One of the most disastrous aviation crashes in the United States occurred in San Diego, California on September 25, 1978, at about 0901 Pacific Daylight Savings Time when a Boeing 727-214, Flight 182, collided in mid-air with a light, four-place, single-engine Cessna 172. Killed were a crew of 9, 128 passengers and 9 persons on the ground; 22 buildings were destroyed. The National Transportation Safety Board determined that the probable cause had been the failure of the flight crew of Flight 182 to comply with the provisions of a maintain-visual-separation clearance, including the requirement to inform the controller when the other aircraft is not in sight. Although not cited as a contributor to the accident by the board, it is possible that sleep loss due to poor shift scheduling and short-term nutrition deprivation may have induced performance decrement in the pilots, exacerbating an already tenuous and confusing situation. Reanalysis of the previous 57 hr of the crew’s activities reveals a sleep-wake schedule which produced a probable sleep deficit of approximately 8 hr over three normal sleep periods. Additionally, although the crew had a legal layover period of 7 hr and 7 min on the night preceding the crash, the time actually available for sleep appears to be only 5 hr and 30 min. Further, lack of available food services may have aggravated already impaired bodily functions.

In the United States, the National Transportation Safety Board (NTSB) is charged with the investigation of all transportation-related accidents. It has determined that approximately 85% of general aviation (i.e., non-commercial) accidents fall into a category called “human error” (STOKLOSA, 1981). As of 1981, however, it was determined by an independent reviewing organization that the NTSB did not investigate the reasons for “human error” (CONNOR and HAMILTON, 1981). Indeed, one of its most senior members stated as late as 1978, one month after the PSA accident that the Board had “... self-imposed restraints in its accident investigating procedures of hidden human factors which cause accidents” (McADAMS, 1978). Only now is the NTSB attempting to find a way to
investigate the underlying causes of "human error" (STOKLOSA, 1981).

Among the contributors to human error must be the effects of sleep loss due to abnormally shortened sleep periods. DEMENT et al. (1982) find in partial sleep deprivation studies that sleep limited to 5 hr allows sleepiness to accumulate after a slight nocturnal disturbance. The direct effect of a single night's sleep restriction (5 hr sleep) is sleepiness during the day. The sleepiness manifests itself in feelings of exhaustion, lethargy, depression, fatigue, and drowsiness in daytime with the added impairments of interpersonal relations and ability to get work done. It should be noted that momentary subjective sleepiness may vary considerably due to muscular activity, excitement, pain, startle, high motivation, and other such acute factors and can counteract the feeling of sleepiness for a short time. The overall physiological tendency toward "sleepiness", however, is usually not affected as quantitatively measured by Multiple Sleep Latency Test (MSLT).

The occurrence of performance decrements following acute alterations in the amount of sleep is well documented (BUCK, 1973; FENZ and CRAIG, 1972; HAMILTON et al., 1972; JOHNSON and NAITO, 1974; TAUB and BERGER, 1969, 1973, 1976a; TAUB et al., 1971; WILKINSON, 1969; WILKINSON et al., 1966). WILKINSON (1969) has shown that even moderate loss of sleep impairs performance. Losing 5.5 hr of a single night's sleep caused subjects to miss more signals in a signal detection task than did no sleep loss. TAUB and BERGER (1972, 1976a) have shown that significant deficits of vigilance performance, calculating tasks, and subjective mood occur following a 2–4 hr displacement of sleep in either direction within a 24 hr period when total amount of sleep is held constant. Performance decrements in flight crews were found to be significantly larger (33% compared to 11%) and recovery less complete for crews whose schedule began during a low point of the subject's preflight circadian performance rhythms (at 0400 hours) than crews which began at 1600 hours (COATES et al., 1974). In sleep reduction studies, JOHNSON and MCLEOD (1973) observed that as sleep was gradually reduced to 5.5 hr and lower subjects reported being less happy, less friendly, less energetic, more fatigued, increasingly more irritable, and had problems in sustained concentration. The researchers suggest that individuals who are acclimated to 7–8 hr of sleep have great difficulty in reducing average sleep to 5 hr or less even when done gradually. They note that even when sleep is reduced gradually, during the reduction period, changes in mood, sleep parameters, and performance may occur.

