AIRCREW PERFORMANCE
CUTTING-EDGE TECH

by
Kris M. Belland, Commander, USN

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AIRCREW PERFORMANCE CUTTING-EDGE TECHNOLOGY: EMERGING HUMAN PERFORMANCE ENHANCEMENT TECHNOLOGY VISION IN SUPPORT OF OPERATIONAL MILITARY AVIATION STRATEGY

Kris M. Belland, Commander, USN

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Commander Kris M. “Doc” Belland, USN, is a 1984 graduate of the United States Naval Academy and 1989 graduate of the Philadelphia College of Osteopathic Medicine. He is board certified in family practice and licensed as a physician and surgeon in California. After a general surgery internship at Oakland Naval Hospital, he attended the Naval Aerospace Medical Institute in Pensacola, Florida where he was designated a naval flight surgeon. This was followed by operational combat tours aboard the aircraft carriers USS Midway (CV-41), USS Independence (CV-62), and USS Carl Vinson (CVN-70), during Operation Southern Watch with Carrier Air Wings five and fourteen respectively. He was then selected for flight training, leading to an additional designation as a naval aviator. He has accrued over 1,200 hours of flight time in various aircraft including the F/A-18, F-14, EA-6B, and S-3 with over 112 arrested landings aboard aircraft carriers and 25 combat missions over Iraq. The Society of U. S. Naval Flight Surgeons has bestowed him with both the Richard Leuhrs Flight Surgeon of the Year Award for U.S. Navy and Marine Corps in 1994 and the Sonny Carter Memorial Award in 2000. He has been a co-investigator for Navy/Air Force photorefractive keratectomy (PRK) studies and battlefield laser experiments and is a Navy subject matter expert in directed energy weapons (battlefield lasers), Joint Strike Fighter, human performance maintenance during sustained/continuous operations, and human factors as they relate to mishap avoidance and mission accomplishment. He has served as senior dual-designated flight surgeon at Naval Strike and Air Warfare Center (NSAWC)/Navy Fighter Weapons School (TOPGUN) in Fallon, Nevada and is serving as the battle group Force Surgeon and Senior Medical Officer aboard (CV-63), USS Kitty Hawk, during Operation Iraqi Freedom.

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Abstract

Using cutting-edge technology to create a human factors advantage in military operations will contribute to success on the battlefield of the future—whether below the surface, on the surface, in the air, or in space. Human factors system selection in the past has appeared to be arbitrary and intermittent, with no unifying vision and apparently little or no coordination between the military services. Mature, timely applied technology will reduce risk and enhance combat capability. By decreasing mishaps during training and combat, there will be a reduced number of lost lives of highly trained and costly aircrew, while preserving training and combat assets—both manned aircraft and unmanned air vehicles. A concomitant increase in survivability through better understanding of human factors technology will ultimately give the modern aviation warrior a tactical edge throughout the full spectrum of combat and provide secondary benefits to the civilian aviation sector as well. This paper explains currently available and emerging aviation human factors technological advances in today's military aviation weapons systems and recommends a vision and direction for the most promising of these emerging aviation human factors-related technological advances.

I. Introduction to Human Performance

> *The quality of the box matters little. Success depends upon the man who sits in it.*
>
> — Baron Manfred von Richthofen
> 80 Victories, WWI

Manned flight will be around for a while:

No doubt, the future will hold an increasing emphasis on unmanned aero-vehicles and unmanned combat aero-vehicles to address the rapidly changing scenarios of war. However, current DOD procurement commitments and planning have guaranteed that manned aircraft will be in combat airspace of the future well beyond 2050. An example of this commitment to manned combat aircraft is the Joint Strike Fighter competition won by Lockheed Martin Aeronautics Company on 26 October 2001. The Joint Strike Fighter is scheduled for initial operational capability in 2011 for the Air Force and 2012 for Navy, with significant service life to follow, most likely past 2050.[1] CAPT William Miller, a U.S. Navy dual-designated flight surgeon and pilot, when discussing technology and human factors advances states:

> I think it is a matter of consciousness, bandwidth, and economy. The USAF proved that the required level of artificial intelligence is not here yet with "pilot's associate"…. There is no replacement for the combat aviator. The unpredictable flight environment demands a robust, reliable real-time operator. He or she has to be located in the battle space. How do you do the economic comparison when there really is no competing system available at any price?[2]

Manned combat aircraft are a fact of operational life for the near- and mid-term; even so, many human factors technological advances are equally applicable to both manned and un-manned military and civilian aviation environments. For the foreseeable future, human control over flight is here to stay.

Why are human factors so important to flight?

Atlas of Injuries in the U. S. Armed Forces, the latest and only study of its kind to determine the magnitude of the injury problem in the armed forces, covers a fifteen-year period between 1980-1994. This study shows that the highest cost for personnel mishaps was aviation, at a cost of $381 million dollars for fiscal year 1994 alone, with overall Department of Defense aviation losses calculated to be $632 million dollars.[3] The loss in life and National treasure is significant. The good news is military aviation mishaps continue to decrease. The bad news is the Department of Defense still loses an average of one to two aviators per week as an aggregate of all flying, including operational and training flights.[4]

In military aviation operations, one measure of human performance is human factors mishap rates. The Navy, as a representative service for mishaps, had total Naval aircraft losses between 1987 and 1996 recorded at $13.4 billion.[5] Of the 268 aircraft lost and 192 aircrew killed or severely injured, approximately fifty-five lives and over half of the lost aircraft could have been saved if technology available today had been implemented prior to the mishaps.[6] This represents a potential savings of between 3.52 and 7.15 billion dollars.[7] Estimated savings may have been realized if the technology of today was available in the studied mishap aircraft of the past. Some may dispute this claim due to the many variables involved, but it is one way to consider the benefits of implementing cutting-edge technological advancements.

Can't Technology fix it?

Americans are enamored with technology for technology's sake and all too often forget the critical man-machine interface piece of the equation when developing new weapon systems. Given that the human being matters most, there has been a paradoxical paucity in incorporating existing human factors specific technologies in combat aircraft. This is typified by the "stove-pipe" development of aircraft systems that rarely integrate multiple existing and emerging human factors concepts. Often, discovered technological advances and safety-related systems go unincorporated in current aircraft, primarily because of the military prioritization of weapons systems over human engineering/safety systems.[8] One example of this dearth of incorporated safety systems is the Automatic Ground Proximity Warning system that has been developed for fourteen years yet is still not included in many operational aircraft. Given the competitive nature of current DOD budgets, this prioritization is somewhat understandable; but this myopic view of technology incorporation is not a new thought. Azar Gat, when discussing Napoleonic Warfare wrote, "techno-tactical developments…had been virtually ignored by the military thinkers of the enlightenment."[9] So too is remains today, at least for human factors emerging technologies.

Is there any good news?

Although there has been a steady decrease in all types of mishaps over the years, there is still significant room for further reduction in the numbers of mishaps through the implementation and advancement of human factors technology development. There is a great potential for a significant savings of priceless lives and valuable training/combat assets. One should guard against merely accepting an improved status quo or even a single human/aircraft loss as the "cost of doing business." A quantum leap in civilian and military aircraft efficacy and safety is currently attainable if only the right resources are applied and senior leadership commitment is obtained.

Aviation human factors advances will decrease mishaps by freeing up the pilot from distracting aircraft operations and add an additional benefit of an increased ability of the pilot to employ the aircraft in combat. Workload will be decreased during all phases of flight, thus freeing pilot's cognitive processing to address tactical situations in a timely manner. Advances are almost universally applicable to manned and unmanned aircraft.

The remainder of this paper will describe emerging, cutting-edge human factors technology and put forth the methods to achieve them. Technology areas addressed here include fatigue, vision enhancement, NBC/DEW threats, and mishap reduction, as well as more nebulous areas of culture, situational awareness, spatial disorientation, simulators, and training. It is hoped that this vision will focus technological direction, so that the advances may be incorporated more rapidly into operational aviation combat systems. There is reason for hope.

II. Fatigue Operations

> *My mind clicks on and off…I try letting one eyelid close at a time while propping the other open with my will. But the effort is too much. Sleep is winning. My whole body argues dully that nothing, nothing life can attain, is quite so desirable as sleep.*
>
> C. A. Lindbergh
> The Spirit of St. Louis
> Reflecting on his 33 hour transatlantic solo flight

When fatigued, a pilot has decreased ability to handle an aircraft emergency or a surprise combat situation. Research has shown that after 17 hours of wakefulness, performance degradation is equivalent to an individual imbibing two drinks of alcohol. After twenty-four hours of wakefulness, that performance is degraded equal to a blood alcohol level of legal intoxication (0.10%).[10] However, many of us would readily drive a car or fly an aircraft after seventeen to twenty four hours of wakefulness, even though our performance would be equivalent to being “drunk.” Undoubtedly, fatigue is an insidious problem that most of us do not fully appreciate.

It is insightful to understand that since the beginning of aerial combat, the first pilot to detect the enemy enters the Observation-Orientation-Decision-Action (OODA) loop soonest. This allows that pilot to seize the tactical edge and to ultimately defeat the enemy. As John Boyd stated in his discourse on *Winning and Losing*, “Get inside adversary OODA-loops (at all levels) by being more subtle, more indistinct, more irregular, and quicker—yet appear to be otherwise.”[11] To win the conflicts of the future, aviators will need to be at and perform at their peak, and clearly, fatigue is a significant inhibitor of peak performance that must be controlled.

Fatigue is not due to lack of motivation or poor attitude. Sleep loss, circadian rhythm disruption, nutrition, environmental conditions, and hard work combine to produce fatigue. Sleep cannot be stored or built up prior to continuous or sustained operations, despite what some aviators may think. As a result, most aviators will become fatigued prior to combat flights due to extensive flight planning, nervousness, chair-flying mission, etc. Standardized tests show there are performance peaks and troughs throughout the day referred to as circadian rhythms.[12] Circadian rhythm, physical/mental fatigue, stresses, and cumulative fatigue all work against an aviator to impair performance to one degree or another.

Fatigue is Endemic to Military Operations

Between 1974 and 1992, the Air Force Safety Center attributed twenty-five percent of night tactical fighter Class A (greater than one million dollars damage or permanent disability/death), mishaps to fatigue.[13] The Naval Safety Center attributed twelve percent of Class A mishaps between 1977 and 1990 to fatigue.[14] Fatigue signs and symptoms include forgetfulness, poor decisions, fixation, reduced vigilance, poor communication, slowed reaction time, apathy, lethargy, change in mood, and micro-sleep.[15] Micro-sleep is very short periods of sleep, and may be as short as the momentary closure of the eyelids. Prior to combat flight operations, many aviators, particularly the senior ones, were heavily involved in strike planning and were fatigued to one extent or another.[16] Senior aviators flew all the early-on strikes into Iraq during Operation Southern Watch due to their rank and experience.[17] If an aviator is significantly fatigued at the start of combat operations, chronic or acute fatigue may ensue. Fatigue affects cognitive functions, which are the higher orders of thought processing that are used in combat. Other less obvious areas affected by fatigue includes leadership and supervisory duties.

