AIR WAR COLLEGE

AIR UNIVERSITY

AIRCREW FATIGUE MANAGEMENT

by

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Biography

Lt Col Christian G. Watt is a student at Air War College, Maxwell AFB, AL, where he is completing a master's degree in strategic studies. He has served as a Commander, Director of Operations, instructor weapon systems officer, flight examiner, and mission commander in the F-15E community. Colonel Watt has accumulated 170 combat sorties and more than 600 combat hours in Operations PROVIDE COMFORT, DENY FLIGHT, SOUTHERN WATCH and IRAQI FREEDOM. His staff experience includes duty as Chief of Standards and Evaluations at Prince Sultan AB, Saudi Arabia, Aide de Camp to the Superintendent at the United States Air Force Academy, and Chief of Offensive Plans at NATO's CAOC SIX.

Preface

Throughout my flying career as an F-15E Weapons System Officer (WSO), I've had the privilege of serving on multiple deployments in support of Operations PROVIDE COMFORT, DENY FLIGHT, SOUTHERN WATCH, IRAQI FREEDOM (OIF) and ENDURING FREEDOM (OEF). Throughout most of my career, and on all but the last deployment, I was subject to the whim of the flying schedulers. In fact, I would classify myself as a scheduling "victim" on many occasions, even when I was the scheduler myself.

From my perspective, the flying schedule became much tougher to manage as the years went on. Missions seemed to increase in length and complexity from the deployments in the early '90s to the deployments to support OIF and OEF in 2003 and 2006. Nine-plus-hour fighter missions ceased to be noteworthy—the record F-15E mission is in excess of 15 hours. Our F-15E, in addition to all of its other missions, began conducting Close Air Support (CAS) missions—employing ordinance in close proximity to friendlies. To add to the challenge, we went from a primarily day flying schedule with occasional no flying days to a true 24/7, 100%-output-every-day-of-the-deployment force.

The 2003 deployment, which included the initial combat phases of OIF, was the wake up call for me. As an assistant director of operations who was qualified for instructor and supervisory duty, my work schedule moved about the 24-hour clock on a daily basis depending on where the schedulers required those capabilities or when they needed me to fly. Crew rest regulations were always complied with in the plan, although some of our missions required waivers because of combat necessity. Circadian rhythms, however, were not adequately addressed. My body had no idea when to get up and when to rest. I became dependent on sleeping pills to the point that I wrote my wife to advise her that if I was still taking the pills when I returned home, there was a problem. I watched my crewed pilot, a “new guy” who had to follow me through this erratic schedule, disintegrate due to fatigue. I knew that if I were ever given the chance to do it a different way, I would.

I got my chance with the 2006 deployment. As the new Director of Operations (DO) of the 335th Fighter Squadron, I was given responsibility for the squadron’s flying mission. We came up with a scheduling plan designed to accomplish the mission and sustain our crews without overreliance on pharmacological solutions. It worked well. It is presented later in this paper for your consideration.

I would like to thank several people for their assistance in completing this research, including Mr. William Redmond, Col Todd Westhauser, Lt Col Ed Vaughan, Capt Lynn Lee, Dr. Lynn Caldwell, and Dr. Nancy Wesensten.

Lastly, I will save the reader the trouble of deciphering my bias. I believe that suitable scheduling practices have not been adequately incorporated in fielded fatigue management strategies and too much emphasis has been placed on drugs as a solution. It is not the purpose of this paper to prove or disprove that bias, but it will certainly be evident.

Abstract

The purpose of this paper is to examine the problem of aircrew fatigue management and provide recommendations based on the latest advances on the subject. My research method included literature research and interviews with field professionals. Much of my research led to literature written by medical professionals and aerospace physiologists, with relatively little by aviators. This paper is intended to complement the plethora of existing information on the subject from an aircrew perspective.

Research shows that aircrew fatigue is still a significant concern. The author believes that aircrew fatigue will become even more important to manage due to the increased cognitive requirements of the net-centric warrior. Further, management will become increasingly problematic as the number of air assets available to respond to 24/7 tasking and to maintain 24/7 pressure on the enemy decreases.

Research also shows that while pharmacological options are available, they are recommended by most authors as a last resort when other methods to mitigate fatigue have been exhausted. Recommendations for "sound scheduling practices" permeate the literature. Unfortunately, there is little written on "how" to do that—no readily available model for unit-level schedulers to emulate.

New technology and scheduling concepts are available to compliment the pharmacological options. These new methods address the root cause and only cure for fatigue—sleep—verses just the symptoms. The author recommends that the 335th "scheduled sleep" model be tested with actigraphs, formalized in doctrine, and integrated with a computerized program, perhaps the new Flyawake program, to make sound scheduling truly attainable at the unit level.

In short, the 335th model is thus: schedule circadian-compliant sleep in addition to work so aviators' bodies know when to sleep and when to get up; aggressively protect sleep quality by protecting facilities and encouraging good neighborship.

Finally, it is important to note that aircrew fatigue is not just a tactical problem. In today's operational environment, every bomb has a potential strategic effect. The fatigue problem breaches tactical, operational, and strategic levels, and many of the same considerations that apply to tactical aircrew also apply to the operational and strategic decision makers that control those aircrew. Thus, the fatigue management considerations discussed in this paper apply throughout the spectrum of warfare

Chapter 1

Introduction: What is Aircrew Fatigue?

Before we examine the clinical data to define aircrew fatigue, it may be useful to visualize how aircrew fatigue looks in practice from this real-world example:

Al Udeid AB, Mar 19, 2003, approximately 0630 hours:

We had just returned from a successful bombing mission that targeted an airfield in Western Iraq as a response to Iraq's offensive actions against our forces. Operation IRAQI FREEDOM (OIF) had not yet started, but tensions were escalating again as they had many times over the past 12 years. We congratulated ourselves as we watched the sun rise. This was my normal schedule—I had been a night flyer for three weeks leading up to the war and was completely acclimated. Watching the news, we learned of the "decapitation" strike that the F-117s had just attempted on Saddam. Major conventional operations seemed probable this time—"shock and awe" was set for 21 March unless Saddam capitulated.

Al Udeid AB, Mar 21, 2003, approximately 1900 hours:

I awoke from 10 solid hours of sleep to have "breakfast" and watch the "shock and awe" coverage. That's when things changed. A squadron mate tracked me down at 2100 hours to inform me that I would be flying the following morning with a 0900 show time. For a normal "8-to-5er," that's the equivalent of waking up at 0700 and finding out your 12-hour shift doesn't start until 2100, and that you won't get off work until 0900 the next morning. This is certainly not optimum, particularly when faced with the potential of dropping bombs in close proximity to friendlies and non-combatants.

