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A NEW BASELINE FOR CHRONIC FATIGUE: WHY MEASURING FLIGHT TIME IS THE
WRONG APPROACH

by

John C. McClelland Jr., Maj, USAF

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Advisor: Dr. Gregory F. Intoccia

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Abstract

The Air Force recognizes the effects of high operational tempos on aircrew and currently limits workload by a quarterly maximum flight time period (FTP) requirement, not maximum flight duty period (FDP). Long FDP/Long FTP crews, like those flying the surveillance and refueling missions, are adequately protected from chronic fatigue because their work period and flight hours are both coincident. Long FDP/Short FTP crews, like those flying inter-theatre airlift are not properly protected and have to create ad-hoc programs at the squadron level, through the manipulation of the Operational Risk Management (ORM) process. The current measurement creates an imbalance in maximum quarterly workload of long FDP/long FTP aircrew when compared to long FDP/short FTP aircrew. Admittedly, adding new restrictions could require the USAF to increase the amount of airlift crews. However, costs associated with this increase could be offset by preventing catastrophic losses like the gear up C-17 landing in 2008 (\$19 million in damages) and the C-17 long landing crash in 2010 (\$78 million in damages), accidents in which pilot error was found to be either causal or contributory.

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List of Acronyms

AFI – Air Force Instruction

AMC – Air Mobility Command

AOR – Area of Responsibility

ARMS – Aviation Resource Management System

CAS – Close Air Support

CFR – Code of Federal Regulations

FAA – Federal Aviation Administration

FAST – Fatigue Avoidance Scheduling Tool

FDP – Flight Duty Period

FTP – Flight Time Period

ORM – Operational Risk Management

PIC – Pilot In Command

SAFTE – Sleep, Activity, Fatigue, and Task Effectiveness

SWA – Southwest Asia

TACC – Tanker Airlift Control Center

USAF – United States Air Force

USTRANSOM – United States Transportation Command

Preface

The first time I was deployed to Iraq, it was as a finance officer. The deployment lasted three months and was not particularly difficult. The hours were long, but without having to worry about daily items such as laundry and social activities, I found the twelve hours a day that I was not at work more than enough to spend time at the gym and get plenty of rest. After a couple of years, I cross-trained and was now assigned as a pilot to a C-17 squadron and it was time to deploy again. This deployment was difficult. As a C-17 crewmember, a twelve hour day was short duty. Many times we would alert and then spend the next twenty-four hours on a mission that would take us across five time zones before I got back to my home airfield, grabbed a bite to eat and collapsed from exhaustion in my room. The plan was usually for my crew to get sixteen hours on the ground and after the mission the day before, about fourteen hours of this time would be spent asleep. This continued for four months.

Half way through that C-17 deployment, I ran into a friend that I had graduated pilot training with. We sat and discussed our deployments and how things were going. I explained how tired I was and how worn out I felt. I was shocked to learn that he did not feel the same way. His deployment, I learned, was only eight weeks in duration and involved duty days of no more than twelve hours. Upon further discussion I learned that the reason for his shorter deployment was because of the amount of flight time he was accruing. He was spending most of his time on his mission in the air, and there were rules as to how much time he could log in three months. He wondered how I was not accruing more flight time. I explained that the majority our mission time was spent on the ground at the “out base”, loading and unloading our aircraft. I explained that on a twenty-four hour duty day I might only record four hours of actual time aloft.

I still remember his response to my explanation of the situation. My friend turned to me and termed the most succinct summation of the situation that I have heard. He said, “That stinks.”

The differences in our two situations struck me as odd. I worked longer hours, with a more complicated mission and yet he was the one that the rules protected. He was the one that the USAF regulations said should be more tired, because he was the one accumulating more flight hours. I was exhausted, melancholy and just plain worn out. He was fresh and ready to finish his deployment. How did we get to this point and why was this the best solution that the greatest air force in the world could come up with? I set forth to further research the topic and see whether a better solution existed. That search has culminated in this paper.

Introduction

In the post-Cold War, post nuclear world, the real strategic military headquarters is not the Strategic Air Command at Offutt AFB in Nebraska, but the United States transportation Command at Scott AFB, Illinois.

--Col Harry Summers, USA

“The Rise of Air Mobility and Its Generals”

There is a critical link between today’s military response to the threats the United States faces in the world and airlift doctrine.¹ The United States Armed Forces face continual need for equipment and troops during our long war against international terrorism. The country turns to the men and women of the US Transportation Command (USTRANSOM) to make these logistical needs a reality. The aerial arm of USTRANSCOM is largely made up by the United States Air Force’s (USAF) Air Mobility Command (AMC) by way of the 618th Air and Space Operations Center (TACC). In 2011, TACC controlled 89,399 sorties, delivering 1,918,085 passengers and 707,028 tons of cargo.² These missions are paramount to the USAF’s ability to realize the National Military Strategy and more specifically to the USAF’s core competency of providing Rapid Global Mobility. A poorly thought out or ineffectively executed airlift doctrine can have far ranging impacts on national military strategy.³

The success or failure of TACC relies on the concerted effort and teamwork of every Airman in AMC. However, no single Airman contributes more to the success or failure of an aerial cargo mission than the actual crewmembers of the aircraft performing the mission. Aircrews are frequently deployed to austere locations and asked to perform non-standard, time-

critical missions. Many times the aircrew member is asked to perform flight duties into the twenty-fourth hour of a workday. After being given as little as sixteen hours to rest and recover they are asked to then perform the same mission again. This maximum effort requirement can persist throughout an aircrew member's entire deployment, up to six months in length. To combat against overwork and fatigue, the USAF employs several regulatory limits and uses fatigue models to best utilize aircrew. The USAF regulations are based on flight hours. Flight models are based on several factors but only look back at the crews' previous seven day history.

Fatigue in all persons, including aircrew, makes them more susceptible to making mistakes. One can easily assume that longer work length periods increase fatigue. The USAF realizes that many aircrew members perform missions in which the majority of their flight workday is spent on the ground. If this is all true, then is measuring flight time and a seven day history, as the basis for measuring all types of fatigue during a lengthy deployment, safe for aircrews flying high tempo combat airlift? Is there are better method to predict and combat chronic fatigue?

