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PHYSIOLOGICAL STUDIES ON AIR TANKER PILOTS FLYING FOREST FIRE RETARDANT MISSIONS

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I. Introduction.

The causes of forest fires are many and varied, including sparks from trains, airplane crashes, campfires and unextinguished cigarettes. However, most forest fires are caused by lightning strikes when thunderstorms pass over the great coniferous forests. Since these storms are randomly distributed geographically, probability factors dictate that most of the fires will be in remote areas where they cannot be readily reached with surface vehicles.

Attacks on fires in remote or wilderness areas are primarily by aerial means. Men and equipment are dropped by parachute near the fire to attack it from the ground and retardant solutions (thick, brick-red ammonium phosphate solutions called "slurry") are dropped from air tankers on or near the fire to reduce it and retard its spread.

In order for the retardant to be placed effectively on the fire, the air tankers must be flown at approach speed at tree-top altitude while loaded to near maximum gross weight. Fires are commonly located in canyons that are filled with smoke. Turbulence over the fires is said to range from moderate to severe. These conditions are considered to create a high potential for accidents. The risk is considered to increase in proportion to the length of time that these factors impinge upon the pilot and cause fatigue to develop.

In recognition of these stressors, the U.S. Forest Service has set empirical limits for flight duty. These limitations provide that a pilot may not fly more than 8 hours in any one day if no more than 4 hours were flown the previous day. No more than 6 hours may be flown in any one day if the preceding day's flight time exceeded 4 hours. No more than 38 hours of flight time may be accumulated in any 6 day period. Pilots are required to have 1 day of rest if 26 hours or more were flown in the previous 6 days. No pilot is allowed to fly more than 6 hours without a 1 hour rest period, exclusive of ground duties related to flight.

This study represents an attempt to test objectively the validity of those regulations.

In the summer of 1964 a project was designed to evaluate stress and fatigue in pilots flying forest fire control missions. That project was carried out in July and August of that year with Forest Service pilots and FAA pilots serving as subjects. The conclusion drawn from data collected during simulated missions was that the fatigue incurred by the pilots flying 8 hours per day was not cumulative over a period of 3 days and that no alteration of flight hour limitations was necessary[4]. Because there were few fires calling for air tanker operations in 1964, a plan was tentatively made to return for further studies under actual fire conditions. The project described here was carried out in August 1967, in conjunction with the Missoula Equipment Development Center, U.S. Forest Service, at the Aerial Fire Depot, Missoula, Montana.

II. Methods.

Five TB-M (Fig. 1) air tanker pilots were subjects in the experiment. These pilots were contract pilots and were induced to participate in the project by offering them a bonus of $5/flight hour and $10/day.

Necessarily, this was a project of opportunity so that no pre-set design specifying degrees of freedom was possible. The in-flight parameters selected were (1) heart rate, (2) rectal temperature, (3) cockpit temperature and (4) voice transmissions. Ground studies included pre- and post-flight, (1) a questionnaire, (2) blood pressure, and (3) psychomotor performance (Fig. 2). Urine collections were planned to provide for a

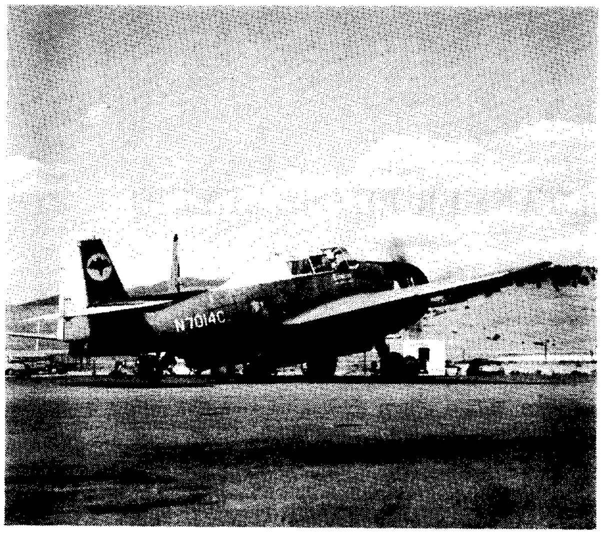

FIGURE 1. TB-M (Pilot #4) leaving the slurry pit for a retardant mission.