I told him there must be a mistake—I was a night flyer. He said it was no mistake and had to be done. He told me it would be a simple four-hour counter-air mission, which was a relief since we didn't expect much resistance from the Iraqi Air Force. I exercised and ate, then did my best to get some rest. After two sleeping pills, I got perhaps two hours of low quality sleep by the 0900 show time. We took off around 1200. The mission changed while airborne. Our four-hour counter-air mission turned into a nine-plus-hour emergency CAS mission that went through the day and into the night. Near the end of that mission, we conducted air-to-air refueling for our near-empty jets while the Kuwaiti airfields that we were near endured Scud attacks. This was my 25th hour since waking from my last real rest. At this point, I was legally intoxicated by blood alcohol equivalences, and we were still an hour away from our recovery field.

> For the next few weeks, my schedule continued its erratic pattern of nights and days with no rhythm. The schedulers ensured that we complied with crew rest rules and the flight doctors supplied us with pharmaceuticals. I became dependent on sleeping pills for rest—I often could not get to sleep on my own without it. The sleep I did manage was lacking in both quantity and quality. Fortunately, I had experience to fall back on and flew with some outstanding pilots who could make up for any degraded performance. My regular crewmate, however, was new to the aircraft and did not have the advantage of experience. Within a couple weeks on this schedule, his body began to give out. One night, he missed the bus ride in for a mission. We tracked him down in his tent—sound asleep. He took a prescription "go" pill (amphetamine). On the ride in he took another. Then another. Luckily, our mission was cancelled as we departed for our jets. We separated to return our mission materials. Moments later, when we rejoined in the briefing room to discuss the missed-bus incident, I found my crewmate curled up in the corner asleep…after three "go" pills!
>
> The Author

With this common appreciation of what aircrew fatigue looks like in practice, we will examine the clinical literature to be clear on what we mean by "aircrew fatigue." There are many sources with many definitions of fatigue. Hawkins describes four interpretations of fatigue, which can be summarized as: [1]

- *Fatigue caused by inadequate rest.*
- *Fatigue caused by disturbed or displaced biological rhythms (jet lag).*
- Fatigue caused by excessive muscular or physical activity.
- Fatigue caused by excessive cognitive work.

From the US Air Force Research Lab's Dr. James Miller, we garner the following five interpretations of fatigue: [2]

- Physical fatigue, which is overexertion in terms of time or relative load.
- *Circadian effects, which encompasses disruptions to human 24-hour biorhythm cycle.*
- *Acute mental fatigue, caused by wakefulness in excess of 16 hours.*
- *Cumulative mental fatigue, caused by successive disturbed or shortened major sleep periods.*
- *Chronic mental fatigue, caused by exposure to fatigue inducers from varied sources for at least one month, including disrupted sleep, stress, and excessive work hours.*

Note the similarities in approaches. Rest (sleep) and biological (circadian) rhythm issues account for six of the combined nine interpretations. While excessive physical and cognitive activity, which account for the remaining three interpretations, are certainly factors, the author believes that these are part of the unavoidable demands of flying and are a constant. Our aircrew are selected based on their ability to cope with those stresses. It is when sleep and circadian problems manifest themselves that there is a change. Thus, when discussing aircrew fatigue, we will focus mainly on physical and/or mental fatigue from sleep or circadian disruptions.

Unfortunately, despite widespread research on the subject, the challenge of aircrew fatigue remains an issue. Do some leaders and aviators still think "sleep is for wimps"[3] despite all the data to the contrary? Do some still believe that "dedicated and professional Airmen can overcome the problems associated with fatigue by simply gutting it out" as Dr. John and Dr. Lynn Caldwell describe in their book *Fatigue in Aviation: A Guide to Staying Awake at the Stick*?[4] Or is aircrew fatigue just too tough to solve for the operators in the field? Perhaps the lingering problem is caused by a little of all of these factors. This paper will show that aircrew fatigue is still a significant concern and attempt to make this challenge easier to solve at the unit level. To do this, we will survey and update the basics of aircrew fatigue, then discuss initiatives and techniques to manage this problem. The paper will conclude with a recommended course of action.

Additionally, it is important to note that aircrew fatigue is not just a tactical problem. In today's operational environment, every bomb has a potential strategic effect. The fatigue problem breaches tactical, operational and strategic levels, and many of the same considerations that apply to tactical aircrew also apply to the operational and strategic decision makers that control those aircrew. Thus, the fatigue management considerations discussed in this paper apply throughout the spectrum of warfare.

Chapter 2

Historical Cost of Aircrew Fatigue: Does This Still Matter?

The purpose of examining the historical cost of aircrew fatigue is to demonstrate that aircrew fatigue has been and is still a problem. There are many ways to articulate the costs of fatigue. For instance, we could review some of the globally known and notorious high-profile accidents, although not necessarily aircrew related. We don't have to look hard to find high profile disasters where fatigue has been implicated as a causal or contributory factor: the Chernobyl nuclear reactor meltdown;[5] the Exxon Valdez catastrophe;[6] the Three Mile Island nuclear power station accident;[7] the loss of the Challenger space shuttle;[8] and the death of 228 from the crash of Korean Air flight 801.[9] These vivid examples are relatively infrequent, but are tremendously costly in terms of lives, dollars, public confidence, and the environment.

For more frequent incidents of fatigue problems, which are aircrew specific, we need only look at published military aviation statistics. These statistics tend to articulate cost in terms of percentages where fatigue was a causal or contributing factor in Class A mishaps, defined as mishaps with $1 million or more in direct cost, a fatality, or permanent full disability:[10]

- 1972-2000: fatigue was a causal or contributing factor in 12.7 percent of the Air Force's Class A aircraft mishaps.[11]
- 1974-1992: fatigue was attributable in 25 percent of the Air Force's night tactical fighter Class A accidents.[12]
- 1977-1990: fatigue was attributable to 12.2 percent of the Navy's total Class A mishaps.[13]
- Fiscal Year 2006: fatigue was cited as present in 21percent of the Air Force's Class A mishaps.[14]
- Fiscal Year 2007: fatigue was cited as present in 23 percent of the Air Force's Class A mishaps.[15]

Although the verbiage used in the statistics is not identical ("causal or contributory," "attributable" and "present"), it is clear that aircrew fatigue has been a steady, if not increasing, safety factor for at least the past 35 years.

Cost figures in terms of dollars are not as readily available. An Air Force Research Laboratory (AFRL) report issued in 2003 cited the average dollar cost of aircrew fatigue to the Air Force at approximately $54 million a year.[16] This was based on an average of 7.5 Class A mishaps per year where fatigue was shown to be causal or contributory.[17] However, this figure does not capture the total dollar cost of aircrew fatigue, as less costly mishaps (Class B, Class C etc.) are not included in the total, nor are intangibles such as loss of productivity, etc. Such research would be cumbersome, but as a way to motivate decision makers, it might be valuable for the human factors community to conduct the research to demonstrate how the true dollar cost of aircrew fatigue has changed over time.

