TITLE

Effect of backpack shoulder strap lower attachment point on the load distribution to the torso

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EFFECT OF BACKPACK SHOULDER STRAP LOWER ATTACHMENT POINT ON THE LOAD DISTRIBUTION TO THE TORSO

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EFFECT OF BACKPACK SHOULDER STRAP LOWER ATTACHMENT POINT ON THE LOAD DISTRIBUTION TO THE TORSO

by

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Table of Contents

Figures

Tables

Abstract

The objective of this study was to conduct biomechanical testing of pack component options to determine the optimal location for the lower attachment of the shoulder strap for the CTS Integrated Patrol Pack and Rucksack.

A model of a 50 percentile male torso has been split transversely at T12/L1 and instrumented with two six degree of freedom load cells. One is located at T12/L1 and the second is positioned at the base Using the load cell results, the force distribution between the upper and lower parts of the body can be calculated. The shoulder area of the mannikin was instrumented with Fscan™ sensors to record the contact pressure distribution in the axilla (armpit) and anterior of the shoulder under the shoulder strap The effects of moving the attachment point vertically, parallel to the body axis, and horizontally towards the body midline were examined. A 25 kg fixed payload was used for all test configurations Waist belt, load lifter and shoulder strap tensions were constant during testing

Output variables were: reaction forces at T12/L1, (which reflect the magnitude of shear and compressive force on the spine), waist belt lifting force, average, and peak contact pressures about the shoulder. These were examined as a function of the attachment point location and as a function of the angle the shoulder strap made with respect to the body long axis

Attachment points above the iliac crest significantly increased skin contact pressures in the axilla. Strap angles above 30 degrees resulted in peak axilla contact pressures ranging from 35 to 64 kPa These values may result in unacceptable discomfort levels in users Lumbar shear was reduced as the strap angle decreased but this also increased anterior shoulder loading At strap angles less than 24 degrees, anterior shoulder peak pressures of >32 kPa were recorded. These two effects determined the upper and lower bounds of an optimal range of 24 to 30 degrees with respect to the vertical axis of the body Strap angles of 24-30 degrees were achieved in two configurations. with the attachment point at the lowest point on the pack, and when the attachment point was moved forward towards the body midline in the transverse plane

These results cannot be extrapolated to other attachment locations that were not tested and pertain only to the type of strap tested

1.0 Introduction

This work was undertaken in support of the major Crown Project 1.2646 "Clothe the Soldier" under which a number of improved personal clothing and equipment items are being acquired or developed in the near term for Canadian Forces soldiers. The objective of this study was to conduct objective biomechanical testing of a shoulder strap to determine the optimal location for the lower attachment point for the CTS Integrated Patrol Pack and Rucksack

2.0 Scope

This study was to determined the magnitude of the horizontal lumbar force (lumbar shear) and the load share borne by the shoulders and hips for a minimum of four vertical and three horizontal locations A total of six vertical and seven horizontal locations were tested and the results for all locations have been included in this report.

Outcome measures include: lumbar shear, and load distribution between the upper and lower torso, peak and average pressures experienced about the shoulder. These variables are plotted as a function of shoulder strap angle

Finally, a range of acceptable strap angles is recommended based on these results

3.0 Test Method - Load Distribution

3.1 Load Distribution Mannikin

A model of a 50th percentile male torso has been split transversely at T12/L1 and instrumented with a six degree of freedom load cell at this location. A second six degree of freedom load cell (force plate) below the hips permits calculation of the load sharing between the upper and lower parts of the body. Additionally, the shoulder area of the mannikin is covered with Bocklite™ and instrumented with Fscan™ sensors to record the contact pressure distribution in the axilla (armpit) and anterior of the shoulder The experimental setup is shown in Figures 3.1-1 and 3 1-2.

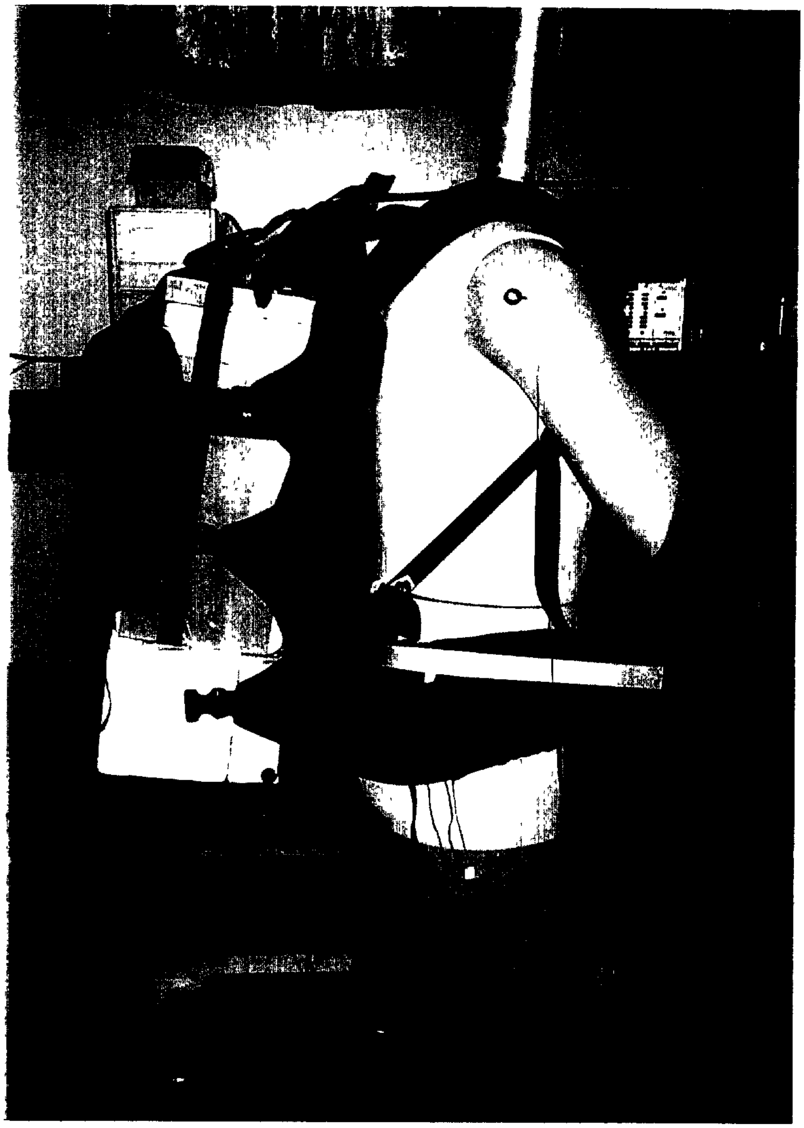


Figure 3 1-1   Experimental Setup - 41° Shoulder Strap Angle

Figure 3 1-2 Load Distribution Mannikin, Shoulder Detail with F-Scan™ pressure sensors

