AD

TECHNICAL REPORT

70-51-CE

ADVANCED AIRCREW ARMOR SUSPENSION SYSTEMS

by

F. C. Scribano and M. Burns

IIT Research Institute
Chicago, Illinois

Contract No. DAAG17-68-C-0029

January 1970

UNITED STATES ARMY
NATICK LABORATORIES
Natick, Massachusetts 01760

U.S. ARMY MATERIEL COMMAND

Clothing and Personal Life Support Equipment Laboratory
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FOREWORD

This is the final report for IIT Research Institute Project No. J6053, "Advanced Aircrew Armor Suspension Systems." The program was conducted for the U. S. Army Natick Laboratories by the Engineering Mechanics Division of the IIT Research Institute (IITRI) under Project No. 1F162203A150, Reduction in Vulnerability for Army Aircraft. This report covers the work performed from August 7, 1968 to April 30, 1969.

The Project Officer for the U. S. Army Natick Laboratories, Mr. E. R. Barron, provided guidance and assistance which substantially enhanced the results of the program. Cooperation of the Wilson Sporting Goods Company of River Grove, Illinois, supplemented the program by supplying knowledge accumulated in the sporting goods field. Dr. Ronald Singer, Anthropologist and Head of the Anatomy Department of the University of Chicago, imparted his knowledge and background to the effort.

In addition to the authors, the following IITRI personnel contributed to the program: K. Mayerhofer, R. Rodzen and C. Lamber.

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ABSTRACT

The improvement of aircrew armor suspension systems was the goal of this project. Deficiencies in armor carriers were recognized in earlier armor programs. Attempts were made to eliminate these deficiencies, but the results were minimal since the major design effort was focused on the optimization of armor configurations and the development of an armor sizing system.

Armor suspension systems received prime consideration in this program, and the goals were to design those which would improve comfort. Mobility, peripheral protection, ventilation, and rapid doffing characteristics were also given consideration.

The suspension and load distribution principles used in other fields involving load-bearing equipment were surveyed and applied wherever practicable in the improvement of armor suspensions. The aircrew armor suspension systems designed, developed and fabricated during this study indicate significant advances over previous armor carriers.

The suspension concepts developed are reviewed. The prototypes incorporating the suspension techniques derived from the study are discussed in detail, and the results of a prototype evaluation study conducted on a group of test subjects are presented.

ADVANCED AIRCREW ARMOR SUSPENSION SYSTEMS

Introduction

Armor suspension systems are used to support, position, and retain heavy rigid ballistic plates on the body. Early armor development programs concentrated on the shaping, contouring, and sizing of armor plates, with some consideration being given to the method of suspending heavy elements on the torso.

As armor work progressed, it became apparent that due to the urgency of providing armor to Southeast Asia, the suspension systems must be improved to take full advantage of the anthropometric armor shapes. It was suggested that advances could be made by applying load distribution and weight-carrying principles used in related fields of protective, shock-absorbing, or personnel load-carrying equipment. Athletic, sporting goods, medical devices, military equipment, and industrial protective equipment were surveyed. The principles of load distribution and shock absorption used in this equipment were observed and applied to the design of armor suspension systems, with noticeable advances in comfort. In addition, a capability which permitted the wearer to transfer or redistribute load from one area of the torso to another was developed. This permitted armor to be worn for extended periods of time with improved comfort, increased endurance and reduced fatigue.

Aspects such as ventilation, donning, doffing, and increased area coverage were improved.

This report reviews the suspension concepts developed. It discusses in detail the prototypes which incorporate the suspension techniques derived from the survey study, and presents the results of a prototype evaluation study conducted on a group of test subjects.

PART I. SUMMARY

A. Suspension Systems Prototypes

Three suspension system concepts were developed as a result of the Phase I survey conducted in this program. The survey included related fields where load-bearing, weight distribution, and shock-absorbing principles were used in designing protective or load-carrying equipment worn on the body. The suspension concepts may be listed as follows:

- Over-the-Shoulder Suspension
- Tension-Web Suspension
- Waist Augmentation Suspension

The purpose of each of these suspension concepts is to improve comfort, distribute load on the optimum load-bearing areas of the torso, and to minimize pressure points. The three concepts were integrated into the final suspension prototypes.

Prototype #1 - Over-the-Shoulder Raschel Knit, Tension-Web Suspension with "Quick-Release Buckle" Shoulder Breaks

The over-the-shoulder raschel knit and tension-web suspension concepts were combined in a single suspension system prototype. The method of integration is shown in Figure 1.

The rear armor element is supported on the torso with a combination raschel knit and tension-web suspension. The front armor element uses only a tension-web suspension. The raschel knit supports the armor from the bottom of the fabric carrier and extends upward across the back, and over the shoulders to the armhole area where it joins to the front armor element. This type of suspension permits the top end of the rear armor element to swing away from the torso, pivoting about its line of contact with the body at the base of the armor. The raschel knit, being inextensible and highly flexible, conforms to the body contours under load. This results in maximum load distribution over the greatest area of the shoulders and back.

The tension-web suspension consists of raschel knit sewn to the fabric suspension system so that it lies taut along the chord line formed by the curved inside surface of the front and rear armor elements. The raschel knit is

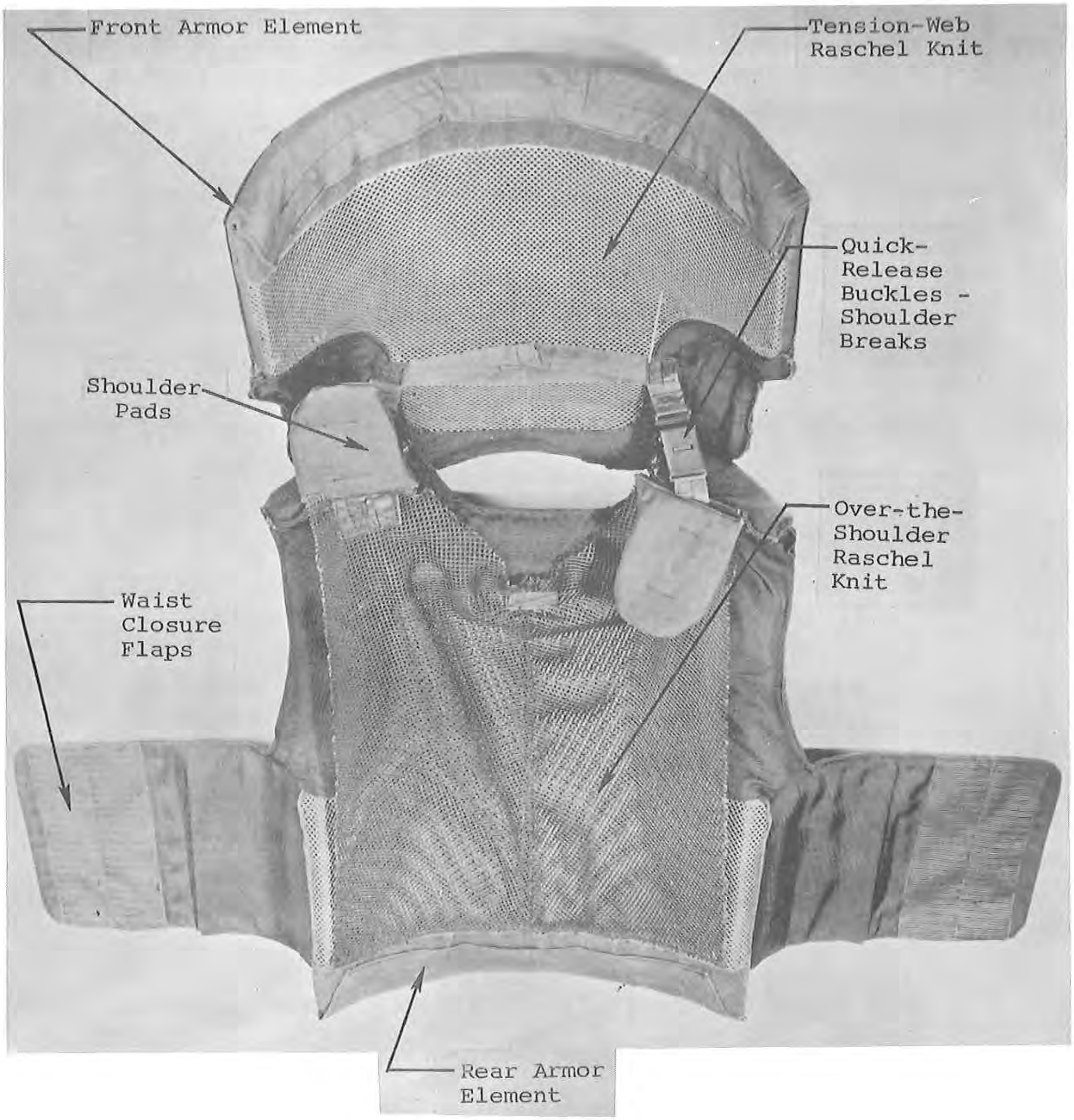

Figure 1. Prototype #1 Layout - Over-the-Shoulder Raschel Knit, Tension-Web Suspension with "Quick-Release Buckle" Shoulder Breaks

put into tension by two forces when worn, armor weight and the clamping force of the waist closure. (Note that the front armor element does not use the over-the-shoulder suspension technique.)

A front view of Prototype #1 is shown in Figure 2. It illustrates the double-flap waist closure, the pull tabs used to release the shoulder fasteners, and the treatment of the peripheral protection at the shoulder breaks. A specially designed "quick-release buckle" developed under this program is used in both shoulder breaks. A lanyard, fastened to the release lever of the buckle and leading through a buttonhole in the peripheral ballistic nylon of the front armor suspension, terminates in a pull tab. The tabs may be pulled individually to release either shoulder break, or simultaneously for rapid doffing.

The combined suspension systems approach used in Prototype #1 has the following advantages:

- Improved load distribution over greater areas of the torso
- Transfer of load to optimum load bearing areas of the torso (shoulders, back, chest)
- Rigid armor elements are held slightly away from the torso to minimize contact and reduce possible pressure points
- Improved ventilation
- Positive armor positioning and increased stability

Prototype #2 - Over-the-Shoulder Raschel Knit - Tension-Web Suspension with "Fabric Pin Quick-Release" Shoulder Breaks

The combined over-the-shoulder raschel knit and tension-web suspensions are also used in Prototype #2 (Figure 3). The methods of integrating the two suspensions into the carrier is basically identical with the approach described for Prototype #1, with the exception that both front and rear armor elements are supported with a combination raschel knit and tension-web suspension.

Another difference between Prototypes #1 and #2 is the method of fastening and releasing the shoulder breaks. Prototype #2 uses a fabric pin approach shown in Figure 3. The tension-web raschel of the front armor suspension has

Figure 2. Prototype #1 Front View - Over-the-Shoulder Raschel Knit, Tension-Web Suspension - Quick-Release Buckle Shoulder Breaks

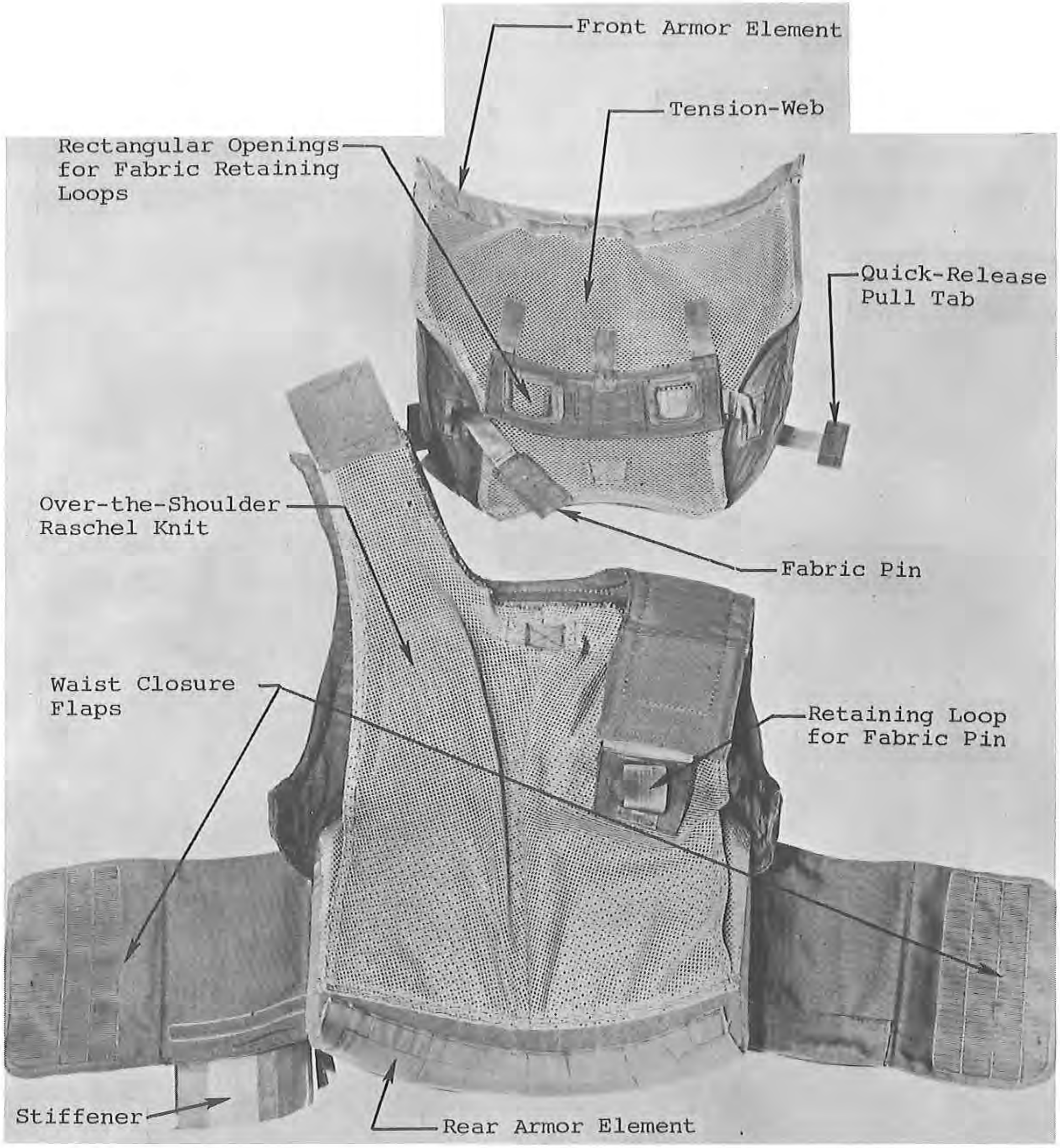

Figure 3. Prototype #2 Layout - Over-the-Shoulder Raschel Knit, Tension-Web Suspension with "Fabric Pin Quick-Release" Shoulder Breaks

a fabric reinforcement section sewn to it containing two rectangular openings. Fabric loops sewn to each of the shoulder straps, support the back armor element. The loops fit through the rectangular openings for assembly. A fabric semirigid pin is then inserted through the loop to complete the shoulder break. A strap is stitched to the release pin and passed through a slot sewn in the peripheral protection of the front armor carrier. It terminates in a fabric "T" which prevents the strap from pulling through the slot. This gives the wearer something to grab when releasing the shoulder breaks (Figure 4).

