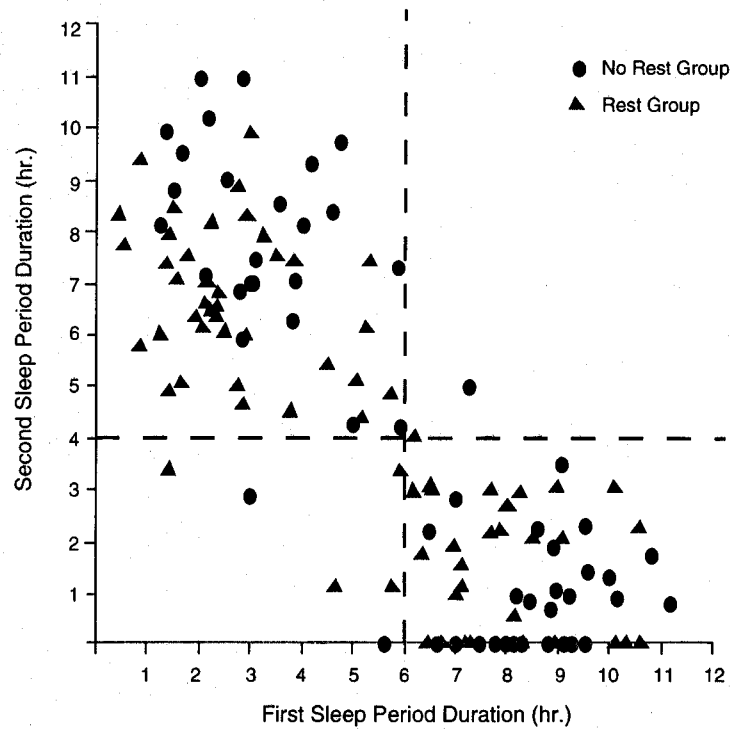

Figure 28. Duration of second sleep episodes on layover as a function of the duration of first sleep episodes for RG and NRG.

5.0 DISCUSSION

5.1 Study Limitations

This study involved only one trip pattern on a commercial airline. The study trip pattern was chosen according to predetermined criteria, but clearly the variety of trip schedules currently and potentially available is tremendous. Also, it is difficult to assess how the specific airline cultures may have affected the study outcomes. The study was conducted on transpacific flights to utilize the opportunity of scheduling the planned rest periods during cruise over water. Therefore, the low-workload portion of flight identified in this study occurred over water. The intense physiological and performance data collection occurred during a specific and restricted middle segment (four consecutive flight legs) of the trip schedule. Therefore, the initial home-to-flight-schedule transition is quantified only with logbook and actigraph data. Also, the final trip legs, which may represent the highest levels of accumulated fatigue, were not studied except for logbook and actigraph data. This study involved B-747 aircraft flown by three-person crews. Questions have already been raised regarding the applicability of this study to the two-person cockpit. There were two NASA researchers on the flight deck during the in-flight data collection periods. Although they were instructed to minimize their interactions with the crew and to make their presence on the flight deck as unobtrusive as possible, there is no question that having two extra persons in the cockpit may have potentially altered the regular flow of cockpit conversation and interaction. It is important to remain cognizant of these limitations when generalizing these results. As always, it is not appropriate to generalize the study results to scenarios that extend beyond the scope of the specific scientific issues addressed here.

5.2 Findings

5.2.1 EEG Sleep Results

On 93% of the rest period opportunities available for analysis, volunteer pilots were able to sleep in their cockpit seat. On average, they slept for 26 min., about 64% of the allotted rest opportunity. As a group, they took approximately 6 min. to fall asleep. The sleep was composed of 30% light sleep (NREM stage 1), 62% of slightly deeper sleep (NREM stage 2), and 8% deep sleep (NREM slow-wave sleep). There was no REM sleep (the sleep state associated with dreaming) observed in any of the naps. It generally can take 60-100 min. for the first occurrence of REM sleep during a regular nocturnal cycle of NREM and REM sleep states. Therefore, it was not expected that the 40 min. nap opportunity in this study would provide sufficient time for REM sleep to occur.

