THE CONTRIBUTION OF MILITARY FLIGHT BOOTS TO THE DEVELOPMENT OF NON-FREEZING COLD INJURY

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INTRODUCTION

Footwear worn by U.S. military aircrew personnel provides inadequate levels of protection from a prolonged cold and wet exposure when compared with that wore by ground-based, combat troops. On June 2, 1995, a U.S. Air Force F-16 C aircraft was shot down by a mobile SA-6 surface-to-air missile over Bosnia-Herzegovina while conducting a routine NATO reconnaissance mission. The pilot survived the missile blast and ejected safely, hiding during the day and moving by night, surviving on bugs, ants and rainwater. The pilot spent a total of six days evading capture and was eventually rescued during a daring mission into the rugged terrain of northwestern Bosnia. While on the ground, the pilot was unable to dry his standard-issue flight boots and socks, which had become progressively wetter due to his traverse of the mountainous terrain combined with periodic rainfall.

After returning to the U.S. the following week, the pilot experienced such pain in his feet that he was unable to walk. The pilot was hospitalized, diagnosed with a moderate case of non-freezing cold injury (NFCI) to the feet (immersion foot), and confined to a wheelchair for ten days. Overall, the pilot required sixteen days of medical care before military doctors would allow him to return to limited duty.

This study includes a biophysical evaluation of the same type of boots worn by the downed pilot in Bosnia along with other standard-issue aircrew footwear and how they could contribute to the development of NFCI when worn in a wetted condition for an extended period. For comparison purposes, a series of new commercial aircrew boots utilizing improved leathers, vapor-permeable membranes, micro fibrous insulations and insulating socks was also evaluated.

MATERIALS and METHODS

All footwear was evaluated for thermal insulation properties using an automated, heated foot model (1). The model calculated a total insulation value, I_t ($m^2 \cdot K \cdot W^{-1}$) of the complete boot system and a regional insulation value, I_r for each of the 29 thermally-isolated sections of the model. All footwear was tested in a new, dry condition (DRY) and then after 18 hours of upright placement in approximately 6 to

7 cm of water (WET). The water level was adjusted for each boot so that the welt stitching, a major area of water ingression, was completely immersed. The DRY evaluation is useful only as a reference point and would represent the conditions before an individual donned the boot and sock. Wearing tightly-laced, leather boots over thick woolen socks can quickly cause an increase in foot sweat production (2), which effectively reduces the protective capabilities of the footwear. The WET evaluation represents a worst-case scenario where the boot is exposed to the extreme conditions of a cold and wet environment for an extended period. All footwear components were weighed on an electronic balance pre- and post-WET to calculate any changes due to absorption of water. The following is a description of the test footwear systems:

CONTROL. Standard Flyer's Boot (MIL-B-21408), Addison Shoe Co., stock no. 84014, with uninsulated leather upper and integrated safety toe, over insulating insole and Standard Cushion Sole Sock (8440-00-960-2505).

1. Royer Cosmos boot, stock no. 552687X with leather upper, Thinsulate® (micro fibrous polyester) insulation, integrated safety toe, over insulating insole, removable Gore-Tex® (micro porous polytetrafluoroethylene) liner, Insulating Sock (MIL-S-405, 75% wool/25% cotton), and wicking sock (70% Thermax® hollow-core polyester/30% nylon).

2. Ranger Firewalker boot, stock no. 3032A with fire-retardant leather upper, Thinsulate insulation, Sympatex® (hydrophilic polyester)/Kevlar® (ballistic-proof nylon)/Nomex® (aramid fiber) lining, integrated safety toe, over insulating insole, Insulating Sock, and wicking sock. This boot passes all National Fire Protection Association Standards.

3. Ranger Firewalker boot, stock no. 3031A was constructed the same as the Ranger no. 3032A except for the elimination of the integral Thinsulate insulation in the lining. A removable Cambrelle/Thinsulate lining was utilized to provide insulation.

RESULTS

Table 1. shows that the standard boot and sock combination worn by most U.S. military aircrew personnel had a DRY I_t of 0.16 and was reduced by a full 38% to 0.10 as a result of WET. Similar losses occurred in I_r at foot model regions such as the toes, sole, and heel where an extended cold-wet exposure can cause a more severe injury to the human foot. Even when enhanced with commercial waterproof and insulating socks, this boot only measured 0.25 DRY with a reduction of 24% to 0.19 when WET.

In comparison, the three newly-developed commercial flight boots using improved leathers, integrated waterproof/breathable membranes, and micro fibrous insulations over various insulating socks had a range of DRY I_t from 0.33 to 0.37. Reductions in I_t due to WET averaged 6%.

Table 1. Total thermal insulation values (I_t, $m^2 \cdot K \cdot W^{-1}$) of all test systems as a result of DRY and WET. The loss of insulation due to WET (%) is also presented in the results.

Boot	I_t DRY	I_t WET	% change
Standard	0.16	0.10	-38
1.	0.37	0.35	-5
2.	0.33	0.31	-6
3.	0.35	0.33	-6

Table 2. shows that the current-issue boot experienced a substantial increase in boot weight as a result of WET when compared with the other test footwear. In addition, a measurable amount of water was poured out of this boot post-WET. Boot numbers 2 and 3 which employed the hydrophilic polyester, waterproof/breathable membranes were especially effective in minimizing water absorption. The negligible weight increases after immersion indicate the use of advanced, waterproof leathers in these two boots.

Table 2. Pre- and Post WET weights (kg) of each test boot. The increase in boot weight (%) and the presence of any sensible water in the boot post-WET is included in the results.

Boot	pre-WET (kg)	post-WET (kg)	Interior wet?
Standard	1.04	1.32 (+27%)	Yes
1.	1.29	1.42 (+10%)	No
2.	1.30	1.34 (+3%)	No
3.	1.23	1.25 (+2%)	No

CONCLUSIONS and RECOMMENDATIONS

These results show that current military aircrew footwear allows significant moisture ingression to interior insulating layers causing large reductions in thermal insulation. Even short-term use of these boots in a wetted condition could predispose personnel to NFCI with the potential for permanent impairment. A study using infrared thermography to measure passive rewarming of Argentine soldiers who were diagnosed with NFCI after the Falkland Island Conflict showed that these individuals may be at constant risk for further injury when exposed to the appropriate cold and wet environmental conditions (3).

It is recommended that U.S. military aircrew personnel be issued new protective footwear systems that will provide improved environmental protection capabilities. The use of any one of the above commercial footwear systems incorporating state-of-the-art insulating and moisture protective materials could help reduce the incidence of NFCI to aircrew personnel during emergency operations in cold-wet environments.

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