SLED TESTS OF THREE-POINT SYSTEMS INCLUDING AIR BELT RESTRAINTS

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FINAL REPORT

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16. Abstract

This experimental test program included six sled tests using five unembalmed cadavers and one anthropomorphic test dummy to evaluate a three-point belt restraint system. The tests were conducted on the Calspan HYGE sled facility simulating 30 mph frontal collisions for the three-point belts and 47 mph frontal collisions for the air belt systems.

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Approved by:

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1. INTRODUCTION AND SUMMARY

1.1 Introduction

This final summary report is submitted to the National Highway Traffic Safety Administration, Office of Vehicle Structures, by Calspan Corporation in fulfillment of Contract No. DOT-HS-5-01017, Task Order Two, Evaluation of Three-Point Harness with Lap Belt attached to Seat.

As stated in the task order, the objectives of the program were to evaluate with unembalmed cadavers the effectiveness of a three-point belt restraint to reduce the severity of abdominal injuries when the ends of the lap belt are attached directly to the seat rather than to the vehicle frame.

The task order was modified after three cadavers and one 50th percentile male dummy had been utilized in evaluating the concept to read "evaluate with unembalmed cadavers an air belt system developed under Contract Number DOT-HS-4-00917."

Five unembalmed cadavers and one 50th percentile humanoid systems test dummy were instrumented and used on the Calspan HYGE sled in this program. Test equipment and procedures are discussed in Section 2. Engineering test data are discussed in Section 3 and medical reports are presented in Section 4. Conclusions concerning the overall performance of the restraint systems are presented in Section 5.

1.2 Summary

Three unembalmed cadavers exposed to the three point belt restraint system showed no injuries to the lower abdominal soft tissue. Calman 3, an osteoporotic subject, exhibited crushing of both the left and right anterior superior spines of the illium. All three subjects exhibited injuries to the upper abdominal organs in varying degrees. Multiple rib and sternum fractures were evident in all cases and Calman 1 further suffered multiple fractures of the right orbit and its supporting skeletal structures as well as fracturing of the cranium regionally associated with the orbit and a laceration of the frontal lobe of the brain. Calman 3 also exhibited a complete fracture of the odontoid process.

A 50th percentile anthropomorphic test dummy was exposed for purposes of comparison with Calman 2. Data shows a difference in head motion and head resultant acceleration as well as overall belt loads. Chest accelerations and chest severity index are similar.

Two unembalmed cadavers exposed to the air belt system showed rib fractures and one clavicle fracture only. Calman 4 exhibited fractures of the right and left ribs 2 through 5, and a fracture of the lateral aspect of the left clavicle with separation of the acromio-clavicular joint. The fracture of the ribs as a group were undisplaced and frequently incomplete extending only partially through the height or through only the external (subcutaneous, ventral) surface.

Where chest deflection, aortic pressure and belt loads were measured there is fair correlation in peak reading and time between the three measured quantities.

Calman 5 had a fracture of the left rib 4. This fracture was in the same area as a faint overlying subcutaneous discoloration. This information, coupled with the fact that petechial hemorrhages were also present in the pericardial sac, suggest that they, as well as the fracture of the rib, may have been caused by terminal external cardiac massage.

2.0 TEST EQUIPMENT

2.1 Accelerator Sled

Calspan's HYGE impact sled facility was employed for these tests to accelerate the body buck, test subject, and equipment to a nominal velocity of 30 mph in the first four tests, and a nominal velocity of 47 mph in the last two tests. The sled is a rearward firing type with energy and velocity capabilities well above the requirements of this test. A "square wave" metering pin was selected for the first four tests, to produce the acceleration wave shape. For the last two tests a "double hump" metering pin was selected to produce the required acceleration wave shape. Specific operating and performance data concerning this HYGE sled is presented in Appendix I of this report.

2.2 Sled Body Bucks

The first body buck used was designed to duplicate the dimensions of the driver's compartment of a Citroen automobile. Drawings were supplied by the Citroen Corporation for fabrication of the structure. All dimensions in the drawings were converted from metric to English units and the overall tolerances are approximately ± 1/4 inch (6 mm). The frame of the structure was fabricated from 1-1/2 inch steel pipe and welded together. In addition to the external frame, a Citroen steering column and bucket seat were installed in the appropriate positions within the compartment. After the third run, the steering column was removed. Restraint belt anchor points, for a Citroen 3-point system, were also installed at their actual locations with the lap belt anchors located at each side of the seat.

The second body buck used was designed to duplicate the dimensions of the passenger compartment of a Pinto automobile. The frame of the structure was fabricated from 1-1/2 inch steel pipe and welded together. In addition to the external frame, a bucket seat was installed in the appropriate position within the compartment. Restraint belt anchor points, as specified by Minicars, were also installed at their actual locations with the lap belt anchors located at each side of the seat and reinforced to the sled structure.

An automatic cycling system for arterial pressures was mounted on the aft frame members of the body buck. Side views of the structures are presented in Section 3.0

2.3 Recording Instrumentation

Instrumentation employed for these tests are presented in Table 1.

TABLE 1 TEST INSTRUMENTATION

Parameter Measured	Instrumentation
Head Acceleration - External	Triaxial Endevco Type 7267C-750S
Head Acceleration - Internal (dummy)	3-Endevco Type 7231C-750S
Chest Acceleration - External	Triaxial Endevco Type 7267C-750S Accel'tr. mounted to a 2.13 in. dia. disc x .2 in. thick
Chest Acceleration - Internal (dummy)	2-CEC Type 202-250G; 1-Endevco Type 7231C-750S
Arterial Pressure	Mikro-Tip Pressure Transducer Type PC-350A, Millar Instr'ts.
	Tank Regulator, Solenoid and Valves (for Air Reserve)
Lung Pressure	Statham Model 131TC-25 psi
Restraint Belt Loads	Lebow Cells, Model 3371 (one at each anchor pt.)
Belt Elongation	Spring Loads Pot, 10 Turn, 500 Steel Wire - .012 in. Inside Sheath
Air Belt Pressure	Viatran Model 222-100 psi
Chest Deflection Cadavers	Inductive Deflection Sensor Coils (Uses Inductive Coupling)
Chest Deflection Dummy	Rotary Potentiometer hinged with movable arms
Cameras	Stalex WS ICE (4 units) Lens - ILEX 8 mm fl .5 Cine Paragon
	Graph-Check Sequence (8 Photos per Test)
Tape Recorders	Sangamo Model 3562

2.4 Test Subject Preparation

2.4.1 Calman 1

The subject was delivered at the HYGE sled facility after x-rays, dressed in two layers of stretch long underwear, with a Foley #12 French catheter, 5 cc balloon, inserted through the left femoral artery. Another Foley #12 French catheter, 5cc balloon, was in place in the trachea. A Millar Instruments type PC-350A pressure transducer was in place in the arch of the aorta, through the left common carotid artery.

X-ray examinations had shown that the arterial system catheter had not made the bifurcation of the abdominal aorta and was still in the illiac artery. This catheter was worked further in to a length that would indicate entry into the abdominal aorta.

The balloon was inflated with air to occlude the lower arterial system, and a solution of Gelgard M was introduced to the upper arterial system while the pressure was monitored as measured by the Millar T/D. When approximately 250 ml of Gelgard M had been inserted, and a pressure of approximately 70 - 80 mm Hg was being maintained, the measured pressure dropped to 17 - 20 mm Hg. Introduction of another 100 ml Gelgard did not increase the arterial pressure and it was decided that we had failed something internal, and the effort was suspended. It was decided to record the output from the T/D during the run anyway.

The balloon of the Foley catheter in the trachea was inflated with air to occlude the trachea and approximately 1000 cc of air were introduced into the lungs. There was a noticeable change in the chest dimension as the air was introduced and a small back flow was felt from the catheter. The catheter was clamped off and no effort was made to record dynamic pressure during the sled test.

2.4.2 Calman 2

The subject was delivered at the HYGE sled facility after x-rays, dressed in two layers of stretch long underwear, with a Foley #12 French catheter, 5cc balloon, inserted through the left femoral artery. Another catheter (Foley #18 French, 5cc balloon) had been introduced into the trachea. A Millar Instruments type PC-350A pressure T/D was in place in the arch of the aorta through the left common carotid artery.

X-ray examinations had shown that the arterial system catheter had not made the bifurcation of the aorta and was still in the left illiac artery. Efforts to thread the catheter into the aorta were unsuccessful and it was decided to enter the right common carotid artery with another Foley catheter for pressurization of the arterial system. An incision was made and the right common carotid artery was exposed. A Foley #12 French catheter, 5cc balloon, was inserted and the bulb inflated with air. The incision was closed with a running suture. The balloon of the catheter at the bifurcation of the aorta and the illiac arteries was inflated to occlude the lower arterial system. Approximately 250 ml of Gelgard M was introduced through the right common carotid artery while the pressure was monitored by the Millar T/D. The system was tight with approximately one mm Hg per second leak rate. The catheter was connected to the Calspan developed automatic pressurization system and cycled from 70 mm Hg to 90 mm Hg on demand.

The trachea catheter balloon was inflated with air to occlude the trachea and approximately 1200 cc air was introduced into the lungs. There was a noticeable change in the chest dimension as the air was introduced and a small back flow was felt from the catheter. The catheter was clamped off and no effort was made to record dynamic pressure during the sled test.

2.4.3 50th Percentile Anthropomorphic Dummy

The subject was dressed in two sets of stretch long underwear and the external head and chest accelerometer instrumentation used on Calman 1 and Calman 2 was attached in a similar manner. The anthropomorphic dummy was not certified prior to the test but all joints were set according to Federal Motor Vehicle Safety Standard No. 208.

A caliper type chest deflectometer was installed over the right shoulder with the active arm extending to the mid sternal position.

2.4.4 Calman 3

The subject was delivered at the HYGE sled facility after x-rays, dressed in two layers of stretch long underwear, with a Foley #14 French catheter, 5cc balloon, inserted through the left femoral artery. Another catheter (Foley #14 French, 5cc balloon) had been introduced into the trachea. A Millar Instruments type PC-350A pressure T/D was in place in the arch of the aorta through the left common carotid artery. The arterial catheter balloon was inflated with a radio-opaque substance for ease of location in x-rays.

Approximately 250 ml of Gelgard M was introduced while the pressure was monitored by the Millar T/D. The system was tight with approximately 1 mm Hg per second leak rate. The catheter was connected to the Calspan developed automatic pressurization system and cycled from 70 mm Hg to 90 mm Hg on demand.

The trachea catheter bulb was inflated with air to occlude the trachea and approximately 1200 cc air was introduced into the lungs. There was a noticeable change in the chest dimension as the air was introduced and a small back flow was felt from the catheter. The catheter was connected to a 25 psi pressure transducer to record dynamic pressure during the sled test.

2.4.5 Calman 4

The subject was delivered at the HYGE sled facility after x-rays, dressed in two layers of stretch while leotards, with a Foley #14 French catheter inserted in the left femoral artery. Another catheter (Foley #14

French) had been introduced into the trachea. A Millar Instruments type PC-350A pressure T/D was in place in the left common carotid artery.

Approximately 250 ml of Gelgard M was introduced while the pressure was monitored by the Millar T/D. The system was tight with approximately 1 mm Hg per second leak rate. The catheter was connected to the Calspan developed automatic pressurization system and cycled from 70 mm Hg to 90 mm Hg on demand.

The trachea catheter bulb was inflated with air to occlude the trachea and approximately 1200 cc air was introduced into the lungs. There was a noticeable change in the chest dimension as the air was introduced and a small back flow was felt from the catheter. The catheter was connected to a 25 psi pressure transducer to record dynamic pressure during the sled test.

2.4.6 Calman 5

The subject was delivered at the HYGE sled facility after x-rays, dressed in two layers of stretch white leotards, with a Foley #12 French catheter inserted in the left femoral artery. Another catheter (Foley #18 French) had been introduced into the trachea. A Millar Instruments type PC-350A pressure T/D was in place in the left common carotid artery.

Approximately 250 ml of Gelgard M was introduced while the pressure was monitored by the Millar T/D. The system was tight with approximately 1 mm Hg per second leak rate. The catheter was connected to the Calspan developed automatic pressurization system and cycled from 70 mm Hg to 90 mm Hg on demand.

The trachea catheter bulb was inflated with air to occlude the trachea and approximately 1200 cc air was introduced into the lungs. There was a noticeable change in the chest dimension as the air was introduced and a small back flow was felt from the catheter. The catheter was connected to a 25 psi pressure transducer to record dynamic pressure during the sled test.

3.0 ENGINEERING TEST DATA

3.1 Test Conditions

Table 3-1 lists the test conditions for each of the six HYGE sled runs of this program.

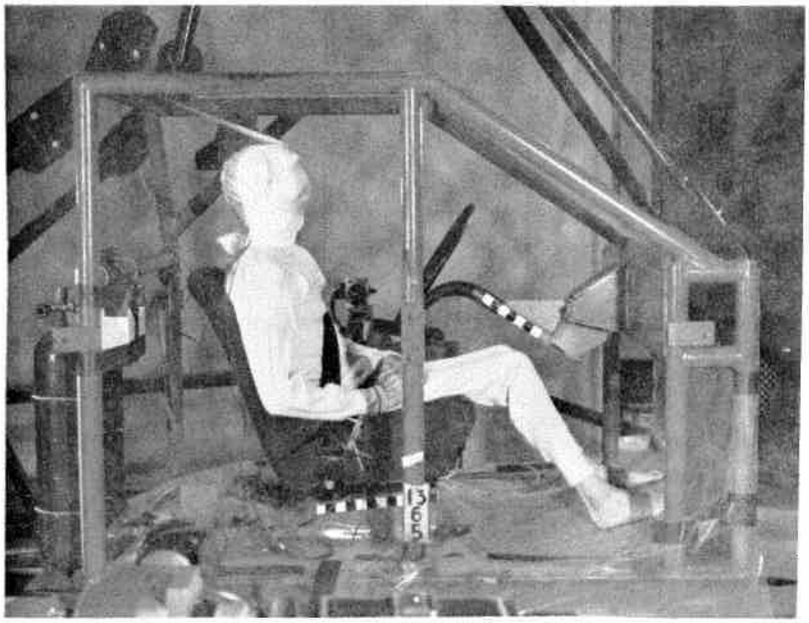
Four high-speed movie cameras were mounted on the sled. Nominal film speeds of 1000 pictures per second were used in all tests. Camera coverage was from the subject; right, left, overhead and rear on Calman 1, Calman 2, and the 50th percentile dummy; right, left, overhead and front for Calman 3; right, left and overhead for Calman 4 and Calman 5.

TABLE 3-1 TEST CONDITIONS

Calspan Run Number	Body Buck	Test Subject	Sled Accel'tn. Peak g's	Sled Velocity MPH	Sled Pulse Time msec	Comments
1365	Citroen	Calman 1	29.5	30.4	69.4	----
1366	Citroen	Calman 2	29.0	30.3	69.8	----
1367	Citroen	Anthropo-morphic Dummy	29.0	30.2	70.0	----
1368	Citroen	Calman 3	28.4	30.1	67.4	Removed Steering Wheel
1404	Pinto	Calman 4	34.0	46.7	105.3	Air Belt
1414	Pinto	Calman 5	34.0	46.9	106.1	Air Belt

3.1.1 Calman 1

The pretest position of Calman 1 in the driver's seat of the Citroen boyd buck is shown in the upper photograph of Figure 3-1. Following impact, the subject's final position is indicated in the lower photograph. The lap belt restraint was attached directly to anchor points on each side of the lower seat frame. The lower end of the chest restraint strap was connected through the slip joint of the right side seat anchor and its upper end attached to an anchor point on the body frame. Piror to the test, a small pretension force (5-10#) was set into both straps. Since the neck of the test subject was not sufficiently rigid to



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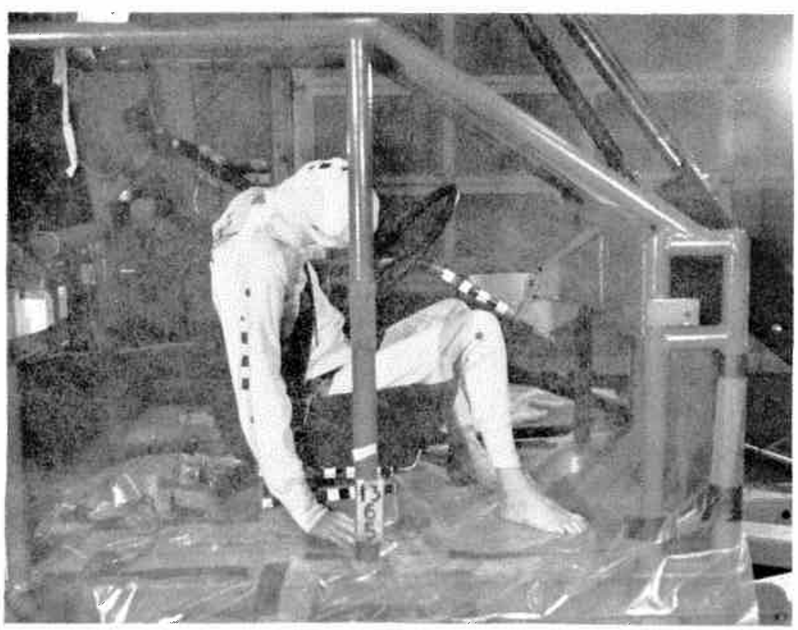


POST TEST CONDITION

FIGURE 3-1 CALMAN 1 TEST POSITIONS

support its head in a natural upright position, two strips of light tape were attached from the top of the head to the rear frame of the body buck. The hands of the subject were positioned in the lap.

Figure 3-2 shows the body buck, steering wheel on seat configurations for the first three tests.

3.1.2 Calman 2

The pretest position of Calman 2 in the driver's seat of the Citroen body buck is shown in the upper photograph of Figure 3-3. Following impact, the subject's final position is indicated in the lower photograph. The lap belt restraint was attached directly to anchor points on each side of the lower seat frame. The lower end of the chest restraint strap was connected, through the slip joint, to the webbing of the lap strap at the right side of the seat. The upper end of the chest restraint was attached to an anchor point on the body frame. Prior to the test, a small pretension force (5 to 10 lbs.) was set into both straps. Since the neck of the test subject was not sufficiently rigid to support its head in a natural upright position, two strips of light tape were attached from the top of the head to the rear frame of the body buck. The hands of the subject were lightly taped to the steering wheel rim.

Elongations of both the upper strap and lap belts, during the impact, were measured by two .012 inch wires (one on each strap), which were connected to spring loaded potentiometers mounted to the body frame. The wires, guided inside of plastic sheaths, were secured to the outside of each of the straps. The ends of each of the two wires were terminated at the lower ends of their respective straps. As the webbing stretched, the wires were pulled out of the pots, thus measuring the elongations.

A scale drawing of the Citroen body buck is presented in Figure 3-2 to show the relative positions of the seat, restraint belt anchor points, and steering assembly.

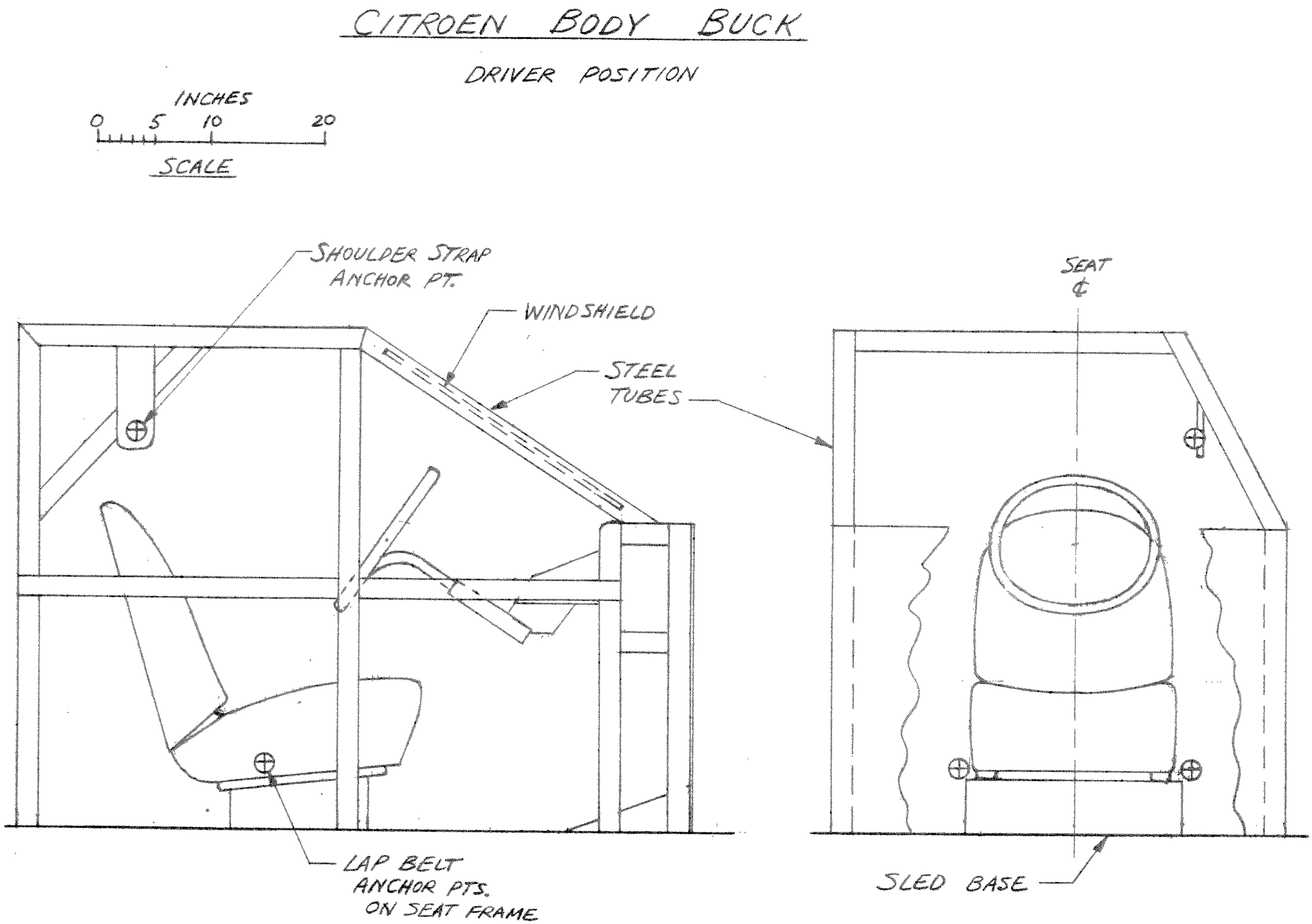
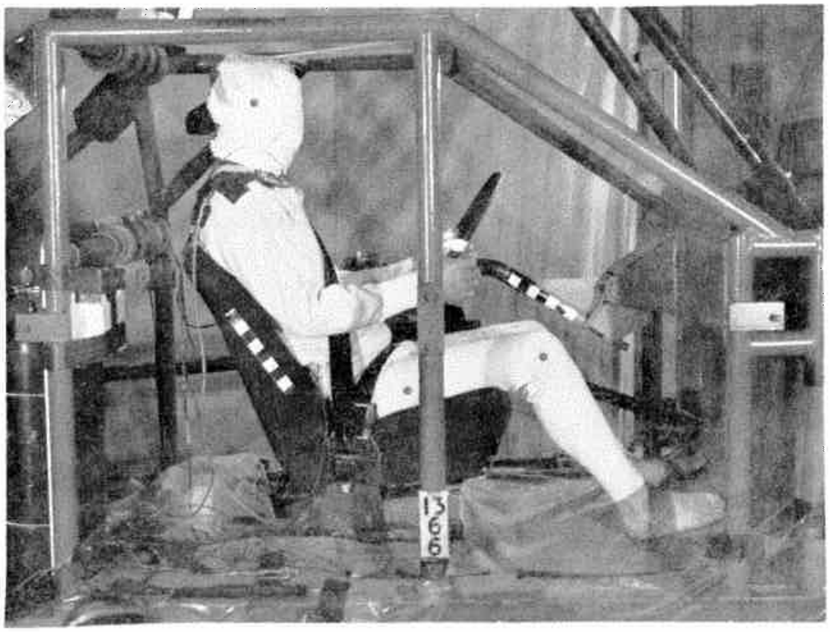


FIGURE 3-2 CITROEN BODY BUCK, SEAT, AND STEERING ASSEMBLY POSITIONS



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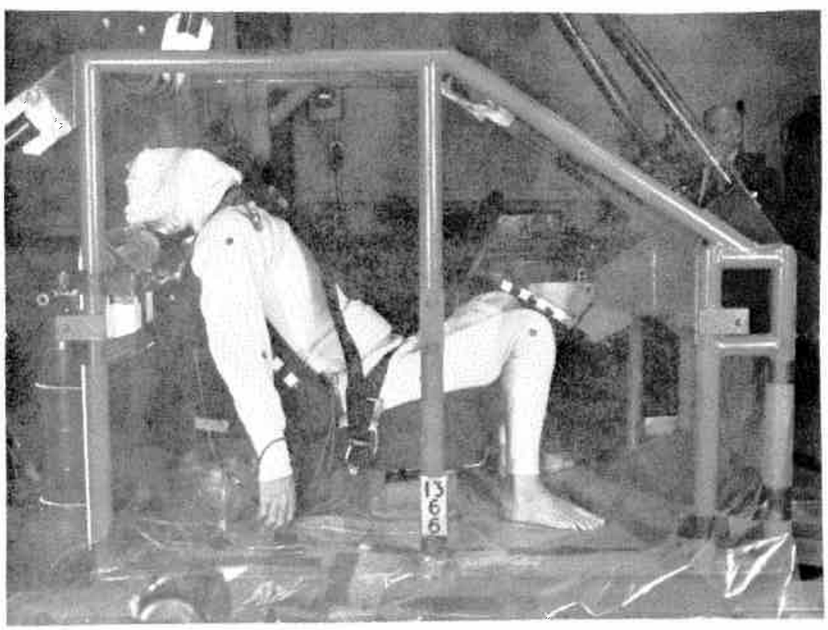


POST TEST CONDITION

FIGURE 3-3 CALMAN 2 TEST POSITIONS

3.1.3 50th Percentile Anthropomorphic Dummy

A 50th percentile Humanoid Systems anthropomorphic dummy was tested under the same conditions as performed for Calman 2 for direct comparison purposes. The pretest position of the dummy in the Citroen driver seat is shown in the upper photograph of Figure 3-4. Following impact, the dummy's final position is indicated in the lower photograph.

External accelerometers were attached to the head and chest of the dummy in the same manner as secured to Calman 2. In addition, the standard triaxial accelerometer packages were installed inside of the head and chest for direct comparison with the external instrumentation.

For measuring chest deflections during the run, a device was fabricated which contained a rotary potentiometer connected to a movable arm. The device was mounted on top of the right shoulder with the end of the arm positioned in the middle of the thorax. Deflections of the chest were thereby transmitted to the arm and then monitored by the potentiometer.

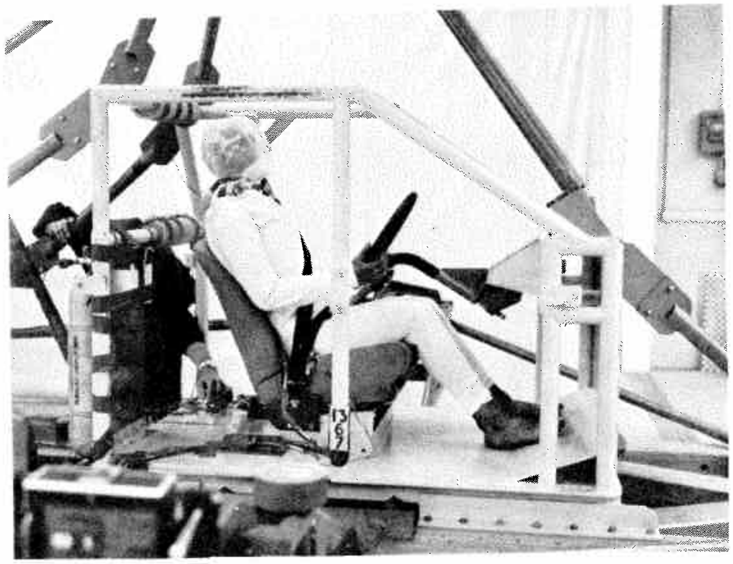
Belt elongation instrumentations were the same as used on the previous Calman 2 test.

A scale drawing of the Citroen body buck is presented in Figure 3-2 to show the relative positions of the seat, restraint belt anchor points, and steering assembly.

The four high-speed movie cameras were mounted on the sled platform to record the motions of the dummy in all three primary reference planes.

3.1.4 Calman 3

The pretest position of Calman 3 in the driver's seat of the Citroen body buck is shown in the upper photograph of Figure 3-5. Following impact, the subject's final position is indicated in the lower photograph. The lap belt



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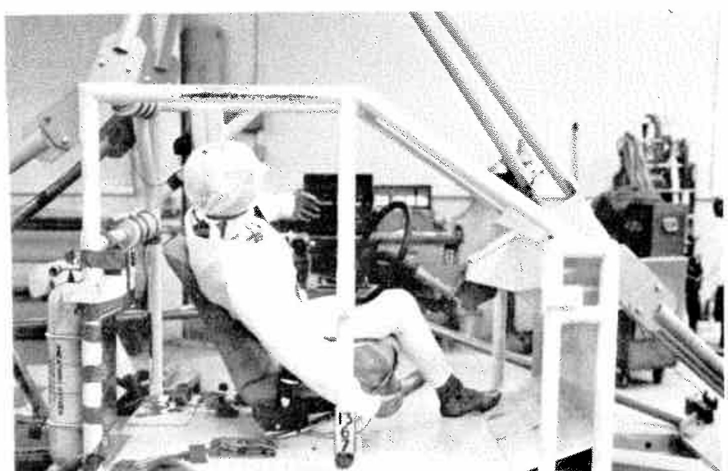
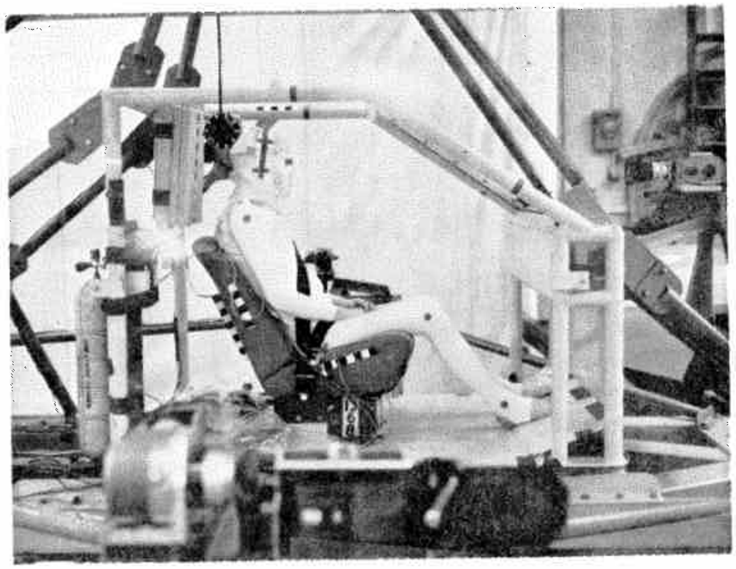
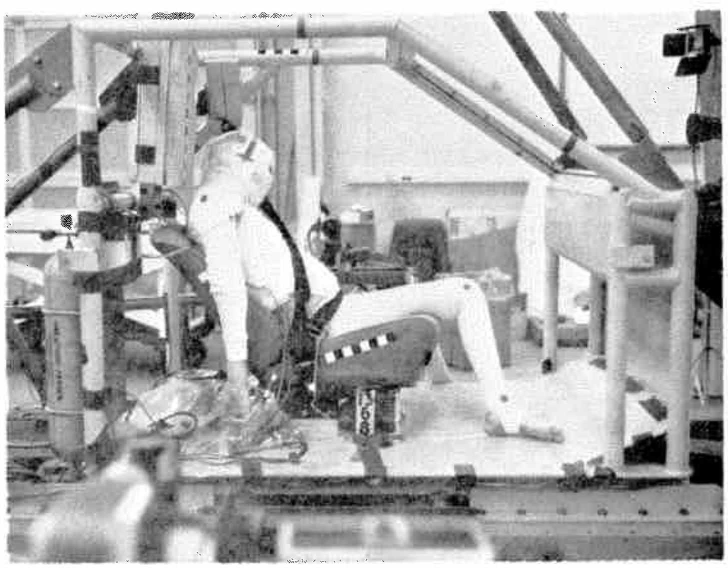


POST TEST CONDITION

FIGURE 3-4 ANTHROPOMORPHIC TEST DUMMY POSITIONS



PRE TEST SETUP



POST TEST CONDITION

FIGURE 3-5 CALMAN 3 TEST POSITIONS

restraint was attached directly to anchor points on each side of the lower seat frame. The lower end of the chest restraint strap was connected, through the slip joint, to the webbing of the lap strap at the right side of the seat. The upper end of the chest restraint was attached to an anchor point on the body frame. Prior to the test, a small pretension force (5 to 10 lbs.) was set into both straps. Since the neck of the test subject was not sufficiently rigid to support its head in a natural upright position, two strips of light tape were attached from the top of the head to the rear frame of the body buck. The hands of the subject were placed out from the seat touching his thighs.

Elongations of both the upper strap and lap belts, during the impact, were measured by two .012 inch wires (one on each strap), which were connected to spring loaded potentiometers mounted to the body frame. The wires, guided inside of plastic sheaths, were secured to the outside of each of the straps. The ends of each of the two wires were terminated at the lower ends of their respective straps. As the webbing stretched, the wires were pulled out of the pots, thus measuring the elongations.

A scale drawing of the Citroen body buck is presented in Figure 3-6 to show the relative positions of the seat and restraint belt anchor points and removal of the steering column.

The rear mounted high speed camera was replaced by a front-mounted one. This view afforded more detailed observation of the shoulder belt loading the cadaver.

3.1.5 Calman 4

The pretest position of Calman 4 in the passenger seat of the Pinto body buck is shown in the upper photograph of Figure 3-7. Following impact, the subject's final position is indicated in the lower photograph. The lap belt restraint was attached directly to anchor points on each side of the seat frame. The lower end of the chest restraint air belt was connected, through a slip joint, to the webbing of the lap strap at the left side of the seat. The upper

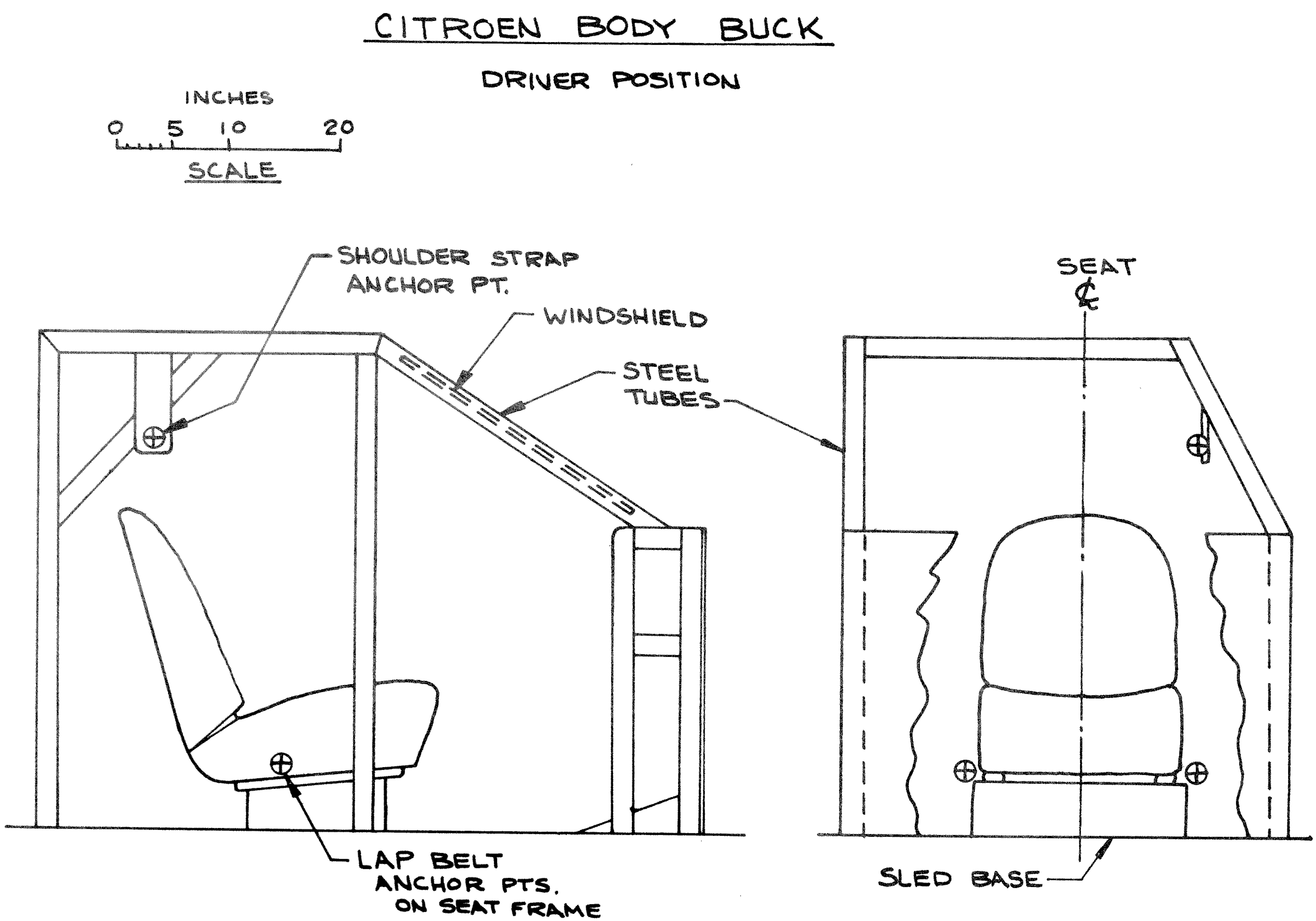
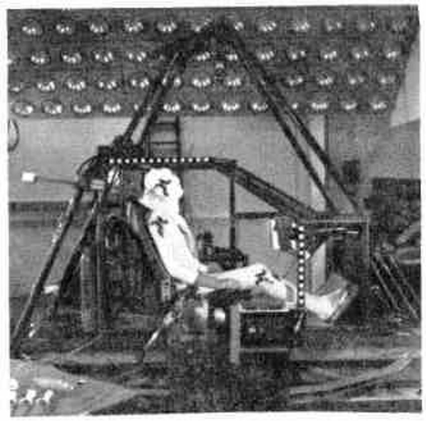


FIGURE 3-6 CITROEN BODY BUCK, SEAT ASSEMBLY POSITIONS



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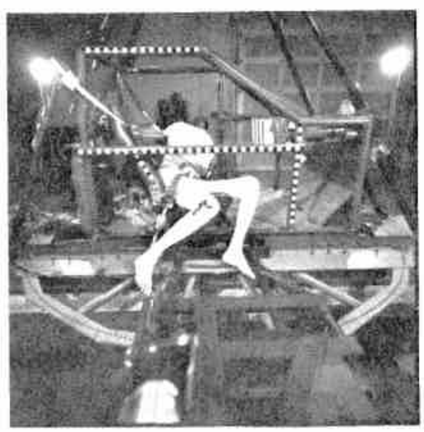


POST TEST CONDITION

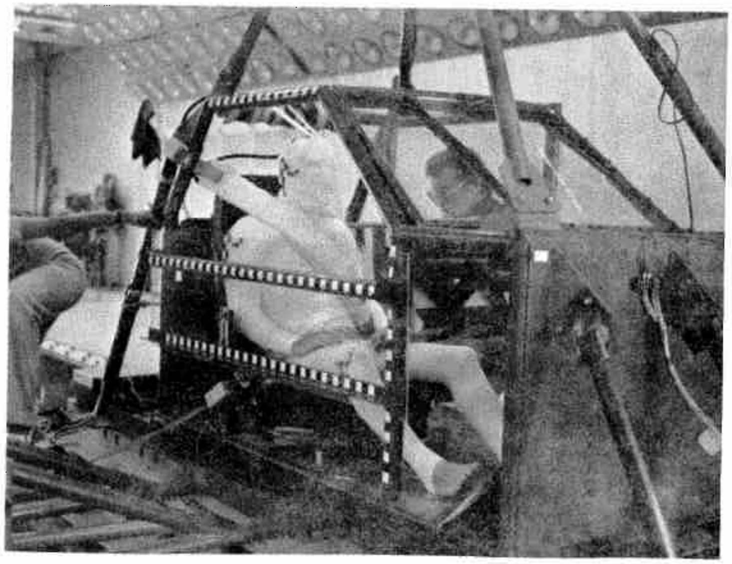
FIGURE 3-7 CALMAN 4 TEST POSITIONS

end of the chest restraint was attached to an anchor point on the body frame. Load limiting devices were installed at all three anchor points. Prior to the test, a small pretension force (5 to 10 lbs) was set into both straps. Since the neck of the test subject was not sufficiently rigid to support its head in a natural upright position, two strips of light tape were attached from the top of the head to the rear frame of the body buck.

A total of three high-speed movie cameras were mounted directly on the sled platform to afford the best photographic coverage of the subject's motions. Two side view cameras, one on each side of the body buck, were employed to obtain horizontal and vertical subject kinematic (X-Z plane) data. Both side camera lenses were approximately 55.8 inches from the body buck frame. In addition, an overhead camera obtained subject data in horizontal and lateral motions (X-Y plane) and was about 22.5 inches above the top frame.

3.1.6 Calman 5

The pretest position of Calman 5 in the passenger seat of the Pinto body buck is shown in the upper photograph of Figure 3-8. Following impact, the subject's final position is indicated in the lower photograph. The lap belt restraint was attached directly to anchor points on each side of the seat frame. The lower end of the chest restraint air belt was connected, through a slip joint, to the webbing of the lap strap at the left side of the seat. The upper end of the chest restraint was attached to an anchor point on the body frame. Load limiting devices were installed at all three anchor points. Prior to the test, a small pretension force (5 to 10 lbs) was set in to both straps. Since the neck of the test subject was not sufficiently rigid to support its head in a natural upright position, two strips of light tape were attached from the top of the head to the rear frame of the body buck. Minicars required the seat to be in the rear most position thereby allowing recording of lap belt loads only on the right belt due to the length of the shoulder bag.



