

Development of a Dynamic Biomechanical Model
for Load Carriage: Phase I Part B:

Technical Manual with Update for Fastrak Analysis and Report
Program For LC Simulator

by
J.M. Stevenson, G.W. Pearce, J. A. Good, and
S. A. Reid

Ergonomics Research Group,
School of Physical and Health Education
Queen's University, Kingston, Ontario, K7L 3N6

Project Manager:
J.M. Stevenson, PhD.
(613) 533-6288

PWGSC Contract No. W7711-0-7632-01
on behalf of
DEPARTMENT OF NATIONAL DEFENCE

as represented by
Defence Research and Development Canada -Toronto
1133 Sheppard Avenue West
North York, Ontario, Canada
M3M 3B9

DRDC Scientific Authority:
Maj Linda Bossi
(416) 635-2197

August 2005

The scientific or technical validity of this Contract Report is entirely the responsibility of the contractor and the contents do not necessarily have the approval or endorsement of Defence R&D Canada

© Her Majesty the Queen as represented by the Minister of National Defence, 2005

© Sa Majesté la Reine, représentée par le ministre de la Défense nationale, 2005

Abstract

The objective of this report is to write a technical manual for the further development of the Fastrak™ software for the Load Carriage (LC) Simulator. The Fastrak™ system use has been extended to provide phase shift and amplitude information about the motion of the pack relative to the mannequin. A Fastrak™ purpose-built computer program called *APLCS* was designed to produce specified statistical and graphical reports from the data files. This is a new software analysis program and can be used for several purposes: a) it can examine the frequency content of the pack and person during standardized motions on the LC Simulator, b) it can be used to determine whether a suspension system can be designed to transfer mechanical energy within the gait cycle to assist the person in walking, and c) can be used to create a better dynamic biomechanical model (DBM) as it can help model the actions of the pack-person interface force requirements. The hardware adaptations for use with this software were reported in PWGSC# W7711-0-7632-01 Phase I. This report is designed to document the software program's functions and replace Section 8.5.3 from the report of PWGSC # W7711-7-7420 Section B of the User's Manual for the Load Carriage Simulator (V1.02). This report is divided into four sections that describe: data files and their loading, statistical computations, tabular reports and graphical reporting.

Résumé

Le présent rapport a pour objectif de rédiger un manuel technique pour le perfectionnement du logiciel Fastrak^{MC} du simulateur de transport de charge (LC). L'utilisation du système Fastrak^{MC} a été élargie de manière à fournir l'information sur le déphasage et l'amplitude du mouvement du sac à dos par rapport au mannequin. Un programme informatique appelé *APLCS* a été conçu exprès pour le logiciel Fastrak^{MC} afin de produire des rapports statistiques et graphiques précis à partir de fichiers de données. Il s'agit d'un nouveau logiciel d'analyse qui peut servir à différentes fins, soit a) examiner les fréquences produites par le sac et la personne durant des mouvements normalisés effectués avec le simulateur LC, b) déterminer si un système de suspension capable de transférer l'énergie mécanique au cycle de marche peut être conçu afin de faciliter les déplacements d'une personne et c) améliorer le modèle biomécanique dynamique (DBM) en modélisant les forces exercées au niveau de l'interface sac-personne. Le rapport TPSGC n° W7711-0-7632-01, phase I, énumère les adaptations qui ont été apportées au matériel pour son utilisation avec le logiciel. Le présent rapport vise à documenter les fonctions du programme et remplace la section 8.5.3. du rapport TPSGC n° W7711-7-7420, qui correspond à la section B du manuel de l'utilisateur du simulateur de transport de charge (User's Manual for the Load Carriage Simulator) (V1.02). Le rapport est divisé en quatre sections qui décrivent les fichiers de données et leur chargement, les calculs statistiques et les rapports en formats tabulaire et graphique.

Executive Summary

The Fastrak™ is a six-degree of freedom tracking instrument that uses electromagnetic fields to determine the position and orientation of a remote object. Our original set-up had the source mounted on the mannequin and either: 1) one sensor placed in the pack for pack-person motion or 2) four sensors placed in the soldier's kit for kit-person motion. This set-up provided 3D pack-person motion; however, it did not tell us whether the pack and kit were in-synch with the person. Hence it was necessary to revise it for the dynamic biomechanical model. The required set-up and software development was completed to add a second sensor as a ground reference point. This approach allows us to determine if the pack and person are in-phase or out-of-phase and the relative amplitudes of their motions.

