Interactions between Night Vision and Brownout Accidents: The Loss of a UK RAF Puma Helicopter on Operational Duty in Iraq, November 2007

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Abstract

Night vision devices (NVDs) mitigate risks in low visibility operations. However, NVDs also create new hazards. They contribute to different forms of spatial disorientation. Prolonged operation can also be associated with increasing levels of fatigue. The following pages describe how these problems can combine to exacerbate the demands of 'brown-out' landings when visibility is reduced by airborne particles, typically from helicopter downwash. We present a detailed case study of the loss of a Royal Air Force Puma on operational duty in Iraq during November 2007. Environmental conditions limited the effectiveness of NVDs. Contributory factors included organizational issues, such as a failure to follow Standard Operating Procedures, and a host of human factors concerns, including the loss of situation awareness across multiple teams. A companion paper in this conference shows that this was not a 'one off' accident. Both papers argue 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 'brown out' conditions.

Introduction

There have been more than 120 US Army helicopter crashes in Iraq since 2001; just over 40 were caused by enemy action. In Afghanistan, there have been approximately 40 helicopter crashes, around one quarter were due to hostile fire. Many of these accidents have occurred while crews were using night vision equipment. For instance, the US Army recently found that there were 7.7 serious incidents per 100,000 hours of daylight flight in their helicopter fleet. The rate rose to 13.9 per 100,000 hours for night flight. Of those, the rate for unaided night operations was 9.3 while 15.8 incidents occurred per 100,000 hours for night operations involving vision enhancement systems (Ref. 1). There are many reasons for the higher incident rates associated with the use of night vision technology. For example, night operations carry an inherently greater risk than missions that are conducted during daylight hours. Image intensification and infrared systems tend to support operations that would not otherwise be attempted. There are also technological and human factors limitations; night vision devices do not turn night into day. The relatively constrained field of view afforded by many applications can lead to spatial disorientation. Macuda et al. (Ref. 2) have investigated the difficulties that aviators experience when using night vision systems to identify forms that are recognised by their motion. The studies of Macuda and their colleagues have shown that the relatively low image quality of many night vision systems can impair aviator performance and increase workload. Existing applications provide relatively grainy images that can prevent users from identifying depth, motion, resolution, form, size and distance information.

Many of the accidents that occur during night vision operations stem from several different contributory factors. In particular, the limitations of these devices can be exacerbated by the 'brown out' conditions that occur when visibility is reduced by airborne particles. The hazards created by 'brown out' incidents are exacerbated by the restricted peripheral vision and low resolution that is provided by night vision systems. Debris on landing and take-off obscures visual references and increases the spatial disorientation that is a common cause of many accidents involving image intensification and infrared technologies. These problems are compounded by a sense of complacency that can arise when aircrews rely on the images provided by night vision technology. Many incident reports refer to the sense of surprise when pilots are first engulfed by the dust brought up in the wash of their own rotors (Ref. 5, 6). The operational characteristics of existing rotary aircraft, such as the CH-47, has led to an increasing number of accidents in which debris from helicopter downwash has obscured crew vision during landing and takeoff (Ref. 3). The decision to focus on the interaction between night vision and 'brown out' incidents is further justified by the operational demands that continue to face the NATO International Security Assistance Force (ISAF) in Afghanistan and coalition troops in Iraq. The operational context for these conflicts has created a requirement for formation flying to deliver troops and supplies into the field. The first aircraft to land or take –off in a formation stands a greater chance of avoiding the debris that affects their colleagues. However, in some areas even a single take-off can generate a dust cloud that extends for miles. A recent US Air Force report argued that the task of landing in desert environments was the "most dangerous aspect of flying in combat helicopters today" (Ref. 4). Fixed wing vehicles also suffer from the problems of 'brown out', especially during sandstorms. However, the frequency of these incidents is much lower and the consequences are typically less serious than for helicopter operations (Ref. 5).

This paper shows how the use of night vision equipment combined with brown-out conditions and a host of other operational concerns the led to the loss of a UK Puma helicopter on operational duty in Iraq during November 2007 (Ref. 7). Contributory factors included organizational issues, such as a failure to follow Standard Operating Procedures, and human factors problems, including the difficulty of maintaining distributed situation awareness across multiple teams. The aircraft involved in this incident formed part of a mixed formation of two Pumas and two Lynx helicopters. During the afternoon before the accident, a plan emerged to attack a series of targets under the cover of darkness. However, intelligence updates forced the Mission Leader to re-brief the formation on a revised scenario for the attacks. During the flight, the lead Lynx became separated from the rest of the formation and radio contact was lost. However, the Mission Leader believed he had correctly identified one of the targets. During an initial approach, the second Puma struck the ground and rolled over under 'brown-out' conditions as debris was lifted into the air from the downwash of the rotors. The aircraft caught fire shortly after impact; two passengers were trapped in the wreckage and were later found to be dead by a subsequent rescue crew. The damaged Puma was destroyed in place by coalition forces.

