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Measurement of Gunner Head Acceleration During Firing of High Impulse Guns on Lightweight Armored Vehicles and the Assessment of Gunner Tolerance to such Impact

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This report provides gunner head acceleration data from the live firing of 105 mm and 152 mm turret guns on the M-551 and M-60 tanks. The head accelerations were measured with a gunner volunteer and with an anthropomorphic dummy with stationary tanks. The head acceleration values ranged from 4 Gs in the heavy M-60 tank up to 14 Gs in the light M-551 tank. A comparison of these acceleration levels to the known human tolerance data indicates no problem for single exposures for most gunners, but it is possible that some gunners will experience headaches and neck strain. The effect of repeated exposures at the 14 G level is not known and further research is recommended.

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INTRODUCTION

The stated intent of the US Army and US Marine Corps to field a lightweight armored vehicle, equipped with a high-impulse gun, has raised concerns about the possible effects of the recoil on the gunner. These concerns are primarily about the effects on the physical and psychological condition of the gunner and on his ability to maintain an operationally-acceptable rate of accurate fire. The Human Engineering Laboratory (HEL), Aberdeen Proving Ground, Maryland, initiated an effort to address these questions, but was hindered by a lack of data describing the recoil forces transmitted to the gunner. HEL learned that the US Navy and US Marine Corps also were concerned about potential problems and were conducting firing tests with an M-551 Sheridan tank to obtain vehicle response data. This represented a good opportunity to obtain transmitted recoil force data for the gunner's position.

A meeting was held 28 January 1981, at the Naval Biodynamics Laboratory (NBDL) at Michoud Station, Louisiana, to establish and coordinate a test plan to gather the transmitted recoil data in conjunction with Navy tests at the Naval Surface Weapons Center (NSWC) at Dahlgren, Virginia (USAARL trip report by Goldstein, 4 February 1981). Subsequent to the 4 February 1981 NBDL meeting, HEL informally requested the United States Army Aeromedical Research Laboratory (USAARL) to gather transmitted recoil data and to relate that data to human head impact tolerance. USAARL, with the encouragement of the US Army Medical Research and Development Command (USAMRDC), agreed to assist HEL and NSWC in gathering the recoil data.

Initially tests were scheduled for mid-April 1981, but conflicts in programmed tests at NSWC caused numerous changes in the schedule, with the test finally being conducted the week of 17 August 1981 at NSWC.

A second test series was conducted from 30 November to 7 December 1981, at NSWC. HEL desired firing data from an M-60 A2 and from an operational M-551 with an anthropometric dummy, and with a human in the gunner's position. HEL provided the test protocol, the human subject, obtained human use approval, and provided the vehicles and ammunition to NSWC for this series of tests.*

The results of these tests were used by HEL to develop mathematical equations for the prediction of the gunner's firing response in future vehicle configurations, but validation of the equations will require some additional test firings. These results also will be used to program the US Army Tank Command Ride Simulator to evaluate the effects of multiple gun recoil on gunner firing accuracy.

The dummy and human head and chest accelerations measured in the tests reported here were provided to HEL in the 1982 and 1983 time frame, but recent requests for data on repetitive head impact tolerance prompted the publication of this report.

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* Funding for this series was provided by the Mobile Protected Weapon System (MPWS) project office at the Marine Corps Development Center, Quantico, Virginia. (The MPWS was originally a US Marine Corps project.) After Congress mandated a joint Army-Marine Corps program, the name was changed to Mobile Protected Gun System (MPGS) with the program manager residing in the US Army Tank-Automotive Command (TACOM), Detroit, Michigan.

METHODS

The initial test series began in August 1981 with the M-551 Sheridan vehicle equipped with the standard 152 mm gun (Figure 1). An instrumented dummy was placed in the gunner's position with his head against the brow pad of the night-firing sight. Five shots were fired with the barrel pointing straight ahead over the front of the vehicle (0 degree azimuth, 0 degree elevation). The dummy's head was repositioned against the brow pad prior to each shot (Figure 2). Upon completion of the 10 shots, the 152 mm gun was replaced with the 105 mm gun and the same shot sequence was repeated.

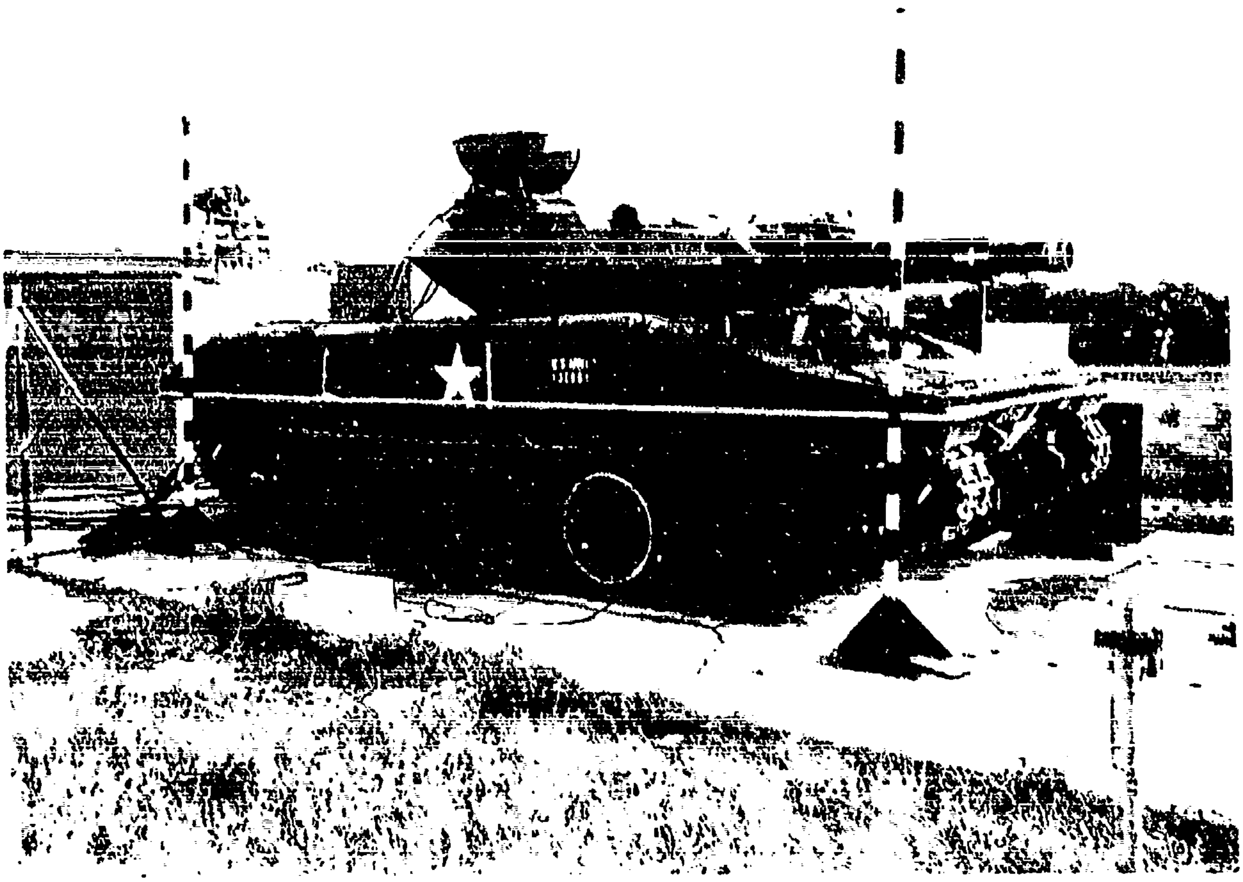

FIGURE 1. M-551 Sheridan Test Vehicle with 152 mm Gun (Aug 81).

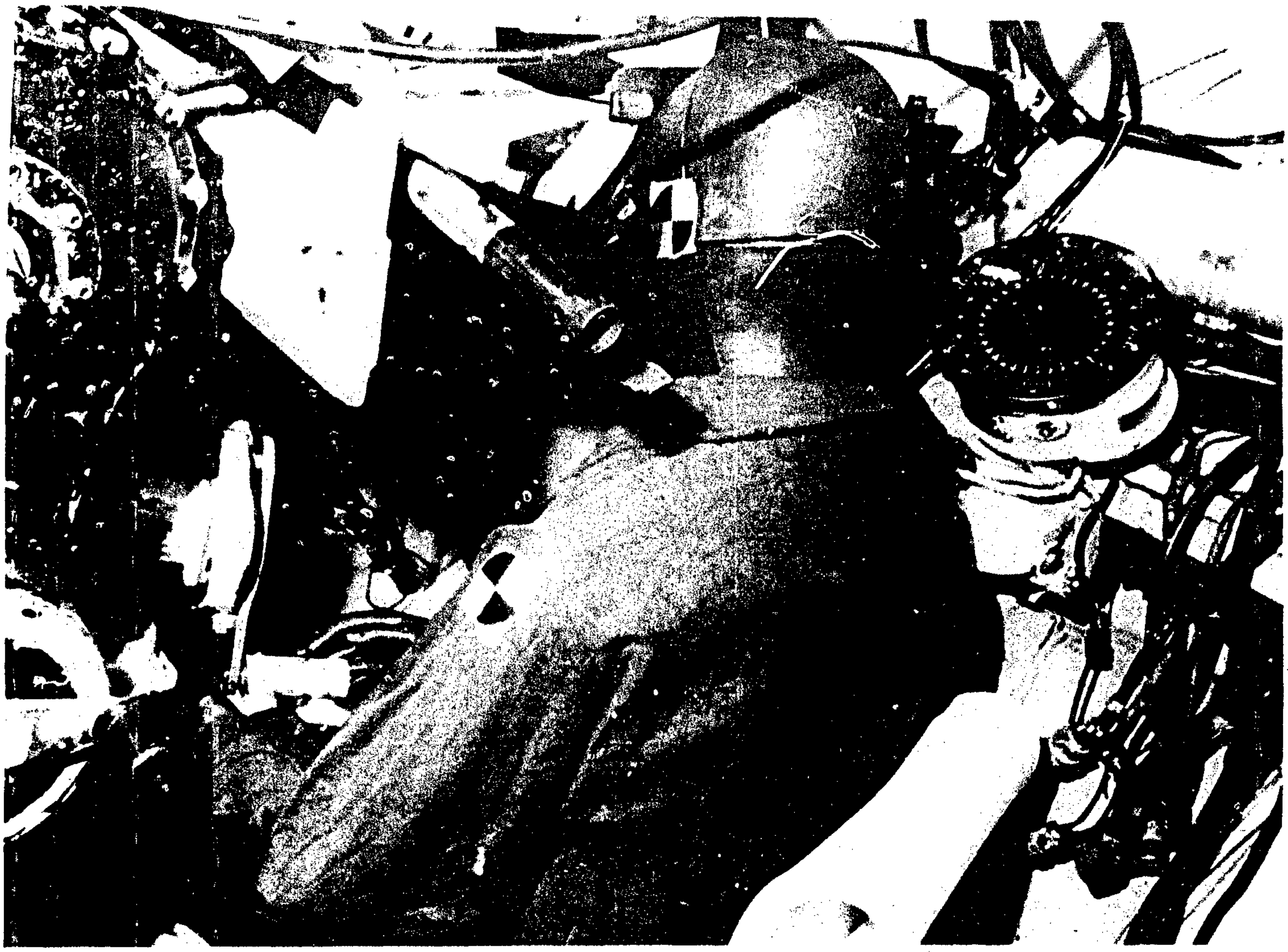

FIGURE 2. Instrumented Dummy in M-551 Gunner's Position.

The November-December 1981 test series began with the M-60 A2 vehicle (Figure 3). The gun was the same 152 mm gun that is standard on the Sheridan. The ammunition used in all the 152 mm firings was the standard high-explosive, antitank (HEAT) round. The instrumented dummy was placed in the M-60 A2 in the gunner's position (Figure 4). His head had to be bent forward approximately 40 degrees relative to his torso in order to have his forehead in contact with the brow pad. Five shots were fired over the front (0 degree azimuth, 0 degree elevation) and five were fired over the right side (90 degrees azimuth, 0 degree elevation). The dummy then was removed and the instrumented human subject was seated in the gunner's position (Figure 5). Five shots were fired over the right side (90 degrees azimuth, 0 degree elevation) and five were fired over the front (0 degree azimuth, 0 degree elevation). The series then was repeated in the Sheridan M-551 (Figure 6) with the human subject in the gunner's position (Figure 7). The dummy then was placed in the M-551 for the final shots (Figure 8). Two rounds of ammunition failed to fire, so only three shots were fired from the side position (90 degrees azimuth, 0 degree elevation). The final five rounds were fired over the front (0 degree azimuth, 0 degree elevation).

