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The Development of a Buoyant-Ballistic Vest for Naval Forces

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NAVY CLOTHING AND TEXTILE RESEARCH UNIT

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by Z. Kupferman and J. Silvia

Work Unit No.
523-003-12

Technical Report No.
104

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ABSTRACT

The Navy Clothing and Textile Research Unit (NCTRU) has developed a buoyant-ballistic protective vest which provides inherent buoyancy by the use of three plies of 1/4-inch unicellular, polyethylene foam totalling approximately 12 ounces. Designed primarily for Naval crews subjected to enemy shelling, the vest affords ballistic protection by employing six plies of ballistic nylon cloth in front of eight plies of a lightweight, needlepunched, polypropylene felt. In addition, each of the two ballistic assemblies are encapsulated in eight mil vinyl film to prevent wetting-out and to impart added buoyancy. Ballistic tests have shown the new vest to have equivalent ballistic protection to the nylon cloth vest, and pool tests have shown excellent buoyancy characteristics. A user evaluation of a Model I buoyant-ballistic vest reported that improvements in comfort and basic vest design were necessary and recommended changes. A redesigned Model II vest, which provides excellent buoyancy, was developed, user tested, and conditionally accepted.

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THE DEVELOPMENT OF A BUOYANT-BALLISTIC VEST FOR NAVAL FORCES

INTRODUCTION

The Navy's area of responsibility has been expanded to include shoreline and river patrol duties. Because patrol boats offer excellent targets from the shore, crews are subjected to shelling and to mortar and hand-grenade attacks and are harassed by small arms fire. These small boats afford the crews limited protection from hostile attacks. The mission of the boats requires that they be constructed of lightweight materials for maximum maneuverability close to the shore. The low gunwale of the boats expose the crews to shoreline fire while the small deck area restricts them from protecting themselves. If their boats are sunk, crews are in danger of possible drowning due to wearing excessively negative buoyant equipment or of becoming dazed or rendered unconscious by exploding shells.

As a result, the Navy Clothing and Textile Research Unit (NCTRU) was assigned the task of developing a buoyant-ballistic protective vest by the Naval Ordnance Systems Command. The vest design was based on that of the 12-layer ballistic nylon cloth vest and the following technical characteristics were requested:

(a) Same area coverage as the nylon cloth vest
(b) Same ballistic limit as the nylon cloth vest
(c) Average weight of 9.5 pounds for a size medium vest
(d) Minimum buoyancy of 30 pounds, of which 20 pounds should be inherent for emergency flotation.

Based on these characteristics, ballistic protective vests were engineered with built-in buoyancy, forwarded to Vietnam Naval personnel for evaluation and conditionally approved. It was, however, considered desirable to continue research and development work to obtain improved ballistic protection assemblies, new lighter weight materials, significant reduction in thickness and a modified design for improved fit, comfort and mobility.

The purpose of this report is to discuss the development of ballistic protective, fibrous material assemblies and the design and evaluation of the buoyant-ballistic vest.

MATERIALS

Along with the standard, woven-nylon cloth the polypropylene fiber and felt structure was chosen because previous results (1) showed that the fiber should possess high tenacity and elongation at rupture and that low-density felt structures demonstrated good ballistic-resistance characteristics--fiber-to-fiber friction, fiber straightening and transverse elongation. NCTRU personnel obtained the following types of fibrous materials for this development work.

Ballistic Materials

Polypropylene needle-punched felts, obtained from Troy Mills, Inc., Troy, New Hampshire, were constructed from Herculon type 20, polypropylene fiber. The fiber was delivered to Troy Mills containing an anti-static finish, which has been retained in the finished ballistic felts. The primary physical characteristics for type 20 fiber are listed as follows:

1 3 denier per filament
2 2-1/2-inch staple length
3. 5.5 grams per denier breaking strength
4. 30% breaking elongation

Individual properties for all experimental felts and felt assemblies are shown in Tables I through .

Needle felting was the method used to mechanically interlock loose fibers to form a felt nap or fabric. (Figure 1 shows the basic components of the needle-felting machine.) All of the experimental felts constructed for this study were given one pass, front and back, through the needling machine to produce felts with balanced constructions and reduced thickness. Cold calendering was accomplished by passing the finished felt between rollers under pressure.

Nylon ballistic cloth, for armor conforming to Military Specification MIL-C-12369, is of the same type employed in the standard nylon cloth vest and obtained from Government stock. Physical characteristics are listed below:

1. Weight: 14 0 ounces per square yard (tol. $\pm$ 1.0 - 0.5 oz.)
2. Warp and filling yarns: 1050 denier, multifilament, 3 to 4 turns per inch, "Z" twist
3. Two-by-two basket weave
4. Yarns per inch (Min.): 46 warp by 42 filling
5. The ballistic limit, V50, for 12 layers of unbonded cloth is not less than 1225 feet per second when tested in accordance with MIL-STD-662, Ballistic Acceptance Test Method for Personal Armor Material

Buoyant Material

One-quarter-inch, unicellular, polyethylene foam was chosen because it has inherent buoyancy and contains skin on both sides for minimum water absorption. It has a listed density of 2.0 to 2.6 lbs/ft^3 and a buoyancy value of 55 lbs/ft^3 (2). Laboratory test data on 1/4-inch foam, from production runs, show an average buoyancy of 21 lbs/lb material, indicating that the density of commercially available foam is approximately 2.6 lbs/ft^3. Accordingly, these figures were used to establish the total ounces of foam to be used in the buoyant-ballistic vest.

Polyethylene foams with thickness of 1/2 and 3/4 inches were tested and also exhibited buoyancy results of 21 lbs/lb material--equal to results obtained for the 1/4-inch foam. The 1/2- and 3/4-inch-thick foams were not used, however, because, with increasing thickness, unicellular, polyethylene foam becomes stiff and boardy and thus unacceptable for use in garments. Accordingly, layers of 1/4-inch foam were chosen which showed the minimum number of design problems when fabricated and used in the protective vest.

