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Human Factors Engineering in the Development of a New Load Carriage System for the Canadian Forces

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Summary

Human Factors Engineering (HFE) is contributing significantly to Canadian soldier protective clothing and personal equipment development and acquisition. From the conduct of user surveys and studies of baseline system performance, through the execution of controlled trials with representative users in the laboratory or the field, HFE is now impacting on virtually every stage of the Canadian soldier system development and acquisition cycle. This is especially the case for the development and acquisition of a new load carriage system for the Canadian Forces, under the auspices of the 'Clothe the Soldier" project. The integrated design team, led by DCIEM, involved experts in HFE, biomechanics and load carriage system design from the Department of National Defence, academia and industry. The team followed a user-centered iterative design and evaluation process to rapidly develop an integrated load carriage system that will meet the range of needs of Canadian soldiers. The system includes a tactical vest, a large rucksack and small pack system, each with removable and interchangeable storage pouches making it adaptable or configurable according to mission, environment, and individual needs. The paper will present an overview of the Human Factors systems design approach used to identify and validate user requirements, and will highlight some of the many lab and field evaluations and analyses used to make design and procurement decisions.

Introduction

Human Factors Engineering (HFE) input throughout the military equipment development and acquisition process has been invaluable for the cost-effective procurement and integration of military systems that will enhance operator performance as well as operational capabilities. HFE applies knowledge of human capabilities, limitations and needs to the system design process and strives for systems that are easier to learn, use and maintain. HFE ensures that systems are compatible with the full range of users, their equipment and tasks, that foster wider user acceptance, and that improve operator and system safety, reliability and efficiency.

Human Factors specialists in Canada are providing scientific support throughout the development, acquisition and life cycle management process (as shown at Figure 1) for many items of soldier clothing and equipment. HFE support has helped to maintain a user-centered focus and has included the following activities:

- the conduct of surveys of user characteristics or user opinion and conduct of baseline system performance studies to help define and validate user requirements;
- the development and validation of performance-based specifications for the acquisition of commercially-available products or new products that can be developed for the military by industry;

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- participation as members of integrated development teams to provide design input based on user needs and knowledge of human capabilities and limitations, and to test product iterations with users in the laboratory and field environments in order to validate that user requirements are being met and that soldier safety, performance and satisfaction are being improved with each design iteration;
- the conduct of highly controlled human-centered bid evaluation trials to ensure compliance with human-based performance specifications and user requirements and to ensure that there is empirical evidence of compliance or non-compliance with performance-based specifications;
- conduct of anthropometric surveys to characterize the user population, and product fitting trials to determine item sizing (who fits which size) and size tarriffing (how many of each size should be procured);
- development of user training materials to assist with effective system implementation; and
- continuous monitoring of system performance and user satisfaction post-implementation (to ensure the success of training efforts, to monitor any changes in user requirements and to collect evidence of user requirements for future replacement items)

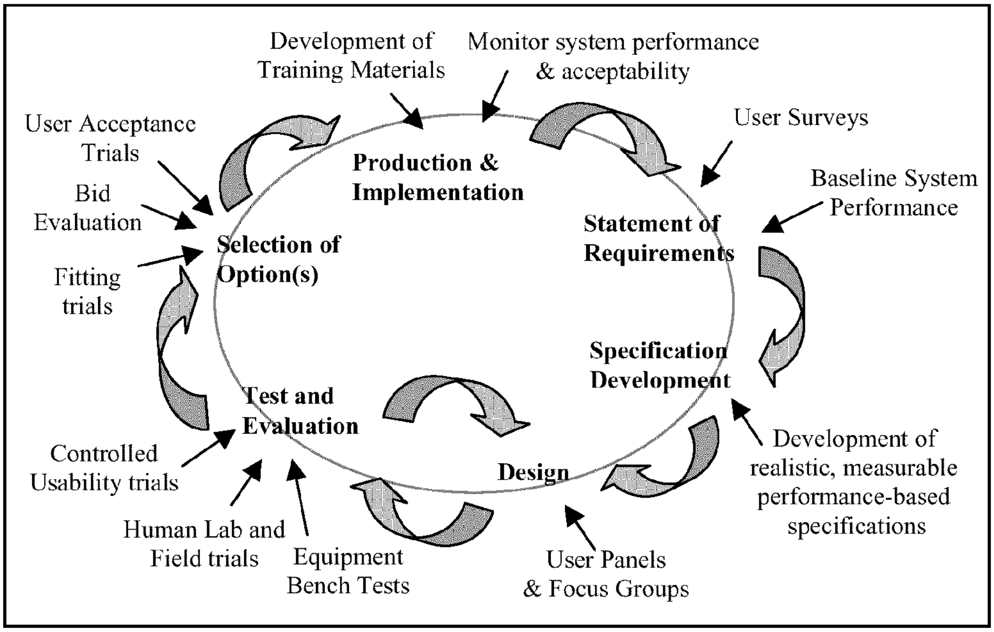

Figure 1. HFE Input throughout DND's materiel development and acquisition Cycle (actual process highly iterative)

A Human Factors systems approach may be characterized by the following:

- user-centered design philosophy
- multi-disciplinary team
- rapid prototyping
- iterative design and testing cycle

Soldier involvement throughout the iterative development and testing process is considered essential to achieve the following: identification of detailed deficiencies about the in-service product; determination of user and mission requirements for the new system; development of test and evaluation criteria and methods that will best assess system suitability in terms of user requirements; concept validation; identification of the positive and negative aspects of each concept or design iteration; solicitation of ideas for product improvement; validation that the product will support performance, comfort and mission effectiveness when users perform tasks under the range of operational conditions; and perhaps most importantly, user acceptance and buy-in.

Human Factors Engineering has made important contributions to the development of a new load carriage system for the Canadian Forces including many of the activities mentioned above. This report will present the rationale for a new load carriage system, the design philosophy and approach taken by the team responsible for the system's design, and will highlight the range of Human Factors activities undertaken throughout the development process. The new load carriage system (comprising a Tactical Vest [TV], rucksack and small pack system) will be described and recommendations for the successful fielding of the system will be given.

Load Carriage Design Team Approach

DCIEM was tasked by the Clothe the Soldier (CTS) project[1] to validate the user requirements and lead the development of a new load carriage system, due to prior successes with HFE intervention in other projects, and expertise gained through their load carriage biomechanics research and development programme (described in Bossi et al, 2000). An integrated multidisciplinary product development team was formed, combining expertise from the Department of National Defence (DND), industry and academia. The team comprised DCIEM, as overall design team leader, two experienced vest and pack design/manufacturing firms (Pacific Safety Products & Ostrom Outdoors), an HF consultancy with over a decade of experience in the soldier systems domain (HumanSystems Inc.), as well as a team of load carriage biomechanists (Ergonomics Research Group, Queen's University). DND participation on the design team also included staff from the Directorate of Land Requirements (DLR) and the Directorate of Soldier Systems Program Management (DSSPM).

Figure 2 depicts the multidisciplinary and user-centered iterative process used to develop the new load carriage system. The extent of user involvement is quite evident. Their participation ranged from participation in focus group assessments of allied and commercial load carriage systems and early prototypes through to intensive controlled user trials in the field.

It may also be seen from Figure 2 that lab-based biomechanical assessments also contributed throughout the design process. These assessments made use of a new suite of objective measurement tools that are described in several separate papers in these proceedings (Bossi et al, 2000; Reid et al, 2000a; Reid & Whiteside, 2000b; Stevenson et al, 2000). They permitted efficient and quantitative assessment of a range of vest and pack design iterations, both for feature as well as overall system performance. Specific design questions that were answered using these tools will be highlighted throughout the paper.

Sequence of Development Activities

The same sequence of development activities was followed for each component of the load carriage system. As shown in Figure 2, the first step involved a literature and state-of-the art review by the HF, biomechanics and designer members of the team to identify the issues and technologies relevant to the system. User requirements were drafted by the staff of the Directorate of Land Requirements and validated by the HF and design members of the team through surveys, interviews, focus groups and/or tests with representative users. The in-service systems plus a range of commercial and allied military load carriage systems and components were acquired and reviewed with users to identify deficiencies, user needs and preferences for features and functionality, and to determine methods and criteria that would adequately test functionality and performance requirements. The designers were then allowed to translate the findings into prototype designs. In every case, at least two opposing design alternatives were fabricated, to ensure that users would be exposed to the range of available options and to control for design team bias. The prototypes would then be tested in two ways: through user-based testing by the HF team members, and quantitative biomechanical testing by the Ergonomics Research Group at Queen's University.

