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FATIGUE IN AVIATION ACTIVITIES

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I. Introduction.

On October 14, 1963, an air-transport helicopter operating on a regular schedule crashed on Long Island. Fatigue failure of the drive quill shaft is given as the probable cause of the accident by the Civil Aeronautics Board.[26]

This is an example of "structural fatigue," a circumstance clearly detrimental to air safety. But how about the role of "biological fatigue" in air safety? Biological fatigue is less readily measured after the fact than is structural fatigue and is more difficult to relate as a casual factor to accidents.

The Civil Aeronautics Board has listed fatigue as a causal factor in a number of relatively recent accidents. For example, on September 26, 1962, an air transport-category aircraft (not on a regularly scheduled flight landed at Spartanburg, South Carolina, during the night in light rain conditions. While swinging into position at the ramp, the tail of the airplane hit a large object in the ramp area, substantially damaging the stabilizer and elevator.

The investigation revealed that the Captain and his copilot had been on duty for almost 19 hours at the time the accident occurred and that "impaired efficiency of the pilots caused by fatigue" was a probable cause of this incident.[23]

It is not unusual to find fatigue listed as a probable cause in aerial applicator accidents. In one example as a probable cause in aerial applicator accidents. In one example, a pilot stalled in a procedure turn to the left and reported later that he had sprayed 700 acres between 8:00 a.m. and 6:00 p.m. just prior to the accident, and was "just plain tired."[22] In another example, the pilot over-controlled on takeoff and caused his landing gear to fail. He had been flying for a considerable time on the day of the accident and was "very tired."[21] Another pilot veered his plane off the runway during the landing roll. It nosed over. Investigation showed that the pilot had had only 8 hours sleep during the 48-hour period preceding the accident.*

*CAB Docket 2–4442.

Among light-aircraft business or pleasure flights, fatigue is listed as a probable cause on one case of "leveling off too high."[25] In another case, fatal to all three occupants, which occurred during poor-visibility weather conditions near Pinta, Arizona, "reduced physical and mental efficiency of the pilots caused by fatigue," is listed as a probable cause.[24]

It is clear, therefore, that the deleterious effects of excessive fatigue continue to take a toll in general aviation activities, since all of the above examples occurred relatively recently. Not so clear is the true impact of fatigue in air-carrier activities.

Fatigue is a concomitant of all protracted human endeavor. In general, fatigue is produced more readily by more demanding tasks. It may also be markedly heightened through the imposition of "time pressure" on the operator. At some point in the buildup of fatigue in a given person, rest becomes mandatory. At an earlier point, the developing fatigue results in a degree of deterioration in the quality of performance that, of itself, makes task discontinuation desirable.

This all sounds very simple and has led, from time to time, to an oversimplification of the fatigue matter as it is found intertwined today in aviation activities. For reasons given later, fatigue should neither be dismissed as an unimportant entity nor conveniently embraced as the culprit in various untoward situations in air-carrier activities.

Definitions of fatigue in humans are often stated in general terms and may include the term "weary." They may primarily reflect physiological changes (as occur during heavy physical exertion) or may focus on "subjective" changes, as produced by stressful mental demands, lack of sleep, or monotony, and include biochemical and reaction-time measurements. Of course, fatigue can also arise as a result of certain medical conditions (anemias, cardio-vascular defects, etc.), advanced aging changes, and even enforced bed rest, but we are not concerned with these latter matters here.

There is a nebulous nature in the conceptualization held in various quarters of this fatigue matter. Just as some might define increasing amounts of cold in terms of decreasing amounts of heat, fatigue has been thought of as the depletion of some physiological substance. Others have conceived of fatigue as resulting from the gradual increase of some substance during the work period. Actually, all this is now known to be too simple and is remiscent of the ancient Greek attempt to explain the events of nature in terms limited to earth, air, fire, and water.

II. Definitions and Considerations.

The word fatigue is derived from Latin and French origins, and is defined as "weariness from bodily labor or mental exertion." [85] Weariness is defined in the same reference as "the state of being tired, having lassitude, or exhaustion of strength."

Physical fatigue, which may be objectively measured (increased reaction time, decreased strength, increased blood lactic acid, decreased blood glucose, increased lag in pupillary response time to light, decreased ability for rapid binocular fusion, increased time of visual accommodation to alternating near and far points of vision, decreased muscle tonus, increased loss of electrolytes through cutaneous excretory organs, decreased circulating blood volume, increased urinary corticosteroids and catecholamines, decreased muscle glycogen, increased instability of neuromuscular coordination, etc.), is well documented as resulting from alterations of such environmental factors as: temperature, humidity, color, light intensity, noise, vibration, odors, gases, barometric conditions, and ozone. Several references cover these points.

In addition, physical fatigue results from protracted immobility, excessive loss of sleep, illnesses, and advanced aging changes.

Interestingly, since the mind cannot be separated entirely from the "whole" individual, the mind is, therefore, the end "receptor" for the perception of the degree of physical fatigue. Consequently, although certain pharmacologic agents (amphetamines, ethyl, alcohol, certain tranquilizers, Spartase,* (see footnote) and other drugs)) may modify the perception of the degree of physical fatigue (and, in the case of Spartase, may actually diminish certain objectively measured physical-fatigue states), the physical results of expending kinetic, chemical, thermal, and electromagnetic energy, from potential energy stores, are biologically inevitable.[80]

Biological restitution of the above consequences of physical effort follows rest, sleep, food ingestion, and metabolic-waste removal. Anything interfering with these restrictive processes (cutting too many time-zones, inadequate accommodations, outside disturbances, etc.), will heighten the unresolved sequelae of physical fatigue.

