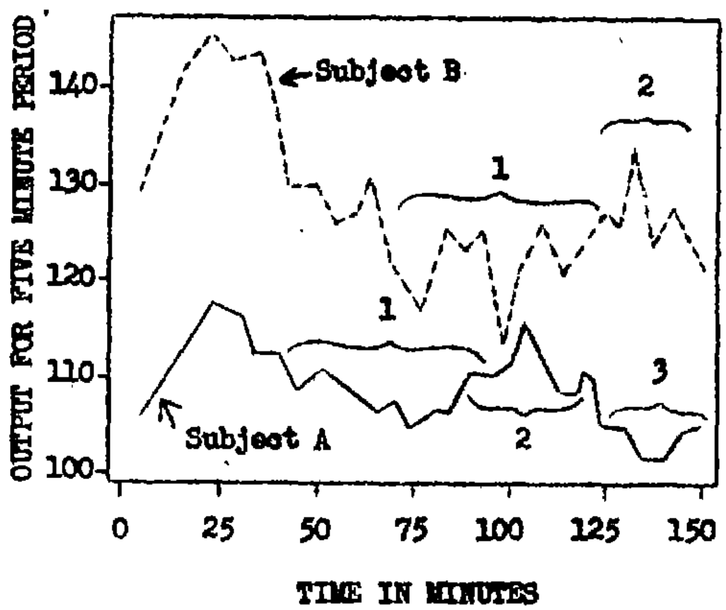
Work accompanied by monotony is characterized not only by a feeling of dissatisfaction and tension, but by a distinct change in the rate and regularity of production. This includes, primarily:

a. A drop in the rate of work in the middle of a working spell.

b. An increased variability in the rate of work (59).

Figure 2 indicates the typical production curve which is found in monotonous work.

When the task does not demand the entire attention of the worker, feelings of boredom arise; under such conditions time intervals tend to be overestimated. Bordeom is expêrienced more frequently by workers of higher intelligence.



1. Work very monotonous.
2. Believed end of test to be near.
3. Disappointed at delay.

FIGURE 2

RATE OF WORK IN COMPARISON WITH
SUBJECTIVE STATES DURING MONOTONOUS WORK

Wyatt, Fraser, and Stock (68) approach the problem of boredom by contrasting it with interest, since one is due to the absence of certain elements which are present in the other. To be interested means that we attend spontaneously to the object or situation which appeals to our inclination or desires, and we continue to do so until either satisfaction is achieved or the tendency is neutralized by the effects of fatigue. A characteristic feature of interesting activities is that they are performed with a minimum of effort. The curve of work under such conditions usually exhibits a high level of performance and only begins to decline as the effects of fatigue increase. Conversely, activities that fail to harmonize with the desires of the individual are usually uninteresting and unsatisfying. Activities which are unpleasant are continued only at the expense of increased volitional effort. In such cases, effort is not only required to perform the necessary movements, but it must also be used to repress the intruding ideas and desires. Work under such conditions may very quickly become distasteful and unsatisfying, and the resulting experience is known as boredom. It is obvious that boredom, at least in its early stages, is something quite distinct from fatigue.

In another report, Wyatt and Fraser (67) make the interesting comment that while we can be unconsciously fatigued, we cannot be unconsciously bored.

In industrial situations, boredom is most often associated with monotonous, repetitive tasks. It is most marked in semi-automatic processes which require enough attention to prevent mind-wandering but not enough for the complete absorption of mental activity.

In connection with the present problem, it is suspected that boredom is a condition which obtains on long flights, especially when this automatic pilot is in use.

II. CAUSES OF FATIGUE

One of the necessary considerations in any study of fatigue in pilots is that of factors which produce fatigue and not only which factors produce fatigue, but which are most important in the production and course of fatigue, both in and out of the work situation. Thus, there are two partially independent groups of factors to consider, the first being those which influence fatigue aside from the work situation, the others which are present in the work situation.

There are considered first those which are antecedant to the job, but which may influence the onset and course of fatigue after work begins. Many reports dealing with these have been reviewed and there is, on the whole, a rather high degree of agreement among different authors. Some of the lists compiled by various authors will be presented here in illustration. These have been compiled both by civilians and by members of the military services, especially flight surgeons and other people most closely concerned with pilot performance.

One of the earliest investigators of fatigue in pilots was McFarland. He lists (40) as factors contributing to fatigue:

a. Worry

b. Personal maladjustment

c. Lack of exercise

d. Improper diet

e. Excessive use of alcohol

f. Excessive use of tobacco

g. Fear or anxiety

This, as McFarland says, is not by any means a complete list but those mentioned constitute some of the major contributing factors. He discusses each of them briefly in this report and in a later report (41) gives a more complete discussion of each and its influence on pilot performance. It is not the purpose of this section of the report to present the details of the development of these lists, but simply to present them so that readers may see what those people most closely concerned with pilots think are the important factors in pilot performance. Some of these will be more fully discussed in later sections of the report.

In a letter to the Coordinator of Safety Regulations of the CAA, Delaney, of the CAA Operations Office, divides factors influencing fatigue into three different groups or classes (17). The first of these groups consists of factors operating prior to reporting for duty; the second, factors while on duty; and the third, factors after duty is completed. Those in the first group are:

a. Physical condition and temperament of pilot.

b. Home conditions.

c. Financial circumstances.

d. Business other than that of flying in which the pilot is concerned.

e. Days off since last flight and how time is spent.

f. Duration of rest period (actual sleep) prior to departure.

g. Rest facilities and hours during which rest must be obtained, (that is, day or night, quiet or noisy, cold, cool, hot, damp, dry, etc.).

h. Each pilot's wakeful period prior to reporting to duty.

i. "Dead-head" time to duty location.

j. Time required to travel from home or rest location to point of duty.

k. The hour of day or night at which the pilot must report for duty.

The third group contains factors at end of flight and prior to next flight. These are:

a. Terminal on duty period.

b. "Dead-heading time" to home or next duty location.

c. Days off at home or at rest location.

d. Length of layover period.

e. Rest period after arrival at home or rest point.

f. Rest facilities and hours during which rest must be obtained, (day or night, quiet or noisy, cold, cool, hot, damp, dry, etc.)

g. Actual flying time of the last trip and conditions of last trip, whether the trip was excessively fatiguing or not.

Delaney offers the opinion that the factors in these two groups fall within the realm of company control, and general regulations should be provided to comply with which would require companies to investigate and take appropriate action. Items falling in the second group, i.e., those factors operating while on duty, will be considered presently.

In a discussion of "pilot staleness" (28), Kalez and Hovde list among contributing causes:

a. Bad news from home.

b. The loss of the girlfriend back home to the local boy.

c. Unavoidable delays in training due to illness.

d. The early adjustment to married life and the growing cleft between combat forces and high paid civilian workers.

Although made from observations of military pilots, this list contains items which are equally applicable to civilian pilots.

Also dealing with the military pilot, a report by the Aviation Psychology Branch of the Bureau of Medicine and Surgery of the Navy Department (87) lists the following as factors tending to promote war weariness. (War weariness is defined as "the partial disintegration of the personality under stress").

a. Worry over family.

b. Predisposition toward neurotic involvement.

c. Fear of death, injury, and especially capture.

d. Personal quarrels and incompatibilities with squadron mates.

e. Lack of recreational facilities and liberty.

f. Doubt as to quality and condition of aircraft.

g. Monotony of long standbys.

h. Poor food.

i. Interruption or lack of sleep.

j. Dislike of a particular flight or plane.

This does not represent the complete list given, but only those factors operative while the pilot is on the ground and which are applicable to civilian as well as to military flying. They were derived from many observations made by veteran squadron commanders, flight surgeons, and pilots themselves. Though many of them are not directly measurable and cannot be quantified in any known way, they do exist and are important in the fitness of a pilot for flying duty.

In a study made on truck drivers by the Public Health Service (71) a list of factors contributing to fatigue was given. These, although applying to truck drivers, are equally true in relation to pilots. Those which influence fatigue previous to going on duty are:

a. General irregularity of habits, particularly in respect to sleep, food, recreation, and exercise.

b. Failure to obtain satisfactory rest or sleep during rest periods at work or on "off duty." (This may be due in part to the nature of the schedule; deficiency in facilities for rest; dissipation; or failure to take proper advantage of free time.)

c. Physical condition and general health status, especially with regard to physical handicaps such as visual defects (the latter would not operate in the case of pilots).

d. Social factors in environment or occupational tradition tending toward irregularity of habits, among which are: enforced absence from home and the roving character of the driver's career.

e. Use of coffee and the effect of nervous strain in causing insomnia.

f. The effect of alcohol and other drugs.

g. Economic security, fear of losing job, especially in the case of older men.

h. Sedentary occupation, effect of posture.

If we substitute in the above list the word "pilot" for "driver," and "flying" for "driving," the list is applicable to pilots and almost exactly duplicates the list given above.

Those factors which influence fatigue while the pilot is actually on the job constitute the other group. Many of these are to some extent measurable and can be more easily quantified than those in the first group. Again, reference will be made to studies, some of which will be discussed in other sections of the report. McFarland (40) lists the following:

a. Noise

b. Vibration

c. Illumination

d. Altitude

e. Fear and anxiety

Delaney's letter mentioned above (17) gives a set of factors which operate while the pilot is on duty. These are:

a. Time in advance of departure pilot is required to report for duty.

b. Weather study time preceding departure.

c. Pre-flight inspection time of equipment by pilots.

d. Dead-head time prior to departure.

e. Dead-head time in flight prior to acting as relief pilot or to assume flight duties as regular pilot or co-pilot.

f. Scheduled to fly time.

g. Scheduled to elapse time.

h. Intermediate stop time.

i. Scheduled active "on duty" period, during which time it is necessary to consider weather encountered, amount of actual instrument flying time, elevation of flight, oxygen deficiency, weather conditions at terminal entry, icing conditions, mechanical difficulties encountered, season of year, etc.

Many of the factors which are concomitants of the flying situation are operative during subsequent flying, as well as productive of adverse effects while the pilot is off duty. For instance, in the War Weariness Report (87) such factors as fear of death, injury, and especially capture, worry over family, predisposition toward neurotic involvement, doubt as to quality and condition of aircraft, and dislike of a particular type of flying duty or plane, are present at all times. The division of the factors into two groups is largely arbitrary and for the sake of convenience in exposition.

In the truck driving study cited (71) several factors are mentioned which operate mainly under conditions of driving:

a. Performance of a skilled operation requiring a high degree of alertness and attention, i.e., the fundamental work of the driver.

b. Nervous strain due to driving under adverse conditions. Fear of accidents and a feeling of responsibility for cargo play a part in causing strain, also the pressure of keeping on schedule especially when certain types of freight are handled, e.g., explosive, perishables, inflammables, etc.

c. Muscular exertion in loading and unloading, and in repair and maintenance of vehicles.

d. Constant use of eyes, frequently under unfavorable conditions, effect of glare and faulty illumination generally.

e. Monotony and other factors inducing sleepiness.

f. Exposure to atmospheric forces, cold, heat, wind, weather, etc.

g. Exposure to toxic fumes and gases.

h. Noise.

i. Vibration.

Again, substituting "pilot" for "driver" and "flying" for "driving" the factors are identical with those found in the flying situation with the possible exception of c.

In a study made by the British (63), 100 experienced pilots were asked to rate on a five-point scale those factors that they thought caused fatigue in flying. These are shown below in rank order:

a. Formation flying.

b. Intensive flying (i.e., two nights running).

c. Bad weather.

d. Strong opposition.

e. Long flight.

f. Instrument flying.

g. Cold.

h. Being lost.

i. Waiting to take off.

j. Difficulty in finding target.

k. Low flying.

l. Briefing too early.

m. Cancellation of flight.

n. Noise.

o. Vibration.

p. Oxygen heights, using oxygen as against flying lower.

It will be noted that 2 of the 3 most important of these are intensive flying and bad weather, both of which are operative in civilian as well as in military flying. These pilots were also asked general questions as to whether they suffered from fatigue after long flight or after 2 consecutive nights of flying. Sixty-seven per cent of them answered yes to the first part of the question, and 70 per cent answered yes to the second part. They were also asked if they suffered from fatigue at the end of a tour of duty. Less than half or 42 per cent said yes, which indicated that the fatigue suffered on long flights after 2 consecutive nights is transitory in nature, but none the less real.

The above may be summarized by saying that there are factors which influence the onset and course of fatigue during 24 hours of a pilot's day, there are some which are specific to the flying hours, and some which may be specific to the non-flying hours. Those specific to the non-flying hours should be reduced as far as possible by the pilots themselves and by company rulings. Those specific to the flying hours should be reduced as far as possible by careful job analyses and resulting modifications of the job to lessen "fatigue" as it may be found in any of its aspects.

Some attempts have been made to determine which factors reduce fatigue as found in the flying and driving situation. Most of the flying reports have to do with combat pilots, but many of those factors said to reduce fatigue by military pilots and by those most closely associated with them are applicable to civilian pilots as well. For example, McFarland (40) says that the pilot should keep in physical condition by taking exercise, his diet should be adequate, he should not over-indulge in alcohol and tobacco, he should have a regular home life with adequate sleep and should be as far as possible free from worry of a financial nature. Delaney's recommendation (17) has been mentioned above concerning the treatments of pilots during their time off duty, as well as time on duty. Hovde and Kalez (28) mentioned the following things as valuable in the prevention of pilot staleness.

a. Improvement of standards of physical and psychological selection through the use of laboratory aids.

b. Improvement in standardization of methods of elimination or reassignment of pilots failing to maintain standards.

c. Establishment of appropriate rest for pilots subjected to depleting aviation experiences; improvement of morale by establishment of a reasonable goal with the assignment of a definite time latitude.

d. Improvement of recreational facilities throughout the pilot's leisure hours.

e. Frank discussion of the lack of exhilaration from flying in proportion to the effort expended.

f. Frank discussion of the psychology of fear.

g. Flight surgeons' sympathetic understanding.

h. Maintenance of standardized personal history records on all pilots.

i. Vocational rehabilitation for grounded pilots with the establishment of a satisfactory replacement goal.

It is well to note that it is possible for many of these things to be considered in relation to civilian as well as to military pilots.

In the War Weariness Report (87), the following are suggested among those things which tend to reduce pilot fatigue or war weariness:

a. Confidence in planes.

b. Lack of delay in starting operation.

c. Good living conditions and maintaining group identity.

d. Compatibility of squadron members.

e. Spare time occupied with sports, hobbies, etc.

In the British study mentioned above (63) pilots were also asked to state, in order of importance, those factors which they thought relieved fatigue on long flights. The list is given below in rank order:

a. Confidence in the navigator.

b. Good intercommunication.

c. Comfortable clothing.

d. Automatic pilot.

e. Good helmet.

f. A successful sortie.

g. Second pilot.

h. Coffee and rations.

i. Moving around aircraft.

j. Deliberate stretching in pilot seat.

k. Sleep before a flight, especially directed to the flight.

l. Caffeine.

As is evident from the foregoing lists a great deal of thought and considerable effort have gone into attempts to classify or categorize those factors which influence fatigue and those which tend to reduce fatigue. The object behind these investigations is the improvement of pilot performance in the work situation and the increasing length of pilot life, i.e., the flying life of a pilot. Military organizations in the war were especially concerned with this, as relief and rotation policies were based largely upon reports such as those mentioned.

There is little objective evidence to show just to what degree each of the factors mentioned is responsible for fatigue in pilots, but apparently all are responsible to some degree. Following sections of this report present objective evidence obtained from studies made on pilots in the flying situation and on the ground in laboratory situations, as well as evidence from fields other than flying.

III. ADVERSE EFFECTS OF FATIGUE

1. Fatigue and Accidents. Our concern with the problem of fatigue is pertinent to the TWA request in as much as fatigue is a factor in the causation of accidents.

The crucial aspect of a long range flight is the landing which terminates that flight. It is during this landing that the greatest demands for efficient performance are imposed upon the pilot, and it will be at this very time that fatigue will be greatest. Table 1, based upon the 1945 edition of Accident Facts (69), indicates that landing (including forced landing) accidents were nearly half of the total -- fatal, non-fatal, and property damage -- for airline operations and nearly two-thirds for private flying. Personnel errors were the causes of half the airline accidents and more than two-thirds of the private flying accidents.

TABLE 1

FREQUENCY OF THE PRINCIPAL TYPES OF AIRCRAFT ACCIDENTS DURING 1944, AND THE CAUSES FOUND BY INVESTIGATIONS OF THE CIVIL AERONAUTICS BOARD

Types of Accidents	Airlines	Private
All Types	100%	100%
Landing	44	44
Take-off (including taxiing)	22	25
Collision	13	5
Forced landing	4	17
Spin or stall	2	6
Other	15	3
Causes of Accidents		
All Causes	100%	100%
Personnel errors	47	70
Structural failures	14	5
Weather	12	4
Terrain	10	5
Power plant failures	5	14
Other	12	2

Lahy and Korngold (34) have studied the matter of fatiguability as a factor in accident causation. Their hypothesis was that those persons who are accident prone may be more susceptible to fatigue as compared with persons who are relatively free of accidents. The authors distinguish fatiguability from fatigue, and measure the former by auditory reaction time, aiming and punching tests, requiring 10 minutes each. No tendency is found for persons with accident records to show greater decrement in mean reaction time or in variability. The accident cases, however, show more extreme changes in both directions, increment as well as decrement. No differences are found in the aiming or punching tests. The instability in reaction time is attributed to nervous fatiguability. It would appear that reactions of the accident cases would be less predictable. Although they showed extreme changes in both directions, increment as well as decrement, it is the possibility of poor performance which may be related to accident causation.

Viteles (59) has pointed out that investigations both in the United States and Europe have shown that industrial accidents tend to increase with each successive hour of work in the morning, reaching a maximum at approximately 11 A.M., and falling toward zero at the noon hour. The number and rate rise again sharply following the noon hour, reaching a peak toward the latter part of the afternoon, but dropping off somewhat during the last hour of work. The drop in rate in the last hour of the morning and afternoon period, when the worker may be expected to be most fatigued, is explained by the reduced rate of production which occurs, with increasing fatigue, in the last hours of work. The slackening of speed brings with it a decrease in the accident rate. The effects of fatigue upon accident rate are thus explained as being both direct and indirect --both positive and negative insofar as influence upon accident rate is concerned. It must be remembered, however, that the final landing at the end of a long-range flight is not comparable to the last hour of a working period: the pilot cannot allow his performance to deteriorate during these crucial minutes.

One of the reports of the Industrial Health Research Board, in Great Britain, has dealt with the problem of accident causation (86). The contributions of this report may be summarizied as follows:

Every accident obviously has an initial cause. In some few cases it is well defined; in most, however, it is complex, but it may always be regarded as being composed of two factors, one impersonal (relating to the object, material, or machine) and the other personal (relating either to the person injured or perhaps to some other person). If accidents could be classified according to the relative importance of these two factors, we should have at one extreme accidents due to the unforeseen failure of material, such as the bursting of a shell, and at the other, those due entirely to "carelessness," and incurred on a machine or other object regarded as ordinarily quite safe.

In an investigation into more than 50,000 accidents incurred in munitions factories, in which the variations in output throughout the period were measured simultaneously with the variations in accident incidence, Vernon succeeded in establishing the influence of this factor, and also showed the existence of a third factor, namely the psychic state of the worker. The main conclusions may be summarized as follows:

a. The strong qualitative resemblance between the rate of output curves and the accident incidence curves during the day shift shows that varying speed of production is largely responsible for the day shift variations of accidents, and not fatigue.

b. That fatigue may be an important contributing cause, however, is shown by the fact that during a period when a 12-hour day (75-hour week) was being worked the accidents incurred by women were two and a half times more numerous than in the subsequent period when the daily hours were reduced to 10.

c. In addition to speed of production and fatigue, an important part is played by psychical influences, such as alertness and attention. This conclusion is based on a comparison between the accident incidence on the day shift and on the night shift. Whereas in the former, the accident curve follows the output curve very closely, in the latter it is widely different. Here the accident rate is at a maximum at the beginning, then falls sharply and finally sinks to less than half the original value. Further, the total accident rate is lower by an average of 16 per cent, with no decrease in output. Vernon ascribes these differences to psychical influences, assuming that the night workers started work in a careless and excited state and gradually settled down to a calmer mental state than the day workers.

The hourly incidence of accidents experienced by the day shift at the projectile factory showed a qualitative resemblance to the output variations. They were low at first, rose to a maximum in the middle of the shift, and then fell away. The night shift accidents, however, showed no resemblance whatever to output, except during the last two hours. They were at a maximum during the first hour, then fell off sharply, and finally sank to less than half their original number. Probably this incidence was largely psychical in origin.

The influence of fatigue in causing accidents was shown at the 6-in. shell factory. When the women worked the same 61-hour week as the men, their accidents were 91 per cent as numerous, but when their hours were reduced to 39½ a week (those of the men being unchanged), their accidents fell to 78 per cent of those experienced by the men.

Evidence suggests that fatigue is one of the factors in the causation of accidents. This matter is pertinent to the TWA request if the proposed long-range operation should be more fatiguing than the operations obtaining under the present regulation.

2. Fatigue and General Efficiency. Jones (27) has stressed the widely known observation that fatigue and exhaustion often observed in flyers is out of proportion to the physical exertion involved in their work and must be ascribed chiefly to psychological factors such as emotional stress based upon a wide variety of causes. In a later section of this report, mention is made of a study of fatigue occurring in interstate truck drivers. Jones

considers that this study deals with a type of fatigue which appears to be closely related to that experienced by flyers.

Pertinent to a discussion of fatigue and general efficiency are the comments made by Miles (42). He states that flying sickness or pilot fatigue is a difficult condition to study objectively. However, scientific observers agree that it does actually occur as a serious occupational hazard. Apparently, it is unlike ordinary bodily fatigue following excessive muscular work, and more like the fatigue of a psychological depression.

The total amount of muscular work performed by a pilot is usually relatively small, and the food energy cost of this or anyone else's mental work is minimal in physiological terms. But, psychologically the picture is quite different. The pilot's job is heavy in terms of continuous mental adaptations, responsibilities and crucial judgments. He is often hampered in the case of his manipulations by a load of distracting, but necessary, protective equipment. It is under requirements for prolonged flying with weather or military hazards present that typical flying fatigue appears as a serious condition. Learned response habits may remain essentially intact, but when the condition is serious, parts of the habit system split off from the main pattern so that efficiency, usually attained through total integration is greatly reduced.

Another way to express this is to say that the timing integration goes to pieces. Every part and phase of the man's work requires more subjective checking. In fatigue there may be an actual increase, rather than a lessening in the work intensity. But, this increase is at the cost of skill. With the fatigue comes a narrowing of attention. The pilot endeavors to do only what he feels he must do; what, in this ill-organized condition seems absolutely essential. He may forget or ignore the temperature gauge, or the gasoline gauge, because he is completely absorbed in immediate plane manipulation. Like the mentally distracted or depressed person, the fatigued pilot may tend to resort to random responses. It is as if he had forgotten the familiar resources available in his instruments and controls. In this condition he may feel, from his efforts at concentration, that he is doing quite well. Elements of poor performance noted by him he tends to attribute to his plane or mechanisms within it. The importance is clear of continuing studies to determine critical points for lengths and types of flights and favorable treatment in case flying fatigue actually develops.

The effects of fatigue in pilots, as determined from studies of flight and related laboratory studies, are presented respectively in Sections IV and VII of this report.

Fatigue results in a lowering of general efficiency. Well integrated habit patterns may become split up into smaller components. There is a deterioration of skill; timing integration suffers appreciably. This lowering of general efficiency as a result of fatigue must be given due attention when considering the TWA request.

3. The Long-Range Effects of Fatigue. Normal tiredness and even temporary exhaustion are relieved by normal sleep. Fatigue becomes sub-acute

when the degree of exhaustion is so profound that rest serves only partially to restore the energy reserves which have been drawn upon. If the activity which produces fatigue is continued, a progressive depletion begins and a cumulative marked fatigue develops. In relation to the development of morbid fatigue, it must be remembered that it is not work alone which contributes to the progressive deterioration, but unwise recreation and other activities unrelated to the work may be of importance.

In the first section of this report the relationship between fatigue and anxiety has been indicated. Normal fatigue serves to stimulate the anxiety which is latent in all persons. As fatigue accumulates, the manifestations of latent anxiety become more difficult to control, and in the extreme fatigued state, anxiety may become the controlling factor, pervading the total personality and markedly affecting performance.

The effects of incipient morbid fatigue were made manifest in a recent experiment (46). The experiences of 43 adults exposed repeatedly to simulated altitudes of 35,000 ft. with 100 per cent continuous flow oxygen from ground level, reveal 3 types of fatigue; muscular aches, occurring in all, inversely related to decompression sickness, and disappearing with training; fatigue related to boredom during long uneventful exposures; and a more complex emotional type unrelated to the other two. The last began a few hours after descent, continued 1 to 3 days, was not always relieved by rest, but diminished with experience. It was characterized by tenseness, irritability, restlessness, sleep disturbances, and disinclination to work. It mirrored the individual's previous pattern of behavior in anxiety situations. Laboratory data, the EEG's, and circulatory changes were not correlated with any type of fatigue. Fatigue induced by simulated high altitudes does not differ essentially from that experienced in civilian or military life. Emotional flexibility, types of psychologic defenses, the magnitude of the danger provoking anxiety, the suddenness of the experience, identification with the group, and motivation are important determinants of fatigue. This experiment suggests tenseness, irritability, restlessness, sleep disturbances, and disinclination to work as long-range effects of fatigue.

World War II provided the conditions which resulted in the long-range effects of fatigue among aviators. In a Navy Department publication (87) an attempt has been made to define different degrees of war weariness. According to this report, the first step toward adequate administrative handling of the factor of war weariness is the establishment of practical definition. The present war has brought into existence a number of terms which are used loosely and with considerable confusion. Broadly, all such terms as "war weariness," "combat fatigue," and "operational fatigue" may safely be considered as referring to the same entity; the <u>partial disintegration of the personality under stress.</u> The nature of the stress appears to make no real difference in the symptoms. <u>The severity of the stress, its duration, the individual's ability to withstand it, and the constraining influence of group morale, are the main considerations.</u>

Administratively, it is important to recognize different degrees of war weariness. The following classification is suggested as being practical from the standpoint of an integrated personnel program:

a. Transient Fatigue: This may be considered to be the normal transient fatigue manifest in a healthy individual following a period of strenuous effort or excitement. The indicated treatment is normal sleep, rest, and freedom from excitment. The prognosis is for complete recovery without important residual effects with 48 hours.

b. Cumulative Fatigue: This is the fatigue which does not respond immediately to normal rest and sleep. It may occur in individuals who have undergone stress of such intensity that normal recuperation does not take place. At this level the symptoms are primarily subjective and may be characterized by lowered individual morale, reduced aggressiveness, sloppy flying, increased tension, and frequent irritability. Depending upon over-all squadron morale, the individual symptoms may be more or less repressed. The prognosis is for complete recovery following an extended period of less arduous duty.

c. Chronic Anxiety: This is the extreme state of war weariness which is characterized by readily observable symptoms such as loss of appetite, tremors, abnormal fears, etc. Ordinarily, an aviator reaching this stage of fatigue would be grounded as a protection to himself and his teammates. With prolonged rest the prognosis is for recovery with residual effects as far as combat is concerned, i.e., recurrence of symptoms under stress.

From an administrative point of view, these three degrees of war weariness imply different procedures. If a large proportion of the individuals in a squadron show transient fatigue, there may be implied nothing further than the need to give them a day or two of rest. There would be no occasion to believe that their operating efficiency was permanently impaired. If a large proportion of the individuals in a squadron show cumulative fatigue, it must be presumed that the operating efficiency of the squadron is impaired, but that most of the flying personnel is recoverable to combat aviation following a period of rest and rehabilitation. The combat efficiency of such a squadron is declining and a date for relieving it should be determined. If a number of individuals in a squadron show chronic anxiety it must be recognized that those individuals are probably not recoverable to combat. The necessity for continued deployment of such a squadron must be weighed against its decreased efficiency and the probability that a considerable proportion of its experienced personnel will be permanently lost to combat aviation.

The Navy airmen who were interviewed for this study of war weariness provided a list of symptoms on the basis of their own combat experience, indicative of decreasing individual effectiveness. The list does not represent any order of importance or frequency of mention. The symptoms as listed from interview notes, were as follows:

a. Loss of eagerness to fly.

b. Avoiding hops; downing planes; or returning to base.

c. Increase in barrier crashes.

d. Careless air work and deck work around the carrier.

e. Arguments and objections during briefing.

f. Appearance of excuses and alibis in ACI interrogations.

g. Strained personal relations.

h. Disinclination to press home attacks.

i. Loss of interest in ordinary activities.

j. Anxiety and sleeplessness.

k. Increase in drinking.

l. Individual statements indicating "loss of nerve."

m. Criticisms of each other's air work.

In this same report on war weariness appears a list of symptoms based upon reports submitted by flight surgeons. The following symptoms were mentioned at least once in these reports; they have been grouped under four main reaction types.

a. Reactions of pilots to each other:

(1) Irritability (mentioned 12 times).