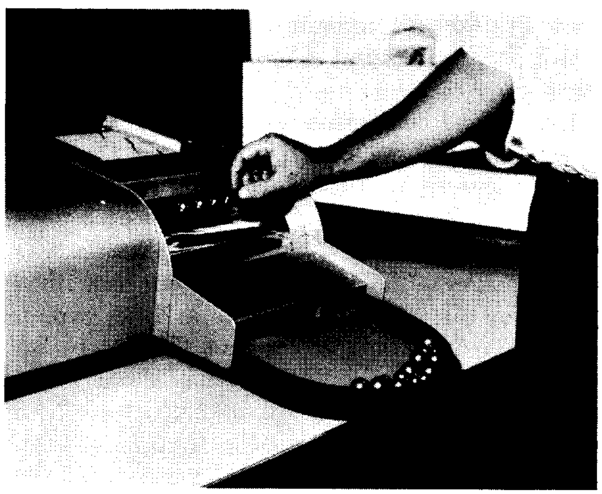

FIGURE 2. "Kugelmaschine." Device consists of a rotating cylinder, bored to receive steel balls of five different sizes. Balls are placed in holes in the steel cover over the cylinder, as shown. When the hole in the cylinder is aligned with the hole in the cover, the ball will drop, activating a switch and registering a hit. If the hole passes empty or if the wrong sized ball is placed in the hole, a miss is registered. The cylinder rotates at different speeds that are pre-programmed. Scores are expressed as a percent of the possible score.

resting specimen upon arising, a pre-flight specimen, an in-flight or during-flight specimen, and a post-flight specimen. The collected samples were analyzed for epinephrine, norepinephrine, 17–OH corticosteroid and creatinine.

The rationale behind the selection of these measurements was that heart rate would serve as an instantaneous indicator of stressful events while urinary excretion of catecholamines and 17–OH steroids would indicate the longer term or total effects of stress. Voice transmissions were used to identify the various episodes during a mission. Rectal and cockpit temperatures were used to evaluate one parameter believed to contribute to the overall job stress. Psychomotor performance was selected as an indicator of fatigue, since it had been shown to be the most sensitive measurement in this regard in earlier studies[7]. Other measures would have been desirable but were not feasible or possible, such as determination of turbulence, quality of job performance, galvanic skin response, in-flight blood pressure and pulmonary ventilation.

In-flight measurements were recorded on two Lockheed 411–C four track instrumentation tape recorders. The recorders, associated amplifiers and sensors were mounted in the two lead tankers at the slurry pit each night in anticipation of flight the next morning (Fig. 3).

FIGURE 3. Lockheed 411–C four track tape recorder in position in TB-M rear cockpit. A 10 hour NiCd battery for operation of the recorder is shown uppermost in the picture. Recordings were made at 3¾ ips.

The pilots were instructed to come to the trailer-laboratory each morning when they reported for work. At that time they were to submit their first urine specimen and undergo pre-flight testing. When a fire call came in, the technical personnel at the trailer were informed if a retardant drop was ordered. If so, the technician would go to the flight operations room and meet the pilot as he left the briefing. The technician would then attach with an elastic strap the stainless steel plate ECG electrodes across the lateral chest wall, give the pilot a lubricated rectal thermistor probe and a urine collection bag. The pilot would then go to the Men's Room where he would insert the rectal probe and make a urine collection after which the technician and he went to the airplane. The pilot was then connected to the recording devices and allowed to depart. The entire instrumentation procedure required less than three minutes, maximally.

When tankers were dispatched to operate out of distant airports closer to the fire, a technician was flown to that site and remained there until the pilot was ordered back to Missoula. Data loss was minimized by this procedure.

Data reduction was carried out over a period of months after the researchers returned to Oklahoma City.

Some of the design goals were not met. The subject-pilots were, at best, reluctant participants in the study because they were not convinced that the project was in their best interests. Urine collections were seldom made according to schedule and there was no way to enforce the collection schedule. Complete urinary data were obtained on only two pilots. One pilot refused to wear the rectal probe, claiming sensitivity; another claimed to have amebic dysentery. The monetary inducement was insufficient to make a pilot delay his takeoff so that he could be instrumented. The pilots readily explained that they could not afford to compromise a chance for a second drop by missing being "first off." Some in-flight data were thus lost.

III. Results.

About 100 hours of in-flight recordings were made from subjects 1, 2, 3 and 4 on 130 flights over 76 fires. Ground observations were made on subject #5, also.

TABLE I—Heart rate by Maneuvers

#1	Resting, 81 bpm		
	Mean	*S.E.M.*	*% of Resting*
Start	105.2	4.07	130
Taxi	96.9	1.59	120
Runup	107.0	5.22	132
T.O.	110.68	3.38	137
Enroute	99.25	6.65	122
Over Fire	99.25	4.09	122
Drop	119.15	3.83	147
Return	101.2	6.72	125
T.D.	95.91	4.39	119
Taxi	97.08	2.75	120

#2	Resting, 76 bpm		
	Mean	*S.E.M.*	*% of Resting*
Start	102.96	2.43	136
Taxi	105.74	2.54	139
Runup	110.20	6.40	145
T.O.	112.42	3.46	147
Enroute	99.04	1.40	130
Over Fire	106.36	1.96	139
Drop	122.67	3.76	162
Return	100.68	1.67	133
T.D.	107.15	2.84	141
Taxi	104.89	3.14	138

