AN INVESTIGATION OF THE IMPACT-ABSORBING
QUALITIES OF VARIOUS FOOTBALL HELMETS

by

WAYNE FLOYD CASE

AN ABSTRACT

Submitted to the College of Education of Michigan
State University of Agriculture and Applied
Science in partial fulfillment of the
requirements for the degree of

MASTER OF ARTS

Department of Health, Physical Education, and Recreation

1957

Approved: Henry J. Montoye, Advisor

It was the purpose of this study to measure the characteristics of football helmets as regards the decelerations of a moving object on impact. This was done by inflicting blows of varying speeds to specific positions on the helmet with a pendulum type mass of .16 slug.

Nine different helmets were examined. Their code names were as follows: MH612, ME610, MH620, RK-TK5, RK-RK4, S3122, S3131, WF2010, and WF2000. They were mounted on a wooden head which was suspended from the ceiling. Each helmet was tested at the following velocities: six, nine, twelve, fifteen, eighteen, and twenty-one feet per second. Four positions, front, back, right side, and top were used. Five blows were averaged at each velocity for the individual helmets in the four respective positions.

An accelerometer measured the deceleration of the .16 slug at impact with the helmets. This was recorded by an oscilloscope which was photographed with a sixteen millimeter camera, hand cranked in order to take the pictures frame by frame.

Conclusions

1. For the helmets investigated, the plastic shell was superior to the leather shell.

2. For the best protection in terms of decelerating a moving object in the front position, helmets should have

a hard plastic shell with a canvas suspension fitting snugly to the head.

3. If at all possible, helmets should be free from rivets. If rivets are used, they must be adequately covered and have as much distance between them and the head as possible.

4. If a canvas suspension is used, it should be constructed in such a way that the suspension firmly fits the head.

5. The review of the literature indicates that concussion is most likely to concur on the flatest portion of the skull. The sides of the head, therefore, must be adequately protected. This can be accomplished by raising the outbend on the sides to allow more room for the ears and leaving more space between the suspension and the shell.

6. The top needs the most protection due to the relative greater mass of the head and body to be moved when struck in this position. This is best accomplished by a plastic shell with a strong suspension and a distance of at least one-inch between the shell and the suspension.

7. An "all-purpose" helmet needs a hard plastic shell with a strong canvas suspension in which the head is firmly fitted, not only on top but around the sides above the ears.

AN INVESTIGATION OF THE IMPACT-ABSORBING QUALITIES OF VARIOUS FOOTBALL HELMETS

by

WAYNE FLOYD CASE

A THESIS

Submitted to the College of Education of Michigan
State University of Agriculture and Applied
Science in partial fulfillment of the
requirements for the degree of

MASTER OF ARTS

Department of Health, Physical Education, and Recreation

1957

5/28/57
g 1225

ACKNOWLEDGMENT

The writer wishes to express his sincere thanks to Dr. Henry J. Montoye who assisted in the general lay out of the experiment and whose constructive criticism was of the utmost value. Acknowledgment also goes to Dr. Wayne VanHuss who assisted in performing the experiment, to Kurt E. Utley who was in charge of all the electrical work, and Everett N. Huby, the photographer, who took all the pictures.

W.F.C.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

THE PROBLEM

There are various types of football helmets in existance today. The most popular have leather shells with a canvas suspension covered by foam rubber and a thin foam rubber padding around the inside of the shell; in others the canvas suspension is not covered. Some have plastic shells with a strong canvas suspension which fits snugly on the head; in others the suspensions vary in regard to covering, e.g. foam rubber, absorblo, and many other new impactabsorbing materials. It is surprising how little actual research has been done to determine the comparative protective qualities of these many helmets being manufactured today.

Statement of the Problem

It was the purpose of this study to measure the characteristics of football helmets as regards the decelerations of a moving object on impact. This was done by inflicting blows of varying speeds to specific positions on the helmet.

Importance of the Study

There are various factors that should be considered in building a well-constructed protective football helmet.

It was but one of these factors, that of deceleration, which was investigated in this study. The importance of a low deceleration may be demonstrated with a hypothetical example. A man wearing a wool glove hits a brick wall with his hand. The possibility of him injuring his hand is much greater than it is for another man who hits the same wall with the same force wearing a heavily padded boxing glove. In this example the hand in the wool glove had a high deceleration and the hand in the boxing glove a low deceleration.

During the past twenty-three years, half of the 409 direct gridiron fatalities have resulted from head injuries. Furthermore, the Cornell tests show that the helmets of today are inadequate to withstand a concussion-causing blow.[1] Research which might in any way help to reduce the number of gridiron fatalities resulting from head injuries must be considered of great importance.

In the 24th Annual Survey of Football Fatalities (1931-1955), it was brought out that fatalities directly due to football have averaged seventeen and one-half per year.[2]

---

[1] William H. White, "Armor That Does As Much Harm As Good," Sports Illustrated, October 31, 1955, pp. 46-47.

[2] Committee on Injuries and Fatalities, American Football Coaches Association, Dr. Floyd R. Eastwood, Chairman, Twenty-Fourth Annual Survey of Football Fatalities, January, 1956, p. 2.

A further tabulation since 1947 of the specific location of fatal injuries showed that: "The head and face area accounted for 59.56 per cent of all fatalities, the spine for 20.59 per cent, and abdominal-internal for 19.85 per cent."[3]

An analysis of the data by specific location of the blow revealed that both spine and head and face injuries were procured by blows to the top of the head. Combining these two results showed that 80.15 per cent of all injuries were due to traumatic blows to the head.[4]

a. Blows to the front and side of the head incurred 23.54 per cent of all injuries.

b. Blows to the top of the head (resulting in spinal injuries) incurred 20.59 per cent of all injuries.

c. Internal injuries ranked third with 19.85 per cent of all injuries.

d. 13.95 per cent of all injuries were acquired by traumatic blows to the back of the head.

This means that the most hazardous areas of the body are ranked: (1) both sides and front of the head, (2) top of the head, (3) internal organs, and (4) back of the head.

It is obvious to see that the head area requires the best possible protection. It might also be noted that more changes have taken place in the manufacture of headgear than in any other piece of equipment. Still the percentage

---

[3]*Ibid*., p. 3.

[4]*Ibid*., p. 3.

of total fatal head and spinal injuries has risen steadily since 1931 and four per cent since 1947. [See Figure 1.] In internal-abdominal injuries, where far less attention has been given in design of protective pads for hips and back, there has been a steady decrease.[5] [See Figure 2.]

Lombard, et al, indicate in their research the need for more precise thinking, in engineering terms, of the mechanical factors involved in the field of head injury, the correlation of the mechanical factors with the biological factors and findings, and further investigation of the general subject.[6]

Limitations of the Problem

It must be realized that a low deceleration rate does not necessarily mean there will be fewer head injuries. There are many other circumstances to be considered such as duration of impact, type of impact, and position of impact. Some types of helmets may lose part of their durability with each blow or series of blows. The temperature

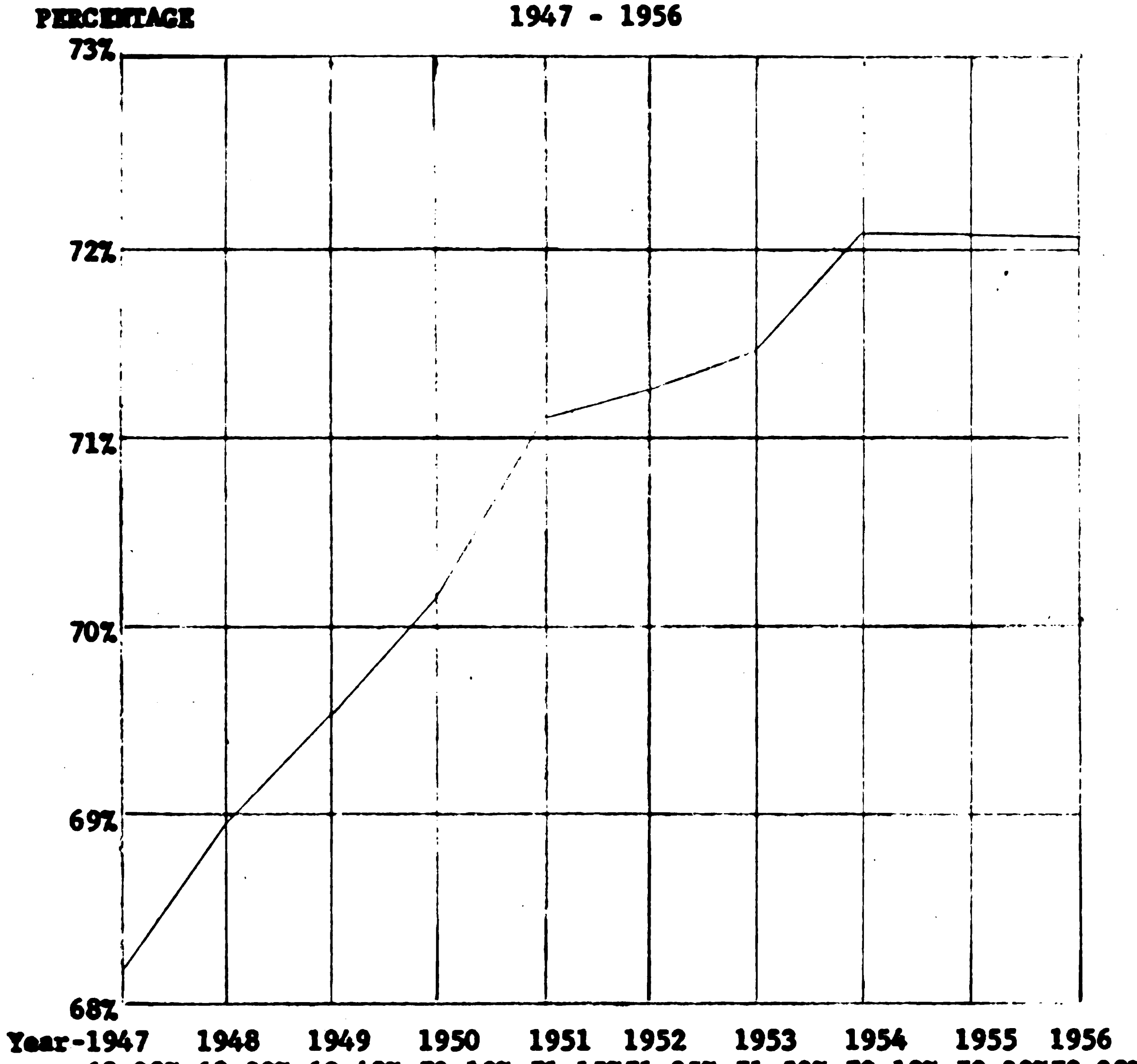
---

[5]Committee on Injuries and Fatalities, American Football Coaches Association, Dr. Floyd R. Eastwood, Chairman, Twenty-Fifth Annual Survey of Football Fatalities, January 7, 1957, pp. 21-22.

[6]Charles F. Lombard, Ames Smith, Herman P. Roth, and Sheldon Rosenfeld, "Voluntary Tolerance of the Human to Impact Accelerations of the Head," The Journal of Aviation Medicine, 22:2:109.

FIGURE 1

PERCENTAGE COMPARISONS*
Head and Spinal Injuries
Direct Fatalities

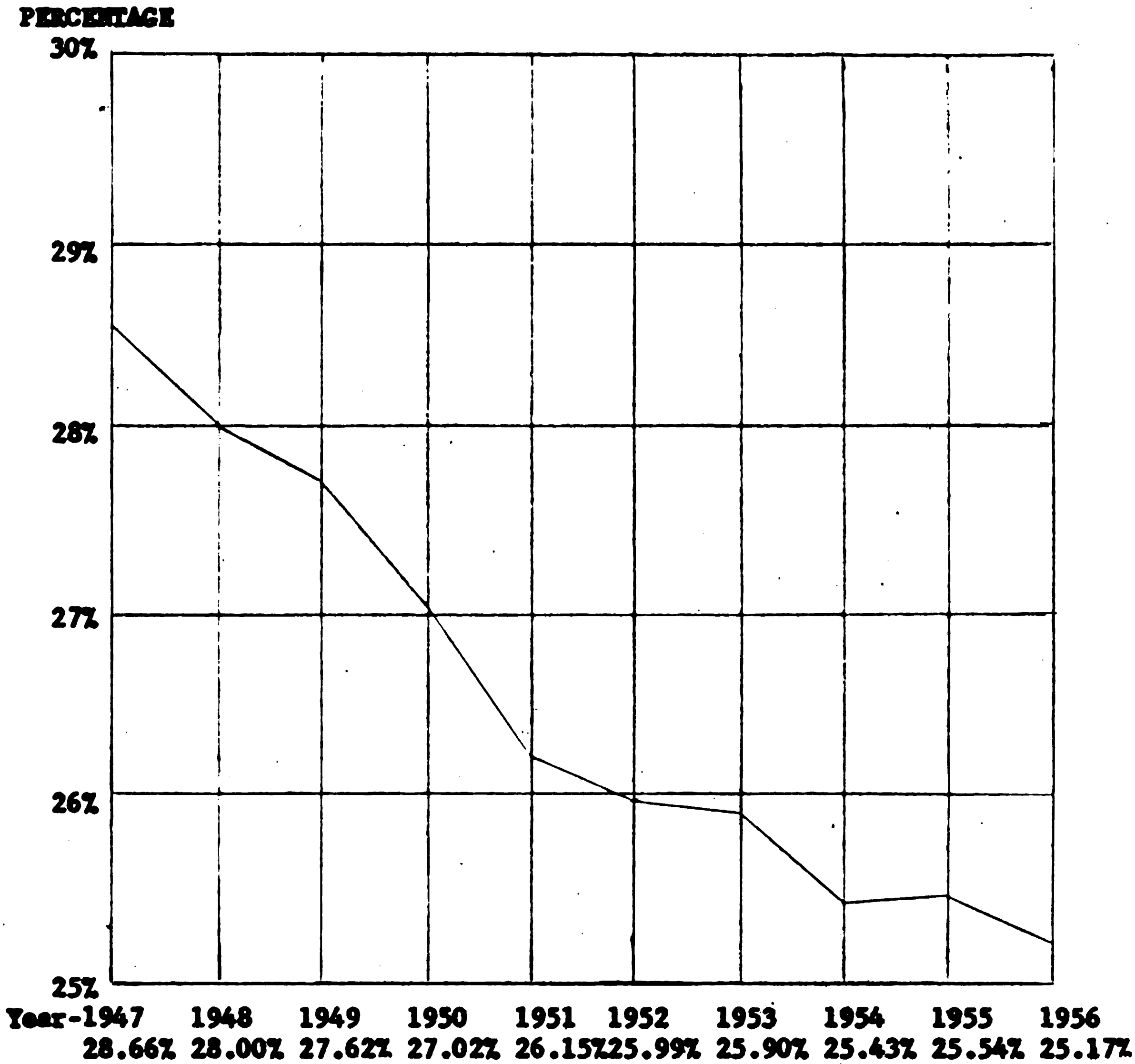


*Cumulative Averages - Based on all fatalities reported yearly since 1931.

FIGURE 2

PERCENTAGE COMPARISONS*
Abdominal and Internal Injuries
Direct Fatalities

1947 - 1956



*Cumulative Averages - Based on all fatalities reported yearly since 1931.

may be an important factor: some types of plastic may become harder in cold weather and softer in warm weather. Results based on this study were made on nine different helmets. It would have been far better to investigate more than one helmet of a given type but lack of funds prohibited this.

The impacts were limited to one location at each position. A cluster of impacts around each position would give a more valid representation of the blows received in football.

It was assumed that the most expensive helmets were of better quality. It would have strengthened the study to investigate all football helmets manufactured by various companies.

No direct conclusions as to the best type of plastic or leather shell, suspension, or foam rubber padding could be drawn until all known types are examined. This could be achieved only with financial help from some large manufacturer.

Only the right side of the helmets were tested, thus the assumption was drawn that both sides were identical. It would have improved the study to test both sides.

CHAPTER II

REVIEW OF THE LITERATURE

The soure of literature in relation to this problem was divided into three categories or fields of work. The first, in the medical field experimenting with concussive effects on the skull; the second, in the field of aviation on new type head gear; and the third, in the field of athletics and physical education.

Medical Literature

Gurdjian, et al,[1] thought it more accurate to measure the acceleration of the skull rather than the object striking the blow as in most previous studies. The accelerometer was attached to the skull on the opposite side to where the blow was struck, due to the fact that the skull deforms markedly under impact. Ball peen hammers of various weights were used on dogs of different weights. The head was free to move at impact, being supported by the left hand while the right hand was used for the hammer. An attempt was made to produce a concussive effect with the first blow, but in some cases two, three, or even more blows

[1] E. S. Gudjian, H. R. Lissner, F. R. Latimer, B. F. Haddad, J. E. Webster, "Quantitative Determination of Acceleration and Intercranial Pressure in Experimental Head Injury," Neurology, 3:6:417, June, 1953.

were required to obtain this effect. In each case minimal or moderate concussive effects were obtained with accelerations ranging from 250 to over 500 Gs.

There were disadvantages of mounting the accelerometer on the skull. The skull was sometimes subject to a slight twisting or turning at impact and the linear accelerometer was thus unable to measure the true value in Gs.

As a result of this preliminary study with twenty-four experiments, no pattern of relationship between severity of concussion and magnitude of acceleration could be determined. A study of the intracranial pressure change at the time of impact suggests that the time duration of the pressure increase is more significant than the maximum levels obtained. It was also brought out that:

> The increase in intracranial pressure at the time of the impact, in a head that is permitted to move, is produced by two separate causes: the first being due to deformation of the skull and the second being due to acceleration or the sudden setting of the head to motion.[2]

It must be remembered though that the skull on the opposite side of the blow may have a pressure which decreases to zero or below.

Gurdjian and Webster[3] bring out the fact that in a direct blow, the head alone is most subject to injury but

---

[2]E. S. Gurdjian and J. E. Webster, "Recent Advances in the Knowledge of the Mechanism, Diagnosis, and Treatment of Head Injury," American Journal of the Medical Sciences, 226:215, August, 1953.

[3]Ibid., p. 422.

in an indirect blow, other parts of the body are also subject to injury.

DeHaven[4] suggests that the majority of severe injuries occur because the victim is thrown about following the initial impact and not just because of the initial impact. Certain measures providing a slow deceleration of the body will make it possible for the human to withstand a large number of Gs without fatality. More research directed at counteracting the effects of impact is needed to help put a stop to the many head injuries imposed by football.

Gurdjian, _et al_,[5] showed in a later study that acceleration, deceleration, and compression may cause the following physical defects on the head and its contents:

(1) Deformation of the skull, producing compression of the contents due to decrease in volume.