The combined suspension systems approach (over-the-shoulder raschel knit and tension-web) used in Prototype #2 has the same advantages listed for Prototype #1. The relative merits of the two shoulder break concepts will be discussed in Part II of this report.

Prototype #3 - Waist Augmentation Suspension

The waist augmentation concept permits the wearer to transfer armor load to the hips and waist. Entire armor weight may be transferred, or any percentage of the load, according to the wearer's option. This is accomplished through the use of a waist augmentation belt (Figure 5).

The waist augmentation belt is worn on the hips and about the waist as shown in Figure 6. It has a Velcro front closure which retains the belt and permits size adjustability. Two vertical Velcro straps, one on each side of the waist augmentation belt located above the hips, are used to lift the armor suspension system (Figure 7). They are then secured to the waist closure flaps of the suspension system (Figure 8). This transfers armor load through the vertical straps to the waist augmentation belt. The belt in turn transfers load to the wearer's hips and waist.

Stiffening elements (metallic or plastic) in the waist augmentation belt and the waist closure flaps act as shear elements and are necessary for proper load transference. They are shown in Figure 3.

The waist augmentation belt may be worn with either Prototypes #1 or #2. The advantages of this suspension system are:

- Armor load may be transferred totally or partially from the shoulders, chest, and back to the hips which are excellent load bearing areas.
- The wearer can select the degree of load transference desired.

Figure 4. Prototype #2 Front View - Over-the-Shoulder Raschel Knit, Tension-Web Suspension - Fabric Pin Quick-Release Shoulder Breaks

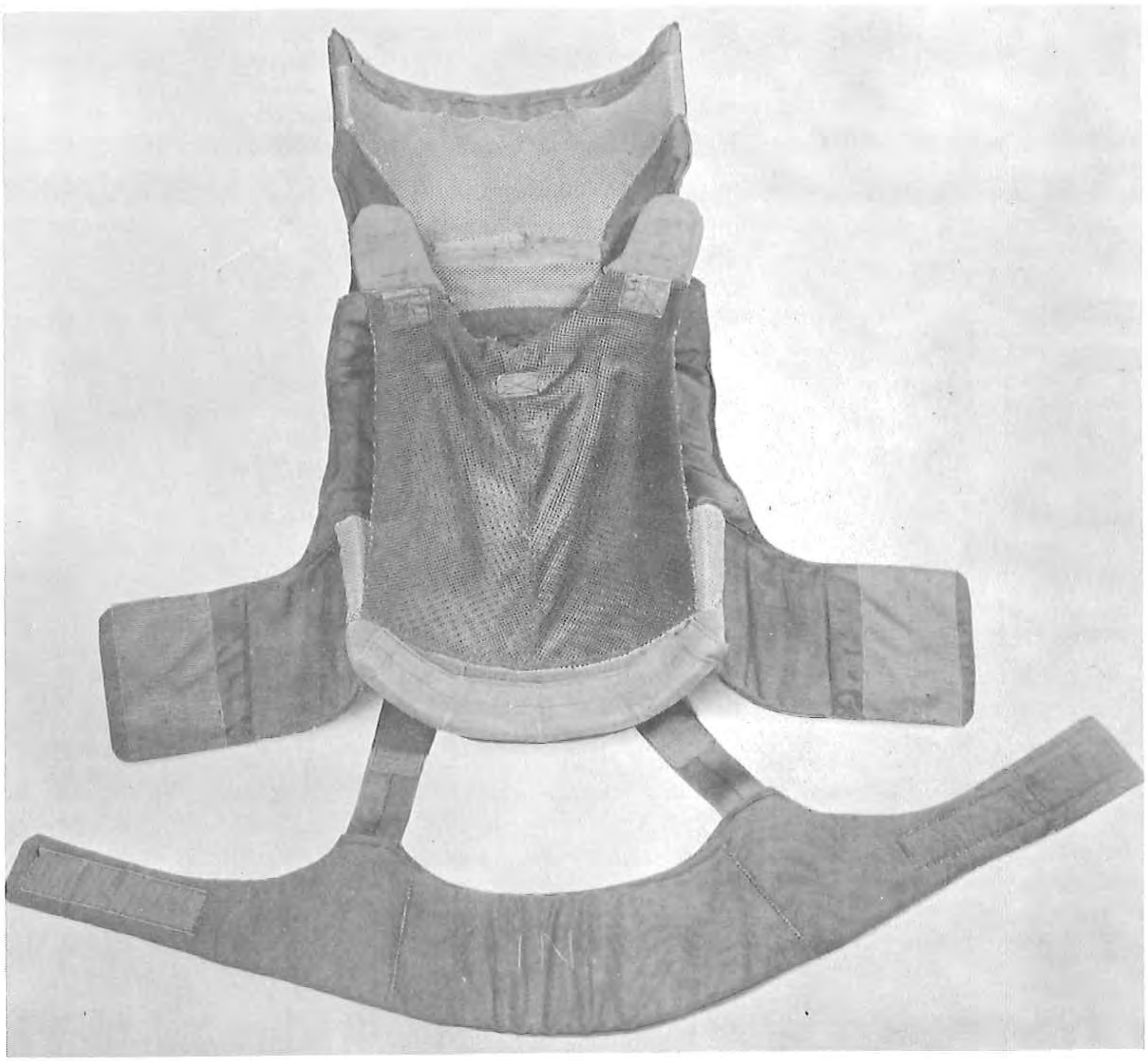

Figure 5. Prototype #3 Layout -
Waist Augmentation Suspension

Figure 6. Prototype #3 - Waist Augmentation Belt as Worn (Not Connected to Upper Suspension)

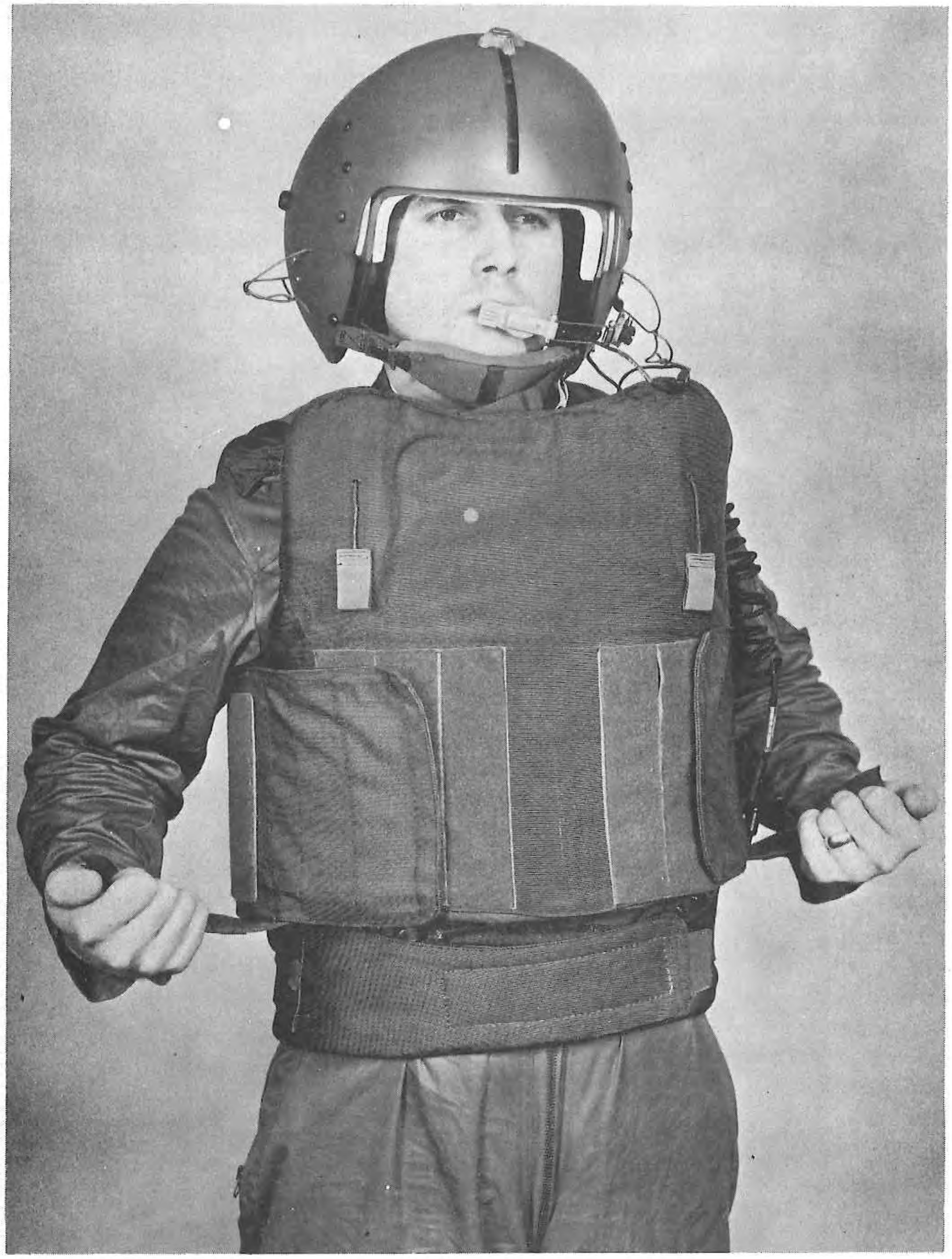

Figure 7. Prototype #3 - Waist Augmentation Belt as Worn (Load Being Transferred)

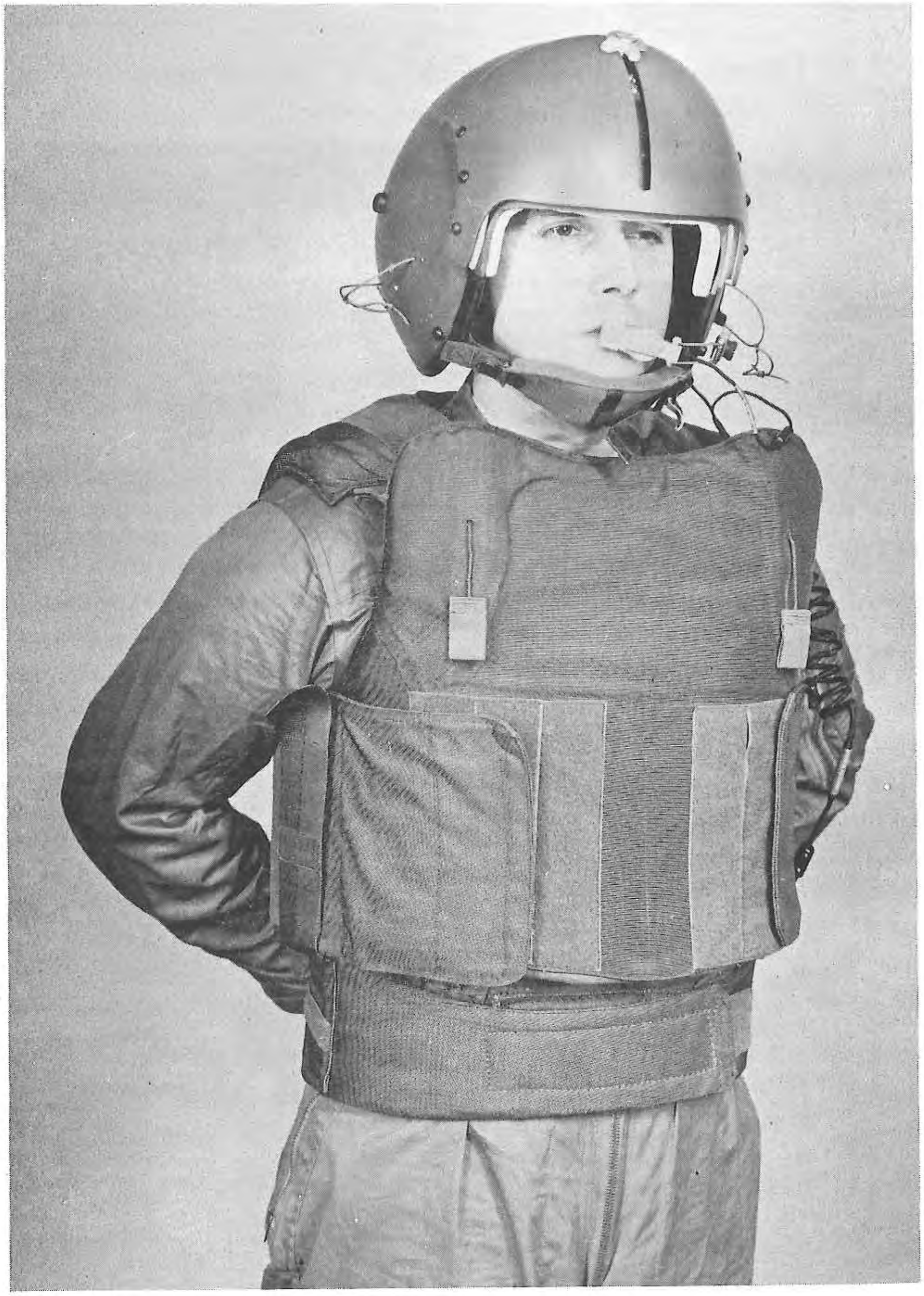

Figure 8. Prototype #3 - Front View Hip Suspension Waist Augmentation Approach

- Comfort, endurance, and fatigue resistance are significantly improved (Suspension Systems Evaluation, Part III of this report).
- The waist augmentation belt can be used with any suitably modified armor carrier.
- The belt is simple to fabricate and inexpensive.

