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and J. Quinn

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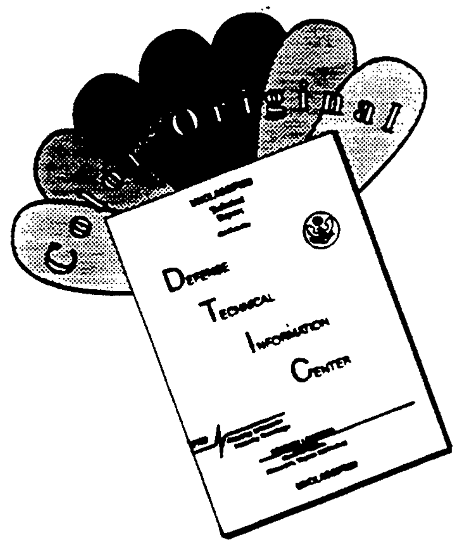

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G. Bajinskis, H. Billon and J. Quinn

Ship Structures and Materials Division
Aeronautical and Maritime Research Laboratory

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ABSTRACT

An electrostatic hazards assessment of procedures and service clothing used during flightline operations that involve electro-explosive devices (EEDs) has been completed. The assessment includes measurements of the body-to-ground resistance, capacitance and body potential for personnel in service clothing. Activities involved in the loading of 20 mm ammunition into an F/A-18 aircraft provide a focus for the investigation.

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Executive Summary

Items possessing a sensitivity to electrostatic discharge are regularly handled by RAAF personnel. These items include electro-explosive devices (EEDs). Uses for EEDs include the initiation of cannon ammunition, rockets and weapons ejection. RAAF was concerned by the possibility that personnel could inadvertently initiate EEDs during flightline operations due to the electrostatic properties of their clothing. Accordingly AMRL was tasked to evaluate the electrostatic hazards from issued service clothing.

Measurements of the body-to-ground resistance, capacitance and body potential of personnel wearing a variety of service uniforms were conducted. Effort focussed on the loading of 20 mm ammunition into an F/A-18 aircraft since 20 mm ammunition is the most electrostatically sensitive item on the flightline.

Most of the tested clothing combinations resulted in personnel electrostatic energies that exceeded the no-fire threshold for a 20 mm round. Because the M52A3B1 primer in the 20 mm round is very sensitive to electrostatic discharge and peak energies were very high, the residual energy on the operator was sufficient to initiate the round even after a relatively long time interval. The longest half-times for charge decay exceeded 25 s and occurred when an operator wore dress shoes or a popular type of casual footwear.

Use of antistatic footwear led to a decrease in the maximum peak energy, which decreased from 1164 μJ to 36 μJ and in the maximum half-time which decreased from 0.9 s to 0.08 s. The combination of a very low resistance (0.4 Ω) earth lead together with issue footwear decreased the maximum peak energy to 0.07 μJ and the maximum half-time to under 0.08 s. The use of a lead possessing such a low resistance to earth is not recommended if any risk of electrocution exists. When a 1 MΩ wrist strap was substituted for the very low resistance lead the maximum peak energy decreased to 0.03 μJ while the maximum half-time decreased to 0.04 s.

When an operator wore issue footwear together with legstats, the peak energy diminished to under 0.001 μJ and when issue footwear was worn together with electrostatic heel protectors the peak energy was less than 0.0003 μJ.

The surface on which an operator stands is also very important. A paint layer on the loader platform surface increased the body-to-ground resistance by a factor of 100 and therefore increased the risk of static discharge.

Essential precautions to be taken when removing a 20 mm round are fully itemised. This information has been conveyed to RAAF personnel and appropriate directions have been issued.

Authors

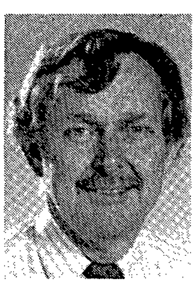
G. Bajinskis
Ship Structures and Materials Division

Gunars Bajinskis joined AMRL in 1961 and was responsible for electrical evaluation of components and materials in the Type Approval Section. In 1967 he was requested to set up an electrostatics investigations unit to serve Defence and industry. Since then his work has covered a wide range of electrostatic topics in manufacturing, clothing, explosives safety, munitions handling and related accident investigations. He has also investigated sealant problems in the fuel tanks of F-111 aircraft and played a major part in the local development and manufacture of new high power HF antennas for the Navy. His current work as Senior Technical Officer involves electrostatic consultancy to the Services and to Australian Defence Industries.

H. Billon
Ship Structures and Materials Division

Horace Billon graduated from Royal Melbourne Institute of Technology with a BSc in Applied Physics. He also has a Graduate Diploma in Mathematical Methods from Royal Melbourne Institute of Technology. After working in the RAAF Quality Assurance Laboratories at Highett he joined MRL in 1986. He works in the Explosives Ordnance Division, and his primary areas of interest are explosives rheology and electrostatics.

J. Quinn
Ship Structures and Materials Division



Jim Quinn obtained his BAppSc(Applied Physics) at the Royal Melbourne Institute of Technology in 1973 and is a Member of the Australian Institute of Physics. He joined the Materials Research Laboratory in 1969 and has been involved in X-ray crystallography, dimensional metrology, X-radiography, image analysis, pattern recognition and simulation methods for electromagnetic pulse effects on electronic systems. He was posted to the Air Force Weapons Laboratory (Now Phillips Laboratory) US for fifteen months during 1986-87 where he worked on electromagnetic pulse effects. In the weapons systems area he has worked on the problems associated with the introduction of software controlled technology into the safety and arming units of fuzes for explosives ordnance. More recently he has assumed responsibility for work involving the protection of defence personnel and materiel from electrostatic discharge, lightning and related effects.

Contents

1. Introduction

Personnel involved in flightline operations regularly handle equipment containing electrically sensitive items, particularly electro-explosive devices (EEDs). Equipment containing EEDs includes aircraft weapon racks, flare and chaff dispensers, 20 mm ammunition, air launched rockets and free fall and laser guided bombs. EEDs initiate rocket motors, warheads, cannon ammunition and the ejection of weapons from racks. In the absence of appropriate precautions, electrostatic discharge (ESD) from personnel could initiate some EEDs and consequently ESD is a recognised hazard.

In evaluating the suitability of clothing for potentially hazardous electrostatic operations it is necessary to assess the associated environment and the activities of personnel while they are wearing the clothing. This assessment includes the identification of devices and materials that are sensitive to electrostatic discharge.

Activities involved in the handling and loading of 20 mm ammunition into the M61A1 (Vulcan) cannon on board the F/A-18 aircraft were chosen as the basis for the present assessment since the M52A3B1 initiator used in 20 mm ammunition is the most ESD sensitive EED encountered by flightline operators. This sensitivity is usually expressed in terms of the no-fire threshold which is a measure of the energy that is expected to initiate only a very small percentage of primers. Because of this it may be used to determine safety margins for hazard analysis.

The no-fire threshold (NFT) energy for the M52A3B1 initiator has been determined as 17 μJ for human ESD [1], including skin resistance and as 2 μJ for ESD from conducting objects with no added resistance [2]. Both of these energy values are related to the energy that will initiate 0.1 % of all M52A3B1 primers. Since this study is limited to the electrostatic effects of human ESD the larger value applies. Ancillary equipment such as the ammunition replenisher, loader and tractor were included in the analysis since they influence the electrostatic hazards from personnel.

