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Reduction and Mitigation of Thermal Injuries; What Can be Done

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Soon after the introduction of the crashworthy fuel system and Nomex® flight apparel, morbidity and mortality rates from thermal injuries in aviation were reduced to zero. Although the incidence of aircraft mishaps involving postcrash fires remained the same then and now, there has been a recent increase in thermal injury morbidity. The case reports describe three different aircraft accidents in which fire was caused by factors other than the crashworthy fuel system. They also describe sustained thermal injuries and compare them to personal protection equipment. We found that the condition of the personal protective equipment and unauthorized use of unapproved apparel were responsible for the sustained injuries. We maintain that personal protection equipment is effective if worn in a manner for which it was designed. We believe that the lessons learned apply to all military operations where the risk of fire is high, not solely aviation. A proactive program focused on education would reduce the thermal injury morbidity.

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Military significance

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Introduction

Prior to 1970, Army helicopters were not equipped with ballistic resistant and crashworthy fuel systems. Consequently, aircraft involved in survivable impact mishaps had a high incidence of postcrash fires from ruptured fuel cells. This resulted in high morbidity and mortality rates from thermal injuries. The Army developed a crashworthy fuel system (CWFS), and installed the first one in 1970.[1] The Army also issued fire resistant Nomex® flight apparel to flight crews in 1968 and to tank crews in 1970 to ensure the best possible protection from fire.[2] Both of these initiatives signaled a new era in system safety and dramatically reduced the danger of postcrash fire. A study of aircraft accidents in 1972,[3] directed at CWFS, showed that there was no significant difference in the risk of postcrash fire without and with CWFS (RR=1.016,CI $_{0.95}$ = 0.900, 1.146) (Table 1). However, as shown in Table 2, for these same mishaps there is a dramatic decrease in the risk of thermal injuries when using CWFS. Postcrash fires still occurred at the same rate, but the CWFS allowed crewmembers and passengers sufficient time to escape from crash-damaged helicopters due to a reduced number of fire sources and the smaller size of the fire initially after impact.

Table 1.
Postcrash fires without and with CWFS in survivable rotary wing mishaps.

	Without CWFS	With CWFS	Total
Postcrash fires	38	6	44
No Fires	693	122	815
Total	731	128	859

* Relative Risk = 1.016, CI $_{0.95}$ = 0.900, 1.146

Table 2.
Thermal casualties sustained in 859 mishaps studied.

Thermal casualties:	Aircraft without CWFS	Aircraft with CWFS
Fatalities	37	0
Injuries	12	0

Although these early statistics indicate an incredible success story, the assumption that thermal injuries as a result of in-flight, ground runup, refueling, and postcrash fires no longer occur is a misperception. The U.S. Army Safety Center (USASC) database shows that from January 1988 through May 1993, 67 Class A accidents occurred involving fires. In these accidents, 50 crewmembers or passengers suffered burn injuries.[4] Recent mishaps also indicate that carelessness in following regulations, operating procedures, and wearing inappropriate clothing (sometimes unknowingly) resulted in injuries.

The three case studies presented involve postcrash and ground fire mishaps. They highlight the success and failure of Aviation Life Support Equipment (ALSE). Although aviation related, these lessons learned apply to all military operations and, indeed, serve to protect all soldiers working in environments where there is potential for catastrophic fire.

Case report 1[5]

During a night approach, a UH-60 Black Hawk struck the ground in a nose high, right side low attitude. The right 230-gallon (noncrashworthy) external fuel tank ruptured on impact. The responding fire rescue personnel contained the postcrash fire within 2 minutes of their arrival. Four personnel on board received fatal injuries, three individuals received major thermal injuries, and one person received minor thermal injuries.

The pilot was wearing leather boots, serviceable Nomex® flight suit, gloves, and jacket (with collar up) and helmet. Although on fire when he egressed, the ensemble worked as designed and the flame extinguished (Table 3).[6] The flight jacket collar and right shoulder burned through the outer layer, but protected him from thermal injury. The stitching on his right boot burned through revealing the inner Gore Tex™ liner, yet protected his feet from injury (Figure 1). He received minor thermal injuries.

Table 3.
Thermal properties of NOMEX® vs nylon.