The subsequent investigation examined the qualifications for the pilot handling the Puma at the time of the crash and found "It was not possible to ascertain his Night Vision Device (NVD) category, as it was not obvious in either his Log Book or his training records. It was clear that he had flown to NVD Cat B limits but there was no reference to any Cat B conversion course having taken place. Therefore although not theoretically qualified as NVD Cat B he had proven himself competent to fly to Cat B limits and the lack of a dedicated training course, although remiss, did not play a significant part in his handling of the events leading up to the crash" (Ref. 7). The training documents for the Non-Handling Person (NHP) in Puma 2 also "indicated that he had not completed the full NVD Cat B work up but he was sufficiently trained and experienced to be expected to carry out the NHP duties as required by his aircraft commander" (Ref. 7). The crewman onboard Puma 2 had completed his Full Mission Qualification workup to a 'high standard' but there was no record in his training folder that the qualification had been awarded. "Neither is there a record in his training folder of his award of NVD Cat B qualification". The Non-Handling Person on Puma 1 was 'suitably experienced and capable' to undertake his role on the operation. However, he too had not completed his NVD CAT B training. His night tactical formation qualification had also expired.

The Board of Inquiry argued that 'in-theatre' experience made up for the lack of NVD Cat B training. This argument is supported by relatively high frequency of brown-out incidents during the initial stages of any deployment (Ref. 4). Aircrews seem to be less likely to be involved in brown-out accidents the longer that they have been deployed in environments where they encounter these conditions. However, the crews involved in this accident did not have the same level of experience in these environments. The handling pilot of Puma 2 was had considerable previous experience as a Non Handling Person with a total of 1,700 flying hours and around 830 in the Puma. The Non-Handling Person (NHP) in Puma 2 had around 430 flying hours on the Puma. However, he had only recently been deployed to Iraq and had limited opportunities to familiarize himself with the rest of his crew. Similarly, the pilot, non-handling person and crewman on Puma 1 had only been together for six weeks at the time of the accident. These findings are particularly significant given the emphasis that many military organizations place on mutual situation awareness and inter-crew communication during brown-out conditions (Ref. 8). RAF doctrine and course descriptions covering the operation of night vision devices also stress the need to provide aircrew not just with practical experience using image intensification and infrared devices but also with a theoretical understanding of the underlying technologies. Brown-out incidents have shown that past experience in a combat area may be insufficient to prepare crews for the particular demands that are created when their approach options are tightly constrained, for example, by enemy fire on an unprepared landing zone.

The crews of Lynx 1 and 2 lacked experience of working with Pumas. There had been no pre-deployment training between Lynx and Puma aircraft nor was there any 'in-theatre mixed-type workup package'. The Puma force argued that the risks of in-theatre training were too great and that the operational tempo left little time for such exercises. However, this training might have improved crew resource management both within and between aircrews in the same formation. For the Puma and Lynx crews, the absence of mixed formation exercises and the relative lack of familiarity between recently formed teams undermined their ability to practice the communications that are vital to maintain mutual situation awareness (Ref. 7). The MOD has taken steps to address many of these issues; for instance by conducting closer audits over the training records of RAF pilots. They have also increased the amount of practice Joint Helicopter Command aircrews receive in the 'desert box' rolling landing techniques, described in previous sections, for example as part of Exercise Jebel Sahara. However, this accident clearly reveals continuing areas of concern in terms of aircrew training and preparation for the interaction between brown-out incidents and the use of night vision devices.

Mission Planning

The initial mission briefing provided generic information about the weather, light levels, intelligence, air tasking orders etc. It also provided an opportunity for the crews to conduct detailed formation planning for night operations, including the development of contingency plans for brown-out landings. However, the accident took place on the same day as a change in the engineering rotation. In consequence, servicing had to take place earlier than might otherwise have been expected, at the start of the aircrews' duty period. Some crewmembers had to support the engineering teams at the same time as others were taking part in mission briefs. These absences together with the uncertainty over the NVD status of crewmembers may be symptomatic of an ad hoc approach, which although it may be understandable given the operational tempo, reveals underlying concerns in the planning and staffing of missions.