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[1] The Clothe the Soldier (CTS) project is an omnibus capital project to acquire 24 items of improved and compatible clothing and equipment for Canadian soldiers, including a new load carriage system.

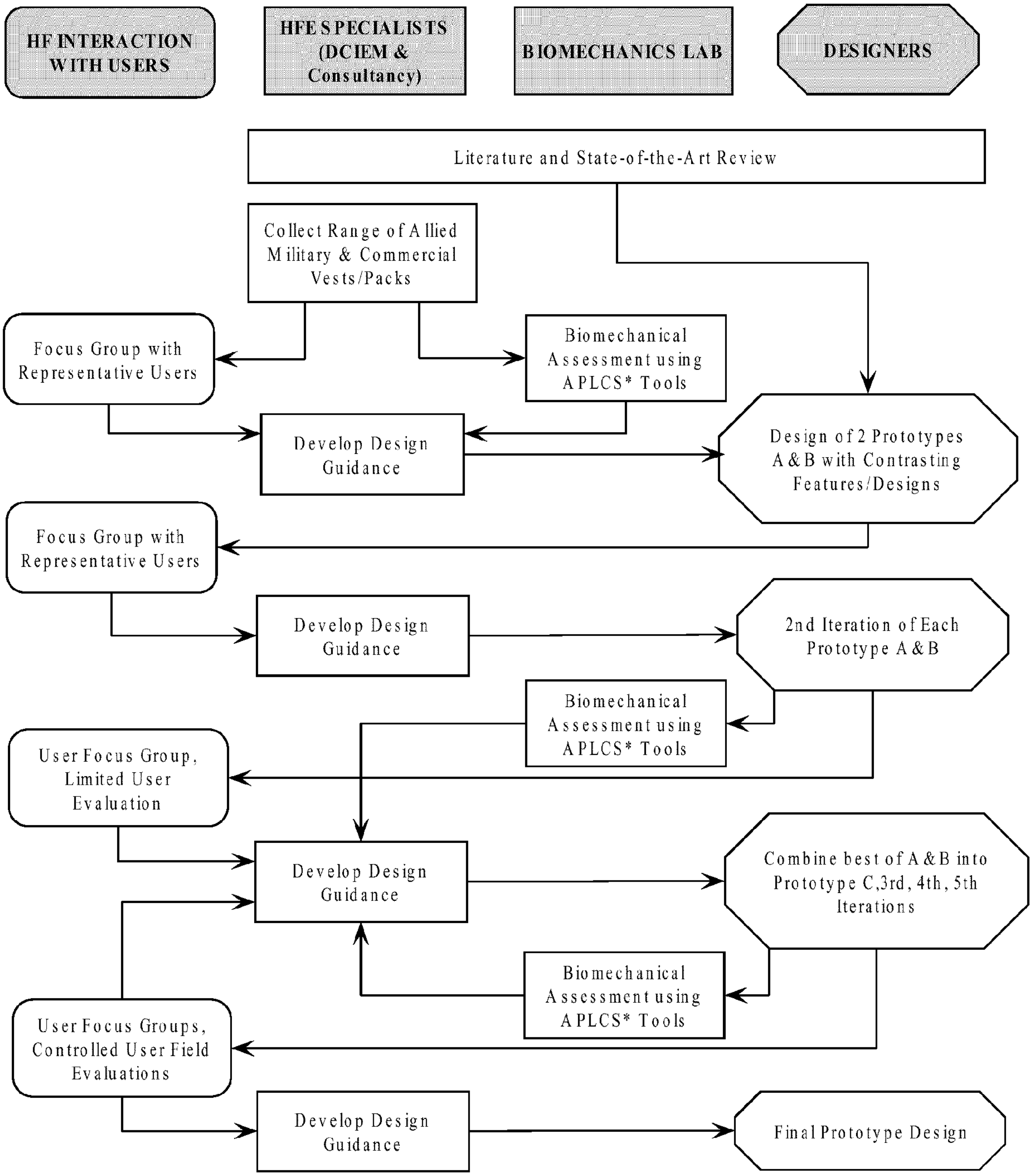

Figure 2. Integrated Load Carriage System Development Process
(*APLCS = Advanced Personal Load Carriage System Evaluation Tools)

User testing was progressive, starting with focus group discussions and limited testing of early prototypes through to highly controlled usability evaluations in the field. Typically, these field evaluations involved representative soldier subjects performing a range of critical tasks, from static/dry compatibility test stands (to examine such factors as fit, range of motion, physical compatibility with other equipment), through to assessment of performance during increasingly complex but realistic soldier tasks (from performance on marches, obstacle courses, or weapon firing ranges, through to vehicle ingress/egress/operation tasks and group level tasks such as house clearing and battlefield assault). Measures of performance included objective task performance (e.g., task timings) as well as subjective opinion and subjective ratings of acceptability collected via questionnaire and focus group discussions. Fitting trials and extended duration cross-seasonal durability and soldier acceptance trials were conducted with the more mature prototypes.

The findings from each interaction with users and every quantitative test were translated into design guidance and performance requirements by the HF and biomechanics team members. The designers were then responsible to modify the design of each prototype to address the identified shortcomings and achieve the necessary functionality and performance. Wherever possible, the team went back to the same users who had provided input for that design iteration to confirm that the functionality and performance objectives of users had been met by the design modification. The final acceptance testing involved an entirely different and larger set of soldiers to reduce the risk of bias. Although Figure 2 indicates only four iterations of the design and testing process, there have been over a dozen iterations of each component prototyped and tested in this development effort.

Statement of Requirements for a New Load Carriage System

The in-service 1982-pattern load carriage system, shown at Figure 3, is modular and includes the following components:

- Webbing, comprising a padded yoke-style shoulder harness and web belt, onto which a range of storage pouches can be attached (via clips that fit into the web belt grommets and velcro tabs that fit around the web belt) to carry the soldier's fighting load (Fighting Order) for sustainment of up to 8 hours (essentially "bombs, bullets and water");
- Small Field Pack ("Butt Pack") , essentially a larger storage pouch or bag that is added to the Fighting Order, attached to the back of the web belt, enabling soldiers to carry up to 24 hours of equipment such as rain gear or extra ammunition (webbing + butt pack = Battle Order); and
- Rucksack, an external wire frame rucksack, onto which the sleeping system (housed in a compressible valise) and main storage bag can be affixed, providing up to 72 hours of sustainment load (Fighting Order + Rucksack = Marching Order).

When soldiers modify or replace their issued equipment, it is usually a good indicator of their dissatisfaction and as well as a failure in the design and procurement process. For example, many soldiers have adopted use of an unstructured small pack, originally intended for carrying the soldier's NBC (nuclear, biological and chemical) Individual Protective Ensemble (IPE), apparently to overcome problems they were experiencing with the 82-pattern system: inadequate storage capacity in the Butt Pack; and difficulty removing or attaching the Butt Pack to the web belt, causing users to wear the Butt Pack under the Rucksack (which is incompatible as shown at Figure 3). When fragmentation protective vests were acquired and issued to our deployed troops, problems associated with webbing incompatibility led soldiers to modify their frag vests (i.e., cut slits in the outer shell fabric) to carry items such as bayonets, magazines or field dressings. This precipitated the rapid design and urgent fielding of the Load Carriage Vest (shown at Figure 4), a two-size unstructured garment with large capacity pockets. Such soldier adaptation is an indication that the range of user requirements was not adequately considered when the 82-pattern system was developed and tested.

Figure 3. In-service 1982-pattern load carriage system comprising Webbing (top left)and an external frame Rucksack. Note the incompatibility between Butt Pack and Rucksack in photo on right.

Figure 4. Load Carriage Vest rapidly designed and fielded to overcome problems of incompatibility between the webbing and fragmentation protective vest

Soldier dissatisfaction with the 82-pattern load carriage system has been widespread. In 1992 and 1993, a questionnaire-based mail-out survey of Canadian soldiers (n=487) on UN missions in the Former Republic of Yugoslavia revealed the extent of user dissatisfaction (Shek et al, 1996). Soldiers were asked to rate the acceptability of a range of clothing and equipment items, including the 82-pattern load carriage system. They were also asked to list their 3 'best' and 3 'worst' items of kit. Respondents (n=487) were representative of combat troops, with 64% at the Corporal/Private rank, and 71% being infantry. Half of respondents (n=280) rated the 1982-pattern rucksack as unacceptable and this item ranked at the top of the 'worst kit' list. The 82-pattern webbing was rated only slightly more favourably, ranking eighth on the 'worst kit' list. Interestingly, the IPE bag, which soldiers were using to overcome deficiencies in the 82-pattern system, was ranked seventh among their 'best' items of kit.