Properties of Nomex®	Properties of nylon
Does not propagate flame	Propagates flame
Does not melt or drip	Melts and shrinks
Does not transfer heat	Transfers heat
Does not burn (will char instead)	Burns

The copilot egressed shortly after the pilot. He was wearing gloves with holes in numerous finger tips (Figure 2). As a result, the burns he received to his right hand caused permanent impairment. He also was wearing an Air Force approved flying coverall under his Nomex® flight suit. This Air Force item was not authorized by the Army for aviation use because it had a nylon lining. Where the coverall was covered by both the flight suit and flight jacket, it did not melt or burn. From the waist down, however, the heat and fire melted the coverall into the flight suit and the individual (Figure 3). The thermal injuries this individual received on his legs resulted in his disqualification from aviation and military duties.

One passenger egressed successfully only to return into the blaze to assist another passenger. He was wearing a battle dress uniform (BDU) and a Gore Tex™ field jacket (Figure 4). The Gore Tex™ material did not contribute to injury, but the jacket's nylon inner and outer shell burned and melted into the fabric of his BDU and his skin. He received major thermal injuries.

Case report 2

An OH-6 with a noncrashworthy fuel system crashed and burned.[7] The pilot's thermal injuries resulted from wearing unauthorized boots with nylon uppers. The radiant heat shrunk the nylon boot causing Achilles tendon damage. The pilot was medically retired.

Case report 3

During a rapid (hot) refueling operation, the refueling nozzle quick disconnect fitting failed, spraying fuel onto an operating AH-64 Apache engine. The aircraft immediately was engulfed in flames. The pilot and copilot both received major thermal injuries. The total time from initial fuel combustion to both pilots' egress was 18 seconds.[8]

The copilot egressed immediately and received second degree burns to 21 percent of his body and third degree burns to 3 percent of his body. He wore appropriate flight outer garments, but he did not wear underwear. Consequently, most of his severe thermal injuries were to his buttocks.

The pilot performed the appropriate aircraft shutdown tasks before exiting the aircraft, delaying egress. He was wearing all the appropriate flight uniform articles. He received burns to 41.5 percent of his body; 10.5 percent were third degree, the remainder were medium to deep second degree (Figure 5).

Discussion

Army Regulation 95-1, Aviation Flight Regulations, requires that aviation personnel wear all leather boots, serviceable Nomex® flight suits and gloves, and cotton or wool undergarments. Why then in Case report 1, was the copilot wearing unserviceable gloves? The central issue facility at his installation had a significant supply of flight gloves on hand. Why did he not exchange his unserviceable gloves for a new pair? Who authorized him to wear a nonissue coverall? Was he aware that it was made of nylon? In Case report 2, who authorized the individual to wear nylon boots? Why did the copilot in Case report 3 not wear underwear?[8] These are all clear violations of the regulation.

The need to protect all soldiers from exposure to thermal injuries is equally as important as protecting aviation personnel. Passengers and soldiers in other occupations were not protected by AR 95-1. In Case 1, a passenger got severely burned because he wore an issued Gore Tex™ field jacket. By the same token, who ensures that personnel operating armored vehicles aren't wearing the jacket over the Nomex® tanker's uniform?

Some issue items increase the risk of thermal injuries despite MOS specific fire retardant personal protection. The triservice polypropolene underwear provides a very effective barrier from the cold but is made of 50 percent nylon. Who ensures that aviation and armor soldiers are not wearing this item of clothing under their Nomex®?

Conclusions

Aviation is a dangerous environment where catastrophic fires still occur because of unserviceable equipment or untested innovations implemented in response to mission requirements. Therefore, we must not get complacent with respect to basic protective clothing.

It is clear from the case reports that when aviation personnel involved in fire mishaps dressed in violation of AR 95-1, injuries resulted. Had the copilot in Case 1 worn serviceable gloves, it is doubtful that he would have sustained the extensive burns to his hand. Had he not worn the nylon overall, his leg injuries would not have been severe enough to end his military and flying career. In Case 2, had the pilot worn leather boots, they would have provided the protection necessary to avoid the lower leg injuries he suffered. Had the copilot in Case 3 worn cotton or wool underwear as directed by regulations, his injuries would have been significantly reduced.

Clothing and life support equipment are effective only if worn in a manner for which they are designed. From a medical standpoint, the health consequences of any soldier violating its clothing rules are expensive in terms of lives and recovery costs. A proactive program focused on education in order to reduce or mitigate thermal injury is the key to prevention. Soldiers should be questioned when uniform violations are identified that impact their safety. Commanders, officers, and soldiers must be educated on the dangers of wearing clothing that will not protect them in the event of fire. They must ensure that risk assessment includes the hazard of wearing inappropriate uniform items for the environment in which they operate.

Given the high number of thermal injuries treated yearly at Brooks General Hospital, San Antonio, Texas, reducing the incidence of thermal injury by any percentage clearly is beneficial to the Army in terms of medical costs and with respect to human life and suffering.