The final mission planning was conducted by the Non Handling Person of Puma 1. He was preoccupied in planning and so did not attend some of the mission briefings and arguably could have been better supported by members of the other crews. However, several colleagues were still helping to service their aircraft. The investigators concluded that although the plans were well made; 'there was much confusion as to the exact nature of the target sets and the number of landing sites that were to be visited, suggesting that there was a great deal of confusion amongst all parties' (Ref. 7). A new mission target was identified while the crews were moving to their aircraft. This urgent operational requirement seems to have obscured the fact that the crews had not received an adequate briefing. This may in turn be explained by the lax way in which final mission authorization was interpreted to permit such ad hoc changes late in the planning process. In consequence, the Mission Leader briefed the rest of the formation over the radio. This new tasking required a far more demanding sortie profile than the mission that had previously been planned and briefed. The aircrews may have under-estimated the risks associated with 'in flight' briefings without detailed contingency plans, even given the need to respond to a time-limited target opportunity.

Closing on the Target

It was dusk when the formation departed their 'home' landing site but light levels were high. A number of obstructions were spotted during the flight. These included wires that forced them to fly higher than the crews would have preferred. The Non-Handling Person on Puma 2 reported high levels of workload. Chatter on the Air Traffic and tactical radios interfered with his task of updating successive grid references generated as the target moved position. The formation closed in, a couple of miles before the last known target reference.

With around one mile to go before Puma 2 reached the target, it became clear that Lynx 1 had overshot to the South by around a mile due to an error in their navigational equipment. The over-flight alerted elements of the target forces to the potential attack. In the meantime, Puma 1 and Lynx 2 failed to establish radio contact with the missing crew. The remaining formation could now see that the correct target indication was now some 3 miles behind them to the North. The Mission Leader requested infrared ground illumination on a known location to help navigate back to the proposed landing area. He then instructed Puma 2 and Lynx 2 to join Puma 1 on a direct route to the target. This left Lynx 1 detached from the formation. The Team Leader of ground forces was also on the Mission Leader's Puma 1 and together they conducted a rapid briefing on a revised approach to the target. However, the aircraft were now deployed in an unfamiliar formation without a full briefing and only the most rudimentary of contingency plans. Some of the aircrews were newly formed and all lacked training in mixed formation operations.

The crew of the remaining Lynx 2 struggled to identify the target using their night vision capability during the final stages of their approach. They, therefore, decided to conduct an early overshoot. Meanwhile, the Mission Leader had not registered the latest intelligence updates on the location of the target and so urgently sought further clarification. He assumed that the target was now located to the South. He, therefore, altered course at relatively low levels. These were often below the Radar Altimeter warning which had not been reset below the transit settings. Lynx 2 now rejoined the other two Pumas having recovered from the overshoot. He remained at a safe distance to assess what they were doing. The Handling Pilot of Puma 2 was also unsure about the intentions of the Mission Leader as the target could still not be seen. The crew of Puma 2 now believed that Puma 1 was making a final approach as their speed was further reduced. Puma 1 then performed an abrupt right turn and radioed the other units that they were under fire. This was the first time that any of the units had made visual contact with the targets. Puma 1 then began approaching a field adjacent to the target area in a manner that made it clear to the crew of Puma 2 that they were about to land. The Handling Pilot of Puma 2 elected to follow the Mission Leader and come down in the same field, which appeared to be flat and stable enough to support a landing.

Approach to Landing

It is usual practice for Handling Pilots to announce to others in the formation that they are committed to a landing when the performance characteristics of their aircraft no longer allow for the maneuver to be aborted. However, Puma 2 made the 'committed' call during a very early stage of the approach. This made it difficult for the crew to judge the eventual problems created by the constraints on the landing zone and the brown-out conditions. Their decision to make this early call was justified by their desire to support Puma 1 as it came under enemy fire.

The dust cloud raised by the down wash of Puma 1 demonstrated that ground debris would impair visibility on landing for Puma 2. However, this did not prompt the crew of Puma 2 to revise their radar altimeter settings to provide additional assurance on their descent. The late turn by Puma 1 also left Puma 2 with very limited space to land – this ruled out the rolling 'box' approach techniques that have been advocated in US and British military doctrine. These involve a gradual descent along a preplanned forward trajectory that helps to minimize the disorientation of a rapid descent into brownout conditions. Without the space to conduct a rolling box approach, Puma 2 performed an almost vertical descent from 75 feet. The degree of difficulty was further exacerbated by a surface wind of 5-10 knots. The handling pilot was so focused on the demands of landing the aircraft that he did not notice when one of the troops began firing on the targets from the right door of his Puma. The crewman and the non-handling pilot stated that this did distract them from their tasks.