Test Procedures

Ballistic tests were performed by the Naval Weapons Laboratory, Light Armor Division, Dahlgren, Virginia, in accordance with Military Standard, MIL-STD-662, Ballistic Acceptance Test Method for Personal Armor Material. (The ballistic limit, V50, is defined as the velocity at which the probability of penetration of an armored material by a test projectile is 50%.) This test method was followed for all ballistic limit results reported.

Buoyancy tests, run by NCTRU personnel, were conducted by: (1) immersing the sample in fresh water at room temperature; and, (2) weighing it (in ounces) while it hung static from a direct reading scale.

The procedure was to attach the proper amount of scuba lead weights (ballast) to a length of webbing and immerse it in water. The immersed ballast was hung from a scale and the observed reading was reported as the weight of ballast in water. The ballast was then attached to the sample in such a manner as to cause it to sink vertically below the water surface. The submerged sample was positioned so that the top was approximately 2 inches below the water surface. The weight of the sample and this ballast in water was then reported. The buoyancy of the sample in water was deduced by subtracting the total weight in water from that of the ballast alone. If the total weight in water is lower than the ballast weight, the resulting answer is known as positive buoyancy; if the resulting answer is higher, it is called negative buoyancy.

Discussion of Results for Ballistic Materials

The development of ballistic protective, fibrous assemblies was undertaken with a minimum number of guidelines. It was requested that the protective assembly be equal in ballistic limit to 12 plies of nylon cloth and that a size medium vest should weigh about 9-1/2 pounds. (Final thickness of the ballistic assembly and design of the vest would control the thickness and weight of foam employed.) Based on preliminary tests and with the realization that overall vest thickness was a major characteristic to be controlled, a maximum thickness of 1.5 inches for new ballistic assemblies was established. After considering the additional weight necessary to develop proper buoyancy in the protective vest (foam, leg straps, buckles, etc.), technical personnel decided that the areal density of the new ballistic assembly would have to be significantly less than that of the 12 plies of nylon cloth. Reduced weight is not only necessary to offset the weight introduced by the addition of buoyancy, but also desirable because of the heat load stress on Navy personnel in hot, humid climates.

One area of the vest where a significant weight reduction could be achieved was in the replacement of the 14-ounce, ballistic, nylon cloth with lighter weight, ballistic materials. Previous studies with lightweight, fibrous, needle-punched, felt constructions reported that good ballistic results could be achieved (3, 4). The studies were conducted on low-tenacity fibers for use in cold-weather clothing.

Commercially available, polypropylene, needle-punched felts were obtained at various weights and thicknesses and test firings were performed on felt assemblies. Table I data show that, except for the 20 oz/ft^2 assembly, the tested materials afforded improved ballistic resistance as areal density increased. The 20 oz/ft^2 assembly shows a reduced ballistic limit with increased weight, which is primarily due to the use of a highly calendered 12 oz/yd^2 felt. To meet the minimum ballistic requirement of 1,225 feet per second, however, thickness and weight became critical properties. Ballistic limits greater than 1,300 feet per second were reported, but these limits were shown only by assemblies with thicknesses above 1.5 inches or with areal densities of approximately 19 oz/ft^2, equal to the 12 plies of nylon cloth.

Polypropylene felts alone were not acceptable for use in a buoyant-ballistic vest. Table I data show that heavier and thicker felt assemblies were necessary to provide acceptable ballistic limits. Consequently, new ballistic assemblies were prepared for test firing, using ballistic nylon cloth in conjunction with 4.5 oz/yd^2 polypropylene felt (uncalendered) and 1/4-inch, unicellular, polyethylene foam. These assemblies were prepared to combine the good ballistic properties of the thinner nylon cloth with the lighter weight felt. Accordingly, a weight reduction could be achieved which would allow for the addition of inherently buoyant foam in the finished vest.

Table II data show the ballistic protection afforded when the plies are varied and the position of candidate ballistic and buoyant materials are altered. Positioning of the polyethylene foam behind the ballistic assemblies appears necessary. The foam shows a deleterious effect on the ballistic limit when placed in front of or between the assemblies (C and F). The optimum combination of ballistic materials, as shown in Table II, appears to be 6 plies of nylon cloth positioned in front of 8 plies of polypropylene felt (B), because this assembly possesses a ballistic limit of 1,192 feet per second as compared with 1,181 feet per second for 12 plies of the nylon cloth (A). It should be noted that the ballistic limit of nylon cloth varies between rolls. For example, a significantly higher ballistic limit of 1,300 feet per second was previously obtained from 12 plies of nylon cloth taken from a different roll. Accordingly, when a nylon cloth assembly from a previous roll was test-fired in conjunction with 8 plies of polypropylene felt, a ballistic limit of 1,294 feet per second was reported (see Table V).

Table III data show good ballistic limit correlation for felt assemblies prepared from nine individual rolls of felt. A maximum scatter of 64 feet per second was reported, which can be considered insignificant.

Before Table IV and V results are examined, it is important to understand the changes that might occur in the ballistic limits of assemblies when the plies of nominal 4.5 oz/yd^2 polypropylene felt in conjunction with 6 plies of nylon cloth are progressively increased, and when the fiber mobility and thickness of felts is decreased. (If increasing the plies of felt significantly increases ballistic limits, an increase in thickness and weight of the final assembly might be justified.) A decrease in fiber mobility and thickness of felt can be achieved in two ways: first, by increasing the depth of needling and needle penetrations per square inch; second, by calendering. In either case, the finished felt becomes thinner with decreasing fiber mobility. Past experience indicates that limiting the fiber mobility reduces ballistic resistance (5); however, if this reduction is not significant, denser, but less thick, felts may be considered for use in the buoyant-ballistic vest.

