Fatigue in Naval Aviation

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Note: The opinions or assertions contained in this article are the private views of the author, and are not to be construed as official or reflecting the opinions of the Department of the Navy or the Department of Defense. The author has no material interest, financial interest, or other relationship, with Science Applications International Corp. (SAIC) or the Fatigue Avoidance Scheduling Tool (FAST™). This article was originally published in CONTACT, the Newsletter of the Society of U.S. Naval Flight Surgeons, Volume 29, Numbers 2, 3 & 4; April, July & October 2005.

Part 1

Suppose your squadron is on the last leg of a flight back to home base from a typically busy at-sea workup period. The crews have gassed up, grabbed a bite to eat at the air station gedunk, and are ready to man-up. Your Skipper asks one of the pilots how he's doing, and he replies, "Skipper, I'm good to go – I'm just a little tired."

You can probably imagine how the CO might respond. Maybe he'd ask "you really OK?" expecting some self-assessment and reassurance that his pilot was up for the mission. Or perhaps "yeah, so am I – let's go!"

Now change the scenario just a bit. Suppose your aviator replied, "Skipper, I'm good to go – I'm just a little drunk."

I use this example as an intro to the lecture on fatigue I give Aviation Safety Officers and prospective Commanders here at the School, and typically get a snort and chuckle. It's obviously a ridiculous scenario, since no one would drink before flying, or climb into a plane while intoxicated. But we do fly, and drive, and engage in lots of other demanding activities in a fatigued state. Often we have no choice, and for those of us who have suffered through typically busy residency programs or work-up periods at sea, we've gotten very familiar with the experience. And doctors, aviators and others, of course, make these decisions based on experience, common sense, and knowledge of the data.

So let's look at the data. In an informal review I did of data from the Naval Safety Center on aviation mishaps and hazard reports during the period 1997-2002, I looked for aeromedical factors which were cited as contributory. Over half of the reports had one or more aeromedical factors listed, and when plotted they looked like this (Figure 1.):

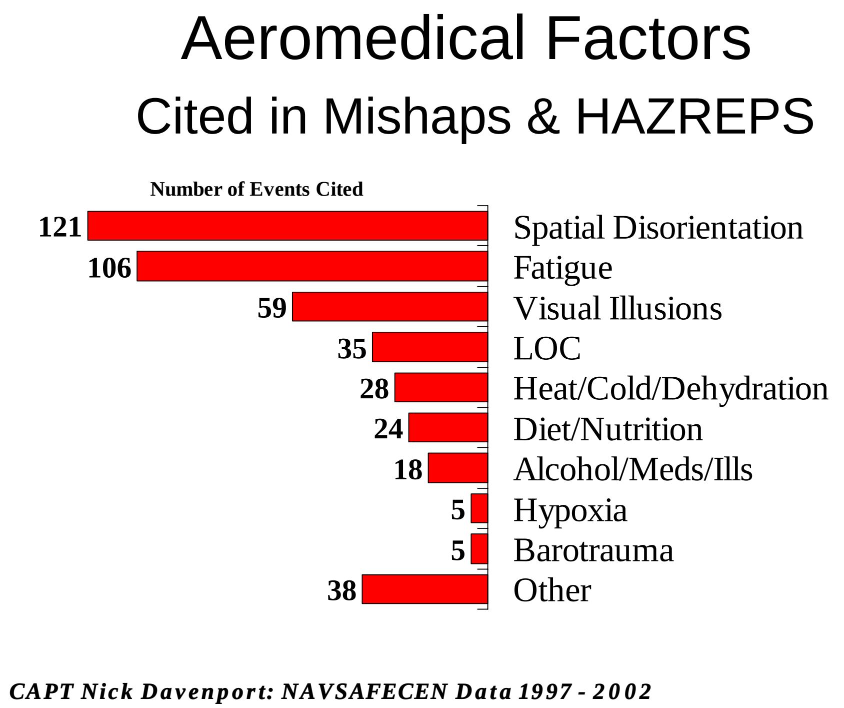
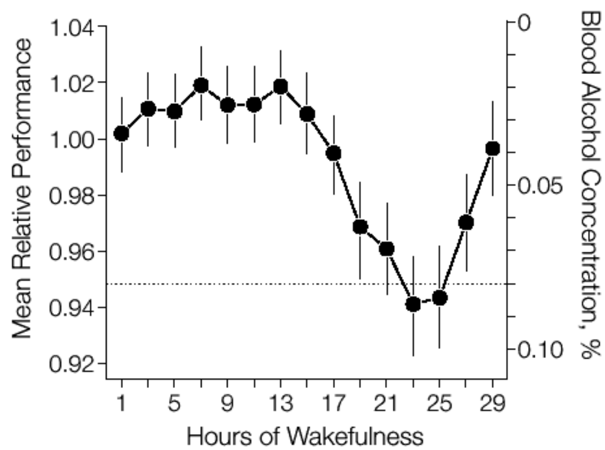


Figure 1.

You'll notice that alcohol is buried along with medication usage and illnesses in general as causal factors, but fatigue was cited as #2, second only to spatial disorientation in these reports. The data seems to suggest that fatigue is a much greater hazard than alcohol. But that seems contrary to our common experience. Is this a statistic leading us to a ridiculous conclusion, or is there something wrong with our current understanding of fatigue as a hazard? My aviators correctly observe that this data is skewed, since we know better than to fly while drinking – it's prohibited by NATOPS. But if you look at NATOPS Chapter 8, on rest, sleep, and flight time, you'll find some suggested guidance on what is ideal regarding work and sleep, but little in the way of mandated rules. So the denominator for flying while drunk is much smaller that it is for those who are flying fatigued - we know better! That's why it appears that fatigue is a greater risk – the number who are exposed to this hazard is much greater.

