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Technical Memorandum 4-73

HISTORICAL DOCUMENTATION OF THE INFANTRY HELMET RESEARCH AND DEVELOPMENT

USAMC Five-Year Personnel Armor System

Technical Plan

Charles W. Houff
Joseph P. Delaney

February 1973
AMCMS Code 564M.55.L40

HUMAN ENGINEERING LABORATORY

ABERDEEN PROVING GROUND, MARYLAND

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February 1973

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ABSTRACT

This report documents the history of U. S. infantry helmets from 1917 to 1971. Major topics are presented in separate sections: Ballistic Protection, Materials Technology, Suspension and Retention, Acoustic Characteristics, Eye Protection and Visual Field, Anthropometrics and Mathematical Models of the Head, Wound Ballistics, and Funding. Discussion of helmet design includes one-piece versus two-piece (shell and liner), one size versus multiple sizes, pad versus multiple-web suspension, and area coverage. The current evaluation procedure, Casualty Reduction Analysis, is also discussed.

The report concludes that the helmet program contained in the USAMC Five-Year Personnel Armor System Technical Plan adequately addresses the major problem areas established by this documentation. It concludes further that the systems approach is appropriate for problems of incompatibility and for optimizing the total ballistic protection for the combat soldier.

FOREWORD

The work contained in this report was funded by the U. S. Army Natick Laboratories, Natick, Mass., under project number 1J664713DL40. The original objective was to retrieve, review and evaluate all pertinent data concerning the research, development, testing and evaluation of the M1 steel helmet and liner. It soon became apparent that, to place the entire helmet development program in perspective, the scope of the report should be expanded to include the efforts that preceded the M1 helmet and those that have followed the adoption of the M1 as the standard helmet.

The authors are extremely grateful for the assistance of Miss Jois Williams of the Biomedical Library at Edgewood Arsenal, Md. Her technical competence and cheerful enthusiasm were a major factor in the acquisition of the literature to document this report. The timely and unfailing support of Mrs. Mary Starr in the voluminous typing is also gratefully acknowledged.

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INTRODUCTION

The Human Factors Group of the Biomedical Laboratory at Edgewood Arsenal, Md., was requested by the Human Engineering Laboratory to retrieve, review and evaluate all pertinent data concerning research, development, testing and evaluation of the M1 Steel Helmet and Liner. This historical documentation was accomplished as a Work Unit, HLR-5, of the U. S. Army Materiel Command Five-Year Personnel Armor System Technical Plan (1971).

The initial step was to retrieve all documents available on infantry helmets from the Defense Documentation Center (DDC), Natick Laboratories Technical Library, Aberdeen Proving Ground and Edgewood Arsenal Technical Libraries, Medical Literature Analysis Retrieval System (MEDLARS), and Scientific Technical Information Office (STINFO).

A chronological history of the U. S. infantry helmet from 1917 to 1971 was prepared from the documents retrieved. To gain a perspective on the M1 helmet, it was concluded that a history of all U. S. infantry helmet development should be included. Therefore, the history covers the M1917, M1917A1, M1 and all documented experimental models developed as candidate replacements for these standard models up to 1971.

Specific problem areas were identified, general overviews of the problem areas encountered and attempted solutions were traced. These problem areas are not mutually exclusive nor exhaustive and include ballistic protection with the associated problems of material, area coverage, silhouette and weight, and lack of stability on the head (or suspension and retention).

The solution to ballistic-protection problems center on materials technology. The specific goal is to increase protection, consistent with human factors, against the projected threat.

Of equal importance to ballistic protection are human factors elements such as weight, weight distribution, presented target area, off-set from the head, ventilation, comfort, stability, hearing, vision-area coverage and protective capability. These parameters directly influence soldier acceptance and the probability of wear of any headgear under combat conditions.

Utilizing casualty reduction analysis and expressing protection in terms of casualty reduction will enhance the combat soldier's ability to understand and appreciate the capability of any protective system.

The developmental history shows that the problem areas discovered during development of the M1 helmet and liner, as well as subsequent candidate helmets, are those addressed by the USAMC Five-Year Personnel Armor System Technical Plan. This detailed plan will generate the basic data to perform the trade-off analysis necessary to optimize future ballistic headgear as a component of the overall ballistic protective system for the combat soldier.

The value of this report is that it establishes what has been done, what approaches have been tried, and for what reasons they have been accepted or rejected. The documentation should eliminate approaches offering little probability of success or illuminate areas previously rejected for reasons that now appear invalid.

DEVELOPMENTAL HISTORY

The historical documentation that follows shows that infantry helmet research and development activity has increased during periods of hostility. Generally the period 1917-1971 can be divided into eras as follows: World War I; 1920-1934; 1935-1940; World War II; post World War II through Korea; post-Korea and Vietnam. It is also evident that helmet research and development over the years can be identified by category of effort.

World War I

The first U. S. Army protective helmet was the British Mk I, which was adopted during World War I, since the British could furnish helmets while the U. S. was setting up production. The Mk I, with a U. S. modification to the suspension system, was designated as the U. S. Model 1917. Concurrently, research was initiated to develop a "distinctly American" helmet. The most promising model, #5, was rejected as being too similar to the pot-shaped German field helmet.

1920-1934

Further testing of experimental models and retesting of the Model 5 between 1920 and 1934. In 1934, the M1917 was modified by the addition of hair-filled pads to the suspension system and designated the M1917A1.

1935-1940

The M1917A1 remained the standard U. S. helmet until 1940, when the Chief of Infantry requested a new helmet. The TS3, a pot-shaped helmet shell with removable liner incorporating a suspension system, was then developed.

World War II

In 1941, the TS3 was tested and approved and designated the U. S. Steel Helmet, M1. During the war, research and development efforts were initiated to improve that standard helmet.

Post-World War II

After World War II, helmet research and development continued in two main directions: (1) to improve the M1 helmet and (2) to develop a helmet to replace the M1 as standard. Product-improvement efforts have included research in ballistic materials for both the helmet and liner, and research to improve the suspension/retention system.

New helmet-development programs have included ballistic materials and suspension/retention systems and have also considered new shapes, sizes, etc. A specific requirement to lighten the infantry soldier's load (the LINCLOE program) led to ballistic-materials research principally in titanium, polycarbonates, nylon, and composites of different materials.

Post-Korea and Vietnam

In 1968 two specific helmet concepts were introduced. The siege helmet was an effort to provide more protection for the head, at an increased weight, in non-mobile situations. The Hayes-Stewart helmet was proposed to give greater coverage at decreased weight and to provide a variety of sizes for greater comfort and stability.

The helmet-development chronology is completed with the approval of a complete and comprehensive development program, the USAMC Five-Year Personnel Armor System Technical Plan (1972). This plan includes both short-range and long-range development programs to be accomplished within the AMC Laboratories. Partial documentation of helmet efforts during the first year of this plan is included in the report.

HISTORY

Men wore helmets and armor for protection against enemy armaments as early as 1015 B.C. Materials used included hair-filled hides, quilted cloth, wood, and various types of metals. Since the armorers of all eras have the task of providing protection, the quality of armor protection increases with the technology of the times to counter the weapons of the times. Armor was also often stylized to provide prestige, recognition and identification as well as protection. But the sheer weight of armor required to protect the wearer defeated the mobility required on the battlefield, and the advent of firearms in the 15th Century began a decline in use of armor. Although specialized armor continued to be worn through the Napoleonic Wars and was reported in isolated instances in the American Civil War, helmets and armor had disappeared from the dress of the U. S. soldier before World War I. Excellent historical accounts of helmets and body armor are provided by Crowell (72), Dean (76), Studler (274), and Coates and Beyer (53).

The early stages of World War I emphasized mobility, but as the war progressed, it became static and developed into trench warfare. Mobility became secondary to a requirement for protection in the trenches from artillery and mortar fire. All the authorities in the field give Intendant-General Adrian of the French Army credit for re-instigating the use of a metal helmet in World War I.

Observing his troops in 1915 General Adrian learned that one of the poilus had been saved from a serious head wound because he had been wearing his metal food-bowl, whereupon the general had a steel skull-cap calotte made to wear under his kepi. Later convinced of its effectiveness, he had helmets fabricated for the French Army which resembled the helmets of firemen. These "casque Adrian," were credited with providing at least partial head protection against lower-velocity fragments.

The French completely equipped their army with helmets in 1915-1916, the British and Germans in 1915, and the Belgians and Italians in 1916. Of special interest is the Mk 1 helmet issued to the British. When the U. S. entered the war in 1917, it had no helmet in its inventory. The Army General Staff reviewed the helmets of its allies and provisionally selected the Mk 1 for issue to U. S. troops. This helmet was already in production and could be bought from the British. The Mk 1 was not ideal since it protected a smaller area of the head then the French and was heavier than the French, but it was simple to manufacture and gave good ballistic protection. Some 400,000 Mk I helmets were shipped to France between July and November, 1917, to equip arriving U. S. troops.

The Mk I helmet was made of manganese steel .036 of an inch thick, weighed approximately two pounds, and contained an integral suspension system. When the U. S. started its own production of helmets, it changed the metal alloy to improve ballistic performance (10% improvement over Mk I) and modified the lining design to provide a cotton-twine mesh. Additionally, the cowhide chin strap was replaced with a web strap and a new buckle arrangement was added. By February, 1918, 700,000 American-made helmets had been delivered. By 11 November 1918, more than 2,700,000 American M1917 helmets had been produced.

Even while the M1917 was being tooled up and produced, the Army Ordnance Department was engaged in developing experimental helmets to replace it. Design objectives of this development were multiple: patriotic, to design a distinctly American helmet; diplomatic, to avoid a charge of favoritism in selecting a foreign helmet; and functional, to provide a superior helmet for U. S. troops.

Numerous design models were developed in the period 1917-1918 to provide additional protective coverage, improved ballistic properties, more adequate suspension, adaptability for special applications (such as tank or aircraft operations), and a distinctive patriotic design.

Some 15 infantry and special-purpose models were developed. Models 2, 3, 4, 5A, 6, 8 and 10 were infantry helmets; 7 was a sentinel's helmet; 9 was a machine gunner's helmet; 12 was a tanker's helmet; 14, 14A and 15 were aviators' helmets; and the Liberty Bell was a variant of Model 4. All these models are described and illustrated in Dean (76). For a variety of reasons, ranging from difficulty of manufacture to unacceptability of design, none of the experimental helmets were adopted in World War I.

The most promising of these experimental models was Model 5A. It had a pot-shaped design, weighed two pounds 6 ½ ounces, offered maximum protection for its weight, and was claimed easy to produce. The Model 5A was designed by the Metropolitan Museum of Art in conjunction with the Ordnance Department, and it was strongly recommended by the General Staff. The Swiss Model 1918 closely resembled the 5A but was independently developed (Dean, 76).

During the period 1918-1940, Ordnance Department research and development continued to strive for an acceptable helmet that offered increased area coverage and improved ballistic protection when compared with the M1917 - M1917A1, and modified the suspension system to make the helmet more stable and thus facilitate troop acceptance.

Comparative service tests of the 5A and M1917 were conducted in 1926 (274). The M1917 was continued as the standard helmet because it afforded greater ballistic protection, was lighter and interfered less with rifle firing. Further comparative tests of helmet-steel composition again proved the M1917 superior, so in 1932 testing of pot-shaped helmets was stopped. In 1934 the M1917 lining was changed to a hair-filled pad and the helmet standardized as the M1917A1 (274). This helmet weighed two pounds 6 ounces.

Between 1934 and 1940, Coates and Beyer report that a lull in helmet development occurred until 1940, when the first draft call was issued. New overtures were made to American industrial firms and to the Metropolitan Museum of Art in an attempt to improve the protective coverage and ballistic limit of the M1917A1 helmet and to take advantage of recent advances in steel alloy manufacture, liner materials, and mass production methods. In addition, a 2-piece helmet was considered desirable to meet the increasing variety and complexity of tactical and climatic conditions. The first problem to be solved was to determine the desired characteristics and a satisfactory shape for a helmet. This problem was given to the Infantry Board, which stated in a report:

> Research indicates that the ideal shaped helmet is one with a dome shaped top and generally following the contour of the head, allowing sufficient uniform headspace for indentations, extending down in the front to cover the forehead without impairing necessary vision, extending down on the sides as far as possible without interfering with the use of the rifle or other weapons, extending down the back of the head as far as possible without permitting the back of the neck to push the helmet forward on the head when the wearer assumes the prone position, to have the frontal plate flanged forward to form a cap style visor, and to have the sides and rear slightly flanged outward to cause rain to clear the collar opening (274).

These characteristics address the problems of providing increased area coverage for the soldier's head, more stability than existed in the M1917A1, compatability with the soldiers equipment and military tasks, (and therefore soldier acceptability). Interestingly enough, the Infantry Board mentioned neither increased ballistic protection nor weight.

Based on the characteristics enumerated, a helmet was developed which basically was the dome of the M1917 with the rim cut off, extended down on all sides, and flanged to provide a visor and to allow rain run-off.

Materials technology indicated that the best ballistic protection to be attained was provided by the Hadfield manganese steel which had been used in the M1917. The pot-shaped helmet was then modified to improve the visual field and sized to provide a uniform standoff.

The helmet was suspended and retained by a fiber liner which fitted into and could be secured to the steel helmet. This liner incorporated a modified Riddell football-helmet suspension system. The proposed helmet and liner system, designated as the TS3, had a total weight of three pounds, with the steel shell weighing 2.3 pounds and the liner and suspension system weighing 0.7 pounds.

During testing at Ft. Benning and at Aberdeen Proving Ground, the TS3 received favorable reports of more coverage, more comfort, more stability on the head, an acceptable visual field, non-interference with rifle firing and a better-than-expected ballistic performance. Where the M1917 specification required it to resist penetration by a 230-grain, caliber .45 bullet with a velocity of 600 feet per second, the ballistic test of the TS3 required penetration resistance by a similar bullet at 800 feet per second. A report from Aberdeen Proving Ground concluded that "The experimental helmet, TS3, is ballistically superior to the requirements for a military helmet" (274).

The TS3 received a favorable report from the Infantry Board in February 1941 as a successor helmet to the M1917A1 and it was standardized on 30 April 1941 as the Army M1 Helmet. It was approved on 9 June 1941.

When the M1 Helmet was standardized, the Ordnance Department was responsible for an initial procurement of approximately 962,000 helmets, including liners. After the initial procurement, the Ordnance Department retained responsibility for developing and procuring the steel helmet and the Quartermaster Corps was assigned responsibility for developing and procuring the helmet liner and suspension system.

Between 1941 and 1945 the Quartermaster Corps continued efforts to improve the M1 helmet liner and the Ordnance Corps continued efforts to develop an improved helmet shell. During the period August 1941 to August 1945, 22,363,015 M1 helmets were produced (53).

The Quartermaster Corps went to work to improve the "Hawley Type" compressed paper-pulp liner, and by July 1944 had developed and type-classified an improved impregnated cloth liner and improved headband and retaining clips. The neckband was modified so that it was more comfortable, provided more stability, and was both detachable and adjustable. Between 1942 and 1945 more than 3,900,000 liners were procured.

The Office of the Quartermaster General commented that "Even more interesting than the quantities procured is the variety of uses to which the liner was put:

> It served as a field hat in temperate zones, as a sun helmet in the tropics, as protective headgear over a woolen cap or toque in cold climates, and of course as a lining for the steel helmet in all combat zones. Furthermore, modifications of the liner were used by jungle troops, parachutists, and armored troops." (207)

Additionally, the Quartermaster Corps initiated work to ascertain the possibility of replacing the liner and steel helmet with a plastic headgear which would be lighter yet offer better ballistic protection. Out of this work came the plastic armor material known as "Doron" (207). The Ordnance Corps made only one significant design change to the steel helmet assembly between 1941 and 1945, modifying the chinstrap fastener to incorporate a ball and clevis device which would automatically release at 15 pounds or more of pull. This redesign was incorporated to offset the possibility of injury to the cervical vertebrae under impact of a nearby detonation blast wave (53). Troop acceptability was fairly high, but a common complaint was lack of stability of the M1 helmet (53).

Although the M1 Helmet was standardized, investigative work to improve the helmet was continued. The Metropolitan Museum of Art, in conjunction with the Ordnance Department and Aero Medical Laboratory, designed three new helmets, the T21, 22 and 23.

The T21 shell had a curvature in all directions at all points in the helmet, established through anthropometric studies of the human head and purported to decrease size with no sacrifice of area coverage, yet increase strength and protection. It weighed two pounds, three ounces and was worn with the standard liner. The T22 was smaller than the T21 and was a one-piece helmet, worn without a liner. The T23 was larger than the T21 and incorporated a thicker liner.

Alternate ballistic materials investigated included Doron, and aluminum and nylon in combination. Helmets and liners using the alternate materials were the T24, T21E1, Doron Type 1 liner for the M1, and the Type II 24-ply nylon helmet.

The T24 helmet had an aluminum shell modeled after the M1, with a laminated nylon liner. The T21E1 utilized the nylon and aluminum but was based on the contour pattern of the T21 (53).

In spite of research and development efforts to field a better helmet than the M1, none of the experimental helmets proved to be sufficiently better than the M1 and none were standardized during the time that the Ordnance Corps had development responsibility for the M1 Helmet, although Army Field Force Board No. 3 commented favorably on the T21E2 and Doron Type II in July 1946 (319).

War Department Memorandum 30-5-2, dated 25 June 1947, assigned responsibility for developing end items of body armor to the Office of the Quartermaster General.

The period 1947-1951 saw research continuing on helmet and liner designs and on new material. The T21 was modified according to test report comments and became the T21E2, having additional coverage at the nape of the neck. However, with the additional coverage, weight increased to that of the M1. In January 1949, a decision was made to suspend development of the T21E2 and the non-ballistic tankers helmet and to concentrate on an all-purpose helmet. The first model was the EX49-3, which became the EX51 after test and modification. The EX51-1 was two-piece, having an aluminum shell and a 9-ply nylon liner. It had two sizes, small, to size 7 1/8, and large, size 7 and larger. The EX51-1 utilized the M1 suspension and weighed under three pounds. It was extensively tested (319, 67, 165, 166, 69, 167, 170).

Tests by Army Field Force Board No. 3 in 1952 concluded that the EX51-1 was unsuitable for the Army Field Force, pointing out that it exposed a larger area of the head to missiles, impaired hearing and interfered with communication equipment. Moreover, the hardware attachments were both fragile and difficult to operate. In this report, Board No. 3 stated that it had commented favorably in 1946 on the T21E2 and the Doron Type II and concluded that they were suitable for further development. The Board questioned the soundness of an "all-purpose helmet" (319).

An Army Helmet Conference at the Office of the Quartermaster General in Washington, D. C., 9-10 December 1952, decided to discontinue the all-purpose helmet and require two helmets -- one infantry and one combat vehicle crewmen -- and developed the military characteristics for these two helmets.

In 1953, the Combat Helmet T53-2 and T54-1 Helmet Liner were engineering-development (ED) tested and engineering service test (EST) quantitities of these items were produced for testing in 1955. The T53-2 was a 35-ounce aluminum shell having a 15-ounce nylon liner. It increased the protected area by 10 percent, provided an improved suspension system, offered better ballistic protection and was considered to be more compatible with the armor vest than the M1.

The T54-1 was a four-ply 13 1/2-ounce nylon liner for the M1 steel shell. This ballistic liner had a V50 of 800 feet per second (fps) and increased the V50 of the M1 steel shell and T54-1 to 1300 fps, an increase of 250 fps. It also incorporated an improved suspension system.

Extensive tests were conducted on the T53-2 helmet and the T54-1 liner. These tests included materials, ballistic, wound ballistic, and field testing (144, 247, 248, 170, 171, 173). However, development of the two-piece T53-2 helmet was discontinued and efforts were concentrated on improving the helmet liner. The T55-2 nylon liner evolved with improved ballistic characteristics, and suspension. This liner was further tested and approved by Continental Army Command (CONARC) and recommended for adoption in March 1958 (321).

Purchases were initiated in 1959 and the liner was type classified in 1961. This liner remains the current standard.

In efforts to find an improved ballistic material for the shell, titanium was experimentally cold-formed in 1953, using the dies of the T53-2. Although weight was reduced from 38 ounces for the M1 Hadfield steel to 27 1/2 ounces, the titanium experiment was considered unsuccessful. Later attempts in 1957 attempted cold-forming titanium alloys, but these too were unsuccessful.