Table IV data show the ballistic protection afforded when the plies of ballistic felt are increased in conjunction with six plies of nylon cloth. The data indicate that the ballistic limit does not increase proportionally with the increasing plies of felt. Doubling the polypropylene felt from 8 to 16 plies increases the ballistic limit by only 89 feet per second. The slight benefit derived is questionable when increased ballistic resistance, exhibited by 16 plies of felt, is compared with markedly increased weight and thickness.

Table V data show the effect on the ballistic limit of felt and nylon cloth assemblies when the fiber mobility and thickness of the polypropylene felt is decreased. For evaluation purposes, areal density can be considered equal for all tested assemblies. Differences in thickness are attributed to the progressive increase in needle penetrations per square inch and to the calendering operation. Assembly No. 204, with the least amount of fiber manipulation, shows a ballistic limit of 1,331 feet per second. As the fibers are further interlocked by increased needling, the ballistic limit decreases to 1,178 feet per second for assembly No. 41438 in which the individual felt plies contained 1,900 needle penetrations per square inch. Further increase in density of the felt with a corresponding decrease in fiber mobility reduced the ballistic limit of assembly No. 41439-C to 1,131 feet per second. From the limited testing performed, as shown by results listed in Table V, it can be concluded that felts containing the least needle penetrations without calendering will give the highest ballistic limits.

Observational insight gained from this experimental program, as well as pertinent literature (1, 3, 4, 5), suggested the necessary physical characteristics which a buoyant-ballistic, protective, fabric system, for use in a finished vest, should encompass. An assembly of six plies of 14 oz/yd^2 nylon cloth in conjunction with eight plies of a needle-punched polypropylene felt, with the nylon assembly in front of the felt, appears to be the optimum combination. The felt should weigh 4.5 $oz/yd^2 \pm 0.5$ ounce, contain approximately 350 needle penetrations per square inch with a finished thickness of 0.150 inch, and be constructed with a balanced needling and a soft hand and be uncalendered. The completed ballistic assembly should weigh about 14.7 oz/ft^2 and be about 1.45 inches thick. The inherently buoyant foam should be placed behind the ballistic assemblies and, to protect the fibrous ballistic assemblies from wetting-out, they should be sealed in individual, 8-mil, vinyl bags. (Sealing the ballistic assemblies in separate vinyl air bags will provide a significant degree of flotation. Dividing the flotation between two air bags will protect the air-bag system against total loss of flotation due to accidental rupture of one of the bags.)

DISCUSSION OF VESTS

Model I Vest

Design. The newly engineered, buoyant-ballistic assembly was used in the Model I vest The ballistic assembly was significantly lighter (about 14.7 oz/ft^2) than the standard 12 plies of nylon cloth (about 19 oz/ft^2). Although lighter, it was thicker than the standard, because of the substitution of eight plies of polypropylene felt (1.2 inches) for six plies of nylon cloth (0.174 inch). Inserting this thicker ballistic package into the same size of outer shell liner as the 12-ply, nylon, cloth vest was found to be impractical. The problem was further compounded by the addition of three plies of 1/4-inch, polyethylene foam for inherent buoyancy.

The design question was also aggravated by the extreme limitation placed on the configuration of the ballistic assemblies--the restriction of having to fit them into a four-size-range vinyl bag (small, medium, large and extra-large). Since the fabrication of water-tight vinyl bags to contain the ballistic assemblies depends on custom-made, heat-sealing dies, the design and development of new dies would have been costly. Therefore, existing dies were utilized. Accordingly, it was determined that the outer shell liner would be used with a vinyl bag that was one size smaller than the outer shell. Each assembly (one polypropylene felt, one nylon cloth) was encapsulated in individual bags (two bags per vest) (Figure 2). It was considered that, if the outer vinyl bag, containing the ballistic nylon cloth, was rendered useless, the inner bag containing the polypropylene felt would continue providing buoyancy along with the inherent polyethylene foam.

The design of the ballistic assemblies used in the initial Model I prototype vests proved unsatisfactory. The outer vinyl bag containing the ballistic nylon cloth ended five to six inches too short in the back due to considerable linear take-up of the bag when configurated into a curve over the shoulder of the wearer. The lack of complete ballistic coverage, however, was compensated for by the stitching of six plies of nylon cloth six inches in width across the bottom of the inner felt assembly (Figure 2).

Stability of the individually encapsulated ballistic assemblies inside the outer shell liner was found unreliable. A positive attachment of the assemblies to the vest could not be obtained because of the profile design of the liner which had no reinforcement strips or facings. Innovations were tried, such as tie-cords and edge-tacking, but were found unsatisfactory. The vinyl bags could not be stitched to the liner, to prevent excessive shifting, because the needle punctures would have destroyed the airtight integrity of the vinyl bags. The problem was resolved by heat-sealing the perimeters of the two vinyl bags together by the use of 1/2-inch bar-seals.

The design for the 1/4-inch foam consisted of three plies of split front/back panels, connected over the shoulders (Figure 3). The foam panels were inserted into the liner after the vest was made but before the bottom seams were closed. The Model I vest had two bellows pockets (with flaps closed by snap fasteners), a collar and elastic side laces for individual adjustment. The front opening consisted of a slide fastener covered by a 12-layer, ballistic nylon flap and secured by a full-length, Velcro tape fastener. Two nylon hold-down straps were added, to be secured around the legs to prevent the vest from rising above the shoulders when the wearer is floating. The straps were attached to the bottom of the vest at each side by being threaded through a dee-ring and secured with a Velcro, tape fastener. Adjustments were made by a slider buckle arrangement. Figure 4 shows the completed vest.

Figure 5 illustrates the positioning of the materials utilized in manufacturing the vest and Table VI lists the materials and pertinent data which show a total areal density of 19.4 oz/ft^2.