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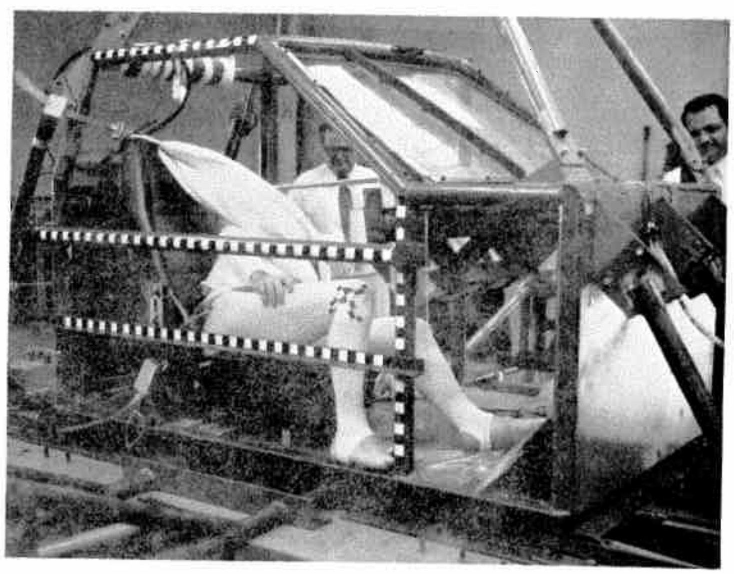


POST TEST CONDITION

FIGURE 3-8 CALMAN 5 TEST POSITIONS

A total of three high-speed movie cameras were mounted directly on the sled platform to afford the best photographic coverage of the subject's motions. Two side view cameras, one on each side of the body buck, were employed to obtain horizontal and vertical subject kinematic (X-Z plane) data. Both side camera lenses were approximately 55.8 inches from the body buck frame. In addition, an overhead camera subject data in horizontal and lateral motions (X-Y plane) and was about 22.5 inches above the top frame.

3.2 Test Results

Plotted test results, using the data acquisition and reduction techniques presented in Appendix II are presented as time histories of the required variables and time histories of computations based on measured variables in Appendix III.

Table 3-2 summarizes the recorded subject data for this program.

The kinematics of Calman 1's motions are presented in the Polaroid sequence photographs of Figure 3-9, which were recorded at time intervals of approximately .040 seconds between frames. Note from the photographs that the head support tape produced negligible effects on the head motions.

Photographic data from the high-speed movie cameras were analyzed on a frame to frame basis to obtain the head trajectory graphs presented in Figure 3-10. In the side view, only the motions of the head in the X-Z plane were recorded, that is, no corrections were applied to the translation motions due to head rotations out of this plane. The same data reduction technique was applied for the overhead view films. Maximum head rotation angle in the X-Z plane of approximately 70 degrees occurred during contact with the steering assembly. This contact appeared to restrict the head motion and prevent further rotation.

TABLE 3-2 SUMMARY TABLE

	Run 1365 Calman 1	Run 1366 Calman 2	Run 1367 50th%tile	Run 1368 Calman 3	Run 1404 Calman 4	Run 1414 Calman 5
Standing Height	71.5 in.	72.0 in.	N/A	69.0 in.	76.0 in.	63.5 in.
Sitting Height	33.25 in.	37.0 in.	35.7 in	33.0 in.	37.5 in.	30.0 in.
Weight	115 lbs	162 lbs	163 lbs	125 lbs	172 lbs	150 lbs
Age	69 yrs	44 yrs	N/A	65 yrs	51 yrs	51 yrs
Chest Circumference	33 in	37 in	37.4 in	34 in	37 in	38 in
Head Resultant Acceleration	136 g	128 g	64-44*	75 g	145 g	72 g
Head Injury Criteria No.-HIC	3493	736	868-348	1540	903	614
Chest Resultant Acceleration	76 g	58 g	53-54*	50 g	68 g	47.5 g
Chest Severity Index	1050	500	370-400	457	600	510
Arterial Pressure	Lost	1760	N/A	1980	680 mmHg	690 mmHg
Lung Pressure	Not Measured	Not Measured	N/A	.75/1.75** psi	---	---
Chest Deflection	2 in	Lost	1.5 in	2.87	1.5 in.	1 in.
Right Lap Belt Load	960	1720	2200	1170	1170 lbs	1200 lbs
Left Lap Belt Load	1040	2200	2480	1420	1020 lbs	Not Measured
Shoulder Strap Load	1330	2200	2320	2050	1360 lbs	Not Measured
Lap Belt Elongation	Lost	4.5 in	Lost	2.25 in	N/A	N/A
Shoulder Strap Elongation	Lost	5.0 in	5.2	5.0 in	N/A	N/A
Right Lap Load Limiter Travel	N/A	N/A	N/A	N/A	.188 in	1.375 in
Left Lap Load Limiter Travel	N/A	N/A	N/A	N/A	3.0 in	4.250 in
Shoulder Load Limiter Travel	N/A	N/A	N/A	N/A	12.0 in	3.625 in
Bag Pressure	N/A	N/A	N/A	N/A	24.0 psi	19 psi
Sled Peak g's	29.5 g	29.0 g	29.0 g	28.4 g	34.0 g	34.0 g
Sled Velocity Change	30.4 mph	30.3 mph	30.2 mph	30.1 mph	46.7 mph	46.9 mph
Sled Pulse Time	69.4 msec	69.8 msec	70 msec	67.4 msec	105.3 msec	106.1 msec

* Internal Instrumentation - Dummy

** Impact/Rebound

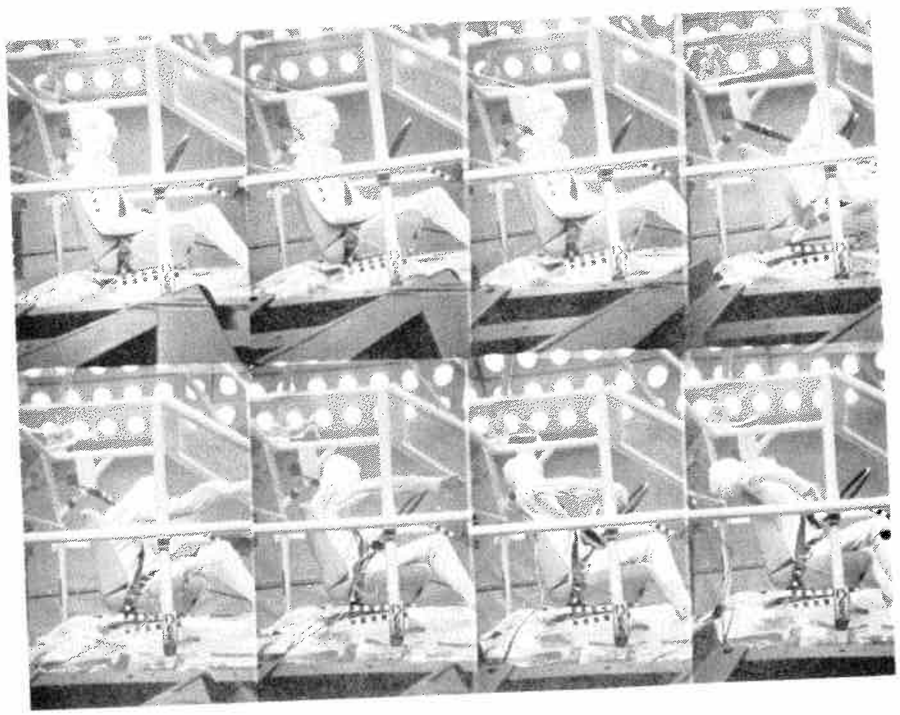


FIGURE 3-9 TIME SEQUENCE OF CALMAN 1 KINEMATICS

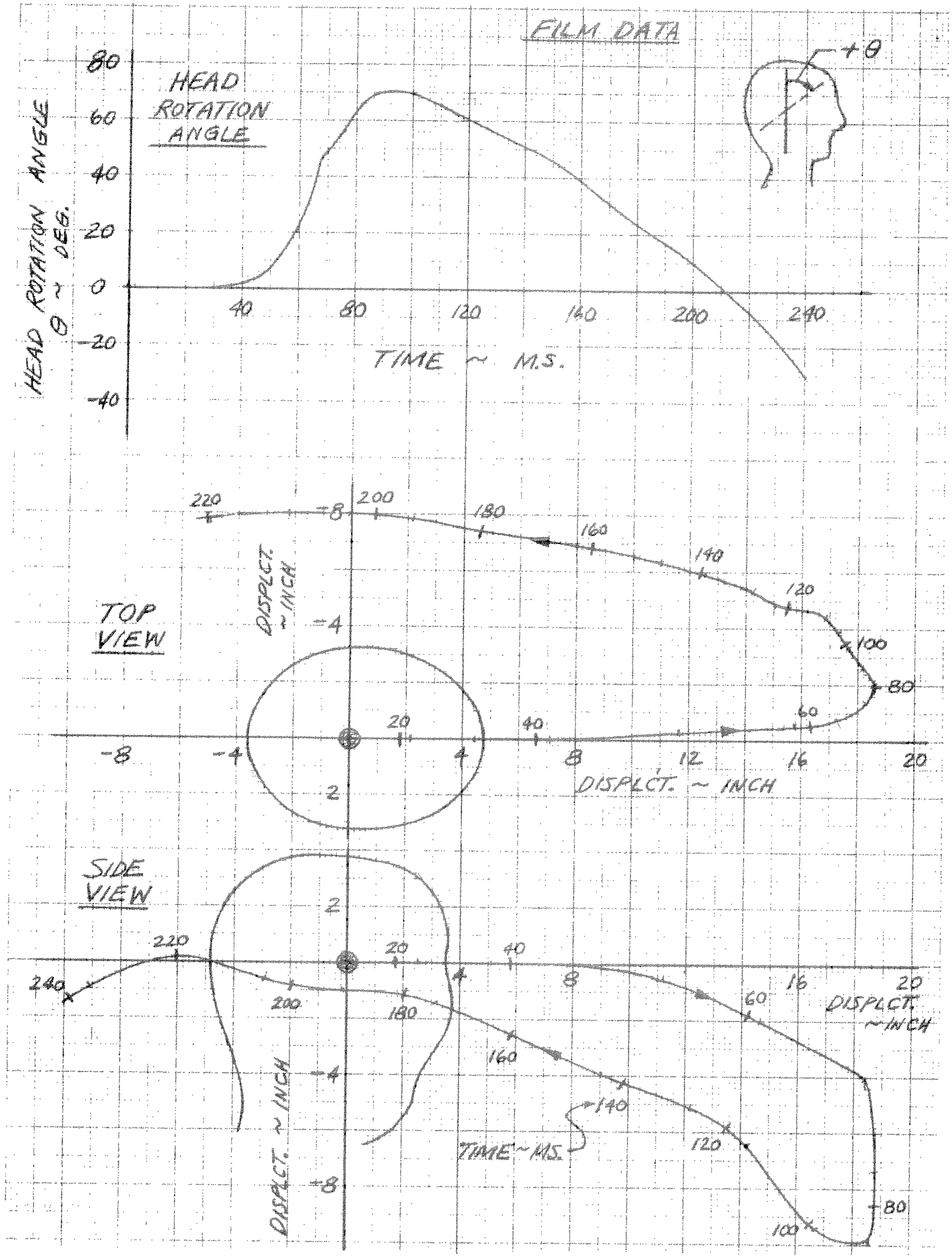


FIGURE 3-10 CALMAN 1 HEAD MOTIONS

The kinematics of Calman 2's motions are presented in the Polaroid sequence photographs of Figure 3-11, which were recorded at time intervals of approximately .040 seconds between frames. Note from the photographs that the head support tape produced negligible effects on the head motions and that the taped hands released quickly from the steering rim.

Photographic data from the high-speed movie cameras were analyzed on a frame to frame basis to obtain the head trajectory graphs presented in Figure 3-12. In the side view, only the motions of the head in the X-Z plane were recorded, that is, no corrections were applied to the translation motions due to head rotations out of this plane. The same data reduction technique was applied for the overhead view films. Maximum head rotation angle in the X-Z plane of approximately 80 degrees occurred during contact with the steering assembly. This contact appeared to restrict the head motion and prevent further rotation.

The kinematics of the test dummy motions are presented in the Polaroid sequence frames of Figure 3-13, which were recorded at an average time interval of approximately .040 seconds between pictures.

Photographic data from the high-speed movie cameras were analyzed on a frame to frame basis to obtain the head trajectory graphs presented in Figures 3-14. In the side view, only the motions of the head in the X-Z plane were recorded, that is, no corrections were applied to the translation motions due to head rotations out of this plane. The same data reduction technique was applied for the overhead view films. Maximum head rotation angle in the X-Z plane of approximately 72 degrees occurred during contact with the steering assembly.

The kinematics of Calman 3's motions are presented in the Polaroid sequence photographs of Figure 3-15, which were recorded at time intervals of approximately .040 seconds between frames. Note from the photographs that the head support tape produced negligible effects on the head motions.

FIGURE 3-11 TIME SEQUENCE OF CALMAN 2 KINEMATICS

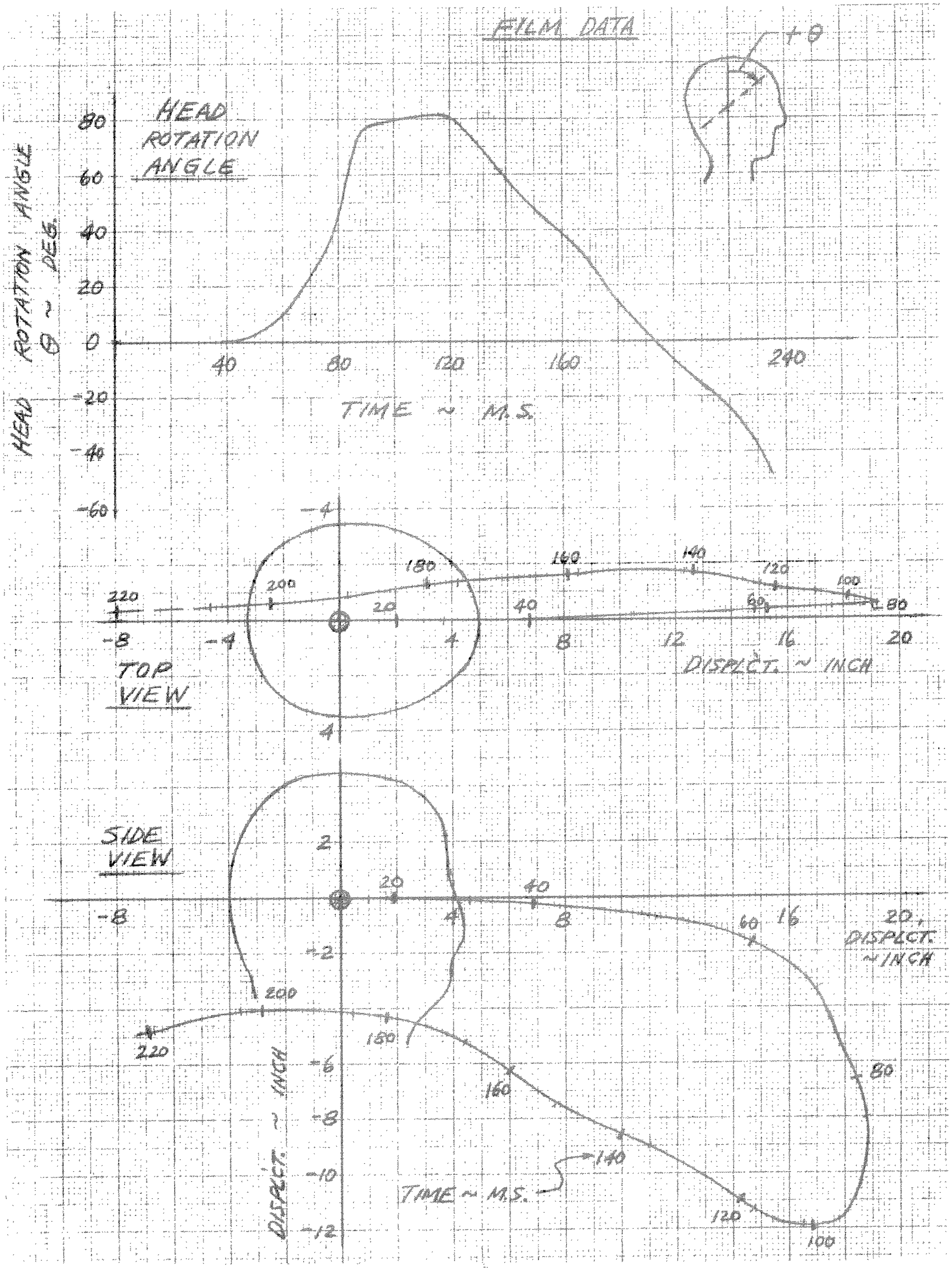


FIGURE 3-12 CALMAN 2 HEAD MOTIONS

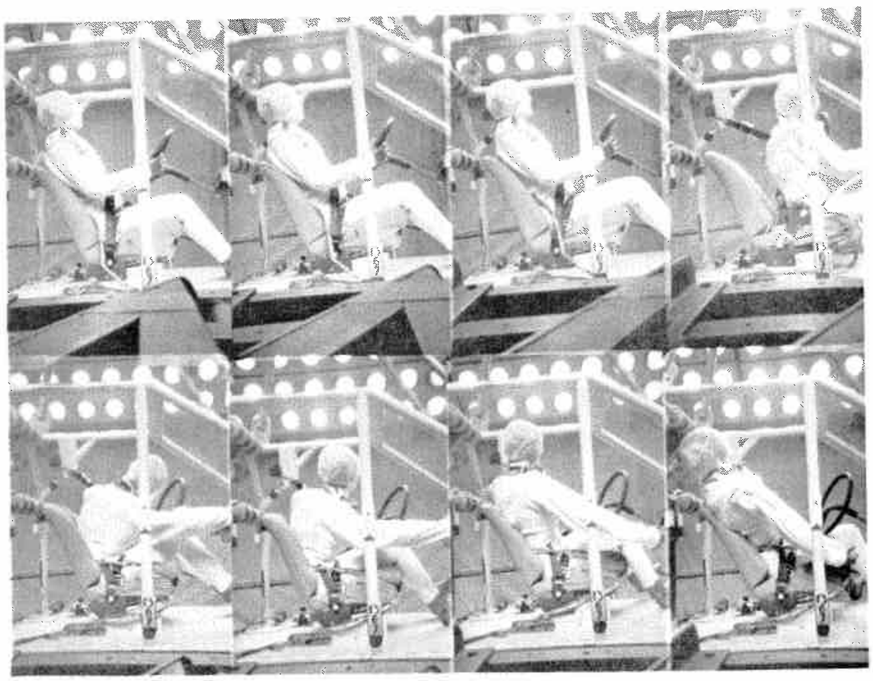


FIGURE 3-13 TIME SEQUENCE OF DUMMY KINEMATICS

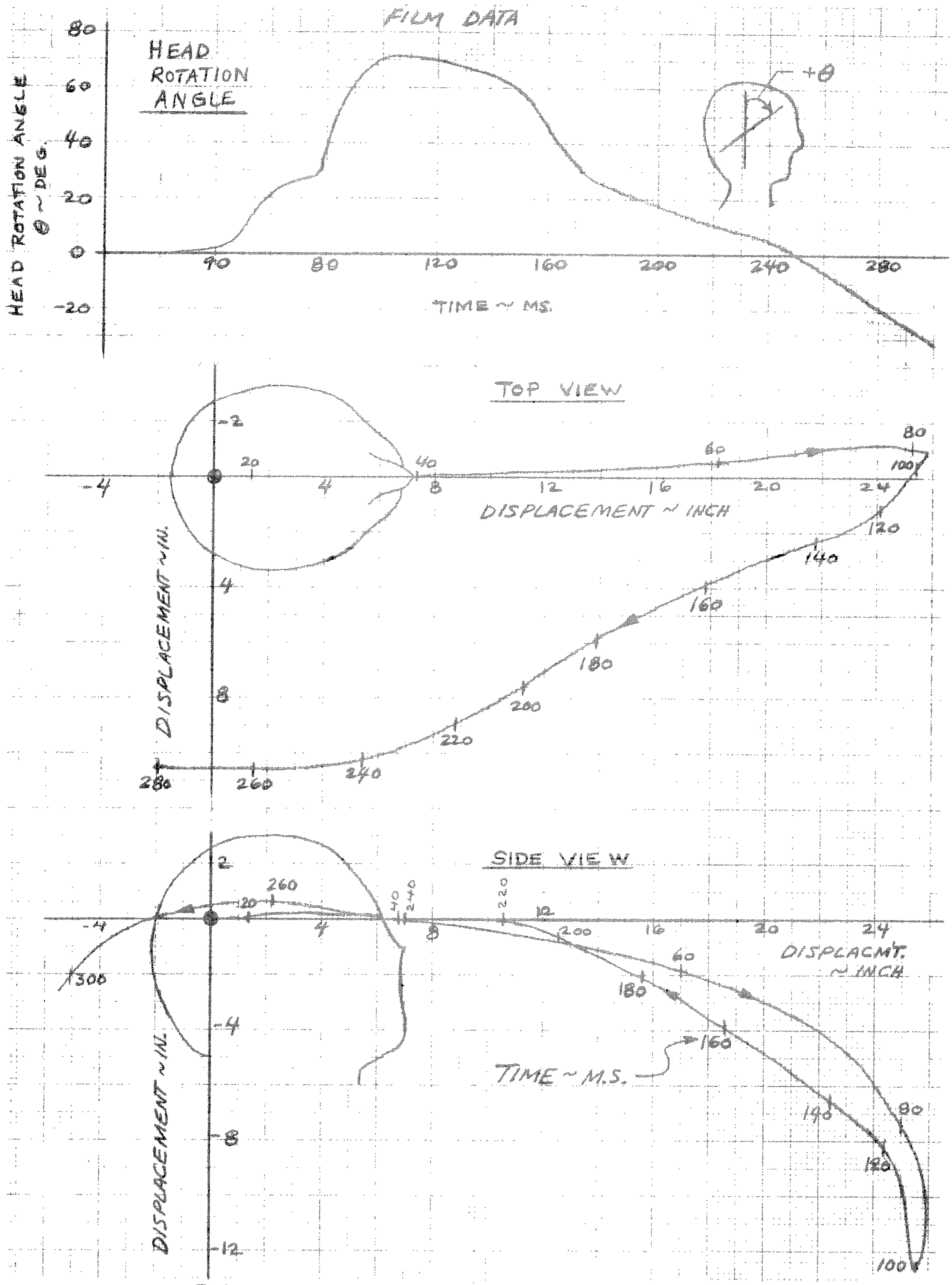


FIGURE 3-14 HEAD TRANSLATION AND ROTATION MOTIONS

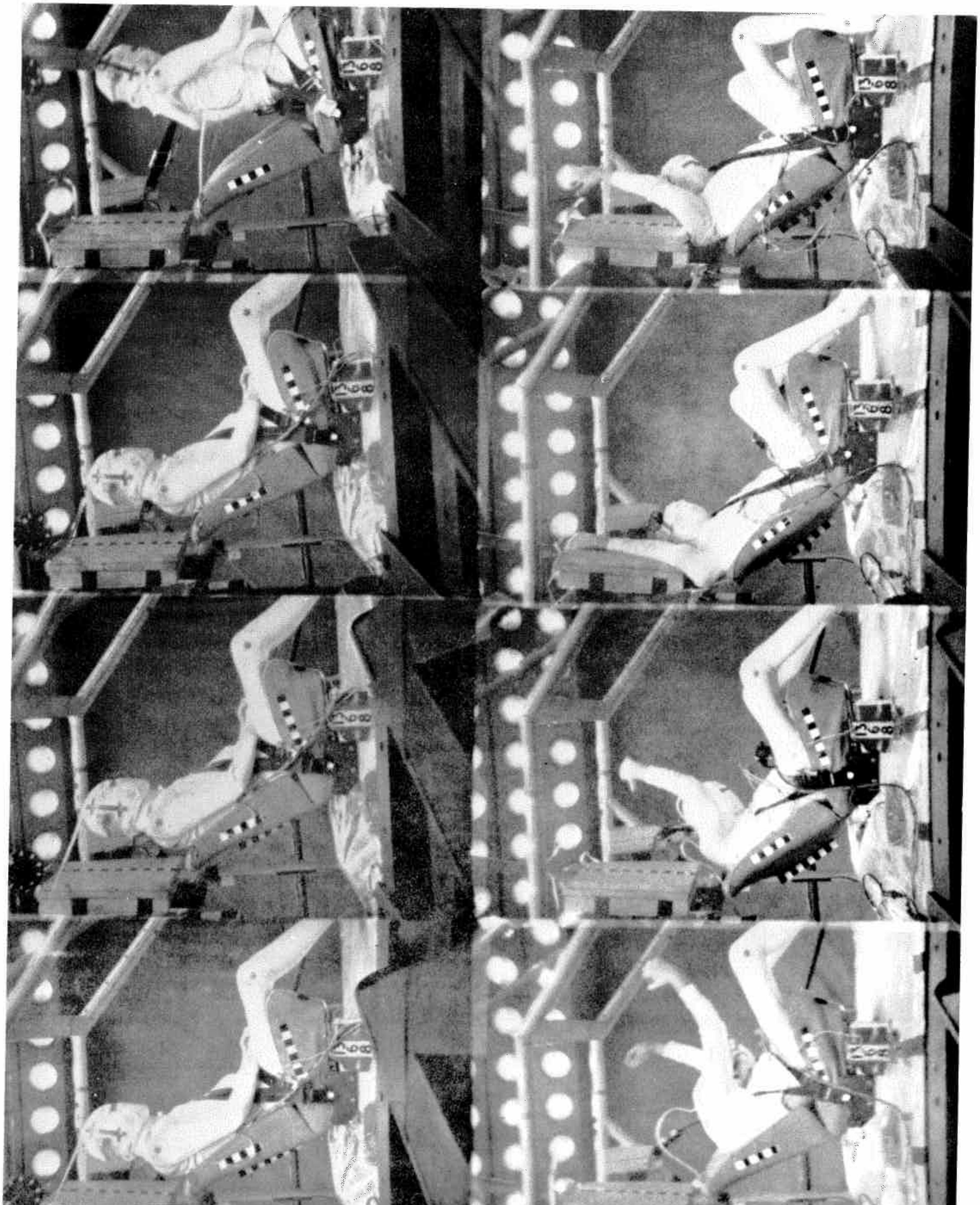


FIGURE 3-15 TIME SEQUENCE OF CALMAN 3 KINEMATICS

Photographic data from the high-speed movie cameras were analyzed on a frame to frame basis to obtain the head trajectory graphs presented in Figure 3-16. In the side view, only the motions of the head in the X-Z plane were recorded, that is, no corrections were applied to the translation motions due to head rotations out of this plane. The same data reduction technique was applied for the overhead view films. Maximum head rotation angle in the X-Z plane of approximatley 100° occurred at approximately 110 msec. This rotation was after the maximum forward motion.

The graph sequence camera failed to operate on sled run no. 1404, therefore, no time sequence of Calman 4 is presented in this report.

Photographic data from the high-speed movie cameras were analyzed on a frame to frame basis to obtain the head trajectory traces presented in Figure 3-17. In the side view, only the motions of the head in the X-Z (vertical) plane were recorded, that is, no corrections were applied to head translation motions due to rotation out of this plane. The same data reduction technique was applied in the analysis of the overhead view films to obtain the top view head trajectory. The maximum head rotation angle in the X-Z plane was approximately 89 degrees, which occurred at about 1.60 seconds from impact. At approximately .120 to .130 seconds, the head appeared very close to the windshield plane and may have lightly contacted it, but there were no indications of direct head contact after the test.

The kinematics of Calman 5's motions are presented in the Polaroid sequence photographs of Figure 3-18, which were recorded at time intervals of approximately .040 seconds between frames. Note from the photographs that the head support tape produced negligible effects on the head motions.

Photographic data from the high-speed movie cameras were analyzed on a frame to frame basis to obtain the head trajectory traces presented in Figure 3-19. In the side view, only the motions of the head in the X-Z (vertical) plane were recorded, that is, no corrections were applied to head translation motions due to rotation out of this plane. The same data

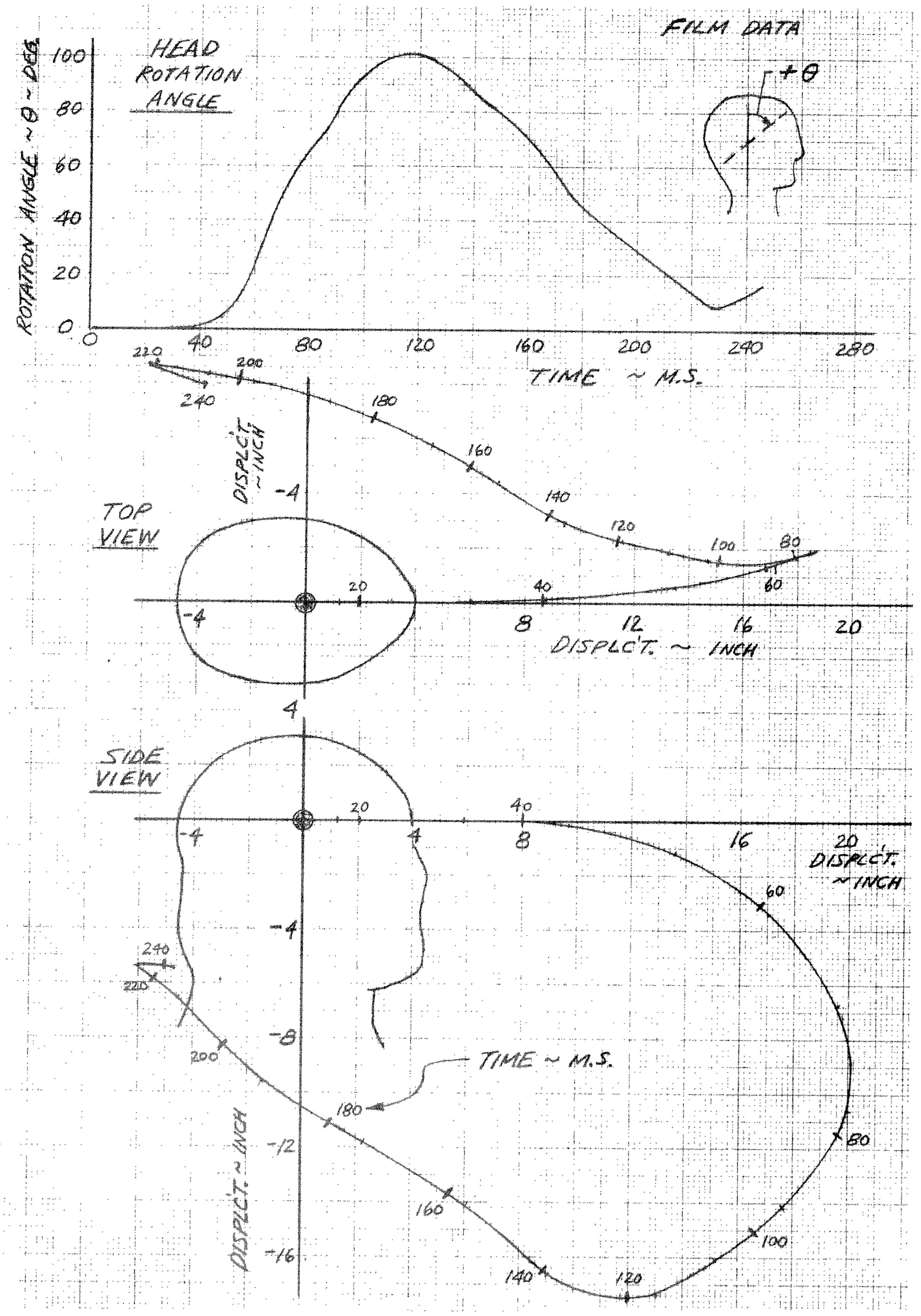


FIGURE 3-16 CALMAN 3 HEAD MOTIONS

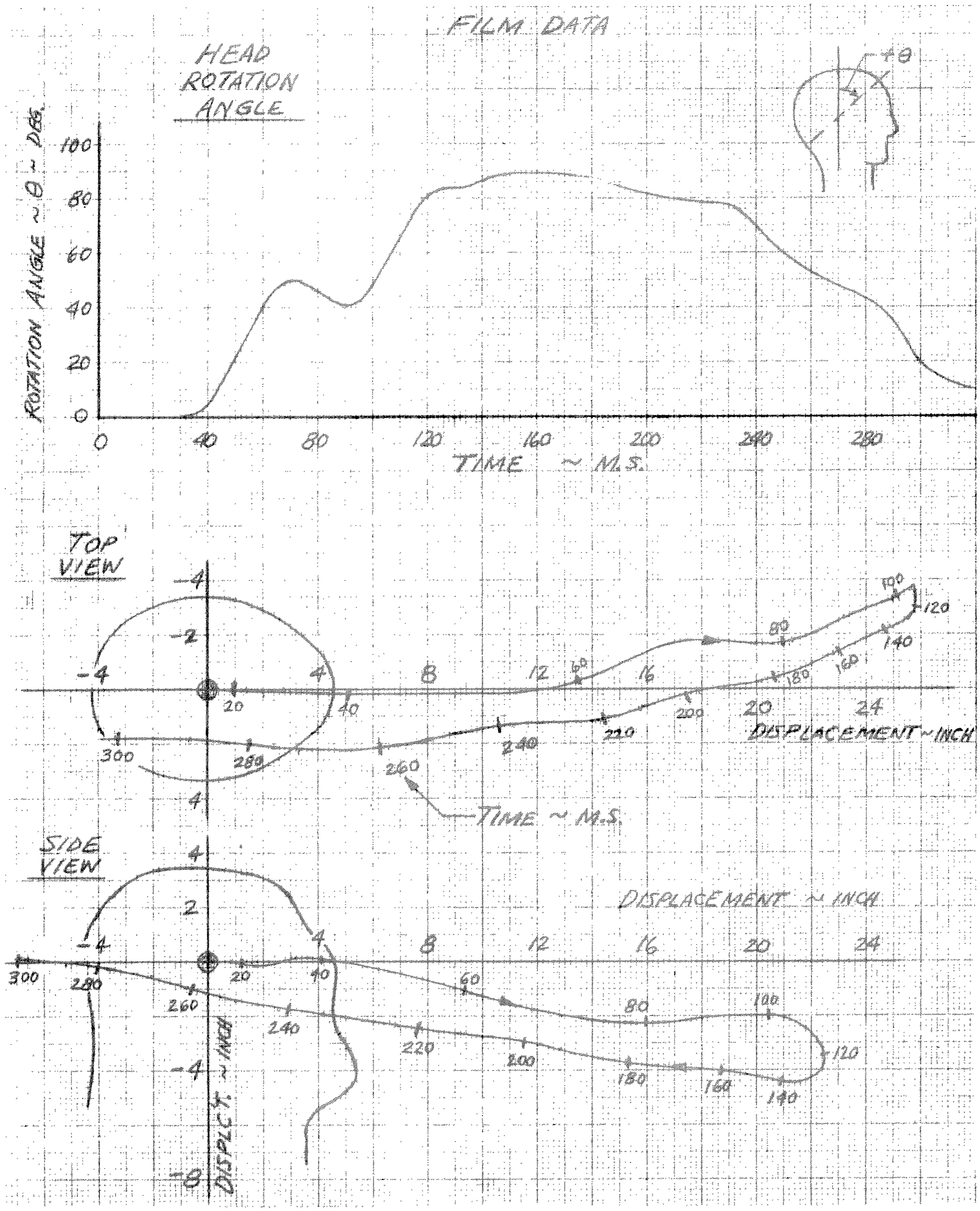


FIGURE 3-17 CALMAN 4 HEAD MOTIONS

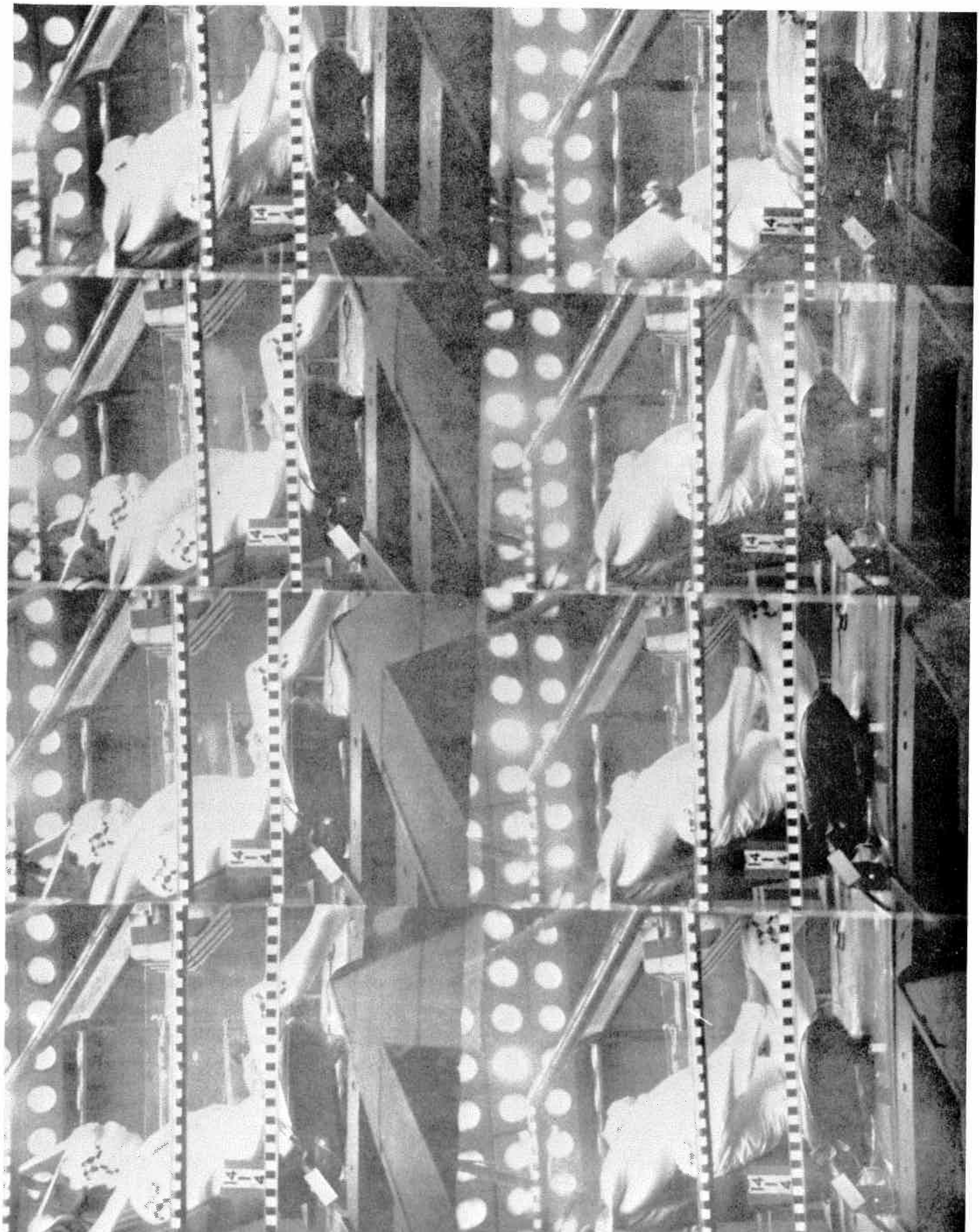


FIGURE 3-18 TIME SEQUENCE OF CALMAN 5 KINEMATICS

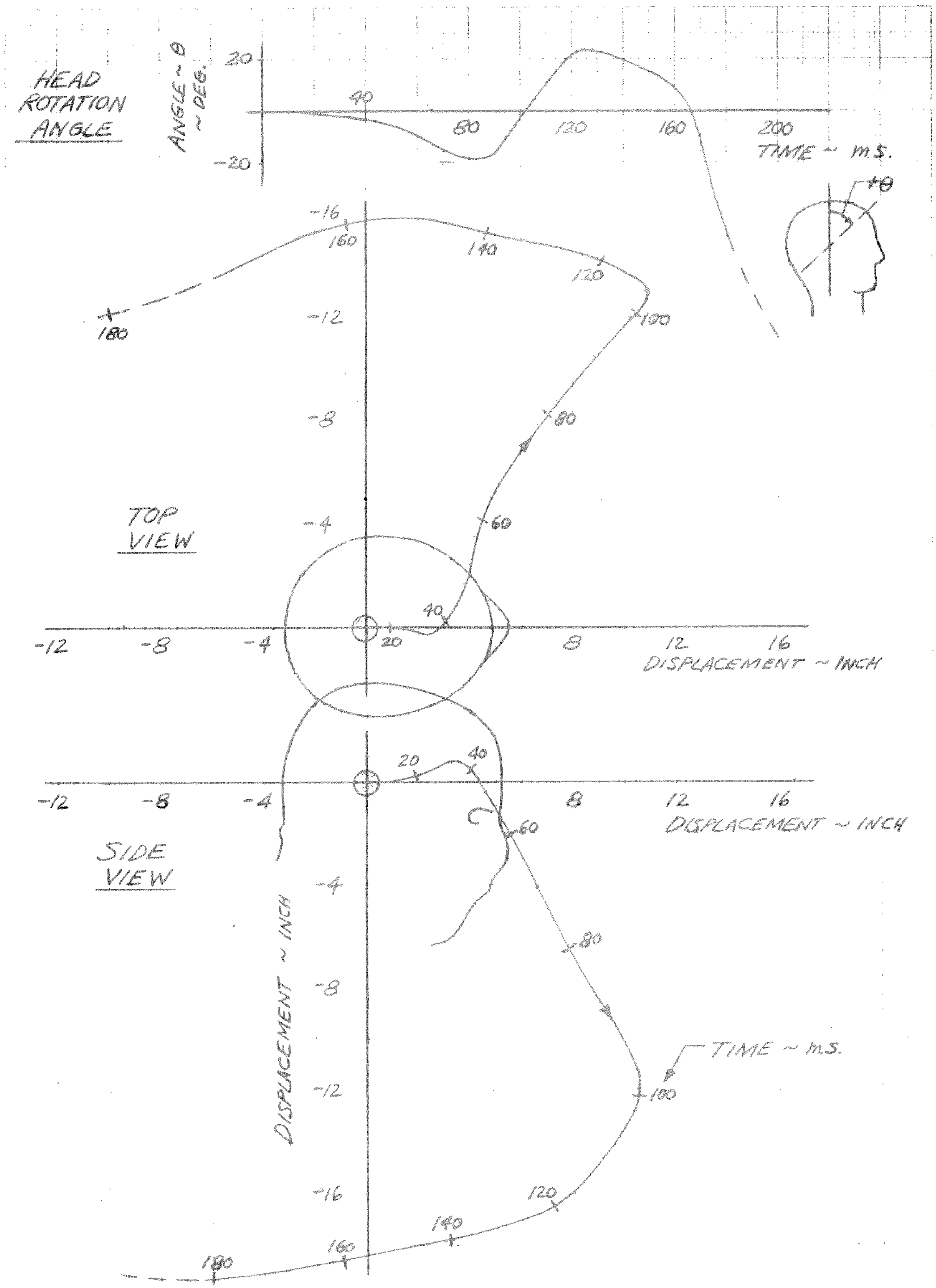


FIGURE 3-19 CALMAN 5 HEAD MOTIONS

reduction technique was applied in the analysis of the overhead view films to obtain the top view head trajectory. The maximum head rotation angle in the X-Z plane was approximately 24°, which occurred at about .125 seconds from impact.