During the development of the Army Clothing and Equipment Survey System (ACCESS), over 700 personnel were surveyed using a range of survey strategies and techniques. Considerable dissatisfaction with the 82-pattern load carriage system was identified with each survey (Tack & Gaughan, 1997a & 1997b; Kumagai & Tack, 1999). Specific problem areas were identified: incompatibility between the webbing and rucksack at both the shoulders and hips; unsatisfactory load order integration (difficulty transitioning from fighting to battle to marching order); poor load distribution; discomfort and circulation problems (rucksack palsy); insufficient load carriage capacity; difficulty changing modular webbing components; poor fit, especially for individuals with shorter torsos; and poor durability (rucksack frame and webbing components).

System Design Goals & Constraints

The team's overall system design goals for the new load carriage system included the following:

- effective load order integration, enabling easy and rapid transition from Fighting to Battle to Marching Order
- modularity and mission configurability
- enhanced task performance
- good fit and adjustability to accommodate not only the range of soldier sizes, but for a given soldier, the range of clothing conditions
- physical and thermal comfort
- compatibility with soldier clothing, equipment, weapons, communications gear, vehicles and tasks
- high degree of user acceptance (so that it would be the load carriage system of choice for military and recreational activities)

Regular design review meetings, user involvement and the multi-disciplinary nature of the team ensured a focus on these design goals. Participation in CTS project review meetings also ensured that the higher-level project goals, constraints and issues were addressed. These included: speedy development to achieve rapid fielding, affordability of the design effort and eventual product, and due consideration of life cycle management costs of the system. The team was asked to develop the Tactical Vest (TV) as a priority and then focus on the integrated small pack system and rucksack. The involvement of the pack designer throughout the TV development process and the commitment of the whole team ensured to a systems approach ensured effective integration of all load carriage system components.

Human Factors Engineering in the Development of the TV

Statement of Requirements Phase. Previously mentioned user surveys (Kumagai & Tack, 1999; Shek et al, 1996; Tack & Gaughan, 1997a & 1997b) highlighted the following problems with the 82-pattern webbing: poor load order integration (difficulty transitioning from Fighting through to Battle and Marching Order), poor compatibility with the rucksack at hips and shoulders (competing hip belts and shoulder straps), difficulty changing modular pouches, and poor durability of the pouch attachment mechanism.

The interim solution to some of the incompatibility problems, the LCV (shown at Figure 4), was rated by ten percent of respondents to an ACCESS newspaper insert survey (n=285) as one of their best items of issued kit (Kumagai & Tack, 1999). Although this number seems unimpressive, very few soldiers would have had experience with the LCV at the time of the survey.

Although the LCV was highly regarded by the troops who had worn it, several concerns with its design led to the decision to develop a replacement vest. These included: vest length (the vest came down to the level of the hips) that precludes effective integration with the hip belt of a new rucksack; excessive insulation due to the material chosen for the vest, its loose fit, and its coverage on the body; excessive stowage capacity, causing troops to overload themselves; and poor load stability, due to its loose fit, limited number of sizes (only 2) and lack of sufficient adjustability (drawstring at the waist only).

Specification Development Phase. The TV design criteria developed by the team included the following (in no particular order): enhance task performance; distribute weight more effectively; minimize load shifting; minimize heat load, reduce bulk; improve the sizing range; allow for customized fit adjustment; support mission and personal preference configurability; integrate well with the rest of the load carriage system; be compatible with other clothing and equipment worn and used by soldiers; incorporate usable closures; be durable and field repairable; and accommodate and ensure accessibility to high priority items. Management criteria included the following requirements: a rapid but affordable design; accommodation and compatibility with the future small pack system and rucksack; compliance with Army doctrine and tactics with respect to load item priorities; and reduced logistics support once in-service.

A user panel of 15 Master Corporal/Sergeants (representing combat arms, combat support arms and combat service support occupations) was raised to support the initial design efforts. Initial focus groups reviewed the in-service webbing and LCV as well as several allied vests. Advantages and disadvantages were highlighted and vest functionality and feature requirements were identified. The pros and cons associated with the 82-pattern webbing and LCV are shown at Table 1.

Table 1. Review of in-service fighting order options by soldier user panel

82-Pattern Webbing		**Load Carriage Vest**	
PROS	CONS	PROS	CONS
Ventilation	Hip bulk	Weight distribution	Fit
Mission/personal configurability	Yoke discomfort	Compatibility with frag vest	Ventilation
	Durability problems	Load volume	Limited modularity
	Poor weight distribution	Pouch durability	Load volume
	Compatibility with frag vest/rucksack		Rucksack compatibility
	Vehicle compatibility		Select features

A rapid prototyping vest was used for determining load placement preferences. This vest comprised a fragmentation vest as well as a number of separate pockets for each of the high priority items of kit (magazines, grenades, water canteens). Users were asked to place the filled pockets in their preferred location on the outer surface of the frag vest (via hook and pile on vest/pockets) and go through a range of typical tasks in order to identify the optimal load placement. A sampling of rucksacks was available for this testing to help ensure that load placement would not interfere with the future rucksack suspension system.

Design Phase. Two opposing vest designs were then developed and tested by the user panel in an iterative fashion: the Modular TV, and the Fixed TV, named for the nature of pocket attachment. Each took the advantages and tried to overcome the disadvantages of the 82-pattern webbing and LCV respectively, as shown schematically in Figure 6.

Both the Modular and Fixed vests had similar construction (mesh and webbing materials), body coverage (cut short to avoid future rucksack hip belt) and pocket placement options. Both had C7 rifle magazines and HE grenade pouches permanently fixed across the chest (no other options were considered suitable by the user panel). However, they differed predominantly in that the Modular TV had removable pouches for the water canteen, C9 ammunition drum and ancillary kit pouches. Additionally, a number of features were varied across the two vest prototypes: vest closure and fit adjustability mechanisms; material options (both used mesh of varying stiffness and weave construction; different padding and width of shoulder harness);

pocket designs (attachment, material, size, closures, hold-open device, stiffness, etc); and the integration of other equipment items (bayonet, flashlight, smoke grenades, web-belt, etc).

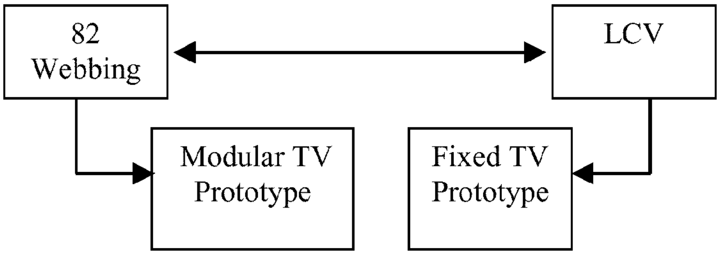

Figure 6. TV Design Options

Many different magazine pockets were prototyped and tested (see Figure 7) to ensure that users would have quick and easy access to their magazines in any firing position, and also be able to return empty magazines to the pockets single-handed. A stiffner, incorporated into the front surface of the pocket, facilitated the latter. User testing confirmed that the use of side-release buckles plus a stiffener in the front panel of the pocket permitted the fastest times for magazine removal and replacement, in both bare-handed and gloved conditions.

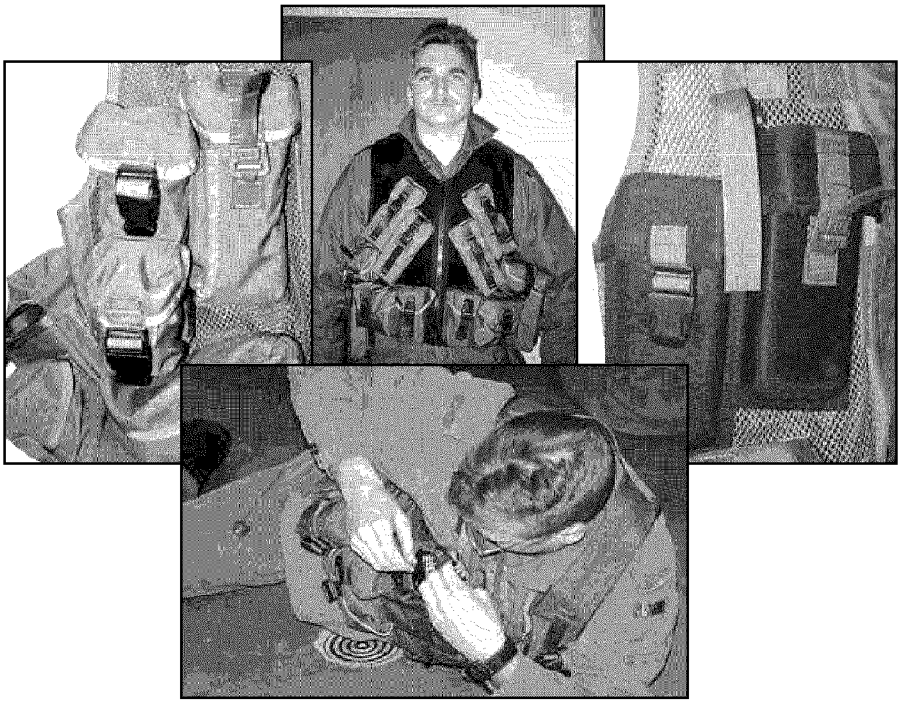

Figure 7. Rapid prototyping vest (top centre) and range of magazine pocket designs and features evaluated for accessibility

Test and Evaluation Phase. During the iterative development of the TV, quantitative biomechanical testing confirmed which pocket design and attachment mechanisms would provide the best load stability, and which shoulder strap designs (varied width, padding versus flat webbing) would minimize skin contact pressures and be most compatible under the future rucksack (Bryant et al, 1997a; Reid et al, 1999a).