Thus far we have examined the cost of aircrew fatigue in terms of notoriety, rates and dollars. We must also consider the costs of fatigue on performance. Professional literature is replete with documentation on how fatigue impairs performance. Consider how these effects impair our tactical, operational or strategic-level leaders and warriors:

- "Motivational decrements, impaired attention, short-term memory loss, carelessness, reduced physical endurance, degraded verbal communication skills, and impaired judgment."[18]
- "Dramatic negative impact on reaction time…"[19]
- "Uncontrollable sleep while on the job, even during very demanding tasks."[20]
- Impaired complex mental operations, "including the ability to anticipate, generate, and execute a plan of action; maintenance of situational awareness; and critical reasoning."[21]
- "Poor assessment of risk or failure to appreciate the consequences of action."[22]

These adverse effects lead to poor decision making. At the tactical level, impaired decision making translates to such problems as higher risk of mission failure, mishap or fratricide. Hursh reports that, during Operation DESERT STORM, there were more friendly fire losses than enemy losses, many due to sleep deprivation.[23] At the operational level, impaired decision making can result in such problems as the misallocation of airpower, delayed and ill-conceived orders, or poorly thought out rules of engagement, any of which can completely undermine the overall success of an operation, regardless of tactical successes. At the strategic level, impaired decision making could cause a senior leader to pursue a flawed foreign policy or engagement strategy, leading the nation down unwise paths which might render any operational or tactical successes void. The point of this commentary is to note that aircrew fatigue has costs which are not captured in accident statistics—fatigue impacts air warriors throughout the battlefield, whether in a cockpit or on the staff.

Chapter 3

Fatigue Factors and Their Effects

According to congressional testimony on pilot fatigue from NASA's Michael Mann, "fatigue is rooted in physiological mechanisms related to sleep, sleep loss, and circadian rhythms" and cannot be willed away or overcome with motivation or discipline.[24] Dr. Steven Hursh describes more specific major fatigue factors to include: time of day (between 0000 and 0600 is bad); cumulative sleep debt (more than eight hours of accumulation is bad); acute sleep debt (less than eight hours of sleep in the previous 24 hours is bad); continuous hours awake (more than 17 hours since the last "major" sleep period is bad); and time on task (continuously doing a job without a break).[25] Thus, for major fatigue factors we will examine sleep quantity and sleep quality—factors directly influencing sleep loss and sleep debt—circadian rhythms, and continuous hours awake.

Sleep Quantity. The optimum amount of sleep for most people is eight solid hours for day-to-day functioning.[26] Later, in the "hours awake" discussion, we will discuss a method to capture the effects of sleep deprivation by comparing it to blood alcohol level, but for now it is sufficient to note that sleep debt reduces performance. With anything less than eight hours of sleep, or whatever a specific body requires, a person begins to accumulate sleep debt and is already, at the very least, in the "acute sleep debt" category.[27] If a person accumulates more than 8 hours of sleep debt, they enter the "cumulative sleep debt" category.[28] Current crew rest regulations account for sleep quantity—the 10 to 12 hours the crews are required off for rest are intended to offer a minimum eight hours of uninterrupted sleep prior to the next flight duty period.[29] As we will see, the ability for that crew member to actually sleep during the crew rest period is another matter.

Sleep Quality. Through this, we consider the effectiveness of the sleep. While someone might get eight hours of sleep quantity, the sleep may of so poor quality as to nullify its benefit such that they are still fatigued. Interruptions to sleep, whether noise, trips to the restroom, vibrations from jets taking off, or a myriad of other factors, disrupt the body's sleep mechanism. Poor sleep quality leads to sleep debt which reduces performance. According to AFI 11-202v3, most aircrew will require two consecutive nights of sleep to fully recover from significant sleep debt.[30]

Circadian Rhythms. Through this, we consider "when" the body wants to sleep. It is assumed that the reader is familiar with the concept of circadian rhythms and the body's basic 24-hour sleep/wake cycle. When this cycle is disrupted, due to jet lag, shift change, etc., negative consequences result. In the author's opinion, this was the biggest factor in causing the sleep loss and resulting fatigue that we experienced in the previous 2003 example, with the second biggest factor being sleep quality. The *Leader's Guide to Crew Endurance*, produced by the US Army Safety Center and US Army Aeromedical Research Laboratory, lists the following as signs and symptoms of circadian disruption:[31]

- Fatigue and sleepiness during the work period.
- Sleep disruptions.
- Poor concentration.
- Impaired decision making ability.
- Digestive disorders.

Hours Awake. Through this, we consider the time elapsed since the last "major sleep period," not "nap." Literature reveals two methods to articulate fatigue based on hours awake. One method is based on a study by Dawson and Reid that related hours awake to blood alcohol content. From the study, we learn that "remaining awake for 24 hours will produce the same performance problems as having a blood alcohol concentration of 0.10 percent,"[32] while only 21 hours awake gets a person to the legal blood alcohol limit of 0.08.[33] Another method is to relate hours awake to a percentage of reduced performance capacity based on performance models. For example, 24 hours of wakefulness, which would yield an equivalent blood alcohol concentration of 0.10 percent, reduces operational performance by 25 percent,[34] whereas 26 hours of wakefulness causes a decline of 45 percent.[35]

While there are many other factors that affect fatigue, these are what the industry considers the major factors. Now that we understand the cost, factors and effects of fatigue, we will examine ways to mitigate aircrew fatigue.

Chapter 4

Methods to Mitigate Fatigue: Theory, Practice and the Latest Initiatives

Before we attempt to cure aircrew fatigue, let us first acknowledge that the only true cure is sleep. NASA's Dr. Samuel Strauss affirms that "the only effective treatment for fatigue is adequate sleep."[36] All controls except sleep should be considered a "band-aid" and only used when other controls are insufficient and the mission must still be accomplished.[37] Thus, the key to aircrew fatigue management is sleep, and any of the fatigue management strategies which we will discuss that do not result in increased or improved sleep are not addressing the root cause of this problem. We will examine aircrew fatigue management in theory, aircrew fatigue management in practice and current initiatives.