The RAAF was concerned by the possibility of electrostatic initiation of EEDs caused by service clothing worn by personnel during RAAF flightline operations and through the Australian Ordnance Council (AOC) requested that AMRL undertake an investigation to evaluate flightline procedures in association with a variety of articles of clothing worn during flightline operations. This paper presents the results of this study.

In addition, tests were performed on an electrically operated hand held drive unit that is used for the F/A-18 loader. This drive unit was suspected of generating electrostatic charge during loading operations. The earthing system in the preparation room where the loaders are replenished was also evaluated.

2. Experimental

2.1 Garment Samples

A range of garments and footwear worn by personnel during flightline operations was obtained for electrostatic testing. Both new and used items were acquired since electrostatic properties of materials can change due to wear and cleaning procedures. In some cases only new samples were available and some of these were subjected to a standard dryclean cycle to simulate aging. The list of submitted items in Table 1 includes items that were already held by AMRL.

Table 1: Samples submitted

Sample	Details
Shirt & Trousers. DPCU(1). New.	Shirt: ADI. Vic. 1990. 8415-66.130.0037. Trousers: Polyester - 50 %. Cotton - 50 %. ADI. Vic. 1992. 8415-66-134-8917.
Shirt & Trousers. DPCU. Used.	Shirt: No information. Trousers: ADI. Vic. 1990. 8415-66.130.0050.
Sweater. DPCU. New.	Wool - 80 %. Nylon - 20 %. Elegant Knitting Company. 1994. 8405-66-134-9383.
Sweater. DPCU. Used.	Wool - 80 %. Nylon - 20 %. Elegant Knitting Company. 1993. 8405-66-134-9381.
Sweater, Blue/Grey. New.	Elegant Knitting Company. 1995. Wool - 80 %. Nylon - 20 %. 8405-66-136-2038.
Sweater, Blue/Grey. Used.	No information
Boots. Black GP(2)	Dunlop
Boots. Brown GP	Oliver & Stevens
Boots. Safety. New.	Upper - Leather. Sole - Nitrile rubber. Plus 50
Boots. Safety. Used.	Plus 50
Shoes. Service dress. New	Leslie Footwear. 1988
Shoes. Service dress. Used	Sole - Non leather. Julius Marlow P/L.
Shoes. Safety. New	Upper - Leather. Sole - Synthetic. Jenkin.
Shoes. Safety. Used	Sole - Vinyl. Jenkin.
Boots. Flying. New.	Oil proof. Goodyear.
Boots. Flying. Used.	Biltrite
Shoes. Antistatic.	"Statsafe" antistatic footwear. Purnell Shoe Company.

Sample	Details
Shirt & Trousers. CWD(3). New.	Shirt: ADI. 1989. 8405-66.108.1507. Trousers: AGCF. Vic. 1988. 8405.66.116.2831.
Shirt & Trousers. CWD. Used.	Trousers: AGCF. Vic. 1988. 8405-66.116.2874.
Shorts. New.	Polyester - 50 %. Cotton - 50 %. ADI. Vic. 1991. 8415-66.133.1914.
Shorts. Used.	AGCF. Vic. 1981. 8415.66.098.6494.
T-shirt. New.	Polyester/Cotton. Clothing Factory.
T-shirt. Used. (2 off)	No information
Jacket. Hooded. DP(4)	Cantas Pty. Ltd. 8405-66-128-2432.
Jacket. Tarmac. Nylon. New. (2 off)	Nylon - 100 %. ADI. 1994.
Jacket. Tarmac. Nomex. New. (2 off)	Nomex - 100 %. ADI. 1994.
Liner. CW(5). New.	Inner - Nylon. Outer - Polyester filled. Walkabout. 8415-66-136-4648.
Liner. CW. Used.	Inner - Nylon. Outer - Polyester filled. Walkabout. 8415-66-136-4646-93.
Jacket. Flying. New.	Fire resistant. CWU-36/P. MIL-J-83382C. Signal One.
Jacket. Flying. Used.	Aromatic Polyamide - 100 %. Isratex Inc. 8415-01-010-1913
Suit. Flying. New.	Nomex - 50 %. Cotton - 50 %. ADI. 1992. 8415-66-131-9680.
Suit. Flying. Used.	8415.66-107.4653
Gloves. Flying. New.	Steinberg Bros. Inc.
Gloves. Flying. Used.	Steinberg Bros. Inc.
Belt. Service dress. New	8440 66 037 6823
Belt. Service dress. Used	No information

(1) Disruptive Pattern Combat Uniform (DPCU)
(2) General Purpose (GP)
(3) Combined Working Dress (CWD)
(4) Disruptive Pattern (DP)
(5) Cold Weather (CW)

2.2 Ammunition Support Equipment

Loading operations for 20 mm ammunition involve a number of support vehicles and equipment. The activities of personnel using the equipment were observed during loading and unloading operations on 16-17 May 1995 at Tindal Air Force Base, Northern Territory. The high (60 %) relative humidity at that time precluded meaningful measurement of charge generation because the moisture absorbed by clothing at high humidities severely reduces electrostatic charging. However, resistance and capacitance measurements were conducted on both personnel and equipment.

To simulate the low humidity conditions that might occur at other times, electrostatic investigations were conducted in an environmental chamber. A metal panel coated on one side with F/A-18 exterior paint was used to simulate the aircraft surface near the M61A1 gun access door. This surface is important because it is contacted by personnel while ammunitioning F/A-18 aircraft. A gun access door (1560-01-166-4558), provided by the RAAF, was also used for some charging trials.

Support equipment used for 20 mm ammunition handling (Figure 1 and Figure 2) underwent limited testing. This equipment is listed below.

(1) Replenisher assembly. PN : 798E885.
Including De-linker. PN : 212F231

(2) Loader Assembly. PN : 212F156.
Including reel, static discharge, grounding. RMU. PN : ML-2930-13 (Hunter Spring).

The assemblies are driven externally by one of the three hand held drive units shown in Figure 3. These are:

(1) An electrical drive unit
(2) A pressurized gas drive unit
(3) A manual drive unit

In addition to the articles described above, two metal platforms were constructed. One of the platforms was painted in order to test the effect of a paint layer on the body-to-ground resistance of an operator standing on the loader assembly.

2.3 Apparatus

The electrostatic potential was measured by means of a Rothschild R-1020 electrostatic voltmeter and data were transmitted to a Hewlett-Packard 54111D digitizing oscilloscope and recorded as a potential-time curve. Body-to-ground resistance was measured either with a Radiometer IM-6 megohmmeter or with a Monroe Electronics Model 278 resistance/current meter. Capacitance was determined with a General Radio Company 1650-A impedance bridge; samples were discharged before testing by means of a Simco Aerojet XC ionizing air blower. The humidity in the environmental chamber was controlled by a Munters M-120 dehumidifier and the temperature was controlled by a Mitsubishi Electric air conditioner.

2.4 Experimental Method

2.4.1 Conditions in the Environmental Chamber

Personnel resistance, capacitance and potential measurements were made in the environmental chamber. The air temperature and relative humidity in the environmental chamber were maintained at 20 ± 2°C and 20 ± 2 % respectively. Garments and footwear were conditioned in the environmental chamber for at least 24 hours prior to testing.

2.4.2 Resistance Measurements

Body-to-ground resistance values were measured at various applied potentials for an operator standing on a metal plate. Point-to-point resistance and resistance-to-earth measurements were made for various objects at Tindal AFB at a variety of applied potentials.