The change in the hardware is very simple in that a sensor is now positioned on a post suspended from the ceiling near the LC Simulator. The relationship of the post to the sensor is not critical in that the software handles the location characteristics. The new software analysis program can be used for several purposes: a) it can examine the frequency content of the pack and person during standardized motions on the LC Simulator, b) it can be used to determine whether a suspension system can be designed to transfer mechanical energy within the gait cycle to assist the person in walking, and c) it can be used to create a better dynamic biomechanical model (DBM) as it can help model the actions of the pack-person interface force requirements.

The objective of this report is to write a technical manual for the further development of the Fastrak™ software for the Load Carriage (LC) Simulator. A Fastrak™ purpose-built computer program called *APLCS* was designed to produce specified statistical and graphical reports from the data files. The hardware adaptations for use with this software were reported in PWGSC# W7711-0-7632-01 Phase I. This report is designed to document the software program's functions and replace Section 8.5.3 from the report of PWGSC # W7711-7-7420 Section B of the User's Manual for the Load Carriage Simulator (V1.02). This report is divided into four sections that describe: data files and their loading, statistical computations, tabular reports and graphical reporting.

Sommaire

Le système Fastrak^{MC} est un instrument de localisation à six degrés de liberté qui utilise des champs électromagnétiques pour déterminer la position et l'orientation d'un objet éloigné. Dans la configuration originale, la source était installée sur le mannequin et 1) un capteur était placé dans le sac à dos pour détecter le mouvement sac/personne ou 2) quatre capteurs étaient placés dans le fourbi du soldat pour détecter le mouvement fourbi/personne. Cette configuration permettait de connaître seulement le mouvement sac à dos/personne en trois dimensions; toutefois, elle ne permettait pas de savoir si le mouvement du sac et du fourbi était synchronisé avec celui de la personne. Donc, il a fallu modifier le modèle biomécanique dynamique. La configuration et le logiciel ont été modifiés en tenant compte de l'ajout d'un deuxième capteur comme point de référence au sol. Cette méthode a permis de déterminer si les mouvements du sac et de la personne étaient en phase ou déphasés et de connaître l'amplitude relative de ces mouvements.

La modification apportée au matériel est très simple : un capteur a été positionné sur un poteau suspendu au plafond, près du simulateur LC. La position du capteur par rapport au poteau n'est pas un facteur critique, car le logiciel tient compte des caractéristiques de l'emplacement. Le nouveau logiciel d'analyse peut servir à différentes fins, soit a) examiner les fréquences produites par le sac et la personne durant des mouvements normalisés effectués avec le simulateur LC, b) déterminer si un système de suspension capable de transférer l'énergie mécanique au cycle de marche peut être conçu afin de faciliter les déplacements de la personne et c) améliorer le modèle biomécanique dynamique (DBM) en modélisant les forces exercées au niveau de l'interface sac-personne.

Le présent rapport a pour objectif de rédiger un manuel technique pour le perfectionnement du logiciel Fastrak^{MC} du simulateur de transport de charge (LC). Un programme informatique appelé *APLCS* a été conçu exprès pour le logiciel Fastrak^{MC} afin de produire des rapports statistiques et graphiques précis à partir de fichiers de données. Le rapport TPSGC n° W7711-0-7632-01, phase I, énumère les adaptations qui ont été apportées au matériel pour son utilisation avec le logiciel. Le présent rapport vise à documenter les fonctions du programme et remplace la section 8.5.3. du rapport TPSGC n° W7711-7-7420, qui correspond à la section B du manuel de l'utilisateur du simulateur de transport de charge (User's Manual for the Load Carriage Simulator) (V1.02). Le rapport est divisé en quatre sections qui décrivent les fichiers de données et leur chargement, les calculs statistiques et les rapports en formats tabulaire et graphique.

Table of Contents

Abstract	i
Résumé.....	ii
Executive Summary	iii
Sommaire	iv
Table of Contents.....	v
List of Figures	vi
1.0 Background.....	1
2.0 APLCS Analysis and Report Program.....	1
2.1 Data Files	1
2.2 Data Analysis	3
2.3 Tabular Reports.....	4
2.4 Graphical Reports	5
3.0 References.....	9

List of Figures

<i>Figure 1: APLCS Data Analysis Program User Interface</i>	<i>3</i>
<i>Figure 2: Tabular Summary Reports.....</i>	<i>5</i>
<i>Figure 3: Graphical Report, Analysis of X Displacement Data</i>	<i>7</i>
<i>Figure 4: Optional Editing of Graph Titles.....</i>	<i>8</i>