To answer the question, this paper will focus on those symptoms of fatigue that do not directly correspond to a lack of sleep. It is important to delineate between different types of fatigue because this paper assumes that acute and cumulative fatigue are properly mitigated by rest in the short term. Acute fatigue is the state of feeling tired due to a lack of sleep, prolonged mental or physical work or extended periods of stress and anxiety.⁴ An example is a person not getting enough sleep the night before and then falling asleep while operating a vehicle the next day. Cumulative fatigue is characterized by a lack of proper sleep over a given course of time creating fatigue of some residual effect.⁵ Cumulative fatigue is the result of what physiologists refer to as "sleep debt". An example of this type of fatigue is a soldier who falls asleep at his

post after repeated nights spent on watch. Lastly, there is chronic fatigue. Chronic fatigue is a complicated subject but is generally characterized by extreme fatigue that cannot be explained by any underlying medical condition. The fatigue may worsen with physical or mental activity, but does not improve with short periods of rest. An example of chronic fatigue is a soldier that has worked seventy hours a week for the last four months of their deployment and feels depressed, uncaring and exhausted. Chronic fatigue is known in Army digests as “burnout”.⁶ Chronic fatigue is also known to predispose workers to chronic job stress and burnout, most commonly manifesting as emotional exhaustion.⁷ It is characterized not by the loss of physical skills but instead by an overall lack of attention to detail, a decrease in morale and a feeling of hopelessness. This is synonymous with what is commonly referred to as a “mental breakdown”.

Fatigue models throughout the military and civilian aviation community deal extensively with the effects of short (24-hour) and medium (96-hour) fatigue. Acute fatigue management models will not be the focus of this effort. Instead, this paper will deal with the effects of long periods of time on task over the course of weeks and months. The author will attempt to gauge the effectiveness of current regulations and techniques in identifying and mitigating the effects of chronic fatigue on deployed combat aircrew.

The author will employ a problem/solution framework along with a phenomenological study to determine what effects chronic fatigue has on aircrew and how the USAF can better execute its chronic fatigue management program. The main focus of this problem/solution framework is to examine past and current operations to identify links between USAF mitigation strategies and their effectiveness in minimizing operational hazards associated with long term fatigue. The effort of the phenomenological study will serve to tie operational leadership attitudes to USAF regulations, accident rates and deployment lengths.

BACKGROUND AND SIGNIFICANCE

The issue of chronic fatigue on a flying deployment is not a new development. During World War II, a British flight surgeon serving with a Royal Bomber Squadron observed the effects of multiple missions on combat aircrews ⁸:

and by the exhaustion of continued emotional strain. None the less, immediately after beginning a tour there is a perceptible rise in morale ; this is due to the feeling of accomplishment and maturity now that the long months of training are left behind, and to the novelty, excitement and interest of this final stage of experience and adventure. By about the fifth sortie this surge in morale has begun to give place to the recognition already mentioned of the formidable reality of the tour. This tends to continue, in some cases almost subconsciously, until by the twelfth or fifteenth sortie the man has reached the stage in which the full realization of the danger and unpleasantness of the job has been forced upon him while there stretches in front of him an ominously large succession of repeated sorties before he can achieve the honourable completion of his tour. Indeed, while seeming more desirable than ever before, this now appears so remote as to be an unprofitable and almost impractical goal on which to pin his hopes.

The problems of chronic combat fatigue are not limited to flying aircrew. US Army studies on soldiers exposed to lengthy periods of combat stress have found that chronic fatigue can lead to motivational exhaustion, commonly referred to as “burnout”, and usually results from excessive unmanaged stress. Restorative measures for chronic fatigue are only temporary if stress continues.⁹ Signs and symptoms of stress related fatigue in an individual include: concentration and attention are difficult, feelings appear dull and sluggish, general attempts to conserve energy, feel or appear careless, uncoordinated, confused, or irritable. Cognitive effects include: “all or nothing” thinking, failure to focus on the here and now, and too many “musts” and “shoulds.” Unfortunately, fatigue is an insidious stressor because warfighters usually become mentally fatigued before they become physically fatigued. In fact, usually the cognitive deficits are seen by others before the physical signs and symptoms are felt by those affected.¹⁰

There are specific guidelines that extensively protect aircrew from acute fatigue, flight time period (FTP) and Flight Duty Periods are strictly monitored and limited on individual

sorties. FTP is the amount of time spent physically aloft in an aircraft. FDP is the amount of time from the beginning of the alert sequence to the shutting down of the aircraft engines. The USAF has a policy that strictly enforces time away from work prior to the aircrew reporting for a flying mission. The time mandatory time away from work is referred to as “crew rest” and is prescribed to with sometimes maniacal devotion. The rules pertaining to crew rest are extensive but for the purpose of this paper the reader needs to know several key points. First, aircrew members cannot fly unless they are given 12 hours away from work. This rule can be broken, but requires a waiver and the waiver is rarely, if ever, issued. Secondly, ten hours must be made available to the crew member for “restful activities” of which eight hours must include the opportunity of uninterrupted sleep. This rule is not subject to waiver.¹¹

DESCRIPTION OF THE PROBLEM

The USAF has failed to adequately address and mitigate the serious effects of chronic fatigue on tactical airlift aircrew. The USAF recognizes the effects of fatigue on aircrew members and has several policies in place to mitigate acute and cumulative fatigue factors. Air Force Instruction (AFI) 11-202 Volume 3 (11-202V3), states that regardless of authorized Flight Duty Period (FDP), the Pilot In Command (PIC) will restrict duty time, extend crew rest periods or terminate a mission/mission leg if safety may be compromised by fatigue factors.¹² The failure lies not in protection against acute fatigue, but in the much harder to detect and therefore potentially more dangerous effects of chronic fatigue. In fact, the Air Force only has two statements regarding and limiting crew exposure to repeated missions involving extended (over 18 hours) FDPs. The first is a general statement from the AFI 11-202V3 that to combat against fatigue, commanders should grant additional crew rest, or limit consecutive duty days, during surge, combat, max-effort, or operations near maximum FDPs. The second, and more regulatory in nature, is the requirement that aircrew members log no more than 330 flight hours per 90 consecutive days.¹³ Both of these statements fail to protect some airlift aircrew deployed on lengthy combat deployments. The first requires action on the part of junior officer acting as the aircraft commander to self identify to more senior leadership when they are too tired to accept a mission. The second does nothing to protect aircrew flying long flight duty missions who log relatively few actual flight hours. This situation is common in aircrew flying tactical air transport missions.

The current system used by the USAF of limiting workload by a quarterly maximum FDP is insufficient because it does not adequately protect aircrew from chronic fatigue in airlift squadrons participating in high tempo combat operations. Airlift squadrons perform high FDP

but low FTP missions due to the start and stop characteristic of their sortie profiles. Asking PIC's to inform command of when they are too tired to safely complete a mission is unreasonable in the short term and inconsistent in the long term. Crewmember fatigue should be tied to crew member workload. Crewmember workload should be measured by considering the amount of time spent performing crewmember duties and tasks. Crewmember duties include, but are not limited to times when the aircraft is in the air.