2.4.3 The Body-to-Ground Capacitance

Body-to-ground capacitances were measured for an operator standing on an earthed metal plate.

2.4.4 Charging from the F/A-18 Panel

Experiments were performed in the environmental chamber to simulate an operator standing on the loader assembly platform during the F/A-18 ammunitioning process. The operator stood on earthed metal sheeting and rubbed his back against an earthed wall-mounted aluminium panel that had been coated with F/A-18 exterior paint. Following this process the operator quickly stepped away from the panel. The operator's potential was monitored as a function of time by means of the electrostatic voltmeter and the oscilloscope.

This procedure was repeated for various garment and footwear combinations. The operator's capacitance C at the position corresponding to the peak potential V_{Peak} was measured in a separate experiment. The peak potential and the time for the potential to decay from the peak value to one half of the peak potential value (half-time) were measured from the oscilloscope trace of the time dependent voltage. The capacitance and the peak potential were then used to calculate the peak energy E_{Peak} using the equation,

$$E_{Peak} = \frac{1}{2} C V_{Peak}^2 \qquad (1)$$

2.4.5 Charging Experiments with the Gun Access Door

The purpose of these experiments was to determine whether the door is capable of inducing a potential on the operator. The access door was charged by rubbing it with either the used blue/grey sweater, used T-shirt or used shorts. These garments simulate cloth samples that might contact the access door.

Wearing a variety of footwear, the operator earthed himself and quickly placed his head under the door. The operator's potential was monitored by the electrostatic voltmeter and recorded by the oscilloscope. The capacitance was measured in a separate experiment and used to calculate the energy on the operator.

2.5 Drycleaning of the Tarmac Jackets

A nomex and a nylon tarmac jacket were subjected to the following drycleaning cycle to simulate usage. A commercial Böwe Permac R312M machine with a 10 kg capacity and using perchloroethylene as solvent was used. A dry cleaning cycle of eight minutes was followed by extraction and drying at 40°C. This cycle was repeated three times for each sample.

3. Results and Discussion

3.1 The Body-to-Ground Resistance and Capacitance of Footwear Samples

Body-to-ground resistance and capacitance values of available footwear items are detailed in Table 2. A useful guide to the dissipative properties of footwear is the quantity obtained by forming the product of the measured capacitance and resistance values. This product, called the time constant, is the time required for the potential on the operator to fall by a factor of 1/e, i.e. to approximately 37 % of the initial value. The time constant has been evaluated for the samples in Table 2.

The voltage decay as a function of time t from peak potential V_{Peak}, for an operator with constant capacitance C, and resistance to ground R, can be expressed by the equation,

$$V(t) = V_{Peak} \exp(-t/RC) \qquad (2)$$

Table 2: *Body-to-Ground Resistance, Capacitance and Time Constant for an Operator Wearing a Variety of Footwear*

No.	Footwear	Foot Down	Resistance (Ω)	Capacitance (pF)	Time Constant (s)
		Right	1.9×10^8	130	0.02
1	Boots, safety, used	Left	2.3×10^8	126	0.03
		Both	1.3×10^8	178	0.02
		Right	9.6×10^8	100	0.1
2	Boots, safety, new	Left	3.8×10^9	100	0.4
		Both	9.4×10^8	128	0.1
		Right	1.0×10^{11}	84	8
3	Shoes, service dress, used	Left	1.0×10^{11}	87	9
		Both	8.0×10^{10}	112	9
		Right	fluctuates	82	Not calculated
4	Shoes, service dress, new	Left	"	81	"
		Both	8.0×10^{11}	104	83
		Right	2.0×10^9	98	0.2
5	Shoes, safety, used	Left	2.0×10^9	102	0.2
		Both	1.2×10^9	136	0.2
		Right	3.4×10^9	90	0.3
6	Shoes, safety, new	Left	3.8×10^9	92	0.3
		Both	2.2×10^9	122	0.3
		Right	1.3×10^{10}	89	1
7	Boots, flying, used	Left	1.2×10^{10}	92	1
		Both	8.0×10^9	116	0.9
		Right	5.0×10^9	84	0.4
8	Boots, flying, new	Left	4.6×10^9	82	0.4
		Both	3.2×10^9	107	0.3
		Right	1.0×10^{10}	90	0.9
9	Boots, black GP	Left	1.0×10^{10}	87	0.9
		Both	6.0×10^9	120	0.7
		Right	1.5×10^{10}	86	1
10	Boots, brown GP	Left	1.3×10^{10}	88	1
		Both	8.5×10^9	112	1
		Right	1.5×10^7	166	0.002
11	Shoes. Antistatic.	Left	2.2×10^7	136	0.003
	"Statsafe".	Both	1.1×10^7	227	0.002

The footwear capacitance lies between 80 pF and 230 pF and is influenced by the area, thickness and composition of the sole. The resistance ranges from approximately $10^7\ \Omega$ to $10^{12}\ \Omega$. The higher resistances result in large time constants and this means that about 80 s are required for the potential on the operator to decrease to a value that is 1/e times the original value of the potential. The shorter the time constant for a footwear item the quicker will the accumulated electrostatic charge be dissipated to ground. In order to determine whether footwear dissipation is adequate the electrostatic energy accumulated by an operator must be related to the sensitivity of the electroexplosive devices being handled.

3.2 The Body-to-ground Resistance of an Operator Standing on the Painted Metal Platform

The body-to-ground resistance of an operator standing on the AMRL-constructed painted metal platform (Section 2.2) while wearing the "Statsafe" antistatic shoes was $10^9\ \Omega$. When the operator, wearing the antistatic shoes, stood on the unpainted metal platform his resistance to ground was measured as $10^7\ \Omega$. These measurements were conducted at an applied potential of 500 V and the results indicate that the presence of a paint layer on the platform significantly increases the body-to-ground resistance.

3.3 Electrostatic Charging Experiments

3.3.1 Charging Experiments for an Operator Brushing against the Wall-Mounted F/A-18 Panel

The results presented in Tables 3 to 10 are from charging experiments where an operator brushed against the wall-mounted F/A-18 panel. The highest peak energy was 1164 μJ and this was obtained for the drycleaned nylon tarmac jacket. The time for this peak energy to decrease to 582 μJ (the half-time) was 0.6 s. An energy of 1164 μJ is nearly 70 times the ESD NFT for the M52A3B1 initiator and this energy corresponds to a probability of 45 % of initiating the 20 mm round. An energy of 582 μJ corresponds to a firing probability of 16 %.

Several trials also resulted in peak energies of around 1000 μJ and this energy value corresponds to a firing probability of 37 %. Personnel energy values that were at least ten times the ESD NFT (i.e. 170 μJ, corresponding to a firing probability of 1.5 %) were recorded for fifty clothing combinations. Personnel energy values that were greater than or equal to 500 μJ (corresponding to a firing probability of 12 %) were recorded for 14 clothing combinations.

Energy values that were less than or equal to the ESD NFT were recorded for thirteen clothing combinations. Low electrostatic energy values were most frequently determined for the clothing combination of T-shirt and shorts and for the CWD shirt and trousers. The new T-shirt and shorts combination tended to produce higher electrostatic energies on the operator compared with the used version of these garments.

Nomex tarmac jackets charge negatively while the nylon tarmac jackets charge positively (for rubbing against the painted metal panel) and these polarities are maintained after drycleaning. Drycleaning reduces charging for the nomex tarmac jacket and increases it for the nylon tarmac jacket.

