Interactions between Brown-out Accidents and Night Vision Equipment in Military Aviation Accidents

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Abstract

Night vision devices (NVDs) mitigate risks in low visibility operations through image intensification or infrared imaging. However, NVDs create new risks, including a host of human factors problems. The operation of night vision equipment has been associated with several different forms of spatial disorientation. The following pages describe how this disorientation exacerbates the hazards created by 'brown-out' landings that occur when visibility is reduced by airborne particles, typically from helicopter downwash. This paper provides a high-level review of night vision operations and previous 'brown out' accidents. A companion paper also submitted to this conference focuses on a detailed case study leading to the loss of a Royal Air Force Puma on operational duty in Iraq during November 2007. These two papers show that there is an urgent need to go beyond existing military Boards of Inquiry if we are to protect the safety of military personnel. We must extend the scope of operational studies across the US and UK armed forced to ensure that we learn the lessons provided by the growing number of similar accidents, which stem from complex interactions between new technology and a range of environmental hazards, including but not limited to 'brown out' and 'white out' conditions.

Introduction

It is difficult to underestimate the impact that accidents have upon military organizations. In 2006, 95 members of the UK Armed Forces were killed in 'mishaps' (50% of all deaths). During the same period, 33 regular military personnel were killed in action and 14 died of wounds as a result of deployment in Iraq or Afghanistan (25% of all deaths) (Ref. 1). The financial consequences of these adverse events are also important given that armed forces must stretch finite resources between many different conflicts. In the last three decades US Army Aviators have been involved in almost 400,000 accidents costing in excess of $4 billion, (unadjusted for inflation). These figures have prompted a succession of safety initiatives across the US Department of Defense. Table 1 shows how these programmes have gradually helped to reduce the total number of Class A to C Army Aviation mishaps from 236 in 2006, to 201 in 2007 and 191 in 2008[1]. However, progress has not been as rapid, or as uniform, as many would like. Expressed as an accident rate there were 7.583 Class A to C flight accidents per 100,000 hours in 2006. This had risen to 10.357 in 2007 but fell again to 7.639 in 2008 (Ref. 2).

It is also important to remember that there is a residual risk in many combat and training activities that create the potential for accidents; where young people are typically asked to make critical decisions in short periods of time with limited information. These complexities do not arise in many civil environments and hence it can be particularly difficult to sustain reductions in the military accident rate (Ref. 3). Most accidents are caused by interactions between multiple causes and contributory factors. They stem from problems that lie undetected for months or years, including flaws in the design of equipment, Standard Operating Procedures (SOPs) or maintenance procedures. These longer term 'latent' issues combine with 'catalytic' events that trigger particular accidents, such as human error or component failures. They are often compounded by operational demands, including meteorological conditions, mission requirements and by enemy action. This paper focuses on the interactions between technology and the environment that pose an increasing risk in many parts of the globe. In particular, we

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[1] Class A mishaps cost $1,000,000 or more and/or destruction of an Army aircraft, missile or spacecraft and/or fatality or permanent total disability. Class B incidents involve damage costs of $200,000 or more, but less than $1,000,000 and/or permanent partial disability and/or three or more people are hospitalized as inpatients. Class C incidents are slightly more complex as the categorization changed in 1992. Prior to that date they were defined to incur damage costs of $10,000 or more, but less than $200,000 and/or non-fatal injury resulting in loss of time from work beyond day/shift when injury occurred and/or non-fatal illness/disability causes loss of time from work. After 1992 this was revised to be damage costs of $20,000 or more, but less than $200,000 and/or non-fatal injury resulting in loss of time from work beyond day/shift when injury occurred and/or non-fatal illness/disability causes loss of time from work.

consider the ways in which the operational limitations of night vision technology can be exacerbated during the brownout conditions that occur when visibility is reduced by airborne particles, typically from helicopter downwash.