Aircrew Fatigue Management in Theory

AFI 11-202v3, the Air Force's regulation on general flight rules, recognizes the importance of aircrew fatigue management. It devotes a chapter to crew rest and flight duty limitations in effort to encourage leaders to address certain aspects of the major fatigue factors we have described. Unfortunately, while it urges leaders to mitigate fatigue and offers general advice, it is admittedly incomplete with regards to solutions. Here is a sample (emphasis added):

> 9.9.5. **The instructions in this chapter cannot provide a solution to all the challenges posed by the 24-hour demands of Air Force flight operations.** It is essential, therefore, that Commanders utilize other reasonable means to sustain crew alertness and performance. Consultation with aerospace medicine or other fatigue management experts is advisable. Examples of alertness management strategies that are currently available include tactics to promote effective rest and minimize pre-mission duration of wakefulness, such as **extended crew rest periods, pre-positioning and sleep quarantine facilities; non-pharmacological countermeasures, such as controlled cockpit rest, bright light or physical activity breaks; pharmacological agents (go and no-go pills); and alertness management education and training**.[38]

From this regulation and other professional literature, we garner several theoretical approaches to managing fatigue, which we will examine next.

Pharmacological Solutions. An extraordinary amount of literature has been written on the subject of using prescription drugs to counter aircrew fatigue. The author's experience proves that they have a place, particularly when unable to mitigate fatigue with other methods. Further, with the increased length of fighter and bomber missions—15.8 and 44 hour records respectively during Operation ENDURING FREEDOM (OEF)[39]—drugs may be required to counter the factor of continuous hours awake, even if sleep quantity, sleep quality and circadian rhythms are perfectly managed. However, the author has personally seen the downside of pharmacological solutions in the forms of dependency and exhaustion that even drugs could not overcome. The author believes that pharmacological methods have masked a problem of poor scheduling practices, and that it is these scheduling practices that are largely responsible for the pharmacological need. Medical professionals recommend caffeine, dextroamphetamine (Dexedrine ®), and now modafinil (Provigil ®) to improve aviator alertness[40] and Temazepam (Restoril ®), Zolpidem (Ambien ®) and Zaleplon (Sonata ®) to help aviators rest when required.[41] However, as Dr. John Caldwell notes, "it must be reemphasized that no stimulant can replace effective crew-rest scheduling or provide a substitute for restful, restorative sleep."[42]

Diet & Hydration. There are certain recommended techniques in literature that utilize diet and hydration to mitigate the effects of fatigue. To fight fatigue, "drink plenty of fluids, especially water," and "eat high protein meals."[43] To help you sleep, a "carbohydrate meal in the evening, particularly when combined with a food high in tryptophan" might be useful.[44] Also, avoid alcohol, nicotine, or caffeine prior to sleep.[45] However, while diet and hydration "might" be helpful in promoting sleep or staying awake in the short term, research revealed nothing to suggest that appropriately fed and hydrated warriors could overcome the severe adverse affects of sleep loss and circadian disruption.

Exercise. Fitness is another topic of interest in the battle to fight aircrew fatigue. Unfortunately, literature shows that fitness is not an effective countermeasure against fatigue. Caldwell states that "being physically fit apparently offers no benefit for sustaining mental alertness."[46] Meadows affirms that "while highly fit individuals are surely more resistant to physical fatigue from prolonged exertion, unfortunately, research has not shown them to be more resilient to mental fatigue from sleep deprivation than their less fit peers."[47]

Sleep Quality. As discussed in the previous chapter, sleep quality directly influences sleep debt. NASA found that random noise is a major contributor to poor sleep quality.[48] Others detractors include vibrations, such as turbulence and door closings, and personal disturbances, such as trips to the bathroom.[49] A good sleep environment is key to both quantity and quality of sleep. "Dark, quiet surroundings and a comfortable temperature and sleep surface" are desired.[50]

Circadian Rhythms. Circadian disruptions have a major adverse impact on fatigue. The body must be on a regular schedule to know when to wake and when to sleep. The Air Force Safety Center recommends that people "establish consistent sleep/wake times and stick to them."[51] Getting on schedule can be particularly difficult for those put on the night schedule (day sleepers). From the 1997 *Leader's Guide to Crew Endurance*, we garner the following countermeasures to help day sleepers adjust to the night schedule:[52]

- Use bright lights during the night work environment to resynchronize the circadian timing.
- "Maintain near to complete darkness in daytime sleeping quarters."
- Reduce daytime noise.
- "Follow a consistent sleep- and meal-timing schedule from day to day."
- "Maintain the same schedule of sleep, wake up, and meal times during days off."

- "Avoid frequent shift rotations. Allow shifts to continue for at least 2 to 3 weeks."

As we will expand upon later, expeditionary operations pose a significant challenge for circadian management. For instance, we know that "inappropriately-timed bright light exposures will aggravate shift lag,"[53] and thus impair circadian adjustment. Consider the effect on sleep quality and circadian adjustment for a night-flying, day-sleeping aviator who requires a mid-sleep restroom break and must walk 150 paces in the mid-day sun and 120 degree heat to the nearest facilities. Further, while shift work has its challenges, expeditionary aviation it is not always a matter of "shift work." The flexible airpower demands of the Army, coupled with 12-hour flight duty days, do not allow for standard day/swing/mid-shifts as in factories or with maintenance on the flight line—one simply can't stop the jet and do a shift change airborne.

<u>Scheduling Practices</u>. The only true method to mitigate the circadian problem and ensure aviators have a legitimate chance of obtaining satisfactory sleep quantity and quality rests with the scheduling function. NASA highlights the need for sound scheduling practices.[54] As Miller describes, "the main cause of fatigue is lack of sleep"[55] and "the best countermeasure is sleep, which is the only countermeasure that provides recovery."[56] Thus, true aircrew fatigue management is not about drugs, diet or exercise. Further, the serious fatigue we are concerned with "cannot be overcome by motivation, training, or experience."[57] **True aircrew fatigue management is about sleep, and sleep is largely a function of effective scheduling and proper facilities that promote good sleep quality.** Thus, the keys to aircrew fatigue management are: 1) a suitable scheduling process and; 2) appropriate sleeping facilities. Ensuring these will likely require aggressive involvement from unit-level leadership. Unfortunately, there is little to assist unit leaders with the very complex scheduling problems

other than general recommendations for sound scheduling practices and affirmation that scheduling is important.

Aircrew Fatigue Management in Practice

Published historical documentation typically reveals pharmacological methods of fatigue management. Amphetamines were used during military operations in WWII[58] and by military aircrew during Vietnam.[59] They were used again during the 1986 Operation EL DORADO CANYON raid on Libya where pilots "flew 13-hour missions after extended planning sessions" accumulating 24 or more hours of wakefulness.[60]

An informal survey[61] of leaders from various flying communities reveals a perception of minimal issues in managing fatigue while at home station. The exception to this is the Predator Unmanned Aerial Vehicle (UAV) units—more will be discussed on this later. For the other communities, a tendency towards pharmacological fatigue management methods, particularly sleeping pills, is evident while deployed. Other methods include: using permanent experienced schedulers to improve continuity and decision making; napping techniques while airborne; adding additional crewmembers; shifting takeoff and land times if able; and physically relocating sleeping quarters to sleep-conducive locations.

