Analysis of Crew Fatigue Factors in AIA Guantanamo Bay Aviation Accident

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Introduction

Flight operations can engender sleep loss and circadian disruption that can affect flight crew performance, vigilance, and mood. Scientific information on sleep and circadian rhythms acquired over the past 40 years has clearly established human requirements for sleep and the detrimental effects of sleep loss and circadian disruption. The application of this scientific information to the 24-hour requirements of flight operations has been underway for over 12 years. A variety of sources clearly indicates that fatigue, as a result of sleep loss and circadian disruption, is an aviation safety issue that warrants attention.

The NASA Aviation Safety Reporting System (ASRS) is a confidential reporting system for flight crews and others to report difficulties and incidents in the National Airspace System. Approximately 21% of the incidents reported to ASRS are fatigue-related (ref. 1). Since its inception, ASRS has accumulated over 261,000 incident reports with about 52,000 of these reporting a fatigue-related occurrence. Since 1980, the NASA Ames Fatigue Countermeasures Program has examined the extent and effects of fatigue, sleep loss, and circadian disruption in a variety of flight environments (refs. 2, 3). This Program has collected anecdotal, subjective, physiological, and performance data documenting fatigue issues in flight operations (e.g., see refs. 4-8). The FAA has identified fatigue research as an important aviation safety issue in its National Plan for Aviation Human Factors. The National Transportation Safety Board (NTSB) has, on several occasions, called for specific actions regarding fatigue, including coordination of federal research activities, review and revision of hours of service regulations, and the dissemination of educational materials. Scientific data has clearly indicated that fatigue can be a factor in 24-hour operational environments, including aviation. This has been recognized at the Federal level by the FAA, the NTSB, other Federal agencies (e.g., Office of Technology Assessment, Federal Highway Administration), and ongoing NASA activities.

Basic Human Physiology: Sleep and Circadian Rhythms

The era of modern sleep research began in the mid-1950's with the discovery of two distinct states of sleep (ref. 9). Over the past 40 years, there has been extensive scientific research on sleep, sleepiness, circadian rhythms, sleep disorders, dreams, and the effects of these factors on waking alertness and human performance (e.g., see refs. 10, 11). Some of this basic information regarding human sleep, sleepiness, and circadian rhythms is presented as a foundation for examining the specifics of the AIA aviation accident at Guantanamo Bay.

1. Sleep is a vital human physiological function.

Historically, sleep has been viewed as a state when the human organism is turned off. Scientific findings have clearly established that sleep is a complex, active physiological state that is

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vital to human survival. Like human requirements for food and water, sleep is a vital physiological need. When an individual is deprived of food and water, the brain provides specific signals—hunger and thirst—to drive the individual to meet these basic physiological needs. Similarly, when deprived of sleep, the physiological response is sleepiness. Sleepiness is the brain's signal to prompt an individual to obtain sleep. Sleepiness is a signal that a specific physiological requirement has not been met. Eventually, when deprived of sleep (acutely or chronically), the human brain can spontaneously, in an uncontrolled fashion, shift from wakefulness to sleep in order to meet its physiological need for sleep. The sleepier the person, the more rapid and frequent are these intrusions of sleep into wakefulness. These spontaneous sleep episodes can be very short (i.e., microsleeps lasting only seconds) or extended (i.e., lasting minutes). At the onset of sleep, an individual disengages perceptually from the external environment, essentially ceasing to integrate outside information. In a sleepy person, performance can begin to slow even before actual sleep intrusions into waking. A microsleep can be associated with a significant performance lapse when an individual does not receive or respond to external information. With sleep loss, these uncontrolled sleep episodes can occur while standing, operating machinery, and even in situations that would put an individual at risk, such as driving a car (refs. 12-14).

How much sleep does an individual need? Basically, an individual requires the amount of sleep necessary to achieve full alertness and their highest level of functioning during their waking hours. There is a range of individual sleep needs and, though most adults will require about 8 hours of sleep, some people need 6 hours while others require 10 hours to feel wide awake and function at their peak level during wakefulness.