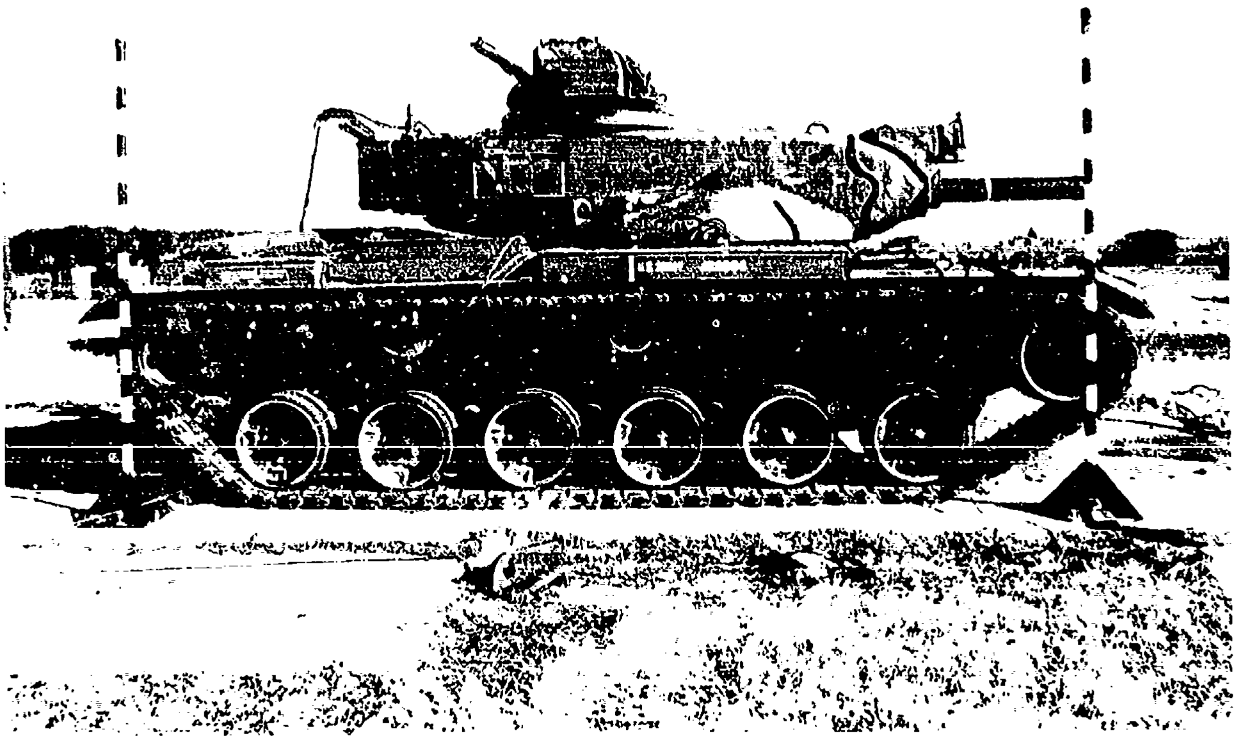

FIGURE 3. M-60 A2 Test Vehicle with 152 mm Gun (Dec 81).

FIGURE 4. Instrumented Dummy in M-60 A2 Gunner's Position.

FIGURE 5. Instrumented Human Subject in M-60 A2 Gunner's Position.

FIGURE . M-551 Sheridan Test Vehicle (Dec 81).

FIGURE 7. Instrum ed Human Subject in M-551 Gunner' osition.

FIGURE 8. Instrumented Dummy in M-551 Gunner's Position.

All vehicle response data were collected by NSWC. Only dummy head and chest and human head and torso acceleration data were collected by USAARL for this report.

MATERIALS

The vehicles used were two M-551 Sheridans and a M-60 A2 (Table 1). The table shows the M-60 to be more than three times the mass of the M-551 Sheridan. The first test firing used a Sheridan that was not considered fully operational because some equipment had been removed. The second firing test used a fully-operational M-551 and a fully-operational M-60 A2. This was necessary because a human gunner was being used in the second test and only a fully-operational vehicle was acceptable for safety purposes.

TABLE 1
Description of Test Tanks

TANK IDENTITY	TANK MISSION	TANK MASS (kg/lb)	GUN* TURRET MASS (kg/lb)	GUN BARREL INSIDE DIA (mm)	GUN RECOIL MASS (kg/lb)	REMARKS
M-551 Sheridan (Modified)	Air Mobile	15,193/ 33,500	4,853/ 10,700	105	1,230/ 2,711	Fires conventional projectile.
M-551 Sheridan	Air Mobile	15,193/ 33,500	4,853/ 10,700	152	499/ 1,100	Fires "Shillelagh" missile or onventional projectile.
M-60 A2	Main Battle Tank	51,250/ 113,000	14,996/ 33,000	152	499/ 1,100	M-60 chassis fitted with modified (152 mm) turret. Fires "Shillelagh" or conventional projectile.
M-60	Main Battle Tank	54,600/ 120,000	14,966/ 33,000	105	1,230/ 2,711	Fires conventional projectile.

* Monocular sights used in both tanks.

The standard brow pad used by the gunner in both the M-551 and M-60 tanks consisted of very soft, flexible 4 cm x 6 cm foam material of approximately 2.5 cm thickness. The pad provided only minimal energy absorption.

All Sheridan firings used the standard HEAT round. This round weighs 22 kg and develops a muzzle velocity of approximately 683 m/sec (2,240 ft/sec). The momentum of the round at the muzzle is approximately 15,000 N-sec (3,374 lb-sec). The M-60 105 mm gun used in the first Sheridan firing test fired an inert training round that simulates the HEAT round. That round weighs 21.8 kg and develops a muzzle velocity of approximately 1,173 m/sec (3,848ft/sec) for a developed momentum of 25,550 N-sec (5,740 lb-sec).

The dummy used in both tests was an Alderson Research Laboratories model CG-98*. This dummy was designed for use in parachute testing. The overall dimensions, mass distributions, and range of limb motions match that of a corresponding 98th percentile human, but the design makes no attempt to match the kinetics of human motion. The joints are simple pinned connections with metal-to-metal contact which tend to cause high-frequency "ringing" when loaded suddenly. The head mass is not rigidly attached to the torso; therefore, it can be used to determine gross acceleration effects of the head's center of gravity (C.G.). The torso consists of a metal-walled cavity which also is subject to "ringing." As a result, acceleration data obtained from the dummy usually has a significant amount of high-frequency "ringing" included that would not be present in a human subject. The chest data presented in this report was filtered at 200 Hz to remove the "ringing."

The instrumentation used in the dummy was a triaxial accelerometer consisting of three orthogonally-mounted Endevco model 2226C accelerometers* in the head and a Columbia model 510-TX triaxial accelerometer in the chest*. The head accelerometer was mounted at the point of intersection of a line through the external ear openings (center of gravity of the head) and the midsaggital plane. The chest accelerometer was mounted on the midsaggital plane of the metal cavity wall at a point in line with the normal location of the heart. The transducer outputs were fed to six Endevco model 2240 charge amplifiers* stored in the chest cavity. From there the signals were transmitted to a Metraplex Series 300 FM multiplex signal conditioner* which provided excitation, gain,

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* See equipment manufacturers at Appendix A.

and offset as required. All signals were frequency modulated to the Inter-Range Instrumentation Group (IRIG) constant bandwidth subcarrier "A" channels (deviation ± 2 kHz). The multiplexed signal was recorded on a Sangamo Sabre VI 14 channel "I" band recorder*. An IRIG time code format "B" signal obtained from the test range broadcast also was recorded for reference purposes. In addition, a voice channel was used to record comments and to identify the recorded data. The multiplexed data were demodulated and fed through a 400-Hz, 5-pole linear phase low pass filter to the analog-to- digital converters of the Systems Engineering Laboratory 85/Engineering Associated, Inc. hybrid computer* for processing. The signals were sampled at a 5714-Hz rate and stored on a 9-track digital tape. Graphic presentation of the traces was done by using a Tektronix 4010 terminal and 4631 hard copy unit*. These traces then were used in preparing this report.

Instrumentation for the human subject was a problem because the package had to be mounted externally and could not be a source of potential injury for the subject. No such instrumentation package was available "off the shelf." The researchers contacted the Naval Biodynamics Laboratory, New Orleans, Louisiana (NBDL) for guidance because of their extensive experience in instrumentating human subjects for acceleration measurements. Their system provides an acceptably rigid coupling to the head, but it requires custom fitting to the subject and involves several different manufacturing steps performed by different groups. This process usually takes a minimum of 6 to 8 weeks to complete. The scheduled test date didn't allow sufficient time to procure a mount of their design.

A second problem with the NBDL system was the accelerometer location in front of the mouth on a frame that is coupled to the upper teeth and gum. This was viewed as less than desirable for this test because of the possibility of the subject striking some part of the sight with the accelerometer mounted and being injured. The researchers elected to modify and use an acceleration measurement device already in our possession. The device used includes five Entran EGAL125-10D piezoresistive accelerometers* mounted in a bar assembly. It is designed to be used as a mouth-mounted acceleration measurement device.

The device was modified to permit mounting on a rigid skullcap made by forming thermoplastic sheets to a plaster cast duplicate of the subject's head. The skullcap was held on the subject's head by straps attached to a custom-molded chin cup (Figure 9).

The human volunteer subject was chosen to be nearly the same size as the dummy. The subject's stature was 183.2 cm, his weight was 195 lb, and his sitting height was 91.1 cm.

FIGURE 9. Instrumented Human Subject.

The system was not as rigid as desired in that relative motion between the subject's head and the skullcap could occur. This tended to introduce higher frequency acceleration components into the data output (especially the z-axis) that would not be present if the measurement device were rigidly attached to the skull bone.

Additional stiffening and dampening materials were added to the accelerometer mount itself to minimize resonant frequency problems, but nothing could be done about the basic problem of skin movement relative to the skull beyond tightening the straps as much as the subject could tolerate.

A triaxial accelerometer consisting of three Endevco* model 2265-20 piezoresistive accelerometers mounted on an aluminum block was attached to the position of the first thoracic vertebra of the subject by using a plastic cup filled with molding compound and held in place with a strap harness around the abdomen and over the shoulders. This is similar to the method used by NBDL. However, the lack of a rigid coupling between the subject's skeletal torso and the accelerometer transducer caused the same problem of high frequency oscillations in the acceleration traces.

Because of the close quarters in the tanks and the need to remove the accelerometer cables for calibration checks, the accelerometers were mounted in the dummy with the axes aligned as shown in Figure 10. This alignment should be kept in mind when comparing the acceleration traces to other reports on acceleration. A similar problem was encountered with the human instrumentation. The accelerometer mount used for the human head was designed for mouth installation. The researchers placed it at the back of the subject's head and thus changed the reference axis system. The human acceleration reference system is shown in Figure 11.

The movable brow pad was adjustable so that the center of contact was aligned with the C.G. of the head and the impact load was oriented along the fore-aft (X) axis of the torso (Figures 7 and 8, pages 13 and 14).

A standard tanker's helmet was not worn by either the human subject or the dummy. The 1.4 kg mass of the helmet would have tended to reduce the head acceleration values; therefore, the present acceleration data are conservative. Since tankers tilt the helmet backward enough to permit forehead-to-brow pad contact during firings, the deletion of the helmet affected the head mass alone and not the mechanism of energy transfer.

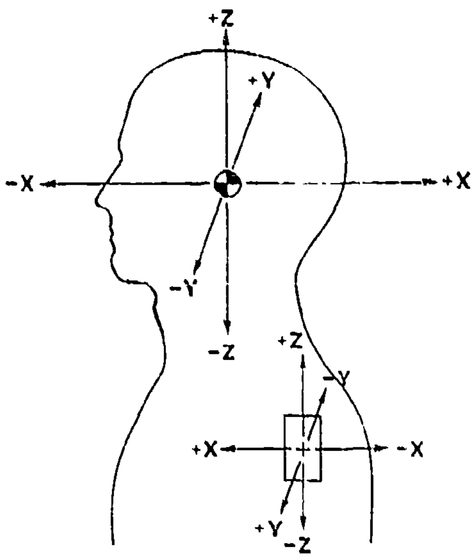

FIGURE 10. Instrumented Dummy Axes.

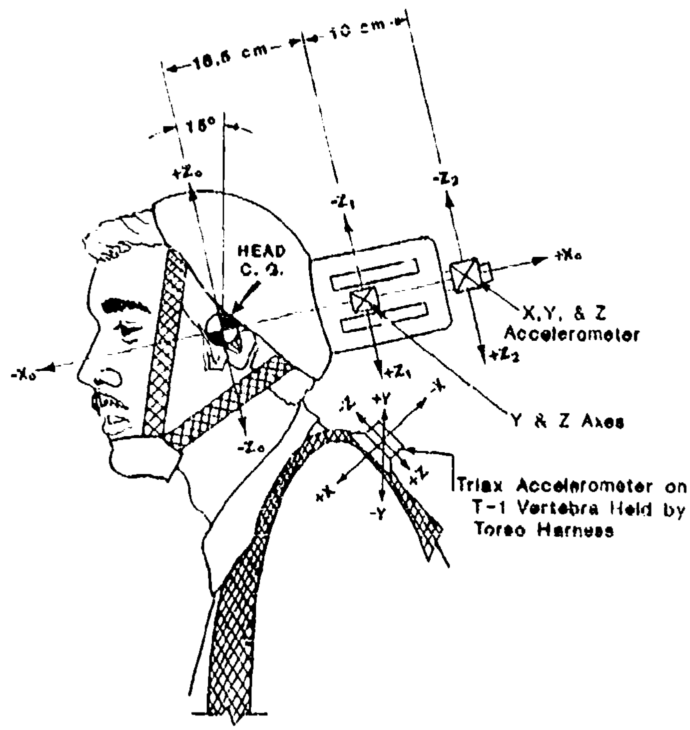

FIGURE 11. Instrumented Human Acceleration Measurement Axis System.

RESULTS AND DISCUSSION

A rather large body of data was generated during these tests. Rather than reproduce it all in this report, selected curves representing the response of the dummy or human for each test condition are provided (Appendix B, Figures B-1 through B-28). No significant difference in subject response for each firing of a given gun was noted.

The head x-axis acceleration was the most significant measurement taken, and these were fairly consistent; however, the "x" accelerometer was orientated at approximately 40 degrees from the M-60 A2 tank's x-axis (due to the excessive dummy sitting height) so that an upward z-axis acceleration also is read on the head in the M-60 tests.

The z-axis and y-axis curves were comparable in overall shape and time duration, but variations in peak accelerations were present. These variations are caused by the rigid metal torso and metal-jointed neck in the dummy, and by the lack of a rigid accelerometer attachment to the head in the human. However, the data is usable for making a general head injury risk determination for gunners using these type vehicles.

A preliminary analysis was done prior to the actual firing tests to try to predict the x- (longitudinal) axis accelerations that would be generated. The US Army Tank-Automotive Command (TACOM) indicated that the measured reaction force at the gun trunnions during firing was 619,606 N (139,300 lb) for the M-551. Using the turret and tank weights shown in Table 1, a range of possible x-axis accelerations can be calculated as follows:

The gun reaction force is assumed to act along the x-axis of the tank. If the turret moves (displaces in the turret ring) independently of the tank, the peak acceleration will be determined by: $a=F/m$.