3.2 Test Protocol

Physical dimensions of the test apparatus and the identifiers for the attachment locations are shown in Figure 3.2-1 A test pack was provided by Ostrum Outdoors and was similar to the CTS Prototype rucksack M1. This rucksack was equiped with a series D-rings sewn along the vertical edge of the framesheet which allowed the shoulder strap to be moved through six vertical locations at approximately 5 cm intervals The lowest of these corresponded to the bottom corner of the frame sheet This resulted in a vertical range of approximately 25 cm. An aluminum bar (25 x 3 mm, T6062) was placed horizontally on the pack side of the frame sheet with its' lower edge aligned with the top of the waist belt. This bar was bolted directly to the two vertical aluminum stays The outer ends of the bar were brought forward to follow the curvature of the waist belt around the hips This bar projected straight forward horizontally, just above the height of the waist belt and corresponded to the third vertical position (V3) It was marked at 2.5 cm intervals and allowed a horizontal variation in the attachment point of approximately 18 cm Horizontal location was referenced to the framesheet such that H0 was at the frame sheet and H7 was at the approximate midline of the body

The position and mass of the payload (25 kg) was placed at the height of the shoulder blades, as close as possible to the body for all testing Strap tensions were set to 51 N (+/- 2) at the shoulders and 45 N (+/- 2) at the waist and recorded for all configurations.

An Optotrak 3-D motion tracking sytem, accuracy +/- 0.1mm, was used to measure torso lean, strap angle and pack angle To determine these variables, position markers were placed in the locations shown as ◇'s in Figure 3 2-1

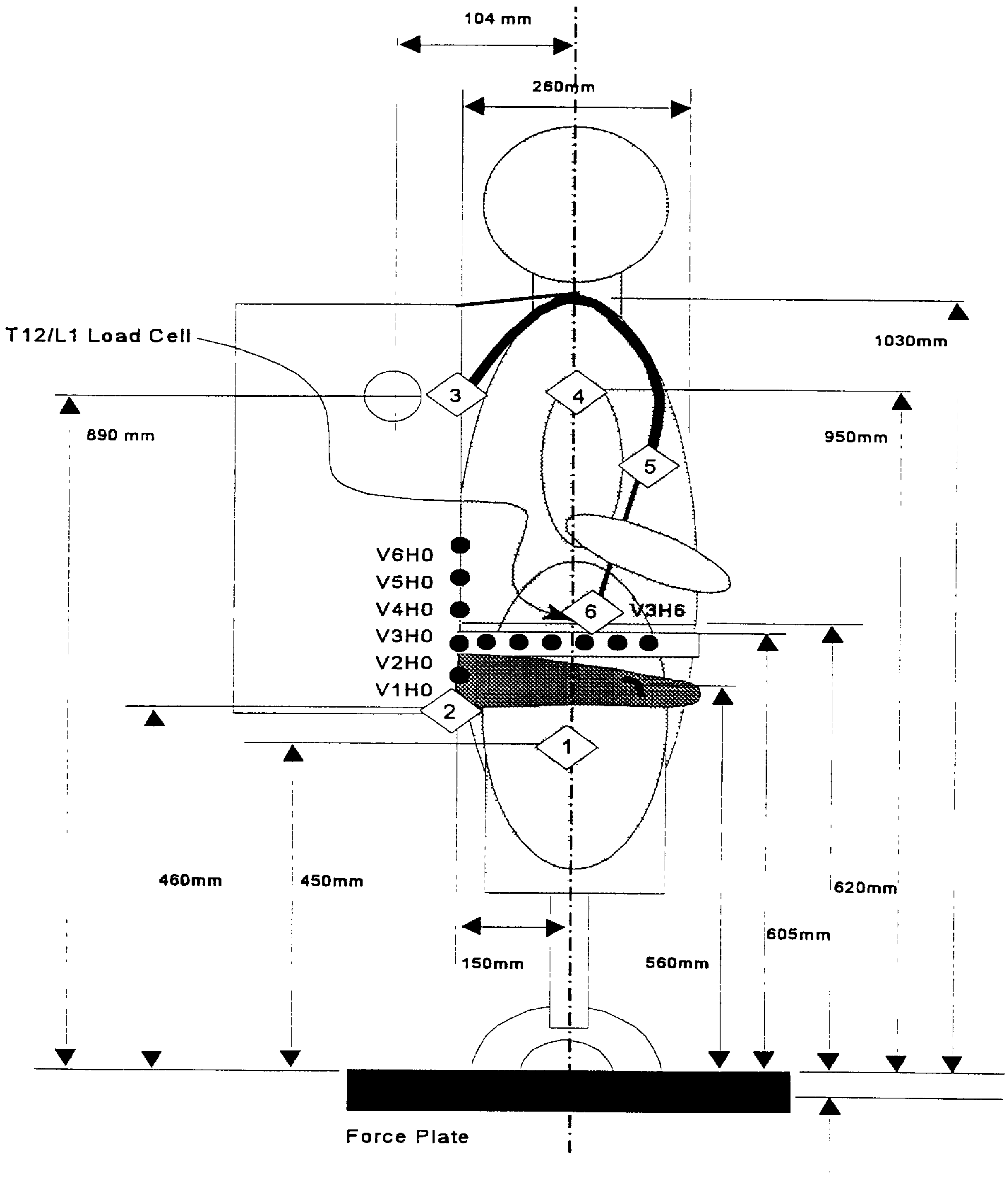


Figure 3 2-2 Load Distribution Test Apparatus - Optotrak position markers ◇

For each test configuration, data was recorded capturing Fx, Fy, Fz, Mx, My, Mz at both load cell locations, shoulder strap tension, waist belt tension and the X, Y, Z position of the 6 location markers.

With the pack in place, the load distribution (LD) mannikin was inclined forward using a rotational vice on the force plate until the moment about the medial/lateral axis was zero This was achieved at 4.6° forward lean Forward lean angle remained constant for all testing as the position of the payload remained fixed for all configurations Calibration of the load cells was done by capturing baseline data for the LD mannikin with no pack at this forward lean This baseline was then subtracted from all data Data from the force plate was transformed using the direction cosine of the forward lean angle to rotate the force plate data into alignment with the load cell at T12/L1 Forces and moments are then reported referenced to the axis of the human spine

The position of the centre of gravity of the pack and the mannikin was determined from the load cell data for the following conditions

Backpack	Lean Angle
on	0°
on	4.6° **
off	0°
off	4.6° **

**Lean angle required for 0 moment about the medial / lateral axis

4.0 Results

4.1 Overview and Summary Tables

Table A 1 (Appendix A), contains a summary of calculated lumbar shear and compression forces over all attachment locations It also shows the vertical lift contribution of the waistbelt. Strap angle refers to the angle between the vertical body axis and the lower portion of the shoulder strap The relationship between the strap angle and anatomical landmarks is shown in Figure 4 1-1

Table A.2 (Appendix A), contains calculated values of peak pressure, average pressure, and force experienced by the body for all the strap configurations tested