2. Sleepiness affects waking performance, vigilance, and mood.

Sleep loss creates sleepiness and often this sleepiness is dismissed as a minimal nuisance or easily overcome. However, sleepiness can potentially degrade most aspects of human capability. Controlled laboratory experiments have demonstrated decrements in most components of human performance, vigilance, and mood as a result of sleep loss. Sleepiness can be associated with decrements in decision-making, vigilance, reaction time, memory, psychomotor coordination, and information processing (e.g., fixation on certain material to the neglect of other information). Research has demonstrated that with increasing sleepiness, individuals demonstrate poorer performance despite increased effort, and may report indifference regarding the outcome of their performance. Individuals report fewer positive emotions, more negative emotions, and an overall worsened mood with sleep loss and sleepiness (for scientific reviews of this area, see ref. 15-18).

Generally, sleepiness can degrade most aspects of human waking performance, vigilance, and mood. In the most severe instances, an individual may experience an uncontrolled sleep episode and obviously be unable to perform. However, in many other situations, while the individual may not actually fall asleep, the level of sleepiness can still significantly degrade human performance. For example, the individual may react slowly to information, may incorrectly process the importance of the information, may find decision making difficult, may make poor decisions, may have to check and recheck information or activities because of memory difficulties. This performance degradation can be a direct result of sleep loss and the associated sleepiness and can play an insidious role in the occurrence of an operational incident or accident (ref. 19-21).

3. Sleep loss accumulates into a sleep debt.

An individual who requires 8 hours of sleep and obtains only 6 hours is essentially sleep deprived by 2 hours. If the individual sleeps only 6 hours over 4 nights, then the 2 hours of sleep loss per night would accumulate into an 8-hour sleep debt. Estimates suggest that in the United States today, most adults obtain 1 to 1.5 hours less sleep per night than they actually need (ref. 22). During a regular work week this would translate into the accumulation of a 5 to 7.5-hour sleep debt going into the weekend; hence, the common phenomenon of sleeping late on weekends to compensate for the sleep debt accumulated during the week. Generally, recuperation from a sleep debt involves obtaining deeper sleep over 2 to 3 nights. Obtaining deeper sleep appears to be a physiological priority over a significant increase in the total hours of sleep (i.e., sleeping 7.5 hours longer on the weekend to "make-up" for the sleep debt accumulated during the week).

4. Physiological vs. Subjective Sleepiness

Sleepiness can be differentiated into two distinct components: physiological and subjective. Physiological sleepiness is the result of sleep loss: lose sleep, get sleepy. An accumulated sleep debt will be accompanied by physiological sleepiness that will drive an individual to sleep in order to meet the individual's physiological need. Subjective sleepiness is an individual's introspective self-report regarding the individual's level of sleepiness (refs. 12, 23). An individual's subjective report of sleepiness can be affected by many factors. For example, caffeine, physical activity, and a particularly stimulating environment (e.g., an interesting conversation) can all affect an individual's subjective rating of sleepiness. However, an individual will typically report being more alert because of these factors. These factors can affect the subjective report of sleepiness and mask or conceal an individual's level of physiological sleepiness. Therefore, the tendency will be for individuals to subjectively rate themselves as more alert than they may be physiologically. This discrepancy between subjective sleepiness and physiological sleepiness can be operationally significant. An individual might report a low level of sleepiness (i.e., that they are alert) but be carrying an accumulated sleep debt with a high level of physiological sleepiness. This individual, in an environment stripped of factors that conceal the underlying physiological sleepiness, would be susceptible to the occurrence of spontaneous, uncontrolled sleep and the performance decrements associated with sleep loss (refs. 24-26).