A summary and comparison chart for Prototypes #1 through #3, and the Army Standard Aircrewmen Body Armor Carrier developed by the U. S. Army Natick Laboratories (NLABS) was compiled in Table I. In this table, the type of suspension, area coverage, suspension weight (fabric carrier and fittings), and total weight of the various suspension systems (including "medium-regular" ceramic/glass reinforced plastic ballistic anatomically shaped armor plates are compared.

A review of the table indicates that area coverage has been increased with only a nominal percent increase in overall weight. The weight increase includes the suspension systems and related hardware (e.g., shoulder breaks).

B. Evaluation Results

An evaluation of the suspension systems was conducted. The purpose of the evaluation was to determine if the suspension principles incorporated in the prototypes did improve comfort and load distribution compared to existing armor carriers.

A group of 21 test subjects was used for the evaluation. Their anthropometric characteristics are listed in Table IV. Each subject wore Prototypes #1, 2 and 3, and the standard Army aircrew armor carrier (modified) with experimental anatomically shaped armor which was used as the control item.

The degree of acceptability of the armor suspension systems, based on the comments of the 21 test subjects, is presented in Table II. The table was compiled from evaluation questionnaires which summarized the individual responses of the test subjects to each suspension system. Samples of the individual evaluation questionnaires are included in Appendix A.

Summarized evaluation questionnaires were compiled for each suspension and are included in Appendix B. They indicate, with Table II, that suspension systems were improved by applying design principles used in related load-bearing and load distribution fields.

Table I

PROTOTYPE SUMMARY AND COMPARISON

	Type of Suspension	Area Coverage			Suspension Weight (Fabric Carrier Plus Fittings) (lb)	Total System Weight (lb)	
		Peripheral (sq ft)	Peripheral Plus Armor** (sq ft)	Increase Over Control Item (percent)		Suspension Plus Armor Plates* (lb)	Increase Over Control Item (percent)
Prototype #1	Combination Cantilever Tension-Web	1.57	4.48	22.3	3-1/2	34-7/8	1.43
Prototype #2	Combination Cantilever Tension-Web	1.57	4.48	22.3	3-1/2	34-7/8	1.43
Prototype #3 (Waist Augmentation Belt Worn with Prototype #1)	Hip Suspension (Waist Augmentation) in Combination w/Cantilever Tension-Web	Waist Augmentation Belt = 1.32 Other = 1.57	5.8	40	Belt = 1-1/2 Other = 3-1/2 Total = 5	36-3/8	5.5
Army Standard Aircrew Carrier***	Padded Shoulder Straps	0.57	3.48	Control Item	3	34-3/8	Control Item

*"Medium-Regular" Experimental Anatomical Shape Armor Plates, Weight: Front = 14.25 lbs
Rear = 17.125 lbs

**Protection Area Coverage: Front = 1.31 sq ft
Rear = 1.60 sq ft

***Mil-C-43544, Carrier, Body Armor, Aircrewman, Small Arms Protective Modified for Experimental Anatomical Shape Armor Plates

Table II

SUSPENSION SYSTEMS ACCEPTABILITY

Suspension System	Load Distribution	Comfort	Mobility	Ventilation	Fatigue Resistance	Armor Positioning	Armor Stability	Ease of Donning	Ease of Doffing	Peripheral Protection
Tension-Web (Front) and Integrated Tension-Web, Over-the-Shoulder Raschel Knit Back Suspension 1	Excellent	Very Good	Good	Very Good	Good	Very Good	Very Good	Good	Excellent	Very Good
Fully Integrated Tension-Web, Over-the-Shoulder Raschel Knit Front and Back Suspension 2	Excellent	Very Good	Good	Very Good	Good	Very Good	Very Good	Good	Very Good	Very Good
Waist Augmentation Worn with Suspensions 1 and 2 Suspension 3	Excellent	Excellent	Fair	Excellent	Excellent	Excellent	Very Good	Good	Good	Excellent
Control Item - Standard Aircrew Carrier (Modified)	Fair	Good	Excellent	Good	Fair	Fair	Good	Fair	Fair	Fair

The following section summarizes the advantages and disadvantages of the armor suspension systems developed under this contract.

C. Suspension Systems Advantages and Disadvantages

Prototypes #1 and 2 combined the over-the-shoulder raschel knit and tension-web suspensions resulting in the following advantages:

Advantages of Prototypes #1 and 2 (Over-the-Shoulder Raschel Knit - Tension-Web Suspensions)

- Improved load distribution on optimum load-bearing areas of the torso (back, shoulders, and chest).
- Tension-web suspension minimizes pressure points by holding rigid armor away from the torso.
- Improved comfort, increased endurance and reduced fatigue.
- Improved ventilation.
- Improved armor positioning and stability on the body. (Front armor may be worn alone without reducing stability.)
- Improved comfort by moving the shoulder breaks off the shoulder and into the upper chest area.
- Shoulder breaks use new concepts of quick-release, primarily (a) quick-release buckle and (b) fabric pin release. Both release rapidly and give the option of releasing either shoulder break or both for rapid doffing.
- Overhead donning and double flap waist closure for simplified donning.
- Increased peripheral protection.
- Properly designed head opening permits overhead donning and eliminates the need for shoulder adjustments.

Advantages of Prototype #3 (Waist Augmentation Suspension)

- Armor load may be transferred partially or entirely from shoulders to hips.
- Load transference capability improves comfort, increases endurance, and reduces fatigue.
- Waist augmentation belt will function with any armor carrier that has been properly modified.
- Increased peripheral protection.

Disadvantages of Prototypes #1, 2 and 3

- Increased complexity of fabrication.
- Higher production costs.
- Wearer must remove helmet when donning overhead.
- Prototype #3 increases doffing time because of two extra side closures.

PART II. DEVELOPMENT EVOLUTION OF SUSPENSION CONCEPTS

A. Design Criteria

The suspension principles surveyed in Phase I were applied to the improvement of armor suspension systems in Phase II. The survey helped formulate design criteria and design guidelines which were useful in improving comfort and load distribution.

The following suspension principles and design criteria resulted from the survey:

- Loads carried on the body should be positioned on optimum load-bearing areas of the body (hips, back and shoulders, in that order).
- Optimum load-bearing areas are the muscular or fleshy portions of the body.
- Load center of gravity should coincide with human body center of gravity as closely as possible.
- Load should be distributed over the greatest possible area of the torso, avoiding naturally sensitive or bony areas which could result in irritating pressure points.
- Semirigid suspension elements can be used in conjunction with fabrics to absorb impact loads and assist in distribution of loads over large areas of the body.
- Load transfer to the hips is desirable. It increases load-carrying capacity, reduces fatigue, and increases endurance as compared to carrying loads on the shoulders or back.
- The "beam-pad" principle should be applied, where possible, for shock absorption and maximum load distribution.

  The "beam-pad" principle is a combination of rigid and flexible materials arranged so that the assembly tends to decrease radius of curvature under load causing the protective device to hug the wearer and distribute load over a greater area. Football shoulder pad construction is an example of this principle.

The preceding design criteria relate to armor suspensions. Other design factors were considered which relate to the psychological parameters affecting suspension systems design.

- Provide maximum ballistic coverage with minimum restriction to articulation
- Provide mobility which will not prevent the wearer from performing his military duties
- Design the protective garment to look like a standard article of clothing familiar to the wearer
- Style the garment to reduce the appearance of bulk
- Design the closures so that they can be easily actuated
- Provide for donning techniques that are familiar to the wearer
- Provide adequate ventilation
- Consider the need for rapid, foolproof emergency doffing to overcome the fear of being trapped in the armor

Suspension and load-distributing techniques surveyed in Phase I and applied to protective and load-carrying systems, are summarized in Table III. The materials used to distribute load, the area of the body on which loads are distributed, the type of loading (long duration or shock), and the load-bearing capability are indicated in the table, which covers sporting, commercial, military, medical and industrial equipment.

The table served as an aid in establishing the principles used to improve armor suspension systems.

B. Early Suspension Approaches

A chronological discussion of all suspension systems developed follows.

Rucksack Carrier Suspension - Concept #1

The rucksack carrier design used heavily padded shoulder straps, with tension straps across the back to distribute load. The suspension system is shown in Figure 9. The rigid armor elements were contained in a fabric carrier. Shoulder

Table III

SUMMARY OF PROTECTIVE AND LOAD CARRYING SYSTEMS

Field Of Investigation		Item	Type Of Suspension: Cantilever Suspension (Rigid Material Plus Padding)	Type Of Suspension: Tension Members (Webbing-Straps)	Compression Members: Resilient Padding	Compression Members: Webbing With Pads	Compression Members: Rigid Mat'ls	Functional Characteristics: Load Distribution On Body	Functional Characteristics: Shock Absorbing Capability	Functional Characteristics: Load Carrying Capability
Early Carriers		Fulcrum (Pole) Carrier					X	Shoulders and Back	Poor	Excellent (To 1500 lbs)
		Yoke Carrier					X	Shoulders and Back	Poor	Excellent (To 500 lbs)
		"A" Frame Carrier		X			X	Shoulders and Back	Fair	Good (To 200 lbs)
		Inverted "A" Frame Carrier		X			X	Shoulders and Back	Fair	Excellent (To 300 lbs)
		Basket Carrier		X				Head and Back	Poor	Fair (To 100 lbs)
		Head Carrier			X			Head	Poor	Poor (To 75 lbs)
Athletics	Football	Shoulder Pads	X	X	X			Shoulders and Chest	Excellent	----
		Aux. Shoulder Protector			X			Shoulders and Chest	Excellent	----
		Kidney Protector	X	X	X			Pelvic Area	Excellent	----
		Helmets	X	X	X	X		Head	Excellent	----
		Forearm Protector			X			Forearm	Fair	----
		Upper Arm Protector			X	X		Upper Arm	Fair	----
		Thigh Protector	X		X			Thigh	Excellent	----
	Baseball	Leg Protectors	X	X	X			Shin & Calf	Excellent	----
		Chest Protectors		X	X			Chest	Good	----
		Face Masks		X	X		X	Face	Good	----
		Helmets	X	X	X	X		Head	Excellent	----
		Gloves (Catchers and Fielders)			X			Hands	Excellent	----
	Basketball	Knee Pads		X	X			Knees	Excellent	----
	Boxing	Head Protector		X	X			Head	Good	----
		Gloves			X			Hands	Excellent	----
	Wrestling	Head Protector		X	X			Head	Good	----
	Hockey	Leg Guards	X	X	X		X	Legs	Excellent	----
		Torso Protectors		X	X			Chest-Thighs	Fair	----
		Helmets	X	X				Head	Good	----
		Knee Pads			X			Knee	Good	----
	Speedboating Polo	Helmets	X	X	X	X		Head	Excellent	----
	Skydiving Motorcycling	Knee Pads			X			Knee	Good	----
Camping and Mountain Climbing		Knapsack Carrier		X				Shoulders and Back	Good	Fair (To 20 lbs)
		Framed Rucksack Carrier		X			X	Shoulders and Back	Good	Good (To 40 lbs)
		Rigid or Semi-Flexible Frame Carrier	X	X	X	X		Shoulders, Back and Hips	Excellent	Excellent (To 300 lbs)
Military Equipment		Rucksack Carrier	X	X	X	X		Shoulders and Back	Good	Good (To 200 lbs)
		Pistol Belt		X				Shoulders and Hips	Good	Good (To 50 lbs)
		Helmets	X	X				Head	Good	----
		Personnel Armor Suspensions		X	X			Shoulders	Fair	Fair (To 30 lbs)
Medical Equipment		Braces		X	X		X	Limbs, Head, Torso	----	----
		Traction Devices		X	X	X	X	Limbs, Torso	----	----
		Casts					X	Limbs, Torso	Good	----
Occupational and Industrial Equipment	Firemen Policemen Steelworkers	Helmets	X	X	X	X		Head	Excellent	----
	Welders Grinders	Face Protectors		X			X	Head	----	----
	Mill Hands Shop Hands	Leg Protectors		X	X		X	Leg and Foot	Excellent	----

Figure 9. Concept #1 - Rucksack Carrier Suspension

straps were sewn to the rear armor carrier, as shown in Figure 10. The front element was supported in a fabric carrier which was sewn to the rear carrier on one side only. The concept was of the front donning type. The front element was positioned and retained by Velcro waist closure straps (Figure 9).

The approach had several advantages. The heavily padded shoulder straps distributed load comfortably. The disadvantages of the concept were difficulty in donning and doffing and confusion in making the waist closures. The shoulder straps did not attach to the front armor element. This made the element unstable and difficult to position. The concept was discarded as a suspension system approach.