(2) A sudden increase in intracranial pressure at the time of impact.

(3) Mass movements of the intracranial contents.

(4) Distortion of the skull and dural septa.

(5) Shearing off of a portion of the head and contents without necessarily producing an increase in intracranial pressure at the time of impact.

---

[4] H. DeHaven, "Injuries," _War Medicine_, 2:586, Aug., 1954.

[5] E. S. Gurdjian, J. E. Webster, and H. R. Lissner, "Observations on the Mechanism of Brain Concussion, Contusion, and Laceration," _Surgery, Gynecology, and Obstetrics_, 101:682, December, 1955.

(6) Shearing and tearing with high levels of increased intracranial pressure such as occur in bullet and shell fragment wounds. Combinations of such effects may occur in certain types of injuries.

Damage to neural tissues in head injuries takes place by pushing the tissues together or compression, such as the scalp being compressed or mashed under the point of a blow; by tension or tearing apart of the tissues because of tension produced as the brain rotates with respect to the skull; and by shearing or twisting because of cavitation and pressure gradients.

Experiments on seventy-two mongrel dogs verified earlier findings that the longer the duration of the pressure exerted upon the brain, the lower the pressure required for a severe concussion. The shorter the duration, the higher is the pressure required for a severe concussion.[6] Figure 3 shows the relationship between pressure, time, and degree of cerebral concussion.[7] Line C shows the slope with most of the severe concussions above the line; line B, the slope with most of the moderate concussions above it; line A, the slope with most of the threshold concussions above.

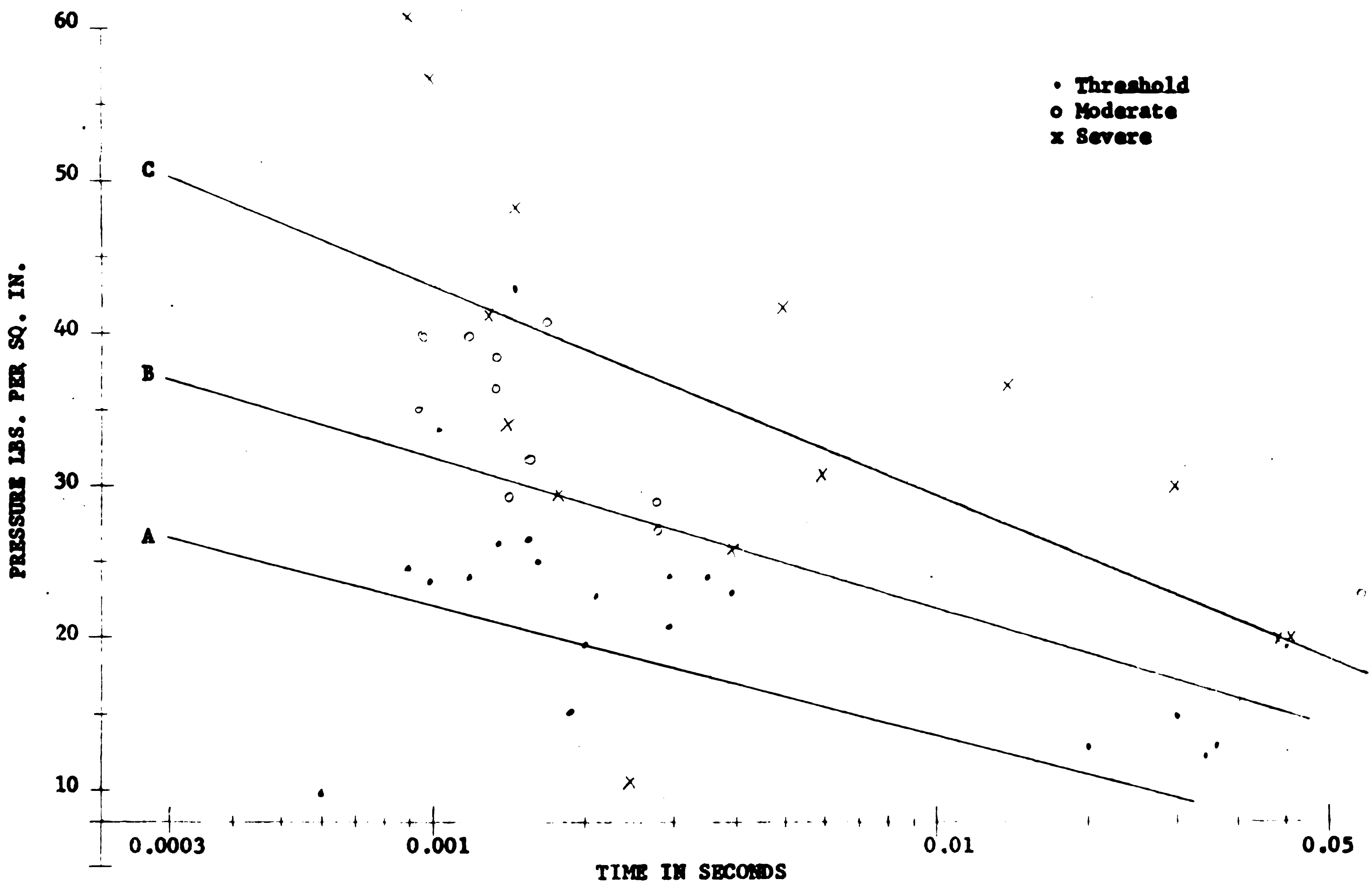
If the head is relatively fixed, a direct blow upon the head results in an increase in intracranial pressure.

---

[6] E. S. Gurdjian, H. R. Lissner, J. E. Webster, F. R. Latimer, and B. F. Haddad, Studies on Experimental Concussion, from the Wayne University Neurosurgical Service, March, 1954, p. 678.

[7] Ibid., p. 680.

FIGURE 3
RELATIONSHIP BETWEEN PRESSURE TIME AND DEGREE OF CEREBRAL CONCUSSION



This lasts for a longer period of time than if the head were free to move at impact with a similar blow. Under the later circumstances higher velocities with effective masses are needed in order to cause a concussion. When the head is fixed, the impact tends to act for a longer period of time upon the cranium and its contents.

In relation to football helmets, it should be mentioned that since the head is less likely to move when struck on the top position, more protection is needed in this area.

Following impact by a direct blow there is always an area of inbending immediately beneath and around the point of the blow. If the time duration is long enough or the velocity is sufficiently high, the area of inbending may fail, resulting in a depressed fracture. If the inbending at the boundary of the inbended area is not severe enough to cause a fracture, the skull rebounds. The outbending may be so severe that a linear fracture results. Thus the fracture line extends both toward the point of impact and in the opposite direction. Linear skull fractures occur at right angles to the maximum tensile stress produced by outbending of the skull at a distance from the point of impact.[8]

---

[8]E. S. Gurdjian, J. E. Webster, and H. R. Lissner, "Observations on Prediction of Fracture Site in Head Injury," Radiology, 60:2:226, February, 1953.

Generally it might be said that the greater the velocity, the more localized the deformation at the area of impact. The shape of the object must also be considered as responsible for the type of fracture obtained.

Tests were conducted on one hundred randomly selected adult skulls. Each skull was divided into twelve parts and a stresscoat applied. The skulls were given a deceleration blow in each area with special care that each area was struck many times. It was shown that if the area of impact is known, a fairly accurate prediction of the location of a linear fracture may be made. By the same way, if the position of the linear fracture is known, the point of impact may be determined.[9]

Lissner, et al,[10] substantiated and added to their earlier work by experiments showing that imbending was always indicated directly under the point of impact. In severe blows, cracks radiated out from the point of impact. The cracks were always greatest along the flatest portions of the skull. The sides of the skull are relatively flat.

Relating this to football helmets, the supposition could be made that the higher the outbend of the helmet

---

[9]Gurdjian, Webster, and Lissner, "Observations on the Mechanism of Brain Concussion, Contusion, and Laceration," op. cit.

[10]H. R. Lissner, E. S. Gurdjian, J. E. Webster, "Mechanics of Skull Fracture," Experimental Stress Analysis (Report from Wayne University and Grace Hospital), May, 1950, p. 62.

for ear placement, the better the design in relation to skull fractures along the sides of the head.

Tests were made on fifty-five completely intact human cadaver heads to find out what effects if any, hair, scalp, and skull contents had on fractures.

It was rather surprising to note that after enough energy had been absorbed to produce a single line fracture, very little more was required for multiple fractures or even complete destruction of the skull. The least energy required for fracture was in the neighborhood of four hundred inch pounds. Above that there were differences due to thickness of scalp, thickness of skull, shape of skull, and a slight change in the position of the blow. In some cases a fracture was not produced even after a force of one thousand inch pounds was administered.

Gurdjian, et al,[11] divided fractures of the skull into three categories where they might occur. The area of primary stress level is the weakest region in the skull and it is here a fracture may start. The area of secondary stress level is the region where a second fracture line may be initiated with additional energy. The area of tertiary stress level is the region where further fracture lines will be caused by more energy, usually resulting in a stellate

---

[11] E. S. Gurdjian, J. E. Webster, and H. R. Lissner, "The Mechanism of Skull Fracture," Radiology, 54:3:338, March, 1950.

pattern. It should be remembered that the area of primary stress level varies in different skulls.

Aviation Literature

Lombard, et al,[12] conducted a study on the voluntary tolerance of the human to impact accelerations of the head. Two different weight pendulums were used, one of thirteen pounds and the other 9.44 pounds. Each was used on seven different football helmets. A strain gauge type accelerometer capable of measuring in excess of five hundred Gs was mounted in the steel head of the pendulum. A thirty-five millometer camera with a film speed of approximately sixteen inches per second was used for recording the characteristics of the pattern. The results of this study showed that the upper limit of linear accelerations which a human can voluntarily tolerate due to impact blows to the head had not been reached. It was shown that:

> Always the effect of the locally applied force causing brusing, tension loads on the ligaments or ligamental attachments of the neck muscles, or sharp burning pains in the joints of the cervical vertebre caused the subjects to voluntarily and/or subjectively limit exposure to no higher energy impacts.[13]

The primary reason for limiting the blows to the top of the head was a generally uncomfortable jolt and local

---

[12]Lombard, Ames, Roth, and Rosenfeld, loc. cit.

[13]Ibid., pp. 111-112.

bruising. For the front blow, it was local bruising, neck pains in either vertebrae or ligaments, and sometimes a generally uncomfortable jolt. For the side blows, it was mostly local bruising and an uncomfortable jolt with slight pain in the ligaments. Back blows were limited to local bruising.

The Gs tolerated were, for the respective sites: top blows, thirty-four maximum, average twenty-three; front blows, thirty-eight maximum, average twenty-two; side blows, twenty-five maximum, average twenty; back blows, thirty-five maximum, average eighteen.[14]

Motion pictures showed a considerable movement for all sling suspension helmets before the head started to move. A considerable distortion of the face was observed with the bony structure of the head being accelerated away from the softer portions, e.g., the cheeks, nose, eyes. The helmet shells having the most resistance to compression and having a sling suspension were the ones which vibrated upon impact.

It is believed from the experience of the authors that psychological factors played the most important part in the limitation of the upper limit of only thirty-eight Gs. Most of the subjects probably have experienced harder blows to their heads in sports and accidents during their youth. This was brought out by Hugh DeHaven who calculated survival

---

[14] Ibid., pp. 111-112.

from falls in the order of two hundred Gs. Of course, the body landed in a supine position giving the head an equal deceleration.[15]

The Air Force upon investigation found it important not only to provide maximum energy absorption but also to limit the acceleration of the head to further help reduce brain injury. It was also found that the greatest disadvantage of using a resilient material between the shell and the head for energy absorption was that during deflection it stored rather than dissipated energy. As it deflected, an increasing restoring force was created which reached a maximum at the point of maximum deflection and the energy was returned in the form of a rebound of the helmet from the object.[16] It was suggested that the space between the helmet and the head be filled by a non-resilient, energy-absorbing material.

The apparatus shown in Figure 4 was developed to provide a dynamic load test. The most successful material tested was cellular cellulose acetate with criss-cross saw cuts into which the foam rubber was molded. The foam rubber was also molded over the surface of the material. It was shown that:

> By selection of the proper spacing and shape of the cuts, characteristics of the foam rubber used and

---

[15] Ibid., pp. 115-116.

[16] "New Helmet Protection Theory Advanced," Aviation Week, 50:4:18, January 24, 1949.

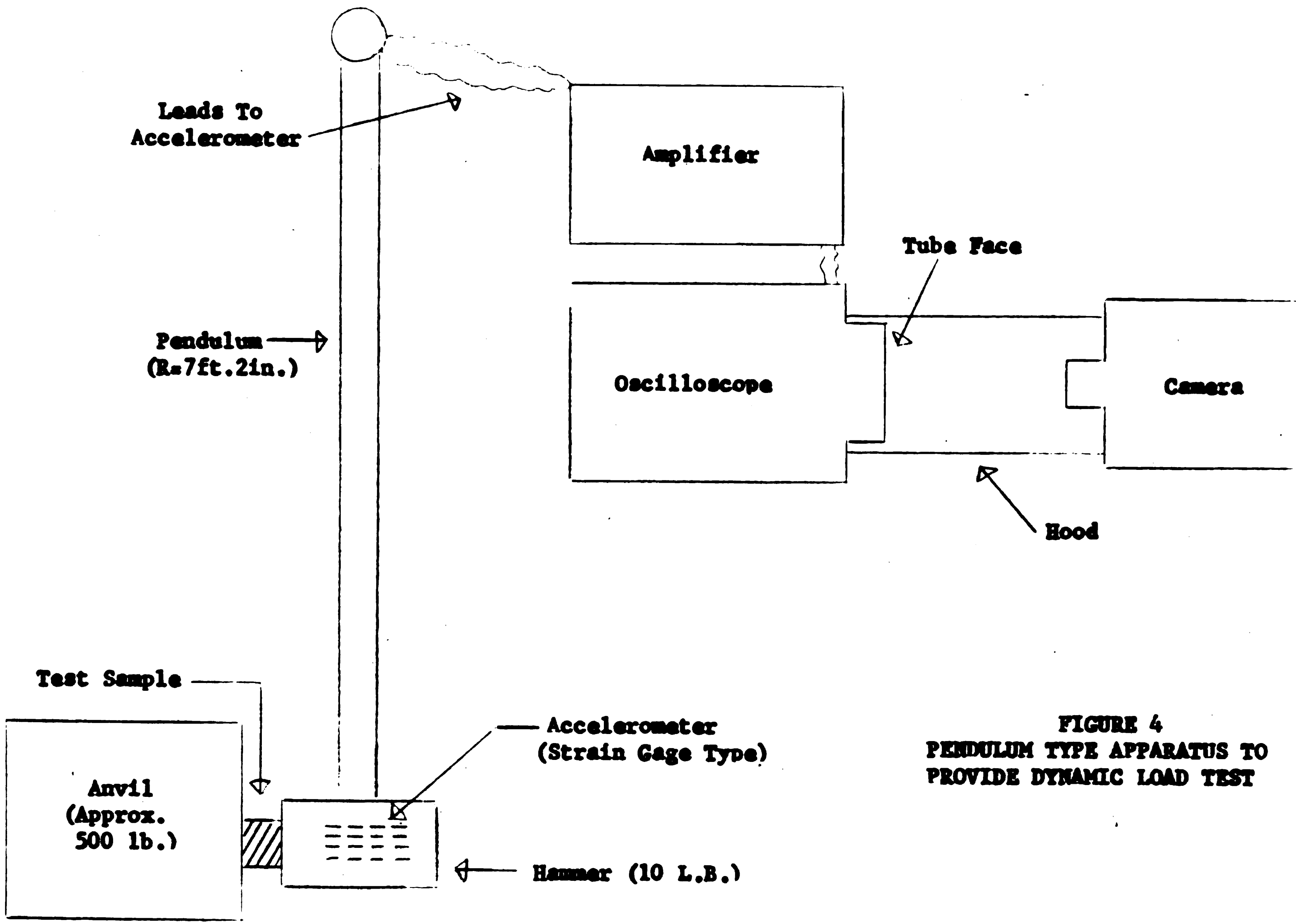


FIGURE 4
PENDULUM TYPE APPARATUS TO PROVIDE DYNAMIC LOAD TEST

> thickness of the rubber in relation to that of the cellular material, a resulting product can be formulated having energy-absorbing characteristics which are controllable throughout a fairly wide range.[17]

Lombard showed that if one considers the effects of a very brief application of a large force to the head, two experimental observations are confronted:

(a) Accelerations of 100 to 200 Gs cause concussion.
(b) The absorption of 200 in-lbs. of energy in a short period of time may cause fatal damage to the brain.[18]

In these observations, however, one only approximates since, (a) the force acted for approximately 0.25 inch, yet may have caused the acceleration of 0.01 inch while, (b) the absorption of two hundred inch pounds of energy may have occurred in either a fraction or a multiple of a millisecond.

In experiments by the Air Force using an aluminum head, the center of gravity was near that of the human head. The accelerometer was mounted near the center of gravity of the brain. It was also shown that since the blow was not delivered on a line with the center of gravity, a certain amount of angular acceleration exists and the accelerometer will only measure the linear acceleration present. The pendulum mass was of the same order of magnitude as that

---

[17] Ibid., p. 20.

[18] Charles F. Lombard, "How Much Force Can Body Withstand," Aviation Week, 50:3:24, January 17, 1949.

of the head, weighing about twelve pounds and moving on an eight foot radius. This allowed practical energy range up to sixty foot-pounds. An accelerometer was also placed in the center of the pendulum. The pendulum was designed to allow various impact-shapes to be used varying from a flat plate to a one-half diameter hemisphere.[19]

The two helmets tested were the U.S.A.F. P-1 and the Protection Incorporation Toptex. Three impact-shapes were used at two impact velocities. Four different positions on each helmet were tested. The acceleration of the head and the deceleration of the impact producing pendulum were measured and recorded.[20] In summarizing it was stated:

> In evaluating this test certain assumptions must be made as to which characteristics are desirable because no explicit criteria for head protection exist. Non-penetration of helmet, minimum movement of head, minimum peak acceleration, maximum energy absorption, minimum tendency to "bottom-out" against heat, uniform protection over entire head and minimum tendency for peak acceleration to become larger with increasing area of contact on helmet, are considered to be desirable. The relative importance of these characteristics is not shown.
>
> The Protection, Inc. helmet is better with respect to motion of the head during the blow. The average peak accelerations were lower for the P-1 helmet. The energy absorbing qualities were found to be the same. The design characteristic of the Protection, Inc. helmet which minimized the tendency to "bottom-out" particularly with small impact-shapes which would penetrate both helmets, is a deciding advantage.