Someone once said that "statistics can be made to prove anything – even the truth." Let's look at some more data. In 1997, Australian researchers reported in Nature a study they did where they compared the effects of fatigue and wakefulness to the effects of alcohol intoxication (1). Reprinted is the following graph:

Figure. Effect of Sleep Deprivation on Psychomotor Performance Compared With Blood Alcohol Concentration



The legal limit for blood alcohol concentration while driving a motor vehicle is as low as 0.08% (dotted line) in some states. Mean relative performance is expressed as percentage of performance at the start of the session. The effects of sleep deprivation on psychomotor performance become equivalent to the effects of acute alcohol intoxication in the early morning after nearly 24 hours without sleep. Reproduced with permission from *Nature* (http://www.nature.com/).[8]

Figure 2.

These researchers discovered similar decrements in performance after 22 hours of sleep deprivation to that seen at a blood-alcohol level of 0.08% - legally drunk! Fatigue-alcohol studies have been replicated by a variety of researchers, who have shown that, although there are some specific differences in levels of performance on individual tests, alcohol and fatigue produce similar levels of performance deterioration. Why do we tolerate aviators flying fatigued when we'd never allow them to fly drunk? Maybe we need to revise our views on fatigue. Let's review our current information on fatigue physiology and sleep deprivation.

The human brain is an extremely complex electro-chemical digital computer. It is estimated to have over 100 billion neurons and many more synapses (logic gates). It cannot run continuously in the awake state. Mammals that are kept awake for indefinite times die – around 2-4 weeks – from insulin resistance, immune system failure and sepsis. With continual awake activity, the neurons may deplete required stores of neurotransmitters and substrate and may accumulate free radicals and cellular damage – much of this is currently being studied. As the brain continues in wakefulness, performance, as measured on a variety of tests, declines. We interpret this as an accumulation of "fatigue." The brain requires regularly-scheduled maintenance and repair intervals to maintain computing efficiency, which we know as sleep. Sleep is as necessary for survival as oxygen, water, and nutrition. Since we evolved around a 24-hour day, these repair intervals follow a 24-hour cycle, and are governed by circadian rhythms.

There are hundreds of individual processes in the body which proceed on 24-hour cycles, and are kept in synchrony by “the circadian rhythm.” It is helpful to consider the circadian rhythm as an alerting signal which programs the brain when to fall asleep and when to wake up. As the brain fatigues, the circadian alerting rhythm helps prop up alertness to maintain relatively constant performance throughout the day. When the depleted brain approaches the normal time of sleep, the circadian alerting rhythm starts declining, unmasking the fatigue and signaling the brain to switch to sleep mode. As the brain recovers during sleep, the circadian alerting rhythm continues its decline to keep the brain asleep until a full 8 hours of sleep has been accomplished. Now restored, when the circadian rhythm begins to alert again, the brain wakes up to start another day. In a well-rested brain without a sleep debt, the periodicity of this circadian clock is remarkably accurate, as you’ll notice on those occasions when you wake up within a minute or two before your alarm clock goes off.

Much research has been done on sleep, and studies are ongoing to help better understand the need for Rapid Eye Movement (REM) sleep, deep or non-REM sleep, and the reasons for both. Consensus is that most people require 8 to 8 ¼ hours of efficient sleep per night. It appears that cellular restoration is accomplished during non-REM deep sleep, and that memory and learning is more dependent on REM sleep, but controversy still exists. It is apparent that whatever the function each supplies, the body requires both, and will compensate to achieve both in sleep periods, depending on need. Healthy sleep efficiency depends on both. Inefficient or fragmented sleep will result in increased fatigue levels and again, declining performance.

There’s more, but the crux of all this is that fatigue is a function of real physiology. It’s the way this digital computer operates. As fatigue accumulates, performance, mood, complex decision making, judgment, response times, error tolerance, risk-taking, motor skills, etc. all start to deteriorate. Our culture, especially in the military (and in my experience, in medical training too), holds that somehow training, habit, motivation and/or attitude can overcome all this. Mishap statistics suggest otherwise. After an aviation mishap, we routinely measure for glucose, alcohol, carbon monoxide, cyanide, drugs, lactic acid, etc., etc. but we have no good measure for fatigue, so we’ve historically missed it as a causal factor. We’re ripe for a cultural change. There are excellent sources of additional information on sleep deprivation, fatigue and performance. One good summary is a report put out by the Battelle Memorial Institute for the FAA (2). If you’re unable to locate this on the WWW, drop me an e-mail and I’ll forward a copy.

Part 2

In the previous issue of CONTACT we discussed some of the current physiology of fatigue and showed data that suggests fatigue ranks high in the aeromedical causal factors in naval mishaps and hazard reports. There are plenty of data out there from scientific studies which show the deterioration in performance that occurs as the brain fatigues. The brain requires regular periods of maintenance and restoration, which we know of as “sleep.” We also know that we’re programmed to obtain this sleep at night and that the circadian alerting rhythm is primarily responsible for telling the brain when to switch into sleep mode, and when to wake up. And the phase of the circadian rhythm is tied to local daylight and its 24-hour period is tied to the orbital motion of the planet. That's how we evolved. The brain can't continue to function in the continuously awake mode. Fatigue accumulates and performance drops. The following plot (Figure 3.) shows both the accumulating fatigue and declining performance in subjects over a three-day sleep deprivation study, along with the modulating effect of the underlying circadian rhythm (1).