Poor combat and safety performance is the ultimate price of fatigue in continuous operations. This is a double threat; not only is the safety margin decreased, but mission performance, which is the ability to defeat the enemy in the air or deliver ordnance on target, can also be adversely affected. The Navy Surgeon General says it best:

> Fatigue in sustained, continuous naval flight operations is expected and can lead to poor flight performance and increased aircraft mishap potential. Thus, preventing fatigue and maintaining optimal performance in sustained operations are primary concerns for squadron commanding officers and their flight surgeons. The uses of sleep, combat naps, proper nutrition, and caffeine are currently approved and accepted ways flight surgeons can

> recommend to prevent and manage fatigue. However, in sustained and continuous operations, these methods may be insufficient to prevent fatigue and maintain combat-ready performance. Properly administered use of stimulant and sedative medications, i.e., Dexedrine, Ambien, and Restoril, is an additional measure flight surgeons can recommend to manage fatigue and maintain pilot performance in continuous, sustained naval flight operations. [18]

Fatigue can and should be managed. The idea is not to create super-human performance, but to maintain an acceptable level of performance and avoid the degradation caused by fatigue during sustained or continuous flight operations.[19]

Go and No-Go Medications

> *They were dull-eyed, bodily worn and too tired to think connectedly. Even a thirty-minute flop on the turf with the stars for a blanket would have doubled the power of this body and quickened the minds of its leaders to ideas, which they had blanked out. But no one thought to take that precaution. The United States Army is indifferent toward common-sense rules by which the energy of men may be conserved in combat…. said Captain Patch of his people on the far right, "They were so beat that they could not understand words even if an order was clearly expressed. I was too tired to talk straight. Nothing I heard made a firm impression on me. I spoke jerkily in phrases because I could not remember the thoughts which had preceded what I said.*[20]
>
> S. Marshal
> *Night Drops: The American Invasion of Normandy*

Stimulant use to sustain performance continues to be controversial, and for some, it is a very emotional topic. Fatigue medications were successfully utilized by the Air Force during Operation Desert Storm.[21] One newspaper article title during the Operation Southern Watch was entitled "Gulf War Pilots Flew on Speed."[22] This article and the controversy surrounding stimulant use apparently resulted in the Air Force Chief of Staff, General Merrill McPeak, banning the use of stimulants on 13 March 1992. Current Air Force policy allows use of stimulants but only in a strictly regulated and voluntary way.[23] The very consideration of chemically influencing something as finely tuned as a military aviator's body and mind can be foreign to many, especially to physicians and flight surgeons whose mandate is "first do no harm." The United States Navy Surgeon General wrote the following in the forward of the Navy's recently released performance maintenance manual:

> Historically, the use of medications to maintain performance in aviators is not a new idea; the British and Germans used amphetamines during WWII in their pilots. Later, the British used sedatives to regulate sleep for pilots during the Falklands conflict. The U. S. Air Force and Navy used amphetamines in aviators during Vietnam, and the Air Force used both amphetamines and sedatives during Desert Storm and have used both off and on since. Use in all these circumstances was reported to be safe and effective.[24]

The Navy's Carrier Air Wing Five promulgated policy approving the use of stimulants and sedatives during sustained continuous operations prior to the beginning of Operation Southern Watch on 27 August 1992, and it additionally requested the use of these medications through the medical chain of command. Higher authority did not approve this request due to no standing policy to address the medication use in combat operations. This initial request from a forward deployed aircraft carrier ultimately resulted in the *United States Navy Performance Maintenance Manual*, initially published in 2000, a process that took over eight years.

The performance maintenance manual was also approved by the Carrier Air Wing commanders conference, a yearly meeting of US Navy Carrier Air Wing commanders, and the aviation board of senior naval aviation flag officers. The performance maintenance manual was also endorsed by the Naval Safety Center as an Operational Risk Management (ORM) tool to minimize the known risk of combat fatigue and was codified in the Naval Aviation Training and Operations Procedures Standardization manual.[25]

The United States Navy performance maintenance manual is now an accepted operational risk management tool to control fatigue during combat or exceptional circumstances of operational necessity as determined by the squadron Commanding Officer following consultation with the Air Wing Commander (or his equivalent) and Flight Surgeon. This guide for flight surgeons provides background on the subject, strategies for fatigue reduction, and guidance in the use of sleep-inducing and anti-fatigue medications (no-go and go pills) in aircrews. Commanding Officers, in consultation with their Flight Surgeons, are authorized the use of any of the strategies including stimulants and/or sedatives for pilots, naval flight officers, and aircrew when mission requirements and operational risk management indicate use would be appropriate.[26] The flight surgeon will consult with his supervisor in the aeromedical chain-of-command. No aviator is required to use these medications; in fact, rest (including combat naps), nutrition, self-regulation, and exercise are recommended and stressed above all other modalities. Only as a last resort is medication use recommended. The approved stimulant in the Navy is dextro-amphetamine, (Dexedrine), and approved sedatives include zolpidem (Ambien) and temazepam (Restoril). The Navy Surgeon General further states:

> The fleet's request to use stimulant and sedative medications during contemplated continuous and sustained flight operations provided the impetus to develop the performance maintenance manual. Naval Strike and Air Warfare Center collaborated with Naval Operational Medicine Institute and Naval Aerospace Medical Research Lab to develop a protocol for appropriate use of stimulants and sedatives. The performance maintenance manual was subsequently recommended by the Aeromedical Advisory Council and approved by Naval Operational Medical Institute as the acceptable standard of care guide for flight surgeons. Naval Operational Medical Institute appropriately cautions that use of stimulants and sedatives should be used only in combat or during exceptional circumstances of operational necessity and only with authorization by the squadron commanding officer.[27]

The military manages maintenance, fuel, and weapons; why not manage fatigue in a similar fashion?[28] That is, minimize fatigue by proper nutrition, exercise and rest, and only when necessary supplement with Go and No-Go medications. Further research is needed on the emerging and potential use of stimulants such as Pemoline, a sympathomimetic,[29] and sedatives/sleep inducing modalities such as Melatonin to support sustained air operations. DOD standardization of a performance maintenance manual type document would go a long way in addressing a known threat to airmen.

III. Vision Enhancement/Refractive Eye Surgery

*The guy you don't see will kill you***.**

Brigadier General Robin Olds, USAF
16 Victories, WWII and Vietnam

Like hands to a surgeon, a pilot maintains situational awareness through his senses, foremost of which is vision, and as discussed earlier, the first pilot to see his adversary enters the OODA loop and will be at an advantage. One emerging way to improve vision is with laser eye surgery. Significant strides have been completed and many more are under investigation in the fields of laser eye surgery. Refractive eye surgery is a surgical procedure on the cornea to adjust the focal point of the eye on the retina. Refractive surgery can correct myopia (near-sightedness), Hyperopia (far-sightedness), and some types of astigmatism (irregularities of the cornea).

Refractive Surgery Origin and History, (RK, PRK, LASIK)

Refractive surgery was first considered as early as 1898 by a Dutch professor and was unsuccessfully attempted in Japan in the 1930's. A Russian physician named Dr. Fyodorov later improved the procedure. His patients' vision markedly improved after a laceration and subsequent scar formation to the globe of the eye. Russian physicians then molded the surgery into a fine art. They would later perform the procedure in a conveyor belt fashion, providing the surgery to the largest number of individuals in the truest form of socialized medicine. This procedure is referred to as Radial Keratotomy (RK) because there are several surgical incisions made radially through the majority of the thickness of the cornea outwards toward the periphery of the eye. This results in fine, almost invisible scars that heal and change the focal point of the eye. This particular form of refractive surgery has now fallen out of favor for several reasons, including susceptibility of the corneal scar to later trauma. The scar can potentially cause a foreign body projectile aimed at the surgerized eye to be directed into the eye, resulting in a worse injury.

The event that most negatively affected the popularity of radial keratotomy, and is most significant to the aviation community, was discovered during a tragic Mt. Everest expedition. Dr. Beck Weathers, an individual who had received radial keratotomy surgery earlier, essentially became blind at altitude. He was disoriented, became lost from the main expedition for twenty-two hours, and nearly died. Later studies have confirmed a hyperopic shift in visual acuity of radial keratotomy patients that occurs at altitude.[30] A study by Mader et al., in 1999 of six radial keratotomy patients, six photorefractive keratectomy patients, and nine myopes (near-sighted persons) showed that with seventy-two hours of exposure at an altitude of 14,100 feet, radial keratotomy eyes had "significant, progressive, and reversible hyperoptic shifts." In other words, patients who received RK became blind at altitude, or their vision was significantly and adversely affected.[31] Additionally, diurnal visual acuity variations of treated eyes as well as glare issues have plagued radial keratotomy patients. As a result, RK is not compatible with military aviation.

Photo-Refractive Keratectomy (PRK)

Photo-Refractive Keratectomy (PRK), a follow-on procedure without many of the RK detractors, has become the laser eye surgery of choice for military aviation. PRK is the laser molding of the cornea with an excimer laser that uses ultraviolet wavelength pulsed energy to remove multiple small disc-shaped tissues. The epithelium or surface layer of the eye is first removed with the laser, and then the cornea is molded. The top layer of the eye rapidly grows back over the newly shaped cornea. Naval Special Forces known as SEALS were the first military group to embrace and financially support this vision correction technology due to operational necessity. It would be awkward at best to lose glasses while underwater, while conducting covert operations, or during hand-to-hand combat. Likewise, aviators have helmet-mounted displays to which glasses or contacts add an unwanted layer. In the possible ejection and survival scenario, the PRK recipient would have the advantage over those aviators with glasses that might be lost during the egress.

PRK Studies

Ongoing areas within the evaluation of photorefractive keratectomy include pressure chamber, centrifuge, contrast sensitivity, and

NVG effects. In 1998, Dr. Schallhorn, a prior TOPGUN Instructor and current navy ophthalmologist, believed that Naval Strike and Air Warfare Center (NSAWC), home of the Navy's TOPGUN School was the next logical step for a study to include naval flight officers. Due to the command's high operational tempo and flight envelope extremes, as well as night vision goggle lab and strong command support, it was an ideal place to conduct the study. A prospective study was constructed to select aircrew (not to include pilots) to evaluate night vision prior to and after photorefractive keratectomy. This evaluation would be one year in length and a joint study with the Air Force Research Laboratories. Out of sixty-five volunteers, thirty individuals passed screening for the study, including fifteen naval flight officers, one physiologist, and one aircrew member. The rest of the participants were non-rated active duty officers and enlisted personnel stationed at Naval Strike and Air Warfare Center in Fallon, Nevada. The results were overwhelmingly positive with better than seventy-five percent of recipients receiving visual acuity of 20/20 or better and night vision returning to better than baseline within two weeks of the photorefractive keratectomy procedure for all participants.[32] Most of the study participants started with visual acuities worse than 20/200. Two of the total NSAWC participants necessitated a second treatment to "fine-tune" their vision and later obtained better than 20/20 visual acuity.[33]

On a personnel morale note, the procedure was subsequently provided to fifty naval flight officers (NFO) stationed at Naval Strike and Air Warfare Center from 1998-2001, with overwhelmingly positive results. Some NFOs requested orders to come to the command so that they could enter the PRK study and receive the procedure, while others pulled letters of resignation in order to receive the procedure. This positive effect, especially during a time of severe aviator shortages, cannot be overemphasized. There were several cases of aviators whose vision had deteriorated to the point that they did not meet minimum visual acuity standards to fly, and their careers were subsequently saved by this procedure.