The lack of quality protections from chronic fatigue in combat aircrew is the result of several factors. The first is the USAF's mirroring of current Federal Aviation Administration's (FAA) Flight Aviation Regulations (FAR) Part 121 Section 521 policies, which limit cumulative aircrew workload by time "aloft". The USAF must adhere to FAA regulations in most cases. The second is an ongoing view of researchers in the civilian and military communities to focus on fatigue in only the short and medium term. Extensive studies have been accomplished to measure reaction times after short term sleep deprivation, but little to no evidence exists of what factors may contribute to additional chronic fatigue in deployed air crew members. Data that does exist pertaining to longer periods of work stress has been performed in flight simulators where the crews were able to return to their regular daily lives after lengthy work shifts.¹⁴ The reason for the oversight is not nefarious. Prior to the existence of a decade long asymmetrical struggle against non-state actors on the other side of the planet, it is doubtful that fatigue researchers saw the need to test aircrew fatigue levels with the added stressors of months away from home, repeated time shifts, and short flight time periods mixed with long duty days. This lack of evidence to the causes of chronic fatigue has left the matter largely un-addressed by USAF regulations.

KEY ISSUES

Human error causes of fatal aircraft accidents constitute more than half of all aviation accidents,¹⁵ therefore every step should be taken to mitigate any factors that contribute to human error. The first key issue to consider is the difference between FTP versus FDP between various aircrew in AMC. Traditional methods of measuring fatigue by observing flight hours logged has very little bearing on deployed aircrew flying tactical transport missions. Their duty day may last over 24 hours, but due to long ground times off-loading and on-loading the aircraft, a small fraction of this time is likely to be recorded in the pilot's logbook. The result is squadrons flying these missions are left to develop their own safeguards when deciding how to measure and mitigate levels of cumulative fatigue. At the aircrew level, the aircraft commander is put in the unenviable position of having to tell his unit leadership when they are too tired to fly. The result is a community within the Air Force that works past the point of exhaustion and has a correspondingly higher level of Class A mishaps.¹⁶

A fatigued aircrew member is more dangerous than a fatigued soldier. A fatigued soldier may fail to properly aim his weapon and this mistake may cost him his life. A fatigued pilot, may fail to properly flair or brake the aircraft, may miss a radio communication and create a hazardous situation with another aircraft, or may fail to properly calculate take off and landing distance and run into one of the several towering mountains in Afghanistan. The margin for error in aircrew is less, and the cost for a mistake is greater. To display the cost of aircrew error, a table below lists every Class-A mishap in AMC since 2002 in which a human factor has been either causal or contributory.

(Table 1) AMC Class-A Mishaps – Human Factors Contributory or Causal¹⁷

Mishap Date, Local	Mishap Class	Cost	One-liner	Contingency Operation
2003	A	\$1,220,016.00	C-17A -- AIRCRAFT LANDED IN CONSTRUCTION ZONE OF OPERATIONAL RUNWAY	Yes
2005	A	\$1,429,361.00	C-17A -- MULTIPLE UNRELATED ANNUNCIATIONS - UNRECOGNIZED WING FIRE	No
2005	A	\$1,608,589.00	C-17A -- HARD LANDING-FUSELAGE UNDERSIDE DAMAGE, NO INJURIES	Yes
2005	A	\$16,600,000.00	C-17A -- RUNWAY DEPARTURE DURING LANDING-ACFT DMG-MINOR INJ	Yes
2005	A	\$1,004,343.00	C-5A -- BRAKE OVERHEAT/FIRE AFTER LANDING/TAXI-NO INJURIES	No
2006	A	\$312,400,000.00	C-5A -- ACFT EMERGENCY RETURN TO BASE-LANDED SHORT-ACFT DESTROYED	No
2006	A	\$5,600,000	C-130 -- FIRE IN WHEEL WELL AFTER LANDING, BRAKE/ MLG DAMAGE	Yes
2006	A	\$18,078,382.00	KC-135R -- GRND COLL WITH HOST NATION/USAF ACFT.WING/ENG DMG, NO INJURY	Yes
2006	A	\$6,529,800.00	C-21A -- ACFT DEPART RWY NEAR APPROACH END/FIRE, CREW EGRESSSED	No
2007	A	\$946,961.00	C-5B -- WING TIP IMPACTS BLAST FENCE WHILE TAXIING	Yes
2009	A	\$18,913,000.00	C-17A -- ACFT LANDED GEAR UP; SIGNIFICANT DAMAGE TO UNDERCARRIAGE; CREW EGRESS OK	Yes
2010	A	\$8,368,481.00	C-17A -- ENTERED SEVERE WEATHER; 4-ENG FLAMEOUT/AIRCRAFT DAMAGE; LANDED SAFELY	Yes
2011	A	\$2,887,689.00	C-130H2 -- ON FINAL APPROACH MIDAIR W/ARMY SHADOW UAV, UAV DESTROYED; NO INJURIES	Yes
2012	A	\$69,400,000.00	C17A -- DEPARTED RUNWAY ON LANDING; NO INJURIES; AIRFRAME DAMAGE	Yes
2012	A	\$1,277,776.00	C-130H -- FIREFIGHTING DUTIES; IMPACTED TERRAIN; 4 FATALITIES	No
		\$449,664,398.00		66%

The second key issue is the lack of attention paid to fatigue, outside of that which is caused by sleep deprivation. The FAA has published new guidelines limiting air crew workload based on daily duty period, but has done nothing to extend the restrictions over a longer course of time.¹⁸ Likewise, the USAF approach focuses quite thoroughly and myopically on acute fatigue symptoms. The current fatigue management system allows for continuous workdays of 24 hours of flight duty followed by 16 hours of rest, with no breaks mandated to account for what a 40-hour daily work and sleep cycle on a four month deployment will do to the health and mental well being of an aircrew member. As Dr. Nancy Wessensten of the Center for Military Psychiatry and Neurosciences Research puts it, “I am looking for a path that gets to what you know from experience is a big problem: a schedule that looks good by one criterion (can be) clearly dysfunctional by another”.¹⁹

Definitions of Cumulative Fatigue

Federal Aviation Administration (FAA)

The following section is how the FAA recently described fatigue in their foundations for the passing of new regulations dealing with aircrew work periods and crew rest facilities that were approved in 2012 and will take effect in 2014. To the FAA, “fatigue is characterized by extreme tiredness, typically resulting from mental or physical exertion or illness.” They go on to say that, “fatigue manifests in the aviation context not only when pilots fall asleep in the cockpit in flight, but perhaps more importantly, when they are insufficiently alert during take-off and landing.” The FAA reports that fatigue-related events have included procedural errors, unstable approaches, lining up with the wrong runway, and landing without clearances.²⁰

Common symptoms of fatigue include: ²¹

- Measurable reduction in speed and accuracy of performance,
- Lapses of attention and vigilance,
- Delayed reactions,
- Impaired logical reasoning and decision-making, including a reduced ability to assess risk or appreciate consequences of actions,
- Reduced situational awareness, and
- Low motivation to perform optional activities.