---

[19] O. T. Strand, "Protective Helmet Impact Testing Equipment," Air Force Technical Report No. 5820, May, 1949 p. 1.

[20] Oliver T. Strand, "Impact Effect on Two Types of Protective Helmets," Air Force Technical Report No. 6020, May, 1950, Index iii.

On the point of uniform protection over the entire head, the Protection, Inc. helmet was considered better. The tendency for the peak acceleration to become larger with increasing contact area of the impact-shape is a distinct disadvantage of the Protection, Inc. helmet. If contact is made over a large enough area, damaging deceleration to the head might occur without crushing any of the cellular cellulose acetate absorbing material. Poor distribution of the blow caused by lack of stiffness in the shell is implied by these data. The distribution obtained by the P-1 helmet is, of course, constant and determined by the suspension pattern.[21]

Hendler and Wurzel[22] stated that evaluation methods developed in the various laboratories have often been ingenious, but can be improved in two respects. First, the velocity change used in applying blows to the tested helmets should be increased, and second, pressure distributions over the head surface during a blow should be measured.

To judge if a helmet is adequate one must have knowledge of: (1) the magnitude of the maximum acceleration that the cushioning permits the head to reach; (2) the form of the acceleration-time relation; and (3) the strength, natural frequencies of vibration, and damping of the structural elements of the head.[23]

---

[21]*Ibid*., p. 17.

[22]Edwin Hendler and Commander Edward Wurzel, "The Design and Evaluation of Aviation Protective Helmets," *The Journal of Aviation Medicine*, 27:1:64-65, February, 1956.

[23]*Ibid*.

It must be remembered that this third factor is undetermined so that any analysis regarding the effects of applied dynamic loads to the head wearing a helmet must necessarily be limited.

Literature in the Field of Athletics and Physical Education

Hawk,[24] commenting on "Brain and Skull Injuries," stated that the one hundred seventy-nine injuries for 3,480 athletes is not as serious as it appears. The Athletic Trainer classifies any dizziness, partial vision, or headache as a "Brain Concussion." Many of these symptoms turn out to be disorders other than brain concussions, as is shown by the fact that the average disability for each individual was only four and three-tenths days. A better helmet, however, will eliminate many of these disorders classified as "other than concussions."

It was shown that 16.7 per cent of all football injuries occurred to the head and neck. This ranks second with the sections of anatomy injured, but is one-tenth of one per cent from being last as for the rate of "days disabled."

This year's survey [Table I] classifies direct fatalities as to the specific location of injuries. It is shown

---

[24]G. Kenneth Hawk, Football Injuries Survey for 1952 Season (Houghton, Michigan: Michigan College of Mining and Technology, 1953), p. 3.

TABLE I

DIRECT FATALITIES: SPECIFIC LOCATION OF INJURIES--1947-1956*

Part of Body	Sandlot	Pro & Semi-Pro	High School	College	Ft.Ball Off.	Total	Percentage
Head Area							
Temple	1	0	0	0	0	1	.65
Front-left	3	0	1	0	0	3	2.60
Front-right	1	0	2	0	0	3	1.95
Side-left	1	1	11	0	0	13	8.44
Side-right	2	3	8	1	0	14	9.09
Back of head	3	0	15	1	0	19	12.34
Nose & Face**	1	0	0	0	0	1	.65
Not specified	12	3	19	4	0	38	24.67
Spine							
Cervical 4th-5th 6th-7th	2	7	16	3	0	28	18.18
Not specified	0	0	1	0	0	1	.65
Internal	7	3	16	1	1	28	18.18
Not specified	0	2	2	0	0	4	2.60
TOTALS	33	19	91	10	1	154	100.00

Source: Committee on Injuries and Fatalities of the American Football Coaches Association, Twenty-Fifth Annual Survey of Football Fatalities, January, 1957.

*Tabulation started in 1947

**Traumatic flow to nose causing rupture of the blood vessels of the neck. (One case,1951) that the head area accounts for 60.39 per cent of the total direct fatalities.[25]

Impacts to the head might be divided into two categories:[26]

(a) Low energy--that type of impact for which current football helmets provide protection.

(b) High energy--that type of impact which inflicts serious injury or even death.

For helmets to accomplish the task of sufficiently reducing both types of impacts they should have (1) a resilient energy attenuating property for repeated low order energy impacts and (2) an energy absorbing property with the ability to handle high order energy impact. Helmets, therefore, should be tested for:

1. Protection against repeated low energy impacts.
2. Protection against single high energy impacts.
3. Protection against blows on the sides, back, front, and top of the head.[27]

For low energy impacts the helmets should be struck ten times in each of the different positions tested. If

---

[25]Committee on Injuries and Fatalities of the American Football Coaches Association, Twenty-Fifth Annual Survey of Football Fatalities, op. cit., p. 23.

[26]Protection, Incorporation, 6521 West Blvd., Inglewood 3, California. Personal correspondence dated June 1, 1956.

[27]Ibid.

there is appreciable increase in the maximum Gs recorded and the rate of increase of Gs occurs between the first and the tenth impact, the helmet should be tested again after twenty-four hours. It is important that the energy attenuating property remains approximately constant. If it does not, then last year's helmet should not be used.

Football helmet design should provide for:

1. Deflection of blows.
2. Resilient attenuation of discomfortable blows.
3. Energy absorption of impact blows which could cause serious, if not fatal injuries.

Specifically, the helmet should consist of:

1. A hard external shell capable of deflecting blows because of its smooth surface and capable of distributing the blow because of its resistance to distortion.
2. An energy absorption layer of not less than one-half inch thickness next to the helmet shell and on the inside.
3. A resilient sizing layer or a sling hatband suspension to attenuate the uncomfortable impacts.[28]

---

[28] *Ibid.*, pp. 6-7.

CHAPTER III

METHODS OF PROCEDURE

In this chapter the methods of procedure are divided into two parts: (1) an explanation of the equipment, and (2) the experimental design.

The Equipment

A strong wooden head was built to fit a football helmet of size seven and one-fourth. The bottom, where the neck and shoulders normally would be, was made to form a solid base to enable the head to withstand a strong force. It was fastened by two steel cables with a sling arrangement attached at the ceiling and, of course, was free to move at impact. Four turnbuckles were used, one at each corner, to raise or lower the head to assure the pendulum of striking in the same spot on each helmet. Figure 5 shows a close up of a helmet on the wooden head.

Nine of the most popular, nationally known football helmets were tested. They were generally considered to be the best in existence today and are used by the majority of college football teams. They were as follows:

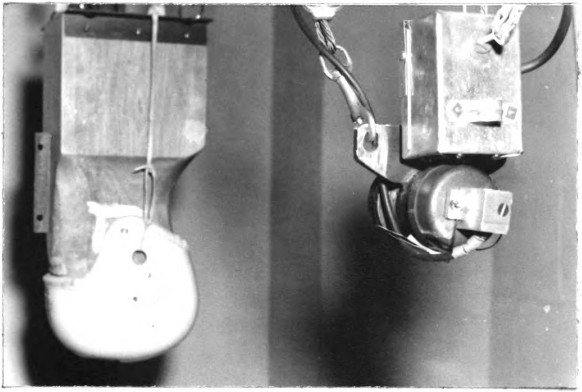


FIGURE 5 Helmet on Wooden Head with Pendulum in Position

FIGURE 6 Close Up of Oscilloscope

	Name	Style	Code Number
1.	MacGregor	H612	MH612
2.	MacGregor	E610	ME610
3.	MacGregor	H620	MH620
4.	Riddell Kra-Lite	TK5	RK-TK5
5.	Riddell Ten-Nite	RK4	RK-TK4
6.	Spalding	3122	S3122
7.	Spalding	3131	S3131
8.	Wilson	F2010	WF2010
9.	Wilson	F2000	WF2000

These helmets had either leather or plastic shells, and the inside was made of heavy canvas suspension, foam rubber padding, a new type of absorblo, or various other combinations. Hereafter the helmets will be referred to by their code names. They were all size seven and one-fourth. To make sure the helmets would not fall off when struck, a shoe lace was loosely tied to connect the chin strap to the other side of the helmet.

A five and thirteen-hundredths pound pendulum type weight which is referred to in the diagrams as a .16 slug was used to strike the helmets. This weight was used because it was the maximum the release could safely hold. It was attached with two steel cables to the ceiling. The striking side was slightly curved to resemble a knee. This facsimile of the knee was chosen at random. In the initial design objects similar to the elbow, knee, and top of the head were thought desirous to use on the head of the pendulum. Due to the lack of time, only the knee was used. On top of the pendulum a small rectangular solid two by three-fourths by three-fourths inches was fastened to the same small steel plate that held the cables. It was slightly movable to help keep the pendulum horizontal to the floor when held at the various heights by the release. On the back side, the accelerometer was securely fastened. The leads were wired from the accelerometer up one side of the cable, across, and down to the recorder. The pendulum is shown in motion in Figure 8 and is secured in the electrical release in Figures 5, 6, and 7.

To hold the pendulum at the various positions an electric release was built. The small rectangular solid from the pendulum was placed in the center of the release box. It was held by a magnetic coil which was turned on and off from a switch box placed beside the oscilloscope. One piece of cord from the release box was fastened to the steel bar above the pendulum, making both the pendulum and release box the same distance from the ceiling at various positions. A small chain ran from the release box up through two pulleys and was hooked with rings at varying distances to a fixed point on the wall. Thus by attaching the various rings to the fixed point the velocity changed. The release box is shown in Figures 5, 7, and 8.

The accelerometer used was a Schaevitz linear variable differential transformer (L.V.D.T.). It measures the force of deceleration accurately up to 500 Gs by the displacement of a spring supported core. The equations used were:

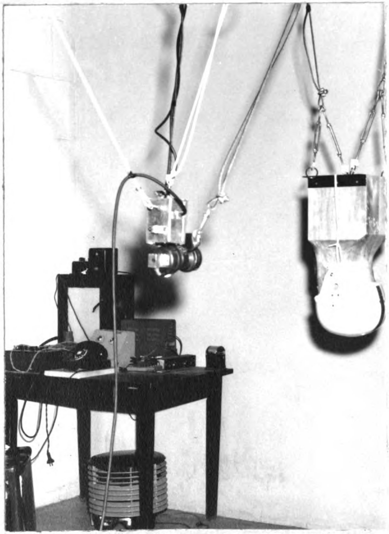


FIGURE 7 - Pendulum in Starting Position

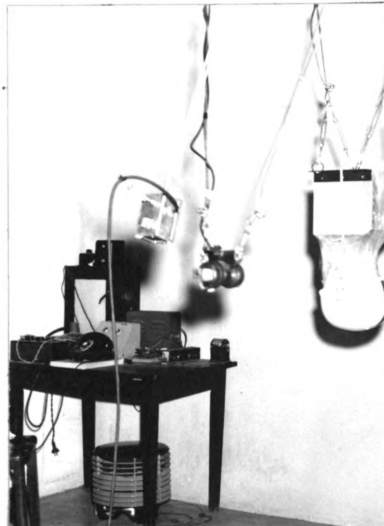


FIGURE 8 - Pendulum in Motion

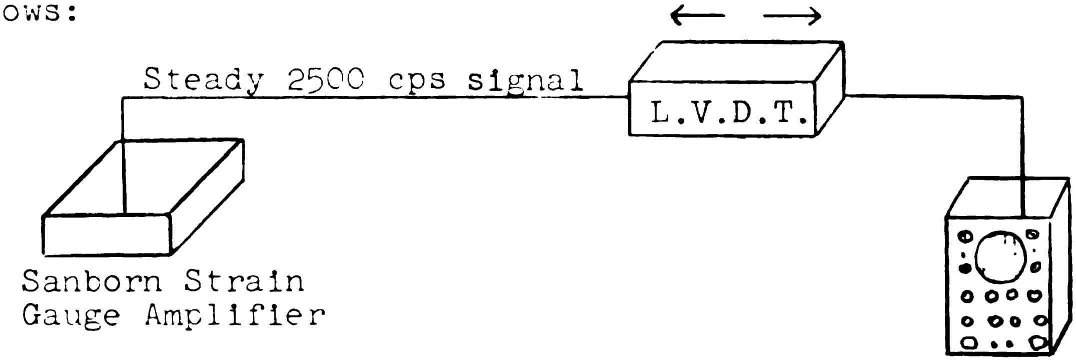
	$F = ma$		[F--force
			[m--mass of core
and		where	[a--acceleration of L.V.D.T.
			[K--spring constant of core springs
	$F = Kx$		[x--displacement of core

These equations combined, show that acceleration is proportional to displacement, i.e., $a = \frac{Kx}{m}$.

The L.V.D.T. operates on the differential transformer principle: A 2500 cps signal is fed into the primary coil of the L.V.D.T. but, due to a counterwound secondary, no output is present when the moveable core is at its mid or neutral position (the pendulum with the L.V.D.T. mounted on the back was in a horizontal position) since the voltages induced in the two halves of the counterwound secondary are equal and opposite in sign. When the core is moved by some force, in this case it was deceleration, then one or the other predominates. Their difference, proportional to the displacement of the core appeared at the secondary terminals, e. g., was shown on the oscilloscope.

The 2500 cps signal was fed to the primary of the L.V.D.T. from a Sanborn Strain Gage Amplifier. It was hoped that the output of the L.V.D.T. could be shown on the strain gauge amplifier and recorded, but the duration of the deceleration was of such small magnitude that the mechanical stylus of the recorder was unable to follow it. Instead the output of the L.V.D.T. was fed into a Hewlett-Packard model 130A oscilloscope and photographed as it appeared on the scope face.

A simple block diagram of the hook up is shown as follows:



It was desired to examine the time ratio factors in relation to G. As demonstrated in the numerous studies by Gurdjian, et al, the longer the time duration of a pressure, the smaller the number of G required to produce a concussion. By increasing the pip, however, it was extremely difficult to record the area under the curve, as almost always part of it did not appear on the scope. This meant that the number of impacts at each velocity would have to vary from helmet to helmet and even position to position. At this stage it was considered unwise, so the idea was abandoned.

The pip on the oscilloscope was set at five-tenths of a second per centimeter. There were ten centimeters across the scope face so it took five seconds to completely cross the screen. As the velocity increased the millivolts per centimeter were also increased to keep the height of the pip from falling off the screen. This meant it took more deceleration to pick up the output from the L.V.D.T. The oscilloscope was built so that a linear relationship existed between millivolts per centimeter and the height of the pip.

As the millivolts per centimeter increased, the height of the pip decreased. Also, as the millivolts per centimeter increased, the intensity was turned up thus making the pip brighter. The pip was checked at each setting to make sure its top, in neutral position, appeared at the edge of the first line below center. This made it easier to check the height of the pip. Figure 6 shows a close up of the oscilloscope.

On top of the oscilloscope a code system was devised so as to show at what velocity the blow was struck, the type of helmet used, and the position on the helmet. This was seen on each frame. Figure 6 shows this code system in relation to its position on the oscilloscope.

An Eastman Cine Special 16 mm. camera was used. It was mounted on a tripod, three and one-half feet from the oscilloscope. The diaphram of the lens was set for a light speed of f 2.8. Pictures were taken with tri-X negative film which was processed and delivered as a negative roll. The shutter was opened by a hand crank and the lens was capped with a rubber cap. Each frame was hand cranked to change the film and open the shutter. The light in the room was very weak, so weak that the needle on the Western Exposure meter did not record it. There was enough light, however, to pick up the code system which was mounted on the oscilloscope. Figure 9 shows the camera, release

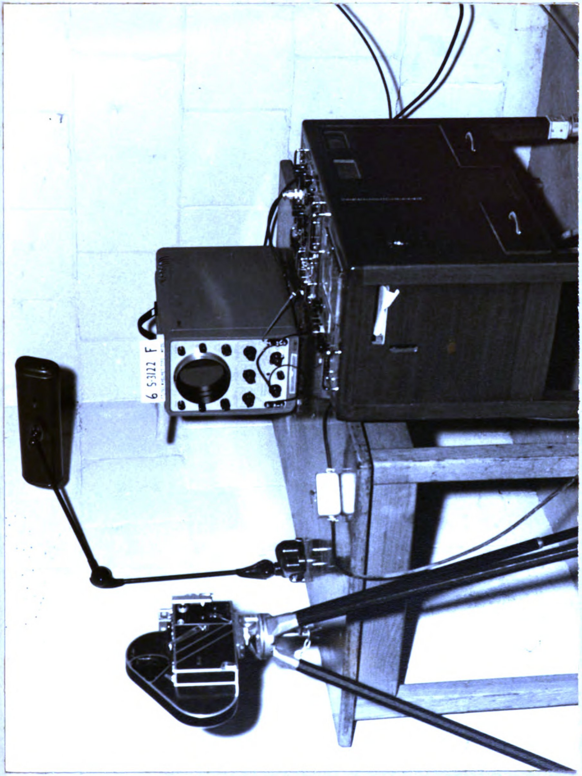


FIGURE 9 Camera, Release Switch, Oscilloscope, and Recorder in Position.

switch, oscilloscope, and recorder in the position in which they were used.

Experimental Design

The helmets were all tested at the following six velocities: six, nine, twelve, fifteen, eighteen, and twenty-one feet per second.

This was in relation to a specific recommendation of Hendler and Wurzel that to improve the design of their experiment, they should have included both low energy and high energy type impacts.

In changing the six velocities to miles per hour, there existed a variance from four and one-tenth miles to fourteen and three-tenths miles per hour. Four and one-tenth miles per hour corresponds to an individual walking into an extended knee or falling off balance and landing on a knee. Fourteen and three-tenths miles per hour was relative to an individual running into an extended knee, or while in a still position being kneed by someone running toward him.

