

CIRCADIAN RHYTHMS AND THE EFFECTS OF LONG-DISTANCE FLIGHTS

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The term "circadian" (derived from the Latin *circa dies*, about a day) was introduced by Halberg in 1959.¹³ It refers to a time period which imprecisely approximates 24 hours in duration, ranging from 20 to 28 hours.⁵ It is commonly applied to rhythmic biologic functions which are geared to (1) an internal "biologic clock" (endogenous rhythm), (2) the intrinsic sleep-wake cycle, and/or, (3) exogenous influences (the solar day-night cycle, temperature, social environment, etc.). Examples of circadian rhythms are diurnal variations in body temperature, heart rate, performance, adrenocortical secretions, eosinophils,⁶ and evaporative water loss.⁸

One of the grievances against the King contained in the Declaration of Independence, July 4, 1776, reads: "He has called together legislative bodies at places unusual, uncomfortable, and distant . . . for the sole purpose of fatiguing them . . .". Thus, the adverse effects of time and odd hour schedules on the subjective and physical state of individuals helped bring about the Revolution.

Air transportation has highlighted the relationship of circadian rhythms to the subjective and physical well-being of travelers, especially when they rapidly traverse more than four time zones. One country is currently proposing to amend its air crew flight time limitations as follows: "In the event of there being a time zone change of four or more hours between the place of departure and the place where duty ends, the subsequent rest period should be not less than twelve hours".¹ This paper will describe some of the implications of such flights for the air traveler.

Prior to November 18, 1883, there were no standard time zones.³ More than one hundred different time zones existed in the U.S., based on "sun" time in individual towns as determined by

the best local estimate of "noon". Michigan had as many as 27 local times. Scheduling coordination problems led the U.S. railroads to spearhead the adoption of standard time zones in 1883. The United States Government gave a legal sanction to the time zone principle by passing the Standard Time Act on March 19, 1918, adopting the "four-zone" system of the railroads.

Biological Aspects

Pincus first described a diurnal periodicity for the excretion of urinary 17-ketosteroids.¹⁴ Adrenocortical secretions begin to enter the blood stream just prior to waking and serve to arouse the sleeper. The plasma cortisol level begins to rise about 0400, reaches a peak at about 0800, and declines to about one-half this level by late evening. These plasma cortisol levels are reflected in increased urinary 17-hydroxycorticosteroid, 17-ketosteroids, aldosterone, potassium, and water excretion 2 to 4 hours later.

✓ There are diurnal variations in body temperature. The lowest values occur about 4 hours after midnight during sleep and are thought to result from variations in cutaneous blood flow (as a heat loss mechanism) and body metabolism (which decreases with sleep).¹⁴ The highest values occur between 1500 and 1700.

✓ Breathing rates change on a circadian basis (diminishing in amplitude and rate during sleep); the vital capacity diminishes after midnight (possibly due to an increased blood volume in the pulmonary vessels). ✓ The heart rate generally reaches a daily peak during the 1500-1800 period.¹⁴

✓ Diurnal changes in human performance have also been noted. Halberg has reported a 70% increase in errors in reading gas meters after midnight.⁶ Chiles has found cycling in performance in several studies.² Walsh and Misiak¹⁷ have reported diurnal variation of critical flicker

frequency. The effects of shift rotation upon mental capability and manual dexterity have been observed in industry.

Travel Implications

In 1952, Strughold described the desynchronization of diurnal rhythms relative to air travel through many time zones.¹⁶ Twenty-one years earlier, Wiley Post reported his anticipation of time zone physiological problems due to long-distance flights.¹⁵ This is the first recorded instance of time zone effects relative to air travel. Mr. Post's successful record-breaking, globe-girdling flights appear to have been successful, in part, due to his recognition of the adverse effects of diurnal rhythm disruption on flight performance. He spent months learning how to eat and sleep at varying times in order to break his regular habits. In 1933 Mr. Post set a new around-the-world record flying alone in his single engine Lockheed Vega, the Winnie Mae. He had readjusted his "biologic clock" so his body was out of phase when he left New York but in phase when he completed one half of his journey over Russia. Because of this, he claims he was able to stay alert without stimulants.

Since the disruption of circadian rhythms may adversely affect human performance, a number of studies have been conducted in an attempt to determine the point at which airline pilots become impaired to an unsafe degree. German scientists have determined, from psychophysiology studies of transatlantic airline pilots, that the greater the interval between the flight departure time and the pilots' "activity peak", the greater the strain of flying.¹¹ They also infer from their data that performance failures and accidents are more likely to occur during the "hour of lowest resistance". As a result of this study, we understand that crews were rescheduled with consideration given to night departure times and multiple landings with intercontinental flights.