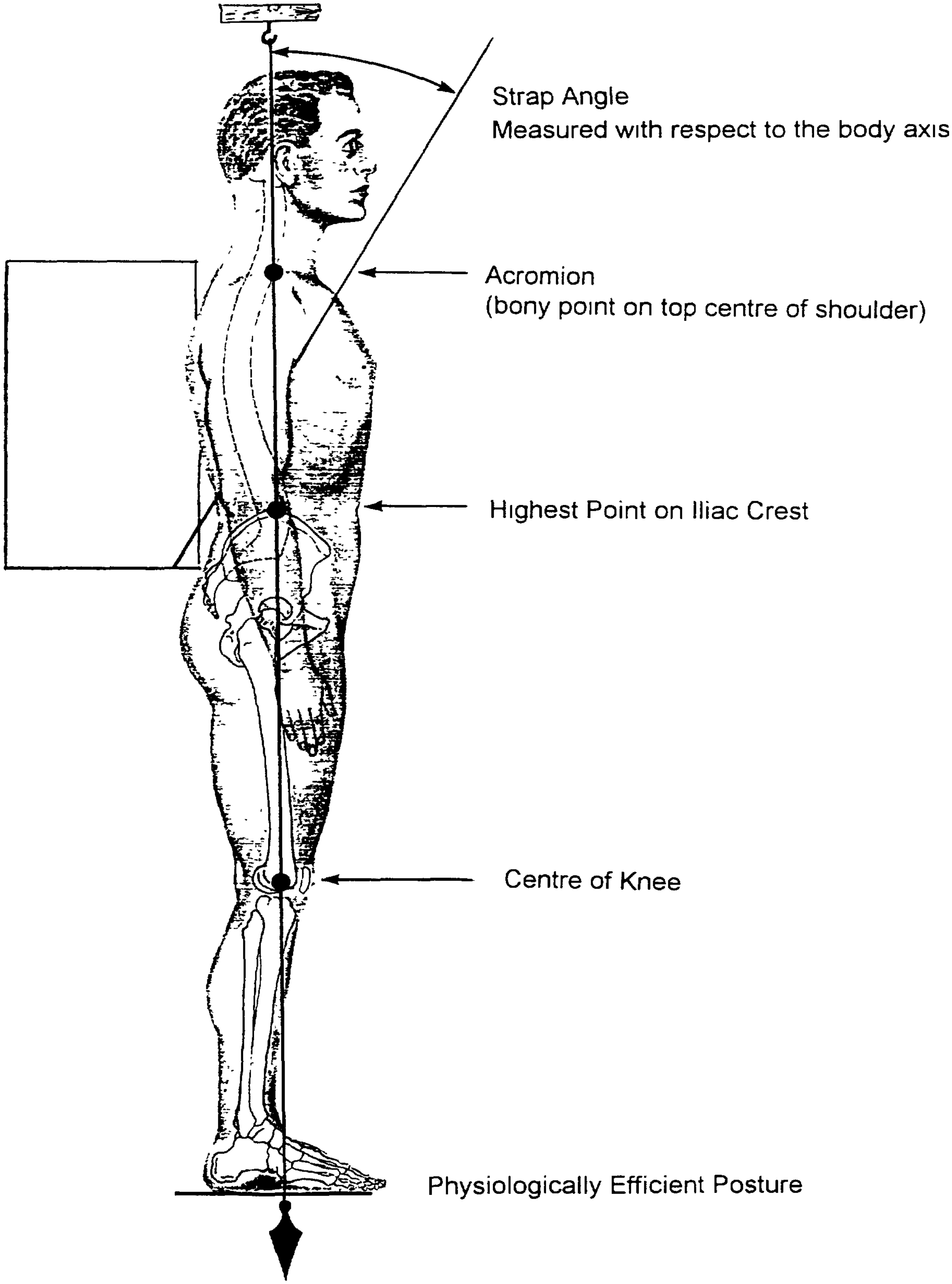
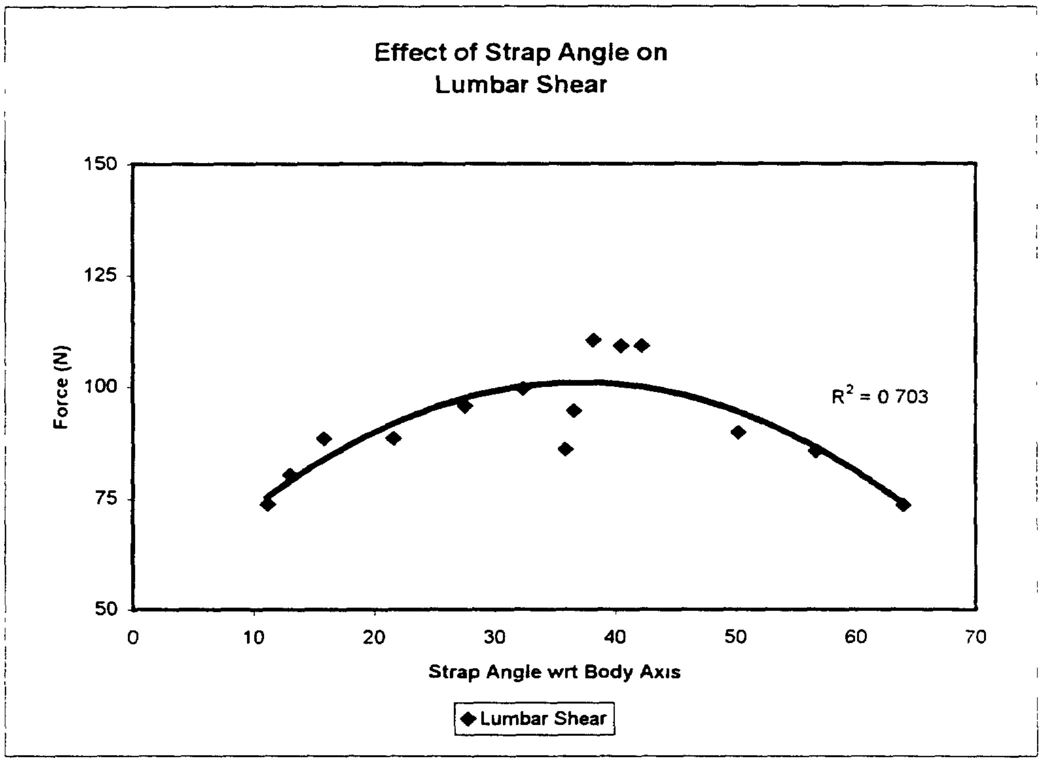


Figure 4.1-1 Relationship of Strap Angle to Anatomical Landmarks

a)