Four different positions, front, back, right side, and top were tested, in that order. Figure 10 shows the helmet outline with arrows indicating the impact points. Each helmet was tested five times at each velocity starting at six feet per second, then nine feet per second, etc. After each blow the helmet was checked to make sure it had not slipped or twisted on the head. This was accomplished

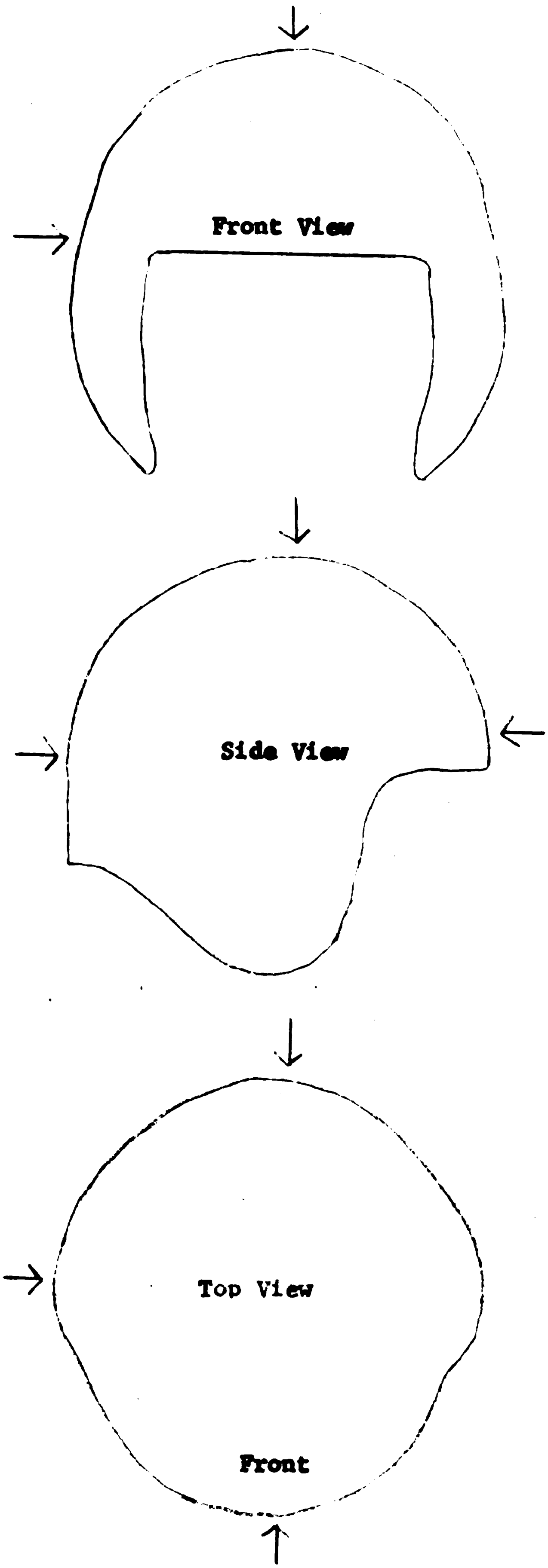


FIGURE 10
HELMET OUTLINE IMPACT POINTS

in two pl

ment.

th, and

ntal

The

periment

is strai

ter eac

The photo

"Ready" a

up from

the third

This indi

ntimete

ial on

C

nce in

mounted

movable

xis of

front p

lacing

ented

llowing

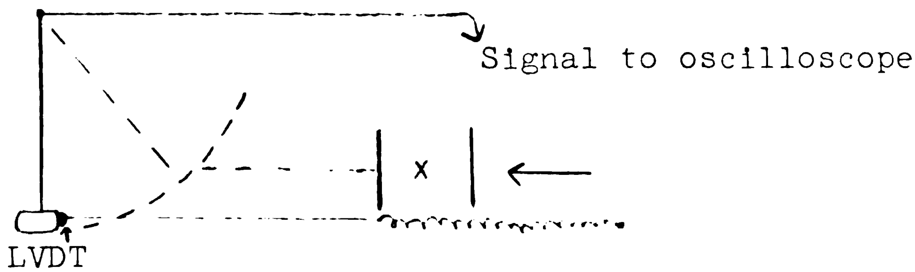
Scope d

with two pieces of tape on the head used as points of measurement. Each helmet was tested at three positions: front, back, and right side. At the end, the head was turned horizontally and each helmet tested at the top position.

Three individuals were required to perform this experiment. One person checked the helmet to make sure it was straight and placed the pendulum in the release box after each impact. Upon completing this he called, "Ready." The photographer, operating the camera, upon the signal "Ready" and when the pip was near center, pulled the rubber cap from the open shutter. As the cap left the open shutter, the third person switched the button to release the pendulum. This individual also kept the records of the millivolts per centimeter used at the different impacts and changed the dial on the oscilloscope.

Calibration was initially made by noting the difference in levels between the signals when the L.V.D.T. (mounted on pendulum) was rotated from a neutral position (movable core horizontal) to one in which the sensitive axis of the L.V.D.T. was parallel to the force of gravity (front part of pendulum perpendicular to ground). In displacing the core, the force of gravity (one G) was represented by the change in single level on the scope, thus allowing the scope to be calibrated in Gs per centimeter of scope deflection.

As a final check, the L.V.D.T. was also calibrated in the following manner:



The L.V.D.T. and attached mass swung and the maximum deflection of the spring was recorded, as well as the amplitude of the deceleration pulse on the oscilloscope.

The equations:

$$F = ma$$

$$F = Kx$$

where

[F--force
[m--mass in slugs of L.V.D.T. and pendulum bob
[a--deceleration of L.V.D.T.
[K--spring constant in pounds of inch deflection
[x--deflection in inches

It was easily shown again that $a = \frac{Kx}{m}$. Since K, x, and m were known, a could be accurately determined from this formula. The signal on the scope in centimeters of deflection represented this deceleration, and another calibration was made in terms of Gs per centimeter of deflection. The initial calibration and this check calibration agreed well within the limits of observational error.

A third calibration used mainly to correlate with Lombard's findings was to check the voluntary tolerance level. In his experiment he obtained one maximum of thirty-eight Gs in the front position. For the two subjects tested in this experiment a maximum of thirty-five Gs were recorded.

After all the helmets were tested and the film developed, the recordings were measured on a viewer. The heights of the pips were recorded, the averages were taken on each helmet at each velocity, and were transferred to G. [See Appendix A.]

The results were shown by graphs. The deceleration rate (G) was plotted against velocity in feet per seconds. The experimental design in this experiment is similar to the one shown in Figure 4 which was developed to provide a dynamic load test, and the Air Force experiment by O. T. Strand, Jr.

As stated before in the letter from Protection, Incorporated, helmets should be tested for:[1]

1. Protection against repeated low energy impacts.
2. Protection against single high energy impacts.
3. Protection against blows on the sides, back, front, and top of the head.

The design of this experiment included all this, plus repeated high energy impacts and the so-called "average" between the low and high energy impacts.

---

[1]Correspondence from Protection, Inc., op. cit.

CHAPTER IV

RESULTS

Upon developing the film, there were no recordings for either helmet ME610 or helmet WF2000. The shutter on the camera had been closed and as a result only blank film developed. Recordings were taken again and as indicated on the graphs the second run was recorded.

For helmet MH612 it was impossible to adequately measure the height of the pip in the front and right side positions, so these were not included in the graphs. This helmet had been used in the sample run and at the high velocities the intensity had not been turned up.

There were nine graphs comparing each helmet with itself in the four pisitions, [Figures 11 through 19], and four graphs [Figures 20 through 23] which compared each helmet with every other helmet in the four positions.

As shown in Figure 20, the lowest deceleration recorded in the front position at twenty-one feet per second was from helmet RK-TK5. It reached a peak of 181.5 Gs at twenty-one feet per second which was 128 Gs below the next lowest recording. It was interesting to note that the three lowest recordings were from the same type helmets, plastic shells with canvas suspensions that fit snugly on the head.

The two helmets with the highest deceleration were MH620 and S3131, both exceeding 440 Gs at twenty-one feet per second. In examining the front of helmet S3131 it was discovered that there were two large rivets covered by a three-quarter inch foam rubber strip. The high velocity blows had forced the rivets partially through the foam rubber.

Helmet MH620 had an exceedingly weak suspension and the inside mounting, which covered one inch above the holes for the ears, was covered by a foam rubber strip about one-quarter of an inch thick.

In the back position, the lowest deceleration at twenty-one feet per second was from helmet ME610 (second run) from which 156.5 Gs were recorded. The highest recording was a leather helmet MH620 from which 486.9Gs were recorded; the highest recording from all the helmets in all positions. However, in its defense, it must be mentioned that another leather helmet, MH612, had the second lowest deceleration.

The lowest recording for the right side position was 72.06 Gs recorded from helmet RK-TK5. Two other helmets, S3122 and MH610 (second run) also recorded under 100 Gs. The highest recording was again from helmet MH620 which read 460.9 Gs. This was 187 Gs above the next highest helmet. The only protection helmet MH620 provided in this position was a one-quarter inch foam rubber padding which was pushed against the leather shell by the head.

The lowest recording for the top position was 67.9 Gs recorded from the WF2000 (second run). This was the lowest recording from any position at twenty-one feet per second. Helmets ME610 (second run) and RK-TK5 recorded under 100 Gs. The highest was 405.2 Gs recorded from helmet WF2010. It was interesting to note the contrast between helmets WF2000 (second run) which recorded 67.9 Gs and WF2010 which recorded 405.2 Gs. Helmet WF2000 (second run) has a canvas suspension covered with a thick foam rubber, of about one-half inch length. Helmet WF2010 has a foam rubber padding which fits loosely to the shell. The shells are almost identical.

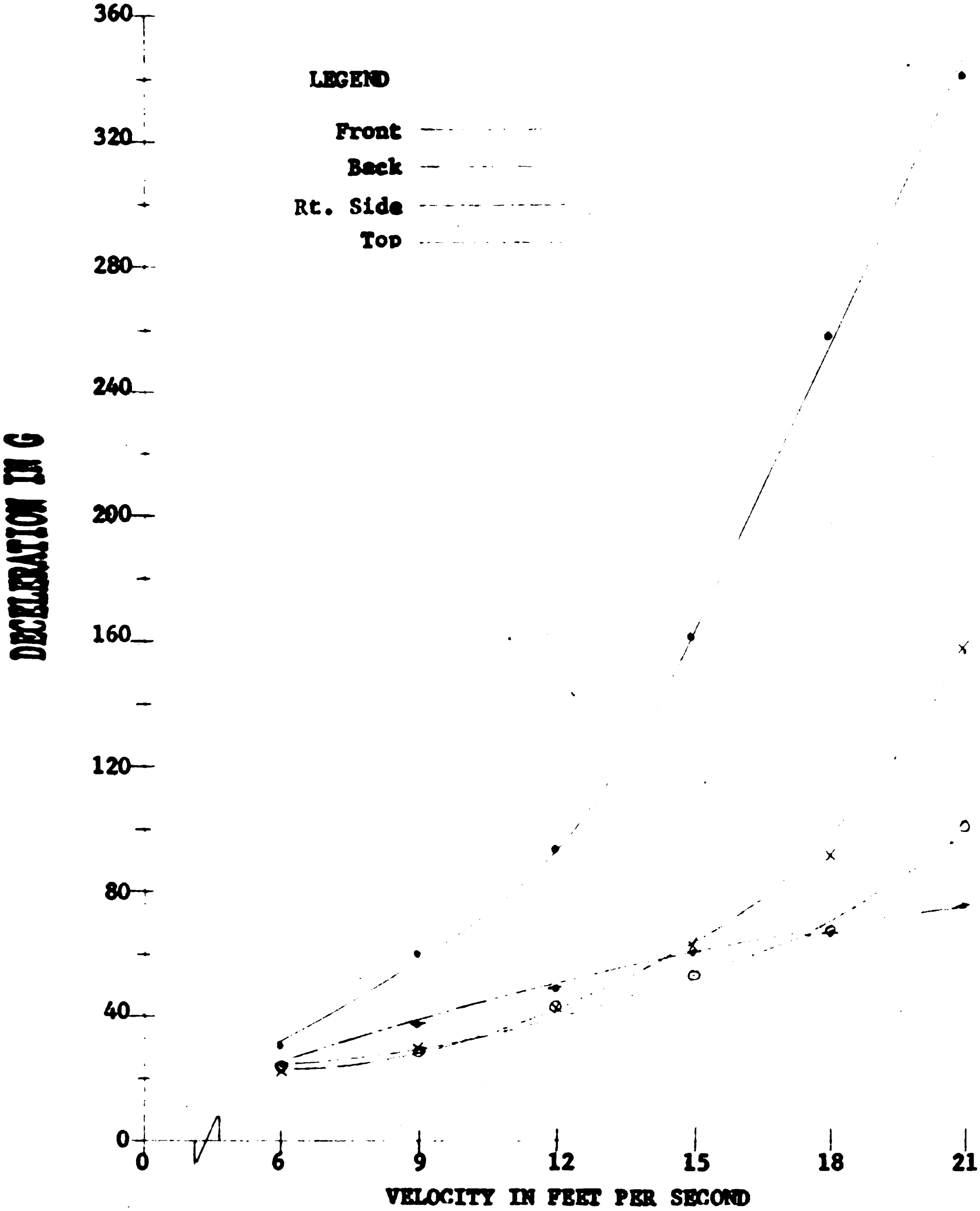
The lowest average in regard to position, was recorded on the right side, while the highest average was in the front position. The review of literature indicated a great deal of protection is needed in the top position because the head is less likely to move when struck at this position. The results of this study show that the majority of helmets give this added protection.

The two lowest over-all recordings for the four positions were from helmets RK-TK5 and ME610 (second run). The highest recordings by far, were from helmet MH620. A comparison must be taken to see why helmets RK-TK5 and ME610 had the lowest recordings. The only difference observed between helmet RK-TK5 and helmet RK-RK4 was the shell. The shell in helmet RK-RK4 was of softer plastic. Helmets ME610 and RK-TK5 had very strong shells.

Helmets RK-TK5 and ME610 both had a very strong canvas suspension, although helmet ME610 had a new type absorblo on the canvas. These suspensions fit around the head above the ears.

A look at the graphs shows that at various velocities the curves accelerated almost straight upward. This seemed to indicate the velocity at which the wooden head made contact with the shell.

FIGURE 11
DECELERATION OF .16 SLUG AT VARIOUS
VELOCITIES UPON IMPACT WITH HELMET
ME 610 (SECOND RUN)



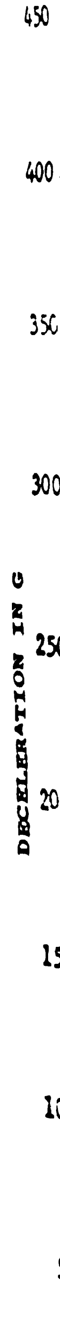

DECELERATION IN G
450
400
350
300

FIGURE 12
DECELERATION OF .16 SLUG
AT VARIOUS VELOCITIES UPON IMPACT
WITH HELMET WF 2010

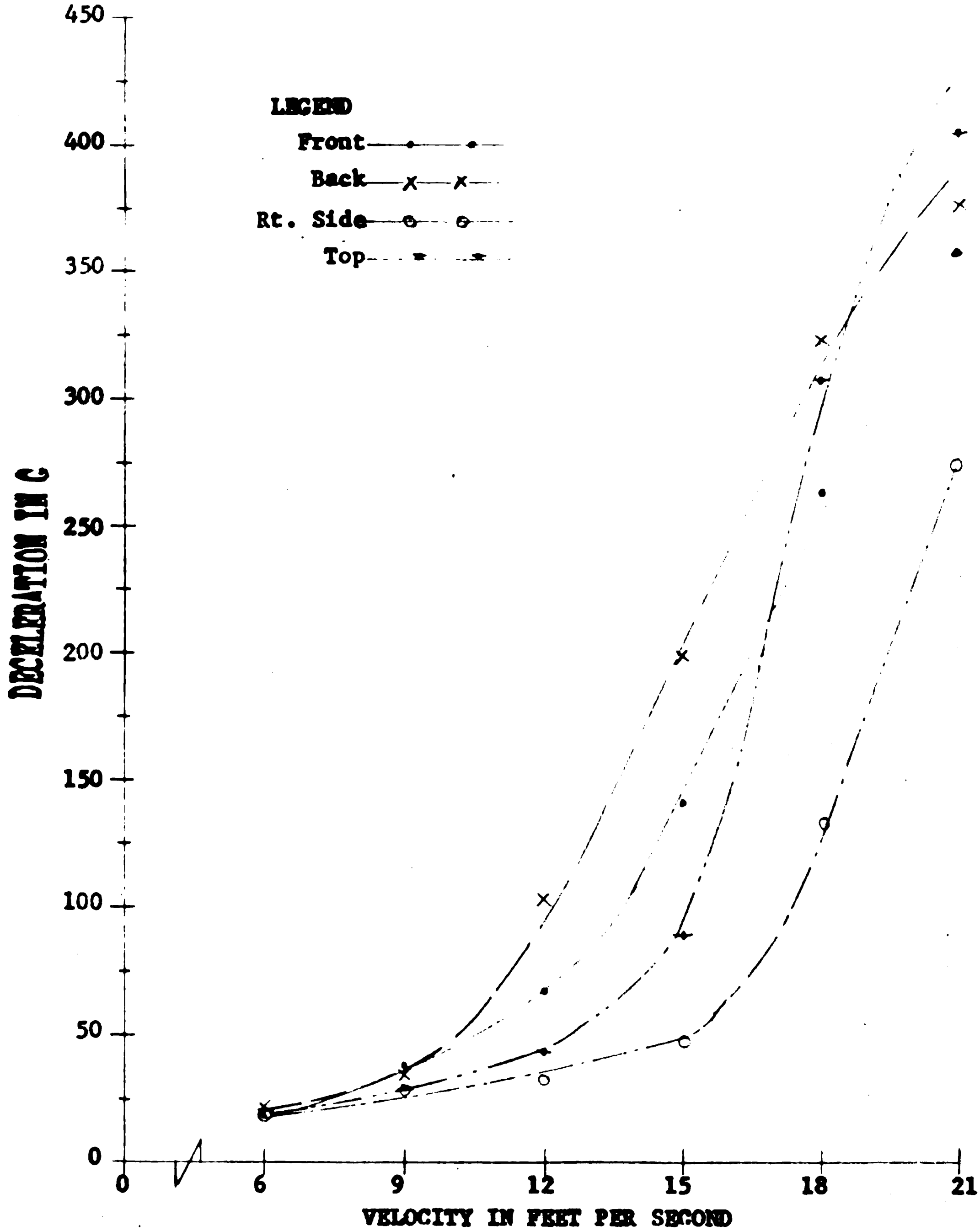
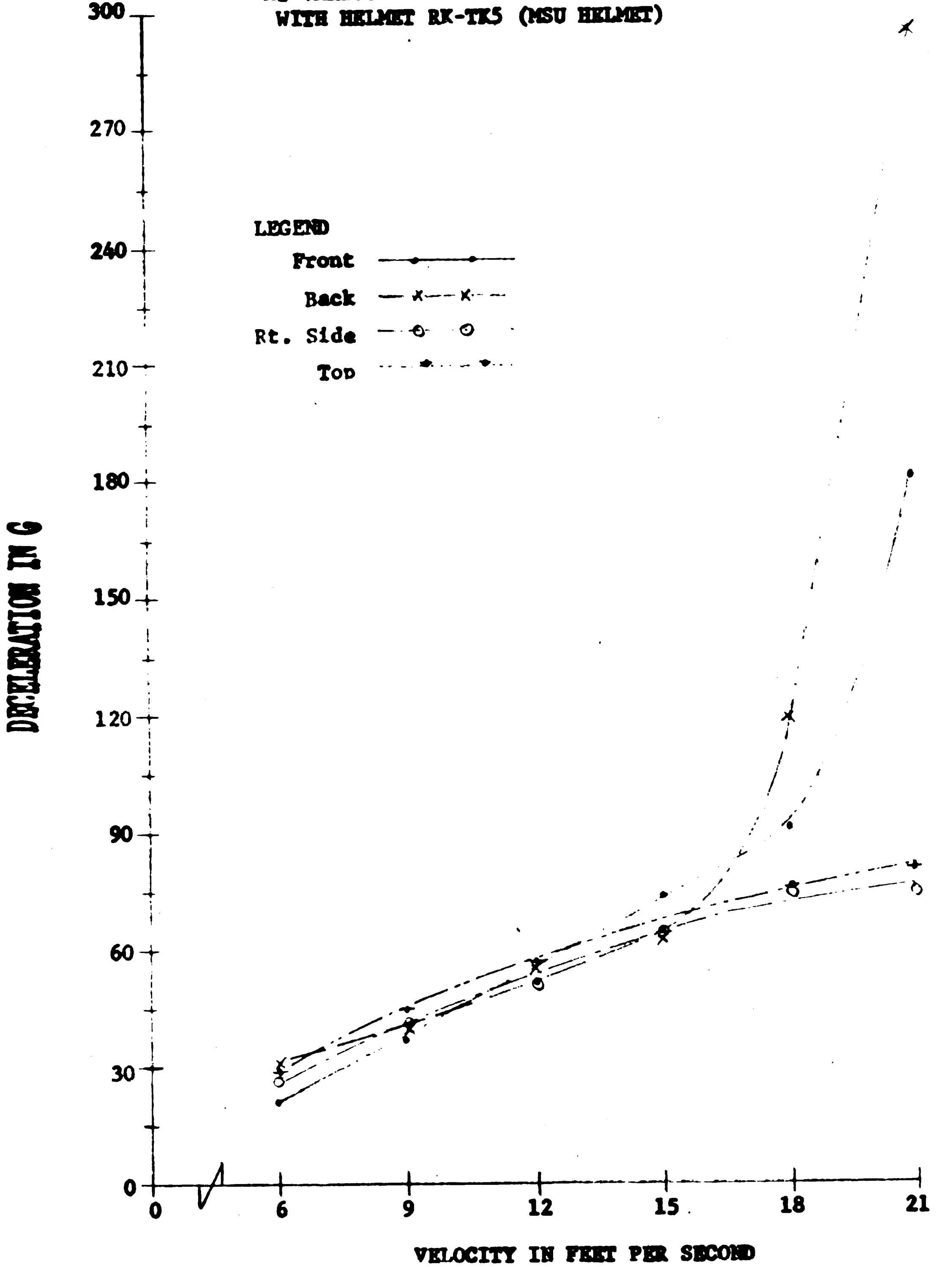