1.0 Background

The main use of the Fastrak™ has been to read the pack-person motion of a load carriage system. Earlier research has confirmed that pack-person motion is collated to soldiers' subjective responses to discomfort (Bryant et al., 1997). Martin et al. (1982) felt that if the load moved independent of the soldier during load carriage, more energy must be used to control the pack and greater fatigue would develop. Therefore, they hypothesized that control of the relative motion between pack and person was important so that load carriage system moved with, rather than oppose the wearer's normal gait pattern. More recently Kram (2001) hypothesized that there would be a natural frequency of vibration that would optimize energy transfer between the pack and the person. The concept of a compliant suspension system was part of the impetus to develop the lateral rods in the Cloth the Soldier (CTS) system where rods under tension could change the required extensor force by the erector spinae and shift some of the force requirements from the shoulders to the waist (Reid et al., 2001).

There are two previous reports that integrate with this equipment development report: 1) the User's Manual for the Load Carriage Simulator (part of PWGSC # W7711-7-7420 Section B by Stevenson et al., 1998) and 2) the upgrade in Fastrak™ positioning (part of PWGSC# W7711-0-7632 Phase I, Stevenson et al., 2001). For the most part, these other reports are excellent references for this report. This report provides sufficient detail to implement the Fastrak™ hardware and APLCS software into the LC Simulator's User's Manual.

2.0 APLCS Analysis and Report Program

APLCS is a purpose-built computer program designed to produce specified statistical and graphical reports from the data files produced by either of two measurement systems used in the simulation apparatus for the APLCS project. The following description of the program is divided into four sections: data files and their loading, statistical computations, tabular reports and graphical reporting.

2.1 Data Files

The data file from both systems are text files and thus readable by any text editor with sufficient capacity and also structured to be readable by spreadsheet programs. The APLCS program can identify the types of data files and can then load the files and translate them into the numerical arrays required for its subsequent work.

The first type of data is produced by a FASTRAK positional measurement system using 1 – 4 receiver sensors and one signal source. The data provided by the FASTRAK for each sensor consists of 6 parameters describing its position and orientation with respect to the source in a coordinate system determined by the source. The instrument cycles through the attached sensors at a repetition rate of about 110 Hz per sensor. The data files consist of 9 header lines of descriptive information followed by the data from 5 collection periods each lasting approximately 11 seconds. The data for each period begins with 1 line giving the time of the beginning of the collection. Following this line come a series of lines – each measurement cycle containing 7, 13, 19, or 25 numbers (the time of the start of the cycle followed by the data for one measurement – six coordinates - from each sensor). The first header line contains an identifier that allows the APLCS program to correctly identify file as being from the FASTRAK system and the second tells the number of active sensors.

The second type of data contains output of the VIEWDAC program that accesses a Keithley Metrabyte DAS1200 A to D card. The inputs to the A to D card are eight in number. There are 2 signals from force sensors measuring backpack strap tension at the shoulder and at the waist. There are 6 signals from a load cell measuring 3 reaction force components and 3 reaction moments caused by the moving simulation model. The measurements repeat at the same frequency as the FASTRAK data. The data files consist of 2 header lines followed by 5 collection period data sets structured similarly to that of the FASTRAK excepting that each measurement line consists of 9 numbers rather than 12. The 9 numbers are the time of measurement followed by the 8 signal values.

For the user of APLCS, loading a data file consists of selecting a filename from a directory contents listbox. The user chooses the appropriate directory and drive by means of listboxes provided for the purpose. These listboxes occupy the left side of the main program window. One initiates loading by either double-clicking the filename or dragging it to a panel at the top right of the window. As the loading and analysis of the data proceed, a message in this panel shows the progress. When analysis is complete, the preview window below shows some of the data to see if it is correct. If the user selects a file of a different type from the two supported types, the program indicates so in a messagebox and refuses to load it. Figure 1 shows the user interface with a relative displacement file “M12_41.dis” selected for analysis.