Thus for the M-551: $$a_{turret} = \frac{619{,}606\ N}{4{,}853\ kg} = 127.7\ m/s^2 = 13.0\ G$$

For the M-60 A2: $$a_{turret} = \frac{619{,}606\ N}{14{,}966\ kg} = 41.4\ m/s^2 = 4.2\ G$$

If the vehicle (turret and tank) moves as a rigid body, then the larger mass must be used in the formula.

For the M-551: $$a_{tank} = \frac{619{,}606\ N}{15{,}193\ kg} = 40.8\ m/s^2 = 4.2\ G$$

For the M-60 A2: $a_{tank} = \frac{619,606\ N}{51,247\ kg} = 12.1\ m/s^2 = 1.2\ G$

Therefore, if the dummy or human subject's head was connected firmly to the vehicle brow pad, we expected to measure an x-axis acceleration from 4.2 G to 13 G in the M-551 and from 1.2 G to 4.2 G in the M-60 A2. The measured test accelerations agreed fairly well with the predictions. It should be noted that the dummy's brow was proximal to the brow pad while the human subject actually compressed the pad with his brow; thus, the human was subjected to less "dynamic overshoot" acceleration than was the dummy. Table 2 shows the mean peak head accelerations for both test series.

An attempt was made to evaluate the performance of the brow pad used in the test tanks as indicated in Figure 12. Quasistatic compression tests were conducted to obtain typical load-deformation data. The pads tested were the standard production configuration with a 2.5 cm thickness for these vehicles. Both the standard production and a proposed new design pad were tested. The standard production pad consisted of a relatively soft (latex rubber type) foam while the proposed new pad consisted of a much stiffer polyvinyl chloride (PVC) foam manufactured by the B.F. Goodrich Company under the trade name Ensolite, type H-H. As can be seen in Figure 12, the new foam absorbs much more energy than does the standard foam, and its use would tend to reduce the "dynamic overshoot" of the gunner's head, especially if the head is not in contact with the pad at the instant the weapon is fired.

TABLE 2

Mean Peak Accelerations of Dummy and Human Head During Tank Gun Firing Tests

TANK AND GUN IDENTITY	AXIS	0 DEGREE AZIMUTH	90 DEGREE AZIMITH
		AUG 81 TEST - DUMMY ONLY	
M-551 152 mm	x-axis	11.2 ± 2.1 g*	17.2 ± 2.0 g
	y-axis	-3.7 ± 4.0 g	1.9 ± 7.1 g
	z-axis	3.6 ± 5.0 g	-8 ± 1.8 g
M-551 105 mm	x-axis	13.8 ± 0.6 g	11.8 ± 4.6 g
	y-axis	2.0 ± 3.5 g	3.5 ± 4.6 g
	z-axis	0.9 ± 2.3 g	-0.1 ± 4.1 g
		DEC 81 TEST - DUMMY	
M-60 A2 152 mm	x-axis	3.5 ± 0.9 g	3.4 ± 0.4 g
	y-axis	-0.2 ± 2.0 g	-1.6 ± 0.2 g
	z-axis	-2.2 ± 0.5 g	-1.6 ± 1.1 g
M-551 152 mm	x-axis	10.9 ± 0.9 g	10.8 ± 2.0 g
	y-axis	3.8 ± 0.5 g	-4.1 ± 0.7 g
	z-axis	2.6 ± 0.3 g	-3.9 ± 0.9 g
		DEC 81 TEST - HUMAN	
M-60 A2 152 mm	x-axis	3.6 ± 0.4 g	3.6 ± 0.6 g
	z-axis	1.9 ± 9.2 g	-0.9 ± 9.5 g
M-551 152 mm	x-axis	7.5 ± 0.8 g	11.1 ± 0.8 g
	z-axis	-6.2 ± 0.8 g	-6.1 ± 0.6 g

* Standard Deviation

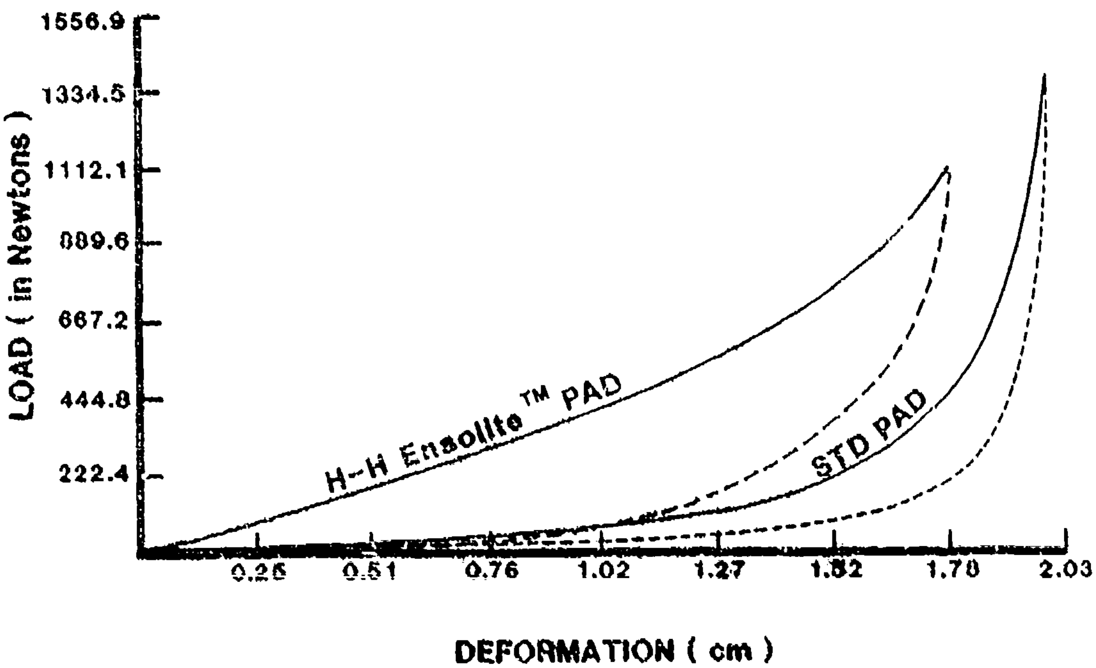

FIGURE 12. Comparison of the Load versus Deflection of the Standard Tanker's Brow Pad (used in these tests to a Pad Constructed with H-H Ensolite™ (Polyvinylchloride Foam)

The principal acceleration axis in the tank-gun firing is the x-axis and the gathered data for the dummy and human head along that axis is acceptably accurate for assessing the health hazard. Of the vehicles tested, the M-551 generated the highest levels of head x-axis acceleration. Mean peak values for the dummy ranged from 10.8 G to 17.2 G for a triangular pulse with an average initial positive pulse duration of 33 milliseconds. The 17.2 G mean was generated by the 90 degree azimuth firings from the first M-551 firing test. The second series of M-551 tests were more consistent with a 10.9 G mean for the 0 degree azimuth configuration and a 10.8 G mean for the 90 degree azimuth configuration. The second test series used a fully-operational M-551 while the first test series used a partially-stripped M-551 which was equipped with an incomplete sight assembly. This may have resulted in a less rigid load transfer path to the brow pad and thus may have introduced some dynamic overshoot. Therefore, the data gathered during the second test will be used to assess potential health hazards. The threat pulse will be defined as a triangular pulse of 30 to 35 milliseconds duration with a peak of from 10 to 14 G.

The available research into the physiological effects of low-level impact acceleration is very limited. The principal area of investigation has been related to sports injuries, principally those from boxing and football. Furthermore, most of the investigations have consisted of postinjury reporting of the amount and type of damage, and the course of recovery or death. Almost no work has been done in evaluating the kinetics of boxing. One of the prominent researchers in the field has published a fairly comprehensive review of boxing injuries with some analysis of the kinetics and injury mechanism (Unterharnscheidt, 1975). In one experiment, he had two physical education students with no boxing training fight for 10 minutes while wearing headband-mounted accelerometers. The boxers used 12-oz gloves rather than the 6-oz gloves used in most professional fights. The 12-oz gloves are thicker and softer and have a cushioning effect that reduces the peak force generated by a given blow. The measurements obtained indicated that 21 blows accelerated the head by 0-5 G, 12 blows by 6-10 G, three blows by 11-15 G, three blows by 16-20 G, and two blows by 21-25 G. Some of the measured pulses in the 0-5 g group were actually defensive movements of the head rather than blows. No injuries or physical problems were reported. Dr. Unterharnscheidt also conducted an experiment to evaluate the severity of a representative blow in a professional boxing match. He used a gloved pendulum to represent the striking fist and arm and a wooden pendulum covered with wool cloth to represent the head. He determined that a representative blow with a 6-oz glove generated approximately 100 G of translational acceleration of the head.

A similar experiment to Dr. Unterharnscheidt's was done in England (Johnson, Skorecki, and Wells, 1975). The researchers instrumented volunteer subjects and struck them at increasing impact velocities with a gloved wooden fist mounted on a rigid pendulum. The glove was a 6-oz professional type. The total impacting mass was 5.5 kg. The impact severity was incremented upward from low levels until the subject's voluntary tolerance was reached. Higher intensity blows were evaluated using an inflated dummy head weighted to duplicate human head mass (4.5 kg) and mounted in such a way as to duplicate the dynamic response characterstics of the head-neck system. The human volunteers sustained blows up to 14 G peak head acceleration with durations of initial positive acceleration of approximately 35 milliseconds. The acceleration-time curve (from the Johnson study) is described as a short-period triangular positive peak followed by a long-period negative acceleration with a peak of about 40 percent of the positive peak and a duration of about twice that of the positive period. The head acceleration curves measured in the M-551 are very similar to those described in the Johnson study. Although the inflated dummy head was struck by professional boxers and 260 G peak (13 milliseconds duration) recorded in the head form, such an impact is definitely assumed to be a "knockout" punch and not to be sustained repetitively.

An earlier experiment was conducted to determine voluntary tolerance to helmeted-head impact (Lombard, et al., 1951). Subjects were fitted with a variety of football and flight helmets and then struck with an instrumented pendulum. The 14 peak accelerations, due to blows to the forehead, resulted in an average tolerance level of 22.6 G with a mode tolerance level of 16 G. The reasons given for the volunteer stop points were local pain, bruising, and neck pain. No evidence of any change in consciousness or reflex action was noted.

Some work has been done in the area of human tolerance to acceleration applied to the whole body while restrained in a seat. One of the major efforts in this area has been conducted by the NBDL. They have subjected numerous human subjects to whole-body (-gx) acceleration of from 5 to 15 G at the sled. The measured x-axis head acceleration has reached peaks as high as 24 G with no reported adverse effects (Ewing and Thomas, 1972).

A somewhat similar study was done in England (Reader, 1979). Reader looked at the effect of head acceleration on psychomotor performance. The subjects were restrained in a seat on a sled and subjected to whole-body acceleration. The highest peak x-axis head acceleration experienced was 26.9 G. A tracking task and EEG recording were used to evaluate the effects of acceleration on psychomotor performance. The report states that a statistically-significant decrease in short-term performance was detected for mean peak head x-axis accelerations greater than 5.3 G. However, the limited number of subjects used in the experiment makes it very difficult to make a general statement about the overall physiological effect of low-level head acceleration on psychomotor performance. The only subject complaints reported were two cases of slight headache, two cases of stiff neck, and several statements of a short-term feeling of detachment or isolation immediately following deceleration.

Although the whole-body acceleration experiments use a different loading mechanism to accelerate the head than does the direct impact method, there are some similarities. With comparable acceleration-time histories, the total velocity and momentum changes will be the same. Human tolerance data gathered from whole-body acceleration experiments can be used as backup for direct impact tolerance data. In this case, it is desirable because of the limited amount of data concerning human tolerance to low-level direct impact acceleration.

As indicated under the Methods section of this report, consideration was given to the effect of the stiffness of the pad on the acceleration of the gunner's head. The existing soft latex foam pad acts too much like a "soft" spring in which both theory and experiment reveal that the movement of the tank turret and pad at velocities up to two meters per second will "bottom" (totally compress) the pad before the head velocity is increased. This results in a sudden increase of head acceleration called "dynamic overshoot." The common idea that a soft "comfortable" pad is best is not true; a relatively stiff pad is preferable for this application.

Regardless of the pad stiffness used, the gunner should press his brow firmly against the pad to minimize the "dynamic overshoot" effect. Firm brow pressure will tend to keep the gunner's head in place with the turret pad motion.

CONCLUSIONS AND RECOMMENDATIONS

The conclusion reached after comparing the measured human and dummy gunner head accelerations along the x-axis to published human tolerance data is that the gun firing in the test vehicles does not exceed human tolerance for single exposures. It is not possible to state that no person will ever experience any discomfort. Based on the limited data available and the large variation in the human population, it is quite possible that some gunners will experience headaches, transitory head pain, and neck strain. If the weapon is fired while the vehicle is in motion (resulting in potential decoupling of the forehead from the browpad), higher recoil forces than are reported herein likely will occur. Furthermore, no conclusion can be reached as to the effects of repeated exposure in terms of number of exposures or frequency of exposures. Studies on boxing imply that subinjurious blows have a cumulative effect that is injurious (Unterharnscheidt, 1975). Unfortunately, the mechanisms of head injury are not well defined in quantitative terms. Therefore, the effects of repeated low-level blows will have to be determined through future research.

The recommendation is that research continue into the effects of recoil on tank gunners by conducting experiments with human volunteers and animals to establish a tolerance level to low-level impact accelerations that includes the effect of magnitude, frequency, and total dose. Such experiments could also provide tolerance data for impacts from boxing. The tolerance limits will have to be the volunteer's own sense of physical well being. Monitoring of physiological parameters such as heartbeat, respiration, brain wave activity, and temperature should be done, but their value in predicting the approach to injurious acceleration levels is not yet explicated fully. Tests that evaluate reflex reaction, fine motor control, and memory may provide better measures for evaluating the effects of acute acceleration if baseline levels of performance for such behaviors can be established and then evaluated immediately after exposures. The use of this approach will permit an assessment to be made of both acute, postinsult effects and (with continued monitoring of the behaviors) of any cumulative and/or chronic deficiencies which result.