Table 1---- US Army Aviation Accidents (2006-2008)

Total Aviation Accidents (Flight, Flight-Related, Ground & UAS)				
	Number of Accidents			
Accident Category	FY 2008	FY 2007	FY 2006	3-Yr Avg
Aviation Class A	26	34	27	29
Aviation Class B	31	32	61	41
Aviation Class C	134	135	148	139
Total Aviation (Class A-C)	191	201	236	209

The Role of Night Vision Devices in Military Aviation Accidents

Night vision devices mitigate the risks associated with operations in low levels of visibility by helping personnel to maximize their visual resources. Night vision devices also create new risks including a host of human factors problems that are implicated in a growing number of military accident reports (Ref. 4). The use of night vision equipment can impair situation awareness (Ref. 5). The prolonged operation of these devices can also increase levels of fatigue. Studies of aviation accidents have identified the spatial disorientation that can be caused by the use of night vision devices in helicopter operations (Ref. 6). Problems with depth perception and orientation were found to predispose aircrew to mishaps involving night-aided flight. Three independent assessors read through each of the incident reports in the A to C categories in order to identify those that involved some form of spatial disorientation. These were then subject to a further analysis that was intended to identify ‘associated factors’ and ‘possible countermeasures’. They found that approximately 43% of all spatial disorientation mishaps occurred during flights that used night vision equipment. Only 13% of accidents that did not involve spatial disorientation involved these devices. An examination of the spatial disorientation accident rates per 100,000 flying hours revealed a significant difference between the rate for day flying and the rate for flight using night vision devices. The mean rate for daytime flight was 1.66, while the mean rate for flight with night vision devices was 9.00. They concluded that the use of night vision devices increased the risk of a spatial disorientation accident by almost five times.

It can be difficult to identify the impact of NVD operation from statistical studies, such as those cited above. These devices tend to be used under adverse meteorological and environmental conditions when accidents are more likely to occur. For instance, approximately half of all accidents involving the US Army’s Black Hawk helicopter fleet have occurred while pilots were wearing night vision devices. However, this does not imply that these incidents were caused by the night vision devices. Many more accidents *might* have occurred if aircrews had not been wearing these devices.

Overview of Night Vision Technology

There are two main classes of night vision devices. Image intensification (I^2) systems enhance the lighting that is available within the existing environment. Infrared (IR) devices, in contrast, will typically use heat emissions to identify objects that cannot otherwise be detected using available light sources.

Image Intensification Equipment: Image intensification systems support direct observations by amplifying low levels of ambient light. Most image intensification systems perform poorly in total darkness. Higher amplification is associated with more expensive devices and can imply increased levels of distortion. The intensified image is, typically, viewed on a phosphor screen that creates a monochrome, video-like image, on the user’s eyepieces. Unfortunately, a number of disadvantages affect the application of this technology. Most image intensification systems are attached to the users’ helmet. Early models included relatively heavy battery packs that restricted the users’ head movements. This problem was exacerbated by the need to move the head because many of these devices offer a highly restricted field of vision. This may only be 40-60 degrees (Ref. 7). Image intensification equipment can also create problems in depth perception. Color cues and binocular information are lost with many commercial systems. All of these limitations are being addressed by technological innovation. In particular, it is now possible to buy light weight and extended field of vision systems. However, these tend to be expensive and can be difficult to maintain under field conditions.

Image intensification systems amplify available light. From this it follows that, I2 systems do not work well in near total darkness. External light sources support the use of this equipment. City lights provide useful illumination when cloud cover reflects available light back onto a scene. However, there is a risk that personnel will fixate on distant light sources (Ref. 4). Looking at the moon has the same effects as looking directly at the sun under daylight lighting conditions. Flares can also provide the indirect light that is amplified by image intensification systems. However, such a strong source will adversely affect device resolution if users look directly at them. Vehicle instrument lights and cockpit displays can create “washout” or halo effects. It is usually possible to turn-off instrument illumination in ground vehicles. However, it is a complex and expensive task to alter cockpit lighting systems without compromising the daytime use of the aircraft. Night vision systems are often particularly sensitive to the red lights that are frequently used in speedometers and engine instruments. The anti-collision lights required by FAA regulations can also be intensified to a point at which they dazzle the wearer of an intensification system.

Visual acuity from night vision devices provides a vast improvement over human night vision. However, it is far from perfect. As with direct sight, higher levels of acuity are associated with closer, slower targets (Ref. 8). The visual acuity offered by image intensification rapidly diminishes for objects over 500 feet away. This distance is further reduced, the faster the target is moving. A number of environmental factors can also reduce the acuity of image intensification systems. In addition to brown outs, performance is also affected by rain, clouds, mist, dust, smoke and fog. All of these factors imply that experience and recurrent training must be provided if personnel are to operate image intensification systems. Risk assessments should also consider the problems that can arise, for example if external lights are likely to create the deep shadows that hide hazards or if the users of image intensification systems are momentarily dazzled by other light sources.