TABLE I (Con't)—Heart rate by Maneuvers

#3	Resting, 90 bpm		
	Mean	*S.E.M.*	*% of Resting*
Start	101.57	4.52	113
Taxi	95.86	3.62	107
Runup			
T.O.	111.58	2.52	124
Enroute	99.63	1.38	111
Over Fire	113.25	3.01	126
Drop	120.80	4.49	134
Return	108.25	4.82	120
T.D.	115.80	9.50	129
Taxi	110.25	8.20	122

#4	Resting, 83 bpm		
	Mean	*S.E.M.*	*% of Resting*
Start	97.79	2.46	118
Taxi	96.56	2.21	117
Runup			
T.O.	100.16	2.25	120
Enroute	92.19	1.58	111
Over Fire	100.52	2.65	122
Drop	111.25	2.65	134
Return	91.89	2.00	111
T.D.	99.91	2.92	120
Taxi	93.94	3.55	113

(1) *Heart rate:* a. *Events giving rise to highest rates:* Invariably, the routine in-flight event associated with the highest rates with all of the subjects was the retardant drop over the fire (Fig. 4, Table I). Two emergencies (hydraulic line rupture) gave rise to higher rates of 152 (#1) and 158 (#4).

b. *Relationship of heart rate to daily flight hours:* The operant hypothesis was that increments in daily flight hours engendered equivalent increments in stress and fatigue and that the latter increments would be reflected in increased

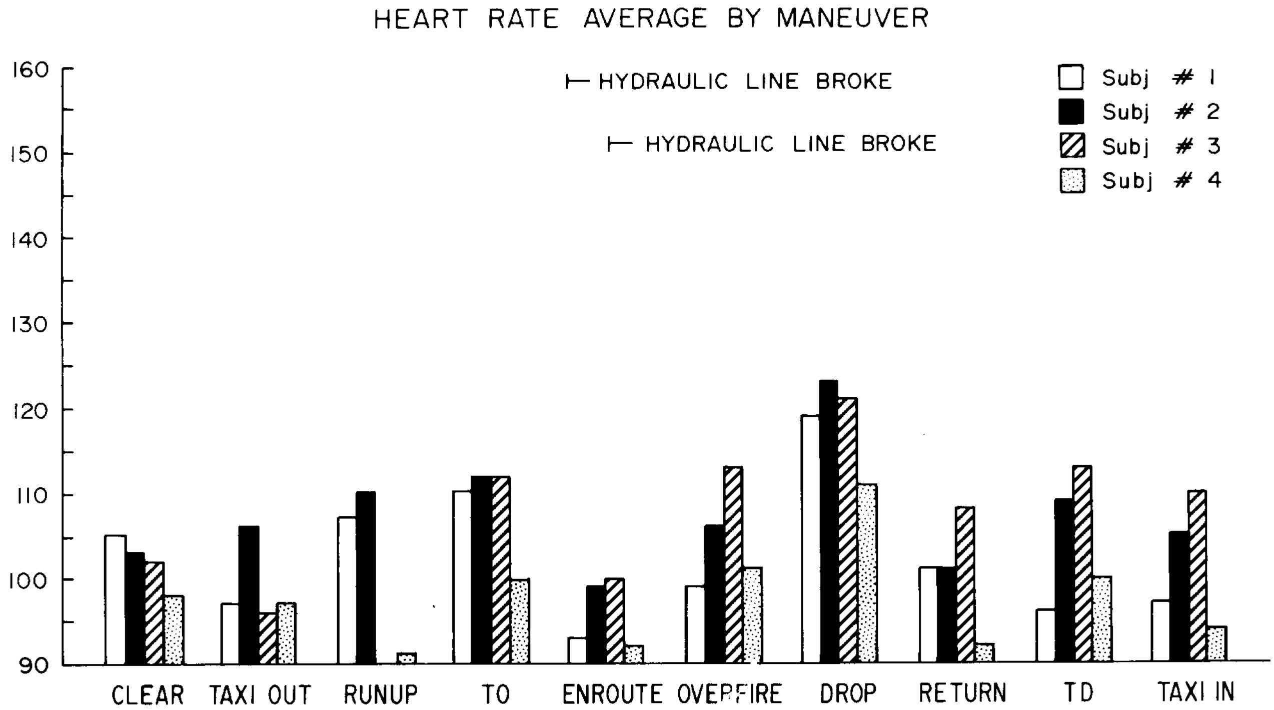

FIGURE 4. Heart rate averages for each subject shown by type of in-flight activity (maneuver). For each pilot the minimum heart rate occurred en route and the maximum occurred at retardant drop.

heart rates. The data were examined to determine if heart rate changed with the number of daily flight hours (Fig. 5). The data showed that the average heart rates were invariably lower on the days of greatest flight hours than they were on the days of least flight hours.

c. *In-flight heart rate compared with resting heart rate:* Heart rates for the entire period of the study showed increases of (#1), 12%; (#2), 13%; (#3), 17%; and (#4), 25% in-flight over resting.