Ballistic Results of New and Used Vests. Vests were manufactured by means of the engineering design concepts and materials discussed in this report, and they were then user evaluated. Three vests, returned after one year's use, were forwarded with two new vests, to Naval Weapons Laboratory, Dahlgren, Virginia, for test firing purposes. Table VII data show that the ballistic limit was not compromised after extensive use in the field. Also, the ballistic limit results were exceptionally high and equal to the results for the standard 12-ply nylon cloth vest.

Buoyancy Results of New and Used Vests. Early in the development program, it became apparent that, if the individual ballistic assemblies were sealed in vinyl bags, over 20 pounds of buoyancy could be achieved. However, this buoyancy was insufficient to meet the minimum requirement of 30 pounds. It was also considered essential that the additional buoyancy needed to meet this minimum requirement be obtained by the use of inherently buoyant polyethylene foam. This was to assure continuing emergency flotation if both the vinyl bags were punctured and rendered useless.

The Model I vest was designed with the two ballistic assemblies, nylon cloth and polypropylene felt, in separately sealed vinyl bags and with 3 layers of 1/4-inch, unicellular, polyethylene foam. This design concept was retained for all prototype work and in the final vests manufactured for user evaluation. The weight of foam employed in a medium size vest was approximately 12 ounces (total weight of foam will vary according to vest size), which produced approximately 15 pounds of buoyancy. (Buoyancy for the foam alone averaged 21 pounds per pound.)

Two buoyant-ballistic, protective vests, size small, were received from the field after a one-year use. To ascertain the loss of buoyancy due to a permanent compression set, the foam was removed from the used vests and laboratory tested. Table VIII data show that the 1/4-inch foam taken from vests A and B exhibited a loss in buoyancy of 3.3 and 4.5 pounds per pound foam, respectively, an average loss of 19 percent. The initial 15 pounds of inherent buoyancy, contained in 12 ounces of foam from a new vest, was reduced to 12.1 pounds buoyancy after one year's use in the field.

The vest can lose buoyancy in two ways: first, if a permanent compression set of the foam occurs, as noted above; second, if the sealed vinyl bags are punctured. As most of the total vest buoyancy is derived from the sealed bags, it was important to evaluate the loss of buoyancy after they were punctured. A new vest, size medium, was test fired with 35 rounds, distributed front and back; 17 rounds were partial penetrations and 18 rounds were complete penetrations (Figure 6). NCTRU personnel then tested the thoroughly punctured vest for buoyancy by suspending it vertically from a scale in water. Table IX data show that the vest retained, after one hour in the water, 20 pounds buoyancy, 56.4 percent of its original buoyancy. After 18 hours, there was no further loss.

Analysis of buoyancy data (Tables VIII and IX) indicated the following:

(a) Initially, the vest contained 35 pounds of buoyancy.
(b) A vest containing multiple holes in both sealed bags lost approximately 44 percent of its total buoyancy, retaining an average of 19-3/4 pounds positive buoyancy (considered adequate to float a man, Figure 7).
(c) An average additional loss of 3.9 pounds of buoyancy could be anticipated after the vest was used, which further reduced total buoyancy of the vest, containing ruptured vinyl bags, to 16.4 pounds (still considered adequate to float a man).

<u>Field Evaluation of Model I Vest</u>. The Model I vest was manufactured in sizes small and medium and was user evaluated. The users reported adequate buoyancy (Figure 8) but indicated the following disadvantages:

1. Zippers corroded and did not work.
2. Vest was too bulky.
3. Vest was very hot.
4. Vest made it difficult to shoulder-fire a weapon.
5. The design of the front/back split-foam panels made Navy personnel doubt that the total area of the vest would offer ballistic protection. (Actually, no area was without equal ballistic protection.)

Model II Vest

<u>Design</u>. Based on user comments, the Model I vest was redesigned. The front zipper closure was removed and replaced by two-inch-wide strips of a Velcro touch-and-close fastener consisting of two overlapping flaps with six plies of ballistic nylon fabric securely stitched to each one. The reported difficulty of shoulder-firing a weapon was due to excessive thickness in the shoulder area. Accordingly, the foam was redesigned as solid, full-width panels and placed into the bottom two-thirds of the vest (Figure 9). The foam weighed approximately 12 ounces and the total vest buoyancy remained equal to the Model I vest, while the objectionable split-foam design and shoulder thickness were eliminated. The position of the side hold-down straps was moved to the bottom rear of each front panel. The straps were now secured by a snap hook, dee-ring assembly. Adjustment continued to be made by slider buckles. Snap fasteners provided quick release of the straps.

In addition, the bellows pockets and grenade straps on the outer shell liner were lowered to allow placement of shotgun patches on the front right and left shoulder areas to eliminate slippage of the gun butt. The inner and outer circumference of the liner was increased to provide for improved comfort and fit with the buoyant-ballistic assemblies inserted and Velcro fasteners secured (Figure 10).

Because of the requested ballistic and buoyancy requirements, the bulkiness of the vest could not be further reduced. However, the other design changes were expected to result in improved comfort and fit.

Field Evaluation of Model II Vest. The Model II vest was manufactured in sizes small, medium and large and was user evaluated. Although results of the evaluation indicated the vest was conditionally acceptable, the following problems were noted:

a. The vest was unsuitable, because of its bulk, for use in enclosed, weapons-firing stations and engine spaces in small river patrol boats. It was suitable for exposed stations, however, and for use by boarding and search personnel.
b. It was difficult to fire a shoulder weapon while wearing the vest.
c. The leg straps were a source of constant irritation, because they restricted the wearer in his movements and caused chafing.
d. The "shotgun pocket" was not adequate.
e. Armholes were too small and the shoulder coverage too broad to permit freedom of arm movement for persons assigned to the helsman station.

Analysis of questionnaires showed that the Model II vest was conditionally acceptable. The crews indicated that they would wear the vest. It was recommended that it be issued to crewmen not assigned to enclosed stations and to personnel engaged in boarding and search operations. The vest should, however, be redesigned for improved comfort, fit, body mobility and reduced bulkiness.