Infrared and Thermal Imaging Systems: Rather than enhance light that is visible to the human eye, thermal imaging systems detect infrared radiation that is emitted by heat sources. These devices use transducers to detect thermal emissions that can then be focussed in the same way as conventional light. The difference in temperature amongst the objects in a scene is translated into a visual contrast represented by different shades on a display. Infrared systems can, therefore, be used in total darkness. They tend to be robust against the light ‘pollution’ that will dazzle users of image intensification systems. Infrared devices can also be used to ‘see through’ some types of fog because they do not rely on visible light.

The sensitivity of thermal imaging systems is measured in terms of degrees Celsius per optical *f*-number. In other words, it provides an indication of the temperature change that would be required to provoke a change in the image. These differences are typically in the region of 0.05-0.2 degrees Celsius. The resolution or sharpness is measured in terms of the instantaneous field of view (IFOV) in milliradians (mrad). 17.5 milliradians is equal to an angle of 1 degree in the instantaneous field of view. The lower the IFOV value is then the sharper the image and the longer the range will be. However, as the magnification of the thermal sensor increases, the field of view decreases. Operators must use scanning techniques to compensate for this limitation. Without well developed methods, it can be easy for users to overlook areas in a scene. As with image intensification systems, individuals can quickly become fatigued by the prolonged scanning that is required to use infrared systems in combat conditions (Ref. 9)**.**

Infrared landing lights are invisible to the naked eye but for can provide useful beacons to aircrews using these night vision systems. Infrared searchlights can be used to pick out objects that could not otherwise be detected using visible light. However, these sources can help enemy personnel if they are also using night vision equipment. There are further human factors limitations. Users tend to limit their attention to the area directly covered by a searchlight. They must be trained to expand their scanning patterns on either side of the beam. There are further limitations. High-humidity reduces the thermal contrast that is amplified by infrared systems. Rain and surface water on runways can create optical illusions; they often appear to be further away as the surfaces cool. Infrared systems cannot be used to identify precise details on remote objects that are not distinguishable by different heat profiles. Brown-out can also occur when there are reflections from an infrared searchlight caused by the dust that is raised in a rotor wash.

Training with Night Vision Devices in Brownout Conditions

The operating characteristics of existing night vision systems make it important that individuals and teams are trained in the operational use of these applications. It can be difficult to master the scanning skills that are required to avoid the ‘washout’ and ‘halo’ effects that occur when image intensification systems are affected by secondary light sources. Similarly, personnel must be trained to overcome the limited field of view provided by most infrared applications (Ref. 10). US Army Training Circular 1-210 ‘Aircrew Training Program Commander's Guide to Individual and Crew Standardization’ summarizes training and familiarization requirements for the use of night vision equipment (Ref. 11). Prior to their first training flight with night vision, aviators must spend more than an hour in the cockpit of a static simulator or aircraft to familiarize themselves with a list of basic tasks including emergency procedures, night vision failure and a ‘blind’ cockpit drill. They must then undergo ten hours further training including: An Introduction to Night Vision Devices; Night terrain interpretation; Night Vision ground and air safety; Night tactical operations, including the impact of lighting; Night Vision navigation, including map preparation; Aircraft modification requirements for night vision flight; Vision, depth perception, and night vision orientation. TC 1-210 also includes requirements for aircrews to conduct refresher training in the use of night vision devices. One hour of refresher training is required if a night vision flight has not been completed on a particular aircraft type within the previous 180 consecutive days. There is also a requirement for aviators to conduct mission training. This involves at least ten more hours of flight using night vision devices followed by a further evaluation.

While it is possible to train personnel during particular flight conditions, it can be far more difficult to prepare operators to resist the broad range of visual illusions that complicate the operation of night vision technologies. For instance, many devices can provide an impression of a false horizon on the boundary between light and dark colored areas of sand, especially when other environmental factors, including dust and haze, obscure the true horizon. Desert conditions often also lack the visual markers and reference points that support accurate height perception. Under such circumstances, ground lights can be mistaken for the lights of other aircraft or even stars. Lack of features and relatively slow speeds may also persuade pilots that they have stopped moving even though the aircraft is actually travelling forward. In flat terrain, such as that found in dry lakebeds, infrared devices create the illusion that terrain slopes upwards at the edges. Particular problems are created when using the infrared searchlights to view other helicopters that may appear to be landing into a crater when they are landing on level ground.