There were two significant findings that emerged from the analysis of the physiological sleep data obtained during the planned rest period. Both findings were related to the percentage of sleep stage that comprised the nap sleep in day versus night comparisons. A greater percentage of light sleep (NREM stage 1 sleep percent) occurred during day sleep than in night sleep, which was complemented by a greater percentage of deep sleep (NREM slow-wave sleep percent) during night sleep than in day sleep. Thus, sleep on day flights was lighter, and sleep obtained on night flights was deeper.

The physiological sleep data were also examined for evidence of sleepiness as indicated by the speed of falling asleep. One possible indication of cumulative sleep loss would have been a faster sleep latency across flight legs, demonstrating increased sleepiness as the trip schedule progressed. However, the results suggested that the RG pilots may have already been at a level of sleepiness that essentially did not allow room for further decreases.

An interesting finding emerged from analysis of the physiological data obtained during the NRG's control periods. Four of nine NRG subjects (44%) had at least one spontaneous episode of sleep during their 40-minute control period. The five sleep episodes lasted from a couple of minutes to over 12 min. To our knowledge, this is the first physiological documentation of an unplanned and involuntary sleep episode during long-haul flight operations. This study was the direct result of reports and anecdotal concerns regarding this kind of activity during long-haul flying. It should be noted that these episodes occurred in individuals aware that they were participating in a fatigue study, undergoing continuous physiological monitoring, and with two NASA researchers on the flight deck. For all of the "motivation" operating in this circumstance, it is clear that the physiological need for sleep was expressed. These findings clearly demonstrate the potential for fatigue and sleep loss to result in unplanned and involuntary occurrences of sleep in long-haul flight operations.

5.2.2 Vigilance/Sustained Attention: PVT Findings

The PVT data generally showed very consistent results across the analytical approaches. In response slowing (median RT), the NRG demonstrated a much greater range of average responses across flight legs and trials than the RG. The response slowing was most evident on the third in-flight trial on study flight legs 2, 3, and 4. On flight leg 1, the NRG and RG had comparable levels of performance. After leg 1, the NRG showed a steady increase in median RT across subsequent flight legs, with significant differences in the middle and at the end of flights. However, the RG did not show these significant changes in RT across flight legs and instead maintained a generally consistent level of performance. Overall, the NRG demonstrated median RTs 10%-16% slower than the RG during in-flight trials and the postflight trial.

There were a total of 283 lapses (i.e., response delay, block, or gap) for all 21 crewmembers, about 1% of all PVT responses. Lapses rarely occurred on early flight legs but increased in frequency as the trip schedule progressed. There were more lapses in the NRG (58% of all lapses) and on night flights for both groups (60% of all lapses). In-flight, the RG (with fewer subjects) had a total of 81 lapses, and the NRG had a total of 124. There was a prominent increase in the

NRG in-flight lapses during trials 2 and 3, though this did not occur in the RG. This suggests that the RG nap after in-flight trial 1 decreased the likelihood of increased lapsing later in the flight. However, there were also wide individual differences in lapse frequency, with five of nine NRG subjects with 10 or more in-flight lapses. Two of these subjects had relatively high numbers of lapses (i.e., 45 and 33). Only 3 of the 12 RG subjects had 10 or more in-flight lapses, with none higher than 14. At TOD on night-flight leg 4, both groups had more lapses than at TOD on night-flight leg 2. However, the NRG had an increase twice as large as that seen in the RG.

The time-on-task PVT performance metric was analyzed as an index of fatigueability (vigilance decrement function) and allowed the comparison of pilots' results with previous laboratory research (ref. 50). Regression lines were fitted to average response speed across the PVT for the RG and NRG on day-flight legs and night-flight legs. This allowed comparison of these two conditions with each other and with laboratory collected PVT data from college students after a normal night's sleep and after a night of sleep loss. Overall, the RG had a higher mean response speed than the NRG. The in-flight mean performance level (y-intercept of the vigilance decrement function) and fatigueability (slope) for the RG was close to that seen in nonsleep-deprived young college students. In contrast, during night flights, the NRG fatigueability function approached a level similar to that of healthy young adults deprived of one night's sleep. One important and significant outcome was that only the NRG subjects showed greater fatigueability (slope) on night flights than on day flights. On night flights, the NRG average response speed slowed twice as fast with time on task as that observed in the RG. Therefore, the RG nap was associated with significantly less fatigueability during night flights than the NRG.