Research and an increasing body of anecdotal evidence suggest PRK is safe for all aviation environments, including ejection. There is a case of a lieutenant NFO who had ejected without subsequent injury after having received PRK a year earlier. The NFO was a qualified instructor in the S-3 Viking aircraft with over seven years of flight experience. During a training flight, his aircraft experienced a catastrophic engine failure, which necessitated an ejection at 120 knots airspeed at low altitude. Post-ejection examination showed that there were no significant injuries and visual acuity was unchanged at 20/20. There were no visual problems before, during, or after the ejection, and the NFO's vision and post PRK status was not listed as a causal factor in the mishap investigation report.[34] This ejection demonstrated one extreme facet of the safety of PRK.

Laser-Assisted *In Situ* Keratomileusis (LASIK)

LASIK offers the greatest potential for improving aviator vision and is the latest PRK-similar procedure. First, a flap of cornea is made and lifted out of the way, and then a laser (the same laser as PRK) is used to mold the cornea. After the procedure, the flap is returned over the laser treated cornea, and it acts as a natural dressing as the eye heals. LASIK eliminates the need for the surface layer or epithelium to grow back and is remarkable in that it begins to improve vision almost immediately after the surgery. The discomfort level is significantly less than for other refractive procedures. A study of altitude effects on LASIK recipients (subjects exposed to 14,100 feet for 72 hours) showed that after LASIK, subjects did not exhibit a refractive shift of clinical significance.[35] Therefore LASIK and PRK, recipients had no significant vision changes at altitude, unlike recipients of RK. The LASIK procedure holds great promise, and early joint research indications are encouraging.[36]

> "LASIK has been performed internationally for approximately 10 years. It was first performed in U.S. clinical trials in 1991. It is important to note that the major components of the procedure have a long history. Ophthalmologists have been reshaping the cornea for over 50 years, creating a protective layer of tissue for over 35 years, and using the excimer laser since the 1980's."[37]

Some of the unique considerations include 'Will the flap be stable at high altitudes especially in situations like explosive decompression of the cockpit in an emergency' and 'What would the effects on high altitude, wind blast, and low oxygenation experienced by the surgical site during a high speed, high altitude ejection be?' The other questions that relate directly to survival, escape, and evasion in enemy territory are 'How will the flap react during an ejection and then saltwater exposure (as many naval aviation mishaps occur over the water)? If the eyes are painful after ejection, then survival, escape, and evasion will be markedly affected. If the LASIK flap is not stable, especially during high-speed ejection, a salt-water exposure could potentially intensify pain and severely affect visual acuity and chances for survival. Some additional questions that need to be answered prior to approving the procedure include, 'Will the circular incision and scar of the LASIK flap interfere with day/night/enhanced night vision' and 'Will Mission Oriented Protective Posture gear required for the nuclear, biological, and chemical warfare environment be compatible with the eye surgery?' As these questions point out, many areas of research need to be conducted prior to approving the LASIK for Department of Defense aviators.

Disadvantages

Potential disadvantages of all refractive surgery are infection, over-or-under correction, and abnormal scar formation. LASIK specific potential disadvantages include questions as to the long-term stability of the flap and durability in the aviation environment, especially in the extreme ejection and survival scenario. There have been anecdotal cases of the LASIK flap becoming dislodged in patients up to two and one-half years after the initial procedure due to severe, direct trauma to the eye. Ongoing animal studies that subject a post LASIK eye to a jet blast of air to essentially recreate ejection forces are encouraging in that the flaps are remarkably stable.[38]

DOD Policy

In accordance with the current US Air Force and Navy policy for the air warfare community, all forms of corneal surgery are disqualifying. Photorefractive keratectomy is the only procedure that will be considered for waiver. Naval air warfare new accession applicants who have had PRK (civilians, Naval Reserve Officers Training Corps, Naval Academy, and enlisted accessions) may be waivered for aviation duty if they meet specific criteria (see appendix A) and are entered into the Navy's study protocol.[39] Even with early encouraging findings with photorefractive keratectomy, a metered, scientific approach is needed in order to conduct a timely evaluation of the efficacy of this procedure in the operational tactical environment of Department of Defense aviation.

Emerging Vision Concepts and Procedures

There are other procedures to correct vision. These include intra-corneal (intra-stromal) rings, which are clear plastic rings that are implanted into the cornea to change the shape and focal point of the eye. The Food and Drug Administration approved use of these rings in March of 1999. Additionally, intraocular lenses are being implanted in eyes to improve vision. These intraocular lenses are similar to contact lenses but are permanently implanted in the eye. Rings and implanted lenses are not currently approved for military aviation because no aviation specific studies have been conducted to prove safety and efficacy through all phases of military aviation.

Recent cutting-edge research is being done on a laser mapping of the eye technique called wave front mapping. A laser is flashed into the eye and the reflected/refracted energy is digitally gathered, stored, and calculated to produce a very exacting map of the imperfections of each eye. It is hoped that this exact mapping of the eye will assist in more precise correction in future refractive surgeries.[40] The theoretical best limit of vision correction for the human eye is approximately 20/10.

Controversies About Vision Correction

These refractive studies raise an interesting question…should these procedures be used to enhance vision? That is, should many aviators be corrected, including those that are already 20/20, to an unheard of visual acuity of 20/10? A super-human group of aviators would then exist who would have the advantage in any visual arena. Is maintenance of human performance the goal or rather enhancement to create a group of super-human weapon systems operators? Military medicine is ideally situated to study and recommend the road ahead in this exciting and emerging area of vision correction.

In the past, visual acuity has been the deciding factor for the initial selection of whether an aviator is a pilot or a flight officer. Now that there exists the ability to make every student aviator 20/20 or better, how will pilots be selected from flight officers? Should it be personal preference, or performance based upon the selection process? These are a few of the interesting and intriguing questions raised by this type of emerging human factors technology.

Parting Shots

Research efforts in the area of vision correction are rapidly progressing and are truly a joint effort. There is strong operational support for PRK, and aviators are pushing for early acceptance of LASIK in the US military aviator community. However, this desire to plunge ahead must be balanced with a measured scientific approach to the medical technology. It is important to ensure that the science supports the procedure for military aviation. It would not be prudent to approve a procedure that later was responsible for the loss of an aviator or loss of an aircraft only because appropriate basic research was not conducted. On the other hand, as soon as military medicine is comfortable with the stability of the LASIK procedure, it should be approved. Critical studies are ongoing and should be completed shortly.

IV. Nuclear Biological and Chemical (NBC) Threat Environment and the Tactical Air (TACAIR) Operator

> *One of the principal advantages of biological agents is that they are almost impossible to detect, which complicates the task of tracing the author of a biological attack. This makes them as suitable for terrorism and crime as for strategic warfare.... It is easier to make a biological weapon than to create an effective system of biological defense. Based on our current level of knowledge, at least seventy different types of bacteria, viruses, rickettsiae, and fungi can be weaponized. We can reliably treat no more than 20 to 30 percent of the diseases they cause.*[41]
>
> Ken Alibek, Secret Bio-weapons
> Soviet Union Biopreparat 1975-92
> First Deputy Chief 1988-92

Problem

Al Qaeda interest in weapons of mass destruction, as well as the weaponized *Bacillus anthracis* discovered in letters mailed within the United States, once again raises concern that nuclear, biological, and chemical (NBC) weapons continue to be an emerging threat. NBC arms are rapidly becoming the weapons of choice by potential enemies of the US including conventional and unconventional actors in symmetric (North Korea, formal Soviet Union, or China) and asymmetric warfare scenarios (Terrorist), as they offer a relatively cheap and expedient way to challenge the US hegemony. The use of these weapons will likely increase across the spectrum of human conflict in frequency and intensity. Major suspected players in the nuclear, biological, and chemical arena include the former Soviet Union, France, Britain, China, Libya, Syria, Pakistan, North Korea, South Korea, Taiwan, Iran, Egypt, Vietnam, Laos, Cuba, Bulgaria, South Africa, Iraq, Israel, and India; non-state proliferants include terrorists and organized criminals throughout the world.[42] As a result, combat aircraft will most likely be required to operate in an environment that increasingly includes chemical, biological, and possibly even nuclear weapons.

According to Dr. Barry Schneider in *Future War and Counterproliferation*, “failure to solve the airbase and aircraft decontamination problem could result in significant portions of U.S. aircraft being put out of action by contamination or because war planners are unwilling to risk sending aircraft and crews into contaminated bases.”[43] It is apparent that DOD aircraft are not optimized to operate in the NBC environment. When tasked to work in this environment, they will be limited in scope and effectiveness during combat operations. These are some key challenges compelling consideration, research, and ultimately evaluation, of proposed solutions in the operational aviation environment to test their validity against the nuclear, biological, and chemical threat.

Arguably, the U.S. is in its infancy as to defense against the NBC threat. Currently, the only defense includes Mission Oriented Protective Posture (MOPP) gear and modifications of aircraft environmental control systems. Rotary wing aircraft are at the highest risk, primarily due to the altitude they operate at and the missions they conduct—particularly the combat search and rescue mission, although scenarios exist that pose threats to all DOD aircraft.

Prevention

A representative example of how NBC countermeasures are difficult to incorporate in operational aircraft is seen in the V-22 Osprey program. The Osprey is the only aircraft designed from the ground-up specifically to counter the nuclear, biological, or chemical threat environment. The Osprey was originally designed to have overpressure and filtration systems, resistant materials, and filtered avionics cooling. The aircraft was further designed to be decontaminable by gaseous, liquid, or elevated temperature with a five-minute turnaround and thirty-minute servicing requirement. Potential on-board systems included long-range standoff chemical and biological agent detection and identification sensors and off-board/on-board chemical and biological agent contact sensors.[44]

Unfortunately, on 22 October 2001, the Marine Corps and Special Operations Command dropped plans for overpressure and filtration systems designed to protect troops carried by the Osprey from nuclear, biological, or chemical weapons because the enhancements are too difficult and expensive to accomplish. The following quote from an insider publication elucidates a recurrent common operational cost-benefit theme during the consideration and implementation of many emerging human factors technologies:

> These enhancements—overpressure and filtration systems—have been planned for years but are not the only means of protecting the Osprey crews from NBC weapons. In halting plans for the systems, however, officials are omitting NBC protection that would have been unique to the Osprey and more advanced than anything in today's military rotocraft. Without the unique overpressure and filtration systems, the Osprey will be relying on special suits to protect any troops in the back of the aircraft, an approach that has some observers of the program concerned…. Due to difficulties encountered in making the features perform adequately, the program office (Marine Corps and U. S. Special Operations Command) determined that the cost vs. benefit of those enhancements was not acceptable…. In an NBC operational scenario, the features would have "limited mission utility," in part because they would not be relied upon as primary personal protection for the passengers or crew, the program office said. The need for the people aboard the V-22 to wear mission-oriented protective posture (MOPP) gear would not be alleviated by the existence of the overpressure or filtration systems, according to the program office. Further, the program office said the features would not save the military the trouble of decontaminating a V-22 that might be exposed to NBC agents if a door were opened, for instance, for troops to deploy during an operation. Third, the program office said the features involved added penalties of weight and increased cost and maintenance…. During development testing, numerous problems were encountered with the seals intended to maintain the overpressure…necessitating the wearing of cumbersome MOPP gear to operate in the contaminated environments required by the JORD.[45]

The USMC operational NBC risk-benefit assessment has resulted in the omission of NBC protective measures; the wisdom of this decision is yet to be determined. Clearly, if the operating threat environment increasingly includes NBC weapons then this decision would be premature.