Physical fatigue is, therefore, but one side of the mind-body "biological coin," since residing within the head side is the mental, or subjective, aspect of fatigue. Mental fatigue can, as is clear from the above, be the result of physical fatigue or can exist as the primary entity in an individual whose physical baseline is within "rested state" limits.

Symptoms of mental fatigue include increased irritability, decreased attention span, increased susceptibility to err (therefore of vital consequence in aviation-accident causation), decreased libido, increased anxiety, decreased recent memory, increased tendency to insomina, decreased cooperativeness, increased susceptibility to depressive states, decreased acceptability to constructive criticism, increased tendency to withdrawal from avocational social undertakings and hobbies, decreased (sometimes paradoxically increased to an excessive point) interest in personal care and hygiene, increased tendency to use pharmacologic crutches (ethyl alcohol, chain smoking, tranquilizers, barbituates, bromides, nerve tonics, etc.) and decreased gastrointestinal efficiency which may result in indigestion, constipation, or in some cases, diarrhea (spastic intestinal states).

Serious performance decrement is likely to result from one or more of the above symptoms. Causes of mental fatigue may be: repeated sleep inadequacies, excessive psychosensory task demands, "time-pressure" stresses (too short a time to accomplish the task, frequent unanticipated interruptions of work procedures, excessive task loading with trivia, frequent emergencies or false alarms,) inadequate compensation for task, inadequate recognition of accomplishments, inadequate task challenge and interest, ambiguous

* Spartase is the Wyeth Laboratories trade name for the potassium and magnesium salts of aspartic acid.

rules and procedures, interrupted family life, family medical and social problems, personality clashes with coworkers and supervisors, nature of punishment for omissions and commissions, monotonous and boring circumstances, and minor discommoding afflctions (pruritis ani, refractive error in spectacles, periodontal neuralgia, certain allergies, etc.).

III. Flight-Time Limitations.

To refresh our minds concerning the specific wording of Part 40.320 of Title 14 of the Code of Federal Regulations, we note that it states:[27]

> (a) An air carrier shall not schedule any flight crew member for duty aloft in scheduled air transportation or in other commercial flying if his total flight time in all commercial flying will exceed the following flight time limitations:
>
> (1) 1,000 hours in any year,
> (2) 100 hours in any month,
> (3) 30 hours in any seven consecutive days.
>
> (b) An air carrier shall not schedule any flight crew member for duty aloft for more than 8 hours during any 24 consecutive hours, unless he is given an intervening rest period at or before the termination of 8 scheduled hours of duty aloft. Such rest period shall equal twice the number of hours of duty aloft since the last preceding rest period, and in no case shall the rest period be less than 8 hours.
>
> (c) When a flight crew member has been on duty aloft in excess of 8 hours in any 24 consecutive hours he shall, upon completion of his assigned flight or series of flights, be given at least 16 hours for rest before being assigned any further duty with the air carrier.
>
> (d) Time involved in transportation, not local in character, required of a flight crew member by an air carrier and provided by the air carrier for the purpose of transporting the flight crew member to an airport at which he is required to serve on a flight as a crew member, or from the airport at which he was relieved from duty as a crew member to return to his home station, shall not be considered as part of any required rest period.
>
> (e) Each flight crew member engaged in scheduled air transportation shall be relieved from all duty with the air carrier for at least 24 consecutive hours during any seven consecutive days.
>
> (f) No flight crew member shall be assigned any duty with an air carrier during any rest period prescribed by this part.
>
> (g) A flight crew member shall not be considered to be scheduled for duty in excess of prescribed limitations, if the flights to which he is assigned are scheduled and normally terminate within such limitations, but due to exigencies beyond the air carrier's control, such as adverse weather conditions, are not at the time of departure expected to reach their destination within the scheduled time.

These duty and flight-time limitations are concerned with scheduled air-carrier interstate operations within the continental U.S. Part 41 governs flight-time limitations with reference to such operations concerning flights involving points outside of the U.S., and Part 42 covers limitations in supplemental air carriers, cargo-only operations ,and other special activities.

Since 1931, when Wiley Post discovered that cutting through time-zones resulted in certain body functions becoming asynchronous with the celestial and social periodicity characterizing the destination, it has become increasingly apparent that "circadian (circa for about,and dian for dies—a day) periodicity" is a contributor to "air-travel fatigue."[75, 86] Individuals vary in their initial susceptibility to this phenomenon and also in their length of time to "fall in step" with the destination period subsequent to arrival. Certain recent CARI findings in this respect will be described later in this paper.