WEBB and AGNEW (1974) noted that when sleep was reduced to 5.5 hr, subjects had difficulty in arousing and felt drowsy all day. MULLANEY et al. (1977) noted that subjects suffered increased difficulty in adjusting to sleep reduction below 6.5 hr as indicated by mood scales and subjective reports of fatigue. FRIEDMANN et al. (1977) reported that as sleep was reduced below 6 hr subjects elected to terminate the decreasing of the sleep period because they were “too tired” and “just wanted to sleep.” Specific reasons included overwhelming fatigue.
and falling asleep while in class, playing cards or visiting friends and difficulty in remaining vigilant while driving.

The increase in private and commercial air travel and the growth in the number of private training aircraft and instructors has placed an unprecedented demand on the limited number of fully weather-instrumented airports. Matters are further complicated by the mix of large, high-speed, turbojet passenger airliners and light, slow flying propeller aircraft competing for airspace and the use of the airport instrument facilities. The flow of this varied traffic is controlled by modern radar. In addition, Federal Air Regulations require vigilance outside the cockpit, so that aircraft which are targeted by radar during good weather conditions must be visually sighted by the pilot receiving the information. The pilot, therefore, must be extremely vigilant and flexible.

Since 1976, the Aviation Safety Reporting System (ASRS), managed and operated by the National Aeronautics and Space Administration (NASA), has collected and analyzed data involving safety and hazardous matters submitted voluntarily by pilots, controllers, or others. An analysis of 20,000 reports revealed a small but significant number of reports that showed performance decrements which were fatigue-related. The performance decrements were associated with awareness and attention loss due to disturbed sleep, in addition to long duty periods and large number of flight segments (LYMAN and ORLADY, 1981). The report was prepared for a Workshop on Pilot Fatigue and Circadian Desynchronosis sponsored by NASA in August, 1980. HOLLEY et al. (1981) prepared an annotated bibliography of materials relevant to pilot performance and circadian phase alterations with a series of review articles covering a major research area within the topic. This was a continuation of previous literature by BELIAN et al. (1972). The NASA Technical Memorandum 81275, April 1981 issued report the results of the Workshop stated that performance decrement is increased with sleep loss or deprivation and alterations on the habitual sleep/work cycles; circadian desynchronization; let down; and less than optimum nutrition. Further, if exogenous demand increases or remains the same and performance reduces as a result of the above impingements, the probability of error increases and the margin of safety decreases.

ACCIDENT SYNOPSIS

Although ignored by the NTSB in its investigation, the collision of a Pacific Southwest Airline (PSA) Boeing 727 with a Cessna 172 over San Diego, California, September 25, 1978, may have had pilot performance decrement due to abnormally shortened sleep as a contributor.

about 3 nautical miles northeast of Lindergh Field, San Diego, California.” The NTSB determined that “the probable cause of the accident was the failure of the flight crew of Flight 182 to comply with the provisions of a maintain-visual-separation clearance, including the requirement to inform the controller when other aircraft is not in sight.”

According to the report, the flight officers were a captain, 42, with a total flight time of 14,382 hr with 10,482 hr in the Boeing 727; a first officer, 38, total flight time 10,049 hr with 5,800 hr in the Boeing 727, and a flight engineer, 44, total flight time 10,800 hr with 6,587 hr in the Boeing 727.

The NTSB’s Human Factors Group Chairman’s Report noted the following concerning the flight crew’s work rest schedule during the 2 days prior to the accident (all times are Pacific Daylight Savings; all stations are in California): “The crew reported in at Oakland after a RON (Remain Over Night) there at 0645 on September 23. They flew 1 hr 26 min and checked out at SAN (San Diego) at 0940. Their total duty time (time from check in to check out “flight time” refers to the time from when the airplane leaves the dock area until it lands and stops to disembark passengers) was 2 hr 55 min. The crew was off duty from 0940 until 1610 on the 24th. The crew checked in at SAN at 1610 and deadheaded (rode as passengers) to LAX (Los Angeles) for sequence 445 (a scheduled flight sequence). Captain checked out in Sacramento (SMF) at 2253. The crew’s total duty time was 6 hr 43 min. On September 25 the crew checked in at 0600 in SMF for flight 182. The first leg of the flight to LAX took 1 hr 3 min.” On the evening of September 24, the entire crew of PSA Flight 182 was registered at a hotel at the airport. “The crew checked into the hotel about 2230 and departed at 0700 the next morning. Interviews with Hotel and PSA employees who were in contact with the crew indicated nothing irregular or suggestive other than a normal restful night.” Nothing more is stated in the NTSB data.