Aircrew Protection Considerations

Current standard operating procedure for many DOD aircrews is to wear MOPP gear in a high threat area as defined by intelligence and the commanding officer's standing orders. However, is this extensive use of MOPP gear necessary? MOPP gear provides adequate protection from chem-bio agents when used properly, however, protection comes at a cost of decreased manual dexterity, reduced range of motion, restricted/foggy vision with significantly reduced peripheral vision, poor verbal communication, increased heat stress, and decreased man-machine interface. All of these negative factors have potentially significant and detrimental effects on flyers, mission accomplishment, and flight safety.[46]

The already extreme aviation environment can only be made more difficult by layers of protective gear. For example, a carrier flight deck in the Persian Gulf during Desert Shield and Desert Storm recorded temperatures in excess of 130-180 degrees Fahrenheit; with temperatures prior to launch in the aircraft already stifling, this limitation that could only be compounded by prolonged transit/loiter times.[47] MOPP gear markedly increases heat exposure and dehydration in the aircraft, especially in warm climates and during aircraft start-up prior to environmental control system (air conditioning) activation.[48] If not prevented or treated, heat stress can ultimately cause unconsciousness and loss of aircraft and crew.

At the other end of temperature extremes, Air Force C-130 crews have reported wind-chill temperatures of minus 110 degrees Fahrenheit, freezing protective gear solid on occasion, making respiration difficult.[49] These extremes of temperature coupled with prolonged use of bio-chemical protective gear can lead to dehydration, reduced performance, compromised mission effectiveness, and ultimately, incapacitation.

Additionally aviators have complained about NBC gear digging into their heads and creating hot spots during flight as well as being unable to perform a valsalva, a potentially sinus-saving maneuver. Most of these issues are being resolved with better-designed systems in the development pipeline.[50] In the past, costs of physical discomfort and inconvenience of MOPP gear outweighed its benefits, and aviators flew without the gear in high threat environments.[51]

Detection and Warning Considerations

There are multiple sensors available on the battlefield and in the airspace, but they are bulky and take time to detect threat contaminates. Additionally, there is a current lack of sophisticated sensors for tactical aircraft, although the technology to alleviate this deficiency is nearly mature. Most airspace is vast, and unless there is a chem-bio sensor near or aboard each aircraft, contamination may only be determined either *post facto* or not at all. We certainly do not know how to treat if we do not even know if we are attacked. In the actual event of aircraft NBC attack or exposure, how much contaminant will reach the aircraft and subsequently the pilot? This is a quite complex calculation, as it must take into consideration environmental variables such as altitude, airspeed, humidity, precipitation and cloud formations, temperature, atmospheric pressure, dispersal, and plume distribution from the release point. Given the speeds and temperatures of operational tactical aircraft and the potential exposure to minimal dispersed particles at altitude, it may be prudent for aircrew to wear MOPP gear only prior to and during critical exposure sorties. Critical exposure sorties must be designated via intelligence collection and confirmed by sensors that record exposures.

Decontamination

Because most aircraft are pressurized from air coming directly from outside the aircraft via a turbine tap-off, if an aircraft were contaminated, internal and external decontamination may be required. Much more research must be accomplished to determine reasonable guidelines for decontamination. For instance, decontamination may already start the minute the aircraft leaves a NBC plume. Air stream, sunlight, jet exhaust, and hydraulic vapors will degrade contaminates to some degree. If contaminate exposure, amount, and type are determined in flight by a sensor prior to landing, specific techniques and decontaminate materials can be utilized post flight, if required at all. It may only be necessary to know an aircraft is contaminated, regardless of origin. Water soaks, similar to what US Navy P-3 Orion aircraft routinely accomplish after long missions to keep their aircraft clean, could potentially eliminate external contaminate from the aircraft, but verification of this supposition would be required and wastewater would have to be collected and treated to avoid secondary ground water contamination.

Parting NBC Shots

Countermeasures to the NBC attack will require timely intelligence, aircrew protection, detection and warning, and decontamination. It is clear that unresolved issues remain. Compact reliable sensors need to be strategically located to detect record and identify threats to air and ground crew. Further understanding of what detection, identification, warning, evasion, and decontamination can do to minimize the risk is required. MOPP gear may only be required in very limited situations, if at all, thus alleviating the aviator of the added burden. Clear guidance to the operator pertaining to when MOPP gear is actually required is vital.

V. Directed Energy Weapons/Battlefield Lasers

> *Directed energy weapons are here today. They will be considerably more widespread, more available, more powerful, and more lethal on the battlefields of tomorrow. As such, the Air Force and DOD must grapple with the strategic implications of these weapons, and that struggle must begin today.*[52]
>
> Lt Col John Geis, USAF
> Air University Center for Strategy and Technology

Problem

Continuous wave lasers in the 2020-2030 timeframe are extrapolated to be of the 10-megawatt class aboard aircraft and ground vehicles, and up to 100-megawatt on fixed ground stations, with significant ranges of effectiveness from 100 to 1000 kilometers. Similar advances are projected for pulsed lasers, with extrapolated power on the 500 trillion watt range.[53] As this Directed Energy Weapon (DEW) threat develops, manned aircrew will be increasingly susceptible.

There is projected to be a significant amount of laser power on the ground and in the air. An example of this vulnerability is chronicled in a *Reader's Digest* article entitled "Shot by a Laser." On 4 April 1997, United States Navy intelligence officer Lieutenant Jack Daly and Canadian helicopter pilot Captain Patrick Barnes were flying aboard a Canadian Armed Forces CH-124 Sea King helicopter that was intercepted a Russian spy ship in the strait separating Washington state from Canada's Vancouver Island. A Far East Shipping Company-owned ship, the *Kapitan Man,* allegedly illuminated the helicopter with a laser weapon. Both officers subsequently experienced pain and visual acuity disturbances consistent with laser injury. Capt Barnes will never fly again.[54]

Tactical aircraft are currently unable to safely operate in a directed energy warfare environment, i.e., laser, radio frequency, and particle beam weapon threats. The ability to rapidly respond to these threats will become a focus of future battlefield commanders. The low cost and proliferation of lasers have led the directed energy weapons community to predict that low- and medium-energy, portable lasers will be increasingly deployed by adversaries as cost-effective tactical weapons.[55] The expanded use of laser technology in military applications, coupled with maturing laser technology and increased availability, combine to increase the risk that military aircrews, aircraft, and aircraft weapons systems sensors will experience hazardous laser exposures. All types of aircraft will potentially be targets, but those most susceptible will be the rotary wing community, which routinely have exposure at lower altitudes—particularly in the combat search and rescue (CSAR) role.

Recent incidences of accidental and purposeful exposure of military and civilian aircrews to hazardous levels of laser light confirm the capability of both military and commercial off-the-shelf (COTS) laser systems to illuminate aircraft at tactically significant ranges and change behavior in the aircraft cockpit (e.g., mission abort/increased workload/decreased controllability).[56] Purposeful or accidental exposure to visible and infrared laser light can result in temporary, prolonged, or permanent changes in aircrew visual function. Additionally, some laser wavelengths may adversely affect other aircraft and weapons sensors (e.g., night vision goggles, and forward-looking infrared sensors). Dr. Reddix from the tri-service command states:

> Depending upon the wavelength, power or energy, modulation format, and divergence of the laser, the effects of an exposure to a laser can be varied from mere distraction to a retinal hemorrhagic lesion or blood eyeball. With respect to human ocular exposures, laser effects are typically delineated as non-lehtal (i.e., glare and flash insensitivity or "flashblindness") or lethal, (i.e., retinal tissue damage).[57]

DOD aviation fixed- and rotary-wing operational environments include lethal and non-lethal DEW threats. The need will only become more pressing as the world threat matures.

Detection

Another piece of the directed energy threat-protection puzzle includes developing sensors to detect, warn and record directed energy attacks. Several projects are underway; one such project is being conducted by NAVAIR to develop and test a low cost laser-warning receiver or (LCLWR). The LCLWR includes a self-contained, self-powered laser hazard sensor with a pulse detection and measurement capability over the 400 to 1600 nm band.[58] Ground testing is scheduled for early fall 2002 and a flight demonstration in the summer.[59] In order to protect against directed energy, we need to know where it is coming from and what type of energy it is. The intelligence obtained by this sensor will allow for appropriate threat area tactics to minimize damage, optimized mission accomplishment and selection of appropriate eye protection for missions into the threat area.

Solution—laser eye protection (LEP)

Laser Eye Protection (LEP) technologies in the cockpit are advancing slowly, and the eye protection options that are available today are neither comfortable nor inexpensive. Research is focusing on the Navy's EDU-5P as well as the next generation of Air Force rugate technology based LEP. LEP can cost up to 400 dollars per visor and can be easily degraded through repeated use. There is no standardization of LEP and no consistent intelligence effort to ensure the right protection is available at the right time in the right place.[60] The operational community may wish to ask whether the current tactics and fielded LEP are necessary, and if so, what is optimal protection. The currently developed EDU 5/P is designed to protect against seven wavelengths, but the down side is the glasses block too much of the visual spectrum for safe operations across all phases of flight. Much more work needs to be done, both in developing LEP and in getting the right protection to the right aviators at the right time.

Solution—computer modeling and mission planning

Aviation laser threat models and algorithms are currently being developed at the Tri-Service Directed Energy Bioeffects Complex at Brooks AFB, Texas to support mission planning functions. This Tri-Service effort includes basic and applied research on laser effects and countermeasures, and one product of this research includes computer-based mission planning as well through joint work with Naval Strike and Air Warfare Center (NSAWC).[61] The Army, Navy, and Air Force team is working on software that allows directed energy weapon threat rings to be incorporated into mission planning so that the DEW threat can be minimized prior to the actual flight. Models have been verified in flight operations held at NSAWC in Fallon, Nevada.

One example of how to deal with the directed energy weapons threat due to the increasing proliferation of lasers in military operations is the development of the Laser Threat and Mission Planning System (LTAMPS) by the Tri-Service team. LTAMPS has evolved from a "digital map" to its current iteration, which includes a laser weapon simulation, and is coupled with the Army's Low Energy Laser Weapon Simulation (LELAWS) software, a laser range safety tool. The system is also integrated with software modules from the Air Force's Laser Hazard Assessment Program (LHAZ 4.0). The LTAMPS computer program can show safe standoff distances for a particular flight path to minimize directed energy threats during a mission. The system allows the aircrew to pre-fly the mission and modify it to reduce exposure to DEW threats; potential applications are for air, ground and sea units. When coupled to an appropriately configured video display, LTAMPS will allow for analysis, mission playback and mission rehearsal to assist in training of threat area tactics.[62] The system has the capability of modeling flash blindness and glare effects for representative scenarios if specific energies and specific task threshold data are provided for these complex visual tasks.