<u>Over-the-Shoulder Raschel Knit Suspension System - Concept #2</u>

The over-the-shoulder raschel knit suspension used the principle of maximum load distribution over the greatest area of the torso. Raschel knit (being a nonextensible, flexible fabric) was used to conform to compound curves of the torso. Under tensile loads, the raschel knit provided excellent load distribution without inducing pressure points on the torso.

The raschel knit was integrated into the armor suspension system as shown in Figure 11. It was sewn to the rear and front armor retention pockets, and to the left-hand closure flap. The raschel knit supported both armor elements halfway up the rigid element. This permitted the armor to be raised high enough on the torso for proper positioning.

The raschel knit suspension system shown in Figure 12 is front donning with a single vertical Velcro flap closure. A ballistic nylon collar was used. Ballistic nylon felt was placed over the armor elements to act as a spall shield. Felt provided protection in peripheral areas such as the upper chest and underarms.

The raschel knit suspension distributed load comfortably without inducing uncomfortable pressure points. The disadvantages of the approach were that it was extremely difficult to don and doff rapidly, and ventilation was poor.

Figure 10. Concept #1 - Rucksack Carrier Suspension with Front Element Released

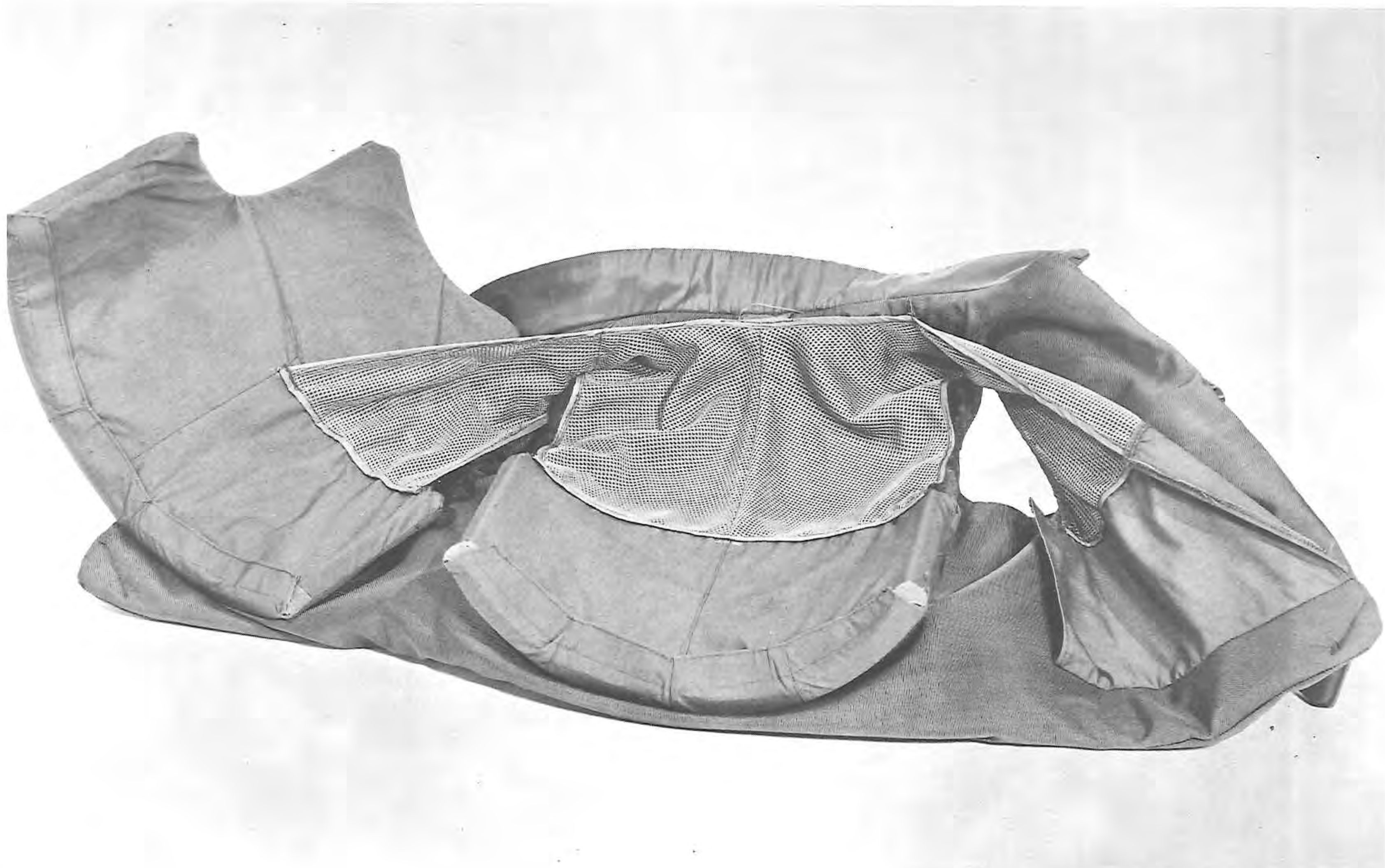

Figure 11. Concept #2 - Over-the-Shoulder
Raschel Knit Suspension Layout

Figure 12. Concept #2 - Over-the-Shoulder Raschel Knit Suspension (Front View)

Tension-Web Suspension System - Concept #3

The tension-web suspension concept was derived from the survey study of rucksack carriers. The carriers used horizontal fabric straps under tension to distribute load across the back and prevent the carrier frame from contacting the body. It was felt that the same suspension principle could be applied to armor suspensions. Several carriers were fabricated where tension webs were integrated into the carrier. These were flexible fabric webs or straps sewn to the suspension so that they would lie along the chord line formed by the inside curvature of the armor elements. Armor weight and the clamping force of the waist closure put the straps or webs in tension. This prevented the rigid armor elements from directly contacting the torso, thereby minimizing possible pressure points. The webs or straps distributed load over greater areas of the back and chest.

The improvement in load distribution and comfort achieved with the tension-web approach led to the development of the advanced tension-web suspension concept shown in Figure 13. A continuous fabric tension member was laced to the front and rear fabric bags containing the armor elements. The laces permitted the tension in the member to be adjusted so that the rigid armor elements could be just lifted off the torso. This prevented direct armor contact with the body. It minimized pressure points and improved comfort through better load distribution. It also provided ventilation by allowing air to circulate between the armor and the torso.

The concept was of the front-donning type. As in other front-donning approaches, it was difficult to put on because of the heavy armor elements being balanced behind the body during donning. The tension-web principle proved sound and was further improved upon in the following concept.

Combined Raschel Knit, Tension-Web Suspension - Concept #4

The application of over-the-shoulder raschel knit and tension-web suspensions in separate concepts produced such promising results that it was decided to combine them. It was reasoned that if each of the suspensions improved comfort and load distribution, then both suspensions combined should result in additional benefits.

Figure 13. Concept #3 - Tension-Web Suspension System

The combined raschel knit tension-web concept is shown in Figures 14 and 15. The tension-web member was fabricated from raschel knit to improve ventilation, and to distribute load more efficiently. The adjustment laces used in Concept #3 (Figure 13) were eliminated.

The tension-web suspension was used on the front and rear armor carriers. It was integrated into the fabric pockets by being sewn to the periphery of the pocket (Figure 14). Fabricating techniques and armor tolerances determined the magnitude of the tension in the web.

The raschel knit over the shoulders was sewn to the bottom of the front and rear armor carriers with the following advantages:

- This permitted the armor elements to be properly positioned on the torso.
- Gripping the elements at the bottom located the armor center of gravity so that the armor plates rotated away from the torso, reducing normal forces on the body produced by armor weight.

The combined over-the-shoulder raschel knit, tension-web suspension improved comfort. It presented a clean appearance when worn (Figure 15). The raschel knit over the shoulder distributed the load well. It was learned that edge treatment of the raschel knit could be critical. The addition of seam binding or other edge treatment (heat sealing or coatings) tended to stiffen the edges which produced pressure lines.

Velcro was used in the shoulder breaks. It proved unsatisfactory because the material build-up produced uncomfortable pressure on the shoulders. The Velcro breaks (Nylon Hook No. 80, Standard Nylon Pile, #660 Green, American Velcro Inc.) had insufficient retention and tended to separate during donning.

The raschel knit over the shoulder positioned the front and rear armor elements well. The tension-web stretched across the chord line of the elements held the armor away from the torso. The overall effect was improved comfort.

Rigid side plates were added to the waist closure flaps (Figure 14) to help stabilize the front and rear armor elements. They were contained in pockets. The plates permitted the fabric side closure to take vertical shear loads in

Figure 14. Concept #4 - Over-the-Shoulder
Raschel Knit, Tension-Web Suspension

Figure 15. Concept #4 - Over-the-Shoulder Raschel Knit, Tension-Web Suspension (Front View)

addition to mechanically coupling the front and rear armor elements together. They increased peripheral protection. The waist closure flaps served the purpose of clamping the armor elements to the torso in addition to providing the tensile force necessary to activate the tension-web suspension members.

Hip Suspension-Waist Augmentation Suspension - Concept #5

The survey study of Phase I concluded that the hips and waist were excellent load-bearing areas. Many designs and potential applications to suspension systems were investigated, and a discussion of these designs and their evolutionary development follows.

Approach #1

The initial idea of a hip suspension system began with the conceptual sketch shown in Figure 16. A waist closure strap which was integral with the basic carrier included two large sponge rubber hip pads. The pads were sewn into pockets in the waist closure straps. They rested on the hips of the wearer when the closure was secured. The pads were to lie beneath the rear armor element and support it, transferring armor weight to the hips and waist. Similar pads were successfully used in rucksack carrier design.

Approach #1 was fabricated in mock-up form (Figure 17) using two large hip pads secured to the rear armor element with straps. (The pads lay beneath the rear element.) Load transference was not accomplished. The flare-out at the bottom of the rear armor element made it impossible to transfer load through the hip pads.

Approach #2

A broad stiff fabric waist band was fabricated in an attempt to distribute load to the waist and hips, (Figures 18 and 19).

The band went across the back of the waist and around the sides to the hips. The top of the band was sewn to the bottom of the fabric carrier containing the rear armor element. The weight of the front and rear elements was to be transferred through the carrier to the waist band. The system proved to be uncomfortable even though it did transfer weight. The belt stiffness produced pain and made it difficult to manage while donning.

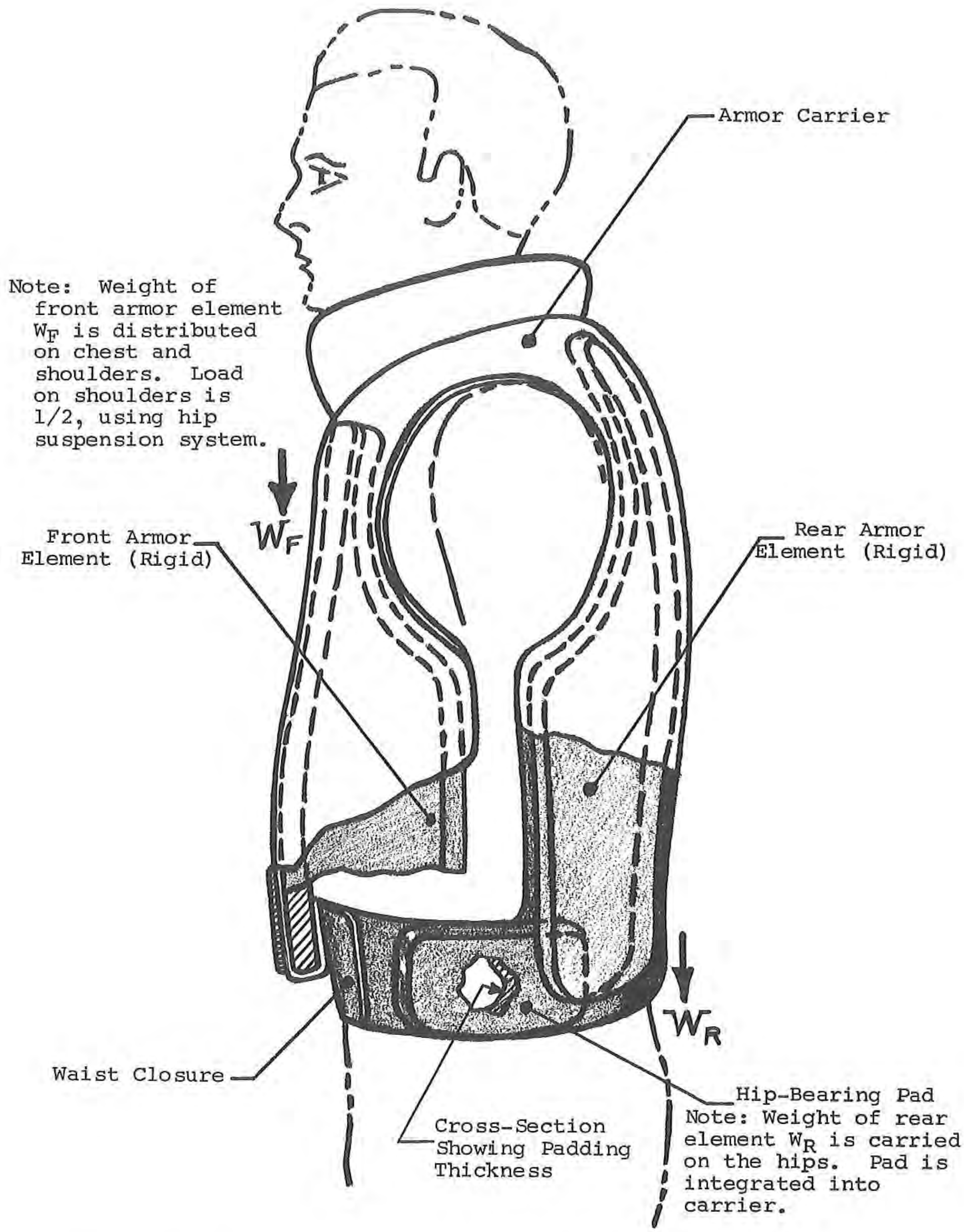

Figure 16. Approach #1 - Hip-Bearing Suspension System

Figure 17. Approach #1 - Elementary Hip Suspension System

Figure 18. Approach #2 - Waist Band Hip Suspension

Figure 19. Approach #2 - Rear View of Waist Band Hip Suspension

Approach #3

Improvement of load distribution on the waist and hips was attempted in Approach #3 (Figures 20, 21 and 22). A broad heavily padded waist band was integrated into the basic carrier as shown in the layout view of the suspension (Figure 20). It was believed that armor load could be more effectively transferred to hips and waist by the broad band which covered a maximum area of the torso (Figure 21).

