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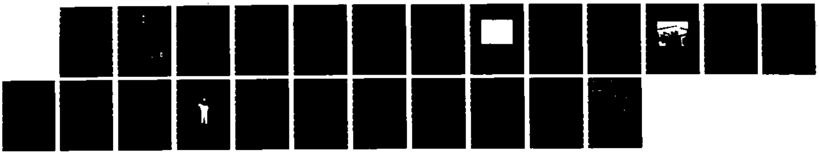

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DEFENCE RESEARCH ESTABLISHMENT OTTAWA
TECHNICAL NOTE 86-5

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ABSTRACT

The maximum stresses were measured in Canadian Forces combat clothing and were found to be of the order of 3000 to 3500 N/m. The stresses were found to be higher in the coveralls than in the shirt and trousers, and higher in wear than in donning the clothing. (Canada).

RÉSUMÉ

Les tensions maximales ont été mesurées à l'égard des tenues de combat des Forces canadiennes; elles se sont révélées être de l'ordre de 3500 N/m. On a pu constater qu'une tension plus élevée s'exerçait sur la combinaison couvre-tout que sur la chemise et le pantalon, d'une part et, d'autre part, qu'on soumettait un vêtement à une tension plus élevée en le portant qu'en l'endossant.

INTRODUCTION

This paper continues the study of stress in clothing by presenting the results of stress measurements in the previously-identified areas of maximum stress in the Canadian Forces (CF) combat shirt, trousers and coveralls (Crow and Dewar, 1984, 1985).

REVIEW OF LITERATURE

Worthington (1974) and Nestler and Schlegel (1978) had measured stress in clothing, Worthington with his bridge-clip and Nestler and Schlegel with an extensometer. Worthington had measured stress in men's and women's trousers, in men's jacket seams and seams of shirts, frocks and girdles while the subjects took a variety of stances such as sitting, bending, crouching and stretching. He had not pre-determined the locations and stances which would cause maximum stress. He reported his results as percent frequency of recorded stress for various stress regions.

Of the five men's jackets tested, only one gave stresses above 2940 N/m, as measured across the back armhole seam, 19 to 24 cm below the shoulder. The maximum recorded stress for the men's shirt across the armhole seam at the back and across the centre-back was 1460 N/m, and for the woman's frock in the same location, 1960 N/m. For the trousers, he reported some stress measurements above 3430 N/m as measured across the centre back seam, 19 to 24 cm below the waistband.

Nestler and Schlegel did determine the location of stress in clothing as described earlier (Crow and Dewar 1984), and determined the stances which caused maximum stress. They report the maximum stress obtained. Of the clothing they used, only the "sports jacket of a woven fabric" could be comparable to the clothing used in our study. However, they found the maximum stress to be in the waist area of the centre-back seam, presumably because of the cut of the jacket, and found it to be 3000 N/m. This was the greatest reported stress in any of the garments they tested.

The Method for Measuring Stress in Clothing

A previous paper (Crow and Dewar, 1984) gave a detailed review and critique of possible methods for measuring stress in clothing. Briefly, it was found that common brittle-coatings were incompatible with textile fabrics; gauge-length methods could be used on textiles, but were unsuitable for relatively inextensible clothing over a curved-body surface; go-no-go techniques gave relatively crude results. The remaining method used strain gauges mounted on some type of metal carrier which could be easily attached to clothing at various locations. Of those described in the literature, the bridge clip by Worthington (1974), was found to be the most sensitive and most easily located on the clothing. We are not totally convinced that this is the best method for measuring strain in clothing, or in fact, if this method does measure the actual stress due to the interaction of the carrier with the fabric or if the response time of the recorder (0.25 sec) is fast enough to measure the peak, maximum stress. However, nothing better has been found or developed and this was deemed the best method available.

Schematic drawings of the bridge clip and the mounted dummy strain gauges are shown in Figure 1, their placement on the shirt in Figure 2 and the associated circuitry in Figure 3. A stop was added to the clip of the bridge-clip to allow for reproducible positioning of the bridge-clip when it was moved from one fabric location to another.

Our system differed from Worthington's in that one active strain gauge R_A, was used on the bridge-clip with three dummy strain gauges, R_D, to make up the Wheatstone bridge. The resistance of each was nominally 120 Ω. Worthington had placed all four strain gauges on the bridge-clip, two on the top and two on the underside. We could see no particular rationale for having more than one active strain gauge on the bridge-clip other than for temperature compensation and to nullify the lead-wire resistances. Since applying strain gauges to metal is very much an art and skill, it was found more practical to apply one strain gauge to the top of the bridge-clip and three dummy strain gauges to a piece of 0.64 cm thick aluminum which could be pinned on the clothing near the bridge-clip. In this way, the effect of temperature on the gauges was eliminated. Further, the dummy gauges had leads of identical length to those of the active gauge to nullify lead-wire resistances.