(2) Impatience.

(3) Criticism of other squadron members' personal and tactical characteristics.

b. Reactions of pilots to their own fears:

(1) Noticeably tired-haggard looking.

(2) Lassitude-lethargy.

(3) Loss in weight (one man lost 28 pounds, another 12 pounds in 2 weeks).

(4) Nausea.

(5) Vomiting.

(6) Fainting.

(7) Pylorospasm (gastric pain and/or vomiting).

(8) Anorexia (disinterest in, aversion to, food).

(9) Non-specific diarrhea.

(10) Vague muscular aches.

(11) Tachycardia (accelerated heart action).

(12) Brooding.

(13) Nervousness.

(14) Insomnia.

(15) Jumpiness.

(16) Restlessness.

(17) Anxiety.

(18) Worry.

(19) Failure to relax.

(20) Asthenia (general feeling of physical weakness).

c. Reactions of pilots to flying:

(1) Loss of interest in flying and "things in general."

(2) Abhorrence of flying.

(3) Over-cautiousness.

(4) Poor landings.

(5) More wave-offs.

d. Reactions of pilots to their environment:

(1) Preoccupation with leave and relief.

(2) Criticism of food.

(3) Criticism of planes.

This Navy Department report concludes that it becomes clear that "war weariness" is not a specific entity. It is a term deriving its significance from the situation in which any of the common neurotic syndromes may appear. There is no one syndrome which characterizes it. It is interesting to note that all of the symptoms which might be called "physical" are well-known hysterical or conversion symptoms, those which may arise without an adequate organic basis.

Another concept of the long-range effects of fatigue is that of "pilot staleness" described by Kalez and Hovde of the U. S. Navy. They define "pilot staleness" as a temporary loss of confidence, due to the emotional stress of depleting aviation experience producing excessive stimulation of inherent and acquired characteristics of self-preservation. The emotional stress gives rise to apprehension for security, with resulting conscious and subconscious establishment of emotional reactions, subjective and objective signs and symptoms, directed toward escape from danger. Pilot staleness occurs in varying degrees at some time during the first 600 training hours in approximately 25 per cent of pilots (28).

They list its subjective symptoms, divided into early and late tendencies, as follows:

Early Tendency:

(Increased vaso-motor tension)

a. Vague headaches.

b. Anorexia.

c. Diarrhea.

d. Polyuria.

e. Physical exhaustion:

   (1) During the day.

   (2) 10-12 hours sleep on successive nights.

Late Tendency:

(Withdrawal symptoms)

a. Vague disturbances of vision or hearing.

b. Vague chest disturbances: left sided chest pain, palpitation, difficulty breathing.

c. Burning urination (high conc. and acidity).

d. Constipation and distension.

e. Vague extremity aches or sensations.

f. Insomnia and restlessness.

g. Lack of ability of lengthy concentration

h. Reduced interest in the opposite sex.

i. Immediate fainting history.

They list the following objective symptoms, also divided into early and late tendencies:

Early Tendency:

(Increased vaso-motor tension)

a. Teneness, tremor.

b. Increased startle response.

c. Increased use of alcohol and tobacco.

d. Increased interest in the opposite sex.

e. Irritability, fault finding, over-criticalness.

f. Worried and anxious (verbally and in appearance).

g. Recent preoccupation and absentmindedness.

h. Non-conformity as evidenced by: Failure to attend mess, missed flights, AWOL, and flat-hatting escapades, etc.

Late Tendency:

(Withdrawal findings)

a. Decreased startle response.

b. Confusion, depression, fearfulness.

c. Resentfulness against others.

d. Lack of interest, drive, attention and memory.

e. Decreased personal cleanliness.

f. Social withdrawal, butt for jokes of other pilots, or considered "nuts."

g. Recent facial or lid spasms.

h. Recent stuttering.

i. Extra-systole.

A report of the Flying Personnel Research Committee (53) relates neurosis to the degree of danger of the duty rather than to fatigue. There appeared to be a direct relationship between the incidence of neurosis attributed to flying duties and the degree of danger of the duty. The opposite appeared to be the case when the neuroses are not attributed by the physicians to flying.

Neuroses arising from flying duties were equally distributed between men who had not flown on operations, who had started their tour, and who had had considerable experience of operations. Five per cent of cases arose in men who had not flown at all. By contrast, more men ceased flying with neurosis, lacking confidence, at the beginning of the tour than at any other time.

Over half of the patients had not been exposed to more than slight stress while flying, and nearly a third to none at all; two-thirds had experienced no psychological stress apart from flying.

The main cause in almost every case was psychological and the most important single cause was fear, fatigue playing a subsidiary part if present at all. Physical injury contributed to the neurosis in 18 per cent and illness, 9 per cent. Airsickness and exhaustion were each contributory in only 2 per cent, and cold and altitude were never considered causal. As fear is the most important single cause it follows that there is a direct relationship between the incidence of the neurosis and the degree of risk encountered.

A number of opinions regarding the effects of aviation duty in the military situation may be of interest. Commodore (then Captain) J. C. Adams (MC) U.S.N., has made the following statement regarding operation fatigue:

"In aviation, flying personnel are not concerned so much with physical work and physical exhaustion. Their fatigue is more directly the result of emotional stress and nervous exhaustion. We should remember that man's strongest urge is that of self-preservation. Any time a person's life is endangered he should, and does, develop a perfectly normal apprehension for his security. Consciously or unconsciously, he establishes emotional reactions directed toward escape from danger. Our primitive instinct is to flee. Obviously, we cannot resort to such a measure, especially in a military organization. Therefore, we suppress our fears -- we stand and face danger. It is this distinctly awkward and rather abnormal state of affairs that brings about our troubles. Certain individuals cannot face danger calmly. Some can't face it at all; they are what we call cowards. We all vary in our reactions in this regard, depending upon our constitutional endowment and also upon the severity or seriousness of the danger. Physical influences such as fatigue, hunger, loss of sleep, sickness, etc., are seriously depleting to stamina and morale. Under these emotional and physical stresses the inadequate personalities crack early. The rugged personalities are able to carry on longer, but in time will also succumb if sufficiently stressed."

Regarding fatigue factors in flying personnel, A. W. Eyer has made the following statement:

"There seems to be no actual yardstick by which fatigue can be measured, but its effects appear to be sufficiently constant to merit its description in the terms of a group of signs or symptoms occurring in flying personnel when they have passed their peak of operational efficiency. The effects produced by operational flying often appear disproportionate to the physical effect involved, with the most frequent complaint of personnel that they felt all "washed out." Mental tension before flight can be a potent factor in producing fatigue, and operational flying hours alone cannot be used as a complete guide in assessing it. This is particularly true where there are frequent false alarms which heighten tension and excitement. Pilots frequently appreciate the decline in their abilities, and this is followed by a diminished enthusiasm for operational work. There is a lack of drive and initiative necessary for combatant duties and carelessness begins to enter the picture. This is soon followed by the appearance of nervous symptoms which have an anxiety background. It should be stressed that pilots with a strong sense of duty will try as far as possible to avoid bringing their subjective feelings to the attention of their commanding officers or the medical officer. There is more often a tendency to attempt to go on, and they reach a breaking point and become definitely ill."

Major Gen. (then Brig. Gen.) David Grant, Air Surgeon, U.S.A.A.F., has made the following statement regarding flying fatigue:

"There is no yardstick to determine flying fatigue. It is not related to the lack of sleep, poor diet, or other indiscretions. It is primarily and essentially due to tension, psychic for the most part, which may develop on the ground as well as in the air. This tension is proportionate to the individual's physical status prior to its inception, depending upon the nature of his missions. The average pilot after flying 100 to 150 hours, is nearing the onset of fatigue. It is at this point that precautions for prevention of this condition should be taken. After about the 150th hour limit of safety in flying is reached, even minor injuries sustained on a trip end in a sudden breakdown of the individual and he is no longer capable of flying, while an aviator who has not had as much flying hours may sustain even severe injuries and on recovery is able to resume his flying duties. It appears that this type of individual gets to the point where anxiety factors and neurosis make him careless and he does not care consciously or subconsciously what happens to him. Very often these individuals even after the onset of fatigue will not complain of being unable to fly and will not see their medical officers. This undoubtedly is due to the fact that they are not consciously aware of the impending illness."

Probably the granting of the TWA request would not result in the conditions productive of cumulative fatigue and chronic anxiety comparable to the conditions existing during the war. But, the very fact that fatigue can be cumulative makes it desirable to raise the question if long-range operations will be more fatiguing than the operations under existing regulations. Further, it would be of interest to know how the TWA pilots spend their off-duty periods, since we have seen above that unwise recreation can be equally fatiguing as work itself. The question might be raised if the proposed long-range operations might not be conducive to a better utilization of off-duty time, since the pilots presumably could spend more time with their families.

IV. STUDY OF FATIGUE IN PILOTS

This section of the report deals only with studies made on pilots or individuals who were in training to become pilots and thus had had some flying time. Many of the studies were made on the ground, but they were as closely related to performance in the air as possible under the given conditions.

1. One of the objectives of this review was to determine, if possible, whether there is any relationship between hours of flying and accidents. Army and Navy records have been examined and although certain raw data are available, further statistical analyses appear desirable before including the findings in this report. Requests have been made to the Army and Navy for more detailed information in this area and requests for similar data have also been made to the British Air Ministry. Several references have been made in British reports to accidents which might be attributed to long hours of flying, but supporting data are not available and they are not therefore included here.

2. Accidents, Age and Experience. A statistical study made available by the Army Air Forces (79) does not deal directly with hours of flying and accidents, but with age and experience in relation to accidents in the Army Air Forces. This report analyzes flying accidents occurring during 1944 and 1945. A total of 4638 accidents was examined and has been analyzed in terms of pilot age, pilot experience, and accidents per 100,000 hours of flying. Information concerning single engine as well as multi-engine accidents is presented since the trends for both types of planes are almost alike for different age and experience groups.

Figure 3 shows accident rate by experience of pilot for all pilots. It will be noticed that there is a progressive decrease in accidents as experience increases, until approximately 1000 hours have been flown, and then there is a sharp increase in accident rate. If experience is held constant, the factor of age in accident rates becomes apparent; this is shown in Figure 4, for two experience groups in heavy bombers and for three experience groups in fighters.

Tables and graphs are included showing the accidents attributable to pilot error and to other causes. Over two-thirds of all accidents occur through pilot error of one kind or another. This can be seen from Figures 5 and 6. How closely pilot error is related to fatigue or caused by fatigue is not known, but it is reasonable to suppose that the fatigued pilot or one who has been flying for many hours is more likely to make an error than the man who has not flown for so long. Some evidence to support this hypothesis will be presented later in the report.

3. Miscellaneous Studies of Pilots. There are several miscellaneous reports dealing with fatigue in flying for long hours. A report by the AAF (82) concerns the length of mission and replies to a questionnaire. In this report the average length of operational mission in the ETO was 7½ hours and in the APTO, 10 hours. The principal cause of discomfort in the heavy bombardment aircraft under consideration relates to the short-

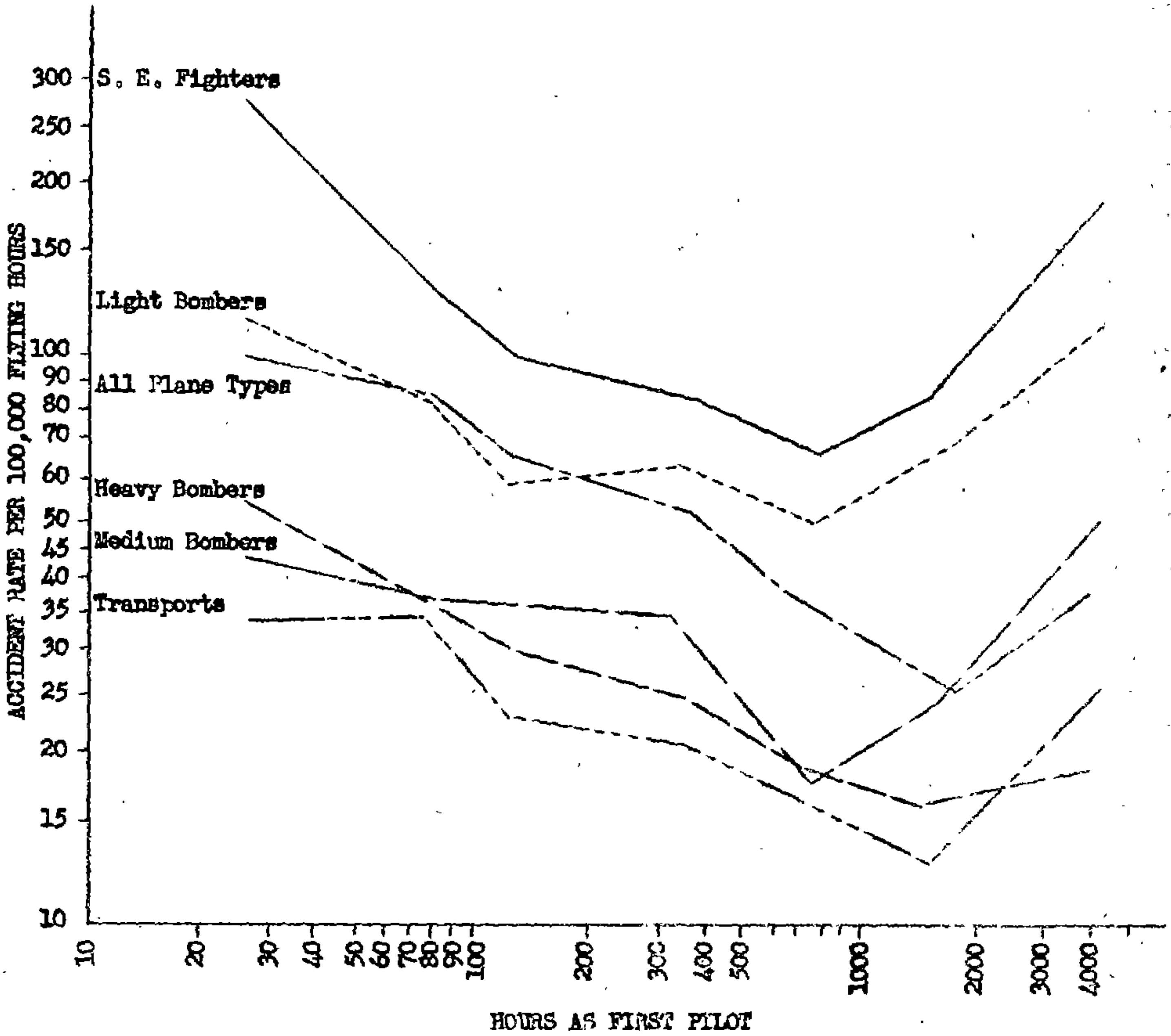


FIGURE 3

ACCIDENT RATE BY PILOT EXPERIENCE OVER A 9-MONTH PERIOD
(July 1944 - March 1945) IN THE CONTINENTAL UNITED STATES

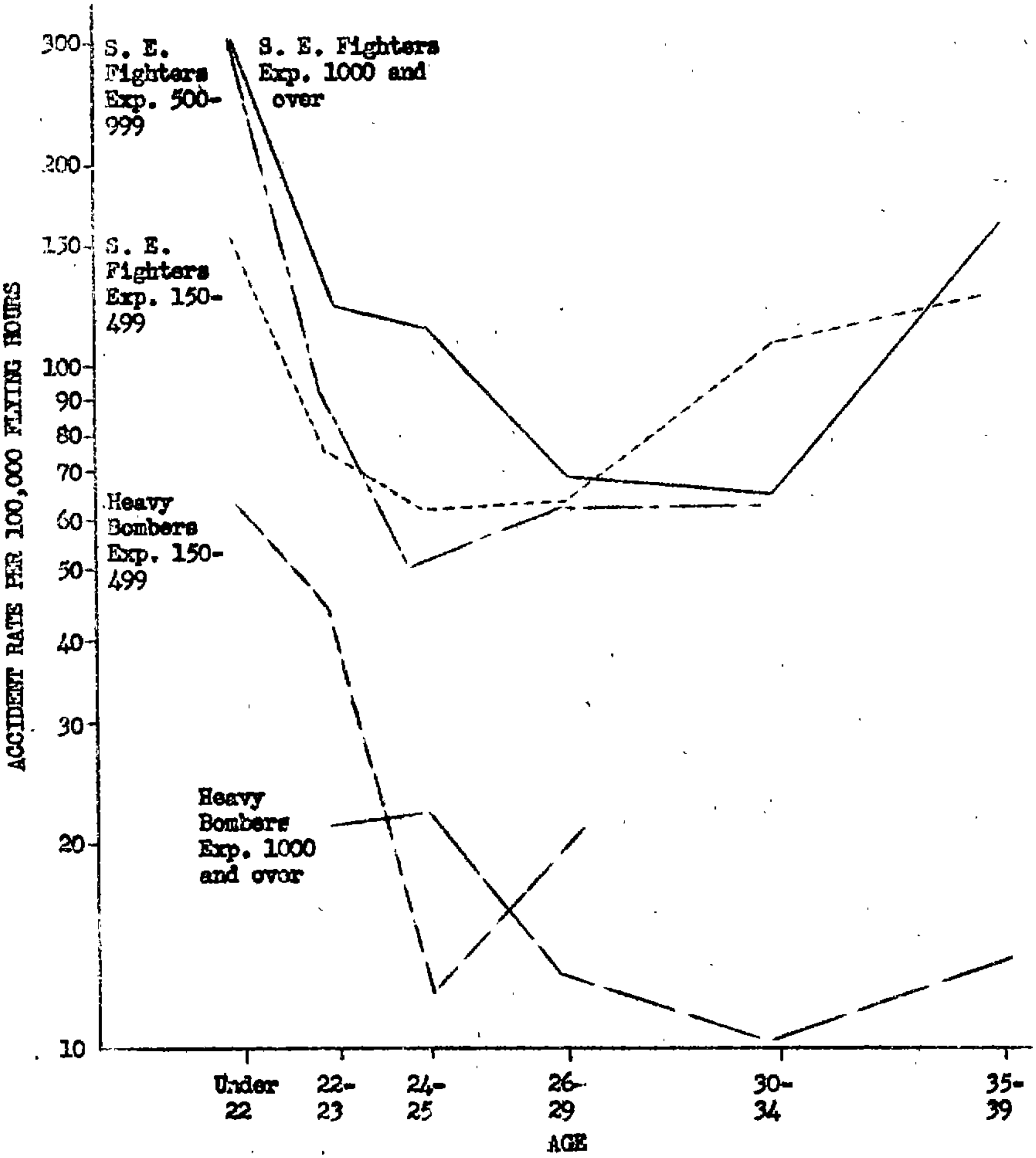


FIGURE 4

ACCIDENT RATE BY AGE OF PILOT FOR THREE LEVELS OF EXPERIENCE OVER A 9-MONTH PERIOD (July 1944 - March 1945) IN THE CONTINENTAL UNITED STATES (SINGLE ENGINE FIGHTERS AND HEAVY BOMBERS)

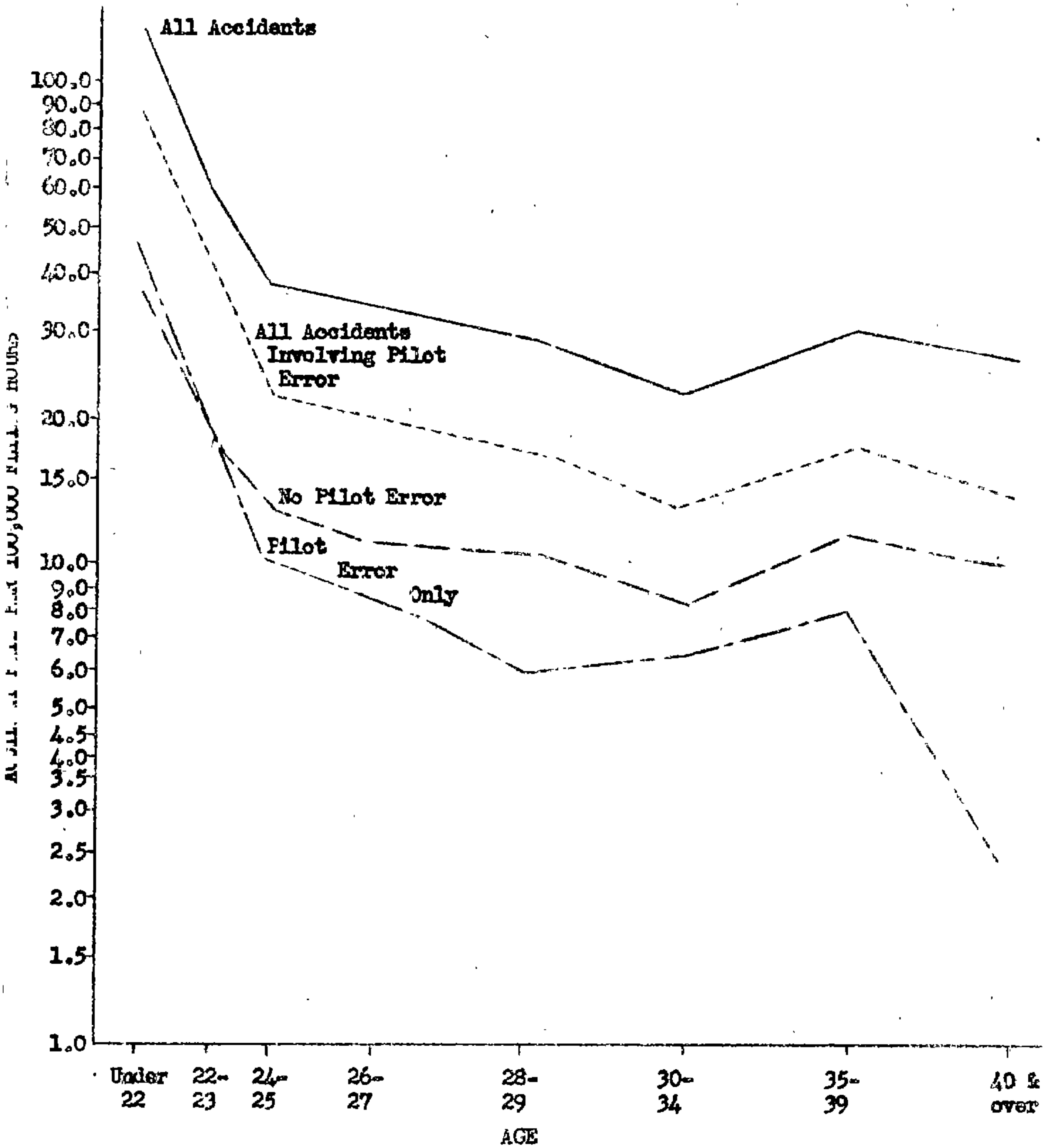


FIGURE 5

ACCIDENT RATE BY AGE OF PILOT FOR ALL ACCIDENTS OVER A 6-MONTH PERIOD (October 1944 - March 1945) IN THE CONTINENTAL UNITED STATES

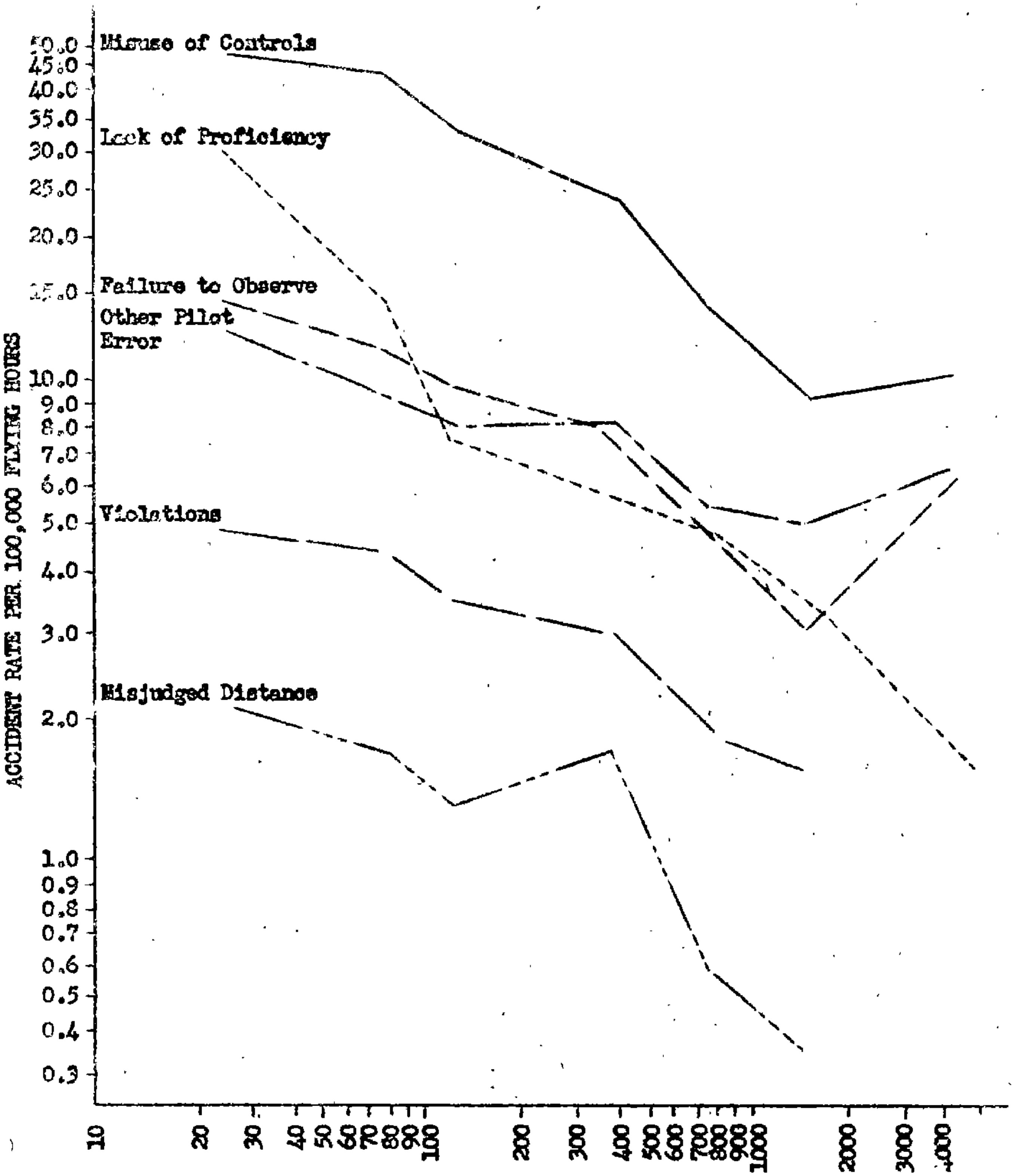


FIGURE 6

ACCIDENT RATE BY PILOT EXPERIENCE FOR ACCIDENTS INVOLVING FIVE TYPES OF PILOT ERRORS OVER A 9-MONTH PERIOD (July 1944 - March 1945) IN THE CONTINENTAL UNITED STATES comings of the seating accommodations of the respective crew quarters. In another report by the AAF (84) 53 per cent of the crew members operating in the ETO and 86 per cent of those in the APTO suggested remedies for fatigue when answering a free response questionnaire. The differences of percentages is attributed to the fact that the APTO flew longer missions, averages being the same as those above. Sleep was said by 75 per cent of all respondents to be the best remedy for fatigue sustained on long missions.

Another unpublished AAF report deals with 46 men who flew 2000 miles in fighter planes, with one stop after five hours flight, during which they remained in the planes. They were approximately 10 hours in the planes before completing the flight. In reply to questions concerning the flight, the most troublesome feature of the flight was seat discomfort, the second was described as boredom or monotony.

a. 28 men complained of sore butts.

b. 24 men complained of cramped space.

c. 22 men complained of stiffness of back and legs.

d. 20 men complained of glare.

e. 19 men complained of difficulty in paying attention and staying awake, but felt they could have "pulled themselves together" in an emergency.

McFarland in a report on a Clipper trip from Alameda to Manila and return (40) took records of blood pressure, basal metabolism, pulse rate, etc., periodically during the total flying distance of 14,141 miles (which was spent at an average altitude of 9460 feet) on 17 airmen and 11 passengers. No mention is made of how the pilots divided up the flying time, how their rest periods were distributed and so on, but he concludes that all the subjects maintained a high degree of mental and physical efficiency throughout the flight. There were some minor variations in partial pressure of oxygen and carbon dioxide in the lungs, slightly lowered blood pressure with increasing hours at altitude, a slightly increased pulse rate, and so on, but these are not considered important factors in the overall picture of success in flying over that length of time and distance.

In a study by Dougherty (18) on the effect of increased flying time on aviation instructors, 20 instructors selected at random were subjected to a fatigue study over a 6-week period. Ages ranged from 21 to 28 years, experience from one to 16 months as instructors. He concludes:

a. The younger men were slightly less affected than the older.

b. The greatest stress occurred when day and night flying both were necessary.

c. Seventeen of the 20 required one to two hours additional sleep each night.

d. Fatigue was manifested subjectively by the following symptoms:

(1) Continuous tiredness.