FIGURE 13
DECELERATION OF .16 SLUG
AT VARIOUS VELOCITIES UPON IMPACT
WITH HELMET RK-TK5 (MSU HELMET)



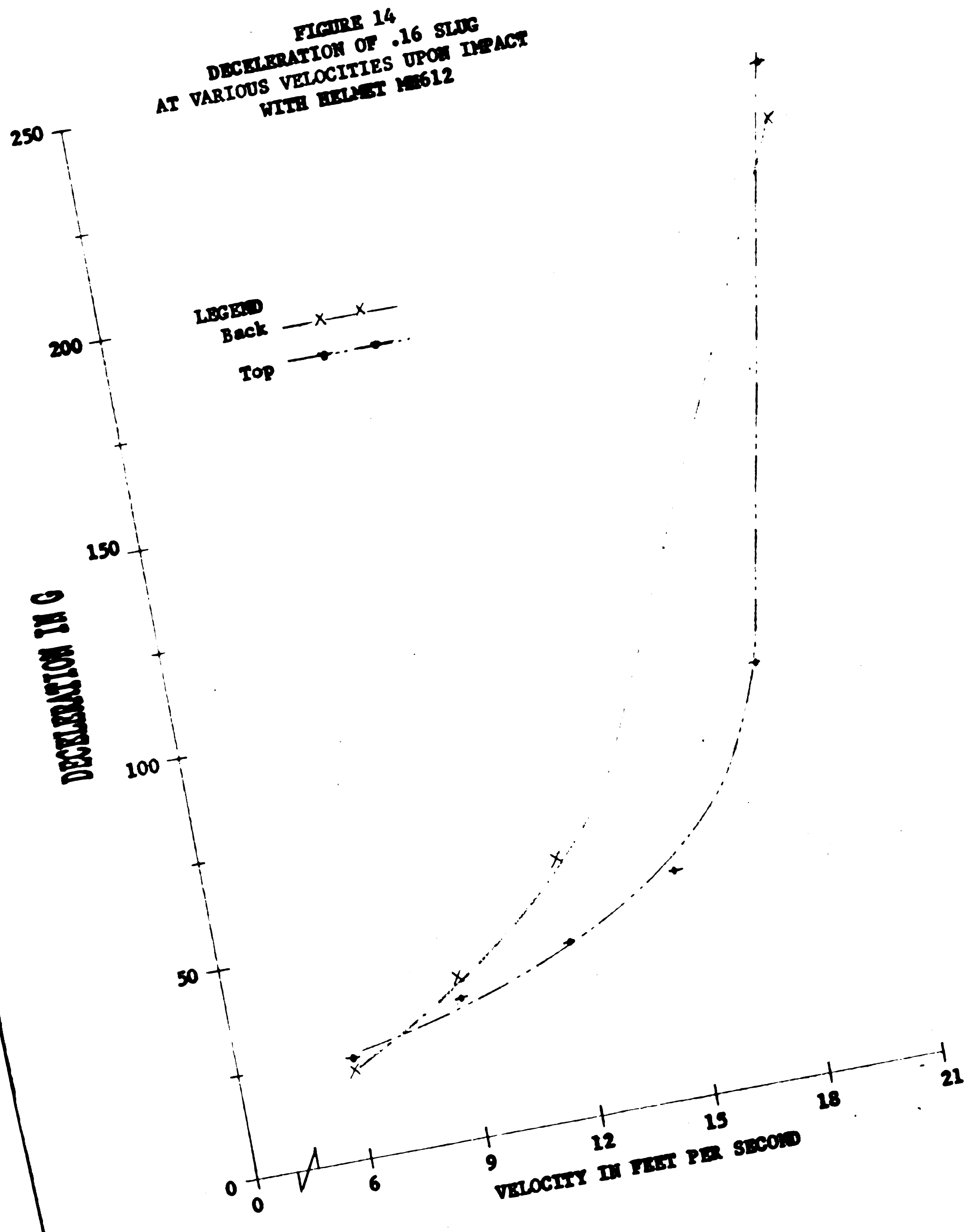
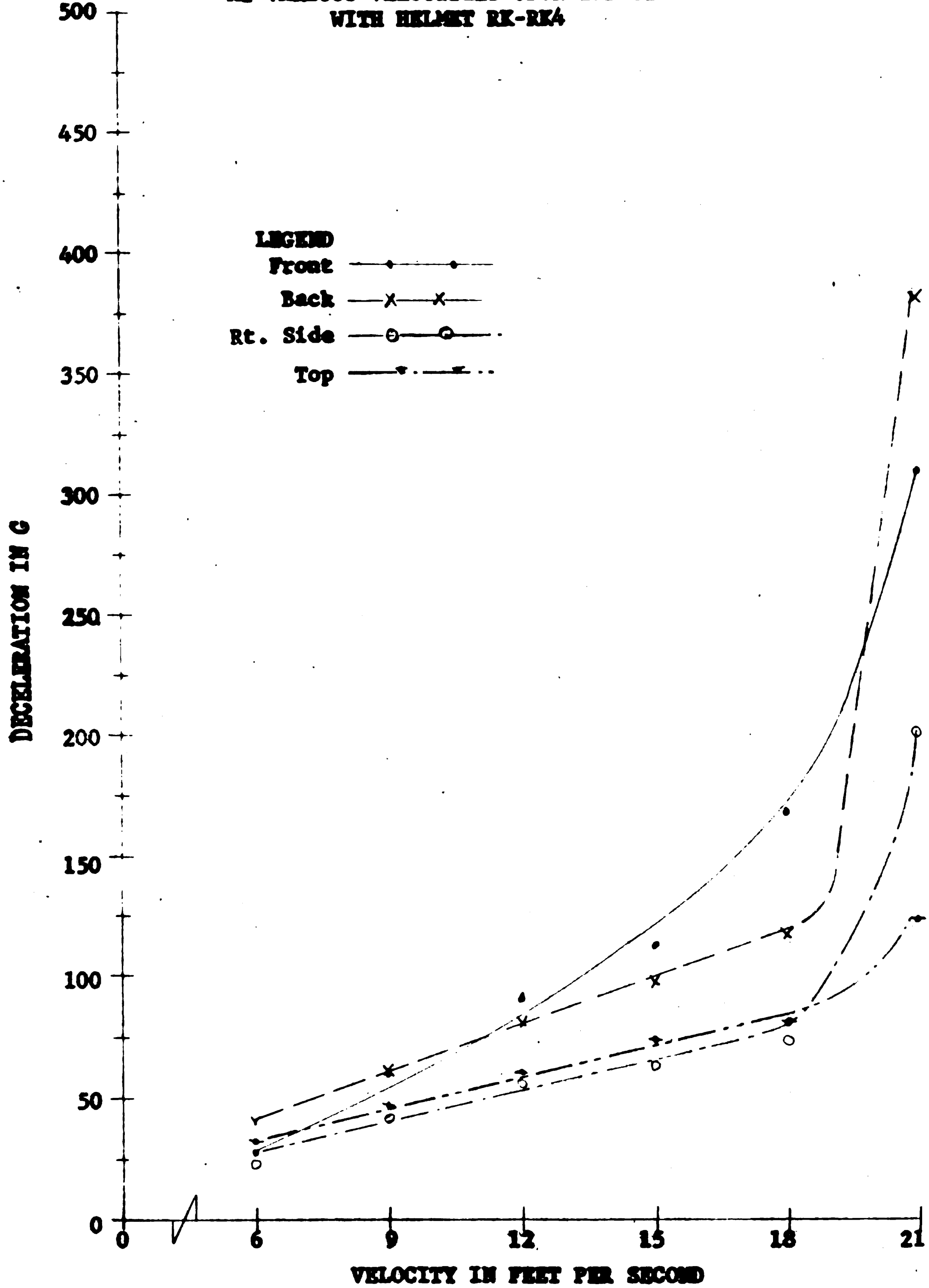


FIGURE 14
DECELERATION OF .16 SLUG
AT VARIOUS VELOCITIES UPON IMPACT
WITH HELMET MH612
LEGEND
Back
Top
DECELERATION IN G
250
200
150
100
50
0
0
6
9
12
15
18
21
VELOCITY IN FEET PER SECOND

FIGURE 15
DECELERATION OF .16 SLUG
AT VARIOUS VELOCITIES UPON IMPACT
WITH HELMET RK-RK4



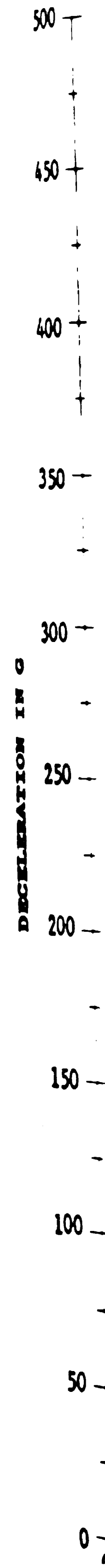

DECELERATION IN G
500
450
400
350
300
250
200
150
100
50
0

FIGURE 16
DECELERATION OF .16 SLUG
AT VARIOUS VELOCITIES UPON IMPACT
WITH HELMET S3131

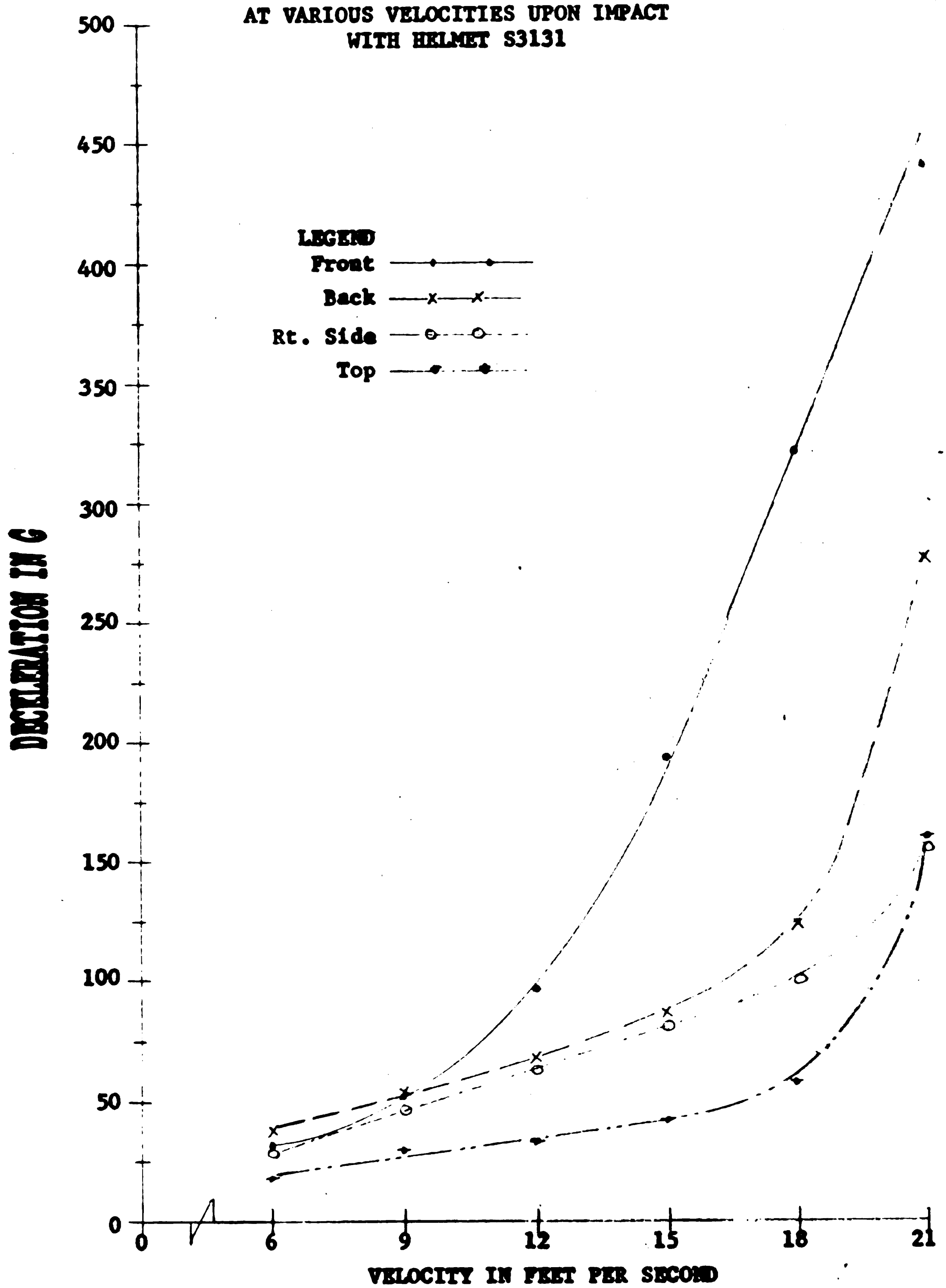
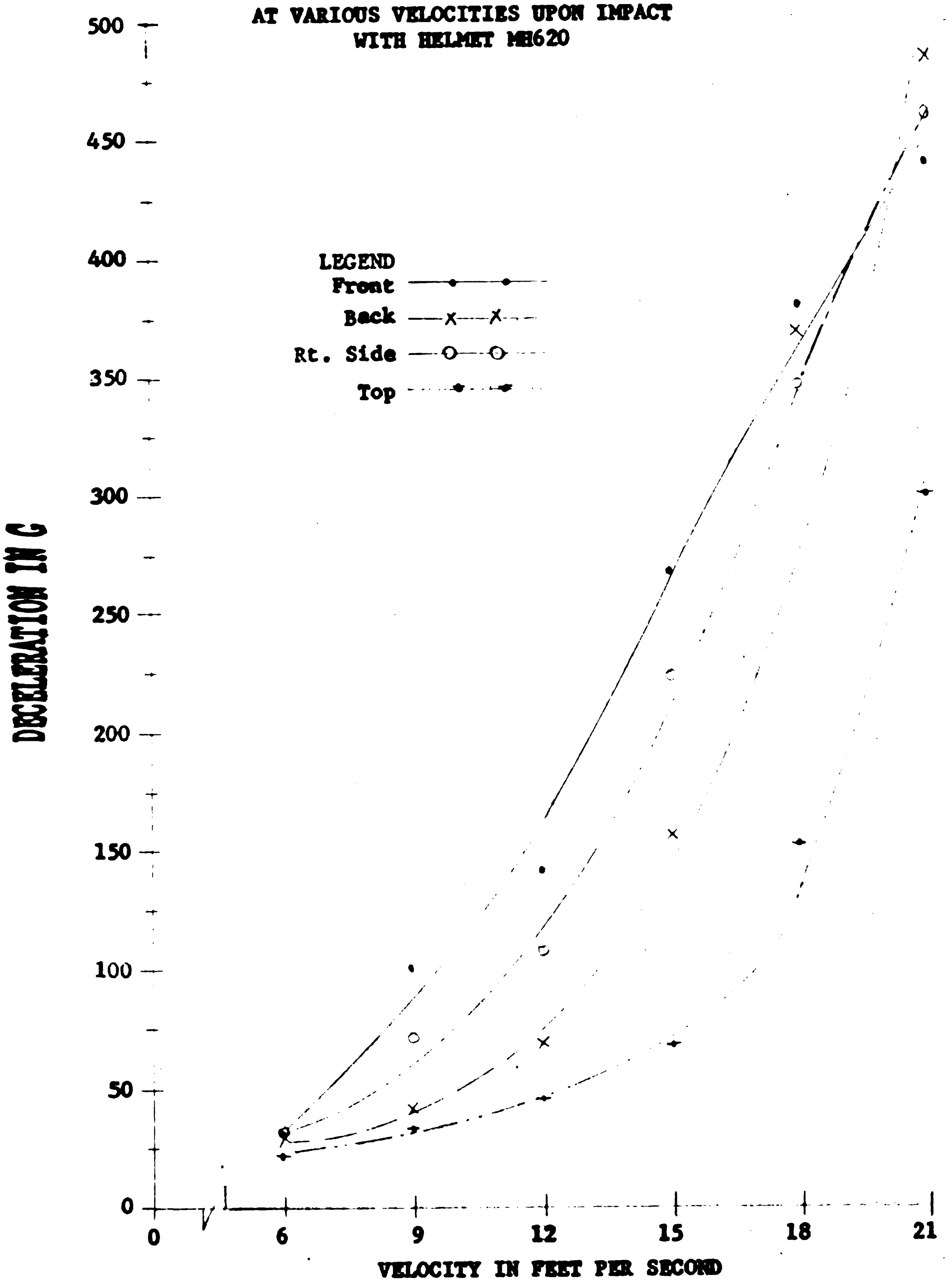