LTAMPS is being used to study current laser eye protection (LEP) and evaluate their protection for the Navy's EDU-5P as well as the next generation of Air Force rugate technology based LEP. The mission flight profiles collected since 1995 in partnership with NSAWC provide the basis of realistic attack profiles, which are graded against man-portable laser threats anywhere on the map representing the target area. These LEP requirement assessment studies are angular vulnerability studies, which help determine the probability of a clear-line-of-sight into the cockpit for various tactical strike aircraft. Limiting the angular protection coverage can significantly reduce the cost of LEP without reducing crew protection and will facilitate getting the LEP to the aviators.[63]

Solution—Threat Area Tactics

Simple threat area tactics are needed to minimize laser energy exposure, especially as we develop LEP and other countermeasures. Initial studies have been completed to develop tactics at NSAWC for both rotary- and fixed-winged aircraft in conjunction with the Tri-Service team. Simple procedures may offer great protection and include common sense solutions like looking away from laser light source, going immediately to an instrument scan, turning the aircraft away form the energy source and putting aircraft structure between the aircrew and the source. Specific maneuvering may also decrease exposure to the aircrew and allow for increased chance of mission accomplishment. Tactics need to be further developed and practiced in simulators and on training flights to increase aviator effectiveness while operating in DEW threat areas.

VI. Mishap Reduction

Good flying never killed an enemy yet.

Maj Edward Mannock, RAF
73 Victories, WWI

Problem

Situational awareness is knowing what is going on in and around your aircraft. Spatial orientation is knowing where your aircraft is three-dimensionally with respect to significant aircraft, maneuvering space, and the ground. From 1980 to 1985, disorientation was a direct or contributing cause of thirty-four percent of pilot error accidents in the Air Force. Spatial disorientation mishap statistics show that from 1980 through 1989 the Air Force experienced 263 mishaps and 425 fatalities at a cost of over two billion dollars. These mishaps resulted from "loss of situational awareness."[64] Between 1989 and 1994, there were eighty-five incidents involving spatial disorientation-related Air Force aircraft mishaps.[65] The Federal Aviation Administration determines that between five and ten percent of all general aviation accidents can be attributed to spatial disorientation, and ninety-percent are fatal.[66]

These are several types of spatial disorientation. Type I is unrecognized, or mis-orientation, where the pilot does not consciously perceive any disorientation. Examples of type I disorientation include a pilot who hits a ridgeline believing he will clear it, misjudging the clearance. Vestibular ocular effect is another example of type I disorientation that frequently occurs on very dark nights, where the positive Gs of take-off give the pilot a continuing nose-up movement sensation of the aircraft resulting in over-compensated stick-down input and subsequent impact with the ground.[67]

Type II spatial disorientation is recognized; the pilot perceives disorientation. This is the classic case of feeling vertigo. An example of type II is the "leans" when a pilot makes a prolonged turn and then returns to level flight after his vestibular-ocular system compensated to the turn. The resultant sensation is that the aircraft is in a banked turn when it is actually flying straight and level. It takes several seconds for the pilot's system to re-set itself. The pilot may only perceive he has a problem controlling the aircraft; while not knowing there is spatial disorientation, he does know something is wrong.

Type III spatial disorientation is incapacitation. There is an overwhelming vestibular ocular mismatch and incapacitation. Nystagmus, or side-to-side movement of the eyes caused by neurologic mismatch, and nausea can occur. The pilot's senses are not telling the pilot what is actually happening as they are overwhelmed with input.

Solution—Ground Proximity Warning System (GPWS)

An example of why spatial disorientation is not optimally addressed in Department of Defense tactical aircraft is seen in the F/A-18 Hornet ground proximity warning system, which is restricted by the on-board radar altimeter limits. The radar does not work when the aircraft is in a greater than forty-five degree nosedive because it is blocked by the nose of the aircraft; it was not designed to work beyond this limit. Additionally the radar system is passive and not predictive in that it does not have a digital database to extrapolate its flight path. In other words, it does not consider the terrain into which the aircraft is flying. It is essentially a dumb system only considering what is directly under the aircraft irrespective of aircraft speed, motion, or rising terrain. Multiple aircraft have impacted rising terrain that was not considered by the current radar and ground proximity warning systems.[68]

The F/A-18 altitude system is redundant in that there are four altitude warning systems comprised of two software and one hardware "bugs" that are set prior to take off and modifiable during flight along with a ground proximity warning system which will give a last-ditch warning if the aircraft gets too low. Because there are four warnings, they desensitize the aviator through repeated simulator and flight re-enforcement. There have been several reported military mishaps where altitude warnings were either ignored or missed altogether.[69] It is understandable to see how an aviator could become task saturated, channelized (over focusing attention), or fixated on the wrong thing at the wrong time and could fly into the ground or another aircraft with only a moment of inattention. If an adequate system were incorporated to guard against controlled flight into terrain or midair collisions, it would save more aircraft to train and fight. Most importantly, however, many more aviators' lives would be saved. The idea is to supplement the pilot's situational awareness by providing a buffer between the ground and other aircraft. The buffer is provided with computer power and system integration that can continuously and reliably monitor safety parameters, a job ideally suited for a computer and one that will better support the pilot's ability to carry out the mission. The good news is there is theoretical room for tactical aircraft to incorporate these emerging technologies as they mature.[70]

Solution—Automatic Predictive Ground Collision Avoidance System (APGCAS)

An emerging technology that addresses aviation spatial disorientation is the Automatic Predictive Ground Collision Avoidance Systems (APGCAS/AGCAS). The technology to produce an APGCAS has been present for many years. It was originally developed by the Air Force and was a requirement prior to night tests of low-level tactical flights using a helmet mounted display system. More recently, an APGCAS has been a joint project developed by the Air Force Research Laboratory, the 416th Flight Test Squadron at Edwards Air Force Base, California, Lockheed Martin, and a Swedish-sponsored (Grippen aircraft) development effort. Flight-testing began in 1998 to address spatial disorientation, loss of situational awareness, and gravity-induced loss of consciousness.[71]

A United States Air Force News release dated 29 November 1999 states:

> The AGCAS provides protection. While active, the system monitors what an aircraft is doing. That includes knowing where the plane is positioned in the air, where on Earth (literally) it is located and how close it is to the ground. If AGCAS believes the plane is going to be flown into the ground, an autopilot system activates and attempts to pull out of the dive. This is done through a series of sophisticated navigation systems, radars, and Global Positioning System monitor to determine the aircraft's position. The system also incorporates voice messages. If a crash is imminent, the AGCAS will tell the pilot to "fly up, fly up." When back in control, the system will chirp, "You've got it." Researchers have tailored other messages for different conditions. Meanwhile, visual messages in the

> cockpit are flashing five seconds before the autopilot would kick in.[72]

This system clearly has great potential to decrease controlled flight into terrain and gravity induced loss of consciousness (G-LOC) mishaps. The aircraft computer knows where the aircraft is going. For example, the F/A-18 Hornet has a computer system that determines a constant computed impact point on the ground for bombs dropped; that is, it calculates the impact point of weapons dropped from the aircraft up to six times a second. The same calculations can be made for where the aircraft is going through space in relationship to the ground. The aircraft computers determine where the aircraft is in three-dimensional space by the on-board inertial navigation system (INS). Modern INS systems use ring laser gyroscopes and incorporate Global Positioning System for accuracy and redundancy. The aircraft database knows what terrain lies ahead by using digital terrain moving map data. Prior to 1996, digital terrain elevation databases had one hundred foot vertical errors and were completely missing some part of the terrain.[73] More recently, the National Imagery and Mapping Agency in conjunction with the National Aeronautics and Space Administration have collected data of the earth. This new database is accurate down to 30 meters or one arc second. This new data has decreased error rate and is much more complete, covering most of the world with fewer holes. This latest data was gathered during a shuttle mission using Shuttle Radar Topographic Mapper from fifty-seven degrees south latitude to sixty degrees north and has produced digital terrain elevation dataset for the Department of Defense.[74]

One tactical advantage of this system, if implemented, would be that if a pilot did have a bandit on his tail, he could essentially do a ninety-degree nose low dive toward the ground and let the APGCAS recover the aircraft with a minimum altitude and pre-set G's. The aircraft will bottom out at a pre-set minimum altitude, say twenty-five feet above ground level, and the pursuing aircraft either will chicken out or be scraped off on the ground. US pilots would have the ability to fly at very low altitudes with little or no chance for an adversary to pursue.

There is much to be optimistic about concerning the integration of this technology into military aircraft. CDR "Rhino" Unterhiner, the United States Navy Joint Strike Fighter (JSF) program manager, has put an APGCAS into the joint operations requirement document (JORD) for the JSF, and the joint and international participants subsequently approved the input. This manufacturer mandate has the potential to make the JSF a safer and more tactical aircraft with a fully integrated APGCAS and midair collision avoidance system (MCAS), thus saving priceless lives and valuable training assets.[75]

These same technologies (APGCAS/MCAS), if applied to unmanned aircraft, commercial aircraft and older military aircraft, would have the potential to significantly decrease human error mishaps associated with controlled flight into terrain, terrorist takeover of the aircraft, and G-induced loss-of-consciousness mishaps. As this system is human engineered, it is imperative that it reduces the number of false warnings in order to compliment the pilot rather than distract or overload him. In fiscal year 1998, 9 million dollars were budgeted for the APGCAS that is currently being investigated by the Air Force. This funding has primarily come from Sweden, approximately 7.5 million dollars, and the United States, 1.5 million dollars.[76] The bulk of the money goes directly to Lockheed-Martin to do the work. There is also promising Swedish follow-on technology that provides digital terrain mapping that is accurate to within one meter and has the potential to make the system even more accurate.[77]

As these automatic systems are continually refined, the developing engineers and test pilots must use common sense algorithms to ensure there will be few if any false alarms. Human reaction time, including perceiving, processing, and reacting, can take approximately 1.5 seconds if the aviator is looking in the right place at the right time. If an aviator did not take evasive action to avoid controlled flight into terrain or a midair collision within 1.5 seconds, then the aircraft would crash. But, if the aircraft has a self-recovery mode that reacts within that 1.5-second human response time and automatically flies the aircraft and aviator to a safe position and altitude, then collision is averted. This just-in-time recovery ensures that the aviator has been given every chance to recover, and if he does not attempt to recover, the aircraft will recover for him. There must always be an override capability similar to the F/A-18 Hornet paddle switch on the control stick that allows the pilot to override the automatic recovery, as there may be times when the pilot does not need the system.

The value-added piece of this technology is that not only is it a safety improvement concept, it has the potential to significantly increase combat capability and increase the safe operating envelope. If these technologies are marginally successful, they have the potential to significantly increase aircraft availability through saved aircraft and decreased loss of scarce aviator assets. Priority fast track funding, research development, and operational test and evaluation and aircraft implementation is imperative.