Table 3: *Charging of an Operator Brushing against the F/A-18 Panel while Wearing a T-Shirt and Shorts. The Relative Humidity was 20 %.*

No.	Garments	Footwear	Peak Potential (kV)	Peak Energy (μJ)	Half-Time (s)
1	T-shirt, new Shorts, new	Boots, brown GP	-2.1	265	1.5
2	T-shirt, used Shorts, used	Boots, brown GP	-0.4	10	0.6
3	T-shirt, new Shorts, new	Boots, black GP	-2.3	291	1.5
4	T-shirt, used Shorts, used	Boots, black GP	0.6	20	0.3
5	T-shirt, new Shorts, new	Boots, safety, new	-2.7	423	0.3
6	T-shirt, used Shorts, used	Boots, safety, new	-0.1	1	0.3
7	T-shirt, new Shorts, new	Shoes, safety, new	-0.2	3	0.3
8	T-shirt, used Shorts, used	Shoes, safety, new	0.2	3	0.3

Table 4: Charging of an Operator Brushing against the F/A-18 Panel while Wearing the DPCU. The Relative Humidity was 20 %.

No.	Garments	Footwear	Peak Potential (kV)	Peak Energy (μJ)	Half-Time (s)
1	Shirt, DPCU, new Trousers, DPCU, new	Boots, brown GP	-0.3	5	0.9
2	Shirt, DPCU, used Trousers, DPCU, used	Boots, brown GP	-0.9	49	0.3
3	Shirt, DPCU, new Trousers, DPCU, new	Boots, black GP	-0.3	5	0.6
4	Shirt, DPCU, used Trousers, DPCU, used	Boots, black GP	-0.3	5	0.6

Table 5: Charging of an Operator Brushing against the F/A-18 Panel while Wearing the CWD Uniform. The Relative Humidity was 20 %.

No.	Garments	Footwear	Peak Potential (kV)	Peak Energy (μJ)	Half-Time (s)
1	Shirt, CWD, used Trousers, CWD, used Belt, SD, used	Boots, brown GP	-0.5	15	0.6
2	Shirt, CWD, used Trousers, CWD, used Belt, SD, used	Boots, black GP	-0.3 -0.3	5	0.6 0.6
3	Shirt, CWD, used Trousers, CWD, used Belt, SD, used	Boots, safety, new	-0.2	2	0.3
4	Shirt, CWD, used Trousers, CWD, used Belt, SD, used	Shoes, safety, new	-0.1	1	0.3

No.	Garments	Footwear	Peak Potential (kV)	Peak Energy (μJ)	Half-Time (s)
5	Shirt, CWD, new Trousers, CWD, new Belt, SD, new	Shoes, SD, new	-1.2	72	> 25
6	Shirt, CWD, used Trousers, CWD, used Belt, SD, new	Shoes, SD, new	-1.4	98	> 25

Table 6: *Charging of an Operator Brushing against the F/A-18 Panel while Wearing a Variety of Sweaters. The Relative Humidity was 20 %.*

No.	Outer Garments (Inner Garments)	Footwear	Peak Potential (kV)	Peak Energy (μJ)	Half-Time (s)
1	Sweater, blue/grey, used Trousers, CWD, used (E,F)	Boots, brown GP	4.1	1009	0.9
2	Sweater, blue/grey, new Trousers, CWD, used (E,F)	Boots, brown GP	3.0	540	0.6
3	Sweater, DPCU, new Trousers, DPCU, new (G)	Boots, brown GP	2.7	437	0.9
4	Sweater, DPCU, used Trousers, DPCU, used (H)	Boots, brown GP	1.3	101	0.3
5	Sweater, blue/grey, used Trousers, CWD, used (E,F)	Boots, black GP	1.9	199	0.6
6	Sweater, blue/grey, new Trousers, CWD, used (E,F)	Boots, black GP	1.9	199	0.6
7	Sweater, DPCU, new Trousers, DPCU, new (G)	Boots, black GP	2.4	317	0.6
8	Sweater, DPCU, used Trousers, DPCU, used (H)	Boots, black GP	1.3	93	0.3

No.	Outer Garments (Inner Garments)	Footwear	Peak Potential (kV)	Peak Energy (μJ)	Half-Time (s)
9	Sweater, blue/grey, new Trousers, CWD, used (E,F)	Boots, safety, new	2.7	423	0.3
10	Sweater, blue/grey, used Trousers, CWD, used (E,F)	Boots, safety, new	2.1	256	0.6
11	Sweater, blue/grey, new Trousers, CWD, used (E,F)	Shoes, safety, new	2.2	307	0.3
12	Sweater, blue/grey, used Trousers, CWD, used (E,F)	Shoes, safety, new	2.5	397	0.3
13	Sweater, blue/grey, used Trousers, CWD, used (E,F)	Shoes, SD, new	3.0	450	> 25
14	Sweater, blue/grey, new Trousers, CWD, used (E,I)	Shoes, SD, new	3.5	612	> 25

Table 7: *Charging of an Operator Brushing against the F/A-18 Panel while Wearing a Nylon Tarmac Jacket. The Relative Humidity was 20 %.*

No.	Outer Garments (Inner Garments)	Footwear	Peak Potential (kV)	Peak Energy (μJ)	Half-Time (s)
1	Tarmac jacket, nylon, new Shorts, new (A)	Boots, brown GP	0.4	10	0.6
2	Tarmac jacket, nylon, drycleaned Shorts, new (A)	Boots, brown GP	3.5	735	0.9
3	Tarmac jacket, nylon, new Trousers, CWD, used (E,F)	Boots, brown GP	3.0	540	0.9

No.	Outer Garments (Inner Garments)	Footwear	Peak Potential (kV)	Peak Energy (μJ)	Half-Time (s)
4	Tarmac jacket, nylon, drycleaned Trousers, CWD, used (E,F)	Boots, brown GP	2.1	265	0.3
5	Tarmac jacket, nylon, new Shorts, new (A)	Boots, black GP	0.5	14	0.3
6	Tarmac jacket, nylon, drycleaned Shorts, new (A)	Boots, black GP	3.8	794	0.6
7	Tarmac jacket, nylon, new Trousers, CWD, used (E,F)	Boots, black GP	1.9	199	0.6
8	Tarmac jacket, nylon, drycleaned Trousers, CWD, used (E,F)	Boots, black GP	4.6	1164	0.6
9	Tarmac jacket, nylon, new Shorts, new (A)	Boots, safety, new	1.7	168	0.6
10	Tarmac jacket, nylon, drycleaned Shorts, new (A)	Boots, safety, new	4.3	1072	0.3
11	Tarmac jacket, nylon, new Trousers, CWD, used (E,F)	Boots, safety, new	2.2	281	0.6
12	Tarmac jacket, nylon, drycleaned Trousers, CWD, used (E,F)	Boots, safety, new	2.9	488	0.6
13	Tarmac jacket, nylon, new Shorts, new (A)	Shoes, safety, new	2.2	307	0.3
14	Tarmac jacket, nylon, drycleaned Shorts, new (A)	Shoes, safety, new	2.9	534	0.3