French aeromedical physicians have reviewed responses of airline pilots undertaking flights through six time zones (Paris to New York) and found that (1) younger pilots suffered less than older pilots, and (2) that the hours of flight from east to west or vice versa should be weighted with an incremental coefficient that

would give pilots more credit than for hours flown in a north-south direction.¹²

British aeromedical scientists have accomplished biomedical studies on transoceanic pilots prior to, during, and after their flights.^{9,10} The investigators found that heart rates varied directly with (1) work load during flight, (2) the specific airplane (peak landing heart rates for the Boeing 707 averaged 128 per minute; for the VC-10, 100), (3) the nature of the approach aids and airfields (higher with limited aids, or more marginal airfields), and (4) the weather. These data, when coupled with circadian rhythm disruption, have obvious implications governing scheduling in relation to departure times and recovery periods after flight across several time zones.

To assess biologic changes in occupants not concerned with aircrew duties, Flink and Doe measured 17-hydroxycorticosteroid, sodium, and potassium levels in 3-hour urine aliquots in a subject who was flown from Minneapolis to Korea (9 hour time zone difference).⁴ The investigators found that the diurnal biochemical excretion patterns synchronized gradually with Korean time, reaching a time displacement of 9 hours from Minneapolis time by the 11th day, a rate of adjustment of approximately 1 hour per day.

Studies conducted by the FAA have indicated that several days are required for complete re-synchronization of the biological rhythms after flights through several time zones; disruption did not occur on a north-south flight.⁸ Subjective fatigue was reported initially after all flights. Impaired psychological performance was demonstrated only after the long east-west flight. Re-adaptation to the "home" time zone was more rapid in most cases. The FAA has been conducting fatigue studies relative to pilots since 1935,¹⁸ but only since the jet age of the past decade have time zone effects become of major importance. With the SST, it should be possible to schedule crews for round trips the same day and keep them adapted for one time zone. Except for possible longer trips with less layovers, the effects of supersonic travel on passengers should not be significantly more (or less) disrupting than present jet travel.

Figure 1 shows a representative (body temperature, heart rate or performance) diurnal