From about 30feet, a significant dust cloud gathered around the descending Puma. Ground references became harder to maintain. The handling pilot stated that he was able to maintain visual references throughout the descent. However, 'they were of varying quality and mainly consisted of moving dust and straw' (Ref. 7). He did not arrest the initial descent in time and hit the ground. The resultant 'heavy landing' did not exceed the 3G limit that would have triggered the Helicopter Emergency Egress Lighting System nor did there appear to be any structural damage. The collective was not lowered and the Puma maintained around 10 degrees of pitch. Partly in consequence, the aircraft continued its forward motion. It also began a rolling oscillation that increased as the aircraft slowed. The handling pilot was concerned that the Puma would roll over. He decided to overshoot the landing without clear visual references. The handling pilot reiterated that he chose a level attitude for takeoff but did not verify this using his instrumentation. He raised the collective and felt the Puma start to climb. The low main rotor RPM audio warning sounded twice; possibly as a result of the handling pilot quickly raising the collective.

At this point, the Non-Handling Person saw a Lynx at 10 o'clock. He informed the pilot but considered that there was no chance of a collision given their relative positions. The pilot also recalls seeing the Lynx through the brown-out and became increasingly concerned that there was a danger of collision. The pilot decided to halt the climb and carry out a level transition into horizontal flight. The intention was to gain airspeed and move the aircraft away from the dust cloud. He did not check his instruments nor did he establish a visual horizon (Ref. 7). As he began this maneuver, the aircraft reentered the dust cloud and the crew lost all visual references. The Board of Inquiry argued that this disorientation prevented the crew from assessing the effects that their commands were having on the aircraft. As the pilot began to level the wings he felt an accelerated roll to the right with the noise and control motions that might be associated with the blades striking the ground. The aircraft continued moving to the right while more dust began to block out all external visual references. The crew could, however, feel the blades striking the ground until the aircraft finally came to rest some 5 seconds after the initial impact. Both of the aircrew had their night vision devices dislodged during the 'landing'. The emergency lighting system was activated to assist the egress from the damaged aircraft. The aircraft caught fire shortly after impact. Two passengers were trapped in the wreckage and were later found to be dead by a subsequent rescue crew. The damaged Puma was destroyed in place by coalition forces.

<u>Contributory and Causal Factors behind the Puma Case Study</u>

The subsequent Board of Inquiry considered a wide range of causal and contributory factors. They discounted aircraft technical failure and aircraft performance. They also excluded 'other hazards'; there were no reports of loose wires or bird activity. Enemy action, sabotage and friendly fire were discounted. The rounds fired towards Puma 1 do not seem to have hit Puma 2. The following section summarizes those contributory factors that were identified by the Board of Inquiry. This analysis provides a clear illustration of the range and diversity of underlying operational and command problems that are exacerbated by brown-out incidents using night vision.

Meteorology: Meteorological conditions contributed to this accident. The crew of Puma 2 experienced significant downwind during their approach. This led to a loss of lift and a higher than anticipated rate of decent earlier than would otherwise have been expected. The initial heavy landing was, therefore, the consequence of an uncorrected increase in the rate of descent caused by this downwind component. Meteorological conditions also had a direct impact on the brown-out. As the crew approached the landing zone, they might have expected the dust cloud to form behind them given their descent profile. However, the downwind component created brown-out conditions below the aircraft at a much earlier point in the landing than might have been anticipated. The wind also blew debris ahead of the aircraft making it much harder for the crew to judge their rate of descent and attitude. Finally, the investigation argued that the downwind component exacerbated the Puma's tendency to over-rotate forward during transition and led to a nose down attitude that increased the rate of descent.

Light Levels and Night Vision Device Performance: The Board concluded that "The Op training directive states that all crews should be both NVD Cat B and Night Tactical Formation qualified prior to Basic Mission Qualification (BMQ) training. The Handling Pilot, Non-handling Person of Puma 2 and Non-Handling Person of Puma 1 were not correctly qualified to NVD Cat B before their BMQ training. A review of qualifications is underway". However, they also argued that the performance of night vision equipment and ambient light levels were not contributory factors in this accident (Ref. 7). The sun set approximately one hour before the crash and the crews reported that ambient light levels were workable. The sun's afterglow was visible in the second Puma's 9 or 10 o'clock position but it was not mentioned as a distraction in testimonies after the accident. It is noticeable that the Board of Inquiry did not consider the operational strengths and weaknesses of the night vision devices that were available to the crews. This was beyond their remit. In contrast, separate hearings in Coroner's courts increasingly criticize the UK MoD for failing to adequately consider the operational performance of the equipment that they provide (Ref. 9, 10, 11). Coroner's hearings give families of the injured and bereaved valuable opportunities to voice their concerns over military procurement. However, their criticisms often lack the detailed engineering and technical input that is required to develop constructive proposals and avoid future failures. There is an urgent need to develop procedures by which the findings of Board of Inquiry can be extended to maximize the lessons learned from previous accidents in a manner that is both technically convincing and which elicits the support of all stakeholders, including both surviving personnel and the relatives of any casualties. This is increasingly important when many defense suppliers take a passing interest in the ways in which their equipment actually performs under operational conditions (Ref. 12). Many night vision developers lack any processes for gathering operational 'lessons learned' from incidents such as the loss of the Puma.