In Great Britain, civil jet-aircrew task-loading factors that contribute to fatigue have been analyzed by Dr. H. P. Ruffell Smith, and cockpit environmental factors have been assessed by Dr. A. J. Barwood.[11, 89] In France, Dr. Gerard Juin has been concerned with jet-pilot fatigue and has published extensively.[59, 60]

In the U.S., Dr. James Crane has been investigating medical leads to what have appeared to be contributing factors in jet-pilot fatigue.[31, 32] Also, Dr. Spealman of the CAA investigated possible environmental factors in certain cases of task fatigue in jet-flight engineers.[94]

The 1960 paper by Captain A. D. Reedy of Pan American World Airways borders on being a classic in the aviation-fatigue literature.[88] Prior to that, the 1946 compendium by Viteles, Brimhall, et al, of the aviation fatigue literature, stands as a landmark.[101]

More than 100 years ago, fatigue in lighter-than-air activities was a well-known phenomenon.[15] In 1914, a top pilot of the day published for physicians information bearing on certain in-flight environmental phenomena that predispose to fatigue.[82] In 1918, the U.S. Army Air Service Medical Research Laboratory at Mineola (the predecessor of todays School of Aerospace

Medicine at Brooks Air Force Base) published certain factors concerned with fatigue. A year later, the Air Service Medical contained information on fatigue, and in the 1920's, Lindbergh became acquainted at first hand with its detrimental effects on flight proficiency.[64, 99]

In the 1930's, Amelia Earhart described factors in cockpit design that foster the onset of fatigue.[39] In the same decade, Dr. Armstrong called attention in his textbook to fatigue, and in the 1940's, Dr Bauer and Dr Kafka discussed it in their respective aviation-medicine texts.[4, 12, 61]

In recent years, Lavnikov of the U.S.S.R. has commented on aspects of pilot fatigue.[62] Also, the January 31, 1964, report by Captain Richard Beck of Trans World Airlines presents a creditable summary of present information relative to jet-crew fatigue.[13]

An excellent report by the Australians Cameron and Cumming describes the fatiguing effects of certain cabin environmental factors.[20]

IV. Indicators of Excessive Fatigue.

The first indication of excessive fatigue in an occupation may appear as what may be termed psychosomatic symptoms. These can include: headaches, burning eyes, sweating, heartburn, chronic constipation or chronically loose bowels, chronic loss of appetite, nightmares, and shortness of breath.

In advanced stages, the symptoms would show as periodic job absenteeism, since they would have progressed to the point of illness, best treated by rest. In one study of jet-pilot absenteeism in a major airline, no increase in absenteeism on the part of pilots was found, apparently indicating that, in general, and with respect to this airline, any fatigue that is present has not progressed to this point of impact on the pilots' work experience.[61a]

Another indication of excessive fatigue is performance decrement. In this case the picture is clouded somewhat, since pilots and other crew members can exhibit an "end spurt," which, coming at the end of a long period of flying, can temporarily erase the effects of fatigue that accumulated during the trip.[51, 93] This study, by Dr. David Simons and his colleagues at the School of Aerospace Medicine, is quite revealing with respect to the complex nature of the fatigue question. It should be pointed out, however, that, although an end spurt may temporarily erase subjective fatigue effects, the period of rest that follows is essential to full recovery from the fatigue. Also, if the number of end spurts required of a scheduled civil air craw attains a certain frequency, full recovery following each individual incident may not be achieved, resulting in a gradual "cumulative fatigue state," which is known colloquially as being gradually "beat down" over a period of time.

Performance decrement due to fatigue may be manifested as "sloppy flying" by a pilot who previously was more meticulous. His own acceptable margins for precision and accuracy become wider.* Ultimately, he may be involved in a number of minor incidents or a major catastrophe. It may be that the fatigue state led him to make an error (the number of errors increases with fatigue, especially errors made under adverse weather or other circumstances) or to fail to respond rapidly and properly in an emergency situation.

There are ways in which these performance decrements can be measured, but great care must be taken in interpreting the measurements and in ascribing a "cause" to an "effect."

A final medical indicator of long-term exposure to fatigue (and stress) is felt by public-health authorities to be the development of clinical illnesses, such as essential hypertension, peptic ulcer, migrane headache, certain skin rashes, and certain other conditions. Of course, not all persons having these conditions necessarily obtained them from stressful occupations. There does, however, seem to be a connection in a substantial number of cases. Do certain airline pilots (for example, jet pilots on East-West runs) have a higher incidence (number of new cases per unit time) of these conditions than they would in the absence of circumstances suspected of producing excessive fatigue? For example, the incidence of these conditions can be determined in piston pilots on North-South runs, matched for age and other factors with the above mentioned jet pilots. Also, how do jet pilots compare with piston pilots, all other factors equal except for the nature of the aircraft and related operational aspects?

It should be noted that only now has the exposure to jets been sufficiently long to begin to

* Precision is how closely several maneuvers (or tasks) executed by a given pilot match with each other. Accuracy is how closely a given maneuver (or task) matches with the "ideal" standard aimed for by the pilot.

result in the manifestation of these advanced psychosomatic signs of protracted fatigue and stress. It should also be noted that among the persons who are most susceptible to developing the conditions noted above are persons who apparently "internalize" their emotions and thus produce prolonged internal gastrointestinal, cardiovascular, and biochemical rearrangements that turn into disease. Not infrequently, these individuals appear outwardly calm and placid while on the job (perhaps even while at home).

Parenthetically, we should be aware that the prevalence (percentage of cases) of these diseases found among airline pilots at a given time may not be helpful to us in our analysis, since, should an individual develop a condition that progresses to an advanced degree, the chances are he will not continue in the pilot population, and a spuriously low percentage will be found. The "incidence" is, therefore, the key point of interest. The incidence of a condition is defined as the number of new cases of the given condition arising within a given period of time in a given population. Incidence is, therefore, a rate quantity and is of primiary interest to us with respect to the fatigue question in a given situation.