The approach did transfer load, but had undesirable features. It was unbearably hot (poor ventilation). The system of redundant waist closures made donning confusing (Figure 21), and weight was excessive because of bulk.

Approach #4

A breakthrough in hip suspension philosophy was achieved in Approach #4. The concept of a waist augmentation belt was conceived. It resulted as an outgrowth of attempts to reduce bulk (Approach #3) and to distribute loads over greater areas.

Another change in design philosophy was that the hip suspension approach should only support the rear armor element which, in turn, supported the front armor element by the suspension system over the shoulders.

The significant design features of the waist augmentation belt is that it supports the front and rear armor elements simultaneously. It raises the entire suspension system as a unit, and transfers armor load to the hips and waist.

A layout of the waist augmentation belt is shown in Figure 23. It is of fabric construction. It is pliable and relatively soft with the exception of two stiffening elements inserted in fabric pockets located on the hips. These stiffeners are necessary to transfer load to the waist augmentation belt. Attached to the tip of the pockets are two straps (one on each hip). The straps pass through buckles fastened to two rigid elements (metallic or plastic) which are retained in the Velcro waist closure of the armor suspension system. The rigid elements act as shear members, and permit the suspension system to be lifted as shown in Figure 24. This transfers armor load from the shoulders to the waist and hips. The wearer can select the degree of load

Figure 20. Approach #3 - Broad Waist Band Hip Suspension

Figure 21. Approach #3 - Broad Waist Band Secured

Figure 22. Approach #3 - Broad Waist Band Hip Suspension Double Flap Closure

Figure 23. Approach #4 Layout - Waist Augmentation Belt

Figure 24. Approach #4 - Waist Augmentation Belt - Load Transference Technique

transference. The entire armor weight may be transferred, or any portion of the load, to suit the wearer's requirements for comfort. The straps, through the buckles, lock the suspension system into the selected position (Figure 25).

The disadvantages of the system are complexity of donning (because the waist augmentation belt is an integral part of the armor suspension assembly), and reduced mobility when bending sideways at the waist.

Approach #5

The waist augmentation belt was made completely separate in Approach #5. It is shown in a layout view (Figure 26) and being worn (Figure 27). The buckles and extended sideplates of Approach #4 (Figure 23) were eliminated. Velcro pile was sewn to the lifting straps of the waist augmentation belt. Velcro hook was added to the side closure flaps of the suspension system (Figure 28). The rigid shear elements are still employed in the waist closure flaps (Figure 26) and the waist augmentation belt to accomplish load transference properly. After armor load is transferred, the lifting straps are secured, as shown in Figure 29.

The advantages of this approach may be listed as follows:

- The waist augmentation belt is worn as a completely separable item which simplifies donning.
- The belt can be worn with any suitably modified suspension system.
- The belt is completely fabric with the exception of the stiffeners. This makes it comfortable, easy to fabricate, and inexpensive.
- It does not restrict mobility.
- It increases peripheral protection.
- The waist augmentation belt provides any desired degree of load transference. It improves comfort and endurance.

Approach #5 was chosen for the final prototype fabrication.

Figure 25. Approach #4 - Waist Augmentation Belt - Load Transferred to Waist and Hips

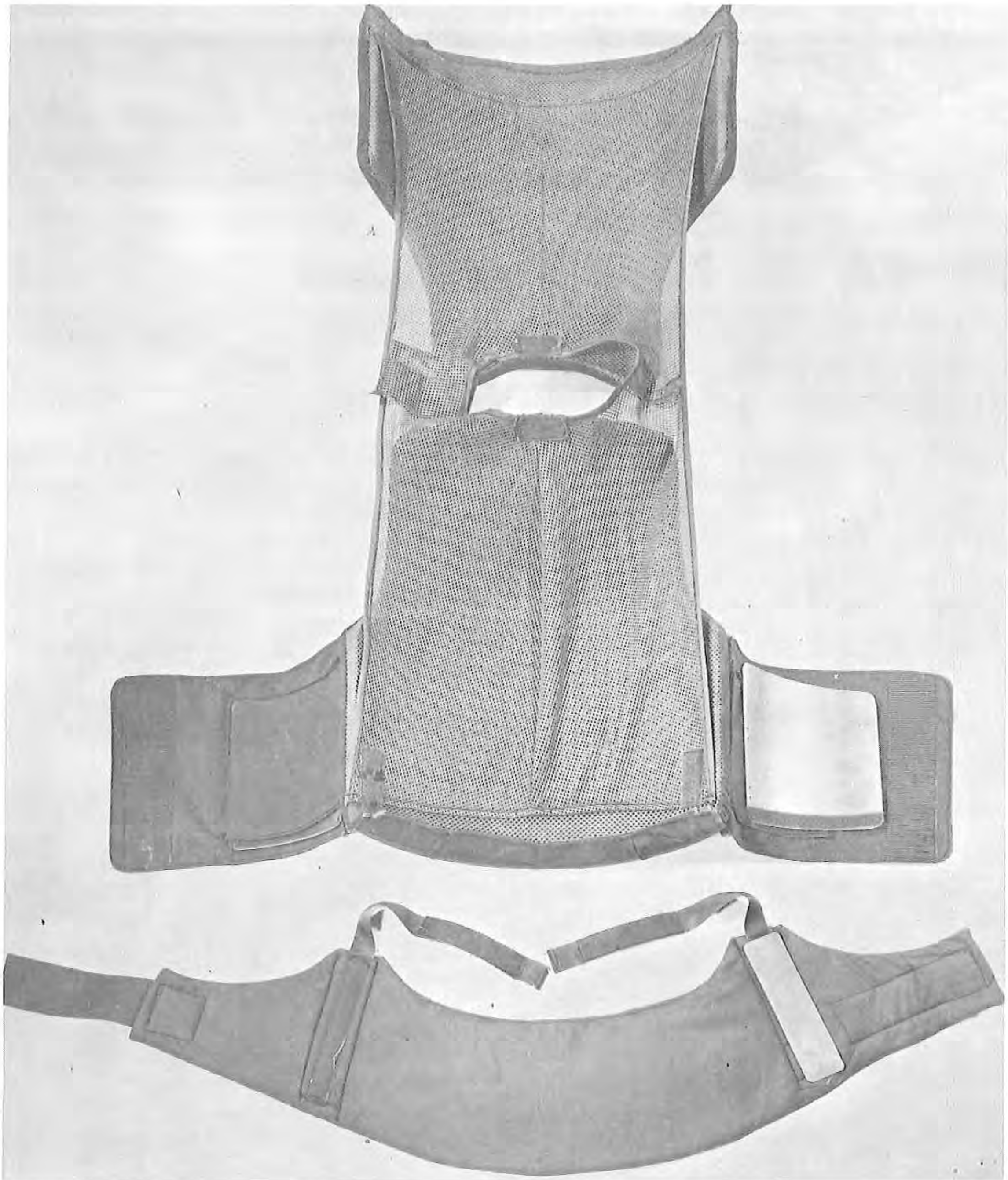

Figure 26. Approach #5 - Layout of Improved Waist Augmentation Belt

Figure 27. Approach #5 - Waist Augmentation Belt Being Worn (Completely Separable from Armor Suspension System)

Figure 28. Approach #5 - Method of Load Transference to Waist Augmentation Belt

Figure 29. Approach #5 - Load Transferred and Secured - Waist Augmentation Suspension Belt

C. Other Areas of Development

Armor suspension systems development included improvements in peripheral protection, ventilation, and quick-release closures.

1. Quick-Release Hardware Development

A mechanical device similar to the seat buckle used in automotive and aircraft safety belts, was developed. The buckle was miniaturized so that it might be used as a shoulder break for armor suspensions. It incorporates a quick-release feature, making it desirable for this application.

Several buckle approaches were developed (Figure 30). A cam lock device using serrated teeth (Figure 30a) was fabricated. A cord passing between the cam teeth locked in place when pulled to the left, and released when pulled to the right. It was discarded because of the abrasive action of the cam teeth against the cord which would limit life expectancy.

Two seat buckle concepts were developed (Figures 30b and 30c), and they differ in the manner of strap adjustment. The buckle in Figure 30b passes the strap around a serrated rod (Rod B) which, under tension, jams the strap between itself and the rearmost rod (Rod A) of the seat buckle. Lifting up on the loose end of the strap relieves the locking action of the serrated rod and permits readjustment of the strap.

The same adjustability was provided in the buckle shown in Figure 30c without the use of moving parts. However, this approach had a tendency to slip under load.

The quick-release characteristics of both buckles was accomplished with a tongue and groove configuration (Figure 31). The buckle male insert (d) contains a rectangular hole. The base plate (b) of the buckle has a spring-loaded release lever (c) which contains a triangular wedge (d) of metal which inserts into the rectangular hole of the male insert when both parts are locked together (e). Lifting up on the release lever immediately disconnects both members. The buckle locks positively and will not release until the release lever is lifted. It can withstand high tensile loads, and the component parts of the buckle are relatively simple, lending themselves to mass production.