5. The Circadian Clock.

Humans, like other living organisms, have a circadian (circa=around, dia=a day) clock in the brain that regulates physiological and behavioral functions on a 24-hour basis. In a 24-hour period this clock will regulate our sleep/wake pattern, body temperature, hormones, performance, mood, digestion, and many other human functions. For example, on a regular 24-hour schedule we are programmed for periods of wakefulness and sleep, high and low body temperature, high and low digestive activity, increased and decreased performance capability, etc. An individual's circadian clock might be programmed to sleep at midnight, awaken at 8 AM, and maintain wakefulness during the day (with an afternoon sleepiness period), and then the 24-hour pattern repeats itself. The circadian rhythm of body temperature is programmed for the lowest temperature between 3 and 5 AM on a daily basis (ref. 27).

When the circadian clock is moved to a new work/rest (or sleep/wake) schedule or put in a new environmental time zone, it does not adjust immediately. This is the basis for the circadian disruption associated with jet lag. Once the circadian clock is moved to a new schedule or time zone, it can begin to adjust and may take from several days up to several weeks to physiologically adapt to the new environmental time. Also, the body's internal physiological rhythms do not all adjust at the same rate and therefore, may be out of synch with each other for an extended period of time. Again, it can take from days to weeks for all of the internal rhythms to come together in a synchronous 24-hour rhythm on the new schedule or time zone. There are some specific factors that can affect the circadian clock's adaptation. Day/night reversal can confuse the clock so that the cues that help it adjust and maintain its usual physiological pattern are disrupted. Moving from a day to night schedule and back to days can keep the clock in a continuous state of readjustment, depending on the time between schedule changes. For example, severe effects would accompany a 12-hour day to night to day schedule alteration. Another factor is crossing multiple time zones. While there is some flexibility for adjustment, putting the circadian clock in a time zone three or more hours off home time will require a reasonable amount of physiological adaptation. Another factor can be the direction the clock is moved. Shortening the period (e.g., moving to a 21-hour cycle or day) is generally more difficult to achieve than is lengthening the period (e.g., moving to 25 or longer hours), which is the natural rhythm of the circadian clock. Therefore, it can be more difficult to cross time zones in an eastward direction compared to westward movement. It can also be more difficult to move a work/rest schedule backwards over the 24-hour day compared to moving it forward (e.g., forward from day to swing to night shift). All of the associated difficulties of moving the clock, such as poor sleep, sleepiness, effects on performance, etc., will be affected until the circadian clock physiologically adapts to the new schedule or time zone (refs. 28, 29).

Scientific studies have revealed that there are two periods of maximal sleepiness during a usual 24-hour day. One occurs at night roughly between 3 and 5 AM, and the other in midday roughly between 3 and 5 PM. However, performance and alertness can be affected throughout a 12 AM to 8 AM window. Individuals on a regular day/night schedule will typically sleep through the 3-5 AM window of sleepiness. The afternoon sleepiness period can be masked by factors described previously, or present a window when individuals are particularly vulnerable to the effects of sleepiness. This also means that individuals working through the night are maintaining wakefulness from 3-5 AM when their circadian clock is programmed for sleep. Conversely, individuals sleeping during the day are attempting to sleep when the circadian clock is programmed for wakefulness. However, individuals searching for specific windows when they are physiologically prepared to sleep, either for an extended sleep period or a strategic nap, can use these periods to their advantage (ref. 12).

Specific Fatigue Factors to Examine in Investigations

Based on the previous scientific information regarding sleep and circadian rhythms, there are at least three core physiological factors to examine when investigating the role of fatigue in an incident or accident. The first is cumulative sleep loss. An individual's usual sleep amount is established based on their reported total sleep time at home. Using this figure as an individual's baseline sleep need, the amount of actual sleep obtained over a period of time can be used to calculate the cumulative sleep loss (i.e., sleep debt) or potentially, the sleep gained. Unless physiological or behavioral data is available, the reported amounts of sleep usually rely on subjective estimates of total sleep time. It is important to note that there is often a discrepancy between subjective sleep estimates and physiologically the amount of sleep obtained. Therefore, an important caveat is the self-report nature of the data, often obtained (i.e., recreated) after an incident or accident. The second factor is the continuous hours of wakefulness prior to the incident or accident. A general sleep/wake pattern will have an individual awake for about 16 hours and sleep for about 8 hours. However, operational requirements can involve extended duty periods that require continuous hours of wakefulness beyond this usual pattern. The third factor is time of day. This involves the time of operations and the time at which the incident or accident occurred. The time of day can also be a factor when examining when sleep periods occurred and the potential disruption of a usual circadian pattern.