Recent years have seen a move away from training individual crewmembers to recognize the optical illusions that affect night vision equipment. These illusions can be so persuasive that individuals will still fall prey to them even though they have been trained to recognize that they can occur. In contrast, greater attention has recently been paid to team and crew coordination as a potential barrier to incidents and accidents. For instance, the US Army Safety Center’s Southwest Asia Leaders' Safety Guide emphasizes the need to synchronize crew observations and communications in order to combat some of the problems created by these illusions. Guidance is provided on scanning responsibilities for pilots and non-rated crewmembers in different types of flight. These responsibilities must be planned and rehearsed prior to any mission so that team members can detect and compensate for the current limitations of night vision technology.

Brown-out, Rotor Wash and Military Aviation Accidents

Training requirements, such as those presented in TC1-210, have improved competency to a point where most military mishaps are the result of several different causal factors. Operational demands combine with environmental conditions to exacerbate the problems of using complex technologies; including night vision equipment (Ref. 12). As we have seen, the operation of night vision equipment has been associated with several different forms of spatial disorientation. These effects are exacerbated during a ‘brown-out’ landing or take-off when visibility is reduced by airborne particles. These particles are, typically, raised from helicopter downwash in the last 20 to 30 feet of an approach. The interaction between night vision equipment and brown-out incidents is important because it typifies a growing number of ‘complex’ or ‘systemic’ military accidents.

Brown-out accidents were relatively rare during the Cold War; given the small number of operations in arid desert regions. However, the importance of these mishaps has steadily increased even though brown-out accidents tend to be more ‘survivable’ than other aviation incidents. They, typically, occur close to the ground and at low airspeed. The UK MoD has lost 16 helicopters in brown-out incidents between 2000 and 2007. Between 2002 and 2005, the

US Army suffered 41 brown-out accidents. Approximately, 80 percent were during landings and 20 percent during takeoffs (Ref. 13). The percentage of these accidents as a proportion of all Class A mishaps rose from 9% prior to the invasion of Iraq to 18% during it (Ref. 14). Since 1991, the US Army has reported more than 230 cases of aircraft damage and/or injury due to unsuccessful take-offs or landings in brown-out conditions. One reason for the importance of brown-out incidents is that they lead to spatial disorientation which exposes other underlying vulnerabilities. These include human factors issues. Inadequate training, problems in cockpit resource management, high levels of workload combine and undermine attempts to cope with the loss of visibility during an approach (Ref. 15). Brown-outs also expose flaws in the design and maintenance of airframes. For instance, mechanical failures have been triggered by the ingestion of sand. Brown-outs accelerate wear on rotor blades and gear as well as engine components and air filters. Secondary effects include the reduction of maintenance intervals and the consequent increase in demands on support crews. High levels of maintenance workload continue to be a significant cause of other military accidents.

Effects of Brown-out on Different Platforms: New generations of aircraft, such as the HH-60G PaveHawk and the MH-53 PaveLow, have been specifically developed to support extreme low-level operations. However, the threats created by 'brown-out' conditions are beginning to constrain the 'all-terrain' landing capability that these platforms provide. This is particularly important because the amount of debris generated in brown-out incidents is also determined by the downwash characteristics of the airframe or airframes involved in an approach. For instance, the performance characteristics of the V-22 Osprey make it particularly susceptible to these incidents. This aircraft relies on tilting rotors that increase the velocity of the downwash compared to other rotary winged aircraft such as the CH-46, which it was intended to replace. However, the precise relationship between rotor aerodynamics and downwash incidents is far from simple. For instance, the Osprey seems to be less prone to low altitude brown-out. In other words, the debris clears in the last few feet before the tilt-rotor makes a landing. Further study is required to develop a comprehensive account of the downwash characteristics of different aircraft. The Osprey observations are largely based on accounts from aircrew transitioning between the V-22 and the CH-46. Accident data provides more quantitative insights. For example, the CH-47 made 7% of all U.S. Army helicopter flight hours from February 2003 to June 2005. However, it was involved in 30% of all brown-out mishaps, 12 out of 41 in total between FY 2002 and 2005 (Ref. 16, 17).

Downwash directly influences the likelihood of brown-out mishaps. A number of other design factors influence the consequences of these incidents. For example, the AH-46D Apache has a relatively narrow stance; the pilot sits in a rear section of the cockpit while the co-pilot/gunner sits immediately in front. This tandem layout makes the aircraft more susceptible to 'roll-over' incidents in a brown-out compared to the parallel cockpit layout and broader stance of UH-60s. However, the Apache also provides a Forward Looking Infra Red vision system that is being integrated with image enhancement systems as part of the Arrowhead upgrades. This arguably helps the aircrews to avoid the disorientation associated with brown-out incidents. UH-60s only provide image intensification technology.