FIGURE 17
DECELERATION OF .16 SLUG
AT VARIOUS VELOCITIES UPON IMPACT
WITH HELMET MH620



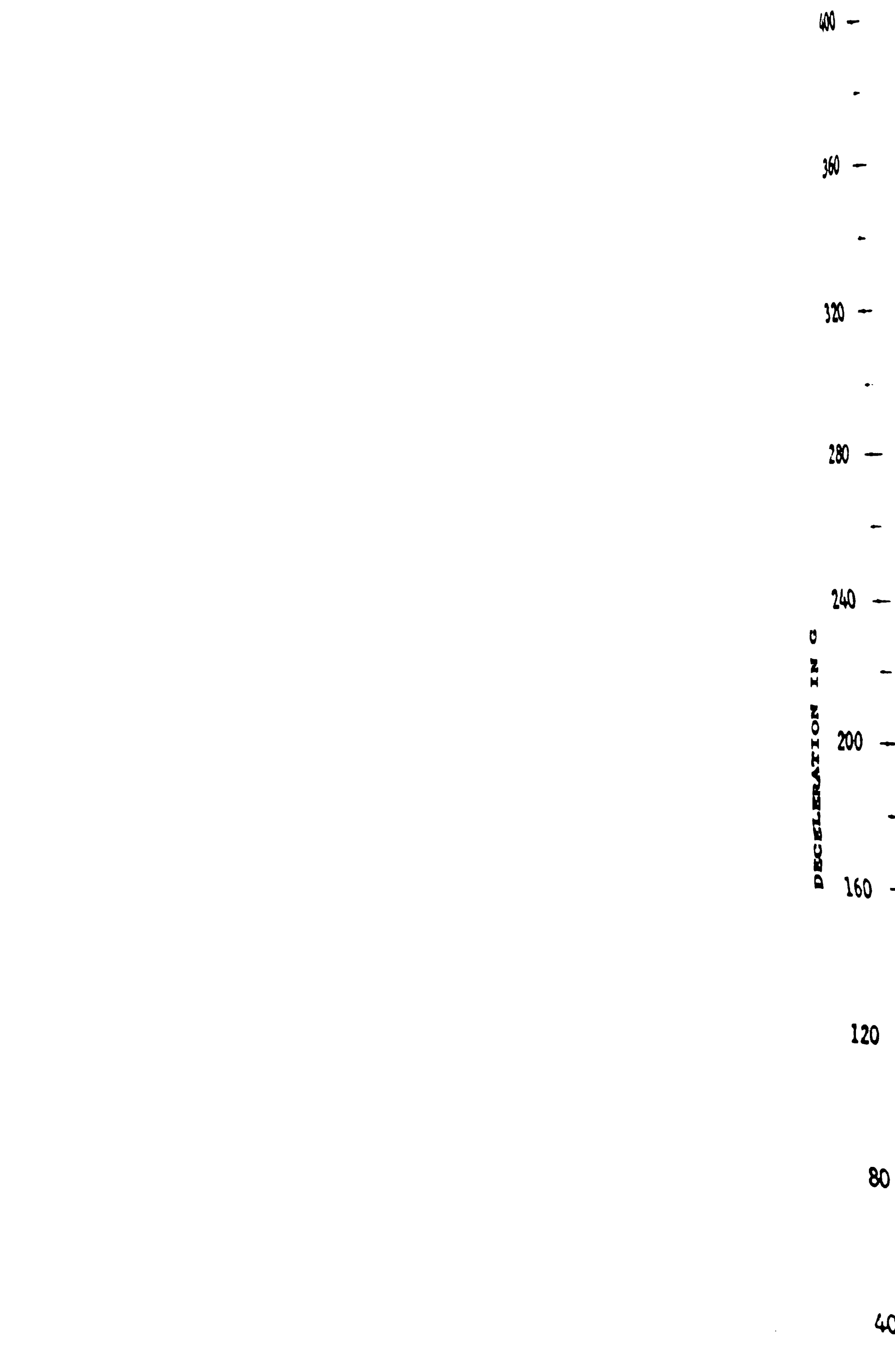
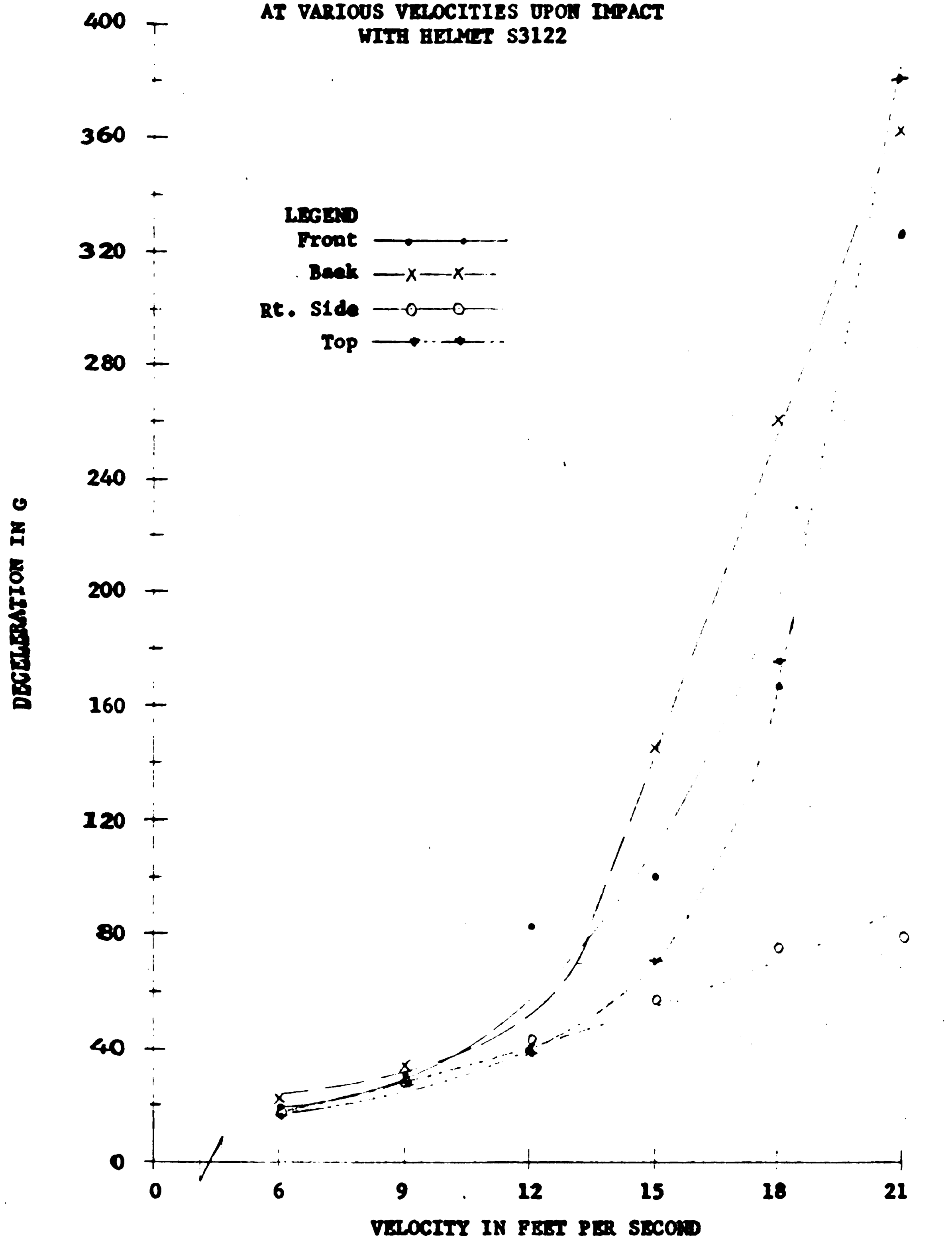

DECELERATION IN G
400
360
320
280
240
200
160
120
80
40

FIGURE 18
DECELERATION OF .16 SLUG
AT VARIOUS VELOCITIES UPON IMPACT
WITH HELMET S3122



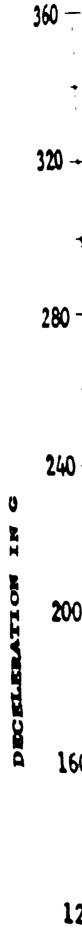

360
320
280
240
200
DECELERATION IN G

FIGURE 19
DECELERATION OF .16 SLUG
AT VARIOUS VELOCITIES UPON IMPACT
WITH HELMET WF2000 (SECOND RUN)