To minimize the effects of recoil acceleration "dynamic overshoot," a stiffer foam pad is recommended (with performance similar to that shown in Figure 12).

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APPENDIX A

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APPENDIX B

PLOTS OF ACCELERATION VERSUS TIME

FOR DUMMY AND HUMAN HEAD AND CHEST ACCELERATIONS

DURING TANK GUN FIRINGS

FIGURES B-1 THROUGH B-28

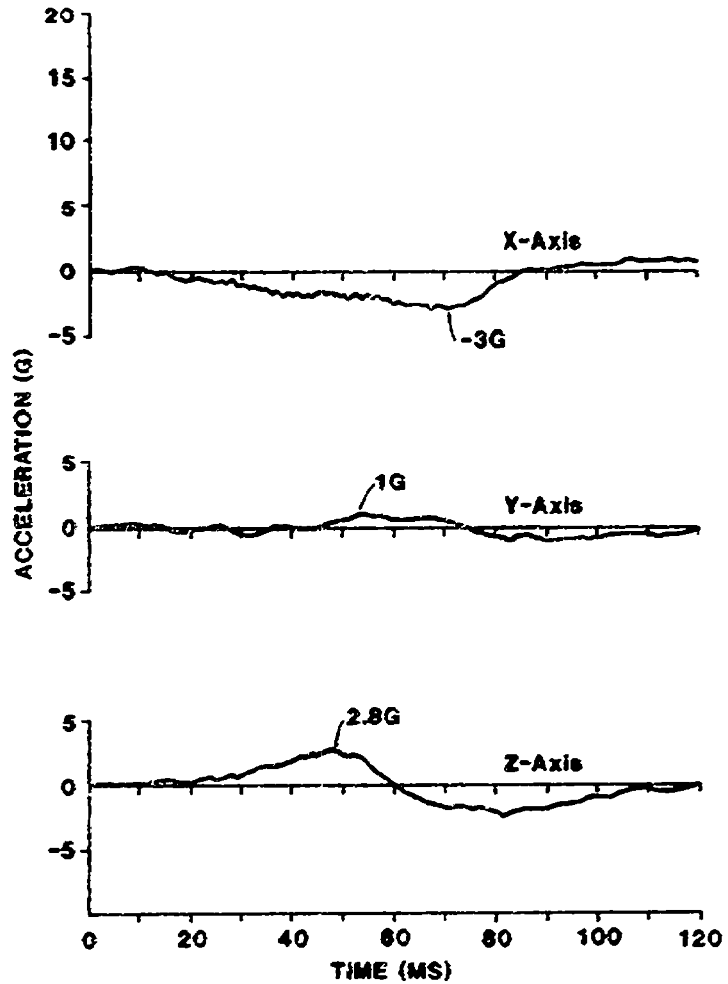

FIGURE B-1. Dummy Head Acceleration - M-551 Sheridan With 152 mm Gun - 0 Degree Azimuth, Round No. 3 - (Aug 81 Test).

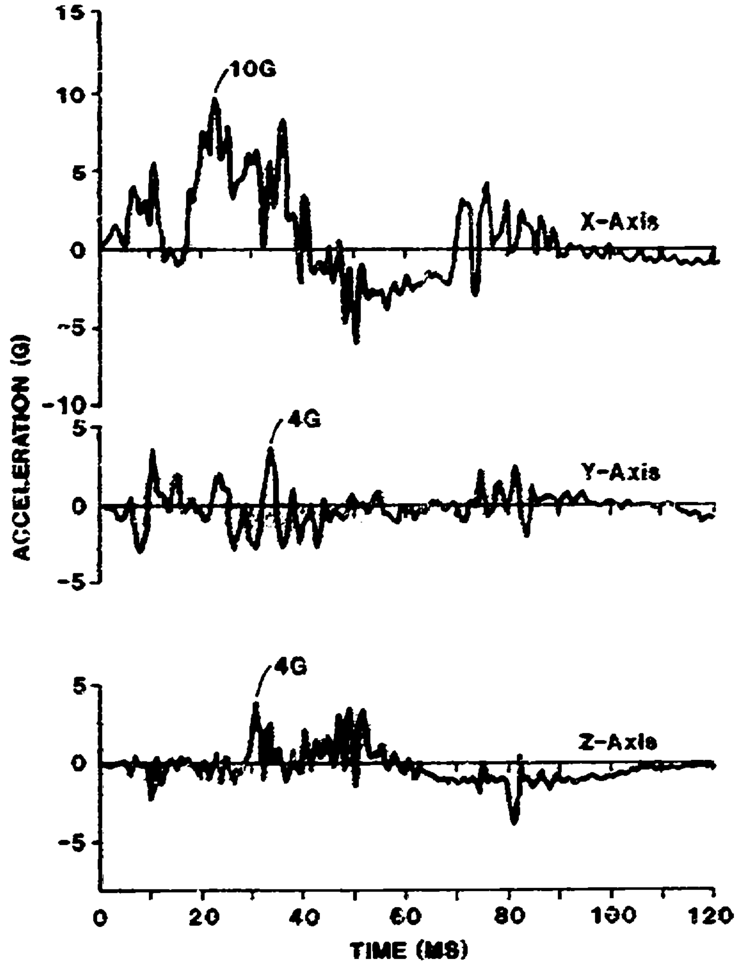

FIGURE B-2. Dummy Chest Acceleration - M-551 Sheridan With 152 mm Gun - 0 Degree Azimuth, Round No. 3 - (Aug 81 Test).

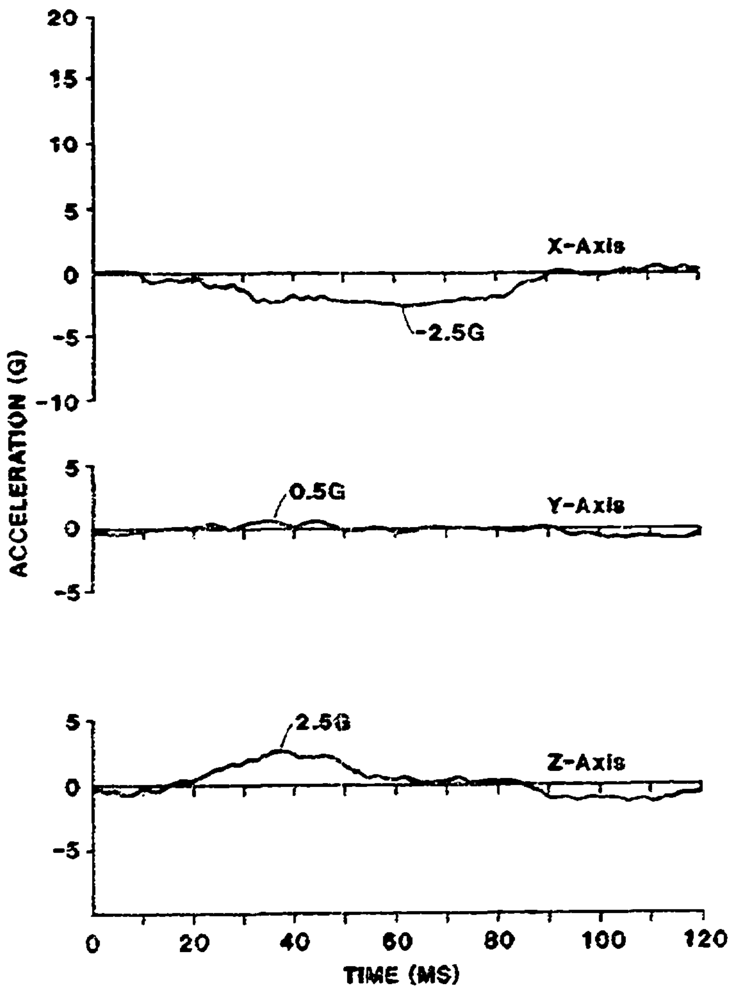

FIGURE B-3. Dummy Head Acceleration - M-551 Sheridan With 152 mm Gun - 90 Degree Azimuth, Round No. 9 - (Aug 81 Test).

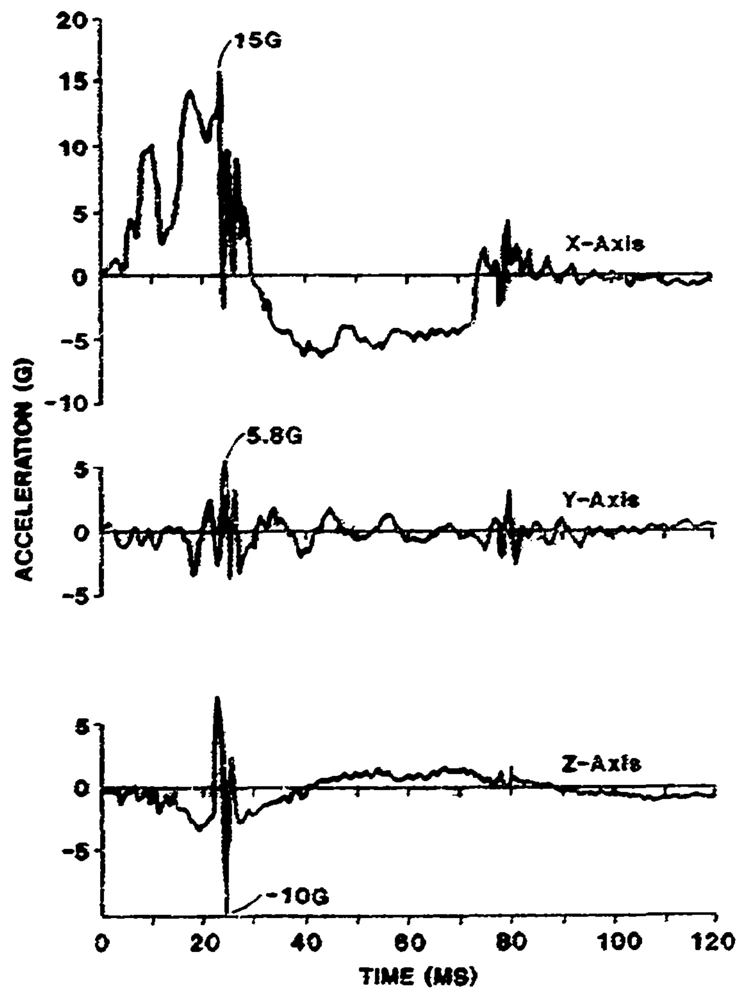

FIGURE B-4. Dummy Chest Acceleration - M-551 Sheridan With 152 mm Gun - 90 Degree Azimuth, Round No. 9 - (Aug 81 Test).

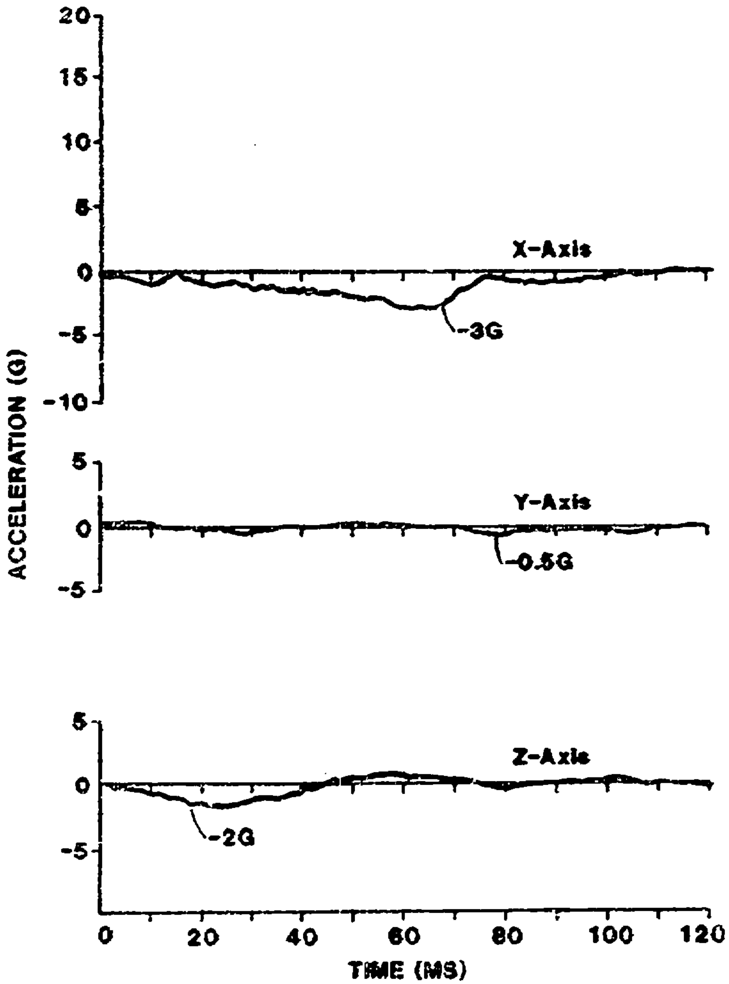

FIGURE B-5. Dummy Head Acceleration - M-551 Sheridan With 105 mm Gun - 0 Degrees Azimuth, Round No. 1 (Aug 81 Test).