3.3 Post Test Observations

Calman 1

The head externally mounted triaxial accelerometer recorded a peak resultant acceleration of 136 g at approximately .090 seconds, which correlates well with the time from the high-speed films indicating head contact with the steering rim and column. This impact resulted in a HIC number of 3493.

Observations from the film data showed that the torso restraint strap penetrated deeply into the lower portion of the torso, under the rib cage, and the right side of the head struck the steering wheel. See medical report for injury details. The upper thorax showed a maximum resultant acceleration of about 76 g and a calculated severity index (CSI) of 1050, both of which are at a fatal injury level. The lap belt appeared from the film data to perform satisfactorily in that it did not appear to ride up over the iliac crests. Peak loads were recorded on the right and left sides of the strap as 960 lbs and 1040 lbs, respectively.

The thorax deflection instrumentation (two coils), that were taped onto the sternum and thoracic vertebrae areas, recorded a maximum displacement of about two inches. The event time of this peak occurred at about the same time the upper strap load peaked - at .053 seconds.

The seat frame hold-down hardware failed during this test and allowed the seat cushion to rotate forward slightly (aft end rose up) until the frame was about horizontal. It is believed that this additional seat motion did not influence the kinematics of the subject to any extent.

Calman 2

The head externally mounted triaxial accelerometer recorded a peak resultant acceleration of 144 g at approximately .098 seconds, which correlates well with the time from the high-speed films indicating head contact with the steering wheel rim and column. This impact resulted in a HIC number of 736 - a level well above the FMVSS 208 limit value of 1000.

Observations from the film data showed that the torso restraint strap penetrated deeply into the lower area of the torso under the rib cage and the right-front side of the head struck the steering wheel. See medical report for the injury details.

The upper thorax showed a maximum resultant acceleration of about 58 g and a calculated severity index (CSI) of 500, both of which are somewhat below the established fatal injury levels.

The lap belt appeared from the film data to perform satisfactorily in that it did not appear to ride up over the iliac crests. Peak loads were recorded on the right and left sides of the strap as 1720 lbs and 2200 lbs, respectively. The peak shoulder strap load was 2200 lbs.

The aorta pressure transducer recorded a peak value of about 1760 mm Hg, at a time of .065 seconds from impact, which correlated well with the time of the peak shoulder strap load. The arterial pressure cycling and recording system appeared to function well during this test.

Peak elongations of the restraint straps were recorded as 5.9 inches for the upper shoulder belt and 4.5 inches for the lap belt. These traces were relatively smooth and the instrumentation system appears to have operated satisfactorily.

No problems were experienced with the seat frame moving during this test because the seat hold-down structure was modified.

Anthropomorphic Dummy

The maximum head acceleration measured from the external transducers was 64 g compared to 44 g from the internal instruments. The corresponding HIC values were 868 and 348, respectively.

The chest maximum accelerations compared closely with 53 g from the external transducers and 54 g internally. The calculations of the Chest Severity Indices (CSI) showed maximum values of 370 for the external and 400 for the internal transducers, indicating good agreement.

Observations from the film data showed that the dummy kinematics were very similar to Calman 2 motions except during the rebound stage where the dummy exhibited somewhat higher torso twist angles (counterclockwise in the top view) and increased leg motions toward the left side of the sled.

The lap belt appeared from the film data to perform satisfactorily in that it did not appear to ride up over the iliac crests. Peak loads were recorded in the right and left sides of the strap as 2200 lbs and 2480 lbs, respectively. The peak shoulder strap load was 2320 lbs.

Peak shoulder strap elongation was approximately 5.2 inches. The lap belt elongation instrument failed during this run.

Calman 3

The head externally mounted triaxial accelerometer recorded a peak resultant acceleration of 120 g at approximately .094 seconds. This resulted in a HIC number of 1540 - a level above the FMVSS 208 limit value of 1000.

Observations from the film data showed that the torso restraint strap penetrated deeply into the lower area of the torso under the rib cage. See medical report for the injury details.

The upper thorax showed a maximum resultant acceleration of about 62 g and a calculated severity index (CSI) of 500, both of which are somewhat below the established FMVSS 208 allowable injury levels.

The lap belt appeared from the film data to perform satisfactorily in that it did not appear to ride up over the iliac crests. Peak loads were recorded on the right and left sides of the strap as 1170 lbs and 1425 lbs, respectively. The peak shoulder strap load was 2050 lbs.

The aorta pressure transducer recorded a peak value of about 1980 mm Hg, at a time of .045 seconds from impact. The arterial pressure cycling and recording system appeared to function well during this test.

Peak elongations of the restraint straps were recorded at 5.0 inches for the upper shoulder belt and 2.25 inches for the lap belt. These traces were relatively smooth and the instrumentation system appears to have operated satisfactorily.

No problems were experienced with the seat frame moving during this test.

Calman 4

The head externally mounted triaxial accelerometer recorded a peak resultant acceleration of 145 g at approximately .063 seconds. This impact resulted in a HIC number of 903.

The upper thorax showed a maximum resultant acceleration of about 68 g and a calculated severity index (CSI) of 600, both of which are somewhat below the established FMVSS 208 allowable injury levels.

The lap belt appeared from the film data to perform satisfactorily in that it did not appear to ride up over the iliac crests. Peak loads were recorded on the right and left sides of the strap at 1170 lbs and 1020 lbs, respectively. The peak shoulder strap load was 1360 lbs.

The aorta pressure transducer recorded a peak value of about 680 mm Hg, at a time of .058 seconds from impact. The arterial pressure cycling and recording system appeared to function well during this test.

No problems were experienced with the seat frame moving during this test.

Calman 5

The head externally mounted triaxial accelerometer recorded a peak resultant acceleration of 72 g at approximately .053 seconds, which correlates well with the time from the high-speed films. This impact resulted in a HIC number of 614 - a level well below the FMVSS 208 limit value of 1000.

The upper thorax showed a maximum resultant acceleration of about 47.5 g and a calculated severity index (CSI) of 510, both of which are somewhat below the established FMVSS 208 allowable injury levels.

The lap belt appeared from the film data to perform satisfactorily in that it did not appear to ride up over the iliac crests. Peak load was recorded on the shoulder strap of 1200 lbs.

The aorta pressure transducer recorded a peak value of about 690 mm Hg, at a time of .093 seconds from impact. The arterial pressure cycling and recording system appeared to function well during this test.

No problems were experienced with the seat frame moving during this test.

4. MEDICAL REPORT

4.1 Calman 1

Clinical Background

This is a 69 year old caucasian male who died in March 10, 1975. His death was attributed to cardiac failure. He was stored in an unembalmed state under refrigeration and was subjected to a Calspan sled run on March 12, 1975.

Anthropometric Data

Age - 69 years
Height - 71-1/2 inches
Weight - 115 pounds
Chest circumference - 33 inches
Waist circumference - 27 inches
Sitting height - 33-1/4 inches.

Physical Examination of Cadaver Prior to Sled Run

The limbs were all readily movable at their joints with a full range of motion. No gross cutaneous lesions were present. Purpuric areas were noted in the dependent regions and included the posterior two-thirds of the head, the neck including the ears, the back and posterior surfaces of the arms and thighs.

Cadaver Preparation

An incision was made in the left femoral region to expose the femoral artery. The vessel was incised and a Foley #12 French catheter was inserted and threaded 7 inches up to common iliac artery to one inch inferior to the bifurcation of the aorta. The catheter was sutured in place with a running suture and the bulb was inflated to occlude the vessel. An incision was made in left lateral cervical region (anterior cervical triangle) and extended to the midline of the neck inferior to the thyroid cartilage. The common carotid artery was exposed and a transducer was inserted. The tip of the receptor extended to the aorta. The trachea was exposed and a Foley #12 catheter was inserted and threaded several inches inferiorly. The bulb was inflated to occlude the trachea and allow a partial inflation of the lungs with air. The catheter was sutured in place and the incision closed.

Pre-Impact Survey Study (Calman 1, Sled #1365, X-Ray #6967)

Skull

Examination of the skull as seen in antero-posterior, lateral and Towne projections.

There has been a surgical removal of the ramus of the left mandible as well as a large portion of the body of the mandible on the left. No untoward reactive bone change is noted. No abnormality of the cranial vault proper is noted.

Cervical Spine

Studies were carried out in lateral flexion, extension, supine antero-posterior and lateral swimmer's projections.

Narrowing of intervertebral spaces 5, 6, 7 with moderate osteophyte formation is noted. There is anterior luxation of a distance approximately 3 mm. C3 on 4. Narrowing of this intervertebral space is noted. A transducer is in situ to the left of the cervical spine.

Thoracic and Lumbar Spine

Examination of the thoracic and lumbosacral spine, plus the pelvis and hips was carried out with the patient supine as seen in antero-posterior and lateral projections. There is a severe compression with anterior wedging of T11 with extensive osteophyte formation arising from this vertebra as well as the adjacent two vertebral bodies. The vertebral bodies otherwise are normal in size and shape. The intervertebral spaces are essentially within normal limits for the age group. The pelvic bones proper are intact. The sacroiliac and hip joints bilaterally are within normal limits, as are the upper femora. The catheter is noted in the femoral artery, however, it appears to extend up to about the level of the head of the left femur.

The femora were examined in antero-posterior and lateral projections only. No evidence of fracture or other gross abnormality is noted.

Chest

A supine study of the chest including rib detail revealed some aeration of the underlying parenchyma. No fracture of the rib structure could be demonstrated.

Immediate Post-Impact Physical Examination

The cadaver had a transverse 2" x 1/2" abrasion on the forehead 1-1/4" superior to the right orbit. It extended from the midline to the lateral third of the right eye brow. The right malar region is depressed and irregular to palpation. A 2 x 1 inch irregular abrasion overlies the area. A small amount of fluid excudes from the orbit.

An oblique, deep excoriation of the skin approximately 3/4 inch in height by 3-1/2 inches in length is present in the upper left subclavicular-pectoral region. It corresponds in site and direction to the position of the shoulder harness. It initiates in the region of the coracoid process and extends medially to one inch lateral to the costosternal junction at the level of ribs 2 and 3.

There is an obvious depression of the right mid-thorax with a demonstrable grating and movement of the fractured ribs on palpation. Three to five small interrupted, vertical linear scratches about 1/2 inch each are present in the left paramedian line. They lie directly over ribs 3 to 6.

Two superficial abrasions (much lesser in intensity than those of the shoulder and forehead) are present in the anterior lateral regions of the pelvis. One is on the right and the other on the left. The left is somewhat higher and the lesions correspond to the position of the lap belt.

A laceration of the ring finger of the right hand is present. It is 3/4" long and overlies the proximal phalanx. A abraded area is present distal to the laceration. An obvious transverse fracture of the phalanx is identifiable deep to the laceration. Small areas of abrasions are also present on the adjacent middle and little fingers.

Post Test Impact Study (X-Ray) (Calman 1, Sled #1365, X-Ray #6992)

Skull

Re-examination of the skull and facial bones as seen in antero-posterior projection, antero-posterior Towne, left lateral views using the standard lateral technique and the horizontal beam. The zygomatic arch studies were also carried out.

There is a linear fracture of the right cranial vault in the region of the squamous portion of the temporal bone. This shows no evidence of depression at this time. There is also evidence to indicate fracture involving the greater and possibly lesser wing of the sphenoid, with elevation of the greater wing of the sphenoid. There is also evidence to suggest fracture involving the roof of the right orbit. There are fractures involving the right zygomatic arch with buckling posteriorly and flattening anteriorly. There is also fracture involving the infero-lateral aspect of the right maxillary antrum.

In all probability, there is fracture of the inferior orbital margin, but this is not well demonstrated because of the overlying petrous ridges.

Cervical Spine

Examination of the cervical spine was carried out as seen in antero-posterior, lateral flexion, extension and swimmer's projections. With the neck in extension, there is considerable separation of the adjacent end plates of C6 and 7. This is opened up to approximately two cm. and was not present previously. The possibility of fracture of the posterior elements cannot be ruled out but they are not visualized in this study. The marked separation anteriorly would indicate tear and/or rupture of the anterior soft tissue elements.

The Thoracic and Lumbar Spine

Studies were carried out in antero-posterior and lateral views of the thoracic and lumbar spine and antero-posterior views of the pelvis and upper femora was carried out.

No evidence of recent fracture of the vertebral bodies or their accessory processes could be demonstrated. The deformity of the lower thoracic spine was present previously.

Chest and Ribs

These studies were carried out in antero-posterior and lateral projections, no oblique views were obtained.

There is a fracture of the 5th rib in the axillary region on the right with slight angulation. There is a similar fracture of the 6th rib in the same plane with some angulation. The 7th rib is fractured with some separation, coming somewhat anterior to the previous fracture. The 8th rib is also fractured with slight angulation at approximately the same plane as 6. The 9th rib shows fracture. There is also a fracture of the 7th rib anterior to the anterior axillary line without gross displacement. On the left, there is a fracture of the 4th rib in approximately the posterior axillary line. A similar fracture in the same plane in the 5th rib is noted on the left.

Femora

Antero-posterior projections only were carried out and no fracture or other abnormality was noted.

Impression

(1) There are multiple fractures involving the right cranium, right facial bones, with probable depression of the zygoma with resulting implosion fractures.

(2) There has been avulsion of the anterior soft tissue elements of the lower cervical spine, level C6-7 as noted with a lateral extension study.

(3) Multiple fractured ribs bilaterally noted, more marked on the right.

(4) The post-operative status of the mandible should be noted.

Autopsy

The cadaver is a thin, linear caucasian male. The left cervical and left femoral incisions discussed above are noted. There are several old, healed scars; (a) a left cervical scar originating from one inch inferior to the left mastoid process extending anteriorly-inferiorly to the level of the thyroid cartilage (3 inches lateral to it) then coursing inferiorly terminating in an inverted Y above the clavicle. (b) a midline scar from the inferior lip to the midline of the mentum. (c) an old tracheostomy scar is present in the suprasternal notch. The eyes have been removed. The ramus and posterior 1/3 of the mandible have been previously surgically removed. These scars are well healed and not of recent origin.

Face - Dissection of the skin of the superior region of the face reveals a small hematoma in the lateral superior margin of the right orbit. There is also a hematoma in the anterior superior limit of the temporalis muscle contiguous with the margin of the orbit. There are multiple comminuted, depressed fractures of the right orbit. The zygoma is fractured at the lateral and inferior margins of the orbit as well as its articulation with the maxilla. There is a fracture in the lateral margin of the orbital process of the frontal bone. There are also fractures of the inner walls of the orbit including a transverse fracture across the entire superior surface (ceiling of orbit) which also extends across the lateral wall and floor of the space. A fracture is similarly present in the lower medial wall of the orbit. There are two two-inch transverse fractures in the right lateral portion of the frontal bone extending from the orbit posteriorly to the junction with the parietal bone. A depressed fracture of the greater wing of the sphenoid is seen posterior to the orbit. It is depressed, vertical, 3/4 inches in height and exposes underlying brain.

Body - The chest and abdomen are opened with a Y incision. The thoracic musculature is dissected and reflected laterally. Multiple fractures of right and left ribs are present. These fractures include:

Rib Number	Fracture Site: Right	Fracture Site: Left
2	2" lateral to sternum	two fractures, 1" & 2" lateral to sternum
3	3-1/2" lateral to sternum	two fractures, 1" & 2" lateral to sternum
4	6" lateral to sternum	two fractures, 1" lateral to sternum and in mid-clavicular line
5	2 fractures; one 5" lateral of sternum and 7" lateral to sternum	two fractures; 3-1/2" lateral to sternum and at anterior axillary line
6	2 fractures; one in mammary line and one in anterior axillary line	3 inches lateral to sternum
7	2 fractures; 3" lateral to costal margin and 5" lateral to costal margin	
8	2 fractures; 2" lateral to costal margin and 1" anterior to the anterior axillary line	
9	2 fractures; 1" lateral to costal margin and at the anterior axillary line	

There is a transverse, oblique fracture of the sternum extending from the costosternal junction of left fourth rib to the costosternal junction of right rib #6.

The thoracic organ were in their normal anatomical position. The anterior surfaces of the lungs appeared relatively fresh while the posterior portions were relatively solid due to postmortem collection of fluid. The chest cavity was moist but free of excess fluid. Cut section of the lungs revealed they were solid and red in color. The trachea, bronchi and pulmonary vessels were not occluded. The trachea contained a moderate amount of brown liquid.

The pericardial sac contained 5-10 ml pink, relatively clear fluid. The heart was grossly normal size and configuration. The semilunar valves were not remarkable. The aorta contained mural atherosclerotic plaque in the region of the origin of the coronary arteries. The descending aorta similarly had numerous atherosclerotic plaques. No lacerations of the heart or the great vessel were present.

The abdominal musculature was dissected and no tears or hematomas were present. The peritoneal cavity was opened and the abdominal organ were in their usual anatomical positions. No excess amount of peritoneal fluid was present.

A superficial hematoma 2-1/2" by 1" was present on the anterior surface of the right lobe of the liver. The hematoma did not extend deeply into the body of the liver. A superficial linear laceration of the liver approximately 2" in length is present on the lateral surface of the liver and corresponds in position to the fracture of the ninth rib.

The stomach, duodenum, the remainder of the small intestine and the colon are in their normal anatomical relationship and demonstrate no tears or perforations. The intestinal tract is distended with gas. No lacerations of the mesenteries are observed. The spleen is intact.

The kidneys are in their normal position. There are no tears of the kidneys nor of their vessels or the ureters. The cut surfaces of the kidneys demonstrates normal renal pyramids. No hemorrhage or other abnormalities are observed.

The scalp was incised circumferentially at the level of the ears and is reflected anteriorly. The calvarium is removed. It has no fractures. The dura is intact and no lacerations of the inferior surface of the frontal pole of the right cerebral hemisphere. This area is in immediate contact with the underlying orbit and fracture of the right lesser wing of the sphenoid. There is also a transverse fracture in the right middle cranial fossa beginning at its lateral wall in the region of the temporal-sphenoidal articulation and extending to the body of the sphenoid. There is an anterior-posterior 1" fracture in the frontal bone when it forms the floor of the anterior cranial fossa and roof of the orbit.

The cervical vertebrae are exposed by a vertical incision extending from the occiput to the level of thoracic vertebra #1. The cervical musculature is dissected and reflected laterally. The spinous processes are in line and are not fractured. The cervical vertebrae were also removed from the cadaver and examined. No fractures were identified. The dens of C_2 was not fractured.

The superior and inferior limbic were not remarkable and did not demonstrate any fractures with the exception of the one fractured phalanx described previously. There were no fractures of the pelvis.

Summary - The subject was subjected to a Calspan impact sled run and sustained multiple cranial and thoracic cage injuries.

The major injuries include:

1. Multiple fractures of the anterior right and left halves of the thoracic cage as well as the sternum. The greatest number of fractures were sustained in the right chest.

2. Multiple fractures of the right orbit and its supporting skeletal structures.

3. Fractures of the cranium regionally associated with the orbit and secondary 1/4" x 1/4" laceration of the frontal lobe of the brain.

4. Superficial laceration of the liver probably secondary to fracture of rib 9. Superficial hematoma of the liver.

4.2 Calman 2

Clinical Background

This is a 44 year old caucasian male who died on March 9, 1975. His death was attributed to a myocardial infarction. He was stored in an unembalmed state under refrigeration and was subjected to a Calspan sled run on March 13, 1975.

Anthropometric Data

Age - 44 years
Height - 72 inches
Weight - 162 pounds
Chest circumference - 37 inches
Waist circumference - 34 inches
Sitting height - 37 inches.

Physical Examination of Cadaver Prior to Sled Run

The limbs were all readily movable at their joints with a full range of motion. No gross cutaneous lesions were present. Red purpuric areas were noted in the dependent regions and included the posterior of the head and neck including the ears, the back and posterior surfaces of the arms and thighs. There were no marks on the chest.

Cadaver Preparation

An incision was made in the left femoral region to expose the femoral artery. The vessel was incised and a Foley #12 French catheter was inserted and passed several inches up into the common iliac artery. The bulb was inflated with Hypaque thus occluding the vessel as well as rendering the catheter identifiable on the x-rays. The catheter was sutured in place with a running suture.

An incision was made in the left lateral cervical region (anterior cervical triangle) and extended to the midline of the neck inferior to the thyroid cartilage. The left common carotid artery was exposed and a transducer was inserted. The tip of the receptor extended into the arch of the aorta. The trachea was exposed and a Foley #18 French catheter was inserted and threaded inferiorly. The bulb was inflated to occlude the trachea and allow partial inflation of the lungs with air. The catheter and transducer were sutured in place and the incisions were closed.

An incision was made in the right cervical region and the right common carotid artery was exposed. The vessel was incised and a Foley #14 French catheter was inserted. The bulb was inflated to occlude the artery. The catheter was sutured in place and the incisions were closed.

Pre-Impact Survey Study (Calman 2, Sled #1366, X-Ray #7061)

Skull

Examination of the skull was carried out, seen in antero-posterior, antero-posterior Towne and reverse Water's projection. Lateral studies were carried out with the patient oblique lateral as well as using the horizontal beam across the table. No fracture or other abnormality was demonstrated.

Cervical Spine

Studies were carried out as seen in antero-posterior, lateral with the neck in flexion and extension as well as a modified swimmer's view.

No fracture or other gross abnormality was noted. A transducer is in situ to the left of the vertebral column and extending down to just below the level of the aortic arch.

Thoracic and Lumbar Spine Plus Pelvis

Studies were carried out in antero-posterior supine and lateral projections. No fracture or other gross bony abnormality could be demonstrated, other than one would consider for the age group. A catheter is present in the left iliac artery but has not reached the aorta proper.

Chest and Ribs

Examination of the chest including rib detail was carried out in supine antero-posterior and lateral projections. No fracture or other gross abnormality was demonstrated.

Femora

The femora were examined in antero-posterior and lateral projections. No abnormalities were noted.

Immediate Post-Impact Physical Examination

The cadaver had a transverse 1-1/2" x 1" superficial abrasion on the forehead extending from the lateral 1/3 of the right supraorbital region to the right temporal region. There is a deep excoriation on each anterior thigh. The one on the left is 1" x 2-1/2" in length and is located 3" inferior to the anterior superior iliac spine. The one on the right is 1" x 3", is not as deep as its counterpart and is located 1" below the anterior superior iliac spine.

There is an old, healed appendectomy scar. The cadaver is edentulous. There are two small cuts on the dorsum of the right index finger in the area of the proximal phalanx.

Post-Test Impact Study (Calman 2, Sled #1336, X-Ray #7091)

Skull

Re-examination of the skull and facial bones was carried out in antero-posterior Towne, lateral study with the beam horizontal and detailed study of the zygomatic arches.

No fracture or other specific abnormality could be demonstrated.

Cervical Spine

The cervical spine was studied in antero-posterior, lateral flexion and extension as well as swimmer's views. The transducer has been removed.

There is no evidence of fracture or subluxation. The body appears normal in size and shape.

Thoracic, Lumbar Spine and Pelvis

The thoracic, lumbar spine and pelvis were examined in antero-posterior and lateral projections. No evidence of fracture involving the vertebral bodies could be demonstrated. There is an undisplaced fracture involving the transverse process on the right of the first lumbar vertebra. There is also an undisplaced fracture at the tip of the transverse process of L2 on the left. These changes were not present previously.

Chest and Ribs

Examination of the chest and ribs as seen in antero-posterior projection, using different techniques, that is light and dark as well as studies above and below the diaphragms. Lateral studies were also carried out.

The transducer has been removed. There is the overall appearance of a pneumothorax under tension on the right. The right hemidiaphragm appeared to be depressed and considerably flattened, with herniation of the right lung field, well into the mediastinum, displacing the heart and mediastinal contents to the left. These changes were not present prior to impact. It should be noted, however, that insufflation may have been part of the cause and this could represent artifact. There are fractures of the 7th and 8th ribs in the axillary region on the right with minimal angulation. No definite fracture on the left was demonstrated. Studies of the manubrium and sternum failed to demonstrate radiographic evidence of fracture. It is not possible to indicate subluxation of the sterno-clavicular articulation. No fracture at this level is noted.

Femora

The femora were examined in antero-posterior projection only.

Impression

The post-impact studies revealed fractures of the seventh and eighth ribs on the right, as described. Also noted were undisplaced fractures of the transverse process of the first lumbar vertebra on the right and the transverse process of the second lumbar vertebra on the left. No gross displacement was noted. There was an abnormal distribution of air in the right hemithorax which gave the impression of a tension pneumothorax, however, as noted, this could be due to technical difficulty. No other fractures were demonstrated. It should be remembered that costal cartilage is not visible and radiographic studies of these areas fail to visualize separation.

Autopsy

The cadaver is a well developed, well nourished caucasian male. The femoral and cervical incisions are noted.

Face - The face is free of lacerations and swellings. The contour of the orbital margins, the zygomatic and maxillary regions are bilaterally symmetrical and regular. There are no fractures of the facial bones.

Body - The chest and abdomen are opened with a Y incision. The thoracic musculature is dissected and reflected laterally. Multiple fractures of the right and left ribs are present. These fractures include:

1. There is a separation of the right and left clavicles at the claviculosternal junction.

2. There are three fractures of the sternum:

   a. 2" transverse fracture of the sternum at the level of rib 2, i.e., at the junction of the manubrium with the body of the sternum.

   b. Two oblique fractures of the sternum beginning superiorly on the left and proceeding diagonally inferiorly across the sternum. One fracture extends from the level of the costosternal junction of rib #3 to the level of the costosternal junction of right rib #5. The fracture is identifiable only on the pleural surface of the sternum. A second similar fracture extends from the level of the left rib #4 to the level of the costosternal junction of right rib #6.

Rib Number	Right	Left
2		two fractures; one at the costosternal junction and 2" lateral to this point
3		two fractures; 1" lateral to sternum and 2" lateral to sternum
4	2-3/4" lateral to costosternal junction	two fractures; 1/2" lateral to the costosternal junction and one 3" lateral to the costosternal junction. The latter is just a little lateral to the fractures of the superior rib.
5	a fracture is present immediately inferior to the fracture in the superior rib	3" lateral to the costosternal junction. It is inferiorly in line with the fracture in the superior rib
6	7" lateral to midline of thorax (anterior axillary line)	4" lateral to the midline of thorax (at the costo-chondral junction)
7	8" lateral to midline of thorax (anterior axillary line)	
8	8" lateral to midline of thorax (anterior axillary line)	
9	8" lateral to midline of thorax (anterior axillary line)	
10	8" lateral to midline of thorax (anterior axillary line)	

The thoracic organs were in their normal anatomical position. No lacerations or perforations were observed. There was no identifiable shift of the mediastimal contents. The lungs appeared reasonably inflated especially in the right lung. The chest cavity was moist but free of excess fluid. Cut sections of the lungs revealed they were solid, especially in the dependent regions, and red in color. No masses were noted in the trachea and bronchi. The pulmonary vessels were not occluded. Numerous, small, pigmented hilar lymph nodes were identified.

The pericardial sac was intact and contained 10 ml of pericardial fluid. The heart had a 1" hemorrhagic appendage on the surface of the apex of the heart projecting from the right ventricle. Its hemorrhagic appearance is believed to be related to premortem events. The posterior surface of the heart (left ventricle) appeared flabby and had a generally depressed appearance. The aorta contained some scattered atherosclerotic plagues especially at the origin of the aortic arch. The ostium of the right coronary artery was surrounded by intimal elevations due to atheromatous degeneration and was approximately only one half in diameter of the other coronary artery ostium. The descending aorta and common iliac arteries also had atheromatous changes. The alterations in the latter arteries was responsible for the difficulty in passing the Foley catheter through the vessel.

The abdominal musculature was dissected and no tears or hematomas were present. The peritoneal cavity was opened and contained about 100 ml of blood. The abdominal viscera were in their anatomical position. There were 1 or 2 small 1/2 inch tears in the peritoneum in the lateral clavicular line at the level of right ribs #9-10. There was a massive laceration of the anterior surface of the right lobe of the liver. It was V shaped and had a total surface length of 7", extended 2" deep into the substance of the organ. The internal surface of the laceration was exceedingly irregular. There were also two somewhat macerated, irregular, 1-1/2" vertical lacerations of the anterior and posterior surface of the liver at its inferior margin one inch right of the attachment of the falciform ligament. On the posterior, inferior surface of the liver the posterior laceration could be identified as being in the quadrate lobe.

The spleen was prominent in size and had 1-1/2" superficial, capsular laceration on its hilar surface just superior to the origination of the splenic vessels.

The stomach, duodenum, the remainder of the small intestine and the colon are in their normal anatomical relationships and demonstrate no tears or perferations. The intestinal tract is distended with gas. The mesenteries are intact.

The kidneys are in their normal position. There are no tears in the kidneys, ureters or renal vessels. The cut surfaces of the kidneys demonstrate normal renal pyramids. No hemorrhages or other abnormalities are observed.

Skull and Cranial Contents

The scalp is incised circumferentially at the level of the ears and is reflected anteriorly. The calvarium is freed of adherent tissue and removed. It has no fractures. The meninges are inspected, the dura is cut and the brain is removed from the cranial cavity. There are no tears or hemorrhages in the meninges, on the surface of or within the substance of the brain. The internal architecture of the cranium is normal and no fractures are identified.

The cervical vertebrae are exposed by a vertical incision extending from the occiput to the level of vertebra T1. The cervical musculature is dissected and reflected laterally. The spinous processes are in anatomical position with no signs of fracture. The cervical vertebrae are also removed from the cadaver and examined. No fractures are present. The dens (odontoid process) of C2 is not fractured.

Limbs

The superior and inferior limbs are not remarkable and did not demonstrate any fractures.

Summary - The cadaver was subjected to a Calspan sled run and sustained multiple thoracic cage fractures as well as abdominal soft tissue injuries.

The major injuries include:

1. Multiple fractures of the right and left halves of the thoracic cage. The sternum sustained multiple fractures.

2. Massive, 7" laceration of the liver that penetrated deep into the substance of the organ. A second, smaller, macerated laceration of the liver was also present.

3. Small lacerations of the peritoneal wall at level of ribs #9-10; superficial capsular laceration of the spleen.

4.3 Calman 3

Clinical Background

This is a 65 year old caucasian male who died on April 15, 1975. His death was attributed to respiratory arrest; he had a prior diagnosis of amyotrophic lateral sclerosis. He was stored in an unembalmed state under refrigeration and was subjected to a Calspan sled run on April 18, 1975.

Anthropometric Data

Age - 65 years
Height - 69 inches
Weight - 125 pounds
Chest circumference - 34 inches
Waist circumference - 31 inches
Sitting height - 33 inches.

Physical Examination of Cadaver Prior to Sled Run

The limbs were all readily movable at their joints with a full range of motion. The fingers of the right hand were flexed at the proximal interphalangeal joints. They could be extended but returned to this position with release of the pressure. No gross cutaneous lesions were present. He is bald with a fringe of hair around the ears. Red purpuric areas were noted in the dependent regions and included the posterior of the head and neck including the ears, the back and posterior surfaces of the arms and thighs. There were no marks on the chest. There was a small hematoma in the left antebrachial fossa, the site of an intravenous injection.

Cadaver Preparation

An incision was made in the left femoral region to expose the femoral artery. The vessel was incised and a Foley #14 French catheter was inserted and passed several inches up into the abdominal aorta. The 10 ml. bulb was inflated with Hypaque thus occluding the vessel as well as rendering the catheter identifiable on the x-rays. The catheter was sutured in place with a running suture.

An incision was made in the left lateral cervical region (anterior cervical triangle) and extended to the midline of the neck inferior to the thyroid cartilage. The left common carotid artery was exposed and a transducer was inserted. The tip of the receptor extended into the arch of the aorta. The trachea was exposed and a Foley #14 French catheter was inserted and threaded inferiorly to a position superior to the bifurcation of the structure. The 10 mm bulb was inflated with Hypaque to occlude the trachea and allow inflation of the lungs with air. The catheter and transducer were each sutured in place and the incisions were closed.

Pre-Impact Survey Study (Calman 3, Sled #1368, X-Ray #10576)

Skull

The skull was studied in antero-posterior, antero-posterior Towne and lateral. Some degree of osteoporosis is noted, but no fracture or other specific pathology.

Cervical Spine

The cervical spine was studied in antero-posterior, lateral flexion, extension and swimmer's views. No bony abnormality was noted. A transducer is in good position, extending to the level of the aortic arch.

Thoracic, Lumbar Spine and Pelvis

These studies were carried out in antero-posterior and lateral projection of the thoracic spine with an antero-posterior view of the pelvis.

No evidence of fracture or compression was noted. Generalized osteoporosis was noted to involve the pelvis and upper femora. A catheter has been placed in the abdominal aorta at the level of the first lumbar vertebra.

Chest and Ribs

Examination of the chest and ribs as seen in antero-posterior projection and various techniques, using lighter and darker, above and below the diaphragm studies.

An endotracheal tube is in situ. The first study revealed that the distal portion was in the right mainstem bronchus. It was then retracted to the level of the carina. The lung fields are relatively well aerated, however, there appears to be either discoid change at the right base and/or pleural thickening and/or effusion. No rib fracture is noted.

Femora

The femora were studied in antero-posterior and lateral views. Extensive osteoporosis with considerable cortical thinning is noted bilaterally. This is more marked than one would expect just for the age group.

Examination of Cadaver

Immediate Post-Impact Physical Examination

The cadaver had a two-inch superficial excoriation superior to each eyebrow lying in a slight cutaneous depression formed by the metal head band used for attachment of the accelerometers. The head was excessively mobile and the normal cervical restraint to passive movement was lost. The post-mortem erythema of the face was also increased over base line levels. The configuration of the chest was altered. The chest had lost some of its bilateral symmetry with generalized depression of the inferior portion of the right half of the thoracic cage (approximately 2" x 4"). Palpation in this area revealed crepitation as well as grating of the ends fractured ribs.

There were superficial interrupted abrasions beginning at the region of the left shoulder and extending diagonally and inferiorly across the chest. These followed the course of the shoulder harness. There was a palpable irregularity of the lateral 1/3 of the left clavicle indicating a complete fracture.

There was a superficial excoriation on the anterior lateral surfaces of the superior region of each thigh. These bilateral abrasions were transverse in direction with the left one 1" higher than its fellow. The right excoriation was 2" in length, irregular in height and located 3" inferior to the anterior superior iliac spine. The left was approximately 4" long and of irregular height. An addition superficial excoriation was present in the left inguinal region of the abdomen; the dimensions were 2" by 1/4"

The upper 1/3 of the right arm was irregular and was excessively mobile. Fragments of a fractured humerus were palpable.

<u>Post-Test Impact Study (Calman 3, Sled #1368, X-Ray #10629)</u>

Skull

The skull was examined in antero-posterior, antero-posterior Towne, reverse Water's and lateral projections. No fracture or other abnormality was noted.

Cervical Spine

Studies were carried out antero-posterior, lateral, flexion and extension as well as swimmer's views.

There is gross fracture antero-superior margin of C2 with anterior subluxation of the odontoid process. There is tilting with widening of the posterior portion of the intervertebral space and separation of the spinous processes. No other fracture was noted.

Thoracic Spine

Studies were carried out in antero-posterior and lateral projections. There is compression fracture with a moderate degree of compression and anterior wedging of T4. There may be some degree of compression of the centrum of T5. Generalized osteoporosis is noted throughout. The remaining vertebral bodies are normal.

Lumbar Spine, Pelvis and Hips

The lumbar spine, pelvis and hips as seen in antero-posterior and lateral projection and antero-posterior of the pelvis and hips.

No evidence of fracture or compression of the vertebral bodies or their accessory processes was demonstrated. There are comminuted fractures involving the iliac bones bilaterally. On the right, vertical elements are noted above the acetabulum with some degree of overlapping and double density. Radiating fractures are noted to extend toward the anterior superior iliac spine. On the left, there are similar fractures. These are more comminuted and more marked. Overlapping with double density of vertical fracture lines was noted, with lateral extension to the anterior superior iliac spine. The hip joints remain intact.

Right Humerus

This study was carried out in antero-posterior and lateral projection. There is a comminuted fracture inferior to the surgical neck with a moderate degree of medial angulation at the fracture site. There is also fracture, mid shaft of the humerus with anterior angulation to a moderate degree. With the arm in elevation so it lies transverse to the long axis to the axial skeleton there is gross angulation at the upper fracture site.

Right Forearm

This was studied in antero-posterior and lateral projections. Generalized osteoporosis was noted, but no actual fracture was demonstrated.

Chest and Ribs

Examination of the chest and ribs as seen in multiple projections including antero-posterior studies above and below the diaphragm as well as lateral and both oblique views. There is radiographic evidence to suggest a large amount of air in the pericardial sac. Also noted is extensive interstitial emphysema in the region of the manubrium and sternum. This is best seen in the lateral projection. The lung fields remain relatively well aerated throughout without pneumothorax. There is also evidence to indicate small amounts of interstitial emphysema in the axillary regions bilaterally. This perhaps more marked on the left. There is a fracture with some separation in the mid third of the left clavicle. There is also evidence to indicate fractures involving the body of the sternum with slight off setting. However, this is difficult to evaluate because of the overlying air. One fracture appears to lie 3 to 4 cm. cephalad to the base of the xiphoid process. There may also be a fracture 3 to 4 cm. cephalad to this. This is difficult to evaluate. The ribs reveal fractures of 4 through 10 inclusive on the right. At level 4, the fracture is at approximately the posterior axillary line and as the fractures descend, they appear more anteriorly. There is also evidence to indicate probable double fractures of ribs 7, 8 and 9. The 8th rib is markedly comminuted for a rib fracture and is quite far anteriorly. On the left, there is evidence to suggest an undisplaced fracture of the second rib in the posterior axillary line. It should be noted that the transducer has been left in position and shows no gross disturbance. Also, the endotracheal tube remains in a relatively good position and hence probably insufflation of the lungs should be relatively good.

Femora

The femora were examined in the antero-posterior projection and only revealed general osteoporosis but no actual fracture demonstrated.

Impression

1. Skull revealed no evidence of actual fracture.
2. Cervical spine revealed fracture through the base of the odontoid process, with subluxation and angulation at the junction, as described.
3. Thoracic spine revealed fracture with compression T4 and possibly 5.
4. Lumbar spine revealed no evidence of fracture.
5. Pelvic bones revealed fracture of the iliac bone bilaterally.
6. Comminuted fractures of the right humerus.
7. Right forearm revealed no evidence of fracture.
8. Ribs revealed multiple fractures on the right, 4 through 10 inclusive. Some are double, as described and probable fracture of the second rib on the left, as described. There is also evidence to suggest fractures of the sternum with associated interstitial emphysema. Interstitial emphysema in the axillary region is noted bilaterally as well. There is also evidence to suggest pneumopericardium.

9. Fracture, left clavicle.
10. Femora revealed generalized osteoporosis, but no actual fracture.

It should be noted that generalized osteoporosis of the skeletal structures were noted, this could represent disuse atrophy, however, specific pathologic changes other than the age alone may be involved, such as metastatic disease, multiple myeloma and other forms of malignant change. Hemoglobinopathies or even endrocine disorders may have been also present.

Autopsy

The cadaver is a well developed, well nourished caucasian male. The femoral and cervical incisions described previously are noted.

Face - the face is free of lacerations and swellings. The contour of the orbital margins, the zygomatic and maxillary regions are bilaterally symmetrical and regular. There are no fractures of the facial bones.

Body - the chest and abdomen are opened with a Y incision. The thoracic musculature is dissected and reflected laterally. The pectorales major are not prominent and are in fact thinner than usual. Multiple fractures of the right and left ribs are present. The left clavicle and sternum are also fractured. These fractures include:

1. The left clavicle has a transverse complete, irregular fracture at the junction of the medial 2/3 and the lateral 1/3 of the diaphysis.

2. There is one irregular fracture of the sternum. It is at the level of the articulation of ribs #3 and #4. The fracture extends in different directions and is comminuted. The fracture demonstrates a shearing effect with some separation of the outer and inner tables of this bone.

3. Rib fractures.

Rib Number	Left	Right
1	2-1/4" lateral to mid-sternal line	2-1/2" lateral to the mid-sternal line
2	3 fractures (a) 1" lateral to the mid-sternal line (within the costal cartilage) (b) 2" lateral to the mid-sternal line; at the costocartilaginous junction (c) 4" lateral to mid-sternal line (at the anterior axillary line)	3-1/2" lateral to mid-sternal line
3	2 fractures (a) 1" lateral to mid-sternal (within the costal cartilage) (b) 2-1/2" lateral to mid-sternal line	2 fractures (a) 2-1/2" lateral to mid-sternal line (b) 6" lateral to mid-sternal line (in the anterior axillary line)
4	2 fractures One in anterior chest, one in posterior (a) 1" lateral to mid-sternal line (within the costal cartilage) (b) in posterior thorax near the region of the angle of the rib (posterior body wall)-3-1/4" lateral to the mid-line	2 fractures (a) 1-3/4" lateral to mid-sternal line (within costal cartilage) (b) 6-1/2" lateral to mid-sternal line

Rib Number	Left	Right
5		3 fractures (a) 2-1/2" lateral to mid-sternal line (within costal cartilage) (b) 3-1/2" lateral to mid-sternal line (within costal cartilage) (c) 6-1/2" lateral to mid-sternal line
6		3 fractures (a) 4" lateral to mid-sternal line (within costal cartilage) (b) 4-1/2" lateral to mid-sternal line (at junction of rib to costal cartilage) (c) 6-1/2" lateral to mid-sternal line (is somewhat medial to its superior fellow fracture)
7		4 fractures (a) 4-1/4" lateral to mid-sternal line (in costal cartilage) (b) 5" lateral to mid-sternal line (at costocartilage junction) (c) 5-1/2" lateral to mid-sternal line (d) 6-1/2" lateral to mid-sternal line (in mid-clavicular line)
8		3 fractures (a) 5" lateral to mid-sternal line (at costocartilage junction) (b) 6" lateral to mid-sternal line (c) 7" lateral to mid-sternal line
9		2 fractures (a) 6-1/2" lateral to mid-sternal line (b) 7" lateral to mid-sternal line
10		2 fractures (a) 6" lateral to mid-sternal line (b) 7" lateral to mid-sternal line.