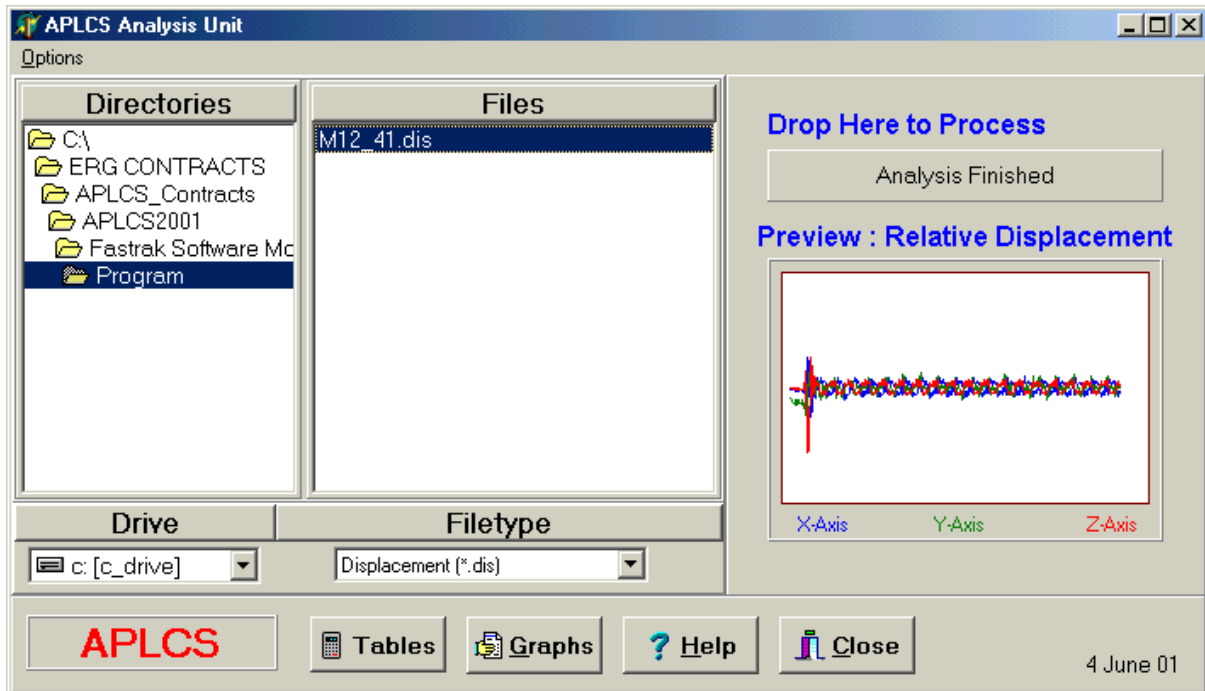


Figure 1: APLCS Data Analysis Program User Interface

2.2 Data Analysis

Analysis of the data differs between the two types, being more extensive for the FASTRAK displacement measurements. The serial communications port used to transfer the data to the computer occasionally loses or distorts the data for a sensor. The program can detect such 'dropouts' under many circumstances and will enter zeros in the data file to represent the lost data. APLCS provides a dropout filter to account for these events if they do not last for more than two successive measurements. When the program encounters such a dropout it substitutes a value that is an average of the points immediately before and after the dropout. After dropout filtering, the program computes the differences between values of the two sensors for each coordinate axis, at each time point. This computation provides the required measurements for this analysis: the relative movement of the two sensors. The sensor orientation data is not used in the current analysis. The program also produces a table of the summary statistics obtained for each collection period.

The statistical analyses for both data types begin with the computation of the average and standard deviation for each data variable for each of the 5 periods, using standard algorithms. As the data has a strong forced periodicity, the program estimates the range for each variable with average peak and trough values computed for each variable for each time period. The program also calculates a summary statistic for the FASTRAK

data, the magnitude of the relative displacement, obtained by subtracting the average trough value from the average peak value for each time period.

The analysis is performed immediately after the loading of the file and does not require any user action.

The analysis for FASTRAK files can be summarized as follows:

- Read in the data and assign it to data structures: linear arrays for each of 6 coordinates (X, Y, Z, azimuth, elevation, roll) for 1 to 4 sensors for each of up to 5 trials
- Fix bad data points: Present method which is the most reliable but not the most accurate is to scan the X, Y, Z arrays for exact 0 values and change these to the last good values for the array. Angular coordinate arrays have not been fixed.
- Statistical Calculations (for X, Y and Z only)
 - o Compute means and standard deviations for each coordinate array
 - o Compute average maximums and minimums for each array. The method consisted of splitting the arrays into 10 sequential sections, determining the maximums and minimums for each section and then computing the averages of the section maximums and minimums.
 - o Each array is converted to deviations from the mean by subtracting the mean from each array point. The statistics were similarly converted.
 - o For sensors 1 and 2 if both present:
 - FFT spectra were computed (algorithm modified from *Numerical Recipes*, Press et al, 1986) for each coordinate. The spectral values were obtained as sine and cosine values. These were converted to amplitude and phase values.
 - A cross-correlation was computed between sensors 2 (global reference) and 1 (pack motion) with lag values of 0 to 64 points (0 to ~1 sec offset) for each coordinate.