A variety of factors contribute to whether an individual experiences fatigue as well as the severity of that fatigue. The major factors affecting fatigue include:²²

- ***Time of day.*** Fatigue is, in part, a function of circadian rhythms. All other factors being equal, fatigue is most likely, and, when present, most severe, between the hours of 2:00 a.m. and 6:00 a.m.
- ***Amount of recent sleep.*** If a person has had significantly less than eight hours of sleep in the past 24 hours, he or she is more likely to be fatigued.
- ***Time awake.*** A person who has been continually awake for a long period of time since his or her last major sleep period is more likely to be fatigued.
- ***Cumulative sleep debt.*** For the average person, cumulative sleep debt is the difference between the amount of sleep a person has received over the past several days, and the amount of sleep he or she would have received with eight hours of sleep a night.
- ***Time on task.*** The longer a person has continuously been doing a job without a break, the more likely he or she is to be fatigued.
- ***Individual variation.*** Individuals respond to fatigue factors differently and may become fatigued at different times, and to different degrees of severity, under the same circumstances.¹⁹

Scientific research and experimentation have consistently demonstrated that adequate sleep sustains performance. Several aviation-specific work schedule factors can affect sleep and subsequent alertness following long haul missions. These include early start times, extended work periods, insufficient time off between work periods, insufficient recovery time off between consecutive work periods, amount of work time within a shift or duty period, number of consecutive work periods, night work through one's window of circadian low, daytime sleep periods, and day-tonight or night-to-day transitions.²³

USAF Physiology & USAF Regulations

The USAF recognizes the effects of fatigue on aircrew members and has several policies in place to mitigate acute and cumulative fatigue factors. AFI 11-202V3 states that “regardless of authorized Flight Duty Period (FDP), the Pilot In Command (PIC) will restrict duty time, extend crew rest periods or terminate a mission/mission leg if safety may be compromised by fatigue factors.” The USAF has two statements regarding and limiting crew exposure to repeated missions involving extended (over 18 hours) FDPs. The first is a general statement from the AFI 11-202V3 that to combat cumulative fatigue, commanders should consider granting additional crew rest, or limit consecutive duty days, during surge, combat, max-effort, or operations near maximum FDPs.²⁴ The second, and more regulatory in nature, is the requirement that aircrew members log no more than 330 flight hours per 90 consecutive days.²⁵

The regulation defines a crew rest period as, “the non-duty period before the flight duty period begins. Its purpose is to allow the aircrew member the opportunity for adequate rest before performing in-flight duties. “Crew rest is free time, which includes time for meals, transportation, and rest.”²⁶ It defines rest as “the condition which allows an individual the opportunity to sleep.” Crew rest is normally 12 hours prior to the FDP and requires at least eight hours of uninterrupted rest within the specific time period. Any official business that results in crew rest interruptions (including telephone calls) results in eight additional hours of uninterrupted rest with additional time provided to dress, eat, travel, etc.²⁷

The AFI defines the FDP as “a period that starts when an aircrew reports for a mission, briefing, or other official duty and ends when engines are shut down at the end of a mission, mission leg, or a series of missions.”²⁸ The Air Force also details the maximum FDP based on the aircraft type; a descriptive chart is provided below with the published guidelines. Total flight

time is limited to 125 hours within any 30 consecutive day period. The instruction has provided other scheduling restrictions that cover SCUBA diving, hypobaric chambers, blood donations, and alcohol consumption. The final portion of the instruction includes waiver authority, which permits the Major Command Director of Operations or the Air National Guard Director of Operations to extend the maximum FDP up to two additional hours if the mission priority justifies the risk of fatigue.²⁹ The PIC is granted this authority if circumstances arise that prohibit the ability to contact the regular approval authority. This is a necessary delegation of authority due to the nature of military operations in which aircrew often operate under electronic emissions restrictions or outside of communication reception ranges. ([Table 2](#)) Maximum FDP:³⁰

Aircraft Type	Basic Aircrew	Augmented Aircrew
Single Control Aircraft	12	NA
Fighter, Attack or Trainer (Dual Control)	12	16
Bomber, Reconnaissance, Electronic Warfare, or Battle Management (Dual Control)	16	24
Tanker/Transport (includes T-39 and T-43)	16	NA
Tanker/Transport (Sleeping Provisions) (includes T-39 and T-43)	16	24
Rotary Wing (without Auto Flight Control System)	12	14
Rotary Wing (with Auto Flight Control System)	14	18
Utility	12	18
Unmanned Aircraft System (Single Control)	12	NA
Unmanned Aircraft System (Dual Control)	16	NA

The USAF uses fatigue management software called “Fly Awake” to schedule crews. Fly Awake is based on the Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE/FAST) model.³¹ The model predicts how effective a crew member will be at certain points during the mission. Variables include sortie duration and the time of day in which the mission begins and ends. The model has some substantial failings when applied to the way in which aircrew are employed in current operations. It was designed to predict how alert an aircrew member would

be on a specific day given enough rest the day before and shifts spent in the time zone after acclimatization. The model is described below.