Speaking for the F-15E community, I can say that we have a tradition of relying on pharmaceuticals and crew rest rules to mitigate fatigue, as seen in introduction. Knowing the dangers of this system, and with no readily-available tools to assist us, my squadron attempted to create a better system for our 2006 deployment. We will discuss this solution in detail next.

The 335th Fighter Squadron Solution

The scheduling challenge cannot be overstated. In one aircrew fatigue research paper that recommended pharmacological solutions, the author noted the "limited effectiveness on countering fatigue obtainable by efforts to maintain a healthy sleep cycle" and suggested that "alertness-enhancing medications may be the only reliable method for maintaining the performance of personnel."[62] I believe that reliance on prescription drugs should be avoided when possible and most authors from my research, including the one quoted in the earlier sentence, agree. My hope is that with the following model, scheduling can be improved to reduce the need of pills or make those pills more effective when they are really needed. Unfortunately, the scheduling problem is extremely difficult to solve, and varies with the aviation communities and the specific situation. Without prior thought, planning, and establishment of a suitable process, crews will likely be forced into circadian disruption, and thus sleep loss—the realities of tight manning and flexible, short notice airpower requirements will overcome any good intentions. For my last deployment, the key to our potential fatigue catastrophe was effective scheduling and adequate sleep facilities. The following discussion details our situation, solution, and lessons-learned to provide a model for other units to consider.

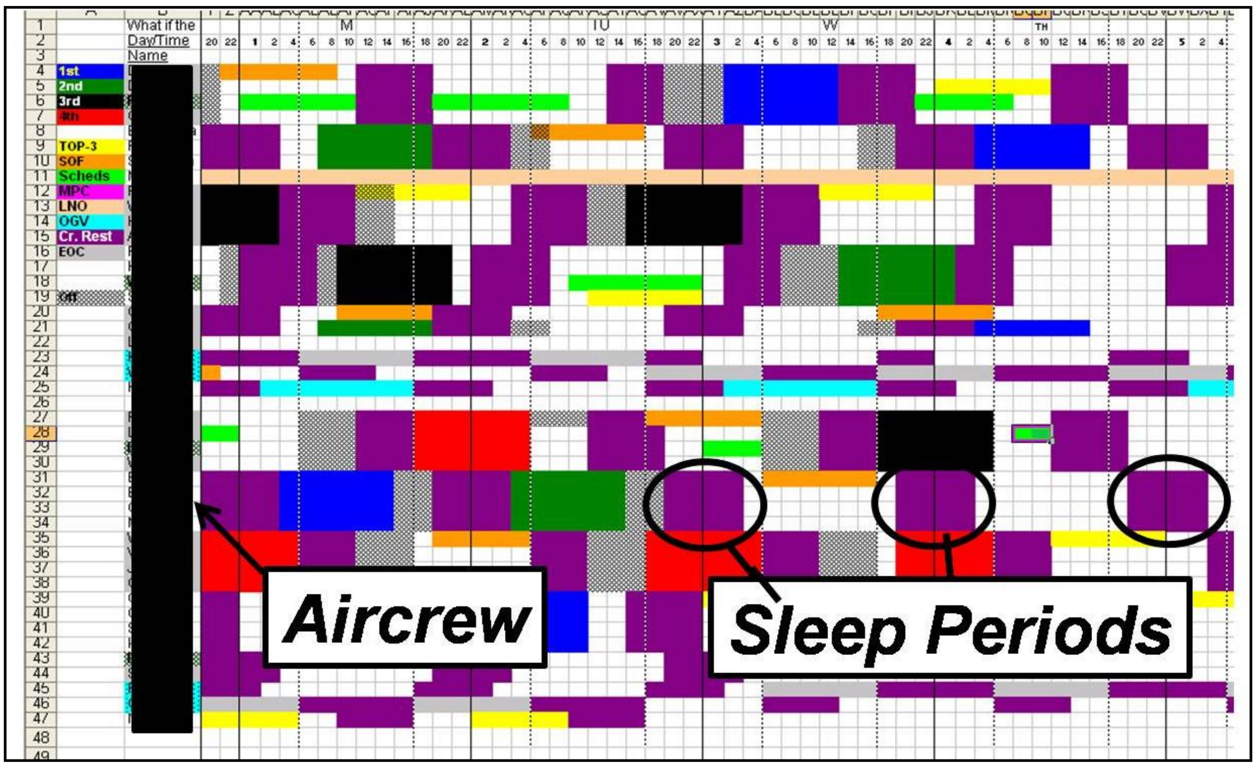
The 335th Fighter Squadron was scheduled to deploy to the Middle East in support of OIF and OEF in May of 2006. As the squadron's Director of Operations (DO), I was responsible for the daily flying mission, to include the scheduling, training, tactics, standardization and safety of the aviators as well as their performance on the battlefield. It was a standard 120-day deployment, May through September.

I contacted the DO of the squadron we were replacing to learn about the current situation and what we should expect. His squadron had gone the entire deployment of 24/7 operations with little, if any, breaks in flying and we were to expect the same. There would be no break in flying during the swap out—we had to be on cycle and ready day one. For us, it would be summer, which meant that daytime high temperatures could exceed 120 degrees. Typical mission durations were long by fighter standards—approximately six hours on the low end and more than 10 on the high end. This flight time does not include mission prep and ground operations time, etc. The flying schedule was erratic. For example, the first takeoff of a given Air Tasking Order (ATO)[63] period might vary 12 hours from day to day—airpower was delivered on the Army's schedule, which meant that missions might launch throughout the 24 hour ATO period or all at once. Further, we often wouldn't know the takeoff times until 12 hours prior based on the flexibility of the ground operations. The flying missions themselves were akin to what we had become accustomed to as of late—hours of monotonous surveillance over areas of interest with occasional moments of extreme intensity when shooting erupted on the ground…at which time we had better be prepared to employ deadly force in close proximity to friendlies and non combatants. Fatigue was a concern. When I asked the DO how he was coping with the schedule and aircrew fatigue, he told me that it was basically too unpredictable to effectively manage and advised me to "get up for it." What that meant in 2003 was pills.

The 335th Combat Scheduling Solution: schedule circadian-compliant sleep in addition to work; aggressively protect sleep quality by protecting facilities and encouraging good neighborship.

We devised the concept of circadian-compliant "purple time" to cope with the unpredictable schedule. Because of the fluid battlefield demands, we couldn't predict far enough in advance when our aviators would work. Instead we scheduled when they would sleep—a circadian-compliant eight-hour block of "purple time" (a.k.a., "sleep cycle") on the schedule. Figure 1 shows an early prototype spreadsheet of our plan. The challenge was to spread the squadron's sleep cycles throughout the day to accommodate all of the additional duties and special qualification requirements, yet have enough aviators available to accommodate heavy flying requirements at any given hour.