The relationship of these factors can be especially informative. For example, an individual requiring 8 hours of sleep, who obtains 8 hours and is then awake for 20 hours will show less performance decrement than the same individual with 6 hours of sleep awake for 20 hours. With 8 hours of sleep, the individual is better prepared for the longer-than-usual period of continuous wakefulness than they would be with the combination of a sleep debt and the extended wake period. All three factors can come together to create the highest vulnerability for a performance decrement. The greatest decrement would be expected when an individual carrying a substantial sleep debt is required to operate for an extended period of continuous wakefulness, and the time of the operation passes through a period of increased sleepiness. Time of day could also affect the cumulative sleep loss if sleep periods were scheduled at less than optimal circadian times.

Analysis of Sleep/Wake Histories for AIA Flight Crew

The three factors described above were analyzed for the AIA Flight Crew involved in the Guantanamo Bay aviation accident. The data analyzed were taken from the NTSB Human Performance Investigator's Factual Report, the Operations Group Chairman's Factual Report, and the Flight 808 Crew Statements. When there were discrepancies among the sources, conservative estimates and averages were used. The sleep/wake histories for the Flight Crew of AIA Flight 808 prior to the accident at Guantanamo Bay on August 18, 1993 at about 1656 EDT are presented in Figure 1. This figure provides an opportunity to examine the temporal organization and amount of sleep and wakefulness over the three days leading up to the accident. The days 8/16/93, 8/17/93, and 8/18/93 are identified at the top of the figure along with a 24-hour clock. The white bars indicate the duty periods and individual black lines show specific takeoff and landing activities during the duty periods. A single horizontal bar for each flight crewmember shows the sleep (black) and wakefulness (shaded) over the period leading up to the accident at about 1656 on 8/18/93.