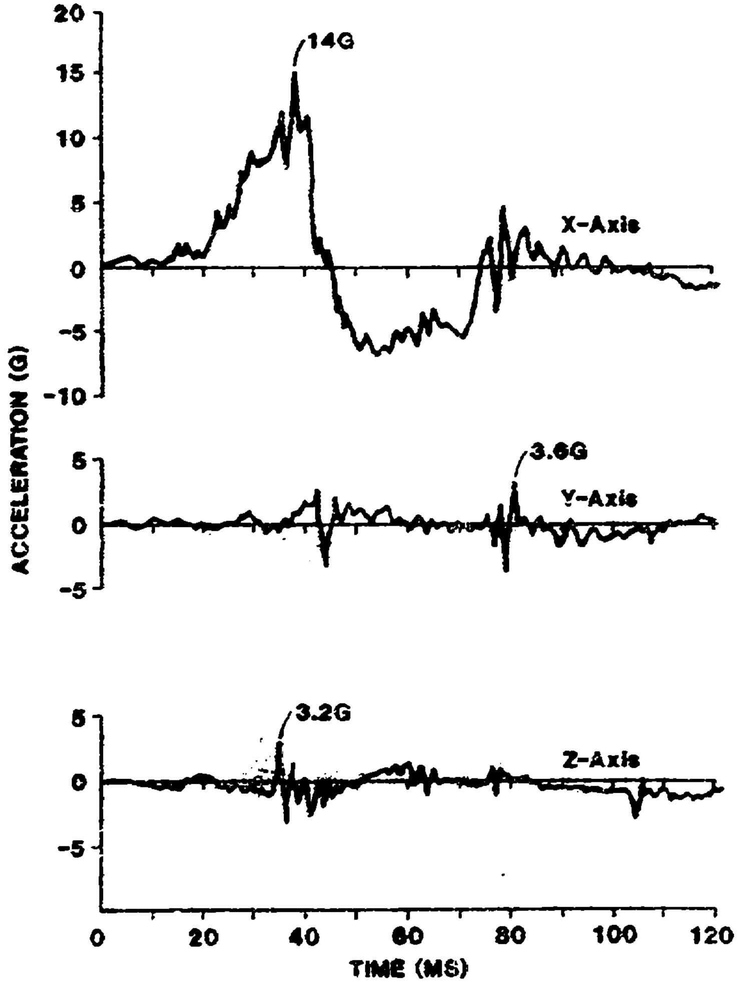

FIGURE B-6. Dummy Chest Acceleration - M-551 Sheridan With 105 mm Gun - 0 Degree Azimuth, Round No. 1 (Aug 81 Test).

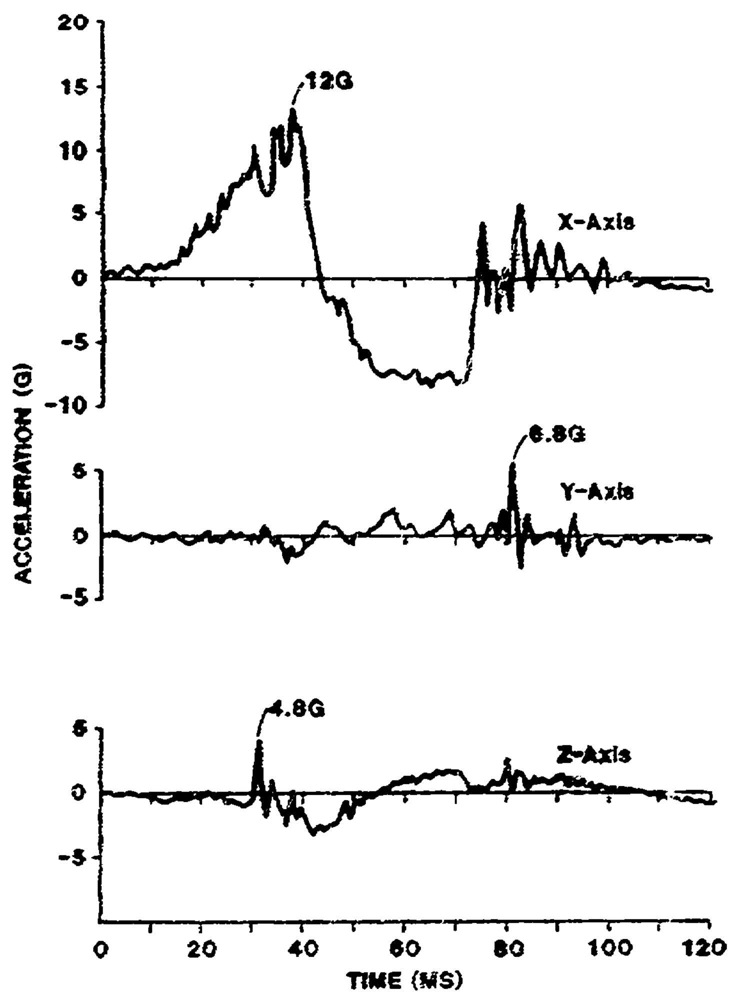

FIGURE B-7. Dummy Head Acceleration - M-551 Sheridan With 105 mm Gun - 90 Degrees Azimuth, Round No. 8 (Aug 81 Test).

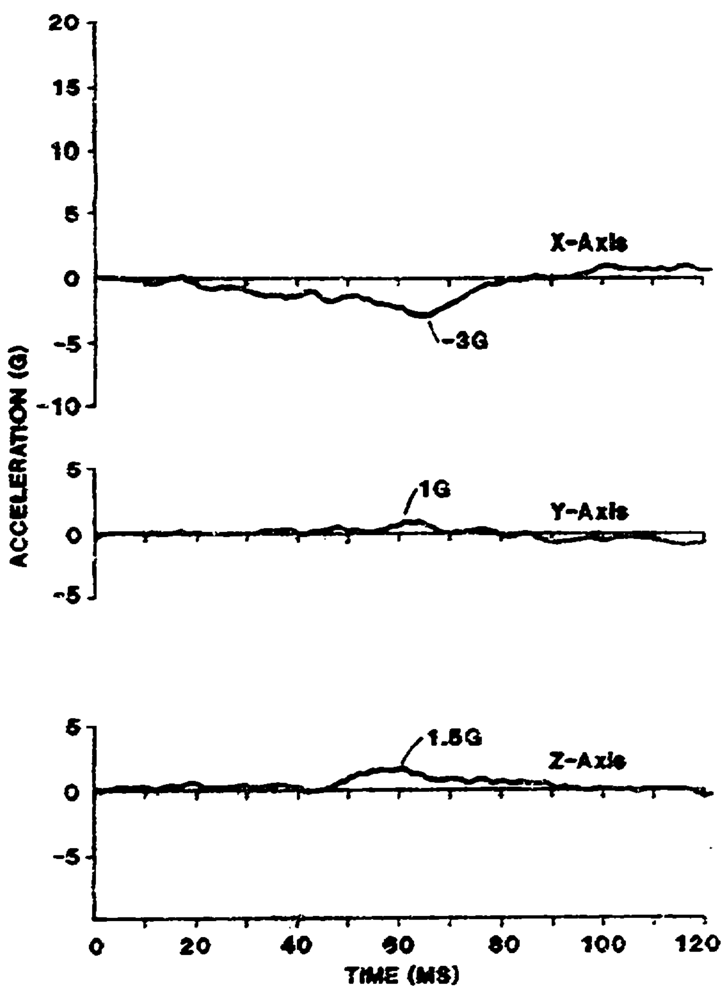

FIGURE B-8. Dummy Chest Acceleration - M-551 Sheridan With 105 mm Gun - 90 Degrees Azimuth, Round No. 8 (Aug 81 Test).

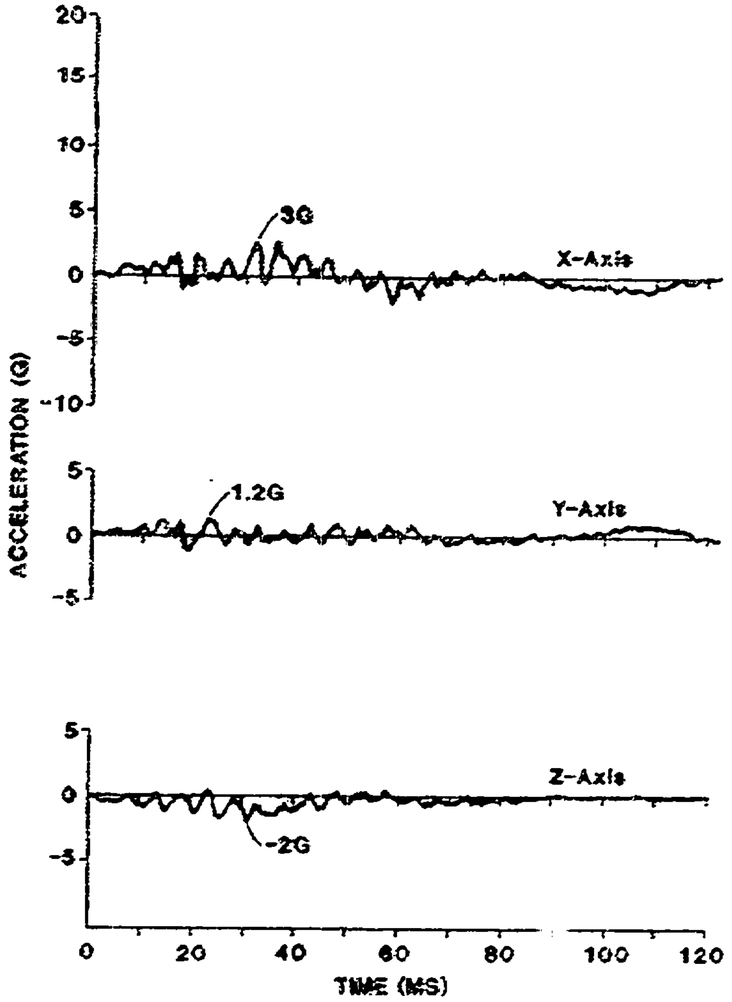

FIGURE B-9. Dummy Head Acceleration - M-60-A2 With 152 mm Gun - 0 Degree Azimuth, Round No. 5 (Aug 81 Test).

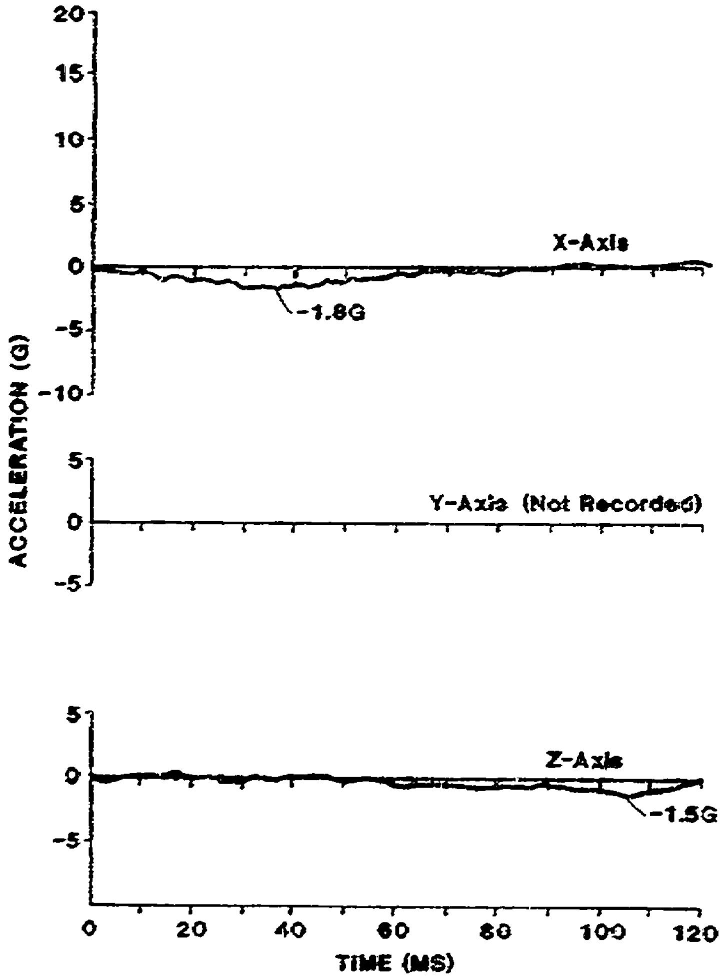

FIGURE B-10. Dummy Chest Acceleration - M-60-A2 With 152 mm Gun - 0 Degree Azimuth, Round No. 5 (Aug 81 Test).

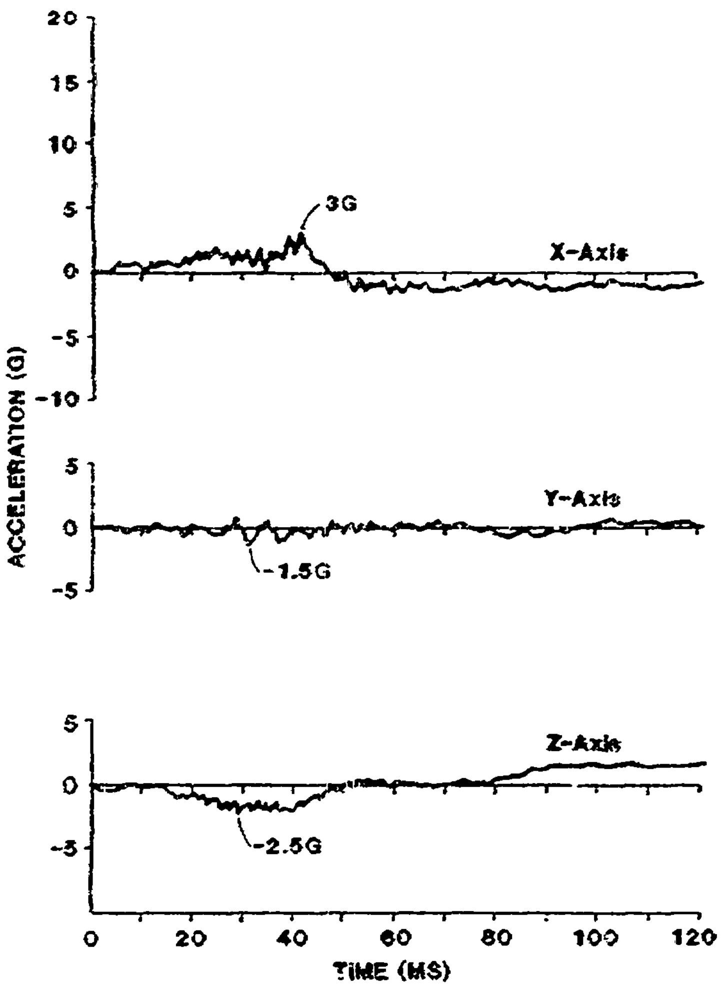

FIGURE B-11. Dummy Head Acceleration - M-60-A2 With 152 mm Gun - 90 Degree Azimuth, Round No. 6 (Aug 81 Test).