A recent review of the Cockpit Voice Recorder (CVR) tapes by the authors discloses that in the first 2 min of the tape, which is 30 min long, while the aircraft was still parked at the gate in Los Angeles, the following conversation ensued between the captain and a cabin attendant:

Attendant: “... tired, are you?”

Captain: “I’m draggin’! It was a short night!”

WESTON (1979) reports the crew’s schedule as follows: September 22, 3 flights beginning 1630 ending 2350; September 23, 2 flights beginning 0645 ending 0940; September 24, 4 flights beginning 1640 ending in Sacramento at 2238; and September 25, departed Sacramento 0700, stopover Los Angeles, crash San Diego 0902. Personal conversation with several PSA pilots has confirmed this schedule.

The actual work-rest schedule of the pilots appears to be as follows: Friday, Sept. 22, check-in 1530 at San Diego and check-out 0015 at Oakland; Saturday, Sept. 23, 0645 at Oakland to 0940 at San Diego (home); Sunday, Sept. 24, 1610 at San Diego to 2253 at Sacramento; Monday, Sept. 25, check-in 0600 at Sacra-
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mento and 0902 crash at San Diego. Layover or off duty times would then be: Friday to Saturday, 6 hr 30 min; Saturday to Sunday, 30 hr 30 min; and Sunday to Monday, 7 hr 7 min.

Available sleep time must be less than layover time. To ascertain what that time could have been, one of the authors, PRICE, who is a professional airline pilot, flew with several PSA crews and reenacted the probable moves of the ill-fated crew. We learned that to walk from the jetway to the hotel, check in and walk to a typically assigned room consumed approximately 15 min; to prepare for bed, 30 min. Interviews with several PSA crews confirmed out findings. They also stated that similar times could be applied to their Oakland layover facility. Available sleep time would thus be: Friday to Saturday, 5 hr and Sunday to Monday, 5 hr 37 min.

The interviews with the PAS crews reveal another possible contributor to that of sleep loss. It was learned that the only available restaurant at Sacramento Airport was closed during the 24th and 25th. The crews stated that this made no difference because they normally arrived after it closed and left before it was opened. The airline at that time was only scheduled within California and carried no food, only beverages, nor were there any items as donuts available. The crew then may have had its last meal about 1800 on Sunday evening, 15 hr before the accident.

To understand more thoroughly how the sleep and diet decrements may have affected the flight crew of PSA 182, an abbreviated transcript of the Cockpit Voice Recorder (CVR), (McCLURE et al., 1981) with comments from the authors follows. A study of the sequence events will provide an insight into how performance decrement affects pilot behavior. The time sequence was from 0859: 30 to 0901: 47, a mere 2 min 17 sec. The far left column will show the time in terms of seconds commencing at T-0, 0859: 30. CAM, Cockpit Area Microphone voice recorder (recovered after crash); RDO, Radio transmission from the accident aircraft (PSA 182); -1, Voice identified as the Captain; -2 , the First Officer; -3 , the Second Officer; -4 , an Observing Captain; APP, San Diego Approach Control; TWR, Lindbergh Tower (San Diego); ATC, Air Traffic Control; N7711G, Cessna 172, N7711G; and (()), Editorial insert.)

PSA 182 CVR AND ATC TRANSCRIPT

| T-0  | 0859: 30, APP: | PSA 182, traffic twelve o'clock, one mile, northbound |
| T-5  | 0859: 35, RDO-1: | We're looking |
| T-9  | 0859: 39, APP: | PSA 182, additional traffic's, ah, twelve o'clock, three miles just north of the field northeast bound, a Cessna 172 climbing VFR out of one thousand four hundred |
| T-20 | 0859: 50, RDO-2: | Okay, we've got the other twelve |

((The first officer who was flying the plane answered that he saw the previous traffic pointed out by ATC. The Air Line Pilots Association carefully analyzed the ATC...)}
Radar tapes and discovered that a Cessna 150 was in the area where the traffic at time 0859: 30 was reported, (McClure et al., 1981).)

((The Cessna was practicing instrument approaches to a runway which was directly opposite to the direction that PSA 182 was going to land. Both aircrafts now were heading in the same direction.))

T-45 0900: 15, APP: PSA 182, traffic's at twelve o'clock, three miles out of one thousand seven hundred

T-53 0900: 23, APP: Okay, sir, maintain visual separation, contact Lindbergh tower one three three point three, have a nice day now.