2.3 Tabular Reports

Pressing the button labeled Table at the bottom of the main program window will invoke a secondary window with a scrolling report window. The text in the window is a report of the statistical parameters described above in a prescribed tabular format. Each datafile type provides a different format. The report window provides a button that prints the report in a simple form to a printer and second button that copies the report to the clipboard in text form. The clipboard text may then be pasted into a document.

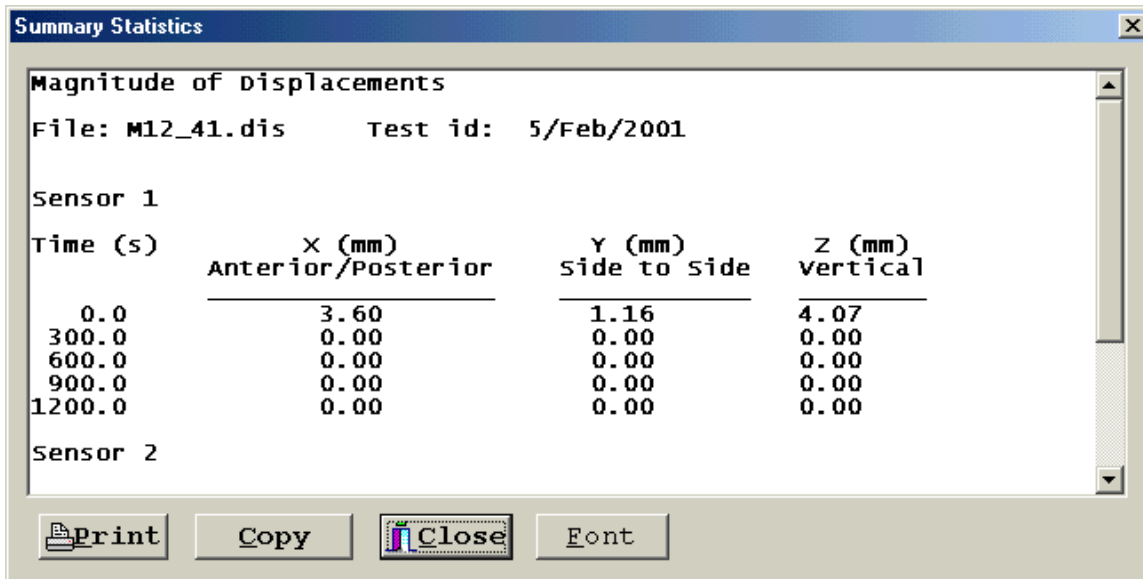


Figure 2: Tabular Summary Reports

2.4 Graphical Reports

Pressing the button labeled Graphs leads to a much more complex report window showing any one of 6 pages for FASTRAK data or of 18 pages for VIEWDAC Force data. Each page will show one or three graphs according to prescribed formats. The pages show the data for each of the 5 measurement periods as well as a summary page. Each period graph shows the first 10 seconds of data and will show 2 or 3 lines. The VIEWDAC data is for strap forces, and reaction forces and moments. At the top of the window is a menu of options available to the user. Figure 2 shows a typical graphical report. The graphical report options are described below.

The **Print** menu option shown in Figure 2, brings up a popup menu consisting of the main print command and a list of the possible pages. This list may include check marks on some pages indicating they have been selected for printing. Clicking on the entry for a page will toggle the selection. The print command at the top of the popup menu opens a print dialog box including the option to print all pages or only those selected. The pages are designed to look best if printed portrait mode on letter size paper.

The **Prev**, **Next** and **GoTo** menu options change the viewed page among the 6 or 18 possible. **Prev** moves to the previous page, **Next** moves to the next page and **GoTo** pops up a menu of possible pages; clicking on an entry displays that page.

The **Selected/Not Selected** menu option is a toggle providing the same function as that described above for the print option.

The **Copy Current** and **Save Current options** each lead to two similar commands.

- You can copy a graphic image of the currently displayed page (**Graphic Page**) in the form of a Windows Metafile to the clipboard (copy) or to a file (save). The clipboard copy can be inserted into a Word document, Excel spreadsheet or Powerpoint slide by the Edit/Paste command in either of these programs. Alternately the saved image file can be imported using the Insert/Image command.
- You can copy the FFT spectrum (**FFT spectrum table**) for the displayed coordinate either to the clipboard or to a file as a tab delimited text table. The clipboard can be pasted into MS Excel as a table or into MS Word or Powerpoint as text (some formatting may then be required for best presentation). The file version can also be loaded through the File/load into these or similar programs.

The **Exit** option closes the graph page window and returns to the main window.