An intensive highly controlled usability evaluation was conducted in August of 1997 to assess the two TV prototypes against the two in-service options. Two groups of sixteen soldiers participated in the five-day field trial at CFB Petawawa. All subjects wore both TV prototypes and one of the 82-pattern webbing or LCV in an incomplete block repeated measures study design. Standardized testing occurred across a range of test stands and activities: three 5 km marches, an obstacle course, weapons firing, grenade throw, battle tasks (section attacks, house-clearing) and compatibility test stands (to test compatibility with the range of clothing conditions, radios, personal and crew-served weapons, vehicles and both in-service and allied rucksacks, since the CTS pack was yet to be designed). In addition to performance measures, subjects gave ratings of acceptability for a range of test criteria after each activity and in an exit questionnaire on the last day of the trial. The Modular TV was preferred over all other options for ease of adjustment, packing, load item capacity, ease of access to items, compatibility with personal weapons and equipment, mission configurability and battle task performance. Both the Modular and Fixed TV conditions were preferred over the in-service options for ease of donning/doffing, compatibility with shoulder-fired weapons, rucksack compatibility, physical comfort, ease of movement, load balance, load stability and casualty extraction. The 82-pattern webbing was preferred over all other options only for thermal comfort.

Since thermal comfort was a concern in the decision to develop a vest, the results will be highlighted here. After each 5 km march, subjects were given a thermal comfort questionnaire. The questionnaire depicted the front and back of the body (predominantly torso) and a rating scale. Subjects were asked to indicate areas of thermal discomfort by circling the area and then entering their thermal comfort rating for that area. Table 2 provides a summary of results across the trial conditions.

Table 2. Percentage of subjects who indicated a thermal comfort rating and the mean of their thermal comfort ratings by body zone across the four Fighting Order conditions. Shaded cells indicate when >50% of subjects reported discomfort (or >70% if bold).

	82-PATTERN		IN-SERVICE LCV		TV FIXED		TV MODULAR	
ZONE	%	Mean Rating*	%	Mean Rating*	%	Mean Rating*	%	Mean Rating*
Shoulders	**80**	3.4	64	4.1	63	3.4	50	3.7
Sternum	33	3.5	**71**	3.8	37	3.2	61	2.2
Stomach	7	3.0	64	4.0	37	4.0	54	3.4
Underarm (front)	**		7	2.0	33	3.3	29	3.8
Waist	13	4.5	21	3.7	11	4.3	4	5.0
Upper Back	**73**	3.5	64	4.1	59	3.3	61	3.1
Middle Back	33	3.8	**93**	4.2	67	3.4	**71**	3.5
Underarm (rear)	**		7	2.0	22	3.8	18	3.6
Lower Back	20	3.7	36	3.6	22	3.5	22	3.7

1=neutral, 2=slightly warm, 3=warm, 4=hot, 5=very hot
** webbing does not cover these areas

It can be seen from Table 2 that the in-service LCV had among the highest thermal discomfort ratings and the highest number of subjects reporting thermal discomfort. Not surprisingly, all three vests solicited more thermal discomfort feedback than the 82-pattern webbing, although the heat build-up under the 82 webbing shoulder harness and yoke are apparent.

At the end of the usability trial, a large exit focus group queried participants about their final overall preferences. Table 3 indicates the results when soldiers were asked to indicate which of the four Fighting Order conditions they would want to walk away with that day, and which they would prefer, if some minor modifications (identified during the trial) were made. Eighty-seven percent were happiest with the Modular TV as designed, and with the minor modifications suggested, that figure was raised to 94%. Surprisingly, none of the soldiers preferred the LCV and a few were happiest with the 82-pattern webbing. Their reasons related to thermal comfort and mission/personal configurability.

Table 3. Final user preferences by Fighting Order condition

Fighting Order	Acceptable As Is		Acceptable with Mods	
Condition:	#	%	#	%
Modular TV	27	87%	29	94%
Fixed TV	1	3%	1	3%
LCV				
82 Pattern Webbing	3	10%	1	3%

Since that usability trial was conducted, a number of design modifications to the TV have been incorporated and validated with users. These came about as a result of this trial and the many sessions with users during the development of the remainder of the load carriage system. Every test session for the rucksack and small pack system naturally included the TV, since it is an underlying layer.

Figure 8 shows a drawing of a near-to-final TV design. It is constructed of mesh fabric, 500 denier Cordura pocket material and a range of webbing materials. It is available in two sizes and accommodates the range of soldier clothing conditions (from combat clothing alone through to the full winter ensemble including fragmentation vest). Adjustability is achieved circumferentially via three pairs of webbing straps with metal ladderlock buckles. Vertical adjustment is available at the shoulder, using hook and pile. To tighten the load immediately prior to an engagement, the soldier can use the load lifter webbing straps on the front of the vest. The vest incorporates a casualty recovery strap across the top of the back in case an unconscious soldier has to be dragged or lifted out of a hazardous situation. 'Daisy-chain' webbing on the back of the vest allows for the attachment of equipment or modular components of the small pack system (to be described). Four C7 magazine pockets, two HE grenade pockets and two ancillary stowage pockets are affixed across the front of the vest. The innermost magazine pockets include stowage for a mini-mag light (inner right) and a whistle (inner left). Two each of modular water canteen and C9 ammunition drum pockets (left and right) are available with each vest. Each of these pockets includes stowage for a smoke grenade. A bayonet can be housed on the front zipper flap with the blade in the up or down position. Inside the vest is a mesh pocket for stowage of maps. Wide flat webbing was chosen to replace the padded shoulder straps in order to minimize pressure points and optimize integration with the new pack system (Reid et al, 1999a).

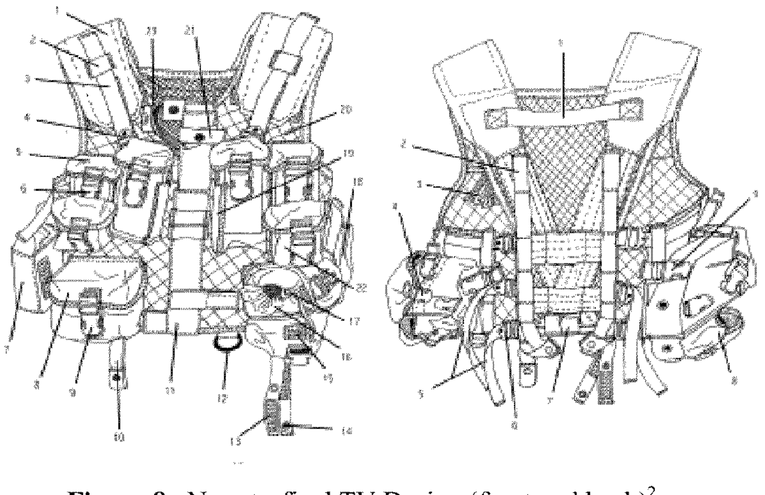

Figure 8. Near-to-final TV Design (front and back)[2]

[2] Drawings used in this paper were taken from questionnaires used in trials and focus groups with trial troops. Numbers and stars refer to specific parts of the item that were rated by users for functionality and durability. Starred items (seen in later drawings) were those found in user trials to require redesign or modification. These have since been modified and have been confirmed by users as acceptable.