No.	Outer Garments (Inner Garments)	Footwear	Peak Potential (kV)	Peak Energy (μJ)	Half-Time (s)
15	Tarmac jacket, nylon, new Trousers, CWD, used (E,F)	Shoes, safety, new	1.6	163	0.3
16	Tarmac jacket, nylon, drycleaned Trousers, CWD, used (E,F)	Shoes, safety, new	2.2	307	0.3
17	Tarmac jacket, nylon, new Trousers, CWD, used (E,I)	Shoes, SD, new	0.8	32	0.6
18	Tarmac jacket, nylon, drycleaned Trousers, CWD, used (E,I)	Shoes, SD, new	4.0	800	> 25

Table 8: *Charging of an Operator Brushing against the F/A-18 Panel while Wearing a Nomex Tarmac Jacket. The Relative Humidity was 20 %.*

No.	Outer Garments (Inner Garments)	Footwear	Peak Potential (kV)	Peak Energy (μJ)	Half-Time (s)
1	Tarmac jacket, nomex, new Shorts, new (A)	Boots, brown GP	-2.8	470	1.2
2	Tarmac jacket, nomex, drycleaned Shorts, new (A)	Boots, brown GP	-2.4	346	0.9
3	Tarmac jacket, nomex, new Trousers, CWD, used (E,F)	Boots, brown GP	-2.6	406	0.9
4	Tarmac jacket, nomex, drycleaned Trousers, CWD, used (E,F)	Boots, brown GP	-2.2	290	0.9
5	Tarmac jacket, nomex, new Shorts, new (A)	Boots, black GP	-2.1	243	1.2

No.	Outer Garments (Inner Garments)	Footwear	Peak Potential (kV)	Peak Energy (μJ)	Half-Time (s)
6	Tarmac jacket, nomex, drycleaned Shorts, new (A)	Boots, black GP	-2.2	266	0.9
7	Tarmac jacket, nomex, new Trousers, CWD, used (E,F)	Boots, black GP	-2.1	243	0.9
8	Tarmac jacket, nomex, drycleaned Trousers, CWD, used (E,F)	Boots, black GP	-1.9	199	0.9
9	Tarmac jacket, nomex, new Shorts, new (A)	Boots, safety, new	-1.9	209	0.6
10	Tarmac jacket, nomex, drycleaned Shorts, new (A)	Boots, safety, new	-1.9	209	0.6
11	Tarmac jacket, nomex, new Trousers, CWD, used (E,F)	Boots, safety, new	-1.9	209	0.3
12	Tarmac jacket, nomex, drycleaned Trousers, CWD, used (E,F)	Boots, safety, new	-1.7	168	0.3
13	Tarmac jacket, nomex, new Shorts, new (A)	Shoes, safety, new	-1.5	143	0.3
14	Tarmac jacket, nomex, drycleaned Shorts, new (A)	Shoes, safety, new	-1.5	143	0.3
15	Tarmac jacket, nomex, new Trousers, CWD, used (E,F)	Shoes, safety, new	-1.3	107	0.3
16	Tarmac jacket, nomex, drycleaned Trousers, CWD, used (E,F)	Shoes, safety, new	-1.3	107	0.3

No.	Outer Garments (Inner Garments)	Footwear	Peak Potential (kV)	Peak Energy (μJ)	Half-Time (s)
17	Tarmac jacket, nomex, new Trousers, CWD, used (E,I)	Shoes, SD, new	-3.2	512	> 25
18	Tarmac jacket, nomex, drycleaned Trousers, CWD, used (E,I)	Shoes, SD, new	-2.8	392	7

***Table 9:** Charging Caused by an Operator Brushing against the F/A-18 Panel while Wearing a Flying Suit. The Relative Humidity was 20 %.*

No.	Outer Garments (Inner Garments)	Footwear	Peak Potential (kV)	Peak Energy (μJ)	Half-Time (s)
1	Suit, flying, used (C,J)	Boots, flying, used	-1.9	242	0.9
2	Suit, flying, new (C,K)	Boots, flying, used	2.2	324	0.3

***Table 10:** Charging Caused by an Operator Brushing against the F/A-18 Panel while Wearing an Assortment of Jackets and Liners. The Relative Humidity was 20 %.*

No.	Outer Garments (Inner Garments)	Footwear	Peak Potential (kV)	Peak Energy (μJ)	Half-Time (s)
1	Liner, CW, new Trousers, DPCU, new (G)	Boots, brown GP	2.1	265	0.6
2	Liner, CW, used Trousers, DPCU, used (H)	Boots, brown GP	3.5	735	0.6
3	Jacket, DP, hooded Trousers, DPCU, new (G)	Boots, brown GP	2.1	265	0.6
4	Liner, CW, new Trousers, DPCU, new (G)	Boots, black GP	3.2	563	0.3

No.	Outer Garments (Inner Garments)	Footwear	Peak Potential (kV)	Peak Energy (μJ)	Half-Time (s)
5	Liner, CW, used Trousers, DPCU, used (H)	Boots, black GP	4.1	925	0.6
6	Jacket, DP, hooded Trousers, DPCU, new (G)	Boots, black GP	1.7	159	0.3
7	Jacket, flying, used Suit, flying, used (C,J)	Boots, flying, used	-1.3	113	0.6
8	Jacket, flying, new Suit, flying, new (C,K)	Boots, flying, used	1.0	67	0.3

***Inner Garments**

A New T-shirt
B Used T-shirt
C Used T-shirt
D New CWD shirt
E Used CWD shirt
F Used SD belt
G New DPCU shirt
H Used DPCU shirt
I New SD belt
J Used flying gloves
K New flying gloves

3.3.2 The Effect of Low Body-to-Ground Resistance on the Peak Energy and the Half-Time

The charge accumulated on an operator can be controlled by lowering the body-to-ground resistance. To evaluate the effects of some practical methods for achieving this, charging experiments were carried out in the environmental chamber on an operator wearing either (1) Issue footwear, (2) Antistatic Footwear ("Statsafe". Purnell Shoe Company), (3) Issue footwear and a 5 metre long, 0.4 Ω earth lead, (4) Issue footwear and a 1 MΩ wrist strap (Plastic Systems), (5) Issue footwear and Legstats (Walter G. Legge, No. 2000) or (6) Issue footwear and heel protectors (Neutro stat PT no. 4000045). Experiments that had yielded the highest peak potential values on an operator in Section 3.3.1 (results in Tables 3 to 10) were chosen for repetition with the inclusion of the resistance-lowering methods. Inspection of Table 11 shows that each method resulted in a marked decrease in both the peak energy and in the half-time.

The substitution of antistatic footwear for the RAAF issue footwear resulted in a decrease in the maximum peak energy from 1164 μJ to 36 μJ while the largest half-time decreased from 0.9 s to 0.08 s. The probability of initiating the 20 mm round is 45 % for an energy of 1164 μJ and is only 0.06 % for an energy of 36 μJ. The maximum peak energy value was also drastically reduced by using an earth lead in conjunction with issue footwear. In this case the maximum peak energy decreased from 1164 μJ to only 0.07 μJ (corresponding to a small firing probability of 1.5×10^{-7} %) and the largest half-time value decreased from 0.9 s to under 0.08 s.

When issue footwear was worn in conjunction with a 1 MΩ wrist strap the maximum peak energy decreased from 1164 μJ to 0.03 μJ (corresponding to a very small firing probability of 2.5×10^{-8} %). The maximum half-time decreased from 0.9 s to 0.04 s. Legstats (worn over issue footwear) were effective in reducing the peak energy from 1164 μJ to less than 0.001 μJ. The heel protectors reduced the peak energy from 1072 μJ (corresponding to a firing probability of 41 %) to less than 0.0003 μJ.