CONCLUSIONS

Model I and II buoyant-ballistic vests were engineered for use by Naval crews subjected to enemy shelling. The vest is equal in area coverage to the 12-ply nylon cloth vest. The ballistic assembly, weighing approximately 14.0 oz/ft^2, is composed of 6 plies of 14 oz/yd^2 nylon cloth and 8 plies of 4.5 oz/yd^2 polypropylene needle-punched felt, and exhibits a ballistic limit greater than 1,225 feet per second. The new experimental vests showed excellent buoyancy of more than 30 pounds, of which 15 pounds buoyancy is provided by 12 ounces of 1/4-inch unicellular, polyethylene foam for emergency flotation. The vests have been field evaluated and found conditionally acceptable. Certain design changes were recommended in the initial Model I vest and these were effected. The principle cause of complaint for both the Model I and the redesigned Model II vests was excessive bulkiness which restricts normal body movement in tight quarters. The majority of the evaluators indicated, however, that they would wear the vest if supplied to them, but they would like further redesign work for improved comfort, fit, body mobility and reduced bulkiness. It is recommended that further research and development efforts be continued to improve buoyancy and ballistic resistance and redesign the vest to be more responsive to the needs of Naval personnel.

APPENDIX A. ILLUSTRATIONS

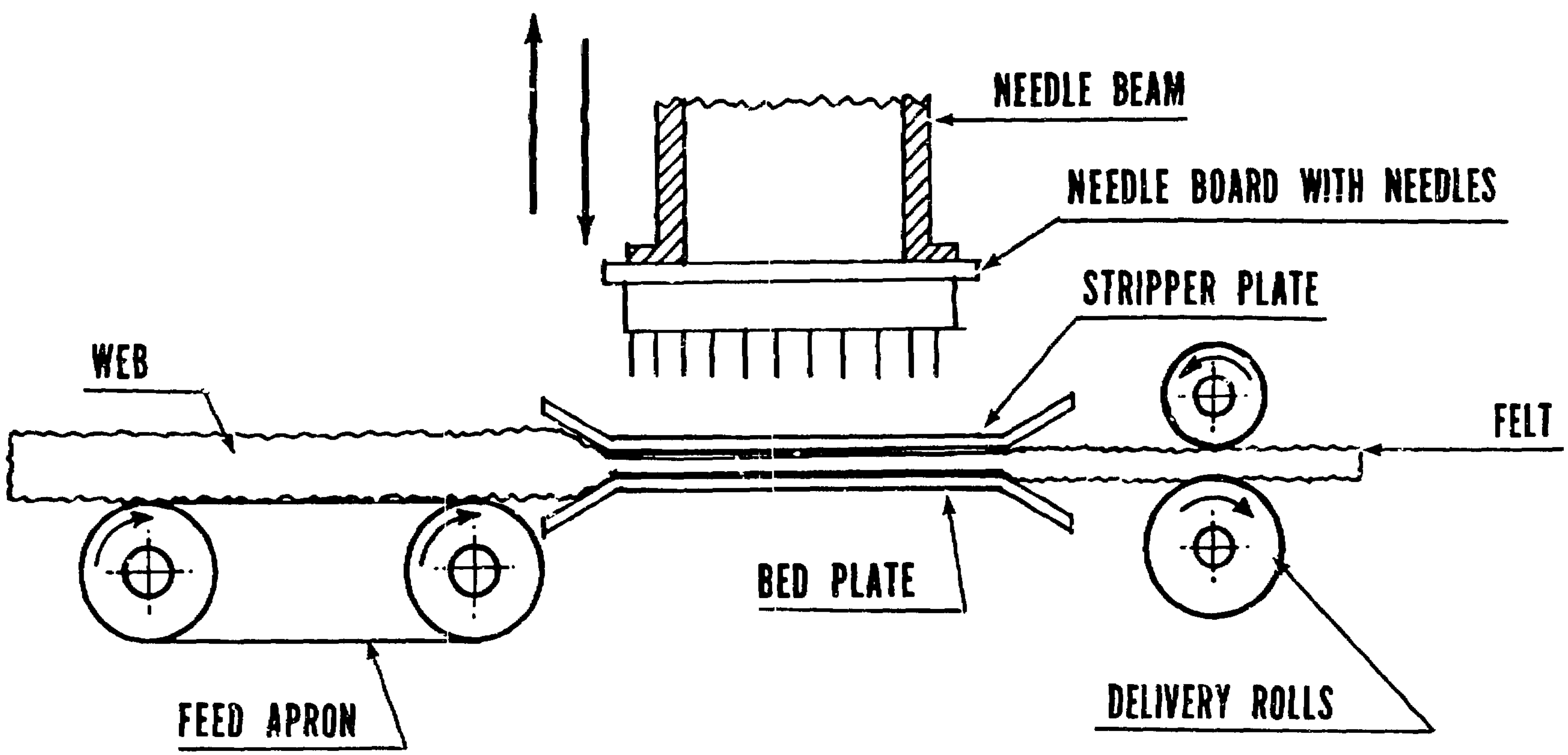

FIGURE I- BASIC COMPONENTS OF THE NEEDLE FELT MACHINE

Figure 2. Ballistic Assemblies Sealed in Vinyl Bags.