Solution—Training/Simulators

Distributed mission training and rehearsal capability, as promoted by General Hawley, former Commander of Air Combat Command, is an Air Force concept for future conduct of operational training. This will most likely become a joint services program in the next ten years.[78] Distributed Mission Training is a program to provide aircrews advanced training in complex multi-aircraft environment through a multi-linked-simulator environment and is a supplement to actual flight operations. The advantages are multiple, including threat simulation, concentration on specific skill areas, fuel conservation, and a safer learning environment. The Air Force will eventually acquire new, multi-ship simulators for every aircraft in its operational inventory.[79]

Simulators alone will never replace live exercises, but distributed training will allow many of the procedures to be rehearsed before aircraft leave the ground. Under a 335 million dollar contract, fourteen sites around the world will be linked together. At each site, suites of four F-15 training devices will be installed that can be used in a local network or linked to remote locations. When these sites are networked, forty-six pilots will be able to fly against each other on a given mission.[80]

It is important from a human factors position to identify the salient differences between simulator and in-flight training in order to determine those skills which will be most degraded by heavy reliance on simulators. Of concern are decreased pilot tolerance for acceleration effects including gravity-induced loss of consciousness tolerance as well as near- or almost-loss of consciousness (G-Loc and A-Loc, referring to cognitive deficits in high gravity force flight), changes in visual scan patterns (3-D environment modeled by 2-D near-field representation), and simulator sickness, which even highly seasoned aviators can experience.

Nevertheless, high fidelity simulation, or virtual reality training, can significantly enhance operational training in DOD aircraft if used in an augmentation role.[81] There is great potential to increase combat effectiveness, extend airframe service-life, and at the same time, preserve valuable lives and combat assets by avoiding training mishaps. Simulators can sharpen and augment many areas, especially "switch-ology" and refreshing and reinforcing productive habit patterns. Having said this, there is no replacement for actually sweating, straining, and problem solving real-time in flight; simulators must augment rather than replace actual flight time.

Simulator Mishap Reduction

One method of reducing the impact of spatial disorientation on pilots is through enhanced awareness and training. A simulator is a safe and effective environment to develop skills for coping with spatial disorientation. The resulting visual simulator scenarios can be used to train aviators to recognize, avoid, and overcome spatial disorientation. This reinforces aircrew coordination concepts, improves judgment skills, develops decision-making skills, and enhances real-time risk assessment and management. Other areas that should be pursued to supplement training include low-cost technologies that improve situational awareness and intuitive decision-making capabilities.

The United States Army Aeromedical Research Laboratory has developed a visual simulator flight that exposes helicopter pilots to actual conditions that result in mishaps.[82] These simulator sorties decrease spatial disorientation mishaps through enhanced awareness and training. By safely and effectively demonstrating actual spatial disorientation mishaps in a visual flight simulator, the sorties help aviators identify, avoid and overcome spatial disorientation.[83]

The United States Air Force and Navy should implement specific spatial disorientation simulator training using the top-ten most commonly occurring spatial disorientation mishaps or "actual" representative mishap recreations similar to the Army program. It is recommended that the most common human factors scenarios specific to aircraft type be reviewed. Service safety centers already compile mishap records and hazard reports that show the most common scenarios of each airframe that have resulted in a degraded mission and or mishaps. In the best framework of risk management, these high-risk areas should be taught to students via simulator recreations and compilations. The idea is to continuously identify the highest risk areas of mishaps via the service safety centers and keep modifying the simulator scenarios to address these highest risk areas as they change. This self-updating process will continue to address the highest risk human factors areas of flight in a timely fashion and result in a decrease of human factors related mishaps.

Solution—Situational Awareness/Spatial Disorientation Training Flights

Another excellent example of this type of integration of common mishap scenario training into an actual flight is the British Army Air Corps spatial disorientation sortie trainer, where an instructor pilot demonstrates several spatial disorientation maneuvers to build a knowledge base the student can later draw upon. Following didactic instruction, the British helicopter student receives airborne demonstration of the limitations of their orientation senses. In published reports, the maneuvers performed in the spatial disorientation demonstration sortie, and the sortie overall, were extremely effective at demonstrating the limitations of the orientation senses. Analysis of helicopter accidents demonstrates that this training is operationally effective by contributing to a reduction of spatial disorientation mishaps.[84] A spatial disorientation sortie similar to the British example should be considered for training in the DOD rotary wing community.

Solution—Vibro-Tactile Situation Awareness System (TSAS) suit

There is also promising technology that has the potential to significantly improve a pilot's situational awareness, particularly for the rotary wing communities in brownout scenarios. Captain Angus H. Rupert of the Naval Aerospace Medical Research Laboratory's Spatial Orientation Systems Department, in conjunction with NASA, is developing a Tactile Situation Awareness System (TSAS), which provides accurate orientation information through a tactile sensory pathway in aerospace, land, and sea environments.[85] This torso suit provides vibration to keep the pilot informed of where the ground is at all times and has the ability to give the pilot threat warnings such as surface-to-air missile firings or anti-aircraft fire location. The suit provides correct perception of attitude, altitude, or motion relative to the earth or other significant objects by providing non-visual orientation information to operators aboard aerospace platforms and the diving community. The suit improves the ability of personnel to detect and determine relative position and motion of targets. This system, which is currently under development, has great potential in navigation and communication as well as training and simulation. Continued development and funding of this promising technology should be encouraged.

Solution—Computer Assisted Performance Analysis System (CAPAS)

There is promising work being conducted at North Island in San Diego, California, by the S-3 Viking community on Computer Assisted Performance Analysis Systems (CAPAS).[86] This commercial off-the-shelf system is one of a number of computer-aided debriefing tools for flight training currently being developed. It provides standardized data (audio-visual) collection and performance measurements throughout the training process. Flight instruments, gauges, flight paths, and tactical plots can be displayed. Three-dimensional graphics of the simulated aircraft can be viewed from any external angle (from a wingman's view, the landing safety officers (LSO) platform, tower, or pilot's view inside the cockpit). The system has the ability to mark, record, and retrieve technical and human factors performance data during brief, flight, and debrief, making it a great teaching tool that provides detailed feedback to aircrews and instructors.

Currently, the data, which is scenario-based using the fleet replacement squadron-training syllabus, has successfully assisted in training aviators to recognize emergencies and has helped in cognitive skills development. This system allows trend analysis of groups and individuals by creating a database for comparison to standard performance from previous students/peers at same stage of training. It has improved the quality of instruction by creating a higher reliability in observation and grading. The data can also identify behavior and skills that lead to consistent, successful performance.[87] The CAPAS system may be the intervention strategy of the future in the training and operational environment.

The routine extraction of flight data in order to screen for limits that are exceeded would be of great benefit in the identification of skill-based errors or violations that would go otherwise unrecognized. It is important to extract this information in a non-attribution manner, one in which the information can be used to modify behavior not punish it, especially in operational world. This would be a powerful tool that would allow for the correction of deficiencies before those deficiencies led to a mishap.[88] The debriefing and training benefits of a tool that combines flight visualization software that collects aircraft data to display and replay the mission would help our aviators remain proficient with their flying skills at reasonable costs.[89]

The next logical step in the development of an intervention strategy to reduce skill-based errors is to move beyond the training scenario and adopt the data-centric-aircraft concept for daily operations. Flight Information Recorders, which include Flight Data Recorders, and combination devices similar to CAPAS are a part of this development. Although these systems were designed to reconstruct mishaps, the information recorded can be extracted for other very important purposes to include flight debriefs, aircraft maintenance, and trend analysis.[90]

Solution—Culture/Operational Risk Management (ORM)

Operational Risk Management was introduced to the Air Force and U.S. Navy in 1995. It was an adaptation of the US Army aviation's highly successful program. The Navy's Air Board identified Risk Management as one of three initiatives they would take to reduce Class A mishaps in Naval aviation (the other two being Human Factors Boards/Councils and Aircrew Coordination Training – ACT). A Process Action Team was formed and met at the Naval Safety Center in the fall of 1995. The team consisted of naval reservists with commercial airline, aviation safety, and command experience. These reservists worked with Safety Center personnel to produce the Navy's approach to risk management. A message was promulgated to all wing and squadron commanders with recommended implementation steps, and finally, OPNAVINST 3500.39/Marine Corps Order 3500.27 was signed-out as a combined instruction in the spring of 1997.

ORM is a decision-making tool used by people at all levels to increase operational effectiveness by anticipating hazards and reducing the potential for loss, thereby increasing the probability of successful missions. The five-step process consists of identifying hazards, assessing hazards, (Air Force adds a sixth step to analyze risk control measures), making risk decisions, implementing controls and supervising the implementation of decisions. Operational risk management (ORM) consists of three levels: time critical or "on the run," deliberate and in-depth. There are four main principles: first, accepting risk when benefits outweigh costs; second, accepting no unnecessary risk; third, anticipating and managing risk by planning; and finally, making risk decisions at the right level.[91]

As with any undertaking where hundreds of thousands of people are involved, it has taken time to communicate, train, implement and internalize ORM. The task is far from over, but there are many outstanding examples of implementation and lessons learned to date. Another encouraging sign of the embrace of ORM and senior commitment to the effort is the DOD injury and occupational illness prevention committee (IOIPC), which was chartered on 13 August 1999 and includes a Joint Operational Risk Management Team (JORMT).

Solution—Cultural Workshop (CWS)

The Culture Workshop, or "Safety Culture Workshop" as it was known when first introduced to Naval Aviation in 1997, is a risk management tool for commanding officers to use in identifying cultural hazards that exist in their squadrons. This, like ORM, was an adaptation of a highly successful program from another service. "Safety Culture Workshops" had been used in the US Air National Guard for most of the 1990's and was credited with a fifty percent reduction in Class A mishaps over that period.

The workshop is based on the premise that "a good squadron culture is based on trust, integrity, and leadership, which are created and sustained by effective communication."[92] Culture Workshops are conducted in strict confidentiality for the sole benefit of the unit by Commanding Officer, at their invitation only. The workshop identifies the culture of the organization and relates this culture to mishap prevention. Culture is the non-physical operating environment. It supports a wide range of informal rules and attitudes that profoundly affect how the organization works and trains. Culture is impacted by past and present leadership styles, as they exert great influence on the attitudes and operating rules that form the culture. Leaders communicate acceptance of specific attitudes and rules either through direct and visible action of support or through sustained tolerance.[93]

The process uses a senior reserve officer facilitator teamed with a junior aviator and senior enlisted maintenance member from a sister squadron. The three-member team begins by conducting individual informal interviews throughout the squadron. The facilitator then conducts three seminars composed of horizontal cuts of the organization, i.e., E-5 and below, E-6/7, and officers/senior enlisted. The mission or goal of the workshop is to paint a picture of the unit's culture for the commander, which is developed by listening to the unit's members in the seminars and individual conversations. This provides credibility, as it is not an evaluation by the team, but rather, a forum for the unit's members to communicate to the commander. The results are briefed to the commanding officer as both good things that were relayed to the team and as potential hazards to the organization. The facilitator briefs the team members that everything that was discussed during the visit is strictly confidential to that unit and not to be discussed after the completion of the workshop. No reports are written; the only take-away for the facilitator is a short evaluation form filled out by the commanding officer (CO) or executive officer (XO) of the unit, grading the value of the workshop to them.[94] The culture workshop has had great success and even greater potential to further reduce mishaps through a better understanding of how culture and communication affect a squadron's safety and working environment.