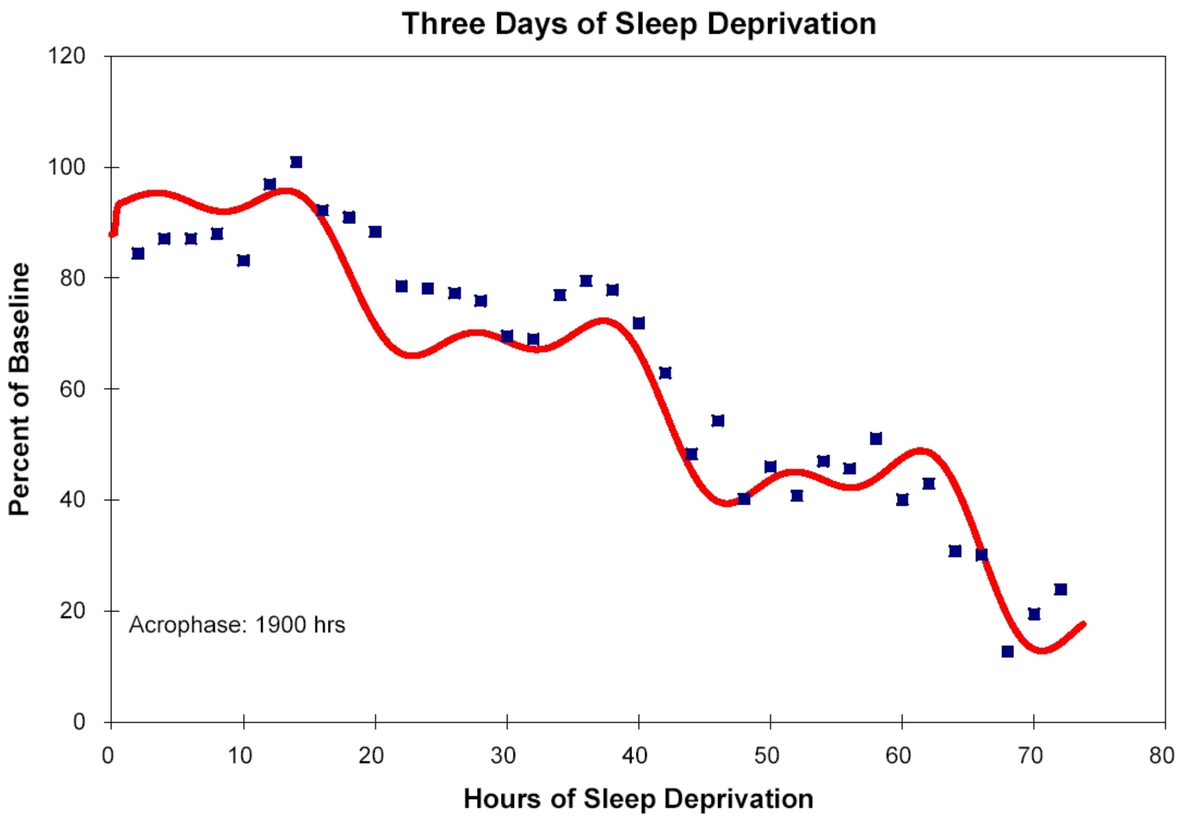


Figure 3.

Another problem with accumulating fatigue is that the brain will try to insert snatches of sleep to restore itself – lapses or "microsleeps." These typically last 5-15 seconds or so, during which the individual may appear awake with eyes open, but is actually asleep. The brain has switched to sleep mode and is not processing external stimuli. Performance deteriorates due to fatigue, but during these lapses, performance drops to zero. These lapses become more frequent as fatigue accumulates. What's most dangerous is that individuals are often unaware that these are occurring. External events – radio calls, warning lights, sudden threats, or mandatory responses – don't get recognized and aren't processed during lapses.

Like most of you, one of my past life experiences included medical residency training. In my case, I selected a general surgery residency program in a typically busy major metropolitan area. And one particularly brutal rotation involved spending 3 months on a service where the work-week was limited to 168 hours. If you do the math, that's 24-on/24-on. Days off? – nope!

Surgery residents typically would grab 1 ½ - 2 hours sleep per 24-hour shift if they were lucky. In my three months on this rotation, I once managed to get 4 hours of uninterrupted sleep (on a night when The Boss was out of town). Residents rapidly degenerated into walking zombies as the fatigue overwhelmed us. Short-term memory disappeared – I had to write down notes on everything. Simple tasks became impossible. I had difficulty deciding which was right and left when putting up an x-ray; I couldn't do the mental rotation in my head. We'd doze off while examining patients, leaving them to wake us up. On rounds, we'd envy the sick, since at least they were lying down. If we made mistakes (which were frequent), The Boss would taunt us - "… are you stupid, doctor, or do you just don't care?" We were too fatigued to realize we had a third choice – fatigue! This might have even been considered useful training if we'd remembered more of it.

I'm sure you've had similar experiences with fatigue. Let's review the symptoms and signs:

- High-level frontal lobe stuff goes first: The fatigued individual gets irritable and cranky – not good for Crew Resource Management.
- Complex decision-making suffers, personality changes, and mood deteriorates.
- Communication is impaired – people quit talking.
- Vigilance decreases and people become inattentive.
- Task-fixation develops as brain processes slow.
- Tolerance for both error and risk increase.
- Motivation is reduced, and effort is conserved – the brain tries to preserve its remaining resources.
- Short-term memory declines.
- Reaction times increase – this is one of the most fundamental measurable changes with fatigue.
- And as mentioned, the risk of microsleeps goes up.

It's completely obvious that none of this is desirable when doing something so demanding and potentially dangerous as caring for patients or flying a plane.

We can measure the performance deterioration that results from fatigue, and observe for the signs and symptoms of fatigue, but unfortunately we don't have any ready measure of the brain's fatigue level itself. But can we predict fatigue levels based on knowledge of work and sleep cycles, time of day and circadian rhythms? Turns out that we can, and with surprisingly good accuracy. Which brings us to FAST™ – the Fatigue Avoidance Scheduling Tool.

Several teams of researchers have attempted to take the known physiology of work and sleep cycles, sleep deprivation and circadian rhythms, and predict the accumulation of fatigue and the level of resulting performance deterioration. These computer models were compared with each other on standard data sets of performance in sleep-deprived subjects in a "shootout" of which program performed best. The full report of this evaluation was published in Aviation, Space and Environmental Medicine in a March 2004 Supplement (3). Luckily for us, the "winner" was a program developed with Department of Defense sponsorship and is licensed for our use in official military applications. The FAST program is based on a mathematical model developed by Dr. Steven Hursh at the Science Applications International Corporation, and is specifically designed to help optimize the operational management of aviation flight and ground crews. It displays a graphical plot of predicted performance after you specify times for sleep and work, and will accept events such as transmeridian travel, and calculate the phase of the circadian rhythm and anticipate how it adjusts to travel over time zones. It calculates light and dark cycles depending on latitude and longitude, and will recommend sleep intervals once you've specified duty periods.