Training, Tactical and Procedural Countermeasures: As with night vision related accidents, many military organisations have developed Training, Tactics and Procedures (TTPs) to reduce the likelihood of brown-out mishaps. One reason for this is that the US Army has identified 'spikes' in the accident rates. Brown-out incidents are more likely to occur in the early stages of combat deployment (Ref. 18). Aircrews must rely on unprepared field sites prepared – for example in forward arming and refuelling laagers, combat outposts etc. Over time these sites are upgraded with hard-standing areas using gravel, concrete and polymer coverings that are less prone to brown-out. However, aircrews cannot assume that they will be able to land on a prepared area. There is, therefore, a continuing requirement to ensure they are proficient in the monitoring skills that are essential to maintain situation awareness during brown-out conditions.

Arguably one of the most effective Training, Tactics and Procedures is to keep the debris behind the pilot's door by performing a rolling landing. This helps to ensure that the crew have a clear view of the Landing Zone (LZ) ahead of them. Rolling approaches are less effective if the wind changes during a landing or if the prevailing wind prevents such an approach in the first place. There are further limitations. For example, ground obstacles and wires often restrict the area available within a landing zone. Other aircraft may require additional space to make their own approach. They can also create debris ahead of the potential LZ; obscuring the view of the rest of the formation. There may not be time for a prolonged rolling approach in medical evacuations (MEDEVAC), unscheduled supply drops or rapid troop transports. These techniques cannot be used in situations where enemy action may target the aircraft as it moves forward through the dust cloud. These factors constrain the airspeed and rate of descent needed to maintain aircraft control under brown-out conditions (Ref. 19). More acute descent and ascent profiles have been developed to minimise the impact of brown-out. However, these manoeuvres create their own risks by placing heavy demands on the skill and proficiency of aircrews.

The US Army has also developed their TTP support to ensure that instructors from units that are being rotating out of a combat area are then heavily involved in training their colleagues from new rotations. This was not always the case. One of the reasons why brown-out incidents have been so prominent in recent military accidents is because there has been a mismatch between pre-deployment training and operations experience. Early US rotations in Iraq were more accustomed to the dry lakebeds and scrub of the National Training Centre. This left aircrews unprepared for brown-outs and a host of other operational conditions. They had relatively little experience of shifting sand dunes and the impact that extreme temperatures can have upon night vision equipment. For instance, crews found that their training manuals authorized airspeeds that were too fast to safely operate at night over sand dunes with night vision equipment; "the authorized airspeed for nap of the earth flight is 40 knots, but an aircraft flying in zero illumination at 25 feet in sand dunes should fly just ahead of effective transitional lift…Just keep in mind that at airspeeds below Effective Translational Lift (ETL), you may encounter rotor induced blowing sand" (Ref. 12).

Other TTP countermeasures focus on crew resource management. There is a temptation to 'stack the deck' with additional pairs of eyes during landing – for instance by requesting input from the door gunner in another platoon. However, there is a risk that misunderstandings and other forms of communication failure will compromise shared situation awareness. The use of TTP solutions is further limited by one of the fundamental paradoxes of military risk assessment (Ref. 3). In order to become proficient in the communication and planning techniques that reduce the threats created by brown-out incidents, it is necessary for crews to practice these skills. However, it can be difficult to train in brown-out conditions when Standard Operating Procedures (SOPs) are intended to limit aircrew exposure to these hazards. In the decade between the Gulf War and Operation Enduring Freedom, the U.S. Army recorded over 40 cases of brown-out accidents during training. Some units in the US Army have begun to remove the cabin doors to increase visibility for the aircrew during brown-out landings. Pilots and co-pilots can make more accurate direct visual observations by maximizing their field of view so that they can spot any 'breaks' in the clouds of dust and other debris. As with the application of polymer binding agents, this solution has not been adopted across all units. In particular, the US Air Force TTPs have not approved the removal of cabin doors because there remain considerable concerns about the consequent loss of protection in combat areas.