The circuitry was changed somewhat from that of Worthington's. The voltage reference was replaced with a constant-voltage power supply and the differential amplifier with a floating-type voltmeter. These changes made the bridge easier to zero and the output more stable. Only the most sensitive range was used for our study.

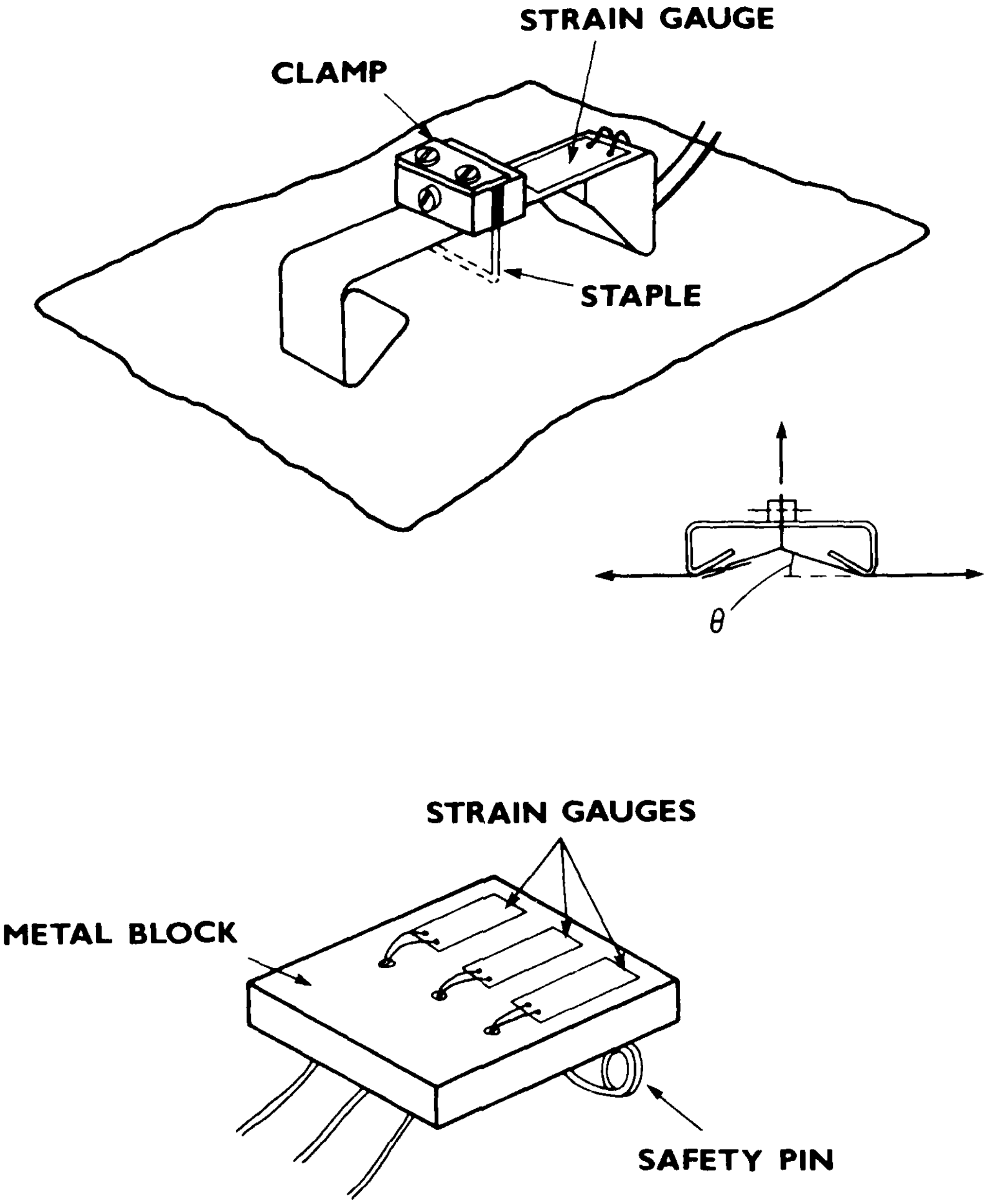


Figure 1: Schematic Drawings of Bridge-Clip and Mounted Dummy Gauges.