VII. Conclusions/Recommendations

> *Victory smiles upon those who anticipate the changes in the character of war, not upon those who wait to adapt themselves after the changes occur.*
>
> Guilio Douhet
> *The New Form of War*

Private, commercial and military manned flight will continue with increasing military emphasis on un-manned aerial and combat vehicles. Human factors technological advances are applicable to both the manned and un-manned cultures/environments. Far too many human factors errors can be avoided by the proper application of technology and training today to settle for the status quo in development and implementation of these systems. Appropriately applied technology will not only make aircraft safer, but also will decrease workload and increase ability to focus and accomplish a mission. The return on minimal investment would be tremendous.

Fatigue is endemic in military aviation; it is dangerous and kills on a regular basis. Fatigue should be managed like fuel and bullets utilizing nutrition, exercise, sleep and only when necessary, go and no-go medications.

PRK surgery should be approved for all military aviation, requiring initial waiver application and then service specific follow-up as dictated by operational commitments. LASIK should be approved for military aviation as soon as it is proven safe in all phases of military flying.

We are entirely ill prepared for combat aviation in the NBC or DEW environments. We conclude either future losses are the price of doing business, or we adequately prepare and protect our aviators and aircraft through focused research, development, test, and evaluation processes. For the DEW environment, timely, adequate, robust, and cost-effective LEP is necessary. Mission planning tools, threat areas tactics and integrated laser sensors are needed to adequately operate in the emerging environment.

Loss of situational awareness and spatial disorientation are major killers in all forms of aviation. Better training is needed to include real re-creation scenario simulator flights (re-creation of top-ten killer scenarios in the simulator) and actual aircraft sorties dedicated to spatial disorientation, especially in the rotary wing community. The technology is here today to field automatic predicative ground proximity warning systems and automatic midair collision avoidance systems that will save lives and aircraft. These systems not only create a safety buffer for the aircraft, but as an added advantage improve tactical capability, especially if a pilot can take advantage of the ability to fly closer to the ground or closer to another aircraft. This area, above all others of human factors technology, will save aircraft and priceless aviators' lives almost immediately and will more than pay for any investment within one year of implementation.

Network centric aircraft and simulators that include digital playback capabilities and recorders must be integrated better into training and routine sorties as training aids and for mishap re-creation. The computer assisted performance analysis concept holds great promise for cognitive flight training and flight debrief.

Vibro-tactile situation awareness system suits hold great promise for increasing situational awareness, particularly for the rotary-wing community; it is important that we continue funding and development of this system.

Operational risk management and organizational culture are the most difficult areas to address because we need to understand them so much more, but the potential to save additional aircraft and lives is significant. Continued concerted efforts and funding need to be focused on joint integration of the study of human factors issues as they relate to aviation, as well as across all disciplines of aviation research development test and evaluation. Dual-designated aviators and flight surgeons are ideally suited to take the lead in this emerging area of study. Cultural workshops and operational risk management tools are starting to get at a most difficult area of organizational culture as it relates to aircraft mishaps and should be strongly supported.

Manned and unmanned aircraft can benefit from human factors advances. It is recommended that greater coordination, emphasis, and resources be given to developing the human factors technologies discussed in this paper. As Baron Manfred von Richthofen said, "the quality of the box matters little, success depends upon the man who sits in it." Given the pace of technological advancement in military aircraft, we need to prepare the man or woman in the box to be successful in every engagement. That box may either be air born, or ground based in the case of non-piloted aero-vehicles. Complete human factors incorporation can only be done through an integrated effort of instructors, researchers, scientists, developers and operational test pilots that make the training more relevant, the box more efficient, and the weapon system more lethal so that the man or woman in the box continues to have the edge in the combat airspace of the future.

Appendix A: US Navy corneal surgery policy

All forms of corneal surgery are disqualifying. Photorefractive keratectomy is the only procedure that will be considered for waiver. Air warfare new accession applicants having had photorefractive keratectomy (civilians, NROTC, Naval Academy and enlisted accessions) may be waivered for aviation duty if they meet all the following criteria:

a. Accepted into a Navy-approved photorefractive keratectomy study protocol for long-term follow-up
b. Pre-photorefractive keratectomy refractive error was less than or equal to plus or minus 5.50 (total) diopters in any meridian with less than or equal to plus or minus 3.00 diopters of cylinder and anisometropia less than or equal to 3.50 diopters.
c. Civilian applicants must provide detailed pre-operative, operative, and post-operative PRK follow-up records prior to acceptance into a Navy approved photorefractive keratectomy study.
d. At least three months have elapsed since surgery or re-treatment and evidence of stable refractive error is demonstrated by two separate examinations performed at least one month apart.
e. Meet all other applicant entrance criteria as delineated in references (the Manual of the Medical Department (NAVMED P117)) and (the 1997 Navy Aeromedical Reference and Waiver Guide) and as specified by approved aviation PRK-study protocols.

Designated Naval aviation personnel (flying class one, flying class two, and class three designated enlisted aircrew and flight deck personnel), upon approval by their commanding officers, may seek acceptance into a Navy photorefractive keratectomy aviation study protocol involving actual PRK surgery. A waiver to return to flight duties will be recommended if they meet all study requirements and all other physical standards as delineated in references (the Manual of the Medical Department (NAVMED P117)) and (the 1997 Navy Aeromedical Reference and Waiver Guide).

Personnel electing the surgery must receive authorization from their commanding officer prior to the procedure.

For more information concerning corneal refractive surgery and photorefractive keratectomy in the Navy/Marine Corps, go to http://navymedicine_dev/refractive_questions.htm.

Notes

[1] H*JointH Strike Fighter Program Briefing*, December 2002. Available from Hhttp://www.jsf.mil/Program/Prog_Brief.htmH.

[2] Personal email correspondence with CAPT William Miller, USN, Command Physician, US Navy and Marine Corps School of Aviation Safety, Naval Postgraduate School, Monterey, California.

[3] *Military Medicine*, Supplement to Military Medicine volume 164, no 8 August 1999. Table depicting % of costs by mishap type for military personnel showed 81% were due to Aviation for FY 1994, with a total dollar cost of $ 381million. By comparison, places two through four for the same year were Shore operational (5%), Afloat (5%) and Non-operational Private Motor Vehicles (5%).

[4]*American Journal of Preventive Medicine*, Supplement to American Journal of Preventive Medicine, "Injuries in the U.S. Armed Forces Surveillance, Research, and Prevention," April 2000, 30-31. Department of Defense publication, re-printed with permission.

[5] Elsa J. Hennings, *Mishap Data Evaluation of Current Naval Aircraft 1987–1996*, NAWCWPSN-TP-8332 (China Lake, CA, Naval Air Warfare Center Weapons Division, August 1998). Cost data determined by China Lake research team.

[6] Ibid.

[7] Ibid.

[8] This statement is based on conversations between the author and United States Navy N-78, RADM Michael McCabe, Assistant Chief of Naval Operations, in charge of Air Warfare. The hard truth is that the DOD buys bombs and the ability to put them on target, while year after year, safety enhancements are either under funded or partially funded.

[9] Azar Gat, "Jomini: Synthesizing the Legacy of the Enlightenment with Napoleonic Warfare," in *The Origins of Military Thought from the Enlightenment to Clausewitz*, (Oxford: Oxford University Press, 1989), 106-135.

[10] Hohn A. Caldwell, "Sleepiness in the Cockpit," *Combat Edge*, August 1999.

[11] John Boyd, "A Discourse on Winning and Losing," August 1987, 175.

Notes

[12] Mark R. Rosekind et al., "Crew Factors in Flight Operations X: Strategies for Alertness Management in Flight Operations," NASA Technical Memorandum, final draft (NASA Ames Research Center, Moffet Field, CA, 1994); U.S. Congress, Office of Technology Assessment, "Biological Rhythms: Implications for the Worker," OTA-BA-463 (Washington, DC: U.S. Government Printing Office, September 1991); and Meir H. Kryger, Thomas Roth, and William C. Dement, editors, "Principles and Practice of Sleep Medicine," W. B. Saunders Company, 1989.

[13] LeClair, Michael "Fatigue Management for AEF Deployment and Sustained Operations." Air Command and Staff College, Air University, April 2000. Class Alpha mishap occurs when an aircraft is destroyed or missing, a fatality occurs or there is an injury that results in permanent total disability, or the total cost of damage is $1,000,000 or greater.

[14] Carol S. Ramsey and Suzanne E. McGlohn, "Zolipidem as a Fatigue Countermeasure," *Aviation, Space, and Environmental Medicine*, 68, no. 10, (October 1997): 926-931.

[15] M. R. Rosekind et al., "Managing Fatigue in Operational Settings I: Physiological Considerations and Countermeasures," *Behavioral Medicine* 21 (1996): 157-165.

[16] K. M. Belland and C. Bissell, "A Subjective Study of Fatigue During Navy Flight Operations Over Southern Iraq: Operation Southern Watch," *Aviation, Space, and Environmental Medicine* 65, no. 6 (June 1994): 557-561.

[17] Ibid.

[18] RADM R. A. Nelson, Surgeon General of the Navy, Forward to "Performance Maintenance During Continuous Flight Operations, A guide for flight surgeons," First edition, Naval Strike and Air Warfare Center, 1 Jan 2000, 1. Available on-line from
Hhttp://www.safetycenter.navy.mil/aviation/aeromedical/downloads/performancemanual.pdfH.

[19] Ibid.

[20] S. Marshal, *Night Drops: The American Invasion of Normandy*, (Boston, MA: Little, Brown, 1962).

[21] "Desert Shield/Desert Storm Aerospace Medicine Consolidated After-Action Report." USAF (only) summary of 29 individual after action

Notes

reports, proceedings of the Squadron Medical Element (SME) After Action Conference at Langley AFB, VA 20-22 May 1991 and telephone conversations between CENTAF(rear)/SGPA and individual SME's and CAPT Dave Brown, Navy dual-designated flight surgeon and pilot.

[22] Mark Sauter, "Gulf war pilots flew on speed, Air Force approved of pill use," *Morning News Tribune* (Tacoma, WA), 9 April 1992, and *Associated Press* article "Air Force admits pilots used uppers in gulf war," 12 April 1992, *Pensacola News Journal*.

[23] Colonel Peter Demitry, USAF, International Association of Military Pilots President, interviewed by author.

[24] RADM R. A. Nelson.

[25] OPNAV Instruction 3710.7S, *Naval Aviation Training and Operations Procedures Standardization General Flight and Operating Instructions*, 15 November 2001, available on-line from Hhttp://www.hq.navy.mil/natops/37107s.pdfH.

[26] Ibid., 8.3.3.

[27] RADM R. A. Nelson.

[28] Ibid., 2.

[29] Anthony N. Nicholoson, "Intensive and Sustained Air Operations: Potential Use of the Stimulant, Pemoline," *Aviation, Space, and Environmental Medicine* 69, No. 7 (July 1998), 647-655. Sympathomimetic describes a drug that has the effect of stimulating the sympathetic nervous system; the actions are adrenergic (resembling those of norepinepherine).