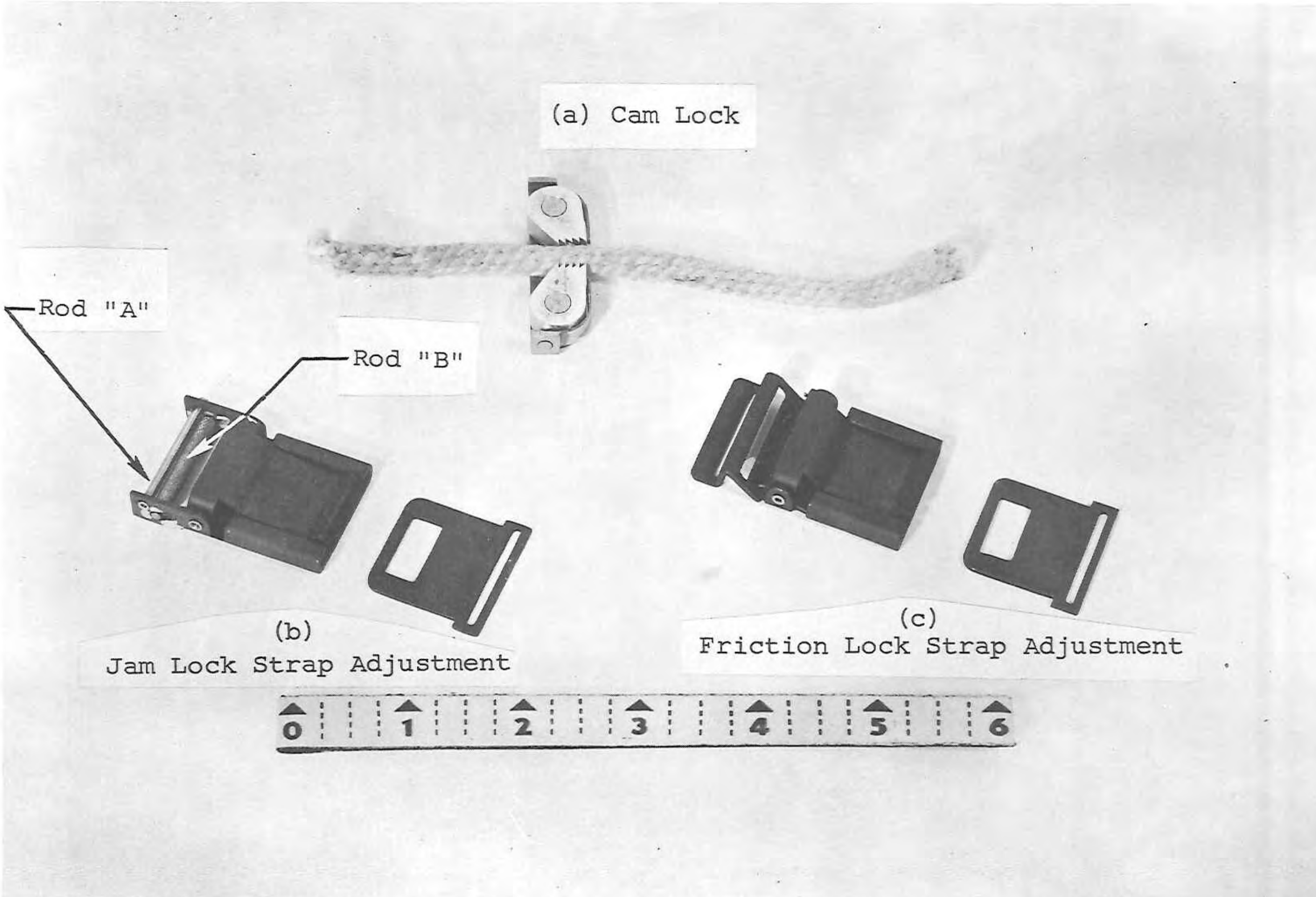

Figure 30. Quick-Release Buckle Approaches

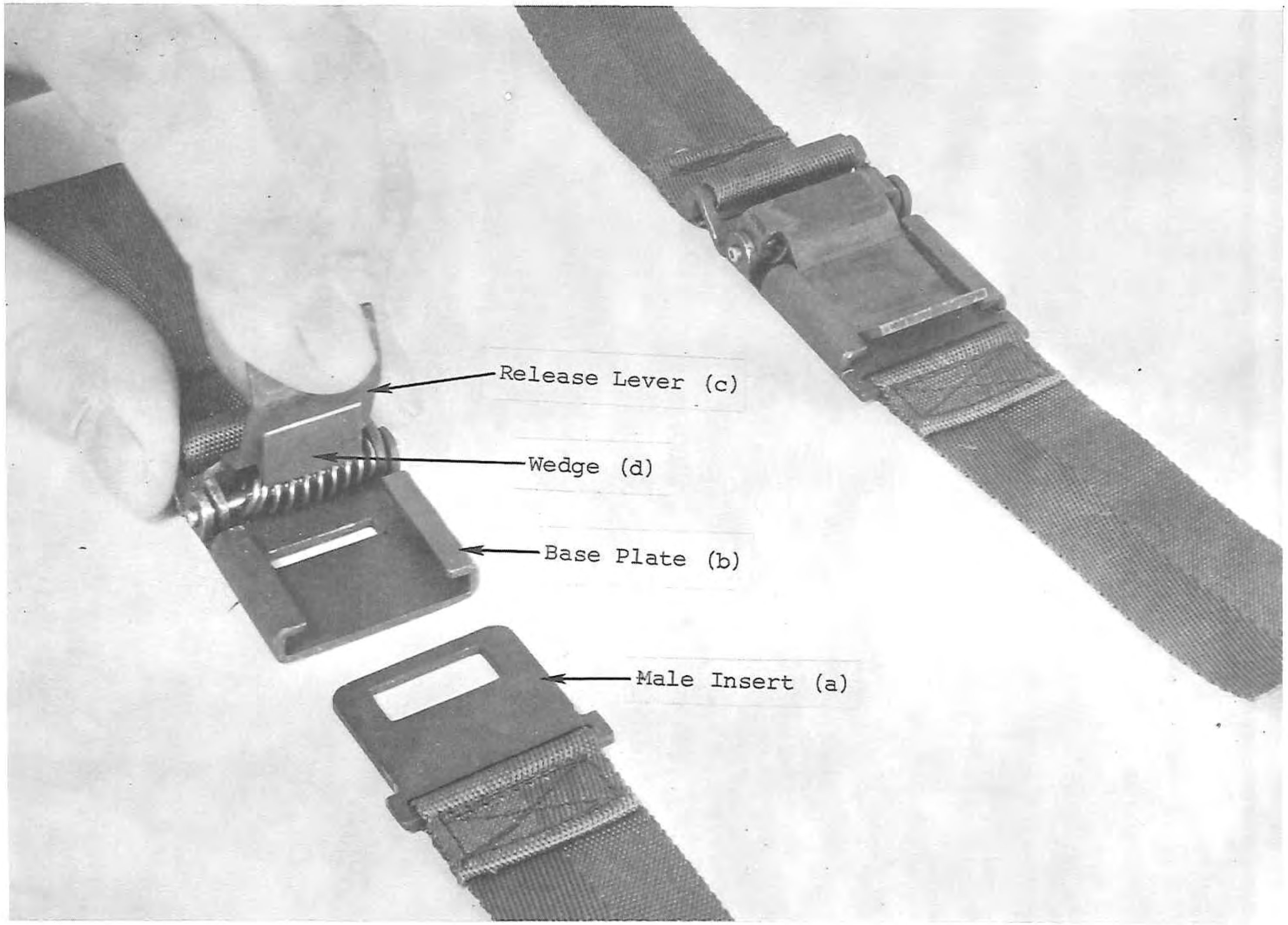

Figure 31. Miniaturized Quick-Release Buckle

2. Quick-Release Shoulder Break Concepts

a. Modified Army Carrier with Snap Shoulder Breaks

A standard Army armor carrier (modified) was used to study the problem of quick-release shoulder and waist closures for rapid doffing. A carrier was modified (Figure 32) by adding a network of guided straps leading to the shoulder and waist closures. They were secured with snaps. By pulling on the vertical strap (Figure 33), it was possible to rapidly break both shoulder and waist closures simultaneously. The rapidity of release momentarily left the back armor suspended in position before falling (Figure 34).

The system worked well, but was not adaptable to the latest suspension systems under development. However, the approach did form the foundation for some of the quick-release features finally incorporated in the finished prototypes.

b. Velcro Closure Shoulder Break

Velcro was used in the shoulder breaks for quick release (Figures 14 and 15). Velcro pile (2 in. x 4 in. rectangle) was sewn to the raschel knit shoulder straps supporting the back armor element. The hook (2 in. x 4 in. rectangle) was sewn to the raschel knit shoulder straps supporting the front armor element. The shoulder breaks, when secured, rested on the shoulder. They could be released by pulling up on a release flap sewn to the flap of the Velcro closure.

The approach appeared sound initially, but problems arose. Treatment of the peripheral protection was difficult, since overlapping the felt at the shoulder breaks was too bulky. Alternatively, a butt joint was tried. The ends of the peripheral protection were sewn to the ends of the shoulder breaks so that when the closure was secured, the peripheral material formed a butt joint. This gave continuous protection over the shoulder.

The Velcro closure concept worked, but exhibited the following disadvantages which caused it to be discarded:

- The Velcro pads tended to release during donning.
- Material buildup (2 layers of Velcro) on the shoulder produced pressure points and discomfort.

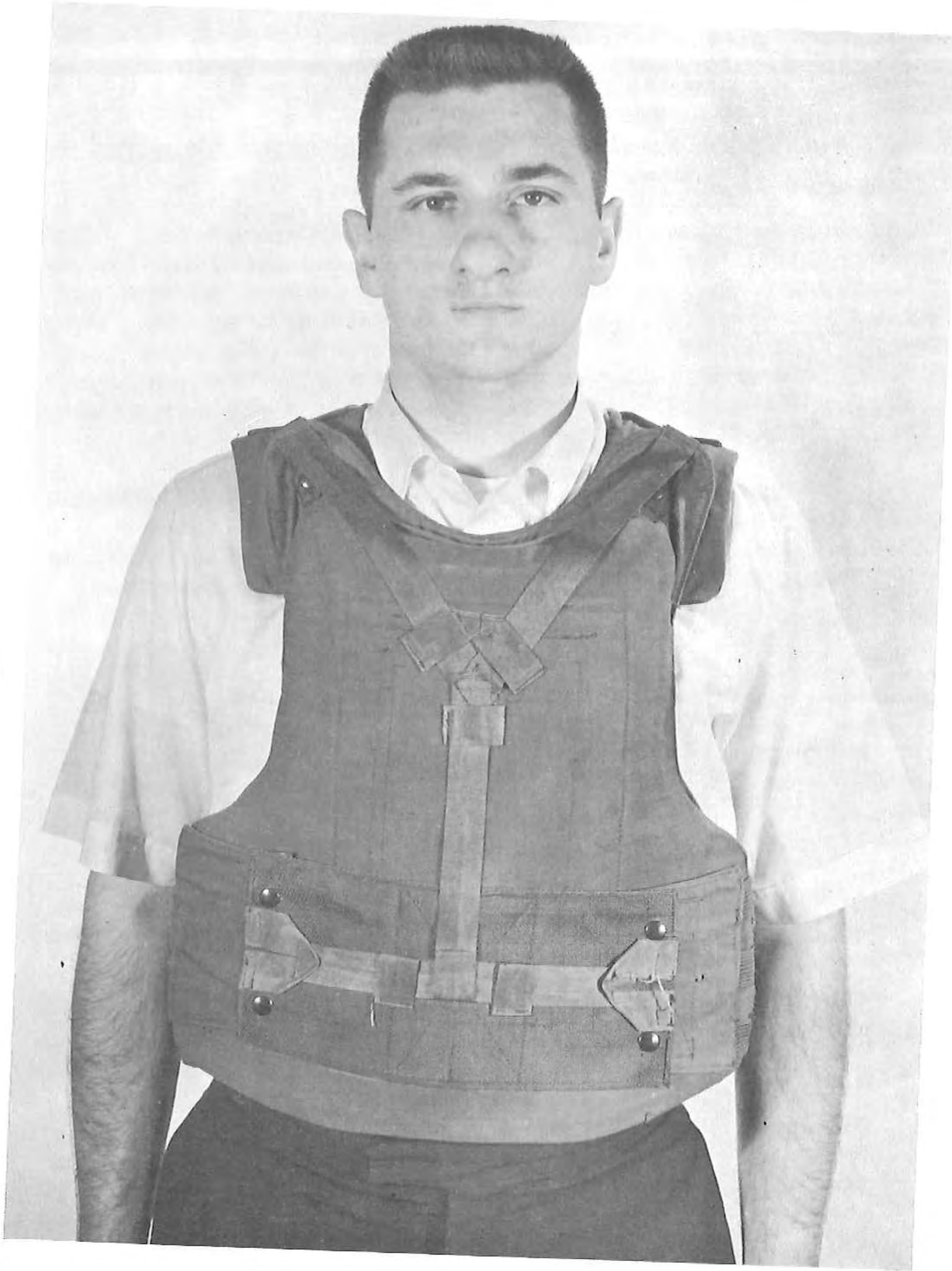

Figure 32. Modified Army Carrier for Quick-Release Rapid Doffing

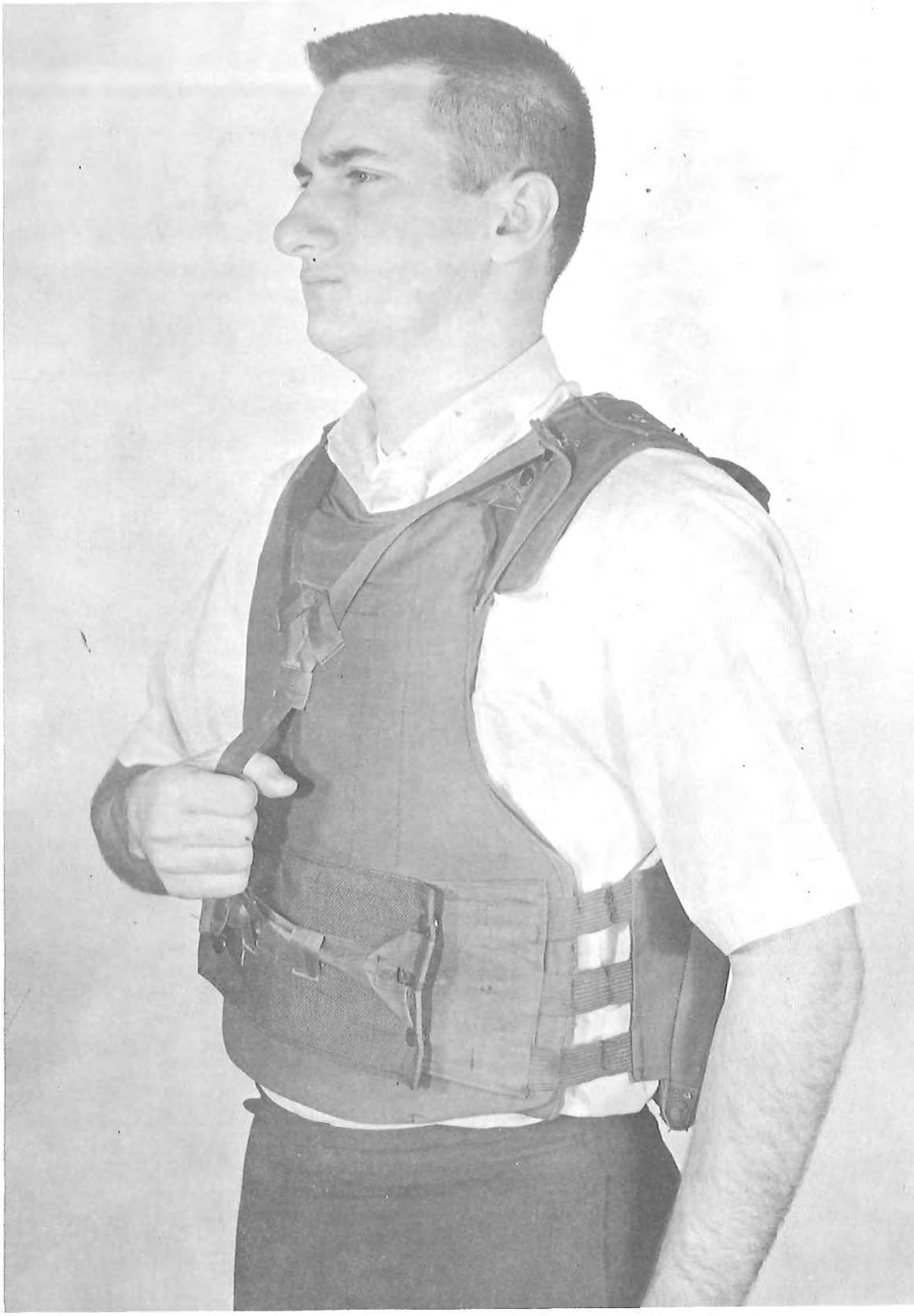

Figure 33. Quick-Release Actuation
(Modified Army Carrier)

Figure 34. Shoulder and Waist Closures Completely Released (Back Armor Shown Falling to the Floor)

- Alignment and positive securing of the Velcro closure, when reassembling the shoulder breaks, was difficult.

c. Snap-Closure Shoulder Breaks

Snaps have been used almost exclusively on the closures of most armor carriers because they are simple to install, easy to assemble, and inexpensive. Early approaches continued to use snaps in a variety of quick-release shoulder straps integrated into the over-the-shoulder raschel knit suspensions.

Approach #1

One of the approaches used two snaps in each shoulder break arranged in a vertical pattern (Figure 35). A reinforcing strap was sewn to the raschel knit to distribute load to the loose weave of the raschel knit, and the snaps were secured to the strap.