SAFTE/FAST

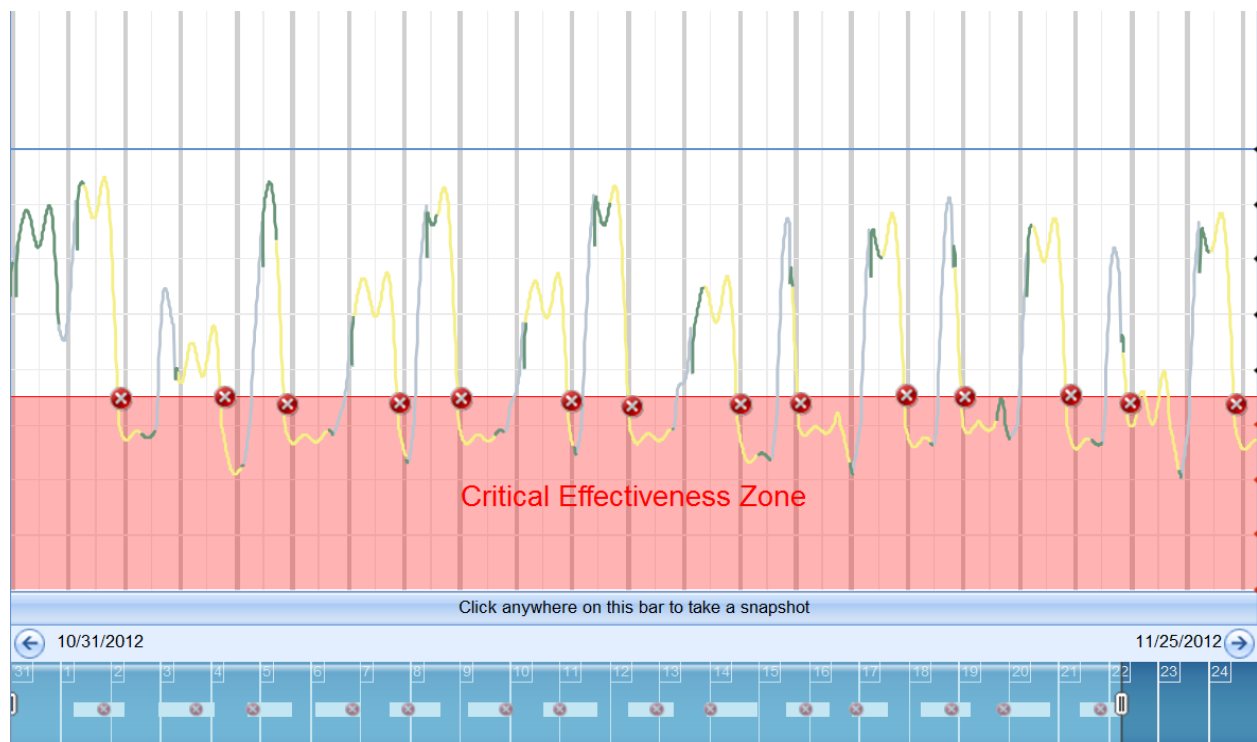
The Department of Defense's Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) model produces an "applied model of human cognitive performance effectiveness" by integrating the effects of prior wakefulness, the amount of sleep, and circadian rhythms.³² The Fatigue Avoidance Scheduling Tool (FAST), based on the SAFTE model, allows users to predict level of fatigue based on work and sleep cycles and circadian rhythms. The SAFTE/FAST model is now used in civilian aviation operations as well.³³ The limitations on the model are in the long term causes of fatigue. The model deals with acute fatigue from variables that are measured no more than seven days in the past. It works well when seen through the prism of the next mission, but not when seen on fatigue mitigation during the course of an entire deployment.

Flyawake

Flyawake is an initiative created by the Air National Guard and marketed to the USAF 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.³⁴ The maximum system look back is seven days,³⁵ a severe limitation when considering cumulative fatigue built up over a three to six month period. One simply has to load a fictitious crew into the model to see exactly how severe these limitations can become. For example, below is the Flyawake prediction for a crew that has been on eighteen hour missions with fourteen hours of crew rest for one-hundred and eighty days. In reality, any rational person would doubt that a crew member working a 94-hour average work

week, continuously for one half of a year, would not be suffering from some type of chronic fatigue. However, since the model fails to capture any residual sleep debt outside of seven days, it shows the crew completely ready to report for duty. Please note in the chart below, the scheduler has set the crew on near maximum FDP missions for the last 21 consecutive days of the crew's deployment. As the chart shows, the Flyawake model will return consistently optimistic results, so long as the crew has had enough time to sleep and does not experience day/night or night/day shifts in alert time. It does not consider the chronic effect that long duty days would have on an aircrew over the course of this three week simulated schedule. Further tampering with the model reveals that it will never take into account the overall fatigue that is acquired beyond seven days. Every day the crew is shown to report fully or nearly fully effective for the following sortie despite their harrowing schedule.

(Table 3) Flyawake Results:



Comparing Different Air Mobility Command (AMC) Airframes

To illustrate the difficulties facing crews deployed on inter-theater airlift missions we will compare three typical two week periods for three different AMC aircrew. The platforms were chosen to demonstrate the differences in the inter- (non-deployed) versus intra- (deployed) theater missions for the same major weapons system platform and then the variance for crews deployed to the same geographical locations with different missions. Two popular platforms in the deployed area are the C-17A Globemaster III and the KC-135R Stratotanker. The 14-day crew mission histories are replications of actual mission histories acquired by the author during time spent serving as the senior mission director serving at an undisclosed location in Southwest Asia.

The C-17 flies a varying assortment of inter- or intra-theater airlift missions. The inter- or strategic missions alert crews from home station where they are assigned on trips with varying lengths predetermined at day one. These trip lengths vary, but are usually 14 to 21 days in length. C-17 crew members on deployments can expect to be gone for four months. There are several main hubs for operations, but as one might expect of a tactical airlift resource, deployed crews fly to many fields throughout the area of responsibility (AOR). C-17 crews normally fly every other day, with duty days lasting over 18-hours.

Deployed KC-135 crews fly refueling missions throughout the AOR from several primary bases. Rarely if ever, will a KC-135 land at somewhere that is not a primary hub. A KC-135 deployment almost never extends beyond 60 days. This deployment length is restricted in length due to maximum quarterly flight time limits imposed by the AFI 202v3. KC-135 crews typically fly everyday with duty days averaging 12 or more hours.

Sample 14 day missions:

(Table 4) C-17 Non-Deployed to Southwest Asia (SWA) CONUS/OCONUS

Day	Depart	Arrive	FTP	FDP
1	US	US	0.4	4
	US	Europe	8.7	9.7
2				
3	Europe	SWA	6.7	10.7
	SWA	SWA	3.8	5.8
4	SWA	SWA	2	7
	SWA	Europe	5	6
5				
6	Europe	SWA	6.4	8.4
	SWA	SWA	3.6	7.6
7	SWA	SWA	2.6	7.6
	SWA	SWA	0.3	1.3
8				
9	SWA	Europe	6	8
10	Europe	US	6.7	9.3
	US	US	3.3	5.3
	US	US	1.4	2.4
11				
12				
13				
14				
Totals			56.9	93.1
Ratio of FTP to FDP			61%	

(Table 5) C-17 Deployed to SWA

Day	Depart	Arrive	FTP	FDP
1	SWA	SWA	2	5.5
	SWA	SWA	0.7	1.8
	SWA	SWA	0.6	1.6
	SWA	SWA	0.4	1.3
	SWA	SWA	1.6	2.6
2				
3	SWA	SWA	1.2	7.2
	SWA	SWA	1.2	2.8
	SWA	SWA	0.5	2.4
	SWA	SWA	0.8	2.3
4				
5	SWA	SWA	2	6.5
	SWA	SWA	1.4	3.5
	SWA	SWA	1	3
	SWA	SWA	1.5	2.5
	SWA	SWA	1.2	3.3
6				
7	SWA	SWA	1	6.3
	SWA	SWA	0.5	2.2
	SWA	SWA	1.5	3.8
	SWA	SWA	0.9	1.8
	SWA	SWA	1.6	2.6
8				
9	SWA	SWA	3.2	7.5
	SWA	SWA	3.5	4.5
	SWA	SWA	3.8	6.6
	SWA	SWA	4.4	5.4
10				
11				
12				
13	SWA	SWA	2	6.5
	SWA	SWA	0.5	1.6
	SWA	SWA	0.7	2.8
	SWA	SWA	0.4	2.3
	SWA	SWA	1.5	2.6
14				
Totals			41.6	102.8
Ratio of FTP to FDP			40%	