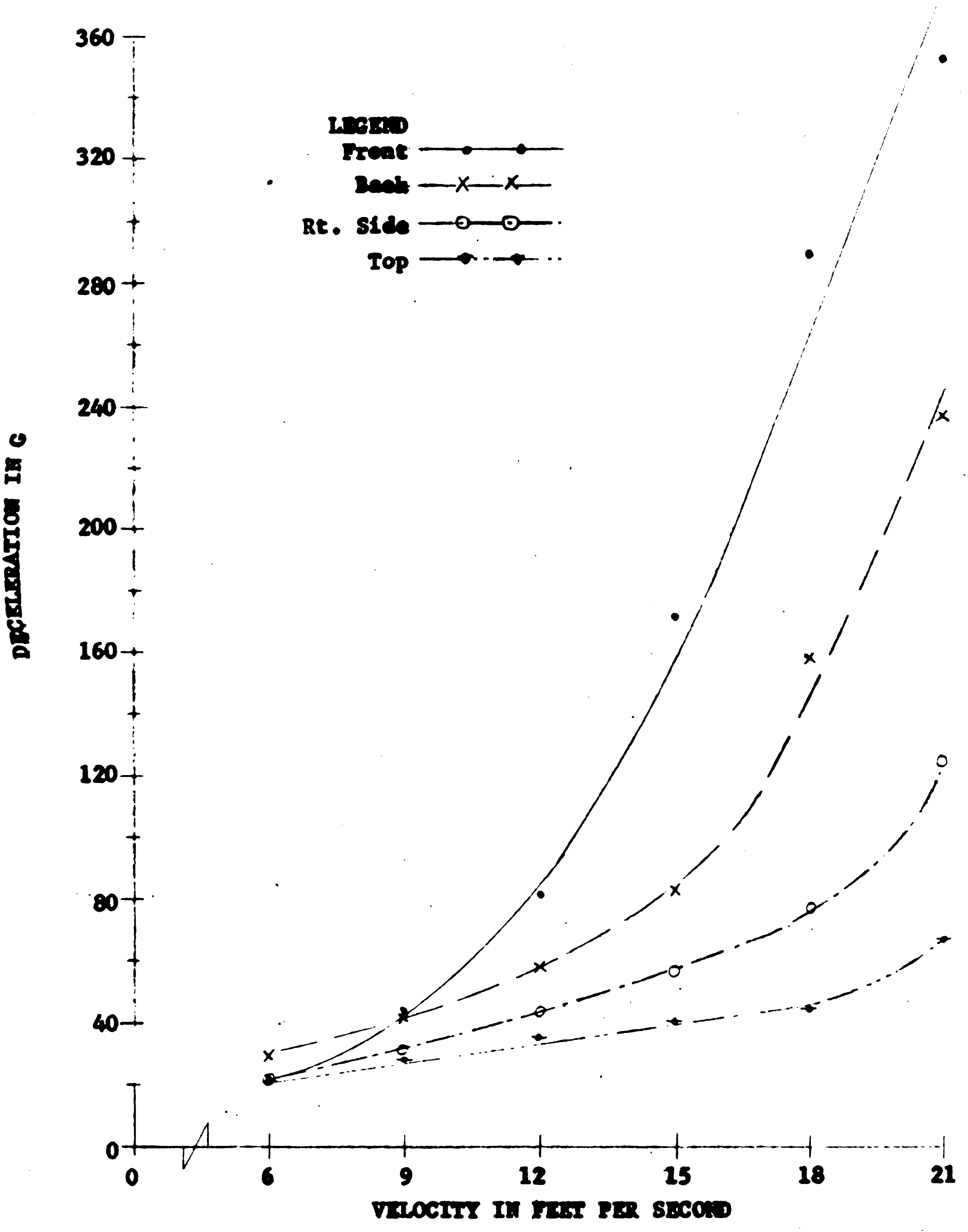


FIGURE 20 - COMPARISONS OF HELMETS IN DECELERATION OF .16 SLUG MOVING AT VARIOUS VELOCITIES FOR FRONT POSITION

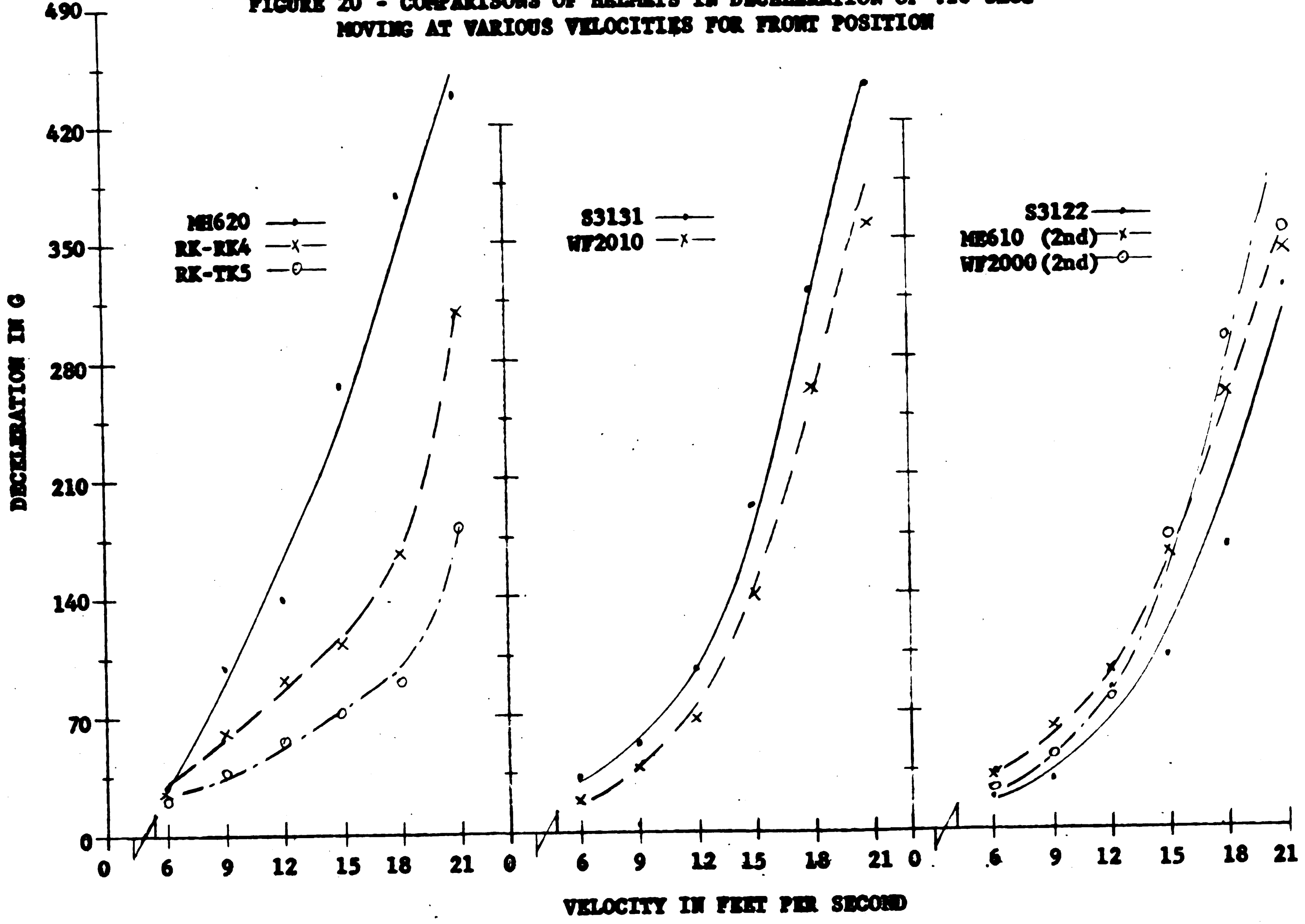


FIGURE 21 - COMPARISONS OF HELMETS IN DECELERATION OF .16 SLUG MOVING AT VARIOUS VELOCITIES FOR BACK POSITION

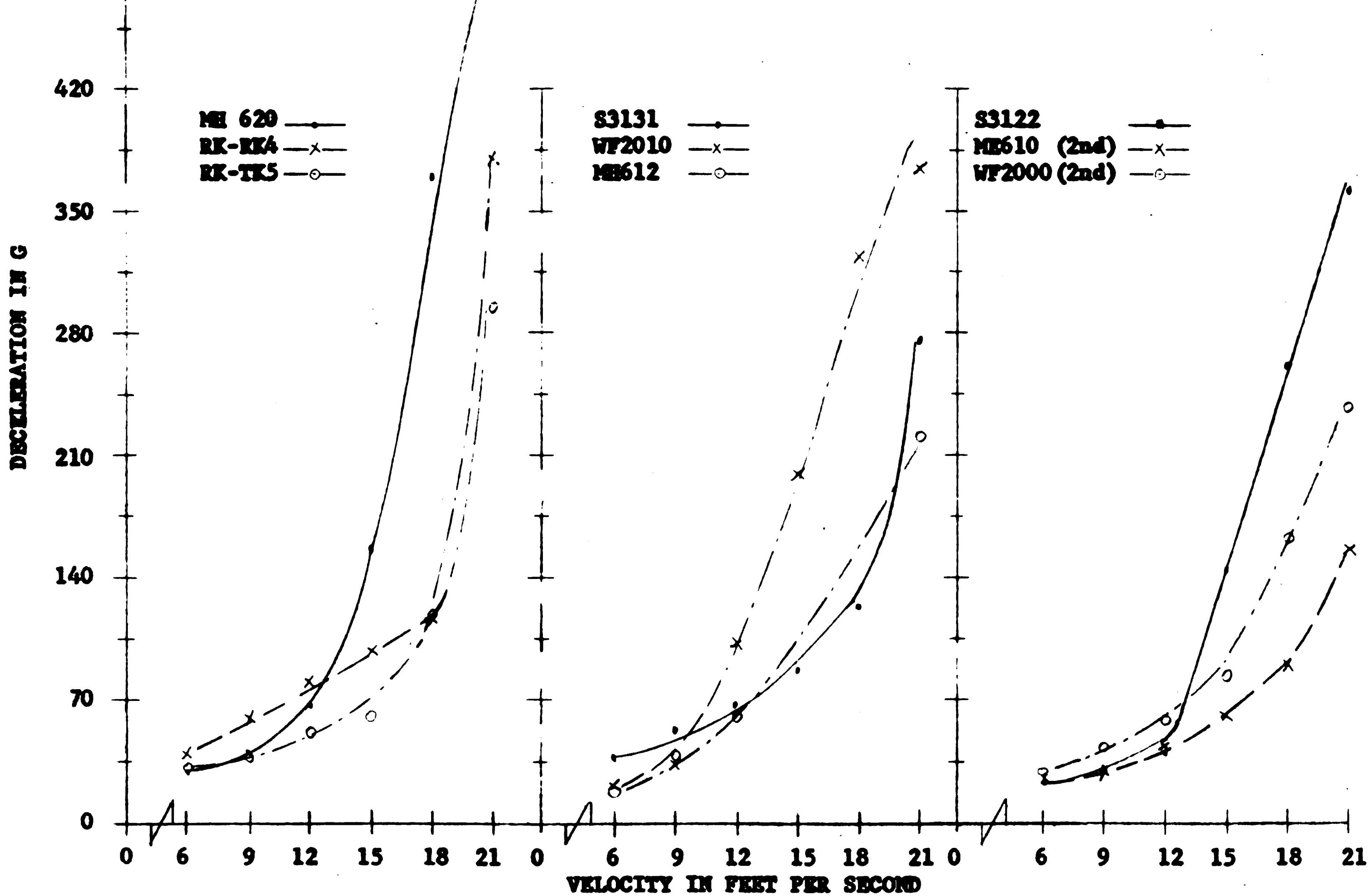
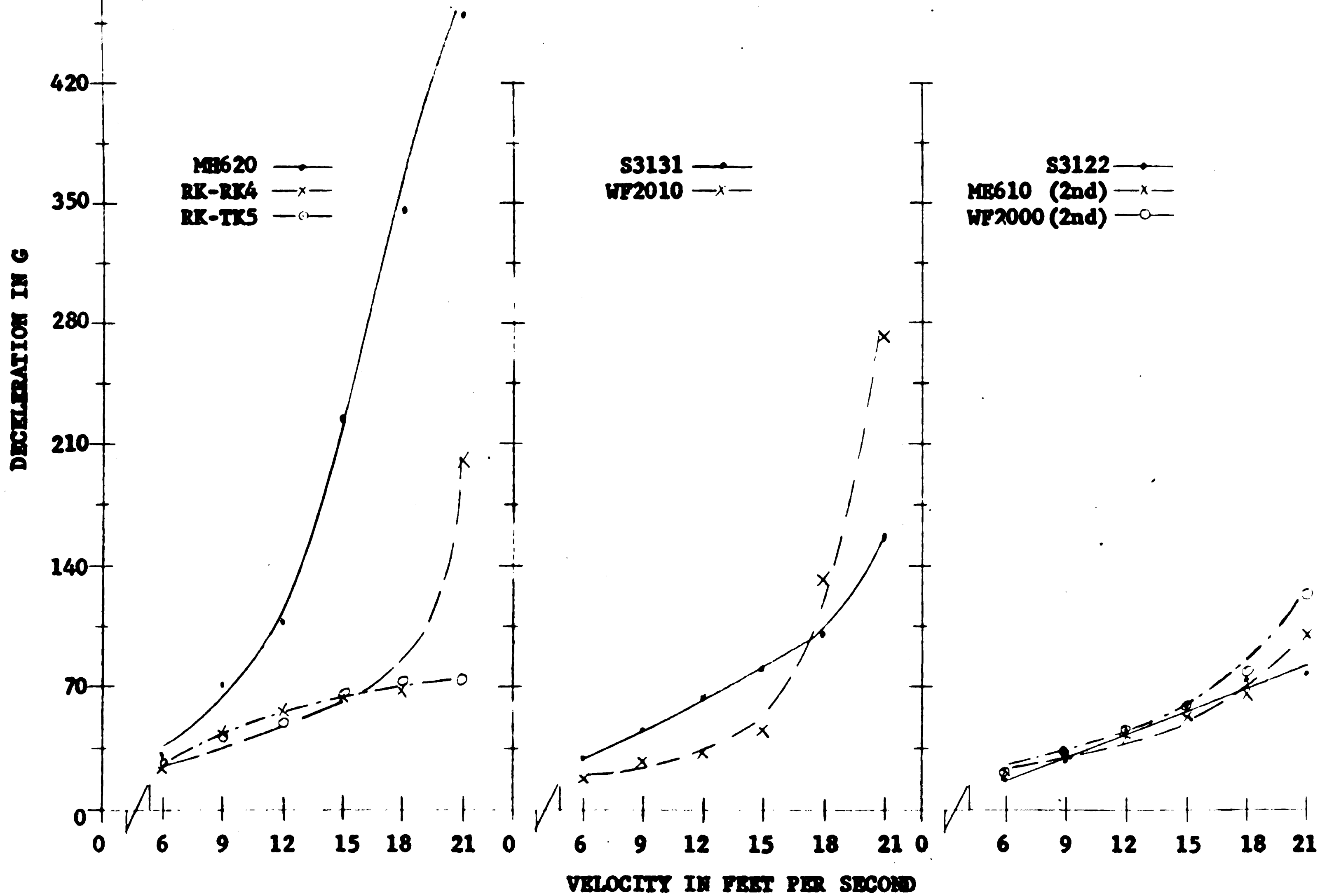


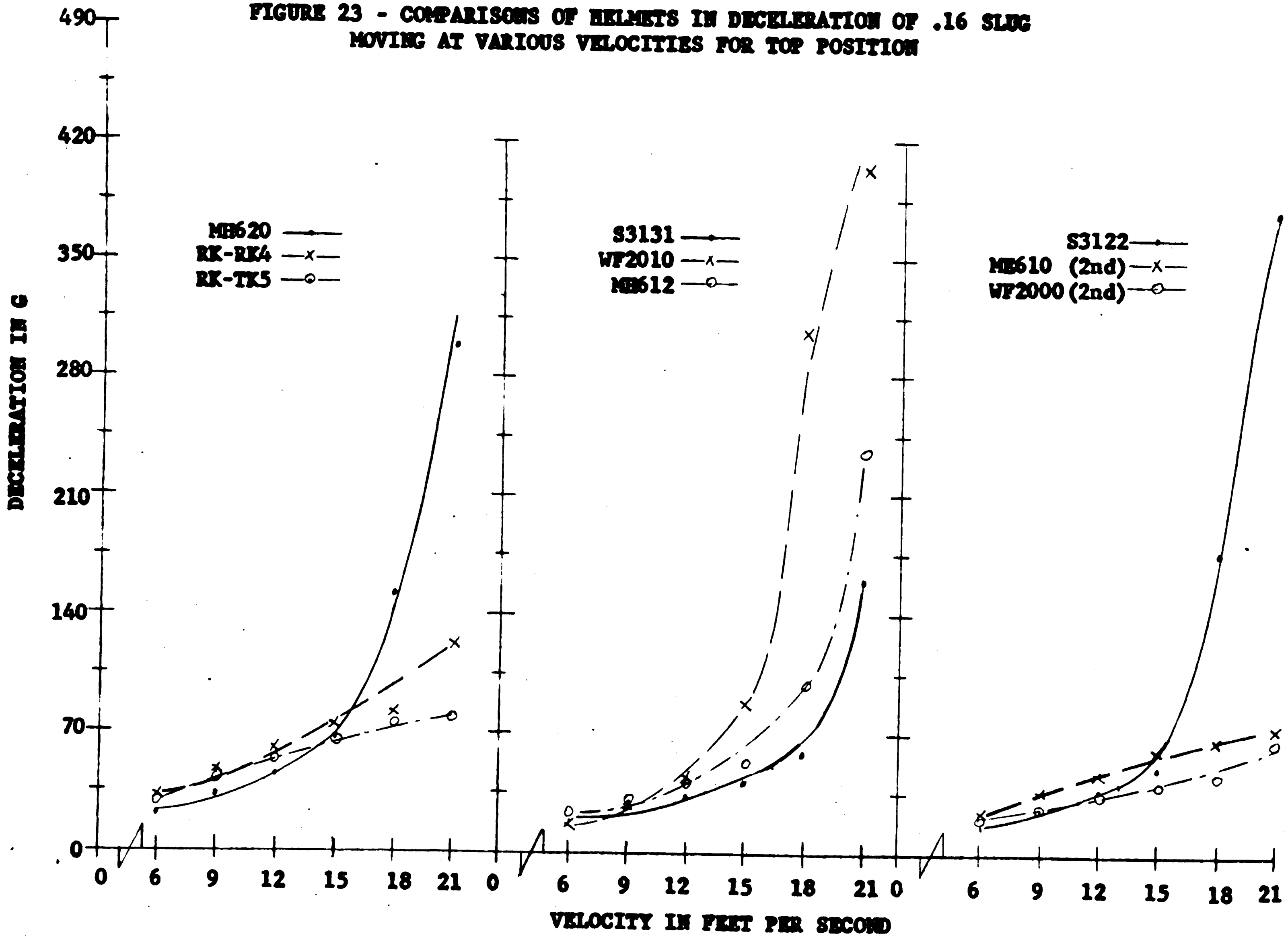
FIGURE 22 - COMPARISONS OF HELMETS IN DECELERATION OF .16 SLUG MOVING AT VARIOUS VELOCITIES FOR RIGHT SIDE POSITION



490

FIGURE 23 - COMPARISONS OF HELMETS IN DECELERATION OF .16 SLUG MOVING AT VARIOUS VELOCITIES FOR TOP POSITION

FIGURE 23 - COMPARISONS OF HELMETS IN DECELERATION OF .16 SLUG MOVING AT VARIOUS VELOCITIES FOR TOP POSITION



CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

It was the purpose of this study to measure the characteristics of helmets as regards the decelerations of a moving object on impact. This was done by inflicting blows of varying speeds to specific positions on the helmet with a pendulum type mass of .16 slug.

Nine different helmets were examined. Their code names were as follows: MH612, ME610, MH620, RK-TK5, RK-RK4, S3122, S3131, WF2010, and WF2000. They were mounted on a wooden head which was suspended from the ceiling. Each helmet was tested at the following velocities: six, nine, twelve, fifteen, eighteen, and twenty-one feet per second. Four positions, front, back, right side, and top were used. Five blows were averaged at each velocity for the individual helmets in the four respective positions.

An accelerometer measured the deceleration of the .16 slug at impact with the helmets and this was recorded by an oscilloscope which was photographed with a sixteen millimeter camera, hand cranked in order to take the pictures frame by frame. The results were clearly shown with nine

graphs plotting each helmet against itself for the four positions and four graphs plotting each helmet against every other helmet in each position.

Conclusions

1. For the helmets investigated, the plastic shell was superior to the leather shell.

2. For the best protection in terms of decelerating a moving object in the front position, helmets should have a hard plastic shell with a canvas suspension that fits snugly on the head.

3. If at all possible, helmets should be free from rivets. If rivets are used, they must be adequately covered and have as much distance between them and the head as possible.

4. If a canvas suspension is used, it should be constructed in such a way that the suspension firmly fits the head.

5. The review of the literature indicates that concussion is most likely to concure on the flatest portion of the skull. The sides of the head, therefore, must be adequately protected. This can be accomplished by raising the outbend on the sides to allow more room for the ears and leaving more space between the suspension and the shell.

6. The top position needs the greatest protection due to the relatively greater mass of the head and body to be moved when struck in this position. This is best

accomplished by a plastic shell with a strong suspension and a distance of at least one-inch between the shell and the suspension.

7. An "all purpose" helmet needs a hard plastic shell with a strong canvas suspension in which the head is firmly fitted, not only on top but around the sides above the ears.

Recommendations

The following problems are recommended as a result of this study:

1. Pressure gauges on the four positions inside the head as well as on the pendulum might be used; thus recording the difference in Gs that is transmitted through to the head.

2. The fatigue factor should be studied by continued impacts on the helmets with high velocity blows until they "break down."

3. The various comfort factors such as weight, shape, and stability might be investigated.

4. The effect of temperature on the different type plastic helmets should be studied.

5. The weapon angle should be examined, e.g., the effect of the shape and padding on the outside of the helmet in relation to injuries.

6. The time-ratio factor should be studied, e.g., the duration of the blow in relation to the extent of the injury.

BIBLIOGRAPHY

Committe

Committe

DeHaven

Gurdji

Gurdji

Gurdji

Gurdji

Gurdji

Gurdj

Hendl

Hawk,

BIBLIOGRAPHY

Committee on Injuries and Fatalities, American Football Coaches Association. Dr. Floyd R. Eastwood, Chairman. Twenty-Fourth Annual Survey of Football Fatalities. January, 1956.

Committee on Injuries and Fatalities, American Football Coaches Association. Dr. Floyd R. Eastwood, Chairman. Twenty-Fifth Annual Survey of Football Fatalities. January, 1957.

DeHaven, H. "Injuries," War Medicine, 2:582-588, Aug., 1954.

Gurdjian, E. S., et al. "Quantitative Determination of Acceleration and Intercranial Pressure in Experimental Head Injury," Neurology, 3:6:417-423, June, 1953.

Gurdjian, E. S. and J. E. Webster. "Recent Advances in the Knowledge of the Mechanism, Diagnosis, and Treatment of Head Injury," American Journal of the Medical Sciences, 226:214-20, August, 1953.

Gurdjian, E. S., J. E. Webster, and H. R. Lissner. "Observations on the Mechanism of Brain Concussion, Contusion, and Laceration," Surgery, Gynecology, and Obstetrics, 101:680-90, December, 1955.

Gurdjian, E. S., et al. Studies on Experimental Concussion. Wayne University Neurosurgical Service, March, 1954.

Gurdjian, E. S., J. E. Webster, and H. R. Lissner. "Observations on Prediction of Fracture Site In Head Injury," Radiology, 60:2:226-35, February, 1953.

Gurdjian, E. S., J. E. Webster, and H. R. Lissner. "The Mechanism of Skull Fracture," Radiology, 54:3:313-39, March, 1950.

Hendler, Edwin and Commander Edward Wurzel. "The Design and Evaluation of Aviation Protective Helmets," The Journal of Aviation Medicine, 27:1:64-70, February, 1956.

Hawk, G. Kenneth. Football Injuries Survey for 1952 Season. Houghton, Michigan: Michigan College of Mining and Technology, March, 1953.

Hawk, G. Kenneth. Football Injuries for 1953 Season. Houghton, Michigan: Michigan College of Mining and Technology, March, 1954.

Lissner, H. R., E. S. Gurdjian, and J. E. Webster. "Mechanics of Skull Fracture," Experimental Stress Analysis. Report from Wayne University and Grace Hospital, May, 1950.

Lombard, Charles F. "How Much Force Can Body Withstand," Aviation Week, 50:3:20-28, January 17, 1949.

Lombard, Charles F., et al. "Voluntary Tolerance of the Human to Impact Accelerations of the Head," The Journal of Aviation Medicine, 22:2:109-16, April, 1951.

"New Helmet Protection Theory Advanced," Aviation Week, 50:4:18-20, January 24, 1949.

Protection, Incorporation, 6521 West Blvd., Inglewood 3, California. Personal correspondence dated June 1, 1956.

Strand, O. T. "Protective Helmet Impact Testing Equipment," Air Force Technical Report No. 5820, May, 1949, p.1-9.

Strand, O. T. "Impact Effect on Two Types of Protective Helmets," Air Force Technical Report No. 6020, May, 1950, Index iii.

White, William H. "Armor That Does As Much Harm As Good," Sports Illustrated, October 31, 1955, pp. 46-47.