Human Factors Engineering in the Development of the Rucksack and Small Pack System

Statement of Requirements Phase. Surveys previously mentioned (Kumagai & Tack, 1999; Shek et al, 1996; Tack & Gaughan, 1997a & 1997b) point out the extent to which Canadian soldiers were dissatisfied with the 82-pattern rucksack. Problems reported included: incompatibility with webbing; unsatisfactory load order integration; poor load distribution; discomfort (including rucksack palsy); poor fit, especially for individuals with shorter torsos; and poor durability (rucksack frame). The fact that soldiers were using the IPE bag to augment their load carriage system indicated their desire for a small pack. The design team reviewed the feedback that had already been gathered in order to refine and validate the Statement of Requirements for the new small pack system and rucksack.

Specification Development Phase. The same approach was taken for the development of the integrated small pack system and rucksack. Biomechanical testing of a range of commercial and allied military packs (Bryant et al, 1997b; Stevenson et al, 1995 & 1997) led to biomechanical design goals and test criteria. A user panel of 15-17 experienced soldiers (Master Corporals/Sergeants, predominantly infantry but also representing other combat arms and combat support trades) were involved in at least six design review focus group and testing sessions. Initial sessions reviewed in-service, commercial and allied packs to identify and prioritize functionality and feature requirements. Table 4 provides the mean ratings of importance in rank order for a range of criteria. It is interesting to note how low on the list thermal comfort scored in the criteria importance (although it is still rated as important). Together with their dissatisfaction with the external-framed 82-pattern pack, this may help to understand the overwhelming preference of the user panel for an internal framed pack design. The design team also favoured an internal frame pack, knowing that it would help keep pack centre of mass as close as possible to the body, for less back strain and better load control and stability.

Table 4. Mean pack criteria importance ratings of user panel participants.

Criteria	Mean Rating	Criteria	Mean Rating
Physical Comfort	6.5	Bulk	5.6
Fit	6.3	Pocket Closures	5.6
Balance	6.0	Capacity	5.4
Equipment Compatibility	6.0	Modularity	5.3
Range of Motion	6.0	Task Performance	5.3
Waterproofness	6.0	Clothing Compatibility	5.2
Adjustability	5.9	Stowage	5.2
Durability	5.9	Ease of Packing	5.1
Item Accessibility	5.8	Thermal Comfort	5.1
Stability	5.8	Camouflage	4.3
Weight of Pack	5.8	Appearance	3.2
Mission Configurability	5.7		

7 point scale: 1 – Unimportant, 7 – Essential

Design Phase. Two opposing internal frame pack prototypes were developed in order to expose users to the range of possibilities. The variables addressed by the opposing designs included: modular versus single bag, suspension system characteristics and features, design and integration of the small pack, design and integration of accessory pouches, mechanism and design of bag compression straps, pack lid designs, access to compartments, compartment closures, quick release options, shoulder strap shape and fit/adjustability features. The main differentiating features are shown in Table 5.

Table 5. Main features of opposing pack design concepts

Modular Packs (M)	Single Bag Packs (K)
Two separate bags (for mounting on pack frame)	Single bag pack with two separable compartments
Pack-board capability	No pack-board capability
Stiff suspension	Flexible suspension
Aluminum stays for head/helmet clearance	Plastic molded head/helmet clearance
No pack handles	Pack handles

The Modular version (Prototype M) comprised an 'internal frame' suspension system in a packboard configuration. Separate small, unstructured packs could be mounted to the pack-board to achieve mission configurability. One of the small packs could be removed from the pack-board and double duty as a small (i.e., patrol) pack if needed. The other prototype, Prototype K (actually for 'Keep it Simple') comprised an internal frame suspension system and a single large stowage bag concept, with access from the top and bottom-front of the pack to two separable compartments. Modularity was achieved with a series of add-on pouches (attached via webbing straps and ladder-lock buckles through 'daisy-chain' sewn to the outer surfaces of the pack). Integration of the small pack could be achieved in one of two ways: by attachment to the 'daisy-chain' on the outer surface of the pack (top or front) if loaded with relatively light items; or by putting the whole small pack inside the top compartment of the pack (inside the separate radio compartment) if carrying heavy items such as the combat net radio.

Consultation and increasing levels of testing took place with the representative user panel as well as parachutist instructors (to ensure 'jumpability' and robustness). Quantitative tests of the M and K-series of packs as well as a range of pack components helped to make trade-off decisions and to refine the suspension system design (Bryant et al, 1997c & 1997d; Reid et al, 1998, 1999c, 2000a, 2000b; Stevenson et al, 1998 & 2000; Whiteside et al, 1999). Both user and quantitative testing confirmed the superiority of the K-series of packs in terms of load stability, shoulder strap design, and usability. Meanwhile, the TV design was finalized and tested, both quantitatively and with users, ensuring compatibility with the rucksack suspension system. The findings from all the studies and testing on the opposing pack prototypes enabled the team to refine the design into a single integrated overall system design (with some variation on component and feature design). Figure 9 provides a drawing of the pack that would go on to further quantitative biomechanical assessment (Reid et al, 1999b; Stevenson et al, 2000) and thorough usability testing in the field.

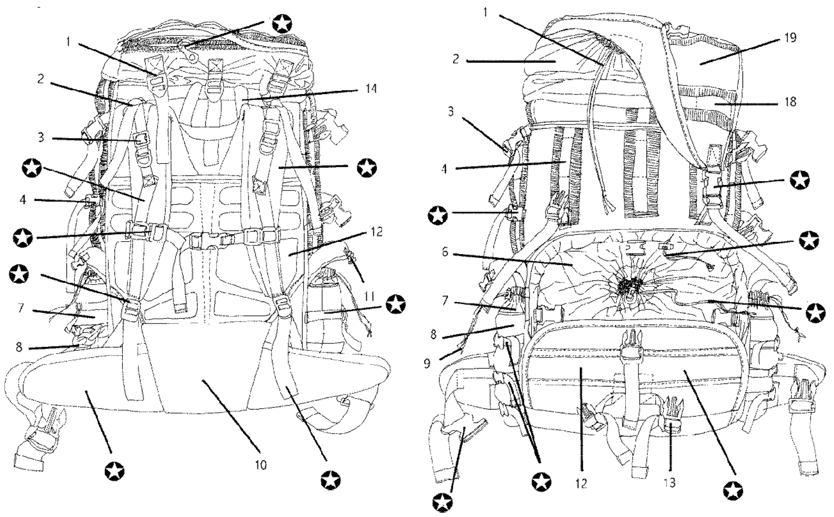

Figure 9. Near-to-final rucksack configuration.

The rucksack (85 litre capacity) incorporated a state-of-the-art suspension system (in 4 frame sizes) including: a Plastizote™ frame sheet, two aluminum stays (custom shaped), a molded lumbar/back pad with channels for air flow and heat dissipation, curved shoulder straps (in 3 sizes), molded hip belts (in 4 sizes), load lifter and hip stabilizer straps, lateral suspension stiffness rods to improve transfer of load to the hips, a sternum strap and quick release capability. The stowage concept was a single large bag design, with top and front access to one large (separable into two) compartment, plus a radio stowage compartment, floating lid, pack handles, two lower lateral fixed pockets (which have since been made removable) and all-over 'daisy chain' attachment capability.

The small pack system comprised a patrol pack (24 litre capacity) and a range of accessory pouches. The small pack (shown in Figure 10) utilized the same molded back-pad as the large rucksack and incorporated a single aluminum stay. Padded shaped shoulder straps, a sternum strap, waist belt (for load stability), load lifters (not shown in Figure 10), all-over 'daisy-chain' for attaching accessory pouches and an internal separate radio compartment characterize this system.

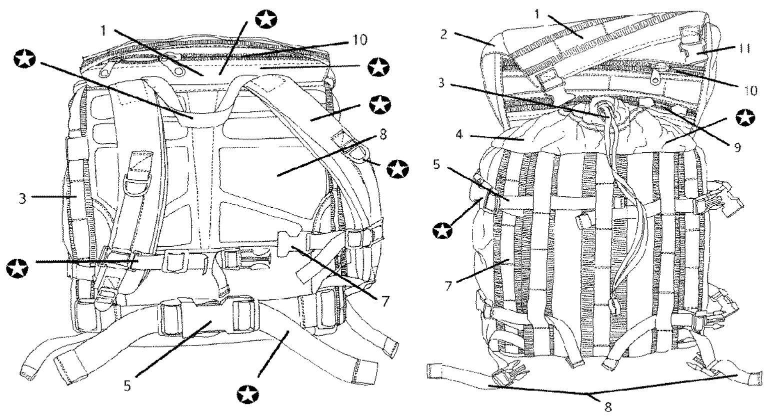

Figure 10. Near-to-final small pack design.