(Table 6) KC-135 Deployed to SWA

Day	Depart	Arrive	FTP	FDP
1	SWA	SWA	6.7	10.7
2	SWA	SWA	6.6	10.6
3	SWA	SWA	7.5	11.5
4	SWA	SWA	7	11
5				
6	SWA	SWA	7.8	11.8
7	SWA	SWA	6.7	10.7
8	SWA	SWA	6.2	10.2
9	SWA	SWA	7	11
10	SWA	SWA	6.8	10.8
11				
12	SWA	SWA	7.2	11.2
13	SWA	SWA	6.1	10.1
14	SWA	SWA	6.8	10.8
Totals			82.4	130.4
Ratio of FTP to FDP			63%	

From the data above, several key elements that contribute to chronic fatigue are evident. The percentage of FTP for non-deployed C-17 aircrew and deployed KC-135 crews are roughly equivalent (61 percent vs. 63 percent). Meanwhile, ratios for deployed C-17 crew members are much lower (40 percent). Total FDP for C-17 deployed aircrews are 110 percent of the non-deployed aircrews (102.8 vs. 93.1), but they log only 73 percent as much flight time (41.6 vs. 56.9). Meanwhile, the deployed C-17 crew works 79 percent (102.8 vs. 130.4) as much as the KC-135, but logs only 50 percent as much flight time (41.6 vs. 82.4). It is logical to assume those aircrews who work longer hours are more at risk of the effects of chronic fatigue over the course of a deployment. However, in these scenarios there are two crews who will reach the 330 per 90-day limit and it is not the two that work the most hours. The KC-135 crew is roughly 25 percent to 330 flight hours after 14 days; while the non-deployed C-17 crew is 17 percent of the way to the quarterly max FTP. Meanwhile the deployed C-17 aircrew is only 12.6 percent of the

way to 330 flight hours. In fact, the deployed C-17 aircrew could deploy continuously, year round with this flying schedule and never reach the USAF prescribed limits.

This dilemma illustrates the problem with cumulative fatigue limitations based on FTP. The logic behind this regulation assumes time spent loading and unloading an aircraft is the same as time spent not working. It assumes that a mission in which there is one takeoff and then a one landing at home station seven hours later is more difficult than a mission where a crew has to takeoff and land at five different airports because the total “gear up” time was only five hours. This assumption is illogical.

Comparing Deployments

Unprecedented demands have been placed on US military forces since September 11, 2001 and the beginning of the long war on international terrorism. These demands have meant long deployment cycles for most military members. The USAF shifted from a four month rotational cycle to a six month rotational cycle in 2010 in a move designed to improve predictability and stability for airman and their families.³⁶ This shift was applied across the board and also applied to aircrew members. This policy shift has been applied to most deploying aircrew members. Aircrew that are not deploying longer are those that cannot extend their deployments because of flight time limits currently contained in the AFI 11-202V3.

Deployment lengths vary for different airframes. While serving as the mission director for a deployed wing, the author was able to observe the different lengths and interview deployed squadron commanders employing different airframes. Fourteen commanders and directors of operations were interviewed and asked the same questions about deployment lengths and cumulative fatigue. Answers varied but every interviewee stated quite candidly that

effectiveness of deployed crews peaks before the end of the deployment. The optimal deployment length varied per squadron but a 30-day deployment was the stated minimum and a 75-day deployment was the stated maximum. The mean for maximum effectiveness was a 42-day deployment.

The most striking difference in the interview responses were those between units with shorter deployments and those with longer ones. The shorter deployment cycles were driven by the 330-flight-hour maximum quarterly requirement. For example, the deployed KC-135 unit averaged 77 days for their active duty and 70 days for their Guard/Reserve augmentees. The commander of this squadron described optimal performance as 30 to 45 days into the deployment with a rapid drop off in effectiveness following 45 days.³⁷ The KC-135 squadron mitigates the effects of time shift (day versus night alert sequences) by placing crews in four hours windows corresponding to their latest alert. This squadron had no cumulative fatigue measures in place, as no aircrew had cancelled a mission due to fatigue. The USAF prescribed limits were effectively limiting the exposure to cumulative fatigue for this squadron.

In another example, the deployed C-17 squadron at the same location had a different view on deployment length and cumulative fatigue. This squadron actively tracked duty times and average crew rest times between missions. The C-17 commander had experienced crews cancelling missions due to over fatigue and had implemented additional measures thru the Operational Risk Management (ORM) construct to attempt to gauge how much the crews were working.³⁸ The squadron managed cumulative fatigue through internal procedures, placing personnel on desk duty, performing theater focused training pertaining to sleep management and sending crew members to the flight medicine office to obtain medicinal sleeping aides.

The responses from the C-130 squadron mirrored the responses from the deployed C-17 squadron located at the same air base. The command element was conscience of the effects of cumulative fatigue and were tracking work load internally in much the same way as the C-17 squadron. Other internal measures included scheduling extended breaks of 72 hours or more when available and tracking how long each crew served flying since their last extended break. Like the C-17 squadron, additional measures had been added through the ORM construct to gauge the level of workload for individual crew members.³⁹

The difference between the approaches of these squadrons is due to the length of deployments they are required to perform. The KC-135 squadron can only deploy for eight weeks, due to the amount of flight time they are accumulating. The C-17 and C-130 crews are not at risk of exceeding the USAF prescribed limits and therefore are able to deploy for a longer duration. The KC-135 squadron does not add measures to combat cumulative fatigue; they simply fly to the maximum extent possible, time out and go home. The C-17/C-130 squadrons are forced to measure workload and add ad-hoc procedures to ensure some protection for the aircrews performing the missions. The current system of measuring fatigue through the prism of time spent in the air is adequately protecting some, but not all deployed squadrons.

DISCUSSION OF POSSIBLE SOLUTIONS

There are several options for aviation cumulative fatigue management that are readily available to the USAF. Using the three key criteria each alternative has been scored using a one to ten scale with ten being ideal and one being not suitable for employment. Ease of implementation is how easily the USAF could implement the policy. Correlation to workload is a reflection of how accurately the proposed solution will tie in hours spent on task to metrics reported and evaluated. Mission uniformity describes how the precisely the proposed solution applies to different mission sets across the USAF spectrum of deployed aircraft and missions.