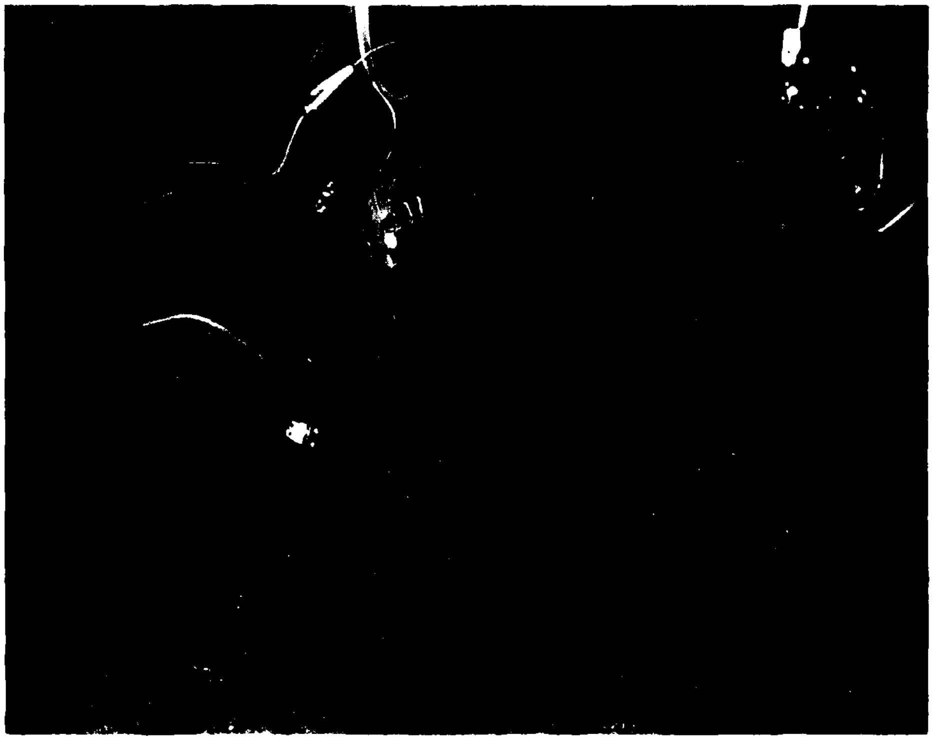


Figure 2: The Placement of the Bridge-Clip and Dummy Gauges on the Shirt.

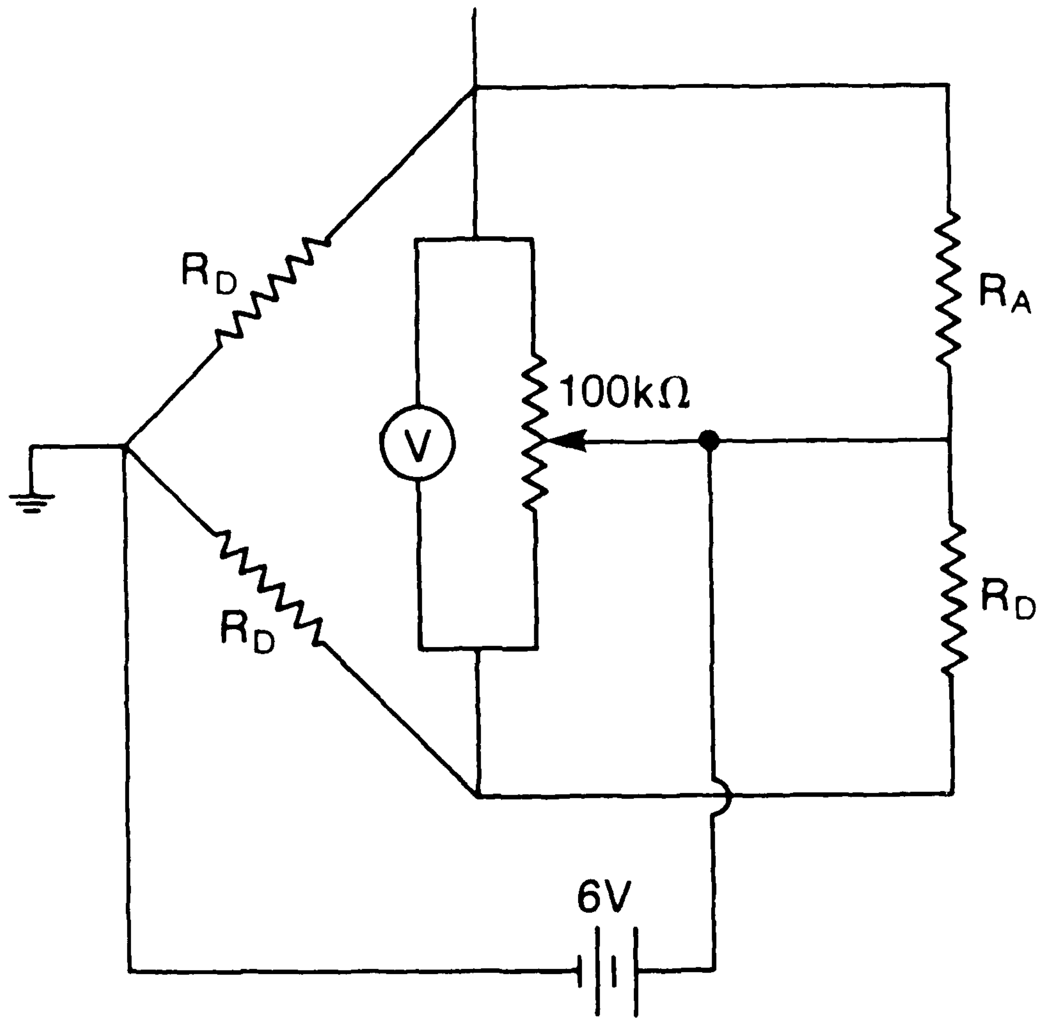


Figure 3: Strain Gauges and the Associated Circuitry.