As a point of consideration, the indications are that relatively short-term physical and mental fatigue is not "cumulative," if adequate rest and recreation follow the activity yielding the fatigue. Thus, repeated bouts with fatigue do not produce certain irreversible changes that accumulate over a period of time (as is the case with repeated bouts with ionizing radiation), and proper postfatigue activity or inactivity can, insofar as modern medical techniques allow us to ascertain, result in complete "biological erasure" of the fatigued state.

Of course, the apparent "price" charged by nature in return for the privilege of living is the gradual development of a "loss of vitality" (termed by some the "force of mortality"), and as the years pass by, living tissue gradually loses its ability to "bounce back" rapidly after a bout with fatigue through the life-long ultimately irreversible process of senescence.[29] It is well-documented, however, that those who frequently subject their body to certain kinds of fatigue-yielding activities develop a "resistance" to fatigue through physical and mental conditioning and may, in fact, live longer than otherwise would have been the case.[78] Actual lowering of the "physiological age" of individuals has been accomplished through graded, properly applied, conditioning programs.[6]

Lack of adequate physical activity (to the point of yielding fatigue) has been recorded as producing insomnia, loss of skeletal- and heart-muscle mass and work efficiency, loss of capillary-bed mass and efficiency, loss of skeletal calcium, and obesity.[78] Once these conditions begin to advance in degree, they tend to further discourage the host from undertaking increased physical activity, since, when he does so, the results are general discomfort, breathlessness, and other unpleasant sensations. The consequence is a vicious cycle known as the "white-collar workers' and executives' decline."

Since no serious person would dismiss potentially detrimental consequences of fatigue to aviation, continuing studies of fatigue are being conducted. Times change, equipment changes, and responsible monitoring of altered conditions in relation to fatiguing factors is a "communal" requirement of those engaged in aviation.

Where fatigue may jeopardize safe operations, remedial action is mandatory. The FAA, recognizing this, has issued a Notice of Proposed Rule Making with respect to the possibility of adjusting the existing regulations relative to air-carrier-crew flight-time limitations in keeping with technological and operational alterations that have occurred in air transportation.[40, 41, 74] Constructive comments and suggestions have been received from a number of quarters, and are undergoing evaluation.

V. New Developments—Intercontinental Flights.

Recent findings by Drs. Hauty and Adams of the Civil Aeromedical Research Institute are showing increasing promise relative to mitigation of fatigue problems.[52] Their study, an example of the fruit that can be harvested through interdisciplinary research (in this instance, collaboration between psychologists and physiologists), involves an investigation of interrelationships between biochemical, physiological, and psychological factors before, during, and after a flight from the U.S. to Japan. Following a period in Japan, the same parameters were measured with respect to the consequences of the return trip to the U.S. A scientific partner in this study is

Dr. Halberg of the University of Minnesota and certain of his associates.

Six healthy subjects were intensively studied with respect to the effects of intercontinental-jet flight on day-night biological cycling and performance. They received 3 consecutive days of biomedical assessment in Oklahoma City at CARI, wihch yielded a reference of biological time (geared to the Central Standard Time zone), and were flown to Tokyo (an 18-hour trip) for a 10-day layover. The biomedical measurements were repeated on alternate days, and the subjects returned to Oklahoma City (again, a trip of about 18 hours). Assessments were continued for 3 consecutive days.

Among the measurements made were rectal temperature (continuously worn thermistor probe—30-minute-interval recordings), reaction time (speed of manual reaction time to an auditory stimulus and certain visual stimuli—periodic intervals), subjective fatigue (a scaled list is checked—periodic intervals) and critical flicker-fusion thresholds (determined periodically each day).

The subjects left Oklahoma City at 0810 CST (2310 Tokyo time) and, following a 1-hour 40-minute wait in Anchorage, landed in Tokyo at 0200 CST (1700 Tokyo time). When they left Tokyo 10 days later, it was 0930 Tokyo time (1830 CST) and, once again, after a wait in Anchorage (this time 2 hours and 30 minutes), the subjects arrived in Oklahoma City at 0200 Tokyo time (1100 CST).

The researchers will report the results of this study through the usual scientific and aviation media. Preliminary findings indicate that, for the group average, the body-temperature cycle peaked about 4 hours early on the first day in Tokyo with reference to Tokyo time (at 1200 Tokyo time—2100 CST—instead of peaking between 1400 and 1700 hours Tokyo time as is the case of those living in Tokyo—the 1400 to 1700 hours temperature local-time peak is characteristic of persons living in a given time zone with reference to their local time—note also that circadian-periodicity studies represent an example of studies wherein the use of Greenwich time can, under certain circumstances, complicate rather than simplify the analyses). By the third day in Tokyo, however, the body-temperature cycle was adjusted to Tokyo time and peaking in phase with Tokyo.

Also, the reaction times were substantially slower during the first day in Tokyo, with return to the earlier "quickness" level by the third day. Mental-decision time as measured with a special technique was impaired to a still greater degree on the first day in Tokyo, with return to the preflight level by the third day.

Subjective fatigue, as felt by the subjects, ranging from extremely alert to extremely tired, hit its low point on the first day in Tokyo but was at the preflight level by the third day. By the fifth day, the feelings of fatigue began to return, possibly indicating that too long a layover can have adverse effects in this respect.

Critical flicker-fusion thresholds did not change significantly in the present subjects, possibly because they did not have actual psychomotor flight-task responsibilities while enroute.