APPENDIX

MH620 Calibration 1 mil/CM = .23

Position and Velocity	Setting	Readings					Average	G's Cal at 1 mil/CM
<u>Front</u>								
6 ft/sec	2 mil/CM	3.5	3.1	3.3	3.8	3.9	3.52	30.6
9	5	3.6	4.4		5.2	5.2	4.6	100.0
12	10	2.5	3.4	2.6	3.6	4.2	3.26	141.7
15	20	3.4	3.9	3.3	3.1	1.7	3.08	267.8
18	20	3.8	4.6	4.5	4.6	-	4.375	380.4
21	20	3.8	5.4	5.4	5.1	5.6	5.06	440
<u>Back</u>								
6 ft/sec	2 mil/CM	3.4	3.4	3.7	3.3	3.1	3.38	29.4
9	5	1.9	1.9	1.8	2.0	1.9	1.9	41.3
12	5	3.1	2.6	3.2	3.6	3.3	3.16	68.7
15	5 1st	off	3.6	4.0	4.0	2.8	3.6	156.5
	10 rest							
18	20	4.0	4.2	4.3	4.4	4.4	4.26	370.4
21	20 1st	--	2.4	2.1	2.0	2.4/	2.24	486.9
	.05 volt/CM					2.3		
<u>Right Side</u>								
6 ft/sec	2 mil/CM	3.5	3.6	3.7	3.0	3.8	3.52	30.6
9	5	2.6	2.7	2.8	2.7	2.6	2.68	71.3
12	5	3.4	5.6	--	5.9	--	4.97	108.
15	10 1st two	5.0	5.6	2.8	2.8	2.7/	5.3/	224.3
	20 rest					2.0	2.58	
18	20	3.6	3.9	4.1	4.0	4.4	4.0	347.8
21	05 volt/CM	2.1	2.1	2.0	2.2	2.2	2.12	460.9
<u>Top</u>								
6 ft/sec	2 mil/CM	2.3	2.2	2.4	2.6	2.8	2.46	21.4
9	2	3.9	3.7	4.0	3.6	3.8	3.8	33.0
12	2 1st	4.7	2.3	1.9	2.1	2.1/	2.08	45.2
	5 rest					2.0		
15	5	3.1	3.0	3.0	3.0	3.5	3.12	67.8
18	5 1st	off	3.3	3.7	3.8	3.3-	3.525	153.3
	10 rest							
21	20	3.2	3.8	3.2	3.7	3.4	3.46	300.9

S3131

Positi an Veloc
Fr
6 ft
9
12
15
18
21
B
6
9
12
15
18
21
Rig
6
9
12
15
18
21
6
9
12
15
18
21

S3131 Calibration 1 mil/CM = .23

Position and Velocity	Setting	Readings					Average	G's Cal at 1 mil/CM
Front								
6 ft/sec	2 mil/CM	3.6	3.7	4.6	3.5	3.7	3.82	33.2
9	5	2.4	2.8	2.4	2.3	--	2.475	53.8
12	5	4.4	4.2	--	--	4.8	4.47	97.2
15	10	3.3	4.1	4.6	4.8	5.4	4.44	193.0
18	20	3.4	3.3	3.4	4.2	3.8/ 4.1	3.7	321.7
21	.05 volt/CM	2.2	2.1	2.0	2.1	1.8	2.04	443.5
Back								
6 ft/sec	2 mil/CM	4.1	3.9	4.6	4.6	4.2	4.28	37.2
9	5	2.4	2.5	2.5	2.7	--	2.525	54.9
12	5	3.1	3.0	3.2	3.1	3.2	3.12	67.8
15	10	1.9	2.0	2.2	1.9	2.0	2.0	87.
18	10	2.3	2.9	3.5	3.2	2.4	2.86	124.3
21	10 1st 20	off	3.8	1.3	3.9	3.7/ 3.2	3.18	276.5
Right Side								
6 ft/sec	2 mil/CM	3.1	3.4	3.5	3.3	3.5	3.36	29.2
9	5	2.0	2.0	2.2	2.2	2.2	2.12	46.1
12	5	3.0	3.2	2.9	2.9	2.7	2.94	63.9
12	10	1.8	2.0	1.8	1.8	1.9	1.86	80.9
18	10	2.3	2.4	2.3	2.2	2.3	2.3	100.0
21	10	3.4	3.4	3.4	3.8	4.0	3.6	156.5
Top								
6 ft/sec	2 mil/CM	2.3	2.1	2.0	2.0	2.4	2.16	18.8
9	5	1.5	1.4	1.3	1.5	1.4	1.42	30.9
12	5	1.8	1.5	1.5	1.4	1.7	1.58	34.3
15	5	1.9	2.0	2.0	1.9	2.0	1.96	42.6
18	5	2.0	2.9	2.3	3.5	2.9	2.72	59.1
21	10 for 4 20 rest	1.4	2.0	5.1	5.4	2.0/ 1.3/ 2.6	3.475/ 1.97	161.2

RK-RK4 Calibration 1 mil/CM = .23

Position and Velocity	Setting	Readings					Average	G's Cal at 1 mil/CM
Front								
6 ft/sec	2 mil/CM	3.5	3.0	3.1	3.2	3.1	3.18	27.7
9	5	2.6	3.0	2.8	2.7	2.8	2.78	60.4
12	5	4.4	4.0	4.1	4.6	3.7	4.16	90.4
15	10	2.9	2.4	3.0	2.2	2.4	2.58	112.2
18	10 1st 20 rest	5	2.0	1.7	2.2	1.5/ 1.7/ 2.5	1.93	167.8
21	20	3.8	3.5	3.9	3.4	3.2	3.56	309.6
Back								
6 ft/sec	2 1st 5 rest	4.9	1.7	1.9	1.8	2.0/ 1.8	1.84	40
9	5	2.8	2.9	2.6	2.9	2.8	2.8	60.9
12	5	3.6	4.0	3.7	3.6	--	3.725	80.98
15	5	4.3	4.7	4.4	4.8	4.4	4.52	98.3
18	10	2.8	2.9	2.5	2.6	2.7	2.70	117.4
21	10 for 3 20 rest	4.1	off	off	3.7	4.6/ 5.1	4.375	380.4
Right Side								
6 ft/sec	2 mil/CM	2.4	2.4	3.5	2.5	2.9	2.74	23.8
9	2	4.9	4.8	4.5	5.3	--	4.875	42.4
12	5	2.7	2.5	2.6	2.7	2.4	2.58	56.1
15	5	2.8	2.9	3.0	3.1	2.9	2.94	63.9
18	5	3.2	3.2	3.2	3.2	2.9	3.14	68.3
21	5 1st 10 rest	4.0	5.0	off	off	4.7/ 3.4/ 5.9	4.6	200.0
Top								
6 ft/sec	2 mil/CM	3.9	3.9	3.6	3.8	3.2	3.68	32.0
9	5	2.3	2.2	2.3	2.2	1.9	2.18	47.4
12	5	2.8	2.9	2.8	2.7	2.6	2.76	60.0
15	10	1.8	1.7	1.7	1.7	1.7	1.72	74.8
18	10	1.7	1.9	1.9	1.9	1.9	1.86	80.9
21	10	2.2	2.5	3.0	3.3	3.3	2.86	124.3

MH612 Calibration 1 mil/CM = .23

Position and Velocity	Setting	Readings					Average	G's Cal at 1 mil/CM
Front								
6 ft/sec	5 mil/CM	1.4	1.6	1.4	1.6	1.6	1.52	32.6
9	10	.8	.9	1.0	1.2	1.0	.98	42.6
12	20							
15	20		Inability to accurately measure pip					
18	20							
21	20							
Back								
6 ft/sec	5 mil/CM	1.0	1.0	1.0	1.0	.8	.96	20.9
9	5	1.6	1.8	1.7	1.8	1.9	1.76	38.3
12	10	--	1.6	1.1	1.4	1.5	1.4	60.9
15	20		Inability to accurately measure pip					
18	20							
21	.05volts CM	-	1.2	.9	.9	1.1	1.025	222.8
Right Side								
6 ft/sec	5 mil/CM	.7	.7	.7	.6	.7	.68	14.8
9	5	1.1	1.2	1.2	1.1	1.2	1.16	25.2
12	5							
15	5		Inability to accurately measure pip					
18	5							
21	10							
Top								
6 ft/sec	2 mil/CM	2.8	2.5	2.7	2.5	3.0	2.7	23.5
9	2	4.3	3.6	3.8	3.4		3.775	32.8
12	5	1.9	1.8	1.9	2.0	2.0	1.92	41.7
15	5	2.6	2.3	2.4	2.4	2.5	2.44	53.0
18	5	4.0	4.3	5.3	4.6		4.55	98.9
21	5 1st 10 2nd 20 rest	off	off	2.8	2.8	2.3/ 3.0	2.725	236.96

RK-TK5 [M.S.U. Helmet] Calibration 1 mil/CM = .23

Position and Velocity	Setting	Readings					Average	G's Cal at 1 mil/CM
<u>Front</u>								
6 ft/sec	2 mil/CM	2.3	2.7	2.3	2.4	2.4	2.42	21.1
9	2 for 1st 5 rest	5.1	1.8	1.6	1.8	1.7/ 1.7/ 1.8	1.73	37.6
12	5	2.8	2.5	2.7	2.6	2.4	2.6	56.5
15	5	3.4	3.4	--	3.3	3.5	3.4	73.9
18	10	2.0	2.0	2.2	2.2	2.1	2.1	91.3
21	10	3.8	4.0	4.1	4.8		4.175	181.5
<u>Back</u>								
6 ft/sec	2 mil/CM	3.6	3.2	3.5	3.4	3.6/ 3.6	3.48	30.3
9	5	1.8	1.7	2.0	1.7	1.9	1.82	39.6
12	5	2.6	2.6	2.6	2.4	2.4	2.52	54.8
15	5	3.0	2.8	3.0	2.8	2.7	2.86	62.2
18	5 1st 10 rest	off	2.8	2.2	3.6	1.7/ 3.4	2.74	119.1
21	20	3.4	1.7	3.5	4.3	4.1	3.4	295.7
<u>Right Side</u>								
6 ft/sec	2 mil/CM	2.7	3.2	3.5	3.0	3.1	3.1	26.96
9	5	2.0	2.0	1.8	2.0	1.8/	1.9	41.3
12	5	2.5	2.4	2.3	2.2	2.7	2.34	50.9
15	5	3.0	3.0	3.1	3.0	2.8	2.98	64.8
18	10	1.7	1.6	1.7	1.7	1.7	1.68	73.01
21	10	1.7	1.8	1.7	1.6	1.6	1.68	73.01
<u>Top</u>								
6 ft/sec	2 mil/CM	3.3	3.5	3.4	3.4	3.3	3.38	29.4
9	2 1st 5 rest	5.1	2.1	2.0	2.1	2.1/ 2.1	2.08	45.2
12	5	2.7	2.7	2.5	2.4	2.7	2.6	56.5
15	10	1.6	1.7	1.4	1.4	1.3	1.48	64.3
18	10	1.6	1.8	1.8	1.8	1.7	1.74	75.7
21	10	2.0	1.6	2.1	1.7	1.6	1.8	78.3

WF2010 Calibration 1 mil/CM =.23

Position and Velocity	Setting	Readings					Average	G's Cal at 1 mil/CM
Front								
6 ft/sec	2 mil/CM	1.9	2.0	2.4	2.5	2.0	2.16	18.8
9	2	4.1	4.4	4.2	4.2	5.0	4.38	38.1
12	5	3.2	3.2	3.0	2.7	3.3	3.08	66.95
15	10	2.7	3.5	3.0	3.4	3.6	3.24	140.9
18	20	3.0	3.1	3.3	2.9	2.8	3.02	262.6
21	20	4.0	4.2	4.3	4.1	4.0	4.12	358.3
Back								
6 ft/sec	2 mil/CM	2.5	2.3	2.0	2.4	2.3	2.3	20.0
9	2	3.7	3.4	4.8	3.8	4.4	4.02	34.96
12	5 1st 10 rest	--	2.8	2.1	2.2	2.4	2.375	103.3
15	20	1.5	2.3	2.4	2.6	2.6	2.28	198.24
18	20	3.7	3.7	3.9	3.7	3.6	3.72	323.5
21	20	4.2	4.0	4.3	4.6	4.5	4.32	375.7
Right Side								
6 ft/sec	2 mil/CM	2.3	2.1	1.7	2.0	2.3	2.08	18.1
9	5	1.3	1.2	1.4	1.3	1.4	1.32	28.7
12	5	1.5	1.4	1.5	1.6	1.4	1.48	32.2
15	5	2.1	2.0	2.3	2.2	2.2	2.16	46.96
18	5 1st 10 rest	--	3.0	2.6	2.7	3.4/ 3.7	3.08	133.9
21	20	3.1	3.0	3.3	--	3.2	3.15	273.9
Top								
6 ft/sec	2 mil/CM	2.0	2.6	2.0	2.0	2.0	2.12	18.4
9	2	3.4	3.4	3.2	3.2	3.3	3.3	28.7
12	5	2.1	2.0	2.0	2.1	2.0	2.04	44.3
15	5	4.1	3.8	4.0	4.5	4.2	4.12	89.6
18	10 1st 20 rest	5.6+	3.4	3.4	3.8	3.5/ 3.6	3.54	307.8
21	20	4.6	4.7	5.0	4.5	4.5	4.66	405.2

S3122 Calibration 1 mil/CM = .23

Position and Velocity	Setting	Readings					Average	G's Cal at 1 mil/CM
Front								
6 ft/sec	2 mil/CM	2.3+	2.2	2.3	2.1	2.3	2.24	19.5
9	2	3.8	3.0	3.5	3.5	3.2	3.4	29.6
12	5	4.4	--	2.7	4.2	3.6/ 4.3	3.84	83.5
15	10	3.2	3.8	1.1	1.2	2.2	2.3	100.0
18	10	4.7	3.1	3.3	4.1	4.1	3.86	167.8
21	20	3.6	3.7	3.9	3.6	4.0	3.76	326.96
Back								
6 ft/sec	2 mil/CM	2.4	2.8	2.3	2.7	2.5	2.54	22.1
9	2	3.7	4.0	--	3.8	3.5	3.75	32.6
12	5	1.8	2.0	1.7	1.7	1.8	1.8	39.1
15	5 1st 10 rest	--	3.4	3.5	3.5	3.0	3.35	145.7
18	20	2.8	3.1	3.0	3.1		3.0	260.9
21	20	4.0	4.1	4.2	4.3	4.3	4.18	363.5
Right Side								
6 ft/sec	2 mil/CM	2.1	2.3	2.2	2.1	1.7	2.08	18.1
9	2	3.2	3.0	3.7	3.1	3.6	3.32	28.9
12	5	2.0	2.0	1.9+	2.1	2.0	2.0	43.5
15	5	2.7	2.5	2.6	2.6	2.5	2.58	56.1
18	10	1.8	1.7	1.7	1.7	1.7	1.72	74.8
21	10	1.8	1.7	1.7	1.9	1.6	1.76	76.5
Top								
6 ft/sec	2 mil/CM	2.0	1.8	2.1	2.0	2.0	1.98	17.2
9	2	3.0	3.1	3.2	3.4	3.0	3.14	27.3
12	5	1.7	1.8	1.8	1.8	1.7	1.76	38.3
15	5	2.3	2.6	2.4	2.4	2.0	2.34	50.9
18	5 1st 10 rest	off	3.4	4.2	4.0	4.1/ 4.6	4.06	176.5
21	10 1st 20 rest	off	4.5	4.0	4.3	4.6/ 4.5	4.38	380.9

ME610 [Second Run] Calibration 1 mil/CM = .23

Position And Velocity	Setting	Readings					Average	G's Cal at 1 mil/CM	
Front									
6 ft/sec	2 mil/CM	3.7	3.7	3.6	3.6	3.4	3.6	31.3	
9	5	3.3	4.0	2.3	2.0	2.0	2.72	59.1	
12	5 1st 10 rest	--	2.2	2.0	2.3	2.0	2.125	92.4	
15	10	4.0	4.0	3.0	3.9	3.7	3.72	161.7	
18	20	3.3	3.2	3.0	2.6	2.7	2.96	257.4	
21	20 for 2 .05 volts/CM	4.0	4.2	1.6	1.5	1.6	1.57	341.3	
Back									
6 ft/sec	2 mil/CM	2.2	2.5	2.7	2.8	2.7	2.58	22.4	
9	5	1.4	1.3	1.4	--	1.6	1.425	30.98	
12	5	2.0	2.1	1.8	2.0	2.0	1.98	43.0	
15	5	2.9	2.8	2.8	3.0	2.7	2.84	61.7	
18	5 1st 2 10	4.0	4.3	2.1	2.2	2.1/ 2.0	2.1	91.3	
21	10	3.5	4.2	2.7	4.0		3.6	156.5	
Right Side									
6 ft/sec	2 mil/CM	2.7	3.0	2.5	2.7	2.8	2.74	23.8	
9	2	3.4	3.8	3.2	3.3	3.8	3.5	30.4	
12	5	2.0	1.8	1.9	2.1	2.1	1.98	43.0	
15	5	2.5	2.6	2.4	2.3	2.5	2.46	53.5	
18	10	1.5	1.6	1.5	1.5	1.6	1.54	66.97	
21	10	1.8	2.4	2.0	2.6	2.7	2.3	100.0	
Top									
6 ft/sec	2 mil/CM 2nd	3.0	2.8	2.7	2.6	3.0	2.82	24.5]	25.1
	1st	3.0	2.9	2.7	3.0	3.1	2.94	25.6]	
9	2 2nd	4.2	4.2	4.5	3.9	4.2	4.2	36.5]	36.7
	1st	4.6	4.5	4.0	4.3	3.8	4.24	36.9]	
12	5 2nd	2.2	2.3	2.2	2.0	2.0	2.14	46.5]	48.1
	1st	2.3	2.3	2.2	2.2	2.4	2.28	49.6]	
15	5	2.9	2.8	2.8	2.5	2.7	2.73	59.3	
18	10	1.4	1.6	1.5	1.5	1.6	1.52	66.1	
21	10	1.7	1.7	1.7	1.7	1.7	1.7	73.9	

WF2000 [Second Run] Calibration 1 mil/CM = .23

Position and Velocity	Setting	Readings					Average	G's Cal at 1 mil/CM
Front								
6 ft/sec	2 mil/CM	2.6	2.8	2.5	2.8	2.8	2.7	23.5
9	2 1st 5 rest	4.8	--	2.2	2.0	1.9/ 1.8/ 2.3	2.04	44.3
12	5	3.6	3.5	3.8	4.1	4.0	3.8	82.6
15	10	4.0	3.8	3.5	4.7	3.8	3.96	172.2
18	20	3.4	3.1	3.4	3.5		3.35	291.3
21	.05 volts/ CM	1.6	1.6	1.8	1.5		1.625	353.3
Back								
6 ft/sec	2 mil/CM	3.2	3.8	3.6	3.1	3.1	3.36	29.2
9	5	2.2	2.0	2.0	1.8	2.0	2.0	43.5
12	5	2.6	2.7	2.7	2.7	2.8	2.7	58.7
15	10	2.1	1.6	2.0	2.2	1.7	1.92	83.5
18	10 1st 20 rest	4.9	1.4	2.2	1.8	2.1	1.875	163.0
21	20	2.7	2.9	2.2	3.1	2.8	2.74	238.3
Right Side								
6 ft/sec	2 mil/CM	2.7	2.5	2.5	2.4	2.6	2.54	22.1
9	5	1.5	1.4	1.4	1.4	1.6/ 1.5	1.47	31.96
12	5	2.0	2.0	2.0	2.0	2.2	2.04	44.3
15	5	2.5	2.7	2.7	2.6	2.5	2.6	56.5
18	10	1.7	2.2	1.7	1.6	1.7	1.78	77.4
21	10	2.3	2.7	3.4	3.0	3.0	2.88	125.2
Top								
6 ft/sec	2 mil/CM	2.3	2.4	2.6	2.6	2.2	2.42	21.0
9	2	3.1	3.1	3.7	3.3	3.1	3.26	28.3
12	2	4.0	4.0	4.0	4.6	4.0	4.12	35.8
15	5	2.0	1.8	2.1	2.1	1.6	1.92	41.7
18	5	2.0	2.0	2.0	2.1	2.3	2.08	45.2
21	5	2.7	3.3	3.0	3.5		3.125	67.9

Date Due

~~Dec 15 '58~~			
~~Jan 59~~			
~~59~~			
~~Feb 23 59~~			
~~29 Ap 59~~			
~~59~~			
~~Jul 59~~			
~~23~~			
~~1 Sep 59~~			
~~28~~			
AUG 8	1960		
~~NOV 14 1961~~			
~~JAN~~			
~~AUG 7 1963~~			
~~AUG 15 1963~~			
~~MAY 23 1964~~			

Demco-293