The accessory pouches included two (7.5 litre capacity) pouches and two small (5 litre capacity) pouches. The large accessory pouches are oblong, zippered bags that provide the option for use and wear as a standalone 'fanny-pack' around the waist. They can be attached to the back of the TV and anywhere on the outer surfaces of the small pack or rucksack (across the top, on the front or sides). The two smaller accessory pouches are essentially square, upright bags with a snow cuff and flap cover. They can also be attached to any of the three load carriage items. These additional pouches are what give the entire system its modularity. They are shown in Figure 11.

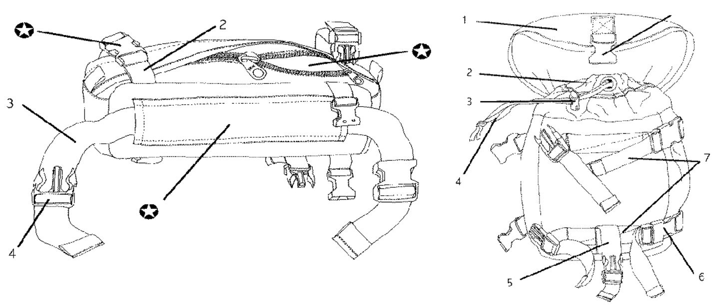

Figure 11. Accessory pouches can be added to the TV, small pack or rucksack for modularity and mission configurability

Because of the preference for a single bag design, the in-service sleeping bag valise was unsuitable for the new load carriage system (insufficient compression made it too large to fit into either the upper or lower compartment of the pack). Furthermore, users wanted a 'waterproof' system, to keep their sleeping system dry under conditions of stream fording or in downpours. The in-service valise does not offer this protection. A range of commercial waterproof compression sacks were acquired and tested with users to identify feature and functionality preferences. The Waterproof Compression Sack (WCS) is still undergoing development

Test and Evaluation Phase. As previously mentioned, quantitative biomechanical testing and qualitative user review of various iterations of the pack were undertaken throughout the design phase. Once the design was refined sufficiently, an intensive two-week controlled user trial of the complete load carriage system was conducted in September of 1998. Twenty-four representative subjects (67% combat arms, 33% non-combat arms; 67% men, 33% women; 3 different Brigades) evaluated the new prototype against both the in-service 82-pattern system as well as an allied system that was considered by troops (in surveys and focus groups) to be the best available. The allied system was included to control for bias against the in-service pack. Field trial test criteria for the Battle Order and Marching Order configurations of each of the three systems included: fit/adjustability, packing drills, accessibility, range of motion, clothing/ equipment/weapon compatibility, feature evaluation, individual task performance (weapon firing, obstacle courses, grenade throw), vehicle stowage, battle task performance (patrolling, fire and movement, house clearing), thermal load, physical comfort, user maintainability and overall user acceptance. There were mini-march work-ups of 2 km, then a mini-assault work-up (in Battle Order only) involving 3.5 km marches, a 1 km patrol through bush, practice section attacks and grenade throw. For each condition, each subject marched 10 km, participated in 2 km night recce patrols, went through field living conditions overnight, and, for Battle Order conditions only, conducted fire and movement, house clearing and small arms firing tasks.

The allied load carriage system was withdrawn by the third day of the trial due to severe discomfort problems. Only the results for the new prototype and the in-service system will therefore be highlighted here. Generally, the new pack was rated significantly more acceptable than the 82 (or allied) systems. The 82 system received many unacceptable ratings. The only mean unacceptable ratings given for the new pack were for the criteria of accessibility to TV C9 drum pockets or pack pockets on the march (normally, the pack would be doffed if the wearer came under attack and needed to access this ammunition). Borderline mean acceptability ratings were given for the hip belt (due to inability to achieve a tight enough fit with resultant slippage on the smaller participants), ease of donning (not surprising given the complexity of the new system), emergency doffing and TV compatibility. The TV shoulder straps were subsequently modified (from padded to flat wide webbing) to improve compatibility and the emergency doffing mechanism has since been modified for ease of use.

Figure 12 shows the mean physical comfort ratings and incidence of reporting for both the new and in-service systems following the 10 km marches. Eighty percent of participants noted discomfort on the anterior shoulders for the 82-pattern system (mean of 3.2 representing noticeable discomfort) versus 42% for the new prototype (mean of 2.4, slight to noticeable discomfort). Half of participants experienced noticeable discomfort on the front of the hips for the new pack system (Figure 12a) due to incompatibility between the hip belt and buttons on the combat trouser pockets (these have since been replaced with hook and pile closures to accommodate the new load carriage system). Physical comfort ratings for the back of the torso were reduced in severity and incidence with the new load carriage system (Figure 12b). The new design virtually eliminated reports of discomfort at the back of the neck.

Figure 13 shows thermal comfort ratings for the back of the torso. Although more thermal discomfort was experienced at the hips with the new pack (due to presence of a padded hip belt[3]), the incidence and severity of thermal discomfort ratings at the shoulders and center of the back were reduced, this despite the fact that the new system uses an internal frame.

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[3] The 82-pattern rucksack has only a webbing strap for hip belt. It is worn infrequently because it does not transfer load to the hips.

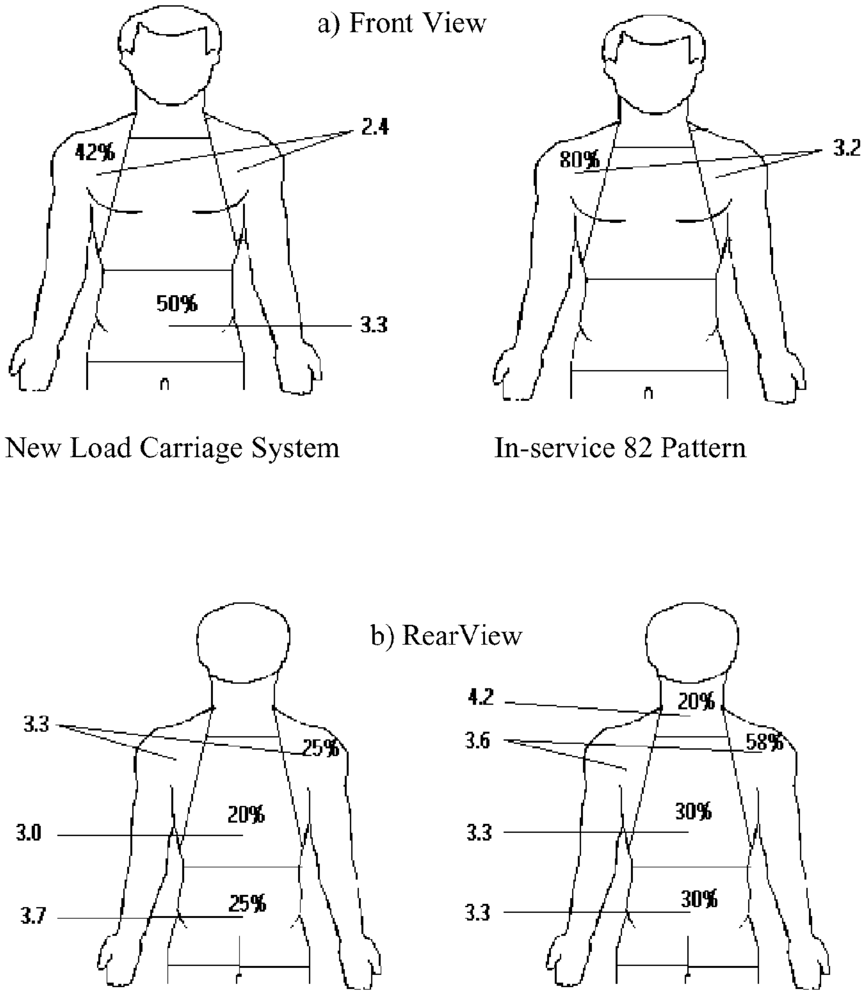

Figure 12. Physical comfort ratings, front (a) and rear (b)
(scale: 1=neutral, 2=slight discomfort, 3=noticeable discomfort, 4=pain, 5=extreme pain)