5.2.3 Physiological Alertness/Sleepiness Findings

Overall, microevents indicating increased physiological sleepiness demonstrated a range of individual differences and variability in their occurrence. For the descriptive analysis of the raw data, the cumulative total number of events for the fewer subjects and fewer opportunities in the NRG was 120 whereas there were 34 events in the RG. For the NRG, 98 total microevents occurred before TOD with 22 events from TOD through descent and landing; while in the RG, all microevents occurred before TOD. The NRG crewmembers had microevents throughout the final 90 min. of each study flight leg. For both groups, study leg 4 (a night flight) had the most microevent occurrences. Although the RG had fewer occurrences earlier in the schedule (only one on study leg 1), 82% of the RG microevents occurred on study leg 4. This suggests that the effectiveness of the nap may have diminished as the trip legs progressed and on the last night flight, a finding also evident in the PVT lapse data. Overall, 69% of the microevents occurred on the night flights, 64% for the NRG and 85% for the RG.

The statistical analysis of the physiological microevents took into consideration, and demonstrated further, the variability of occurrences. Overall, for the transformed data, the average total cumulative physiological microevents for the NRG (6.37) was 2 times greater than the average cumulative total RG microevents (2.90) ($p = .02$). Also, the NRG averaged more SEM microevents (3.72) than the RG (1.95) ($p = .048$). Most of the total microevents occurred in the shortest duration time bin (5-10 sec.). As expected, significantly more microevents that occurred before TOD. There were significantly more SEM microevents on the last study leg and significantly more cumulative total microevents and SEM occurrences on the night flights. Generally, this supports the observation that physiological alertness decreased as the trip schedule progressed, especially on night flights (most likely the effect of cumulative sleep loss and circadian phase).

The physiological microevent results parallel the findings for the PVT lapse data. The nap was associated with maintaining a more consistent pattern of performance, whereas the increased performance (lapses) variability was observed in the control NRG. In a similar fashion, the nap was associated with a more consistent level of physiological alertness compared with the increased variability of microevent occurrences observed in the control NRG.

Another physiological alertness/sleepiness finding emerged from the sleep latency data. In this study, the RG averaged 5.6 min. to fall asleep. (For the RG (24) subjects this average was 4.1

min.) The laboratory standard for a level of excessive physiological sleepiness is a sleep latency of 5 min. or less, sometimes referred to as the twilight zone (refs. 21, 27). This suggests that overall, this group of volunteers fell asleep quickly and close to the laboratory-determined range that indicates excessive physiological sleepiness.

Overall, these findings demonstrate that the sleep obtained by the RG during the planned rest period was subsequently associated with greater physiological alertness—indicated by fewer occurrences of EEG and EOG microevents during the last 90 min. of flight—than was observed in the NRG. Generally, the microevents were brief (5-10 sec.) and represented the overall occurrence of total cumulative microevents and SEMs. SEMs are most often associated with the transition from quiet, relaxed wakefulness to sleep onset. These events have been associated with the perceptual disengagement characteristic of the transition from wakefulness to sleep (refs. 38, 71). This situation and the occurrence of EEG alpha (quiet, relaxed wakefulness with eyes closed) and theta activity (light NREM stage 1 sleep) represent a reduced level of physiological alertness.

The occurrence of these physiological microevents may represent a state of increased vulnerability to decrements in vigilance and performance that is associated with sleepiness, sleep onset, and sleep. When extremely sleepy, falling asleep, or asleep, an individual's capacity to behaviorally respond to his or her environment can be greatly reduced. It is under these circumstances that performance decrements can significantly reduce the safety margin.