Interest continued in titanium-alloy helmets between 1965 and 1968, as the search continued for metals to satisfy the Lightweight Infantry Clothing and Equipment (LINCLOE) requirement for light weight. Four models were developed for test and evaluation:

TABLE 1

Titanium-Alloy Helmets Developed Between 1965 and 1968

Model	Gauge	Shell Wgt	Liner Wgt	Total Wgt
Type I	0.045	23 oz	12 oz	35 oz
Type II	0.052	27 oz	12 oz	39 oz
Type III	0.075	39 oz	12 oz	51 oz
Type IV	0.050	24 oz (w/sus)	None	24 oz

Techniques were studied for mass-production forming and helmets were successfully formed. The Army Materiel Systems Analysis Agency (AMSAA) conducted casualty-reduction studies on the 24, 39 and 51-ounce models and concluded that protection was directly related to area coverage and weight (328, 366, 241, 348).

Design studies were initiated in 1956. A contract was let to Egmont Arens to design, develop and evaluate helmet models. In 1957, a contract was let to Cornell Aeronautical Laboratory (86) to further evaluate the nine concepts submitted by Arens, to develop a one-piece helmet concept, and to develop, fabricate and evaluate suspensions and suspension systems for the T53-2, the standard M1 and the CVC helmet. From their work and from a review of Arens, a determination was made that a one-piece helmet with a movable neck shield showed the most promise (10). Cornell then modified this design, developed the Cornell One-Piece Shell, and recommended that the "visor-type" helmets be submitted for field tests. No data was retrieved from the literature of any tests that were conducted; however, the concept to date had not been accepted.

Material studies had been carried on to evaluate the ballistic qualities of candidate materials for helmets and body armor (180, 99, 315, 261, 100, 101, 102, 103, 104, 105, 106, 50, 51, 150, 151, 184, 185, 94, 95, 88, 135, 136). Attempts continued to form titanium as a helmet, and in 1965 a suitable mass-forming technique was developed to produce a titanium-alloy M1 helmet with increased ballistic protection at no increase in weight.

In 1965 the Quartermaster established a project called "Design Criteria for Combat Infantry Headgear." Also in 1965, a QMR generated a need for a lightweight helmet as a component of the "System of Lightweight Individual Combat, Clothing and Equipment Development (LINCLOE)" (341). This development project had as its goal a 24-ounce helmet for the infantry soldier to provide protection against fragmentation-type weapons. The program was initiated with two objectives:

(1) A lightweight interim helmet (35 oz.)

(2) A lightweight helmet (24 oz.).

Two approaches were followed — a one-piece nylon similar to the nylon liner incorporating a suspension system, and a two-piece polycarbonate helmet, having a polycarbonate shell and a nylon liner. Later, a one-piece titanium was added, similar to the nylon liner.

Simultaneously, contracts were let for suspension development and for casualty-reduction studies. The one-piece nylon work ceased when it was found that it was not equivalent to the M1. The one-piece titanium shell (24 oz.) was eliminated ballistically. The two-piece polycarbonate was eliminated because of poor resistance to hydrocarbons and to ultraviolet radiation.

In an Army Materiel Command (AMC) Helmet Conference held 16 May 1968, Brigadier General Hayes, Office of the Surgeon General, and Mr. George Stewart, Edgewood Arsenal, presented their concept of a new helmet design for use in Vietnam. The design resembed a Roman helmet with protection to the forehead, skull, back of the neck and temples; however, it was cut out over the ears. The one-piece helmet would incorporate a removable cushion-type suspension with a combination chin-nape strap. It would be constructed of nylon and have nine sizes. A test was conducted by the Infantry Board to determine stability, compatibility with equipment, evaluation of human factors engineering, soldier opinion of comfort, and soldier acceptability. Several shortcomings were found: the helmet was incompatible with the M17A1 mask and with body armor; it reduced vision for parachutists; and it was generally not properly human factors engineered. However, it was also found to be more stable and preferred by soldiers (111). In July 1969, AMC directed that a parallel effort be pursued (351). This effort would

include further work on the Hayes-Stewart Helmet and on a helmet that would be completely responsive to the Qualitative Materiel Requirement (QMR), since the Hayes-Stewart will not meet the QMR. The weight is to be approximately 24 ounces, but one or two additional ounces would not be an over-riding constraint if studies indicate such a requirement. Additionally, equal protection level is defined as:

> Providing equal ballistic protection to an area of the head equal to that covered by the M1 Hadfield Steel Helmet against all 4 fragment simulators (1.35, 5.185, 17 and 44 grains) fired at 0 and 45 degrees obliquity (351).

Natick Laboratories (NLABS) requested the Army Materiel and Mechanics Research Center (AMMRC) on 27 August 1969 to recommend materials for both an interim and an optimum item. AMMRC replied on 13 November 1969 that an M1-configuration titanium helmet with standard nylon liner would meet the ballistic requirements and weigh 39 to 41 ounces. AMMRC also provided details on an experimental composite material for the optimum helmet.

An October 1969 engineering design test (EDT) to determine the compatibility of the modified Hayes-Stewart Helmet with standard fatigue uniform, body armor and mask with hood was reported from the USA General Equipment Test Activity, December 1969. This report generally concluded that the helmet was compatible with the clothing and mask, but incompatible with the 12-ply body armor; and that the foam-pad suspension system was not satisfactory, although it was more comfortable and equal to the M1 with respect to stability, preference and effect on performance. This report recommended redesign to overcome these aspects and further testing (157).

While development and testing was continuing on the LINCLOE program, efforts continued from 1966 through 1968 on the M1 Steel Helmet Product Improvement Program. These efforts resulted in a correlation of helmet thickness-V50 ballistic limit which allowed a thickness-inspection plan (259) of helmets fabricated from dual hardness steels. These steels were superior to Hadfield steel but ballistically inferior to titanium alloy.

In 1968 AMC directed NLABS to pursue development of a Siege Helmet (349, 341). Work was contracted for a suspension system and AMMRC was requested to recommend armor material. In the LINCLOE in-process review (IPR) in December 1969, a decision was made to hold this program in abeyance.

In December 1969, AMC directed that a program be initiated to provide information required for the development of LINCLOE and other new helmets. There was an acknowledged information gap in data required to provide a helmet for the 99th percentile population. Consequently, in January 1970, representatives of AMC, the Ballistic Research Laboratory (BRL), the Human Engineering Laboratory (HEL), Edgewood Arsenal, AMSAA and AMMRC met with NLABS to establish plans for an in-depth program. By March 1970 a draft helmet-development plan was prepared and submitted to AMC in July for incorporation into the overall Five-Year Personnel Armor System Technical Plan published in March 1971 (351, 330). The helmet program is divided into two phases, a short-range program and a long-range program. Table 2 lists the work units of the long-range program (330). The short-range program has not been included in tables.

TABLE 2

Helmet, Infantry – Development
(Long Range)

TECHNICAL AREA	WORK UNIT (1498) No.	Description	ABORATORY	FUNDING 10^3 71	72	73	74	75	76
Anatomical Analysis	1	Helmet, Infantry - Mathematical Model of the Head	ARDC-BRL						
	2	Helmet, Infantry - Verification of Math. Model of Head	NLABS						
	3	Helmet, Infantry - Configuration and Production of Research Prototypes	NLABS						
Human Factors Analysis	4	Helmet, Infantry - Sizing Evaluation of Prototype Helmets	NLABS						
	5	Helmet, Infantry - Documentation of M-1 Helmet & Liner	ARDC-HEL						
	6	Helmet, Infantry - Effect of Helmet Form on Hearing	ARDC-HEL						
	7	Helmet, Infantry - Human Factors Engineering Support	ARDC-HEL						
	8	Helmet, Infantry - Physiological Evaluation	ARIEM						
Casualty Criteria Analysis	9	Helmet, Infantry - Casualty Reduction Studies	ARDC-AMSAA NLABS						
	10	Helmet, Infantry - Casualty Criteria	ARDC-BRL						
Materials Development & Evaluation	11	Helmet, Infantry - Ballistic Testing	ARDC-BRL						
	12	See Table IV for Materials Program	AMMRC, NLABS						
Threat, Tactical Doctrine	13	Helmet, Infantry - Tactical Doctrine Interface	NLABS						
	14	Helmet, Infantry - Threat Analysis	ARDC-AMSAA						
Systems Development Plan	15	Helmet, Infantry - Systems Development Plan	NLABS ARDC-AMSAA ARDC-HEL ARDC-BRL						

Funding levels are not included. This information is available from USANLABS on a need-to-know basis.

TABLE 2 (Continued)

TECHNICAL AREA	WORK UNIT (1498) No.	Description	LABORATORY	FUNDING 10^3 71	72	73	74	75	76
Systems Development Plan	15	Helmet, Infantry - Systems Development Plan (cont.)	AMMRC CDC CONARC						
Reliability & Maintainability	16	Helmet, Infantry - Reliability and Maintainability Criteria	NLABS						
Design & Producibility Technology	17	Helmet, Infantry - Suspension Studies	NLABS						
	18	Helmet, Infantry - Retrieval and Analysis of Design Data	NLABS						
	19	Helmet - Infantry - Fabricate Experimental Helmets	NLABS						
	20	Helmet, Infantry - Fabricate ET/ST Helmets	NLABS						
Coordinated Testing & Evaluation	21	Helmet, Infantry - Coordinated Test Plan	NLABS						
Utilization Doctrine	22	Helmet, Infantry - Establishment of Utilization Doctrine	NLABS						
Production Engineering	23	Helmet, Infantry - Production Engineering Effort	NLABS						
Specifications & Quality Assurance	24	Helmet, Infantry - Establish Systems Specifications	NLABS						
	25	Helmet, Infantry - Establish a Type B2 MIL-STD-490 Critical Item Developmental Spec.	NLABS						
	26	Helmet, Infantry - Establish a Type C2b MIL-STD-490 Critical Item Product Fabrication Spec.	NLABS						
	27	Helmet, Infantry - Establish System Technical Data Pkg.	NLABS						

TABLE 2 (Continued)

TECHNICAL AREA	WORK UNIT (1498) No.	Description	LABORATORY	FUNDING 10^3 71	72	73	74	75	76
Final Evaluations	28	Helmet, Infantry - Engineering and Service Testing	NLABS-TECOM						
Personnel & Training Requirements	29	Helmet, Infantry - Personnel and Training	CONARC						
Management Review	30	Helmet, Infantry - Annual Technical Review of Plan	NLABS						
		Total Funding/FY							
		Program Total							
		Funding by Laboratories	AMMRC ARIEM ARDC-AMSAA ARDC-BRL ARDC-HEL Edgewood NLABS Contract TECOM/GETA USABAAR						
		*Funded Outside the Program							

On 13 September 1971 a presentation was made to the Military Personnel Supplies Committee on Helmets of the National Academy of Science's National Research Council Advisory Board in Washington wherein the Five-Year Armor Program was introduced by NLABS. Work accomplished within that program was presented by NLABS, Edgewood Arsenal, BRL, AMMRC and AMSAA in the areas of Ballistic Materials Studies, Casualty Reduction Studies, The M1 Helmet Documentation, Studies to Improve the M1 Suspension, Algorithm for Sizing Helmets, and Human Engineering.

At the Working Committee Meeting No. 3 at HEL, APG, Md. on 15-16 December 1971, William C. Wright, program manager of the Five-Year Personnel Armor System Technical Plan, presented "Recommendations to Establish Standardized Casualty-Reduction Analyses Reporting" (324).

These recommendations were adopted by the committee with the addition of the M-43A1 Grenade as a threat. No documentation on these recommendations has been provided beyond this date.

BALLISTIC PROTECTION

Protection to the head involves a combination of many factors including environmental protection, eye protection, hearing protection, protection from concussive shock, compatibility with equipment such as the gas mask and communication equipment, comfort, and protection against the multiples of combat threats such as the threat posed by ballistic missiles.

The ballistic threat must be defined and analyzed; then protective headgear must be designed to afford the optimum protection consistent with the other factors involved. The true protection requirement, then, results from trading off many parameters, with the major constraints being primarily materials capability and human factors considerations. This systematic approach to protective headgear is currently being pursued under the USAMC Five-Year Personnel Armor System Technical Plan. The ballistic threat for the development of the new generation of personnel armor has been established by the Foreign Science Technology Center and further refined by AMSAA for inclusion in the AMC Armor Plan as Classified Appendix IV.

The ballistic threat from a casualty-producing standpoint has been shown to be primarily from fragmenting-type munitions, as reported by Dean (76), Coates and Beyer (53), Wound Data and Munitions Effectiveness Team (WDMET) and others.

Although the threat has been established as that of fragmenting munitions, the replication or simulation of this threat for evaluating armor materials and end items has been a major problem.

The section on "The Evolution of Ballistic Test Methods and Test Projectiles for Evaluating Armor Materials" which follows is a direct copy of Appendix A of reference 18 and is included in its entirety.

The Evolution of Ballistic Test Methods and Test Projectiles For Evaluating Armor Materials

Ballistic evaluation of lightweight fragment-resisting armor by simulation of service conditions of attack has been a continuously changing problem because of new specialized weapons and materials which are continually being introduced.

During World War I, fragment-resisting armor (the first U. S. modern helmet[1]), was tested with caliber .45 ball ammunition only because it was a standard service round which could be defeated by the helmet. Consequently this ammunition was adopted for evaluating the ballistic performance of fragment-resisting armor. As the years passed on, this test was questioned by many research laboratories and testing stations. The mechanism of penetration by the very deformable mushrooming pistol ball projectile is markedly different from that of steel or cast iron shell fragments which were the major cause of battlefield casualties. Armor materials that offer superior resistance to caliber .45 ball ammunition may provide reduced resistance to HE shell fragments. It has also been found, to the great confusion of testing facilities, that the caliber .45 ball, M1811, ammunition was far from being sufficiently uniform in production and in ballistic performance to be satisfactory for use in ballistic testing and evaluation. (The lack of uniformity did not affect its suitability for combat use). This test was replaced by one using a fragment-simulating projectile.

Another early empirical approach was the array test (or arena test, "Yankee Stadium" test). A test was conducted by placing test samples in a circular arrangement[2] (varying the radius from the point of detonation) and detonating a HE shell placed at the center of the circle. These tests were evaluated on a statistical basis in an effort to obtain reliable and reproducible results. The ballistic characteristics of the armor were expressed in a number of ways, such as (a) the number of perforations per unit area of armor surfaces; (b) the percent of impacting fragments which perforate the armor; and (c) the residual energies of perforating fragments which may be evaluated by means of a series of witness plates placed behind the armor. The number of witness plates one behind the other, which could be perforated provided an index of the residual energy possessed by the fragments. A large area was needed to conduct these tests, which were very costly since many samples were placed around the shell in order to obtain statistical data. This type of test is still employed occasionally. This test suffers from the limited sampling by the armor of the non-uniform distribution of fragment sizes, shapes and weights. The results are dependent upon the selected height of burst; the detonation is static instead of dynamic; no information is obtained that associates fragment weight and velocity with penetration.

A similar test, which was employed to evaluate personnel armor, was set up by the Army Ordnance Corps[3] during World War II. Armor materials were tested by a controlled fragmentation side-spray test. A 20MM shell, HEI MK-I, was statistically detonated inside a rectangular or triangular box test set-up. Three or four recovery boxes 12"x12" were used to recover the fragments that perforated the armor samples being tested. (See Figure I for a triangular test arrangement). A total of twenty 2024-T3 aluminum alloy sheets, 0.020" thick, were spaced at one-inch intervals behind the armor samples. The 20MM shell was suspended nose-up in the center of the square or triangle, and the shell was statically detonated. The HE fragments which perforated the test panels were recovered and identified as to the box and zone number in which the fragments came to rest. The firing process was repeated until the desired number of samples had been tested. The recovered fragments were weighed and the weighted totals computed accordingly to set standards. Some of the disadvantages of these tests were: (1) they were cumbersome; (2) they required a large quantity of test panels; (3) they were expensive to perform; (4) they yielded data difficult to reduce to simple expressions of ballistic merit such as a merit factor or a ballistic limit. Other disadvantages cited for the array test also apply here.

A controlled forward spray type of test was employed by the Naval Proving Ground, Dahlgren, Virginia[4], for rating lightweight armor materials. In this test a 20MM HEI shell is fired with a striking velocity of 2700 + 50 feet per second at a 0.125" cold-rolled mild steel plate (hardness of RB50 ±10), which is called a triggering plate since it detonates the HE shell. The armor sample which is being tested is mounted normal to the line of fire and three feet beyond the triggering plate. The triggering plate is positioned so that the projected line of fire passes through the center area of the triggering plate and through the center area of the test sample. The result of any round whose center of impact on the mild steel triggering plate is greater than 5" from the center of the detonating plate is discarded. The firing process is repeated for a number of samples. A statistical analysis is made on the number of complete penetrations obtained for given areal densities of armor. The material which has the least number of penetrations for a given areal density is rated as the best from a protection viewpoint. This test has the characteristics cited for the array test except it is a dynamic test. However, the triggering plate provides additional fragments that impact the armor.

Multiple cube testing was investigated after World War II. In this test approximately 31 cubes of uniform weight were fired in a phenolic plastic sabot. The 3/16", 1/4", 5/16", 3/8" and 1/2" cubes employed weighed 13, 31, 61, 104 and 245 grains respectively, and were hardened to a hardness of Rockwell "C" 23 to 28. The plastic sabot which contained the number of cubes of uniform size was fired from a rifled 57MM M1 gun, and the velocity of the forward cube was measured and taken to be representative of the velocities of all cubes. The mean velocity and percentage of complete penetrations were determined for each round fired. A V_{50} limit velocity* and a limit penetration coefficient** were computed and used as a basis for comparing material. Other criteria used in obtaining ballistic limits are given on Inclosure 1 of this Appendix. Criticism of this test include; (a) there were variations in results since the measured velocity employed was that of the fastest cube, whereas a velocity distribution actually existed, (b) the velocity spread between the highest measured velocity and the mean velocity varied considerably, especially for the smaller size cubes, and (c) the non-uniform dispersion of cubes from round-to-round added to the confusion and caused difficulty in interpretation of results.

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*A V_{50} limit velocity is an estimate of the mean velocity at which, on the average, 50% of the cubes striking the target will defeat it. A defeat is considered to have occurred when there is a through hole in the target which will allow the cube or major portion thereof to pass through.

**A limit penetration coefficient F is defined as follows:

$$F = \frac{M \times V_{50}}{e \times A}$$

Where: M = Cube Mass (grains)
e = Equivalent plate thickness (inches)
A = Cube face cross section (inches)
V_{50} = Limit velocity (feet per second)

The multiple cube test was abandoned in favor of the single cube test. Steel cubes of known sizes were sheared from cold rolled square bar stock having a hardness of approximately 28 Rockwell "C". The cubes were individually mounted in plastic carriers (See Figure 2) and fired from rifled guns. The plastic carrier provided for rotation and gas seal for the missile. The cube broke out of the carrier upon emerging from the muzzle of the gun and traveled downrange to the target. The cube may impact the target with various orientations including those for which an edge, corner, or side is presented. These variations increase the scatter in the ballistic evaluation because the shape factor of the cube varies from impact to impact depending upon how the cube strikes the target. Its average shape factor is within the range of values for fragments. Cubes have been used for several decades and are still being used for wound ballistic studies and for input data into casualty reduction assessments. Obtaining either a random or a specified set of orientations has proven difficult.

Single and multiple sphere types of ballistic tests have been conducted by some research establishments in evaluating fragment-resistant armor. In the single sphere test the sphere is launched from a smooth-bored gun (or the sphere can be placed in a plastic cup and launched from a rifled gun). In a multiple sphere test a plastic sabot is employed to launch spheres. These tests are similar to the cube tests that were described in the preceding paragraphs. A major disadvantage of this test is that spheres do not have jagged or sharp edges. As a result they do not exhibit the same mechanism of penetration as HE shell fragments. Also, the sphere geometry is limited to one value of shape factor.