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Figure 1. All leather boots provided 100% protection even when stitching burned and the seam failed.

Figure 2. Unserviceable gloves contributed to injury.

Figure 3. Nylon coveralls worn as an undergarment melted to the flight suit and the individual from the waist down.

Figure 4. The Gore Tex™ field jacket, an item of issue, performed poorly in a fire as the inner and outer nylon shell melted to the individual.

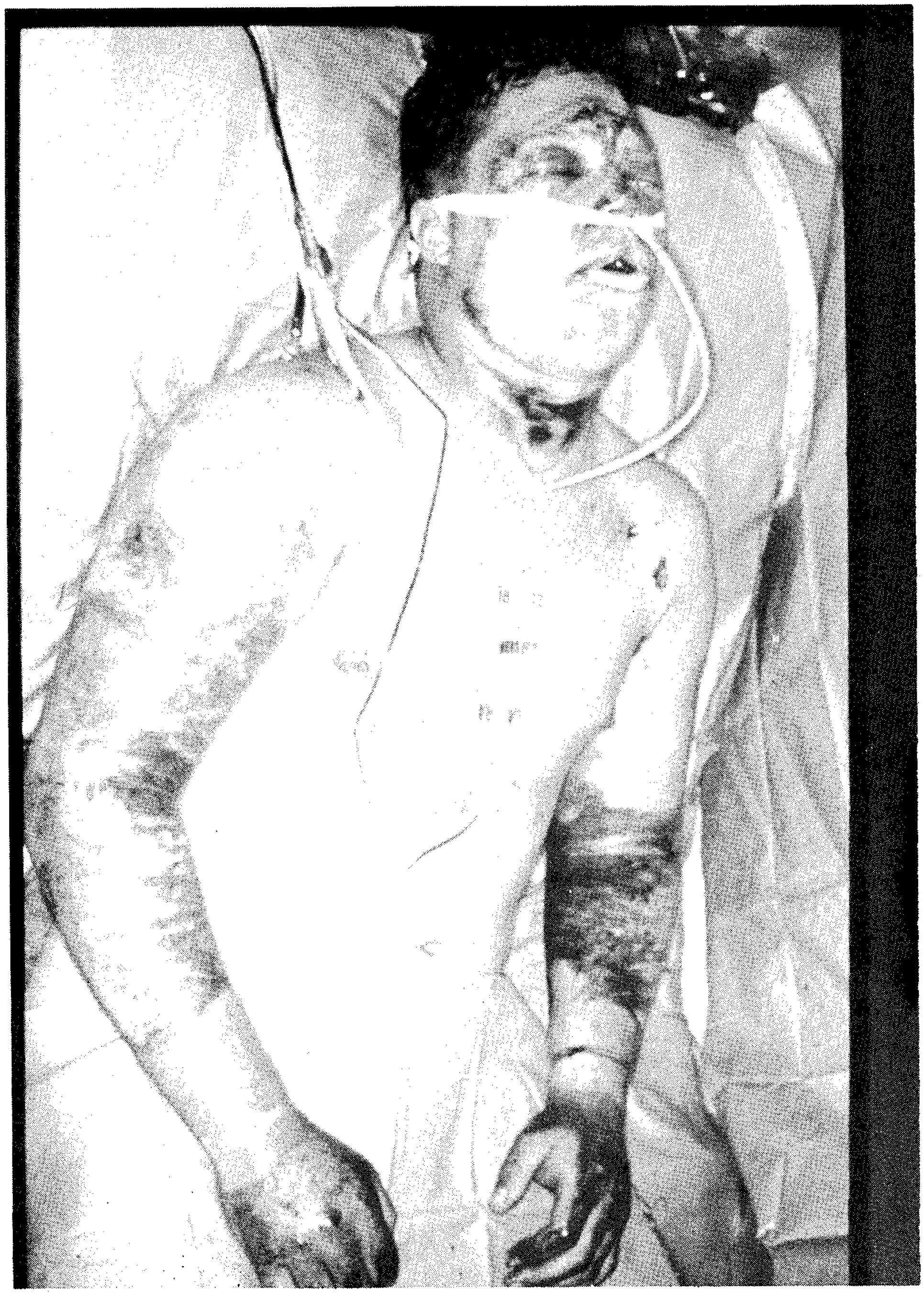

Figure 5. **Where the Nomex flight suit overlapped cotton undergarments, injury was mitigated.** Note: The pilot was protected in the wrist area because his flight gloves were worn under the flight suit, as directed.