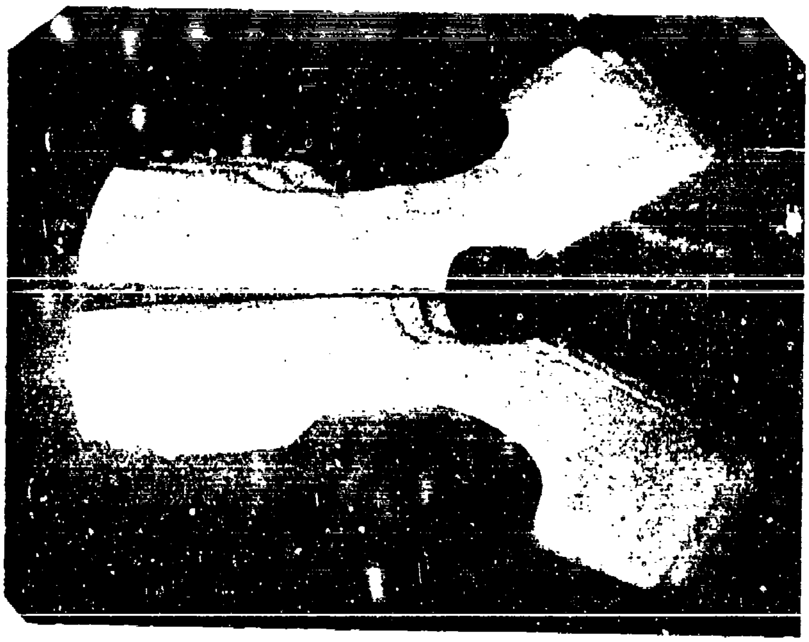

Figure 3. Split Foam Front/Back Panels for Model I Vest.

Figure 4. Front View of Model I Vest.

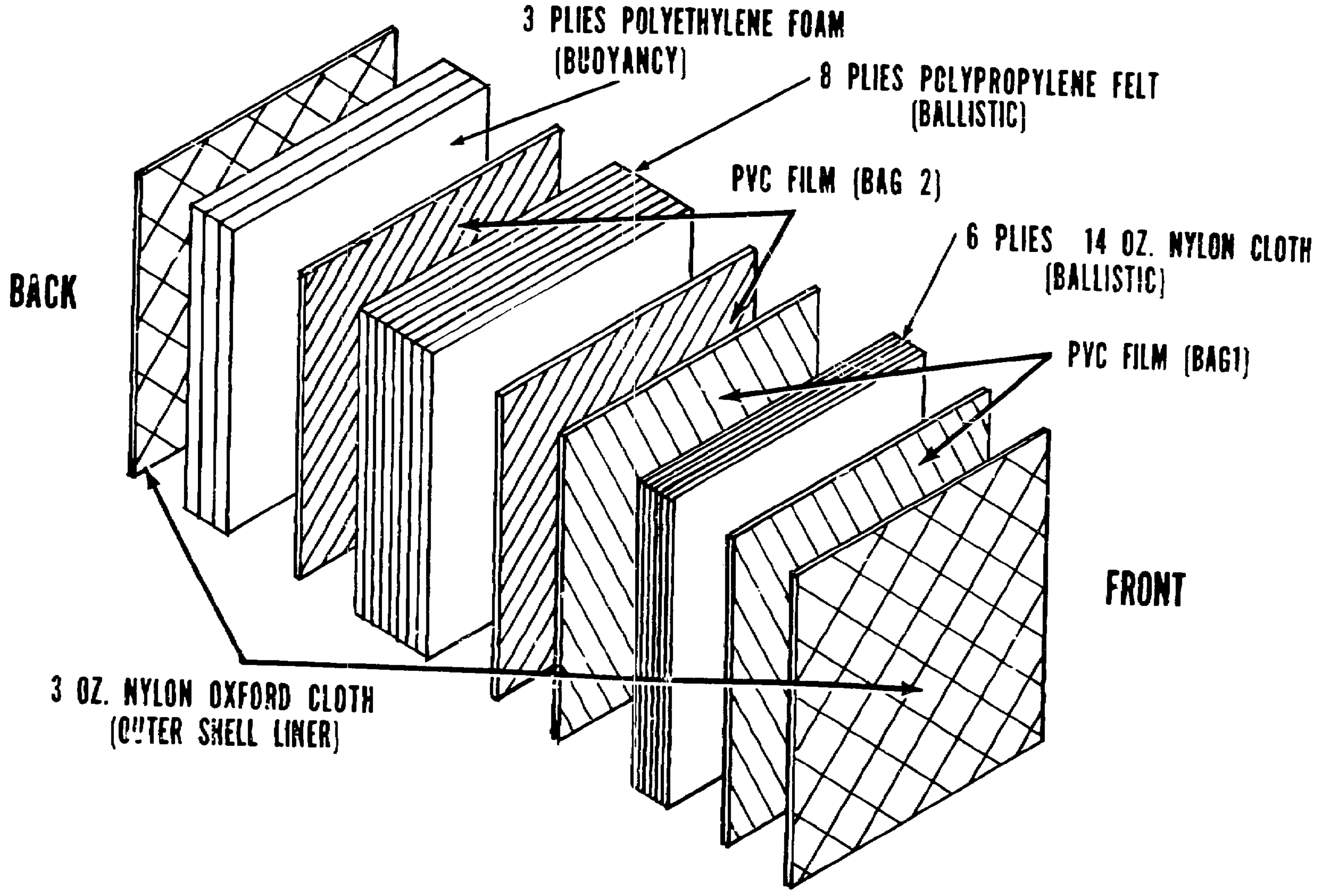

Figure 5. Position of Materials in Buoyant Ballistic Vest.