(2) Pronounced afternoon fatigue.

(3) Increased irritability.

(4) Less patience.

(5) Less concern with progress of students.

(6) Diminution in mental alertness.

(7) Tinnitus aurium. Loss of appetite, insomnia, were relatively infrequent.

e. Objective manifestations of fatigue were:

(1) Heterophoria in 13 subjects on 25 occasions.

(2) Blood pressures of 110 millimeters.

(3) Low results (less than +8) on the Schneider Index.

The instructors in this study were averaging 118 hours of flying per month, as compared to an average of 81 for some period in 1941, for another group of instructors.

In a report by Clinton and Thorn (15) 21 airline pilots between 27 and 50 years of age were given a physical examination with special reference to conditions which might have resulted from long continued flying, and a psychiatric evaluation, including their aviation history. They were in generally good health. They were in most respects psychologically mature and well adjusted. They were cooperative and intensely interested in aviation as a career. The sources of fatigue as mentioned by these men were:

a. Lay-overs at airports.

b. Lacking facilities for rest and recreation.

c. Irregularities of schedules.

d. Prolonged instrument flying.

One of the items mentioned by the authors as a major problem is the disposition of pilots no longer capable of active service. Their ability to fly is curtailed before they are physiologically old and the majority of these men are unsuited for desk work. It has been mentioned that fear of losing jobs and worry about the future after driving has to be discontinued is one of the causes of fatigue in drivers. The same appears to be true of pilots.

Walsh (61) discusses fatigue as a depletion of nervous energy reserve. He says that subjective concomitants are warnings that sufficient rest for the anabolic process is needed. The value of frequent rest periods to all pilots who fly high powered machines and operate at high altitudes has been forced upon the attention of airplane manufacturing companies which employ test pilots. For test pilots a rest of at least one week in seven is recommended. The prevention of acute fatigue among pilots consists simply in their obtaining enough rest, and in taking advantage of that modern equipment which is available to counteract the occupational causes of fatigue.

Almost all of these studies indicate that increasing flying hours increases fatigue, but to what extent is unknown. It is impossible to say what the other factors in the situation were and to what extent they influenced the onset and course of fatigue.

Studies concerning anoxia in pilots are not included in this section, as a more detailed summary is included in Section VII of this report.

4. British Studies of Pilots. A series of studies made by the Flight Personnel Research Committee of the Great Britain Air Ministry on fatigue in pilots contains a wealth of data concerning the development of fatigue in an experimental situation. The first of the series describes in detail the apparatus used, and the results obtained on a large group of pilots in training who went through the experiment (19). The apparatus consisted of a standard Spitfire cockpit rigged with the usual instrument panel and steering controls. The instruments were set to respond to changes in the controls, and also set to respond to changes so that actual flying conditions were approximated.

Automatic records were taken of deviations from course in terms of side-slip, airspeed, and errors in altitude and compass reckonings. One hundred and forty subjects were employed who had from 10 to more than 200 hours flying experience although none of them had had any operational experience. Each subject was given a practice period to familiarize him with the controls and instruments and then was given a 2-hour session in the cockpit, during which he had 7 periods of intensive activity interspersed with 3 periods of level flying. The level flying period did not allow the subjects to relax completely as an arrangement similar to the Link Trainer rough air attachment was in operation, and the subjects had to fly the machine even though they were in straight and level flight.

The experimenter took great care to determine whether the changes in behavior during the progress of the test were due to fatigue or to boredom. In the first place, he obtained introspective reports from the subjects, a great majority of which showed clearly that they experienced the subjective malaise characteristic of fatigue. Relatively few of them had formulated their uneasiness as fatigue, but they characteristically remarked on getting out of the cockpit that they couldn't have gone on with it much longer or that they would like to do a lot more if only they could have a rest first. It was clear from their remarks and their enthusiasm about the test that the signs to be discussed below are not those which might arise from boredom, lack of interest, lack of adequate motivation, or other factors which might lead them not to do their best. In the second place, the after effects, though not quantitatively analyzed because of the impossibility of doing so, indicate that the subjects were really fatigued rather than suffering boredom. One of the factors was the absence of enthusiasm. This shows itself as a rather sleepy attitude developing soon after the completion of the test. The subjects liked to sit, smoke and talk and were obviously reluctant to start activities which demanded more alertness. It was also noted that the subjects tended to pay more social visits in the 24 hours following the test than they normally did.

Certain medical findings indicate that the subjects were fatigued, the most common of which is the development of a severe headache. This does not normally develop immediately, but is first noticed some few hours after the completion of the test. In some cases, subjects have reported feeling dizzy when they started to smoke, some even reported vomiting on smoking. Medical examinations, however, made immediately after the completion of the test and again 24 hours later were completely negative in their findings. These facts are described merely because taken with the other evidence given, they do tend to suggest that the experiment does succeed in producing fatigue. In the third place, certain members of the department volunteered to be trained to the required state of proficiency on the machine, and then to subject themselves to the test procedure for as long as might be required to produce in them an advanced state of fatigue bordering on exhaustion. Several such tests were carried out, some lasting for as long as from 6 to 7 hours.

The results obtained from them were so similar to those obtained on the 2-hour course that it was inconceivable that the symptoms in the 2-hour test were caused by anything but fatigue. In the longer tests, the symptoms were exaggerated, deterioration in performance as recorded was slightly more marked, though of the same general type, the same type of amnesia developed and the subjective symptoms became greatly exaggerated. The subjects reported extreme awareness of fatigue and marked physical discomfort. Outside the apparatus they were uncoordinated in their muscular adjustment, and in some cases found difficulty in relating their ideas sufficiently to form coherent sentences. Furthermore, all the quantitative signs which appear were detectable before the end of the first 2 hours. After that period, the tendency was not for new symptoms to develop, but rather for the ones already noted to become more marked.

The results of this study will be discussed; quantitative changes in performance will be considered first.

Records for side-slip and airspeed are shown in Figure 7. Both side-slip and airspeed show deterioration at the end of the test of 45 to 50 per cent, and both of these findings are statistically significant at the one per cent level. Changes in altitude and compass course scores, indicated in Figure 8, show a somewhat different shape than airspeed and side-slip because they show an initial practice effect with deterioration due to fatigue being superimposed upon the practice effect.

It was found that two aspects of behavior changes are recorded in these measures. It was noted that the courses required not only the ability to

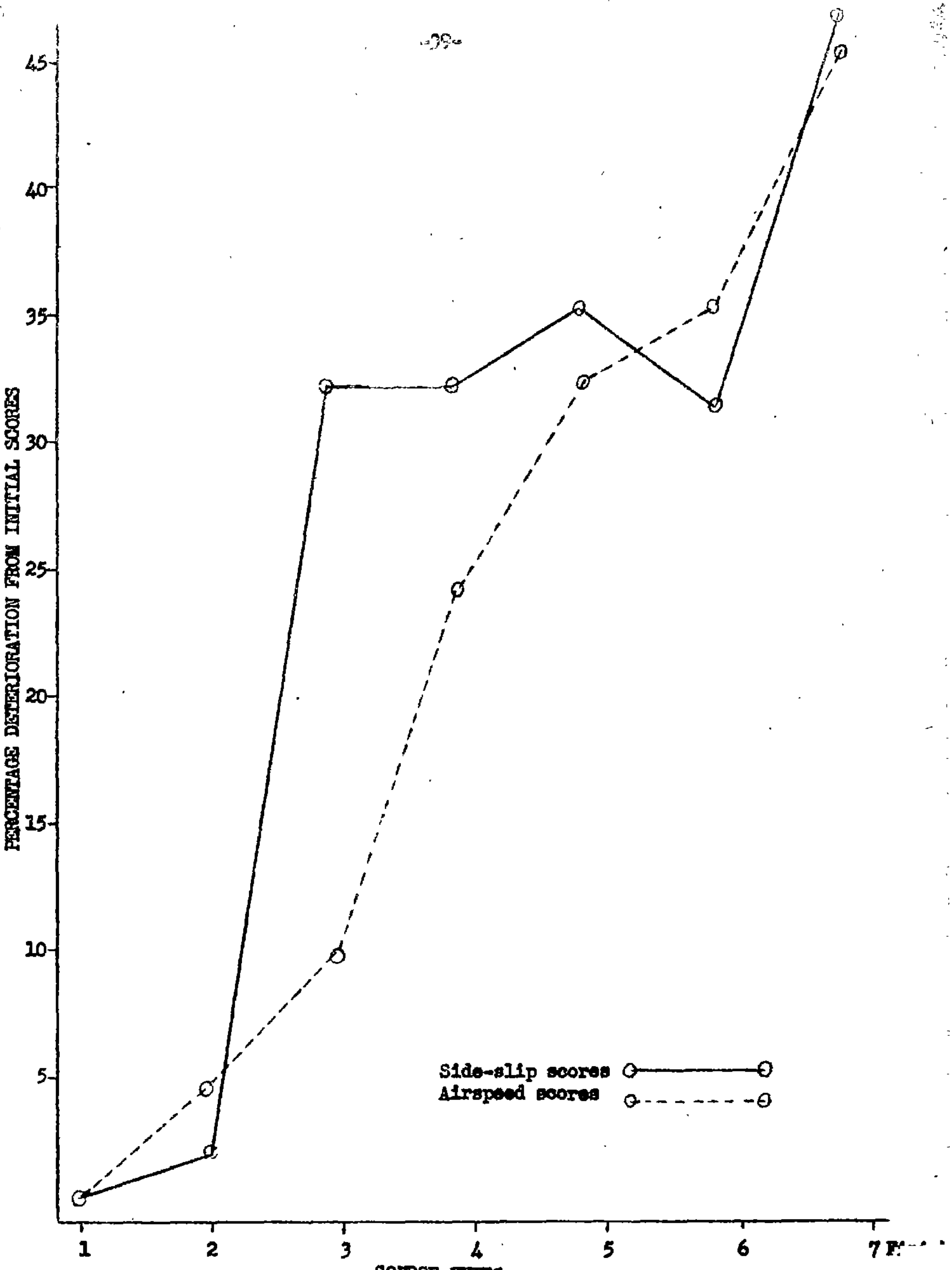


FIGURE 7
DETERIORATION OF SIDE-SLIP AND AIRSPEED SCORES RELATED TO FATIGUE

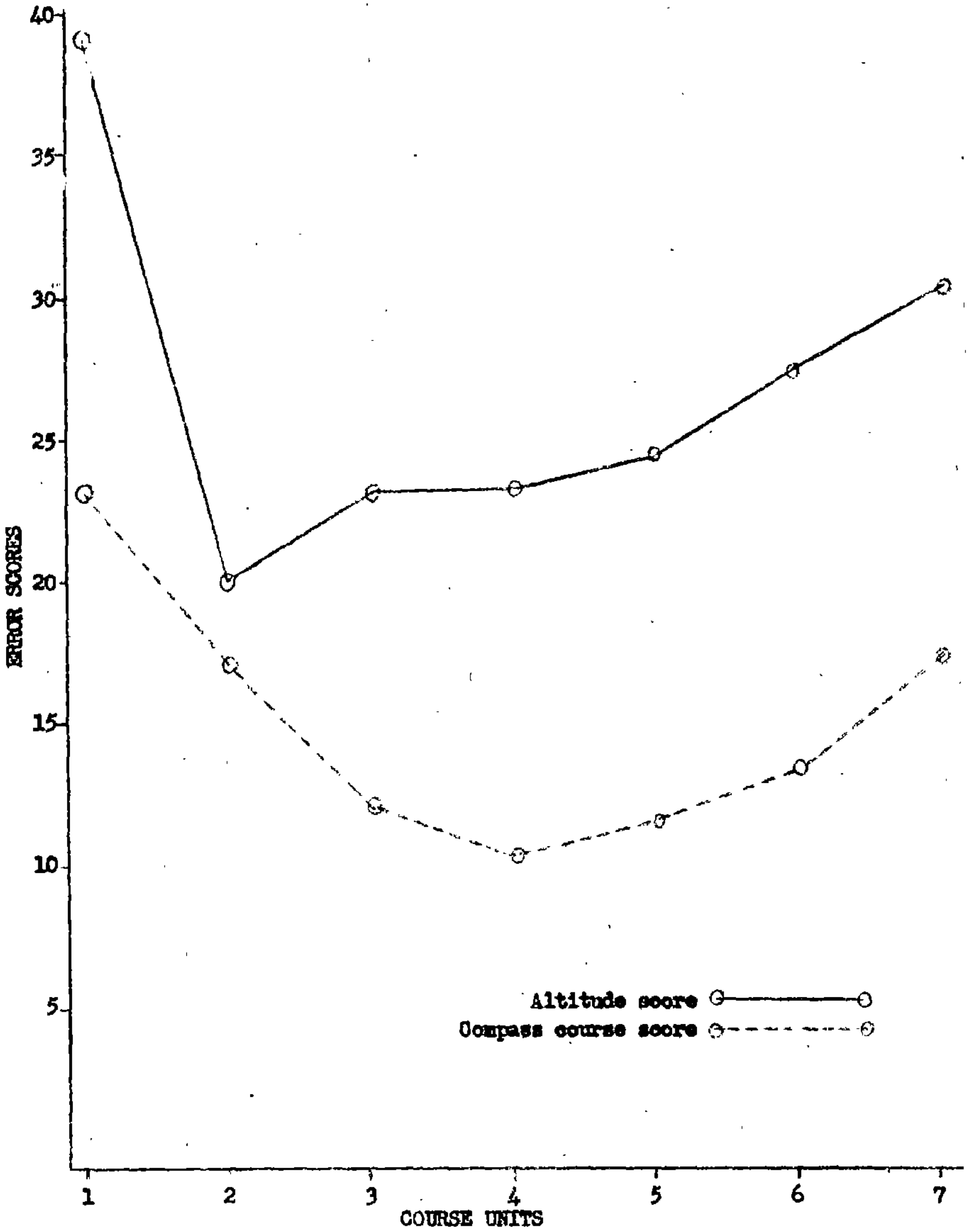


FIGURE 8

ERROR SCORES FOR ALTITUDE AND COMPASS COURSE IN RELATION TO FATIGUE carry out the appropriate maneuvers, but also required very careful attention to the time factor. The scores due to doing the wrong thing decreased steadily throughout the test, indicating that with practice the subjects were learning how to carry out the required maneuvers and were paying careful attention to them in spite of fatigue. The scores due to timing errors, however, gave a different picture. These scores showed an initial improvement with practice, but then increased rapidly and in a positively accelerating gradient, indicating that timing was suffering more and more as fatigue developed. In other words, the deterioration in altitude and compass course scores was entirely due to an increasingly faulty timing, the actual maneuvers required being performed consistently better at the end than they were at the beginning. The deterioration in timing scores is statistically significant, t equaling 3.2 for altitude scores and 4.1 for compass scores. The p value in each case is less than .10.

In addition to the general deterioration just mentioned, it was observed that the slope of the curve was much greater from Unit 6 to Unit 7 than at any other point after the third unit. This was thought to be of extreme importance because it represented the reaction of pilots who knew that the seventh unit was the last. It was noted that the effect on a tired pilot's behavior of knowing that he is approaching the end of his task is to make him much worse than he would have been had he not known. The difference in scores of these two units is statistically reliable, approximating a p value of .05. As might be expected from the preceding discussion, the effect was one of a further deterioration in timing rather than in errors in carrying out the required maneuvers. In some cases the difference was enormous, approximately 150-200 per cent.

These findings suggest a "fatigue" rather than a "boredom" factor.

The reasons for deterioration in performance scores are discussed under several headings, the first of these being lowered standards. It was observed that the subjects started the tests with a keen interest in them and a determination to do as well in them as they possibly could. In consequence, early parts of the testing were marked by a consistent effort on the part of the subjects to keep all of their instrument recordings true, and whereas, in the case of side-slip, they were unable to keep the needle absolutely central, to allow the smallest swing possible. Their courses were attended to carefully and they tried hard to get their timing accurate.

As they became tired, the picture changed, and all aspects of their performance became less efficient. Evidence indicated that this was because the subjects set themselves a progressively easier task as they got tired. They were satisfied with wider and wider approximations to the true positions of the needle. When they were fresh, the side-slip needle was regarded as being satisfactorily central if it fluctuated only within 2 to 3 degrees each side of the vertical. As fatigue developed this arc of allowance movement was unknowingly widened from 2 or 3 degrees each side of the vertical to 5 degrees, and then to 10 degrees, until ultimately, when the subjects were really fatigued, the needle was allowed to swing from side to side and was regarded as being perfectly satisfactory providing it still passed through the vertical and was not jammed either one side or the other.

The interesting thing was, however, that almost without exception, the subjects finished the tests perfectly satisfied that they had improved steadily throughout. They were, even at the end, still aware of their dissatisfaction with their attempts at control in the early stages, and they were also aware of a gradual change in their attitude to satisfaction in the later stages. They were completely unaware, however, that this change represented a satisfaction with an increasingly lower standard of performance.

In the early stages airspeed was kept within 5 or 10 mph of the correct speed. As the test developed the variation became greater until in the fatigued state little or no attempt was made to control it. In consequence, the number of stalls increased rapidly as fatigue developed. For airspeed, the mean difference in percentage increase of large over small errors from Units 4 to 7 was 92 per cent.

This deterioration in course scores was probably also due to lowered standards of performance, although there was no proof of this apart from the subjective reports afterwards. It was very common for the pilots to state that toward the end of the test they had given up looking at their clock and stop-watch and had decided to estimate time intervals between maneuvers. The intervals ranged from one and one-half to 5 minutes and they were convinced that such estimates were within their powers and that such errors as they might make would be small. In actual fact, the estimates of time intervals could be and were as much as 200 per cent wrong.

The shape of the fatigue curve represented two changes in behavior, the first being a worsening of the ability to carry out a qualitatively similar task and a second (represented by the relatively flat part of the curve) the qualitative rather than the quantitative change in which the subject is setting himself a progressively easier task. From this a pilot is likely to make increasingly dangerous errors the more fatigued he becomes.

It was further noted that in addition to lowering standards the pilot showed a growing tendency with the onset of fatigue for the complex task to split up into component parts. When the pilots were fresh the 6 central flying instruments were regarded as being closely interconnected and a movement in any one instrument was associated with corresponding movements of other instruments. The task set was essentially a unified one, complex and having many clues on which the pilot had to base his movement, but still essentially unified. This was not so when the pilot was fatigued. Then he tended to forget that he was flying an airplane and regarded the task in more simple terms. He no longer regarded movements of the needles as symptomatic of the behavior of the aircraft, but merely as a stimulus demanding an immediate response from him to get the needle back where it should be.

The authors state that it is apparent that in a machine as complicated as an aircraft there are a number of reactions which can produce the same results. For example, a movement of the side-slip needle and of the compass may indicate that rudder has been applied or that sufficient deflection of the ailerons has taken place to produce an aileron turn. Only an examination of the artificial horizon will tell which of these controls needs correction. If the wrong control is moved the machine will tend to be to a greater or less extent out of control for the time being. A fresh pilot confronted by the above situation will glance at this instrument panel as a whole and will know immediately which of the possible movements is the one he should make in this instance. A fatigued pilot will not look at his panel as a whole. He will, instead, make whichever of the conventional movements to correct that kind of situation that first occurs to him.

An example of this which frequently arose was the airspeed indication. It was calibrated from 40 to 160 mph in a clockwise direction. If the machine were put into a dive of 4000 feet per minute or steeper, and the throttle were left on, the airspeed would exceed 160 and the needle would rotate past the 150 mark into the low range of airspeeds once more. Fresh pilots found this a very easy situation to cope with, but the fatigued pilot found it very difficult. The fatigued pilot who had allowed his airspeed to rise so high typically realized that he was diving rapidly, but in attempting to pull out of the dive would observe the airspeed apparently dropping off toward the stalling speed. He would become frightened and push the nose of the machine down into as steep a dive as he could and at the same time open his throttle wide. He would again attempt to climb, find the same occurrence and push his nose down once more. All the time he would be losing height rapidly and would be well aware of this. He was quite unable, however, to relate the various factors together and so obtain a picture as to what the machine was actually doing. Many pilots would continue to fly straight at what corresponded in the experiment to the ground. They would then say that something had gone wrong with the machine and that they had in consequence crashed. In other words, they were accepting their instruments at their face value and were quite unable to see beyond them to a picture of the behavior of the machine.

The author gives an interesting interpretation of the fact that side-slip errors increased more rapidly than any others and showed more deterioration during the test. He blames it on the intrinsic difficulty in interpretation of the artificial horizon. This, he says, is because the movement to correct the artificial horizon is one in the direction of the apparent movement on the instrument rather than away from it. This is not the immediate response one normally makes to the movement of a plane to starboard or port. He believes that the abnormally large and rapid deterioration in side-slip control with fatigue is due to this difficulty. The pilots take longest to become familiar with the artificial horizon, and in fatigue it is the first instrument to cause difficulty precisely because, for its proper management, it requires an intellectual appreciation of its meaning and it is this intellectual grasp of the situation which most characteristically disappears in the fatigued state.

A further reason for deterioration in scores with fatigue is a rapid increase in the irritability of the subjects as they become tired. This is shown in two ways. Firstly, by the flow of oaths they keep up and secondly, by an increasingly violent manipulation of the controls. The pilot starts over correcting because he is feeling irritable and his over corrections make him more irritable. The result is an increasingly poor control of the machine.

Another reason for deterioration in performance was amnesias for side instruments. Comparatively few of the 140 subjects forgot to check their instruments during the first hour of the test, but after that the curve of forgetting rose very steeply until 60 per cent forgot about them at the end. A comparable curve could be plotted for the time elapsed between the movement, for example, of the needle giving the radiator temperature and the subject's response to it. This rose rapidly as the subjects became fatigued. A further difficulty with these gauges is that with the exception of the gasoline gauge, none of them carried any indication of the correct reading, so even when the subjects did look at them when they were tired, they were unable to remember what the correct temperature and pressure should be, and so refused to react to them. Many explained afterwards that they were not unduly worried by being unable to remember the correct readings because they trusted themselves to be able to diagnose any change in the engine note sufficiently accurately to be able to tell which instrument was reading incorrectly. In other words, they ignored their instruments almost completely and used auditory cues to enable them to interpret the instrument panel. This seems to be a reversal of the designer's conception of the value of the panel. The landing gear switches were also frequently overlooked by fatigued pilots. It was one of the most common of all faults for the pilot to land with his landing gear up, and to explain that he had completely forgotten about it. More than 80 of the 140 pilots tested landed with the landing gear up.

Qualitative changes in performance are next considered. The first of these is the unreliability of subjective evidence. As the pilots became progressively fatigued, their reports of what had occurred were progressively unreliable. Gross changes in the stimulating conditions were not only overlooked but were strenuously denied. Their evidence was equally unreliable when they repeated what had happened. They made claims that they had performed certain maneuvers, that they had heard noises, such as the screaming of their propeller tips, etc., and that changes had occurred in the machine which had never happened. For example, they were certain that the controls got "sloppy" at low airspeeds and thanked the experimenter for making their task easier. In actual fact there was no change of any description in the feel of the controls throughout the test.

The second change was in the awareness of physical discomfort. Pilots became more aware of physical discomfort with the development of fatigue. They frequently complained at the end of tests that their helmet was too heavy for them, that the string tying the pad of instructions to their leg was too tight and hurt them, that the cockpit was too hot, the seat was hard, and the position they had to sit in too crowded. With this awareness of discomfort was a growing inability to interpret kinesthetic sensations correctly and a tremendous growth in the illusions they had.

The third change was in the amount of irritation shown by the pilots. When the tests started the pilots were completely silent. Gradually they would start to sigh when things were going wrong, then mild expletives took the place of sighs, and before the end of the test most subjects kept up a flow of the most violent oaths they knew, and the handling of the controls became increasingly violent. It was characteristic of the state of fatigue that the errors made by the pilot were projected by him onto the machine. Some said that the machine had a jinx on it at the end. For example, when they had rolled the horizon over so far that it jammed, and were holding it there by giving stick in the wrong direction, they would pound the instrument panel with their fists, explaining that the needle had stuck. Some complained that the experimenter had given them bumpy weather at the end because they were holding the stick perfectly still and yet the machine was rolling and turning erratically. One subject even refused to carry on the test saying it was useless for him to try if the experimenters were going to play the fool outside. All the control cables had to be strengthened considerably in view of the violence of the behavior of the fatigued pilots.

The fourth change was in the number of lapses. Along with deterioration, in general, entirely abnormal and apparently stupid behavior was very frequent when the pilots were tired. Many of these lapses occurred when landing. Told to regard their airdrome as being zero feet, pilots would land at 9000 feet. They would start to stall the machine at 3000 feet, hesitate and put the nose down again and continue until they were 3000 or 4000 feet below sea level. Then they would give up and say, "It's no good, I've crashed." Details such as gliding angle, airspeed on the approach, etc., were almost always ignored.

Several follow-up studies were made to determine, if possible, whether the results would be the same for different groups. These are summarized as follows in another British Air Ministry Report (7). It was thought possible, that the results obtained might be peculiar to or exaggerated by the inexperienced type of pilots being used in the first experiment. The experiment was therefore repeated with a smaller number of operational pilots who had prolonged fighting records. There was no substantial change in the nature of the results, though in most instances there was now increased resistance to the onset of fatigue. The work was repeated with an independent experimenter to decide the extremely unlikely possibility that in some way the experimenter himself was influencing the effects which had been observed. This was done and once more the original results were confirmed. Finally, it was considered possible that the results might have been affected by the design or fittings of the cockpit, and the opportunity was accordingly taken to carry out a series of practically similar observations on skilled operational pilots in a Wellington fuselage with full cockpit equipment. Once again there was no important difference in the character of the results secured except that as in the earlier cockpit experiment with operationally experienced personnel, the appearance of fatigue was delayed.

This report states there can no longer be any doubt whatsoever that the air pilot, whether experienced or inexperienced, is liable to fatigue; that the signs and symptoms of flying fatigue remain substantially the same from individual to individual; that the pilot himself often does not know what the signs are or when they begin to find expression in his behavior; that there are periods and types of maneuver in a prolonged flight which are particularly liable to deterioration caused by fatigue; and most important of all, that the signs of flying fatigue rarely if ever indicate a state in which the correct behavior or the desired skill cannot be performed but only a state in which it will not be performed unless particular care is taken.

These studies have been reported in some detail because they are the only ones of their kind known to the present authors. Adequate care and experimental safeguards have been observed in the design and in the execution of the experiments. Although the results were obtained on the ground in cockpit mock-ups, it is possible to conclude that pilots do show fatigue after long hours at the controls and to accept the facts discovered in this experiment as those indicative of fatigue. It should be mentioned, however, that the pilot of a multi-engined plane with a co-pilot and an automatic pilot to help him, with opportunity to get up and move around, to eat, sleep, and otherwise carry on a relatively easy routine, is probably not subjected to the same strain as the men in these experiments, and to infer fatigue after flying 5, 6, 7 or even 8 to 10 hours in a large airplane from the results just described, is not an acceptable procedure unless and until it has been shown that the cockpit used in the experiments is a close analogue of the cockpit of a large aircraft in flight. This also applies to other studies cited in this report.

In another report by the British Air Ministry, R. H. Winfield made a detailed study of factors influencing onset and production of fatigue in Catalina Flying Boat crews (65). The report is the result of 100 hours operational flying with different crews of a Catalina Patrol Boat Squadron. He says that factors influencing the onset and production of fatigue in long patrol flights are:

a. Diet

b. Noise and vibration

c. Cabin heating

d. Vision

e. Air sickness

f. Morale

An interesting observation was made which relates to the cockpit studies just reported. Winfield states that the visible signs of fatigue begin to show themselves after about 12 hours flying and consist in an increasing irritability and loss of memory for relatively simple tasks. For instance, when a change of course is required, the navigator passes to the pilot a slip of paper on which is written the fresh course and the time on which he is to turn onto it. The pilot receives this about 4 minutes before he is to make the change. Normally, he has no difficulty in turning onto the course at the given time. As fatigue sets in he will forget to alter his course on time, and 2 or 3 minutes may elapse after the given time before he realizes that he has forgotten. Finally, he will begin to doze and may actually fall asleep. It is possible that some of the aircraft which have disappeared for no known reason may have been lost because of this.

One of the reports of the Flying Personnel Research Committee (45) is concerned with fluctuations in navigator performance during operational sorties. It is reported that the errors in calculation and plotting wind vectors made by navigators engaged in a series of night bomber operations sorties have been analyzed. By an arbitrary division of the routes to and from the target and plotting the sections where opposition was encountered it was possible to compare the fluctuations in performance with the times of occurrence of acute hazard. Compared with fluctuations in navigator performance during a series of non-operational flights, the level of efficiency during the operational sorties, which is lower at all stages than in the non-operational controls, varies considerably. The average error rises to a maximum during and after enemy opposition and falls again on the last part of the route back to base.

It is suggested that these fluctuations are successively due to the effect on performance of anticipatory, acute, and persistent anxiety. These effects seem to be larger than the effects of fatigue in the latter stages.