Following the return to Oklahoma City, the investigators found certain surprising things. The subjects' average temperature returned rapidly to CST time with respect to peaking. In fact, in this respect, the subjects were back on schedule in 1 day. There was, however, some depression on the first day in the amplitude of the body-temperature swing of the subjects (the full report will discuss this in detail).

An increase in reaction time occurred on the first day of return to Oklahoma City, greater in extent than on the first day in Tokyo. Decision time increased only slightly, however. Subjective fatigue showed a decrease on the first day "back home" in Oklahoma, perhaps because of relief from the boredom that apparently arose toward the end of the long layover in Tokyo. Fatigue feelings did develop on the second day home, however, but began to disappear on the third day. Critical flicker-fusion thresholds showed little change.

The mean for all subjects with respect to rectal temperature demonstrated that biological time had shifted from Oklahoma City to Tokyo time within 3 days. On the return trip, only 1 day was required for the shift to Oklahoma City time. Drs. Hauty and Adams report that there is a considerable variation in individual response in adjusting to local times. One subject shifted to Tokyo time in 1 day, while another had not accomplished a phase shift on any of the days in Tokyo. The proficiency in accomplishing task functions was adversely affected (to a substantial extent) during the first day in Tokyo, and to a lesser extent, during the first day of return to Oklahoma.

This data, the first ever collected in the civilian-aviation context with respect to human biological time/time-zone interrelationships, performance alterations through the associated fatigue, and trip-recovery times, will be amplified through the findings of subsequent studies. An example is a recent study, also accomplished by Drs. Hauty, Adams and Charles Crane (a CARI biochemist), which is concerned with another group of subjects transported to the Philippines. The investigators will report their data in subsequent months, which include information obtained with a newly developed "evaporative water loss" device designed and constructed by Dr. Adams to measure the water loss through the skin (a process intimately associated with skin blood-vessel tonus, this latter condition reflecting in large measure—environmental factors accounted for—upon the state of "nervous tension").

VI. New Developments—Forest Service Flights.

Another recent interdisciplinary CARI study, conducted by Drs. Balke and Melton (a medical doctor and a neurophysiologist), with the assistance of Dr. O'Connor (a psychologist), and other CARI investigators (including CARI's flight-research pilots Messrs. Hasbrook and Burnworth), in cooperation with U.S. Forest Service Personnel of the Department of Agriculture, involves the use of inflight telemetry techniques as developed at CARI. Certain biomedical data is telemetered during flight from the pilots being studied and recorded on tape in receivers carried by an accompanying aircraft. The studies are being made in Montana on Forest Service fire-fighter pilots, using single- and multi-engine aircraft. The pilots are at times subjected to long periods of demanding flight tasks, with the development of varying degrees of fatigue. Correlation of the various biomedical factors during specific portions of the flight task are made possible by CARI's biomedical telemetry techniques.

As a side dividend, since this type of "borate-bomber" aerial-applicator work does not involve the organophosphate and highly toxic substances often utilized in crop-control activities, the findings will help us separate out the effects of fatigue per se generated by stress-flight performance from the combined picture of fatigue effects plus toxic factors seen in crop control.

Inflight stresses and the resulting fatigue were measured in Forst Service pilots recently near Missoula, Montana. Prescribed missions were flown continuously for 8 hours (with short refueling breaks), involving low-altitude "canyon runs" that require a high degree of vigilance and flight proficiency on the part of the pilot. Among the aircraft used was CARI's custom-equipped Beechcraft T-34B Mentor.

The telemetered information was picked up by a flying receiver-platform (a specially modified Beechcraft Twin-Bonanza with special receivers and tape-recording equipment), and by CARI's portable ground-telemetry equipment contained in a specially designed van.

Included in the preflight and postflight assessments of the pilots are such items as the physiological-response pattern during standardized exercise tasks (bicycle ergometer) and response patterns to a psychological-performance test (complex coordinator—an improved version of the device reported by Mashburn[68]). Inflight measurements included heart rate, blood pressure, pulmonary ventilation, and other psychophysiologic parameters.

The canyon runs (reminiscent of United Artists 633 Squadron) and U.S. Army "knap of the earth" flights demand a great deal of the pilots. Should vigilance deteriorate in these activities below a certain point, the consequences are tragic. The study, therefore, represents an attempt to determine the psychophysiologic cost of flying these missions.

Among the check-pilot's observations in the study are an increase in "roughness" on the controls during the latter part of the 8 hours, including the development of a certain degree of sloppiness.

These inflight-performance observations are being correlated with the psychomotor task tests. Also, a degree of cardiovascular system fatigue was detected. At times, pilots who had pulses in the 60- to 70-beat-per-minute range while flying routine profiles, demonstrated 120 beats per minute or more during certain portions of the canyon runs and at later periods during the flight day.

The complete analyses of the study will be published by the investigators in the following months.

VII. Selected Comments.

Steady but slow progress is being made in gaining control of the fatigue matter on various fronts. Assisting to alleviate the problem are several occurrences that have materialized independently of direct efforts to mitigate fatigue. For example, since 1959 many airport runways have been lengthened, fan jets have been introduced, certain types of air-traffic assistance have markedly improved, and runway lighting systems have been augmented, all of these developments helping to ease the stress of the jet-pilot's occupation.