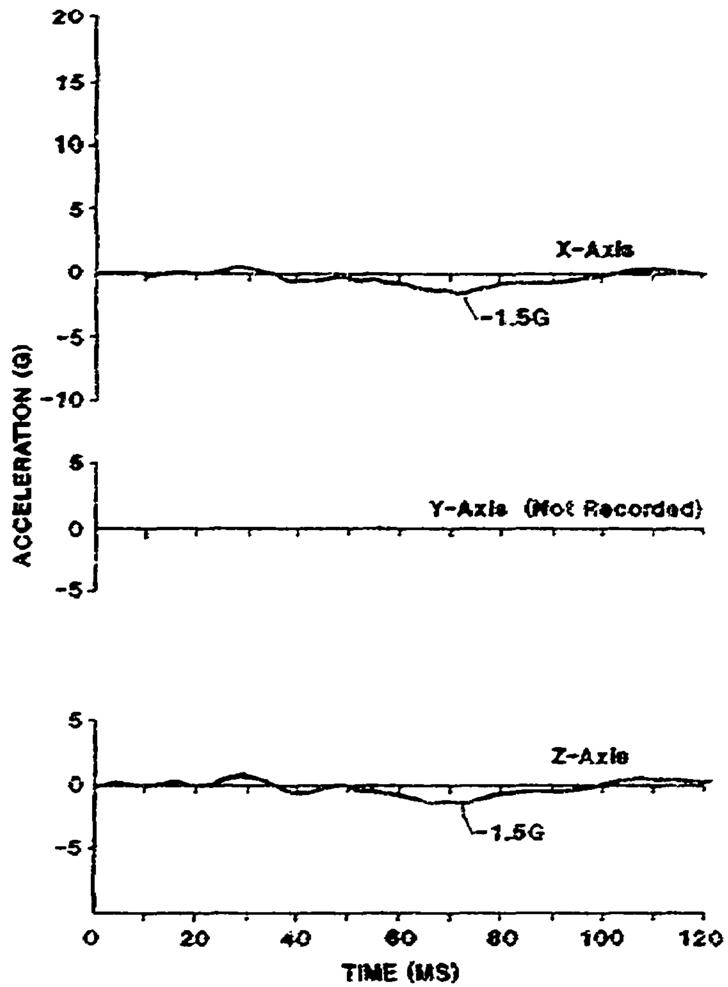

FIGURE B-12. Dummy Chest Acceleration - M-60-A2 With 152 mm Gun - 90 Degree Azimuth, Round No. 6 (Aug 81 Test).

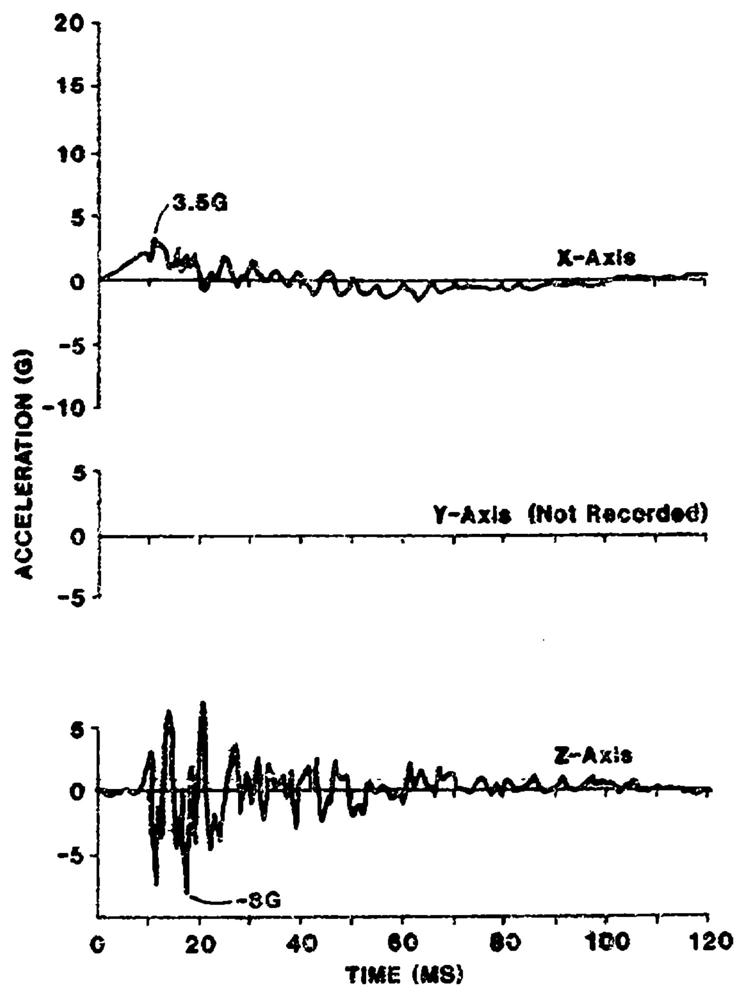

FIGURE B-13. Dummy Head Acceleration - M-60-A2 With 152 mm Gun - 0 Degree Azimuth, Round No. 20 (Aug 81 Test).

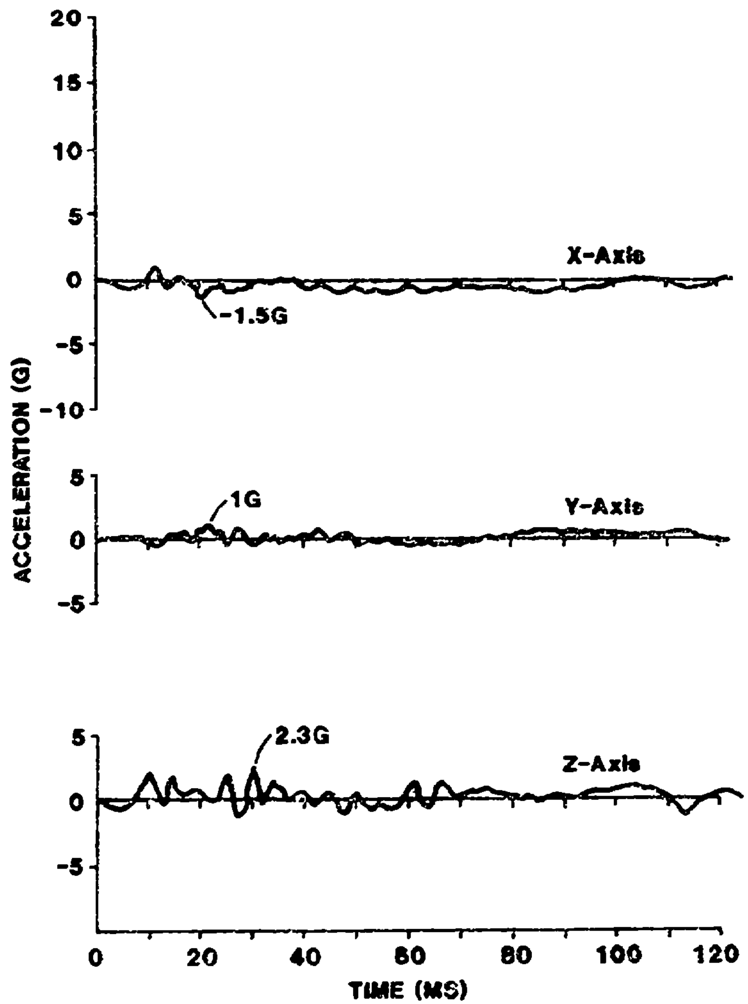

FIGURE B-14. Dummy Chest Acceleration - M-60-A2 With 152 mm Gun - 0 Degree Azimuth, Round No. 20 (Aug 81 Test).

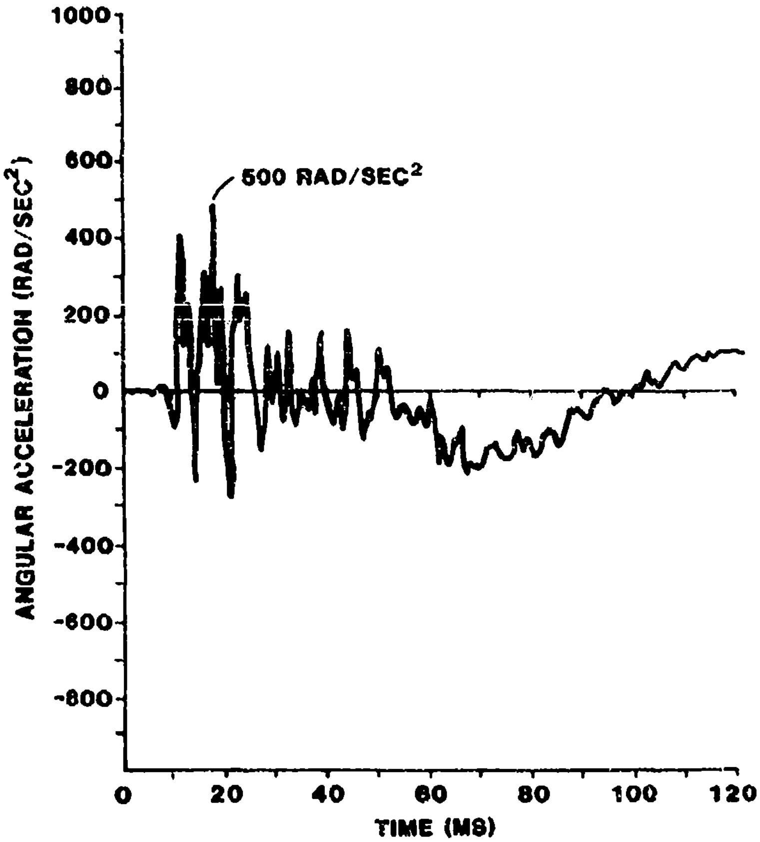

FIGURE B-15. Human Head Pitch Acceleration - M-60-A2 with 152 mm Gun - 0 Degree Azimuth Round 20 (Dec 81)

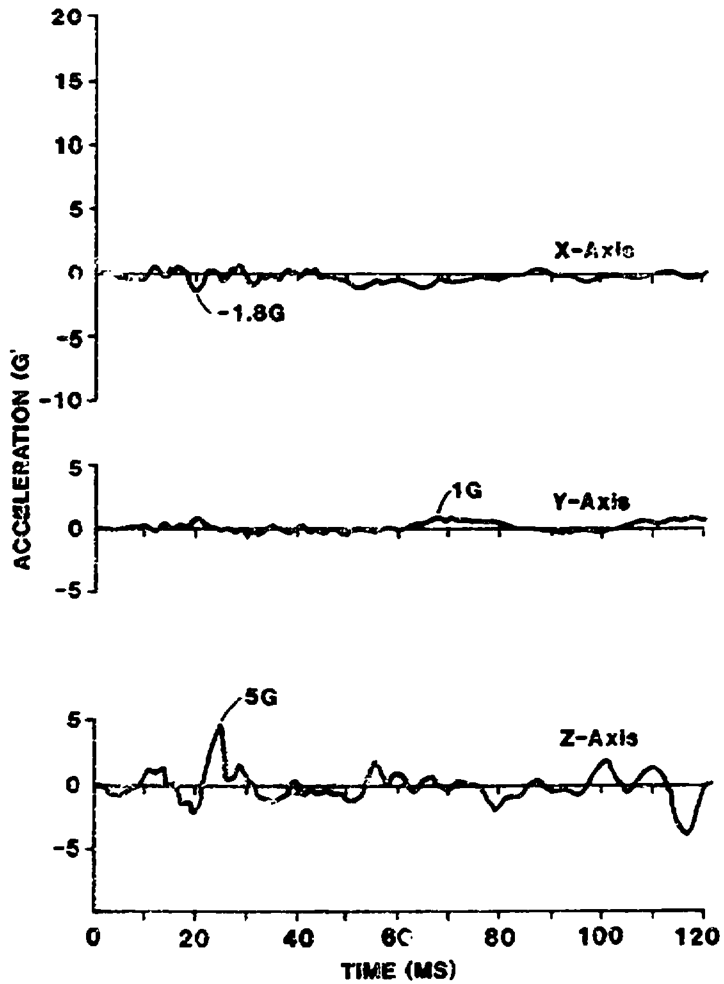

FIGURE B-16. Dummy Head Acceleration - M-60-A2 With 152 mm Gun - 90 Degrees Azimuth, Round No. 12 (Dec 81 Test).

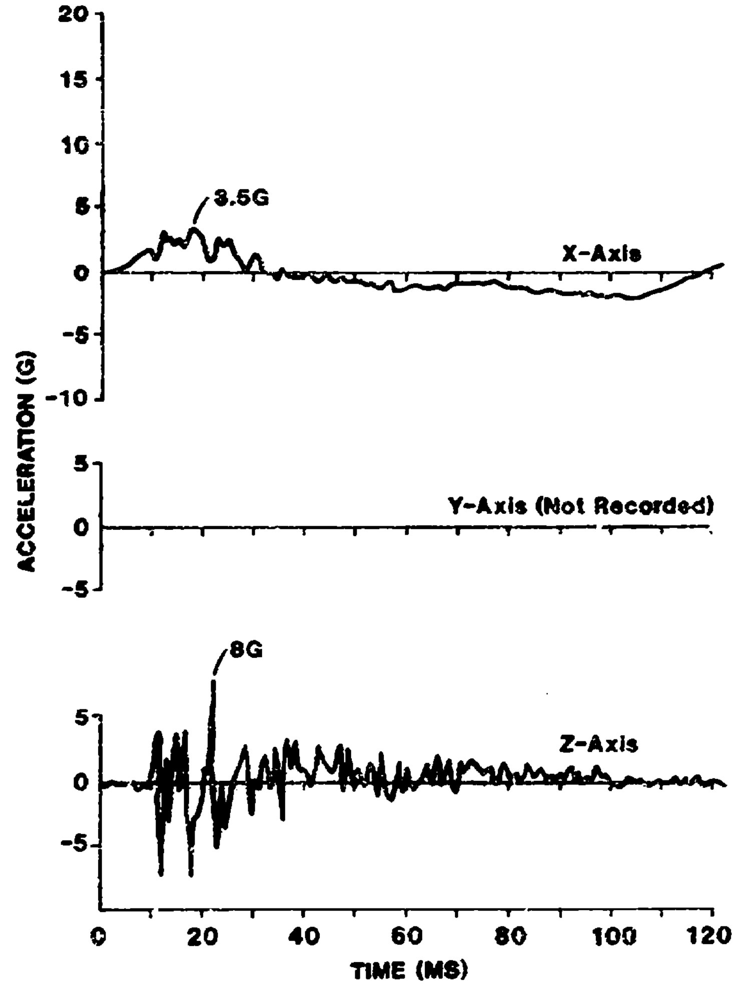

FIGURE B-17. Human T1 Acceleration - M-60-A2 With 152 mm Gun - 90 Degrees Azimuth, Round No. 12 (Dec 81 Test).