The double snap concept proved to be objectionable because it released prematurely during donning. The heavy armor elements went out of control and could have been dropped or damaged. A second objection was the material build-up of reinforcing strap and snaps positioned on the shoulder. This produced uncomfortable pressure points. A third objection was caused by the narrow reinforcing strap activating only a portion of the raschel knit shoulder strap. The raschel knit behaved like a narrow strap under load and produced a pressure line on the front of the torso. For proper load distribution, the full width of the raschel knit shoulder strap should be in tension. The snaps and narrow reinforcing straps deactivated most of the raschel knit, and defeated the desired action of this type of suspension system.

Approach #2

Three snaps arranged vertically were tried in each shoulder break as a possible solution to inadvertent releasing while donning (Figure 36). The snaps were mounted to a reinforcing pad extending the full width of the raschel knit shoulder strap. The raschel knit became completely activated under tension and improved the load distribution. A load concentration area on the shoulder still resulted because of material build-up, which eventually produced discomfort.

Figure 35. Dual Snap Shoulder Break Approach

Figure 36. Triple Snap Shoulder Break Approach

Several snap patterns were tried. The snaps were arranged in a square pattern on each shoulder, a total of eight snaps per suspension. A triangular pattern was tried (six snaps per shoulder). Evolution eventually produced the vertical pattern discussed in Approaches 1 and 2 (Figures 35 and 36).

Snaps arranged in any pattern did not have sufficient holding power, and the addition of more snaps did not improve holding power. All released prematurely during donning. However, once donned, the snaps held and did not release.

A method of releasing the shoulder break snap is shown in Figure 37. Two straps were fed through buttonholes sewn in the front armor peripheral protection. The straps were sewn to one end of the raschel knit reinforcing pad/snap complex; the other end terminated in a fabric "T". The "T" prevented the strap from being pulled through the buttonhole. To release the shoulder breaks, the wearer simply pulled downward on either or both straps to disengage the shoulder breaks.

d. Quick-Release Fabric Pin Shoulder Breaks

Two major changes in design philosophy occurred at this point in the program. One change was to discard snaps as a quick-release approach, and the second was to move the shoulder breaks off the shoulder and into the upper chest area (on to the pectoral muscles of the chest which are good load-bearing areas). One outgrowth of this design concept was the creation of an all-fabric quick-release shoulder break. This approach had never been attempted before.

A raschel knit, tension-web suspension system using an all-fabric shoulder break approach was designed and fabricated (Figures 3 and 4). The raschel knit suspension extended over the shoulder and into the upper chest area where it terminated in a fabric bearing pad. A fabric loop was sewn to the bearing pad. The front armor carrier was fitted with the mating element sewn to the raschel knit, tension-web member. This consisted of a reinforced fabric element with two large square buttonholes (Figure 3). Two fabric semirigid pins were sewn to straps which passed through slotted buttonholes sewn in the front carrier peripheral protection. A fabric "T" sewn to the end of each strap retained each pin assembly.

Figure 37. Quick-Release Straps for Snap Fastened Shoulder Breaks

To assemble the shoulder breaks, the fabric loop of the rear shoulder strap was passed through the large square buttonhole of the front shoulder strap. The fabric pin was then inserted through the loop to lock the assembly in place. To release the shoulder breaks, the wearer simply pulled on either or both straps as shown in Figure 4.

The advantages of this approach were:

- Shoulder break located in the upper chest area eliminates pressure points on the shoulder and used the raschel knit load distribution characteristics to the fullest advantage.
- All fabric construction eliminated possibility of secondary missiles.
- The pins positively locked the shoulder breaks during donning and under load, and would not release until actuated.
- Simplified treatment of peripheral protection over the shoulder (Figure 4), and protective surface was continuous.

The disadvantages of this approach are:

- It was difficult to reassemble the shoulder breaks.
- Increased complexity of fabrication and higher cost.

e. Quick-Release Buckle Shoulder Breaks

The miniaturized seat buckle with quick-release features (Figure 31) developed in this program was used as a quick-release shoulder break. The buckles were positioned in the upper chest area over the pectoral muscles. This was possible because the front armor element stands away from the torso in this area.

The buckle application is shown in Figure 1. The portion of the buckle with the quick-release lever (Figure 31) is sewn to the strap which ties to the tension-web member of the front armor element. The male insert of the buckle is sewn to a strap attached to a bearing pad that distributes tensile load across the entire width of the raschel knit shoulder strap. The peripheral protection over the shoulder attaches at this point (Figure 38).

Figure 38. Quick-Release Seat Buckle Approach

To assemble the shoulder break, the male insert is inserted into the base plate of the buckle. To release the shoulder break the wearer pulls on either of two release cords (Figure 38). The release cords are fastened to the release lever of the buckle, pass through buttonholes in the front armor peripheral protection, and terminate in two fabric pull straps. The buckles have more than adequate tensile strength when assembled, and will not release accidently during donning. To release either or both shoulder breaks, a slight tug on the release cords instantaneously disconnects the buckles.

The advantages of the seat buckle approach may be listed as follows.

- Improved comfort level compared with other approaches. No pressure points or material build-up on the shoulders.
- Instantaneous release of either or both shoulders with negligible effort.
- Distributes load optimally over full width of raschel knit shoulder strap for maximum comfort.
- Two-piece buckle construction makes reassembly of shoulder breaks simple. The buckle helps orient the armor to eliminate donning confusion.
- Will not release accidently.
- Concealed location of buckles behind the front armor minimizes danger of secondary missiles.

3. <u>Peripheral Protection</u>

The suspension systems developed included peripheral protection in the following areas.

a. At the sides and beneath the arms

b. In the armhole area at the front and rear of the carrier

c. Over the shoulders

The early suspension concepts did not have peripheral protection to simplify solving the basic suspension system problems. The peripheral coverage was added to the systems later. The waist augmentation belt suspension (Figure 5) increased peripheral protection about the hips and waist, and the rigid side plates necessary to make the hip suspension system work upgraded the ballistic capability of peripheral protection at the sides and beneath the arms. Peripheral protection was added in the upper chest areas, front and rear. Six layers of ballistic felt (MIL-SPEC-G43635) were used, covered with two layers of ballistic nylon (MIL-SPEC-B-12369E(GL), and the same construction was used over the shoulders.

The ballistic collar was excluded at this time because collars were considered a hindrance and could cause severe chafing about the neck.

4. Adjustability

All size adjustments were eliminated from the shoulder breaks. Earlier aircrew carriers, including the Army standard carriers, used adjustable shoulder straps primarily to permit donning. The carriers were overhead donned which required a head opening large enough to permit head passage. With the shoulder straps adjusted so that the armor elements were correctly positioned on the body, it was impossible to don or doff without releasing these carriers because of the small head opening.

All of the suspension concepts developed in this program did not have shoulder adjustment. This was possible because of the use of raschel knit suspensions which permitted a large enough head opening to be designed into the system. The head opening was also elliptical in shape to more closely conform to the actual contours of the human head. The same treatment was given to the peripheral protection over the shoulders.

The theory that shoulder adjustments were necessary to properly position armor on the torso was fallacious. Insufficient head opening was the real reason. Proper suspension system design correctly positions the front and rear armor elements on the torso without adjustment. Adjustable shoulder breaks are complex and do not produce enough benefits to warrant their use.

Size adjustment in the waist closure was accomplished with a double flap waist closure and an extra wide strip of Velcro pile on the front of the carrier (Figures 1, 5 and 8).

5. Ventilation

The raschel knit, tension-web suspension, in combination with the waist augmentation belt, improved ventilation. The tension-web members hold the armor away from the torso (Figure 1), while the raschel knit suspension over the shoulder moves the peripheral protection away from the torso, allowing air to circulate (Figure 2).

The overall effect, as the wearer moves about, is to pump air past the armor elements. The open weave of the raschel knit permits body sweat to evaporate, producing additional cooling.

D. Final Suspension System Prototypes

The final suspension prototypes incorporated three suspension principles.

1. Distribution of load over the greatest possible area of the body (over-the-shoulder raschel knit suspension (Figures 1 and 14).
2. Support of rigid elements to isolate direct contact of hard surfaces with the body (tension-web suspension, Figures 1, 13 and 14).
3. Transfer of armor loads to the optimum load-bearing areas of the body, primarily the hips and waist (waist augmentation suspension, Figures 5, 6 and 7).

Three prototypes were fabricated. Prototypes #1 and 2 combined the over-the-shoulder and tension-web suspension principles in the following combinations (Figure 39). The tension-web suspension was used in the front armor carrier of Prototype #1, while the tension-web over-the-shoulder suspensions were combined in the rear armor carrier of Prototypes #1 and 2, and the front armor carrier of Prototype #2. Another difference between Prototypes #1 and 2 was in the method of making and releasing the shoulder breaks. The quick-release buckle was used in Prototype #1 (Figure 39). Prototype #2 used the quick-release fabric pin (Figures 3 and 4).

Prototype #3 was the hip suspension or waist augmentation belt suspension (Figures 5, 6 and 7). It effectively transferred load to the hips and waist, and improved comfort noticeably. It worked in the seated or standing position, and could be used with the front armor element alone.

Figure 39. Prototype #1 - Over-the-Shoulder
Raschel Knit, Tension-Web
Suspensions - Layout

All three prototypes provided peripheral protection consisting of six layers of ballistic felt and two layers of ballistic nylon. These were not encased in vinyl protective envelopes. Prototypes #1 and 2 carried this protection over the shoulder and into the front upper chest area and upper back. Underarm and side protection was provided by the rigid (metallic or semirigid plastic) shear elements contained in pockets sewn in the waist closure flaps.

Double flap waist closures with provisions for adjustment were used with a broad band of Velcro pile on the front of the carrier. The shoulders do not have adjustment features in any of the prototypes, and ballistic collars were eliminated.

PART III. SUSPENSION SYSTEMS EVALUATION

A. Test Subjects

Twenty-one test subjects were used in the suspension system evaluation. The anthropometric data for these subjects are listed in Table IV.

The majority of the test subjects had never worn armor nor had any previous experience with armor, and the responses to the questionnaires were unbiased and based purely on the test subject's reaction to the particular suspension system being evaluated.

B. Test Procedure

The test subjects wore a total of three armor prototype systems and a standard Army aircrew (modified) carrier in the evaluation. The standard aircrew (modified) carrier was used as the control item. Armor elements of the same size and configuration were used in all the suspension systems.

- Prototype #1 - Over-the-Shoulder Raschel Knit, Tension-Web Suspension with "Quick-Release Buckle" Shoulder Breaks
- Prototype #2 - Raschel Knit, Tension-Web Suspension with "Quick-Release Fabric Pin" Shoulder Breaks
- Prototype #3 - Hip Suspension Waist Augmentation Belt
- Army Standard Aircrew Carrier - Modified for experimental anatomical shape armor plates (Control Item).

The test procedure was to first collect the anthropometric information listed in Table IV for each test subject. The subject was then instructed to don each of the items listed above. For each prototype, the test subject was gymnasticated through the following movements: (1) standing (arms at side and arms overhead); (2) sitting (arms at side and arms forward touching the fingers); (3) bending forward at the waist (arms at side); and (4) bending sidewards at the waist (arms at side). The test subject negotiated through these movements while wearing each suspension system. His response to comfort, pressure points, degree of mobility,

Table IV

SUMMARY, ANTHROPOMETRIC DATA
FOR SUSPENSION SYSTEM TEST SUBJECTS

Test Subject No.	Height	Weight	Age	Chest Circum.	Waist Circum.	Physical Build
1	5'-10½"	190	44	39-1/4	38	Fleshy (Heavy)
2	5'-8"	155	25	34-1/2	32	Average
3	5'-10"	145	28	36	30-1/2	Slender
4	5'-11"	175	39	39-1/4	34	Average
5	5'-6"	155	46	38	36	Average
6	5'-10"	159	38	35	34-1/2	Slender
7	5'-9"	146	27	35-1/4	34	Slender
8	5'-10"	178	34	36-3/4	35-1/8	Average
9	5'-6"	150	31	35-1/2	30	Muscular
10	5'-10"	160	38	37-1/8	35-3/4	Average
11	5'-7"	145	46	34-3/4	34-1/8	Slender
12	6'-1"	165	32	39	33-1/2	Muscular
13	6'-1"	190	34	40	37	Muscular
14	5'-11"	195	41	39-1/2	35-1/2	Average
15	5'-9"	175	48	40-1/2	29-1/2	Muscular
16	5'-10"	165	45	37	34	Average
17	5'-10"	155	46	35-1/2	34-3/4	Slender
18	5'-8"	190	38	39-1/4	35-1/8	Average
19	5'-11"	210	43	40	42-1/4	Fleshy
20	5'-11"	145	32	32	30	Slender
21	5'-7"	185	52	40-1/8	41-3/4	Fleshy (Heavy)

donning ease, quick doffing, projected endurance, and resistance to fatigue, was then recorded on the questionnaires. Sample questionnaires are listed in Appendix A. Appendix B includes the questionnaires summarizing the individual responses for each of the 21 test subjects for each suspension system.

C. Test Results

The test results were summarized and used to compile Table II (suspension acceptance). A preference for the over-the-shoulder raschel knit, tension-web suspension was indicated. It distributed armor load more effectively and minimized pressure points when compared with the control item. The test subjects estimated they could probably tolerate this system for greater periods of time with less fatigue.

Acceptance of the waist augmentation hip suspension belt (Prototype #3) was unanimous. All test subjects indicated that this approach provided maximum comfort. The ability to redistribute load was considered to be a great advantage. Load could be easily transferred at the first sign of fatigue, endurance was improved, and the waist augmentation belt was relatively easy to don and doff.