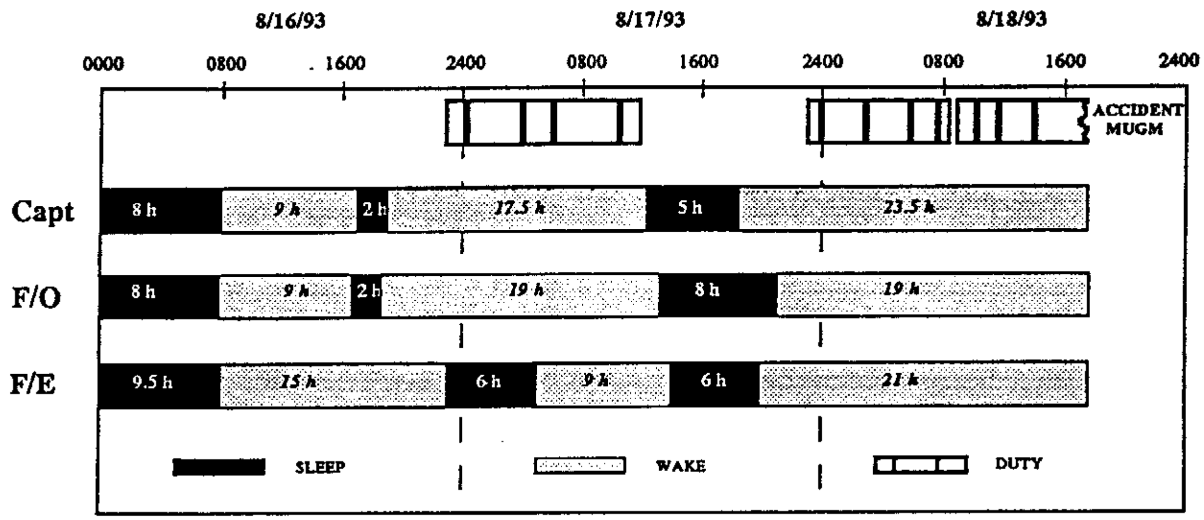

Figure 1. AIA Flight 808 Crew Sleep/Wake Histories

The first horizontal bar in Figure 1 displays the sleep/wake history of the Captain. He reported a typical sleep requirement of 8 hours. The Captain awakened on 8/16/93 after 8 hours of sleep and was awake for 9 hours before taking a 2-hour nap prior to his all-night duty period. Following his nap, the Captain was awake for 17.5 hours. He reported a 5-hour sleep period during a daytime sleep opportunity in a Dallas-Ft. Worth Airport hotel during layover. The Captain was then awake for 23.5 hours until the accident occurred at Guantanamo Bay. This 23.5 hour period included an all-night duty period after which the Captain was released from duty. However, he was called back to operate Flight 808 prior to his return home, and therefore was continuously awake until the accident.

The second bar in Figure 1 displays the sleep/wake history of the First Officer. He also reported a usual sleep requirement of 8 hours. The First Officer awakened on 8/16/93 after 8 hours of sleep and was awake for 9 hours before taking a 2-hour nap prior to his all-night duty period. Following his nap, the First Officer was awake for 19 hours. He reported an 8-hour sleep period during a daytime sleep opportunity in a Dallas-Ft. Worth Airport hotel during layover. The First Officer was then awake for 19 hours until the accident occurred at Guantanamo Bay. This 19-hour period included an all-night duty period after which the First Officer was released from duty. However, he was called back to operate Flight 808 prior to his leaving the airport, and therefore was continuously awake until the accident.

The third bar in Figure 1 displays the sleep/wake history of the Second Officer. He reported a usual sleep requirement of 9.5 hours. The Second Officer awakened on 8/16/93 after 9.5 hours of sleep and was awake for a usual 15-hour day before going to sleep at 2300 for a usual night of sleep. The Second Officer was then called at home after 6 hours of sleep and reported for duty at the airport, joining the Captain and First Officer. The Second Officer was then awake for 9 hours. He reported a 6-hour sleep period during a daytime sleep opportunity in a Dallas-Ft. Worth Airport hotel during layover. The Second Officer was then awake for 21 hours until the accident occurred at Guantanamo Bay.

An examination of the cumulative totals for sleep and continuous wakefulness is informative. For the entire 65-hour period portrayed in Figure 1, which includes the last full 8-hour sleep period at home, the Captain was awake for 50 hours with 15 hours of sleep. Including the 2-hour nap, in the last 48 hours, the Captain was awake for 41 hours with 7 hours of sleep. For the 46 hours after the nap, the Captain was awake for 41 hours with 5 hours of sleep. In the last 28.5 hours prior to the accident, the Captain was awake for 23.5 hours with 5 hours of sleep.

For the entire 65-hour period portrayed in Figure 1, which includes the last full 8-hour sleep period at home, the First Officer was awake for 47 hours with 18 hours of sleep. Including the 2-hour nap, in the last 48 hours, the First Officer was awake for 38 hours with 10 hours of sleep. For the 46 hours after the nap, the First Officer was awake for 38 hours with 8 hours of sleep. In the last 27 hours prior to the accident, the First Officer was awake for 19 hours with 8 hours of sleep.

For the entire 66.5-hour period portrayed in Figure 1, which includes the last full 9.5-hour sleep period at home, the Second Officer was awake for 45 hours with 21.5 hours of sleep. In the last 42 hours, the Second Officer was awake for 30 hours with 12 hours of sleep. In the last 27 hours prior to the accident, the First Officer was awake for 21 hours with 6 hours of sleep.