Another method of assessing the performance of armor for protection against shell fragments, which was developed by Watertown Arsenal Laboratories, consists of detonating a standard HE shell, recovering the fragments, screening them into weight classes, and then selecting and firing individual shell fragments from a given weight class at the armor sample to determine a V_{50} ballistic limit in the conventional fashion; i.e., firing enough fragments of a selected weight group. The shell fragments are individually mounted in plastic cups (Figure 2) in which they are held in place by sealing wax and fired from standard rifled guns. The fragment breaks out of the cup upon emergence from the gun tube and proceeds down-range to impact the armor.

Although this method represented an improvement over previous tests it still has several limitations. First, it is necessary to secure and detonate HE shells, recover, screen, and weigh fragments – a not inconsiderable task. Furthermore, variations in mass, shape factor and geometry of shell fragments falling within one weight class introduce sufficiently wide scatter in test results (wide zone of mixed results), to necessitate firing a moderately large number of fragments to obtain a reproducible (V_{50}) ballistic limit. Finally, variations in the mechanical properties of shell steel are so wide that shell fragments display a broad range of deformation and fracture characteristics, thus influencing their ability to penetrate hard metallic armor materials and affecting the ballistic limit. However, against fabric or plastic armors which are relatively soft the projectile's hardness does not affect the ballistic performance significantly.

During World War II, Watertown Arsenal Laboratories experimented with design of fragment simulating projectiles for evaluating personnel armor[15]. A homologous series (1.35 to 830 grains) of fragment simulating projectiles (Figure 2) were developed, which consists essentially of cylinders having blunt, chisel-shaped noses and raised flanges at their bases to act as gas-seals and rotating bands[16&17]. These missiles are hardened to Rockwell "C" 28-32. This hardness level was selected after determining that this represents the average hardness range of recovered fragments of detonated 20MM, 37MM and 105MM HE shell of domestic manufacture. Ballistic tests of these fragments simulating projectiles demonstrated that they were stable in flight and rated personnel and lightweight armor on a basis compatible with experience.

Firing a fragment simulating projectile is fairly simple compared to testing with HE shell or individually-fired shell fragments. In addition, the scatter of the resulting data is quite small thereby providing greater accuracy and reproducibility with a minimum number of rounds.

These projectiles are currently used for material studies, for the evaluation of armor end items and for acceptance testing of personnel armor production. The test projectiles are procured through the use of Military Specification MIL-P-46593, Projectile, caliber .22, .30, .50 and 20MM Frgament-Simulating. A test procedure is given by Military Standard MIL-STD-662, Ballistic Acceptance Test Method for Personal Armor Material.

At the time of its development it was recognized that it did not match ballistic limits obtained with actual fragments fired individually in some cases[17].

A yawed dart projectile was developed by the Naval Research Laboratory for testing and screening experimental lightweight armor materials. The dart, Figure 2, is a cylindrical missile with 90^{o} cones ground on each end and heat treated to a very high hardness (approximately Rockwell C 60-63) so that the projectile is essentially nondeforming during impact. The technique used for making controlled yaw impacts involves firing into a ballistic plate testing pendulum at close range through a blast deflector. A light upsetting or tipping plate is fastened to the rear of the blast deflector in such a position that the dart missile will graze the edge of the upsetting plate. Projectile yaw develops depends upon the dart velocity. Precise velocity control is desirable both for the purpose of closely bracketing limit velocity points and for the purpose of maintaining accurate control of yaw. Generally, the dart missile is deflected such that it will impact the armor broadside. A sufficient number of complete and partial velocities are fired so that the limit velocity may be calculated. The yaw dart missiles provide less kinetic energy per unit presented area than do most shell fragments. Its shape factor is at the high end of the range for munition fragments, but is lower than shape factors for most fragment simulators.

Parallelepipeds, (Figure 2) flat-end right circular cylinders and hemispherical nose-type missiles and others have also been investigated and employed in the ballistic testing of armor. Tests have shown that each of these missiles differ somewhat in its mechanism of penetration into an armor material. When metallic armor is perforated by HE shell fragments, there are two principal ways or mechanisms by which the perforation is effected. These may be called the "pushing-aside" or "ductile" mechanism and the "plugging" or "shearing" mechanism. In the first, the missile forces its way through the armor by displacing the material sideways, buidling up a bulge on the front surface and depressing the back surface and laterally compressing the material in the interior of the plate. The harder the material the more resistant it is to lateral displacement. Thus, when the pushing-aside mechanism of penetration is the one that occurs, the resistance to penetration increases with increasing hardness of the armor. The plugging mechanism involves the shearing out from the metallic armor of a cylindrical disc, which is ejected ahead of the missile. There is relatively little deformation and no lateral compression of armor when this type of penetration occurs. Harder materials tend to plug more readily and completely than softer materials, and thus above a certain hardness, the plugging mechanism of penetration is involved, and the resistance to penetration decreases. Armor much harder than the projectile may deform or shatter it. Other factors besides hardness of the armor which determine the mechanism of penetration include the following:

1. Ratio of plate thickness to size of the HE fragment; the larger the presented area of the missile at impact, the greater the tendency toward penetration by the plugging mechanism.

2. Blunt-nosed missiles tend to plug the metallic armor while sharp-nosed missiles tend to pierce and laterally displace the plate material. When plugging occurs, less energy is absorbed than when penetration is affected by the pushing-aside mechanism. Since shell fragments are blunt missiles, the penetration of armor by HE fragments generally involves plugging. Perforation of some materials such as aluminum and magnesium alloys, which are soft and overmatch (armor thickness greater than the projectile diameter) the projectile, is effected by a combination of the two mechanisms of penetration. The material is displaced sideways during the first stage of penetration and then finally plugs when the fragment approaches the rear surface of the plate.

Residual velocity measurements can be obtained for most of the tests that have been discussed by instrumenting the test set-up with added electronic measuring equipment or by photography. Measurement of the energy absorption of a material from a penetrating missile can be readily calculated from the difference in kinetic energy of the missile before and after penetration. Three measurements are required for each round fired: the mass of the projectile; its striking velocity as it contacts the target; and its residual velocity as it just leaves the target.

Ballistic Research Laboratories at Aberdeen Proving Ground have conducted extensive tests[10, 11, 12], on residual velocity investigations. The velocity-reducing characteristics of materials when impacted by various missiles are useful in developing lethality and vulnerability data for use in the design of experimental armored vehicles and in making estimates of casualty reduction offered by various personnel armors. The behavior of most armor materials is similar. As the striking velocity is increased from a very low velocity to the ballistic limit of the material, theoretically no complete penetration occurs. When the striking velocities are in excess of the ballistic limit, the fragment will pass through the material with a residual velocity, the amount of which depends upon the excess of the striking velocity over the ballistic limit. As the striking velocity tends to approach the striking velocity. When the striking velocity of the missile is considerably in excess of the ballistic limit, damage to the plate generally becomes less severe and more localized, and less energy is absorbed during penetration. Glass and ceramic faced composites show more of a straight line relationship between residual and striking velocities.

The difficulty of measuring the velocity of a given fragment in the presence of a shower of other fragments of metallic armor thrown from the back of the plate also affects the test results on some residual velocity measurements. For nonmetallic armor there may be no secondary missiles thrown off the back of the armor. In rigid plastic armor, (Doron and bonded nylon), when striking velocities approach the ballistic limit the material is damaged by splitting and bending. Deformation of these plastic materials is greater when there is no performation since all of the missile's energy is absorbed by the material.

The measurement of transient and permanent deofrmation in a material may be necessary in testing fragment-resistant armor materials. This information is useful to designers of helmets and helmet liners so as to enable the headpiece to have the required offset (distance between the head and the inside of the headpiece). A helmet[13] can have extensive transient and permanent deformation when impacted by the missile at velocities approaching the ballistic limit. The full force of the impact may well be transmitted to the head behind the helmet, and serious and extensive wounds may result even though the helmet has not been perforated. When deformation tests are conducted, a ballistic limit is first obtained on the end item and then velocities are selected, which are slightly less than the ballistic limit velocity, since maximum deformation and damage occurs at this velocity level. Elaborate instrumentation is required to obtain transient deformation ballistic data[13].

BALLISTIC LIMITS

All ballistic penetration tests may be termed as a resistance-to-penetration type of evaluations. The resistance of a material against penetrating forces of missiles which are classified as penetrators is measured. These penetrators may be of any regular or irregular shape and may be applied to materials at either slow or rapid rates of loading. An illustration of a commonly used static type of penetration (indentation) test with a spherical indenter is the Brinell test for hardness measurements. The Brinell hardness of a metallic material is nothing more than the resistance-to-penetration of that material by a spherical penetrator applied at slow rates of loading under definite conditions of test. The ballistic test for resistance-to-penetration is an illustration of rapid rates of loading with various shaped objects known as projectiles, missiles or fragments. The material under this condition is the armor. At the high rates of application of load, the resistance that the material offers is a result of a complex combination of factors (physical, mechanical and metallurgical) which are affected by high rates of strain. To date there is no one simple measure of the resistance-to-penetration of armor. Instead, there are in use several measures of the resistance-to-penetration of armor. Each of these is based more or less on practical considerations and is expressed as the striking velocity of a given projectile or fragment causing a preselected amount of damage. Therefore, the amount of preselected damage serves as the criterion for these different measures of penetration. Three such criteria, the Army, Protection and Navy Ballistic Limits, which are employed in rating armor materials are defined as follows:

Army Ballistic Limit – The critical or limit velocity at which the specified projectile will be borderline in penetrating the armor being impacted according to the "Army" criterion. (Although historically it was first employed in Army studies, it should only be considered at present as a term which defines a specific type of ballistic limit). In this ballistic test a complete penetration occurs whenever a projectile or fragment has penetrated the armor sufficiently to permit at least a pinhole of light to pass through a hole or crack developed in the armor, or the front of the fragment or nose of the projectile can be seen from the rear of the armor. A partial penetration occurs when lesser damage to the armor occurs.

Protection Ballistic Limit – The critical or limit velocity at which the specific projectile will be borderline in penetrating the armor being impacted according to the "Protection" criterion. In this case a complete penetration occurs whenever a fragment or fragments from either the impacing projectile or the armor are caused to be thrown from the back of the armor with sufficient remaining energy to pierce a sheet of 0.020" thick 2024-T3 aluminum alloy placed paralell to and 6" behind the target. Any fair impact which rebounds from the armor plate, remains embedded in the target, but with insufficient energy to pierce the 0.20" thick aluminum alloy witness plate, is termed a partial penetration.

Navy Ballistic Limit – The critical or limit velocity at which the specified projectile will be borderline in penetrating the armor being impacted according to the "Navy" criterion. Athough historically it was first employed in Naval activities, it should only be considered at present as a term which defines a specific type of ballistic limit. In these ballistic tests a complete penetration occurs whenever the entire projectile or essentially the entire projectile passes completely through the armor. All other penetrations are classified as partial. No witness plates are employed in these tests.

Employing the above criteria, in assessing partial and complete penetrations, a ballistic limit can be defined as a striking velocity (feet per second) of a kinetic energy fragment or projectile above which complete penetrations (as defined above) of the armor will predominate and below which partial penetrations of the armor will generally predominate. This is generally expressed as a Army, Protection or Navy (V_{50}) ballistic limit and is a critical velocity of a fragment or a projectile at which 50% complete penetrations and 50% partial penetrations of the armor target can be expected on a limited statistical test. A protection (V_{50}) ballistic limit is now generally employed by all of DOD is assessing the ballistic efficiency of armor materials.

The inherent variables within a material and the variables in any ballistic test such as slight difference in weights of projectiles, orientation of projectiles at time of impact, etc., introduce into the test a probable "zone of mixed results". As the name implies, this zone of mixed results may contain one or more impacts which completely penetrate the material under test at velocities below those of other impacts which fail to effect complete penetration. This zone of mixed results can vary up to several hundred feet per second depending upon projectile reaction and the mechanism of penetration. However, in tests of lightweight armor against fragment simulating projectiles, the zone of mixed results is generally less than 100 feet per second.

A protection (V_{50}) ballistic limit of fragment resistant materials is generally computed by averaging ten fair impact velocities comprising the five lowest velocities resulting in complete penetration and the five highest velocities resulting in partial penetration. A maximum spread of 125 feet per second is permitted between the lowest and highest velocities employed in the determination of the ballistic limit. In cases where the spread between the lowest complete and highest partial velocities is greater than 125 feet per second the ballistic limit shall be based upon 14 velocities, 7 of which result in the lowest complete penetrations and 7 which result in the highest partial penetrations. All velocities employed in the determination of the ballistic limit are corrected to striking velocities.

The Program on the Development of Improved Test Methodology for Evaluating Armor Materials Versus Fragmenting Munitions is contained in the USAMC Armor Plan (330) as Materials Work Unit No. 18, with the objective stated as "The development of an integrated ballistic testing system for personnel armor materials and end items;

1. Yields results that can be correlated by the use of appropriate factors or procedures to results derived from actual munition fragments. Direct simulation while acceptable is not considered essential.

2. Can be applied by the selection of appropriate options if necessary to, primarily: (a) the evaluation of materials being considered for armor applications, (b) the evaluation of flaws in materials or end items; and secondarily to: (c) provide the input data for casualty reduction assessments (d) the evaluation of production material and (e) the evaluation of newly developed armor items as part of the required engineering testing. For purposes of correlating the test methods and projectiles that will be developed with actual fragments, laboratory tests and analysis will be used to obtain ballistic data and comparisons of test projectiles with selected fragments covering a wide range of fragment shapes and sizes."

The work unit gives an excellent digest on munition fragments, characteristics of armor materials, and ballistic-test methods and projectiles.

In a report on the status of the methodology program (18), AMMRC reported the following:

a. There was some difficulty involving experimental methods for controlled shell-fragment launch and flight to obtain ballistic data on personnel armor materials. The problem was successfully resolved, and an experimental basis was developed for future experimental work in shell-fragment ballistic-data acquisition.

b. An improved model, which represents an improved method of data representation, was developed for residual velocity versus strike velocity. The model provides a technique for quantitatively comparing simulator residual-velocity data population and provides an objective method for dealing quantitatively with the question of shell-fragment residual-velocity data simulation.

c. Data indicate that the slope of the residual-velocity curve versus strike-velocity curve is very steep at the critical or cut-off velocity and changes abruptly to a constant value in a relatively short velocity range. That range has been identified as the velocity range over which data generation is most critical for defining the armor response to an attacking projectile and for distinguishing the relative performance of armor materials.

Pending completion of the above described effort, the AMC family has agreed to utilize the fragment simulators as a screening technique for armor materials and to employ "cube" projectiles with related residual velocity/striking velocity relationships as material input data into casualty-reduction methodology.

Under the USAMC Five-Year Personnel Armor System Technical Plan, the Army has agreed to employ casualty reduction to express the effectiveness of armor materials and end items. The Joint Service Materiel Need (JSMN) for a Personnel Armor System for Ground Troops (PASGT), which has been agreed upon by the Navy and Marine Corps and which is being prepared for world-wide coordination by the Combat Developments Command, reflects the statement and application of protective characteristics in casualty-reduction terminology.

The casualty-reduction methodology is reflected in models developed by AMSAA to predict reductions in casualties provided by helmets and body armors for ground troops. Detailed descriptions of these models are given in AMSAA Report No. 1, ARDC Report No. 2 and AMSAA Technical Memorandum No. 126.

The following extract from Appendix III of the USAMC Armor Plan prepared by AMSAA briefly describes casualty-reduction methodology:

...the models attempt to predict the number of casualties produced by a given fragmenting munition in a simulated battlefield environment. Two types of personnel targets are generally considered. These are armored and unarmored personnel. In one battlefield, no personnel wear the protective gear of interest (unarmored). In the other, all personnel wear the protective gear of interest (armored). The difference between the number of casualties predicted for the two battlefields (targets) is the number of casualties saved because personnel wore the protective gear of interest. Generally, reduction in casualties is expressed as a percentage of the number of casualties produced when the protective gear of interest is not worn. Several types of fragmenting munitions are usually considered in a casualty reduction analysis to cover a wide range of battlefield threats.

These casualty reduction models can be used to obtain answers to a number of important questions relating to personnel armor systems. Listed below are some limited studies that could be conducted with the models:

– The level of protection provided by end items.

– The alternative(s) of a given type of personnel armor system that maximizes protection.

– The candidate materials that appear most promising for the design of personnel armor systems.

– The effect of armor configuration and body area covered on protection.

– The effect of the weight of the personnel armor system on protection.

In broader systems analysis studies, the models can be used to assist in the estimation of the number of casualties saved in a hostile environment such as SEA or Europe. A casualty reduction model is a powerful tool that can be used in a number of different ways.

One of the most important aspects of casualty-reduction methodology is that the protective capabilities of materials and end items will now be expressed in a terminology that is meaningful from the standpoint of personnel survival, related to the real world and not in terms of V_{50}, etc., which did not, and does not, relate directly to protection. In other words, casualty-reduction analysis bridges a communication gap between the developer and user and should improve the probability of wear under combat conditions because the user in the future will be able to relate the protective capabilities of his equipment to the combat environment.

At Working Committee Meeting No. 3 on the AMC Five-Year Personnel Armor System Technical Plan, 15-16 December 1971, the AMC Program Manager, Mr. William C. Wright, included as an agenda item a Review of Casualty-Reduction Methodology and presented a prepared paper entitled "Recommendations to Establish Standardized Casualty Reduction Analyses Report" (377). This paper had as its objective "to achieve standardization and repeatability of casualty reduction analysis, to issue dissemination and reporting of non-conflicting and consistent results, and to insure that the AMC family is addressing the program and methodology inputs to meet agreed upon needs." Within the parameter of the term casualty reduction, characterizing personnel protective armor, the Army Materiel Systems Analysis Agency (AMSAA) has the responsibility for establishing the methodology and any changes to it. Performing activities, primarily the Army Materials and Mechanics Research Center (AMMRC) and Natick Laboratories (NLABS), are responsible for performing analyses properly.

Wright recommended two tables of criteria as a standard base for characterization. In both of the tables, Casualty Criteria are defined and quantified in ARDC Technical Report No. 2, September 1969, A Parametric Analysis of Body Armor for Ground Troops (367).

Table A would be used in material evaluations as would be prepared by AMMRC and NLABS. It considers ballistic data, coverage, casualty criteria and threats. Table B would be used for proposed system or component evaluations as would be performed by NLABS and verified by AMSAA. Table B considers the criteria in Table A, and in addition, data to support systems analysis, cost effectiveness and/or trade-off studies. These include, but are not limited to:

a. Estimated cost of the item based on a lot size of 50,000 units.

b. Projected Army user, i.e., mission profile.

c. Weight of total system and each system component.

d. Number of sizes.

e. Estimated service life (years-min).

f. Estimated storage life (years-min).

g. Maintainability, scheduled hours per year.

h. Personnel training requirements.

i. Special maintenance equipment, if applicable.

j. Production feasibility.

k. Adequacy of available manufacturing techniques.

l. Physiological assessment.

m. Human factors parameters including compatibility, mission effectiveness, mobility, attitudes, sizing assessments.

n. Projected environmental usage conditions.

o. Assessment against all military-need (MN) characteristics.

As has been shown above, substantial progress has been made in the methodology of ballistic material evaluation, and the scope has been expanded to include the application of casualty-reduction methodology.

As reported by Coe (58), by Coates and Beyer (53), and by the R&D Liaison Office, Fort Benning, Ga., in interviews with returning Vietnam veterans, lack of stability of the M1 helmet has been and continues to be a complaint. Related to this complaint and to ballistic protection has been the requirement that the helmet must be off-set from the head a specified distance as a result of transient deformation of the helmet material when subjected to a hit.

Coates and Beyers (53) state that "A suitable offset will always be necessary to counteract the denting of a metallic helmet or the transient deformation of a non-metallic helmet, but the prime objective of any military protective headgear is to prevent the entrance of missiles into the cranial cavity. This entrance might be prevented over a wider range of missile weights and velocities by modification of the present effort concept in helmet design. The missile defeat might result in skull fractures in a number of casualties, but the skull fracture type of injury is amenable to successful treatment by the neurosurgeon."

Different materials react differently in resisting penetration and in defeating impinging missiles. One of the results of these differences is reflected in varying degrees of transient deformation which is critical to helmet design. Until recently, there was no standardized procedure for determining transient deformation. However, Prather and Hawkins of the Biomedical Laboratories of Edgewood Arsenal have reported, in the 1st Year Summary of Progress and Up-dated Milestone Schedule USAMC Five-Year Personnel Armor System Technical Plan, their successful effort to establish a standardized methodology for determining transient deformation of lightweight armor materials. Work is now progressing to develop from the procedure casualty criteria assessments for input into casualty-reduction models.