(2) *Psychomotor performance:* In earlier studies by Fiorica, et al.[7] it was shown that physiological parameters changed insignificantly during 86 hours of sleep deprivation but that psychomotor performance was a good indicator of the fatigue brought on by the sleeplessness. For that reason the "Kugelmaschine" test was incorporated into this study. Figure 6 shows that in 82% of the cases post-flight performance was better than pre-flight performance. In 90% of the cases the afternoon performance was better than the morning performance on non-flight days. In 64% of the cases, post-flight performance was better than the afternoon non-flight-day performance.

(3) *Urine Chemistry:* The original high hopes for the value of urine chemistry faded when it was realized that so many urine specimens were not collected. Values for all four specimens on flight days and non-flight days were obtained only on subjects #1 and #2. Meaningful statements thus cannot be made about #3, #4 and #5 (Fig. 7). Pilot #1 showed an increase in excretion of all metabolites, except norepinephrine in the third specimen which was unchanged. Pilot #2 showed an increase in epinephrine excretion on all flight days in all four specimens; he showed a decrease in norepinephrine excretion on flight days, except for the second specimen which was elevated; an increase in 17–OH corticosteroid excretion in the first three specimens on flight days and no change in #4.

In summary, the urinary excretion of adrenal medullary and adrenal cortical products was increased on flight days.

(4) *Miscellaneous observations:* Cockpit temperatures ranged from 63°F on the ramp in the morning to 125°F over the fires when rectal temperature reached 101°F. Pilot #1 averaged 6.5 hours of sleep per night with a range of 5.0–9.0;

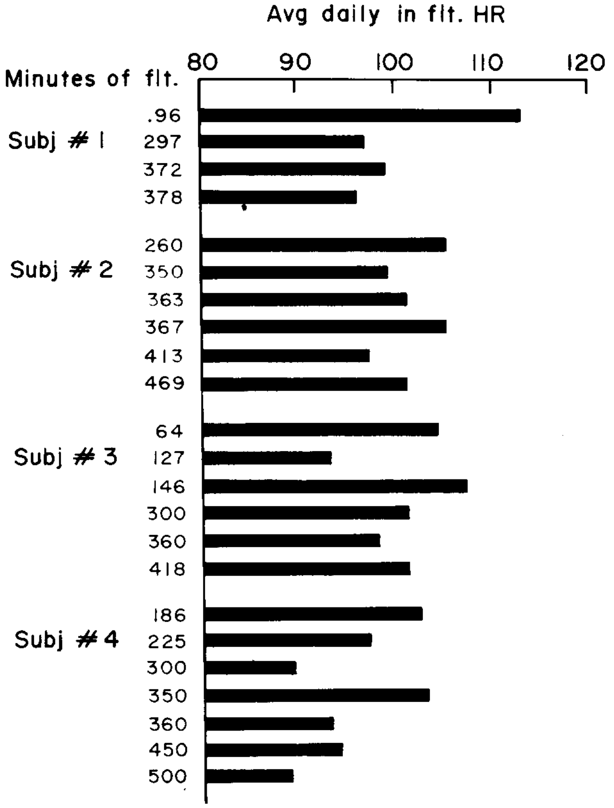

FIGURE 5. Average daily in-flight heart rate graphed against the daily accumulated number of minutes of flight. For each pilot, the average heart rates are lower on the days of greatest flight activity than on the days of least flight activity.

#2 averaged 6.8 hours, with a range of 3.0–9.5; #3 averaged 6.0, range 4.0–7.0; #4 averaged 7.7, range 4.0–9.0 (Fig. 8). Reported hours of sleep were examined with reference to the number of hours flown prior to a given night and with reference to the hours flown after each night. The rationale behind this approach was that if fatigue was present, the pilots should seek rest and that fatigue should increase in proportion to the duration of flying. Thus, the hypothesis was that a greater amount of flying should be followed by a greater amount of sleep. There is no apparent relationship between the hours flown and subsequent amounts of sleep (Fig. 8). Likewise, there was no apparent relationship between anticipated flight hours and duration of sleep (Fig. 8).

IV. Discussion.

This project is similar to many others that have been underway in this laboratory as well as at other installations[2–4, 9, 11–17]. All of these projects are based on the assumption, probably valid, that fatigue is accompanied by or causes a performance decrement[14]. In fact, most tests for fatigue involve the measurement of some function, a decrement in which is referred to as fatigue. Thus, the cause is defined in terms of its effect.