The thoracic organs were in their normal anatomical position. No lacerations of the lungs were observed. There was no identifiable shift of the mediastinal contents. The surface of the lungs revealed several small (2-3 mm) white calcified nodules. The posterior (dependent) portions of the lungs were red and heavy.

The pericardial sac did not present any obvious lacerations. On opening of the sac, however, it was readily apparent that the entire base of the aorta had been completely transected 1/4 to 1/2 inch superior to its origin from the heart. The pericardial sac contained some clotted blood derived from the aorta. The pulmonary artery was intact. Dissection revealed that it was not occluded.

The root of the aorta was soft, pliable and free of atheromatous plaques. The descending aorta on the other hand had a moderate amount of hard, calcified material in its wall.

The abdominal musculature was dissected and no tears or hematomas were present. The peritoneal cavity was opened and contained some bloody fluid. The organs were in their anatomical position. The stomach was distended with gas and the great omentum arranged in its "apron form" as seen in classical texts.

There was a massive laceration of the liver in the superior, anterior region of its right lobe. The laceration was circumlinear in form with its convexity directed inferiorly. It was 7" in length and irregular. The exposed surfaces of the laceration were markedly irregular and penetrated 1" to 1-1/2" deep into the substance of the organ. Three-fourths inches inferior to this laceration is another approximately 4" in length but does not penetrate into the liver. An irregular, 1-2 inch area of laceration-maceration is also present on the inferior surface of the liver in the region of the guadrate lobe.

The root of the mesentery has at least two sub-peritoneal hemorrhagic regions approximately 2-3 inches in diameter. One of these is in the region of the first part of the duodenum. The spleen and kidneys are normal in size and location. They are intact and not lacerated. Cut sections of the kidneys reveals normal renal pyramids. No hemorrhages or other abnormalities are observed.

There are extensive fractures of both wings of the ilia. In both instances the fractures are depressed, comminuted and are displaced laterally. In the left ilum the fracture is present in essentially the entire wing superior to a line at the level of the anterior inferior iliac spine. The height of the fracture is 1-1/2"-2"; only the most medial segment of the iliac wing is intact. Very similar fractures are present in the right ilium. The greatest height of the fractures in this case is 2-1/2 inches.

Cervical Spine

The cervical vertebrae are exposed by a mid-line vertical incision extending from the occiput to the level of thoracic vertebra #1. The cervical musculature is dissected and reflected laterally. The spinous processes are in their appropriate anatomical line and are not fractured. The cervical vertebrae are removed from the cadaver and examined. Cervical vertebrae #1 and #2 are dissected free of adherent structures. There is a complete transverse fracture at the base of the odontoid process (dens) of the second cervical vertebra.

Summary

The cadaver was subjected to a Calspan sled impact and sustained multiple bony as well as abdominal soft tissue injuries.

1. Complete transverse fracture of the odontoid process of cervical vertebra #2.

2. Massive 7" laceration of the right lobe of the liver that penetrated 1" to 1-1/2" into the organ. A more superficial 4" laceration of the liver was also present inferior to this. A small laceration of the quatrate lobe of the liver was also present.

3. Multiple fractures in the left and especially the right halves of the anterior thoracic cage. Rib #4 sustained one fracture in the posterior thorax. The sternum had a prominent, irregular fracture at the level of ribs #3 and #4.

4. Fracture of the left clavicle.

5. Fracture of both wings of the pelvis.

6. Fracture of the right humerus.

7. Complete transection of the root of the aorta.

4.4 Calman 4

Clinical Background

This is a 51 year old caucasian male who died June 11, 1975. His death was attributed to cardiac arrest. He had a history of cardiac surgery with an implantation of a cardiac valvular prosthesis in March, 1975. The cadaver was stored in an unembalmed state under refrigeration and was subjected to a Calspan sled run on June 18, 1975.

Anthropometric Data

Age - 51 years
Height - 6'4"
Weight - 172 pounds
Chest circumference - 37 inches
Waist circumference - 35 inches
Sitting height - 37 1/2 inches.

Physical Examination of Cadaver Prior to Sled Run

The limbs are all readily movable at their joints with a full range of motion. There are a few post-mortem pink erythremic areas in the dependent regions notably on the back. There is a recent, healed vertical midsternal surgical incision extending from the base of the neck to the xyphoid process. The scar is approximately 13 inches. There are also two old, healed paraumbilical, vertical scars on the abdomen. A recent, healed surgical incision 7 inches in length is present in the left femoral region.

Cadaver Preparation

An incision was made in the right femoral region to expose the femoral artery. The vessel was incised and a Foley #14 French catheter was inserted and passed several inches up into the abdominal aorta 1-2 inches superior to its bifurcation. The 5 ml bulb was inflated with Hypaque thus occluding the vessel as well as rendering the catheter identifiable on the x-rays. The catheter was sutured in place with a running suture.

An L shaped incision was made in the left anterior cervical region and extended to the midline of the neck inferior to the thyroid cartilage. The left common carotid artery was exposed and a transducer was inserted, the top of the receptor extending into the arch of the aorta. The trachea was exposed and a Foley #14 French catheter was inserted and threaded inferiorly to a position superior to the bifurcation of the structure. The 5 ml bulb was inflated with Hypaque to occlude the trachea and allow partial inflation of the lungs with air. The catheter and transducer were each sutured in place and the incision was closed.

Pre-Impact Survey Study (Calman 4, Sled #1404, X-Ray #16878)

Skull

Examination of the skull as seen in AP, lateral and Towne projections. The findings are within normal limits.

Cervical Spine

Lateral studies were carried out in flexion, extension, a swimmer's view was also carried out. The vertebral bodies are normal in size and shape. No fracture or compression is noted. Minimal osteophyte formation is noted.

Thoracic and Lumbar Spine and Pelvis

There is incomplete fusion of the posterior laminae and spinous process of L5 and possibly the first sacral segment. The vertebral bodies are otherwise normal in size and shape. The pelvic bones proper are intact. There is a catheter which has been introduced in the right femoral artery, the balloon tip distended with contrast medium lies at the level of the fourth lumbar vertebra and within the abdominal aorta. There may be some air superior to this, possibly within the aorta proper.

Chest and Ribs

The sternum and manubrium have multiple metal sutures post-operative. An aortic prosthetic valve is in situ. There is air in the ascending thoracic aorta. A catheter has been placed in what appeared to be the bracheal artery, the top of which is extended to the level of the aortic arch. The lung fields are relatively well aerated, no pleural effusion is noted. The heart is not grossly enlarged. There is evidence of a uniting fracture, 4th rib posteriorly on the left in the plane of the posterior axillary line. No definite fracture on the right is noted.

Humeri and Femora

The humeri and femora were studied and no fractures were demonstrated.

<u>Examination of Cadaver</u>

A. Immediate Post-Impact Physical Examination

The cadaver demonstrated no major alterations post-impact with the possible exception of some minor abrasions and an increased mobility of the left shoulder. There was no increased mobility of the neck and the configuration of the chest was unchanged. Palpation of the chest did not reveal any areas of crepitation.

Post-Impact Study (Calman 4, Sled #1404, X-Ray #16929)

Skull

Re-examination of the skull as seen in AP, lateral and Towne projections revealed no interval change. No fracture was demonstrated.

Cervical Spine

Repeat studies were carried out in the same manner. No fracture or dislocation was noted. Considerable air in the soft tissue anterior is present on this study. These planes were delineated with air prior to impact.

Thoraco-Lumbar Spine and Pelvis

No fracture, subluxation or other gross abnormality was demonstrated.

Chest and Ribs

There is radiographic evidence of an undisplaced fracture, fourth rib posteriorly on the right. This would most likely be in the posterior axillary or perhaps mid axillary line. This was not identified on the pre-impact study. No evidence of pneumothorax, pneumocardium or other additional change was demonstrated.

Humeri

The humeri were examined. There is now evidence to suggest an undisplaced fracture involving the lateral aspect of the left clavicle. The acromioclavicular joints are intact, as are the humeri.

Femora

The femora examined in AP projection only are intact.

Impression: The post-impaction study compared with the pre-impaction study revealed what appeared to be a fracture, fourth rib on the right posteriorly or perhaps in the axillary region. There is also evidence of an undisplaced fracture involving the lateral aspect of the left clavicle. These were the only two fractures demonstrated. As noted, no other specific abnormality or gross change is demonstrated between the pre- and post-impact study.

Autopsy

The cadaver is a well developed, well nourished, caucasian male. The femoral and cervical incisions described previously are noted.

Face - the face is free of lacerations and swellings. The contour of the orbital margins, the zygomatic and maxillary regions are bilaterally symmetrical and regular. There are no fractures of the facial bones.

Body - the chest and abdomen are opened with a Y incision. The thoracic masculature is dissected and reflected laterally. There are several undisplaced fractures of the right and left ribs. There are multiple wire sutures through the sternum, the site of the surgical approach for prior cardiac surgery. There are no fractures of the sternum and the earlier mid-sternal surgical separation has fused and healed.

The fractures of the ribs include:

Rib Number	Right	Left
2	3" lateral to the mid-sternal line	2" lateral to mid-sternal line
3	3" lateral to the mid-sternal line only the superior 1/2 of the rib is fractured	3" lateral to the mid-sternal line. The fracture extends only through the external cortex and not through the posterior.
4	Fracture in the anterior axillary line	3 3/4" lateral to the mid-sternal line. Only superior 1/2 of rib is fractured.
5	4 1/2" lateral to mid-sternal line. Only the external cortex is fractured.	3 3/4" lateral to the mid-sternal line in line with the superior fracture.

As a group the fractures are undisplaced and frequently incomplete either extending only partially through the height of the rib or only through the external (ventral, subcutaneous) surface.

The thoracic organs were in their normal anatomical position. No lacerations of the lungs are observed. There is no shift of the mediastinal contents.

The pericardial sac did not present any obvious lacerations and was free of excessive fluid. Cardiomegaly was present and upon exposure of the intra-auricular and ventricular surfaces an aortic ball and cage valvular prosthesis was found. The root of the aorta was soft, free of atheromatous plaques and the coronary ostia were patent. The base of the aorta demonstrated a healed transverse surgical incision. A number of large varied colored clots were present surrounding the valve.

The abdominal musculature was free of hematomas and lacerations. A large number of adhesions were present between various sections of the intestine. These were apparently caused by prior abdominal surgery. The abdominal organs were in their normal position. The liver was enlarged as was the spleen. Neither organ however presented any lacerations or hematomas. The root of the mesentery was similarly devoid of lacerations or hemorrhages. The kidneys were in undisturbed and free of pathology.

Summary

The cadaver was subjected to a Calspan sled impact and sustained several fractures of the right and left halves of the anterior thoracic cage.

The fracture of the ribs as a group were undisplaced and frequently incomplete extending only partially through the height or through only the external (subcutaneous, ventral) surface.

Fracture of the lateral aspect of the left clavicle with separation of the acromio-clavicular joint as demonstrated by x-ray studies.

Aortic valvular prosthesis and hepatosplenomegaly.

4.5 Calman 5

Clinical Background

This is a 51 year old caucasian male who expired July 27, 1975. His death was attributed to a myocardial infraction. The cadaver was stored in an unembalmed state under refrigeration and was subjected to a Calspan sled run on July 31, 1975.

Anthropometric Data

Age - 51 years
Height - 63 1/2 inches
Weight - 150 lbs.
Chest Circumference - 38 inches
Waist Circumference - 31 inches
Sitting Height - 30 inches

Physical Examination of Cadaver Prior to Sled Run

The limbs are movable at their joints with a full range of motion. The finger nails of both hands are markedly cyanotic while the toes are not. There are sutures in the right brachial fossa. There is a circular 2-3 inch mark on the right chest inferior to the nipple and a vague, subcutaneous discoloration of the left chest inferior to the left nipple.

Cadaver Preparation

An incision was made in the left femoral region to expose the femoral artery. The vessel was incised and a Foley #12 French catheter was inserted and passed several inches up into the abdominal aorta. The 5 ml bulb was inflated with Hypaque thus occluding the vessel as well as rendering the catheter identifiable on the X-rays. The catheter was sutured in place with a running suture.

An L-shaped incision was made in the left anterior cervical triangle and extended to the midline of the neck inferior to the thyroid cartilage. The left common carotid artery was exposed and a transducer was inserted, the tip of the receptor extending into the arch of the aorta. The trachea was exposed and a Foley #18 French catheter was inserted and passed inferiorly. The 30 ml was inflated with Hypaque to occlude the structure and allow partial inflation of the lungs with air. The catheter and transducer were each sutured in place and the incision was closed.

Pre-Impact Survey Study (Calman 5, Sled #1414, X-ray 21479)

Skull - Examination of the skull as seen in AP, lateral and Towne projections. The findings are within normal limits.

Cervical Spine - Lateral studies were carried out in flexion, extension, as well as AP projections.

The vertebral bodies are normal in size and shape. No fracture or compression was noted. The intervertebral spaces are well maintained.

Thoracic and Lumbar Spine and Pelvis - The vertebral bodies are normal in size and shape. The intervertebral spaces and posterior articulations are intact. The pelvic bones proper are within normal limits, as are the upper femora. The sacroiliac joints bilaterally are within normal limits. A catheter has been introduced into the left femoral artery, the tip of the catheter as represented by a balloon distended with contrast appears at the level of the second lumbar vertebra.

Chest and Ribs - No evidence of fracture or other bony abnormality was noted. A transducer lies anterior the chest wall. A catheter appears in the left carotid artery, extending down at the level of the aortic arch. The heart is not grossly enlarged. The lung fields have been distended and have the general appearance that one usually associates with pulmonary edema.

Humeri and Femora - The humeri and femora were studied in AP projection only and no fractures were demonstrated.

Examination of Cadaver

A. Immediate Post-Impact Physical Examination.

The cadaver demonstrated no major alterations post-impact. There was an increased mobility of the head. The configuration of the chest was unchanged and palpation in this area did not reveal any loci of crepitation. Both thighs demonstrated a horizontal, approximately 2 inches long cutaneous abrasion in the region of the anterior, superior iliac spine.

Post-Impact Study (Calman 5, Sled #1414, X-ray 21584)

Skull - Re-examination of the skull as seen in AP, lateral and Towne projections reveals no change. No fracture is demonstrated.

Cervical Spine - Examination of the certical spine as seen in AP, lateral flexion and extension studies, as well as swimmer's view. No fracture of subluxation could be demonstrated. There is no evidence of subluxation of the lateral axial articulation.

Thoraco-Lumbar Spine and Pelvis - No fracture or compression of the vertebral bodies or their accessory processes could be demonstrated. The balloon at the tip of the catheter appears distended with more contrast at this time and is at the level of L2. The pelvic bones proper are intact.

Chest and Ribs - The manubrium and sternum are intact. The heart now appears displaced slightly to the left. There is an air distribution which is different than on the original and most of the alveolar filling would appear to be in the left hemithorax. No evidence of pneumothorax could be demonstrated. No evidence of pneumopericardium could be demonstrated.

Humeri and Femora - The humeri and femora were examined and no evidence of fracture was noted.

IMPRESSION: PRE AND POST IMPACTION STUDIES FAILED TO DEMONSTRATE A GROSS FRACTURE OR DISLOCATION. NO MAJOR ALTERATION OF THE SOFT TISSUES SUCH AS PNEUMOMEDIASTINUM, PNEUMOTHORAX OR PNEUMOPERICARDIUM WERE DEMONSTRATED.

Autopsy

The cadaver very well developed, well nourished caucasian male devoid of excessive subcutaneous fat. The femoral and certical incisions described previously are noted.

Face: The face is free of lacerations and swellings. The contour of the orbital margins, the zygomatic and maxillary regions are bilaterally symmetrical and regular. There are no fractures of the facial bones.

Body: The chest and abdomen are opened with a Y incision. The thoracic musculature is dissected and reflected laterally.

The external surface of the thoracic cage is examined and then the individual ribs are cut along the lateral margin of the cage to permit removal of the ventral thoracic wall *in toto* and examination of its internal surface. The clavicles were dissected free of tissue and examined. They are both free of fractures. There is one minimally displaced green-stick fracture of the left rib #4, four inches lateral to the mid-sternal line. The fractured ends are directed posteriorly 1-2 mm. The fracture is identifiable only on the pleural surface of the rib cage.

The thoracic organs are in their normal anatomical position. No lacerations of the lungs are observed. There is about 100 ml of pink, watery fluid in the thoracic cavity. It contains the granular material of the suspension injected into the cadaver, to assist in the maintenance of the hydrostatic pressure. The tracheal catheter is observed lodged in the right main bronchus.

The pericardial sac does not present any lacerations; it contains several ml of clear pink fluid. A group of tiny petechial hemorrhages are present in the cardiac surface of the posterior wall of the pericardial sac. The heart is of normal size. There is a considerable amount of clotted blood in the ventricles as well as a mural thrombus in the left ventricle. The cut surface of the ventricle in the area demonstrate evidence of subendocardial hemorrhage.

The root of the aorta is soft, pliable and contained only tiny, sub-endothelial atheromatous accumulations. The coronary ostia are both patent.

The abdominal musculature is free of hematomas and lacerations. The loop of bowel are mobile and free of adhesions. The abdominal organ including the liver spleen and kidneys are in their anatomical positions and free of lacerations. The root of the mesentery is similarly devoid of lacerations and hemorrhages. Cervical Vertebrae: The cervical vertebrae are exposed by a mid-line vertical incision extending from the occiput to the level of thoracic vertebrae #1. The cervical musculature is dissected and reflected laterally. The spinous processes are in their appropriate anatomical line and are not fractured. The cervical vertebrae are removed in toto from the cadaver and examined. Cervical vertebra #1 is dissected away from vertebra #2. Both vertebrae are dissected free of adherent tissues particularly in the region of the odontoid process. No fractures are identifiable.

Summary

1. The cadaver was subjected to a Calspan sled impact and sustained a minimum of injury.

2. There was a fracture of left rib #4. This fracture was in the same area as a faint overlying subcutaneous discoloration.

This information, coupled with the fact that petechial hemorrhages were also present in the pericardial sac, suggests that they, as well as the fracture of the rib, may have been caused by terminal external cardiac massage rather than Calspan sled impact. The recently sutured cutdown in the right brachial fossa also attests to terminal medical manipulations.

5.0 INTERPRETATION OF RESULTS

5.1 Calman 1

Instrumentation recorded levels of acceleration, at both the head and upper thoracic regions, above those accepted as FMVSS 208 limits. The frontal lobe of the brain was lacerated by a fracture of the sphenoid bone. That along with the sternum factures, flailed chest and liver laceration would probably have registered a fatal AIS7 since:

Head and Neck	AIS5
Chest	AIS5
Abdominal	AIS6.

The lap belts, being mounted to the seat, showed smaller than expected belt loads. This is attributed to the seat track yielding, thereby absorbing some of the energy. There were no injuries noted to the illium, ischium, or pubis.

5.2 Calman 2

Instrumentation recorded levels of acceleration at the head below those accepted as FMVSS 208 limits. The multiple rib fractures (flailed chest), sternum fractures, liver laceration and spleen laceration would probably have registered a fatal AIS6 since:

Head and Neck	AIS0
Chest	AIS5
Abdominal	AIS6.

The lap and shoulder belts showed normal belt loads for a subject of this size. While the clavicles were cracked there were no injuries noted to the illium, ischium, or pubis. The arterial pressure peak of 1760 mmHg was considered high but the autopsy showed no cardio-vascular damage.

5.3 Anthropomorphic Dummy

External as well as internal instrumentation recorded levels of acceleration at the head below those accepted as FMVSS 208 limits. The external accelerometer package (the same as that used on Calman 2), while recording a higher level than that of the internal package (64 g's vs. 44 g's), gave a HIC number of 868 which would indicate survivability.

The 50th percentile anthropomorphic dummy was very close to size to Calman 2. Figure 3-13 shows, in the fourth frame, the shoulder strap intruded under the rib cage similar to frame No. 4, Figure 3-11. While the CSI values of Calman 2 (500) and the 50th percentile dummy (370-400) are well within survivable limits, Calman 2 was probably fatally injured by a lacerated liver and spleen. Since the kinematics of the two test subjects, on impact, are very similar and the chest instrumentation recorded levels very close, it is reasonable to assume from the photographs that the shoulder strap is doing the internal damage to the cadavers.

5.4 Calman 3

Instrumentation recorded levels of acceleration at the head above those accepted as fatal limits. The steering wheel had been removed and the head did not make contact with any part of the vehicle on impact. From analysis of the high-speed movies, the subject appears to have broken the odontoid process early in the sled acceleration. This fracture, plus the flailed chest, fractured vertebra process, lacerated liver and transected aorta would probably register a fatal AIS9 since:

Head and Neck	AIS6
Chest	AIS6
Abdominal	AIS6.

Calman 3 was an osteoporatic subject which probably contributed to the extreme damage observed.

5.5 <u>Calman 4</u>

Instrumentation recorded levels of acceleration at the head below those accepted as fatal limits. Although the chest peak acceleration measurement was 68 g's, if a 3 millisec exclusion were taken the level would be below 50 g's. This coupled with a CSI of 600 and the medical report of rib fractures as a group being undisplaced, and frequently incomplete extending only partially through the height or through only the subcutaneous, ventral surface, must lead to the interpretation that this 46.7 mph crash would have been painful but not life endangering since:

Head and Neck	AIS0
Chest	AIS3
Abdominal	AIS0.

5.6 <u>Calman 5</u>

Instrumentation recorded levels of acceleration at the head below those accepted as fatal limits. The chest peak acceleration measurement was 47.5 g's. This coupled with a CSI of 510 and the medical report of one rib fracture possibly caused by terminal external cardiac massage lead to the interpretation that this 46.9 mph crash may have been painful but not life endangering. Taking the most conservative position, that the cause of the rib fracture was the impact test exposure, this subject diplayed:

Head and Neck	AIS0
Chest	AIS2
Abdominal	AIS0.

6. CONCLUSIONS AND RECOMMENDATIONS

The concept of attaching the lap belt to the seat instead of to the frame of the vehicle does appear to prevent submarining thereby lessening the danger of injury to the lower abdominal regions. None of the three cadavers tested with the three-point belt system exhibited submarining nor were any injuries to the lower abdomen found in the autopsies. Calman 3 did suffer crushing of the illium but his osteoporotic condition probably was the cause since a non-osteoporotic subject of even greater age (Calman 1) showed no illium injuries. A 50th percentile anthropomorphic test dummy likewise exhibited no submarining.

It should be pointed out that the scope of the program was changed, after Calman 3, to an evaluation of an air belt system thereby precluding evaluation of this three-point restraint system with lap belt attached to the vehicle frame. It may be that the anti-submarining effect comes more from the geometry of the belt anchor point attachment than from the seat attachment of these anchor points.

All three cadavers suffered injury to the upper abdominal organs and extensive damage to the thoracic cage. From the high-speed movie film and the sequence camera views, it is observed that the shoulder strap tends to rope (fold upon itself) and underrides the rib cage on the right hand side. The liver lacerations are then attributed to this action.

Shoulder strap roping and the numerous rib and sternum fractures could be caused by the same phenomenon. In these tests the shoulder straps lay across the upper left rib cage coming diagonally down the sternum to the lower right rib cage in the area of the costal cartilage attachment of the sixth through ninth ribs. On impact the shoulder straps appear to underride the cartilage and thereby loading on the junction between the cartilage, sternum and xiphoid process. By its shape, this pointed bone can start the strap roping; it also can act as a stress raiser to the sternum. All sternum fractures were noted to be in the direction of the shoulder strap, that is descending from left to right. This may then be the cause of the thoracic cage damage observed in the Calman 1 through 3 tests. Photo instrumentation on the test using the 50th percentile dummy showed similar belt intrusion by the shoulder strap to that of the cadaveric subjects.

It is difficult to make an absolute statement on the cause of the sternum and rib fractures as being the geometry of the junction between the cartilage, sternum and xiphoid process; since the starting phenomenon of fracture is not observable due to the two layers of clothing covering anatomical landmarks on the subject. Since observed rib and sternum fractures of cadaver subjects appear to be more prevalent than they are in in-vivo subjects this problem should be investigated further with the objective of defining the failure mechanism, thereby defining a remedy for it.

Upper arterial pressures measured in the arch of the aorta showed a reasonable relationship to the restraint system being tested. Calman 2 and Calman 3, testing the three-point belt system, recorded arterial pressures that were extremely high (1760 and 1980 mmHg, respectively). The aorta of Calman 3 was completely separated from the heart. Calman 4 and Calman 5, testing the air belt system, recorded much lower level peak pressures of 680 and 690 mmHg, respectively. It is reasonable to attribute the differences in pressure measurements to the larger area of loading afforded by the air belt system.

Calman 4 and Calman 5, testing the air belt system, exhibited fewer injuries than the subjects testing the three-point belt system. Head motion was dependent on subject size. Calman 4's head rotated in the X-Z plane through about the same angle as Calman 1 through 3. He was 76 inches tall. The total movement in the X direction was also about the same. Calman 3, a shorter subject at 63.5 inches, had a much smaller head rotation angle and an X direction excursion of about half that of the other four subjects.

APPENDIX I

SLED TEST FACILITY

HYGE SLED TEST FACILITY

The HYGE unit is functionally simple, with a minimum of moving parts. Figure 1 illustrates the basic operating principal for the impact sled. The device consists of a long tube with an orifice at its approximate midpoint. A piston and a thrust column which extends through a packing gland at the end of the cylinder are located on one side of the orifice. This piston has a metering pin attached axially on its center line. The metering pin extends through the orifice plate, and an O-ring forms a seal between Chamber B and Chamber C. Chamber A is initially pressurized to a preselected value up to several hundred psi. Chamber B is initially loaded to much higher pressures than Chamber A without creating an impulse on the sled because of the reduced piston area upon which it can act. The ratio of the piston area of Chamber A to B is about 7 to 1. To fire the sled, gas from a small pressurized bottle controlled by a solenoid valve is admitted to Chamber C, thereby unseating the O-ring and exposing the entire piston area to the high pressure in B. The rate at which the force is applied to the piston is controlled by throttling the air flow through the orifice by means of the metering pin. From a selection of 11 metering pins of various contours available at Calspan and by altering chamber volumes and pressures, a wide variety of acceleration pulse shapes can be produced.

The thrust column pushes on the sled and imparts an impulse to it determined by the choice of pressures, volumes and metering pin. At the end of the stroke the sled is at the terminal velocity and brakes can be applied. The sled coasts on twelve phenolic pads and is guided down the track by eight phenolic pads, two in each corner. Air-operated brakes can be set before firing the sled or at any time during the test. A solenoid valve opens at a predetermined time to apply air pressure to sixteen 2-1/2 inch diameter brake pads that clamp on the rails to stop the sled. The brake pressure can be varied to achieve a desired braking g level. Normally, the brakes are actuated after the sled has traveled a distance greater than that where meaningful data would be generated. Figure 2 is a general view of the 12" HYGE sled test facility.

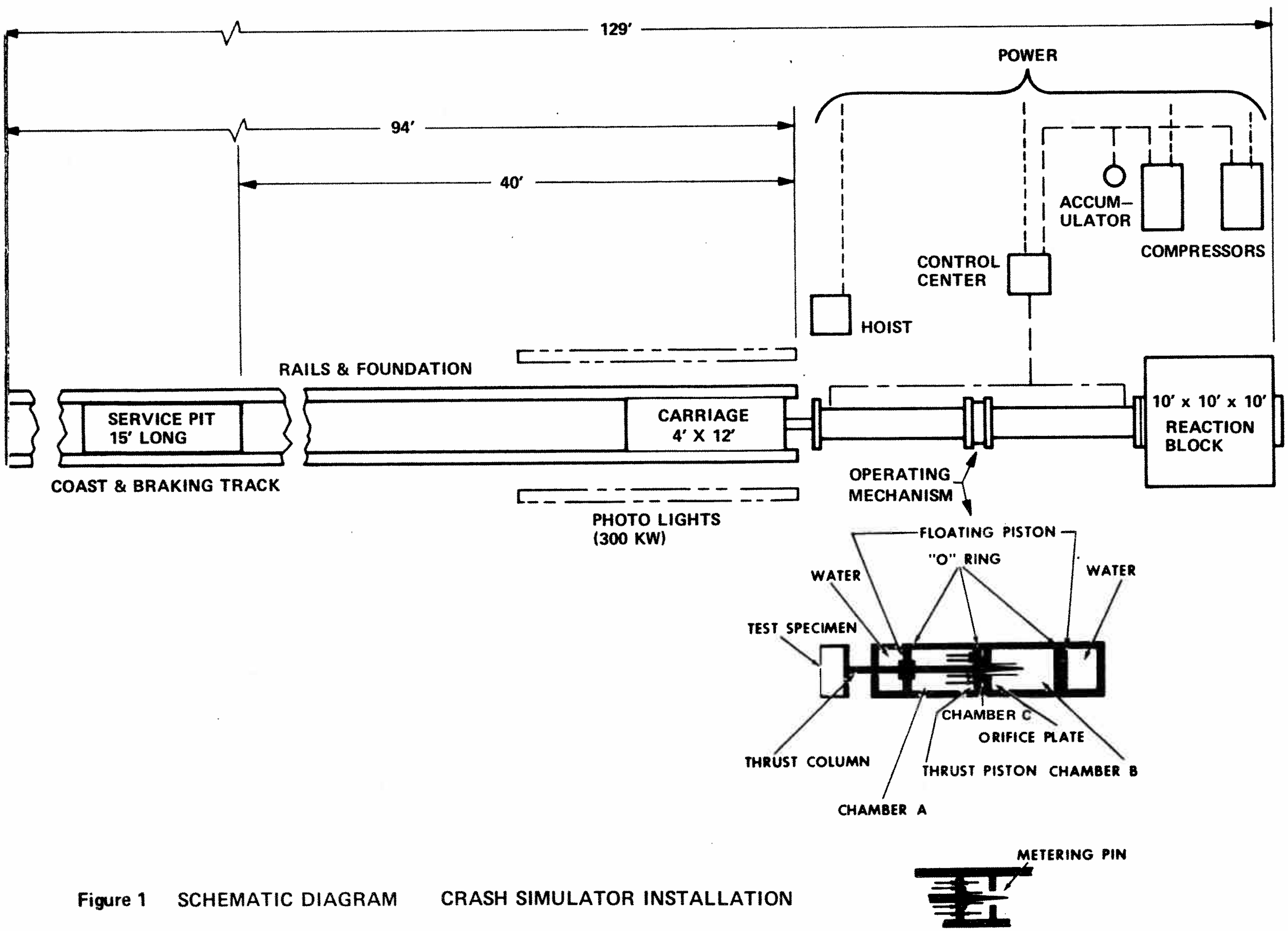


Figure 1 SCHEMATIC DIAGRAM CRASH SIMULATOR INSTALLATION

Dummies are instrumented as needed for a particular test series, i.e., head, chest, pelvis triaxial accelerometers, femur loads, etc., in accordance with the Recommended Practice of SAE Technical Report J211. Cadaver and human volunteer instrumentation presently available, includes chest deflection measuring devices; both inductive coupling sensor coils and caliper type, EKG monitoring system (human) blood pressure monitoring system (human), arterial pressurization and monitoring system (cadaver), lung pressurization and monitoring system (cadaver) and head and chest triaxial accelerometers.

Kinematic data are normally obtained through the use of high-speed motion pictures. The test area is illuminated by 270 overhead 1000-watt spotlights that permit high quality pictures to be obtained at camera speeds in excess of 2000 frames per second. The cameras can be either mounted on the sled or stationary. The sled presently has provisions for six on-board cameras. Normally, two stationary cameras are used but additional coverage is possible. All film, both black and white and color, is processed at Calspan, and is available for viewing in a few hours after each run if necessary for decision making. In addition to the high speed motion picture cameras, an on-board sequence camera, utilizing Polaroid film, gives an immediate 8 picture record of each run, Figure 3.

On some types of testing, closed-circuit television and a video tape system is used for qualitative evaluation of results. The video tape can be relayed immediately after each run.

Acceleration, pressure, strain gauge, load cell, etc., data are recorded on both analog tape and digital tape. The analog tape can be played onto a pen recorder for a quick look at the data. The digital tape is used in conjunction with the Calspan 370/168 computer for programmed data reduction.

A wide variety of accelerometers, pressure transducers and calibration equipment is available and are periodically calibrated to maintain an off-the-shelf capability. Special calibrations for specific needs are on site.

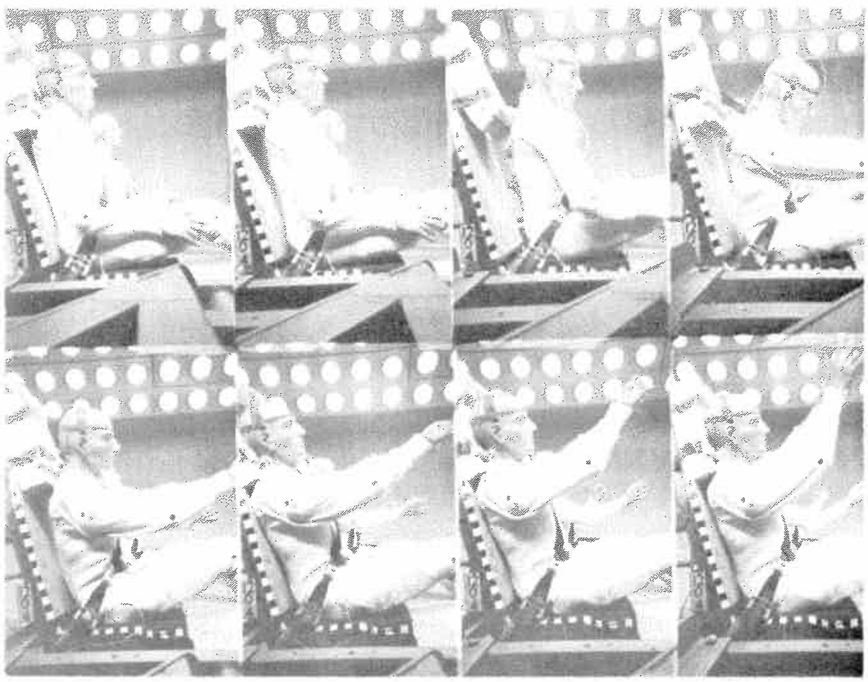


Figure 3 SEQUENCE CAMERA

The following table indicates the types of instrumentation available for use in the Sled Testing Facility.

A)	Dummy Acceleration	1)	Endevco 2262	
		2)	CEC Type 4-202	
		3)	Statham Type A69	
		4)	Kistler Triaxial Model 833 (Piezoelectric)	
B)	Sled Acceleration		Kistler 305T/515T Servo-Accelerometer	
	Displacement	1)	Calibrated Potentiometers	
		2)	Motion Pictures	
	Load	1)	BLH Load Cells	
		2)	Lebow Belt Load Transducers	
		3)	Foil Strain Gauges	
		4)	Semi-Conductor Strain Gauges	
	Velocity		Calspan Designed Electro-Optical	
	Time	1)	Strobe Lights	
		2)	Timing Marks	
	Recording		Direct Write Oscillograph	
			Tektronix 565 Oscilloscope	
			Ampex Tape System, FR 1900H	
			Sangamo Tape System, 3500	
			COREC Data System	
	Cameras	(6)	Photosonic 1B	1000 FPS Max
		(2)	Photosonic 1C	4000 FPS Max
		(1)	Hycam 100	8000 FPS Max
		(3)	Hycam 400	22000 FPS Max
		(1)	Hulcher 70 mm	20 FPS Max
		(4)	Fastax WF2	8000 FPS Max
		(2)	Fastax WF4	11000 FPS Max
				3000 FPS Max
		(1)	Graph-Check Sequence 8 pictures at .015 sec. to 1.0 sec. intervals, variable	

As part of Calspan's HYGE Sled Facility, a dual (side-by-side) sled seat fixture is available for testing two subjects simultaneously per sled run. This arrangement insures both test subjects are exposed to the same sled impulse, thereby providing a direct comparison between any two subjects. In fact, the test subject mix could be any combination of human, dummy or cadaver.

APPENDIX II

DATA GATHERING, RECORDING AND REDUCTION SYSTEM

The large volume of dynamic measurements necessary in the development of crashworthy structures dictates an efficient data handling scheme. The variety of components and test methods requires flexibility in application of that scheme. Automobile crashworthiness is the context of the following descriptions but the same descriptions apply almost without change to sled test vehicles.

The data gathering, recording, and reduction system currently in use at Calspan will be described below. It is believed that the system is sufficiently flexible to meet the current needs of this program as well as any additional requirements which may arise in the immediate future with a minimum of modification. The salient features of the system will be discussed and the listing of the various components of the digital program presented.

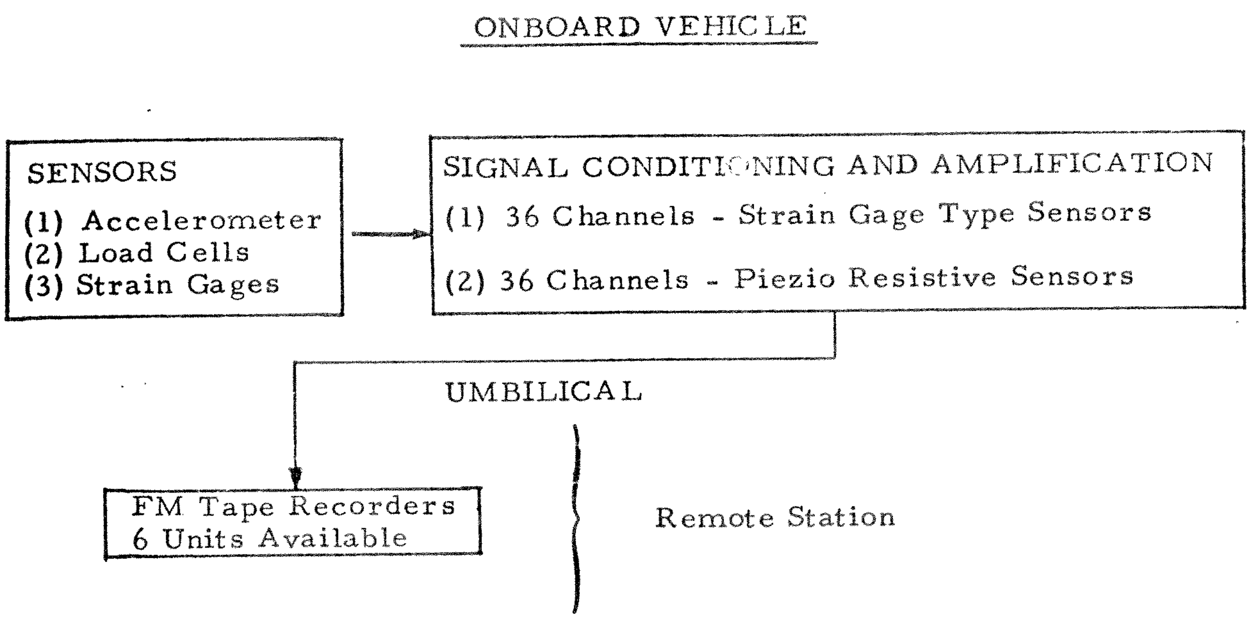
Data Gathering and Recording System

The data gathering and recording system consists of three main groupings of instrumentation:

1. The sensors
2. The signal conditioning and amplification equipment
3. The signal recording equipment

A schematic of this system is presented in the following block diagram.

The sensors consist of a variety of transducers which sense a particular physical quantity and produce an electrical signal which is proportioned to it, e.g., accelerometer, load cells, and strain gages. These units are mounted on-board the vehicle. The location of the vehicle sensors and dummies will be standardized to fit the specific vehicle being tested but will conform to the basic layout as noted in the following schematic. Each package consists of three accelerometers oriented to read the accelerations in three orthogonal directions (axial, lateral, and vertical). The package locations will be numbered sequentially and will be adhered to in the presentation of the plotted data obtained from the digital data reduction program.



Block Diagram of Basic Data Recording System

VEHICLE MOUNTED SENSORS

PROJECT ____________________

TEST NO. ____________________

DATE ______________________

P. ENG. _____________________

CAMERA

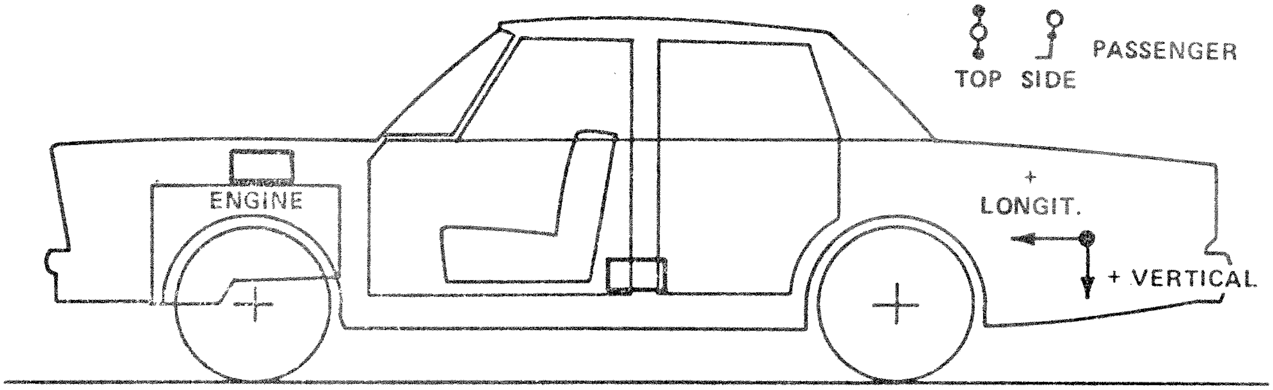
LOAD CELL

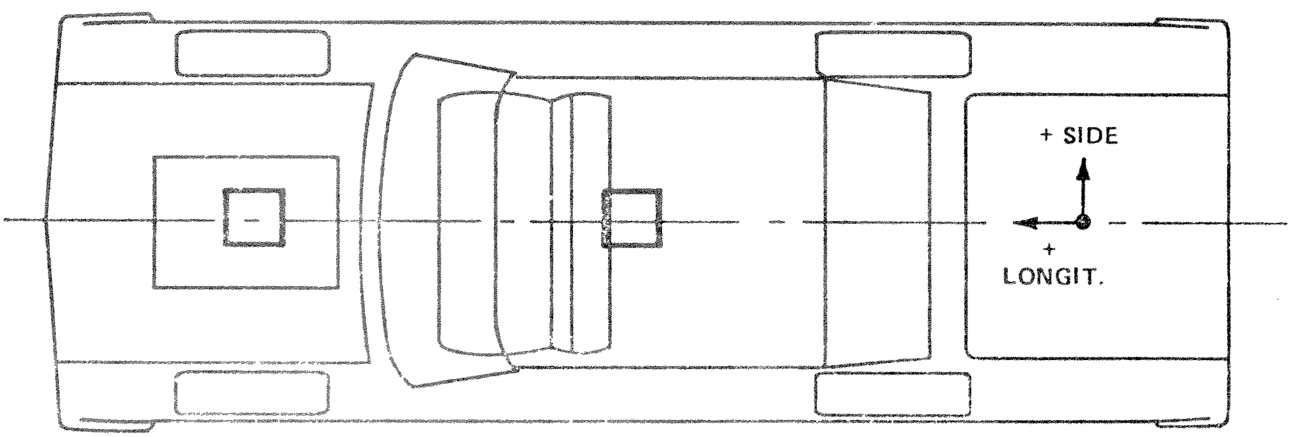
STRAIN GAGE

ACCELEROMETER

PASSENGER

TOP SIDE





REMARKS:

Also mounted on-board the vehicle are the signal conditioning and amplification equipment. A typical crash test instrumentation setup is shown in the following figure.