The Dust Cloud: The Board of Inquiry treated the dust cloud as a distinct issue from the light levels and the performance of night vision equipment. It was argued that light levels did not contribute to the accident, even though the crew was wearing NVG's for which they did not have the full CAT B training. However, the approach was conducted into a 'significant' dust cloud that robbed the handling pilot of visual references; "Despite the crew's utilization of the latest UK NVD technology they ended up being close to the ground but unable to see the surface due to dust" (ref. 7). This sentence illustrates how the Board viewed night vision technology as part of the solution to brown-out and low visibility landings rather than a potential exacerbating factor in spatial disorientation. In contrast we have sought to draw links between the spatial disorientation that has been identified as a key problem both in the use of night vision equipment and in brown-out landings.

Disorientation: The loss of the Puma stemmed in part from the disorientation of the crew. The Handling Pilot initially reported that he lost visual references at around 15 feet on final approach. However, he subsequently contradicted this statement. It is clear that he experienced some difficulty in judging his rate of descent and after the first impact was 'flying blind' within the debris that was raised by the rotor wash. He could not, therefore, judge the extent of the subsequent roll. This contributed to his decision to overshoot. His attention was focused on external cues rather than monitoring his instrumentation. This made it difficult for him to obtain adequate visual references so that he could judge the rate of climb. The crew was able to glimpse the Lynx but this was also in motion. Any references would be relative to the trajectory of that aircraft and could be very misleading. The crew, therefore, lacked the necessary information to identify the effects of any attempts to transition forward. Arguably, they could not determine whether they were ascending, descending or turning (Ref. 7).

Terrain: The landing area was relatively flat, however, it was crossed by a rectangular grid of irrigation ditches around 2 feet deep and smaller furrows of around one foot in height. It was very dusty. There was a significant risk that an aircraft might strike one of these ditches. The subsequent investigation argued that "if a thorough recce of the field had been carried out, these features would have been noticed and an appropriate landing would have been chosen to avoid any run on, making oscillations (following a ground strike) unlikely" (Ref. 7). Of course, any decision to reduce the run-on would have correspondingly increased the likelihood and consequences of a brown-out by further constraining the use of the rolling box approaches that have been described in the opening sections of this paper. This argument again stresses the need to look in more detail at the complex interactions that arise under military operations; where a change in tactics might reduce exposure to one potential risk while at the same time increasing the likelihood of other hazards. By trying to avoid the terrain hazards through a vertical descent, the aircrews would increase the dangers of a brown out landing.

Approach Profile: The landing area was seen by the crew very late in the approach of Puma 2. There was also pressure to land when they observed the tracer close to Puma 1. The handling pilot may, therefore, have felt very constrained in terms of the potential areas in which he could complete a landing. This led him to follow a non-standard vertical approach profile that was 'inappropriate in dusty conditions as height judgment is very difficult and references are very difficult to maintain" (Ref. 7). In consequence, the handling pilot lost the cues necessary to arrest the descent.

Supervision: Puma 2's handling pilot had not passed an appropriate Cat B NVD training course. The Board argued that this might have reflected a potential problem in crew selection procedures. One possible consequence of this decision to assess NVD competency within crew selection was that the Board rejected the handling pilots NVD training as a contributory factor 'in itself'. Similarly, the non-handling person's lack of training was also considered narrowly in terms of the insights it provided into the supervision of crew composition rather than the 'systems issues' in terms of the interaction between terrain, meteorology, NVD operation and approach trajectory. The observation that the non-handling person's logbook indicated NVD CAT B competency when he had not completed the desert environment qualification was, therefore, dismissed as a contributory factor by the Board. Instead they argued that the Handling Pilot's concern to reduce the inexperienced Non-Handling Person's workload, by taking over the tactical radio net etc, may have contributed to the accident. Similarly, the Non-Handling Person in Puma 1 was found to be 'incorrectly qualified' for the mission having an out of date 'Night Tactical Formation' qualification and not possessing the NVD Cat B qualification. Again, these omissions were not found to be contributory factors except that they showed the crews were working at, or beyond, their operational capacity; "the fact that all 4 crewmembers were working very hard meant that no one took stock of the situation and no one was balancing the risks that were taken" (Ref. 7).