Calibration

A calibration rig, similar to that used by Worthington, was made and is shown in Figure 4. Initially, fabric in the shape of a cross had two of its arms clamped in the two rubber-lined vises, and the other two arms passed over low friction rollers. Weights were hung from these arms. The bridge-clip was placed at the centre of the cross, parallel to the free arm to which the range of weights were hung. The crosswise arm was tensioned under a constant weight which was then varied for the range of weights on the "parallel to the bridge-clip" arm. We found only small variations in the stress measurements as the crosswise tension was varied, as did Worthington. Therefore, further calibrations of the bridge-clip were carried out on a strip, rather than on a cross of fabric.

The fabrics used for the calibrations were those used in the Canadian Forces lightweight combat shirt and trousers and the Canadian Forces flying coveralls. The pertinent fabric properties are given in Table 1.

Initially, we calibrated the bridge clip on 4,6 and 8 cm wide strips of fabric as we were somewhat concerned about edge effects of the strips. This was repeated periodically over a few months, generating a family of similar curves for the varying widths. What was of greater concern was the mediocre reproducibility of the curves when the calibrations were repeated, especially when using the larger loads. When we examined the calibration results, we found that the first voltage reading was always higher than the subsequent readings taken for any particular load placed on the fabric strip. We then realised that the staple which held the bridge-clip in the fabric was slipping slightly out of the clamp with each loading of the fabric, causing the angle Θ to vary (Figure 1). Therefore, for the final calibration, the staple was replaced in the bridge-clip after each measurement. In order to have the calibration curve extend over the range of forces measured in the actual clothing, it was necessary to use strips 2 cm wide as well as the strips of 4 cm width. Lines of best fit were calculated for the calibrations for the two fabrics using the values obtained for both the 2 and 4 cm wide strips. The curves and equations are given in Figure 5.

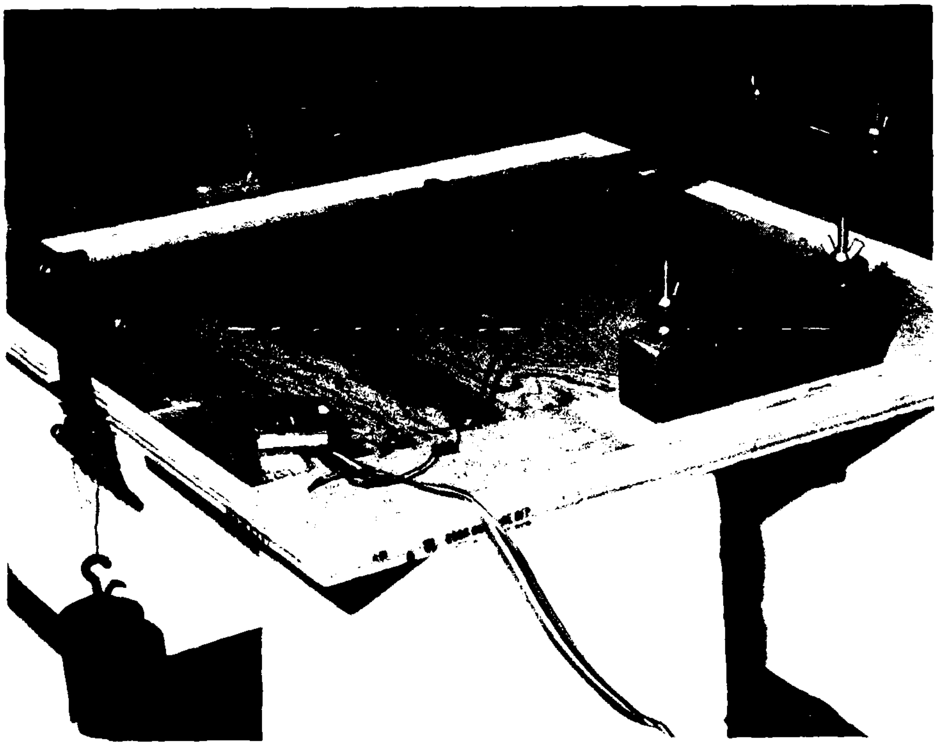


Figure 4: The Calibration Rig for the Strain Gauge on Bridge-Clip.