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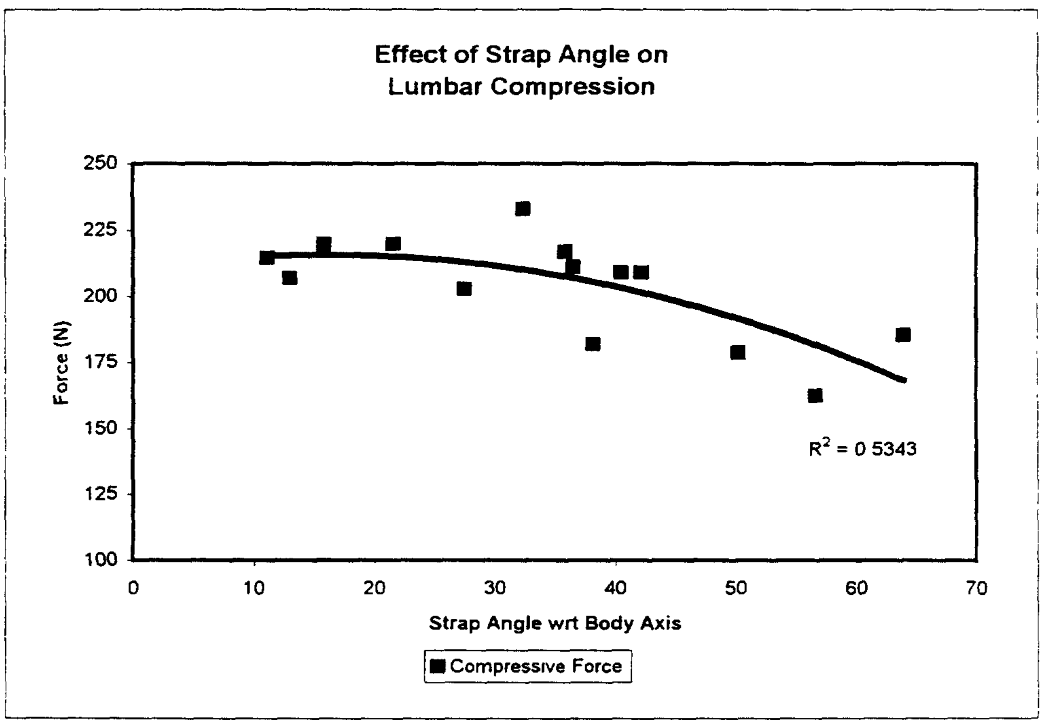

Figure 4 1-2 Effect of Shoulder Strap Angle on the (a) Shear and (b) Compressive Forces in the Lumbar Spine.

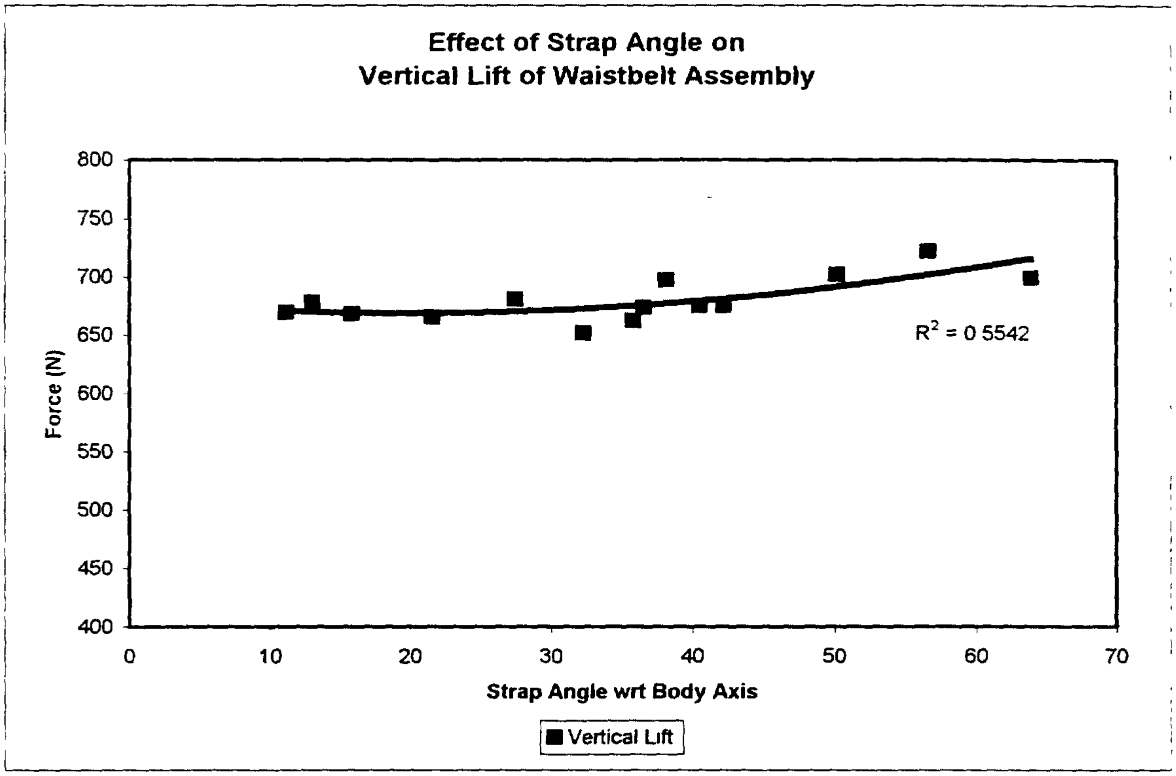

Figure 4.1-3 Effect of Shoulder Strap Angle on the Vertical Lift supplied by the Waistbelt/Lumbar Pad Assembly

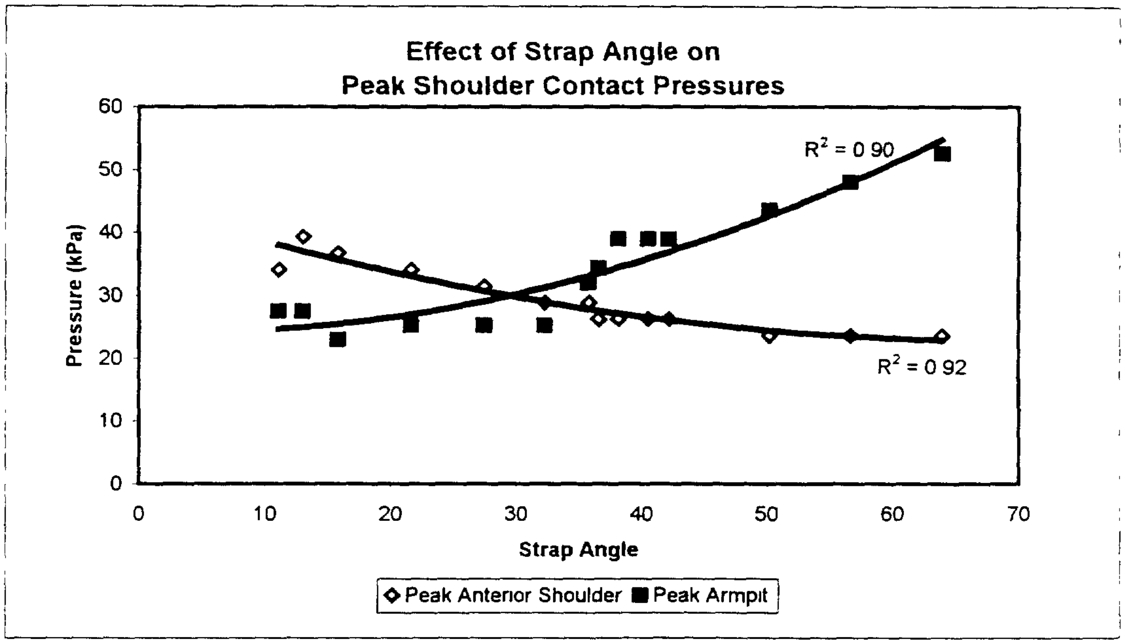

Figure 4.3.1 Peak Pressure about Shoulder vs Strap Angle
The effect of shoulder strap angle on peak contact pressures in the axilla and on the anterior shoulder