Take a look at figure 3 again. The little squares plotted are the actual data taken on the sleep-deprived test subjects, but the smooth curve isn't some "best fit" approximation to the data, but a predicted line generated by the FAST program. In this case, the predicted performance curve matches the actual data to an accuracy of 94% - pretty impressive for a software program predicting something as notoriously variable as human performance!

A typical plot from the FAST program is shown in figure 4.

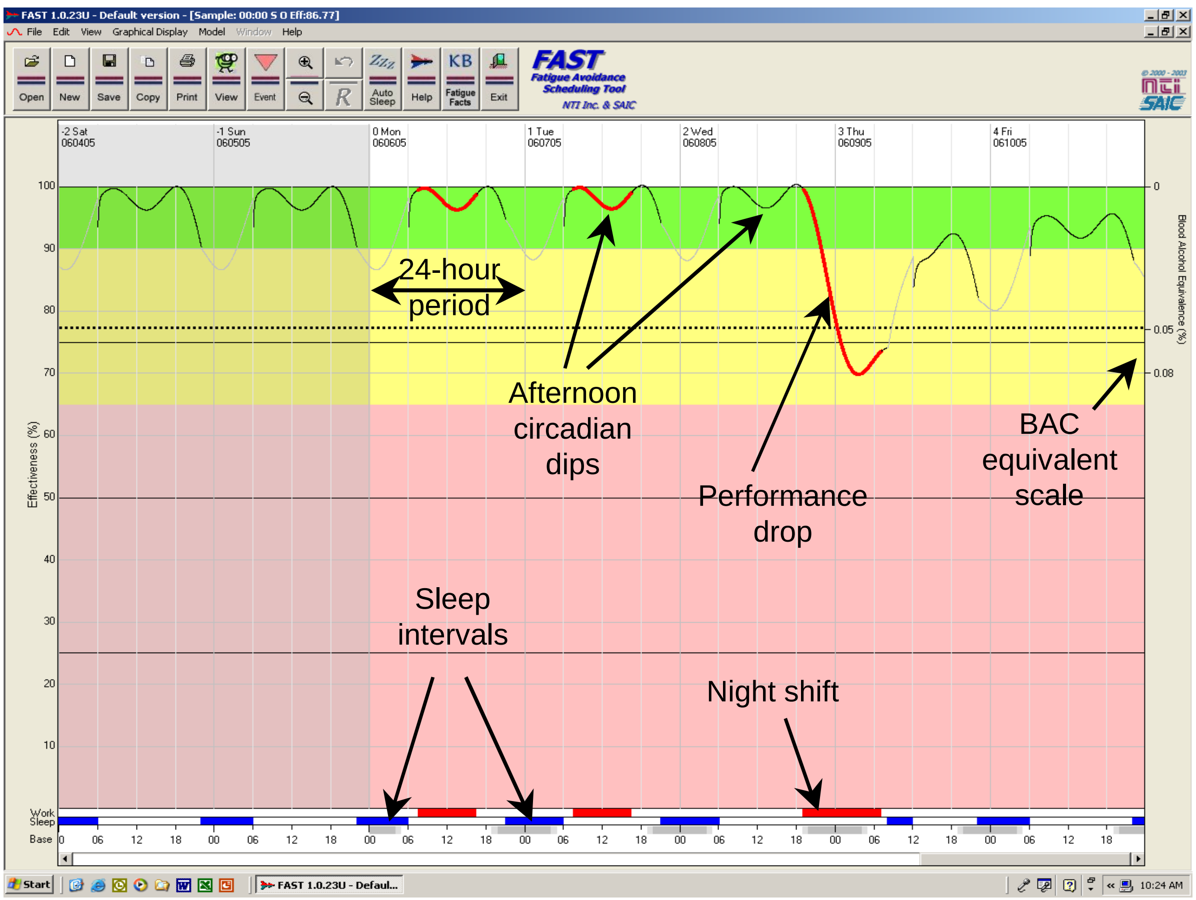


Figure 4.

In this particular example, the program plots a performance curve, and the expected deterioration while working an all-night shift. The dotted line – a criterion line - represents a level of performance which is degraded enough to be a safety hazard. In this instance it's set to a similar deterioration in performance that would be seen in a subject who is intoxicated at a blood alcohol concentration (BAC) of 0.05%. The program also plots a BAC equivalent of the 0.08% level, which is considered legally drunk for driving in all U. S. states. At this level of impairment, performance drops to 70% of baseline. Our theoretical shift worker in figure 4, during the last half of his work shift, is performing at a level the same as if he were drinking on the job!

FAST promises to be an excellent tool to do trial runs on schedules, assist your aviators in planning flight schedules and travel across time zones, and in analyzing the contribution of fatigue as a causal factor in mishaps. The software is available for download to authorized users, and I'd encourage you to install a copy on your computer, and become familiar with its use. Drop me an e-mail for more information on obtaining a copy of the software and in using the program.

Part 3

In the two previous issues of CONTACT, we reviewed what we know about the physiology of fatigue, and how it affects performance. Fatigue and sleep deprivation are significant causes of mishaps, but we've been slow to spot these as causal factors, probably because we have no good measures for fatigue. And our culture doesn't recognize fatigue as out of the ordinary, since it's so common in our 24-hour work-round-the-clock culture. We also looked at a tool, the Fatigue Avoidance Scheduling Tool (FAST™), which takes the known physiology of fatigue and predicts a person's performance based on sleep and work cycles, "jet lag" issues, and quality of sleep. In this issue, we'll take three hypothetical examples and see how FAST might help us analyze the contribution of fatigue to some issues we might face in Naval Aviation.