5.2.4 Layover and Cumulative Sleep Loss WAM Findings

Eighteen of the 21 crewmembers (86%) developed a cumulative sleep debt of at least 4 hr. by the ninth day of the duty cycle. The worst accumulation represented 22 hr. of sleep loss by the ninth day. The overall average accumulated sleep loss was about 9 hr. One subject (5%) gained at least 4 hr. by the ninth day, whereas two others had neither a sleep debt nor gain. There were no significant differences between the RG and NRG in cumulative sleep loss. Further analysis did not demonstrate a significant effect of the cockpit naps on the cumulative sleep loss in the RG. This supports the notion that the beneficial effects of the cockpit nap were not created by a reduction of the cumulative sleep loss experienced by the RG. Rather, the cockpit nap provided acute relief for fatigue and, though briefly improving alertness, did not allow enough sleep to overcome the sleep loss accumulated over several days. By the ninth day of the duty cycle, crewmembers had averaged a loss of about one full night of sleep, whether they had a cockpit nap or not.

When the entire 36 hr. duty period is considered (12 hr. duty cycle followed by a 24 hr. layover), the percentage of layover sleep time is 28%. This is roughly 5% less sleep than typically obtained on off-duty home days and accounts for the net sleep loss for most crewmembers.

The analysis of layover sleep patterns also demonstrated that 77% of the 135 layovers involved two or more sleep episodes. Most layovers (70%) had two sleep episodes. There was a significant and striking difference between the duration of each sleep episode within a layover. If a first sleep episode was long, 6-11 hr. in duration, then the second sleep episode was either under 4 hr. in duration or did not occur. Conversely, if the first sleep episode was short, under 6 hr., then there was almost always a second sleep episode that lasted between 4 and 11 hr. in duration. Future analyses will focus on the pattern of layover sleep relative to flight legs.

5.2.5 Subjective Alertness Ratings

The analysis of the alertness ratings showed that subjective alertness was lower on night flights than on day flights and after the rest/control period than before the rest/control period. However, this last finding varied with flight leg, with significant decreases in subjective alertness ratings pre- to post-rest/control period only for flight legs 2,3, and 4 but not for leg 1. It appears this effect was simply a decrease in subjective alertness across flight time. Overall, the nap did not significantly affect the subjective ratings of alertness. There is, generally, a well-documented discrepancy between subjective reports and physiological and behavioral measures. The results of this study add to this scientific literature. Although the physiological alertness and behavioral performance

measures demonstrated a clear improvement related to the cockpit nap, this was not reflected in the subjective reports of alertness. This again highlights the concern that sleepy pilots may not provide reliable subjective estimates of their physiological and behavioral state; it appears that the tendency is to underestimate the level of physiological sleepiness. The current analyses of the subjective alertness data were based on averaging responses because of missing data. Future analyses will explore alternative approaches.

5.3 Scientific and Operational Issues

Several specific scientific and operational issues were raised in the introduction of this report. These will be addressed first, based on the results of the study. Next, other questions will be raised and addressed that are related to the study outcomes or to the operational implications of the results.

1. Given the opportunity, will pilots be able to sleep in their cockpit seats? What will be the quantity and quality of the sleep obtained in the cockpit environment?

   On 93% of the rest period opportunities, the pilots were able to sleep in their cockpit seat. Generally, they fell asleep quickly (in about 6 min.) and slept for about 26 min. (64% of the 40 min. rest period). The physiological sleep data demonstrated that the pilots were able to sleep on both day and night flights, and there were no significant differences related to trip legs, halves of the trip, or flight deck position. The sleep obtained on day flights had a higher percentage of light sleep, whereas the sleep obtained during night flights had a higher percentage of deep sleep, although all naps contained proportionally more light (stage 1) than deep (slow-wave) sleep. Another interesting finding was that the average time to fall asleep (about 6 minutes) was close to the level of excessive physiological sleepiness found in sleep deprived laboratory subjects and in sleep disorders patients.

   All pilots who were given the opportunity to nap in-flight were able to do so on at least three of the four flight legs.