TABLE 1

PERTINENT FABRIC PROPERTIES

	FABRIC	
	LIGHTWEIGHT COMBAT	COVERALL TWILL
MASS (g/m^2)	154	220
FIBRE CONTENT	NYLON/COTTON	NYLON
WEAVE	PLAIN	2/1 TWILL
COUNT (yarns/cm)		
WARP	24	46
WEFT	20	25

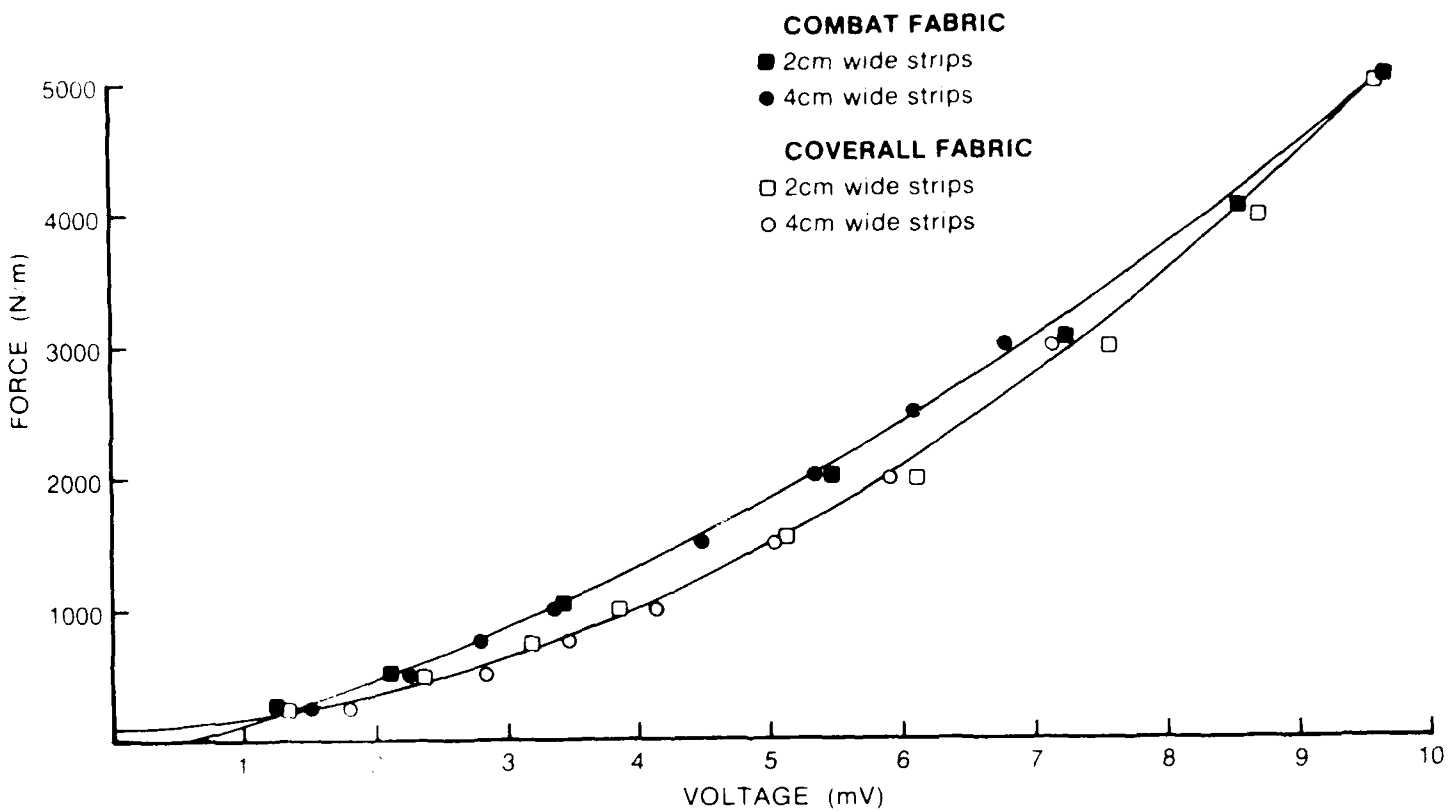


Figure 5: Lines of Best Fit through Experimental Results. For the Combat Fabric $y = 29.7x^2 + 237.8x - 145.9$. For the Coverall Fabric, $y = 49.7x^2 + 27.8x + 87$.

THE MEASUREMENT OF MAXIMUM STRESS IN CLOTHING

Five male subjects, who are members of the Canadian Forces, participated in the measurements of stress in clothing. Their physical characteristics are given in Table 2. They all donned: a combat shirt (formally called a coat), Size 2, short medium, to fit those with a height of 160 to 170 cm and a chest of 95 to 105 cm; combat trousers, Size 4, Regular Small to fit those with a height of 170 to 190 cm and a waist of 70 to 80 cm; CF flying coveralls, Size 7037 to fit those of a height of 178 cm and a chest of 94 cm. The clothing was selected to be somewhat on the small side for the majority of the subjects so that maximum stress readings could be obtained for the upper limits of the CF population.