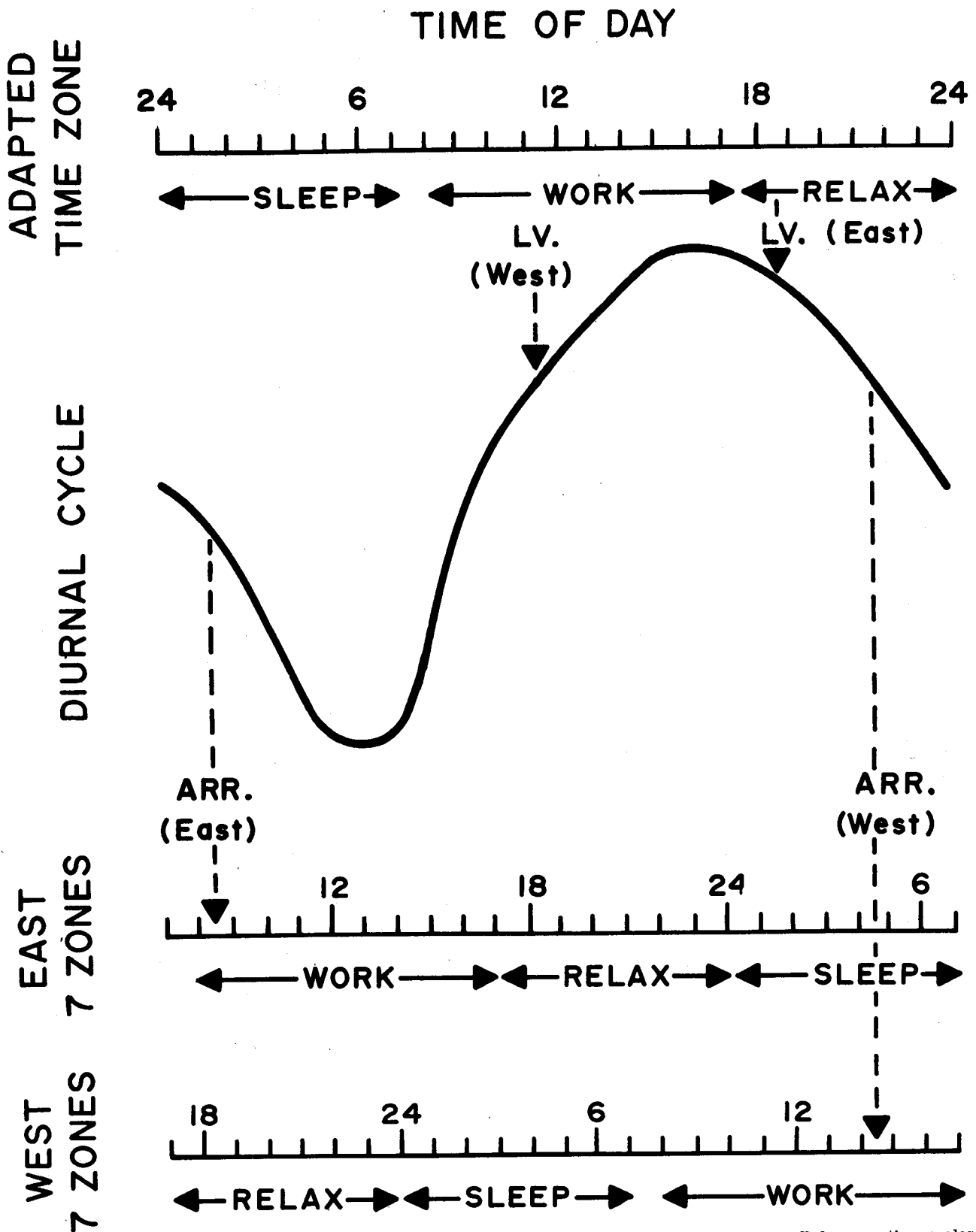


FIGURE 1. A representative diurnal cycle for body temperature, heart rate or performance. Below are time scales corresponding to time zones 7 hours east and west of the home zone. Departure and arrival times are given for non-stop jet flights across seven time zones in both eastward and westward directions.

curve. A time scale for a time zone to which an individual is adapted is shown above the curve. Time scales for zones 7 hours east and west are shown below the curve.

If a traveler leaves on a non-stop flight from New York to Rome (a 7-hour flight, crossing seven time zones) at 1830 hours, he will arrive at 0830 local time, but 0130 home time. He is thus biologically ready to sleep and not hungry. However, with sufficient conscious effort, he *can* immediately engage in business meetings, tours, meals and social functions, but probably at less than peak performance for the first 24 hours.

The return flight, after full adaptation to the local zone, leaves at 1100 hours and arrives at 1415 after a 10-hour flight. Sleep, which is "due" in 2 or 3 hours, may be delayed for a while but the "biologic clock" starts its awakening process by late evening and sound sleep, once attained, is hard to maintain. Sleep cannot be achieved by the conscious effort which permitted acceptable performance after arrival in Rome. In addition, the stomach is very time conscious and hunger for breakfast, which is "due" at 0100, may add further to the discomfort. Adaptation on westward flights can thus be expected to take longer than on eastward flights of the same length.

These are but two examples given in general terms. There are obviously many variables which affect any individual's experienced symptoms. These include times of departure and arrival, length of flight, direction of flight, layovers, travel experience, stress, age, physical condition, food and liquor consumed inflight, sleep inflight, climate changes, and the new social environment. The normal temperature and heart rate diurnal curves can be affected by the social environment.

A recent paper by Hartman and Cantrell recommends appropriate laboratory experiments and field studies to determine more adequately the loss in piloting skill as a result of alterations in cyclical physiological functions.⁷ To this end,

the Civil Aeromedical Institute is now planning the conduct, and/or support, of such studies.

Ameliorating Time-Zone Effects: Conclusions

Ordinarily the long-distance east-west or west-east air traveler cannot prevent entirely the effects of "time-zone fatigue". The methods of ameliorating such effects are similar for members of aircrews or passengers.

1. If the life habits, environmental factors and "clock" time at the destination are kept similar (by simulation) to those of the origin, the biologic rhythms will not be disrupted greatly. This approach is not practical in most cases.

2. With the advance knowledge that time-zone rephasing of biologic rhythms will begin at the destination and may require several days for most of the affected cycles to rephase, the traveler should plan to depart on a long east-west or west-east trip in as rested a physical state as possible. Businessmen and tourists should allow a day at the destination for accomplishing the initial rephasing of cycles prior to engaging fully in the demanding (and often excessively fatiguing) activities associated with international travel. If this is not possible, flights should be scheduled which arrive before nightfall in order to get a good night's sleep.

- ✓ 3. A long-distance traveler should definitely pace himself during the asynchronous period if he wishes to receive the least biological and mental strain.

- ✓ 4. Heavy increases in consumption of rich and unaccustomed foods and alcohol are often concomitants of foreign travel. Since such consumptions are stresses in themselves, combining these with biological asynchrony is doubly fatiguing.

5. Physical fatigue is one of the best means of inducing sleep. Exercise is particularly beneficial to permit sleep at local times before "normal" bedtimes.

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