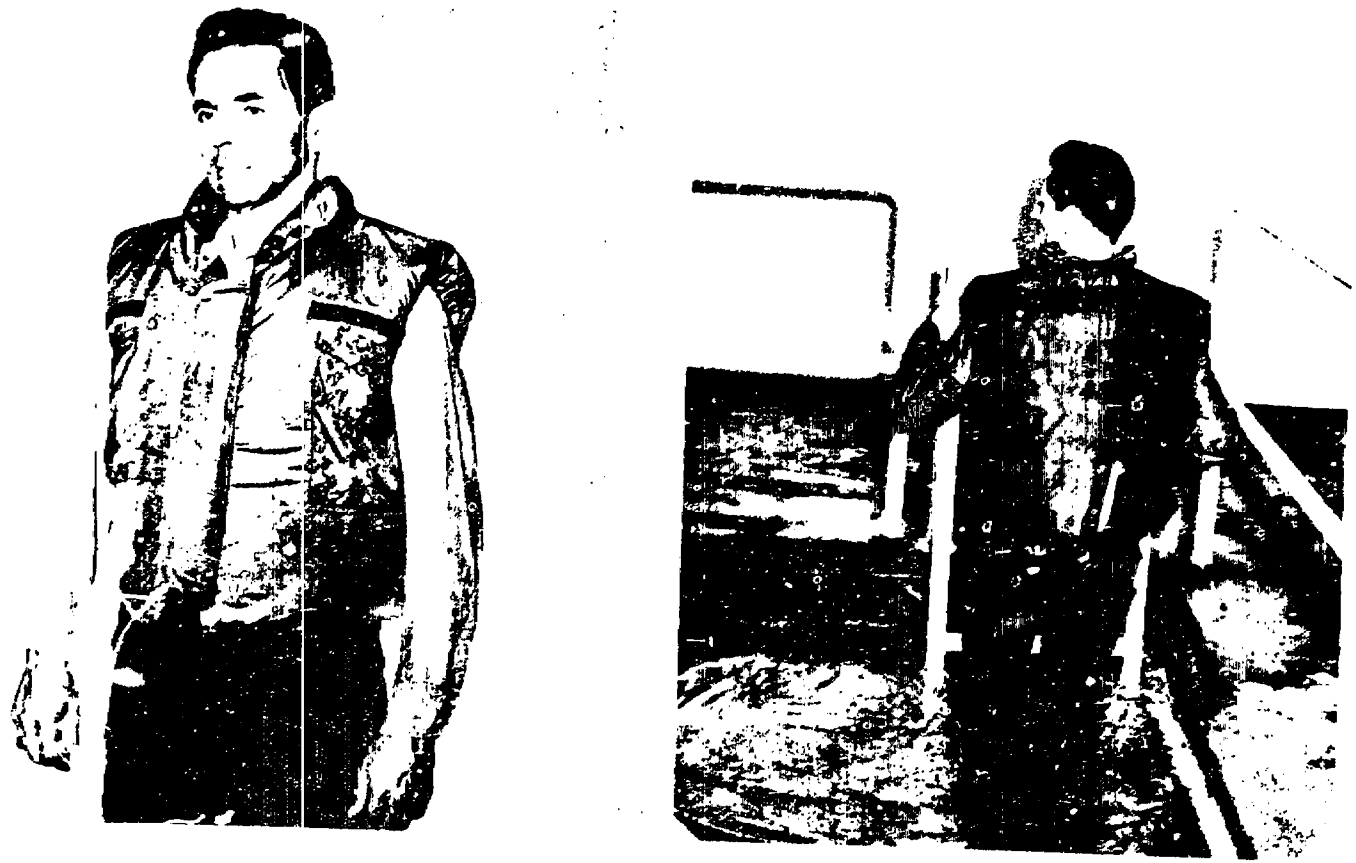

Figure 6. Model I Vest Showing Front and Back Views of Test-Fired Panels.

Figure 7. Flotation Characteristics of a New Model I Vest (Left) Compared with a Test-Fired Vest (Right).

Figure 8. Swimmer Wearing Model I Vest.

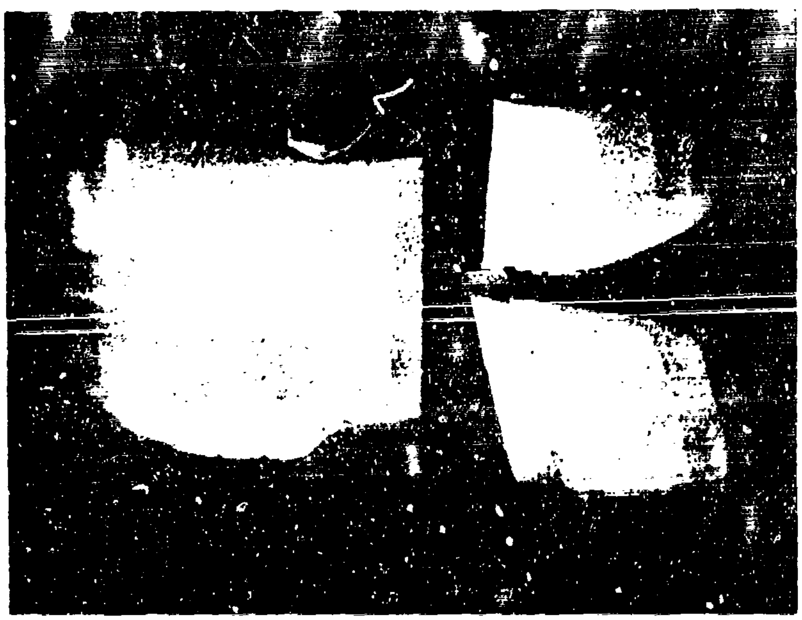

Figure 9. Solid Foam Inserts for Model II Vest.

Figure 10. Front View of Model II Vest.

APPENDIX B. TABLES

Table II. Ballistic Limits When Varying Plies and Altering Position of Materials in Assembly.

Assembly	Front		Middle		Back		Assemblies		Ballistic Limits (ft/sec)
	Plies	Mat'l	Plies	Mat'l	Plies	Mat'l	Thickness (inches)	Weight (oz/ft^2)	
A	12	Nylon	--	--	--	--	0.35	19.0	1181
B	6	Nylon	8	Felt	3	Foam	2.13	15.7	1192
C	6	Nylon	3	Foam	8	Felt	2.13	15.7	1099
D	6	Nylon	6	Felt	3	Foam	1.83	14.7	1042
E	8	Felt	6	Nylon	3	Foam	2.13	15.7	1169
F	3	Foam	8	Felt	6	Nylon	2.13	15.7	1040

NYLON, Cloth, Ballistic for Armor, MIL-C-12369.