Also, in a number of locations, the "parkway syndrome" has diminished as a factor relative to its 1959–60 significance. Additionally, the jet pilots, as a group, have now become so familiar with the operational characteristics of the jets, and have become so intimately acquainted with their craft, that any earlier existing "fatigue of transition" has essentially vanished. Another consideration is that the earlier "bugs" that plagued the newly introduced jets, notably hydraulic failures, have apparently been pretty well eliminated, again helping to diminish the overall number of occupational stresses to which jet pilots are subjected.

Interestingly, certain of the newer jets have such improved handling characteristics and operational features that trips are concluded with less physical and mental demands on the pilots than was the case with other craft.

Recently, a longtime airline Captain in his early fifties, with thousands of piston flying hours, who now makes the run between Dallas and Miami in the new Boeing 727, told the author that the 727 is considerably less demanding and fatiguing to him than the older piston craft. The short-field characteristics of the 727, its simplified cockpit displays and pilot tasks, and its ease of landing, coupled with other factors such as the virtually vibration-free cabin, are undoubtedly factors producing the Captain's experience. Actually, to project into the future for a moment, there is no reason why the same "antifatigue" qualities cannot be obtained in the evolving supersonic transport (SST), a consideration that will weigh in such questions as the retention of older pilots for SST's, the nature of SST scheduling practices, etc.[74]

Various types of air transports differ in their "fatigue-promoting" qualities, as was pointed out by Mr. Jerome Lederer in the 1930's, who noted that the new-style all-metal aircraft (Boeing 247's, DC–2's, and Northrops), had "less vibration and infinitely more comfort than previous airplanes (except the Curtiss Condors)."[63] The installation of autopilots did much to relieve the fatigue of pilots, and the use of flight-stability augmentation and automatic throttles on future craft such as the SST should have similar beneficial consequences.

Mr. Lederer's observations were made at a time when "biological engineering" was coming into being and, bit by bit, began to find its way into the features of production-line aircraft and associated equipment.[37]

One could scarcely locate a manufacturer today who does not, to one degree or another, incorporate biological or "human-engineering" data in his designs.[14, 43, 79] Much remains to be accomplished, however. For example, the comfort of certain jet-pilot oxygen masks, as reported by many pilots, can stand improvement. The development of skeletal dimension data on today's air-transport pilots so that design engineers can tailor the cockpits, seats, and associated apparatus to the present pilot population would be valuable.

Various populations are "selected" and are not representative of the general public. Air-transport pilots are physically superior as a group, with good executive health programs and frequent physical exams, and cannot be characterized by physical anthropological data obtained from the general population or from studies conducted years ago. CARI anthropologists have obtained data on air-traffic terminal and enroute controllers that is finding its way into improving the environmental circumstances of the controller, enabling him to accomplish his duties under more convenient circumstances.

The same can be accomplished with today's air-transport pilots, and CARI is working with ALPA with respect to obtaining the data for the design engineers. A useful application will be in restraint-system design, since there exists today certain combinations of shoulder harnesses and seats that, if the pilots wore the harnesses during takeoff and landing, would, by virtue of undue body-motion restrictions with respect to certain controls, create a greater hazard with reference to potentiating possible accidents than the safety protection afforded by wearing the harnesses. Anthropological data, placed in the hands of the engineers, plus cockpit and seat dimensions, coupled with range of motion requirements, would preclude such unhappy situations and further decrease the annoying circumstances that enhance the evolution of fatigue states.

Fruitful studies of the conditions that can foster occupational fatigue and fatigue-related symptoms have been accomplished by CARI psychologists in cooperation with air-traffic controllers. These studies involve various scheduling procedures, VFR versus IFR situations, and other considerations, including age.[53] Among the interesting findings were the detrimental effect of rotating from one shift to another in 8 hours or less, the increased incidence of stress-related symptoms with years of experience (from which the investigators are now attempting to separate the factor of aging), and the finding that a wide difference existed in all of these considerations between certain facilities. The long-term level of morale in a given component appears to be highly significant with respect to the degree of symptoms, and it is beginning to appear that aging alone, as a factor in this respect, is not as significant as "occupational exposure," or "experience."

A point for all of us to keep in mind, however, is, as Richard Pearson has noted, that there is no necessary relationship between performance and subjective fatigue.[83] In other words, work-decrement criteria do not always demonstrate a performance deterioration with fatigue. This is an important matter, since, although a given occupational population continues to turn out a creditable service, it may be doing so under adverse circumstances that ultimately take a toll in terms of permanent protoplasmic alterations. The physician in industrial health is, thus, through considerations associated with his Hippocratic Oath, obligated to remain cognizant of the long-range medical consequences of occupational stresses on his patients and to do what he can to alleviate the evolution of functional or organic untoward conditions.[70, 71, 96, 100, 105]

Similarly, the individual has the reciprocal obligation to avoid detrimental activities during off-duty hours that compromise the industrial physician's efforts. For example, the mind and body are inseparable, and a certain amount of off-duty time should be devoted to physical conditioning. The better the individual is in this respect, the less susceptible is he to the onset of fatigue.