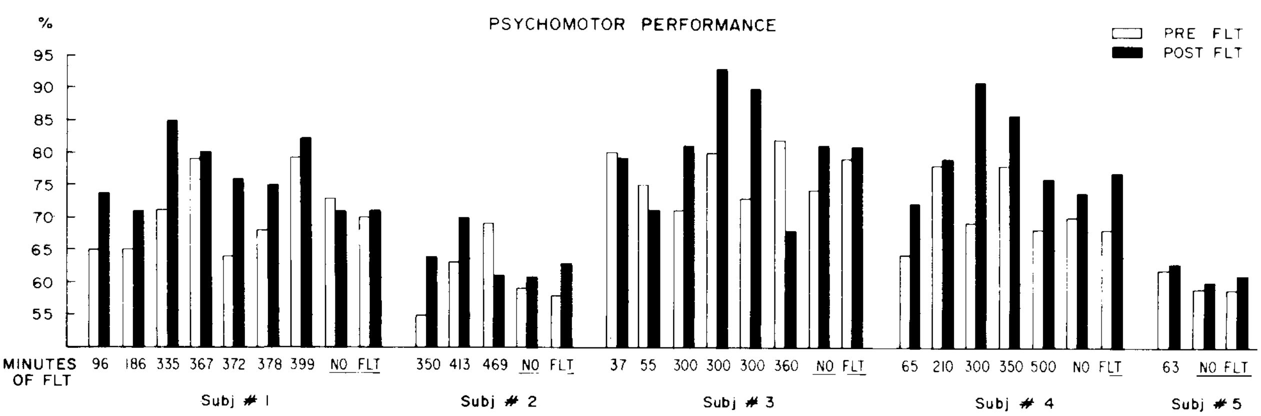

FIGURE 6. Psychomotor performance in percent of the possible score plotted against the number of minutes of flight and on no-flight days.

A good definition of fatigue is still lacking because fatigue is a sensation common to many causative factors. Commonly, one hears differentiations made between "physical" and "mental" fatigue. As Bartley[5–6] points out, after the person has stated the distinction he feels better for having said something but he has shed no light on the problem. A person may experience just

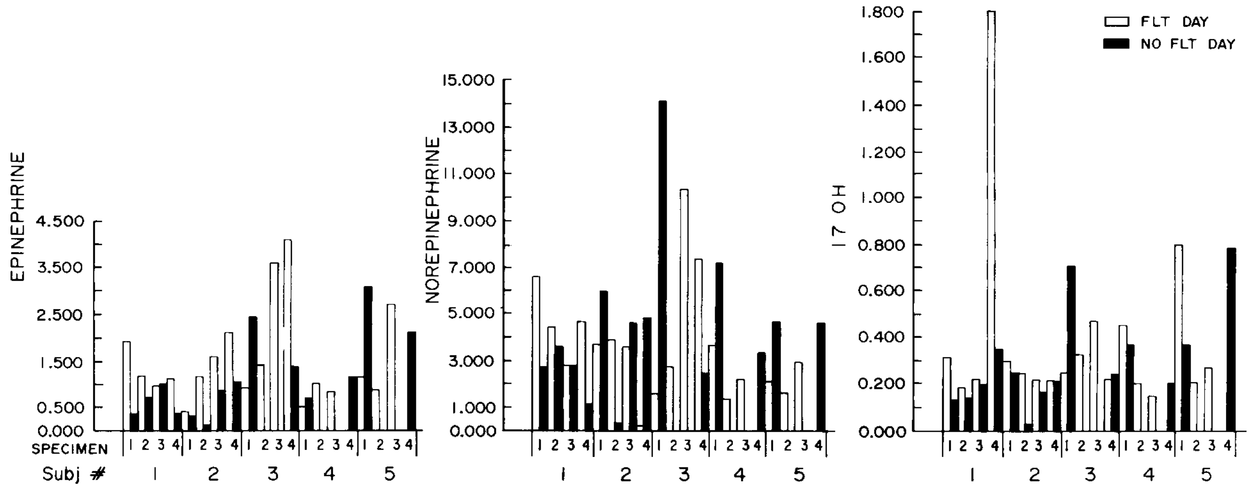

FIGURE 7. Urinary excretion of adrenal products in μg/hr. for catecholamines and in mg/hr. for steroids for each subject.

as intense a sensation of fatigue from dealing with problems from behind a desk as from dealing with problems from behind a lawnmower. The paradox is that the sum of the efforts, desk and lawnmower, may not produce twice the amount of fatigue.

Stress is likewise elusive of good definition and is usually described in terms of the stressor such as cold, heat, injury, etc. Again, differentiations are made between physical and emotional causes. The responses to stress are well recognized and all, at least initially, involve an increased output of adrenal medullary and adrenal cortical hormones.

Thus, the terms "stress" and "fatigue" have the common property of vagueness. However, intuitively they seem to be related in that a continued stress gives rise to fatigue. That assumption also underlies this project as well as the ones mentioned above.