((This terminology is routinely given to pilots following traffic for landing, thus reinforcing the First Officer's impression that the traffic reported at 0900: 15 was the Boeing 727.))

T-56 0900: 26, CAM-2 Flaps two

((The First Officer is preparing for the final landing phase. This is a very precise maneuver, requiring concentration to small detail. The airplane is slowing, descending, and turning. The pilot is aiming for a spot near the end of the runway of about 150 m in length on which to make his initial touch down.))

T-64 0900: 34, RDO-1 Lindbergh PSA 182 downwind

((The pilot is telling the tower that the airplane is paralleling the runway, heading in the opposite direction from the landing direction with the wind on the tail.))

T-68 0900: 38, TWR PSA 182, Lindbergh tower, ah, traffic twelve o'clock one mile a Cessna

T-71 0900: 41, CAM-2 Flaps five

((The First Officer is continuing to slow the airplane and descend. The Captain reaches over to move the flap handle.))

T-73 0900: 43, CAM-1 Is that the one we’re looking at

T-73 0900: 43, CAM-2 Yeah, but I don’t see him now

T-74 0900: 44, RDO-1 Okay, we had it there a minute ago

((At time 0859: 50 the First Officer reported seeing a Cessna, “the other twelve” no doubt refering to the Cessna 150.))

T-77 0900: 47, TWR 182, roger

T-80 0900: 50, RDO-1 I think he’s passed off to our right

T-81 0900: 51, TWR Yeah
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T-83 0900: 53, TWR  How far are you going to take your downwind 182, company traffic is waiting for departure
T-87 0900: 57, RDO-1  Ah probably about three to four miles
T-89 0900: 59, TWR  Okay
T-97 0901: 07, TWR  PSA 182 cleared to land
T-98 0901: 08, RDO-1  182's cleared to land
T-101 0901:11, CAM-2  Are we cleared of that Cessna?

((For some reason the First Officer becomes suspicious that the traffic pointed out at 0859: 30 may not be the Cessna that he had seen.))
T-103 0901:13, CAM-3  Supposed to be
T-104 0901:14, CAM-1  I guess
T-110 0901:20, CAM-4  I hope
T-111 0901:21, CAM-1  Oh yeah, before we turned downwind, I saw him about one o’clock, probably behind us now

((The Captain confirms that he saw a Cessna earlier, before they turned to parallel the runway. He also confirms that he saw it on the First Officer’s side of the airplane.))
T-128 0901:38, CAM-2  There’s one underneath
T-129 0901:39, CAM-2  I was looking at that inbound there

((The First Officer realizes that the traffic pointed out at 0900: 15 was not the Boeing 727 but another Cessna which he had not seen (McCLURE et al., 1981).))
T-147 0901:47, CAM  Sound of impact.

ACCIDENT ANALYSIS

The preponderance of literature shows that the effects of abnormal sleep reduction affects the very faculty which the pilots of Flight 182 needed most, vigilance. As a result of an error of omission by the controller at time 0900:15, T-45, the pilots were led to believe that all was normal. When the traffic was not identified as a Cessna 172, the pilots may have assumed that the traffic was an inbound 727. This is a normal assumption, as will be discussed in more detail. Although there were several alerts to the traffic (the Cessna), these also could be construed by the pilots as referencing the 727. Since there were other exogenous conditions which may have precluded the pilots from actually seeing the Cessna 172, they would be required to mentally sort out the confusing information. When they did, it was too late to react because of the speed of their aircraft.

The official NTSB accident report notes the following meteorological conditions and hindrances to vision. The weather was clear, the heading of PSA 182 was 090 degrees, looking directly into a morning sun. Both aircraft were on the same heading the Cessna’s “apparent motion could have been lost making the target (Cessna 172) difficult to discern; there would have been a foreshortening of the Cessna’s fuselage which would have made the target more difficult to sight ...”. The Cessna was painted white with a mustard stripe. As reported by the NTSB, viewed against the multi-hued residential area beneath it, the ratio of the white aircraft against the color of the ground would be minimal. In the case
of PSA 182, the ability to see the Cessna 172 was greatly reduced because of exogenous physical obstacles as looking into the sun, color blending of the target aircraft into the background and lack of clear discernability due to angle of observation and small relative speed difference.