Ground-Based Countermeasures: In addition to specialised 'brown-out' approach profiles, US Army SOPs require that aircrews use prepared landing zones (LZ) whenever possible. These are mostly confined to established bases and outposts. Prepared LZs are seldom available in forward operating areas or for deliberate air assaults. Aircrews must improvise landings on dirt roads, open dry areas, or dusty mountain peaks (Ref. 19). The hazards associated with landing on unprepared surfaces are exacerbated by the difficulty of conducting detailed landing site surveys in hostile areas or where operational demands force late changes to the location of a mission. In other words, crews often do not know whether or not they will face brown-out conditions when they are tasked with a particular mission. A range of materials have been developed to reduce the amount of debris that can be raised during take-off and landing. The US Army have laid down polyester Mobi-Mats, or 'triscuit pads', since the late 1990s. These are temporary pads that can be unrolled to provide a stable surface for rotary wing operations. However, they are heavy and can be unwieldy in the field. In consequence, the US Marine Corps have experimented with light-weight HeliMat alternatives (Ref. 20). These do not have the load bearing characteristics of the Mobi-Mats. They also wear out under a high tempo of operations. Operational deployment has, therefore, revealed the need to carry both type of synthetic surface.

'Rhino snot' polymers provide a further alternative to these pre-formed surfaces and mats. These substances bind together debris prior to any landing. In order to apply these polymers, ground forces must first scrape off as much dust as possible. The area is then soaked with water, leveled and topped with gravel. Several coats of 'Rhino snot' are then applied and left to harden. Eventually, the surface breaks up to minimize longer-term environmental effects. However, the polymers offer a different set of logistic problems to those created by HeliMats and MobiMats. In order to bind surface layers, the polymers are very adhesive. This makes them difficult to handle. If clothes are contaminated then they, typically, must be destroyed. This makes the polymers very unpopular with some of the units that have to apply them. The difficulty of cleaning the equipment used to lay down the surfaces often forces ground units to reserve a small number of vehicles for this purpose. This also means that the approach cannot easily be used in forward areas.

Airborne Countermeasures: The operational risks associated with brown-out landings and take-offs have motivated initiatives to find technological countermeasures. The most obvious approach is to redesign rotors that reduce the likelihood of a brown-out occurring in the first place. The US 101 variant of the Augusta-Westland EH101 has been designed with blades that are intended to push debris away from the fuselage. Traditional designs tend to propel dust towards and around the cockpit area. However, brown-out performance is one of several competing requirements for blade design and here can be trade-offs with efficiency/power, noise etc. Aerodynamic solutions to the hazards created by brown-out remain the subject of basic research (Ref. 21). It is unlikely that aerodynamic innovations in rotor design will provide a panacea for brown-out incidents in the short term. Flight information systems provide an alternative approach. For example, some MH-53's present a cross in the middle of the head-up display at 15 knots of descent. As the pilot decelerates this cross descends towards a reference box and hence can be used to monitor vertical velocity (Ref. 22). The Brown-out Situational Awareness Upgrade (BSAU) extends this approach. Vertical speed and vector information is mapped using data from radar altimeters and the Global Positioning Systems (GPS) on aircraft including the UH-60 and CH-47. Aircrews can access BSAU information using their standard head-up displays as well as through their night vision goggles. The design teams first identified information needed by aircrews to mitigate the risks of brown-out accidents. They then traced this required information back to the available input from sensor data. These sensors had to be sufficiently accurate to ensure that the application did not increase the cognitive load on aircrews when they used the symbology during a brown-out. However, US Army studies concluded that BSAU was only an initial step; "While the system proved its value during this and many other approaches, good crew coordination, briefing of go-around procedures, and power management remained critical tasks" (Ref. 23).

Flight systems, such as BSAU, help pilots to monitor their attitude and rate of descent into brown-out landings. They cannot at present be used to help aircrews avoid terrain features or ground obstacles. Night vision equipment can provide pilots with additional cues. They may also reduce the impact of disorientation. However, these devices often limit aircrews' field of view and hence may exacerbate rather than reduce the problems of spatial awareness. The underlying technologies are also susceptible to brown-out failures. Dust particles can completely obscure the narrow field of view provided by image intensification equipment, such as that installed on most Blackhawk aircraft. Airborne debris reduces the temperature profiles that are augmented in infrared systems. Further problems arise from the interaction between night vision equipment and the hazards created by brown-out incidents. For example, the FLIR (Forward Looking Infra-Red) pod and infrared countermeasure equipment have been slung beneath the HH-60G. The location of these devices makes them particularly vulnerable; "even the most experienced pilots are not immune from breaking FLIRs or rolling an aircraft due to a brown-out approach" (Ref. 24).