Figure 1. Prototype Duty Schedule With Sleep Cycles



We had the squadron that we were replacing send us a few days of their schedule so we could test our concept. My original "simple" idea to divide the squadron in three, with 0000-0800 sleepers, 0800-1600 sleepers, and 1600-2400 sleepers, did not work—it was too inflexible to meet the erratic scheduling demands. Fortunately, my MIT-graduate chief of scheduling[64] was able to solve this complex problem. The solution was to stagger the sleep cycles throughout the

24-hour period so that we sent a couple of crews into crew rest every few hours. This system was flexible enough to meet demands and within a few weeks of tracking metrics, my schedulers achieved a "compliance" of 97%. On the occasions that they could not accommodate an individual's sleep cycle due to mission requirements, it was a conscious decision in which risk was mitigated as much as possible.

My schedulers were allowed to impinge upon the purple time up to two hours without DO approval, but returned the aviators to their "home" purple time as soon as possible. We favored letting our aviators sleep in or stay up late verses getting them up early or "sending them to bed" early because our bodies seemed to tolerate it better. These sleep cycles became a key scheduling factor alongside other factors, such as meeting crew rest requirements and ensuring each formation had the right qualifications and experience levels. The bottom line was that my aviators' bodies knew when it was time to sleep. It was on their name magnets that we used to build the schedule. The master "purple time" spreadsheet was posted for all to see. Crews knew when their down time was, and they grew to "expect" it, which, in turn, helped to keep the scheduling process accountable.

We had several issues to overcome in meeting this challenge. Next we will examine those issues and the lessons we learned in addressing them.

Manning. We make an assumption with this solution that significant increases in manning are impractical. Else, at an extreme, with triple manning, no additional duties, and typical flight requirements, we could revert to pure shift work. We deployed at the full authorized 1.5 crew ratio—everyone our squadron could take plus some outside help to complete our manning requirements. The result was that a little less than half of our aviators flew each day at our nonsurge sortie rate. However, we had to support several other positions throughout the base which took from our reserve to a point where we had just enough crews to cover a spare pilot and WSO for each takeoff timeframe. As we became more proficient towards the end of the tour (e.g., needed less manpower for mission planning duties) and realized economies of scale with our sister units (e.g., combined supervisory duties with our F-16 partners), we were able to free up more crews for reserve and even get our crews some leisure time. Another key for us was to train a sufficient number of crews in special duties ((squadron supervisors, Wing Supervisors of Flying, schedulers, safety officers, Combined Air Operations Center Liaison (CAOC) Officers, mission planners, etc.)) and spread their sleep cycles throughout the day so we could cover the duty requirements without impacting purple time. To train enough crews, we were forced to selectively qualify aircrew who complied with regulated minimum requirements, but were less experienced than we would normally have considered for certain positions. To mitigate the risk this caused, we employed a thorough screening and selection process and provided increased instruction and supervision.

Crew Rest. Crew rest in and of itself was not overly difficult to comply with if we were willing to significantly alter a crew's sleep period from day to day. The difficulty was keeping crews on sleep cycle throughout the process. The flyers from one day often could not takeoff any sooner than they did the day prior—their missions were so long that when they landed, they sped off to get their 12 hours of crew rest just in time to be able to report back for duty no earlier than their previous report time. If the following day's takeoff times shifted earlier, crews often could not fly that following day and remain in sleep cycle. We overcame this by carefully managing the additional duties to keep everyone in cycle and provide flexible options. This meant that while we could reasonably fill a position's 24-hour requirement with just two 12-hour shifts, we often found ourselves spreading the requirement amongst three or more aviators to keep crews in cycle.

Sleep Quality. Sleep quality was a constant battle. Each aviator had a private, windowed and air conditioned room in a trailer-type living facility. Doors were loud and acoustics terrible—boots or normal talking in the rooms or hallway would broadcast throughout the 30-room facility. Noise discipline was established immediately and enforced draconianly. Hallways were rugged as much as possible, doors were padded and windows were blacked out. Earplugs were readily available. Air conditioners were a source of white noise as well as heat relief, so if response to repairs was slow, leadership became involved. For those on base who had to share rooms, our private rooms were an irritant and several attempts were made to force us to double up. Because of room design and construction, it was impractical for a roommate to enter or depart that room without interrupting the other's rest and we felt that this was unacceptable. We fought for and maintained private rooms throughout the deployment. Another challenge was the remote location of the restroom facilities, especially for our day sleepers. Shower and restroom facilities were located in separate buildings approximately 100 to 500 feet away from our sleeping quarters depending on specific circumstances. While a mid-sleep trip to the restroom is a common nuisance, especially in a location where hydration is critical, it can be a sleep destroyer when one returns from a 300-pace, 120-degree walk in the afternoon sun. We went through many disposable "aircrew relief devices" on that deployment, and consider the money well spent.

We were very pleased with the results of our approach. Hopefully the reader can see that we attempted to address all of the major fatigue factors, including sleep quantity and quality, circadian rhythms and continuous hours awake. I can't prove objectively that this system worked—we were not collecting data and conducting surveys at the time. But I stake 18 years of aviation experience that it worked. I was ADVON (advance team member) for our deployment and spent 10 days flying with the squadron we replaced before the rest of our squadron arrived for the swap out. The fatigued flyers we replaced reminded me of my OIF crewmate in 2003. In contrast, my crews looked remarkably healthy after 120 days of continuous 24/7 operations. I believe they could have executed this schedule indefinitely and fatigue would not have been a problem.

There are limitations to this approach. For instance, while this approach worked well for our deployed 24/7 operations, Predator squadrons who are "deployed" at home station may not find this as useful. They have lives, spouses and children that don't necessarily conform to our sleep-cycle system and draconian sleep quality measures. A recent Naval Postgraduate School paper on Predator aircrew fatigue concluded that scheduling recommendations may only be part of the solution for that community. Increased manning, which we assumed was not possible in our case, may be necessary to provide sufficient recovery opportunities for those aviators.[65] One advantage for the Predators is that, unlike some manned aircraft, they can do shift work. With enough manpower, they should conceivably be able to create a workable shift system as with other 24/7 occupations. They may be able to incorporate some of our lessons to enhance effectiveness as well.