Overall, this information demonstrates that the entire crew displayed cumulative sleep loss and extended periods of continuous wakefulness. It should be noted that the cumulative sleep loss can be partially attributed to the reversal of the circadian pattern, with nighttime sleep periods at home followed by daytime sleep periods due to all-night duty periods. Sleep obtained in opposition to the body's circadian rhythms is more disturbed than sleep that coincides with times when the body is programmed for sleep. The time of day factor also played a role. Also, the accident occurred at about 4:56 PM in the 3-5 PM window of sleepiness.

In a typical 24-hour period, most individuals would be awake about 16 hours and sleep about 8 hours. This represents a 2:1 wake/sleep ratio. Based on this general pattern, a calculation of the cumulative sleep/wake debt is portrayed in Figure 2. The wake/sleep ratio is displayed along the left axis. A ratio of 2:1 or 2 represents a usual baseline pattern (shown by the solid line) with a wake/sleep ratio less than 2 representing a sleep gain. A wake/sleep ratio greater than 2:1 or 2 would represent a sleep loss. The three days prior to the trip are portrayed on the horizontal axis.

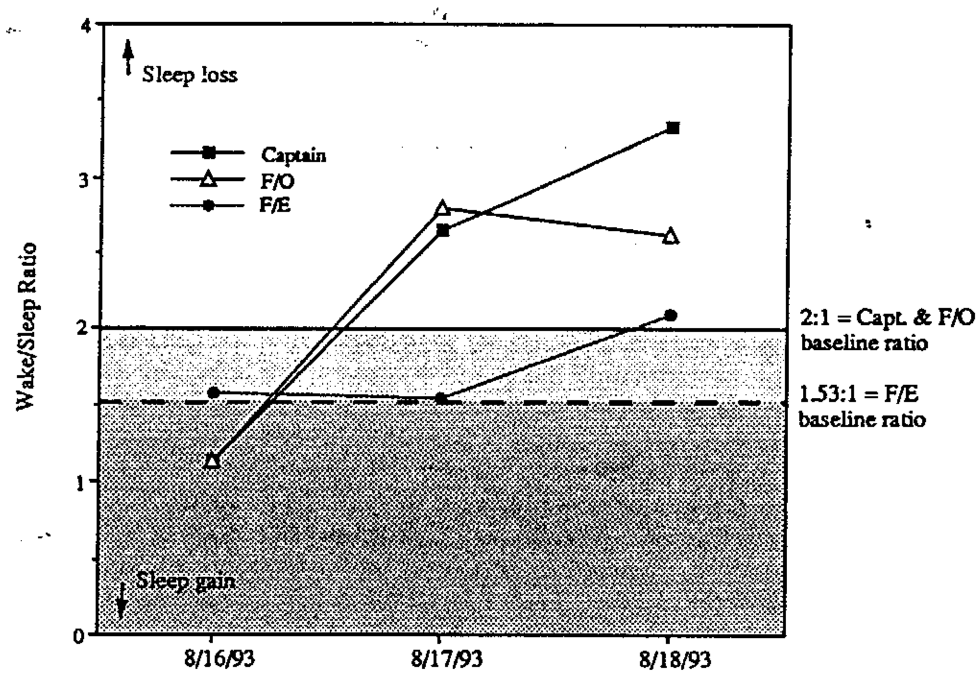

Figure 2. Cumulative Sleep/Wake Debt

The Captain and First Officer reported a usual sleep requirement of 8 hours and therefore, a wake/sleep ratio of 2 would be their appropriate self-defined norm. As evidenced in Figure 2, the wake/sleep ratio for both the Captain and First Officer is greater than 2 (indicated by the solid line) over the two days prior to the accident, reaching greater than 3 for the Captain. The Second Officer reported a usual sleep requirement of 9.5 hours. This represents a wake/sleep ratio of 1.53 as his self-defined norm (indicated by the dashed line). He approximates this on 8/16 and 8/17 and exceeds a ratio of 2 prior to the accident.