A follow-up study was made on 346 pilots who had been through the Spitfire cockpit test described (16). The scores of these men were analyzed and grouped into different classes (1, 2, and 3), depending upon the extent of disorganization of the skill of flying the machine, ability to follow instructions, etc. Ten of the 346 pilots sustained fatal accidents and 121 had non-fatal ones. Considering fatal accidents and flying hours it was found that there was one accident in 5305 flying hours for members of class 1; one accident in 4578 hours for those in class 2; and one accident in 399 flying hours for those in class 3, or 13 times as often as in class 1. Non-fatal accidents were distributed differently. Class 1 in the cockpit test was divided into three sub-groups; plus, average, and minus, and it was found that a large number of those men who sustained non-fatal accidents fell in the minus sub-class. These were the men who had been (at the time of the test) graded as erratic, and who had failed to carry out the test instructions properly. The findings are explained in hypotheses that pilots sustaining non-fatal accidents had a strong tendency to become preoccupied with one aspect of the test instead of distributing their attention appropriately over all aspects. Many of the accident reports did indicate that the pilots were neglecting something when the accidents occurred. The results will not be reported further because the number of accidents both in the fatal and non-fatal classification is too small to be of real significance. However, the results are indicative of the fact that there may be a relation between "fatigue" as measured by the cockpit test and accidents. The authors themselves state that though the contribution which the experiment has made to the knowledge of accident causation is small, it should not be underestimated. The problem is an important one and though progress may be slow and gradual, further experiments are imperative. The results obtained, although meager, give promise that advance of knowledge in this field will accelerate as adequate follow-up of cases can be obtained.

V. STUDIES FROM THE TRANSPORTATION INDUSTRY

1. A Study of Fatigue from Automobile Driving. Ryan and Warner (47) conducted a study, the purpose of which was "to determine the effect of a moderately long day of driving on the efficiency of the driver and thus indirectly to throw some light on the causes of accidents."

The 6 subjects ranged in age from 18 to 30 years; all were high school graduates and 2 were college graduates; they worked on alternate days. Between 8 and 9 on the mornings they worked, they drove over a specified route through the city. At 9 A.M. they reported to the laboratory for a series of tests which included vascular skin-reaction, postural steadiness, hand-eye coordination, visual efficiency, color naming, and mental addition. After these tests, they started on the rest of the driving, which lasted until approximately 7:30 P.M. with an hour out for lunch. At 7:30 the drivers returned to the laboratory for the tests. On control days the drivers drove for one hour in the morning, but spent the rest of the day in light activity or recreation; meals and times of testing were spaced as on experimental days.

The vascular skin-reaction test involved timing the interval between stroking the skin with a blunt instrument and the beginning of the fading of a faint white streak.

Postural steadiness score was the average of 3 one-minute trials with an ataxiameter.

Hand-eye coordination test, Form A, involved inserting a stylus into holes, the smallest of which was 1/8 inch in diameter, and which became progressively larger in increments of 10 per cent of the diameter of the hole next smaller in size. The diameter of the stylus was 3/32 inch. The subject started with the largest of the 20 holes and proceeded until contact with edge was made. Score was the average of 5 trials.

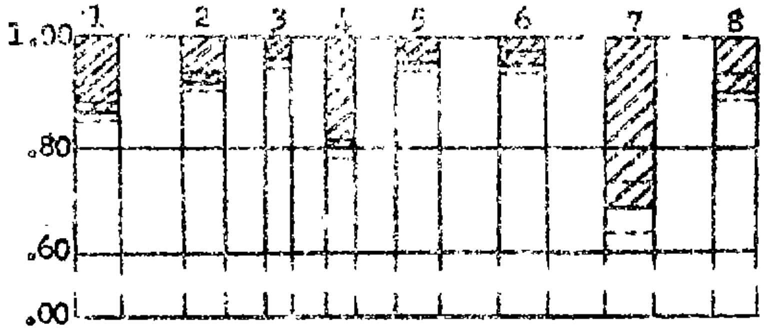
In Form B, the subject inserted the stylus 180 times, at the rate of 1 per second, into a hole slightly larger than the hole determined by this average score in Form A.

Visual efficiency was measured by the blurring of the letters li fixated for 3 minutes. The number of blurs, and the total time of blurring were recorded.

In color naming the subject named colors of which 100 squares appeared on each of 3 cards. The score was the time required for the naming of 1200 colors.

Mental addition material consisted of 3 cards having 7 typewritten columns of 15 digits each. Score was the time required to add the 21 columns correctly.

Figure 9 shows the changes occurring in the tests after the drives; Figure 10 indicates the changes in the tests on the control days; Figure 11

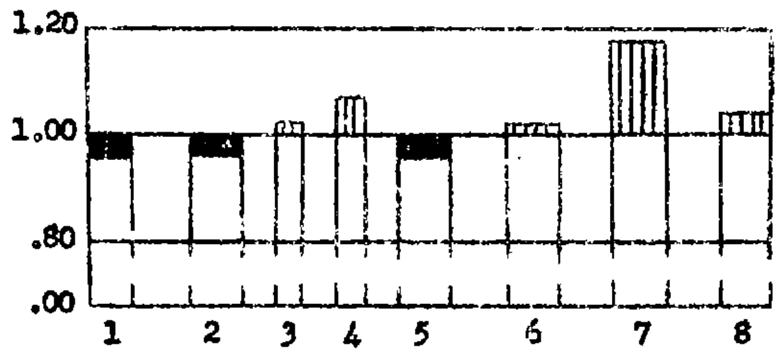


1 - Vascular skin-reaction
2 - Postural steadiness
3 - Hand-eye coordination, Form A
4 - Hand-eye coordination, Form B
5 - Visual efficiency
6 - Color-naming, Time
7 - Color-naming, Errors
8 - Mental addition

FIGURE 9

CHANGES OCCURRING IN THE TESTS AFTER THE DRIVES
(Based on 120 driving days with 6 Ss.)

The means for the morning scores of all tests are indicated as 1.00. The shaded area indicates the average amount by which the evening scores deteriorate from the morning level. The dotted lines show the magnitude of the probable error of the mean for each test.

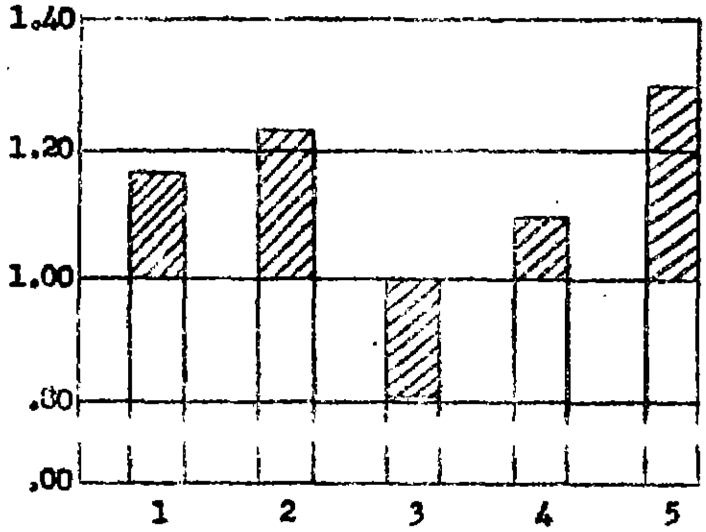


1 - Vascular skin-reaction
2 - Postural steadiness
3 - Hand-eye coordination, Form A
4 - Hand-eye coordination, Form B
5 - Visual efficiency
6 - Color-naming, Time
7 - Color-naming, Errors
8 - Mental addition

FIGURE 10

CHANGES OCCURRING IN THE TESTS ON THE CONTROL DAYS
(Based on 28 days with 6 Ss.)

The solid areas indicate the average loss and the vertically shaded areas the average improvement in the evening scores. The morning scores are represented as 1.00.



1 - Postural steadiness
2 - Hand-eye coordination, Form A
3 - Color-naming, Time
4 - Color-naming, Errors
5 - Mental addition

FIGURE 11

COMPARISON OF THE VARIABILITY OF PERFORMANCE BEFORE AND AFTER THE DRIVES

Shaded areas indicate the change in variability after the drives compared with the variability before the drives, which is indicated as 1.00.

presents a comparison of the variability of performance before and after the drives.

The results showed that there is a demonstrable fatigue effect from a long automobile drive. For vascular skin-reaction the average decrease in time was 12.4 per cent. The average increase in body sway was 8.3 per cent and the variability of performance was greatly increased after driving. Hand-eye coordination showed a decrease of 2.0 per cent on Form A, and 23.6 per cent on Form B, in both cases variability was increased. Visual efficiency was decreased 2.6 per cent by driving. Time required for color naming was increased 3.9 per cent and errors were increased 46.8 per cent by driving; variability in errors was increased, but variability in time was decreased by driving. Time required for mental addition was increased 8.5 per cent while the errors increased 17.5 per cent; variability was very much increased by driving.

"The tendency of long automobile drives is to produce a loss of effectiveness of certain sensory discriminations, association processes, and motor reactions similar to those required in driving. These observations suggest that the effect of a long automobile drive may render a driver temporarily prone to accidents."

The findings are of interest relative to the TWA request in that they indicate a decrement in the efficiency and accuracy of performance, apparently as a result of fatigue. Further, these findings indicate a greater variability of performance under conditions of fatigue, and such variability may be a crucial factor in a hazardous situation.

2. Reports of the National Safety Council. The National Safety Council has published two booklets concerned with accidents occurring when the driver has fallen asleep (85, 78).

In the first report, entitled Too Long at the Wheel, it was anticipated that driver-asleep accidents could be explained by fatigue due to the number of hours at the wheel. The conclusions of this report are as follows:

Many motor vehicle accidents occur because drivers fall asleep or become so tired that they cannot drive safely. Such accidents are much more liable to cause death (particularly of the driver) and serious injury or damage than the general run of motor vehicle accidents.

"Fatigued" or "asleep" accidents are more likely to occur to truck drivers than to private passenger cars.

Drowsiness is often contributed to and complicated by other factors, especially alcohol and carbon monoxide.

Driving excessively long hours is a common practice on American highways; but starting trips after considerable periods of wakefulness (occasioned by work or even by waiting) is equally important in producing dangerous fatigue.

For purposes of safety legislation, the total hours on duty, including time for loading, unloading, and waiting, are the important factors -- not merely the hours actually at the wheel.

As shown in Figure 12, most driver-asleep accidents happen after only a few hours at the wheel, especially those occurring with passenger cars. According to the report, entitled How Long on the Highway, nearly half of the passenger cars had been driven less than 2 hours when the drivers fell asleep but 5 drivers out of 8 had been awake for more than 16 hours, and nearly half had had less than 4 hours' sleep in the past 24. Most common hour: 2 A.M. A third of the truckers had been driving from 4 to 8 hours, but about as many had had no sleep in more than 16 hours. In the last 24 hours, 8 in 10 truckers lacked normal sleep; and 9 in 10 lacked it in the previous 48. Most common hour for truckers-asleep accidents: 5 A.M.

Among inter-city truckers (in 1937) one in three is at the wheel for more than 8 hours without any rest; one in 5 is on duty continuously for

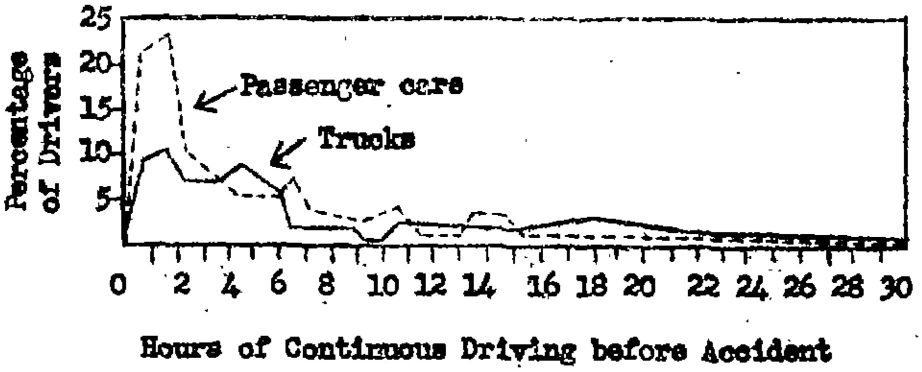


FIGURE 12

MOST DRIVER-ASLEEP ACCIDENTS HAPPEN AFTER ONLY A FEW HOURS AT THE WHEEL, ESPECIALLY THOSE OCCURRING WITH PASSENGER CARS

more than 12 hours; and one in 5 is awake more than 16 hours when his driving ends. One in 20 has had less than 7 continuous hours in bed for more than 4 days and 4 nights.

Figure 13 shows the relation between the number of hours since last sleep and the frequency of driver-asleep accidents. It is surprising that among the truck drivers so many driver-asleep accidents occur within 4 or 5 hours. The National Safety Council report explains this as due to the fact that the sleep of the truck drivers was so short that only 5 hours of wakefulness were needed before they fell asleep at the wheel.

It is of interest to note that the curves for both passenger cars and trucks rise considerably after about 11 hours.

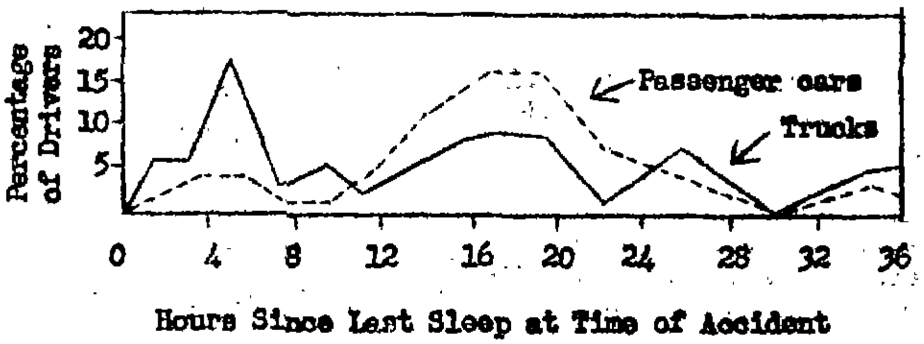


FIGURE 13

NUMBER OF HOURS SINCE LAST SLEEP IS THE BEST MEASURE OF DANGER FROM DRIVER-ASLEEP ACCIDENTS, UNLESS, AS IS APPARENTLY THE CASE WITH SOME OF THESE TRUCKERS, THE SLEEP IS SO LITTLE THAT ONLY FIVE HOURS OF WAKEFULNESS IS NEEDED TO BRING ON DROWSINESS AGAIN

Evidence suggests that driver-asleep accidents are due to fatigue; but it is important to note that fatigue from activities other than driving -- indicated by hours since last sleep at time of driver-asleep accident -- is an important factor. This suggests that the problem occasioned by the TWA request is not simply a question of whether 12 hours of flight are more or less fatiguing than the shorter number under existing regulations. Fatigue from any source is of importance, and not just fatigue from flying. It would be of interest to know what is the condition of the pilot -- in relation to fatigue -- when he begins the flight. How many hours has it been since last sleep? How were those hours spent? How long and how restful was the sleep? Would the granting of the TWA request permit the pilot to be with his family more often and would this tend to permit him to have more sleep prior to the flight?

3. Fatigue Among Truck Drivers in France. Lahy (32) has described an interesting study concerned with fatigue found in drivers of heavy trucks working extremely long hours and traveling considerable distances.

Work begins at about 9 in the morning when the 2 drivers arrive at the garage where they connect the tractor unit to the already loaded trailer. After a light meal they drive away traveling 35 kilometers through the very heavy traffic found in the center of Paris; they cover a total of 200 kilometers by dinner time. After eating dinner, but having no rest of duration longer than that required for dinner, they continue and drive 250 kilometers farther, arriving at their destination between 5 and 7 o'clock the following morning. If they have arrived an hour or two before the opening of the establishments to which delivery is to be made, they are able to rest in their vehicle. During the day they travel within a radius of 80 kilometers making local deliveries and helping with the unloading of 14 metric tons of miscellaneous merchandise. Early in the evening they go to a warehouse where the trailer is loaded with 14 tons to be taken back to Paris. Dinner is eaten a few kilometers from the point of their departure for Paris.

Accidents occur most frequently between midnight and 5 o'clock the following morning. There is an almost irresistable desire for sleep. The tractor does not maintain a straight path; the trailer swings from one side of the road to the other. The man at the wheel is at times awakened by collisions with trees; his eyes have been wide open, yet unseeing. These drivers love their work and would not trade it for any other. Yet they experience great fatigue; they report sensory disorders, particularly tactile and visual. They do not feel the wheel nor hear the motor; they experience hallucinations such as an apparent narrowing of the road.

In the experiment it was planned to use certain tests before and after the routine trip, and to give others at intervals along the way. A second truck, a traveling laboratory, carried the equipment necessary for the examinations.

The tests given before and after the trip were:

a. Blood samples for determining alkaline reserve.

b. Psychological tests of memory, attention, following directions, the rapid repetition of simple gestures.

c. Undirected attention.

The tests applied along the route were:

a. pH of urine,

b. Blood pressure.

c. Simple reaction time.

d. Dynamometer for measuring strength and endurance.

e. A device for measuring motor skills and sustained attention in following simple gestures.

Two drivers were tested, P, age 29, and M, age 38. They were examined on a Monday morning after rest and again Tuesday morning when they went to the garage. Examinations were made along the way and at the destination. After 18 hours of work, the drivers did not report fatigue. However, great fatigue was experienced during the return trip. The tour ended on Friday at 3 in the afternoon. The drivers were examined immediately; they reported again on Saturday for further examinations.

The tests of memory, concentrated and diffused attention, and sustained attention showed no decrement with fatigue. Small amounts of rest may have been sufficient to mask any influence of fatigue. Other tests did show variations concomitant with fatigue. These were urinary pH, simple reaction time, and the dynamometer. Measures of blood pressure showed considerable difference from one subject to the other. Records for M indicated little change; for P, relatively great variations. Reaction time became longer, presumably due to fatigue. Measures of urinary pH indicated an increased acidity generally higher than the normal values. Curves for an ammoniacal coefficient were highest during the period of greatest fatigue. Strength measured by the dynamometer did not decline for M, but it did somewhat for P. A similar result occurred for endurance.

The following conclusions are drawn:

a. Tests which are exclusively psychological lack sufficient sensitivity to detect the change which presumably occurred.

b. The dynamometer tests of reaction time, and urinary pH are sufficiently sensitive.

c. Fatigue is related to the continuity of intense effort, and the interference with the diurnal activity of the organism. It is the latter which produces hallucinations.

d. Although the two subjects were chosen because of physiological and psychological similarity, individual differences were found. Results for M tended to be constant, and those for P very variable.

e. It is recommended that a mandatory rest coincident with the discussed cycle be imposed. The local deliveries at the destination could be made by a relief crew, thus providing an entire day of rest.

While the demands upon the body among these truck drivers are greatly in excess of the demands imposed upon aircraft pilots, nevertheless, this study furnishes another example of the decreased efficiency associated with hours of work. It must be admitted that some part of this decrease was due to lack of sleep and would have occurred for that reason even if the men were not driving. There is little question that their driving is unsafe, especially toward the end of their trip.

4. <u>Fatigue and Hours of Service of Interstate Truck Drivers.</u> In 1938 the Interstate Commerce Commission requested the U. S. Public Health Service to make an intensive study (71) of truck drivers to investigate the problem of fatigue and hours of service. A total of 1200 examinations were made on 889 drivers in three cities. The average age of the drivers was 31.9 years; 87 per cent of them were between 20 and 40 years of age; and only 5 per cent were over 45 years of age. The drivers worked 5.6 days per week and drove 10.7 hours per day for a total of 59.4 hours per week. The average mileage driven by the drivers in one trip was 251.3 miles. For purposes of this study, the term fatigue refers to an altered psycho-physiological state in relation to the status of recovery of normal capacity.

Tests given to the drivers consisted of two kinds: (a) performance, and (b) non-performance tests. In addition, medical and occupational habit studies were made. The tests were as follows: (a) a battery of 9 psychological tests: spatial perception; the estimation of known sizes; manual steadiness; precision of movement-aiming; reaction-coordination times; reaction time; speed of tapping and work decrement; strength of grip-dynamometric measures; static equilibrium, postural steadiness by Miles ataxiameter. (b) A series of tests with the DeSilva Driver-Vigilance test apparatus: accelerator-brake foot reaction time; steering efficiency test (eye-hand coordination test of the pursuit-meter type); vigilance test (steering efficiency combined with brake reaction time); complex vigilance test (steering efficiency combined with choice-reaction time test). (c) Glare tests in which resistance to glare and recovery time after exposure to glare were measured. These tests were given with (b) above as a unit or "battery." (d) Measurement of the speed of eye movement (saccadic interval, by photographic means during the performance of an imposed visual task). (e) Determination of the critical fusion frequency following exposure of the eye to flicker at two levels of illumination. (f) A snap acuity test. (g) Determinations of total leucocytes and relative proportions of different types of white blood cells in circulating blood (differential and total white blood cell counts). (h) Determination of concentrations of potassium and total base in blood serum. (i) Determination of carbon monoxide content of blood.

The medical study of drivers included a medical history and physical examination, supplemented by determination of visual acuity by the use of Snellen test. Clinical laboratory tests of blood and urine were also made. During the physical examination, an attempt was made to estimate the general physical fitness of the drivers and the impression of the examining physician was noted.

In the occupational and habit study of drivers, the effect of driving was studied by comparing scores made after driving with scores made by drivers in a state of rest. The state of rest was defined as the condition of men who had not driven since a major sleep (6 hours or more). There were 103 of these men and their condition was considered to be a fair representation of drivers in the most rested state they achieve in the course of their regimen, and therefore, provide a good basis for comparison. The coefficient of comparison was calculated by subtracting the individual's after-driving score from the mean of the rested scores and dividing by the standard deviation of the rested scores. Thus, a positive coefficient of comparison indicates better test performance, a negative one indicates poorer performance.

A summary of the results of the tests is shown in Figure 14, which indicates the symptom-complex of driving fatigue so far as it has been determined by this study. In Figure 14, the functions tested have been classified by the degree of difference found between drivers and non-drivers, and by the consistency of the change with hours of driving. This complex includes roughly in order of importance as indicating factors, (a) reduction in speed of tapping, (b) lengthening of the time required to make a coordinated movement, (c) increase in body sway, (d) decrease in speed of reaction, (e) decrease in steadiness of the hands, (f) decrease in vigilance as measured by the driving test, (g) decrease in ability to perceive flicker and probably also, (h) ability to distinguish objects in the presence of glare, (i) reduced speed of eye movement, (j) reduced accuracy in aiming, (k) reduced efficiency in steering, (l) decreased heart rate, (m) increased white cell count, (n) lengthened brake reaction time, and (o) increase in blood pressure. The average functional efficiency as expressed by coefficients of scoring progressively decreased with the increased hours of driving. The results of almost all other tests, in general, supported this conclusion and none offered contradictory evidence.

Figure 15 indicates the combined effects of age and hours of driving as shown by coefficients of scoring based upon simple reaction time, reaction-coordination time, muscular steadiness, and speed of tapping. For these 4 tests, the age trend was consistent for the first 3, but the speed of tapping did not show this trend. The authors state that although the functional efficiency (as indicated by the coefficient of scoring) of men who have driven declines with advancing age, this does not necessarily mean that the older men are less capable drivers. It is not known to what extent the greater experience and possibly more regular habits of the older men compensate for this apparent decrease in functional efficiency.

The authors conclude, "Thus while many factors in the daily lives or background of the drivers may operate to reduce the efficiency and, therefore, the safety of driving, long hours of driving have

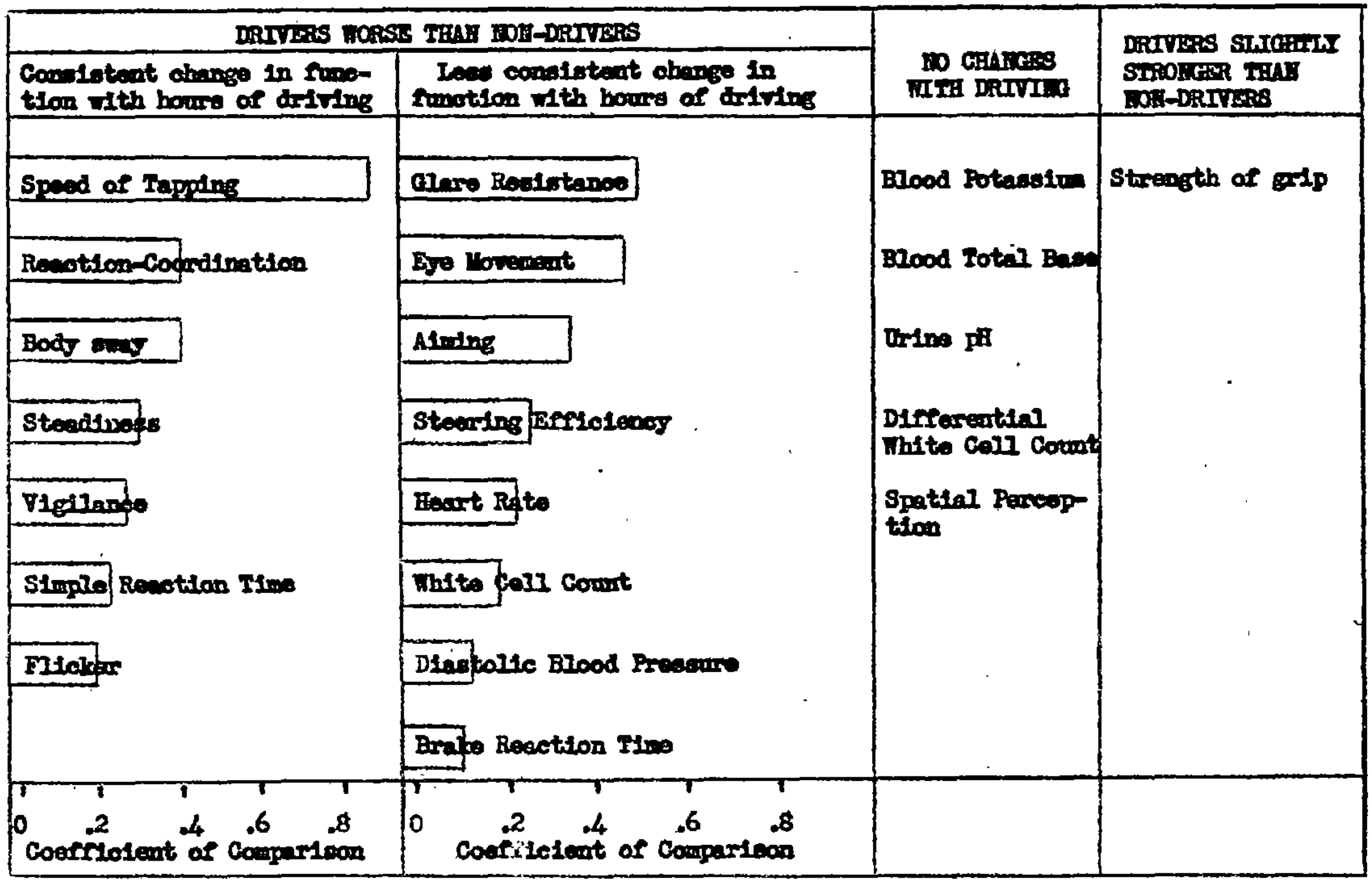


FIGURE 14

A LIST OF THE FUNCTIONS TESTED CLASSIFIED BY THE CONSISTENCY OF THE CHANGES FOUND WITH HOURS OF DRIVING. THE LENGTHS OF THE BARS INDICATE THE RELATIVE DIFFERENCE BETWEEN THE MEAN SCORES OF THE MEN WHO HAD DRIVEN AND THOSE WHO HAD NOT DRIVEN SINCE MAJOR SLEEP

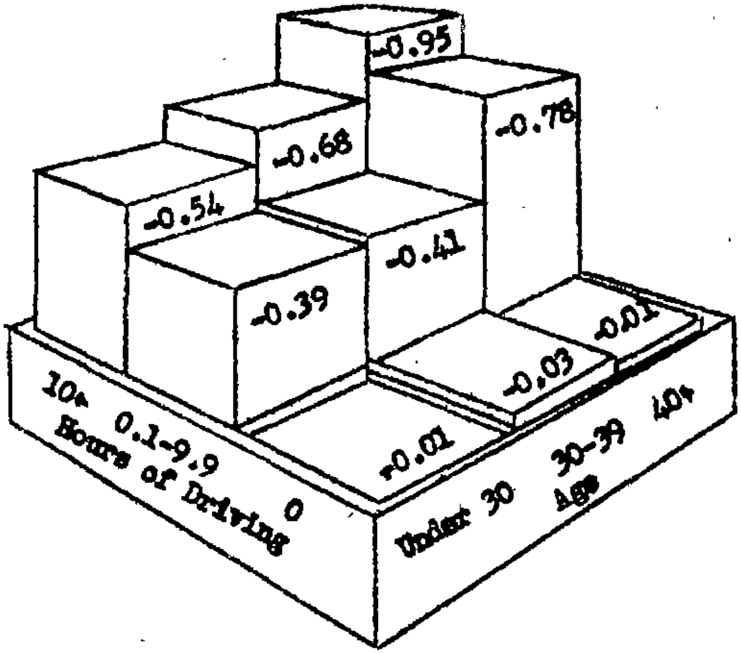


FIGURE 15

FATIGUE OF TRUCK DRIVERS. COMBINED EFFECTS OF AGE AND HOURS OF DRIVING AS SHOWN BY COEFFICIENTS OF SCORING

been shown to be important in this respect. Furthermore, hours of driving are controllable while many of the other factors are not readily controlled except by the drivers themselves. It would, therefore, appear that a reasonable limitation of the hours of driving would at the very least reduce the number of drivers on the road with a very low functional efficiency. This, it might reasonably be inferred, would act in the interest of highway safety."