2. Will a nap improve subsequent performance, such as sustained attention or vigilance, or prevent it from worsening? Will performance be maintained or improved during critical phases of operation, such as descent and landing?

   All PVT performance parameters improved as a result of the nap. Generally, the reaction-time/performance data showed no differences between the RG and NRG before flight. However, on a variety of performance factors (e.g., response slowing, lapsing, optimal responding) the RG clearly demonstrated better performance than the NRG during flights, especially just before TOD on night flights. The NRG showed worse PVT performance across flight legs, and on night versus day flights, and the performance grew progressively worse within flight legs, with poorest performance near the end of the flights. However, the nap in the RG resulted in the maintenance of consistent performance across flight legs, on day versus night flights, and within flight legs, with no significant change in performance near the end of flights. Therefore, the RG nap appeared to mitigate the performance decrements that were observed in the NRG.

3. Will a nap improve subsequent alertness, as indicated by physiological measures of alertness/sleepiness, or prevent it from worsening? Will alertness be maintained or improved during critical phases of operation, such as descent and landing?

   The EEG and EOG microevents indicating reduced physiological alertness clearly differentiated the NRG from the RG. The sleep obtained during the planned rest period in the RG was followed by fewer microevents (i.e., indicated a higher level of physiological

alertness) in the last 90 min. of flight than in the NRG. The overall rate of microevent occurrence was 2 times greater in the NRG. There were no occurrences of microevents during the last 30 min. of flight in the RG, whereas there were 22 microevents during descent and approach in the NRG. Overall, the RG nap was followed by a higher level of physiological alertness than was measured in the NRG, including during the critical phases of operation during descent and landing.

4. If a planned nap improves alertness and performance, how long do the positive effects last?

   There were significant positive effects on both performance and alertness as a result of the cockpit nap. This study does not provide an answer as to the duration of the positive effects beyond the several hours post-rest period in this study. It is not possible to determine whether the effects would have been maintained another 30 min., 1 hr., 2 hr., etc.

   Conceptually and operationally, methods to minimize or mitigate the effects of sleep loss, circadian disruption, and fatigue in flight operations, can be divided into two main approaches: preventive strategies and operational countermeasures. Preventive strategies involve those approaches that result in more long-term adjustments and effects on underlying physiological sleep and circadian processes. Examples of potential preventive strategies that require future research are pre-shifting of the circadian phase before multiple time-zone changes, the use of bright light or exercise or both to rapidly readjust the circadian clock to a new time zone, and maximizing the quantity and quality of sleep before, during, and after trips. These preventive strategies affect underlying physiological sleep need, sleepiness, and circadian phase in a more long-term or chronic manner. Operational countermeasures are focused, acute strategies to reduce sleepiness and improve alertness and performance during actual operations. These short-acting countermeasures are not intended to relieve underlying physiological sleepiness but rather to increase alertness and performance during operational tasks. Examples of proved operational countermeasures are the judicious use of caffeine, increased physical activity, and increased interaction. One acute, short-acting operational countermeasure that can temporarily reduce physiological sleepiness is prophylactic napping (ref. 13). A short nap will not reverse a severe, accumulated sleep debt, but it can reduce sleepiness and improve performance for some finite period after it. The planned cockpit nap in this study would be considered an operational countermeasure that provided an acute, short-acting improvement in alertness and performance. Therefore, the cockpit nap would not be expected to provide long-term relief or to alter the underlying circadian and physiological processes to any great extent. This is substantiated by the study results that indicated that the cockpit nap had no effect on layover sleep.

   It has been noted that differentiating countermeasure approaches in this manner is analogous to the concepts of error resistance and error tolerance (ref 72). Error resistance is designed and built into a system to reduce the initial occurrence of errors. However, acknowledging that this error resistance may not be absolute, error-tolerant designs provide another level of error protection. Similarly, preventive strategies may minimize some or many of the effects that might result from the sleep loss, circadian disruption, and fatigue in long-haul flight oper-ations. Operational countermeasures provide the next level of acute intervention (i.e., like error tolerance), acknowledging that the preventive strategies may not be absolute.