Conclusions

The USAMC Five-Year Personnel Armor System Technical Plan aggressively addresses the problem areas of determining adequate ballistic test methodology, and refinement of casualty reduction methodology.

MATERIALS TECHNOLOGY

As long as man has desired to protect himself with "armor," he has concerned himself with a search for better materials from which to fashion armor. Dean (76) gives a comprehensive survey of armor materials up through the end of World War I. Of particular interest to this documentation is a rank-ordering of factors involved in evaluating armor materials:

"Ballistic value	45%
Weight	15%
Comfort in wearing	10%
Security in support	10%
Ease of recognition and the opposite (non-visibility)	10%
Noiselessness	3%
Cleanliness	3%
Durability	2%
Adaptation	2%

Egmont Arens (10), in a contract for "Analysis of Design," considered materials to provide ballistic protection including transient deformation in a helmet. He stated that there were three variables in helmet design:

(1) weight and material

(2) size

(3) suspension

With respect to weight, Arens said that the maximum protection was desired for the smallest weight per inch and that thinking should be directed toward reinforced plastics.

An additional interesting reference in Dean (76) is that the "two layered condition... is but a reappearance of an ancient principle...that the best armor should have an outer skin of extreme hardness, which prevents the entrance of a missile, while the inner substance of the plate should be tenaciuos and prevent the armor from shattering." This principle resurfaced when the U.S. experimented with the ballistic liner and various hard shells.

Another aspect to be considered in armor development must always be the practicality and efficiency, including the cost per item, of mass producing helmets from a candidate armor. Sir Robert Hadfield's manganese steel was the choice for the U.S. M1917 Helmet, and after all the research and testing, was again the choice for the U.S. M1 helmet in 1941. During World War II, research in armor for helmets continued and as early as 1942 a glass laminate, DORON, was fabricated and tested (207) and found not acceptable as a replacement for the Hadfield steel. Still later tests by the U.S. Marine Corps found that it would not be practicable to replace the M1 steel helmet with the new plastic (DORON) helmet (159).

When the U.S. M1 steel helmet was standardized in 1941, the Quartermaster Corps initiated research on alternate materials for the helmet liner, feeling that a plastic liner would be superior to the resinated duck material (207). In 1947, the Quartermaster assumed entire responsibility for helmet development and production. In 1949, a project was initiated to develop an "all-purpose" helmet with an aluminum shell and a nylon liner. The helmets developed during the period 1949-1954 did not meet all the requirements of the Army Field Forces (AFF), and effort then was initiated to provide improved ballistic protection to the M1 through the use of a ballistic liner. The cotton duck liner, weighing 10 ounces, contributed little or no ballistic protection. A four-ply nylon liner, weighing approximately the same as the duck liner, provided 250 feet per second more ballistic protection, thus providing increased protection at no increase in weight (341). This liner was type classified and is the standard liner.

The search continued, however, for improved ballistic materials for helmets. Candidate materials included aluminum, polycarbonates, nylon, various steel alloys and titanium. Combination materials occurred when shells of aluminum, polycarbonate, other steels, and titanium were placed over a nylon liner. It may be generally said that of all the materials and combinations tested, none was found to be sufficiently promising to warrant adoption as the new helmet armor material. Although increased ballistic protection could be gained for a given weight of material, or equal protection for a smaller weight of material, testing indicated that none of these materials were satisfactory. In some of the promising materials, the production methods were unsatisfactory, and in essentially all candidate materials, the relative gains afforded by a new material or combination thereof were not considered to be cost-effective (Table 3) (92).

In 1968, Natick Laboratories received a report from AMSAA on casualty-reduction studies which essentially concluded that casualty reduction was directly related to area coverage and weight (350). In 1969, in direct response to an inquiry from NLABS, AMMRC replied that an M1-configuration titanium helmet with a nylon liner would meet the ballistic requirement and weigh 39-41 ounces. This appeared to satisfy the material requirement for an interim helmet, and AMMRC also provided classified details of a new composite material as a candidate for the optimum helmet of 24 ounces (351).

TABLE 3

Standard and Experimental Helmet Data[a]

	Weight	Shell	Liner	Shell Area in^2	Liner Area in^2	Shell Areal Density ($02/ft^2$)	Liner Areal Density	Composite Areal Density	Shell Material	Liner Material	Sizes
M1 Steel + Nylon Liner	50.0	40.0	10.0	190	170	30.3	8.5	37.8	Hadfield Steel	Ballistic Nylon Fab.	1
T21E2 Nylon + Alum	41.0	34	7						Aluminum	Nylon	4
E49-3 Alum + Nylon	38 41			154 195					Aluminum	7-Ply Nylon	2
E51-1 Aluminum	43 47	21 23	22 24						Aluminum	9-Ply Nylon	2
E53-2 Aluminum	51.0	35.5	15.6	204					Aluminum 24 ST	Nylon	1
T55-2 Nylon	14.5	N/A	13.5	N/A	170				N/A	4-Ply Nylon	1
Type III Titanium + Aluminum	50.0	40.0	10.0	190	170	30.3	8.5	37.8	Titanium Alloy	Ballistic Nylon Fab.	1
Polycarbonate Nylon Liner	22.0	12.0	10.0	187	170	9.2	8.5	16.9	Polycar-bonate	Ballistic Nylon Fab.	1
One Piece Titanium	20.0	20.0	N/A	165	N/A	17.5	N/A		Titanium Alloy	N/A	1
One Piece Nylon	19.0	19.0	N/A	180	N/A	15.2	N/A		Ballistic Nylon Fab.	N/A	1

[a] NLABS Ltr, 3 Sep 1970 (341).

Under the AMC Five-Year Personnel Armor System Technical Plan a search is continuing for materials for helmets and work is continuing on material evaluation in methodology.

As recommended by Wright (377) at Working Committee Meeting No. 3, 15-16 December 1971, a standardized evaluation and reporting procedure for materials has been adopted. In this procedure, Table A includes ballistic data, coverage, casualty criteria and threats. The procedure is to be used by AMMRC and NLABS in performing casualty-reduction analyses.

Under the USAMC Five-Year Personnel Armor System Technical Plan, a broad, aggressive materials research and development program directed toward materials of high casualty-reduction potential is being pursued.

The following is extracted from the Summary contained in the plan dated March 1971 (331):

The Materials Research and Development Program is concentrated on composite materials containing ceramics, textiles, polymers, and/or metals. It encompasses the following areas:

(1) Establishment of the fundamental mechanism by which fragments are defeated.

(2) Synthesis of new materials having required properties.

(3) Development and optimation of composite compositions.

(4) Experimental fabrication and processing of mock-up models.

(5) The ballistic evaluation and medical assessment of the research product, and

(6) Formulation of specific recommendations for hardware development.

The Armor Plan First-Year Summary of Progress and Up-dated Milestone Schedule dated March 1972 gave a further report:

A standardized high speed photographic methodology for determining transient deformation of armor materials has been achieved which will allow the evaluation of all potential armor materials. Effort is continuing to develop criteria for injury assessment from transient deformation.

An economic substitute (glass ceramic) for boron carbide (B_4C) for protection against fragments and ball projectiles has been established and development of material processing to employ this material in curved shapes for body armor applications is progressing. In this latter regard AMMRC has reported that "Pyrex glass helmet shapes can be made by press molding to cover the range of wall thicknesses of interest." (Materials for Personnel Armor, First Status Report to the Senior Steering Committee, 16 September 1971).

Flexible structures in ceramic composite armor have been demonstrated, and an extensive design effort is being applied to utilize these rigid and semi-rigid materials in helmet and torso armor applications.

TABLE 4

Materials Program

TECHNICAL AREA	WORK UNIT (1498) No.	WORK UNIT (1498) Description	LABORATORY	FUNDING 10^3 71	72	73	74	75	76
Materials Development and Evaluation Research, Development Testing and Evaluation (RDT&E)	1	Development of Transparent Polymers for Armor	AMMRC						
	2	Effectiveness Analysis for the Development of Personnel Armor Materials	AMMRC						
	3	Synthesis of Boron Compounds	AMMRC						
	4	Ballistic Behavior of Composite Armor	AMMRC						
	5	Transparent Ceramics for Armor	AMMRC						
	6	Master Ballistic Penetration Curves and Tables	AMMRC						
	7	Nature of Fiber Deformation and Rupture Under Missile Impact	AMMRC						
	8	Research on Ceramic Gradient Armor	AMMRC						
	9	Spark Sintering of Metal - Ceramic Armor Materials	AMMRC						
	10	Transparent Armor Development	AMMRC						
		Total RDT&E Funded	AMMRC						
	11	Mechanical Processing of Polymer Into Sheet and Thin Film Armor	AMMRC						
	12	Metal/Metal Composites for Armor	AMMRC						
	13	Development of Advanced Ceramic and Ceramic/Metal Gradient Armor	AMMRC						

Funding levels are not included. This information is available from USANLABS on a need-to-know basis.

TABLE 4 (Continued)

TECHNICAL AREA	WORK UNIT (1498) No.	Description	LABORATORY	FUNDING 10^3 71	72	73	74	75	76
Materials Development and Evaluation Research, Development Testing and Evaluation (RDT&E)	14	Reactive Processing and Fabrication of Boron Ceramics into Helmet and Body Armor Components	AMMRC						
	15	Materials Processing Research of Composite Configurations	AMMRC						
	16	Energy Dissipation and Absorption Mechanisms in Personnel Armor	AMMRC						
	17	Evaluation and Application of Novel Improved Material Forms, Compositions and Arrays in Helmet and Body Armor Configurations	AMMRC						
		Total 1971 Unfunded							
		Total RDT&E	AMMRC						
Supporting Ballistic Test Methodology (R&D) and Armor Production (MM&TE), (O&MA)	18	Improved Test Methodology for Evaluation Armor Materials vs. Fragmenting Munitions	AMMRC BRL, EA Labs NRL(Navy)						
	19	Engineering Support Data for Specifications	AMMRC, BRL NLABS						
	20	Processing MM&TE 1706073 of XP Proprietary Plastic Material for Lightweight Armor Applications	AMMRC						
		Total MM&TE, O&MA	AMMRC						
		Total AMMRC							
Research, Development, Test and Evaluation (RDT&E)	21	Toxicity Screening of Implantable Body Armor Material	EA Labs						
		Total EA Labs $1,100,000							

TABLE 4 (Continued)

TECHNICAL AREA	WORK UNIT (1498) No.	Description	LABORATORY	FUNDING 10^3 71	72	73	74	75	76
Materials Development and Evaluation (cont.)	22	Textile Fiber Evaluation and Chemical Modification to Maximize Ballistic Performance	NLABS						
Research, Development, Test and Evaluation (RDT&E)	23	Engineering of Textile Materials to Obtain Optimum Form Factors for Translation of Fiber Properties Into Fabrics	NLABS						
	24	Correlation of Fiber and Fabric Properties with Ballistic Performance	NLABS						
	25	Utilization of High Tenacity Textile Fibers in Laminate Form in Helmets and Body Armor	NLABS						
		Total NLABS							
		GRAND TOTAL MATERIALS							

Significant progress has been made in the toxicity study of candidate armor materials. To date preliminary measurement of acute toxicity in vitro for the following items has been completed: Boron Carbide, Silicon Hexaboride, Calcium Hexaboride, $A1_2O_3$, ZRO_2, TiO_2, Y_2O_3, woven roving and titanium.

To retain the unclassified status of this report, the classified contents of various materials reports are not being included but the reports may be obtained by qualified persons.

SUSPENSION AND RETENTION

Lewis, in his Military Helmet Design (154), indicates the great importance of the suspension system: "The suspension may be the deciding factor regarding level of protection, compatibility under various environmental conditions, and acceptance of a helmet design by the individual wearer and his unit." However, in spite of the importance of the suspension system, helmets seem to be designed with the suspension as an after thought to the ballistic shell. The requirements of suspension systems are presented by Lewis as are the general suspension designs that have evolved over the past 50 years. There are five general practical systems:

1. Several (multiple pads and a crown restrainor
2. Multiple-web arrangements (triangulation system)
3. Continuous padding over the cranial area
4. Combination of flat springs and cap
5. Combination of the above

He further breaks the suspension system down into seven main subsystems:

1. Shell-to-suspension attachment
2. Offset
3. Headband or pad backing
4. Sweatband or pad backing
5. Weight-bearing crown
6. Shock absorbers
7. Chin and nape strap

Lewis also indicates the variety of possible materials that could be or have been used in the helmet suspension subsystems (Table 5).

TABLE 5

Helmet Suspension Materials[a]

1. Shell-to-suspension attachment
   a. Rivets
      (1) Metal
      (2) Plastic
   b. Liner (Friction-held)
      (1) Textile laminates
      (2) Glass fiber laminates
      (3) Metal
      (4) Plastic
   c. Welded metal lugs or screws
   d. Web, cord, or bolts (through holes)
   e. Snaps
   f. Cement
   g. Slots or keyways
      (1) Metal
      (2) Plastic

2. Spacing
   a. Metal
      (1) Spring
      (2) Rigid
   b. Webbing--natural or synthetic fibers
   c. Leather
   d. Cords or laces
   e. Plastic
   f. Pads
      (1) Ununited fibers, natural and synthetic
      (2) Felts and bats, natural and synthetic
      (3) Plastic foam
      (4) Sponge rubber

3. Headband or pad backing
   a. Textile webbing or cloth, natural or synthetic
   b. Leather
   c. Metal
   d. Plastic
   e. Textile or glass fiber laminates

4. Sweatband or pad covers
   a. Leather
   b. Textiles, natural or synthetic
   c. Plastics
   d. Foam "skin"
   e. Latex film

5. Weight-bearing crown
   a. Leather
   b. Textile, natural or synthetic
   c. Plastic
   d. Plastic foam
   e. Fiber pads
   e. Buckles, D-rings, snaps, etc.
   f. Springs

6. Shock absorbers
   a. Plastic foam
   b. Ununited fiber pads
   c. Felt or bat
   d. Crushable metal structures

7. Chin and nape straps
   a. Leather
   b. Webbing, natrual or synthetic
   c. Cords, natural or synthetic
   d. Pads (nape)

[a] Lewis, 1968

Lewis lists 12 general requirements for an ideal suspension system:

(1) Maintain sufficient offset of the helmet to provide impact protection and ventilation.

(2) Allow minimum relative motion between helmet and head while the wearer is in motion or when the head is moved suddenly or violently.

(3) Be capable of balancing uniformly and distributing uniformly the static and dynamic focus caused by helmet weight, motions of the head, and the impact of missiles and larger objects upon the helmets: application of excessive forces to the relatively weak temporal region of the skull should be avoided.

(4) Protect the upper spinal cord and neck from injury due to the impact on the helmet of missiles or shock waves.

(5) Be non-toxic to skin surface and open wounds.

(6) Provide ventilation or insulation, as required by the climate in which the helmet is worn.

(7) Be compatible with other clothing and equipment (communications, protective, optical, etc.).

(8) Provide adjustments for fit which are simply and easily made, few in number, and self-maintaining.

(9) If removable from helmet shell, be capable of replacement simply and securely without tools.

(10) Be simple and cheap to manufacture.

(11) Withstand field conditions and storage for extended periods (resist fungus attack, rot, mildew, abrasion, perspiration, corrosion, and metallurgical failure).

(12) Maintain design properties for reasonable periods of actual use in any climate where combat is possible.

Dean (76) states that there are two principal lines in which armor may be studied objectively: Utility (including ballistic value, weight and comfort in wearing), and beauty. In this discussion, beauty will receive essentially no consideration, although form, surface and color are considerations in helmet design from a utilitarian point of view. Additionally, soldier acceptability does hinge to some degree on appearance.

With the entrance of the U.S. in World War I, it was decided that the U.S. would adopt the standard British Mk I, although this helmet was recognized to possess some notable defects. Among these was that the center of gravity was not placed so as to reduce wobbling on the head, and that the lining was uncomfortable and disregarded the anatomy of the head. Consequently, the U.S. redesigned the helmet lining. The U.S. lining was woven of cotton twine in meshes 3/8 of an inch square. This web, fitting closely upon the wearer's head, evenly distributed the weight of the two-pound helmet and in the same way distributed the force of any blow upon the helmet. The netting, together with small pieces of rubber around the edge of the lining, kept the helmet away from the head so that even a relatively large dent could not reach the wearer's skull (72).

Additionally, the chin strap was modified by replacing the cowhide strap with an olive drab web strap incorporating a buckle-hook. This chin strap rested upon the point of the wearer's chin instead of near the angle of the jawbone.

As experimental efforts continued during World War I to develop a distinctly American helmet, the helmet linings incorporated were a variant of the German model, which is described by Dean (76):

"The helmet lining is borne on a sweat band of cowhide, which is fastened to the helmet at three points. To this band are attached three pads which fold upward within the dome of the helmet and are backed (i.e., next to the helmet shell) each by a cushion. The pads are then so arranged that one comes to lie against the forehead and one against each side of the head. In the specimens examined, the pad has been formed of calfskin so cut that the end which is attached to the sweat-band is the wider part; the opposite and divides into two lobes, each of which is pierced and threaded by a string which is so arranged that it draws together the free ends of all the tabs and forms an elastic carrier for the weight of the helmet. It should be noted that each tab bears an inner pocket which contains a small mattress filled with curled hair. This mattress is kept in position in the pocket by means of tapes which can be tied. The entire lining weighs 4 1/2 oz. It is so designed that it fits the head easily and allows free spaces (one on either side of the head and one at the back of the head) through which ventilation is secured and by means of which the weight of the helmet upon the head is carried on the three cushions described above. The scalp or the top of the head may thus still receive its supply of blood freely; for the vessels (and for that matter the nerves) which transmit the blood along the sides of the head upward or downward are not compressed by the constricting rim of the usual "hat-lining" of a helmet but have open passageway, thanks to the three spaces in the cushions. Another advantage of this type of lining is the way in which the wearer can adapt it comfortably to his head. Thus if he feels that the supporting cushions are too hard or too thick, he is quite at liberty to remove some of their stuffing to the desired degree; if on the other hand he finds that the helmet sits upon his head too loosely, he has merely to open the drawing strings of the enclosed pads and thrust behind each mattress the needed amount of stuffing, in the shape of a bit of burlap, a folded strip of handkerchief, a layer of cotton wool etc."

Although none of the U.S. experimental helmets was adopted, the most promising models all incorporated the three-pad lining, which as Dean (76) said, localized weight where best supported, cushioned the weight at points of support, and decreased pressure on the temples as well as provided abundant ventilation to the head between the cushions. While attention was being given to the helmet linings, security was a major consideration in addition to comfort. The center of gravity and balance were designed into the helmet to keep it stable on the head when the chin strap was secured.

Dean (76) indicated that great stress was laid on comfort but that comfort could not be achieved even under the best of conditions so he emphasized the requirement for discipline in enforcing helmet wear.

In 1934, a determination was made that none of the candidate designs for a new helmet was acceptable, and a decision was made to modify the M1917 helmet by the addition of an adjustable hair-filled pad. This helmet was designated the M1917A1 (274).

In November 1940 the Chief of Infantry complained that the M1917A1 helmet did not offer adequate protection to the sides and back of the head, was poorly balanced, and sat too high on the head. In January 1941 the Chief of Infantry recommended that Ordnance initiate a project to develop a better helmet. The Type TS3 was developed, found suitable after testing and standardized as the M1 Steel Helmet. The TS3 had a fiber liner, of the same shape as the helmet shell, which contained the Riddell-Type suspension system for the helmet. The suspension consisted of a spidew-web arrangement of lightweight webbing straps. Three straps were looped over a strong lace that formed a center ring below the crown and their ends were riveted at six points to the sides of the liner; another strap, which formed the periphery of the web, was attached to the liner at the same six points. The headband, which was attached to this peripheral strap of the suspension by snap fasteners, was a non-adjustable band made of fabric with a soft leather facing on the side against the head. The neckband was a short webbing strap, also non-adjustable, that stretched across the lower back part of the liner where it could rest just below the pole of the head and thus add to the suspension and stability of the liner. The leather chin strap, which was adjustable and removable, hung by triangular steel holders that looped over garter studs riveted into the sides of the liner; this strap could be worn on the chin or over the front brim of the liner. The Riddell suspension was modified to include an adjustable headband with self-locking clips. Later, an adjustable neckband was developed and incorporated into the liner (274, 53, 236, 238).