AFRL's C-130 Solution

An example from the mobility community may help illustrate another scheduling solution. Consistent with the problems we were experiencing, the mobility community's C-130 units experienced enough difficulty with their standard aircrew fatigue management methods to spark an external study to try and fix their fatigue problem. In 2004, a study was conducted by the USAF Research Laboratory (AFRL) to address aircrew fatigue problems for intra-theater 24/7 tactical airlift operations.[66] At that time, "40% of intra-theater C-130 aircrew members reported such strong symptoms of excessive daytime sleepiness that, without the known, work-related cause, they would have been examined for sleep disorders."[67] One reason highlighted for the fatigue was the "irregularity of the schedule for a given crew across days."[68] Based on this study, AFRL published a technical memorandum in 2005 that addressed a large contributor to the fatigue—the scheduling process. Several scheduling factors were addressed, including manning ratios, crew duty periods, number and sequence of work and free days, etc.[69] However, of the seven scheduling principles discussed, these two, designed to keep crews on some sort of work/rest cycle, seem key to this puzzle:

- Either schedule "a long sequence of night shifts in a slowly rotating schedule (with adequate sleep facilities) to allow acclimation to night work and day sleep"[70] or
- Schedule "a minimum number of consecutive night shifts in a rapidly-rotating schedule to minimize exposure to night work where sleeping facilities are inadequate."[71]

Of note, at about the same time we were developing our method to cope with our erratic schedule, AFRL was publishing this study for the C-130 community that may have helped us, although many of the recommendations would not have worked in our situation do to our specific mission demands.

Current and Future Initiatives

Recent technology may aid us in the efforts to manage fatigue. Existing models and programs (SAFTE/FAST, described below) are able to predict performance capacity based on known fatigue factors. There is now a scheduling program overlay (Flyawake)[72] which incorporates the SAFTE modeling program and can be tailored to each flying community's needs. There are even wristwatch-type monitors that can be downloaded, or conceivably transmit a signal, to show an individual's fatigue level.

- SAFTE/FAST. The Department of Defense's Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) model produces an "applied model of human cognitive performance effectiveness"[73] by integrating the effects of prior wakefulness, the amount of sleep, and circadian rhythms.[74] The Fatigue Avoidance Scheduling Tool (FAST), based on the SAFTE model, allows users to predict level of fatigue based on work and sleep cycles and circadian rhythms.[75]
- Flyawake.[76] Flyawake is a new initiative created by the Air National Guard and marketed to the Air Force to help mitigate fatigue. It is intended to address the scheduling challenges through an easy, web-based computer interface which uses the predictive capabilities of the SAFTE model. By combining this model with existing scheduling programs used in the field, it aims to help schedulers avoid a poor scheduling decision. The author believes that a "335th scheduled sleep" system could be modeled and incorporated with a suitable scheduling program, perhaps Flyawake, to make an easy, doctrinized and supported system for schedulers of fatigued flying communities. With this, schedulers could address the scheduling challenges of

contemporary, unpredictable, 24/7 airpower demands while ensuring we don't ask the impossible of our aircrew.

- Actigraph. Actigraphs record whole body activity and permit inferences about sleep timing, quality and quantity.[77] Actigraph variations include a wrist-worn monitor that records and downloads fatigue-predictive data over infrared signal across the Internet for analysis.[78] Thus, with this technology, reliable data can be obtained with no more intrusion to the aviator than wearing a watch.[79]

There are other initiatives as well. The 56th Services Squadron at Luke Air Force Base has introduced CrossFit fitness training to supplement existing physical training classes for the base general populace. In addition, the program is being used to augment the G-Tolerance exercise regimen for F-16 basic course student pilots. While we have already discussed the limitations of exercise in countering fatigue, one self-professed lifelong "gym rat" has noticed benefits in the last four years that he's been doing CrossFit that he didn't get with his other workouts—he enjoys "more restful sleep" and "recovers quicker" from fatigue. Of the factors we discussed, this anecdotal evidence implies benefits to sleep quality. In fact, the officer notices a reduction in sleep quality when he breaks from his CrossFit regimen.[80]

Chapter 5

Conclusions and Recommendations

In today's operational environment, every bomb has a potential strategic effect. We can ill afford the mistakes associated with aircrew fatigue, especially in this setting. Unfortunately, aircrew fatigue has a persistent history of causing problems which continues to this day. As documented by Caldwell in a recent *Air and Space Power Journal* article, "fatigue from sleep loss and body clock disruptions is a widespread problem in military operations, particularly in recent high-tempo operations associated with the global war on terror."[81]

It will become more challenging and more important to manage aircrew fatigue in the future as resources to perform 24/7 operations become fewer in number and the cognitive requirements of our net-centric warriors increases. As we become an even more network-centric force, which will require increased cognitive ability, the effects of fatigue could be magnified.[82]

The adverse effects of fatigue are widely known and documented. We understand the major factors that influence fatigue. There are ample tested and understood methods to remedy fatigue. While it is known that sleep is the only true cure, much literature focuses on pharmacological solutions verses effective scheduling—the key ingredient to solving the major factors of aircrew fatigue.

Further, for as much as we understand about fatigue, advice for operational units centers on "what to consider" with regards to scheduling, while there is little to "show them how" to solve this very complex problem, especially considering the challenges in the real world. These challenges should not be underestimated. From the fighter world, we have seen six-hour missions grow to nine-to-15 hour missions once airborne. These missions are challenging enough without showing up to work already behind the fatigue power curve. For the flying squadron, this challenge is often not simply solved with shift work. The CAOC demands, and the Army lives by, flexibility in airpower, which is too fluid and dynamic to relegate to shift work. We need a practical, easily implementable scheduling solution to be provided to operational units so they can continue to succeed in future, net-centric environments.

The 335th model deserves consideration. The system of scheduling circadian-compliant sleep periods as well as work and aggressively ensuring adequate sleep facilities and good neighborship solved our challenges. New technology is available that could make this system easier to tailor and distribute to aviation communities that experience similar fatigue challenges.

Therefore, it is my recommendation that the 335th model be tested with actigraph. If proven suitable, it should then be incorporated with a suitable scheduling program, perhaps Flyawake, to make this challenging problem as easy as possible to solve at the unit level.

By solving the scheduling problems that contribute to aircrew fatigue, we will reduce the probability of tactical errors, some of which might have adverse strategic consequences. Further, by applying these lessons broadly and adopting a corresponding respect for the fatigue problem in general, our tactical, operational, and strategic decision makers will reduce their probability of fatigue-induced decision errors and improve effectiveness at all levels.

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Notes

(All notes appear in shortened form. For full details, see the appropriate entry in the bibliography.)