Scenario #1:

You've gotten settled in as the Senior Medical Officer on the fusion-powered USS ESSESS (CVF-80), the latest and greatest carrier in the U. S. Naval Fleet, and are looking forward to your first port call on this WestPac Cruise. But sure enough, at the last minute, the carrier has been ordered to the Persian Gulf at best possible speed, where you'll work with a sister carrier in 'round the clock operations. And since you've got a fresh crew, you're going to be the "night carrier," conducting flying operations from 1900-0700 each day. Your CO, Captain Charger, wants to know how best to transition to a night shift for the ship's crew. His idea is to keep everyone up and hold a party all night long the day before you enter the Gulf, then have everyone except the watchstanders go to bed at 1000 – 1800, and remain on that schedule until the exercise is over. You, however, armed with the latest knowledge of fatigue physiology, suspect that this will only add another 8 hours of sleep debt to your already tired crew, and suspect your Skipper is making a huge blunder.

"Let me thoroughly research this, Skipper, and I'll get back to you shortly with the best scientific recommendation possible based on our current knowledge of human fatigue physiology, ensuring that the crew functions at their optimum, and that you keep your front runner status for flag rank", you say fawningly as you retreat to your stateroom to work your magic in FAST. You open the program and tell it you want to look at a month-long schedule. Plugging in the existing sleep schedule of 2200-0600 up to the day of transition, you then skip the first night's sleep, and plug in day sleep from 1000-1800 for the rest of the month. FAST plots the following (Figure 5):

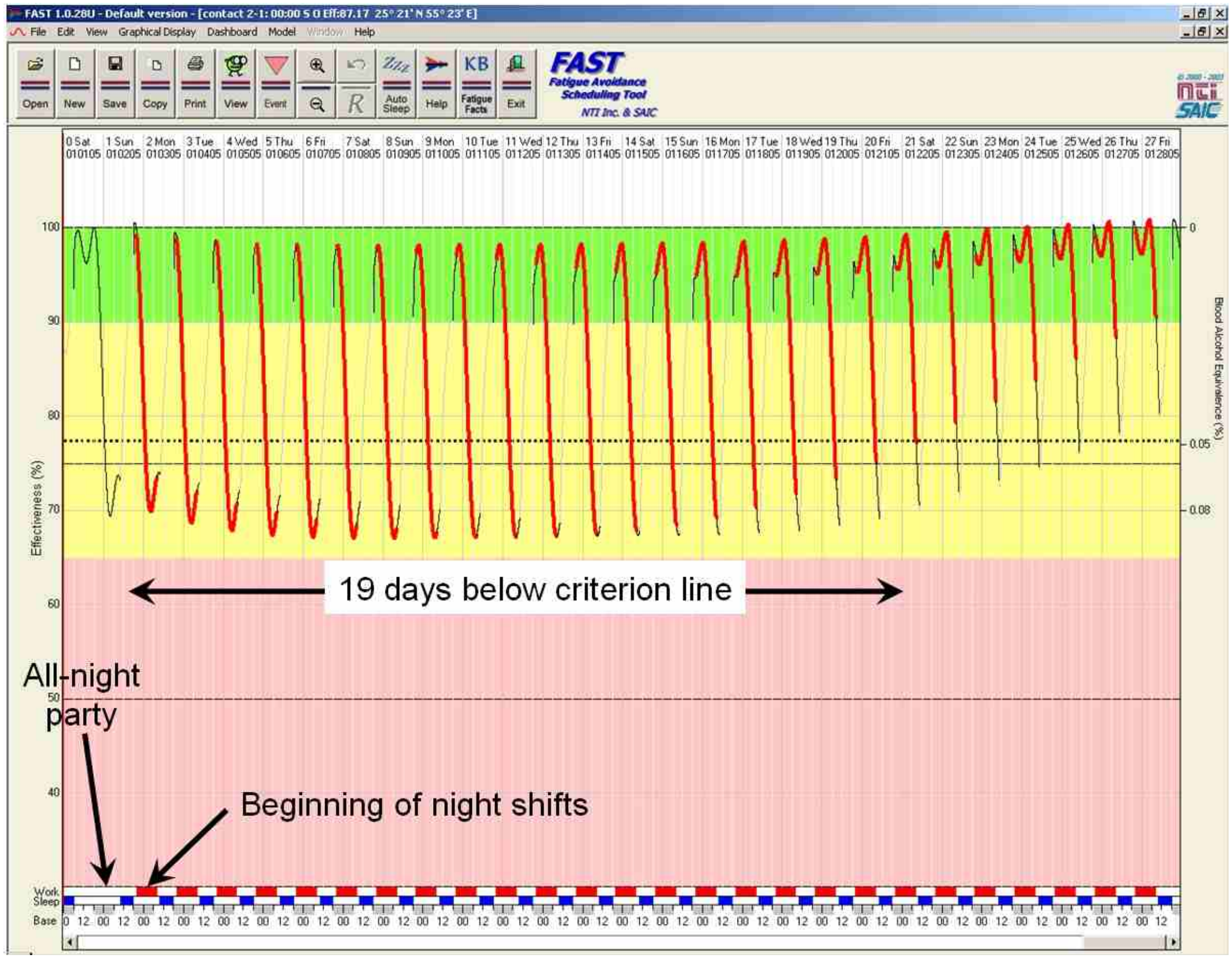


Figure 5.

Wow, the Skipper's plan is even worse than you thought! FAST predicts the crew will be spending the latter part of each shift well below the 90% effectiveness level, and won't be fully adapted to the night shift until after 25 days. For nineteen days, they'll spend at least some time toward the end of each shift below the "criterion line" where performance is predicted to be 77% or less, equivalent to having a blood alcohol concentration (BAC) of 0.05%.