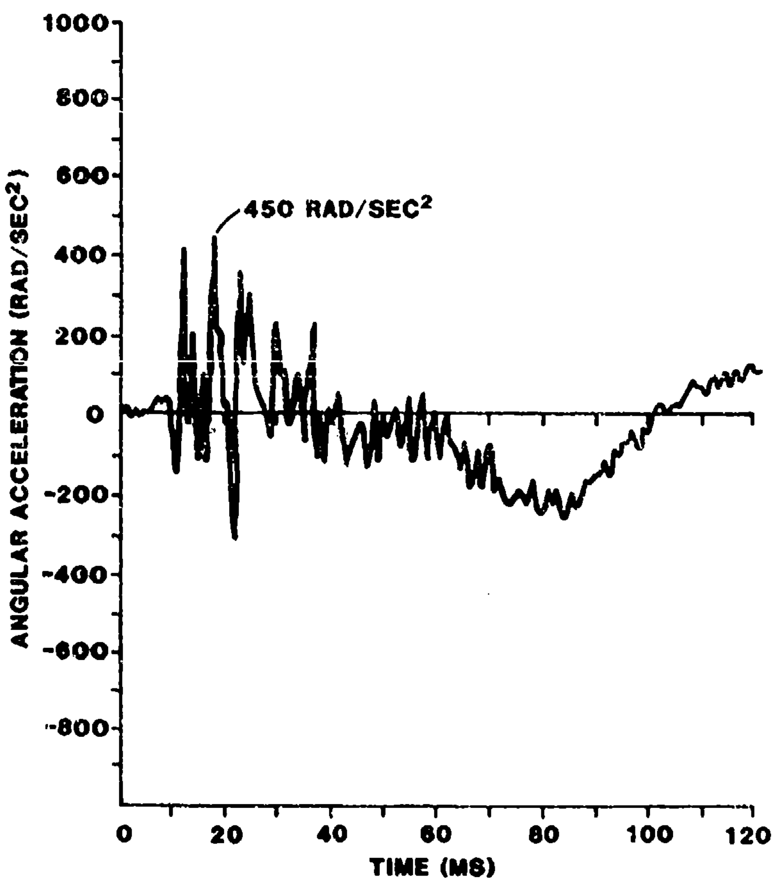

FIGURE B-18. Human Head Pitch Acceleration - M-60-A2 With 152 mm Gun - 90 Degrees Azimuth, Found No. 12 (Dec 81 Test).

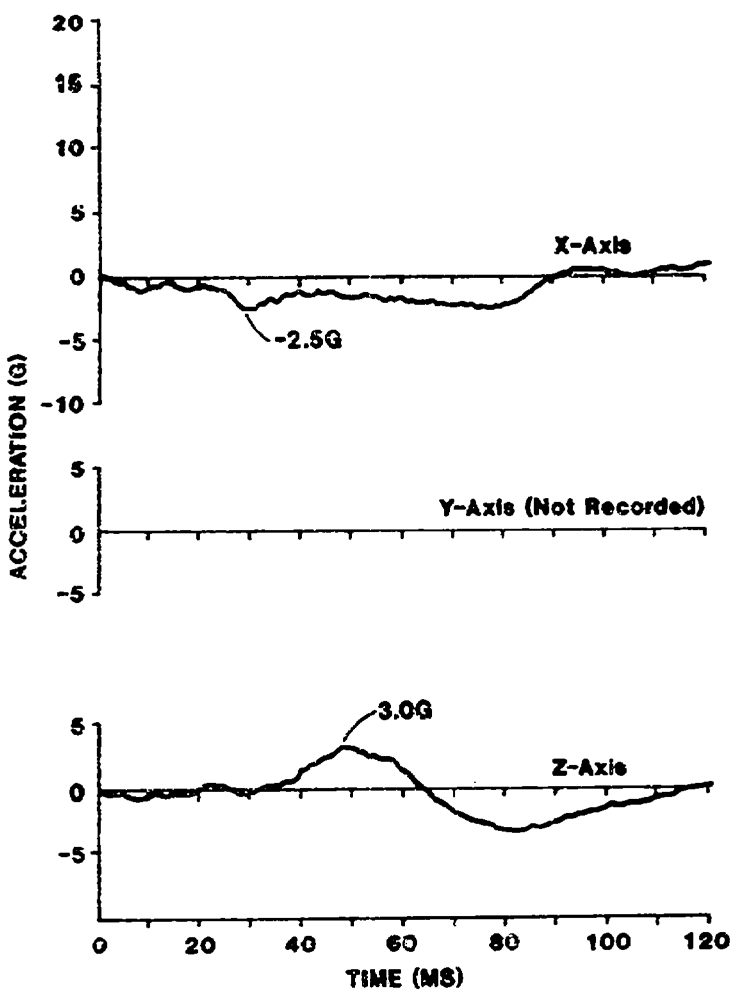

FIGURE B-19. Dummy Head Acceleration - M-551 Sheridan 152 mm Gun - 0 Degree Azimuth, Round No. 38 (Dec 81 Test).

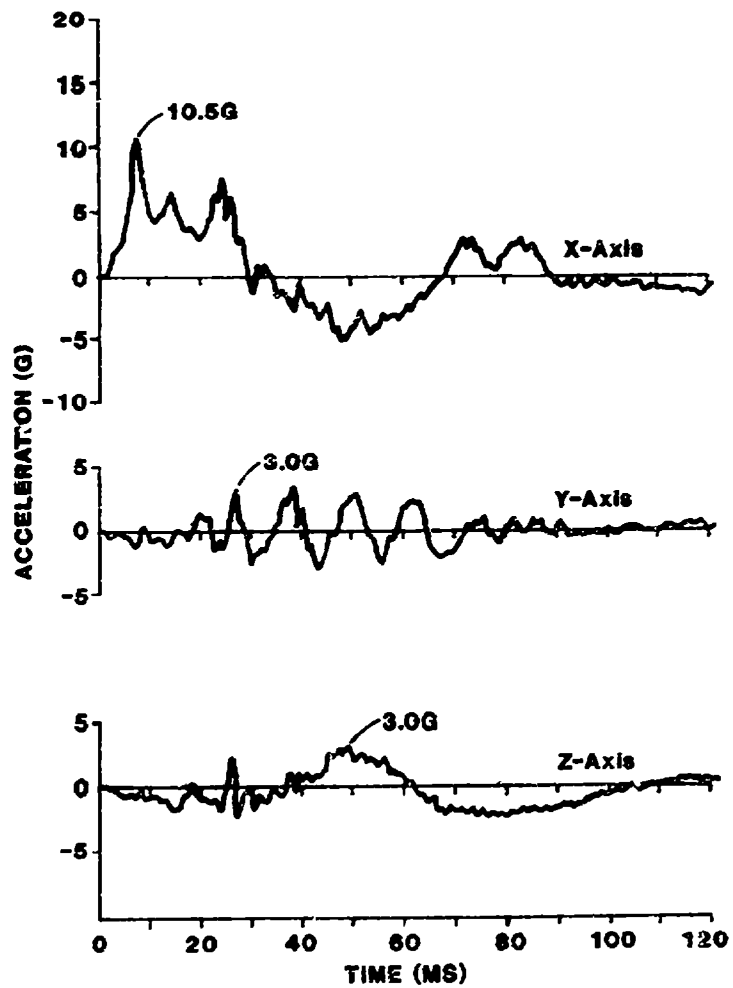

FIGURE B-20. Dummy Chest Acceleration - M-551 Sheridan 152 mm Gun - 0 Degree Azimuth, Round No. 38 (Dec 81 Test).

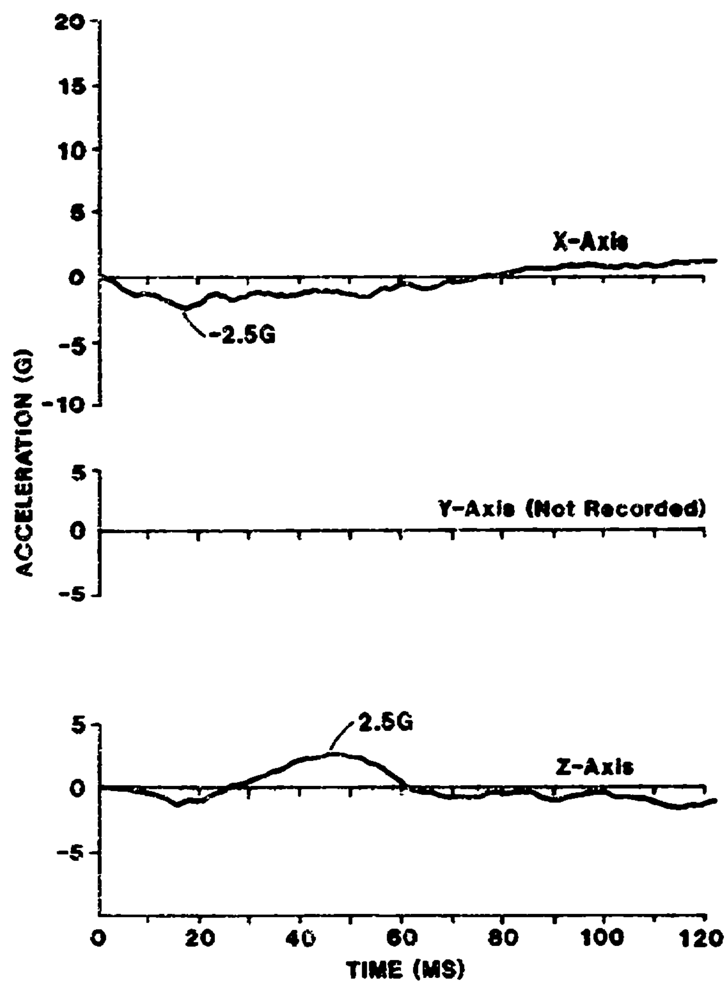

FIGURE B-21. Dummy Head Acceleration - M-551 Sheridan 152 mm Gun - 90 Degree Azimuth, Round No. 32 (Dec 81 Test).

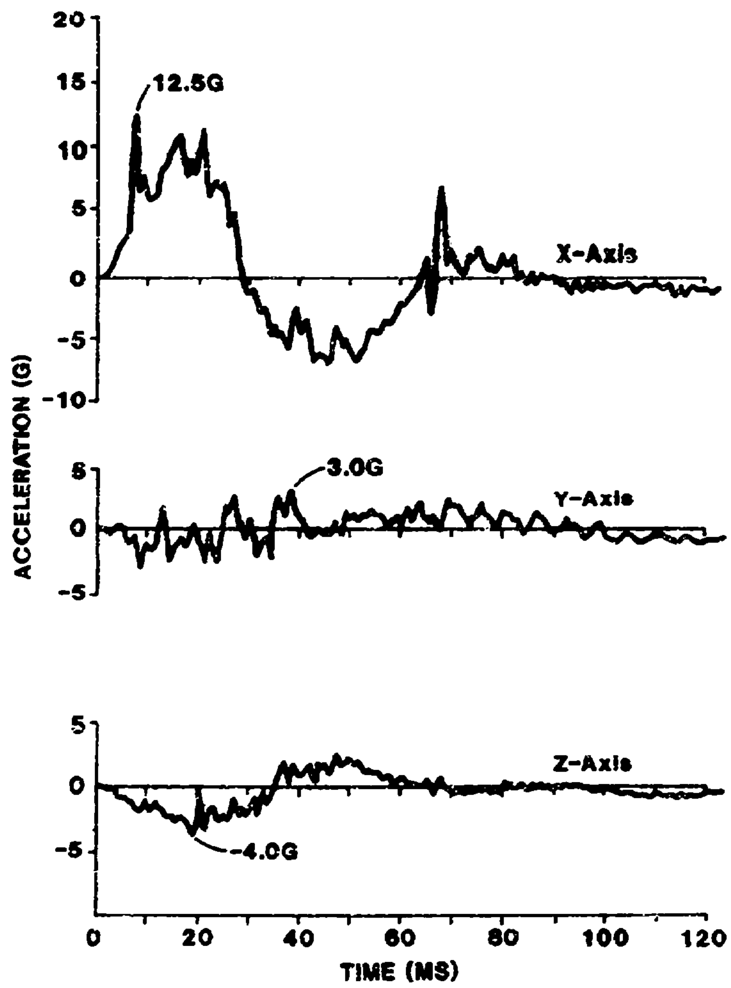

FIGURE B-22. Dummy Chest Acceleration - M-551 Sheridan 152 mm Gun - 90 Degree Azimuth, Round No. 32 (Dec 81 Test).