In regard to the TWA request, this study is pertinent in that it furnishes further evidence of a decrease in efficiency associated with hours of service. It is significant that in this study only a general trend was revealed; the data did not permit a statement as to beyond what number of hours of driving impairment of efficiency was accelerated. The trend associated with age is of interest, especially the comment that perhaps greater experience and more regular habits of the older men may compensate for the apparent decrease in functional efficiency. Again this suggests that it would be desirable to know more about how the TWA pilots spend their off-duty hours. If the granting of the TWA request should prove to be conducive to more regular habits, this would tend to compensate for any decrement due to the proposed increase in the number of on-duty hours.

5. Some Data from the Interstate Commerce Commission. Data published by the Interstate Commerce Commission (80) generally confirm the National

[illegible] duty group.

The data for the year 1938 on hours on duty of motor truck drivers involved in accidents indicate the greatest number of accidents occurring when the truck driver has been on duty between 5 and 6 hours. Eliminating the type of accident in which there is no apparent "driver responsibility," that is, eliminating accidents involving loading and unloading, fires, explosions, etc. - the largest number of accidents, or 11 per cent of the total of the "driver responsibility" accidents also occurred in the 5 to 6 hours on-duty period.

This ICC report considers the most significant feature of the tabulation of accidents by hours on duty to be the high percentage of drivers involved in accidents who have been on duty more than 10 hours. This group (in 1938) represents 11.7 per cent of the total collision and non-collision accidents.

It is an interesting question if the reduction of on-duty hours of these drivers really did result in a less fatiguing tour of duty. It is believed that drivers seldom drove steadily, but rather they stopped frequently for coffee and relaxation. This was equivalent to the introduction of rest pauses which have been shown to reduce fatigue in industry generally. If, after the 10-hour law became effective on March 1, 1939, the drivers were required to cover the same distance as previously, but within the 10 hours, the effect would be to shorten or to reduce the number of these stops and this might possibly offset any gain associated with the 10-hour limitation.

Another Interstate Commerce Commission report (81) indicates that in 1939 the per cent of all truck accidents occurring after 10 hours on duty dropped to 5.8. The ICC report states that this may be a reflection of the hours of service regulations promulgated by the Commission, which became effective March 1, 1939. It is, of course, apparent that this drop from 11.7 per cent to 5.8 per cent merely reflects the fact that fewer trucks were driven longer than 10 hours during 1939. The ICC report does not attempt to evaluate its regulation of hours of service in terms of accident reduction.

As did the National Safety Council publications, these ICC reports point to the importance of considering fatigue from all sources in relation to the decreased efficiency which increases accident liability. Hours on duty is not the sole consideration since many of the accidents occur after but a few hours at the wheel.

6. <u>Some Data on the Effects of Off-Duty Activities</u>. In a study of hours and truck accidents, Morgan (43) presents data which confirms that which we have reported above, that the percentage of accidents occurring after but a few hours of driving is greater than the percentage occurring after many hours of driving. Morgan's data indicate that the ratio of ac-

cidents to hours on duty shows an increase up to 6 hours on duty and a decline thereafter. He considers this as evidence that long tours of duty are not necessarily dangerous from the accident point of view.

The occurrence of accidents in the early hours on duty suggested that this might be the result of too little off-duty time preceding the tour on duty when the accident occurred. To study this matter a questionnaire was circulated asking the time off duty preceding the on-duty time during which 327 accidents occurred. It is reported that in the highest percentage of accidents, the drivers had been off duty 12 to 16 hours immediately preceding the tour in which an accident occurred. Further, there was no relation between the number of hours off duty and the time of the accident in the on-duty period.

A study of the stops or rest pauses showed that the stops have no relation to accident frequency which appears to be the same regardless of the duration of the stop or the time elapsed after a stop.

The major conclusions of this study may be summarized as follows:

a. Hours of duty have no relation to accidents, at least up to 16 duty hours. There may be a period when the hours on duty will bring on sufficient fatigue to make a driver unsafe, but what that period is cannot be determined from this study which includes almost no material on driving accidents occurring after 16 hours of driving.

b. Hours of rest before any period of duty have no effect on the frequency of accidents after going on duty. Further, the time and duration of stops have no effect upon accident frequency.

c. A final inference is that perhaps one of the contributary causes in highway accidents is being "too fresh," or too well rested. Accidents happen in the early hours of duty on the early time after a stop. It may be deducted, therefore, that these drivers of motor trucks become safer the longer they remain at the wheel within reasonable limits. Drivers when first behind the wheel are so refreshed and rested that the duties of driving do not take all of their energy, either physical or mental.

This last conclusion is interesting in comparison with that of the report, How Long on the Highway, which explains similar data due to the fact that the sleep of the truck driver was so short that only a few hours of wakefulness were needed before they fell asleep at the wheel. It is true, of course, that Morgan's study does not deal exclusively with accidents due to falling asleep.

While this study on truck drivers presents rather confusing evidence, it does suggest the desirability of exploring thoroughly the relation between off duty activities and the incidence of fatigue during flights of long range. The off-duty factors might be much more important in producing impaired performance than any difference in the fatiguing effect between eight hours of flight and the proposed long-range flight. There is a need for studies in commercial airlines of the problem of off-duty hours and the time and incidence of accidents or other indices of impaired performance, and, further, the problem of the time of accidents or impairment in relation to the last stop, where a number of landings are involved.

VI. STUDIES FROM OTHER INDUSTRIES

1. A Study of Twelve American Industrial Plants. The Bureau of Labor Statistics has made a study of the effects of long working hours in twelve metalworking plants (30, 31). The findings are well summarized in the second part of the report (31) and they are presented with but slight alteration below.

It appears that hours worked beyond 40 or 48 per week result in additional output but at the price of continuous decreases in efficiency and marked increases in absenteeism as hours rise. A point is finally reached at which the longer work schedule is no more productive, and actually may be less productive, than a shorter work schedule. With few exceptions the longer working time in the plants studied resulted in a general slowing down, not only during the added hours, but throughout the entire work week.

Another point illustrated by the survey of the additional plants is that the 7-day week, as a steady program, is uneconomic and may actually result in less production than the 6-day week.

Among the 12 metalworking plants studied, the operations varied from foundry and forge-shop work to bench operations which required the processing of metal parts weighing as little as one ounce. There was no intention to study metalworking operations exclusively; it simply happened that long working hours were found most frequently in these industries. The material worked, however -- whether metal, or wood, or leather, or paper, or any other substance -- is of no great significance. Given the same types of exertion requirements, control over speed, and wage incentives, the work performance under the same hours schedules will probably follow much the same patterns.

In regard to hours in relation to output the surveys make clear that there is no such thing as an "optimum hour schedule" for all of industry. What appears to be a satisfactory schedule of hours for a plant with light machining operations may be economically wasteful in a foundry. Further, there is a marked difference in the performance of men working under wage incentives and those working at straight hourly rates without any kind of wage incentive. Much depends on the type of work and the requirements it exacts from workers, the degree to which workers can control the speed of operations, and the incentives which motivate them -- whether volume of pay, participation in the war effort, labor relations, or working conditions generally.

The available evidence indicates that, on the whole, the 5-day week and 8-hour day are more efficient than a work schedule with longer hours. That does not mean, however, that longer hours are not productive. There is little sacrifice of efficiency, for instance, if a sixth day of 8 hours or less is added.

The sharper break comes when daily hours are raised from 8 to 9½ or 10 or 11, provided the workers operate under an incentive-wage system.

The primary effect of this lengthening of daily hours for workers on the day shift, when the 5-day week is maintained, is to wipe out the midweek spurt. The analysis of daily production patterns in several plants under a 40- or 48-hour schedule shows a building up of hourly efficiencies toward a peak on the third and fourth days of the week, with a slight drop thereafter. When daily hours were lengthened to 9½ or more, however, this peak disappeared. The production curve for the successive days of the week flattened out, and any one day was about as good as any other day. When a sixth day was added, the line of production remained flat, but dropped to a lower level. The data indicate clearly that workers adjust themselves to longer hours by slowing down, not because they want to, but because they have to.

For workers on the second or night shift, the pattern is somewhat different. Their daily efficiency performance under the 8-hour day and 5-day week looks much like that of the day shift on the 10-hour day. There is practically no midweek spurt, and production tends to flatten into a fairly level line. The reason for this appears to be that these workers are somewhat tired when they come to work, having been up for some hours and probably at work around home. In any case, they are not so refreshed when they come on the job as the men on the day shift who have their leisure hours after, not before, the day's work. When a sixth day is added to stretch the week to 58 or 60 hours, the result is likely to be a steady decline in the efficiency level, day after day, with the peak points on Monday or Tuesday, at the very beginning of the week.

These "fatigue patterns" furnish a reasonably accurate basis for anticipating, for incentive-wage workers, the result of changing (a) daily hours from 8 to 10, or from a 40-hour week to one of 50 hours, and (b) from this level to a still higher one, by adding a sixth work day. The first change may cause a decrease in efficiency of about 5 per cent; and the second, of 7 to 10 per cent if hours do not exceed 58 to 60, but may be as high as 20 per cent if hours reach 66.

For men on straight day-work rates, the lengthening or shortening of hours seems of considerably less significance. This was observed in two foundries. In one, daily scheduled hours remained at 10, but the sixth day was dropped. In the other, daily hours during a 6-day week were raised from 8 to 9½. In each plant the hourly efficiency level remained essentially unchanged under the different levels of hours. Apparently the pace at the shorter hours was not so fast that the addition of extra hours caused a slowing down; nor did the shortening of hours bring about any quickening of the work tempo.

In plants in which work was light or very light, the general tendency for workers under incentive systems, and with weekly hours ranging between 55 and 58, was to produce about a 2-hour volume of production for every 3 hours added above 48 per week (i.e., 6 days at 8 hours each). When work was heavy as in foundries, the ratio was more nearly one hour's additional output for every additional 2 hours worked. One reason for this was the greater need for rest pauses.

The studies included two plants in which shorter hours were found to result in a volume of output as great as or greater than was the case under longer hours. In a forge shop, where the work was both hot and heavy, a 52-hour week was found to be as productive as a 58-hour week. In a shell plant, in which morale was excellent and the work medium heavy, the lengthening of daily hours from 8 to 10 for the day shift and 11 for the night shift, and of weekly hours from 40 to 60 and 66, had such unsatisfactory results that the plant eventually changed to a 48-hour week. The average increase in output under the longer schedule was only about 7 per cent above that for the 40-hour week -- a result which could have been achieved easily by increasing weekly hours from 40 to 43 or 44. The additional 20 hours were sheer waste of time.

The experience of one plant which had operated extensively on Sundays under a 7-day weekly schedule demonstrated the undesirability of continued Sunday work. While remaining on the 8-hour day, this plant worked a 7-day week for over a year. It then dropped out every third Sunday, later every other Sunday, and finally every Sunday. The analysis of this plant's performance shows that efficiency was lowest during the 7-day week, and highest during the 6-day week when no Sundays were worked at all, and that efficiency mounted as additional Sundays were dropped. The data indicate that efficiency was about 36 per cent better and total output about 13 per cent greater during the shortest work schedule. In terms of this performance, the 7-day week amounted to 8 days' pay for 5 days' output. The 30 identical operators traced throughout the entire period involved in these changing schedules actually produced one more day's output during the straight 6-day week than they formerly produced during the 7-day week.

The relationship between longer hours and absenteeism was found to be the same in nearly every instance: as hours increased -- whether daily or weekly -- absenteeism increased. In most cases the reason could not be determined from plant records. Some of the data suggest a higher incidence of illness. In some instances it was quite clear that workers wanted or required more time for leisure or to attend to personal matters. It is also likely that the strain of longer hours and the fact that the weekly pay envelope was higher than it had been for years combined to induce workers to pay more attention to their health and well-being. The fact that workers were limited in the items their money could buy was also cited by some plant executives as a reason why men took more time out, or why they absented themselves for reasons which they would not have needed under shorter work schedules and with smaller earnings.

As a rule, absenteeism was higher for the night shift than for the day shift under the longer work schedules. This was particularly true of women, whose absenteeism rates generally exceeded those of men.

In the absence of effective safety programs, work injuries tended to occur relatively more frequently under longer hours. In one plant they occurred only one-third as frequently when the daily hours were reduced from 10 to 8. Where plants had good, active accident prevention programs, the lengthening of hours did not bring about a disproportionate increase in work injuries.

Women were found to be more efficient than men at light, repetitive and rhythmic operations requiring nimble fingers and little physical exertion. On the other hand, men were superior on machines which required close adjustments or which were complicated.

The merit of an incentive-wage system as a spur toward greater production was well observed in a foundry. It was found that the change from day-work to piece-work rates resulted in slight increases in output even when hours remained at 10 per day and 58 per week. The result was dramatic when the introduction of the incentive coincided with the reduction in weekly workdays from 6 to 5, even though the 10-hour day was maintained. Output during the shorter work week was 13 per cent greater than it formerly had been under the 6-day week. In terms of the production level which had prevailed during the longer work week, the men -- at piece rates -- produced as much in 5 days as they formerly had in 7 days without a wage incentive.

While findings in 12 metalworking plants do not bear directly upon the TWA request, they do provide evidence which corroborates the findings of the studies in the transportation industry and those of the laboratory. An increase in the number of hours of work is usually productive of increased fatigue which is manifested as a reduction of efficiency on the part of the worker. This reduction of efficiency is reflected in a falling off of the production rate, an increase in the number of errors which causes a greater spoilage of materials, unauthorized absenteeism, and an increase in the number of injuries and accidents. It must be remembered, however, that sufficient motivation, as seen in the effect of incentive-wage systems, can maintain efficiency at a high level or even increase it. If the proposed long-range flights mean more predictable schedules for the pilots, if they permit the pilots to spend more time at home, if they reduce the amount of time the pilots have to spend waiting for take-offs, then it may be considered whether these factors are motivational to the extent that any possibly greater fatigue associated with the longer flight becomes of little significance.

2. <u>Reports of the Industrial Health Research Board of Great Britain.</u> The Industrial Health Research Board has published reports of many studies of the effects of fatigue and problems of health occurring in industry. These studies have recently been summarized by Smith (50). A few of these studies will be reviewed to illustrate that they generally corroborate the findings in American industry.

In the heavy work of charging blast furnances by hand, Vernon (55) recorded for three shifts the time in minutes required for each change and the actual hours when each occurred. The results showed that (with the exception of the brief spell 6 to 8 A.M.) the rate of charging fell off during the last period of each spell, showing an average decline of 14 per cent; also that this effect became exaggerated during the morning and afternoon shifts of Sunday when the men worked a continuous shift of 16 hours (6 A.M. to 10 P.M.) in order to enable the shifts to change over. Hourly output was low to begin with, followed by a rise, and towards the end of the work spell a fall in hourly output which is believed to be due to the effect of fatigue.

In the process of weaving, variations on hourly output over the working day have been shown by independent workers for silk, fine linen, and cotton weaving (22, 62, 66). In the case of the weaving figures, the looms were working up to the end of the day, so that no loss in mechanical efficiency occurred. In the silk weaving investigation it was found that a longer time was required at the end of the day to perform the manual operations. This was believed to be due to fatigue. In the cotton weaving industry where observations were taken every quarter of an hour, it was found that a rise in production occurred during the first hour of the morning and that there was a gradual fall during the last hour of the afternoon.

In a study of shift systems in the glass trade (20) it was clear that the relative hourly efficiency in bottle blowing has been increased by shortening the hours of work, though this increase is in no case so great as to bring the output of the 8-hour shift to the level of the 10-hour shift. It must, however, be borne in mind that the plant employing the 3-shift system is being productively used for 24 hours per day, whereas in plants employing the 2-shift system it is only being productively used for 20 hours a day. From this it follows that the total output per day is greater with the 3-shift system than with the 2-shift system.

Night work in the 3-shift system does not appear to put a markedly greater strain on the men than day work. The night shift is always more efficient than the morning shift and not much less efficient than the afternoon shift. When 12 hours' work out of 24 hours is done in alternate 6-hour shifts, night work is consistently less efficient than day work.

In a study dealing with rest pauses (57) it was found that the rest pause increases the efficiency of the workers, for in various occupations (with 4½-hour work spells) the immediate effect of introducing a rest was to increase output by 2.8 per cent, while the improvement in other groups of workers who were tested some months after the introduction of the rest appeared to reduce 6.2 per cent. Also the introduction of a rest appeared to reduce the labor turnover greatly.

A compulsory rest pause is disadvantageous to output in a small number of semi-continuous occupations connected with the manufacture of chocolates and biscuits, because it involves the waste of a good deal more time than that of the nominal rest pause. However, this objection can be avoided by employing temporary substitutes, and by arranging that various groups of women take their rest pause successively, and not simultaneously. This princple can be advantageously applied to many other occupations.

For various reasons it is probable that a 10-minute rest pause is better than one of 15 minutes.

In another study of shift systems (51) the operation of the 2-shift system (as compared with a day system of 8 A.M. to 6 P.M.) was studied in detail in eight factories, employing in all about 2,400 workers on shift work. The few comparable data available suggest that the rate of work was often increased when workers were employed on the 2-shift system. Owing, however, to the shorter hours worked by the shift workers (on the average of 40½ hours compared with 46 hours), the weekly output per worker was lowered by 4 per cent. A comparison of the lost time records in one factory suggests that absenteeism among the shift workers was greater than among the day workers. Neither system was shown to have any advantage over the other in respect to the sickness experienced. So far as could be ascertained by questioning the workers, a deficiency of sleep during the week of morning shifts was usually compensated for during the afternoon shifts. In one large factory it appeared that the labor turnover was slightly greater in departments always on shift work than in departments on day work. But in departments in which there were changes from day to shift work and vice versa, the turnover was approximately twice as great.

A frequently quoted study of the Industrial Health Research Board deals with the output of women workers in relation to hours of work in shell making (44). A summary of the findings of this investigation follows.

The investigation was based on data of the hourly output of 43 women in a National Shell Factory engaged on the "ripping" or "part off" operation in the turning of 6-inch shells, during the periods of one week under 2 different systems of employment, namely, 2 shifts of 12 hours each and 3 shifts of 7 to 8 hours each.

Direct comparison of the average hourly output for all shifts under the two systems shows a decided increase in favor of the short-shift system (870 compared with 817). This difference is further accentuated when the effect of the time of actual cutting (a machining operation the speed of which is constant) is eliminated; in the work of fixing and removing the shells, over the speed of which alone the operator has control, the time required for a fixed amount of work shows a decrease of 195 per cent in favor of the shorter shift.

Higher efficiency of the machinery and less idle time in the short-shift system are shown by comparing for the two systems the average output per possible hour of work and the average output per actual hour of work. The output computed on the latter basis shows a decrease of 3.43 per cent on the long-shift system and of only 0.58 per cent on the short-shift system.

A similar comparison for the two systems of the average output per hour in the factory and the average output per actual hour of work indicates by the smaller decrease in the case of the short-shift system (7.59 per cent compared with 14.67 per cent) the advantage of a shift of such duration as to require only one meal break.

The uniformly low efficiency for the long shifts of the last hour is strongly indicated in the curves of average hourly output; no such uniformity exists in the case of the short shifts, on the contrary, several sets of curves exhibit no falling off.

The curves of output for the short shifts give evidence of the possibility of running at full output right to the end of the shift; but the curves for the long shifts give no such evidence.

A comparison of the same worker's output records for the long and short shifts shows inferiority in hourly output during the later hours of the long shifts.

No evidence of detrimental effect of night work in comparison with day work is traceable.

Smith (50) also discusses the variation of output during the week. If the workers become gradually more tired, so that nightly rest is not adequate, a considerable decrease in output at the end of the work should be expected. The results of a number of studies showed that output is nearly always low on Monday and at the end of the week. The general results are consistent with output being affected by two opposing factors: (a) increased efficiency due to practice which causes a rise in output; and (b) fatigue effects which accumulate during the course of the week and tend to cause a fall in output. These opposing factors vary in strength according to the length of the working day, the kind of work, and the experience of the worker. Output may reach its maximum on the second, third, or fourth day of the working week.

In general, the studies of the Industrial Health Research Board confirm the observation that fatigue is revealed in a lowering of the quantity and quality of work. Although accidents have various causes, there is evidence that a state of fatigue due to too long hours and insufficient rest causes an increase in the number of accidents. During a period of the 1914-1918 war when a 12-hour day (75-hour week) was being worked, the accidents incurred by women workers were two and a half times more numerous than in the subsequent period when the daily hours were reduced to 10 (56). These studies have shown that fatigue is productive of organic changes, sometimes expressed in some digestive disturbance, the "too tired to eat" condition, in eye strain, headache, and various minor disorders. There is diminution in the power of concentration, in memory, in ability to see the connection between ideas, all of which are important for efficiency. When fatigued, most people are more easily moved to tears or laughter, less balanced emotionally, more likely to suffer from wounded self-esteem, with easier yielding to fear or irrational stubbornness and a tendency to irritability which may vent itself on the wrong person.

It is true that the hours of work obtaining in the industrial plants studied by the Industrial Health Research Board differ considerably from those of commercial aircraft pilots. However, these studies do illustrate the adverse effect of fatigue from whatever source, upon human efficiency. These studies suggest the desirability of learning the sources of fatigue in the off-duty activities of aircraft pilots and the trend which a granting of the TWA request would effect in relation to those off-duty sources of fatigue. These studies of fatigue in industrial plants throw little light upon the very important question whether a long-range flight involving but two or three landings is more or less fatiguing than the flights under present regulations which often involve more landings -- considering the landing as the crucial aspect of the aircraft pilot's task, an aspect in which any effect of fatigue demands careful consideration.

VIII. LABORATORY AND OTHER STUDIES

This section deals with studies which were done in an effort to determine the effects of various factors on performance. Most of these were not made in the air or on pilots, but were made on the ground on other types of individuals. Some of the results, however, are sufficiently clear-cut so that one may generalize from them to pilot performance, especially those on anoxia. The following factors will be taken up in order; noise and vibration, lack of sleep, long hours of work, and anoxia.

1. Noise and Vibration. Some investigators feel that noise is one of the major contributing causes of fatigue in flying. It has been shown in many studies that noise does have a detrimental effect on performance. However, to just what degree it influences fatigue is not known. In the British survey of pilots mentioned above (63), 100 experienced pilots of heavy bombers rated noise as one of the least of fatigue producing factors. Many of them, in fact, were surprised to know that there was a lot of noise in airplanes, as they said they had not noticed it at all. Modern transport aircraft are so well sound-proofed that the noise level is considerably lower than that in combat aircraft, either bombers or single-engine fighters, and there is every reason to believe that further sound-proofing will decrease the noise level almost to that of ordinary room noise. Nevertheless, some of the studies that have been made on the effect of noise on performance and on hearing will be presented.

Senturia (48) reports a study of 74 cadets, 19 per cent of whom showed hearing losses of 15 decibels after a period of 70 hours' training, and 11 per cent showed gains. Losses were generally associated with frequencies between 2,000 and 5,000 cycles per second. After a second period of 70 hours there was a tendency to regain hearing. Forty of these men were examined after a third 70-hour period of pilot training. A small number of these showed a slight loss of high tones but no case where hearing or speech was affected.

In a study for the CAA, Lewis (36) studied the effect of noise and vibration on certain psychomotor responses. Eighty male students were exposed to noises of from 85 to 110 decibels intensity and to vibrations of from 4 to 6 mils while they were operating a Mashburn apparatus. Measurements were made of Mashburn performance, heart and breathing rates, tilt perception, and brain waves. Exposure to loud noise for as much as one hour raised the threshold for hearing somewhat and there was an indication that breathing rate was accelerated during some of the experimental conditions. On the whole, however, the results were negative. The experiments were repeated with the subjects exposed to noise and vibration for four and a half hours. Again neither noise nor vibration nor the two in combination had any measurably significant effects on reactions. No study was made of fatigue or efficiency under these conditions and the author states that the results cannot be accepted as conclusive in terms of planning a schedule of work and rest periods for pilots.

Senturia and Pergnet (49) give a table showing the noise levels in different situations ranging from the noise of whispered conversation at 5 feet being equal to 25 decibels, to a B-24 aircraft, doing 240 mph, which creates 126 decibels. They state that noise intensity of 90 db or more is fatiguing, although they do not state how this figure was determined.

In a review by Berrien (9) the resultsof a study made by the Aetna Life Insurance Company are recorded; Berrien states that this study has been referred to by Lindahl (38), and by Wilson (64). Typists, clerical checkers, and punch card comptometer operators were checked for "efficiency" for a year prior to installation of sound absorbing materials in the office, and also for a year after the sound-proofing treatment. The semi-monthly efficiency rating based upon bonuses received was 9.2 per cent increased in favor of the quieter condition. At no time during the quiet year did the bonus go below the level of the first year. The quiet condition approximated 35 decibels. The same review cites a report by Laird who measured the metabolic rate of four typists during a half hour of resting and while typing a standard letter over and over again for two hours a day throughout a 4-week period. During the first and last of these weeks the walls of the test room were bare, during the second and third sound absorbing material was applied to walls and ceiling, reducing the noise produced mechanically from 50 decibels to 40 decibels, approximately. On the average, the metabolic rate was 51 per cent higher while working than while resting, and was 71 per cent higher during the noisy weeks. A suggestion that the noisy phase was more fatiguing is found in the data showing that the average time for the last 5 letters was 7 seconds less than for the first 5 letters during the quiet phase while the comparable time was 5 seconds more in the noisier condition. The fast typists improved in speed when the noise was reduced while the slow typists showed little or no change in over-all speed.

The reviewer, Berrien, goes on to state that interrupted noise or discontinuous tones have been generally found to be more annoying than steady noises. In reports by various authors cited in the review, the initial onset of noise produced the greatest adverse effects, hence a discontinuous noise would be somewhat comparable to a rapid series of noise periods each of which demands a new adjustment with initial phases of maximum cost to the individual. He concludes the review as follows:

> "In spite of a widespread interest in noise abatement, relatively few facts have been well established. Popular literature not covered in this review abounds in emotional outbursts against the painful effects of noise. Public support has been enlisted for noise abatement campaigns on the uncritical acceptance of the assumption that noise, because it is annoying, must be harmful. The available scientifically controlled studies are not in complete agreement that tend to show ill effects on output, speed of work, or vital processes. Although a considerable degree of adaptation takes place, the evidence suggests that it is seldom

complete. Marked individual differences and susceptibility to the ill effects of noise have been noted, but no reported attempts have been made to correlate these differences with other aspects of personality. The factors determining annoyance have not been subjected to thorough analyses. Stimulation deafness is an unquestioned result of exposure to loud noises for long periods, but its extent and the critical levels of noise necessary to produce it in humans have not been clearly established. In summary, it is clear that there are many circumstances under which noise detracts from efficiency and well being. Under what circumstances is noise deleterious and for what kinds of people are questions for further physiological research."

A review of experiments on the problem of stimulation deafness by Kemp summarizes as follows:

> "People who work in extremely noisy environments are often found to be hard of hearing, particularly for high frequencies. One investigator has reported deafness for certain low frequencies in people who are working in an environment where it is said these low tones were predominate. In all such cases, the relationship between age and hearing defect needs to be considered. Guinea pigs exposed for a considerable time to tones of high intensity have frequently been found to possess cochlear lesions. It is not certain that low tones are similarly effective. Results with exposure of other animals are not conclusive, but there is evidence that sufficiently intense and prolonged stimuli will produce lesions in white mice and pigeons, and possibly in cats, dogs, and apes. Behavioral examinations before and after such intense and prolonged exposure have usually revealed general rather than specific losses of sensitivity" (29).

In a report by S. S. Stevens (52) on the effects of noise and vibration on psychomotor efficiency, he states:

> "Our experiences to date demonstrate that the effect of noise on human beings is no simple matter. Some aspects of behavior appear to be facilitated by intense sound, others seem definitely to suffer in the presence of noise. Exposure to noises of uniform spectra at 106 db, even for short periods, produces losses in hearing ranging up to about 30 db. These losses are localized at the high frequency end of the audible range. Exposure to airplane noise for periods of about two hours produces losses distributed more widely over the spectrum. Fortunately, these losses are temporary, but evidence from other sources indicate that with sufficient exposure the losses may become permanent. We have not yet determined by how much an airplane noise must be attenuated in order to be rendered innocuous."