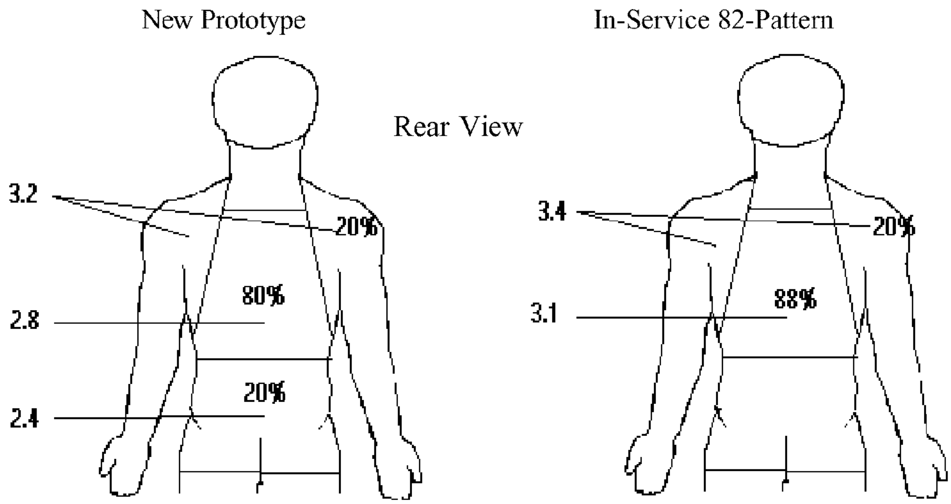

Figure 13. Thermal discomfort ratings for the back of the torso, new and in-service load carriage system
(scale: 1=neutral, 2=slightly warm, 3=warm, 4=hot, 5=very hot)

An interesting finding from testing of various battle order configurations was that users preferred using the TV with accessory pouches instead of the small pack. Cited reasons for rating the small pack less favourably included: less mobility, restricted range of motion, helmet nape clash, load instability and poor back ventilation. However, the accessory pouches provide a lot less storage capacity than the small pack so it was recognized that there would be situations when the small pack would be the option of choice. The small pack has since been modified to incorporate load lifter straps and other features to improve mobility and load stability. The trial also demonstrated the utility of the small pack as an option for sustainment loads of 24-36 hours. It has much more capacity (within the bag itself, plus accessory pouches) than any in-service option (Butt Pack, LCV or IPE bag), so troops considered the possibility that the small pack system could actually replace the large pack for mechanized troops or for operations in temperate conditions (in both cases, the load size is smaller).

Modifications were made to the load carriage system to address some of the lower-rated criteria and deficiencies identified by the user participants. Confirmatory testing sessions were conducted with a sampling of those same trial participants to ensure that the design team understood their concerns and translated them successfully into the system design. A further benefit of this strategy is that it gives confidence to soldiers that their input is being heeded.

Human Factors Support in the Selection of Options Phase

User Acceptance Trials. Several extended duration trials were conducted across a number of Canadian infantry units in order to better address the suitability of the entire load carriage system for field living conditions across each of the seasons, to gather durability data, and to obtain final user acceptance of the overall system. At the beginning of each trial, the design team would brief participants and carefully fit each with a complete load carriage system. The soldiers would then use the new system during already-scheduled training exercises (including arctic). A return visit by the design team, part-way through and at the end of the trial allowed the team to correct any misconceptions or misuses of the new system as well as collect subjective data on system usability, durability and overall user acceptance. The load carriage system was highly accepted by users. The only changes requested (now being implemented) were the enlargement of the front pack opening to facilitate the stowage and removal of the sleeping system, and redesign of the Waterproof Compression Sack (WCS), used to house the sleeping system, since the commercial variants trialled had insufficient storage capacity and durability. That design work has been completed and one final user acceptance trial of the pack and WCS is scheduled for February 2001.

Fitting Trials. A fitting trial was conducted for the complete load carriage system in June of 1999. The aims of this trial were to determine the critical anthropometric dimensions for fitting the new system, and using these, determine the range of measures for each item size. Based on these sizing ranges, it would then be possible to establish item size tariffing in relation to the 1997 Canadian Land Force anthropometry survey (Chamberland et al, 1998).

Methodology involved the fitting of loaded packs onto 193 soldiers by an expert fitter (the pack designer), having soldiers do a shake-out mini-march and then come back for fitting reassessment and adjustment of component size as required. Mean ratings of size acceptability for a range of pack components and dimensions were within 1 point about the center of a 7 point balanced interval rating scale (where 1 = too small, 4 = ideal, 7 = too big).

Analysis of correlations between anthropometric variables and the sizes of components worn by subjects identified which anthropometric variables should be used by supply personnel for determining appropriate component sizes as well as identify the range of a user sizes appropriate for a given component size (simple anthropometric measurements were used so that eventual supply personnel would be able to issue the appropriate sizes to personnel). Having the distribution of body size and shape from the recent Land Force anthropometric survey (Chamerland et al, 1998) enabled the team to develop a sizing system (an example is shown at Figure 14) as well as size tariffs (i.e., how many of each size of each component to procure for the Land Force).

Because those of shorter stature or larger waist circumference were under-represented in this fitting trial, further fitting trials are being conducted to determine the requirement for additional sizes of shoulder harness and hip belt (smaller and larger).

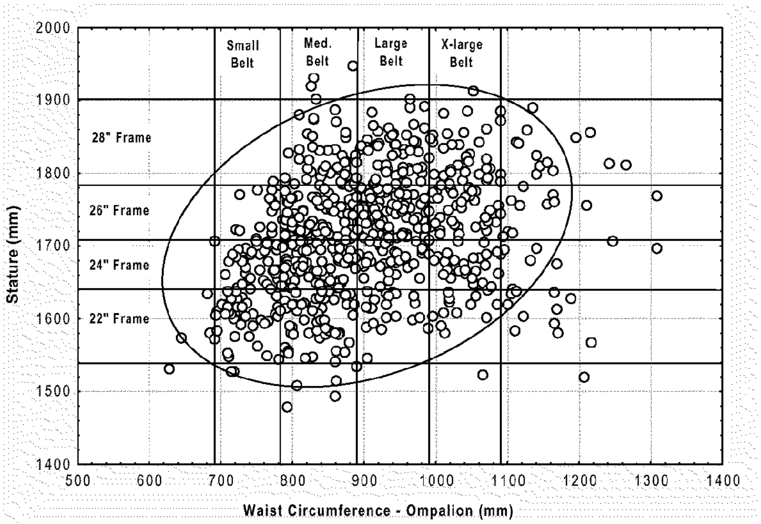

Figure 14. Sizing of pack frame and hip-belt, based on stature and waist circumference

Human Factors Support to the Implementation Phase

The complete load carriage system, as it looks today, is shown in Figure 15. The design team is currently developing a range of waterproof compression sacks for trial this winter. Further sizing and fitting evaluations are planned to determine the requirements for additional sizes of shoulder straps and hip-belts. The sizing and size tariffs will then be revised as appropriate and the technical data packages completed in preparation for the procurement process.

Figure 15. Complete Clothe the Soldier load carriage system comprising tactical vest, small pack, large rucksack, ancillary pouches and prototype waterproof compression sack.

Although the project is shifting from the development to the procurement and implementation phases, a number of HF support activities have been recommended. First and foremost, because of the complexity of system fitting, adjustability and configurability, the design team strongly advocated the development and implementation of effective training strategies, not only for the eventual soldiers who will use the system, but also for those responsible for training and issuing the system. The design team is currently developing material for effective user manuals, based upon their study of skills and knowledge retention by users involved in extended duration trials. But user manuals or videotapes are not likely to be sufficient. A 'tiger team' approach has been recommended whereby a team of skilled and knowledgeable staff visit major formations and units to properly 'train the trainers' until basic military courses offer the training in their curriculum.

The design team advocated the development and implementation of some fitting aids, because appropriate fitting of the new pack is essential to system comfort and acceptability, because it is such a complex system, and because supply staff have limited training or the time for careful body measurement. DCIEM is developing (Meunier et al, 1999) a low-cost Intelligent Clothing and Equipment Sizing System (ICESS) that can quickly capture an individual's major body dimensions (using 2D digital cameras and specialized software) and then indicate the appropriate size of clothing or equipment that should be issued to that individual (assuming a fit/sizing trial has confirmed the sizing for that item, as will be the case for the load carriage system). Such a system, if installed in future at major clothing supply centers, would ensure the correct allocation of load carriage system components. In the shorter term, the designer is developing a fitting jig that will aid supply technicians and users in determining the most appropriate size of pack frame, shoulder strap and hip-belt for their body dimensions. This tool will be tested and validated during upcoming fitting trials.

The monitoring of user satisfaction with the delivered product post-implementation via surveys or other means is also important. Not only will it permit a validation of user acceptance using an HFE development approach, it will also identify and permit the correction of any deficiencies that may arise due to: changes in doctrine, tactics and procedures (i.e., change in load lists); changes in mission environments; changes to other components of the soldier system (i.e., modified frag vest); or any misuses or abuses that arise due to ignorance about the system.