If the lack of NVD qualifications had been identified as a contributory factor in this accident then many crews would have been grounded until they completed the courses that would become prerequisites for subsequent missions. This would have created heavy burdens on those crews that did posses CAT B qualifications at a time of rising operational demands. We must consider whether the risks of deploying personnel without CAT B NVD training outweigh the operational benefits of tasking them to use this technology on missions that have significant tactical importance for ground forces? This question extends well beyond the Puma case study. The development of innovative technologies, including multi-sensor fusion for the visualization of brown-out approaches, increases rather than reduces the need for appropriate training. In the future, leaders will still have to determine whether their troops have sufficient training and expertise to use these systems in complex combat missions.

Operational Pressure: It is hard to underestimate the importance of operational pressure as a factor in the decision to task this mission to the Puma and Lynx crews. There was an urgent need to get the mission underway and this eroded the time that would otherwise have been available for mission planning. Changing intelligence also forced late revisions to the plans. There is a suspicion that had the mission been successful, leaders would have been commended for improvisation. In the circumstances, however, it is clear that a re-brief might have helped crews consider likely contingencies during the approach to the landing sites. The inquiry argued that after the loss of the lead Lynx, the formation did not know the disposition of the target and hence 'operational pressure both real and perceived was a contributory factor'.

The Authorization Process: The authorization of missions provides a process of checks and balances that are intended to safeguard military personnel. However, the formal mission approval process must also provide leaders with sufficient flexibility to respond to changing intelligence; environmental factors; resource constraints etc. The standard format in place at the time of this accident was deliberately designed so that approval did not need to be written out in full for every sortie. Instead, pro forma authorization sheets were used. In this sortie, they were signed at such an early point that the authorizing officer could not discuss the limits or nature of the task. It was, therefore, difficult for the authorized captain to explain those critical mission constraints to the rest of the crews. Many military organizations now have an expectation that leaders will explicitly request briefings or 'resets' when they are unsure of essential mission parameters (Ref. 13). In contrast, the authorization sheets asked the crews to do any tasking that they were asked to do without caveat or recourse to the chain of command. The authorization process had evolved under operational pressures to the point where "it removed the final check of understanding and confirmation of crew suitability for the task at hand" (Ref. 7).

Briefing Process: The failure of the authorization process to establish mission parameters and guide crew composition was compounded by the operational pressures. Together these factors constrained the briefing process that is intended to act as a foundation for mission safety. The briefings described missions that were never flown; changing intelligence forced successive revisions to the plans. Even so, senior personnel were missing from the briefings in order to complete other tasks, including aircraft servicing. This removed an opportunity to provide guidance to the less experienced crew members and, theoretically, alter the deployment and composition of the teams. Quick Battle Orders (QBOs) were used to brief the crews in-flight. These may have been ambiguous – for instance over whether Puma 1 or the remaining Lynx was the mission lead. The QBOs were not passed on to the reserve Puma's 3 and 4. This is a significant omission given that the Deputy Leader was in Puma 3. The reserve Pumas also carried more experienced crews who might then have realized the complexity and risks of what was being proposed.

Formation and Deployment: The task of communicating Quick Battle Orders was complicated by radio problems within the formation. This was said to be a common occurrence – something that itself is a priority 'lesson' from this accident. After the mission it was unclear whether messages were not received, or whether they were missed by crews dealing with high workload or by they were using other radios or that had the volume turned down. Such uncertainty again underlines the need for a more systematic review of communications within these formations. As noted previously, Lynx 1 missed the target area and divided the formation. This created uncertainty for Puma 2's handling pilot about the position of the missing Lynx as he attempted the overshoot. It also created potential confusion amongst all elements by undermining the formation and mission brief. Crews could no longer rely on de-confliction plans between the Lynx and Pumas. The eventual deployment was based on Quick Battle Orders using an untried combination of one Lynx and two Pumas. The nature of the QBO's, the communications problems and the failure to brief all crews on intelligence updates about the location of the target added to the risks associated with this formation. The Board summarized these findings by arguing that 'there was a significant breakdown in Crew Resource Management across the formation with a low standard of leadership and 'followership' being displayed throughout" (Ref. 7).