Evaluation Criteria for Measuring Cumulative Fatigue

Optimal criteria for measuring cumulative fatigue should contain several elements. It should correlate as closely as possible to the amount of time a crew member spends performing their flight related duties. It should also be something that is easily measured and readily managed. In a perfect world, crew members would not be required to track a new item in the Aviation Resource Management System (ARMS). If a new metric is required, it should be one that the crew members currently record. An ideal measurement system should be uniformly applicable to aircrew across different airframes and disciplines. A flight in an A-10 providing Close Air Support (CAS) and a surveillance mission orbiting off the coast of Iran are significantly different in nature and fatigue crews in significantly different ways. An ideal system would measure these different flight stressors and limit chronic fatigue from consistent exposure over a deployment cycle, despite the differences in USAF mission profiles.

Option 1- Measuring Quarterly Flight Hours - Status Quo

(Table 7)

Ease of Implementation	Correlation to Workload	Mission Uniformity
10	5	3

This process is currently used by the USAF to mitigate the effects of cumulative fatigue. As the status quo, it is effortless to implement. All aircrew currently track their flight hours through reporting in ARMS. Flight time is recorded for the aircraft and the aircrew and tracked by the squadron schedulers to ensure that no crew member exceeds the maximum allowable quarterly limits set for in the applicable Air Force Instructions.

From the sample mission histories previously included in this paper, one can see a correlation in mobility aircrew ranges between 40 and 60 percent of the entire FDP is flight time. The correlation of total time spent performing aviation related tasks to the amount of time spent logging flight time is roughly 50 percent, but it varies from mission to mission. The variance is due to mission complexities or time spent performing ground duties in between legs.

Mission uniformity is low because an hour of flight time represents different stress levels for different airframes and missions. For example, many fighter type aircraft have little to no automation, requiring the pilot to remain constantly vigilant to changes in airspeed and altitude. Compared to an airframe that has extensive autopilot and auto throttle systems, this difference represents an increase in work difficulty that contributes to fatigue in the aircrew. Furthermore, some missions are simply more difficult than others. This increased difficulty is the result of an increase in decision points critical to the safety of the aircrew or the mission successfulness in general. For example, some missions may require multiple landings to different airfields in a constantly changing threat environment, weapon employment, aerial refueling, reverse taxiing,

formation flying, etc. Other missions may require little more than a takeoff, eight hours of flight in which aircraft automation is employed the entire time and a single landing to a familiar field.

Option 2 - Measuring Quarterly Flight Duty Periods

([Table 8](#))

Ease of Implementation	Correlation to Workload	Mission Uniformity
9	9	3

Flight duty periods are currently tracked by individual aircrew members because of regulations limiting their work length to 12, 16 or 24 hours (mission, crew and MAJCOM dependent). The expected mission FDP is reported to the crew at the time they are first alerted by the command post or operational scheduler. Since the crew is already aware and keeping track of their daily FDP, asking them to report these numbers to ARMS for weekly, monthly and quarterly recording will be easy to implement. The most difficult portion of implementation will be adding the FDP to the flight histories and adjusting current crew management software to account for a regulatory change.

While not perfect, tracking the time from when an aircrew alerts for a mission to the time they finish the post-flight checklist captures most of the flight workday of a typical deployed aircrew. It captures time spent during intelligence briefs, time spent performing pre-flight checklist, time spent loading and unloading the airframe, time spent briefing the formation, etc. This is all time that is not captured in the current status quo.

This option scores low in mission uniformity for the exact same reasons listed for poor mission uniformity in option one.

Option 3 - Requiring Quarterly Dwell Time

[\(Table 9\)](#)

Ease of Implementation	Correlation to Workload	Mission Uniformity
4	9	3

One option currently under consideration is to base limitations not on how much an aircrew works, but how much down time they get over a period of time. The idea is very similar to the FDP limitation proposal. The major difference is in the ease of implementation. The dwell time option would require personnel to track a new item in ARMS. In practice, operational schedulers would track FDP and subtract it from total time. It would be more efficient to track FDP and limit workload based on ease of implementation.

The correlation to workload would be equivalent to option two and the mission uniformity would be the same as option one and option two.

Option 4 - Measuring Quarterly Flight Tasks

[\(Table 10\)](#)

Ease of Implementation	Correlation to Workload	Mission Uniformity
2	7	9

The FAA is considering limiting FDPs based on flight segments. A flight segment for the FAA consists of one approach and one landing. The USAF could implement a similar system using a point system based on actions of the crew in flight. Points could be assigned for aerial refueling, weapons engagement, takeoffs, landings, taxiing under reverse thrust, etc. The point system would be based on the number of actions a crewmember is required to perform and tailored by the USAF for specific events in specific aircraft types.

The most obvious constraint to this system is the difficulty of implementation and employment. It is extremely difficult for a planning and scheduling cell to know which crews can still perform which actions before exceeding their prescribed point value. This difficulty in planning could prove to be a severe operational constraint for the deployed planning and scheduling cell.

Measuring fatigue by crew action point system would capture more total workload than the status quo, but not as efficiently as measuring FDP. More difficult missions sometimes add to the flight workday of a deployed air crew member, but not always. Many times, missions which require airdrop, multiple stops to unfamiliar fields, weapon employment or heightened combat threats will add to air crew workload, but not necessarily so if the mission has become routine. The best way to capture total air crew flight work day times continues to be measuring from the time the air crew alerts for the mission to the time they are complete with post flight duties.

Periods of action in the cockpit add to operational stress. This option would mitigate the problem of dissimilar missions detailed in option one. It would most nearly capture cumulative fatigue based on in flight stressors caused by multiple points of decision divergence and time spent where the air crew must remain in a more vigilant state of awareness.

Federal Aviation Administration (FAA) Solution

Beginning in 2014 new regulatory changes will be implemented to 14 CFR Parts 117, 119, and 121. The new regulation shifts cumulative fatigue limits from FTP to FDP. The ruling restricts FDP on a daily mission. The total FDP is determined by crew make-up, crew rest facilities on board, flight segments, acclimatization time and mission start time. The FAA ruling

is peculiar. It recognizes the effects of lengthy FDP and restricts the amount of cumulative fatigue that a flightcrew member endures before and during flights. Then it justifies the new restrictions on daily FDP by noting that cumulative duty periods can easily be tracked by scheduling programs currently in use throughout the industry. The FAA goes on to explain that they have decided to eliminate the cumulative duty period limits originally considered in the new regulation.⁴⁰ Since the FAA accepts that FDP is contributory to fatigue and that it easily tracked, one then has to assume that scheduling programs cannot be adjusted to track cumulative FDP. An assumption that is completely false. Scheduling programs could be changed to track FDP as easily as they track FTP. The reason for not changing the cumulative totals to reflect FDP remains a mystery.