During the course of the North African Campaigns in 1943, the rigid hook fastener of the helmet chinstrap was found to be a source of potential danger by remaining intact under the impact of a blast wave of a nearby detonation and thereby jerking the head sharply with the production of fractures or dislocations of the cervical vertebrae. After testing a ball-and-clevis release was designed to release at a pull of 15 or more pounds. This device was standardized in 1944 (53, 160).

During World War II, troop acceptability was fairly high but a common complaint was the lack of stability of the helmet. The frontline combatant must be indoctrinated and impressed with the protective integrity and necessity of the helmet and equally with the ease and comfort with which it can be worn. Helmet design is one field of military design where correct tailoring should be obtained commensurate with the imposed limits of the protective ballistic materials (53).

Throughout World War II, efforts were made to develop new helmet models. Notable among these are the T21-24 series previously described in the history. Among this group, the N21 showed the most promise after test and evaluation. The 21E1 weighed five ounces less than the M1, and had an advantage in having four sizes. It utilized a liner which incorporated the M1 suspension system. This helmet was commented on favorably by Army Field Force Board No. 3 in a test in 1946 (319, 316) and recommended for continued development. Again in a 1952 helmet conference (217) the T21E2 (modified to increase neck coverage, which brought weight up to M1) was favorably commented upon, and questions were asked as to what had happened to this model. The Metropolitan Museum of Art representative attending the conference replied that "the reason for ditching the helmet -- the prime reason -- is that just about the time that it was under consideration, they transferred the activity of the development of body armor from Ordnance to the Quartermaster Corps... The recommendation of the Field Forces was that the helmet not be dropped, but their minor recommendations be met."

In any event, helmet (and liner) development continued, to include the E49 series, the E51 series, the T53, 54 and 55 series.

The E49 helmet, designed in two sizes, had a suspension system that was essentially a modification of the standard M1 system (241).

The EX51, designed in two sizes, also had essentially an M1 suspension system, but included a leather nape strap and a foam disk at the peak of the crown (86, 319, 165, 166, 167).

The T53-2 (144, 248, 86) had an experimental suspension system designed by Cornell Laboratories. The Doron helmets, Types I and II, have suspension systems similar to the M1 (159). This suspension incorporates an adjustable "geodetic" vertical support and an adjustable horizontal support. This system was designed to be entirely removable from the shell.

The T54 liner was also equipped with a modified M1 system. The headband, made in two sizes, regular and large, was lowered and clips redesigned to permit a better fit and adjustment. The cradle was equipped with a buckle adjustment and a floating nape strap added (144, 248).

The T55-2 Type 1 had a new suspension system attached to the liner. The system was 1/8 of an inch lower in front and 1 1/2 inches lower in back than the M1. The suspension system was composed of three web straps, one of which had a cradle loop through which the other two straps passed, eliminating the drawstring lace of the M1. A white name tab was installed on the cradle strap. The headband was attached to the suspension system by six alligator clips; two of these clips were toothed and held the front of the headband static; four of the clips were toothless and allowed the headband to move on the sweatband to allow adjustment to wearer's head contour. To complete the suspension, it had a floating nape strap with horizontal and vertical adjustment. The leather chin strap of the liner was eliminated. The suspension system of the T55-2 Type II was identical to the Type I except that it has an adjustable chin strap for parachutists (321, 44).

The T57-4 liner had the same suspension system as the T55-2 (152). In 1956 a contract was let to Egmont Arens for an "Analysis of Design." He reported that the suspension systems for new helmet designs should be based on refinements of the M1 suspension system. In 1957, a contract was awarded to Cornall Aeronautical Laboratory (CAL) to, in addition to other work, "develop fabricate and evaluate suspensions and suspension systems for the following specific helmets:

Liner, Helmet, Combat T53-2; Liner, Helmet, Steel M1; Helmet, CVC T54-3."

CAL concluded that "the suspension studies for the T53-2, M1 and T54-3 combat helmets have resulted in little improvement over the efforts of the previous contract (OG-998-D-1). It is recommended that no further studies be performed until field tests have been conducted of the systems so far presented" (86). Of the suspensions, the system incorporated into the T55-2 was ultimately adopted when the T55 was user tested in 1957, produced in 1959, and Type Classified as Standard A in 1960 (321, 341).

In 1967 NLABS awarded a contract to International Latex Corporation to develop a Removable Suspension System for the Lightweight Helmet. Three models were submitted, one was found unsatisfactory, and best design features of the other two incorporated into a new design. This last design was also found unsatisfactory because studs for attaching suspension broke when removed, but was later installed in the nylon helmet for Military Potential Test at Ft. Benning, Ga., in 1969. This test concluded that the removable suspension system is suitable for use with lightweight helmets and recommended that consideration be given to redesign of the chin strap to a football-type (350).

During this time period (1968-1969) work continued on improving the standard M-1 suspension per se by making it removable. Six studs replaced the rivets on the liner and clips were attached to suspension system in such a way as to correspond to the studs. The removable suspension was approved for type classification Standard A by ACSFOR in March 1970.

In the LINCLOE Program, two helmets were initially considered, a one-piece nylon with a removable suspension system (developed by International Latex), and a two-piece polycarbonate shell with present nylon liner. Later, the titanium helmets were added for consideration: Types I - III with removable nylon liner and IV, having a removable integrated suspension with no liner.

Burse and Cahill (36) reported on comfort and stability ratings of three prototype LINCLOE suspension designs installed in an M1 helmet liner in a polycarbonate shell.

(1) Pulley and ratchet suspension: flexible plastic headband with ratchet-type lock device adjusted through a cord and pulley arrangement by pulling or releasing the chin strap.

(2) Clamshell suspension: perforated plastic headband adjusted and retained by collar studs with rear nape band and front forehead band acting as a locking device.

(3) Hybrid suspension: perforated plastic headband retained and adjusted by collar studs with plastic nape band.

All three systems had crown pads and chin straps.

While the M1 helmet was rated inferior in comfort and stability, the M1 suspension system was generally rated superior to the experimental systems for comfort and stability.

The suspension system of the Hayes-Stewart helmet was distinctly different from other models as was the helmet itself. In the initial design (which included nine sizes), the so-called trial suspension consisted of five sponge pads permanently affixed to the inside of the helmet shell. After field tests in 1968 found that this suspension system offered improved stability and more comfort than the M1 system, Greaney recommended improvement in design (111). The modifications were made, and the suspension tested in 1969 was removable and consisted again of five flexible foam pads. Each pad is of a sandwich-type construction consisting of a backing of Velcro tape (loop portion), polyethylene foam and polyurethane foam. The pads are attached (inside the helmet shell) by pressing the Velcro tape backing of each pad to counterpoint hook

portions of Velcro tape that are cemented on the inside of the helmet. One pad (7" x 1") is located in the forehead area; two pads (3 1/2" x 1") are located 1 1/2 inches up from the rear bottom periphery and one inch left and right of the center line of the helmet. The suspension straps are made of leather and are designed to form a combination chin and nape strap assembly. They are attached to the temple area and back of the shell by removable fastening devices.

The 1969 test produced four conclusions:

(1) The Hayes-Stewart helmet is compatible with fatigue uniform, mask and hood. However, it is not compatible with the 12-ply nylon vest.

(2) The foam-pad system is not satisfactory since it permits change in fit and does not provide adequate absorption and dissipation of perspiration.

(3) Lighter weight is more comfortable.

(4) The Hayes-Stewart helmet is equal to the M1 with respect to stability, preference and effect on performance of activities on General Equipment Test Activity (USAGETA) Test Facility.

The 1969 report recommended that the suspension and retention be modified and that the armor vest or helmet be redesigned to prevent interaction between the two in the back neck area (157). Based on sizing studies at NLABS, Ft. Devens and Ft. Lee, NLABS developed molds for nine sizes to fit the active army population (341, 351).

A Product Improvement Test was conducted at Fort Benning, Ga., on the M-1 suspension system during the period December 1970 through March 1971 (326). Included in the test were three systems:

(1) A -- Standard suspension system with modified chin strap and plastic chin cup.

(2) B -- Adjustable polyurethane pads secured to nylon liner by velcro tape.

(3) C -- Welson-Davis: two-piece system which attaches in front, back and over the head with velcro tape, and a plastic attachment attached to studs on each side of the liner.

The test report concluded that System B (polyurethane pads) was not suitable for U. S. Army use. System A and System C received high acceptability from the test troops. The report recommended that Systems A and C be further developed and submitted for Engineering Design Test (EDT).

In September 1971 an EDT was initiated at Fort Benning, Ga., on M-1 suspension systems. Included in the test were the following:

(1) The Welson-Davis modified to reduce bulk and facilitate attachment by elimination of the plastic side attachments.

(2) A system identified as HEL (Human Engineering Laboratories) which consisted of the standard suspension with pads attached to the crown and the nape straps.

(3) A four-point retained chin strap fabricated of cotton webbing.

(4) A modified airborne chin strap incorporating the standard parachutist open chin cup.

(5) The standard A M-1 suspension system.

(6) The standard chin strap.

Test instructions required the testing of each suspension system with each chin strap.

The letter report of the suspension EDT indicated that the HEL suspension had high acceptability but suffered from the poor chemical resistance of the pads (crown and nape) used. The modified airborne chin strap had high acceptability. The four-point chin strap, the standard chin strap, the standard suspension system and the Welson-Davis suspension system all had low acceptability. It appeared the Welson-Davis was overcorrected, and the report recommended that further development of this system have for a starting point the original system submitted for PIT in December 1970.

A subsequent IPR on M-1 Suspension Systems and Chin Straps held in February 1972 recommended that the chin strap and suspension system be considered separate actions. It further recommended that the chin strap (modified airboene) be subjected to a two-phase PIT scheduled for fist quarter FY 1973. The first phase will test a two-battalion unit and the second, conducted concurrently at Fort Benning, Ga., will test a unit of 100 men.

Also scheduled for first quarter FY 1973 is a Service Test of the HEL and Welson-Davis suspensions modified to correct the deficiencies noted in the EDT letter. During the period covered, numerous tests and evaluations were made of the various designs. In addition to those tests and descriptions already referenced, there were compatibility tests of the M1 with the T59-1 armor vest (247) and the M1 with cold-wet clothing and communications equipment (182).

The review of literature so far has treated the suspension and retention system collectively, and the literature has revealed that more attention has been directed to the suspension than to the retention. Objectively this is a correct approach, since one assumes a correctly fitting suspension system resting a helmet firmly and comfortably on the head, secured by a chin strap. Lewis (154) indicates that the chin strap completes the suspension system and says that in a properly designed system, there should be minimal tension on the chin strap. The chin strap can compensate for a small imbalance in the helmet on the head but cannot correct an improperly designed system. To be maximally effective, the plane of the chin strap should pass close to the center of gravity of the helmet and should be as close to the head as possible. The chin strap should rest on the point of the chin and have a method of adjustment.

Cold-weather headgear, when worn with a protective helmet, provides an additional problem for consideration. Cold-weather headgear normally worn without a helmet presents a compatibility problem when worn with the helmet unless there is an extensive size adjustment in the protective helmet suspension system. Even the area coverage and silhouette are changed, instability increases, and the design of the helmet is compromised. The Naval Medical Field Research Laboratory designed a cold-weather liner which was reported by Denich and Cole at the Quartermaster Research and Engineering (QMR&E) Armor Symposium, 1960 (351). The QMR&E Command developed a cold-weather head covering for wear with the M1 steel helmet and M1 helmet liner. This item, the T61-3 Cold-Weather Cap was tested by the U. S. Army Infantry Board and the U. S. Army Arctic Test Center, and it was recommended for approval and type classification as Standard A when certain deficiencies were corrected. The Helmet Liner Insulator was tested in 1963 and was found suitable for Army use, replacing four other cold-weather headgears (325).

In summary, two basic types of suspension systems have been utilized by the U.S. protective helmets. These are the multiple pad (variant of German) and the multiple webbing (Riddell type). When a single-size helmet is employed, the benefits of the Riddell type suspension are negated. The result is a variation in offset and increased instability. If the single-size helmet is to be continued, it would appear that a modification of the multiple-padding suspension would be preferable. Multiple-size helmets are required if maximum fit, comfort, stability and offset are to be achieved by the suspension system.

The present retention system appears inadequate in the areas of comfort and stability of the helmet on the head. It is improbable, however, that any chin strap can be designed which will be used consistently by infantry troops.

This survey of the design history of helmet suspension and retention suggests six recommendations:

1. Future design efforts should be limited to multiple-size helmets.

2. Removable and adjustable suspension systems are required through a range of sizes for each selected helmet size.

3. The modified Riddell system should be tested with multiple-size helmets.

4. Additional efforts are required in consideration of alternate methods and locations of attaching the chin strap to the helmet, to include multiple attachment and placement such as inside the helmet rather than on the rim.

5. To assure stability of the chin strap on the chin, and comfort in wearing, a chin cup or open chin strap should be employed.

6. Specific attention should be directed to efforts to design a retention system that does not require a chin strap for non-airborne employment.

ACOUSTIC CHARACTERISTICS

Tanenholtz, in his review of acoustical problems of the military (291), states that the limited development of blast and acoustic attenuating material and devices, as well as greater battlefield noise from more powerful weaponry and more mechanized equipment, increases auditory stress on the individual soldier. "If the sound properties of helmets are not taken into consideration," he says, "amplification of sound could result." Furthermore, not only has the compensation paid for hearing loss increased, but also nearly one-half of firing range personnel have been relieved of their normal duties because of incurred drastic hearing loss.

The early testing of the M1 steel helmet and liner combination revealed that sounds reverberated somewhat in the shell and caused a ringing sensation in the ears. The Bell Telephone Laboratories studied the disturbances and concluded the effect was minimal. They suggested the resonance could be reduced by using felt or foam rubber pads in the liner (rejected because of increased weight), or by perforating the liner and shell (rejected because of moisture in rainy weather). Nothing was done, with the conclusion that the soldiers would become accustomed to the resonance (207).

The M1 steel helmet and liner system is still being criticized for interference with hearing (330). Because of the shape of the M1 helmet there may be resonance effects or standing-wave formation which alter the acoustical characteristics of the helmet according to the size of the wearer (253). The M1 comes in one size with an unfilled volume area that varies with head size. If the individual soldier is wearing his helmet high, the vulnerable area around the ear and neck is left unprotected. When it is worn low, hearing is reportedly impaired (10). When the ear is partially protected, the ear canal is somewhat occluded and, in addition, the rim contour may reflect high-frequency sound toward the ear (253).

One of the disadvantages of the EX-51-1 aluminum helmet was the interference with hearing due to the lower side coverage. It impaired normal hearing to a greater extent than did the standard helmet and interfered with the use of communication equipment (319). The T53-2 design, also with lower side coverage, magnified sounds considerably and diminished hearing appreciably. The sound magnification was to the extent that it was feared it could lead to injuries from concussion (144). The Cornell one-piece shell and Arens Style No. 9 extended protective coverage to provide additional ear and cheekbone coverage, and with the "visor" in the up or forward position, the ear was exposed for improved ventilation, comfort and use of field communication equipment (10 , 86).

Burse and Cahill (36) compared the M1 to an experimental LINCLOE polycarbonate helmet for interference with hearing and for helmet noise. The polycarbonate helmet was rated more favorably than the M1 both for interference with hearing and for helmet noise.

The Hayes-Stewart helmet exposes the ear canal and is designed to be close fitting, with multiple sizes. The unfilled volume is thus reduced and held more constant relative to the size of the wearers head (253). In his comparison of the form of the M1 and Hayes-Stewart on hearing, Randall found that the Hayes-Stewart helmet provides less high-frequency attenuation, and he suggested that the Hayes-Stewart may be preferable to the M1 for a sentry, all other factors being equal. However, he found only a 2-3 dB improvement in the Hayes-Stewart over the M1 (253).

The ear can be ballistically protected with a movable earpiece, hinged flap or movable neck piece with the resultant interference in hearing, or it can be protected with separate attenuating devices -- such as ear plugs, muffs or selective filters -- within acceptable designs. The design goal could be to provide radio communication to the infantry soldier at the same time providing acoustic protection and possible increased stability on the head by using communication head-sets (354, 39, 137, 375, 255, 190).

The conclusion is clear that, while many different designs and shapes of helmets have been proposed with a wide variety of ballistic materials, there is still a problem with acoustics in helmets. The increasing noise on the battlefield makes the problem more severe and research must evaluate the vulnerability of the ear e.g., advantages and disadvantages of protected, partially protected or unprotected hearing versus the requirement to hear in tactical situations. The research should include attention in design and materials to minimize amplification and reverberation.

Specifically, further research in helmet acoustics should pursue three objectives:

(1) To develop a helmet that would incorporate an ability on the part of the wearer to receive non-injurious sounds, particularly in the speech range, yet attenuate damaging noises.

(2) To determine the effect of the helmet form on hearing (sound localization, speech intelligibility).

TABLE 6

Acoustical Characteristics of Helmets

Helmet	Acoustics	Ear Protection	Attempted Solutions
M1917A1		Negative	
M1	Amplification resonance partial occlusion of ear canal	Partial, depending on head size	Pads, perforated shell/liner
EX 51-1	Impairment of normal hearing Vs. M1	Greater Vs. M1	Lower contour - 2 sizes
T53-2	Sound magnified possible concussion	Greater Vs. M1	Lower contour
LINCLOE Polycarbonate	Improved acoustics Vs. M1		Experimental suspensions
Hayes-Stewart	Improved acoustics Vs. M1	Less protection of ear canal Vs. M1	Ear cutout, multiple sizes, closer offset

(3) To assess the relative values of protection to the ear, as opposed to minimum impairment to hearing, in helmet design.

EYE PROTECTION AND VISUAL FIELD

As soon as the French Army had accepted the protective helmet, attempts were made to develop a face shield and eye guard. One, the Polack visor adapted to the helmet, came close to succeeding the Adrian helmet (76). The French-designed Dunand helmet, featuring a visor, was given seriuos consideration as a candidate helmet by the Americans, but the visor proved too fragile (76).

Ordnance Department Experimental Design No. 6 tried a tilting face dome, while Experimental Model No. 8 had a face visor with a narrow slit for vision that could be raised or lowered and could resist penetration of .45 caliber service ammunition of 800 foot seconds. Model No. 8 was carefully balanced and kept its position readily. Dean (76) says this model did not appear to be adequately tested.

The British continued work on a fragment visor in the 1930's (73), while the Americans, by 1944, were working on a visor for the Standard M1 Helmet (256).

In 1946 eye armor designed to fit the M1 Helmet was standardized (53). In research and development helmet studies by Cornell Laboratories, the Quartermaster asked for specific evaluation tests to determine the implications of design prototypes for interference with vision (86). The Arens report designs attempted to increase head coverage with movable visors or extended shell parts which affected visual field (10). Experimental Model No. 7's visor in the up position afforded excellent visibility, while in the extreme down position could result in a fine slit between the base shell and visor affording limited vision but extensive protection.

The size and shape of the visual field during wearing of any headgear was measured for the Quartermaster Handbook as was the size limit of the head and neck area (140). A device for measuring size and shape of the visual field was also developed by the Quartermaster (71). The effect of various helmets on field of vision is shown in Table 6 (186).

TABLE 7

Helmet Fields of Vision

Helmet	Field of Vision in Degrees			
	Horizontal		Vertical	
	Left	Right	Up	Down
USA M1	100	100	15	60
Denmark	45	45	20	N
France	90	90	45	50
Germany	N	N	45	N
Italy	N	N	60	N
UK	33	33	47	N

N = 90^{o} or more

Most countries except the U. S. and Denmark report field of vision vertically up to 45^{o} or more (186).