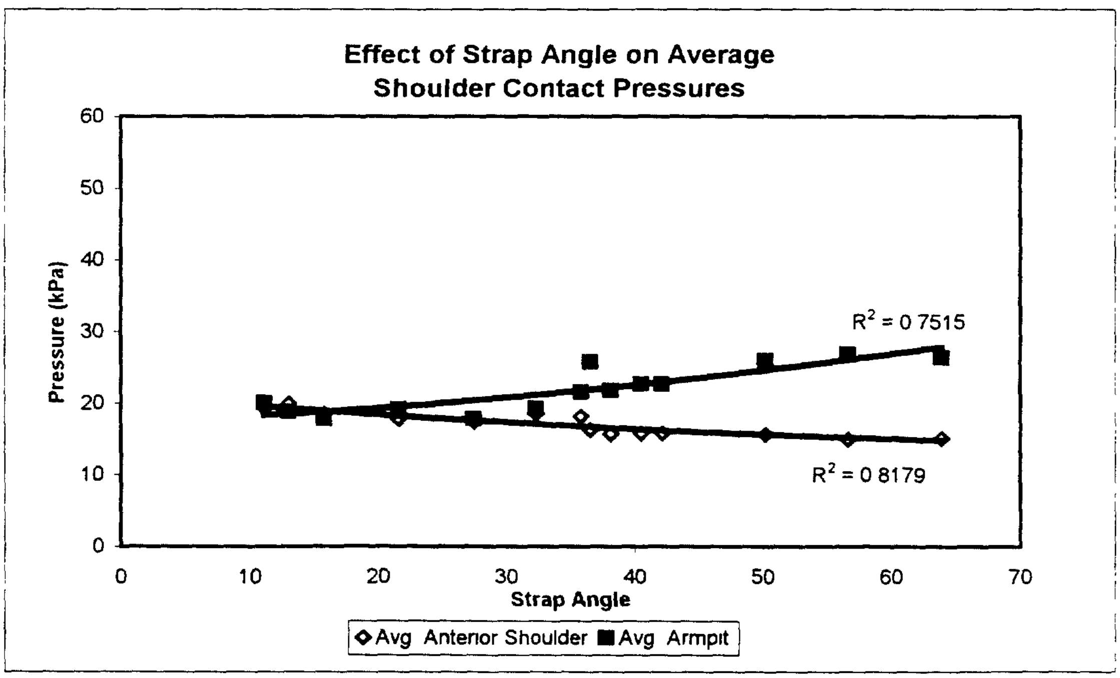

Figure 4 3-2 Effect of Shoulder Strap Angle on Average Contact Pressures in the Axilla and Anterior Shoulder Values greater than 20 kPa are correlated to long term user discomfort

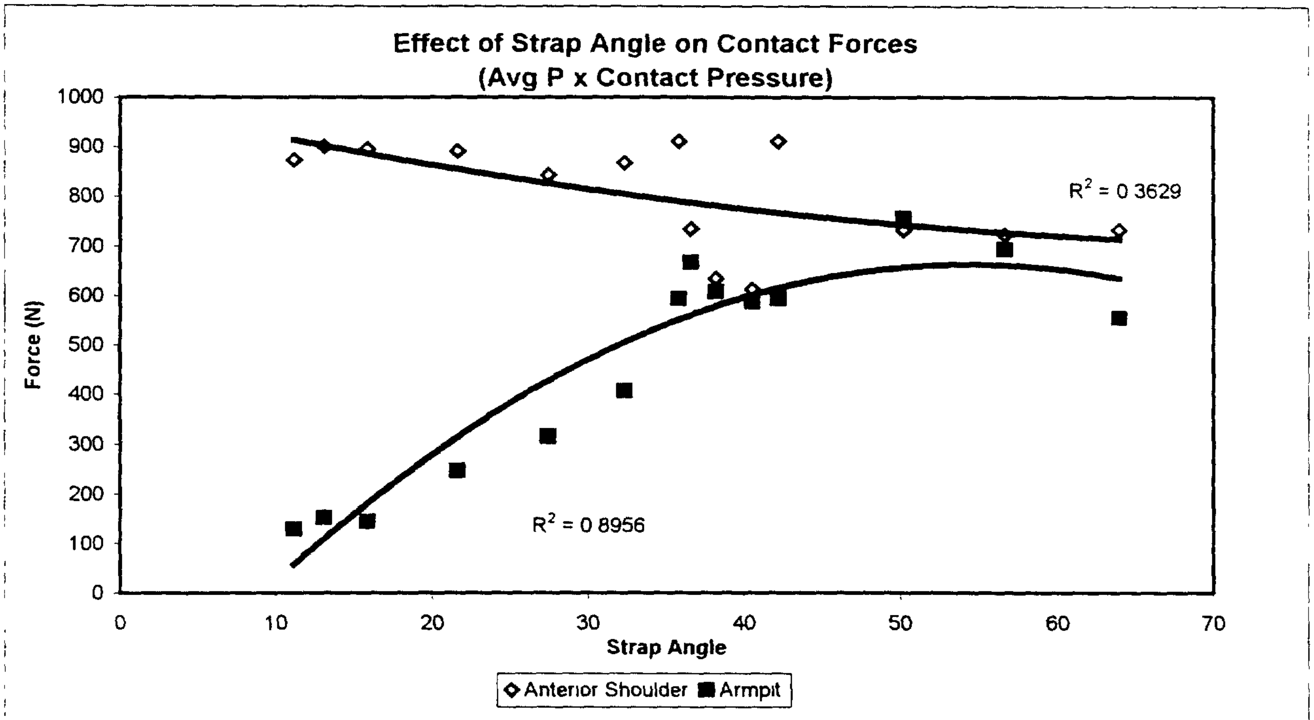

Figure 4.3-3 Effect of Shoulder Strap Angle on the force experienced by the body. These values are calculated by integrating the recorded pressure over the contact area.