A number of research programmes are developing enhanced night vision systems to address the problems created by brown-out landings. These include 'see and remember' applications that take a series of FLIR images of a landing zone before they are obscured by debris from the downwash. Software then recreates a pseudo-3D image for the aircrew to refer to during a subsequent brown-out. The Photographic Landing Augmentation System for Helicopters (PhLASH) has extended this 'see and remember' approach to image intensification systems. PhLASH combines an electro-optical sensor and infrared strobe lights to match a photograph of the ground with a coordinate on the Earth's surface using onboard GPS. The intention is that the photograph would be taken immediately before the brown-out and hence could be ten or twenty seconds out of date during the final stages of the descent. This could create problems is vehicles or other elements of a formation moved into the LZ. It can also be difficult to obtain an accurate image of the LZ during night operations, given the limitations of image intensification and infrared technologies that were summarized in the opening sections of this paper (Ref. 22). This limitation can be addressed through the use of radio wave sampling (Ref. 23). The Defense Advanced Research Projects Agency (DARPA) Sandblaster programme provides an example of one of these 'next generation' initiatives. This integrates four different technologies:

1. *A radar sensor for three-dimensional scanning.* Conventional radar plots provide two dimensional overviews of a potential LZ. Phased and millimeter wave approaches can be used to build up three dimensional representations while the radar signals penetrate the debris that causes brown-out incidents.

2. *A database to store successive scans of a potential landing zone.* The results can also be compared to pre-stored images and maps. This helps to ensure that whenever possible the radar returns can be mapped onto a known potion of the landing zone.
3. *Synthetic vision techniques to generate a representation of the LZ for the crew based on sensor feedback and the pre-stored information in the database.* The intention is that this view will restore aircrew situation awareness that would otherwise be compromised by a dust cloud.
4. *An 'agile' flight control system.* The ambitious aim of this component is to enable the helicopter to 'land itself' under low speed approaches (Ref. 22).

Much work remains to be done before sufficient operational expertise has been gained to demonstrate the reliability of this multi-stage approach – for instance in desert environments where sandstorms continue to alter the landscapes that may be recorded in spatial databases. US Air Force work in this area has focused on Laser Detection and Ranging (LADAR). In contrast to millimeter wave radar based on radio pulses, LADAR uses light sources to scan a potential landing zone. This technology has been applied in 'near operational conditions'. However, there are further technological problems. Ideally, aircrews require high resolution images (e.g., 1280x1080 pixels). However, existing LADAR sensors have low spatial resolution (i.e., 512x512 pixels). Real-time systems also suffer from the same limited field of view, around 30 to 60 degrees, that affects night vision systems. Accuracy requirements for brown-out countermeasures can be expressed in terms of centimeters at rages of 100 to 1000 ft in real time. At present the generation of synthetic images requires additional processing that prevents these resolutions being produced in real time. These limitations are being addressed by technologies that include active gated LADAR imaging and fusion of the millimeter wave radar from other areas of the Sandblaster programme. A recent Department of Defence research call also proposed the integration of LADAR technology with image intensification and infrared night vision equipment (Ref. 25).

The US Army Safety Centre has stressed that these technological initiatives will not remove the need for to train crews to combat brown-out conditions. There is a need to familiarize pilots with the strengths and weaknesses of advanced sensing systems, just as aircrews must gain expertise in the application of infrared and image intensification equipment. The UH-60M and the CH-47G have recently been deployed to US forces and provide technological support for brown-out landings. While they do not provide the integrated sensing systems mention above, they do provide velocity vector, acceleration cursor, instantaneous vertical speed indicators, radar altimeter, and heading information on a common 'hover page'. Pilots are not forced to piece together critical information from numerous displays scattered across the cockpit. However, the Safety Center recognizes that the wider provision of this technology will require "the development of a separate aircrew training manual (ATM) task for landing without visual reference for all airframes, not just special operations aircraft" (Ref. 18).

Combating the Interactions between Night Vision and Brown-outs

Training, Tactics and Procedures (TTPs) have been developed to minimise the disorientation that can be cause by night vision equipment. Previous sections have also described how TTPs have been drafted to address the loss of spatial awareness during brown-out landings. There are strong overlaps between these Training, Tactics and Procedures. For example, the UH-60 requirements include a section on Night or NVG Considerations: "A go-around should also be initiated if visual contact with the landing area is lost. Snow, Sand and Dust Considerations: If during the approach, visual reference with the landing area or obstacles is lost, initiate a go-around or instrument takeoff (ITO) as required, immediately. Be prepared to transition to instruments. Once visual meteorological conditions are regained, continue with the go-around" (Ref. 18).