Work on the aircrewman's helmet in the 50's and 60's resulted in polycarbonate-resin visors that provided eye protection against small fragments (234, 148, 66). An eye shield using the polycarbonate lens was designed by the Navy to attach easily to the M1 helmet (122). It consists of a clear plastic visor mounted on an aluminum frame for raising and lowering. A polycarbonate cover shield protects the visor from being scratched in the "up" position (122). The shield was evaluated in Vietnam by the Navy. It did not reduce field of view and could be worn over prescription lenses. The ballistic limit of the shield is 630 feet per second for a .25 caliber T-37 fragment simulator, and 1050 feet per second for a two-grain steel sphere. The Navy recommended that its evaluation report should be used in any efforts to redesign the M1 helmet so as to incorporate the additional safety feature (122).

A reassessment of eye-protection devices for incorporation in future helmet designs should be made with the casualty-reduction analysis. The Navy visor design seems to incorporate the desired features of ballistic protection, vision, comfort, transmission of sound, ruggedness and compatibility with shoulder weapon.

The importance of vision to the soldier suggests at least three specific recommendations for eye-protection research:

(1) Casualty-reduction analyses of the effect of eye shields should be conducted to determine their value for inclusion in future helmet designs.

(2) Research into the helmet visual field as well as target acquisition and identification should be emphasized in both short and long-range programs of the Five-Year Personnel Armor System Technical Plan.

(3) The physiological and psychological impact on the wearer as a function of protection of the eyes and face should be researched.

ANTHROPOMETRICS AND MATHEMATICAL MODELS OF THE HEAD

The use of anthropometrics in designing and sizing helmets has been long recognized. The French World War I helmet was designed with great precision to fit the wearer as comfortably as possible. The shell came in three sizes: the first size, A, was for heads of size 6 7/8; size B was equivalent to 7 1/8; and size C to 7 3/8. For each of the three shell sizes, four different linings were available (76).

Recognizing the need for suspension and helmet offset, Lewis states that the best method for head protection is to fit the helmet as close as possible to the head (154). This reduces the missile-hit area on the helmet. Since the M1 is available in just one size and approximately 85 percent of them are a larger helmet than the wearers need, the possibility of receiving helmet hits is increased (354). The larger diameter requires more effort to turn the helmet and the excess surface area means more weight, more instability and more offset distance than required (354).

These problems were generally recognized and during World War II work continued to improve the M1. The T21 helmet shape was established through anthropometric studies of the head and provided curvature in all directions at all points on the body of the helmet, decreasing the size with no sacrifice in area coverage. It allowed a lower silhouette and closer fit than the M1 (53). In 1945, helmets of aluminum and nylon combinations were produced on the pattern of the T21.

The experimental EX 51-1 helmet was developed as a possible replacement for the M1 and was to be suitable for airborne and armored personnel as well. The 1946 military characteristics for the EX 51-1 prescribed "the helmet being in two sizes with the size break in the mid range. This results in the great majority of wearers with an 'average' sized head being able to wear either helmet, though both helmets are at the limits of their adjustment." The service test found that many men wear the larger heavier helmet unnecessarily and recommended the break in sizes be not in mid range but near the large size (319).

The assumption of helmet responsibility by the Quartermaster resulted in a review of anthropometric design requirements. The Cornell reports on combat-helmet development provided basic data for statistical average head shapes and sizes and the corresponding ranges. They recommended that two shell sizes (with a dividing point at size 7 1/8 for the larger size) would provide adequate sizing and still maintain a minimum number of shell sizes. The reports state that "in helmet design the first consideration should be given to the head rather than the helmet exterior, for in analysing each desirable or required feature it is the man which must function and be protected within the protective shell" (86).

In Arens' analysis of design it was stressed that by cutting down the size of the helmet to fit average and small heads, a favorable weight, fit and appearance would be gained "However," Arens continued, "after careful consideration by Quartermaster it was felt the two size system should be abandoned in favor of a one size helmet to fit the largest head." This one size was determined to have inside dimension of 9 1/2 inches long x 8 1/2 inches wide. Of primary consideration was the effort to keep Quartermaster inventory at a minimum (10).

The Hayes-Stewart helmet developed during the course of LINCLOE helmet program stresses anthropometry in design. Anthropometric data were established from measuring 500 Air Force heads in four dimensions, taking the mean vector and using the standard deviations for larger and smaller sizes. The resulting nine sizes fitted into the helmet-sizing algorithm within acceptable limits (109).

Attempts to design close-fitting or contoured helmets such as the Hayes-Stewart according to available anthropometric head measurements (length, breadth, height and circumference) emphasized the need for more anthropometric data describing the intervening points between the four basic measurements. Philip E. Durand, Project Engineer for the LINCLOE Helmet, compared this problem to that of a carpenter building a house according to a blueprint which shows only the length, height and perimeter of the house. It was the recognition of this problem and the insistence of Mr. Durand which established a work unit in the Five-Year Personnel Armor System Technical Plan to describe the human head mathematically by depicting all basic planes and coordinates necessary to achieve a close-fitting helmet.

Attempts to describe the upper human head mathematically and to take into account variations of the size and shape of the actual head have been currently assigned to the Vulnerability Laboratory of the Ballistic Research Laboratory (BRL) under the Five-Year Personnel Armor System Technical Plan. They are developing algorithms that can be used as an instrument for sizing prototype helmets and that will give solutions for one through any number of sizes. Using the Cinderella approach, efforts are being made to find heads to fit the algorithms. From measurements of 300 heads it has been found preliminarily that the relationship between head circumference and head height was not as expected. The BRL analysis indicates that an adequate representative anthropometric survey sample size would be 500 and that the number of head models could be limited to five or six sizes of heads (337).

The Suspension and Retention section in this report contains further information on the use of anthropometry in suspension design, as does Lewis' 1958 report (154). Suffice it to say here that the advantages of the Riddell-type suspension are negated by using the one size M1 helmet.

Table 8 summarizes the advantages and disadvantages of single-size and multiple-size helmets.

TABLE 8

Advantages and Disadvantages of One-Size Vs.
Multiple-Size Helmets

System	Advantages	Disadvantages
One Size	Cost	Greater area
	Inventory	More Weight
	Ease of manufacturing	Less stability, appearance
Multiple Sizes	Less weight	Cost
	Closer fit - more stability	Difficulty of manufacturing
	Less area, appearance	Less standoff

In his 1958 report, Lewis argued for multiple helmet sizes:

"The problem of a universal sized helmet versus a helmet available in several sizes should be considered as it has been in the sizing of clothing and other protective devices... Should an item supposedly worn continuously in combat take a subsidiary place in sizing...?" (154) The necessity for several helmet sizes has long been recognized by other nations and is now being recognized by the U. S.

Table 9 presents the sizing and suspension of helmets by various nations.

TABLE 9

Helmet Sizes and Suspensions

Country	Helmet Sizes	Suspensions
USA M1917A1	1	1 Adjustable
USA M1	1	1 Adjustable
USA T21	4	1 Adjustable
USA EX 51-1	2	1 Adjustable
USA 52-3	1	1 Adjustable
USA Hayes-Stewart	9	
Denmark	1	
France	1	
Germany	3	3 Headbands
Italy	1	
UK	1	7 Headbands
Poland	2	7 Liner Adjustments
Australia	1	1 Adjustable
Canada	1	1 Adjustable

Helmet sizing techniques are reported by Punton (234), Lewis (154), Zeigen and Churchill (380), Goulet and Sacco (109), and Allinikov (9).

Multiple sizes for infantry helmets are required because of the problems of fit with variance in head size and shape. There is a requirement for continuous anthropometrical survey to provide current sizing data to designers:

(1) Infantry helmets should be provided in multiple sizes up to five. Beyond five sizes it appears that the payoff in better fit does not equal the requirement for the increased inventory.

(2) A survey of a representative sample of new U.S. Army recruits should be established and updated periodically to maintain current anthropometric data.

WOUND BALLISTICS

Throughout history armed combatants have received injuries and wounds from the weapons of their enemies. The study of wounding, wound ballistics, has evolved from an initial casual observation of injuries to an in-depth analysis, employing the physical and life sciences as well as computer technology.

Blair (28) defines wound ballistics as "the study of the relationship between the physical and ballistic characteristics of kinetic energy missiles and blast, and the nature and severity of the wound produced by same in the human body."

Wounding data was recorded for both the Civil War and World War I. However, in World War II, Korea and Vietnam, efforts to collect field data, and to analyze the data collected, have been greatly increased.

In addition to the value of the medical data collected, when a systems-analysis approach is applied to the wound-ballistics data available, a great deal of additional, vital information may be retrieved and applied to other areas, such as weapons effectiveness studies, design of protective armor, and selection of armor materials.

The Biophysics Division of the Biomedical Laboratory at Edgewood Arsenal, Md., has been extensively involved in wound ballistics since early in the Korean War. Battlefield casualty studies prepared by the then Chemical Corps Medical Laboratory at Edgewood (57, 59, 60) have been extensively studied in relationship to both helmet and body-armor design. Wound ballistics studies have been continued since then in conjunction with the Ballistics Research Laboratories and later the Army Materiel Systems Analysis Agency at Aberdeen Proving Ground, Md., as well as with Watertown Arsenal and NLABS.

During the Vietnam War (1967-1969), the Wound Data and Munitions Effectiveness Team (WDMET) operated from the Research Laboratories at Edgewood and from AMSAA at Aberdeen (29). This team collected data on 7801 cases in Vietnam, drawn from 2734 engagements during its operation, for processing, analysis and evaluation at Edgewood and Aberdeen (284, 278). Two WDMET reports specifically address craniocerebral trauma (282) and head trauma (277). An analysis of data on munitions effectiveness and wounds (28) showed that of 11,206 hits on casualties, neck and face account for 6.5 percent of the body area but received 15.5 percent of the total hits, and those head, neck and face hits were the cause of death in 42 percent of the 456 deaths.

These data correlate with the analysis of Korean experience, where 16.4 percent of the wounds in 7773 casualties were head and neck wounds (53), and with data summarized by Beebe and DeBakey (24) in World War II. Additionally, the casualty studies conducted during the Vietnam War have also found that a major causative factor in wounding is fragmentation. N. A. Hitchman of (ORO) (125), in estimating the protective value of the helmet, has stated that although the head, face and neck mean projected area represent 12 percent of the body, this area took about 30 percent of the wounds received by infantrymen in World War II. He estimates an eight percent savings by helmets in total World War II battle casualties.

The extensive literature on wound ballistics serves to emphasize the vulnerability of the head to wounding. The incidence of head wounds is greater than would be expected from the relative size of this area. In addition to the higher-than-expected incidence of head wounds, wounds in the head area are more critical than in other areas, as reflected in the higher death rate.

In view of the higher relative incidence and the greater criticality of head wounds, the design and development of a new helmet should receive greater emphasis.

Although the goal of an ideal helmet would be to provide maximum area coverage to the head, this maximum coverage will reduce the visual field upward and laterally, and by covering the ear area will impair the hearing capability. An analysis of wound data should provide information about the relative incidence of ear-area and facial wounds. This information could then be used in an evaluation of helmet design to allow trade-offs e.g., do the number of wounds encountered in the facial area warrant an increase in protection at the cost of reduced vision, or, is increased vision more important, or, is a face visor an acceptable or desirable alternative.

Helmet offset is another critical aspect of helmet design as affects wounding. Specific medical guidance must be given to the designer at this critical point to allow the design of a helmet that will be fitted as close to the head as is possible. As offset increases, so does the area and weight of the helmet, with no increase in protection, and the helmet becomes a larger target.

Predictive models developed in laboratories can be compared to actual battlefield data, and vulnerability data can be developed from these same battlefield data. Robinson, Boyd and MacDowell (257) developed a method of estimating the medical workload from fragmentation weapons. Waldon, Kokinakis and Sperrazza (366) developed a predictive model for evaluating the protection offered by infantry helmets. Waldon, Dalton, Kokinakis and Johnson (367) present "A Parametric Analysis of Body Armor for Ground Troops" in ARDC TR No. 2. As determined at the Working Committee Meeting No. 3 in December 1971, ARDC TR No. 2 will be employed in the Standardized Casualty Reduction Analysis Reporting (377) for both materials and systems/components evaluation.

Lewis (154) has included a chapter on Medical Aspects (of head injury) and another on the Protective Value of the Helmet. Other reports on wound ballistics are contained in reports by Handford and Lewis (117), Gardner and Hitchman (96), and Dzemian, Light, Washburn and Coe (85).

The acquisition of wound-ballistic data has been greatly expanded over the period covered by this history. The use of a systems approach has greatly extended the application of these data in armor-design development and evaluation. The utilization of wound-ballistics data, vulnerability data, etc., in mathematical models has led to the development of casualty-reduction analysis techniques, which have greatly enhanced the developer's ability to determine design parameters and effect meaningful trade-offs in evaluation.

Continuing efforts should be made to expand the application of and to improve the casualty-reduction analysis techniques.

The developers should continue their efforts to obtain more specific offset requirements which can be incorporated into casualty-reduction analyses.

FUNDING

In a development program a prime consideration in planning and executing work, particularly as to scope and timeliness of work, is funding, not only for in-house development work but also for a contract program which insures supporting industrial expertise. The following tables showing contract programs and proposals indicate industry's interest and assistance in the helmet program.

TABLE 10

Contract Program

Helmet, Lightweight (LINCLOE) for Ground Troops

Fiscal Year	Contract and Scope
66	Mine Safety Appliances Co. No. 1060: To fabricate one mold and 110 lightweight helmets.
66 & 67	General Tire & Rubber Co. No. 1026: To produce a new mold and 250 Nylon Helmets.
67	Edgewood Arsenal, 67-103: To conduct Casualty Reduction Studies on three Helmet Approaches (Nylon, Titanium, Polycarbonate).
67	International Latex Co. No. 0212: To develop a Removable Suspension System for the Lightweight Helmet.
67	Mine Safety Appliances Co. No. 0191: To procure 300 Lightweight Polycarbonate Helmets for ET/ST.
67	Titanium Metals Corp. of America No. 0183: To fabricate 400 Titanium Alloy Helmet Shells.
67	General Tire & Rubber Co.: To investigate Feasibility of Producing a 1-1/2 lb. Combat Infantry Helmet.
68	I.L.C. Industries: To design and fabricate Integrated Helmets.
69	Ballistic Research Laboratories, Aberdeen, Md.: To evaluate helmets to determine casualty reduction criteria.

NOTE: Contracts include LINCLOE and Hayes-Stewart Helmet.

TABLE 11

Contract Program

Nylon Helmet Liner
(Including Improved Suspension System for the Standard Helmet)

Fiscal Year	Contractor and Scope
54 & 55	Victory Plastics: To develop armor materials for Helmet Liner, Steel.
55	Cornell Aeronautical Lab.: To develop helmet compatible with cold weather headgear.
55	Cornell: To develop helmet suspension.
57 & 58	Victory Plastics: To develop reinforced plastics with improved structural and durability characteristics for application to personnel armor.
59	Victory Plastics: To mold and color nylon helmet liner.
60	DeBell and Richardson, Inc.: To develop an integral finish molding system for helmet liners using a quick-cure cycle.

TABLE 12

Contract Program

Titanium Helmet for Ground Troops

Fiscal Year	Contractor and Scope
54	McCord Corp.: To investigate forming of commercially pure titanium alloy helmets.
55	McCord Corp.: To fabricate high-strength aluminum alloy helmets.
58	McCord Corp.: To fabricate titanium alloy helmets.
59	T.R.W., Inc.: To investigate hot-form titanium alloy helmets.
60	Ryan Aeronautical Co.: To investigate explosive forming of titanium alloy helmets.
65	Titanium Metals Corp. of America: To develop forming techniques and fabricate quantities of various-weight titanium alloy M-1 helmets.
67	Titanium Metals Corp. of America: To fabricate 400 24-ounce lightweight titanium helmets.
68	Whittaker Corp.: To develop a one-step mass-production process for forming titanium alloy helmets.

TABLE 13

Contract Program

M-1 Steel Helmet
(Product Improvement)

Fiscal Year	Contractor and Scope
67	Battelle Memorial Institute: To study various properties of M-1 steel helmets and correlate properties with ballistic protection.
67	McCord Corp.: To investigate hydro-forming of M-1 steel helmets to improve ballistic properties.
68	Battelle Memorial Institute: To strengthen the thickness vs. ballistic-limit correlation and develop a replacement inspection technique for ballistic testing.
69	Philco Ford Corp.: To investigate the use of dual-hardness steel in helmet application.

TABLE 14

Contract Program

Siege Helmet

Fiscal Year	Contractor and Scope
68	B.W. Welson and Co.: To develop a new suspension system for the helmet which will provide stability, proper fit and comfort.
68	Army Materials and Mechanics Research Center: To evaluate and determine the ballistic performance of advanced hemogeneous and composite armor material against small-arms ammunition, fragment-simulating projectiles, cubes and flechettes.

TABLE 15

Personnel Armor Materials and Items

Industry Proposals to Natick Laboratories -- FY 69

Source	Description	Disposition
Avco Space Systems Lowell, Mass.	Non-destructive testing of ceramic armor	Proposal not accepted; a concurrent approach was contained in a formal invitation for bid.
Titanium Metals Corp. of America	Helmets, lighter weight and increased protection	Proposal not accepted because of a lack of funds.
Greer Products, Inc. Los Angeles, Calif.	Titanium combat-helmet program	Proposal not accepted because of a lack of funds.
Titanium Metals Co. W. Caldwell, N. J.	Develop ballistic titanium alloy	Proposal not accepted because of a lack of funds.
Les Yogrem Monterey Park, Calif.	Bulletproof military helmet	Not accepted; concept was considered unfeasible.
Phillips Scientific Corp. Bartlesville, Okla.	Personnel armor material X-P for helmet	Not accepted; concept not considered within state of the art.
Hanes Hosiery Winston Salem, N. C.	Attaching armor plates to knitted fabrics	Not accepted; additional data and cost data not furnished when requested.
Illinois Institute Tech. Chicago, Ill.	Glass ceramic armor plate	Accepted.
Uniroyal Plastic Mishawaka, Ind.	Resin composites for steel helmet and liner	Accepted.

TABLE 16

Personnel Armor Materials and Items

Industry Proposals to Natick Laboratories – FY 70

Source	Description	Disposition
Philco Ford Corp. Newport Beach, Calif.	Body armor	Not accepted because of a lack of funds.
Greer Products, Inc. Los Angeles, Calif.	Titanium combat helmet	Not accepted because of a lack of funds.
Airesearch Mfg. Co. Los Angeles, Calif.	Infantry helmet suspension-system study	Not accepted; similar proposal was already in effect with B. Welson Co., Hartford, Conn.
Whittaker Corp. W. Concord, Mass.	Thermally formed titanium alloy helmet	Contract DAAG17-68-C-0203 awarded to Whittaker Corp.

Two additional documents were retrieved which are worthy of close review. The first is a helmet cost study by Finch and Schroder (92) which studies the cost of development and production of the Titanium Type I and III, LINCLOE Nylon and Hayes-Stewart, and compares them to the M1 Steel. The other document is a classified report by Tropf (296) in which he shows the relative economic breakeven points for infantry helmets of new design. Particular emphasis is placed on titanium.

The funds for the helmet-development programs covered by this historical review were adequate except for the years 1969-1970. In 1969 four industry proposals were not accepted because of lack of funds and in 1970 two industry proposals were not accepted because of lack of funds.

The establishment of the Five-Year Personnel Armor System Technical Plan, with the designation of a Program Manager, will provide for centralized management and greater flexibility in funding.

It appears that the funding has been carefully developed to support the five-year program and that the projected funds are adequate to support the proposed work program.

Inasmuch as the five-year program has been in effect for more than a year, a specific review should be made by the Work Unit Performing Organizations in the Scheduled Management Review to verify that the projected fund requirements are still sufficient to allow the full performance of the Work-Unit Requirements in accordance with the schedule.

DISCUSSION

A reviewer of all the documents that have been retrieved in the preparation of this document is inevitably impressed with the tremendous efforts that have been made to provide the U. S. soldier with the best head protection that can be achieved. There have been continuing improvements in all aspects of the helmet-developing program. Significant improvements have been made in the crucial areas of materials technology, wound ballistics, and test and evaluation methodology. The developer now has available to him a wide range of armor material, a valuable source of wound-ballistic data, additional anthropometric data, and more valid means of testing and evaluating both the helmet components and the helmet design. An additional significant improvement has been the increasing clarity in the military characteristics furnished by the requirements authority. These military characteristics provide the criteria by which the developer and the user testing agencies can evaluate the degree to which a candidate helmet meets the military requirement for protective headgear.