5.0 Discussion

5.1 Comparison to Threshold Limit Values

As seen in Figure 4 1-1, higher attachment points for the shoulder strap, where the strap angle was ≥ 30 degrees, resulted in increased peak skin contact pressures in the axilla Anatomically, this cooresponds to having an attachment point above the height of the iliac crest This result is consistant with the direction and relative magnitude of the body's shoulder force predicted in the biomechanical model[1] Studies[2] indicate that a safe physiological contact pressure limit for continuous pressure over 8 hours is 14 kPa, while the average contact pressure threshold limit for the perception of pain is 20 kPa[3]. The peak contact pressures values measured in the axilla at strap angles greater than 30 degrees ranged from 35 to 64 kPa, see Figure 5.1-1 These values are expected to result in significant discomfort for users This was used to select an upper bound of 30 degrees to the recommended strap angle Figure 5 1-2 shows the reduction in the peak contact pressure in the axilla at a strap angle of 36 degrees, location V1H0

The magnitude of the lumbar shear force decreased as the strap angle decreased (i e the strap became more vertical) but this was tied to an increase in the load experienced by the anterior shoulder. At strap angles less than 24 degrees, the peak anterior shoulder pressures approached 32 kPa High peak pressures on the anterior shoulder at lower strap angles (<<20 degrees) are seen in Figure 5.1-3. Figure 5 1-4 shows the contact pressure distribution at a strap angle of 16 degrees typical within the recommended range of strap angle

A previous study[4] determined a maximum allowable value of 135 N for transverse loads on

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[1]Stevenson, JM , Bryant, JT , Reid, SA , Doan, JB , et al (1995) Research and Development of an Advanced Personal Load Carriage System, Phases I, DCIEM Contract # W7711-4-7225/01-XSE

[2]Stevenson, JM . Bryant, JT . Pelot, RP , Morin, EM , Deakin, JM., Reid, SA , Doan, JB , (1997) Research and Development of an Advanced Personal Load Carriage System, Phases II and III, DCIEM Contract # W7711-5-7273/001/TOS

[3]Holloway, JA . Daly, CH , Kennedy, D , and Chimoskey (1976) Effects of External Pressure Loading on Human Skin Blood Flow Journal of Applied Physiology **40** 596-600

[4]Stevenson, JM , Bryant, JT , Reid, SA . Doan, JB , et al (1995) Research and Development of an Advanced Personal Load Carriage System, Phases I, DCIEM Contract # W7711-4-7225/01-XSE

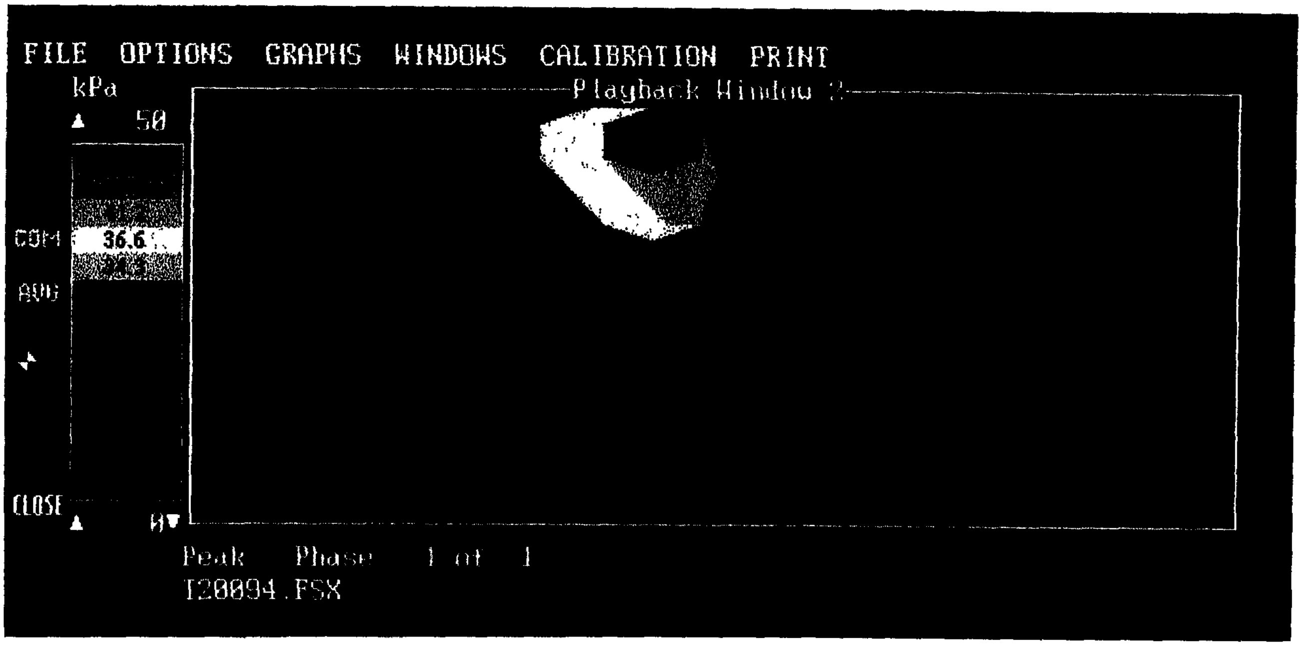

Figure 5.1-1 High peak contact pressure at axilla. Strap angle = 64°, (V6H0)
Peak Pressure is 52.6 kPa, average pressure is 26.4 kPa.

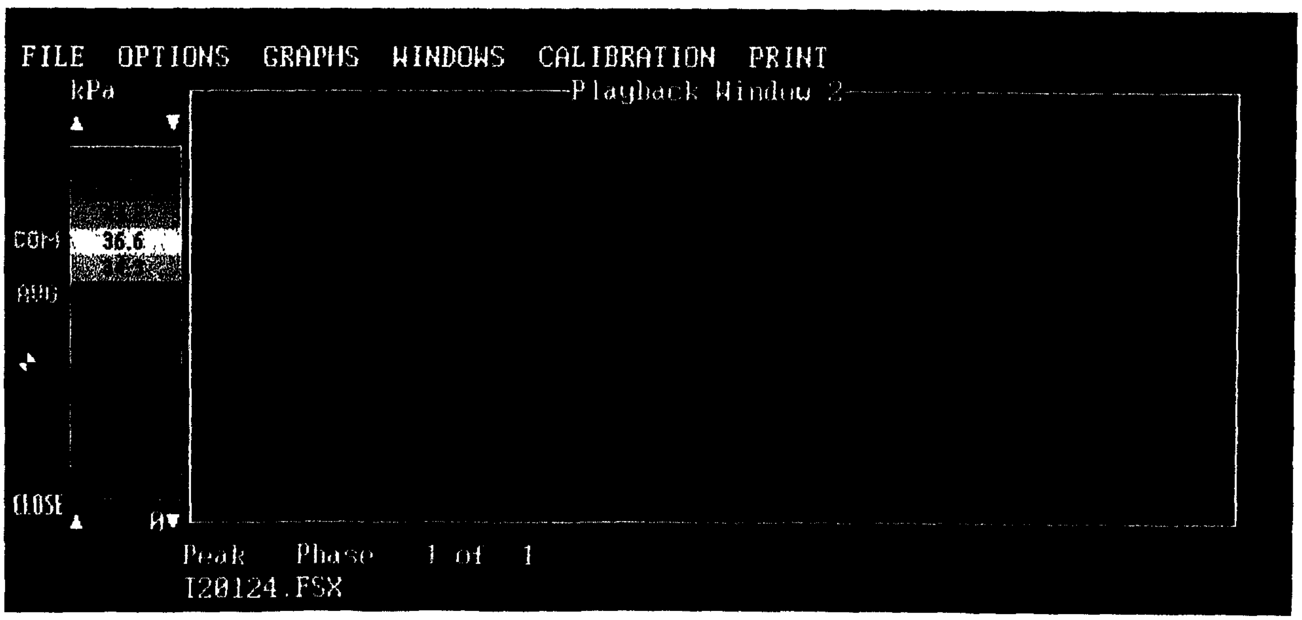

Figure 5 1-2 Contact pressures at axilla for recommended range of strap angle.
Strap angle = 27°, (V3H3)
Peak pressure is 25.2 kPa, average pressure is 17 8 kPa