Finally, it might be prudent to conduct studies of the thermal strain associated with wearing the tactical vest, with and without fragmentation protection, to better understand the impact of replacing webbing with the tactical vest under hot conditions and so that appropriate guidance to commanders can be developed.

Conclusions

A Human Factors user-centered systems design approach was adopted by a multi-disciplinary team to develop a state-of-the-art load carriage system for the Canadian Forces. Every effort was made to ensure that the new system would meet the range of user needs and preferences. Virtually all design decisions were supported by scientific evidence, arising either from carefully controlled user evaluations or objective biomechanical assessment. User involvement throughout the development process has given a host of benefits including: increased user acceptance, product credibility (with users, designers, procurement staff and project decision-makers alike), product and soldier system effectiveness, a reduction of risk, and economy (of sizing, mission/task flexibility, feature utility, etc.).

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References

Bossi L.L., Stevenson, J.M., Bryant, J.T., Pelot, R.P., Reid, S.A. & Morin, E.L. (2000). *Development of a suite of objective biomechanical measurement tools for personal load carriage system assessment.* Paper presented to the NATO RTO Specialist Meeting, HFM SM-002, held in Kingston, ON, Canada, 27-29 June 2000. (report published in these proceedings).

Bryant, J.T., Stevenson, J.M., Reid, S.A., Andrews, D, and Doan, J. (1997a). Prototype load carriage vest design assessment using the Load Carriage Simulator. *DCIEM Contractor Report* (unpublished), submitted by Queen's University in partial fulfillment of PWGSC Contract No. W7711-6-7356/001/TOS, 62 pages.

Bryant, J.T., Stevenson, J.M., Pelot, R.P., Reid, S.A., Doan, J.B., & Rigby, W.A. (1997b) Commercial pack investigations: Osprey Vector One Silhouette 70, Synkron Norrona Para Ranger 135L, and Dana Designs ArcFlex Astral Plane load carriage systems design assessment using the APLCS Load Carriage Simulator. *DCIEM Contractor Report* (unpublished), submitted by Queen's University, in partial fulfillment of PWGSC Contract No. W7711-7-7384/001/SRV, 50 pages.

Bryant, J.T., Stevenson, J.M., Reid, S.A., Doan, J.E.M., & Rigby, W.A. (1997c). Ostrom pack prototype M1 system: design assessment using the Load Carriage Simulator. *DCIEM Contractor Report* (unpublished), submitted by Queen's University in partial fulfillment of PWGSC Contract No. W7711-7-7384/001/SRV, 50pages.

Bryant, J..T, Stevenson, J.M., Reid, S.A., Doan, J.E.M., Rigby, W.A. (1997d). Ostrom pack prototype K1 system: design assessment using the Load Carriage Simulator. *DCIEM Contractor Report* (unpublished), submitted by Queen's University in partial fulfillment of PWGSC Contract No. W7711-7-7384/001/SRV, 50 pages.

Chamberland, A., Carrier, R., Forest, F., and Hachez, G. (1998). Anthropometric Survey of the Land Forces (1997), *DCIEM Contractor Report* No. 98-CR-15, Submitted by Les Consultants Genicom Inc., Montreal Quebec, in partial fulfillment of DCIEM Contract No. W7711-6-7350, (DCIEM, North York, ON).

Kumagai, J.K. & Tack, D.W. (1999). Army combat clothing and equipment survey system (ACCESS) part 3: implementation trials and stakeholder interviews. *DCIEM Contractor Report* No. 99-CR-90, submitted by HumanSystems Inc., in partial fulfillment of PWGSC contract no. W7711-6-7286/01-SRV.

Meunier, P., Yin, S., Brown, P., & Marinelli, R. (1999). Development testing of the Intelligent Clothing and Equipment Sizing System. *DCIEM Technical Report,* No. TR 1999-075. (DCIEM, Toronto, Canada).

Reid, S.A., Bryant, J.T., Stevenson, J.M. & Doan, J.E. (1998). Effect of backpack shoulder strap lower attachment point on the load distribution of the torso. *DCIEM Contractor Report* (unpublished), submitted by Queen's University, in partial fulfillment of PWGSC Contract No. W7711-7-7412/001/SRV, 22 pages.

Reid, S.A., Stevenson, J.M., & Bryant, J.T., (1999a). Load carriage system development phase IIID: system testing using the APLCS assessment tools - Stage 1: Biomechanical evaluation of the tactical assault vest with wide webbing shoulder. *DCIEM Contractor Report* (unpublished), submitted by Queen's University in partial fulfillment of PWGSC Contract No. W7711-8-7461/001/SRV, 9 pages.

Reid, SA, Stevenson, JM, Morin, EL, Bryant, JT, (1999b). Clothe the Soldier (CTS) integrated load carriage system: Phase IIID: Final F design evaluation using the Load Carriage Simulator. *DCIEM Contractor Report* (unpublished), submitted by Queen's University in partial fulfillment of PWGSC Contract No. W7711-8-7461/001/SRV, 46 pages.

Reid, S.A., Whiteside, R.A., Bryant, J.T., & Stevenson, J.M. (1999c). Load carriage system development phase IIID: system testing using the APLCS assessment tools – Stage 2 – Effect of rucksack lateral rods on the load distribution to the torso. *DCIEM Contractor Report* (unpublished), submitted by Queen's University in partial fulfillment of PWGSC Contract No. W7711-8-7461/001/SRV, 10 pages.

Reid, S.A., Bryant, J.T., Stevenson, J.M., Doan, J.B. (2000a). *Biomechanical assessment of lateral stiffness elements in the suspension system of a rucksack.* Paper presented to the NATO RTO Specialist Meeting, HFM SM-002, held in Kingston, ON, Canada, 27-29 June 2000. (report published in these proceedings).

Reid, SA, & Whiteside, RA. (2000b). *Biomechanical assessment of rucksack shoulder strap attachment locations and effect on load distribution to the torso.* Paper presented to the NATO RTO Specialist Meeting, HFM SM-002, held in Kingston, ON, Canada, 27-29 June 2000. (report published in these proceedings).

Shek, Y., Angel, H., and Donati, A.L.M., 1996, *Human Factors Support to Operation Harmony: A Field Survey of Military clothing and Equipment.* DCIEM Report No. 96-R-15. (DCIEM, Toronto, Canada).

Stevenson, J.M., Bryant, J.T., DePencier, R.P., Pelot, R.P., & Reid, J.G. (1995). Research and development of an advanced personal load carriage system: Phase I. *DCIEM Contractor Report* (unpublished), submitted by Queen's University in partial fulfillment of PWGSC Contract No. W7711-4-7225/01-XSE, 350 pages.

Stevenson, J.M., Bryant, J.T., Reid, S., & Sui, D. (1997). Research and development of an advanced personal load carriage system Phases II and III, Section B: analysis of base systems using standardized measuring simulators. *DCIEM Contractor Report* (unpublished), submitted by Queen's University in partial fulfillment of PWGSC Contract No. W7711-5-7273/001/TOS

Stevenson, J.M., Bryant, J.T., Doan, J., Rigby, W.A., & Reid, S.A. (1998). Load carriage system design assessment using the APLCS load carriage simulator: CTS pack testing – prototype packs A&B. *DCIEM Contractor Report* (unpublished), submitted by Queen's University in partial fulfillment of PWGSC Contract No. W7711-8-7414/001/SRV, 102 pages.

Stevenson, J.M., Reid, S.A., Bryant, J.T., Pelot, R.P., & Morin, E.L. (2000). *Biomechanical assessment of the Canadian integrated load carriage system using objective assessment methods.* Paper presented to the NATO RTO Specialist Meeting, HFM SM-002, held in Kingston, ON, Canada, 27-29 June 2000. (report published in these proceedings).

Tack, D.W., & Gaughan, P. (1997a). Army combat clothing and equipment survey system, part 1: survey design and distribution methods. *DCIEM Contractor Report* No. 99-CR-89, submitted by HumanSystems Inc., in partial fulfillment of PWGSC contract no. W7711-93-7198-09/01/SRV.

Tack, D.W., & Gaughan, P. (1997b). Army combat clothing and equipment survey system, part 2: investigation of focus groups in the survey system. *DCIEM Contractor Report* No. CR 2000-139 (in press), submitted by HumanSystems Inc., in partial fulfillment of PWGSC contract no. W7711-6-7302/001-SRV.

Whiteside, RA, Doan, JEB, Reid, SA, Bryant J.T. & Stevenson, J.M. (1999). Integrated patrol pack and rucksack development phase IIIB: performance testing of suspension components. *DCIEM Contractor Report* (unpublished), submitted by Queen's University in partial fulfillment of PWGSC Contract No. W7711-7-7413/001/SRV.