History reveals an interesting pattern in the U.S. helmet program. The M1917 helmet was adopted as an expedient from the British Mk 1. Since the U.S. had no protective helmet, an evaluation of the allies' helmets resulted in a choice of the Mk 1. This choice was made because the British could furnish the U.S. with helmets while the U.S. was tooling for its own production, because it offered the best ballistic protection, and because it was amenable to economic mass production. Research and development efforts toward an improved helmet resulted in numerous designs, all essentially "pot-shaped," which were rejected. In 1940, in response to a requirement from the Chief of Infantry for a new helmet, the pot-shaped TS-3 was designed, developed and standardized as the M1 Steel Helmet. This helmet gave increased area coverage and was determined to be economically mass producible. Additionally, it provided increased ballistic protection. Since 1940, all candidate model new helmets have had the pot shape, with the notable

recent exception of the Hayes-Stewart helmet, which has the look of a Roman Helmet and offers an increase in area coverage.

The point is that a resistance to change kept the M1917 and M1917A1 as standard for 23 years, even though the pot-shaped helmet offered demonstrable improvements. For the next 28 years, experimental helmet configuration was essentially that of the current standard M1, even though alternate designs were proposed in 1956 and 1957, until the Hayes-Stewart configuration was advanced in 1968. Helmet improvements have been evolutionary in nature, producing primarily an improvement to the suspension/retention system and an increase in ballistic protection by the substitution of a ballistic liner for the non-ballistic liner. Currently, improved suspension/retention systems, alternate armor material and the alternate design are being tested. The decision to consolidate the responsibility for development of all personnel armor in the Quartermaster in 1947, rather than to split responsibility between Ordnance and Quartermaster, was a distinct step forward for program management. The establishment of U.S. Army Materiel Command (AMC) as the logistical element of the Army was another step toward central management.

The latest advancement in helmet development was the decision to incorporate the helmet program into the Five-Year Armor Program. The result was the establishment of the AMC Five-Year Personnel Armor System Technical Plan, with Natick Laboratories (NLABS) as the lead laboratory with the program manager.

After due consideration of all aspects of helmet design and acceptability (both test and soldier acceptability), it has become quite apparent that the suspension (and retention) is the most critical aspect of design. Since the suspension system is the key to fit, balance, comfort, stability, hence decreased fatigue or physiological cost, and cumulatively, soldier acceptability or psychological acceptance, it must be realized that this aspect of helmet design must receive consideration comparable to ballistic protection.

The literature on battle casualties contains reports of non-wearing of the helmet for a variety of reasons, such as comfort, (too hot, too heavy, unstable, etc.), detectability (noise on patrol) and hearing deprivation.

Since it is improbable that a truly comfortable helmet can be developed which affords the desired protection, the question is raised as to whether it would not be better to have a ballistically inferior helmet which would be more acceptable to the soldier for essentially constant wear. At the same time, the developer cannot be held solely accountable for the soldier's failure to wear his helmets. The user must by training accustom the soldier to wearing the helmet and then through discipline enforce the wearing.

Suspension systems have been of essentially two types in U.S. helmets: the pad system and the cradle system. The M1 and all experimental helmets developed by the U.S. since World War II have had a variant of the cradle system, except the Hayes-Stewart helmet, which uses a five-pad system. In comparative tests, the trial and modified pad system compared very favorably with the standard M1 system, and it would appear that worthwhile effort could be devoted to overcoming the test shortcomings of the Hayes-Stewart by changing materials, changing the front slope and modifying the chin-nape strap, to accomplish a still better fit and more comfortable as recommended by the test organization.

Sizing of helmets has been contradictory throughout the development since World War II. Sizes have ranged from one size for all wearers, with the M1, to two, four, and nine sizes, as with the Hayes-Stewart helmet. The main argument in support of one size has been the reduction of inventory of helmet sizes. This argument seems to fail at first glance when offset, weight and area coverage are considered for the small, average or medium, and large wearer. It fails even further when stability is considered. Lastly, it would appear that for an item of equipment as valuable to the wearer as the helmet, "tailoring," i.e., a number of sizes, is required to offer improved fit, comfort, stability, proportioned weight and coverage, and proper offset. These factors will be a major contribution to making the helmet more acceptable to the soldier. The Hayes-Stewart Helmet, designed and fabricated in nine sizes, represents a step in this direction. In any event, multiple helmet sizes appear to be required. A multiple-sizing system improves stability, standardizes weight ratio per wearer/helmet, standardizes target-area size and standardizes offset.

During the period from World War II until now, advances in materials technology might well result in a superior ballistic material for a new helmet. Hopefully this material will weigh less per square inch and even more hopefully will be amenable to mass production at a reasonable cost. It would probably be desirable to re-evaluate some of the past most promising ballistic materials and some of the most promising designs, using the improved evaluation technique of casualty-reduction studies as well as applying improved techniques of fragment simulators. This re-evaluation should eliminate doubt, if doubt exists, as to why a given material or design failed.

Two candidate model helmets that were recommended for further development, yet not adopted, should be reconsidered: the T21E3, dropped when the Army changed from a two-helmet doctrine and returned to an all-purpose helmet in 1949; and the T53-E2, dropped when the Army selected the T55E3 nylon liner as a liner for the steel M1 shell after service tests in 1954-1955. Both of these helmets should be reconsidered to determine if they can be improved by material or design or if their good factors can be incorporated into other helmets. The T21E3 design in four sizes was established after anthropometric studies and was purported to offer increased strength and protection, decreased size at no decrease in protection, and less weight than the M1. The T53-2, also of aluminum and nylon, was designed in one size but offered a 10 percent increase in the protected area. This helmet was rejected when the T54-1 helmet liner (later the T55-3) was adopted after ballistic, logistical and acoustic considerations.

Historically, evaluation of a candidate armor material, and/or the evaluation of a candidate system/component, has been critical to the process of selection. From 1917-1918, when selection was essentially a relatively simple go, no-go process of simplified ballistic testing and determination of production feasibility, selection is now an evaluation of many variables far wider in scope and far more complex in application. The increased complexity reflects the great strides forward in materials technology, as well as the ability of managers to integrate the inputs from the physical and life sciences, using a system-analysis approach and taking advantage of computer technology.

The recent effort on the part of the program manager to effect standardization of terminology and methodology for characterization of personnel armor has led to the adoption of a standardized casualty-reduction analysis reporting, with criteria established for material evaluations and expanded criteria established for system/component evaluations. This approach should lead to common understanding among all personnel concerned with personnel armor development. In extension of the casualty-reduction analysis, there is a requirement to obtain more quantified data in the field of human factors for application in the mathematical models. The effects of weight, instability, fit, comfort, visual and acoustic characteristics and the part that they play in soldier acceptability of a new helmet are largely not quantified, but are subjective data obtained from observations, from wearer comments, and from responses to

questionnaires. The importance of objective data, subject to quantification, on soldier acceptability must be emphasized in the five-year plan by appropriate research. The acquisition of hard data will allow realistic trade-offs in helmet evaluations.

The entire problem of helmet design is currently being studied by the five-year plan team. Included in the design studies are studies to determine the requirement for offset. At present the Surgeon General requires an offset and efforts are being made to define the required minimum/maximum offset for helmet design. Helmet-design studies should also produce data indicating a minimum number of helmet sizes, based on defined basic head shapes and a defined number of sizes for each shape.

Throughout the course of U.S. helmet development there has been no reluctance on the part of the Ordnance Department or the Quartermaster Corps to solicit outside help in obtaining design assistance, primarily the Metropolitan Museum of Art in the case of the Ordnance Corps, and industry -- research and design corporations -- in the case of Quartermaster Corps. It might be said that the investment return was greater for the Ordnance Corps than it was for the Quartermaster Corps. Yet who can say as to whether it was a choice of contractor, guidance to the contractor by the government, or what proportion of both? However, even with work in progress, emphasis must be placed on a clearer statement of the problem so that design can be effected to accomplish all of the desired military aspects of a protective helmet. This statement should specifically include but not be limited to the definition of an acceptable weight; a definition of desired as well as required coverage; a specific definition of a minimum acceptable stand-off, minimum acceptable acoustical characteristics and minimum acceptable visual field; a statement as to the requirement for visual protection; a definition as to the minimum and maximum number of sizes that are acceptable; a statement as to priority of requirements for compatibility with various other pieces of the infantryman's equipment (compatibility with a shoulder-fired weapon is the number one priority, but which is more important, compatibility with binoculars, with communications equipment, armor vest or with protective mask? These and other questions must be answered so a material choice can be made, a design established, laboratory tests planned and evaluated, and finally, field evaluations conducted.

In summary, decisions have to be made to resolve the following apparent conflicts in requirements:

(1) Ballistic protection requirement vs. helmet weight.

(2) Material vs. cost.

(3) One size vs. multiple sizes.

(4) One-piece helmet vs. two-piece helmet.

(5) Infantry helmet vs. all-purpose helmet.

(6) Hearing and vision vs. protection.

(7) Pad-type suspension vs. multiple-web suspension.

(8) Protection only vs. ancillary benefits.

In the past, decisions have been made on the basis of subjective opinion, and, with primary weight being given to one aspect of a proposed helmet, as in the case of the Model No. 5 rejection on the grounds that it resembled the German helmet too closely. Such was also the case of the T53-2, which if it had been adopted would have obsoleted the U.S. helmet inventory, or of the decision to develop one size to fit the large man to reduce the inventory. The establishment of a central program manager, with control over all the supporting laboratories, should definitely facilitate the decision-making process, and the program manager can take the necessary steps to acquire the data necessary to systematic decision making.

One conflict which is not so simply listed in tabular form is very important. That is the requirement that the helmet be compatible with all the wearer's clothing and equipment. Ear protection may lead to difficulty in using communications equipment and back of the neck protection may lead to weapon-firing problems in the prone position. Resolution of the conflicts will not be easy since they are so closely inter-related; therefore, the requirements to be satisfied should be weighed, and of particular importance should be the assignment of weights to those factors that have significant importance in influencing soldier acceptability. In the last analysis, the U.S. soldier will not wear the best helmet in the world if he does not want to wear it.

CONCLUSIONS

Selection of an improved armor material for the helmet still ranks as a number one problem even though there has been an aggressive and comprehensive pursuit of new materials and combinations of materials for protective helmets. Even with all the research, testing and evaluation of armor materials that has been accomplished, an acceptable substitute for the Hadfield steel used in the M1 helmet has not been developed. There are, however, candidate materials under current consideration which may be applicable. The technology of evaluating ballistic protection has greatly expanded, and while an acceptable substitute for the current standard M1 helmet has not been developed, techniques for more realistic evaluation have been developed, particularly since World War II and most recently with the acceptance of a standardized casualty-reduction analysis reporting procedure. This procedure should facilitate the development of an improved helmet.

There are two basic types of suspension systems that have been utilized by the U.S. for protective helmets. These are the multiple pad (variant of German), and the multiple webbing (Riddell type). When a single-size helmet is employed, the benefits of the Riddell-type suspension are negated. The result is a variation in offset and increased instability. If the single-size helmet is to be continued, it would appear that a modification of the multiple-padding type would be preferable.

Multiple-size helmets are required if maximum fit, comfort, stability and offset are to be achieved by the suspension system. The present retention system appears inadequate in the areas of comfort and stability of the helmet on the head.

While many different designs and shapes of helmets have been proposed with a wide variety of ballistic materials, there is still the problem of acoustics in helmets. The increasing noise on the battlefield makes the problem more severe, and research must be accomplished to evaluate the vulnerability of the ear, e.g., advantages and disadvantages of protected, partially protected or unprotected hearing vs. the requirement to hear in tactical situations. The research should include attention in design and materials to minimize amplification and reverberation.

A reassessment of eye-protection devices for incorporation in future helmet designs should be made with the casualty-reduction analysis.

Multiple sizes for infantry helmets are required because of the problem of fit with variance in head size and shape. Anthropometrical surveys to provide current sizing data to designers should be continued.

The acquisition of wound-ballistic data has been greatly expanded over the period covered by this history. The use of a systems approach has greatly extended the application of these data in armor design, development and evaluation. The utilization of wound-ballistics data, vulnerability data, etc., in mathematical models has led to the development of casualty-reduction analysis techniques, which have greatly enhanced the developers' ability to determine design parameters and effect meaningful trade-offs in evaluations.

The funding for the helmet-development programs covered by this historical documentation appeared to be adequate and the projected funds for the proposed work plan in the Five-Year Personnel Armor Systems Technical Plan appear to be adequate.

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A modified perimeter devised for measuring restrictions in the size and shape of the available visual field due to wearing army headgear is described. The device is similar to the conventional perimeter, but it is much larger and allows automatic readout and direct control of the visual target by both subject and experimenter. Construction and operating details are furnished.

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84. Dyer, E. G. Individual combat clothing and equipment: Status report 1 June-30 November 1970. Marine Corps Development & Education Command, Quantico, Va., November 1970.

This report covers the period 1 June-30 November 1970 and presents the current status of items of individual combat clothing and equipment considered to offer potential improvement over existing Marine Corps items.

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The purpose of this program is to design, develop, construct, test and deliver engineering design models of night vision goggles (NVG). The goggles are required to meet the detailed requirements set out in the purchase description. Emphasis is to be placed on performance. Reliability, durability, minimum weight and size, maintenance, and compatibility with gas mask and other head or helmet mounted equipment. A total of 18 goggles are to be delivered over a period of 20 months. This report describes the work performed during the first three months of the program. During this period the main effort has been expended in objective lens design, the preliminary design of the monocular, and problems, involved in tube integration. A Human Factors study, was instituted with primary emphasis on the design of a mask for mounting the goggle to the wearer's head. Designs for special purpose test fixtures have been started and some parts procured. The design and fabrication of anticondensation discs is also proceeding. An appendix to the report contains a detailed technical description for the NVG prepared in purchase description form. The appendix also contains descriptions of the test equipment and test procedures (U).

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Monitoring of development progress on combat clothing and equipment comprised the major effort. Specific items discussed, to include the status thereof, are as follows: (1) armored vehicle crewman's uniform; (2) woodsman's Pal 681 survival axe; (3) joint operational requirement for body armor; (4) lightweight intrenching tool; (5) LINCLOE lightweight nylon helmet; (6) overhead cover for foxholes; (7) nomex material in the utility uniform; and (8) high fragment protection body armor.

90. Fassler, G. D. Individual combat clothing and equipment: Status report 1 January - 30 June 1969. Marine Corps Development & Education Command, Quantico, Va., July 1969.

Monitoring of developmental progress on combat clothing and equipment comprised the major effort during the reporting period. Specific items discussed are as follows: Armored vehicle crewman's summer uniform: Machete: Lightweight (JOR) body armor: Lightweight intrenching tool: Lightweight (LINCLOE) helmet: Overhead cover for foxholes: High fragment protection body armor: Winter uniform for armored vehicle crewmen: Camouflaged jungle hat: Temperate zone combat uniform: Flame resistant utility uniform: Zipper lacing for DMS tropical combat boot: Bivouac shoe: Combat life jacket flotation cell.

91. Fassler, G. D. Individual combat clothing and equipment: Status report 1 July - 31 December 1969. Marine Corps Development & Education Command, Quantico, Va., January 1970.

The report presents the current status of items of individual combat clothing and equipment considered to offer potential improvement over existing Marine Corps items. Monitoring developmental progress on the items of interest constituted the major effort during the reporting period. Specific items covered in this report are: Machetes, lightweight (JOR) body armor, rainsuits, wading coverall, small arms/fragment body armor, lightweight helmet, LINCLOE load carrying equipment, life preserver, overhead cover for foxholes, armored vehicle, crewmen uniform, temperate zone combat uniform, zipper lacings for combat boot, bivouac shoe.

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The study provides life cycle cost data on these US Army infantry-type helmets: (1) titanium type I: (2) titanium type III; (3) LINCLOE nylon; and (4) Hayes-Stewart. These data include research and development production, and operating costs. A 95 percent learning (experience) curve gradient is appropriate for helmet production.

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97. General Textile Mills, Inc. Development of tropical helmet. Contract Nr W44-109-qm-1295.

98. General Tire & Rubber Company. Liner (nylon) helmet, soldiers' steel, T57-4: Final report. Contract Nr DA-19-129-qm-1219, Wabash, Ind.

99. General Tire & Rubber Company. Alternate armor materials for helmet liners: Progress report No. 1 November/January 57. Contract Nr DA-19-129-qm-768, Wabash, Ind.

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103. George, T. W., & Furgeson, W. NRL Report October 1950 (U). P. 26. Naval Research Laboratory, Washington, D. C. (Confidential report)

104. George, T. W., Furgeson, W., & Bernstein, H. NRL Report December 1950 (U). Pp. 44-46. Naval Research Laboratory, Washington, D. C. (Confidential report)

105. George, T. W., Furgeson, W., & Ewing, H. NRL Report January 1951 (U). Naval Research Laboratory, Washington, D. C. (Confidential report)

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107. Gilson, R. A., & Quaid, T. B. An integrated circuit helmet radio receiver. Published in IEEE International Convention Record PT6 P106-17, Army Electronics Command, Ft. Monmouth, N. J., 1967.

The design and development of an integrated circuit FM receiver is described, with emphasis on the unique aspects of integrated circuit design. Seven silicon monolithic linear integrated circuits of five different types are used in the VHF receiver, and each of these is described individually. Also discussed is the degree of realization of the overall design goals, namely optimum performance, low cost, low power frain, and high reliability.

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110. Gransucci, J. S., & Kasson, H. D. Operational test and evaluation of AN/PRC-87 pararescue radio. MAC-OT/E-6-1-68, Military Airlift Command, Scott Air Force Base, Ill., April 1971.

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117. Handford, S. W., & Lewis, F. J. Protective and armored garments with related pertinent mechanisms of wounding: The physiologic and pathologic effects of implanted body armor materials. Vol. III, Naval Medical Field Research Laboratory, Camp Lejeune, N. C., July 1951.

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120. Hardigg, W. B., & Eddy, G. G. Test of steel helmets, helmets submitted by the McCord Radiator and Mfg Co. APG-OP-4889-7, Aberdeen Proving Ground, Md., January 1941.

121. Hardigg, W. B. Test of steel helmets: Report No. 1, June 6, 1941. Ordnance Program Nr 4889, Report Numbers 6, 7, 8, 9 and 10. Aberdeen Proving Ground, Md.

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Casualty reports from southeast Asia indicate a need for a small fragment protective eye shield which will not interfere with the normal duties of the user. Commercially available eye goggles which are in accordance with Federal Specification FSN 4240-052-3776 were evaluated and found to provide inadequate ballistic protection. A polycarbonate eye shield which can be easily attached to the M-1 steel helmet was designed and found acceptable in evaluation reports from Vietnam. Ballistic data on the shield and construction details are given in this report.

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127. Holding, D. H., & Dennis, J. Hearing in the combat cap. Report Nr CEPRE 37, Clothing & Stores Experimental Establishment, Great Britain, June 1954.

128. Hurlich, A., & Sullivan, J. F. Metallurgical and ballistic comparison of German, Japanese and American (M1) helmets. WAL 710/776, Watertown Arsenal, Mass., 21 September 1945.

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Experimental ballistic data acquired from the Biophysics Laboratory, Edgewood Arsenal, has been generalized in order to predict the residual velocity of various fragments after striking different types of protective material. The predictions are a function of the initial striking velocity of the fragment and the A/M ratio of the fragment, where A represents the average cross-sectional area of the missile along its trajectory and M represents the weight of the fragment striking the protective material. Generalizations have been made from observations of the behavior of cubes with initial weights ranging from 1 to 225 gr. Data are presented for independent assessments of the 0 and 45 degree obliquity angles (U).

131. Johnson, W. P., Collins, L. I., & Taylor, T. M. Expected residual velocities of cubes perforating armor material as a function of projectile size and obliquity angle (U). Memorandum Report Nr BRL-MR-2011, Ballistic Research Laboratories, Aberdeen Proving Ground, Md., September 1969. (Confidential report)

Experimental residual velocity data, acquired from the Body Armor Branch, Edgewood Arsenal, Maryland, have been generalized for several types of armor materials. These data consisted of firings at both the 0 and 45 degree angles of obliquity with cubes ranging in weight from 1 to 225 grains. A mathematical model is presented which can be used to determine the expected residual velocity of cubes, within the range of the experimental data, that perforate specific armor materials as a function of their size and obliquity angle (U).