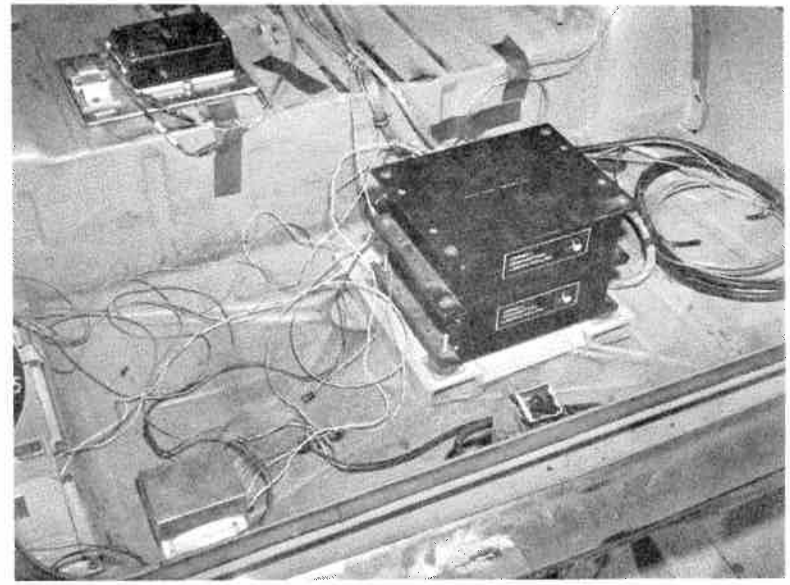
Section (a) of the figure shows the rear seat area with the triaxial accelerometer packaged mounted on the floor pan and drive tunnel. A typical dummy installation is shown in Figure (c). The lap belt load cell is readily apparent. Not visible are the triaxial accelerometer packages located in the dummy head and chest. The packaged signal conditioning and amplifying equipment is shown as the pair of shock mounted, stacked black boxes in Figure (b). There are two types of signal conditioning and amplifying packages:

1. Conditioning for strain gage type sensors.
2. Conditioning for piezio-resistive type sensors.

Also shown in Figure (b) are the two ± 12 volt DC supplies (the two units just visible in the lower left hand portion of the figure) which power the strain gage type sensors. A close-up of one of the amplifier packages and accelerometer packages is presented in Figure (d).

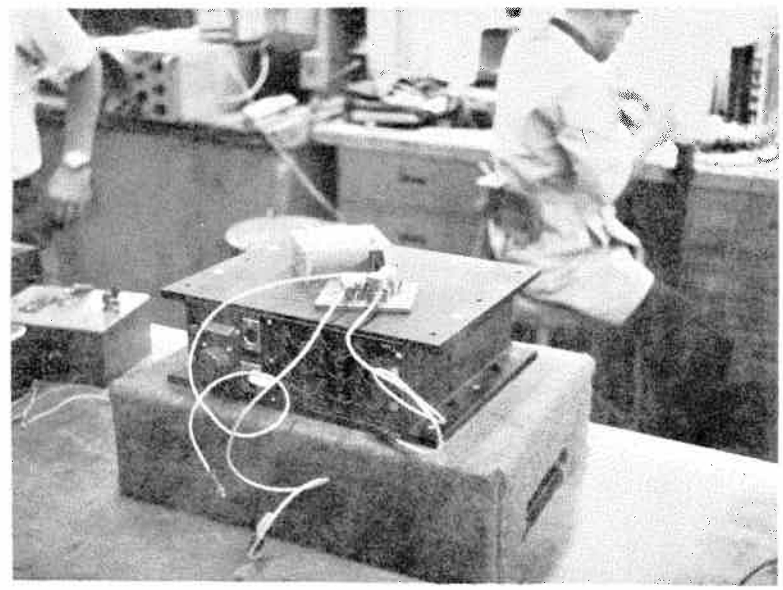
The amplifier signals are carried from the vehicles to the remote recording stations via a multichannel umbilical. The signals are recorded on 14 channel Sangamo FM tape recorders.

(a)



(b)

(c)

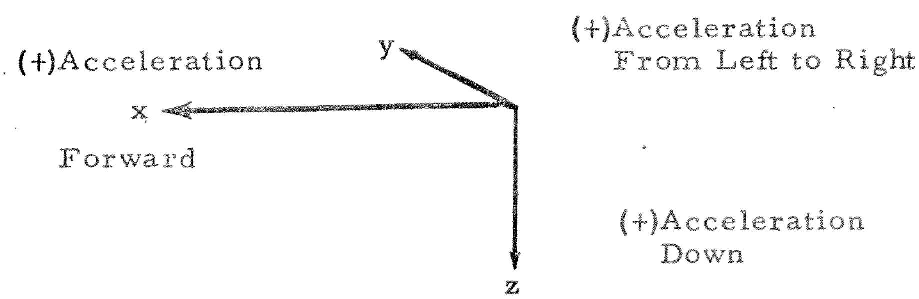


(d)

TYPICAL ON - BOARD TEST EQUIPMENT

The sign convention used on all tests is presented below:

1. For all accelerations - vehicle compartment and anthropomorphic dummy.

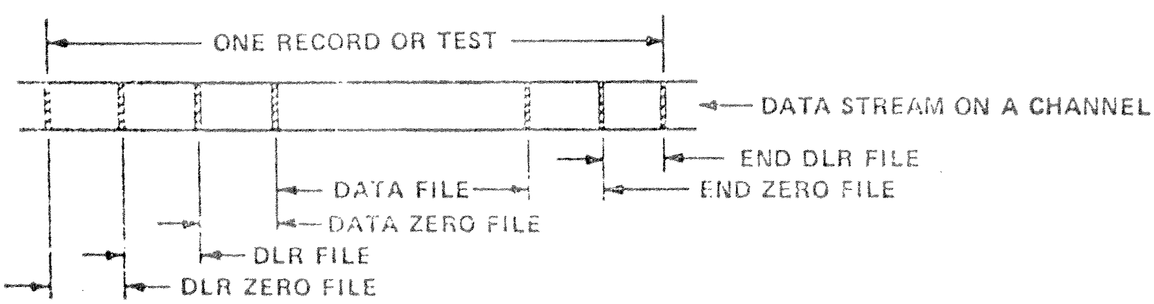


ACCELERATION SIGN CONVENTION

2. Velocity and displacement agree with above convention

3. For all loads - tension is positive

To facilitate the data reduction, a specific sequence of data collection on a given data channel as well as a specific order for the data channels is required. The required sequence of data on any given data channel is shown schematically below:



SCHEMATIC OF A DATA CHANNEL

The designation DLR represents the "dummy load resistance" employed to electrically simulate a given load on a given sensor, thereby providing a calibration signal for that sensor.

The required sequence of data on a given tape is as shown below:

1. Channels 1 to N - Vehicle Accelerations
   a. X, Y, Z components of vehicle (4 corners) Accelerometers
   b. X, Y, Z components of tunnel accelerometers
   c. X, Y, Z components of other accelerometers (May include engine, rear deck, etc.)

2. Channels (N+1) to M - Passenger Accelerations
   a. X, Y, Z components of head accelerations
   b. X, Y, Z components of chest accelerations
   c. X, Y, Z Components of pelvis accelerations

3. Channels (M + 1) to P - Passenger Loads

4. Channels (P + 1) to 13 - Miscellaneous Signals

5. Channel 14 - Time Trave and Event Time Zero Indicator

If more than one analogue tape per test exists, its data are simply stacked behind the data obtained from the first tape and in the same sequence.

Data Reduction System

The conversion of the data recorded on the analogue tape to accelerations, loads, etc., is accomplished by a digital data reduction system (DDRS). The major capabilities of the system are:

1. Converts an analogue record into a digital record.

2. Organizes the digital record into a format compatible with the IBM-360 Mod. 65 digital computer.

3. Operates on the digitized data to convert it to the appropriate accelerations, loads, etc.

4. Performs digital filtering if desired.

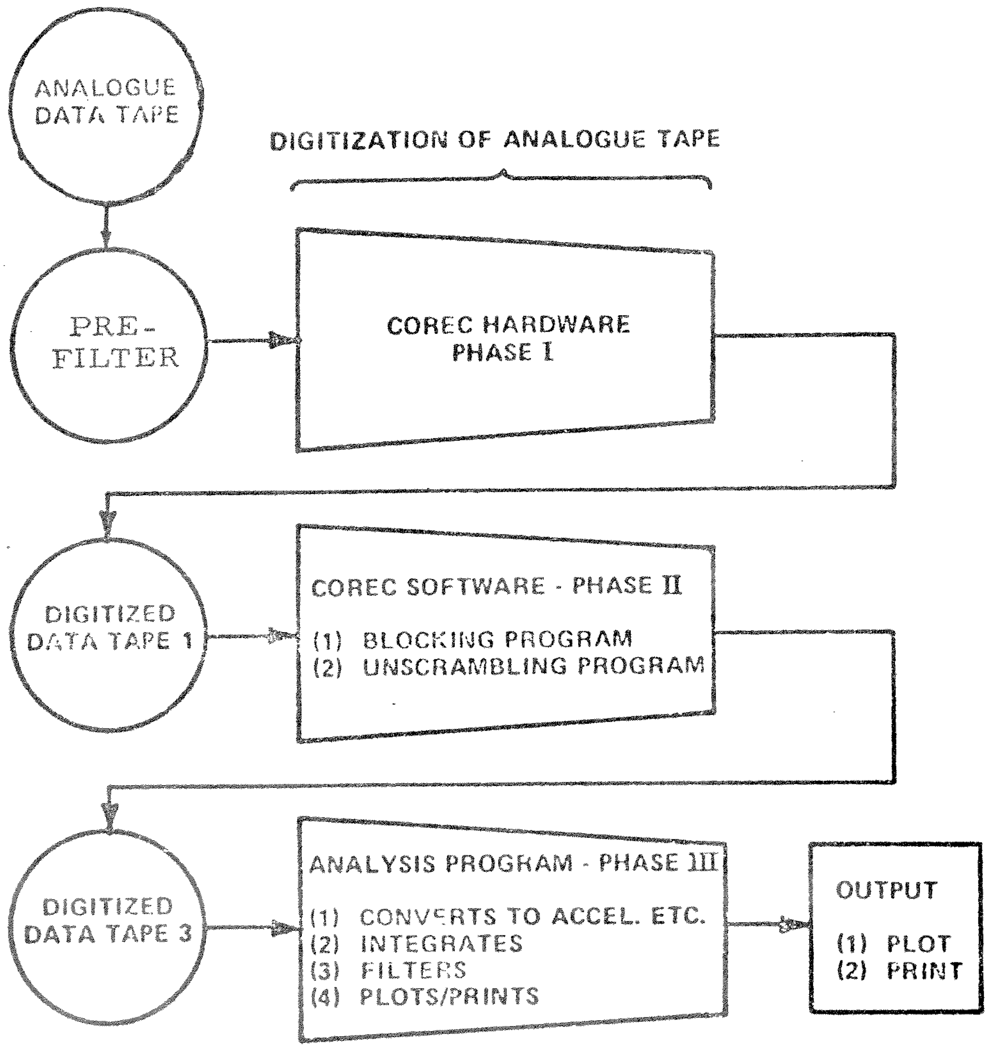
5. Performs further operations on the data, such as integrating to obtain velocity and displacement; obtaining resultants.

6. Provides a convenient plotted output of the reduced data.

A schematic of the DDRS is presented on the following page. Each of the three major phases of the DDRS will be briefly discussed below.

Phase I - Corec Hardware

This portion of the system converts the analogue signals to their digital equivalents (A/D conversion). The data are recorded on the analogue tape at 60 inches per second (IPS) and played back for digitization at 15 IPS, thereby effecting a 4-1 time stretch. The digitized data are recorded on a digital tape (digitized data tape 1) at 45 IPS. As noted in the previous Figure, one analogue record on a given channel consists of six files or segments of information. Each file is sampled for 0.5 sec. of real time at 60 IPS, or in the slowed time for 2 sec. at a tape speed of 15 IPS. Thus, a record consists of 3 sec. of real time data distributed as follows:



SCHEMATIC OF DIGITAL DATA REDUCTION SYSTEM

0.5 sec. - DLR ZERO DATA
0.5 sec. - DLR DATA
0.5 sec. - DATA ZERO
0.5 sec. - DATA
0.5 sec. - END ZERO DATA
0.5 sec. - END DLR DATA

One-half sec. real time was selected because most crash events being monitored are completed within this interval. Provisions have been made to allow additional time increments for A/D conversion of 1.0, 1.5, and 2.0 secs. However, because of the digital software in Phases II and III, these cases are treated specially and the majority of data runs are for the 0.5 sec. intervals.

All analog signals are pre-filtered before the A/D conversion and digitally filtered by the computer to meet the various SAE classes of filters as explained in section on filtering.

The A/D conversion consists of a sample and hold procedure in which the 1st channel of the analogue tape is interrogated at time t_1 and this value converted to its digital equivalent and recorded on the digital tape. The time to accomplish this is Δt. Then the 2nd channel is interrogated at time $t_1 + \Delta t$ and its digital equivalent recorded on the digital tape behind the information from the 1st channel. This procedure is continued until all channels have been interrogated. For the case in hand, 15 channels are interrogated in one scan of the tape width. The 15 channels consist of 14 analogue channels and one digital channel for coding.

The total time required to scan the 15 channels is:

$$15 \ \Delta t = 0.000312 \text{ sec. at } 15 \text{ IPS}$$

Thus, a given channel is sampled once every 0.000312 sec. for a sampling rate of 3200 samples/sec. In real time, at a tape speed of 60 IPS, this slowed time sampling rate would correspond to real time sampling rate of 12,800 samples/sec. (15 Δt = .0000781). Since 0.5 sec. (real time) of data are sampled, 48,000 samples or digital values are obtained from each analogue channel. (It takes 2 sec. to collect these 48,000 samples at a tape speed of 15 IPS.)

The sampling rate was selected because:

1. It provided the maximum scan rate available within the design limits of the A/D converters, and

2. It provided frequency response capability of 4266 Hz (assuming that 3 data points are required to define any given frequency of a harmonic nature).

The end product of Phase I is a digital tape on which there exists six files of digitized data. Within each file, the digitized data from each channel are interspersed in the sequence (Channel 1, t_1); Channel 2, $t_1 + \Delta t$); (Channel 3, $t_1 + 2\Delta t$), ... (Channel 15, $t_1 + 14\Delta t$); (Channel 1, $t_1 + 15\Delta t$); Channel 2, $t_1 + 16\Delta t$), etc.

Phase II - Corec Software

The digital tape obtained from Phase I becomes the input tape for Phase II of the DDRS. In Phase II, two principle operations are performed. These digital operations are programmed for the IBM-360 Mod. 65. The first operation is required because the length of the digital records on DIG TAPE 1 exceeds the storage capacity of the 360 and hence, the record must be broken up into records of acceptable length. The program which does this is referred to as the Blocking Program. The output from the Blocking Program is an intermediate digital tape, DIG TAPE 2.

DIG TAPE 2 can now be processed by the IBM-360 in a conventional fashion; however, the data are still in a scrambled condition (see above).

Hence, DIG TAPE 2 is operated on by a program which unscrambles the data (Unscrambling Program) and produces DIGITIZED DATA TAPE 3.

Phase III - Analysis Program

DIT TAPE 3 is operated on by the Analysis Program which:

1. Reads the DLR ZERO file (48, 000 samples) for each channel and averages overall samples.

2. Reads the DLR file (48, 000 samples) for each channel and averages overall samples.

3. Computes the difference between (1) and (2) for each channel, which in conjunction with the inputed electrical calibration constant (Calibrated load/DLR) allows the determination of the digital calibration constant for each channel.

4. Reads the DATA ZERO file (48,000 samples) for each channel and averages overall samples to get a ZERO reference for use on the data file.

5. Reads the DATA file (48,000 samples) for each channel, subtracts the ZERO reference and multiplies by the proper calibration for that channel at each sample. The result is 48,000 samples (for each channel) of data converted to accelerations or loads, etc.

6. If desired, the data may now be digitally filtered (see section on Digital Filter for a more complete description). A different filter may be selected for each classification of signals noted on pages 19, 20, 21 (i.e., vehicle accelerations, passenger accelerations, etc.).

7. If desired, the vehicle acceleration and passenger acceleration classification of data may be further operated on to:

   a. Obtain velocity and displacement by integration of the accelerations.

   b. Obtain resultant acceleration magnitude (but not orientation) of any sub-group within a given classification, e.g., tunnel resultant acceleration obtained from the tunnel X, Y, Z components.

8. Any or all of the data may be plotted. The plot subroutine provides:

   a. Selection of the size of the plots.

   b. Selection of the plot scale or allows program selection of most convenient scale.

   c. Selection of titles from a preprogrammed group.

   d. Provides dimensions of: G's for acceleration
MPH for velocity
INCHES for displacement
SECONDS for time

Analog Filters (Pre-Filters)

The analog pre-filters will physically operate on slowed-down signals, in the link between analog playback unit and the COREC samples. Fourth order (24 db/octave) Butterworth filters with corner frequency of 450 Hz are used for each analog signal channel.

Recognizing the 4:1 speed reduction (60 inches/second record, 15 inches/second playback), these filters have the effect ("real time) of an 1800 Hz corner frequency. This effective response, in comparison with J211a specs for 1000 Hz filtering in the following figure.

Digital Filters

Digital filtering is used to meet 60 Hz, 180 HZ and 600 Hz specs for overall transfer functions. The Tustin transform approach is used because of its proven stability and efficiency.

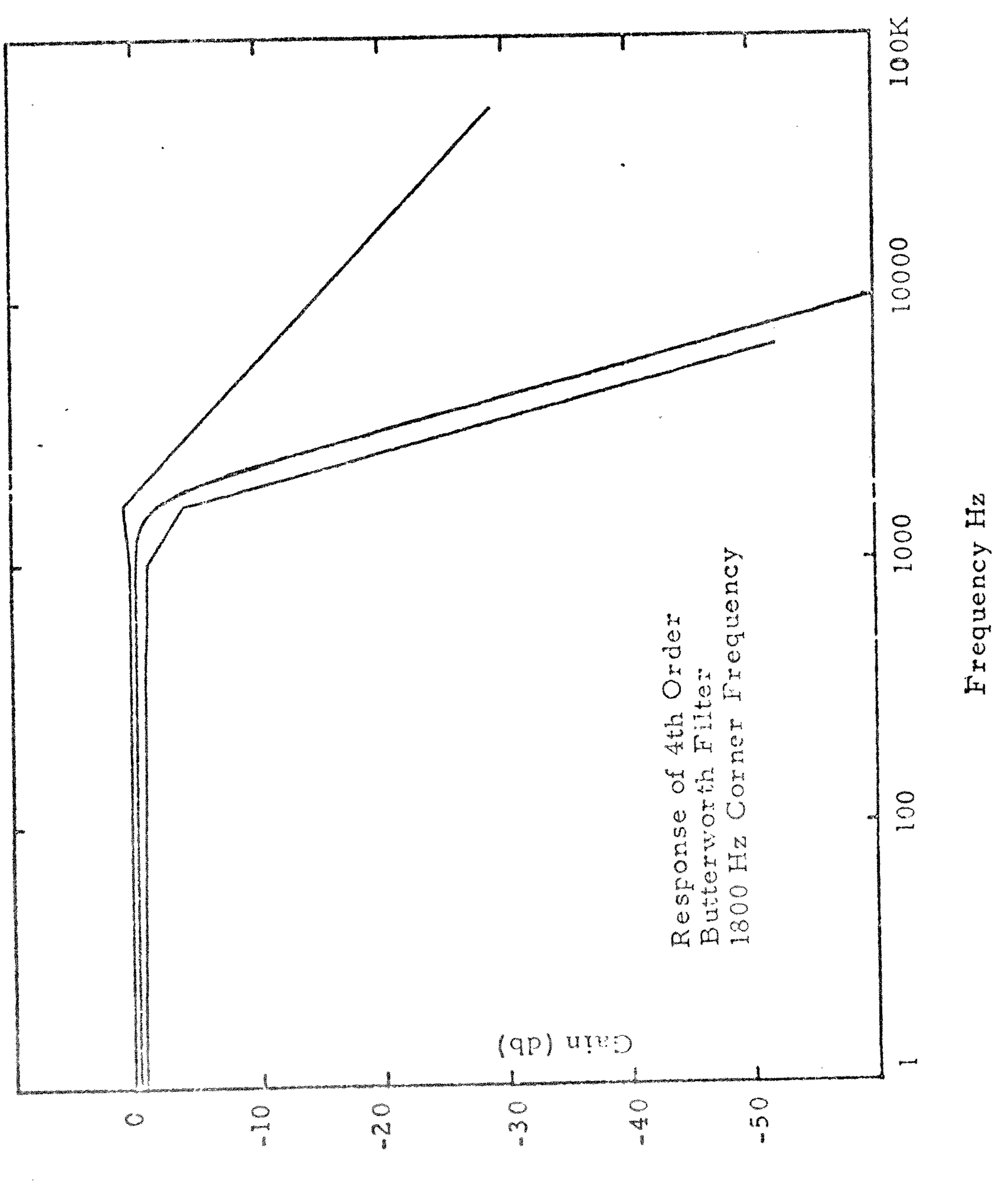
The following design guide lines were used for digital filtering.

1. "True" frequency response for the combined analog-digital filtering action meeting respective J211a specs.

2. A rolloff of 24 db/octave (parallel to the bottom line of the J211a window) was better than a lesser rolloff.

3. Zero phase shift digital filtering is accomplished by two passes (forward, then backwards in "time").

4. Effective (real time equivalent) sampling rate of 12,800 samples/second, hence folding frequency of 6400 Hz.


Response of 4th Order
Butterworth Filter
1800 Hz Corner Frequency
Gain (db)
0
-10
-20
-30
-40
-50
1
100
1000
10000
100K
Frequency Hz

All criteria were achievable with second order digital filters. All were based on the generic form of analog prototype

$$G(s) = \frac{\left(1+\frac{s}{\omega_1}\right)\left(1+\frac{s}{12000}\right)}{1+2\zeta\left(\frac{s}{\omega_0}\right)+\left(\frac{s}{\omega_0}\right)^2}$$

Roughly, the denominator dominates at low frequencies. The numerator terms limit the gain at high frequencies in compensation for (a) the otherwise awkward behavior at the folding frequency, and (b) the fact that the analog filter response takes effect above 1800hz (~11000 rad/sec.). It may be noted that elimination of numerator terms (i.e. G(s) = 1/quadratic) would imply zero gain ($-\infty$ db) at 6400hz in the actual response of the derived filter, and potential violation of specs.

The Tustin transform of G(s) gives a corresponding digital transfer function of form

$$\hat{G}(z) = \frac{a_0 + a_1 z + a_2 z^2}{1 + b_1 z + b_2 z^2}$$

or, equivalently, a computational recursion relationship

$$y_n = a_0 x_n + a_1 x_{n-1} + a_2 x_{n-2} - b_1 y_{n-1} - b_2 y_{n-2}, \quad n = 3, 4, \ldots N$$

where y's are output (filtered) values and x's are input (unfiltered) values. The starting values y_1, y_2 are arbitrary, analogous to initial conditions (electrical) of the corresponding analog filter. A reasonable goal was to choose y_1, y_2 to minimize starting transients ("edge effects"), as for example this default recommendation:

$$y_1 = x_1$$

$$y_2 = a_0 x_2 + (1-a_0)x_1 .$$

For the reverse-time pass needed for zero phase shift and final contribution to transfer gain function, the same filter is used with subscripts beginning at the maximum value (N, say) and decreasing:

$$z_n = a_0 y_n + a_1 y_{n+1} + a_2 y_{n+2} - b_1 z_{n+1} - b_2 z_{n+2}, \quad n = N-2, N-3, \ldots 1$$

with z_N, z_{N-1} in the role of initial conditions, e.g.,

$$z_N = y_N$$

$$z_{N-1} = a_0 y_{N-1} + (1-a_0) y_N$$

The following table lists, for each of the filter classes, the numerical values established for parameters w_o, w_1 and ζ of the G(s) prototype, and the corresponding coefficients a_o, a_1, a_2, b_1, b_2 to be used for actual digital computation.

The following three figures show actual transfer functions for filter classes 600 Hz, 180 Hz, and 60 Hz, respectively.

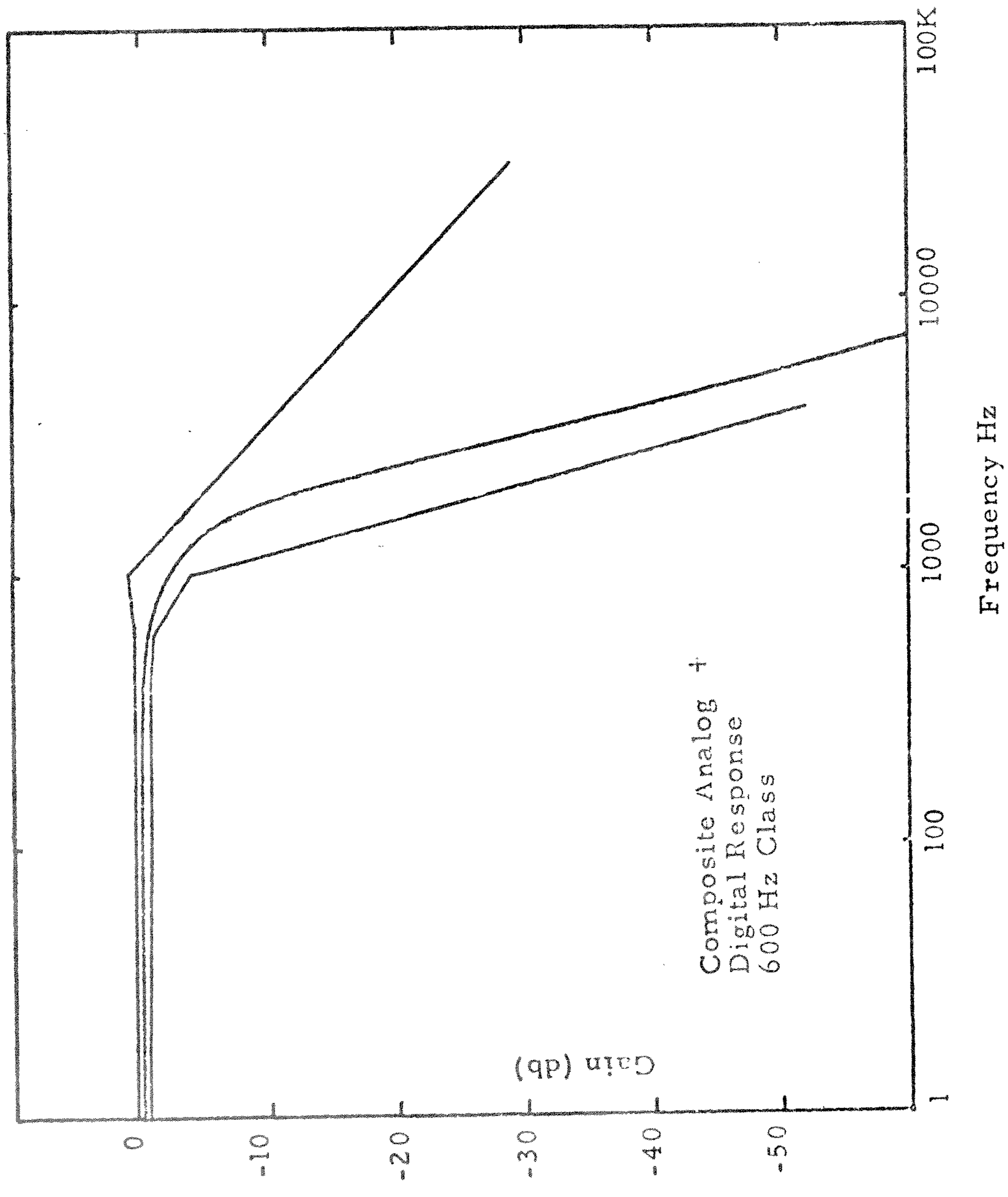
PARAMETERS FOR DIGITAL FILTERS AND ANALOG PROTOTYPES

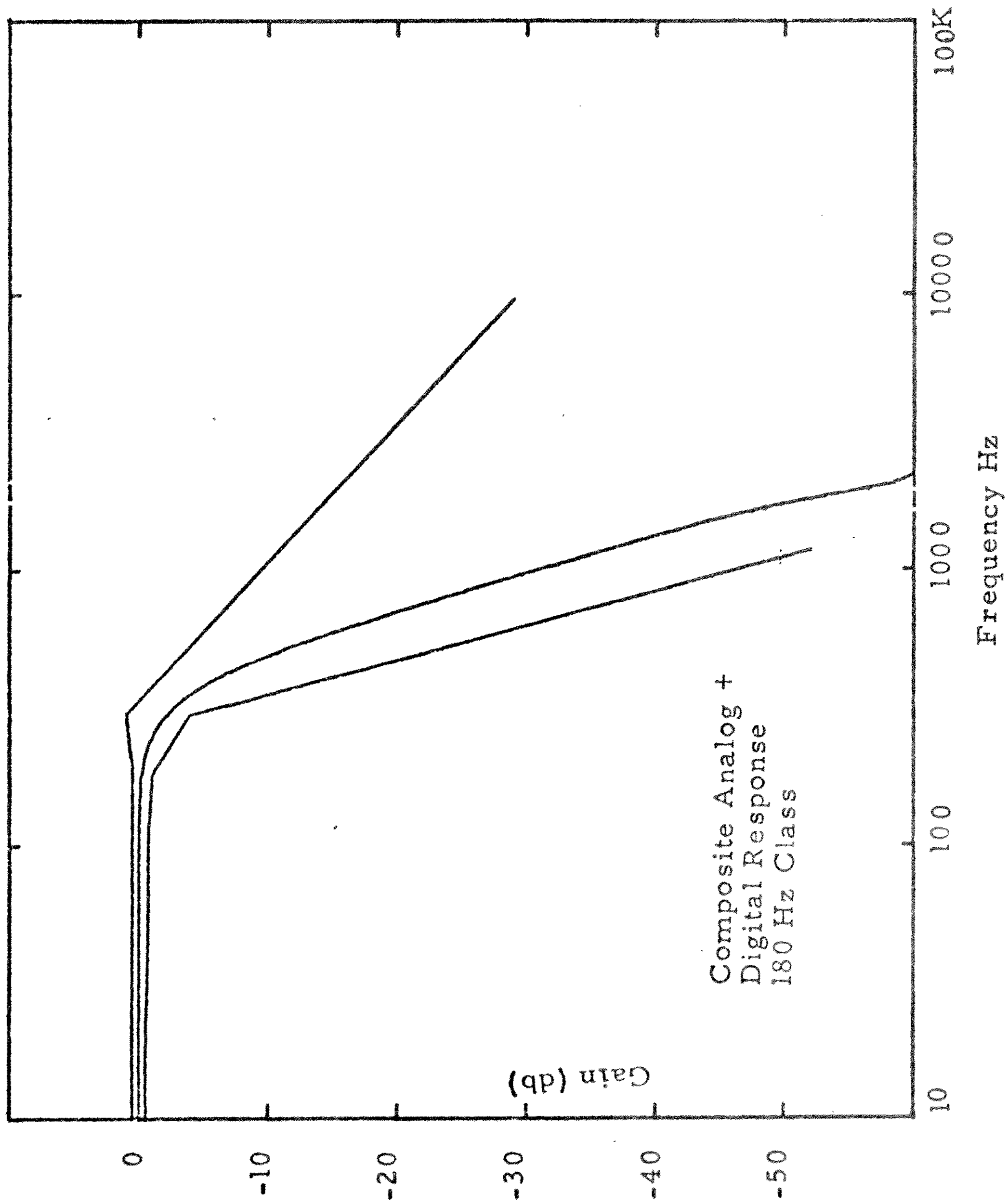
$$y_n = a_0 x_n + a_1 x_{n-1} + a_2 x_{n-2} - b_1 y_{n-1} - b_2 y_{n-2}$$

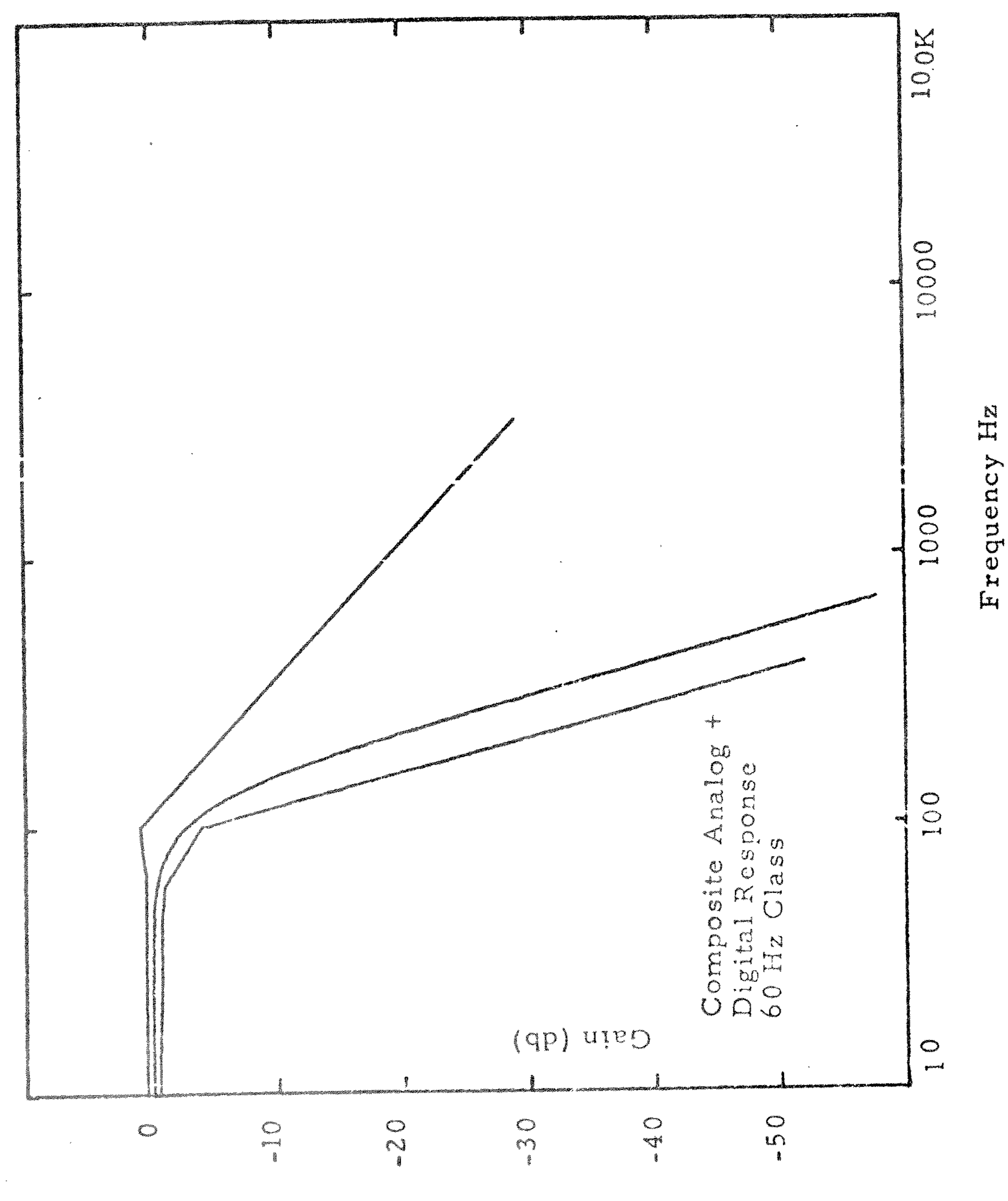
$$\hat{G}(z) = \frac{a_0 + a_1 z + a_2 z^2}{1 + b_1 z + b_2 z^2}$$

$$G(s) = \frac{\left(1 + \frac{s}{\omega_1}\right)\left(1 + \frac{s}{12000}\right)}{1 + 2\zeta\left(\frac{s}{\omega_0}\right) + \left(\frac{s}{\omega_0}\right)^2}$$

	60 Hz	180 Hz	600 Hz
a_0	$4.4266\ 37564 \times 10^{-3}$	$3.9369\ 45058 \times 10^{-2}$	$6.2793\ 59638 \times 10^{-1}$
a_1	$-1.7242\ 10962 \times 10^{-4}$	$-1.5334\ 71789 \times 10^{-3}$	$-5.5604\ 46124 \times 10^{-1}$
a_2	$-5.1676\ 49616 \times 10^{-4}$	$-4.5959\ 83368 \times 10^{-3}$	$1.1897\ 06436 \times 10^{-1}$
b_1	$1.9117\ 06446 \times 10^{0}$	$-1.7261\ 13074 \times 10^{0}$	$-1.1809\ 29381 \times 10^{0}$
b_2	$9.1544\ 38971 \times 10^{-1}$	$7.5935\ 30699 \times 10^{-1}$	$3.7179\ 13761 \times 10^{-1}$
ω_0	800	2500	7000
(f_0)	(127)	(398)	(1114)
ω_1	50000	50000	8000
(f_1)	(7958)	(7958)	(1273)
ζ	0.707	0.707	0.900

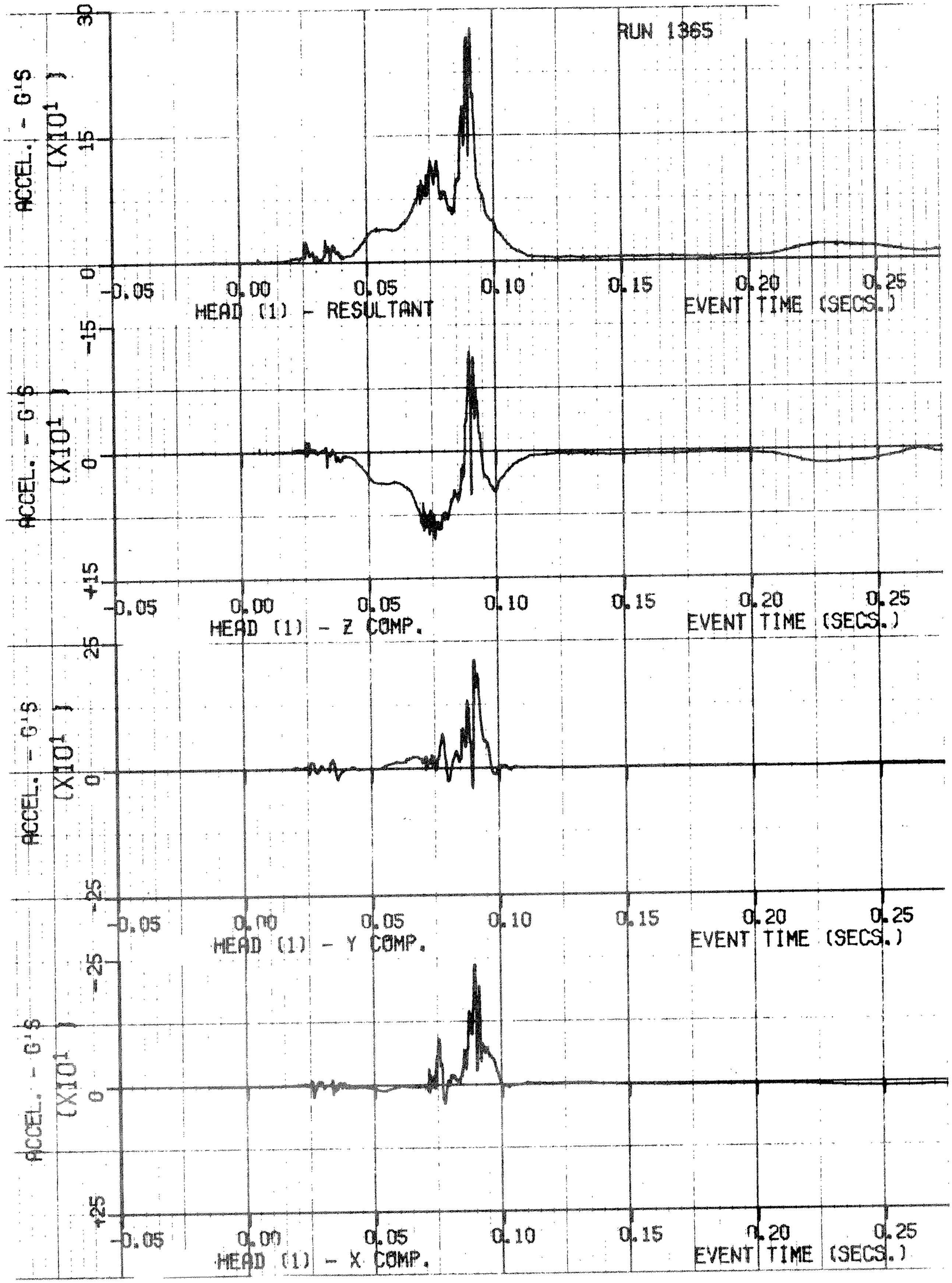

Composite Analog +
Digital Response
600 Hz Class
Gain (db)
0
-10
-20
-30
-40
-50
1
100
1000
10000
100K
Frequency Hz


Composite Analog +
Digital Response
180 Hz Class
Gain (db)
Frequency Hz
0
-10
-20
-30
-40
-50
10
100
1000
10000
100K