5. Could planned rest opportunities, and sleep, compromise flight safety? Will sleep inertia (i.e., the grogginess and disorientation sometimes experienced when awakened from deep sleep) be a safety concern?

   Data on sleep inertia were not available in this project, a result of a measurement limitation. The specific procedural and safety guidelines were followed with no significant deviations, however. There were no reported or observed events that suggested the cockpit naps adversely affected any operational parameters. There are currently no data, anecdotal or in

the PVT results, to suggest that sleep inertia was an issue. The 20 min. period following the nap appeared to provide enough time to allow a return to full recovery from any sleep inertia and to prepare pilots to reenter the operational loop. The short duration of the nap may have been an important factor, since deep sleep, which is associated with sleep inertia, was minimal (8%).

6. What operational and safety guidelines should be considered for implementation of planned cockpit rest in long-haul operations?

   There were eight specific procedural and seven safety guidelines that were successfully implemented in this initial study. However, not all of these would be necessary for a general implementation of planned cockpit rest periods in long-haul flight operations (e.g., two NASA researchers on the flight deck). The following operational and safety guidelines would be the priority considerations for implementation: (1) It was crucial that the rest period was planned with first choice for timing of the nap going to the landing pilot; (2) The rest periods were scheduled during a low workload phase of flight and ended 1 hr. before descent; (3) Only one crewmember was scheduled to rest at a time with a clear rotation plan established before takeoff; (4) The rest opportunity was divided into an initial preparation period, followed by the 40 min. rest period, followed by a recovery period; (5) The rest was terminated at a preset time by a researcher (i.e., an external source) and the resting pilot was fully briefed before reentering the operational loop; (6) It was established that the captain would be notified immediately of the first indication of any potential anomaly; and (7) The safe and normal operation of the aircraft was given the highest priority and, therefore, no cockpit rest procedure or activity was allowed to interfere with this.

7. Would sanctioned planned cockpit rest periods be an improvement over the current situation of uncontrolled spontaneous napping and nonsanctioned naps in nonaugmented long-haul flying?

   Evidence has been cited that both uncontrolled spontaneous napping and nonsanctioned naps occur in long-haul flight operations. Cockpit observers have noted the occurrence of naps in long-haul commercial operations (ref. 12). Gander et al. reported logbook data that provided subjective reports of in-flight naps in long-haul flying (ref. 3). This study provided physiological documentation of spontaneous sleep episodes that occurred during the NRG control period.

   In this study, the RG was able to obtain sleep on 93% of the planned opportunities. This planned nap was associated with better subsequent physiological alertness and psychomotor vigilance performance in comparison with the NRG. The nap resulted in the maintenance of consistent behavioral performance and vigilance. The measures of physiological alertness also indicated that the RG nap was followed by a higher level of alertness during the last 90 min. of flight than for the NRG. Therefore, the sleep obtained during the planned cockpit rest period resulted in levels of performance and alertness that raised the safety margin when compared with the decreased performance, reduced physiological alertness, and unplanned napping that occurred in the NRG.

   In contrast to the current operational situation, this study provided a planned opportunity to sleep, a controlled nap length, and a specified rotation during a low-workload phase of flight. Also, this study demonstrated that planned cockpit rest periods could be implemented according to procedural and safety guidelines that had minimal effect on normal flight operations and, in this study, were associated with no adverse operational effects. These considerations suggest that a planned cockpit rest period would be an improvement over the current situation in nonaugmented long-haul operations.

8. Could the positive effects of the rest periods on PVT performance be explained by motivational factors? That is, did the RG simply try harder, or the NRG try less hard?