The next line of defense is radar monitoring. This brings into play the complexity of human communication which in turn depends on alertness, vigilance, and flexibility of both transmitter and recipient. As can be seen by the literature cited above these faculties are the first to be impaired as a result of sleep loss or severe reduction. There appears to be sufficient evidence to show that the pilots of PSA 182 had, indeed, experienced severely impaired sleep periods and possible short-term nutrition deprivation.

HARTMAN et al. (1974) cite several performance decrements which may help to reveal impairments in alertness: loss of "flexibility of set" described as the loss of the ability to perceive and adjust to new aspects of the task, and "change in controlling set" defined as the reduction of aspiration so that small errors go uncorrected even if they are perceived. They further observe that an individual who routinely eats breakfast will show significant signs of performance decrement if he should omit breakfast. MARKS (1972) notes subacute symptoms of hypoglycemia as a gradually developing sense of lethargy and somnolence associated with a reduction in spontaneous activity, conversation, and movement.

The loss of flexibility of set seems to appear after the First Officer sighted and reported the Cessna 150 at 0859: 50. Although he reported that he had seen "the other twelve", both he and the Captain seemed to have forgotten about the Cessna 172 reported by the controller at 0859: 30, perhaps an example of the change in controlling set. He would further be lulled into thinking that all was routine if he assumed that the traffic pointed out at 0900: 15 was another Boeing 727 landing at Lindbergh. Had the controller stated that the traffic was a Cessna 172, the crew would have been alerted to an anomaly. This is a crucial point because the actual report was routine, the traffic (the 727) was where it should have been, it was the airplane he expected to be pointed out, thus, "all was well."

The observations of DEMENT et al. (1982) may also be applied. The First Officer was flying, involved in a more stimulating activity and probably more alert than the Captain. It was he (the First Officer) who reported seeing both the Cessna 150 and the traffic at 0900: 15, most probably the Boeing 727. The flexibility of set seems even stronger after Lindbergh Tower reported the Cessna 172 at 0900: 38. The First Officer is concerned with the routine of preparing for the landing as indicated by his calls for two flap extensions. It was not until 0901: 11 that he becomes suspicious, "Are we clear of that Cessna?" Until this time both pilots seemed convinced that the reported traffic was the previously sighted Cessna 150. Not until a full minute later, at 0901: 38, did he ascertain the Cessna 172’s existence, "There's one underneath...". He then seems to confirm that his earlier report, 0900: 21, "Got 'em", was in reference to the inbound Boeing. At this
point it was too late, the aircraft was travelling at approximately 3.8 statute miles a minute. The collision occurred 7 sec later.

SUMMARY

Although ignored by the NTSB it is possible that a contributor to the collision of PSA 182 and the Cessna 172 was performance decrement of the crew of 182 due to a probable sleep period of approximately 5.5 hr. The shortened sleep period was a direct result of scheduling which did not take into account the necessity of human beings requiring a minimal sleep period of at least 7 hr. The performance decrement may have manifest itself as decreased vigilance and alertness when vigilance and alertness were needed because of the high workload of flying an approach and landing in a highly congested area. The decrement may have been further exacerbated by hypoglycemia caused by short-term nutrition deprivation because of the unavailability of breakfast.

It is most curious, indeed, that the NTSB did ignore the effects of sleep loss so assiduously in its investigation since the captain made quite clear on the CVR tape that he was tired. To the comment, "... tired, are you?" by a cabin attendant, he replies emphatically, "I'm draggin'! It was a short night!" This almost "death bed testimony" seems to be dichotomous with the findings of the NTSB Human Factors Group Chairman’s Report which states that its investigations "indicated nothing irregular or suggestive other than a normal restful night."

A question arises from our research. Was the decrement, indeed, the same as observed in the controlled environment of the laboratory; sleepiness, fatigue, decreased alertness and vigilance, and the inability to concentrate and possibly remember and separate details from earlier radio reports while engaged in a very complex mental-physical activity? We believe that the findings of the researchers were frighteningly accurate. We therefore hope that these anecdotal accounts may provide scientists in this area, data to design future experiments based on a "real" operational problem.

ADDENDUM:

Subsequent to the submission of the paper to the chairman the following conversation was discovered on the Cockpit Voice Recorder. The conversation occurred before the aircraft departed Los Angeles while it was still parked at the gate. Apparently a stewardess whom the Captain had known and who was working on the flight stepped into the cockpit to say, "Hello!" After a few brief remarks the following conversation ensued:

Stewardess: "...tired, are you?"
Captain: "I'm draggin'! It was a short night."
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