Training is required because there is a position close to the ground where it may be more risky to attempt a go-around rather than complete the landing. Hence, go-arounds should be initiated well before passing below any obstacles. However, brown-outs can occur in the last few feet of a descent. In other words, the aircrew must decide whether or not to abort the landing after they have passed underneath obstacles and at a time when it can be difficult to determine whether the go-around is more risky than the landing. All of these factors are exacerbated when aircrews are under fire or operating in close support of ground troops with an urgent operational need for air support. The use of night vision equipment adds further complexity because it can foster a sense of over-confidence in crews as they approach a potential landing site. This may leave them ill-prepared for the disorientation caused by an unexpected brown-out. In such circumstances, the US Army guidance makes it clear that the greatest risks arise when crews have no contingency plan and so must continue with a landing even though they are uncertain of their precise orientation with respect to the intended LZ. Aircrews must train to continuously scan for any available outside cues and for information from their instrumentation during brown-out contingencies.

Simulators cannot easily be used to prepare for the spatial disorientation that occurs when brown-outs create sudden on-set instrument meteorological conditions (IMC), especially while using night vision equipment. “Simulation is a valuable tool to aid in training aviators in the dust landing profile, and it is getting better all the time, but it cannot replace the feel, motion and characteristics of the real thing” (Ref. 18). Equally, there are significant hazards in practicing under the environmental conditions for which aircrews are not yet fully prepared. In consequence, visors, helmet bags and ‘foggles’ have been developed to restrict the vision of aircrews during exercises (Ref. 26). These help pilots to experience some of the effects of brown-outs under controlled supervision. In particular, a great deal of attention has recently focused on the integration of Night Vision Goggle Power Interrupt Devices (NVGPID) into US military TTPs. NVGPIDs help crews simulate the loss of NVG capability during brown-outs (Ref. 18). Instructors can use the devices to induce a failure in the night vision goggles during a critical phase of a practice landing. By extension, the same technique can also be used to replicate the impact of debris during take-off. The intention is to force the pilot to make use of the instruments and symbology to complete the maneuver. There are three additional benefits. Firstly, the NVGPID device is relatively cheap and simple. Secondly, instructors do not always have to fail the night vision system during practice landings; this makes it possible to mimic some of the uncertainty that arises when crews do not know whether or not a brown-out will occur. Finally, instructors can control the level of risk that is implicit within any brown-out drill outside the constraints of a simulator. Training officers can vary the stage of an approach or landing when a failure is induced. They can also integrate the NVGPID into other operational training scenarios to mimic specific approach patterns. It is far more difficult to preprogram complex simulation software to reflect the specific demands of a deployment. It is important to stress, however, that the use of NVGPID’s is intended not simply to replicate the loss of spatial cues. These devices have been developed to help crews simulate the large volume of communication, coordination, and visual, instrument and symbology scanning that is required following a brown-out.

Conclusions and Further Work

This paper has described how Training, Tactics and Procedures (TTPs) have been used to tackle the threat of brown-outs in night vision missions. For instance, ‘rolling box’ approaches have been developed to provide the forward trajectory necessary to move beyond an initial dust cloud. However, there may not always be the space available to prepare such descents given the obstacles that litter many operational areas. Other constraints stem from the need to coordinate landings with ground forces and with other aircraft. Therefore, simulators and drills have been used to help prepare crews for the spatial disorientation and the loss of situation awareness that can arise during these incidents. For example, the US Army has introduced the Night Vision Goggle Power Interrupt Device (NVGPID) into their aviator training programs. Instructors can use these devices to induce the failure of night vision equipment to simulate debris from rotor-wash during take-off and landing. The intention behind the NVGPID program is to help ensure aircrews “train to continuously scan, and to train the ability to rapidly adjust from outside cues to instruments” (Ref. 18).

The contingencies and characteristics of asymmetric warfare increase the need to use night vision equipment while at the same time raising aircrew exposure to brown-out conditions. The pace of operations in Iraq and Afghanistan has increased the need for helicopter support in areas well beyond the reach of prepared landing zones. Changes in insurgent technology, including the use of remotely detonated IEDs, also encourage deployment under the cover of darkness (Ref. 27). Many military organizations were unprepared for the demands created by these conditions. In consequence, most have seen a rise in the frequency of brown-out-related mishaps. This, in turn, has motivated technological innovations, ranging from rotor aerodynamics through to binding polymers, from LADAR applications to sensor fusion techniques. However, these are active areas of research and much remains to be done before they can be deployed to support combat operations.

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