   Certainly motivation is essential for any kind of performance assessment, and every effort was made in the current study to ensure that crewmembers in both groups performed the PVT task with the highest motivation, always trying to better their performance on it. There are two reasons that suggest that the current results are not attributable to differential motivation on the part of the two groups. First, if the NRG was not as motivated to perform as the RG, there should have been performance differences evident between groups on flight leg 1 and at preflight PVT trials for all four flight legs. This clearly was not the case; rather, performance differences emerged during in-flight trials, especially following rest trials on night-flight legs, precisely the time when fatigue should have resulted in the most adverse effects on PVT performance. Second, the analysis of EEG microevents following rest substantiates the PVT findings. If the performance results were due primarily to differential motivation, there is no reason why the NRG should have had more EEG microevents indicative of increased physiological sleepiness. This fact, and the lack of other evidence that motivation was different between groups, suggests that the PVT performance results genuinely reflected differences in attentional capacity and response speed between groups.

9. Do the performance differences between groups have any relevance to aircraft operation? In other words, what is the operational significance of the PVT differences between groups?

   As indicated in the methods section, the PVT probed one aspect of the behavioral capability of the aircrews, and is *not* specifically a measure of operational performance. However, high levels of performance on the PVT require sustained attention for 10 min. and the fastest response times a person can produce. To the extent that attention and rapid responses are critical features of many tasks involved in the safe operation of an aircraft, the PVT results can inform us about operational readiness. Indeed, it is not unreasonable to assert that during flights, crews should avoid missing signals (i.e., lapses), avoid false responding, and avoid slowed responding, and that if they are having difficulty doing so on the PVT, then there may be some increased likelihood that they will have difficulty doing so on operationally relevant tasks. Finally, in order to understand the relevance of the PVT results in flight crews, comparisons of these study results with data from sleep-deprived young adults and other relevant groups who have been studied are currently in progress. There is some evidence (see fig. 21) that during night flights, no-rest crews were performing on the PVT at a level approaching that of young adults deprived of a full night of sleep. It is reasonable to consider this level of fatigue as operationally undesirable.

10. How robust and solid are the study results?

    The findings for the PVT are enhanced by the consistency of the data across the different analytical approaches. Whether examining lapses, optimal responding, etc., the direction of the results demonstrated the effectiveness of the cockpit nap in maintaining consistent behavioral performance across these dimensions. The physiological microevent data converge with the performance data to provide even stronger evidence for the benefits of the planned cockpit nap. Therefore, it is the combination of the performance and physiological data that provides the greatest confidence in the study results, with both clearly demonstrating the benefits associated with the cockpit nap.

11. What is the significance of the discrepancy between subjective reports and the other performance and physiological measures?

    The scientific literature generally demonstrates a discrepancy between subjective reports and psychophysiological measures, especially regarding sleep and sleepiness (e.g., ref. 23). Therefore, it is not surprising to find that the RG pilots were not able to discriminate

subjectively the improvements associated with the nap that were demonstrated in the performance and physiological data. This raises an extremely important point supported by previous research (refs. 39, 40). Generally, when sleepy, pilots will provide subjective reports that do not correspond to their behavioral or physiological state. That is, asking pilots to rate their alertness/sleepiness will not ensure an accurate assessment of their status. This is especially important for flight safety since the tendency is to *underestimate* physiological sleepiness.

12. How much will cockpit naps affect layover sleep?

Analysis of the actigraphic data demonstrated that the amount of sleep obtained during the cockpit nap did not affect subsequent layover sleep. In fact, overall, about 85% of the study sample accumulated a sleep debt over the course of the flight schedule. This supports the notion that the short-acting nature of this brief nap did not affect subsequent layover sleep or circadian rest/activity patterns, as determined by actigraphic data. On the other hand, knowing that one is going to have a nap opportunity in-flight may prompt some crewmembers to avoid napping on layover in the hours immediately before coming on duty.

(There are several other scientific and operational questions that emerge from the study results or are suggested by the potential use of planned cockpit rest periods. Some of these questions follow.)

13. Should the length of the cockpit rest period be longer or shorter?

This study did not specifically address the effects of nap duration on alertness. Current laboratory data, however, suggest that the cockpit rest period should not be longer than an hour in order to avoid major sleep inertia and effects on layover sleep (see ref. 19, for a review). It is unclear how much less than an hour might be an effective rest period. The 40 min. planned rest period in this study improved subsequent performance and alertness and provided a sufficient length of time for the 26 min. nap that occurred. Each rest period was divided into three phases that totaled about 60 min. The first phase required 3-5 min. for preparation before the rest period, the rest period itself was 40 min. long, and the recovery phase was 20 min. It may be possible to shorten the recovery time to a 10-15 min. period allowing time for sleep inertia to dissipate if present and to brief the rested pilot before reentering the operational loop. This could reduce slightly the overall amount of time required for the entire rest period procedure.