The design of this project was such that individual "little stresses" would be identified by heart rate increases. This measurement is probably the best that is currently available when all factors are considered. It is easily obtained and recorded; the recording of it interferes minimally with the subject and it correlates well with other measurements such as galvanic skin response, pupillary response and pulmonary ventilation.[16] Balke, et al. used heart rate as an index of energy expenditure.[4] The assumption in that case was that the observed increases in heart rate reflected the same increase in metabolic rate as did increases in heart rate caused by exercise. This assumption is probably not valid precisely, but the error would lead to an over-estimation of energy expenditure by the pilot and is thus a safe assumption. Since this over-estimation failed to indicate an accumulation of fatigue, then the valid conclusion could be reached that the allowable flight hours of the pilots in that study did not need to be reduced. Applying the same criteria to the heart rates obtained in this study, the conclusion would be the same; i.e., metabolic rates would only be elevated 12–25% over the resting rate. All of these pilots were lean men in apparently good, and certainly in average, physical condition. They should have been able to perform at a rate of 25% of their maximum capacity for aerobic work without incurring fatigue that would not have been reversed in 16 hours off duty. Applying the criteria of Balke, these pilots should have been able to add 1250 kcal of energy expenditure to their resting metabolic rates within eight hours. If a baseline (but not basal) metabolic rate of 115 kcal/hr is assumed for these men, then simple calculations, based on their inflight heart rate increments, show that their total energy expenditure during 8 hours of flying would range from 1030 to 1150 kcal. In short, their flight activities probably called for less expenditure of energy than almost any other non-flying activity. It must be kept in mind, however, that these pilots did not often sleep eight hours and their off duty energy expenditure must be added to that expended in flight.