FELT, Polypropylene - weight, 4.5 oz/yd^2; needle penetrations per square inch, 352 PPI^2; thickness, 0.150 inch; soft finish.

FOAM, Unicellular Polyethylene, 1/4-inch thick; weight, 7.2 oz/yd^2.

Table III. Ballistic Limits for 8 Plies of Polypropylene Felt.*

Assembly	Weight (oz/ft^2)	Thickness (inches)	Ballistic Limits (ft/sec)
0848	4.16	1.15	1068
0849	3.68	1.14	1069
0854	4.00	1.21	1066
0855	3.84	1.14	1071
0856	4.00	1.22	1099
0850	4.80	1.27	1130
0852	4.32	1.23	1102
0853	4.32	1.22	1100
0847	4.48	1.23	1096

*Felt assemblies were prepared from individual 100-yard rolls of felt containing 352 needle penetrations per square inch.

Table IV. Ballistic Limits with Increasing Plies of Calendered, Polypropylene Felt in Combination with Nylon Cloth.

Assembly	Nylon Plies	Polypropylene Plies*	Nylon Felt Assemblies		Ballistic Limits (ft/sec)
			Weight (oz/ft^2)	Thickness (inches)	
a	6	--	9.4	0.17	953
b	10	--	15.5	0.29	1061
c	12	--	19.0	0.35	1181
d	6	8	13.7	0.61	1173
e	6	12	15.7	0.83	1222
f	6	16	17.7	1.05	1262
g	6	20	19.7	1.27	1277

*Polypropylene Felt - 352 needle penetrations per $inch^2$; nominal 4.5 oz/yd^2.

Table V. Ballistic Limits of 8 Plies* of Polypropylene Felts with Decreasing Fiber Mobility in Combination with 6 Plies of Ballistic Nylon Cloth.**

Assembly	Cold Calendered	Needle Penetrations Per Inch^2	Single Felt Weights (oz/yd^2)	Nylon Felt Assemblies Weight (oz/ft^2)	Nylon Felt Assemblies Thickness (inches)	Ballistic Limits (ft/sec)
204	No	204	5.2	14.4	1.63	1331
352-S	No	352	5.5	14.7	1.45	1294
352-C	Yes	352	4.5	13.7	0.61	1173
41436	No	900	4.8	14.1	1.45	1229
41437-C	Yes	900	4.5	13.9	0.94	1140
41438	No	1900	5.2	14.4	1.31	1178
41439-C	Yes	1900	5.1	14.3	0.70	1131
41440	No	900	9.3	13.9	1.07	1115
41441-C	Yes	900	9.3	13.9	0.63	1167
41442	No	1900	9.1	13.9	0.99	1177
41443-C	Yes	1900	8.9	13.6	0.59	1168

*Assembly Nos. 41440 to 41443 were tested with 4 layers of polypropylene felt in combination with 6 layers of ballistic nylon cloth.

**Ballistic cloth positioned in front of the felt.

Table VI. Materials in the Buoyant-Ballistic Vest (Listed in Order From Front to Back).

Materials	Purpose	Layers	Areal Density (oz/ft^2)
3-ounce Nylon Oxford Cloth	Outer Shell Liner	1	0.336
8-mil PVC Film	Waterproof Bag	1	0.528
Ballistic Nylon Cloth	Ballistic Protection	6	9.696
8-mil PVC Film	Waterproof Bag	2	1.056
Polypropylene Felt	Ballistic Protection	8	4.224
8-mil PVC Film	Waterproof Bag	1	0.528
1/4-inch Polyethylene Foam	Inherent Buoyancy	3	2.688
3-ounce Nylon Oxford Cloth	Outer Shell Liner	1	0.336
		TOTAL	19.392

Table VII. Ballistic Limits of New and Used Buoyant-Ballistic Vests.

Description	Ballistic Limits (ft/sec)
New Vest, Model I	1346
New Vest, Model I	1316
Used Vest, Model I	1374
Used Vest, Model I	1384
Used Vest, Model I	1348

Table VIII. Bucyancy Results of 1/4-Inch Polyethylene Foam From New and Used Vests.

Sample	Dry Weight of Foam (ozs.)	Buoyancy of Foam (ozs.)	Buoyancy (lbs/lb foam)
New Foam	10	203	20.3
A, Used Foam	12	203	17.0
B, Used Foam	10	158	15.8

Table IX. Buoyancy Results of Test-Fired, Medium Size, Buoyant-Ballistic Vest.

Immersion Time	Weight of Vest Plus Ballast in Water*	Buoyancy of Vest
Initial	5 lbs., 8 ozs.	35 lbs.
10 minutes	13 lbs.	27 lbs., 8 ozs.
30 minutes	18 lbs., 11 ozs.	21 lbs., 13 ozs.
1 hour	20 lbs., 8 ozs.	20 lbs.
1-1/2 hours	20 lbs., 12 ozs.	19 lbs., 12 ozs.
18 hours	20 lbs., 12 ozs.	19 lbs., 12 ozs.

*Weight of ballast in water - 40 lbs., 8 ozs.

APPENDIX C. REFERENCES

1. Ipson, T. W. and Wittrock, E. P., Response of Non-Woven Synthetic Fiber Textiles to Ballistic Impact, Denver Research Institute, University of Denver, Colorado, Contract No. DA19-129-AMC-157(N), U. S. Army Natick Laboratories, July 1966.

2. Packaging with Ethofoam, Dow Chemical Corporation, dated 1966.

3. Ballistic Protective Buoyant Materials, Mellon Institute Quarterly Reports 1 through 16, dated 1 November 1959 through 31 January 1964.

4. Jaskowski, M. C., "Buoyant and Ballistic Properties of Fibrous Clothing Insulation," Modern Textiles Magazine, October 1964.

5. Armor Materials Research, U. S. Army Natick Laboratories Technical Report C&OM-5, Part 1, August 1965.