Adherence to Standard Operation Procedures (SOPs): After the mishap it was argued that the crew of the Puma had accepted a role that was not described within the existing SOPs. This contributed to the lack of clarity in mission objectives and tactics that was observed in previous paragraphs. In particular, the emerging plan did not identify an Initial Point (IP). In formation flying, these act as a rendezvous and help to ensure that aircrews approach a target along an agreed route from a known location. Initial Points also help to coordinate a series of final checks, including making adjustments to the radar altimeter warnings. These warnings are initial set en route to a target to a level that ensures they are not triggered every time the aircraft crosses raised ground. However, they are then reset for the descent into a landing zone. The crew of Puma 2 never agreed on the IP and hence they flew a beyond the transit phase without having set the Rad Alt to 25ft for the final approach contrary to the Standard Operation Procedures (SOPs) for Puma dust operations. After the accident, it was found that the Handling Pilot directed the Rad Alt audio warning should not be reset for approaches as a matter of course. This decision was not questioned by the rest of the crew and the same policy also seems to have been adopted by others in the squadron. The subsequent board noted that 'this was not the view of the 22 Squadron training staff who believed it should be set at 25 feet for all dust approaches, without exception' (Ref. 7). This contradiction between official SOPs and everyday operations illustrates the complexity of military accidents. The decision not to reset the Rad Alt warning contributed to this accident. However, the crews' actions were also motivated by a desire to reduce intrusive and distracting warnings. There are further human factors concerns when spurious alarms significantly increase the workload on crews on approach to a landing site. Local practices diverged from SOPs in a number of other ways. For example, Minimum Safe Heights were not commonly calculated for this area of operations. The accident also found examples where there were no SOPs to support crew operations. In particular, the individual SOPs for Puma and for Lynx aircraft did not describe what should be done during joint operations. This created considerable mutual uncertainty; neither knew the procedures associated with their colleague's platform.

Table 1 summarizes the contributory factors that were identified or excluded from the official Board of Inquiry into the loss of the Puma. The scope of this table illustrates a point made in the opening sections of this paper – military accidents are 'systems failures'. They stem from complex interactions between many different issues. The diverse nature of the issues presented in this table also illustrates the way in which the additional demands created by operating night vision systems in brown-out conditions can expose a host of underlying problems in military operations ranging from the documentation of training and expertise through to briefing and approval processes and the development of common SOPs form mixed formations.

Conclusions and Further Work

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. 14). 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 paper has presented a detailed analysis of the particular ways in which the disorientation associated with night vision equipment and brown-out operations can combine to expose underlying weaknesses in military operations. The focus has been on the complex causes and contributory factors that combined during the loss of a UK Puma on operational duty in Iraq. This mishap was triggered by the crews' loss of situation awareness. However, the immediate events leading to the accident stemmed from a wider range of latent issues. These included operational pressures, distractions as the aircraft came under ground fire as well as the loss of spatial awareness during a brown-out while the crew was wearing night vision equipment.

The official Board of Inquiry into the loss of the Puma revealed a number of issues that, although they were not identified as contributory factors, do form a stark contrast with the doctrine and practices in other military organizations. It was not possible for the investigation to use the existing logs and training records to determine the Night Vision Device category of the handling pilot of the aircraft involved in the crash. He had flown in operations requiring NVD Cat B conditions but there was no reference to any conversion course intended to bring him up to this level. Similarly, the Non-Handling crewmember of the Puma had not completed the full NVD Cat B training. Nor was there any record in his training folder that he had completed his Full Mission Qualification. It is difficult to argue with the Board's conclusion that the lack of NVD training was either a cause or contributory factor. They insisted that the operational performance of the crew demonstrated that they could perform to NVD Cat B levels. However, it seems clear from the initiatives in other military organizations that more could be done to train crews for the demands created by brown-out conditions. These initiatives will never be effective unless better records are kept of the training that aircrews have received and that these records must be used to inform mission tasking.

Table 1 --- Summary of Contributory Factors Leading to the Loss of the Puma

	Summary	**Detailed comments**
Cause	CFIT	The cause of the accident was controlled flight into terrain (CFIT) brought about by the handling pilot's disorientation due to the use if an incorrect technique for a dust take-off.
Excluded	Aircraft technical failure	
	Aircraft performance	
	Light levels.	
	Other hazards	Not caused by loose objects, bird strike, incoming rounds.
	Supervision: Crew Composition	Puma 2 handling pilot had not completed Cat B NVD course.
	Supervision: Crew Composition	Puma 2 non-handling person had not completed Cat B NVD course.
	Supervision: Crew Composition	Puma 1 non-handling person incorrectly qualified.
	Enemy Action, Sabotage or Friendly Fire	
	Cockpit Gradient	
Contributory Factors	Weather	Unanticipated downwind component on final approach.
	Dust cloud	Inability to see usable references through dust.
	Terrain	Lack of detailed reconnaissance.
	Supervision: Command & Control	Air Advisor & Tactical Controller inexperienced in helicopter ops.
	Supervision: Crew Composition	Puma 2 handling pilot felt he had to reduce the non-handling persons workload and thereby increased the demands on himself.
	Supervision: Crew Composition	Inexperience in both the crews of Puma 1 and Puma 2.
	Supervision: Operational Pressure	Eroded planning time and left crews ill-informed on mission parameters.
	Supervision: Authorization	Conducted with such broad parameters that it removed a last chance to establish crew suitability for the task at hand.
	Briefing Process	Lack of full brief with all formation elements present.
	Formation and Deployment	Decision to split the formation undermined pre-briefed deconfliction points and attack plans.
	Approach Profile	Choice of vertical approach into a very dusty field.
	Non-Adherence to SOPs	Failure to follow SOPs for dust operations and especially to reset the Rad Alt to 25 feet.
	Disorientation	Puma 2 Handling Pilot was disoriented