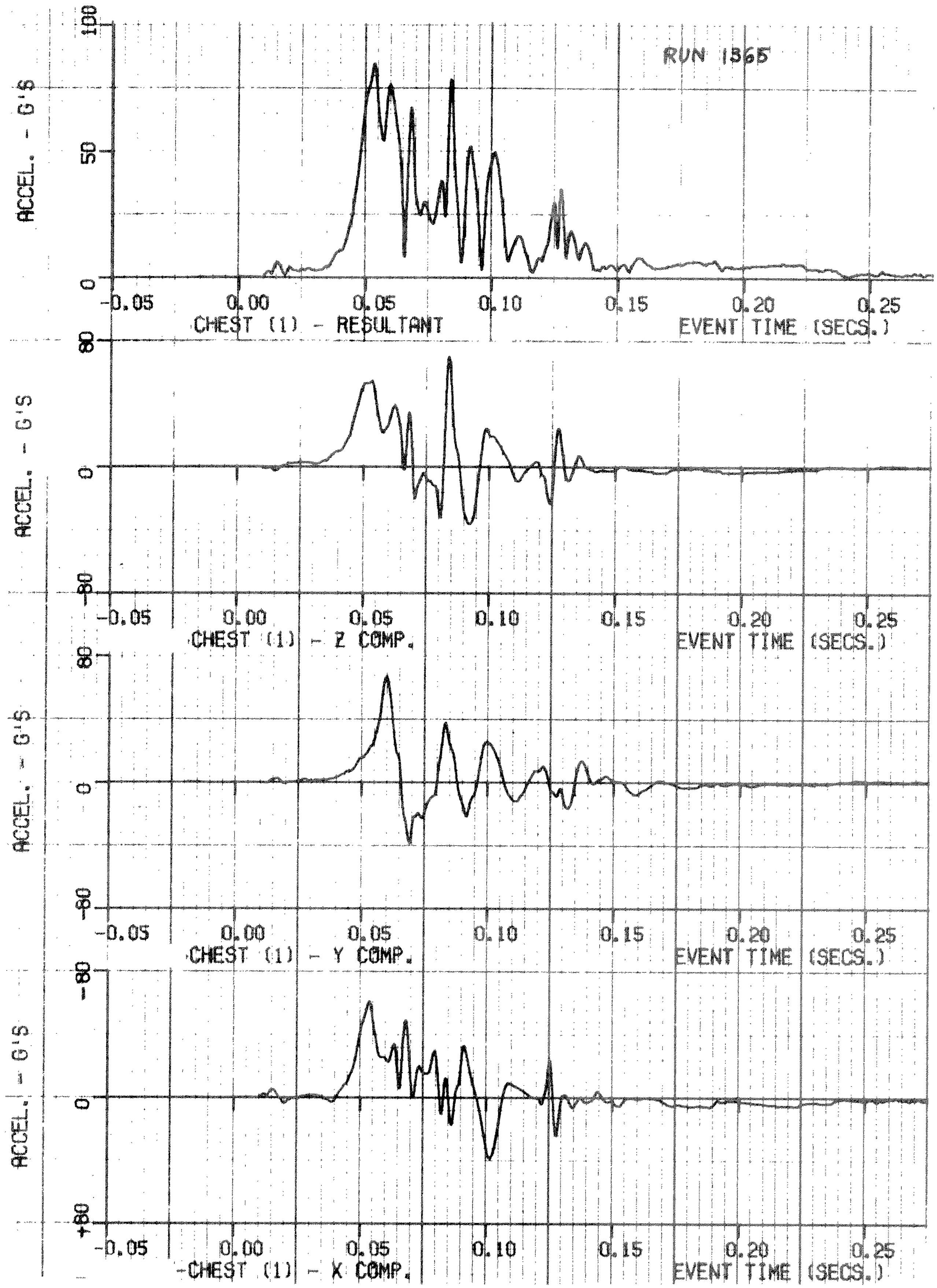

Gain (db)
0
-10
-20
-30
-40
-50
10
100
1000
10000
10.0K
Frequency Hz
Composite Analog +
Digital Response
60 Hz Class

APPENDIX III

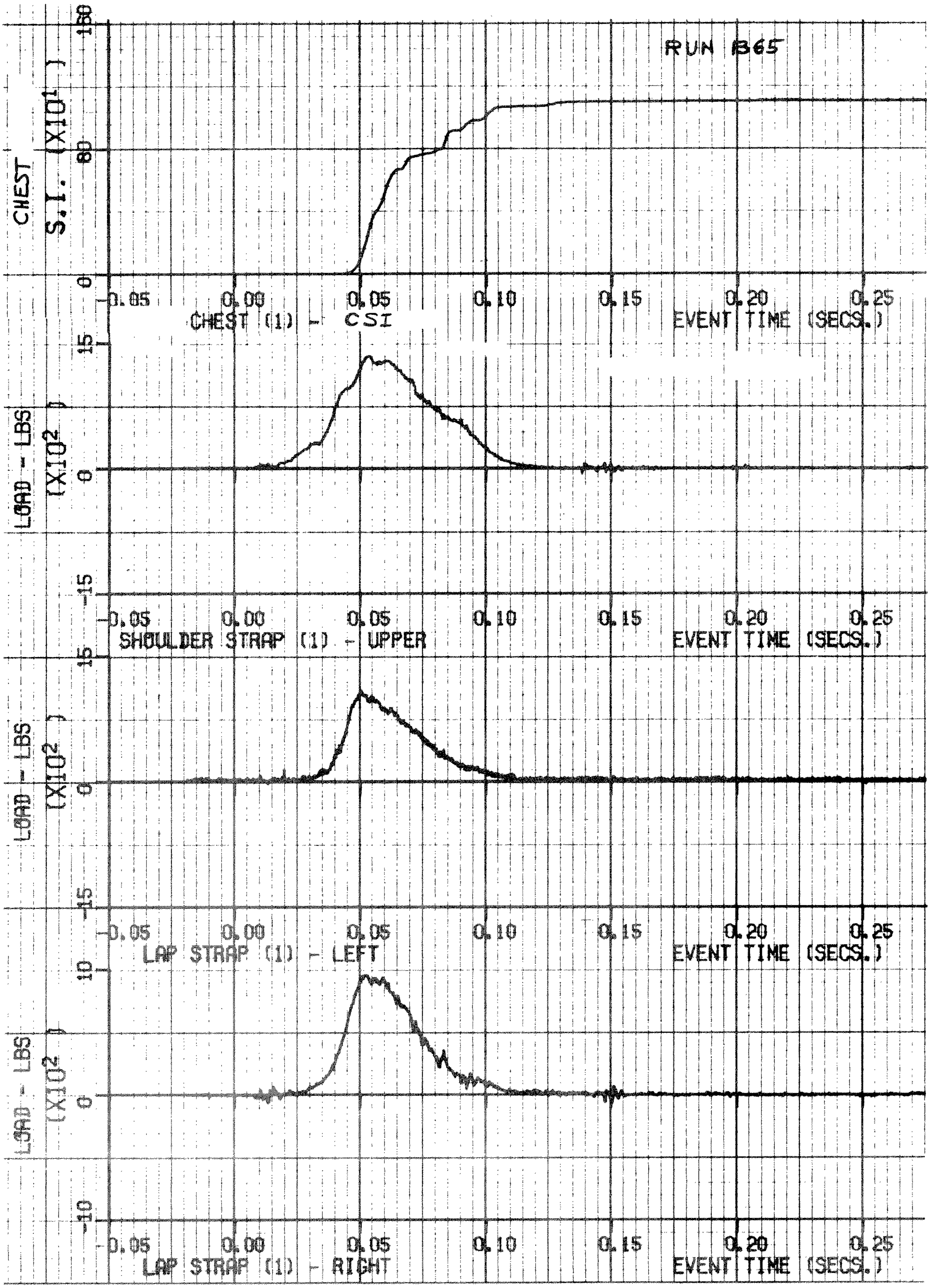
TIME HISTORIES



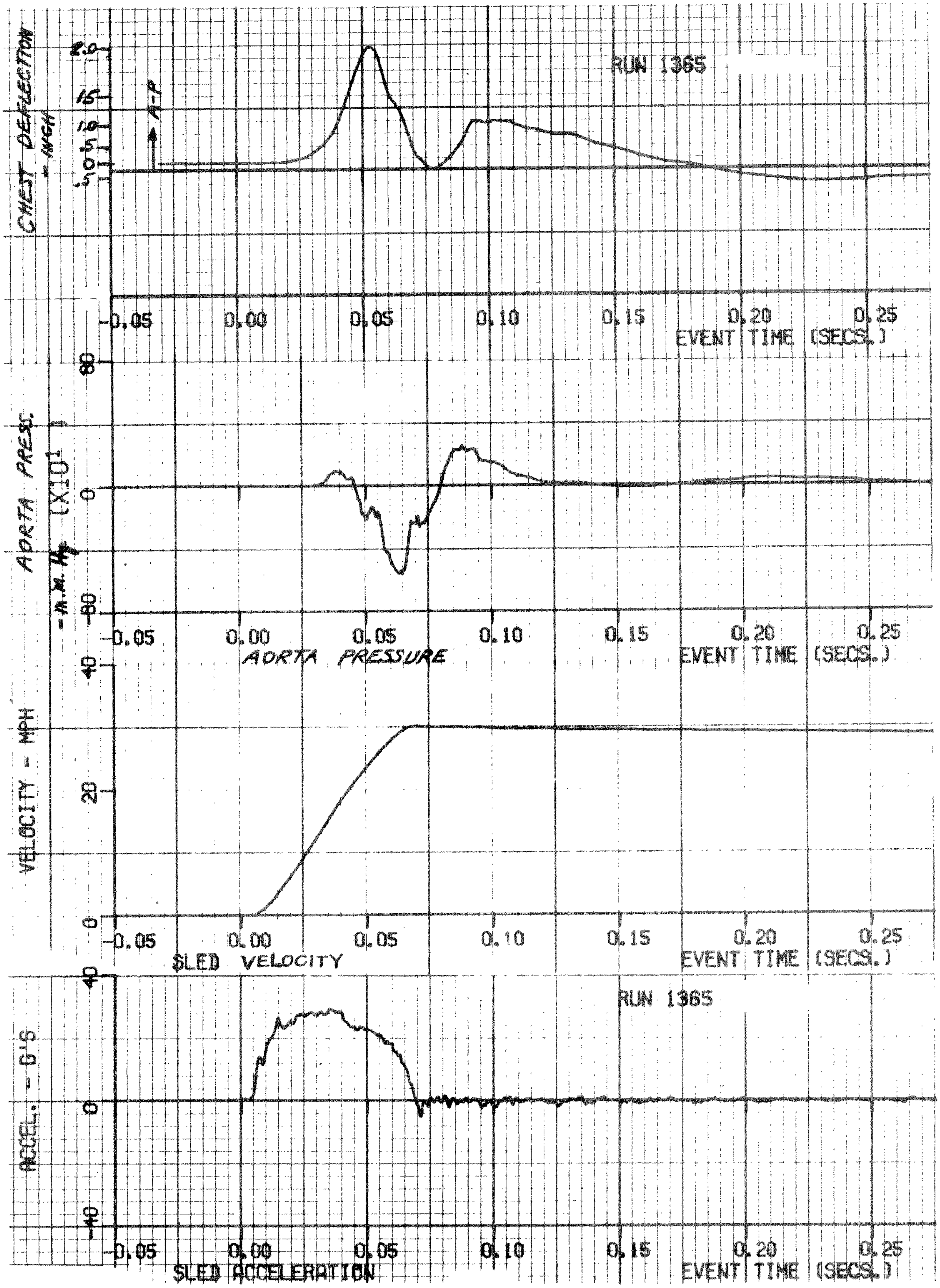
CALMAN 1 HEAD ACCELERATIONS



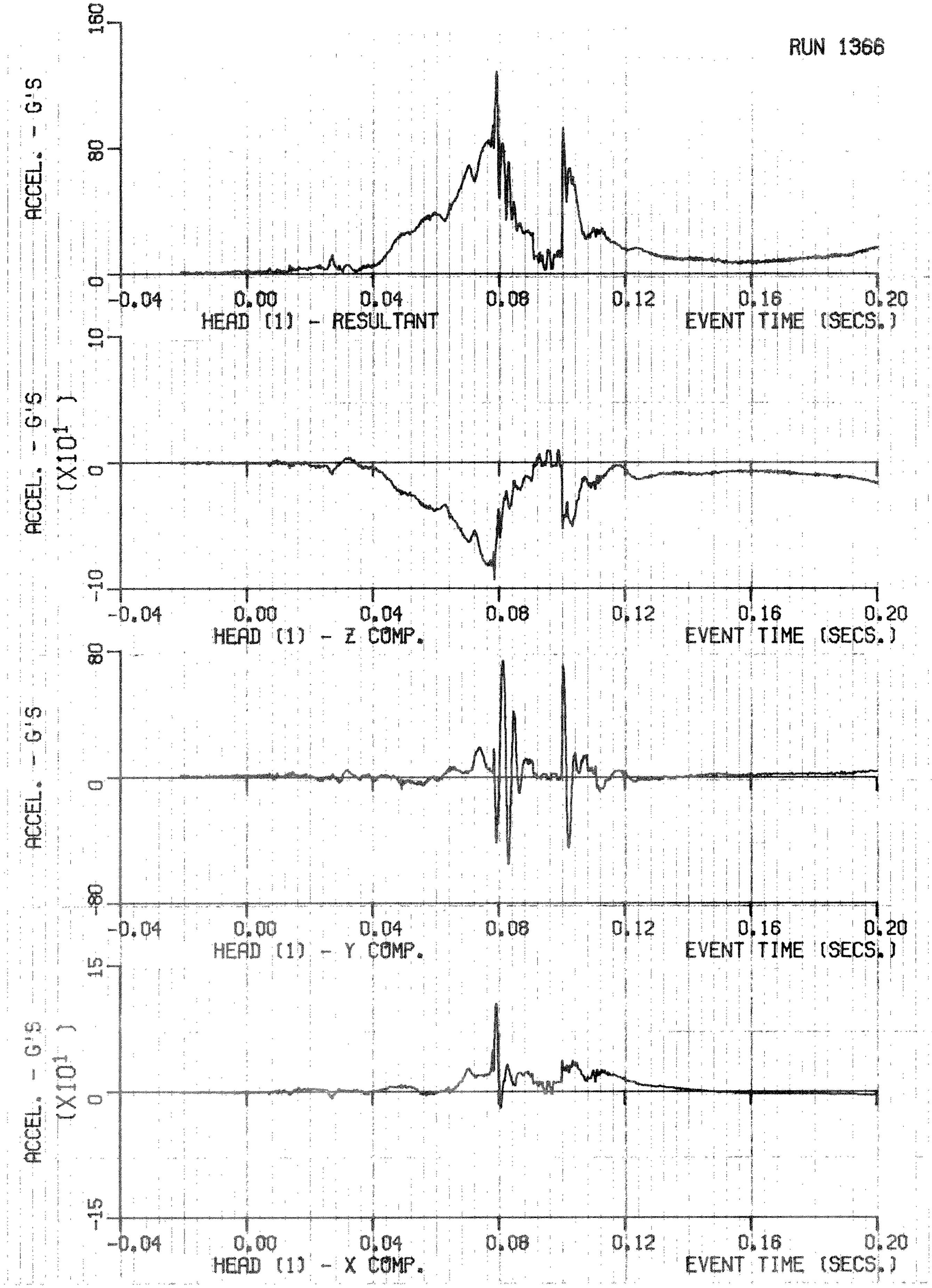
CALMAN 1 CHEST ACCELERATIONS



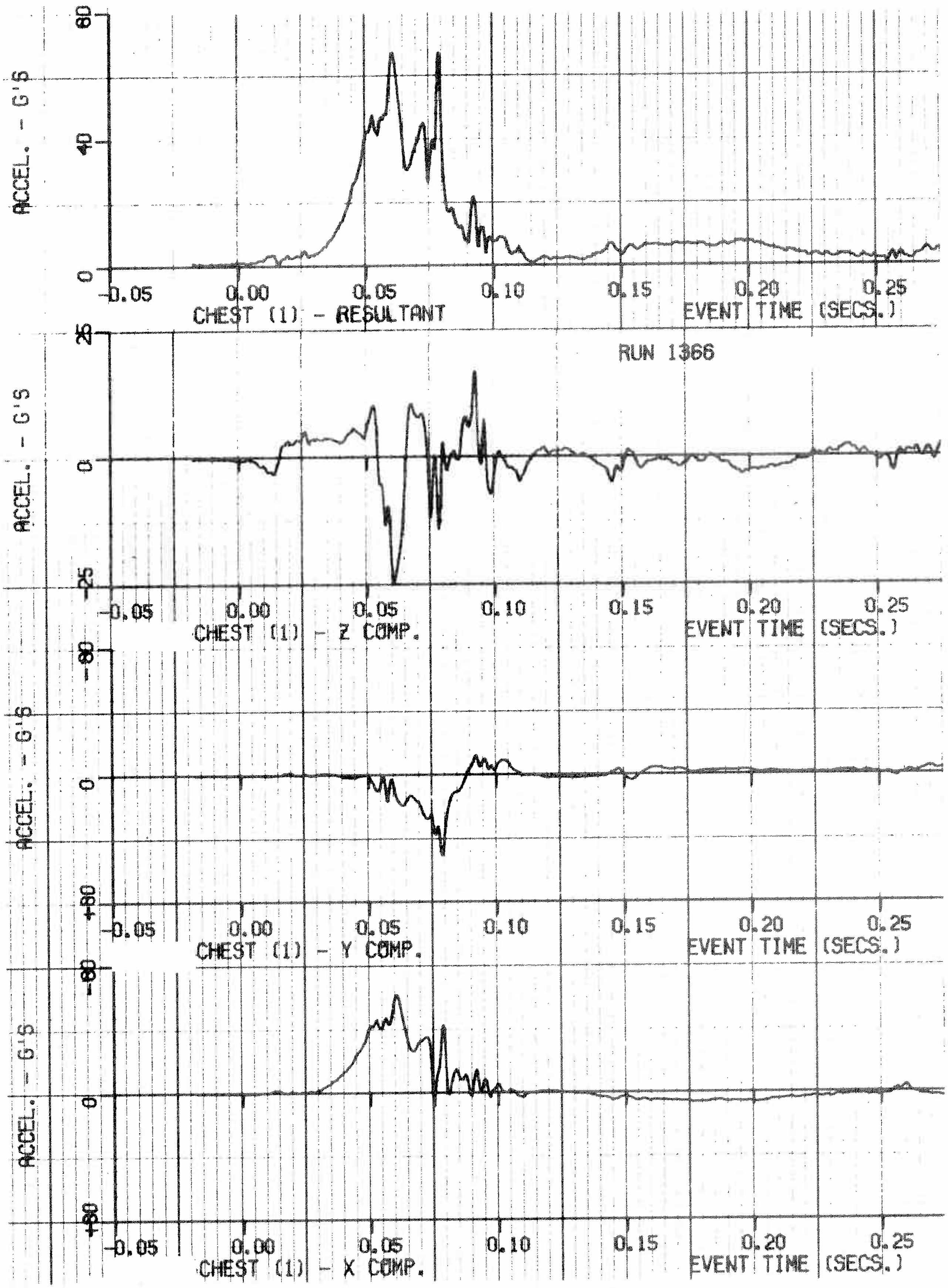
CALMAN 1 BELT LOADS



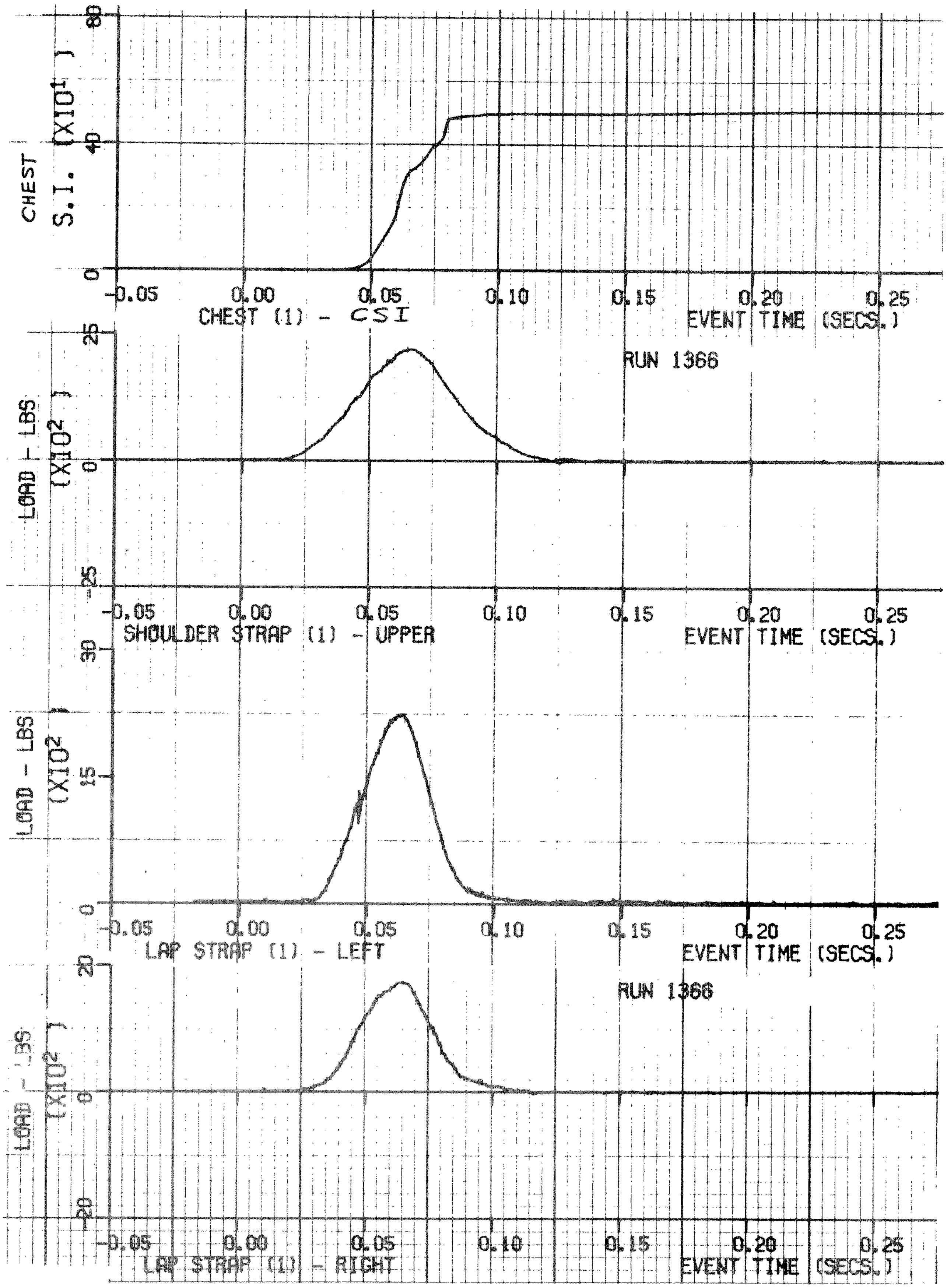
CALMAN 1 DATA AND SLED ACCELERATION



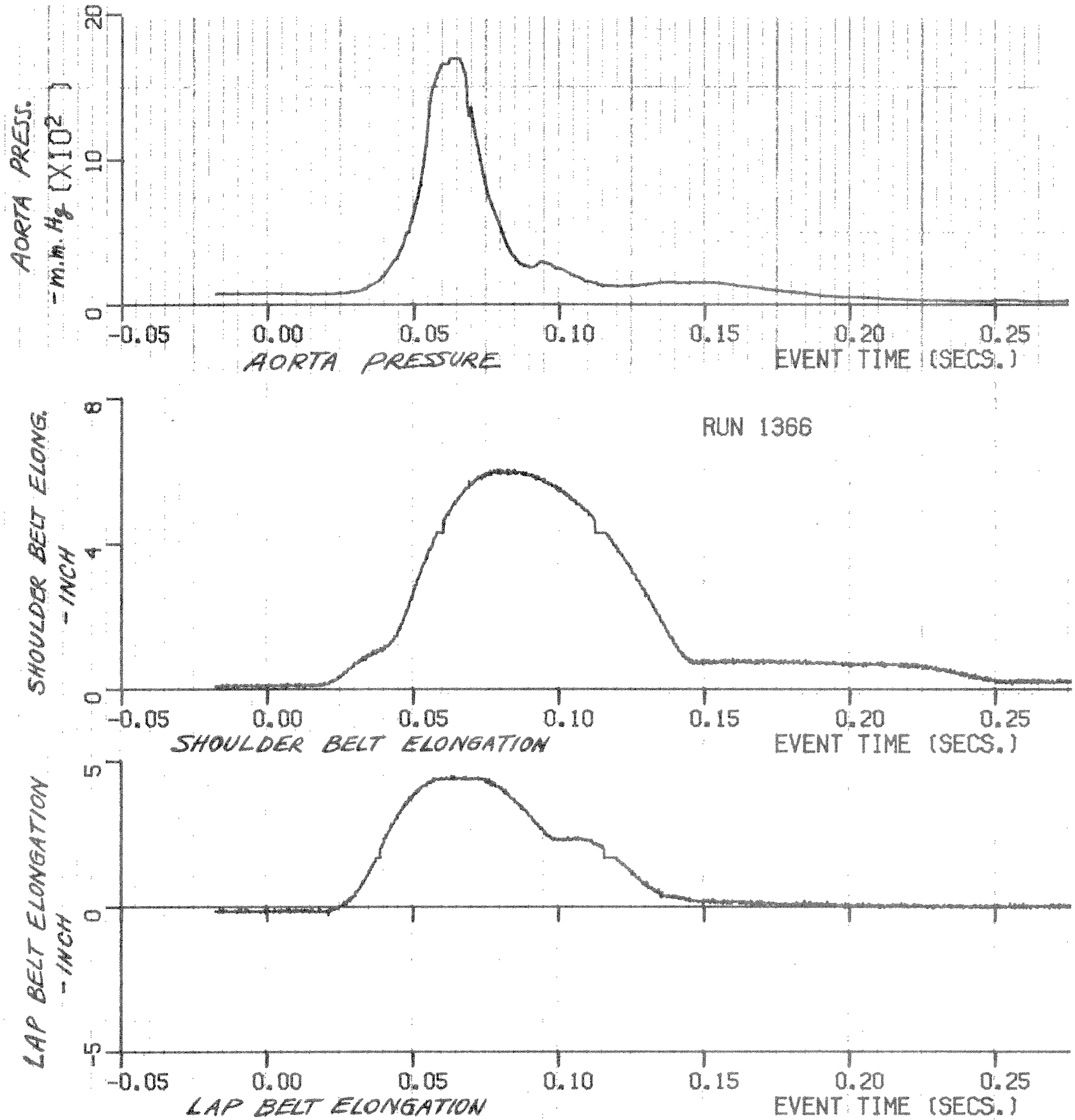
CALMAN 2 HEAD ACCELERATION



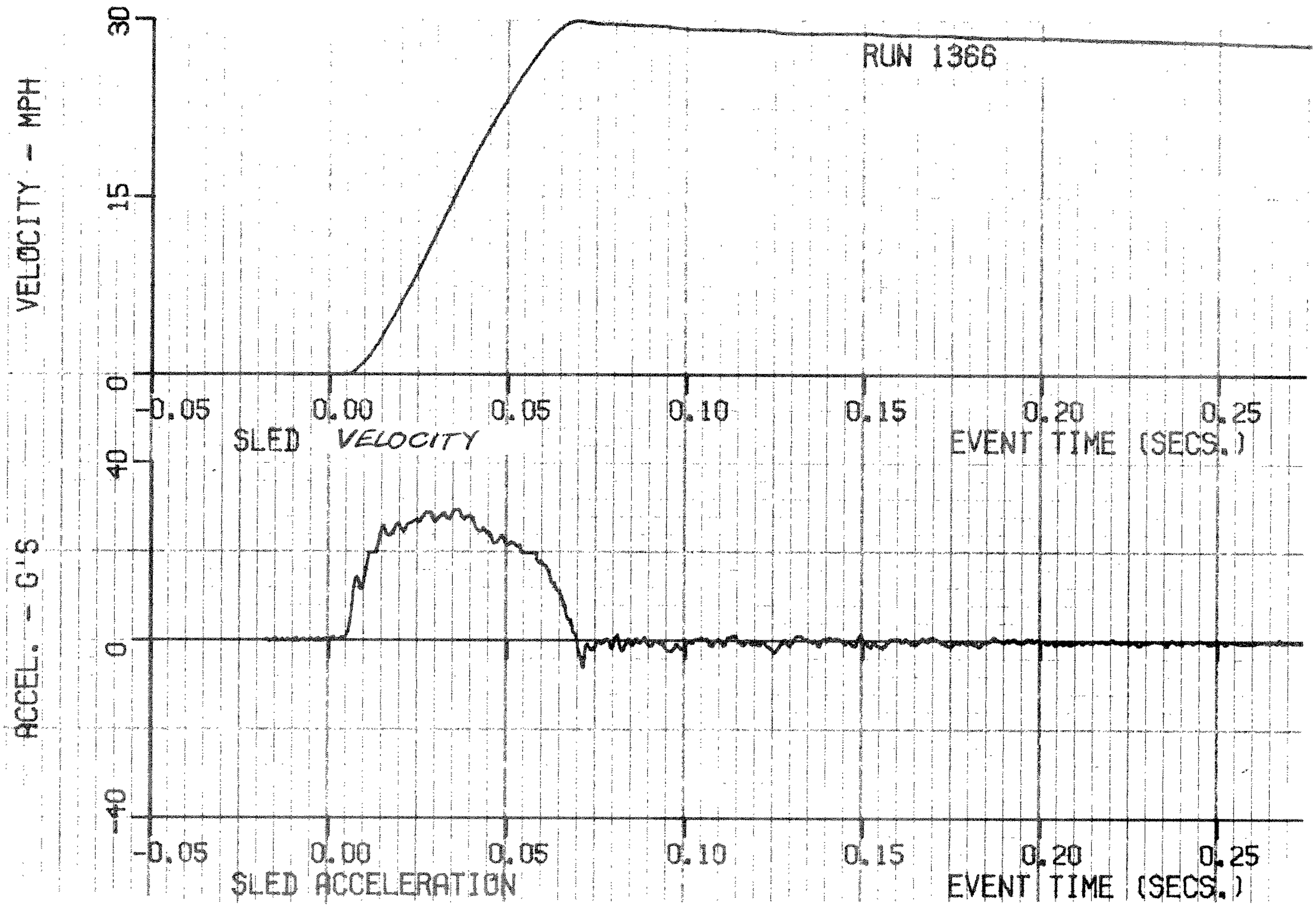
CALMAN 2 CHEST ACCELERATIONS



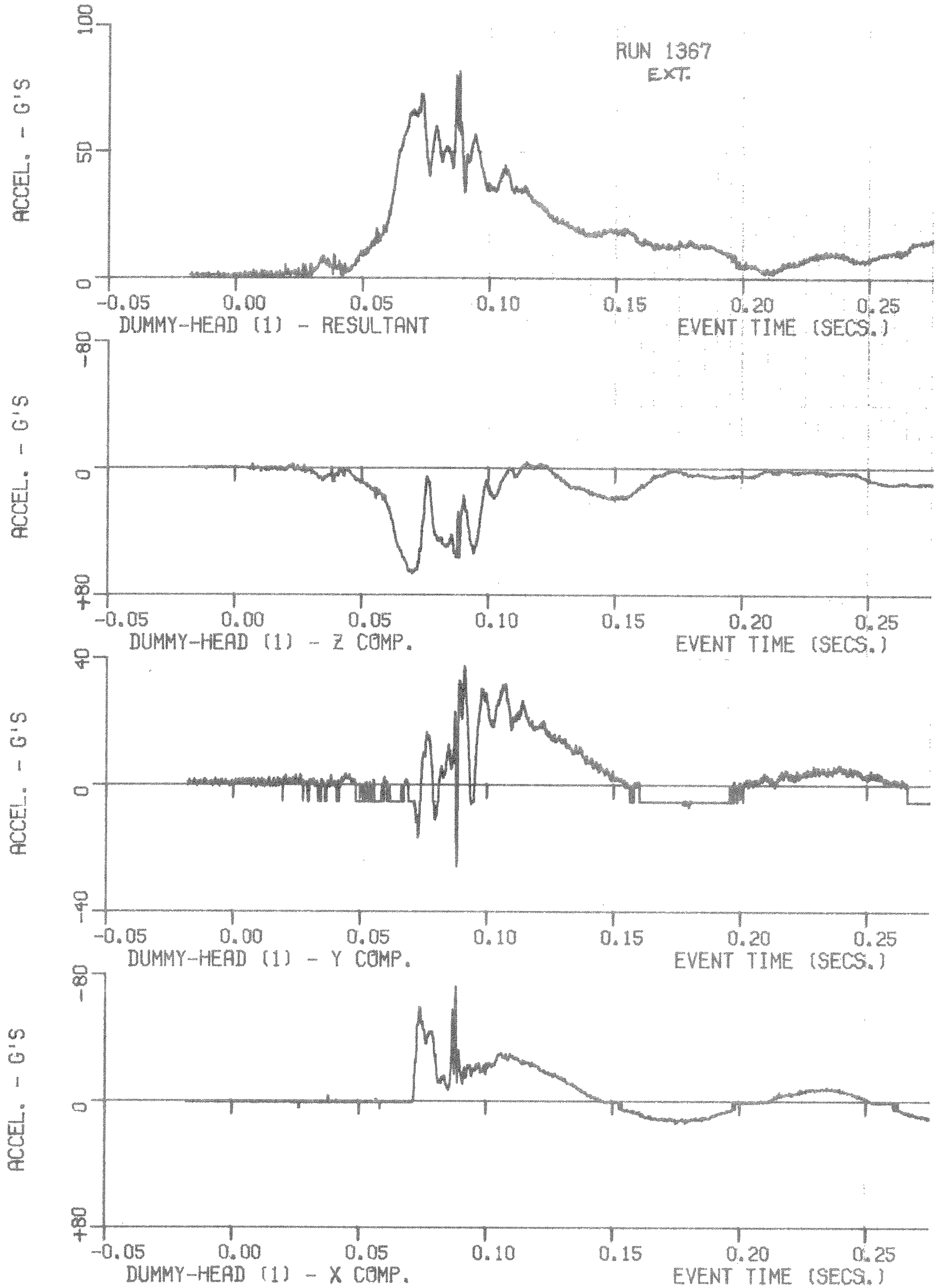
CALMAN 2 SLED DATA



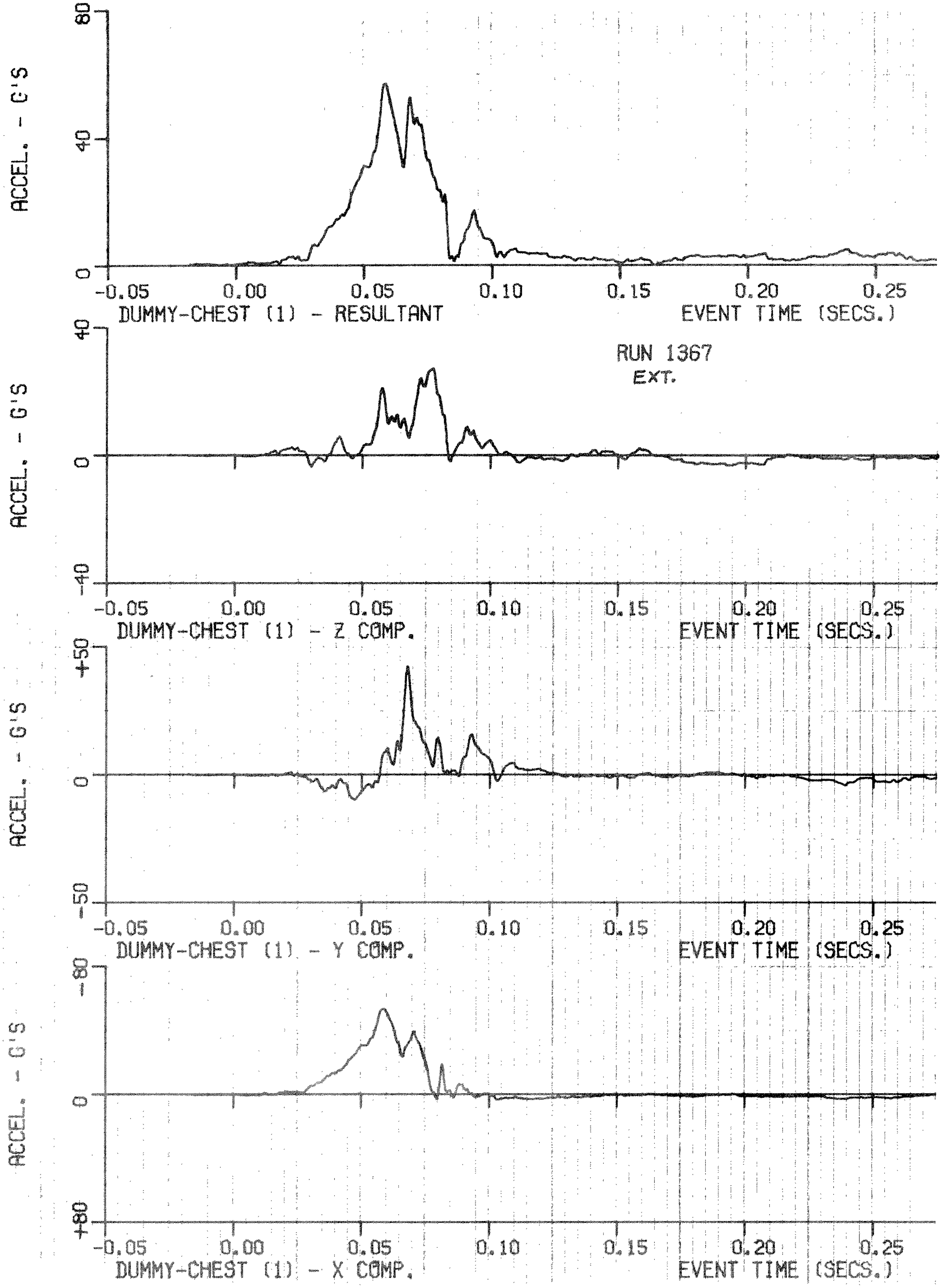
CALMAN 2 BELT ELONGATIONS
AND ARTERIAL PRESSURE