Numerous observations on the above topic in the aviation context have been made, including those by Turner in 1910,[97] Grahame-White in 1912, [47] Hamel in 1914, [50] Scott in 1922,[91] Grow in 1936,[48] Balke in 1962,[7] and Dill in 1963.[35]

Since the factor of aging (biological versus chronological) is intertwined within this total picture, several efforts are bearing fruit in the aviation context. Among them are the "physiologic-age ratio" study of disease-free pilots made at the Lovelace Foundation, the studies by the various airlines (notably United Airlines, at its Washington, D. C., medical facility) and the FAA studies.[6, 49, 73, 87]

For the first time, timely data is now quickly available concerning the total numbers of active pilots in all age groups in all types of aviation (this is made possible through the utilization of modern computer techniques—IBM 7040—as a tool by the FAA's Aeromedical Certification Division in Oklahoma City—active pilots have current medical certificates).[92]

This data is of value to all interested in aviation activities and is especially useful with respect to the continuing review of aeromedical standards.[2] The older, continuously active pilot has survived in large measure because of ability, judgment, good physical condition, and good equipment, and the more we can do to enhance these conditions, the better for all concerned.

Among the existing studies to assist in accomplishing this latter aim are those by Barron on decompression protection and negative-ion electrostatic-field effects on pilots,[9, 10] by Cohen on the measurement of pilot mental effort,[28] by Diamond on the fatiguing effects of red light,[34] by Ganslen et al.,[44] on certain antifatigue drugs, by von Gierke on vibration and noise,[45] by Graybiel on flicker-fusion in fatigued aviations,[46] by Hawnylewicz and Blair on fatigue recovery,[54] by Hornick on helicopter vibration,[56] by Bourne on inactivity effects,[17] by Jackson on longrange aircrew fatigue,[57] by Lowenstein (the inventor of pupillography—an excellent means of measuring eye fatigue) on psychosensory restitution,[66] by Marchbanks et al., on overwater missions,[67] by McFarland on wartime pilots,[69] by Miller on serologic changes in flight fatigue,[72] by Stegall on tilt-table cardiovascular alterations,[95] by Tyler on the drug alleviations of fatigue,[98] by Pierson and Lockhardt on fatigue in women,[84] and by Welford on civil air-crew fatigue effects on performance.[102]

Studies relating to the above areas of inquiry may be found in the early aeromedical literature, including the 1918 report by Wilmer,[104] the 1918 report by Henderson and Seibert,[55] the 1918 report by Dunlap,[38] the 1920 report by Cruchet,[33] and the 1939 report by Barmack.[8]

Recent newspaper and magazine reports have brought to general attention the subject of pilot fatigue.[5, 18, 19, 65] The occupational circumstances of today's air-transport pilot has been reported by various pilots themselves.[30, 88] Fahnestock predicted certain fatigue problems in air-transport pilots at the Second National Clinic for Domestic Aviation Planning held in 1944 in Oklahoma City, and recommended appropriate research.[42] Jordanoff, a year earlier, at the 1943 clinic, discussed the topic also.[58]

Figures on airline-pilot inflight incapacitations have been prepared by Mr. Orlady, and continued observation of these statistics may prove valuable in estimating the role played by fatigue in aviation activities (by a study of the types of incapacitations in relation to the job circumstances).[36, 81]

Fatigue in non-air-carrier flying can become quite serious if the pilot (for example, an executive pilot) is frequently called at irregular hours for flights to unfamiliar fields, often under IFR conditions. Billings et al. have recently discussed this matter.[16]

Recently, Betty Miller (who, with her husband Charles Miller, owns the Santa Monica Flyers), just-announced Harmon-trophy winner for her solo California to Australia flight, told the author that fatigue was her main concern on the hop from Honolulu to the continent. Fatigue, thus, pervades all aviation activities, and the FAA has recently made available (primarily aimed at general aviation pilots) the booklet, free of charge, *Medical Facts for Pilots*.[76] Thousands of copies have been individually requested by general aviation pilots, pilot organizations, and aircraft companies. It has already been translated into Spanish, and the demand for this information, containing comments on fatigue, illustrates the widespread interest in the subject in all parts of the world.

Also, the FAA recently published emergency evacuation information and, as was also pointed out in its Advance Notice of Proposed Rule Making—Notice 63–34, noted that crew fatigue at the time of an emergency (including stewardess fatigue) can impair the efficiency of emergency escape.[40, 77]

ALPA's response to the Notice reflects considerable thought, and the imaginative development of a "duty time" hand computer bears serious study.[3]

The future will bring forth new achievements in the mitigation of fatigue. As pointed out by Dr. Schwichtenberg, new miniaturized portable medical equipment, which measures "rates" of change in psychobiological parameters in real time under actual work conditions through the use of miniaturized computers, stands to revolutionize the practice of aviation medicine.[90] The impact of these developments on scheduling and other aspects of aircrew activities will be immense.

VII. Recommendations.

It is recommended that the following seven approaches be aggressively pursued:

A. The accomplishment of an accurate monitoring system of the incidence (as opposed to prevalence) of appearance of new stress-related symptoms and conditions in specific pilot populations (identified in relation to aircraft, route, and schedule). In this manner, fatigue and stress-producing situations can be pinpointed in an early stage and corrected.

B. The incorporation of recently evolving biological-engineering data in cockpit construction, layout, and environment, including more comfortable oxygen masks, enhanced seat comfort, decreased noise and glare, improved restraint-system efficiency and comfort, and better temperature and humidity control (factual body-dimension figures on present airline pilots—as opposed to existing data on nonpilot populations—should be obtained in order that the cockpits can be engineered for the actual persons who will use them).