The causes of many brownout incidents can be traced back to the operational tempo in Iraq and Afghanistan. Incomplete training records are symptomatic of the common pressures on UK and US forces to take on significant operational demands with finite resources. Ultimately, these pressures are a greater threat than those associated either with night vision operations or with brown-out conditions.

References

1. C.W. Johnson, The Role of Night Vision Equipment in Military Incidents and Accidents. In C.W. Johnson and P. Palanque (eds.), Human Error, Safety and Systems Development, Kluwer Academic Press, Boston, USA, 1-16, 2004.
2. T. Macuda, R. Allison, P. Thomas, G. Craig and S. Jennings, Detection Of Motion-Defined Form Under Simulated Night Vision Conditions. Society of Photo-Optical Instrumentation Engineers (SPIE) Proceedings, 5442-36, 2004.

3. US Army, Army Aircraft Mishaps/Accidents and Percentage of Chinook Accidents, cited in Aerospace Daily & Defense Report, March 7, Volume 221, Issue 44, 2007.

4. U.S. Air Force, J. Sherer, Brown-out, 2nd November 2008. US Air Force Safety Center. http://www.afsc.af.mil/news/story.asp?id=123085802, Last accessed February 2009.

5. US Air Force, National Helicopter Experts Gather to Discuss Aerodynamic Solutions for Brown-out, Wright Patterson Air Force Base, USA, 2007. http://www.wpafb.af.mil/news/story.asp?id=123058808, Last accessed February 2009.

6. US Department of the Army, Aeromedical Training for Flight Personnel, Headquarters, Department of the Army, Washington, DC, 29 September 2000, Field Manual 2-04-301 (1-301).

7. Royal Air Force, Board of Inquiry into an Accident Involving Puma HC1ZA938 on 20 November 2007 while on Operation in Iraq, UK Ministry of Defence, London, UK, http://www.mod.uk/NR/rdonlyres/7B287D03-5FB1-4F5C-951C-7E1E87C0F44A/0/boipuma_za938.pdf. Last accessed February 2009.

8. US Army Centre for Lessons Learned, Night Vision Goggles Desert Operations Lessons Learned - 13 Years in the Making, Flight Fax, Vol. 31, Number 4, April 2003a.

9. BBC. Hercules Safety 'Still Lacking', 2007. Available on http://news.bbc.co.uk/1/hi/uk/6406203.stm, last accessed February 2009.

10. BBC. MoD Criticised over Soldier's Death, 2008. Available on http://news.bbc.co.uk/1/hi/england/tyne/7318813.stm, last accessed February 2009.

11. BBC. Mother Questions Soldier's Armour, 2009. Available on http://news.bbc.co.uk/1/hi/england/leicestershire/7884270.stm, last accessed February 2009.

12. C.W. Johnson, The Paradoxes of Military Risk Assessment. In A.G. Boyer and N.J. Gauthier (eds.) Proceedings of the 25th International Systems Safety Conference, Baltimore, USA, International Systems Safety Society, Unionville, VA, USA, 859-869, 0-9721385-7-9, 2007.

13. C.W. Johnson, Military Risk Assessment in Counter Insurgency Operations: A Case Study in the Retrieval of a UAV Nr Sangin, Helmand Province, Afghanistan, 11th June 2006. In P. Casely and C.W. Johnson (eds.) Third IET Systems Safety Conference, NEC, Birmingham, UK, 2008, IET Conference Publications, Savoy Place, London, 2008.

14. C.W. Johnson and L. Nilsen-Nygaard, A Systemic Approach to Counter the Threat to Public Safety from Improvised Explosive Devices (IEDs), Proceedings of the 27th International Conference on Systems Safety, Huntsville, Alabama, USA 2009, International Systems Safety Society, Unionville, VA, USA, 2009.

15. R. Gant, Night Vision Goggle Power Interrupt Device (NVGPID): A Simple Device to Train Crucial Skills, US Army Aviation, 22-26, April/May 2007. Available from http://www.quad-a.org/Archives/07_Magazine/070405/GantApril-May07.pdf, last accessed February 2009.

Biography

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