Now you revise the schedule, and instead of throwing a party the night of transition, you not only allow the crew their normal night's sleep but add in a 3 hour nap at the afternoon circadian dip the following day, just before the crew starts its first full night of duty. FAST plots the following (Figure 6.):

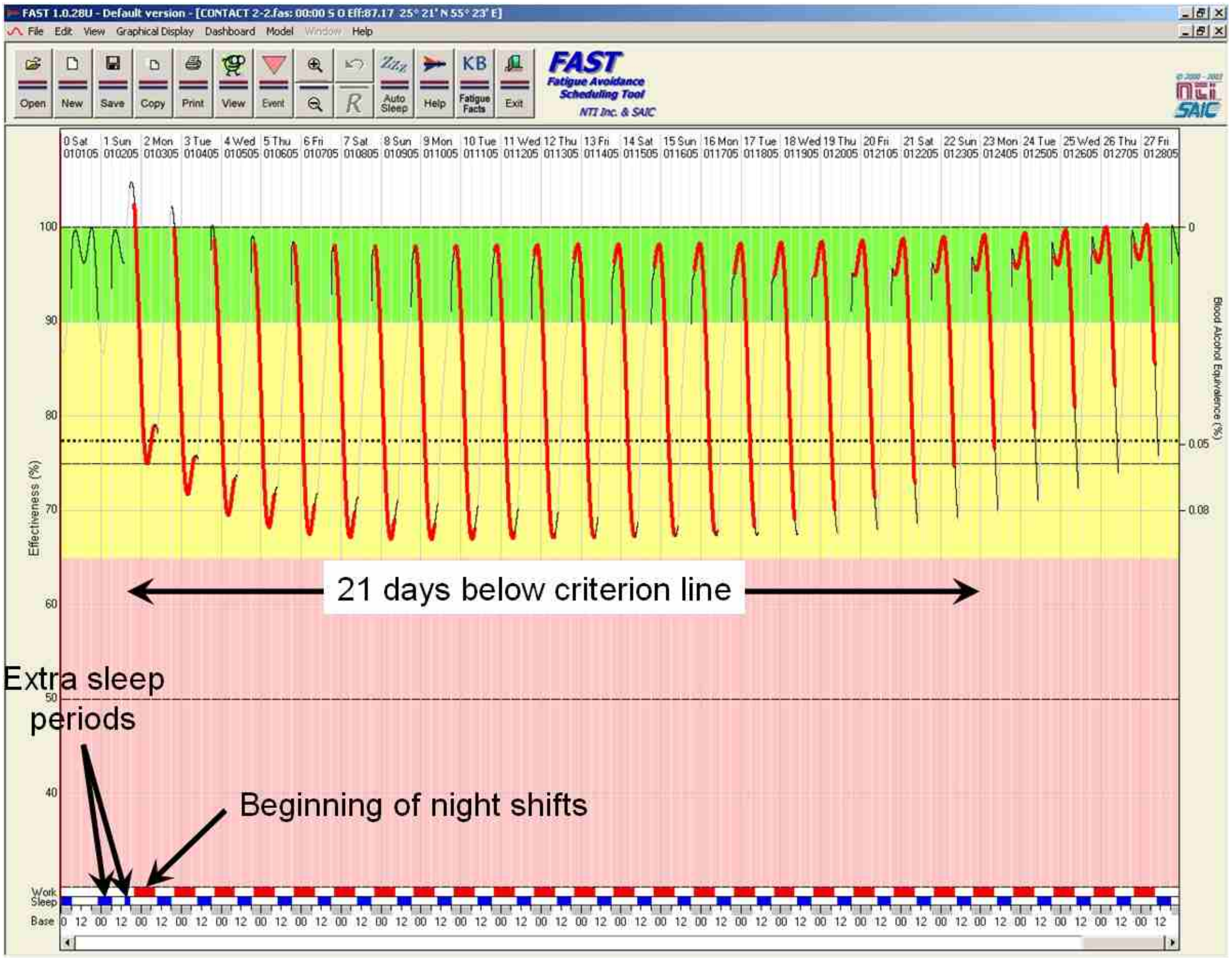


Figure 6.

Holy smokes! This isn't much better. The first few days of the new schedule, people will be working a bit better than before during the first part of the shift, but in fact, it now takes 2 days longer before the crew are fully adapted to the night shift (27 days vs. 25), and for 21 days they're spending at least some of the latter part of each shift below the criterion line. Your plan has given them a bit of an edge during the first few days, at the cost of delaying their ultimate adaptation to a night schedule by another day or two.

You go back to your Skipper, and tell him the crew is going to be significantly degraded with either schedule, and you recommend that the other carrier be designated the night carrier. Your Skipper fires you on the spot, and appoints your General Surgeon to be the new SMO who, having survived a general surgery residency, feels that all this stuff about fatigue is mere piffle.

Dr. Steven Hursh, the inventor of the SAFTE model used in the FAST program, explains that, due to continued daylight exposure with people on a night schedule, they never fully adapt to night shift work. The FAST program projects that it takes 2.6 times longer to shift from a day to night schedule than it would for the equivalent transmeridian travel of 12 hours, based on experimental data. Dr. Nita Miller, fatigue researcher at the Naval Postgraduate School, has shown that crews who are completely below decks and away from daylight exposure, can adjust their circadian rhythms to accommodate night shift work, but those who work the flight deck never fully accommodate. FAST is simply illustrating what shift workers have known for years – few really adapt fully to a night schedule. In order to become the "night carrier" you're going to have to recognize the significant degradation in performance that the crew will be operating under, and develop additional risk controls such as increased error-checking and oversight, more rigorous work rules, simplifying mission demands, and providing backup staffing, among others.

Scenario #2.

You've been in the Gulf awhile now, and are still due for your first port call. With great anticipation, tomorrow you'll pull into Jebel Ali for a well-earned 6-day port visit, beer in the Sand Box, and all the other benefits of beachside life. But one of your Wing Flight Surgeons approaches you with a problem. Turns out that the new Executive Officer of the Dark Clouds is reporting aboard today, and the Carrier Air Group Commander wants him to get his day carrier quals before going into port tomorrow. Oh, by the way, the prospective XO has just traveled from CONUS, with a 9-hour transmeridian time shift, and has been up for the past 45 hours except for 4 hours of sleep he snatched last night in the Dubai airport before reporting aboard this morning. You and your Wing Flight Surgeons suspect fatigue will be an issue, and that it would be better to convince CAG to give this poor aviator a nap instead of a day CQ.