The area of each garment where maximum stress occurred and the movements which caused maximum stress had been identified earlier (Crow and Dewar, 1984, 1985) and are shown in Figures 6 and 7. In order to determine a more precise position and orientation of the brige-clip on the clothing, a series of measurements was made with the bridge-clip variously positioned and orientated in these predetermined areas until a maximum stress reading was obtained. This was done with one subject and then the location and the orientation of the bridge-clip was kept constant for the other subjects. There was one exception to this, the wearing-the-shirt measurement for Subject B. Although he appeared to be the second largest subject, the measurement recorded for him seemed abnormally low. Therefore, the bridge-clip was moved up 5 cm from the "constant" position to see if higher stress readings could be obtained. The locations of the bridge-clip on the shirt, trousers and coverall top are shown in Figure 8. It was found that when the bridge-clip was positioned on the armhole seam, it fell over or twisted out of alignment when the subject moved his arms from the side to the front of the body. For this reason, the bridge-clip was positioned in the centre back of the shirt and the coverall top for the measurements.

For the wearing tests with the shirt and the coverall top, the subject, with a quick, vigorous movement, crossed his arms in front of himself to the fullest extent possible, simultaneously bending his elbows. For the wearing tests with the trousers and coverall trousers, the subject quickly dropped to a squatting position with the knees fully bent and the legs apart. For the donning tests with the shirt and coveralls, the subject was asked to put as much stress as possible on the back as he was donning the clothing. The tests were repeated several times, with the staple of the bridge-clip being repositioned in the clamp before each measurement. The maximum stress for each subject and action was the one recorded. Subjects who were of smaller stature and/or did not exert as much stress on the clothing as the others were not included in some of the measurements. The results of the stress measurements are given in Table 3.

TABLE 2

PHYSICAL CHARACTERISTICS OF SUBJECTS

SUBJECT	HEIGHT (cm)	WEIGHT (kg)	CHEST (cm)	WAIST (cm)	HIP (cm)
A	178	81.5	101	84	98
B	179	80.3	95	87	100
C	169	59.2	89	78	94
D	175	64.0	94	81	92
E	175	76.2	105	87	100