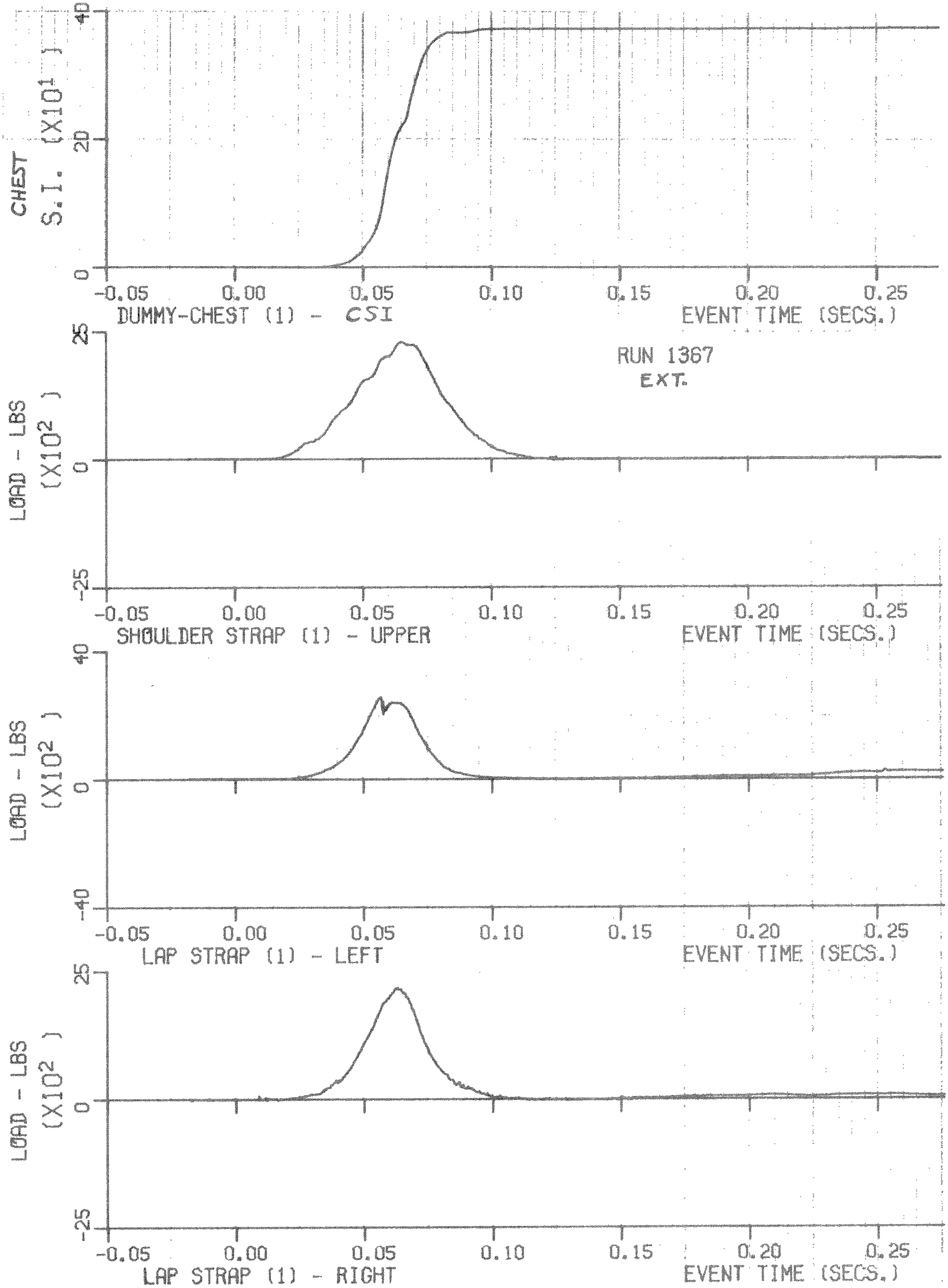
CALMAN 2 SLED DATA



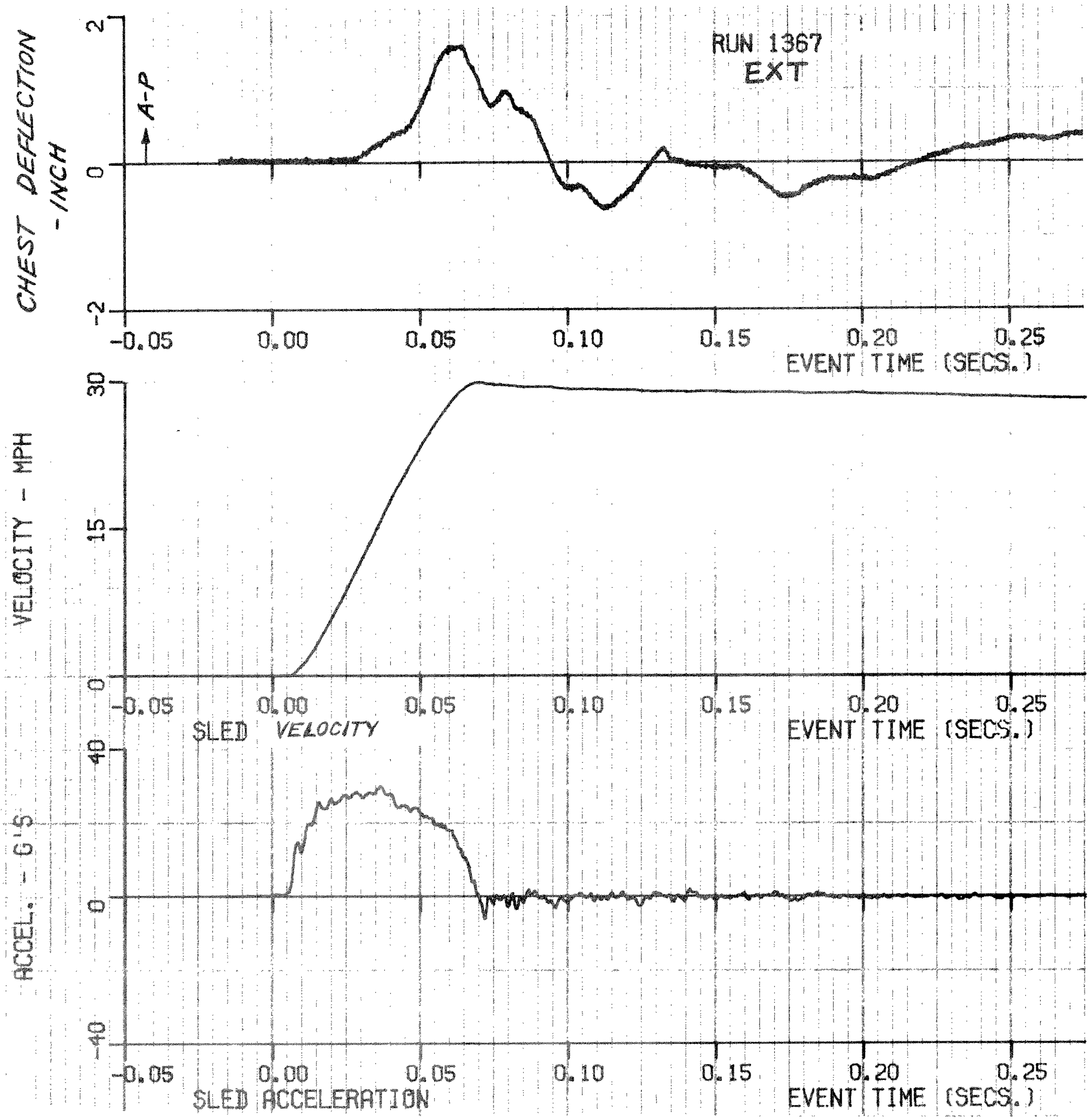
DUMMY HEAD ACCELERATIONS FROM EXTERNAL INSTRUMENTATION



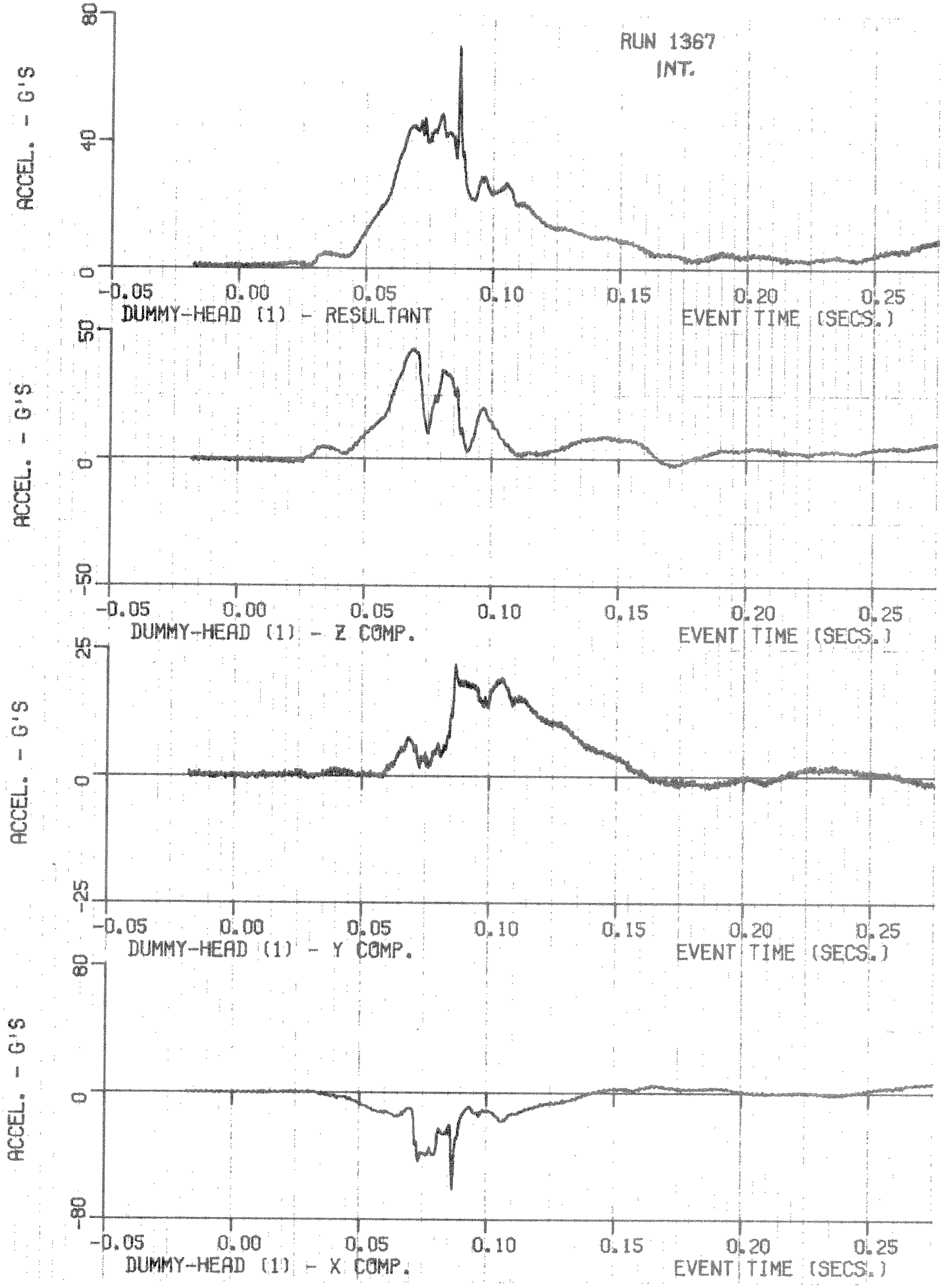
DUMMY CHEST ACCELERATIONS FROM EXTERNAL INSTRUMENTATION



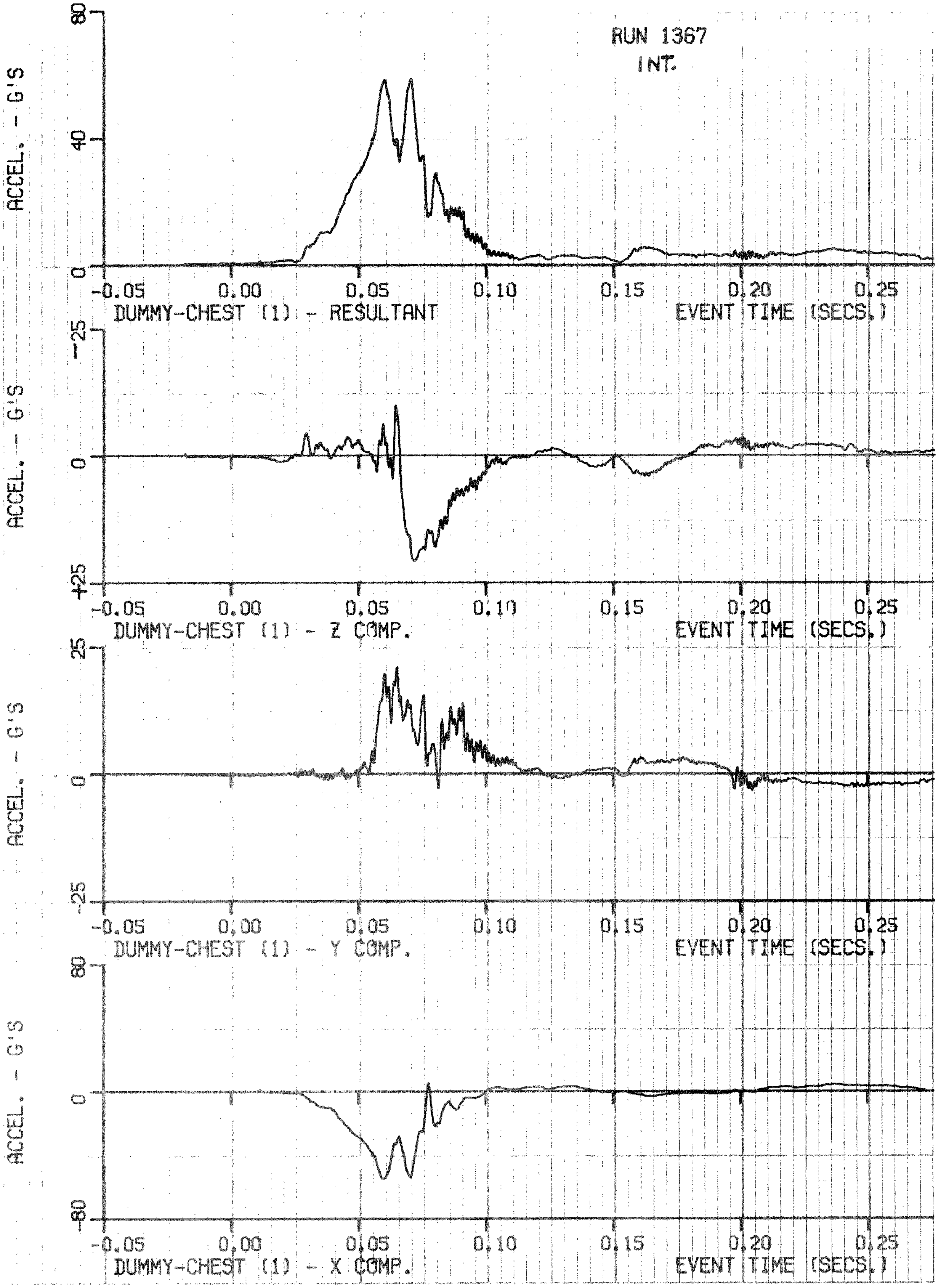
DUMMY BELT LOADS



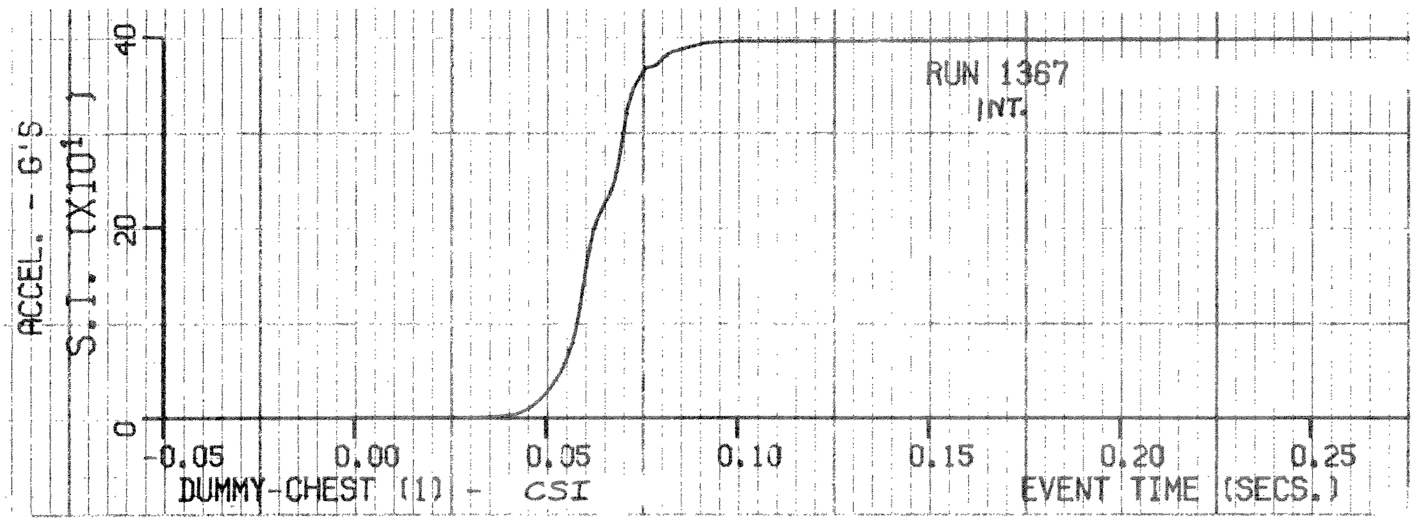
DUMMY CHEST DEFLECTION AND SLED DATA

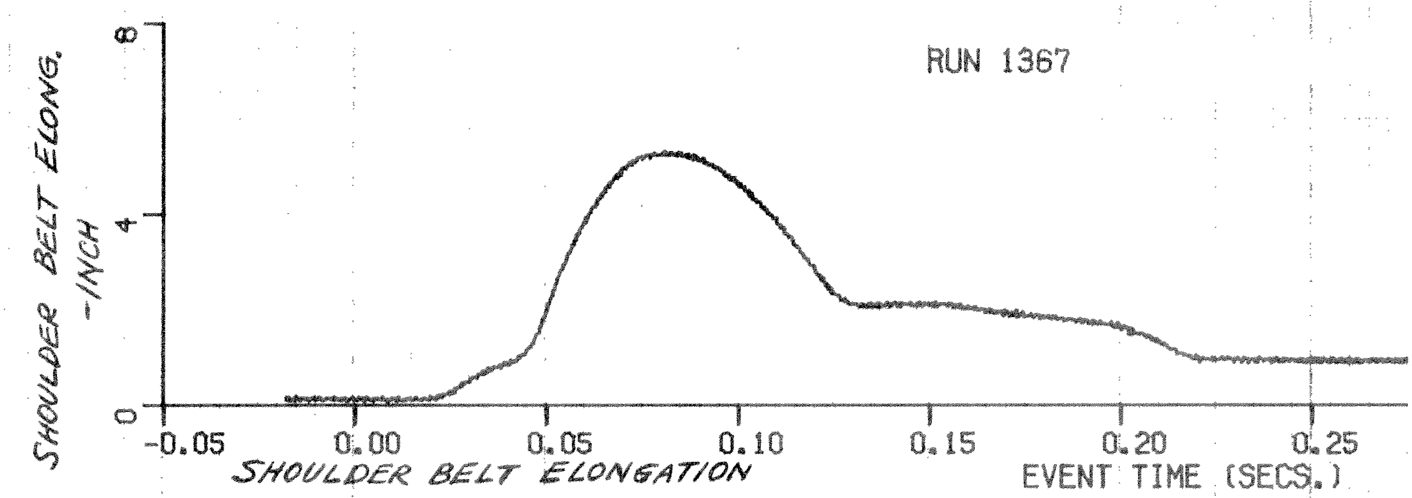


DUMMY HEAD ACCELERATIONS FROM INTERNAL INSTRUMENTATION

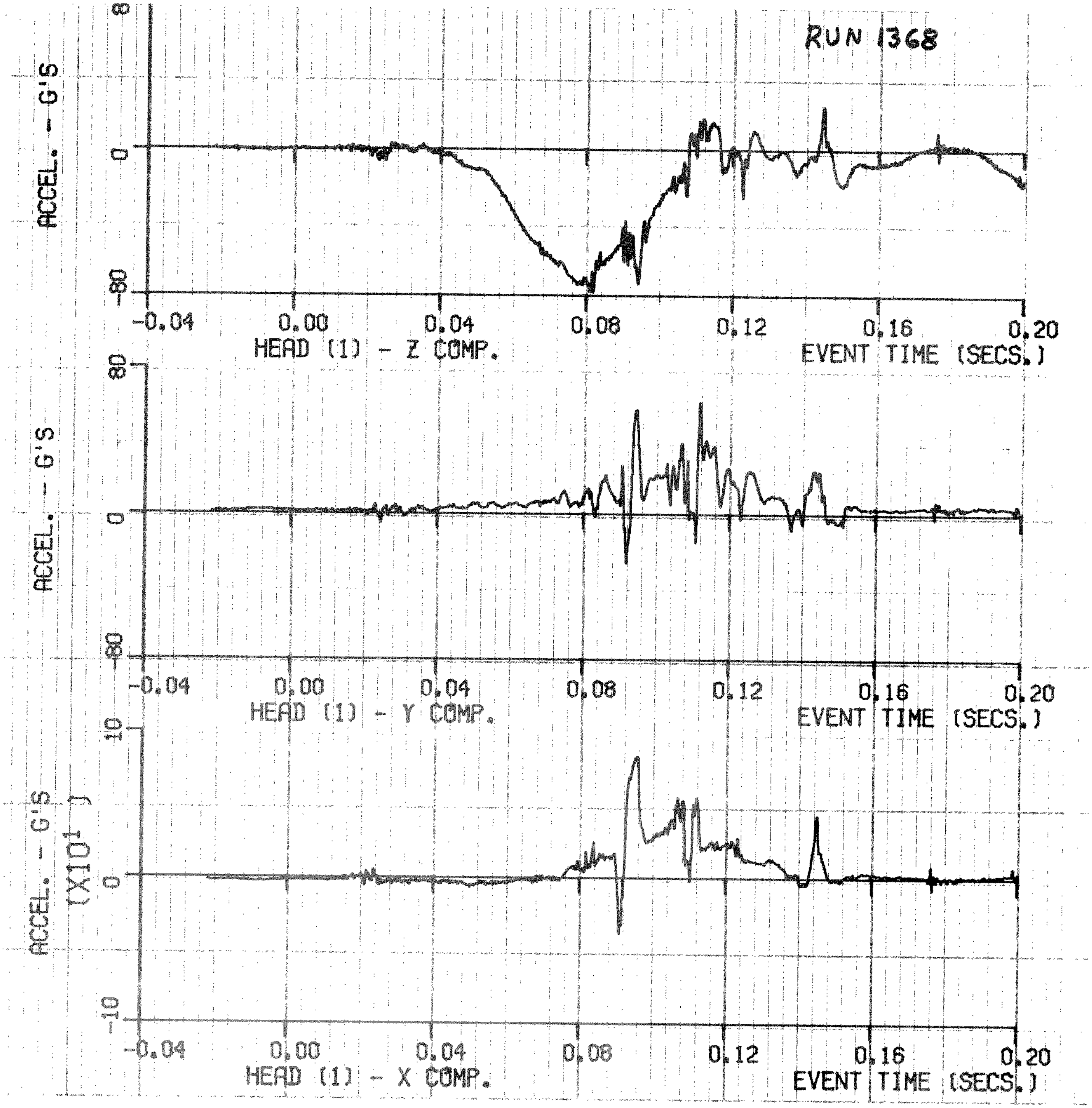


DUMMY CHEST ACCELERATIONS FROM INTERNAL INSTRUMENTATION

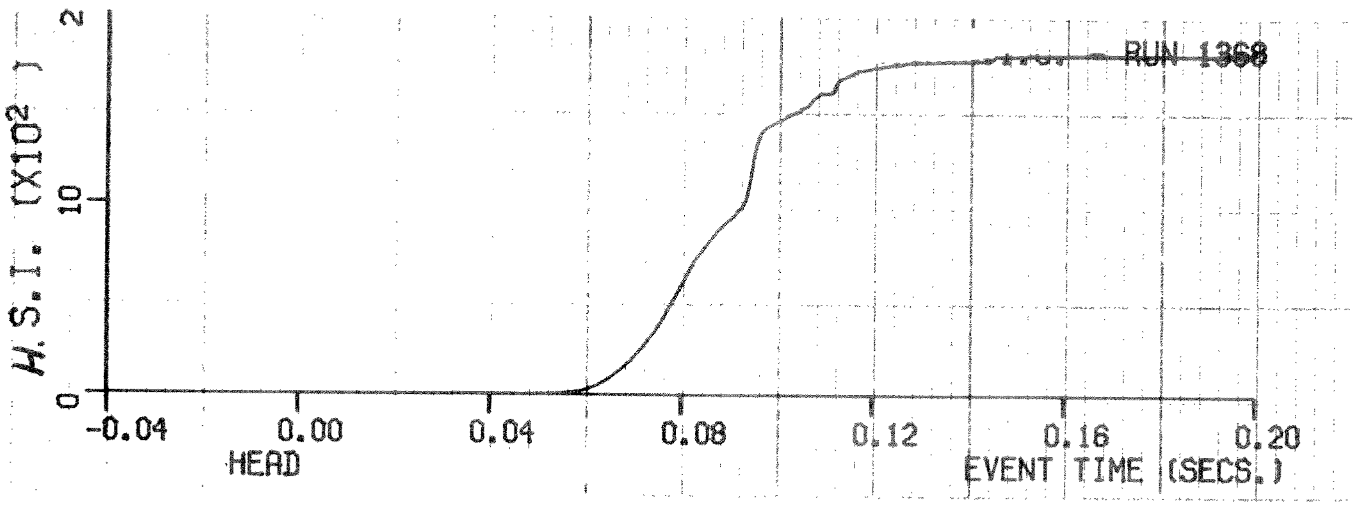


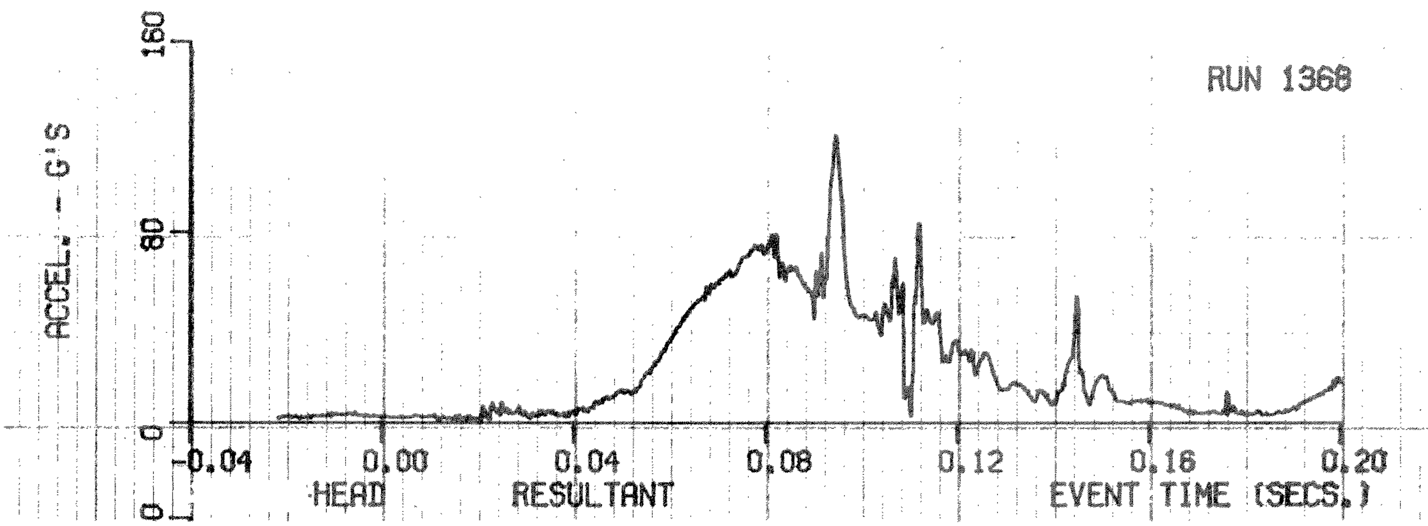


DUMMY CHEST AND SHOULDER BELT ELONGATION DATA

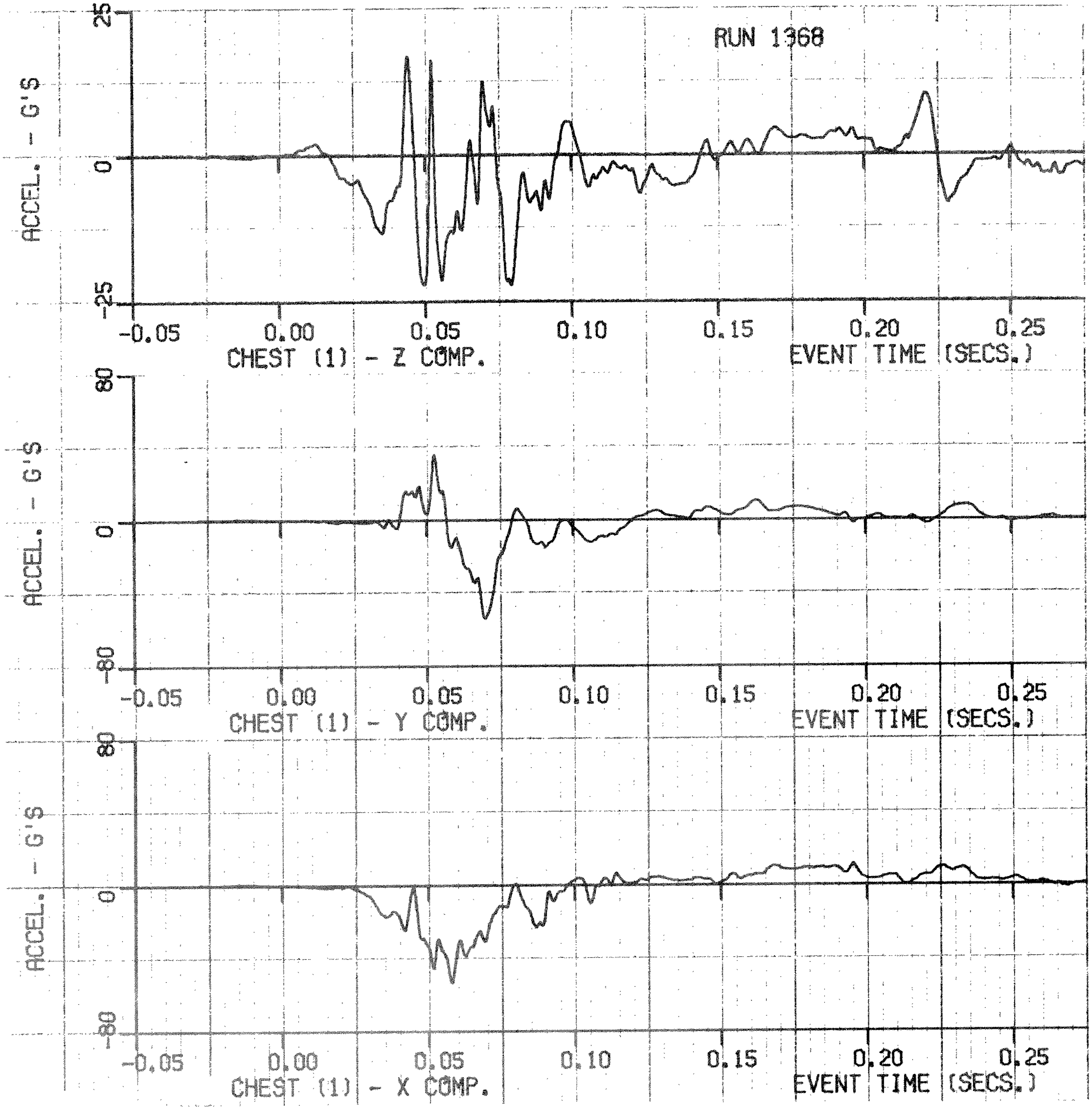


CALMAN 3 HEAD ACCELERATION

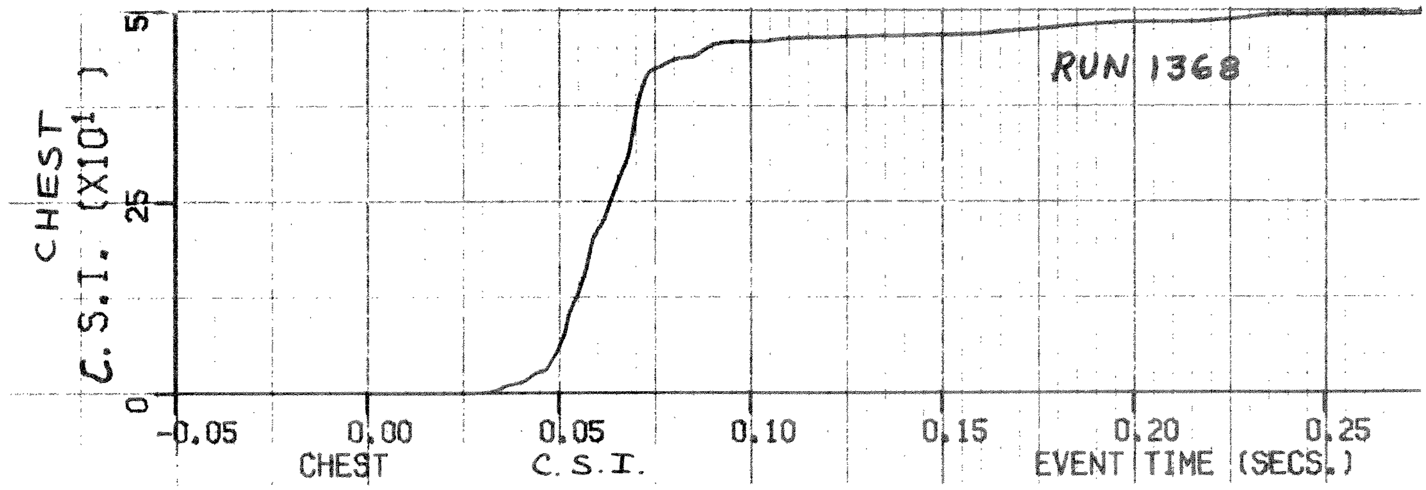


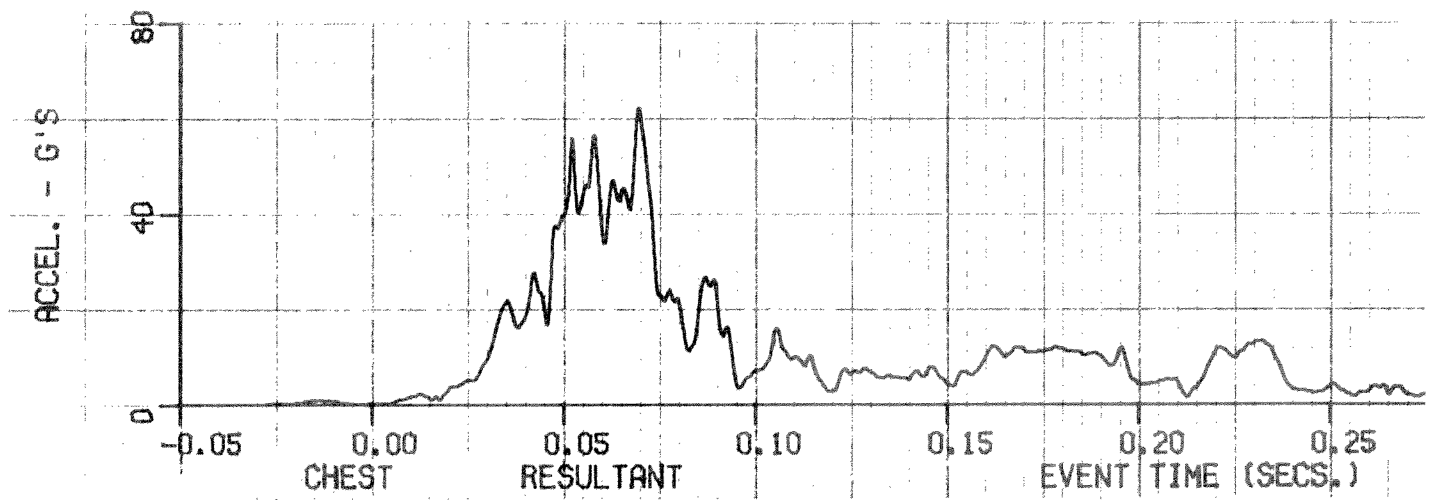


CALMAN 3 HEAD RESULTANT & HSI

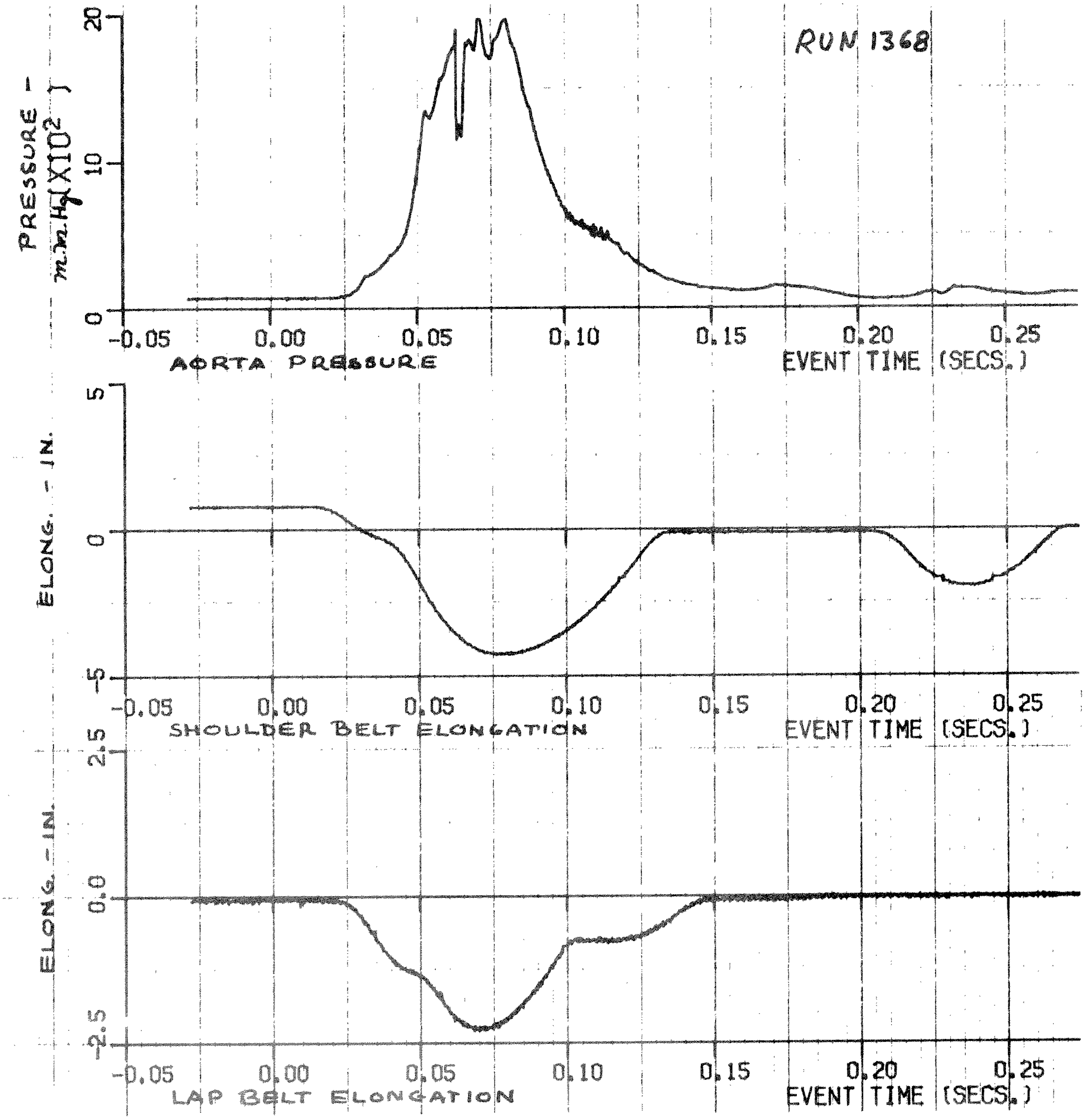


CALMAN 3 CHEST ACCELERATION