Shortcomings aside, the new regulation is a step in the right direction. It recognizes that time spent planning and prepping an aircraft for flight can be as fatiguing as time spent flying. The new rule takes into account the difficulty of multiple leg missions, calling these legs segments. Differences are taken into account for when a crew begins their duty and what types of crew rest facilities are available. Overall, the new rulings are more robust and realistic than the previous FTP focused approach.

The FAA regulation contains exemptions for AMC aircraft participating in emergency and contingency operations, but these regulations will be difficult to implement for several reasons. First, an augmented crew by FAA rule is subject to severe restrictions as to when the additional crew member can be used in the flight and what amount of rest must be scheduled.⁴¹ This is different than the USAF definition in which the crew is considered augmented when a single additional pilot and loadmaster/boom operator (if required) are present.⁴² Secondly, the limiting of FDP by duty start time is not possible because of USAF inefficiencies in crew

alerting procedures and because many of the AMC inter-airlift missions are 24 hours in length and begin and end at night. Lastly, augmented crews per the FAA definition must have adequate crew rest facilities. The crew rest facilities must be free from noise with a 70 to 75-decibel level being the realistic engineering goal.⁴³

Noise reduction has not been a priority for USAF aircraft; the crew rest area of the C-17 sustains an average of 83 decibels at flight level cruise⁴⁴ and therefore would likely not qualify as an adequate crew rest location per the FAA regulations.

The new FAA rule does not completely solve the problem with respects to mitigating long FDP fatigue. It represents a step in the right direction and is the result of FAA personnel asking what is absolutely necessary in regards to improving a situation that had not been addressed in the flight safety community.⁴⁵ Original regulations from FAA regulation Part 121 Section 521, limited aircrew by reference to time aloft and FAA officials recognized the problem with associating limits with time aloft.⁴⁶ Cumulative limit changes in the 30 consecutive days and 90 consecutive days were left unchanged due to a lack of scientific data supporting a change and political realities that dictated a negotiated rather than “all or nothing” approach.⁴⁷

CONCLUSION

Proposed Solution: Measure Cumulative Fatigue by Flight Duty Period

No system is perfectly suited to completely mitigate the risk of cumulative fatigue on an USAF deployed aircrew member. Some solutions are however better suited than others. The current system is inadequate because it fails to offer any level of protection to a large community of deployed aircrews. Measuring downtime is feasible, but is unduly complicated to implement and offers no additional protection from the option of measuring and limiting FDP. Measuring cumulative fatigue by a point system based on aircrew activities is a wonderful solution in terms of measurement and evaluation, but is not flexible enough for deployed environments and is very difficult for schedulers and operational directors to actually implement. Limiting flight crew members by cumulative FDP levels is easy to implement, easy to track and plan for and protects a larger community of deployed aircrew than the status quo. Therefore, tracking and limiting cumulative FDP is the USAF's best alternative for mitigating chronic fatigue in combat aircrew. By measuring FDP instead of FTP, the USAF will; more accurately measure fatigue, have a better comparison between similar AMC deployments, and fix deployment length problems that may be contributing to higher accident rates.

Accurately Measuring Fatigue

Limiting quarterly workload by total FDP will improve safeguards currently employed by the USAF. This approach to preventing chronic fatigue will have several beneficial aspects when compared with the current system of limiting workload by flight time. It will help the USAF compare average workloads of typical AMC aircrew flying different aircraft. It will also

more accurately gauge the amount of time spent on deployment that an AMC aircrew can be deployed and still be reasonably expected to perform in a safe and consistent manner. When applied to aircrew across the USAF, this approach will most likely still not adequately protect those operating short FDP and short FTP missions. For example, even when limits are shifted to FDP versus FTP constraints, it is unlikely that fighter and ground attack operators would ever reach the newly prescribed limits. Even with this shortcoming, measuring workload limits by FDP would at least offer a greater amount of protection in the short-term and provide USAF leadership with more robust statistical database on workloads of crewmembers across the spectrum. Once more data is gathered, the USAF would then be able to more accurately tailor cumulative FDP limits based on typical workloads of varying aircraft in differing commands.

Comparing AMC Aircraft

This paper has attempted to show the differences in the flight logs and duty days of different AMC deployed and non-deployed aircraft. This section was limited due to constraints of research, experience and time. It is logical to assume that a problem shown so consistently when comparing two aircraft types and the aircrew flying them will be shown between other aircraft and aircrew throughout the USAF inventory.

By limiting cumulative FDP over the course of a deployment, the USAF in general and AMC more specifically, should be able to begin the process of reworking the deployment cycle ensuring that all aircrew are more adequately protected. The author is not able to predict with confidence what the new limits on FDP versus FTP should be at this time. The lack of not knowing what the exact solution should be, does not limit the author's confidence that a problem exists in consideration of those elements that are contributory factors to chronic fatigue and are

inconsistently mitigated by current regulations between different airframes of the same command. Also, the lack of an exact solution does not limit the confidence that through more research and better data an adequate solution can be found and implemented.

At this time, there is no definitive link between high rates of FDP and aircraft accident rates. This is not surprising when one considers that since the USAF does not limit workload by FDP, they do not have a clear picture of aircrew quarterly FDP statistics. It is impossible to measure against a number that one does not have. Furthermore, the author cannot prove a link between high FDP rates and pilot retention rates, because again, the number for cumulative FDP rates does not exist. At the very least, the USAF can begin to measure cumulative FDP so that a number will exist and a hypothesis can be either validated or disproved.

Measuring cumulative flight duty periods will require a new tracking item in aircrew member's flight records. Tracking FDP will, over time, give the USAF leadership a realistic view of how many hours the aircrew across the USAF communities are working in support of contingency missions, allowing them to set new limitations to better protect aircrew from chronic fatigue. Once a realistic benchmark is set the USAF can then begin the process of setting realistic limits on weekly and quarterly FDP.

Fixing Deployment Lengths

From the interviews with deployed squadron commanders mentioned earlier in this report, it is apparent that a shorter deployment cycle for aircrew members would be advantageous to mission effectiveness. The shorter cycles would mean more frequent deployments which would keep aircrew more current on procedures unique to airfields where they current deploy to. The increase in familiarity would mean less time spent during the

beginning of a deployment dedicated to re-indoctrination. The increased cost of more personnel movements is not borne as heavily in AMC as it might be in other commands and certainly not as much as it is by other departments such as the US Army. In fact, when one looks at typical duty histories of AMC aircrew and aircraft, one can see that there is a constant rotation of aircraft in and out of theater due to home station maintenance requirements. This constant rotation means that AMC aircrews would see little change in aircrew utilization rates. Rotating aircrew members would simply operate the inter-theater missions.

End Notes

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

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