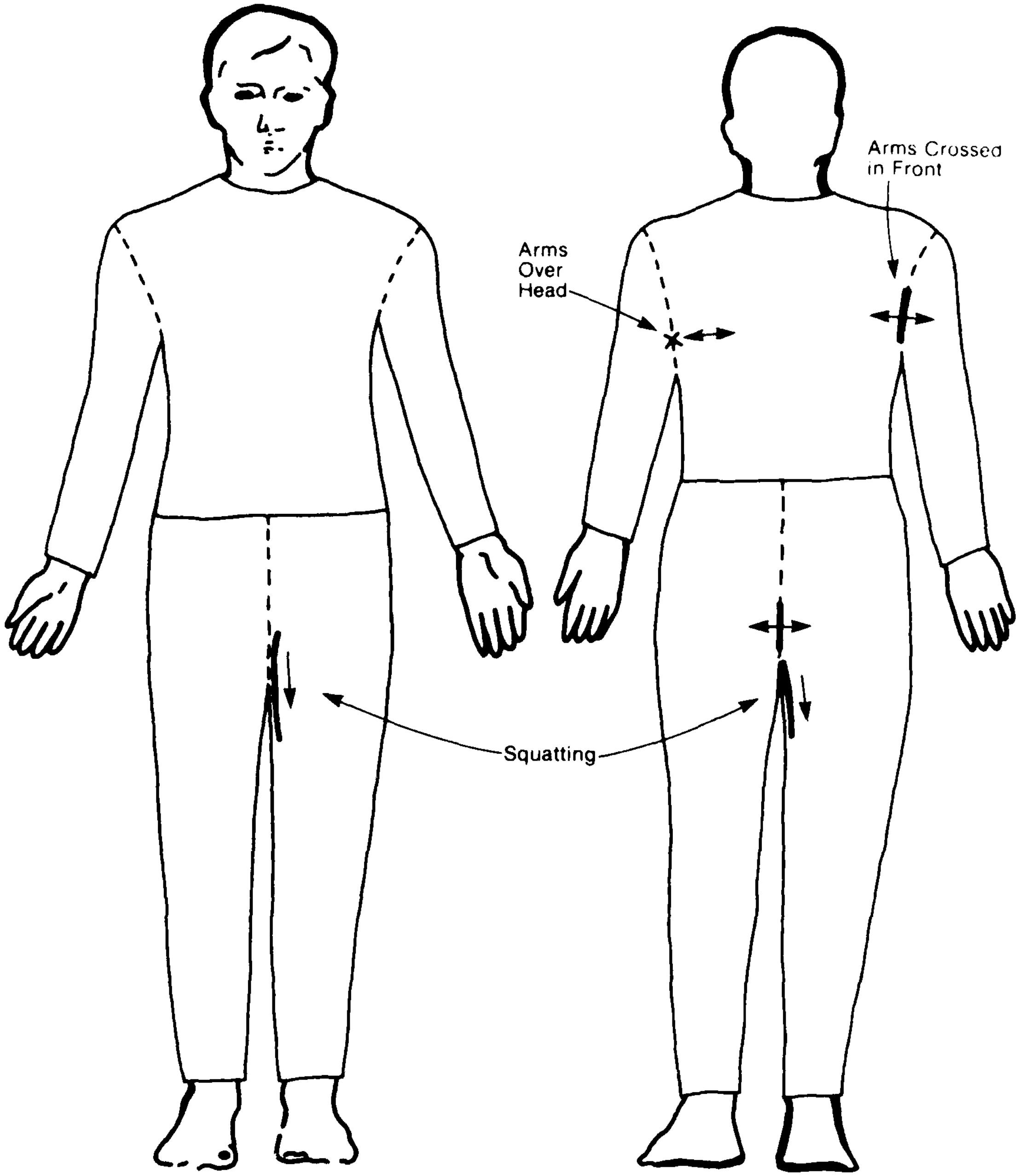


Figure 6: Location and Direction of the Maximum Stress Regions in Seams of Typical CF Clothing.

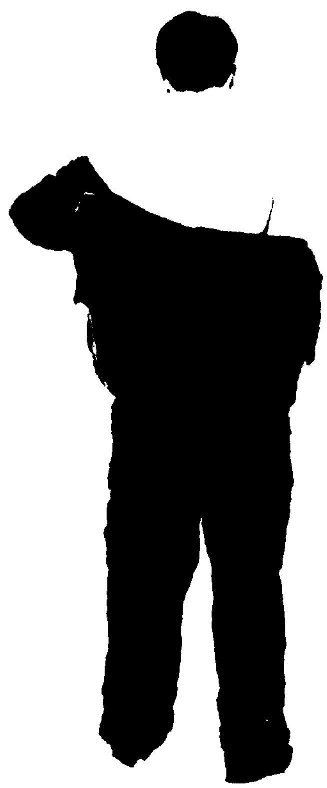
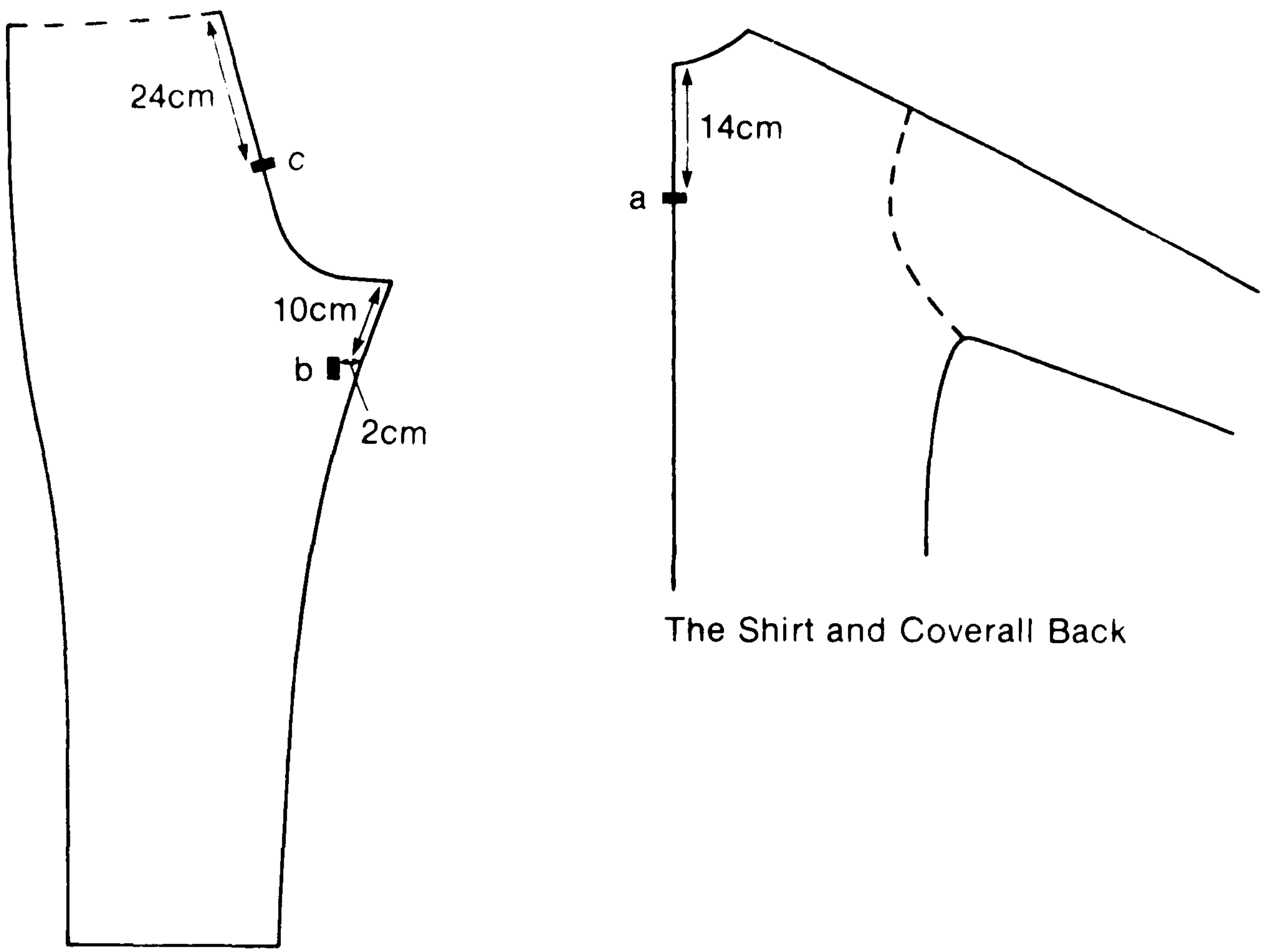