He continues that preliminary results point to a certain amount of facilitation in subject performance on motor tests. Exposures up to 3 hours in noise show an improvement in some aspects of the subject's performance on coordinated serial reaction time on the pursuit rotor test, and on tests of marksmanship. On the other hand, the almost unanimous report of the subjects performing these tests in the presence of intense noise is that they feel more tired and "washed out" than when the same tests are run in quiet.

The evidence thus far obtained from measurements of muscular tension would suggest that the subjective fatigue reported after exposure to noise may be due in part to a tendency for a slightly greater tension to be maintained in the various muscles of the body. On the other hand, subjects tested in noise for speed of accommodation required a definitely increased time for changing their point of fixation from near to far and from far to near. Also there is some evidence that the speed with which subjects can move their eyes is reduced by intense sound fields. Limited tests with vibration chairs have shown a striking reduction in visual acuity when subjects are vibrated through an amplitude of one mil. For ten subjects these reductions in acuity ranged from 10 to 46 per cent, with an average of 25 per cent.

2. Lack of Sleep. The following studies were carried out in an effort to determine to what extent lack of sleep influences performance of certain tasks. Again there was no measurement made of actual performance of pilots in airplanes, and again we must generalize from laboratory studies to the flying situation.

At Tufts College Laboratory (77) a group of four observers were put through an experiment lasting 74 hours of which only 16 hours were spent in sleep while 42 hours were spent on duty. While on duty they were on the alert and were required to spot and report signal lights appearing in the area allotted to them for observation. At intervals these observers reported for duty on a stereoscopic training instrument. Measurements were made on this instrument of tracking and stereo performance. During the 3-day period decrement in performance was not indicated either by stereo or tracking measurements.

Although the objective results of this test showed no change with increasing hours on duty there were several subjective reports of behavior of subjects which have interest. The observers during the 4 A.M. to daylight shift experienced difficulty in staying awake. They complained of sleepiness during early hours of the morning, leg soreness from standing and hill climbing, eye fatigue from sun glare during daytime alerts. Tracking was reported as being increasingly difficult toward the end of the 3-day test, requiring more effort to maintain performance. Stereo ranging determinations were reported as being of uniform difficulty throughout. Eye fatigue during daytime alerts was reported as more noticeable during the latter part of the test. The authors conclude that in order to produce performance decrement in short tracking tests due to physiological fatigue a schedule similar to the one reported here would have to be extended over a longer period of time, as observers can muster for a brief test sufficient energy to maintain a standard of performance.

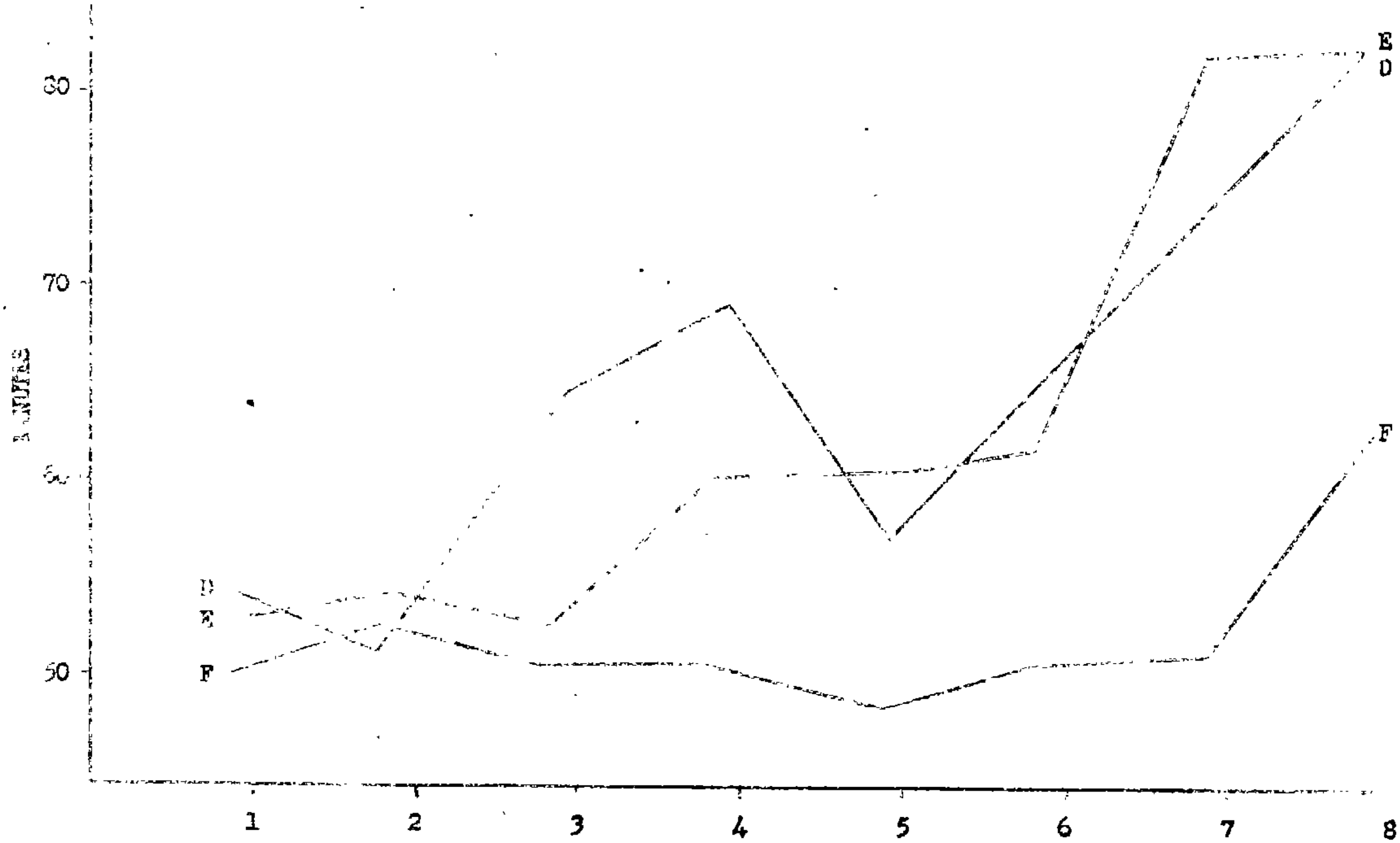
In another study from the same source (74) ten observers stayed awake for 50 hours and had various tests given to them at intervals throughout this 2-day period. These tests were of reading, arithmetic, steadiness, tracking an aerial target, and range determinations. All test performances except reading speed either remained the same or improved during the 2-day period. This showed a decrement in the two final tests.

A third report from Tufts (72) describes a 6-hour sequence of activities that was repeated 8 times, without intervening sleep. During each of the 6-hour cycles subjects were given a stereo test which consisted of 40 settings being made on a fixed target. In addition, they were given an alert apparatus test. The length of time taken on this test varied depending on the accuracy and alertness of the subject. The average time was approximately one hour. No differences were noticed in the stereo test from first to last cycle.

In the alert apparatus test the results were different. This test requires considerable attention and is much more complex than a simple test such as the stereo. The subject has to keep track of several dials, perform certain things at certain times by a clock, he has to move a small airplane, score a map, spot another airplane that appears periodically on a screen, and match various dials which are to the right and left of the central screen. The total time taken to complete this test and the errors made in dial matching and the different cycles are shown in Figures 16 to 19, for 2 groups of 3 subjects.

It will be noted that only one of the subjects showed an increasingly good performance throughout the test or throughout the 48-hour period. The subjects in this test were motivated by being paid on the basis of trials and errors. They got one dollar per period on the alert apparatus plus or minus 10¢ for each minute gained or lost over the average total time score of their preliminary training trials. It was noted that all the graphs but one showed some decrement. However, the individual differences in the slope of the lines suggests that individual operators may "fatigue" at their own rate. As has been found in other and similar experiments, the change in behavior, personality, and physical appearance was much more pronounced than these graphs of objective performance would suggest.

The foregoing studies do not demonstrate conclusively that performance on short tests with sleep lack is increasingly worse with successive trials. However, the reports do state as reported in the last paragraph that the behavior of the subjects was vastly different from the first to last of these periods. Although no continuous test was made of ability to perform certain functions with sleep lack, it is suggested that if subjects were required to perform tasks spread out over a longer period of time that their performance would show decreasing accuracy with time in the test situations.



TRIALS

FIGURE 16

TIME REQUIRED BY THREE SUBJECTS IN COMPLETE ALERT APPARATUS TEST
ON EIGHT TRIALS AFTER 6-HOUR PERIODS OF ACTIVITY

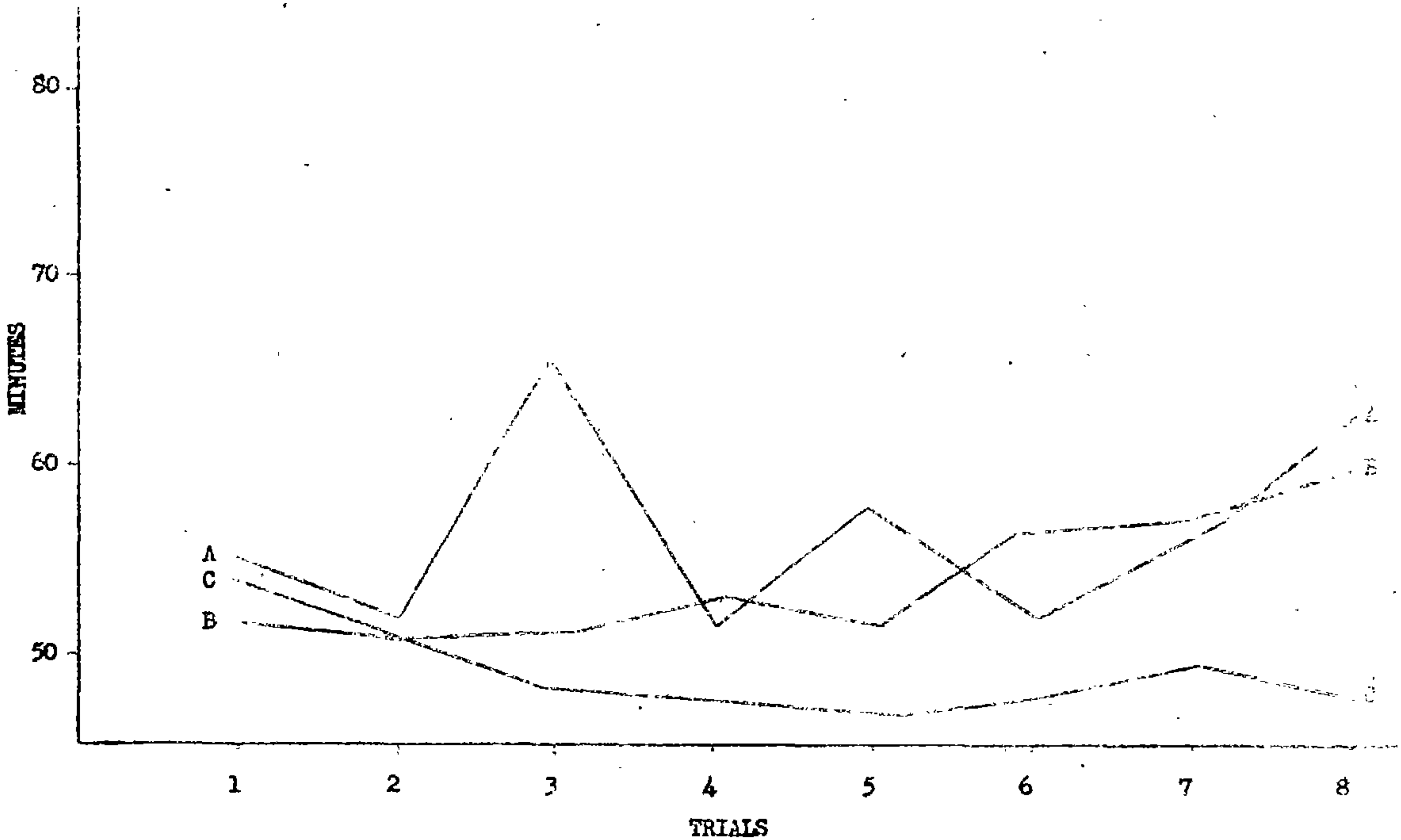


FIGURE 17

TIME REQUIRED BY THREE SUBJECTS IN COMPLETE ALERT APPARATUS TEST
ON EIGHT TRIALS AFTER 6-HOUR PERIODS OF ACTIVITY

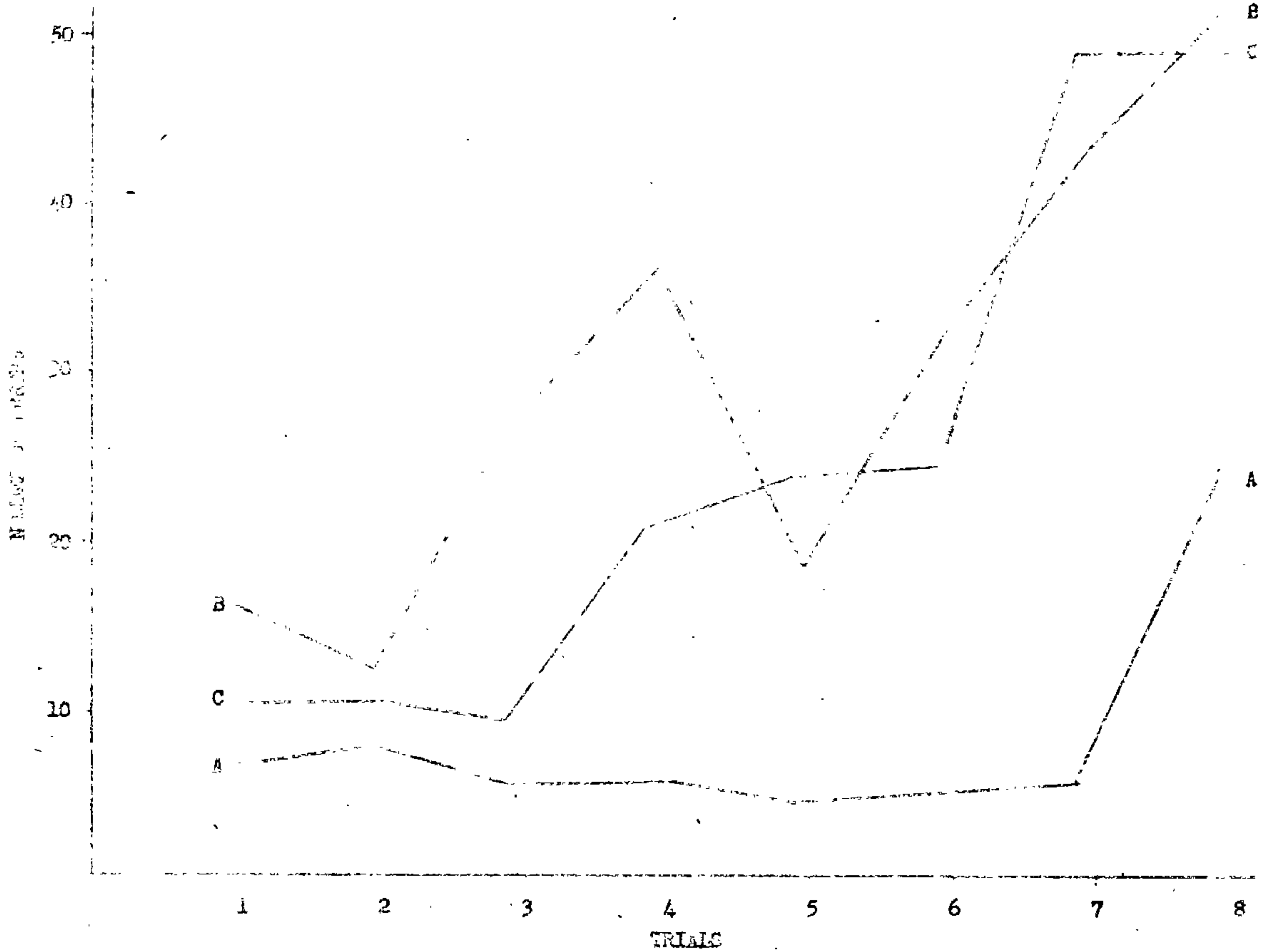


FIGURE 18

DIAL MATCHING ERROR FOR THREE SUBJECTS ON EIGHT TRIALS
AFTER 6-HOUR PERIODS OF ACTIVITY

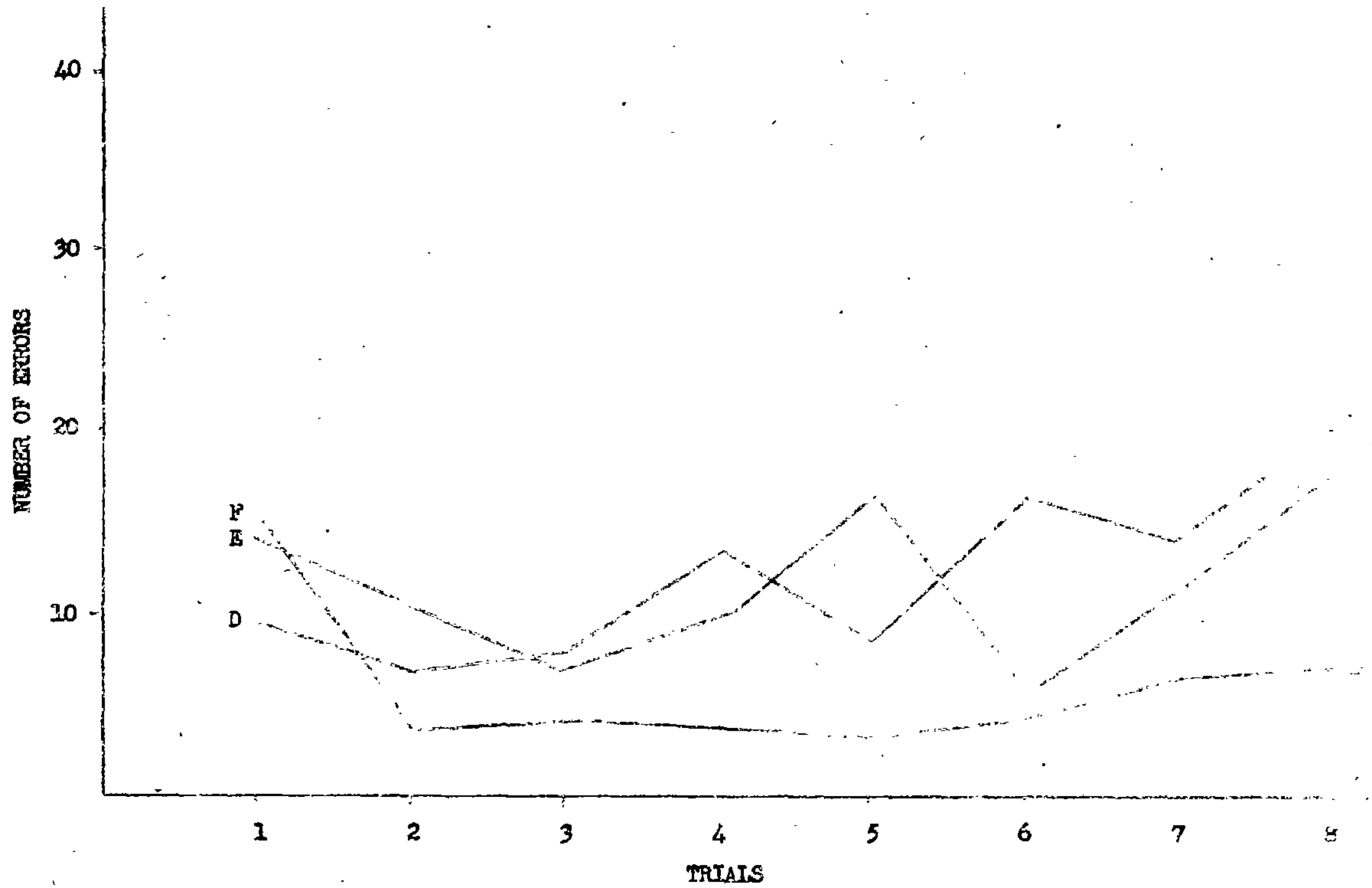


FIGURE 19

DIAL MATCHING ERROR FOR THREE SUBJECTS OF EIGHT TRIALS
AFTER 6-HOUR PERIODS OF ACTIVITY

3. <u>Long Hours of Work.</u> Subjects were required in an experiment at Tufts (24) to perform on an apparatus (described in 72) for a continuous 4-hour period. Record was made of scores for the first half of the run and for the last half of the run, in each of 3 trials during the 4-hour period. There were, therefore, available 6 scores of each type for each subject's 4-hour experimental period. It was noted that none of the trial variation was significant and it was concluded that no significant change in performance occurred during the 4-hour period, i.e., no decrement or improvement in performance. It is further concluded that a subject may work continuously and effectively at a psychologically complex task of this type for several hours without any significant change in level of performance.

It is understood that this study is being continued, but it is not known whether it has been completed. Attempts are being made to determine whether longer hours of the test will produce a decrease in performance.

Another study at Tufts College (73) shows the results of continuous 13½ hours of tracking on a Navy Mark II Trainer. Only one subject was used in this study. Five minute samples of performance were taken and scored immediately every 15 minutes. Motivation in terms of encouragement and pay increases was given when performance fell below a specified level. No increase in motivation was necessary during the first 8 hours. At this point the subject was encouraged to hold the error score down. At 8½ hours this encouragement was repeated, at 8 3/4 hours his pay was doubled, and again at 11¼ hours. At 11½ hours the observer was given a 3-pound weight to hold and 11.7 hours this weight was increased to 8 pounds, at 11.9 hours pay was tripled for a period during which performance was satisfactory. At 12.8 hours triple pay was reestablished.

The authors conclude it is evident that with the onset of fatigue as measured by performance added motivation was not effective in restoring a performance to its initial level. From the subject's reports and from his attitude it is believed that this curve of performance decrement includes a minimum of the effect of boredom and a maximum of physiological fatigue, particularly of the arm and hand. It is significant to note that performance is improved only momentarily by added motivation, the improvement lasting for less than 5 minutes. The primary locus of the effort of this prolonged test was in the arm and hand, which reduced the observer's efficiency and the fine muscular coordination necessary for accurate tracking. The secondary locus was in the back and neck muscles.

While limited to one case the study suggests that continuous work of 13½ hours affects accuracy in performance including a visual factor of the type involved most during instrument flying or landing. Of particular importance is the fact that the reduction in the efficiency of performance is not to any large extent counter-balanced by motivation -- a form of motivation which is not present to the same degree in flight operation as in the case of the experimental situation.

A study made under the auspices of the NDRC (83) deals with the selection and training of oscilloscope operators. Under conditions closely simulating those of the actual radar screen and field operation the ability of 8 men previously trained to high level of proficiency was tested during 4-hour periods of continuous operation on successive days for a period of approximately 3 weeks. During each daily 4-hour period each subject was presented 1116 targets. Figure 20 shows curves and number of omissions for each hour for each of the successive days, accumulated by days for all subjects. It will be seen that daily repetition of a 4-hour period of oscilloscope operation causes a progressive loss of efficiency in the detection of signals. Loss of efficiency is related to the length and repetition of the operating periods, as can be seen by the increase in the number of signal omissions. Loss of efficiency did not become apparent until after the third day of repeated 4-hour operating periods. This may indicate that occasional prolonged periods of operation may be served without appreciable loss of efficiency, but in general, it does not appear wise to prolong daily operating periods more than 40 minutes if such periods of operating are to be repeated daily without intervening days of rest.

A study from the Psychology Laboratory of New York City by Barmack and Woodruff (6) reports the effect of Postum, decaffeinated coffee, water, and coffee, on performance in a simple pursuit meter test. This study was undertaken because reports from the European Theatre of Operations indicated that a high percentage of landing accidents might be due to a loss of alertness, fatigue, emotional exhaustion, emotional letdown and oxygen want in pilots. Fifty-four subjects in the experiment operated a pursuit meter for 2 hours. At 15-minute intervals the subjects provided the experimenters with indices of their feelings, with measures of restlessness, and the extent to which they could attend to their simple continuous task. After something over one hour of operation, the subjects were given one of the beverages mentioned and it was found that not only performance, but subjective feelings improved for 15 minutes thereafter. Coffee was the most effective in reducing the symptoms of fatigue. Other beverages not containing caffeine were also effective. The data suggest that it would be profitable to attempt on a sample pilot population the regimen of administering either decaffeinated coffee or Postum 10 to 15 minutes prior to landing. The effect of such regimen on landing accident rate would provide the only test as to whether the findings of the experiment were relevant to the solution of the original problem.

In a study effected at the Tufts College Laboratory (75), the visual performance of 10 subjects was tested before, after, and twice during a 30-mile hike. The functions measured were stereoscopic acuity, tracking accuracy, brightness discrimination, and reaction time. Special monetary incentives were used to keep effort at a high level. Scores of both average performance and of variability of performance were derived for each trial. The ability of the subjects to persist at a task was also measured before and after the 30-mile hike. The several scores derived in this experiment were analyzed to determine whether the amount of physical exercise influenced performance. The conclusion drawn from these analyses is

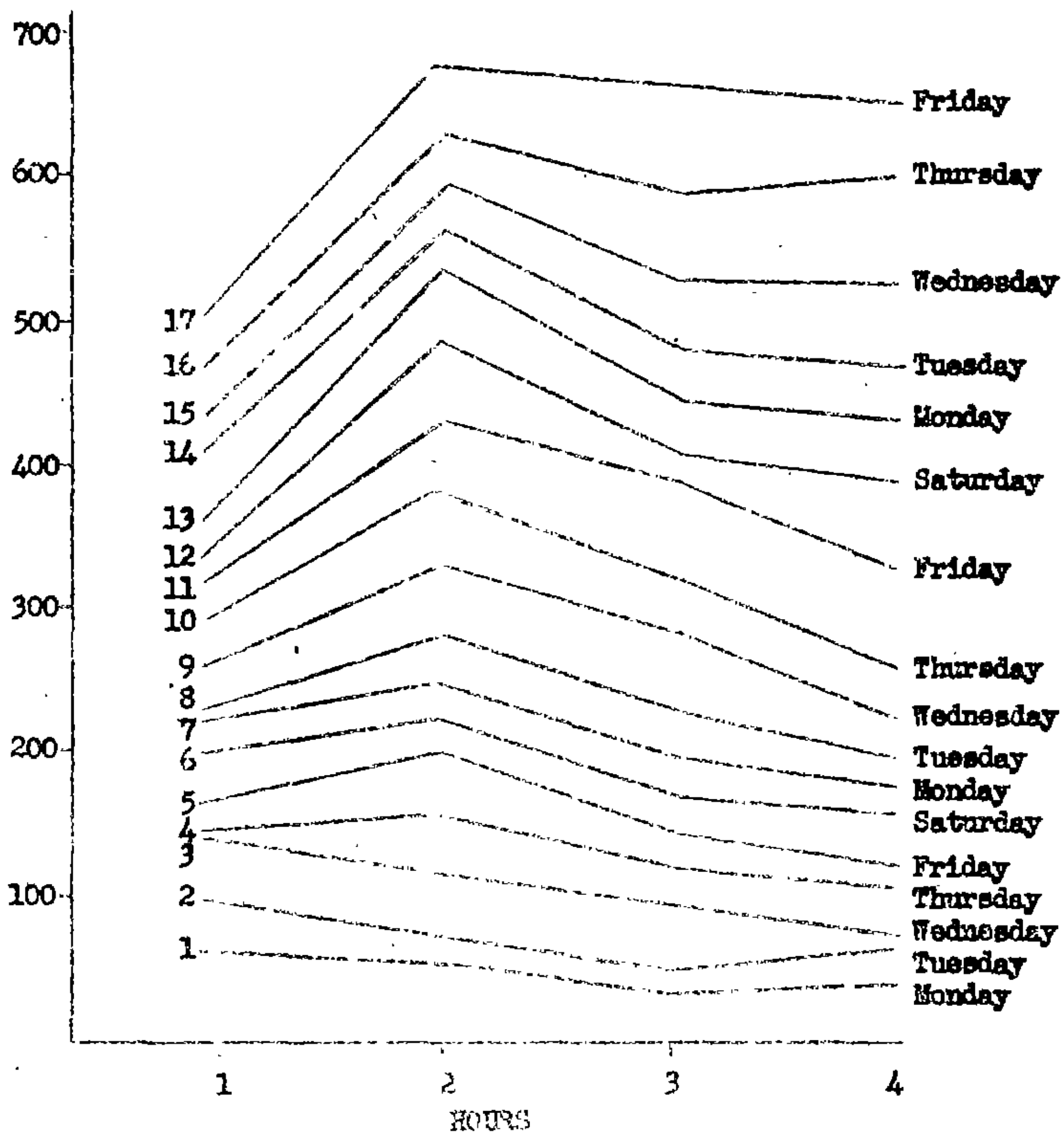


FIGURE 20

CURVES OF NUMBER OF OMISSIONS ON EACH HOUR FOR EACH OF THE SUCCESSIVE DAYS, CUMULATED BY DAYS that performance during short, periodic intervals of visual work remains relatively constant despite clinical signs of fatigue. The results of a persistence test, however, show that fatigue operates to produce a decrement in the observer's readiness to maintain a high level of performance for long work periods.