It should be mentioned that legstats and heel protectors only provide limited electrostatic protection. Legstats fit across the footwear instep, therefore a hazard exists if personnel rock on to their heels or toes while wearing legstats because these actions can eliminate contact between the legstat and the ground. Similarly, heel protectors may have their effectiveness negated by such actions. In addition, the protectors cannot be used with boots that have high sides because the ends of the protectors cannot then be placed inside the footwear.

The practice of wearing a very low resistance earth lead, although effective in reducing charging, introduces the possibility of an electrical shock hazard if personnel contact a high voltage source while wearing the lead. The possiblity of a high voltage shock can be reduced if a wrist strap with an appropriate series resistance is used instead of a very low resistance earth lead.

Table 11: A Comparison of the Charging Caused by an Operator Brushing against the F/A-18 Panel while Wearing either (1) Issue Footwear, (2) Antistatic Footwear, (3) Issue Footwear and an Earth Lead, (4) Issue Footwear and the 1 MΩ Wrist Strap, (5) Issue Footwear and the Legstats or (6) Issue Footwear and the Heel Protectors. The Relative Humidity was 20 % during the Tests.

No.	Outer Garments (Inner Garments)	Footwear / Leads	Peak Potential (kV)	Peak Energy (μJ)	Half-Time (s)
		Boots, black GP	4.6	1164	0.6
1	Tarmac jacket, nylon, drycleaned Trousers, CWD, used (E,F)	"Statsafe" antistatic shoes	0.3	9	0.08
		Boots, black GP & earth lead	0.003	0.02	< 0.08
		Boots, black GP & 1 MΩ wrist strap	< 0.001	< 0.0001	< 0.01
		Boots, black GP & legstats	< 0.001	< 0.001	< 0.01
		Boots, safety, new	4.3	1072	0.3
2	Tarmac jacket, nylon, drycleaned Shorts, new (A)	"Statsafe" antistatic shoes	0.3	9	0.04
		Boots, safety, new & earth lead	< 0.001	< 0.003	< 0.01
		Boots, safety, new & 1 MΩ wrist strap	< 0.001	< 0.0001	< 0.01
		Boots, safety, new & heel protectors	< 0.001	< 0.0003	< 0.01

No.	Outer Garments (Inner Garments)	Footwear / Leads	Peak Potential (kV)	Peak Energy (μJ)	Half-Time (s)
3	Sweater, blue/grey, used Trousers, CWD, used (E,F)	Boots, brown GP	4.1	1009	0.9
		"Statsafe" antistatic shoes	0.3	9	0.08
		Boots, brown GP & earth lead	< 0.001	< 0.003	< 0.01
		Boots, brown GP & 1 MΩ wrist strap	0.006	0.005	0.04
4	Liner, CW, used Trousers, DPCU, used (H)	Boots, black GP	4.1	925	0.6
		"Statsafe" antistatic shoes	0.6	36	0.08
		Boots, black GP & earth lead	0.005	0.07	< 0.08
		Boots, black GP & 1 MΩ wrist strap	0.014	0.03	0.04

***Inner Garments**

A	New T-shirt
B	Used T-shirt
C	Used T-shirt
D	New CWD shirt
E	Used CWD shirt
F	Used SD belt
G	New DPCU shirt
H	Used DPCU shirt
I	New SD belt
J	Used flying gloves
K	New flying gloves

3.3.3 Charging Caused by Leaving a Vehicle

Previous work has focussed on the case of an operator leaving a vehicle while wearing brown or black GP boots [3]. The highest energy obtained was 5500 μJ (300 times the NFT of the M52 primer and representing a 95 % firing probability) and the longest time recorded for the potential to decay from the peak potential value to a value corresponding to the NFT of an M52 primer was 3 s. These results are relevant to the vehicle that is used to transport the loader assembly since personnel may attain sufficient energy while leaving the vehicle to initiate the 20 mm round.

3.3.4 Charging Experiments with the F/A-18 Gun Access Door

The highest energy resulting from the charging experiments with the gun access door (Section 2.4.5) was 1 μJ and this is less than the M52A3B1 NFT energy value of 17 μJ [1].

3.4 Experiments at Tindal Air Force Base.

3.4.1 Footwear Survey

A footwear survey was conducted for RAAF workshop personnel. The body-to-ground resistance (at an applied potential of 250 V d.c.) and capacitance were measured for an operator standing on a metal plate which allowed the time constant to be determined (see section 3.1). The purpose of the survey in Table 12 was to establish whether RAAF issue footwear adequately dissipates electrostatic charge.

Table 12: Resistance and Capacitance Measurements for Personnel at Tindal A.F.B.

Operator	Footwear	Usage Period(1)	Resistance (Ω)	Capacitance (pF)	Time Constant (s)
1	Black 'Star'	1 yr	5.0×10^{7}		
2	Hushpuppies		3.0×10^{11}	170	51
3	Jenkin	New	6.0×10^{7}	270	0.02
4	Black 'star'	2 yr	8.0×10^{8}	230	0.2
5	Black GP 'diamond'	6 mth	3.0×10^{8}	225	0.07
6	Black shoe 'Hytest'	8 wk	5.0×10^{8}	250	0.1
7	Black 'star'	6 mth	1.5×10^{8}	270	0.04
8	Black 'Jenkin'	2 mth	6.0×10^{7}	280	0.02

Operator	Footwear	Usage Period(1)	Resistance (Ω)	Capacitance (pF)	Time Constant (s)
9	Brown GP	5 days	4.5×10^8	183	0.08
10	Brown GP	2 days	9.0×10^8	163	0.1
11	Black 'diamond'	3-4 mth	3.0×10^7	275	0.008
12	Black GP	About 1 wk	6.0×10^8	162	0.1
13	Black 'Blundstone'	About 3 hr	1.2×10^9	180	0.2
14	Black Service Shoes	3 yr	1.0×10^9	300	0.3
15	Black 'Blundstone'	About 1 wk	2.5×10^9	260	0.7
16	Black Safety Shoes	2 mth	3.5×10^7	300	0.01
17	Black GP 'diamond'	8 mth	3.0×10^8	240	0.07
18	Blundstone safety shoes	About 6 mth	2.6×10^7	160	0.004

(1) The usage period is the time elapsed since the footwear was issued to the operator

The results of the survey indicate that the footwear issued to personnel in the electronic workshop area at Tindal Air Force Base exhibited time constants of less than 1 s. An exception is found in measurement 2. In this case the shoes, described as Hushpuppies, had a time constant of 51 s. The largest time constant constitutes a clear hazard both because of the level of charge an operator can accumulate and the time for the charge to decay to a safe level. Footwear with time constants of less than 51 s can also constitute a hazard during handling of 20 mm ammunition due to the level of accumulated electrostatic energy on the operator.

3.4.2 Resistance Measurements on Flightline Equipment

Resistance measurements (Table 13) were conducted on the replenisher assemblies to determine whether all the conducting sections were electrically bonded and that the assembly was earthed. All resistances were measured at an applied potential of 250 V and all values were low except for the drive socket and the sloping tray. These are acceptable values, however, from the point of view of electrostatic dissipation. Unless stated otherwise the assembly serial no. was 3000072.