[30] "History of Laser Eye Surgery," LaserSurgeryForEyes.com, on-line, Internet, 26 May 2003, available from Hhttp://www.lasersurgeryforeyes.com/history.htmlH

[31] T. H. Mader and L. J. White, "Refractive Changes at Extreme Altitude after Radial Keratotomy," *American Journal of Ophthalmology* 119, no. 6 (Jun 1995): 733-7; T. H. Mader et al., "Refractive changes during 72-hour exposure to high altitude after refractive surgery." *Ophthalmology* 103, no. 8 (August 1996): 1188-95; and R. K. Winkle et al., "The etiology of refractive changes at high altitude after radial keratotomy. Hypoxia versus hypobaria," *Ophthalmology* 105, no. 2 (February 1998): 282-6.

Notes

[32] Personal conversations with Refractive Surgery professionals assigned to the Naval Medical Center San Diego. Also see "PRK in Naval Aviation," The Society of U.S. Naval Flight Surgeons Newsletter vol. XXIV, no. 1, January 2000, 11. Available on-line from Hhttp://www.aerospacemed.org/newsletter/vol24-1jan00.pdfH.

[33] Ibid.

[34] CDR Dave J. Tanzer, Co-Director PRK program Naval Medical Center San Diego, lecture to the Aerospace Medical Association Conference, Reno NV, May 2003.

[35] S. E. Kaupp et al., "Quality of vision changes during prolonged exposure to altitude following refractive surgery" (paper presented at Association for Research in Vision and Ophthalmology Conference, Fort Lauderdale, FL, 2000).

[36] Personal conversations with Refractive Surgery professionals assigned to the Naval Medical Center San Diego.

[37] "History of Laser Eye Surgery."

[38] Personal conversations with Refractive Surgery professionals assigned to the Naval Medical Center San Diego.

[39] The United States refractive surgery Navy team, led by CAPT Steve C. Schallhorn and CDR Dave J. Tanzer, are actively engaged jointly with the Air Force Colonels Doug Ivans and Bruce Baldwin, and Army Colonel Corina VandePol, Lt Colonels Morris Lattimore and Major Scott Barnes to thoroughly evaluate photorefractive keratectomy.

[40] Research conducted by Naval Medical Center San Diego Refractive Surgery Department in conjunction with the Naval Strike and Air Warfare Center, Fallon Nevada. See "PRK in Naval Aviation," The Society of U.S. Naval Flight Surgeons Newsletter vol. XXIV, no. 1, January 2000, 11. Available on-line from Hhttp://www.aerospacemed.org/newsletter/vol24-1jan00.pdfH.

[41] Ken Alibek, *Biohazard*, (New York: Random House, 1999), 176 and 281.

[42] Peter L. Hays, Vincent J. Jodoin, and Alan R. Van Tassel, *Countering the Proliferation and Use of Weapons of Mass Destruction*, (New York: McGraw-Hill, 1998) 4; Kris Belland, "Battlefield Lasers," *Naval Strike and Air Warfare Center Journal,* Fall 1999; and Alibek.

Notes

[43] Barry R. Schneider, *Future War and Counterproliferation U.S. Military Responses to NBC proliferation Threats*, (Westport, CT: Praeger Publishers 1999), 98.

[44] Norm Josten, "V-22 Shines in simulated force protection scenario," Bell Boeing Tiltrotor Team's *Osprey Facts* 12, no. 2 (February 2001), 3. Available on-line from Hhttp://www.boeing.com/rotorcraft/military/v22/tilttimes/feb01.pdfH.

[45] Christopher J. Castelli, "V-22 Program Cancels Plans for two Chem-Bio Protective Features," *InsideDefense.com* Special Report: V-22 Crash, 12 December 2000, n.p.; on-line, Internet, 2 July 2003, available from Hhttp://www.insidedefense.com/public/special.aspH

[46] See, for example, Schneider or Hays et al**.**

[47] Belland and Bissell.

[48] Author's experience in the Gulf during Operation Southern Watch, flight deck temperature in excess of 130 degrees Fahrenheit, and EA-6B prowler environmental control system not working adequately until power on the aircraft and airborne. With sometimes ten- to thirty-minute waits prior to catapult, dehydration rapidly becomes a factor.

[49] Lt Col John Geis, C-130 aircrew member, reported temperatures in cockpit of 136 degrees Fahrenheit in Florida, and anecdotal reports of greater than 150-degree temperatures in Arizona and over 180 degree Fahrenheit in Saudi Arabia operations also exist. AC-130 H gun ships have recorded wind chill factors to minus 150 degrees Fahrenheit for the aircrew (Gunners, loadmaster) in the aft of the aircraft, with MOPP gear freezing solid on occasion, making respiration impossible.

[50] U. S. Navy Aircrew Systems Operational Advisory Group (OAG), 1998 and 1999. Air Crew Systems OAG executive steering committee member and chairperson of the fixed wing, ejection seat aircraft group.

[51] USMC pilots during operation DESERT STORM, conversations with USMC flight surgeons.

[52] Lt Col John P. Geis, *Directed Energy Weapons on the Battlefield: A new vision for 2020*, Center for Strategy and Technology, Air University Press, 2003.

[53] Ibid.

[54] Michael Waller, "Shot by a Laser," *Readers Digest*, October 1999.

Notes

[55] Statements are based on the author's discussions with various members of the directed energy technology community while attending the International Military Laser Conference in London, England, in 1998 and 1999.

[56] Ibid.

[57] Naval Health Research Center Detachment, Tri-Service Directed Energy Bioeffects Complex at Brooks AFB, Texas.

[58] Event laser sensor/recorder developed under a Phase I SBIR grant from the National Institute for Occupational Safety and Health, (NIOSH), Naval Health Research Center Detachment, Tri-Service Directed Energy Bioeffects Complex at Brooks AFB, Texas.

[59] Jeri Tribble, Vision Lam Manager (Code 4.6.3.1) Patuxent River MD, Life Support and Personal Protection and Norman Barsalou, US Navy detachment Brooks Air Force Base, interviewed by author, Naval Strike and Air Warfare Center, May 2001.

[60] Ibid.

[61] Bryant, Rentmeister and Barsalou, Norm, of the Naval Health Research Center Detachment, Tri-Service Directed Energy Bioeffects Complex at Brooks AFB, Texas.

[62] Naval Health Research Center Detachment, Tri-Service Directed Energy Bioeffects Complex at Brooks AFB, Texas. The LTAMPS modeling/simulation system provides a flight simulation and data playback capability using reconstructed test range flight/weapon delivery profiles based on TSPI/GPS (Time-Space Position Information/Global Positioning System) test range data bases. Integrated into aircraft wire-frame models (both fixed and rotary wing) are an anthropometric representation of the pilot head-LEP spectacle geometry. The wireframes can then be modulated via TSPI over National Imagery Management Agency (NIMA) tactical pilotage charts and Digital Terrain Elevation Data (DTED) through use of the Advanced Distributed Interactive Simulation (ADST) or IEEE Distributed Interactive Simulation protocol (IEEE 1278.1-1994). This allows LTAMPS to provide aircraft (or any allowable DIS vehicle) entity locations and orientations to any simulation which communicates via this protocol, thus allowing LTAMPS to be incorporated in simulation war games involving the use of lasers as counter sensor weapons. LTAMPS uses NIMA products directly in the

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format as produced by NIMA. These products include the aforementioned Tactical Pilotage Charts in the Advanced Digitized Raster Graphics (ADRG) format, terrain, or topographical relief data in the DTED format, and for appropriately configured video systems, playback over imagery provided by NIMA.

[63] US Navy detachment Brooks Air Force Base, Tri-Service Directed Energy Bioeffects Complex at Brooks AFB, Texas

[64] Air Force News release dated 29 Nov 1999 originally found on website Hhttp://www.af.mil/news/Nov1999/n19991123_992139.htmlH.

[65] Ibid.

[66] Melchor J. Antunano, Medical Facts for Pilots Publication AM-400-00/1, *Spatial Disorientation: Visual Illusions*, 11 September 2002, Federal Aviation Administration, Civil Aerospace Medical Institute Aeromedical Education Division.

[67] Kent Gillingham and Fred Previc, *Spatial Orientation in Flight*, (Williams & Wilkins, 1996), 309-98.

[68] Author's personal experience investigating controlled flight into terrain mishaps, discussing mishaps with other investigators, and participating in high visibility mishap reviews.

[69] Author's personal experience in over 30 mishap investigations, several of which included spatial disorientation, loss of situational awareness and ignored or missed altitude warnings.

[70] Elsa Hennings, United States Navy Active Network Guidance and Emergency Logic, China Lake Naval Air Station, interviewed by author.

[71] Air Force News release dated 29 Nov 1999.

[72] Ibid.

[73] ESOH TPIPT Need Assessment Summary, Need #: 1903, Hhttps://xre22brooks.af.mil/NASs/purpcont1903.htmH

[74] Ibid.

[75] CDR "Rhino" Unterhiner, Program Manager, United States Navy Joint Strike Fighter Program, interviewed by the author, 2001.

[76] Air Force News release dated 29 Nov 1999.

[77] Ibid.

[78] "TASC Wins Big on Air Force DMT Contract: Distributed Mission Training Program Will Link Aircraft Training Simulators Worldwide," *Northrop Grumman Information Technology Prism* 7, no. 2 (June 2000),

Notes

n.p., on-line, Internet, 2 July 2003, available from Hhttp://www.tasc.com/news/prism/0006/1.txt.shtmlH.

[79] Ibid.

[80] Tim Ripley, "Distributed mission training," 2000 Global-defence.com, n.p., on-line, Internet, 7 July 2003, available from Hhttp://www.global-defence.com/2000/pages/distrib.htmlH.

[81] Eric Pagenkopf, Naval Strike and Air Warfare Center/Navy Fighter Weapons School (TOPGUN) flight surgeon, internal trip report from USAF simulator utilization conference.

[82] Arthur Estrada et al., *Spatial disorientation awareness training scenarios for US Army aviators in visual flight simulators*, USAARL Report No. 98-17 (Fort Rucker, Alabama: US Army Aeromedical Research Laboratory, January 1998). Available from Hhttp://www.usaarl.army.mil/TechReports/98-17.PDFH. Related USAARL reports 97-11, 97-15, 97-26, 97-22 and 97-13 are also available from the website.

[83] Ibid.

[84] Braithwaite, Malcom G. "The British Army Air Corps In-Flight Spatial Disorentation Demonstration Sortie." *Aviation, Space, and Enviornmental Medicine*, Volume 68, No 4 April 1997, 342-345.

[85] Angus H. Rupert, "Tactile Situation Awareness System" program overview briefing, Joint NASA/Naval Aerospace Medical Research Laboratory, 10 August 1999. Available on-line from Hhttp://www.namrl.navy.mil/TSAS/H.

[86] CAPT Donald Hepfer, Commodore S-3 Viking Command, Crew Resource Management (CRM) initiative presentation to Human Factors QMB/Training Improvements Working Group, NAS North Island 4 February, 2000.

[87] Ibid.

[88] Ibid.

[89] Ibid.

[90] Ibid.

[91] Captain J. J. Skip Lind, USNR, Commander Naval Air Forces Pacific, Cultural Workshop Facilitator.

[92] Ibid.

[93] Ibid.

[94] Ibid.