The graph page itself provides two additional user options. There are three title lines at the top of the page. These lines are editable by the user - if he should click the main mouse button while the mouse is over the text, a dialog box appears to allow such editing. Clicking the mouse button over any graph opens a dialog box providing a means of changing both axes legends and ranges.

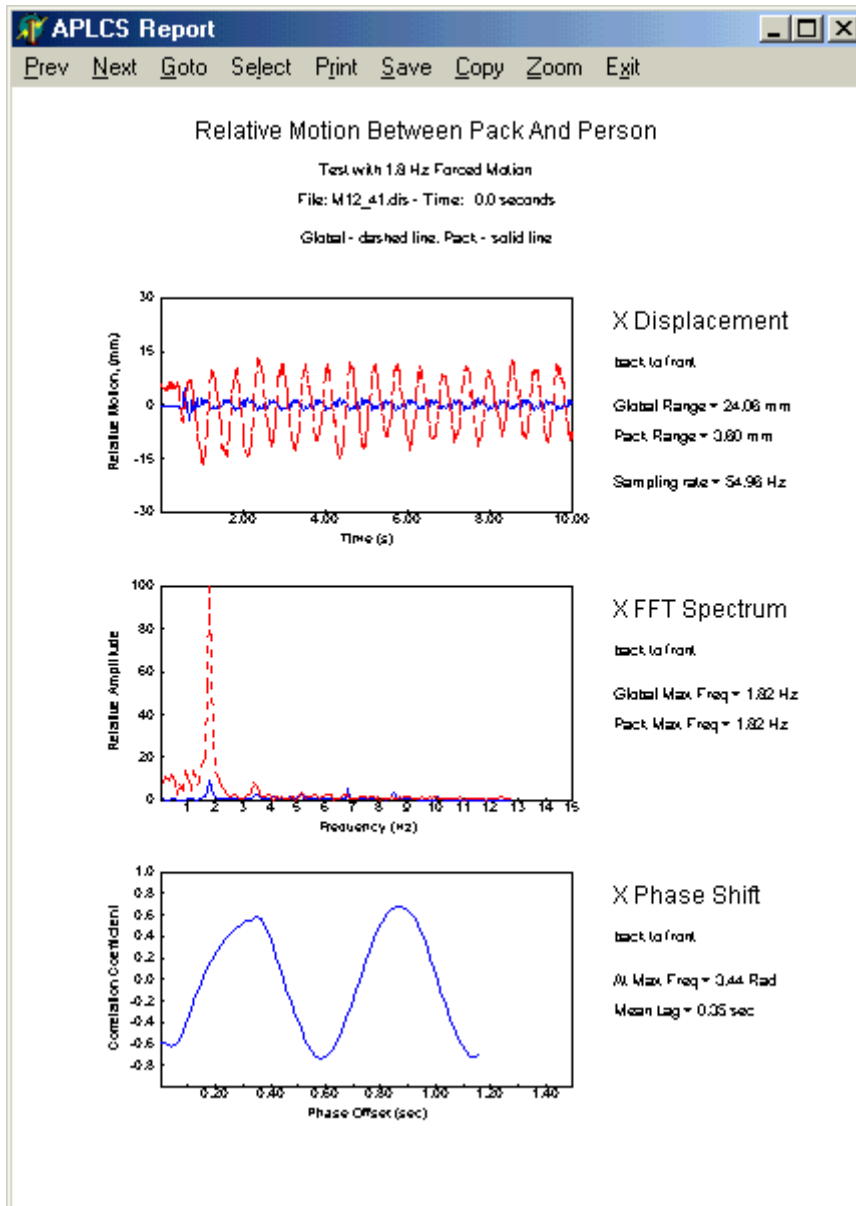


Figure 3: Graphical Report, Analysis of X Displacement Data

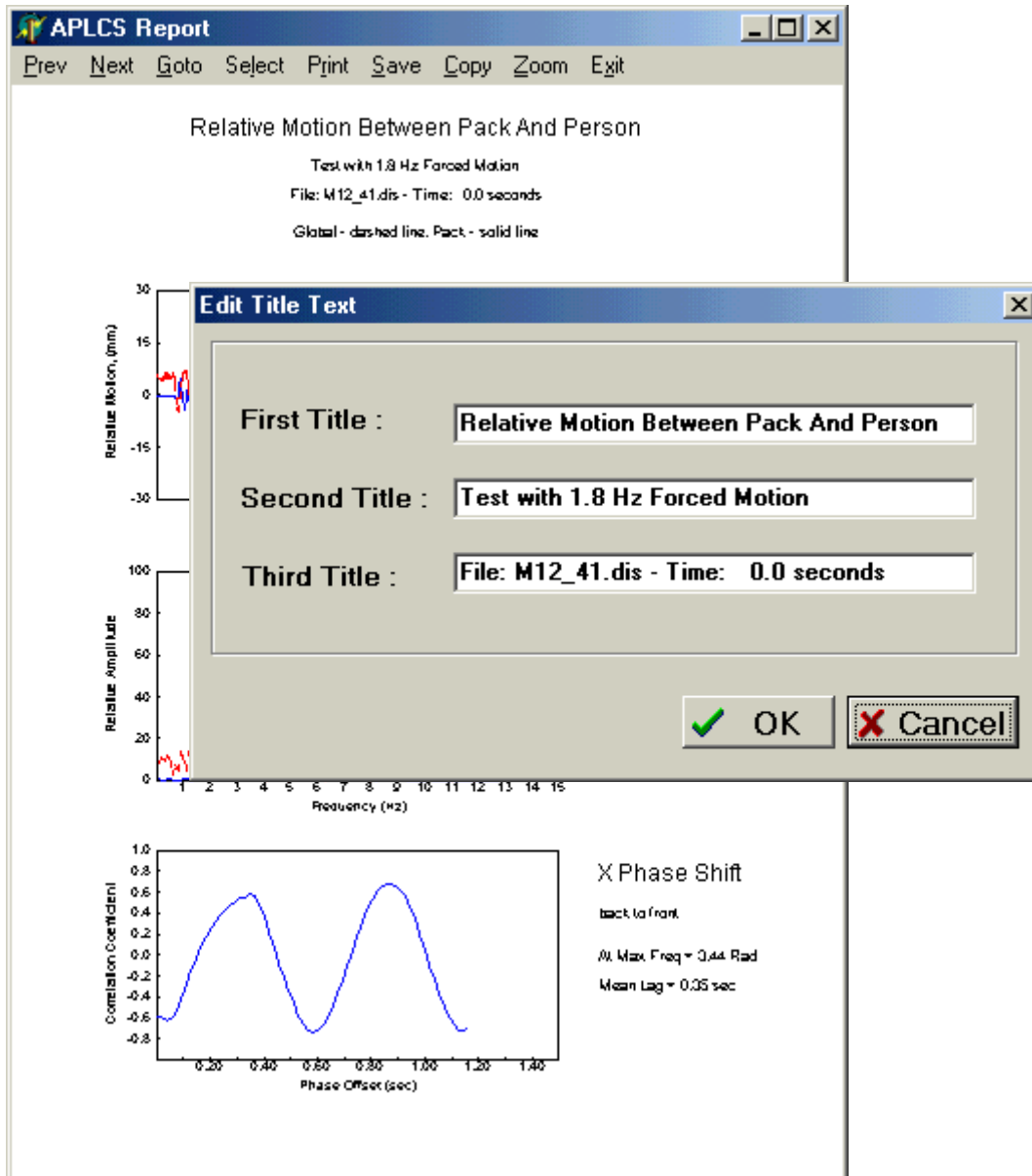


Figure 4: Optional Editing of Graph Titles

3.0 References

- Bryant, J.T. Stevenson, J.M., Pelot, R.P., Reid, S.A. and Doan, J.B. (1997) Research and Development of an Advanced Personal Load Carriage System (Phase II and III Section D. PWGSC Contract #W7711-5-7273/001-TOS (27 pages).
- Kram, R. Carrying loads with springy poles. *J. Appl. Physiol.* 72: 1119-1122, 1991.
- Kram, R. Load Lugging Locomotion: Lessons from Indigenous People, Rhino Beetles Wallabies. RTO Proceedings. RTO/NATO 2001, 7 pages.
- Martin, P.E. and Nelson, R.C. Effects of Gender, Load, and Backpack on the temporal and kinematic Characteristics of Walking Gait. Vol III Natick/TR-82/021, Technical Report, III, 1-78, 1982.
- Reid, S.M., Whiteside, R.A. Biomechanical Assessment of Lateral Stiffness Elements in the Suspension System of a Rucksack. RTO Proceedings. RTO/NATO 2001, 6 pages.
- Stevenson, J.M., Bryant, J.T., dePencier, R.D., Pelot, R.P., and Reid, J.G. (1995) Research and Development of an Advanced Personal Load Carriage System: Phase I. PWGSC Contract# W7711-4-7225/01-XSE. Report to DCIEM by Queen's University, 250 pages.
- Stevenson, J.M., Bryant, J.T., Morin, E.M., Pelot, R.P., Reid, S.A., Doan, J.E.B. (1998). Research and Development of an Advanced Personal Load Carriage System: Phase IV. Section B: User's Manual of the Load Carriage Simulator. PWGSC Contract# W7711-7-7420/A. Report to DCIEM by Queen's University, 30 pages.