14. What should be considered in determining where within the flight leg cockpit rest period should be scheduled?

The primary concern in this study was to utilize a low-workload phase of flight. During the transpacific schedules studied, this involved cruise over water. The low-workload, cruise portion of flight seems to be the crucial factor in scheduling the rest period; whether it takes place overwater may be less crucial. However, procedural and safety guidelines for flights over congested land areas were not addressed in this study.

15. Should planned cockpit rest periods be considered for implementation in two-person crews?

As indicated in several previous areas of this report, this study does not provide data on the use of planned cockpit rest periods in two-person flight operations. In consideration of the potentially long flight lengths of two-person automated aircraft, the future increased use of two-person crews, and the fact that these two-person crews will face similar sleep loss, circadian disruptions, fatigue, and sleepiness when flying long-haul operations, the potential use of planned cockpit rest should be studied in that environment. A primary concern, as generally raised with two-person operations, is that the redundancy in the system is reduced by

one human. In the current study, there were two pilots maintaining the flight while one rotated through the planned rest period. In a two-person crew, the pilot remaining awake has added responsibility to maintain wakefulness, vigilance, and level of performance. One possible approach is the development of operational countermeasures that utilize the automation available in the cockpit to maintain alertness in the awake crewmember (refs. 2,10). Another possibility is to consider whether other personnel may be made available to assist the awake crewmember in maintaining alertness while the other pilot naps.

16. Is a rest period the same as a sleep period?

NO. It has been shown clearly that rest is not the same as sleep (ref. 73). A rest period with reduced physical or mental activity does *not* produce the same effects as sleep. Sleeping is a vital biological function like eating and drinking (ref. 74). One result of an individual's inability to obtain the usual and required amount of sleep, whether related to multiple time-zone changes, a sleep disorder, or whatever, is physiological sleepiness (ref. 75). Only sleep can reverse this physiological sleepiness, a rest period can not. Some activities can mask the level of underlying physiological sleepiness and acutely increase the level of subjective alertness.

This point is raised to address the purpose of the planned cockpit rest period. Although evidence suggested that pilots would be able to nap if given the opportunity, one purpose of this study was to determine how often sleep would occur within the rest period. That is, a rest opportunity period could be provided, but would pilots be able to nap during this period in their cockpit seats? Obviously, yes they can, and did so on 93% of the rest opportunities. Therefore, in light of the study results and the previous point that rest is not sleep, the planned cockpit rest periods are more accurately identified as *planned sleep opportunities.* It is the planned opportunity for sleep that will provide the acute countermeasure and safety valve for the physiological sleepiness and fatigue experienced in long-haul flight operations.

5.4 Future Considerations

It is clear from the results of this study that planned sleep opportunities can significantly improve performance and physiological alertness in nonaugmented long-haul flight operations. The convergence of the behavioral performance data and the physiological data to demonstrate the effectiveness of the cockpit nap lend support to the robustness of the findings. However, the limitations of the study also must be acknowledged and the generalizability of the results should not be considered beyond the scope of the scientific and operational issues addressed.

The current results support the implementation of planned cockpit sleep opportunities in nonaugmented long-haul flight operations involving three-person crews. If planned cockpit sleep opportunities were sanctioned, each airline could determine the appropriate incorporation of procedures into its specific mode of operation following the guidelines established by the FAA. If implemented, a joint NASA/FAA follow-up study should be conducted within 6-12 months to examine how planned cockpit sleep opportunities have been incorporated into airline procedures. The study could examine how the procedures were implemented and their effectiveness. This might take the form of a survey or include some field data collection. The results of this follow-up study may lend support for further refinement of procedures and other future implementation.