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The report discusses the use of both alloy and commercially pure titanium metal for fabrication of infantry helmets. The use of titanium metal allows a weight reduction without impairing the ballistic protection of the helmet.

133. Kane, R. L., & Smith, R. S. A forming technique for soldiers titanium helmets. Technical Report Nr 69-32-GP, Army Natick Laboratories, Natick, Mass., July 1968.

134. Kastenbein, E. L., Mclaren, M. G., & Matolka, R. W. Investigation of low density and reinforced ceramic structures for application in helmet and body armor (U): Final report. Contract DA 19-129-qm-1974, Project Nr 7 80 05 001, Rutgers - The State University, School of Ceramics, New Brunswick, N. J., September 1963. (Confidential report)

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136. Kauffman, J. W., & George, T. W. NRL Report August 1949 (U). Pp. 30-31. Naval Research Laboratory, Washington, D. C. (Confidential report)

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138. Keithley, S. M., & Fry, D. Product improvement test of infantry helmets, special array test: Final report 12 June-15 December 1968 (U). Report Nr APG-MT-3076, Materiel Test Directorate, Aberdeen Proving Ground, Md., March 1969. (Secret report)

139. Kleiman, F. G. A field test of cap, pile T56-3 and liner, helmet, soldiers, steel, T55-2A. FEA 56036, Quartermaster Research & Development Field Evaluation Agency, April 1957.

140. Kobrick, L., & Crist, B. Quartermaster human engineering handbook series: VII. The size and shape of the available visual field during the wearing of army headgear. Technical Report Nr EP-133, Quartermaster Research & Engineering Center, Natick, Mass., May 1960.

141. Kobrick, J. L. Quartermaster human engineering handbook series: VI. Size limits of the head and neck area of the soldier wearing QM gear. Technical Report Nr EP-107, Quartermaster Research & Engineering Center, Natick, Mass., March 1959.

142. Kokinakis, W., & Sperrazza, J. Criteria for incapacitating soldiers with fragments and flechettes (U). Report Nr BRL-1269, Ballistic Research Laboratories, Aberdeen Proving Ground, Md., January 1965. (Secret report)

143. Land Vehicle Board. Test of liner and helmet, T19E1. Project 49, Ft. Ord, Calif., 7 August 1945.

144. Landsberg, M. I., & Lewis, J. L. Final development and engineering test report of liner, helmet, soldier's, steel, T54-1 and helmet and liner, combat, T53-2. Technical Nr CP-2, Project Nr 7-80-05-001, Quartermaster Research & Development Center, Natick, Mass., November 1955. (Confidential report)

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149. Lastnick, A. Development and fabrication of polycarbonate eyeshield for USA flyer helmet. Technical Report Nr 71 3 CE, Army Natick Laboratories, Natick, Mass., June 1970.

150. LaTorre, R. R., & George, T. W. NRL Report February 1949 (U). P. 27. Naval Research Laboratory, Washington, D. C. (Confidential report)

151. LaTorre, R. R., & George, T. W. NRL Report May 1949 (U). P. 44. Naval Research Laboratory, Washington, D. C. (Confidential report)

152. Lepore, R. R. Alternate armor materials for helmet liners. Contract Nr DA 19-129-qm-768, General Tire & Rubber Company, Wabash, Ind., December 1960.

153. Lewis, F. J. Note on a method for producing experimental helmet models in plastic. Naval Medical Field Research Laboratory, Camp Lejeune, N. C., June 1950.

In the design and development of helmets for various applications, it is often necessary to fabricate several experimental models. Various changes and modifications are incorporated in each successive model, with the final model representing the optimum compromise between natural anthropometric factors and military requirements. This report describes a rapid, economical and flexible method for the production of these experimental models.

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159. Marine Corps Equipment Board. Helmets, plastic, test of. Project Nr 411, Marine Corps Equipment Board, Quantico, Va., 15 June 1945.

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161. Marine Corps Landing Force Development Center. Cold weather helmet system service test: Report of (U). Marine Corps Landing Force Development Center, Quantico, Va., June 1961. (Confidential report)

162. Marine Corps Development & Education Command. Status report of USMC Project Nr 42-68-02, individual combat clothing and equipment (as of July 1968). Marine Corps Development & Education Command, Quantico, Va., July 1968.

A requirement exists for improved items of lightweight clothing and equipment to lighten the load of the infantryman. In this respect, acceptance of reduced service life will permit the utilization of new designs and lighter weight materials which will contribute significantly to reducing the weight of clothing and individual equipment. The modifications made to the Marine Corps M-1967 Load Carrying System to permit attachment of the lightweight intrenching tool (FSN 521-878-5932) and carrier will increase the overall versatility of the M-1967 Load Carrying System. The exploratory development of a prototype lightweight helmet (GRP) by the Marine Corps will provide extensive support to the product improvement efforts addressed in the Army QMR for LINCLOE.

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164. Mascianica, F. S. Personnel armor; ballistic evaluation of aluminum alloy helmet shells and laminated nylon liners, Models EX 49-3. Report Nr WAL 710/999, Watertown Arsenal Laboratories, Watertown, Mass., February 1952.

165. Mascianica, F. S. Personnel armor, ballistic evaluation of M1 and experimental EX 51-1 helmets (U). Report Nr WAL 710/1013, Watertown Arsenal Laboratories, Watertown, Mass., 21 August 1953. (Confidential report)

166. Mascianica, F. S. Ballistic and metallurgical evaluation of Soviet infantry helmets and comparison with American helmets. Report Nr WAL 710/1015, Watertown Arsenal Laboratories, Watertown, Mass., 3 January 1954.

167. Mascianica, F. S. Ballistic evaluation of experimental nylon helmet liners, T54-1 with and without M1 steel helmet shells (U). Report Nr WAL-TR-710/1048, Watertown Arsenal Laboratories, Watertown, Mass., 11 October 1954. (Confidential report)

168. Mascianica, F. S. Ballistic and metallurgical evaluation of a Danish helmet (U). Report Nr WAL-TR-710/1050, Watertown Arsenal Laboratories, Watertown, Mass., 23 November 1954. (Confidential report)

169. Mascianica, F. S. Ballistic and metallurgical evaluation of a Canadian Army helmet (U). Report Nr WAL-710/1051, Watertown Arsenal Laboratories, Watertown, Mass., 19 September 1955. (Confidential report)

170. Mascianica, F. S. Ballistic evaluation of experimental helmet and liner, combat T53-2 (U). Report Nr WAL-TR-710-1061C, Watertown Arsenal Laboratories, Watertown, Mass., October 1955. (Confidential report)

171. Mascianica, F. S. Ballistic and metallurgical evaluation of a Swedish helmet (U). Report Nr WAL-TR-710/1063, Watertown Arsenal Laboratories, Watertown, Mass., 16 August 1956. (Confidential report)

172. Mascianica, F. S. Ballistic and metallurgical evaluation of a Norwegian helmet (U). Report Nr WAL 710/1064C, Watertown Arsenal Laboratories, Watertown, Mass., November 1956. (Confidential report)

173. Mascianica, F. S. Ballistic evaluation of an experimental Canadian helmet (U). Report Nr WAL 710/1072C, Watertown Arsenal Laboratories, Watertown, Mass., January 1957. (Confidential report)

174. Mascianica, F. S. Ballistic concepts employed in testing lightweight armor: Monograph series. Report Nr WAL-MS-12, Watertown Arsenal Laboratories, Watertown, Mass., October 1959.

The ballistic testing techniques which are described have been developed by various research establishments with a view toward improving ballistic testing techniques, especially with regard to determining ballistic limits with minimum number of rounds and developing a simple and reproducible test. Much thought has been given to developing and standardizing a ballistic test for use in rating, comparing, and testing fragment-resistant armor. The ballistic test that is currently in use by the Ordnance Corps for specification acceptance of lightweight armor materials is the one employing fragment-simulating projectiles. It is considered to be the simplest, most reproducible, and most meaningful of any test developed to date.

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A program was conducted to design and fabricate an integrated helmet for the thermalibrium ensemble, a universal protective clothing system. Using the government furnished integrated helmet as a guide, the design goals included increasing the stability of the present ballistic helmet assembly and reducing the outer shell area. The helmet designed and fabricated consists of a laminated ballistic nylon outer shell and a polycarbonate inner shell. The head is completely encapsulated by the helmet, a retractable polycarbonate face shield and an airtight neck-shroud helmet seal. The inner shell contains the head suspension, filtered air inlet connector, communications and the emergency filter.

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This report describes a versatile, compact, squad radio set that consists of two different but related components. One component is the AN/PRR-9 radio receiver that is normally attached to the helmet of its user, the other is the handcarried AN/PRT-4 radio transmitter. The set is intended to help the leader of a small unit maintain control in future warfare operations (present doctrine calls for wide dispersion of small units), outposts, observation posts, and crew-served weapons leaders can issue orders through the set without the necessity of shouting or leaving covered positions.

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Although body armor and helmets developed in WW II saved the lives of many ground troops and fliers, they were effective only in defeating shell fragments. Since then, new materials and better designs have permitted the fabrication of lighter, more comfortable armor that gives protection against caliber .30 and 7.62-MM ammunition. Modern armor is articulated so that it responds to bodily movements and does not hamper the wearer's activities. Designers of body armor have as their objective the defeat of caliber .50 bullets without an increase in the weight of the armor or a lessening of its flexibility. Noteworthy developments of recent years are armored seats for pilots and copilots for protection in the back, the sides, and the front, and from below, and small arms protective armor for aircrewmen (U).

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Development of integrated crash helmet and helmet sizing techniques.

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236. Quartermaster Board. Test of clips for linear, helmet, M1. Project Nr T-20, Department of the Army, Camp Lee, Va.

237. Quartermaster Board. Final report of test clips for liner, helmet, M1. Project Nr T-20 (supplement). Department of the Army, Ft. Lee, Va., 16 March 1943.

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240. Quartermaster Board. Report of test of neckband for liner, helmet, M1. Project Nr T-385, Report Nr T-1483, Department of the Army, Ft. Lee, Va., 29 December 1944.

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258. Robinson, R. C., Jr., & McDowell, E. C. Medical workloads from fragmentation munitions, 1969-1974, Vol. II. The Pharac(F) user manual. Report Nr RAC-R-65-VOL-2, Contract Nr DA 44-188-ARO-1, DAHC19-69-C-0017, Research Analysis Corporation, McLean, Va., July 1969.

Report RAC-R-65 describes the research undertaken in the development of a simulation, and its use in estimating medical workloads resulting from attacks with fragmentation munitions, including opfrag. The workloads are obtained in terms of the number of outpatients and the number of hospitalized patients, and the time-phasing of the need for hospitalization (until recovery or death). The number killed in action and the number of noncasualties are also determined. Estimates of initial surgical treatment requirements in hours, are provided. The model developed, named the Pharac(F) Simulation, can be run on both the IBM 7040/44 and IBM 7090/94 computer systems to provide estimates from fragmentation attacks in scenarios for which input data can be adequately specified. Mathematically it is a four-dimensional space model that considers the interaction of individual fragments with air, vegetation, helmets, armo and body tissues. It is a stochastic simulation, and statistical analyses are automatically provided.

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A strong, linear relationship between the ballistic limit (the current inspection parameter) and thickness was found. This relationship serves as the justification for the recommended change in inspection procedure. An inspection by attributes plan is recommended for use with the thickness inspection.

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261. Scherrer, V. E., & George, T. W. NRL Report October 1948 (U). P. 25, Naval Research Laboratory, Washington, D. C. (Confidential report)

262. Schladermundt (Peter) Associates. Design, develop and produce functional production models of head-wound protector mask. New York, N. Y.

263. Skvaril, W. J. ERDL patterned camouflaged lightweight utilities and ERDL patterned camouflaged helmet covers: Final report. Marine Corps Landing Force Development Center, Quantico, Va., February 1967.

An immediate requirement exists for a camouflaged utility uniform with matching helmet cover for marines in RVN. The ERDL patterned camouflaged tropical utilities and helmet cover in the configuration of the latest test items are suitable for Marine Corps use in RVN with certain minor modifications. A requirement exists for a distinctive field utility uniform. To include a matching helmet cover for Marine Corps use world-wide, the ERDL pattern is the best and most suitable camouflage presently available. Further field testing of the ERDL patterned tropical utility uniform and helmet cover is not considered to be warranted or necessary in view of the minor modifications recommended for incorporation in the latest test item. Camouflaged patterned field uniforms offer an added degree of concealment over the solid state OG-107, making enemy target acquisition more difficult. The camouflaged uniform is a troop prestige item and would do much to enhance esprit-de-corps.

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266. Sperrazza, J. Probabilities of incapacitation of helmeted troops by a heavy steel fragment (U). Technical Note, Report Nr BRL-TN-1235, Project Nr DA 5803-04-010, Ballistic Research Laboratories, Aberdeen Proving Ground, Md., December 1958. (Confidential report)

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268. Steele, W. M. Helmet, T21E1: Test report. Project Nr 503, Marine Corps Equipment Board, Quantico, Va., 31 May 1946.

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272. Stone, J. T. O&TE of dual visor assembly TAC-TR-70A-123F, July 1971: Final report. Tactical Fighter Weapons Center (TAC), Nellis AFB, Nev.

273. Stuart, W. A. US Army protective headgear analysis of design. Contract Nr DA 44-109-qm-1821, Arens (EGMONT) Industrial Design, N. Y., March 1956.

274. Studler, R. R. The new combat helmet. Development of a superior head armor for the US soldier. Army Ordnance, 1942, Vol. 22.

275. Sturdivan, L. M., Bruchey, W., Jr., & Whitmire, R. A preliminary frequency analysis of WDMET Data-I (U). Memorandum Report Nr BRL-MR-1992, Project Nr RDT/E-1-T-062110-A-027, Ballistic Research Laboratories, Aberdeen Proving Ground, Md., July 1969. (Confidential report)

A method is presented for handling data from the Wound Data and Munitions Effectiveness Team (Vietnam). The method, which is applied to the first 930 cases covered by WDMET, consists of compiling by high-speed digital computer, the rate of occurrence of the factors contained in the data collection format as well as two- and three-way correlates of these factors (U).

276. Sullivan, J. F. Comparative resistance of various components of experimental helmet T21E1. Report Nr WAL 710/788, Watertown Arsenal Laboratory, Watertown, Mass., 29 November 1945.

277. Sunshine I., Campana, H. A., & Smith, H. T., Jr. Head trauma: Analysis of 120 casualties in Vietnam from July 1967 to January 1968. Technical Report Nr EA-TR-4359, Edgewood Arsenal, Md., March 1970.

To assist in the development of models for the study of head injury, 120 consecutive case histories of men who sustained head wounds were selected for analysis from the files of the Wound Data and Munitions Effectiveness Team (WDMET) at Edgewood Arsenal. The sample consists of 60 men who died and 60 who survived. These casualties were incurred by combat units of the US Army in Vietnam during the period of July 1967 to January 1968. It was concluded that when the brain is penetrated by a missile in combat, the prognosis is poor. Only 31% of our sample with penetrating injuries (32 cases) survived this type of injury. The prognosis of multiple lobe injuries is very poor. In our sample of fatalities, 21 of 60 men (35%) sustained this type of injury. This was the largest category of injuries to the central nervous system in the fatalities. Frontal lobe damage was observed in 50% of the survivors with open head wounds. This corresponds with reports in the literature regarding the relatively less severe prognosis of frontal lobe injury. Conversely, injuries of the parietal area accounted for the largest number of deaths in single lobe injuries. The data suggest that the helmet offers more protection against fragments than against bullets and may retard a bullet sufficiently to convert a potentially perforating wound into a penetrating one.

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281. Sunshine, I. Injuries of extremities in 369 US Army and Marine Corps casualties in Vietnam. Edgewood Arsenal Technical Report Nr 4402, WDMET, Edgewood Arsenal, Md., April 1970.

282. Sunshine, I. Craniocerebral trauma in Vietnam. Edgewood Arsenal Technical Report Nr 4412, WDMET, Edgewwod Arsenal, Md., July 1970.

283. Sunshine, I. Intrathoracic combat wounds. Edgewood Arsenal Technical Report Nr 4422, EDMET, Edgewood Arsenal, Md., August 1970.

284. Sunshine, I. Analysis of 500 US Army combat fatalities in Vietnam, July 1967 - November 1963. Edgewood Arsenal Technical Report Nr 4432, WDMET, Edgewood Arsenal, Md., September 1970.

285. Sunshine, I. Combat wounds of abdominal organs. Edgewood Arsenal Technical Report Nr 4447, WDMET, Edgewood Arsenal, Md., September 1970.

286. Sydenham, H. G. Steel helmets. Report Nr 1186. Infantry Board, Ft. Benning, Ga., January 29, 1941.

287. Sydenham, H. G. TS-3 helmet: Report of tests. Report Nr 1211, Infantry Board, Ft. Benning, Ga., April 29, 1941.

288. Sydenham, H. G. Improved steel helmet TS-3 and liners. Report Nr 1221, Infantry Board, Ft. Benning, Ga., June 3, 1941.

289. Tactical Fighter Weapons Center. OT/E of custom-fit liners and modified HGU-17/P liners. Nellis AFB, Nev., April 1968.

290. Tactical Air Warfare Center. Exploratory test, polycarbonate visor. TAWC-Test-69-2B, Elgin AFB, Fla., December 1969.

291. Tannenholtz, S. D. Research on acoustical problems of the military: A review and future aspect. Technical Report, Army Natick Laboratories, Pioneering Research Laboratory, Natick, Mass., October 1968.

A review has been made of the literature in the area of acoustics, vibration, shock, and blast phenomena related to effects on the physiological system and attenuation effects of materials and devices. In addition, information from sources other than the literature pertinent to an evaluation of the significance of acoustic hazards in the military environment, is also presented. Damage-risk and standards criteria are presented, and further studies are suggested to advance the state-of-the-art in acoustic hazards protection as well as to exploit the potentials of acoustic phenomena for the investigation of material properties.

292. Thompson, Ramo-Woolridge, Inc. Deep drawing of titanium alloy helmet shell 6A1-4U. Contract Nr DA 19-129-qm-1430, Project Nr 7-80-05-001.

293. Thrasher, G. D., & Neely, K. K. Acoustic properties of headgear (U): VI (R). Report Nr 100 7, Defence Research Medical Laboratories, Toronto, Ontario, August 1959. (Confidential report)

294. Thrasher, G. D., & Neely, K. K. Acoustic properties of headgear: X. RCAF prototype helmet-earmuff devices (U). Report Nr TM100 11, Defence Research Medical Laboratories, Toronto, Ontario, August 1960. (Confidential report)

295. Tolson, J. A note concerning impact tests carried out on a fibre glass helmet. Report Nr TM10, Clothing and Stores Experimental Establishment, Great Britain, November 1952.

296. Tropf, W. J., Jr. An analysis of the relative economic breakeven points for infantry helmets of new design (U). Technical Report Nr TR-69-18, Army Materiel Command, Systems and Cost Analysis Division, Washington, D. C., May 1969. (Confidential report)

This report provides a breakeven analysis in terms of costs and benefits of helmets of new design. For the purposes of this analysis these helmets are of two categories. On one hand, those helmets which provide improvements to physiological factors through a decrease in weight and an improvement in configuration, and on the other, the helmets which provide increased protection. The report will address the cost and benefits of the new helmet designs, the resulting breakeven points, and the conclusions derived (U).

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13. ABSTRACT

This report documents the history of U. S. infantry helmets from 1917 to 1971. Major topics are presented in separate sections: Ballistic Protection, Materials Technology, Suspension and Retention, Acoustic Characteristics, Eye Protection and Visual Field, Anthropometrics and Mathematical Models of the Head, Wound Ballistics, and Funding. Discussion of helmet design includes one-piece versus two-piece (shell and liner), one size versus multiple sizes, pad versus multiple-web suspension, and area coverage. The current evaluation procedure, Casualty Reduction Analysis, is also discussed.

The report concludes that the helmet program contained in the USAMC Five-Year Personnel Armor System Technical Plan adequately addresses the major problem areas established by this documentation. It concludes further that the systems approach is appropriate for problems of incompatibility and for optimizing the total ballistic protection for the combat soldier.

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