Figure 7: Maximum Stress in Donning Garments.



Back of the Trouser and Coverall Bottom

The Shirt and Coverall Back

Figure 8: Various Locations of the Bridge-Clips on the Clothing.

TABLE 3

STRESSES RECORDED IN CF CLOTHING

ACTION	SUBJECT	POSITION OF BRIDGE-CLIP	MAXIMUM STRESS RECORDED (FORCE PER UNIT WIDTH) (N/m)
IN WEAR			
i) Across Shirt Back	A	a	1680
	B	a	80
	B	a + 5 cm	90
	C	a	350
	D	a	10
	E	a	1650
ii) Across Coverall Top Back	A	a	2080
	E	a	3430
iii) Trousers Inner Leg	A	b	1430
	B	b	1510
	C	b	430
	D	b	700
	E	b	860
iv) Across Trouser Back Seam	A	c	2410
	B	c	1980
	C	c	470
	D	c	1360
	E	c	2360
v) Across Trouser Back Seam of Coveralls	A	c	2900
	B	c	1200
	E	c	1230
IN DONNING			
vi) Across Shirt Back	A	a	990
	E	a	400
vii) Across Coverall Top Back	A	a	2040
	E	a	2170

DISCUSSION

The maximum stresses we measured are similar to those reported by Worthington and Nestler and Schlegel, being 3430 N/m across the coverall top back and 2900 N/m across the coverall trouser back seam. This is in good agreement, considering the different types of clothing used and in the case of Nestler and Schlegel, the different measuring device used.

We found, in general, the larger the subject (or the closer the fit of the clothing), the greater the stress on the clothing. However, the ranking of the body measurements did not necessarily coincide with the ranking of stress. The degree of stress a subject put on the clothing appeared to depend as well on his muscular development and on his aggressiveness in exerting stress on his clothing.

The subjects stressed the coveralls more than the shirt and trousers, the trousers or coverall back seam more than the inner leg and the shirt and coverall back more in wear than in donning. It would appear that when the fabric is stressed in more directions than that of the principle axis, the force components add up to give greater stress than when the force is predominantly in one direction. Although the coveralls had approximately the same dimensions as the shirt and were slightly larger than the trousers, they did not separate at the waist as the shirt and trousers did. Thus there was a vertical component down the length of the coverall back giving a greater measured stress in them. Similarly in the back trouser seam, there were multi-directional stresses, whereas in the inner leg area, the stress was unidirectional and parallel to the warp.

In donning, the back of the shirt is stressed, or stretched, between the elbows which act as tie points. In wear, the shirt back is stretched around the back, with the elbows actings as "levers" and so generating a higher stress across the back. The coveralls are more difficult to don than the shirt because the trouser portion restricts one's movements in donning the upper portion of it. This would give rise to the higher stress measurements with the coveralls, although the same donning method was used for the shirt as for the coverall top.

CONCLUSIONS

1. The maximum stress which occurs in clothing is of the order of 3,000 to 3,500 N/m. The stresses were found to be higher in the coveralls than in the shirt and trousers, and higher in wear than in donning the clothing.

ACKNOWLEDGEMENTS

We would like to thank the members of the CF DREO Test Team for their cheerful participation in this study.

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