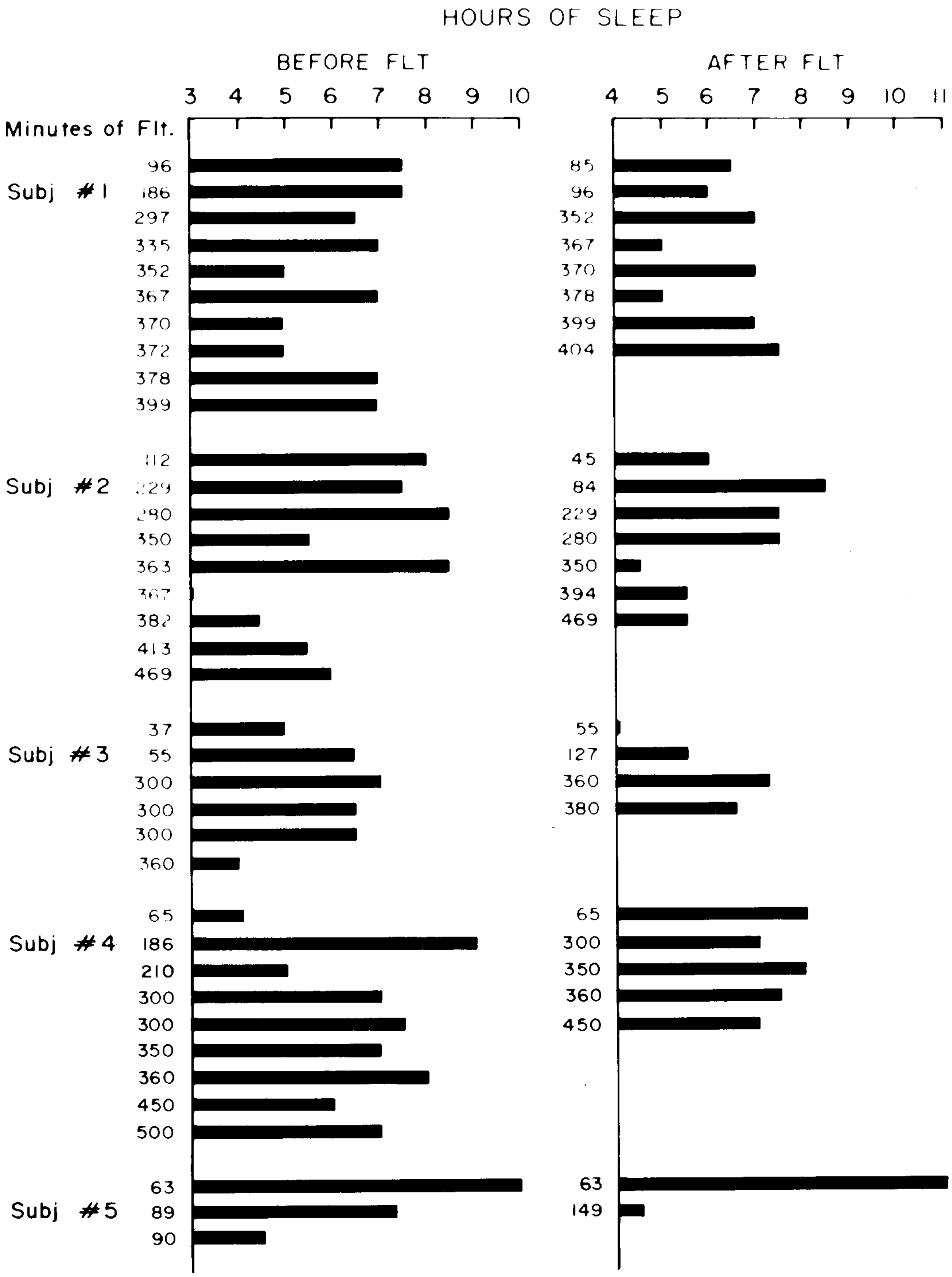

FIGURE 8. Reported hours of sleep the night before flights plotted against the accumulated number of minutes of flight each day and the reported hours of sleep plotted against the minutes of flight on the preceding day.

The heart rates registered in-flight during the project were also not consistent, on a comparative basis, with great physical effort or emotional extremes. Andersen[2] has plotted heart rates for Caucasian men representing three professions—office work (sedentary), industrial work (intermediate), and lumbering (heavy work). The office workers showed an average heart rate of about 90 bpm, the industrial workers about 110 bpm and the lumberjacks about 125 bpm. The pilots averaged 91, 86, 105 and 104 bpm in flight. Thus, their work, when based on this one criterion, falls between office workers and industrial workers.

Andrews[3] has related heart rate to metabolic rate in people undergoing physical activities of various intensities. For arm work, Andrews' regression line, when applied to these pilots, shows that the energy expenditure of pilot #1 would be increased by 0.8 kcal/min. or 384 kcal/8 hr.; the energy expenditure of pilot #2 by the same amount; #3 by 576 kcal/8 hr.; and #4 by 769 kcal/8 hr. Assuming a baseline metabolic rate of about 920 kcal/8 hr. and a maximum metabolic rate of about 5500 kcal/8 hrs., the total energy expenditure of pilot #1 would be 1304 kcal/8 hr. (24% maximum); 1304 kcal/8 hr. (24% of maximum) for #2; 1496 kcal/8 hr. (27%) for #3; and 1689 kcal/8 hr. (31%) for #4. These values are close to those reported as allowable for day to day expenditure of energy for men in good physical condition (25% of maximum). It is to be re-emphasized, however, that these figures overestimate the in-flight energy expenditure of the tanker pilots since the correspondence between heart rate and metabolic rate was established under conditions of physical exercise. It must also be remembered that these pilots seldom flew 8 hours per day.

The heart rate data may be summarized by stating that the heart rates in flight are generally those of men engaged in light to moderate physical work. Certainly, the moderate increases in heart rate in-flight do not indicate a great degree of fear or anxiety by these pilots in the execution of these hazardous missions. Student pilots have in-flight heart rates that commonly average more than the maximum rates shown by the tanker pilots[15]. It is doubtful that the student pilots actually do more physical work than the tanker pilots; the heart rates are a reflection of the great anxiety of students and the virtual absence of it in the tanker pilots. The tanker pilots' voice transmissions, also, indicated their relaxed attitude by singing, joke telling, etc. en route to fires. However under conditions of a genuine emergency, as happened twice when hydraulic lines broke, the heart rate went as high as any ordinary pilot's would under similar circumstances. This serves to underscore the pilots' attitude toward retardant missions which they apparently view as routine. To the untrained and unskilled their job may appear almost suicidal, but to them the task is one of which they have a thorough understanding and mastery.

The urinary data are almost too scanty to be of value. Many of the values are for single specimens only. The conclusion that all metabolites are elevated on flight days is probably indicative only of a slightly greater activity. Tables II & III and Figure 7 compare the pilots in this study with themselves, with pilots from other studies and with control non-flying people. These results, weakly valid only for #1 and #2, show that their adrenal activity is increased on flight days but within the range reported for the normal population.[1,8,10]

One great difficulty in drawing conclusions from the urinary data is that literature values are not reported in standard units. One investigator may report excretion products on the basis of 100 mg of creatinine, another as mg per 24 hours, another as μg per kg body weight per 24 hours, and another as μg per milliliter. In bringing all figures to common units, unavoidable errors are introduced in assuming a value for creatinine excretion or in assuming a body weight or in multiplying values per hour to ob-

TABLE II.—Urinary 17–OHCS Excretion

Aircraft	*Non-Flight Days*	*Flight Days*	*Ref.*
B–29	8.9 mg./24 hrs.	15.2 mg./24 hrs.	(11)
B–52	6.0 mg./24 hrs.	8.5 mg./24 hrs.	(12)
F–104	384 μg/100 mg. creatinine	344 μg/100 mg. creatinine	(9)
F–100 & F–104	280 μg/100 mg. creatinine	373 & 298 μg/100 mg. creatinine	(13)
Normals	1.25–19.95 mg./24 hrs.		(8)
Tanker Pilots			
#1	5.5 mg./24 hrs.	18.00 mg./24 hrs.	
#2	4.1 mg./24 hrs.	6.00 mg./24 hrs.	
*#3	12.0 mg./24 hrs.	7.40 mg./24 hrs.	
*#4	7.0 mg./24 hrs.	6.50 mg./24 hrs.	
*#5	14.2 mg./24 hrs.	10.10 mg./24 hrs.	