"CAG, Sir, I've heard that CDR 'Roger' Ball arrived this morning by helo, and that you plan to have him do his day CQ this afternoon? Are you crazy, Sir?"

You explain what you know about fatigue physiology, sleep deprivation, circadian shifts, and the resulting performance decrement and increased risk of mishaps, but CAG tells you that: a) no, he's not crazy; he's CAG; b) that CDR Ball is a senior, experienced Naval Aviator, a great stick, and that he can hack it, and that; c) this fatigue stuff doesn't apply to Naval Aviators, who are not made of mere mortal flesh.

Muttering under your breath, you retreat to your office and crank up the computer. You enter what you know about the XO's sleep schedule before he reported aboard, and the latitude and longitude of Norfolk, his point of origin; London, where he changed planes; and Dubai, his ultimate destination, 9 time zones to the east (FAST calculates this automatically based on the coordinates of the origin and destination). You enter all times into the program based on local time in Norfolk. When you enter the sleep period in the Dubai airport, you rate it as "poor" (you have two other choices, "excellent" and "fair"), based on your extensive experience sleeping in airports in the past. FAST gives the following predicted performance plot for CDR Ball (Figure 7):

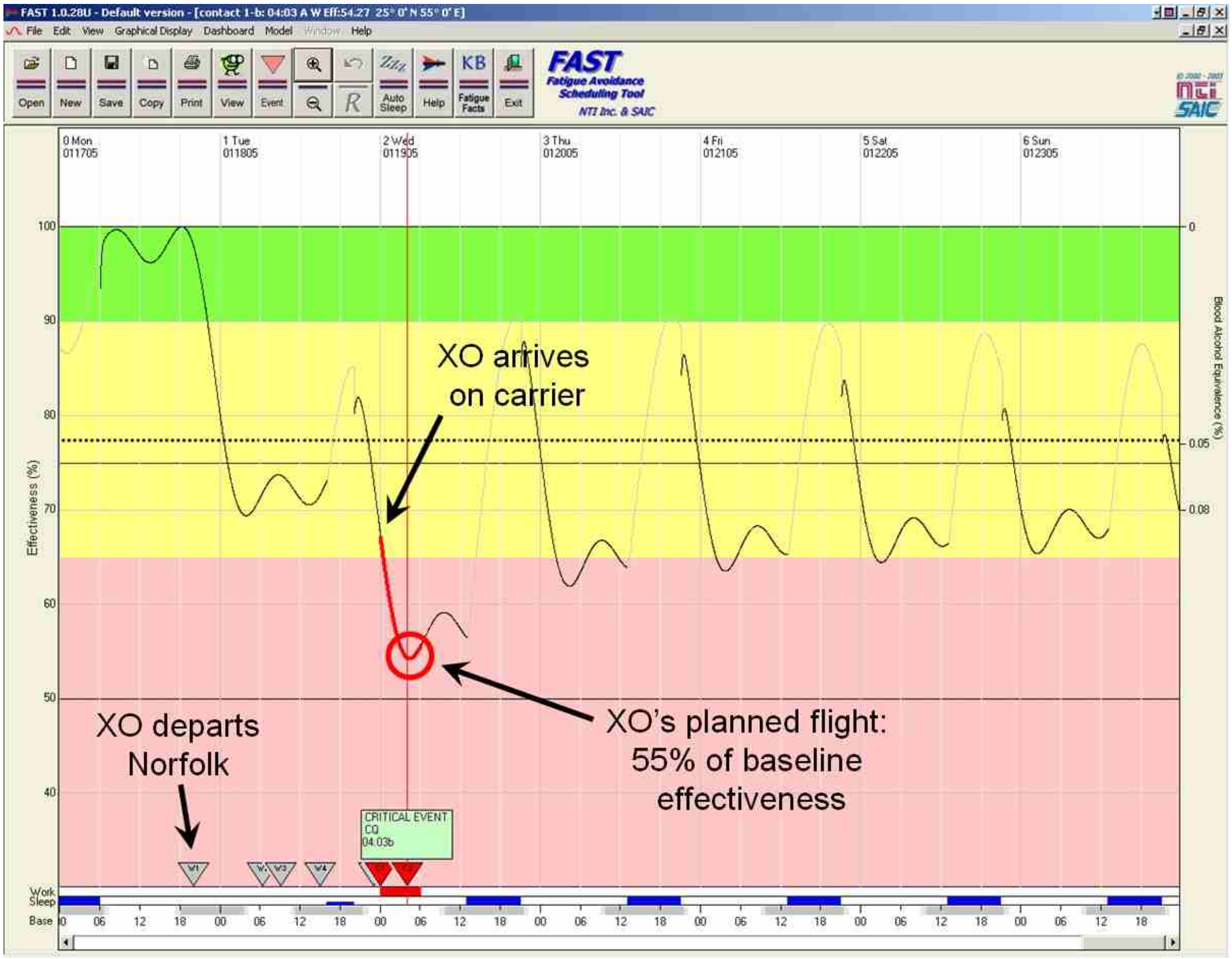


Figure 7.

As you suspect, FAST predicts that CDR Ball is significantly fatigued, and that at the time of his scheduled flight, he'll be around 55% of baseline effectiveness, and much worse than the equivalent legally intoxicated line of a BAC of 0.08%. FAST predicts that the whole day the new XO is aboard ship, his performance would be more impaired than if he were legally drunk! You go back to CAG and give him the plot, showing your numbers.

"CAG, Sir, you can put this into your Operational Risk Matrix worksheet concerning CDR Ball's flight," and you harrumph off. CAG, being an aviator, is able to ignore the best of medical advice, but he cannot ignore a number. He decides to postpone CDR Ball's Day CQ until after the port call.

Scenario #3:

You're the Flight Surgeon investigating a mishap where you think fatigue might be an issue. The mishap involves a flight crew that gets distracted by a missing strobe light on approach, allows the plane to get dangerously slow, with an eventual departure from controlled flight and impact short of the runway. The mishap happened a little after 1600 local time, after the pilot had been continuously awake for 29 hours. You take a very good 72-hour history on the involved fight crew (who survived the mishap), along with some knowledge of their usual sleep habits, and plot these in FAST (Figure 8).