In another study at the Tufts College Laboratory (76), a test was conducted to determine the effect of strenuous physical activity upon stereo range-finding accuracy. Nine subjects, who had been well trained over a period of several months, were given two preliminary tests of stereo ranging on the Mark II Navy Trainer. These tests were followed by a period of rapid stair-climbing with a heavy load, immediately after which the stereo test was again administered. A significant increase in the variability of range settings occurred as a result of the exercise, but the effect was of short duration; the precision of settings returned to its previous level in less than 5 minutes. These results are consistent with those of previous experiments which have investigated the effects of hyperventilation on stereo acuity. The finding that stereo acuity is affected for a similar period of time by abnormally deep breathing suggests that the present results may be accounted for in part as hyperventilation effects.

These experiments are of interest since it is known that hyperventilation occurs in pilots, particularly during let down and landing procedures.

The studies reported above indicate that long hours of work regardless of the nature of the work tend to have a deleterious effect on performance in some instances and not in others. However, the level of motivation must be considered in any of these studies. Apparently, when motivation is high, good performance does not drop off, although in one case increased motivation in terms of increased pay did not maintain a high level of performance over a long period.

It can be seen from the above that the evidence is conflicting and that in order to determine whether additional hours of duty for pilots will produce a decrement in performance it will first be necessary to determine exactly what the pilot does, both on and off the job, and to what extent the job is fatiguing. To the authors' knowledge no such study has as yet been carried out, though the Army and the Navy are both planning to carry out long research programs on pilot performance. Observations are to be carried out while pilots are in the air flying airplanes rather than in so-called analogous situations on the ground. It may be possible to develop more objective measures of fatigue and of pilot performance in terms of liability to accidents. Until this has been done we can only generalize from the foregoing sections of the report, and such extrapolation may be dangerous because the similarity between the performances measured in the foregoing and pilot performance in the air is entirely unknown.

4. Anoxia. The effect of various degrees of anoxia on performance on various tests has been studied. These may be divided into tests of

vision, psychomotor tests, and physiological measures. Since airline pilots fly at intermediate altitudes between 5,000 and 10,000 feet and sometimes higher, it seems appropriate to report a number of studies that have been made at these altitudes.

a. <u>Visual Tests:</u> The visual tests may be divided into those testing normal or daylight vision, and those which study effects of anoxia on night vision. In a study reported by the Material Division of the U. S. Army Air Corps (70), 7 subjects were completely dark adapted at ground level and the least intensity of light necessary to stimulate the retina was determined in the standard way with the Hecht dark adoptometer. They were then taken to a simulated altitude of 5,000 feet and after 10 minutes the least intensity of light necessary to stimulate the eye was again determined. This procedure was repeated at altitudes of 8, 10, 12, 14, and 16 thousand feet. The results of these tests indicate that dark adaptation shows a progressive decline with altitude. Table 2 shows the approximate percentage increases in light intensity being necessary to produce an equivalent stimulus on the retina at the altitudes given.

TABLE 2

PERCENTAGE INCREASES IN LIGHT INTENSITY NECESSARY TO PRODUCE AN EQUIVALENT STIMULUS ON THE RETINA AT VARIOUS ALTITUDES

Altitude	Per cent
800 feet (ground level)	100
5,000 feet	126
8,000 feet	138
10,000 feet	159
12,000 feet	178
14,000 feet	195
16,000 feet	240

The recommendation is made that on all night flights on which maximum dark adaptation of the flyer is desired, oxygen should be used at all altitudes above ground level in such quantities as to maintain a normal oxygen partial pressure in the lungs.

In a study by the Committee on Aviation Medicine of the National Research Council (23), the results of measurement of visual threshold under dark adaptation agree with those in the previously mentioned study. Although only two subjects were used in this study, the findings also agree with work that has been done previously by other investigators. As in the first study, the recommendation is made that even at moderate altitudes, say 8,000 feet, extra oxygen be taken under all illuminations except during full daylight.

In studies of visual function under greater illuminations, that is, when using daylight vision, the results are again clear-cut. In the study just mentioned (23) contrast discrimination was measured at three brightnesses, which correspond to visual conditions between dawn and sunrise or between sunset and dark, using cone or day vision only. The results of these measurements are shown in Table 3.

TABLE 3

THE DETERIORATION OF CONTRAST DISCRIMINATION AT DIFFERENT ALTITUDES GIVEN AS PERCENTAGE INCREASE IN JUST RECOGNIZABLE CONTRAST COMPARED TO SEA LEVEL

Oxygen Concentration in per cent	Computed Altitude in feet	Percentage Increase in Just Perceptible Contrast ($\Delta I/I$) at 1/1000 Millilambert	1/100 Millilambert	1/10 Millilambert
16.6	6,200	9.1	3.0	4.8
14.9	8,600	27.6	10.1	12.4
13.2	11,500	33.7	31.5	20.5
12.2	13,200	84.9	52.8	31.5
11.1	15,300	100.4	66.0	38.7
10.3	17,000	115.3	82.0	77.8

It will be noted that at a simulated altitude of 8,600 feet there is a percentage increase of 27.6 at the dimmest of the measures taken, 10.1 at the middle one and 12.4 at the brightest one. These measurements were made on 7 men and 1 woman between the ages of 17 and 25 years.

In one of a series of studies made in the University of Chicago School of Medicine under the direction of the Committee on Aviation Medicine (25), the neuro-psychological effects of chronic intermittent anoxia have been studied in 7 male subjects, ranging in age from 17 to 28 who were variously exposed to simulated altitudes in low pressure chamber ranging from 10 to 18,000 feet for 4 or 6 hours per day, 6 days per week, for a period of 4 to 6 weeks.

One of the tests given during these periods was known as the Dynamic Visual Field Test. In this test the subject is required to determine the presence of a graduated circular patch of light briefly exposed in the periphery of his monocular visual field at the same instant that a form and color discrimination is being made at the fovea or center of the visual field. All subjects examined by this test became markedly impaired in their performance during the period of the experiment. This impairment is not of a transitory nature, but is lasting. It often does not show up until the subject had had several weeks in the experimental situation.

This impairment cannot be detected at any time by conventional methods of mapping the visual field on a tangent screen. The impairment does not appear until the third or fourth week of exposure and does disappear on a return to ground level, but its complete disappearance is a matter of days or weeks rather than of hours. It is of particular importance that the form of blindness detected by the Dynamic Visual Field Test develops insidiously while the subject is exposed intermittently to altitudes as low as 10,000 feet. The subjects in the experiment tended to be completely unaware of their altered performances.

A graph showing the perf[illegible] subject is shown in Figure 21. The impairment mentioned [illegible] not relieved immediately

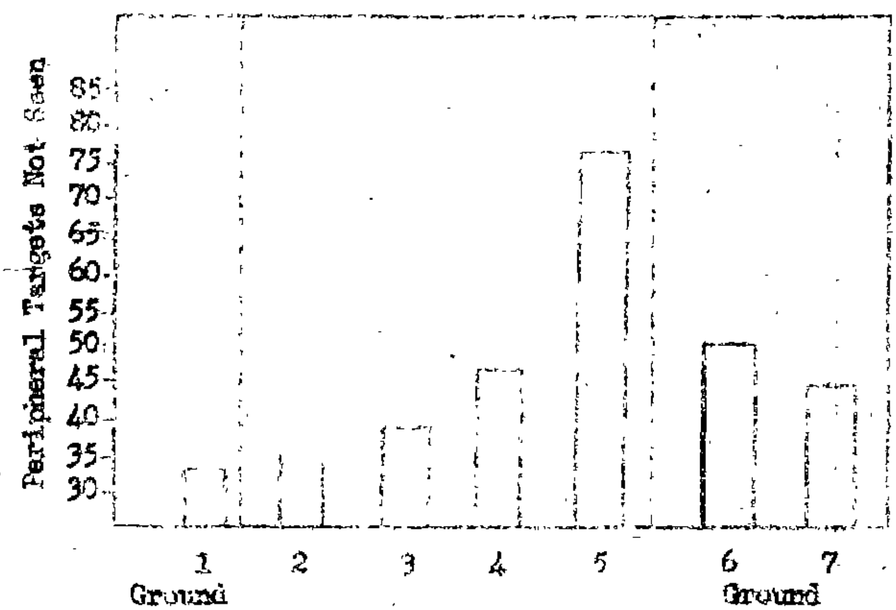


FIGURE 21

INCREASING NUMBER OF PERIPHERAL TARGETS MISSED DURING SUCCESSIVE WEEKS AT SIMULATED ALTITUDE OF 10,000 FT. AND SLOW RETURN TO NORMAL AFTER RETURN TO GROUND LEVEL

by breathing 100 per cent oxygen. In two subjects, this was attempted; nevertheless, no improvement in performance resulted and tests made 2 hours later on the same day at ground level showed only slight improvement over the performance at altitude. This test is particularly interesting because other tests administered at intermediate altitudes do not show the same decrease in performance over a period of weeks. There are temporary losses in [illegible] functions at altitudes of 10,000 feet and higher, [illegible] and the individual quickly [illegible], to [illegible]

[illegible]

b. <u>Psychomotor Tests:</u> In the report mentioned (22), in addition to the Dynamic Visual Field Test a series of psychomotor tests were given. Twelve tests were given at various altitudes during the period of the investigation. These were: (a) the Schematic Face Test, (b) Formboard Test for Special Localization, (c) Time-sense Test (vision), (d) Time-sense Test (memory), (e) Category Test, (f) Halstead Aphasia Test, (g) Airplane Spotting Test, (h) General Intelligence Test, (i) Rate of Tapping Test, (j) Ishihara Color Vision Test, (k) Critical Fusion Frequency Test, (l) Solution of Navigation Problems. In none of these tests was a significant difference found between performance at ground level and at altitude. This study seems to indicate that with the exception of the Dynamic Visual Field Test, there is no measurable change in performance up to altitudes of 10,000 or more feet after prolonged intermittent exposure.

In another study made at the Aero Medical Research Unit, Yale University, New Haven (37), intellectual and motor performances were measured at each of the following altitudes: 3,000, 10,000, 13,000, and 16,000 feet. The two intellectual tests showed no evidence of impairment at 10,000 or 13,000 feet, and performance on the motor test reflected little impairment even at 16,000 feet. However, performance on the intellectual test between 13,000 and 16,000 feet was greatly impaired, showing that the altitude interval between 13,000 and 16,000 feet is obviously critical for performance on intellectual tasks.

Another report from the same source (4), relates measures of reaction time, steadiness, speed and accuracy of coding, and visual discrimination of names and numbers at 15,000 feet for each of two hours. The results indicate that the impairment and performance during the second hour is no greater than the impairment measured within the first hour. There is a significant tendency for an individual to suffer relatively equivalent degrees of performance of impairment during successive exposures to anoxia. This study was made at altitudes which do not concern us, however, so no results will be presented here.

In a further study (26), to determine the effect on performance of the Dynamic Visual Field Test of exposure to a pressure altitude of 10,000 feet, 17 male subjects, ranging in age from 17 to 29 were exposed in a low pressure chamber to an altitude of 10,000 feet for 5 hours a day, 6 days a week for a period of 4 to 6 weeks. Ten of the 17 developed a marked impairment of the Dynamic Visual Field after 3 or 4 weeks, while 7 did not. However, including the earlier results 13, or 65 per cent of 20 subjects, developed a visual impairment at 10,000 feet. The conclusion is again stated that the impairment is effectively a form of blindness which develops insidiously during chronic intermittent exposure to altitude as low as 10,000 feet above sea level. It was found that if the subjects were given oxygen one hour of the 5 hours per day, that the Dynamic Visual Field did not change and there was no performance decrement on the test.

c. Physiological Tests: It has been generally accepted that exposures to altitudes of 10,000 feet are harmless. Oxygen saturation of the blood has often been shown to approximate 92 per cent as compared to 96 per cent normal. However, when it was discovered that performance on the Dynamic Visual Field Test was altered by exposures to 10,000 feet, further studies were made in Chicago in an attempt to determine whether some measurements could be made of blood oxygen or other changes in physiological conditions at these altitudes. In one investigation (8) the blood lactic acid content was determined at sea level and at 10,000 feet after controlled amounts of exercise. The results of the study are summarized in Table 4.

It will be seen from Table 4 that 14 out of 17 subjects showed an increase in the lactic acid content of the blood at 10,000 feet. The writers conclude that these 14 subjects showed varying degrees of anoxia as evidenced by the positive blood lactic acid at 10,000 feet as compared with the sea level values.

In an investigation made at the University of Chicago (3), the effects of several weeks of chronic intermittent exposure to altitudes of 10,000 to 18,000 feet were studied. It was found that this chronic intermittent exposure produced no immediate detrimental effects on the kidney. It is not known, however, what the remote effects will be, but it seems improbable that they will be harmful.

In a study of kidney function of altitude made at Yale University Aero Medical Research Unit (5), it was observed that exposure to low partial pressures equivalent to 15,000 feet for two hours has very little effect on kidney function. Such effects as were noticed are in accordance with the belief that the effects on the kidney are the consequence of a mild respiratory alkalosis rather than tissue anoxia.

One of the most striking reports from the Chicago studies (1) is concerned with the subjective observations of investigators who spent many hours in the pressure chamber with the subjects of the various studies. These investigators had duties to perform in the chamber of a highly skilled nature. Each man made ascents on the average of one to three times per week. Their ages ranged from 30 to 45, and all were trained in scientific observation. There were 8 of these men and they unanimously agreed that when working at 10,000 or 11,000 feet without oxygen they experienced definite impairment in muscular coordination, efficiency, memory, and clarity of thinking.

There was marked loss of initiative, and unusual concentration was necessary in making observations. These effects were not noticed at 16,000 or 18,000 feet while using oxygen or, of course, at ground level. Some of the tasks they performed were complicated and most of them involved considerable manual dexterity and accurate timing and recording, but they were perfectly familiar to the various operators by reason of previous experience. Nevertheless, minor errors in technique were more frequent in spite of extra

TABLE ?

EFFECT OF CONTROLLED EXERCISE (3100 Kg-m FOR FIVE MINUTES) ON THE LACTIC ACID CONTENT OF THE BLOOD AT SEA LEVEL AND AT 10,000 FEET. THE FIGURES GIVEN ARE THE AVERAGE VALUES FOR EACH SUBJECT.

		Lactic acid values, mg%					
Subject	No. of Experiments	Before Exercise	5 min. after Exercise	45 min. After	Altitude	ΔL.A.	ΔL.A. 10,000 ft. - ΔL.A. Sea Level
I.	4	13.6	48.0	19.2	Sea level	5.6	4.04
M.D.	3	7.46	38.3	17.1	10,000	9.64	
II.	3	16.86	36.24	20.12	Sea level	3.26	16.38
M.D.	3	18.78	72.2	38.42	10,000	19.64	
III.	4	15.21	39.4	19.93	Sea level	4.72	2.9
M.D.	3	15.9	57.1	23.51	10,000	7.61	
IV.	3	13.65	87.7	34.48	Sea level	20.8	1.8
M.D.	2	12.23	62.7	34.83	10,000	22.6	
V.	3	8.3	71.3	26.4	Sea level	18.1	-0.4
Ph.D.	3	14.0	82.9	31.7	10,000	17.7	
VI.	4	9.85	48.2	26.0	Sea level	16.15	2.25
	3	12.4	63.0	30.8	10,000	18.4	
VII.	2	11.3	25.0	17.0	Sea level	5.7	1.8
Student	1	8.3	40.1	15.8	10,000	7.5	
VIII.	2	9.15	34.6	10.5	Sea level	1.35	4.55
Student	2	15.8	59.7	21.7	10,000	5.9	
IX.	2	2.37	23.6	14.15	Sea level	4.78	4.32
Student	1	8.0	37.0	17.1	10,000	9.1	
X.	2	10.85	68.6	23.15	Sea level	18.3	
Student	1	22.15	83.2	34.35	10,000	12.2	0
XI.	1	8.4	88.1	23.5	Sea level	15.1	
Student	2	13.7	98.1	32.0	10,000	18.3	3.2
XII.	2	7.7	53.2	16.4	Sea level	8.7	
Student	2	10.7	91.0	28.3	10,000	17.6	8.9
XIII.	1	8.8	47.8	21.0	Sea level	12.2	
Student	1	8.3	65.0	22.3	10,000	14.0	1.8
XIV. Sore	2	11.0	52.0	18.5	Sea level	7.5	
Throat	2	16.83	60.3	20.72	10,000	3.9	-3.6
XV.	2	11.3	48.6	13.57	Sea level	2.27	
	2	10.86	56.8	16.11	10,000	5.25	3.0
XVI.	2	9.62	66.7	16.36	Sea level	7.24	1.8
	2	14.67	74.7	23.71	10,000	9.04	
XVII.	1	14.32	40.4	14.14	Sea level	0.18	2.2
	1	16.45	56.0	18.47	10,000	2.02	

effort, and the smoothness of operation was noticeably diminished. A sense of vagueness was sometimes present. Procedures involving stooping were accompanied by slight giddiness, which interfered with steadiness of control and manual movements.

The members of the group were at first not inclined to attach much importance to the circumstances described, believing that they may have been contributable to psychological factors incident to the newness of the situation, but as time went on and all became accustomed to working in the chamber, it became apparent to each of the investigators that at 10,000 and 11,500 feet he was just "not as good a man" as usual. It may well be that the subjective observations of trained workers are of more value in this type of situation than specific tests subject to scoring. In the latter, it is possible to summon all one's energy, so to speak, and with effort turn out as good a score as at ground level without there being any way of measuring the extra concentration required. This is well brought out in the scores for the navigation problems which the experimental subjects solved as quickly at altitude as at normal atmospheric pressure.

In conclusion the authors feel that in the course of the routine work in the chambers the observers were incidentally, but still quite effectively, testing the influence of anoxia on the peculiar skills which they had acquired through long training and that their situation in this respect closely resembled that of a trained pilot. Thus, performance in special skills would probably be impaired by the degree of anoxia present at 10,000 feet.

In a summary report (2), the Chicago investigators made the following conclusions. Exposure to anoxia at simulated altitudes at 10,000 and 11,500 feet from 4 to 6 hours daily, 6 days a week, from 4 to 6 weeks produces in human subjects definite deleterious effects which would probably interfere with the efficiency of the military flyer operating on a comparable schedule. The most important of these are: (a) a measurable impairment of visual function amounting in effect to partial blindness, as shown by a decreased ability to detect the presence of a briefly exposed spot of light in a peripheral field at the same time a form and color discrimination is being made at the fovea or the center of the visual field, (b) a tendency to sleepiness, irritability, moodiness, and boredom.

In addition to the effects of chronic exposure just described, it is evident from the observations of the investigators upon themselves that acute exposure at these altitudes interferes with efficiency in the performance of tasks requiring the application of previously acquired skills. Other studies made during chronic anoxia show results which are either negative, equivocal, clinically insignificant, or difficult to interpret in terms of being beneficial or harmful. The evidence obtained in these studies indicates that flying at 10,000 feet without oxygen should not be permitted. Further work is needed to determine the maximum base altitude under these conditions.

VIII. DESIGN OF EQUIPMENT AND FATIGUE

Time has not permitted an extensive investigation into the literature dealing with the relation of design of equipment to fatigue. However, since this is an aspect of importance in any discussion of fatigue of the aircraft pilot, a brief consideration of this topic is essential.

1. Fatigue and Machine Design in Industry. Machine design represents a field in which a great deal can be accomplished in reducing fatigue. In the early days of machine construction little attention was paid to the make-up of the worker operating the machine. For this reason it is still possible to find machines that call for extremely awkward posture on the part of the worker, for unnecessary reaching in handling levers and cranks, for the use of the entire bodily musculature when only the movement of a single muscle would suffice to operate the machine (60).

The psychological approach in machine design calls for the construction of machines with due regard for the mental and physical make-up of the workers who are to operate them. Possibilities in this direction were early recognized by Lahy, who pointed out the inadequacies of the universal keyboard on the typewriter and demonstrated the desirability of rearranging the keys to provide the most frequent alternation of hands in combinations of strokes (33).

Early studies in the field of machine design by English investigators have included observations of machines in laundries, leather-working plants, machine shops, and other factories (35). Although exact data on energy employed in the use of various machines could not be gathered, observation showed the following to be the factors which must be given serious consideration in the elimination of fatigue through improved machine design and operation.

a. Extent, kind, speed, rhythm, and combinations of movements.

b. Height and position of work in regard to posture.

c. Effort involved in motive power or in operating controls.

d. Danger from machines, the working of which is attended by risk of being cut, crushed, drawn in, etc.

e. Shock attending upon arrested movement or cessation of resistance.

f. Vibration of the whole machine or of the part held or operated.

g. Noise produced by the machine or by the material upon which it operates.

h. Obstruction of part of the machine to the operative or to his vision.

i. [illegible] of [illegible] angle of vision.

j. [illegible] by uncontrollable causes involving uncomfortable posture and avoidable work.

As a single example of recent experiments having general application to the problem of machine design the following is offered (58). It has been found desirable in various types of controls where the movement of control handle brings about a corresponding displacement of something displayed to the operator, as in tracking, to introduce a non-linear relationship between the control movement and displacement of the display. The total range of movement of the control handle is usually limited, and in this way it is possible to make advantage of a low gear ratio in the central region where fine adjustments are required, while coarse "switching" movements which do not require such a high degree of accuracy become proportionally smaller.

Thus the necessity for the human being to make very small corrective movements accurately can be partially eliminated. But it raises a further problem; is the benefit obtained by increasing the amplitude of small adjustments in any way counteracted by confusion due to the variable gear ratio? This might be the case if the human being were found to work according to a fixed gear ratio, and were unable to adjust himself to one which was steadily changing.

This problem has been investigated in several experiments designed to answer the following questions:

a. Does the human being behave as if he expects a control to be linear?

b. Is there any difference in accuracy between results obtained with a control handle which gives a linear response and a similar one, where there is a variable gear ratio between control handle and display?

c. Is it possible to train people to use a non-linear control as accurately as a linear one?

The results have been summarized as follows:

a. Errors made with the non-linear control lever showed that subjects were expecting a linear response to their control movements.

b. In a continuous tracking task there was no consistent difference between results obtained with linear and non-linear lever. When large, discrete movements were being made, and the non-linear relationship was not explained, there was a marked advantage in favor of the linear lever, and in all cases this [illegible] [illegible] statistically significant.

d. When the nature of the non-linear lever was fully explained, and large, discrete movements made, errors were much decreased; but little improvement was made with practice. When the means of linear and non-linear control results over the whole practice period were compared the difference was found to be statistically significant.

2. __Fatigue and the Design of Aircraft.__ While the concept of the need for adapting the machine to the man who is to use it is hardly a new one, it would hardly be questioned that progress in this respect has fallen far behind the mechanical advances which have been made.

Some attention has been given to problems of seating, obstructions to vision and freedom of movement, the location of instruments, the design of instruments and controls. Studies of controls have been concerned with the location of controls, the direction of their movement, resistance to movement, speed of wrist and hand movements, and the radius of winding handles. Attention has been given to adequate lighting, brightness contrast, the style of lettering and the matters of spacing, grouping, etc., of letters, figures, and other dial markings.

There are further studies concerned with anthropometric data. Physical measurements of the pilot provide the basic data which should be employed in the design of the seat, and such measurements are related also to the location of controls. The variability of physical measurements is of importance in relation to the possible adjustments of the seat up and down, and forward and backward, and in relation to tilt. Measurements of facial contour have found application in the design of oxygen masks. The location of the center of gravity of the human body has significance for the location of controls, the movements demanded, and for the design of seats. Posture as affected by design is related to the strength of pull by hand and arms, and the pressure which can be exerted by the feet. These are a very few of the areas in which some study has been made of design of aircraft; they have been presented as illustrative of some urgent problems which require investigation.

Recently, Fitts (23) has presented a proposed list of psychological requirements which may be considered as very general guiding principles for the more intensive study of aviation equipment design. Most of the requirements listed in this paper refer either to perceptual display or to the control system of the airplane. Display refers to any visual, auditory, tactual or other type of indication which provides information to the operator. The term control is used to refer to both hand and foot controls, and includes all varieties of switches, knobs, levers, etc., as well as the conventional flight controls. The suggested list of psychological requirements is as follows:

a. __Every display should be designed for quick and accurate perception.__ A first requirement for intelligent operation of an airplane and its equipment is that all visual indicators should be legible, and all auditory signals distinguishable and clearly audible above background noise.

b. Every display should be designed so that the meaning of the indication is immediately apparent. The pilot or other member of an aircrew must be able not only to perceive an indication quickly, but he should be able to comprehend immediately the significance or meaning of the display. It is of little value, for example, to notice a dangerous loss of power unless it is apparent what corrective action should be taken.

c. A display should provide information that is precise and complete. Man's adaptive behavior is limited by the information which he secures through his sense organs. Aircraft instruments should provide all of the basic information required for safe and effective flight in sufficient detail to meet operational requirements.

d. Single displays and entire display systems should be as simple as possible. If a pilot only needs to know his absolute altitude to the nearest 25 feet, it is useless to give him an altimeter which is designed to be read to the nearest foot. Since a pilot can attend only to a limited number of things in a given period of time, each unnecessary detail or signal that is added to his display equipment tends to lessen his ability to secure information that is vital.

e. Different displays and controls should be easily distinguishable. In a recent study of pilot experiences in using equipment it was found that many pilots reported that they had mistaken one instrument for another on several occasions, or had confused controls. Many pilots, for example, have had the unfortunate experience of retracting their wheels when they intended to raise their flaps.

f. Displays which provide related information or which are referred to in rapid succession should be grouped. It is the opinion of pilots, supported by some research data, that associated instruments should be located close to each other in order to minimize eye movements and fixation time. It is especially important to make it easier for the pilot to look out of the cockpit and back again at the instruments, or for the navigator to look at the ground and then back at his maps.

g. Controls and instruments should be designed so that they move in the "expected" direction. Every one has become habituated in the use of certain types of controls, as, for example, automobile controls. Frequently, therefore, individuals expect that a control should move in a given direction in relation to the desired result, and in relation to the movement of the display.

h. Controls should be designed to permit the required speed, precision, timing and/or smoothness of operation. Different control tasks frequently require quite different operator skills.

The quick rudder control movements required on the ground, for example, are quite different from the smooth coordinated movements required in flight.

i. <u>The mode of action, location and arrangement of controls should provide for over-all simplicity of operation and movement efficiency.</u> Attention should be given to the location of controls so that movements made in reaching from one control to another are as simple and systematic as possible. Errors in the use of controls occur not only from misuse of individual controls, but also from mistakes in procedure when carrying out a sequence of control operations such as the procedure for a single engine operation of a twin engined airplane.

j. <u>Equipment should be designed for use by operators who have only a moderate amount of training, who are of less than average skill, and who will use the equipment under adverse conditions.</u> The structure of an airplane is stress tested at loads in excess of anything expected in normal flight. It is just as important to design equipment in relation to the human capacities of the least proficient person who is likely to use it. There is a limit to every man's skill, just as there is a limit to the number of discrete movements that a man can make in a given period of time. These human limitations in equipment operation should be determined, and the operator task designed so that it is well within the limits of capacity of even the inferior individual.

k. <u>Equipment should be designed so that continued operation for a number of hours results in minimum fatigue or loss of operator efficiency.</u> This point needs little elaboration. In studies of equipment design special attention should be given to the ability of individuals to use the equipment at the end of a flight of maximum duration.

l. <u>Principal aspects of design, arrangement and location of display and control equipment should be standardized.</u> Man is capable of learning to carry on highly complex skills. Maximum learning can be realized, however, only when the individual uses the same equipment at all times. Standardization does not mean that all cockpits should be exactly identical, but rather that the basic arrangement, location, appearance and mode of indication or action of instruments and controls should be relatively uniform from one airplane to the next. In some respects standardization is the most important of the present list of requirements. It is hoped, however, that as standardization is achieved the best equipment design principles can be adopted for general use.

While these proposals are too general for direct application in engineering, they do provide a frame of reference within which detailed psychological studies may be made to the end that the specific data needed by the engineer may be made available.

There has been no attempt to cover thoroughly the problem of fatigue in relation to aircraft design in this section. It has been suggested that there is room for a vast amount of research in this general area. The problem is mentioned in passing because the commercial airlines might well contribute to the definition of more specific problems by compiling lists of pilot's complaints and suggestions regarding seats, controls, instruments, lighting, visibility, pressurization, temperature, ventilation, etc., and promote research activities. In doing so the airlines could make a definite contribution toward the reduction of fatigue, and the solution of operating problems related to fatigue.