Table 13: Resistance Measurements on the Replenisher Assemblies

First Measuring Point	Second Measuring Point	Resistance (Ω)
Inner end of static reel	Outer end of static reel	5*
"	"	4.9
"	Drive socket	2 - 10^6
"	Spring near reel end	0.5
"	Link on bed	120
"	Sloping tray	0.4
"	Lid on sloping tray	0.4
"	Drive union	180
Sloping tray	Earthing strip (on wall). Earth lead disconnected	4×10^5

* This reading is for serial no. 3000073.

Resistance measurements were also conducted on the loader assemblies at an applied potential of 250 V (Table 14). Wheel resistance measurements are shown in Table 15 and resistance measurements between the assembly drum and earth are presented in Table 16. Resistances are below 10^9 Ω for all measurements which is acceptable for electrostatic purposes. The measurements in Table 15 were conducted with the wheel resting on a metal plate on the floor. The purpose of these measurements was to determine whether the loader assemblies provided a path to earth of sufficiently low resistance to dissipate electrostatic charge and also to determine whether the assembly components were bonded together.

Table 14: Resistance Measurements on the Loader Assembly

First Measuring Point	Second Measuring Point	Resistance (Ω)
Inner end of static reel	Outer end of static reel. Unwinding reel.	5.6 (no change)
One end of static strap	Other end of static strap	10^5

Table 15: Wheel Resistance Measurements on the Loader Assemblies

Loader Assembly Serial No.	Wheel	Resistance (Ω)
1000109	Rear left	2×10^8
"	Rear right	3×10^8
"	Front left	1×10^8
"	Front right	3×10^8
1000145	Rear left	1×10^8
"	Rear right	2×10^7
"	Front left	4×10^7
"	Front right	4×10^7

Table 16: Resistance Measurements Between the Loader Assembly Drum and Earth

Loader	Earth Lead	Strap & Trail Chain	Resistance (Ω)
Moving	None	Down	7.5×10^4 to 3.2×10^5
Moving	None	None	2×10^5 to 3.7×10^5
Static	None	None	1.4×10^5 to 1.8×10^5

3.4.3 The Resistance of the Earthing System in the Preparation Room

The resistance measurements in Table 17 were made between selected points within the preparation room. All measurements were conducted at an applied potential of 250 V. These measurements were undertaken in order to check the integrity of the earthing system and they indicate that the electrostatic earthing system is adequate for hazard control during handling of M52A3B1 primers.

Table 17: Resistance Measurements of the Earthing System in the Preparation Room

First Measuring Point	Second Measuring Point	Resistance (Ω)
Black Floor Area	Earth point	9×10^3
Painted Concrete Area	Earth point	6×10^5 to 1×10^7
Point on wall earthing strip	Earth point on floor. "Serial no. 1.10"	1.2×10^2 to 1.7×10^2
"Main Earth" outside room	Strip on lightning rod	0.2 to 0.3 (lead resistance)
"Main Earth" outside room	Earth point on floor. "Serial no. 1.10"	4.6×10^2
"Main Earth" outside room	Earth strip	0.2
Earth strip	Earth point on floor. "Serial no. 1.39"	41 to 56
Base plate of the lightning mast.	Earth point	8×10^7

3.4.4 The Resistance of the F/A-18 Aircraft Body to Earth

The resistance to ground of the F/A-18 aircraft was measured while the aircraft earthing lead was disconnected. The resistance was measured between the aircraft body and an earth plug on the floor that was inscribed "serial no. 112". The resistance was $1.7 \times 10^5\ \Omega$ at an applied potential of 250 V. The capacitance to ground of the aircraft was not measured. A common capacitance value used for aircraft is 5 nF and, together with the resistance value, this results in a time constant of 0.001 s which is adequate from the point of view of controlling static electricity on the aircraft.

3.4.5 The Electrostatic Potential on the Electric Drive Unit

The electrically powered loader drive unit was tested to check whether its operation could generate a static charge. An operator wearing brown GP boots stood on a polyethylene sheet, picked up the loader drive unit and started the motor. No electrostatic potential was detected on the loader drive unit when it was operated in this way and therefore no evidence was found for the assertion that an operating electric loader drive unit could generate a static electric charge.

4. Summary

An investigation of the clothing and equipment associated with the loading of 20 mm ammunition into the F/A 18 aircraft has revealed the following:

1. Most of the clothing combinations tested resulted in personnel electrostatic energies that exceed the no-fire threshold for a 20 mm round. While the no-fire threshold for personnel electrostatic discharge into the M52A3B1 primer is 17 μJ, energies of the order of 1000 μJ were possible. An energy of 1000 μJ corresponds to a 37 % probability of initiating the 20 mm round.

2. The effect of drycleaning on the tarmac jackets was variable. In most cases the drycleaned nylon tarmac jacket resulted in a higher electrostatic energy than the as-received jacket while the drycleaned nomex jacket tended to cause a lower energy when compared with the as-received version.

3. The observed times for the potential to drop to half the peak value (the half-times) are less than or equal to 1.5 s (excluding results obtained with the service dress shoes). However, because the peak energies are usually extremely high and the NFT for the 20 mm round is extremely low, the residual energy on the operator at the termination of the half-time is still, in most cases, sufficient to initiate the 20 mm round. For example, the maximum peak energy recorded was 1164 μJ and this dropped to an energy of 582 μJ after 0.6 s. However, 582 μJ corresponds to a 16 % probability of initiating the round and this clearly constitutes a safety hazard.

4. The dress shoes and the footwear described as Hushpuppies possess half-times that exceed 25 seconds.

5. Use of antistatic footwear in place of issue footwear caused the maximum peak energy to decrease from 1164 μJ to 36 μJ and the maximum half-time to decrease from 0.9 s to 0.08 s. Given that the no-fire threshold for the M52A3B1 primer is 17 μJ, the probability of initiating the 20 mm round is 45 % for an energy of 1164 μJ and, by comparison, is only 0.06 % for 36 μJ.

6. In laboratory experiments where the operator (still wearing issue footwear) wore a very low resistance (0.4 Ω) earth lead, the maximum peak energy value decreased from an original value of 1164 μJ to a value of 0.07 μJ (firing probability only 1.5×10^{-7} %) while the maximum half-time decreased from 0.9 s to less than 0.08 s. However, a lead with such a low resistance should not be worn if there is any chance of electrocution from a high voltage supply.

7. When the operator wore issue footwear and a 1 MΩ wrist strap, the maximum peak energy dropped from 1164 μJ to 0.03 μJ. The value of 0.03 μJ corresponds to a

very small firing probability of 2.5×10^{-8} %. The maximum half-time decreased from 0.9 s to 0.04 s.

8. When the operator wore issue footwear together with legstats, the peak energy decreased from 1164 μJ to under 0.001 μJ.

9. When the operator wore issue footwear and the heel protectors, the peak energy decreased from 1072 μJ to less than 0.0003 μJ.

10. The presence of a paint layer on the metal surface of the loader platform can increase the body-to-ground resistance by a factor of 100. This represents an increase in the resistance from 10^7 Ω to 10^9 Ω for an operator wearing the antistatic shoes. An increase in resistance would increase the risk of static discharge from personnel because of the increased half-time for the decay of accumulated charge.

5. Recommendations

Most clothing combinations have the capability of generating sufficient electrostatic energy to initate a 20 mm round. This is not a hazard while the rounds are contained within the conveyor belts of the loader on the aircraft and are not being touched by personnel. A hazard exists when a round needs to be removed from the belt by an operator. In this case precautions need to be taken, namely:

(1) Personnel must be trained not to touch the primers on the 20 mm rounds.