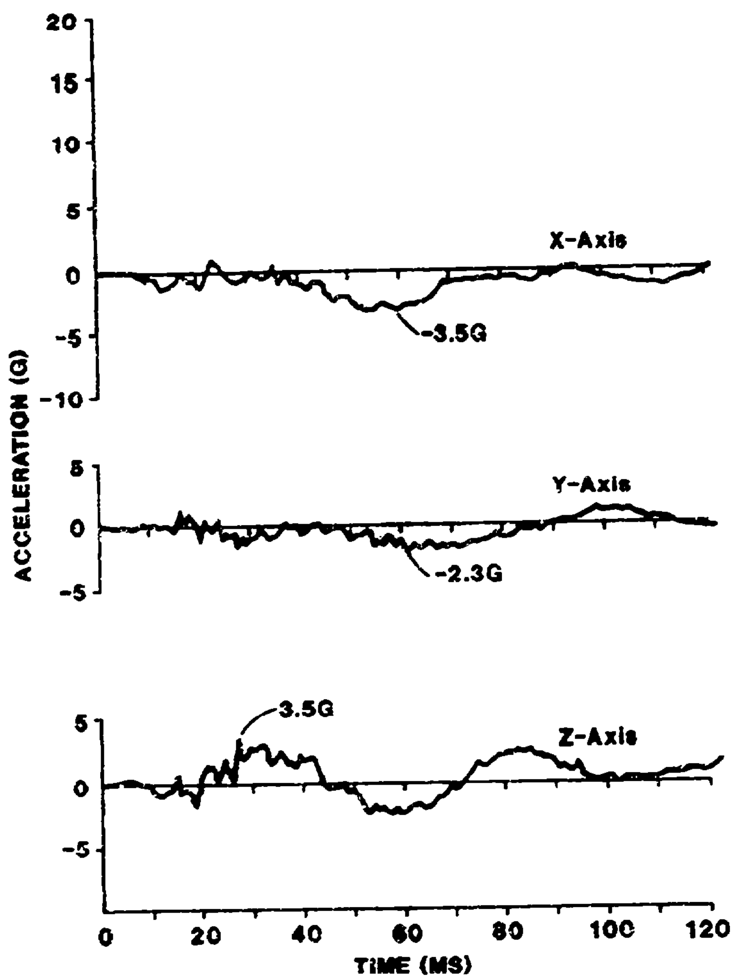

FIGURE B-23. Dummy Head Acceleration - M-551 Sheridan 152 mm Gun - 0 Degree Azimuth, Round No. 22 (Dec 81 Test).

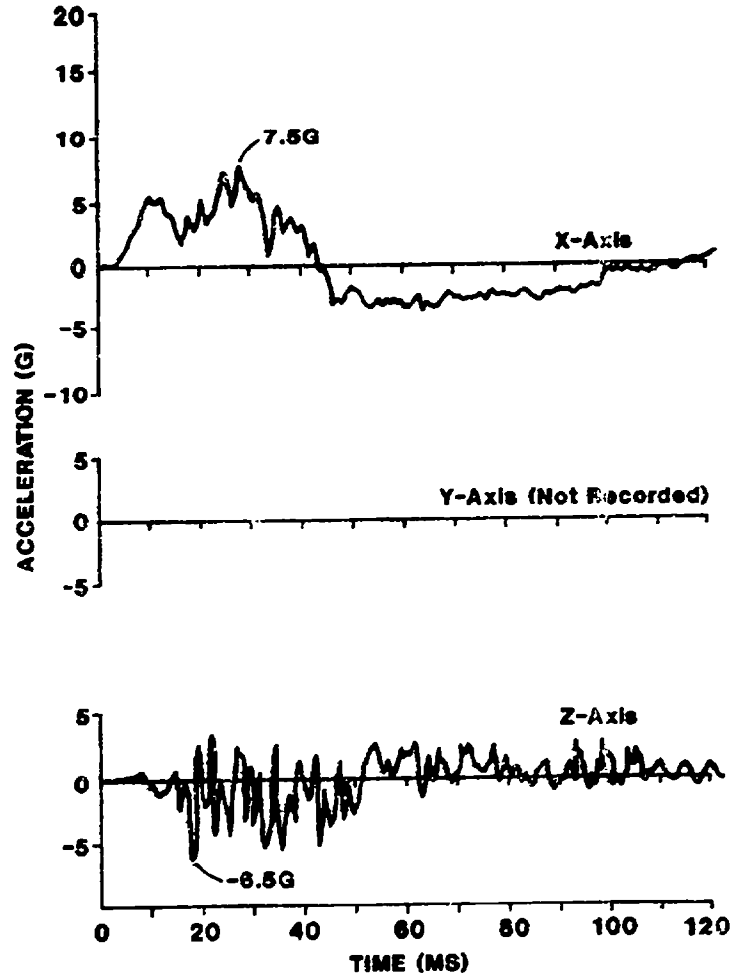

FIGURE B-24. Dummy Chest Acceleration - M-551 Sheridan 152 mm Gun - 0 Degree Azimuth, Round No. 22 (Dec 81 Test).

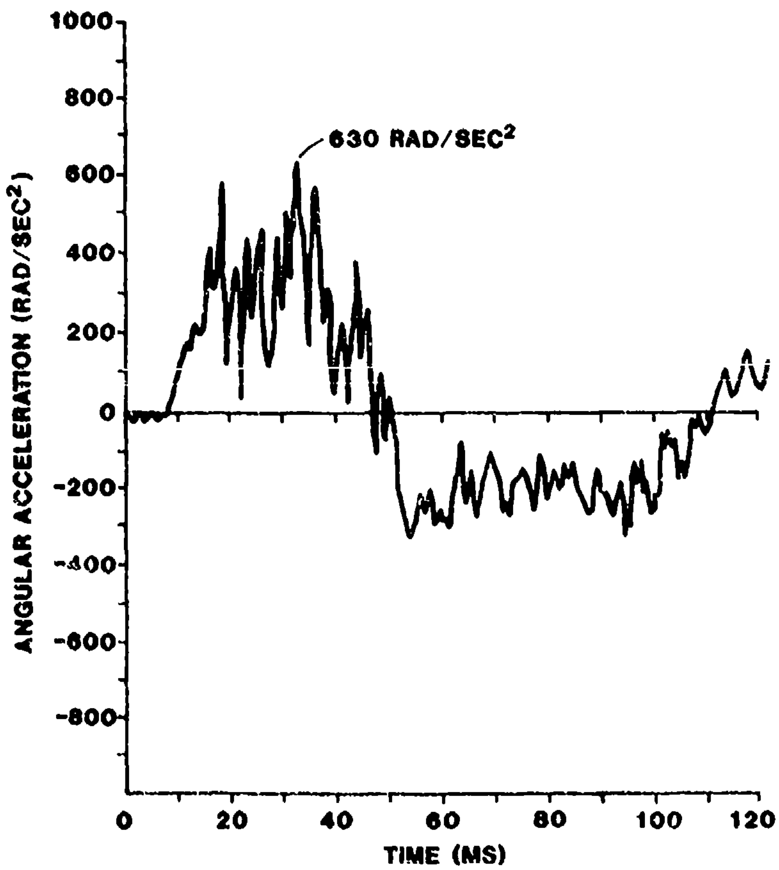

FIGURE B-25. Human Head Pitch Acceleration - M-551 Sheridan With 152 mm Gun - 0 Degree Azimuth, Round No. 22 (Dec 81 Test).

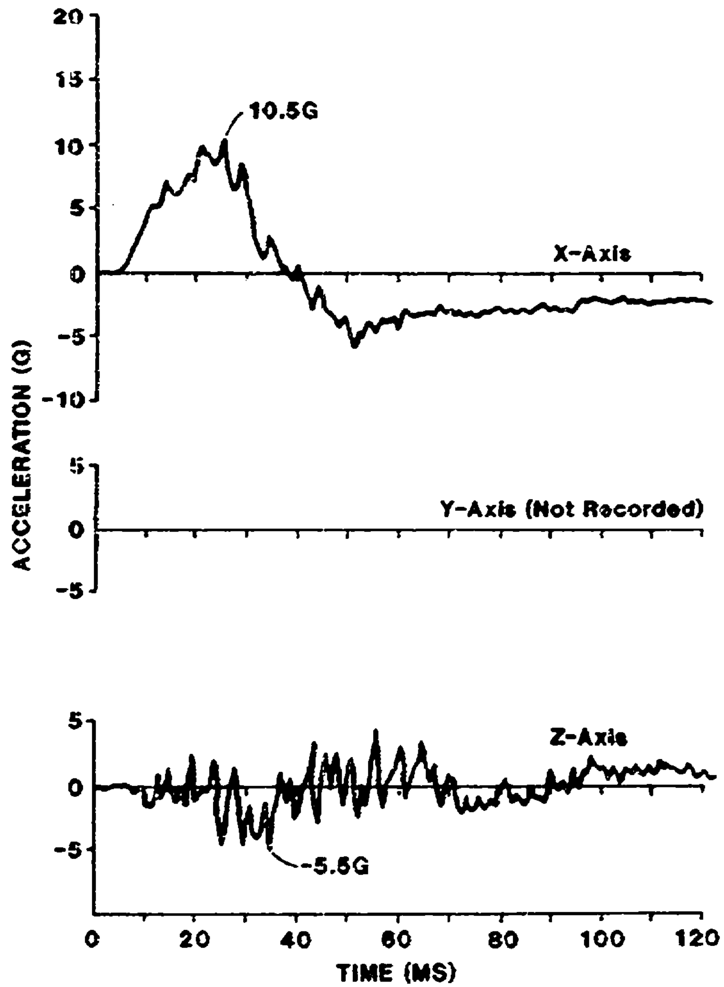

FIGURE B-26. Human Head Acceleration - M-551 Sheridan With 152 mm Gun - 90 Degrees Azimuth, Round No. 28, (Dec 81 Test).

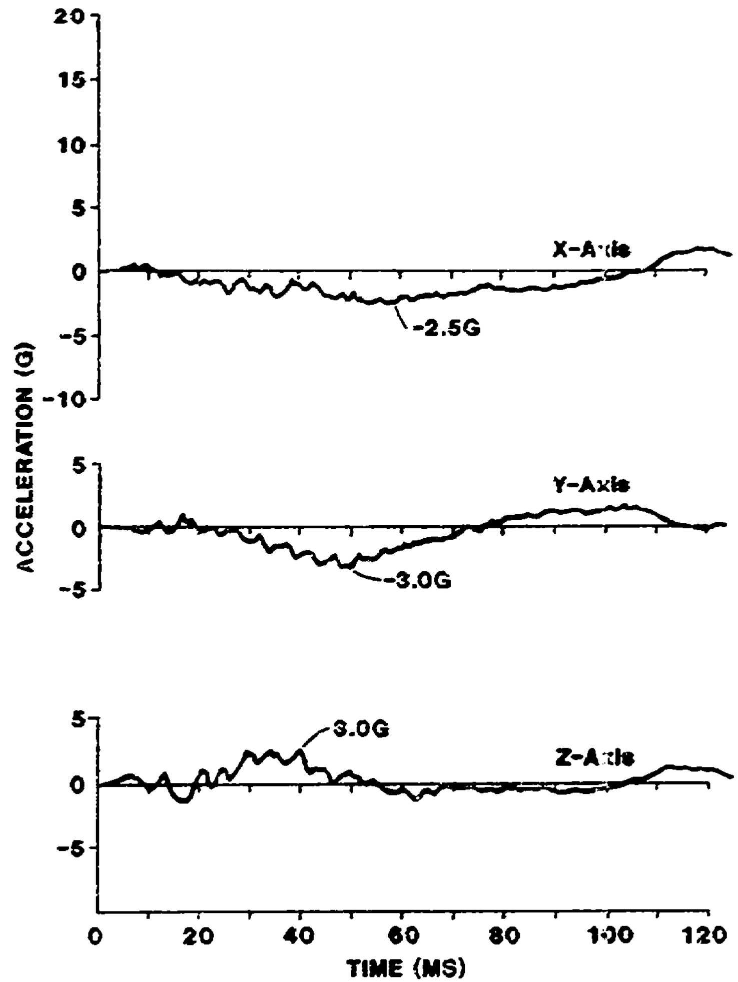

FIGURE B-27. Human T1 Acceleration - M-551 Sheridan With 152 mm Gun - 90 Degrees Azimuth, Round No. 28 (Dec 81 Test).

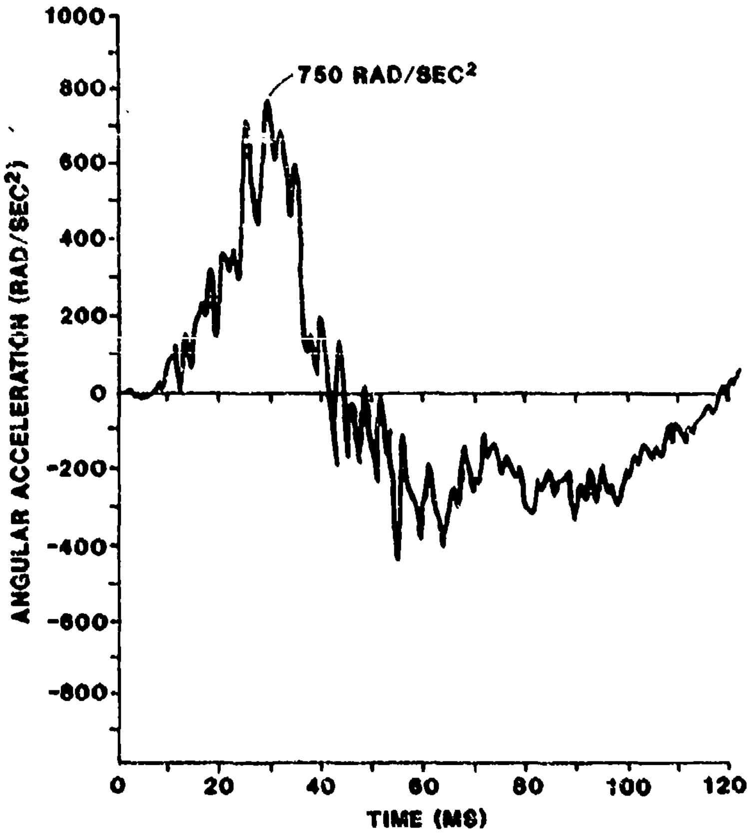

FIGURE B-28. Human Head Pitch Acceleration - M-551 Sheridan With 152 mm Gun - 90 Degrees Azimuth, Round No. 28 (Dec 81 Test).

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