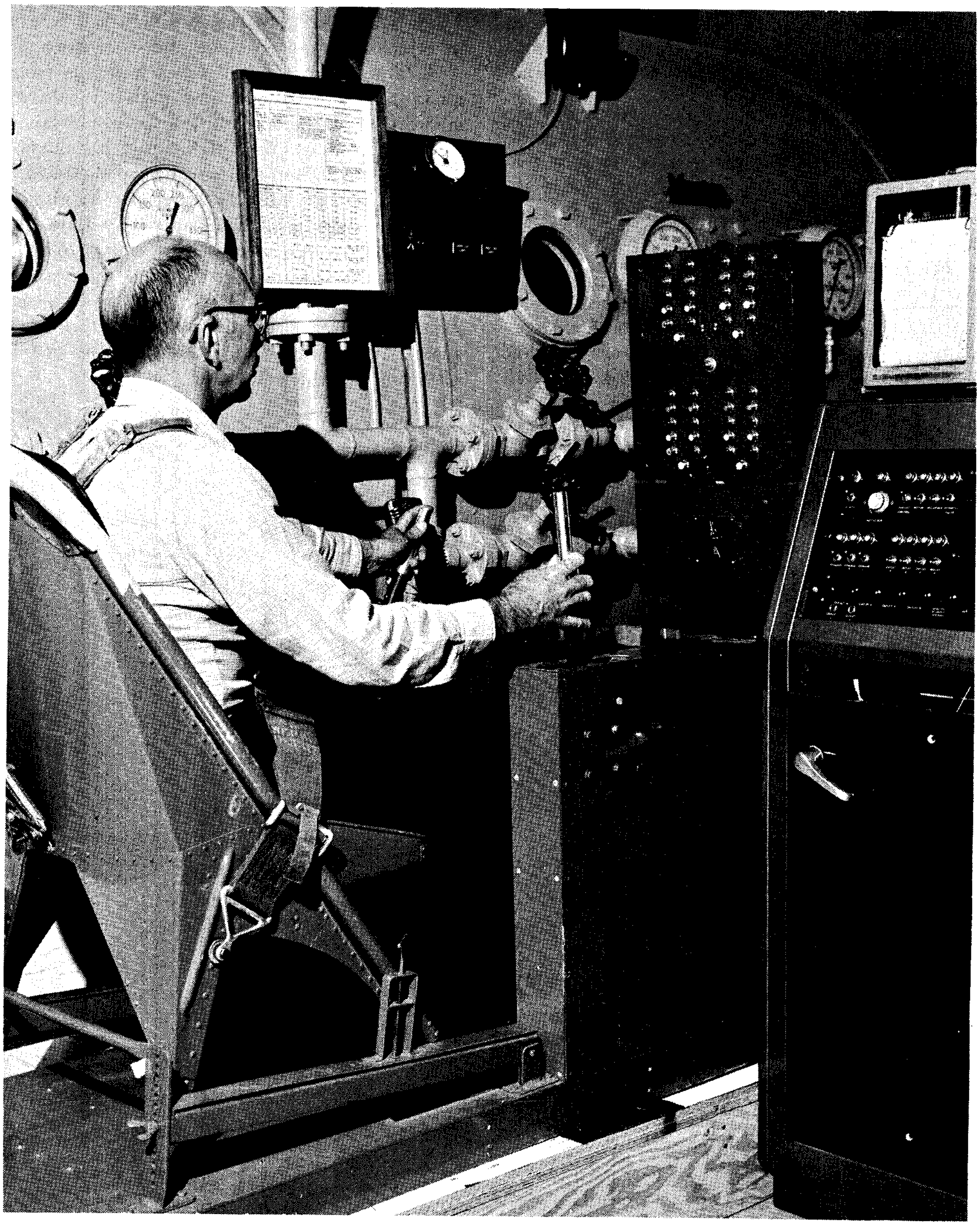
C. The individualization, insofar as possible, of scheduling regimens, so that those who are least susceptible to East-West time-zone biological asynchrony are assigned to these routes (there is apparently a wide individual variation in susceptibility to this effect).

D. The continuation of close rapport on the subject of fatigue among pilots, manufacturers, airline management, and flight surgeons, nationally and internationally, so that all practicable means can be utilized to keep fatigue at a minimum under the requisite operational circumstances.

E. The continuation of interdisciplinary aeromedical research on fatigue in aviation activities, since there exists a distinct problem (more apparent in the non-air-carrier segments of aviation as revealed by Civil Aeronautics Board accident reports) from which airline pilots are by no means immune.

F. During its investigation of air-carrier accidents, the accomplishment of a more detailed assessment by the Bureau of Safety of the Civil Aeronautics Board of the possible role of fatigue in relation to the accident under scrutiny.

G. The designation within each airline (scheduled and nonscheduled and with or without a medical department) of one person who will have the responsibility of keeping his finger on the "fatigue pulse" of the aircrews, maintaining a repository of crew observations of apparent fatigue-promoting circumstances associated with the respective airline equipment, routes, operating practices, and schedules. In this way, periodic scrutiny of the data relative to respective equipment, schedules, etc., would afford a clearer picture of specific fatigue-promoting circumstances and enhance remedial activity.



The illustration above shows the complex coordinator and decision task device, used at the Civil Aeromedical Research Institute in pilot-fatigue studies. The device is placed in altitude and environmental chambers for the assessment of the effects of these factors and also measures performance decrements resulting from various schedule regimens, sleep losses, and other circumstances. It has been transported to various locations for field studies.

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