UNCLASSIFIED

DOCUMENT CONTROL DATA (Security classification of the title, body of abstract and indexing annotation must be entered when the overall document is classified)		
1. ORIGINATOR (The name and address of the organization preparing the document, Organizations for whom the document was prepared, e.g. Centre sponsoring a contractor's document, or tasking agency, are entered in section 8.) Publishing: DRDC Toronto Performing: Ergonomics Research Group, School of Physical and Health Education, Queen's University, Kingston, Ontario K7L 3N6 Monitoring: Contracting: DRDC Toronto		2. SECURITY CLASSIFICATION (Overall security classification of the document including special warning terms if applicable.) UNCLASSIFIED
3. TITLE (The complete document title as indicated on the title page. Its classification is indicated by the appropriate abbreviation (S, C, R, or U) in parenthesis at the end of the title) Development of a Dynamic Biomechanical Model for Load Carriage: Phase I Part B: Technical Manual with Update for Fastrak Analysis and Report Program for LC Simulator (U)		
4. AUTHORS (First name, middle initial and last name. If military, show rank, e.g. Maj. John E. Doe.) J.M. Stevenson; G.W. Pearce; J.A. Good; S.A. Reid		
5. DATE OF PUBLICATION (Month and year of publication of document.) August 2005	6a NO. OF PAGES (Total containing information, including Annexes, Appendices, etc.) 19	6b. NO. OF REFS (Total cited in document.) 7
7. DESCRIPTIVE NOTES (The category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of document, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.) Contract Report		
8. SPONSORING ACTIVITY (The names of the department project office or laboratory sponsoring the research and development – include address.) Sponsoring: Tasking:		
9a. PROJECT OR GRANT NO. (If appropriate, the applicable research and development project or grant under which the document was written. Please specify whether project or grant.) 12CM03		9b. CONTRACT NO. (If appropriate, the applicable number under which the document was written.) W7711-0-7632-01
10a. ORIGINATOR'S DOCUMENT NUMBER (The official document number by which the document is identified by the originating activity. This number must be unique to this document) DRDC Toronto CR 2005-116		10b. OTHER DOCUMENT NO(S). (Any other numbers under which may be assigned this document either by the originator or by the sponsor.)
11. DOCUMENT AVAILABILITY (Any limitations on the dissemination of the document, other than those imposed by security classification.) Unlimited distribution		
12. DOCUMENT ANNOUNCEMENT (Any limitation to the bibliographic announcement of this document. This will normally correspond to the Document Availability (11). However, when further distribution (beyond the audience specified in (11) is possible, a wider announcement audience may be selected.)) Unlimited announcement		

UNCLASSIFIED

UNCLASSIFIED

DOCUMENT CONTROL DATA

(Security classification of the title, body of abstract and indexing annotation must be entered when the overall document is classified)

13. **ABSTRACT** (A brief and factual summary of the document. It may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C), (R), or (U). It is not necessary to include here abstracts in both official languages unless the text is bilingual.)

(U) The objective of this report is to write a technical manual for the further development of the Fastrak™ software for the Load Carriage (LC) Simulator. The Fastrak™ system use has been extended to provide phase shift and amplitude information about the motion of the pack relative to the mannequin. A Fastrak™ purpose-built computer program called APLCS was designed to produce specified statistical and graphical reports from the data files. This is a new software analysis program and can be used for several purposes: a) it can examine the frequency content of the pack and person during standardized motions on the LC Simulator, b) it can be used to determine whether a suspension system can be designed to transfer mechanical energy within the gait cycle to assist the person in walking, and c) can be used to create a better dynamic biomechanical model (DBM) as it can help model the actions of the pack-person interface force requirements. The hardware adaptations for use with this software were reported in PWGSC# W7711-0-7632-01 Phase I. This report is designed to document the software program's functions and replace Section 8.5.3 from the report of PWGSC # W7711-7-7420 Section B of the User's Manual for the Load Carriage Simulator (V1.02). This report is divided into four sections that describe: data files and their loading, statistical computations, tabular reports and graphical reporting.

14. **KEYWORDS, DESCRIPTORS or IDENTIFIERS** (Technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus, e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

(U) Load carriage; Dynamic Biomechanical Modeling; Compliance Tester; Pressure Measurement System; Fastrak™; LC Simulator; Pack-person motion; APLCS

UNCLASSIFIED