(2) Personnel should minimize the amount of rubbing of their garments against any surface prior to handling the 20 mm rounds.

(3) One of the following options should be employed to reduce the peak energy as well as the time for the energy to decay to one half of the peak value. The most strongly recommended options are towards the top of the list.

a. Antistatic footwear with a resistance not exceeding 10 MΩ may be substituted for issue footwear.

b. Personnel may wear issue footwear in conjunction with a wrist strap that possesses a 1 MΩ series resistor. The resistor will enhance protection against mains voltage shocks.

c. Personnel may wear issue footwear in conjunction with legstats. However these only provide limited protection because a hazard may still exist if personnel rock on to their heels or toes and therefore negate the effectiveness of the legstats.

d. Personnel may wear issue footwear together with heel protectors. However, as with legstats, these only provide limited protection since it is possible to negate their effectiveness by rocking on to the toes. In addition, the protectors cannot be used with boots that have high sides because the ends cannot be placed inside the footwear.

(4) If the round needs to be removed it should be placed directly into a suitable container. During this process the operator should ensure that the primer on the round does not contact any objects.

(5) It is also recommended that the metal surface of the loader platform be left in an unpainted state. If the platform has a previously painted surface then this paint should be removed before the platform is placed in service.

(6) It is recommended that insulating materials such as plastic sheeting be kept out of the area where the rounds are being handled. Insulating materials might also include garments that have been removed from personnel.

(7) It is recommended that all metal objects in the vicinity of the rounds be earthed. A simple method for accomplishing this is to place the metal objects on the ground or in electrical contact with an earthed object.

6. Acknowledgements

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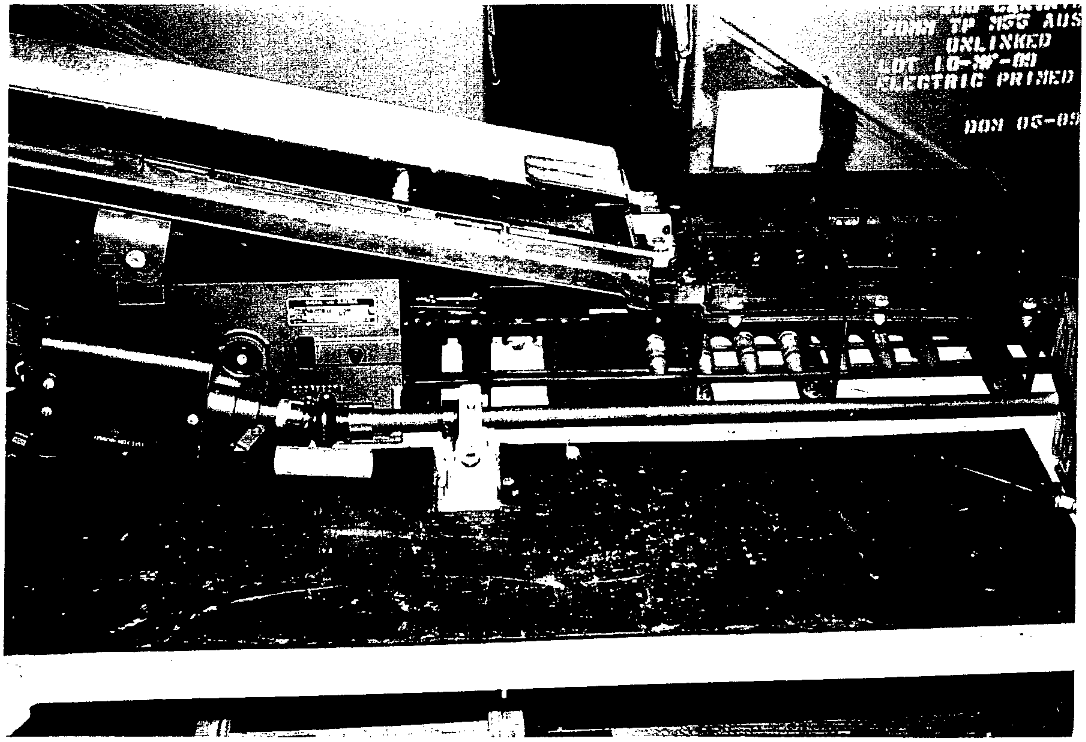

Figure 1: A replenisher assembly.

Figure 2: A loader assembly

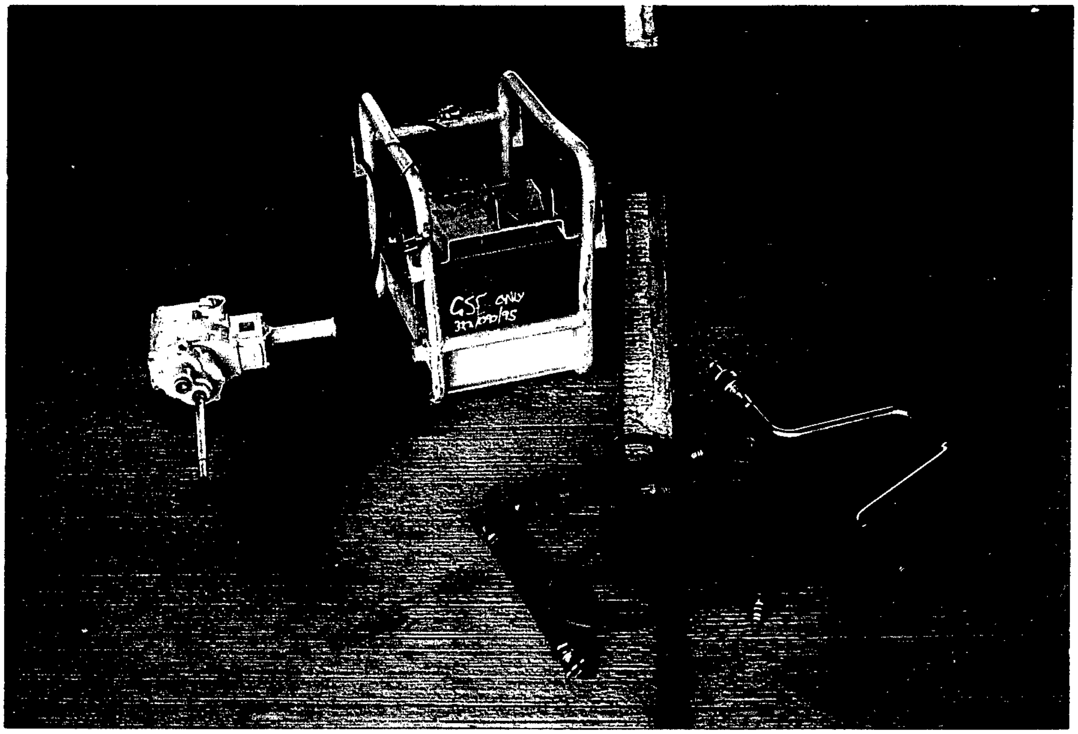

Figure 3: The three different types of loader drive unit

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19. ABSTRACT
An electrostatic hazards assessment of procedures and service clothing used during flightline operations that involve electro-explosive devices (EEDs) has been completed. The assessment includes measurements of the body-to-ground resistance, capacitance and body potential for personnel in service clothing. Activities involved in the loading of 20 mm ammunition into an F/A-18 aircraft provide a focus for the investigation.

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