Taken together these data demonstrate that the entire flight crew displayed cumulative sleep loss, operated during an extended period of continuous wakefulness, and obtained sleep at times in opposition to the circadian clock time for sleep, and that the accident occurred in the afternoon window of physiological sleepiness. In consideration of the previous scientific information and the specific factors examined in this accident, the data clearly support the finding that fatigue was a physiological factor for the entire crew.

Evidence that Fatigue Factors Affected Performance

The data presented in the previous section demonstrated that the entire crew had experienced sleep loss, extended periods of continuous wakefulness, and circadian disruption (both the timing of sleep periods and time of accident). However, unlike alcohol, there is no chemical test for fatigue. Therefore, it is extremely difficult in an accident investigation, after the fact, to specifically demonstrate that fatigue was causal or contributory. However, as noted earlier, pilots cite fatigue as a common reason for incidents they report to ASRS. Over the past 10 years, the majority of aviation accidents were attributed to flight crew or human error. It is critical to more fully understand the specific sources of those errors if the current incident and accident rate is to be reduced further. Given the sleep/wake and circadian history of the entire flight crew, it is clear fatigue was present. However, to determine how fatigue may have contributed, one would have to determine from other sources whether performance and behavioral changes associated with fatigue were evident before the accident.

Two sources of data available for examination provide specific information regarding flight crew performance and behavior before the accident. The transcript of the cockpit voice recorder (CVR) was made available at the NTSB hearing on this accident, and the Captain provided testimony at the hearing.

1. Information from the CVR prior to the accident.

The CVR transcript provides information about flight crew performance, decisions, and responses leading up to the accident at Guantanamo Bay. There are four specific pieces of information that are relevant to the analysis of fatigue factors. The first piece of information is the decision to use runway 10. Two of the crewmembers, including the Captain (the pilot flying), had never flown into Guantanamo Bay; the First Officer had only flown into Guantanamo Bay years before in small military jets. The crew acknowledged that it was a difficult airport with special considerations. The plan had been to use the straightforward approach available on runway 28. With essentially no discussion, the Captain decided to change plans and use runway 10, which requires a more severe maneuver to complete the landing. By all reports, the Captain was lauded for his airmanship and good judgment, especially in emergency and landing procedures. Therefore, for an experienced Captain to make a sudden decision to change runways, with no prior experience at a special airport and with minimal crew discussion, suggests a degraded decision-making process. Fatigue can affect an individual's decision-making. In this situation, fatigue may have affected the crew's decision-making in the following ways: a) they did not consider important information (i.e., their unfamiliarity with the airport, their level of fatigue), b) their lack of discussion about the decision to change runways, and c) misreading of potential outcomes. In this case, the decision-making process was shared by the entire flight crew, all of whom were affected by the fatigue factors outlined.

A second piece of information from the CVR was the Captain's fixation on the strobe light. In the transcript, the Captain makes seven (possibly eight) references to the strobe light. During the critical period leading up to the accident, the Captain displayed an overwhelming focus and concern to locate the strobe light. This fixation on the strobe light, to the exclusion of other critical information, could also be an expression of the effect of fatigue on performance. It would fit laboratory research that demonstrates that this effect can result from sleep loss (ref. 15-21).

A third piece of information from the CVR was the Captain's disregard of critical information just prior to the accident. While the Captain was fixated on locating the strobe light and was making multiple references to its location, another crewmember questioned whether they were going to make the landing. The Captain did not acknowledge the question, certainly did not process the potential implications of the question, and finally disregarded the critical information to continue his search for the strobe light.

A fourth piece of information from the CVR was the response to the stall warning when the operation was clearly in trouble. Several pilots reviewed the CVR transcript and spontaneously commented on how slowly the Captain and crew responded to the stall warning prior to the accident. The warning is intended to provide a window for immediate response and an opportunity to recover the aircraft. An experienced pilot will have been trained to immediately respond to the stall warning with an automatic response. However, fatigue can degrade reaction time and psychomotor responses. Therefore, the Captain and crew may have been slow to respond to the stall warning as a consequence of the prior sleep loss, circadian disruption, and extended period of continuous wakefulness.