* Incomplete Data

tain 24 hour excretion figures. The urine values from the tanker pilots must be cautiously interpreted since the data are too scanty to permit statistical treatment that might reveal the significance of flight day vs. non-flight day differences.

TABLE III.—Urinary Catecholamine Excretion
μg/100 mg. Creatinine

Tanker Pilots	*Epi* *Flt*	*No Flt*	*Nor Epi* *Flt*	*No Flt*	*Ref.*
#1	2.06	0.86	7.08	3.95	
#2	1.96	0.86	4.12	5.70	
#3	1.46	1.19*	3.52	5.19	
#4	1.01	1.19	3.11	6.84	
#5	1.59	2.75	2.30	4.87*	
F-100 & F-104 Pilots					
	1.28–1.82	0.25	3.57–	1.23	(13)
Non-Flying Civilians		0.006		1.49	(1, 10)

* Incomplete Data

Heart rate patterns show much the same things that have been shown in other studies. Events that are associated with highest heart rate are low altitude, low airspeed maneuvers; in this case, the retardant drop is associated with maximum heart rates, emergencies excepted. Student pilots show maximum heart rates during short field landings[15]. Navy carrier combat pilots show maximum heart rates at launch and recovery, being lower than those during actual combat bombing runs[17]. Pulmonary ventilation in light plane pilots increases during takeoff and landing[16]. With the tanker pilots it is probable that physical work controlling the heavy TB-M at low airspeeds and the heat over the fire also contribute to the increased heart rate during drops.

The post-flight improvement in psychomotor performance deserves some comment. Insofar as this measurement is indicative of fatigue in other circumstances, one would conclude that the tanker pilots were not fatigued sufficiently to cause a decrement in psychomotor performance. Since performance improved in the afternoon of non-flight days, one cannot ascribe the improvement to flight itself. All that can be said is that flight does not prevent the improvement.

The pilots seldom complained of fatigue post-flight nor did they admit to it on query. Pre-flight questionnaires in the mornings revealed an occasional admission of fatigue ascribed to the previous night's social activities and lack of sleep. The amount of sleep that they sought, however, did not appear to be related to the number of hours of flying that day.

Systolic blood pressure decreased 53% of the time post-flight. On non-flight days the systolic blood pressure decreased 40% of the time in the afternoon.

The general evaluation of these pilots based on the data, observation and interview is that they do not appear to be fatigued by their occupation. This is borne out by estimates of energy expenditure and by their psychomotor performance. Their urinary output of steroids and catecholamines is consistent with a mild stress. This latter statement should not be taken to mean stress in excess of a normal "rate of living," for their values are within the normal range.

Bartley[5,6] views fatigue as a sensation rather than a metabolic entity. Common to all causations of fatigue is some form of conflict. Conflict occurs when any contradictory conditions or negative motivations exist, including pain, boredom, physical exertion, anxiety or frustration.

The tanker pilots comprise a rather unique group, distinctly different from military or airline pilots primarily on the basis of the method of their payment. No system could be devised that would inspire stronger positive motivation to fly than the per flight hour method of payment coupled with the short season within which much of their yearly income must be earned. Thus conflict exists for these pilots when no flight task exists rather than when one does exist. This outlook is underscored by their eagerness to be first off in order that they may get to make an additional drop and by their rather ambivalent attitude toward forest fires. They, as citizens, are concerned about the destruction of forests but as professional tanker pilots they cannot help but hope for thunderstorms.

On the basis of this study and recognizing that there are unmeasurable factors involved, it can only be said that there is no indication for reduction of allowable flight hours of these pilots. Questions may be logically raised about off-duty activities contributing to fatigue, the quality of the aircraft, the presence of carbon monoxide in the cockpit and the willingness of the pilots to wear oxygen masks, and the effect of all factors on these pilots as they get older. It is the impression of the researchers on this project that these same pilots continue their work year after year. Activities that are now insignificant in terms of a compromise with safety may in later years become significant.

While the accident potential would seem to be high in this flight activity, the safety record is impressive. It is reported that there have been only 26 accidents and incidents for all agencies in over 50,000 flying hours in the years 1961–1967, for a rate of about one accident or incident per 2000 hours. These figures include mechanical failures as well as pilot errors. Figures are not available that would give an estimate of how many accidents are believed to be fatigue-related.

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