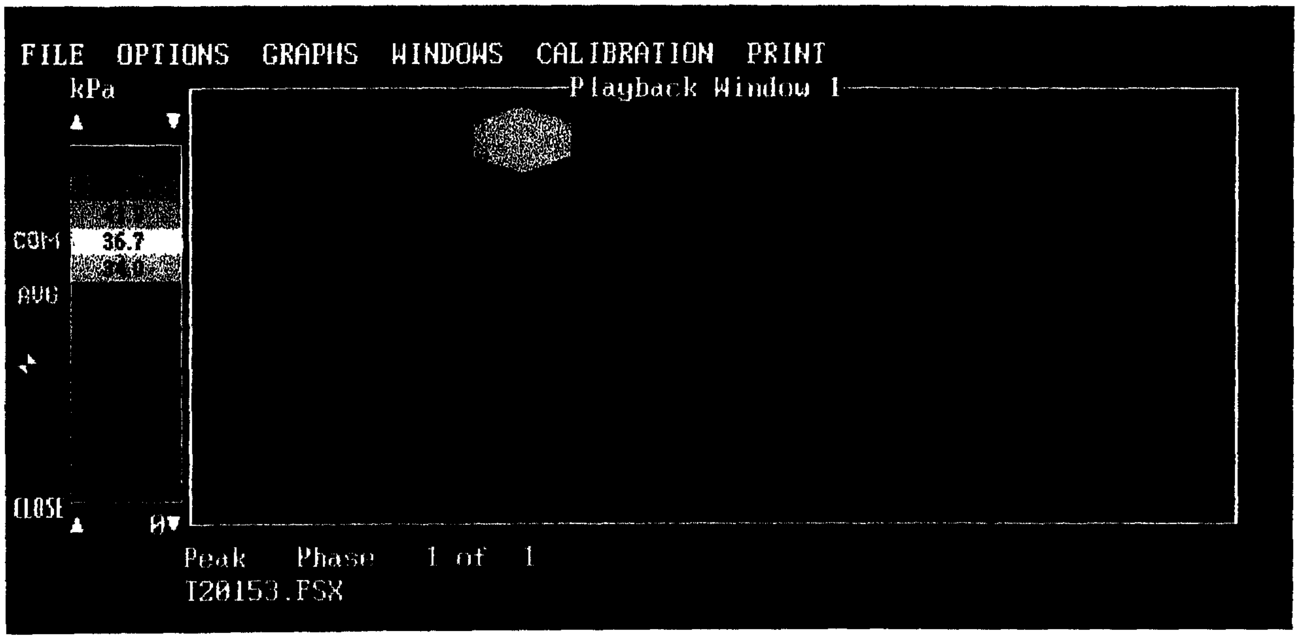

Figure 5.1-3 High peak contact pressure at anterior shoulder Strap angle = 13°, (V3H6)
Peak pressure is 39.3 kPa, average pressure is 19.9 kPa.

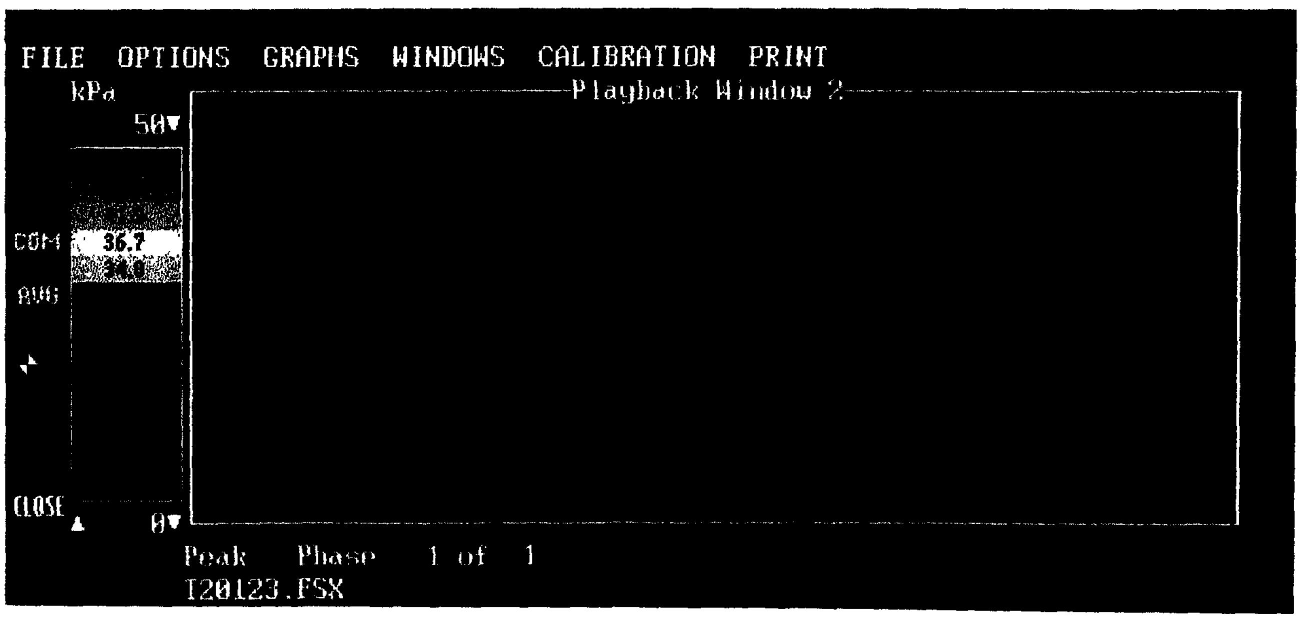

Figure 5 1-4 Contact pressures at anterior shoulder for recommended range of strap angle
Strap angle = 27°, (V3H3)
Peak pressure is 31.4 kPa, average pressure is 17 4 kPa

the spine based on achieving optimal human load carriage performance. Although no attachment location resulted in a lumbar shear force greater than 135 N, there was a twofold change in the magnitude of the lumbar shear over the range of strap angles tested

These factors were used to determine a recommended lower bound on the optimal strap angle range of 24 degrees. Strap angles of 24-30 degrees can be achieved in two configurations with the attachment point at the lowest point possible on the pack, and when the attachment point was moved forward towards the body midline In the test rucksack provided, the strap angle was 35 degrees at the lowest point possible on the pack and would have to move an additional 5 cm lower to reach the optimal range

6.0 Conclusions and Reservations

Note that only single measures were recorded at each configuration which limits the strength of conclusions based on these data. Additionaly, these results cannot be directly applied to other possible attachment locations that were not tested.