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[1] Hawkins, *Human Factors in Flight*, 57. According to websites, Frank H. Hawkins was a researcher of aviation human factors.
[2] Miller, *Operational Risk Management of Fatigue Effects*, 2. Dr. James C. Miller served as a Project Scientist for AFRL at the time these reports were published.
[3] Communication with Dr. Nancy Wesensten (experimental psychologist with the Department of Behavioral Biology, Division of Psychiatry and Neuroscience, Walter Reed Army Institute of Research), interview by author, 3 February 2009.
[4] Reeder, "Avoiding Fatigue Risks While Behind the Wheel," 25.
[5] Briefing, Hursh, Modeling Fatigue and Predicting Performance, slide 6.
[6] Ibid.
[7] Hawkins, *Human Factors in Flight*, 63.
[8] Ibid., 58.
[9] Caldwell, Gilbreath, Erickson, and Smythe, *Is Fatigue a Problem in Army Aviation?,* 1.
[10] AFI 91-204, *Safety Investigations and Reports*, 15.
[11] Meadows, "Fatigue in Continuous and Sustained Airpower Operations," 9.
[12] Caldwell, Gilbreath, Erickson, and Smythe, *Is Fatigue a Problem in Army Aviation?,* 1.
[13] Ibid.
[14] Reeder, "Avoiding Fatigue Risks While Behind the Wheel," 25.
[15] Ibid.
[16] Miller, *Aircrew Fatigue in 24/7 Intra-Theater Operations*, 3
[17] Ibid.
[18] Caldwell, *An Overview of the Utility of Stimulants as a Fatigue Countermeasure for Aviators,* 2-3.
[19] Caldwell, *An Overview of the Utility of Stimulants as a Fatigue Countermeasure for Aviators,* 2, and Spilker, "The Use of Stimulant Medication to Enhance Human Performance in Extended Military Operations," 4.
[20] Ibid.
[21] Wesensten, Belenky, and Balkin, "Cognitive Readiness in Network-Centric Operations," 99.
[22] Briefing, Hursh, Modeling Fatigue and Predicting Performance, slide 4.
[23] Ibid., slide 6.
[24] US House, *Pilot Fatigue,* Testimony of Michael Mann. At the time of this testimony, Michael Mann served as the Deputy Associate Administrator for NASA's Office of Aero-Space Technology.
[25] Briefing, Hursh, Modeling Fatigue and Predicting Performance, slide 5.
[26] Caldwell, "Go Pills in Combat," 100.
[27] Briefing, Hursh, Modeling Fatigue and Predicting Performance, slide 5.
[28] Ibid.

[29] AFI 11-202, Volume 3, *General Flight Rules,* 70-71.
[30] Ibid., 71.
[31] Comperatore, Caldwell, and Caldwell. *Leaders Guide to Aircrew Endurance,* 15.
[32] Reeder, "Avoiding Fatigue Risks While Behind the Wheel," 25.
[33] Briefing, Hursh, Modeling Fatigue and Predicting Performance, slide 20.
[34] Caldwell, "Go Pills in Combat," 100.
[35] Spilker, "The Use of Stimulant Medication to Enhance Human Performance in Extended Military Operations," 5.
[36] Strauss, "Pilot Fatigue," 1. Dr. Samuel Strauss worked in NASA's Department of Aerospace Medicine at the time of his writing.
[37] Miller, *Operational Risk Management of Fatigue Effects*, 12.
[38] AFI 11-202, Volume 3, *General Flight Rules,* 73.
[39] Meadows, "Fatigue in Continuous and Sustained Airpower Operations," 8.
[40] Miller, *Operational Risk Management of Fatigue Effects*, 9-10.
[41] Ibid., 10-11.
[42] Caldwell, *Short Term Fatigue Management*, 27. Dr. John A. Caldwell, widely published on human factors topics, wrote this report while serving with AFRL's Human Effectiveness Directorate.
[43] Strauss, "Pilot Fatigue," 5.
[44] Hawkins, *Human Factors in Flight*, 81.
[45] Miller, *Operational Risk Management of Fatigue Effects*, 15.
[46] Caldwell, *An Overview of the Utility of Stimulants as a Fatigue Countermeasure for Aviators,* 15.
[47] Meadows, "Fatigue in Continuous and Sustained Airpower Operations," 13. Major Andrew Meadows, USAF Bio-Service Corp, completed this research as an Air Command and Staff College student.
[48] Rosekind, Gregory, Co, Miller, and Dinges, *Crew Factors in Flight Operations XII*, 2-31.
[49] Ibid.
[50] Ibid., 4.
[51] Reeder, "Avoiding Fatigue Risks While Behind the Wheel," 26.
[52] Comperatore, Caldwell, and Caldwell. *Leaders Guide to Aircrew Endurance*, 18.
[53] Miller, *Operational Risk Management of Fatigue Effects*, 8.
[54] US House, *Pilot Fatigue*, Testimony of Michael Mann.
[55] Miller, *Operational Risk Management of Fatigue Effects*, 7.
[56] Ibid.
[57] Caldwell, *An Overview of the Utility of Stimulants as a Fatigue Countermeasure for Aviators,* 16.
[58] Spilker, "The Use of Stimulant Medication to Enhance Human Performance in Extended Military Operations," 3.
[59] Caldwell, "Go Pills in Combat," 100.
[60] Meadows, "Fatigue in Continuous and Sustained Airpower Operations," 22.
[61] This information is not from a formal survey with a large sample size. Brief interviews were conducted with experienced aircrew or former commanders from bomber, airlift, and fighter communities. Information was also included from discussions with field professionals. The

information in this paragraph is included to provide the reader with a sample of practiced fatigue management techniques, some of which might be useful in the reader's community.

[62] Spilker, "The Use of Stimulant Medication to Enhance Human Performance in Extended Military Operations," 6.

[63] The Air Tasking Order (ATO) is the plan that directs the flying operations for a given 24-hour period in a theater of operations.

[64] Major Paul Birch.

[65] Tvaryanas, Platte, Swigart, Colebank, and Miller, "A Resurvery of Shift Work-Related Fatigue in MQ-1 Predator Unmanned Aircraft System Crewmembers," iii.

[66] Miller, *Scheduling Aircrews 1,* iv.

[67] Miller, *Aircrew Fatigue in 24/7 Intra-Theater Operations,* ii.

[68] Ibid.

[69] Miller, *Scheduling Aircrews 1*,v.

[70] Ibid.

[71] Ibid.

[72] All information on Flyawake provided by Capt Lynn Lee (Executive Officer, Air National Guard Safety Directorate), interview by author, 5 January 2009.

[73] Miller, *Operational Risk Management of Fatigue Effects*, 13.

[74] Ibid., 4.

[75] Command Flight Surgeon, "Fatigue in Naval Aviation," 4.

[76] See note 71.

[77] Briefing, Hursh, Modeling Fatigue and Predicting Performance, slide 30.

[78] Caldwell, "A Recent Advance in the Objective Quantification of Operational Fatigue," 821.

[79] Ibid.

[80] Information for this paragraph was provided by Brigadier General Kurt Neubauer (Commander, 56th Fighter Wing, Luke Air Force Base, AZ), interview by the author, 20 November 2008.

[81] Caldwell, "Go Pills in Combat," 100.

[82] Wesensten, Belenky, and Balkin, "Cognitive Readiness in Network-Centric Operations," 100.