The comfort of Prototype #1 was considered to be slightly better than that of Prototype #2. No pressure points could be felt in the upper chest areas which contained the quick-release buckles for the shoulder breaks (Figure 1). With some subjects, a slight amount of pressure, induced by the material build-up of the fabric pin shoulder breaks of Prototype #2, could be felt in the upper chest areas (Figure 3). This was not too objectionable, but the wearer could sense the presence of the fabric pins.

Both suspensions demonstrated significant improvement in comfort over armor carriers which used snaps in the shoulder breaks.

The rapid doffing features of Prototypes #1 and #2 were judged excellent. The shoulder releases were simple to actuate with minimum effort. The versatility of breaking either over-the-shoulder releases simultaneously was considered to be a very good feature. The seat buckle concept (Prototype #1) was easier to reassemble and actuate than the fabric pin and loop approach (Prototype #2).

The doffing time of Prototype #3 (waist augmentation belt) was greater than Prototypes #1, 2 or the control item since an additional element had to be handled. However, the test subjects all agreed that the advantages of the system outweighed the one disadvantage. The waist augmentation belt could be used with both front and rear armor elements or just the front armor element without affecting stability.

Mobility for all three prototypes was considered to be good despite the addition of peripheral protective material. The control item provided the best mobility since it lacked peripheral protection.

The majority of the test subjects felt that Prototypes #1 and 2 could be worn for at least an hour without excessive fatigue. All agreed that the waist augmentation belt improved endurance and would permit the suspension to be worn for several hours.

The double flap waist closure was preferred over the overlapping waist closure flaps of the control item, less confusion was experienced in donning, and flap positioning was not as critical.

The responses of the test subjects to each suspension system were purely subjective. Individual tolerances to load-bearing and pain vary considerably. Coupled with the capability of humans to adapt rapidly to conditions of stress, the evaluation may not be relating a true picture of how effective the new suspensions really are. Individuals may also psychologically accept a system based on its appearance, color, or familiarity related to other equipment which may have been worn in the past.

A "Load-Measuring Device" capable of locating and measuring forces transmitted to the torso by body armor is currently being developed for NLABS. The device will assist in isolating prejudiced human response to a specific suspension system. The wearer's impression of comfort can be interpreted analytically by comparing responses to the numerical and topographical output of the load-measuring device. Similarly, if pain, discomfort, or excessive fatigue is induced by a suspension system, the device will indicate the location and magnitude of the stress-inducing forces.

The load-measuring device will be of great value in evaluating not only armor suspension systems, but all load-carrying devices normally worn by military personnel.

PART IV. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

Armor suspension systems have been developed in this program, incorporating suspension principles derived from many types of load-bearing and impact-absorbing equipment. The suspension prototypes have demonstrated the effectiveness of these principles by significantly improving comfort, load distribution, and endurance of the wearer. Peripheral benefits were also achieved by improving closures, quick-release techniques, load transference capability and ballistic protection in peripheral areas. The prototype suspension systems successfully demonstrated in essence, that heavy, anatomically shaped, rigid elements can be effectively positioned and stabilized on the torso with minimum restriction to the mobility of the wearer under test conditions.

The evaluation phase of the program involving 21 test subjects, indicated that comfort and endurance were improved, and awareness of armor load was minimized through better distribution of load on the body. Fatigue was reduced (allowing armor to be worn for greater periods of time), utilizing a suspension concept which permitted the wearer to transfer load selectivity to optimum load-bearing areas of the torso.

The following conclusions relate to design principles for <u>torso armor suspensions</u>:

- Comfort of armor suspension systems can be increased by greater load distribution on optimum (higher tolerance) load-bearing areas of the torso.
- Isolation of rigid elements from the torso (tension-web principle) can reduce pressure points by preventing load concentrations.
- Suspension systems should avoid loading naturally sensitive areas of the torso, specifically the neck/shoulder junction, the nipple areas of the chest, and the anterior rib cage.
- Load transference to the hips and waist can result in superior comfort and tolerance for the armor.
- The overhead donning principle in carrier design is favored for ease of handling, positioning, and control of heavy elements by the wearer during donning.

The following conclusions relate to armor suspension closures and quick-release features:

- The double flap closures used in Prototypes #1 and 2 are effective, and reduce confusion during donning and doffing. The rigid shear plates (side elements) improve armor stability by mechanically coupling the front and rear rigid armor elements to each other.
- The miniaturized positive locking buckle, quick-release shoulder breaks are extremely effective, permitting the wearer to select either or both breaks for rapid doffing. The breaks can be actuated almost instantaneously and reassembled with minimum effort.
- Shoulder breaks located in the scye area (off the shoulder) significantly improve comfort by eliminating material build-up in the most highly loaded areas of the shoulder.

The following conclusions relate to hip suspensions and waist augmentation:

- Load transference to the hips and waist through the use of a waist augmentation belt dramatically improves comfort.
- The ability to selectively transfer load between shoulders and hips, at will, improves endurance and reduces fatigue.
- The waist augmentation belt increases peripheral protection, and can be made to function with any armor suspension system which has been suitably modified.
- The all-fabric construction permits ease of fabrication at low cost, using standard tailoring techniques.

The following conclusions relate to peripheral protection:

- Proper integration of peripheral protection with the other suspension elements (providing for suitable head clearance) permits overhead donning without shoulder adjustments.
- Peripheral protection in the anterior and posterior scye areas must not restrict the wearer's mobility or produce uncomfortable pressure points.

- Continuous over-the-shoulder peripheral protection can be successfully integrated with quick-release shoulder breaks (off the shoulder, as demonstrated in Prototypes #1 and 2).

B. Recommendations

- Suspension systems developed under this program should be sized to accommodate the four-size armor system recently being considered by NLABS. A suitable statistical sampling of test subjects (appropriately sized) should then be selected to more thoroughly evaluate the various system concepts, especially when supporting the largest and heaviest armor elements.
- The quick-release buckle closure developed in this program, and used on Prototype #1, should be considered for other military load-carrying applications, and as a replacement for current mechanical closure devices used in armor carriers.
- Environmental tests should be conducted to study the effectiveness of the ventilating qualities of the latest suspension systems. Physiological reactions should be assessed, with instrumented tests, to ascertain the potential for reducing heat stress with the prototype systems.
- An instrumented load-measuring system should be employed to quantitatively assess load transference characteristics of various suspension systems when worn on the torso. Future generations of suspension systems can then be improved by precisely proportioning and distributing the load to the higher tolerance zones of the torso.

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Appendix A

EVALUATION QUESTIONNAIRES

EVALUATION QUESTIONNAIRE

Test Subject No. ____

Prototype #1

Over-the-Shoulder Raschel Knit, Tension-Web Suspension
(Quick-Release Buckle Shoulder Breaks)

Question	Response
1. Can you don the armor easily?	
2. Where do you feel the armor load most?	
3. Are there noticeable pressure points which produce discomfort? Can you tolerate them?	
4. How long could you wear this armor: 1/2, 1, or 2 hours?	
5. Can you move your arms overhead and forward?	
6. Can you bend forward and sideward at the waist?	
7. Can you doff the armor easily?	
8. Is the armor stable with just the front element?	

EVALUATION QUESTIONNAIRE

Test Subject No. ____

Prototype #2

Over-the-Shoulder Raschel Knit, Tension-Web
Suspension (Fabric Pin Shoulder Breaks)

Question	Response
1. Can you don the armor easily?	
2. Where do you feel the armor load most?	
3. Are there noticeable pressure points which produce discomfort? Can you tolerate them?	
4. How long could you wear this armor: 1/2, 1, or 2 hours?	
5. Can you move your arms overhead and forward?	
6. Can you bend forward and sideward at the waist?	
7. Can you doff the armor easily?	
8. Is the armor stable with just the front element?	

EVALUATION QUESTIONNAIRE

Test Subject No. ____

Prototype #3

Waist Augmentation - Hip Suspension
Worn with Concept #2

Question	Response
1. Can you don the armor easily?	
2. Where do you feel the armor load most?	
3. Are there noticeable pressure points which produce discomfort? Can you tolerate them?	
4. How long could you wear this armor: 1/2, 1, or 2 hours?	
5. Can you move your arms overhead and forward?	
6. Can you bend forward and sideward at the waist?	
7. Can you doff the armor easily?	
8. Is the armor stable with just the front element?	

EVALUATION QUESTIONNAIRE

Test Subject No. ____ Army Standard Aircrew (Modified) Carrier

Question	Response
1. Can you don the armor easily?	
2. Where do you feel the armor load most?	
3. Are there noticeable pressure points which produce discomfort? Can you tolerate them?	
4. How long could you wear this armor: 1/2, 1, or 2 hours?	
5. Can you move your arms overhead and forward?	
6. Can you bend forward and sideward at the waist?	
7. Can you doff the armor easily?	
8. Is the armor stable with just the front element?	

Appendix B

SUMMARIZED QUESTIONNAIRE DATA

EVALUATION SUMMARY

Prototype #1

Over-the-Shoulder Raschel Knit, Tension-Web Suspension
(Quick-Release Buckle Shoulder Breaks)

Question	Response (Percentage)	
1. Can you don the armor easily?	40% Yes	60% No - head opening uncomfortable.
2. Where do you feel the armor load most?	70% (Shoulders)	30% (Shoulders, back and chest)
3. Are there noticeable pressure points which produce discomfort? Where are they and can you tolerate them?	80% No	20% Pressure noticeable on clavicles, shoulders and back. (Can be tolerated for short periods.)
4. How long could you wear this armor: 1/2, 1, or 2 hours?	90% - 1 hr.	10% - 1/2 hr.
5. Can you move your arms overhead and forward?	80% Yes	20% Yes - but with some restriction to movement.
6. Can you bend forward and sideward at the waist?	85% Yes	15% Yes - but with some restriction to mobility.
7. Can you doff the armor easily?	100% Yes	
8. Is the armor stable with just the front element?	70% Yes	30% Armor appeared to ride lower on torso with some instability.

EVALUATION SUMMARY

Prototype #2

Over-the-Shoulder Raschel Knit, Tension-Web
Suspension (Fabric Pin Shoulder Breaks)

Question	Response (Percentage)	
1. Can you don the armor easily?	50% Yes	50% No - armor is heavy and head opening scrapes ears.
2. Where do you feel the armor load most?	80% (Shoulders)	20% (Shoulders, back and chest)
3. Are there noticeable pressure points which produce discomfort? Where are they and can you tolerate them?	70% No	30% Some pressure in scye area which can be tolerated.
4. How long could you wear this armor: 1/2, 1, or 2 hours?	85% - 1 hr.	15% - 1/2 hr.
5. Can you move your arms overhead and forward?	75% Yes	25% Yes - but with restriction to mobility.
6. Can you bend forward and sideward at the waist?	80% Yes	20% Yes - but with pressure points on sides and waist.
7. Can you doff the armor easily?	95% Yes	5% Yes - but with some difficulty in pulling pins to side.
8. Is the armor stable with just the front element?	75% Yes	25% Not sure but stability seemed satisfactory.

EVALUATION SUMMARY

Prototype #3

Waist Augmentation - Hip Suspension
Worn with Prototype #2

Question	Response (Percentage)	
1. Can you don the armor easily?	45% Yes	55% No - armor too heavy. Hit nose on front armor. Scraped nose.
2. Where do you feel the armor load most?	100% On the hips and waist.	
3. Are there noticeable pressure points which produce discomfort? Where are they and can you tolerate them?	100% There are pressure points on the hips, but they can be easily tolerated.	
4. How long could you wear this armor: 1/2, 1, or 2 hours?	80% - 1 hr. or more	20% - At least 2 hrs.
5. Can you move your arms overhead and forward?	70% Yes	30% Yes - but with some restriction in the scye area.
6. Can you bend forward and sideward at the waist?	60% Yes	40% Yes - but with some restriction to sideward bending.
7. Can you doff the armor easily?	65% Yes	35% Yes - but extra waist closure complicates doffing.
8. Is the armor stable with just the front element?	80% Yes	20% Yes - but stability seems to be less than with both elements.

EVALUATION SUMMARY

Control Item

Army Standard Aircrew (Modified) Carrier

Question	Response (Percentage)
1. Can you don the armor easily?	50% Yes 50% Yes - but experienced confusion with shoulder adjustments and waist closure.
2. Where do you feel the armor load most?	100% Across the back and shoulders.
3. Are there noticeable pressure points which produce discomfort? Where are they and can you tolerate them?	80% Yes - across the back. Can be tolerated only for short periods. 20% Yes - on shoulders, for short time only.
4. How long could you wear this armor: 1/2, 1, or 2 hours?	85% - 1/2 to 1 hr. 15% - less than 1/2 hr.
5. Can you move your arms overhead and forward?	100% Yes - little restriction to movement.
6. Can you bend forward and sideward at the waist?	100% Yes - no reduction in mobility.
7. Can you doff the armor easily?	70% Yes 30% Yes - but some confusion with shoulder breaks and waist closure.
8. Is the armor stable with just the front element?	70% Yes 30% Yes - but not as stable as with both elements.

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13. ABSTRACT

The improvement of aircrew armor suspension systems was the goal of this project. Deficiencies in armor carriers were recognized in earlier armor programs. Attempts were made to eliminate these deficiencies, but the results were minimal since the major design effort was focused on the optimization of armor configurations and the development of an armor sizing system.

Armor suspension systems received prime consideration in this program, and the goals were to design those which would improve comfort. Mobility, peripheral protection, ventilation, and rapid doffing characteristics were also given consideration.

The suspension and load distribution principles used in other fields involving load-bearing equipment were surveyed and applied wherever practicable in the improvement of armor suspensions. The aircrew armor suspension systems designed, developed and fabricated during this study indicate significant advances over previous armor carriers.

The suspension concepts developed are reviewed. The prototypes incorporating the suspension techniques derived from the study are discussed in detail, and the results of a prototype evaluation study conducted on a group of test subjects are presented.

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