1 The optimal configurations for load distribution to the body resulted when the lower part of the shoulder strap achieved an angle of between 24-30 degrees with respect to the vertical axis of the body

2 Strap angles in this range can be achieved by locating the attachment point at locations V3H2 and V3H3, just posterior to the body midline at the height of the iliac crest A strap angle of 35 degrees was achieved at the lowest point on the pack frame sheet as tested If this location was an additional 5 cm lower, the resulting strap angle would be within the optimal range

Acknowledgements

This report is part of the deliverables for Public Works and Government Services of Canada contact W7711-7-7412/001/SRV and was undertaken in support of the Crown project "Clothe the Soldier" and in direct support of design work by Bill Ostrom of Ostrom Manufacturing and Designs Inc in Nolalu, Ontario First, I would like to acknowledge the vision of Bill Ostrom who came to listen and learn from speakers at the International Symposium on Military Load Carriage in October 1996 at Queen's University Since getting to know Bill, our Queen's load carriage team has learned just as much from him. We are kindred spirits in that we just want to design a better system for the soldiers Thanks Bill

In addition. I would like to acknowledge Major Linda Bossi from DCIEM who has kept us focused and provided much valuable support. We appreciate the support and cooperation of Clothe the Soldier Project staff at NDHQ, specifically, LCol Chris Davis and Major Nick Mattern It remains our belief that the current design-based approach used in this project, where designers are working with theevaluation teams, will lead to the level of understanding needed for an innovative breakthrough in design for future load carriage systems

I also wish to acknowledge the great work and positive atitudes of the members of the Ergonomics Research and Clinical Mechanics Groups of Queen's University Joan Stevenson, Tim Bryant and Evelyn Morin continue to add the useful ingredients of scientific understanding and new questions to the mix. My assistant Jon Doan, can be counted on to keep ten things on the go at any given moment and to always come through for the team Al Rigby has been a great addition to ERG, bringing strong analysis skills, a notable work ethic and fresh enthusism Finally, the core Clinical Mechanics Group people continue to contribute daily to the sucess of this program, thankyou Lee Watkins, Gerry Saunders and David Siu

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APLCS Project Manager, Ergonomics Research Group
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Appendix A

Test Results - Summary Tables

Table A 1	Force Results Summary Table
Table A.2	Pressure Results Summary

Table A.1 Force Results Summary Table

Purpose: Examine the effect of location of the lower attachment point of the shoulder strap on contact pressures and lumbar forces.

Location	Strap Angle Degrees	Lumbar Shear (N)	Compressive Force (N)	Waist Belt Lift (N)
H7V3	11.12	73.7	214.6	669.5
H6V3	13.03	80.3	206.8	677.9
H5V3	15.82	88.4	219.7	668.3
H4V3	21.59	88.4	219.7	665 4
H3V3	27.46	95.7	203.0	680.4
H2V3	32.31	99.5	232.8	651.4
H0V3	35.84	86 1	216.8	662.3
H1V3	36.59	94.7	211.1	673.5
H0V2	38.19	110.4	181.9	697.3
H0V3	40.53	109.2	209.0	675 5
H0V1	42.21	109.2	209.0	675.5
H0V4	50.22	89.8	178.6	702.3
H0V5	56.65	85.7	162.3	721.9
H0V6	63.93	73.5	185.1	699.5

Table A 2 Pressure Results Summary Table

Purpose

Examine the effect of location of the lower attachment point of the shoulder strap on contact pressures and lumbar shear
The bottom most D ring on the pack is V=1, the highest point V6 is at the 6th D ring
H=0 is at the framesheet, H=7 is approximately 7 inches in front of the frame sheet
V=3 cooresponds to the top edge of the waist belt
Locations are at 1 inch intervals

			Peak Pressure kPa		Average Pressure kPa		Average Body Force (N)		
Vertical Location	Horizontal Location	Strap Angle	Peak Anterior Shoulder	Peak Armpit	Avg Anterior Shoulder	Avg Armpit	Anterior Shoulder	Armpit	Total
1	0	35 84	28 8	32	18.2	21.6	910	591 8	1501 8
2	0	38 19	26 2	38 9	15 7	21 8	632 8	606	1238 8
3	0	40 53	26 2	38 9	15 8	22 7	611 5	585 7	1197 2
4	0	50 22	23 6	43 5	15 6	26	730 1	754	1484 1
5	0	56 65	23 6	48	14 9	26 8	721 2	691 4	1412 6
6	0	63 93	23 6	52 6	15 1	26 4	730 8	554 4	1285 2
3	0	42 21	26 2	38 9	15 8	22 7	910	591 8	1501 8
3	1	36 59	26 2	34 3	16 2	25 8	732 2	665 6	1397 8
3	2	32 31	28 8	25 2	18 5	19 3	865 8	405 3	1271 1
3	3	27 46	31 4	25 2	17 4	17 8	842 1	315.1	1157 2
3	4	21 59	34	25 2	17 8	19 2	890	247 7	1137 7
3	5	15 82	36 7	22 9	18 5	17 8	895 4	144 1	1039 5
3	6	13 03	39 3	27.4	19 9	18 8	899 5	152 3	1051 8
3	7	11 12	34	27 4	19.3	20	872.4	129	1001 4

Body Force is calculated from the Fscan data by integrating the pressure over the recorded contact area It reflects the total load felt by the body

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14. ABSTRACT

(U) The objective of this study was to conduct biomechanical testing of pack component options to determine the optimal location for the lower attachment of the shoulder strap for the CTS Integrated Patrol Pack and Rucksack.

A model of a 50 percentile male torso has been split transversely at T12/L1 and instrumented with two six degree of freedom load cells. One is located at T12/L1 and the second is positioned at the base. Using the load cell results, the force distribution between the upper and lower parts of the body can be calculated. The shoulder area of the manikin was instrumented with Fscan sensors to record the contact pressure distribution in the axilla (armpit) and anterior of the shoulder under the shoulder strap. The effects of moving the attachment point vertically, parallel to the body axis, and horizontally towards the body midline were examined. A 25 kg fixed payload was used for all test configurations. Waist belt, load lifter and shoulder strap tensions were constant during testing.

Output variables were: reaction forces at T12/L1, (which reflect the magnitude of shear and compressive force on the spine), waist belt lifting force, average, and peak contact pressures about the shoulder. These were examined as a function of the attachment point location and as a function of the angle the shoulder strap made with respect to the body long axis.

Attachment points above the iliac crest significantly increased skin contact pressures in the axilla. Strap angles above 30 degrees resulted in peak axilla contact pressures ranging from 35 to 64 kPa. These values may result in unacceptable discomfort levels in users. Lumbar shear was reduced as the strap angle decreased but this also increased anterior shoulder loading. At strap angles less than 24 degrees, anterior shoulder peak pressures of >32 kPa were recorded. These two effects determined the upper and lower bounds of an optimal range of 24 to 30 degrees with respect to the vertical axis of the body. Strap angles of 24-30 degrees were achieved in two configurations: with the attachment point at the lowest point on the pack, and when the attachment point was moved forward towards the body midline in the transverse plane.

These results cannot be extrapolated to other attachment locations that were not tested and pertain only to the type of strap tested.

15. KEYWORDS, DESCRIPTORS or IDENTIFIERS

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