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SUPPLEMENT

PHYSIOLOGICAL STUDIES OF FATIGUE

1. FATIGUE AND FATIGUE PRODUCTS

It was the hope of early investigators that the problems of human fatigue would find adequate solution in the physiological laboratories. Experiments with muscle preparations had defined fatigue as a progressive loss of irritability as a result of repeated stimulation. Howell (24) defined fatigue as more or less complete loss of irritability and contractility due to functional activity. This property of muscle to become fatigued has been studied continuously through the years and is still being studied today. Ranke (37), who was the first to investigate this subject thoroughly, believed that chemical changes in muscle during contraction form certain substances that depress or inhibit contraction. He showed that extracts made from fatigued muscles of one frog caused appearance of fatigue when injected into the circulation of another fresh frog. Hence the concept of fatigue toxins grew and made its way outside the specific meanings attached to it in the physiological laboratories. What could be more workable than the hypothesis that fatigue as found in everyday life, in industry especially, occurs as a result of the accumulation of waste products of metabolism. There was hope, as a result, that perhaps a single chemical discovery, an antidote, might banish fatigue forever.

On the other hand, as work in the laboratories progressed, other theories sprang up. It was pointed out that fatigue could occur in the muscle, at the motor end plate or at the synapse. Furthermore, it was soon pointed out that fatigue of the total organism was a different and much more complicated phenomenon than fatigue of a single muscle. When a muscle does work, according to Dill (12), reviewing studies of A. V. Hill and others, one of the earliest reactions is the breakdown of phosphocreatine to inorganic phosphate and free creatine. This is an energy-yielding reaction which is reversed by the formation of lactic acid (formerly considered the toxin of fatigue) from a precursor, probably glycogen. The lactic acid in turn is reduced by oxygen supplied by the blood. But these first two reactions can supply energy for work in excess of the ability of oxygen to remove the lactic acid. The muscle working thus anaerobically runs into an "oxygen debt" and the lactic acid escapes from the muscle and spills over into the blood stream, its concentration there furnishing an index to the size of the debt. A muscle incurring an oxygen debt soon becomes exhausted and incapable of further effort. But according to Dill the lactic acid itself is not necessarily a sufficient cause for this result as it has been shown that the heart, for example, prefers lactic acid to dextrose as a fuel and that the attainment of high levels of oxygen intake may be favored by the accumulation of lactic acid to a certain degree.

It will be noted that from the point of view of the total organism, several possibilities for fatigue occur in this process. If the fuel sup-

... as "energy reserves" of the metabolic process are exhausted then work cannot even be commenced, but among normal human individuals working under normal conditions no investigator considers this a serious possibility. Second, it is clear that when the supply of oxygen is no longer adequate and the body accumulates an oxygen debt then fatigue occurs very rapidly and all work is stopped. Under what conditions can this occur? Oxygen is supplied to muscle as a result of respiratory and circulatory functions and these in turn are part of a complex interrelated pattern in balance throughout the whole organism. When exercise is undertaken there occurs an immediate response on the part of the system to supply the needed increase in oxygen. Respiration, heart rate and blood pressure are increased and other regulatory mechanisms such as temperature control become adjusted to the new state of activity. So long as this adjustment assures an adequate oxygen supply the exercise may be continued; the internal environment remains constant and the person may be said to be working in a "steady" state. But if the exercise is so strenuous that an oxygen debt is incurred thereby upsetting the constancy of the internal environment, fatigue sets in very rapidly and forces a cessation of work.

There are wide differences between the tolerance of different people in this respect. The Harvard Fatigue Laboratory (29, 17, 12, 11) has studied extensively people trained and untrained in physical exercise and has found that the athlete can perform a prodigious amount of work compared with the non-athlete yet still show a physiological steady state. That is, the pulse and respiration remain within fairly constant limits, there is no accumulation of lactic acid and the "alkali reserve" is undiminished. Performing the same work, the untrained subject, on the other hand, shows inability to maintain steady state by quickly running into oxygen debt. The lactates accumulate and the pulse rises rapidly to maximum where exhaustion sets in and exercise cannot be continued. When once started, this is a rapid process and not a slow accumulation of fatigue over a period of time. In other words, once homeostasis is upset a rapid failure follows.

This constancy of the internal environment can be upset in ways other than by strenuous exercise involving oxygen debt. Although the mechanism is different according to situation, the apparent results may be the same -- fatigue, exhaustion, and inability to continue work. Thus, working on a bicycle ergometer in a room with high external temperature, subjects showed a constant body temperature after a small initial rise providing conditions for heat dissipation were favorable (steady state). Otherwise body temperature rose until exhaustion intervened. It was observed also that the heart rate increased with the external temperature even when the internal temperature remained constant, although its output per unit time might increase only slightly. Some of the subjects became exhausted at the high temperature when doing work which they carried on easily at a low temperature. "Yet there was no considerable lactic acid accumulation, no exhaustion of fuel reserves, and there was a large reserve of pulmonary ventilation." This failure was explained on the hypothesis that the heart muscle itself had reached the limit of its capacity, for it had attained its maximum rate while no other part of the organism was working at capacity. In still other experiments during 1932, Dill and Talbott visited the construction works at Boulder Dam where they investigated a curious form of heat prostration accompanied by muscular cramps. This they found to be related to an upset in homeostasis as a result of excessive loss through sweating of sodium chloride. But here again, up to a point where the constancy of the internal environment could be maintained, no symptoms occurred. Beyond that point the failure was rapid.

The conclusions drawn from all these investigations is that work can be performed only in a steady state and that if a steady state is achieved the work can be continued indefinitely. Interruptions of the steady state occur from a variety of causes depending on the individual and the environment. Some of these are demand for strenuous muscular exertion involving oxygen debt, excessive high temperature, oxygen deprivation as at high altitude, diseases involving physiological malfunction, depletion of fuel reserves, etc. The results of such interruptions may resemble each other in that rapid disaster and inability to continue working usually follow. But to group them together as a causal entity called fatigue is to overlook their separate organic and environmental origins.

Our description so far has left no room for a physiological explanation of ordinary industrial fatigue. Since it has been pointed out that the results observed occur only when the steady state is interrupted, and since such interruptions require a stimulus of exaggerated magnitude such as the extremes of environment or unusually strenuous activity, it should follow that where these are absent as in ordinary everyday work activity there should be no work decrement or fatigue. From a physiological point of view this is for the most part true: There is no fatigue. Thus it is that investigators searching for physiologic changes concomitant with observed work decrement and feelings of fatigue in normal activity have turned up very little of significance. The hope of a simple physiologic index of fatigue has not been realized.

Thus Lovekin (28) studying oxygen consumption, pulse pressure, pulse rate, etc., of factory employees engaged in different kinds of work found that energy expenditure varied according to type of work but that on the whole, factory workers exhibited low and steady pulse products, that is they were working in a steady state. The Public Health Service studying truck drivers (46) was unable to find any relationship between most of their physiological measures (blood potassium, blood total base, urine pH, differential white cell count, heart rate, blood pressure, etc.) and the number of hours driven. Nor were Delaville and Lahy (10), or Ryan and Warner (36) in their driving studies (reported later in the paper) able to find physiologic indices to fatigue. Gillespie (18) studying patients suffering from neurasthenia or "complaints of fatigue" was unable to find any reliable relation between these symptoms and physiologic measures of fatigue. Dill (11) concludes that during work where the amount of energy transformed is relatively small and the effects of the environment are negligible "if fatigue occurs it is of remote rather than of direct interest to the physiologist." And Forbes (17) summing up the work of the

Harvard Fatigue Laboratory states "The first two or three years were spent establishing the normal values for everything we could measure in the blood, urine, sweat and in studying normal circulation and respiration. Having done this we were in a position to see what was changed in industrial workers by a long day at their jobs. Nothing that we could measure was changed significantly even though the man was tired.... Having the techniques well developed it was then natural to go to what could be measured -- the results of extreme muscular work in athletes (and others) and of extreme environments in steel mills or at great altitudes and the like."

Professor Mayo and his group found that "output then was controlled mainly by the psychological, and not by the physical, atmosphere. How can this sort of atmosphere be measured? That is the biggest problem in the study of most of the fatigue in the world."

2. FATIGUE AND THE NERVOUS SYSTEM

Not all investigators agree with this conclusion. Those disagreeing do not dispute the findings supporting the conclusion but hold that the seat of such fatigue is one or two steps removed from peripherally integrated metabolic function, and that it shows up, therefore, in a different way. Thus, Simsonson (38) states, "It is estimated that in about 80 per cent of all jobs in industry muscular effort is slight or moderate, so that general fatigue is due to fatigue of the central nervous system." Under this theory it would be quite proper to include Dr. Forbes' conclusions concerning the psychological basis of fatigue, but Simonson has more specific neurological function in mind.

It was pointed out above that fatigue may be considered to occur not only in muscle but also at the motor nerve end plates in the muscle fiber, the sensory end organs, the nerve cell body, and at the synapses within the central nervous system (1). Baetjer (3) showed that when a muscle was stimulated through the spinal nerve, the added stimulation of its autonomic nerve was without definite effect, but, after the onset of fatigue, stimulation of the autonomic nerve resulted in a definite increase in the muscular activity. This was, of course, not due to an increased blood supply nor to any substance carried by the blood. The direct action of the autonomic nerve in this case is probably related to the local formation of hormone sympathizers which Cannon and Bacq (6) have studied. Going another step back, numerous investigators (13) have found marked histological changes in the nerve cell during activity and fatigue. These changes involve primarily a chromatolyses or fragmentation and dissolution of the Nissl granules.

With respect to fatigue at the synapse, Forbes (16) showed that by stimulating a second sensory nerve, a muscle showing fatigue as a result of previous stimulation through a first sensory nerve could be made to respond again. Likewise, Reid (35) argued that fatigue resulting from voluntary muscular work is actually central nervous fatigue because additional response could be obtained from a voluntarily fatigued muscle by stimulating it directly through the nerve trunk.

The way is open, therefore, for a concept of central nervous system fatigue which might account for the fatigue observed in workers engaged in continuous work involving only light to moderate muscular effort. The need is to find some index which will measure fatigue of this sort. Because of a lack of biological or physiological measures most investigators have turned to measurements of work output, accidents, sickness rates, etc., to measure fatigue. But to do so immediately involves one in a consideration of motivational, environmental and social factors (21) which are outside the scope of this paper. The other alternative, which has not been widely exploited, is to investigate possible biological measures of central nervous system fatigue. Among such measures are simple and complex reaction time, speed of tapping, steadiness, and other psychomotor tests, and on the sensory side, the critical fusion frequency of flicker (38, 46, 39, 41, 22). Simonson (38) distinguishes between fatigue of the motor centers and fatigue of the sensory centers and claims that there is little correlation between the two in different types of work, in pathological conditions of hypothyroidism and circulatory insufficiency (14, 15), and after administration of benzedrine and pervitin to relieve fatigue (40). Motor center fatigue is more pronounced in types of work involving motor components while critical fusion frequency is considered to be a sensitive index to fatigue of the retinocortical system, reflecting the fatigue of the central nervous system in general, and related most closely to sensations of fatigue. In a study of office, laboratory, and dispensary workers it was found that fusion frequency of flicker was lower in the late afternoon than in the morning (39) and that marked changes were found in pathological conditions and after the administration of drugs to relieve fatigue, as noted above.

One of the most pertinent studies in this connection was conducted by the Public Health Service (46) in a study of fatigue, hours of driving and physical fitness of truck drivers as determined by psychological, physiological and medical tests. Eight hundred eighty-nine drivers were examined in three cities. As many as possible of 22 special physiological and psychological tests were given to each driver. The drivers themselves were classified according to the number of hours they had recently driven, whether or not they had driven since sleep, the amount of sleep obtained, etc. The conclusions of the study were as follows:

1. The incidence of poor eyesight, bloodshot eyes, high white cell counts, and tremor of the hands was higher than is usually found in healthy men of like age groups.

2. The men who had not driven at all since sleep had the highest average efficiency, those who had driven less than 10 hours had the next highest efficiency, and those who had driven over 10 hours had the lowest average efficiency on the following tests: speed of tapping, reaction-coordination time, simple reaction time, manual steadiness, body sway,

driving vigilance, and the critical fusion frequency of flicker.

3. Men who had driven at all (regardless of number of hours) performed on the average less efficiently than those who had not, with respect to: aiming, resistance to glare, and speed of eye movements.

4. The average heart rate decreased slightly with hours of driving and the average white cell count was higher in men who had driven than in men who had not driven since sleep.

5. No trends with hours of driving were found in the estimation of size of known objects, the differential white cell counts, the hemoglobin content of blood, the acidity of urine, the specific gravity of urine, visual acuity, and the total base and potassium concentration of blood serum.

Other driving studies cited in this work reported much the same findings. Lahy (25) and Delaville and Lahy (10) studied two truck drivers during a journey from Paris and return of approximately 560 miles lasting 60 hours. Each driver was tested once every 6 hours in a mobile laboratory which followed the truck. Memory, attention, tapping speed, simple reaction time, alkaline reserve of the blood, the pH and ammoniacal coefficient of the urine, arterial blood pressure and strength of grip were all measured. Only the strength test, reaction time, and urinary acidity showed significant changes during the experiment, but the authors report that the two subjects were quite different with respect to the constancy of their responses. One subject showed small variability and quick returns to normal while the other showed wide variability and slow returns. Some sensory disturbances including possible hallucinations were reported by these drivers.

Ryan and Warner (36) report similar findings (except for sensory disturbances) after investigating six automobile drivers who drove for moderately long periods of time.

These studies show quite convincingly that although the drivers were working in a physiologically steady state, nevertheless, their work did result in changes integrated on a central neurological level, motor center fatigue being demonstrated by loss of efficiency in psychomotor tests, and "general" or sensory fatigue being indicated by reduction in flicker fusion frequency, resistance to glare, etc. There is no doubt that the changes occurred, but their interpretation as manifestations of central nervous fatigue is up to the bias of the reader.

3. EFFECT OF HORMONES AND DRUGS ON FATIGUE

Hoagland (23) and Pincus and Hoagland (33, 34) have described a series of experiments whereby they related the end product of steroid hormone metabolism, the 17-ketosteroids found in the urine, to states of fatigue in pilots as measured by percentage of time spent in the air as well as by their scores on a special pursuit meter. The stress 17-ketosteroids are believed to come from adrenal cortex chemical percursors and hence are a sign of adrenal cortex activity. They claim a correlation of .978 ± <.01 between steroid output and per cent time in the air for their sample of 16 pilots on 152 flights. Repeating the experiment on seven Pratt & Whitney test pilots during 56 flights gave a correlation of .922± <.01. A rank order correlation between 17-ketosteroid output and ratings of fatiguability made by the pilot's commanding officer yielded an r of .67. Similar correlations were found using fatigue scores on a special pursuit meter. Administration by mouth of steroid $\Delta 5$ pregnenolone resulted in improved scoring and fewer feelings of fatigue compared with control periods during which inactive placebo pills were given. The authors believe that the effect of Δ^5 pregnenolone in combating fatigue is variable, being most efficacious in situations where motivation is high (25 per cent improvement) compared with 10 per cent improvement where the only incentive was pay. Where even the pay incentive was removed, pregnenolone did not increase performance over placebo levels (23).

Simonson (38) reviewing the recent literature on the effect of drugs in relieving fatigue concludes that the transitory increase in performance which occurs would be followed by an increased need for recuperation. No sustained effect could be expected, but if it is necessary in emergency conditions to perform overwork in spite of fatigue then the administration of amphetamine (benzedrine) or desoxyephedrine (pervitin) might be indicated. The effect of both drugs is similar but pervitin appears to have less side effects and requires less dosage. Caffeine has similar but less pronounced effects (38).

4. LOCAL FATIGUE

There is evidence to show that visual and auditory fatigue occurs as a result of constant overstimulation of those senses. Various recent studies, reviewed by Simonson (38) show that visual work increased the threshold of electrical stimulation of the eye, determined by the appearance of phosphenes. Also recognition of letters at dim illumination decreased excitability after a short time. The time of fading of after-images is increased after types of work involving visual effort. And the recovery time of visual discrimination, measured after exposure to glare, was prolonged in fatigued truck drivers (46).

Simonson reports an agreement in the literature regarding the cumulative effect of noise which results finally in permanent hearing loss. Ears exposed for a long time to high noise levels such as aviation engines, riveting, etc., suffer hearing loss which parallels the duration of exposure.

5. FATIGUE AND HEALTH

The relationship between fatigue and health is an important question in industry. Are there diseases which render the patient more susceptible to fatigue and, conversely, and perhaps more important, does fatigue increase a person's susceptibility to disease? Regarding the former question the answer is usually affirmative, fatigue being often described as a symptom of certain infectious diseases such as tuberculosis, cardiac deficiencies, and psychogenic syndromes such as neurasthenia, the "fatigue" disease (14, 15).

But, with regard to the latter question, the answer is not at all clear-cut. According to Simonson (38) there is no direct evidence yet available that fatigue decreases the resistance power against disease. However, many doctors feel that there is some relationship between the two, and Vernon writes, "There can be little doubt that in many cases fatigue is a predisposing cause of sickness, even if it is not the direct and immediate cause" (47). Conflicting evidence on this point comes from various kinds of attacks on the problem and the resulting attempts at generalizations are confusing because of the equivocal meaning of the word fatigue.

If fatigue is assumed to be the result of hard work, then it might be expected that its importance as a predisposing cause of illness might be discovered from a statistical comparison of disease rates among various more or less arduous occupations. Many studies of this kind have been made (8, 49, 51, 9, 27, 44, 45) with conflicting results. There is evidence that some kinds of disease go with certain types of work, for example, occupations that are classed as "Heavy Manual Labor" experience excessive mortality from diseases of the heart. But, no investigator or reviewer has been able to demonstrate in this way that fatigue per se is the essential factor. Too many other variables such as socio-economic status, motivation, climate, and in some cases poor statistical treatment of the data cloud the issue.

If disease rates for various occupations do not demonstrate clearly the effect of fatigue, might it not be shown by comparing the rates when the number of hours worked is increased or diminished. In 1936 Ascher (2) claimed to have shown the isolated effect of working hours on the sickness and death of workers. He found that the sickness rate of employees of an engineering works in Frankfort-on-the-Main dropped 68 per cent when a 26-hour week was introduced in 1932-33 compared with the full working week of 1928. He states also that these statistics correspond with the statistics of the United States for 1929 to 1933. Likewise, it has been reported (37) that medical examinations of women munitions workers in England during the first World War showed "some fatigue or ill health" in a third of those examined, while 7 per cent showed marked fatigue or ill health. Furthermore, the mortality records of the Registrar-General showed an increase in deaths from phthisis in women aged 15 to 24, the rate for 1918 being 50% higher than the rate for 1911-14.

Studies of tuberculosis showed a like increase for certain age groups, although Vernon (49) pointed out the increase was not restricted to the war years. The implication is that those sickness rates rose as a result of women's increased work under wartime conditions, and hence may be attributable in part to fatigue.

On the other hand, such conclusions are premature when it is considered that the results of a study embracing 20 per cent of English iron and steel workers showed that their days of sickness in wartime (1915-1918) were 31 per cent less than before (49). Likewise, for the second World War, the London correspondent of the American Medical Association has reported that health in English factories is as good as before the war (20).

It would seem, then, that from this point of view also there are no clear-cut results. Some studies conclude that long hours of work and, hence, fatigue result in increased illness. Other studies point out that this is not necessarily true, or, if true, occurs as a result of more factors than simply hours of work or fatigue. For the most part, the conclusions of a study can be predicted from the type of approach the investigator used. Those studies using a clinical approach usually conclude that overwork, fatigue, etc., result in illness. The physician or therapist sees, perhaps, a large number of cases. From an analysis of their individual complaints, their past history, conditions of work, etc., he concludes that fatigue has contributed to their illness and indeed may be a primary cause. Thus, we find studies like Ward's (50) who reported on the symptoms of speed up. He found an increasing number of industrial patients complaining of fatigue, general debility, etc., with occasional somatic symptoms, many of whom were apparently cured by a vacation. Tillisch and Walsh (43) report on chronic exhaustion state in test pilots. Twelve of 20 test pilots studied showed symptoms of exhaustion, anxiety, mental depression, etc. On the other hand in a similar study of 103 transport pilots, Tillisch and Lovelace (42) found not a single incident of chronic exhaustion state. They conclude, therefore, that "exhaustion cannot be attributed to flying alone; but (exhaustion) did occur with long hours of hard work without vacations and with the emotional strain of flying a new, and at times, hazardous airplane. In other words, the exhaustion state seen in pilots is not different from the exhaustion state seen in the average and all too frequently encountered person." Nielsen (31) describes on the basis of several cases of extreme overwork lasting for years a "subacute generalized neuromuscular exhaustion syndrome." Other writers, all from the clinical point of view, (30, 32, 52, 7, 19) believe that fatigue is a causal factor in illness of many types ranging from pneumonia to neurasthenia. The trend of opinion seems to hold that fatigue resulting from hard physical work predisposes towards a physical disease such as tuberculosis, whereas severe mental fatigue resulting from overwork under stress conditions leads to a functional disorder and breakdown. Without wishing to contest these findings it should be pointed out that in most of these clinical studies no special attempt has been made to discover how many people subjected to similar fatigue situations have <u>not</u> developed illness. Without this other half of the picture, a clear-cut case for the effects of fatigue cannot be made.

In contrast to the clinical approach, studies using a statistical survey, and in some instances an experimental approach (4), usually conclude that fatigue or overwork cannot be considered a direct cause of illness. Thus, Vernon (48), after making a study of the sickness and mortality records of about 24,000 iron and steel workers for a six-year period, concludes "The data as a whole appear to indicate that on men of good physique the fatigue of heavy work has, as a rule, but little direct effect on sickness and lo gevity." This is an especially important conclusion when it is realized that the men studied were working 11 and 12 hours a day in occupations which are recognized as severe. From the point of view of a functional breakdown, it might be expected that if mental fatigue resulting from stress, overwork, and general turmoil contributed to the etiology this would be reflected in increased rates of mental disease during times of such stress. But, as Landis and Page (26) have shown, no such increase as might be expected takes place, for example, during World War I or the depression.

In the light of such conflicting testimony what can be concluded concerning fatigue and health? In the first place, as most of the experienced investigators have insisted (38, 29, 17) fatigue cannot be considered as an entity, so that the "fatigue" of Ward's patients is not the same thing as fatigue found among most factory workers, and this in turn does not resemble the fatigue of steel melters working in an excessively hot environment. A generalization concerning fatigue and health not only does violence to the data, but is also an unprofitable orientation towards the problem. When physical disease rates are studied, too many other factors are operating to be able to show any clear effect of either hours of work or type of work. When individual cases are studied, some of them show a history of long hours of work, heavy physical work, or work under pressure during anxiety or fear. Other cases show none of these. Conversely, men and women who have worked under such conditions have not necessarily become patients. Even in syndromes where complaints of fatigue constitute one of the symptoms, a history of long and hard work is not invariable, as can be seen in the conventional case of neurasthenia. Therefore, judgment concerning the effect of hours and type of work on health, except in extreme cases, must be suspended and we return to Simonson's contention that there is no direct evidence showing that fatigue decreases the resistance power against disease.

6. SUMMARY

The sense of the physiological literature on fatigue is as follows: Fatigue cannot be considered an entity in the sense that it is a single underlying physiological, chemical, or electrical process which is the end result of continued activity of any kind. In single muscle preparations, fatigue (in the sense of work decrement) is a fairly well defined phenomenon and a great deal is known about the chemical and electrical changes which occur at this level as a result of exercise. When the total organism is considered, fatigue after exercise is no longer a process solely of changes in the muscle or nerve because of the role played by the self-regulatory mechanisms of the body in maintaining homeostasis.

The body acts to maintain the constancy of its internal environment. Physiological fatigue of muscle through activity constitutes a threat to internal constancy and, as a result brought about by increased oxygen supply, is not permitted to occur. If, however, the exercise is pushed beyond the ability of the organism to maintain homeostasis then fatigue does occur, and very rapidly in the form of exhaustion and cessation of all work. The observable and recordable effect, however, is the upset of homeostasis and not some theoretical accumulation of "fatigue." Homeostasis may be upset in ways other than by excessive exercise and the results may appear much the same.

Ordinary work such as factory work, office work, house work, truck driving, airplane flying, etc., is performed in a "steady" state, i.e., the constancy of the internal environment is able to be maintained. Consequently, although the worker may feel tired, may not accomplish as much and may have more accidents, nevertheless, physiological measures of the state of the internal environment remain relatively unchanged and do not afford an index of the worker's "fatigue." Because of this, there is a distinct tendency in the literature to strip the concept of fatigue of any biologic meaning and to redefine it operationally in terms of output, accidents, etc. This leads to a direct consideration of psychological and social factors, and a great deal of fruitful work in this connection has been done.

The biological approach has been continued, however, with emphasis being placed on possible central nervous system indicators of fatigue. Thus, it has been shown that long hours of certain types of work do produce changes in psychomotor efficiency as measured by various psychomotor tests, and in central nervous system excitability as measured particularly by the critical fusion frequency of flicker. These studies are promising although what they mean in terms of optimal working hours or worker's efficiency at specific tasks has not been established. At a still higher level of central nervous integration, Bartlett (5) has performed an excellent study showing how complex stimulus and response patterns tend to break down in consequence of fatigue incurred from a situation akin to flying, although this, of course, is purely a psychological study. Other fruitful lines of investigation may be the study of adrenal cortex activity and other hormonal influences, the effects of various drugs, and specific sensory fatigue in special environments. Bonnaggio is reported (38) to have developed a "fatigue" reaction which measures the increase of permeability of kidney capillaries.

With respect to long hours of transport flying it might be possible to demonstrate results similar to those found in the truck driver studies. The meaning of such results, however, certainly would not be clear and would depend upon their being related to some measure of efficiency or competency at the specific task under investigation.

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APPENDIX 1

APPENDIX 1

TRANSCONTINENTAL & WESTERN AIR, INC.
Kansas City, Missouri

Original sent S-85
Copy sent Mr. Hoyt
12/12/.45

December 7, 1945

Civil Aeronautics Board
Washington, D. C.

<u>Subject:</u> Exemption from Compliance with Provisions Contained in CAR Part 61, Paragraph 61.518 by Substitution of the Provisions Contained in CAR Part 41, Paragraph 41.3041

Gentlemen:

TWA hereby petitions the Civil Aeronautics Board for exemption from compliance with the provisions of CAR Part 61, Paragraph 61.518 in the operation of Lockheed Constellation type aircraft and also hereby petitions that compliance with the provisions of CAR Part 41, Paragraph 41.3041 be substituted for the exemption from compliance with the provisions of CAR Part 61, Paragraph 61.518.

The provisions contained in CAR Part 41, Paragraph 41.3041 at present apply only to operations outside the continental limits of the United States and were designed primarily to permit long-range operations.

TWA is planning on long-range operation within the continental limits of the United States with Lockheed Constellation aircraft in the near future, but we are prevented from performing an efficient long-range operation by the pilot flight time limitations as now provided for under CAR Part 61, Paragraph 61.518.

The operations planned are schedules from New York to Los Angeles with one undesignated fuel stop and schedules from New York to Los Angeles with two scheduled stops.

The scheduled flight time on these schedules will be minimum, 9:05 hours and maximum, 11:40 hours.

Compliance with the provisions of CAR Part 61, Paragraph 61.518 will require a crew change at some station between New York and Los Angeles with the result that the entire efficiency of the operation will depend upon the weather conditions of that particular station at the time of the arrival of the flight. In the event the weather at the crew change station is below operating limits, it will be necessary to hold or cancel the flight at some station short of the crew change station.

By applying the provisions of CAR Part 41, Paragraph 41.3041, the flight could be operated by stopping at any station for fuel where the weather would permit, then proceeding over other stations to destination. This would also allow a selection of refueling points where the most favorable weather and traffic conditions existed.

This type of operation would also result in better working conditions for the crew members because of the following factors:

1. More time off at the home station would be provided.

2. Under present regulations, flights may be scheduled for as many as seven stops within one crew division point. The ground time at each of these stops may and frequently does, vary from 10 minutes to as much as 3 or 4 hours when it is necessary to hold for weather improvement. This frequently results in elapsed time of considerably over 12 hours.

3. Due to the number of scheduled stops on local flights, several instrument approaches are frequently made on one crew division while under the contemplated operation a maximum of 3 instrument approaches would ever be necessary, and this number would be extremely rare due to the great geographical distances between stations.

4. The Lockheed Constellation airplane is pressurized which will greatly reduce the fatigue of the crew, especially in flying at high altitudes.

5. Due to the pressurization of this airplane, considerable weather that cannot be flown over with non-pressurized airplanes can be avoided by high altitude flight.

6. The Lockheed Constellation airplane is equipped with an automatic pilot which substantially lessens the fatigue of the crew.

Consideration of the Board in this petition is requested in order that TWA may provide the most efficient service possible in the operation of the Lockheed Constellation aircraft.

Very truly yours,

/s/ John A. Collings

John A. Collings
Vice President - Transportation

cc: Mr. T. P. Wright
Mr. James Kenney
Mr. William Clark