There are also several other instances from the CVR that suggest elements of fatigue but are more subtle. For example, there appears to have been excessive checking of information (e.g., were waypoints entered, radio frequencies). These more subtle occurrences may also reflect decreased memory and mental functioning but are less clearly defined than the previous four examples from the CVR.

The level of performance demonstrated by the Captain is below that normally expected of a Captain with his level of experience. However, the Captain's aviation record does not suggest that he was a substandard pilot. The Captain's airmanship was lauded from several sources. Therefore, some factor must have interfered with his performance on this flight. Also note that the CVR performance decrements identified above were all CRM failures. This further supports the previously presented data that the entire crew, not just the Captain, were affected by fatigue.

The examples identified above were summary points available from an initial examination of the CVR transcript made available at the NTSB accident hearing. A more detailed analysis of the CVR transcript could provide more specific information and data regarding the expression of fatigue-related performance and behavioral changes before the accident.

2. Captain's testimony.

The other piece of information available at the NTSB hearing was the Captain's testimony. Perhaps the most telling statement was in response to the question about how he felt just prior to the accident and he said, "lethargic and indifferent." Individuals use a variety of words to express their state associated with sleep loss and circadian disruption, for example, 'fatigued,' 'tired,' 'sleepy,' and 'lethargic.' Also, as previously mentioned, controlled laboratory studies of sleep deprivation have shown that individuals will increase their effort to perform, though their performance is degraded, and they become indifferent to the outcome. The Captain's report of being "lethargic and indifferent" in the period leading up to the accident is quite consistent with the typical pattern of sleep and circadian disruption.

Conclusions

Over the past 40 years, there has been tremendous progress in our scientific understanding of sleep and circadian rhythms. Over the past 12 years, this information has been specifically applied to the operational requirements of the aviation industry. The human need for sleep and the effects of sleep loss and circadian disruption on waking performance are of particular importance in the current aviation accident investigation. The subjective sleep/wake data provided by flight crewmembers was analyzed for cumulative sleep loss, extended periods of continuous wakefulness, and time of day effects. The results demonstrated that these three fatigue factors affected all three flight crewmembers. Based on the known effects of fatigue, sleep loss, and circadian disruption on human performance, other sources of information were examined to determine whether fatigue-related performance decrements occurred prior to the accident. Four examples from the CVR transcript and the Captain's testimony provide information of specific performance and behavioral occurrences that fit the expected effects of fatigue on human functioning. The hypothesis that fatigue affected the crewmembers' performance is supported by the amount of cumulative sleep loss, continuous wakefulness, and circadian disruption experienced by the entire crew. The examples from the CVR and Captain's testimony support the hypothesis that fatigue had an effect on flight crew performance that was related to specific actions involved in the occurrence of the accident at Guantanamo Bay.

Two final notes. First, it is important to acknowledge the limitations of human physiology regarding sleep, circadian rhythms, and fatigue. The flight crewmembers involved in this accident were clearly professional, well-trained, experienced, and highly motivated to perform their best. As humans, there are limitations to our performance that are purely a reflection of our physiological capabilities and are independent of training, motivation, and experience. Second, there is no simple, easy "cure" to fatigue issues in aviation operations. Individuals are different, what they do is different, and the operational demands of the aviation industry are diverse. Therefore, no one approach or "solution" will address the fatigue engendered by some flight operations. An examination of every aspect of the aviation system, including regulatory, scheduling, personal strategies, and the design of technology, is critical in addressing fatigue in flight operations. The task is to apply our scientific understanding of human physiological needs for sleep and circadian rhythms to the 24-hour operational requirements of the aviation industry. Whenever possible, this information should be applied to maintain and improve the safety margin and promote maximal alertness and performance during operations.

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