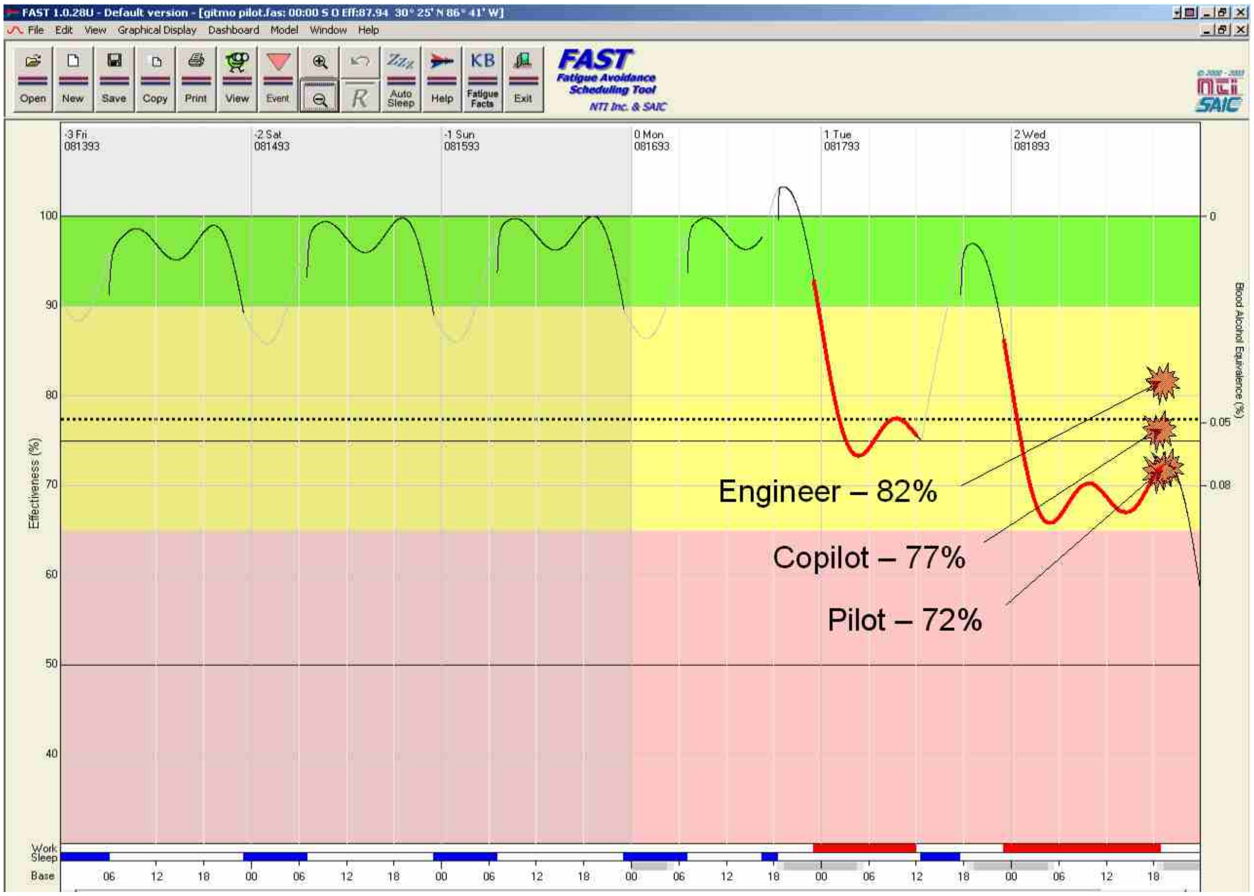


Figure 8.

(For clarity, only the pilot's sleep, duty and fatigue plot is shown, but the results of the copilot and flight engineer at the time of the mishap are also listed). FAST shows us that all three aircrew are projected to be significantly impaired due to sleep deprivation and extended duty periods. (This is an actual mishap example, taken from the National Transportation Safety Board files, at http://www.ntsb.gov/. Search their database for **NTSB Report Number:** PB94-910406, if you're curious about the details).

We've used FAST in these three examples to demonstrate where it might assist you in quantifying the impact of fatigue on performance, based on knowledge of sleep and duty cycles. FAST will also suggest rational sleep schedules, if you specify the duty times involved. Recognize that FAST estimates performance deterioration in average individuals only, and can't account for individual variation. Self-reported sleep is known to be less accurate than sleep that is measured by wrist actigraphy or EEG recordings. And the impairment from fatigue and alcohol isn't strictly comparable on all tests of performance used, only that the general drop in performance between both is similar. FAST currently doesn't account for the effects of performance maintaining drugs like caffeine, amphetamine, or modafinil. Developers are investigating ways to model those effects in newer versions of the program. Yet within these limitations, FAST promises to be extremely useful in assisting with flight schedules, assessing the average deterioration that might be expected from sleep deprivation, and in analyzing mishap scenarios for fatigue effects. And it's an outstanding tool to help you educate your aviators on the detrimental effects of fatigue.

The FAST program is still under development, and is being updated and revised on a continual basis, but you can obtain a copy for download and use if you're in the Department of Defense. Please drop me an e-mail for additional information on obtaining the program, and additional fatigue information. By becoming an expert in the assessment and management of fatigue, you can help protect your aviators and perhaps change the culture on one of our most important mishap causal factors. I look forward to hearing from you.

CAPT Nick Davenport

Figure 2 reproduced in *CONTACT*, the Newsletter of the Society of U.S. Naval Flight Surgeons, Vol. 29, N. 2, April 2005, with permission from *Nature* (http://www.nature.com).

Figure 3 taken from: *The SAFTE™ Model and Fatigue Avoidance Scheduling Tool (FAST™)*. Hursh, Steven R.; Program Manager, Biomedical Modeling and Analysis, Science Applications International Corp.

Figures 4-8 plotted from FAST™; version U-1.28.

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