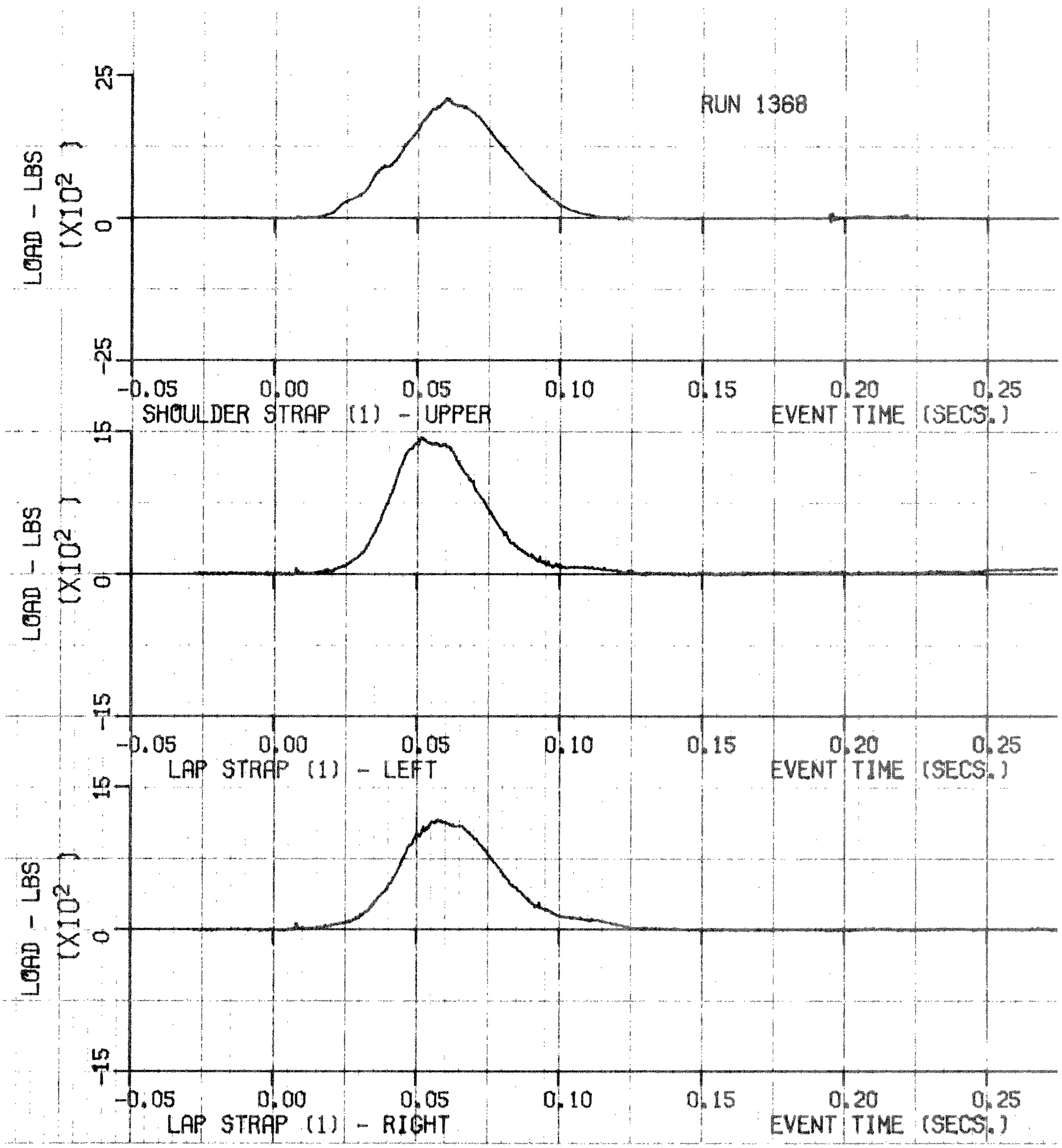




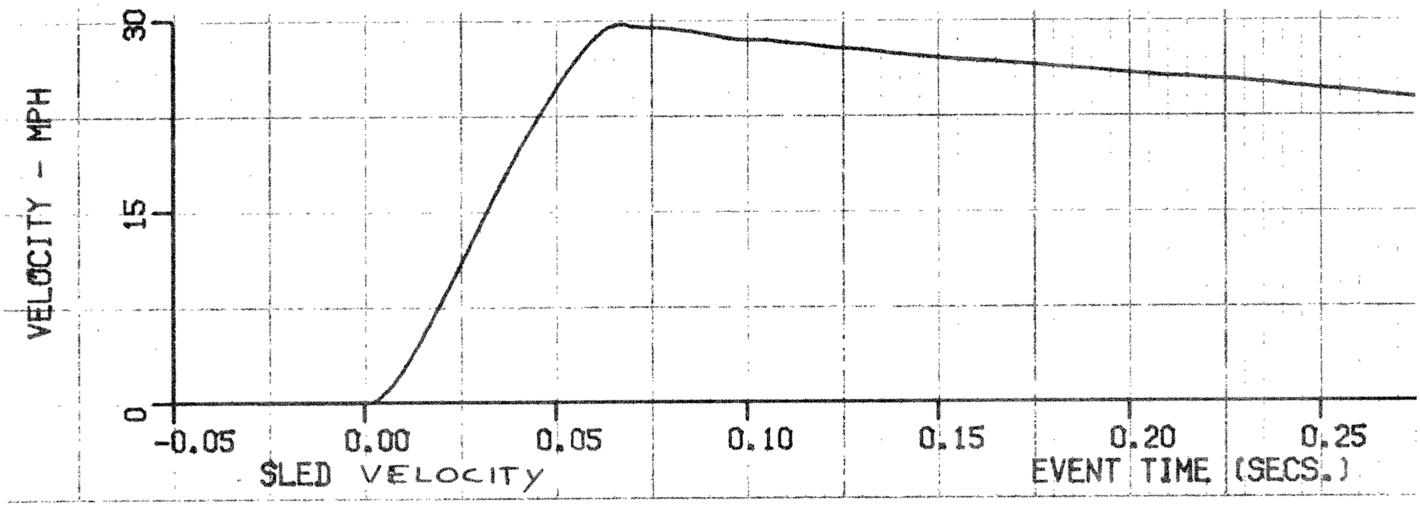
CALMAN 3 CHEST RESULTANT & CSI

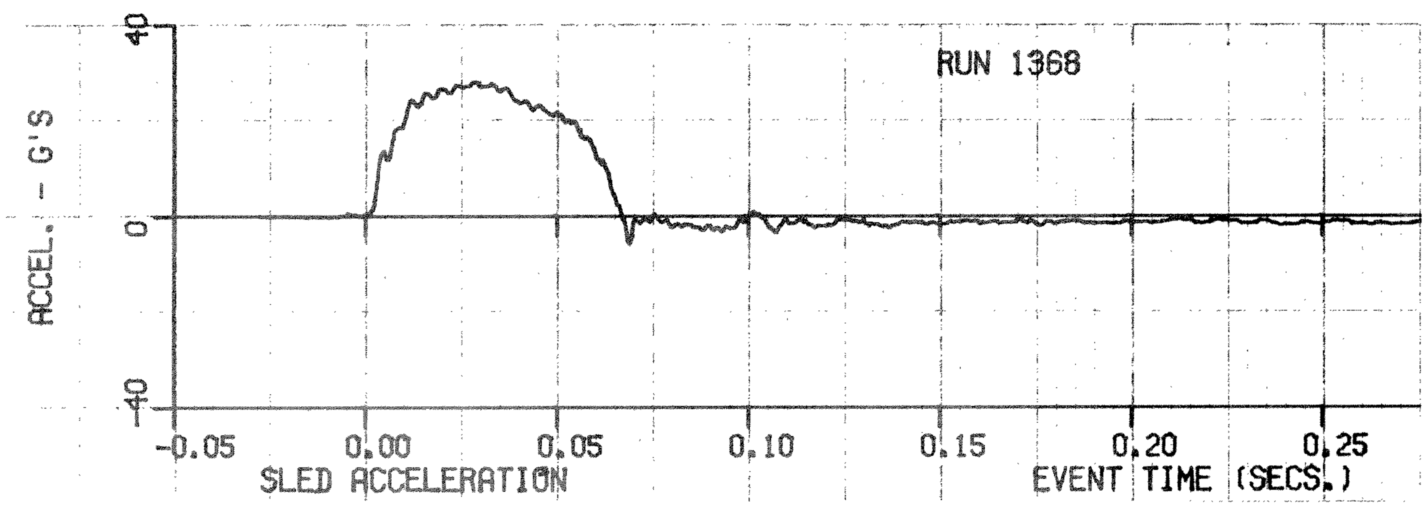


CALMAN 3 AORTA PRESSURE & BELT ELONGATIONS

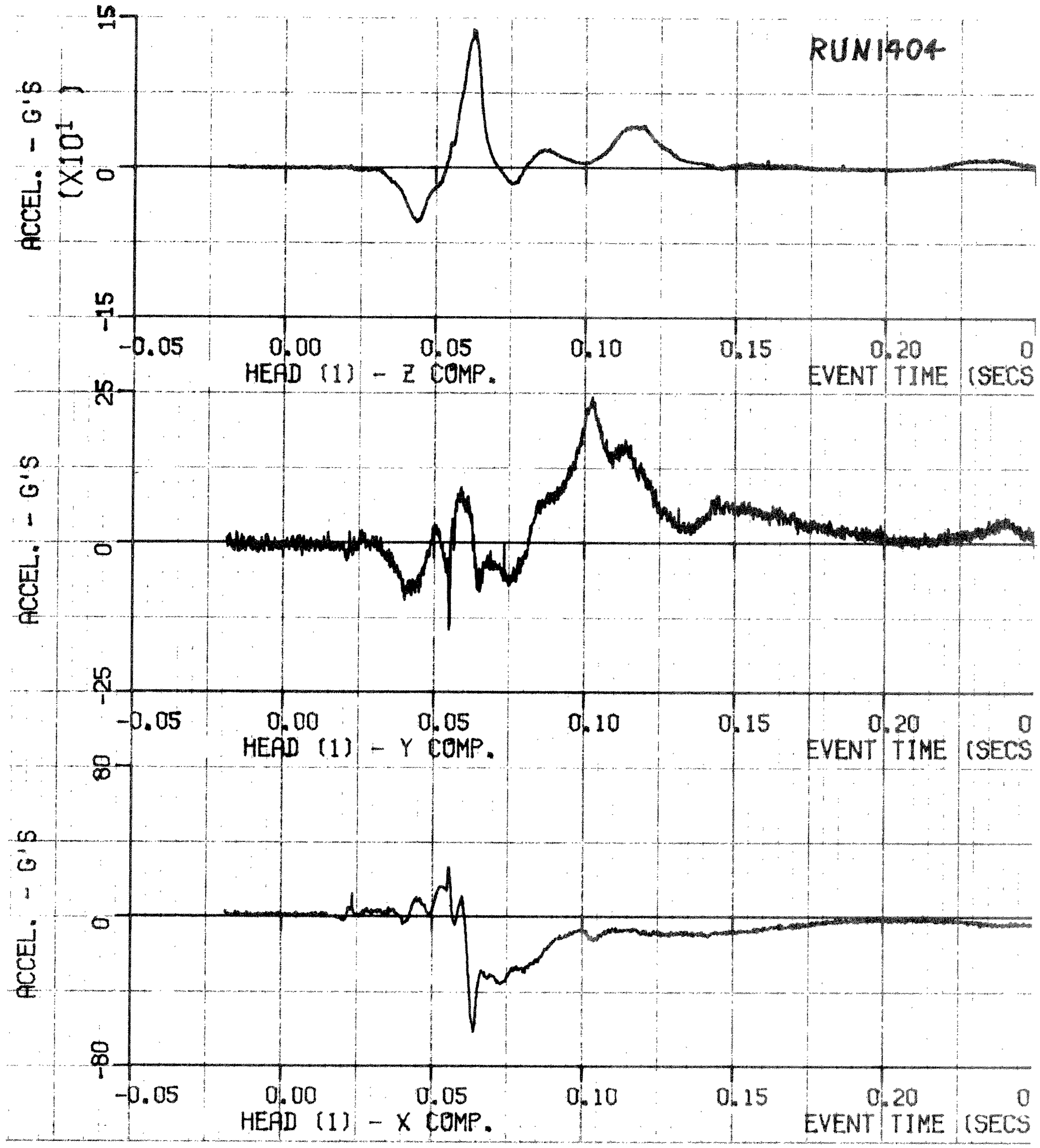


CALMAN 3 BELT LOADS

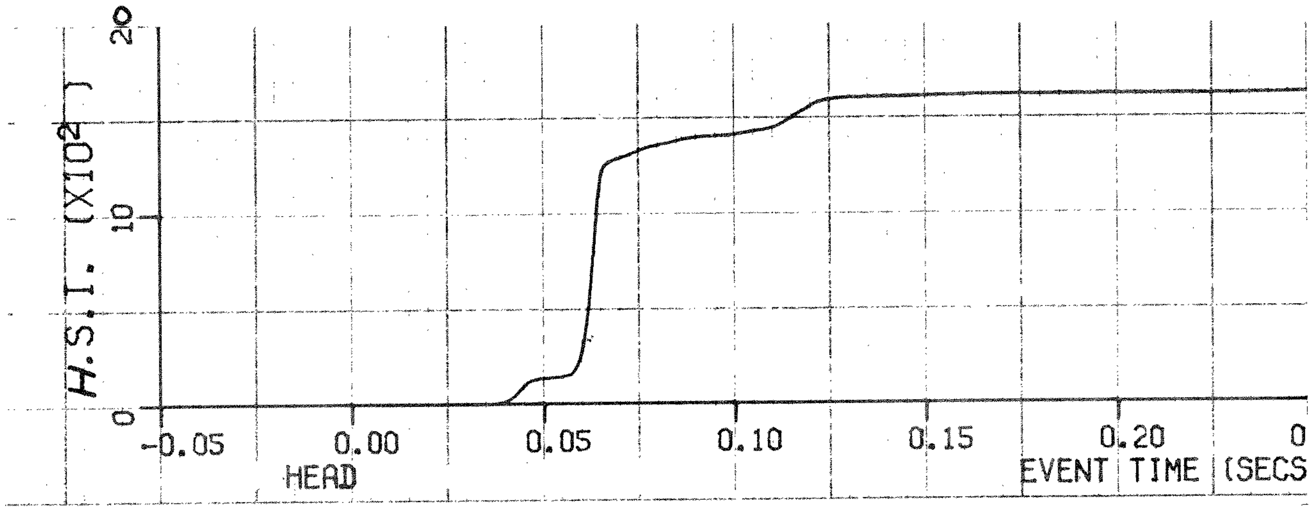


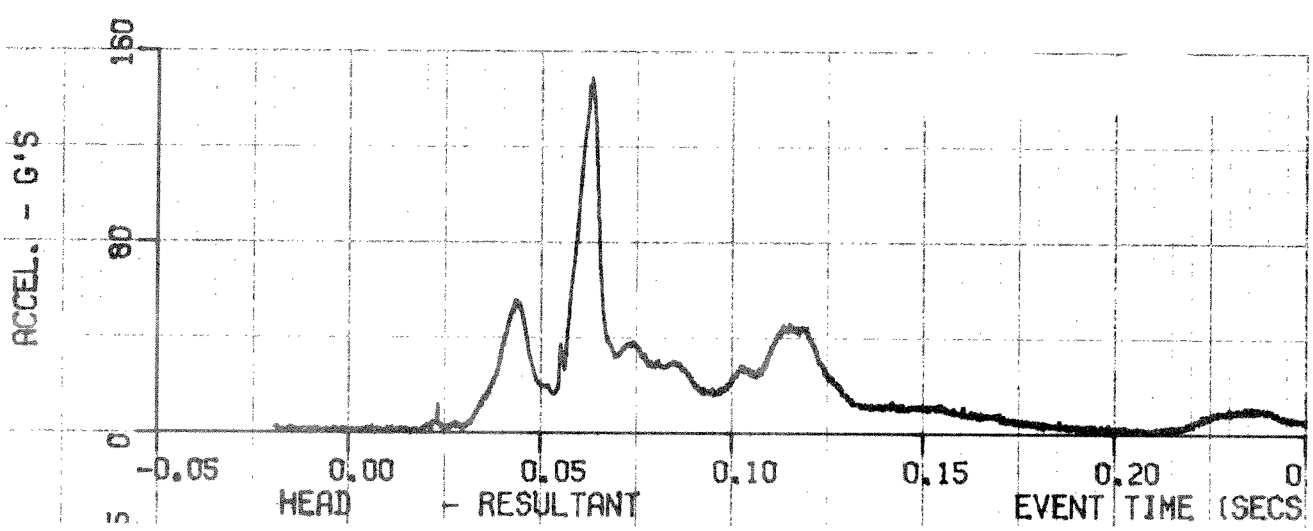


CALMAN 3 SLED DATA

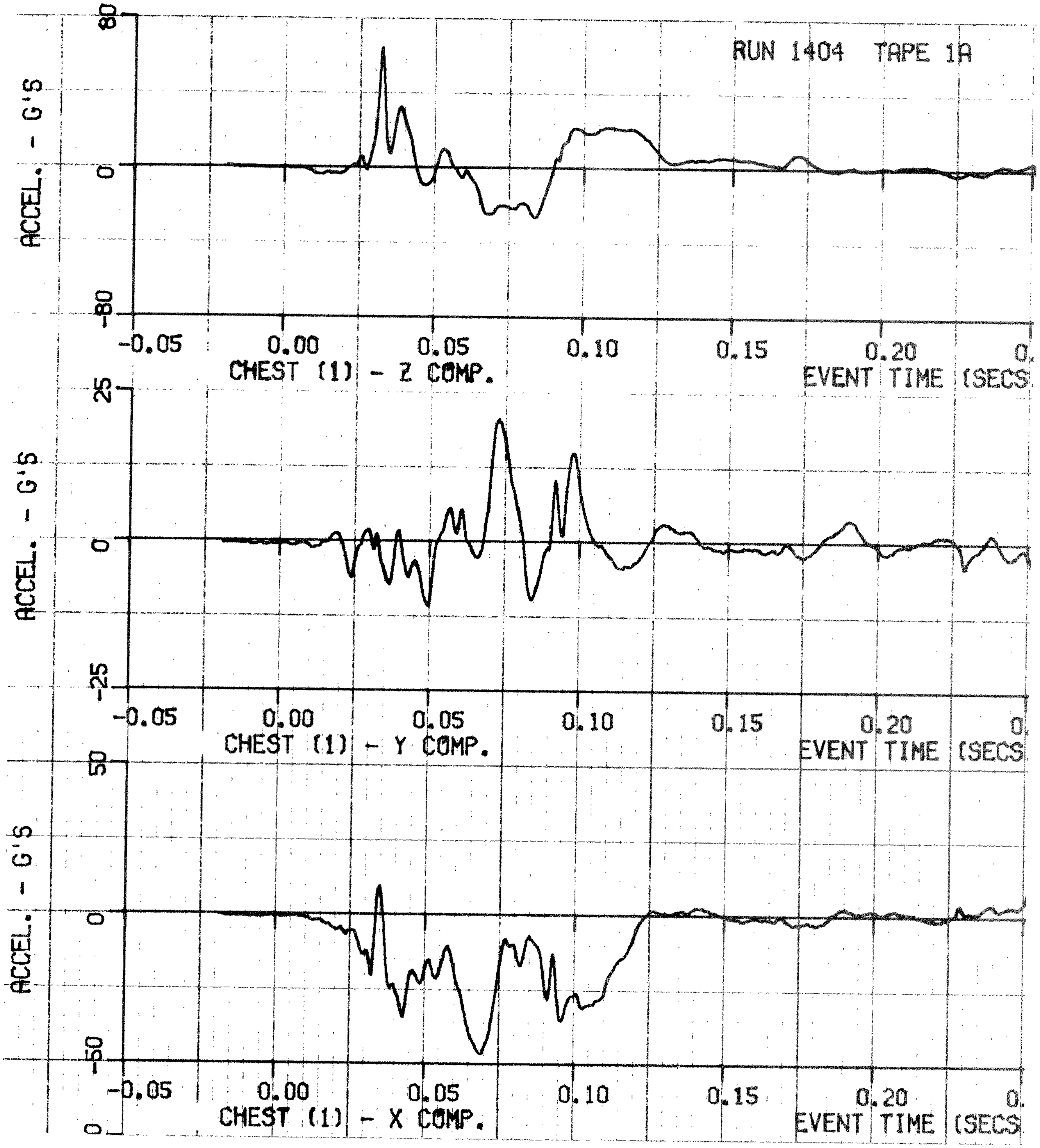


CALMAN 4 HEAD

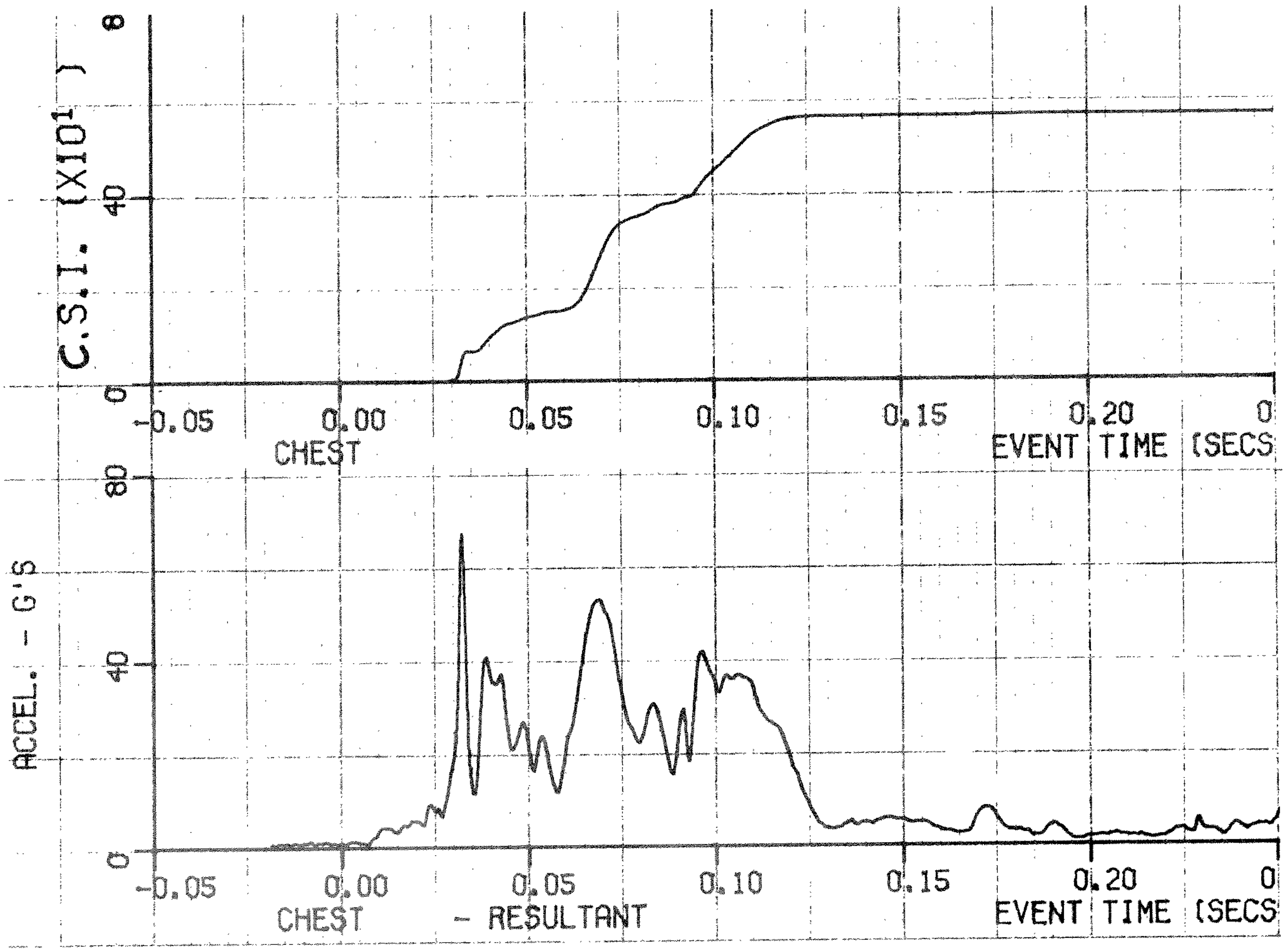




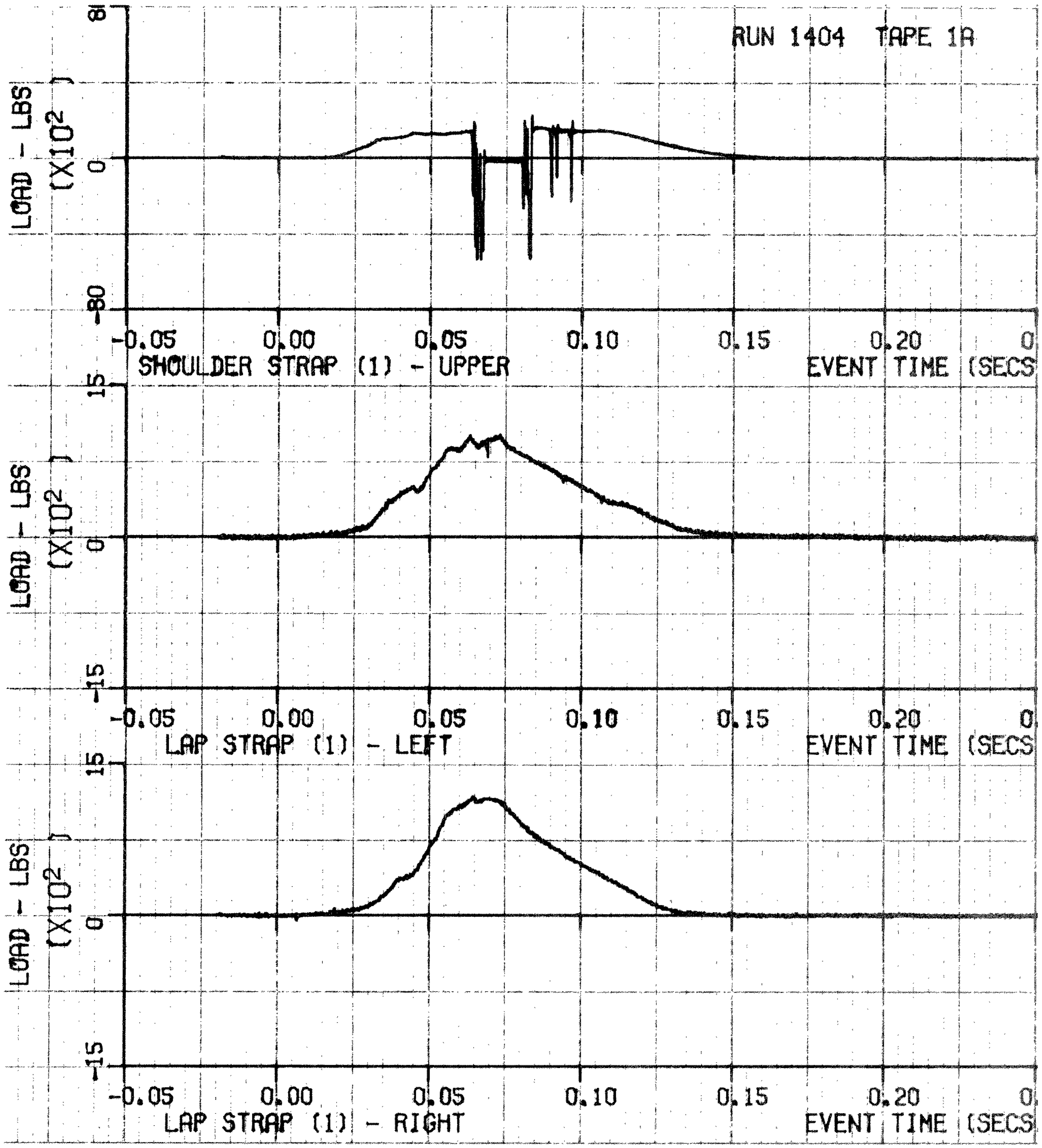
CALMAN 4 HEAD



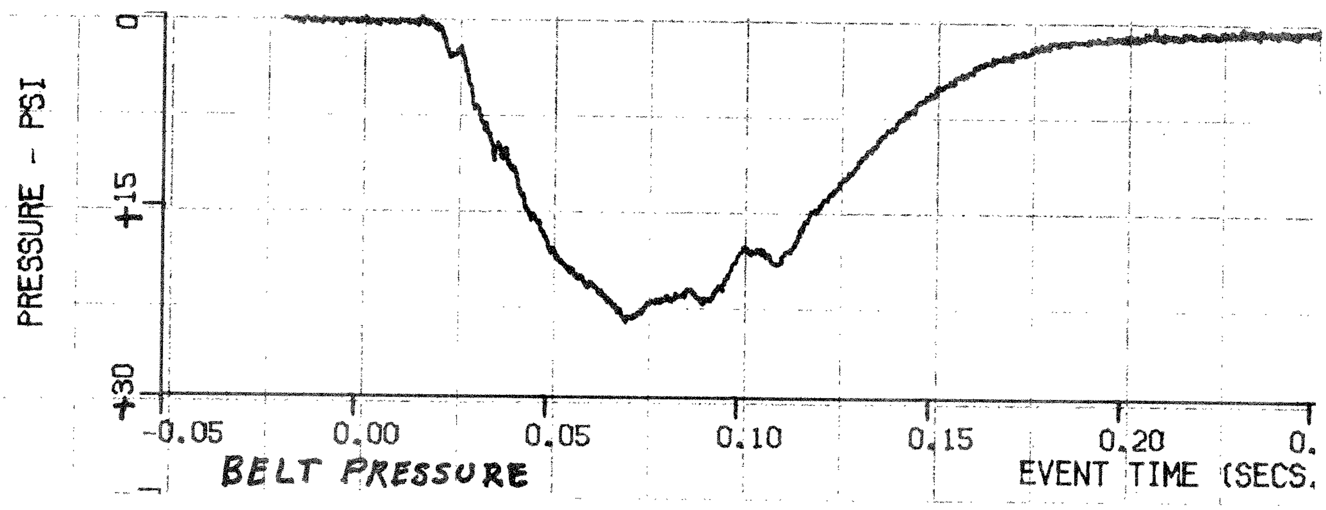
CALMAN 4 CHEST

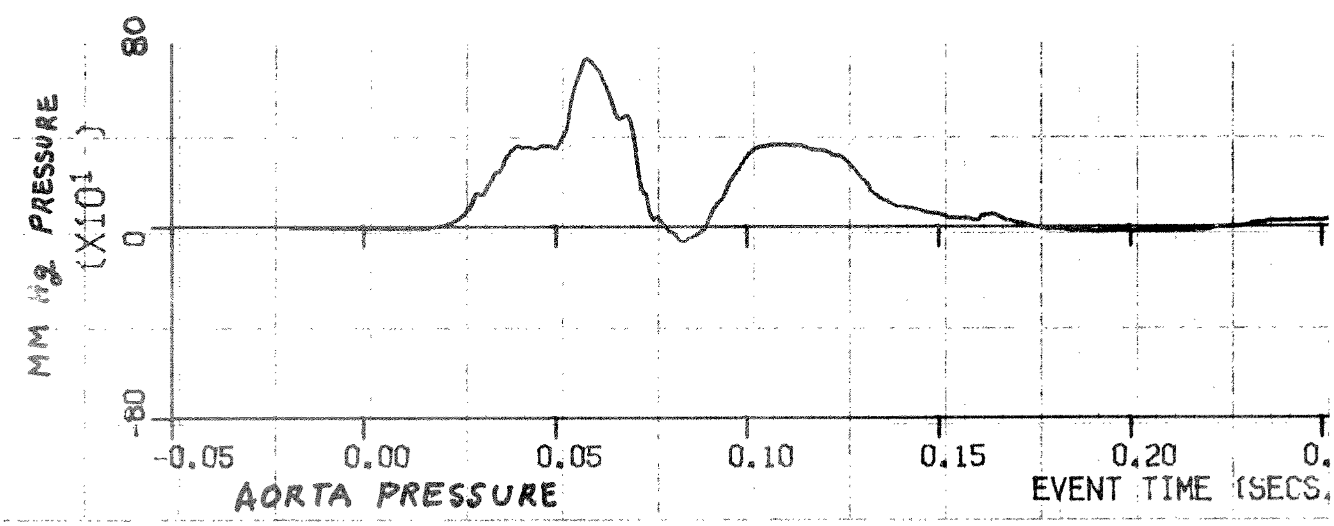


CALMAN 4 CHEST

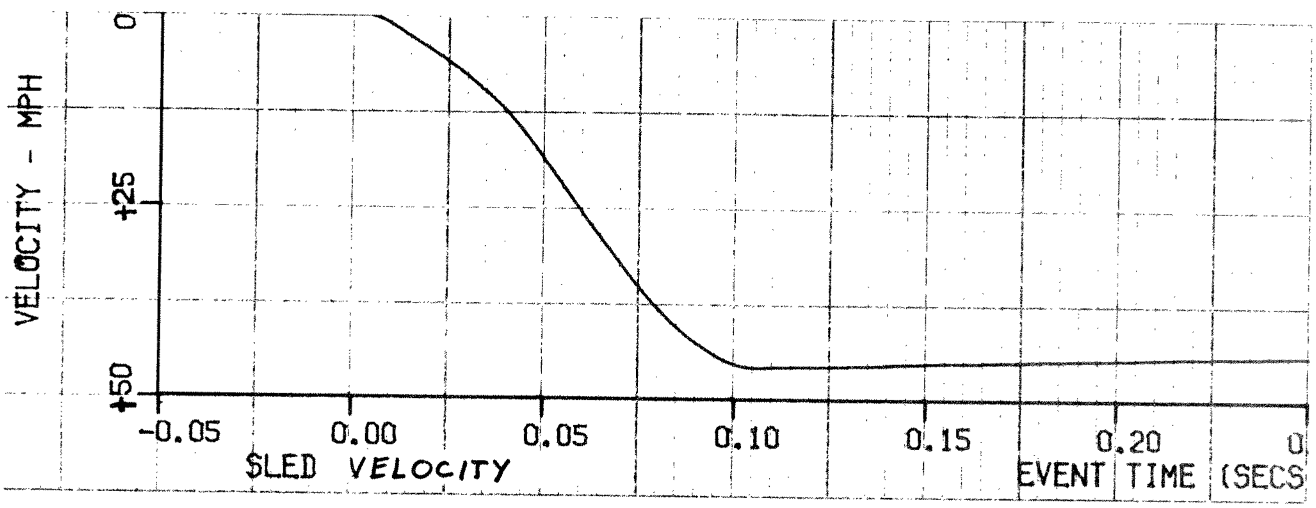


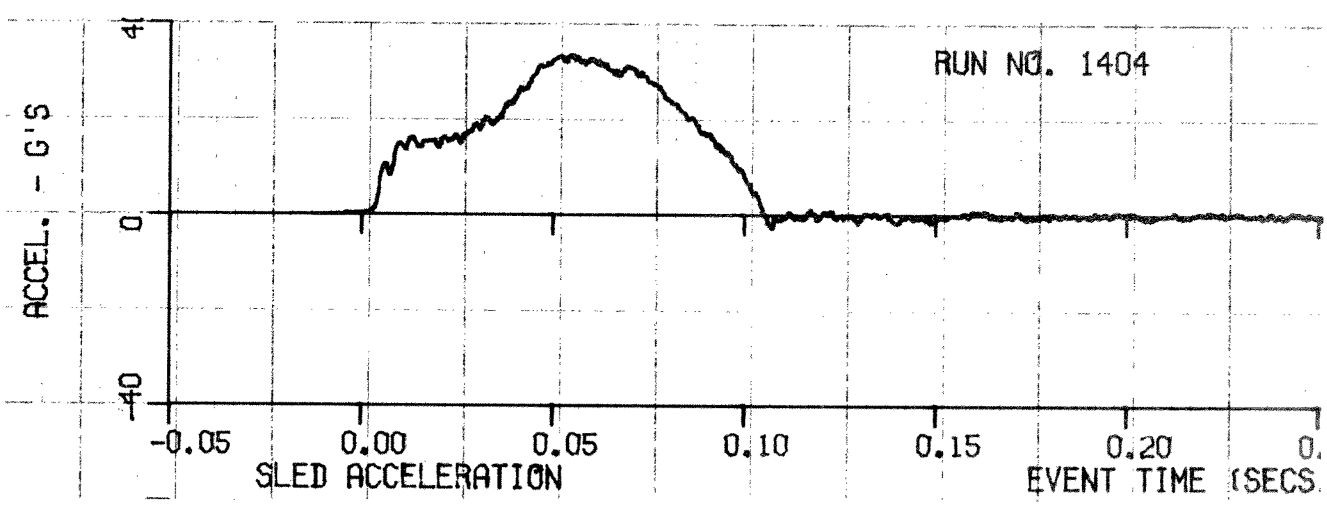
CALMAN 4 BELT LOADS



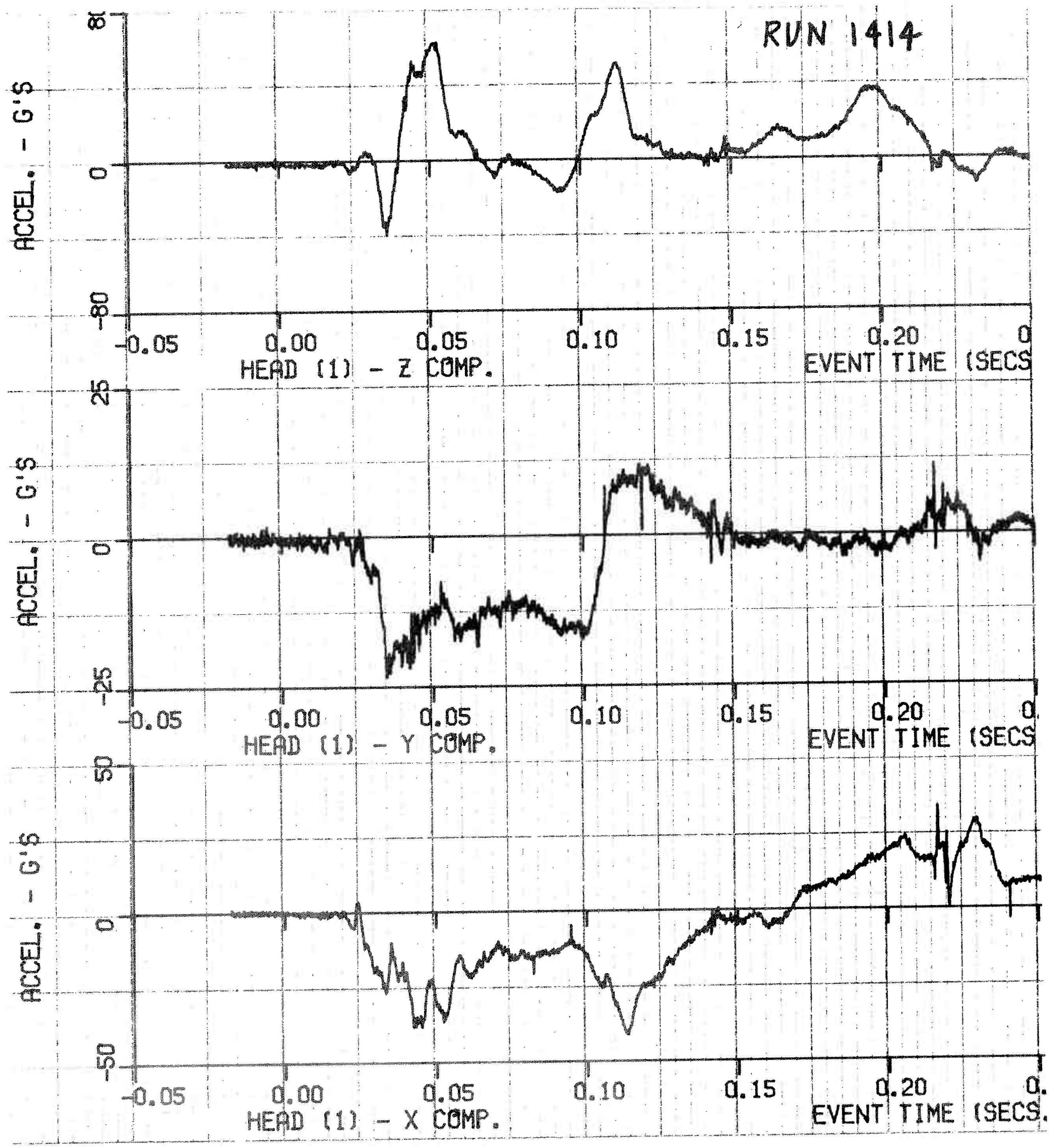


CALMAN 4 AORTA PRESSURE AND BELT PRESSURE

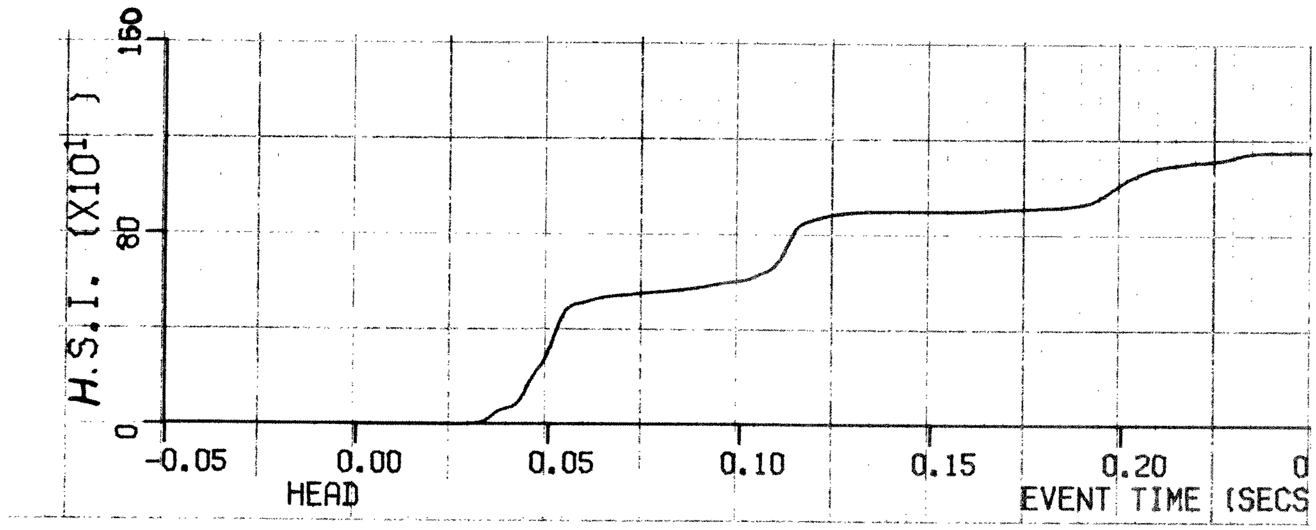


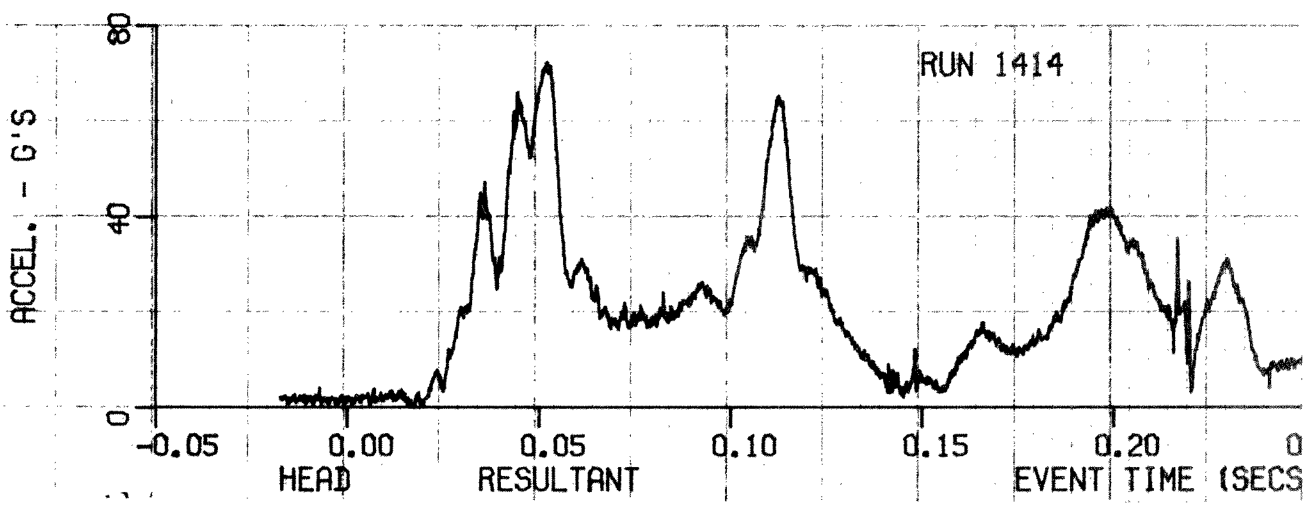


CALMAN 4 SLED DATA

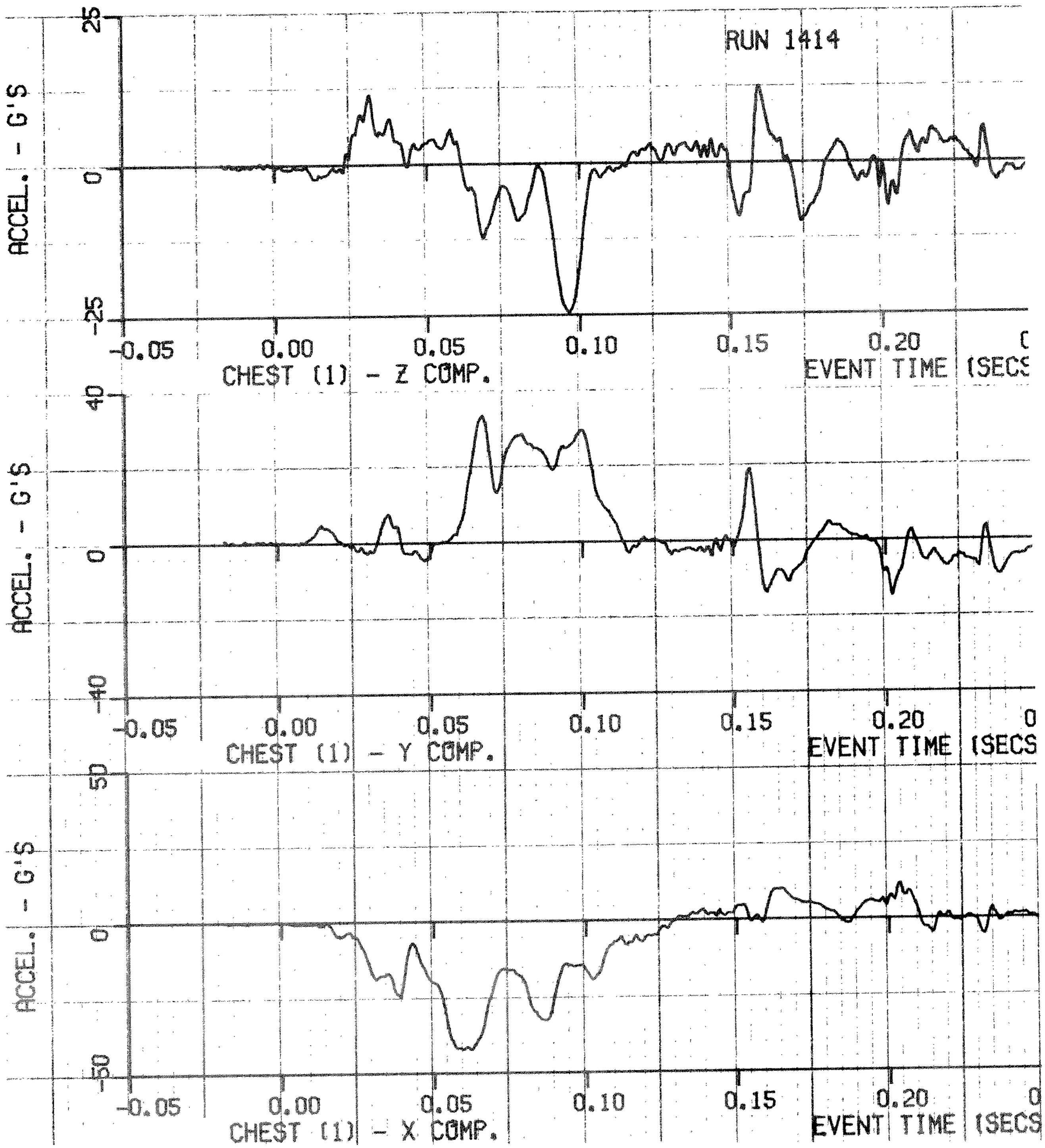


CALMAN 5 HEAD ACCELERATIONS

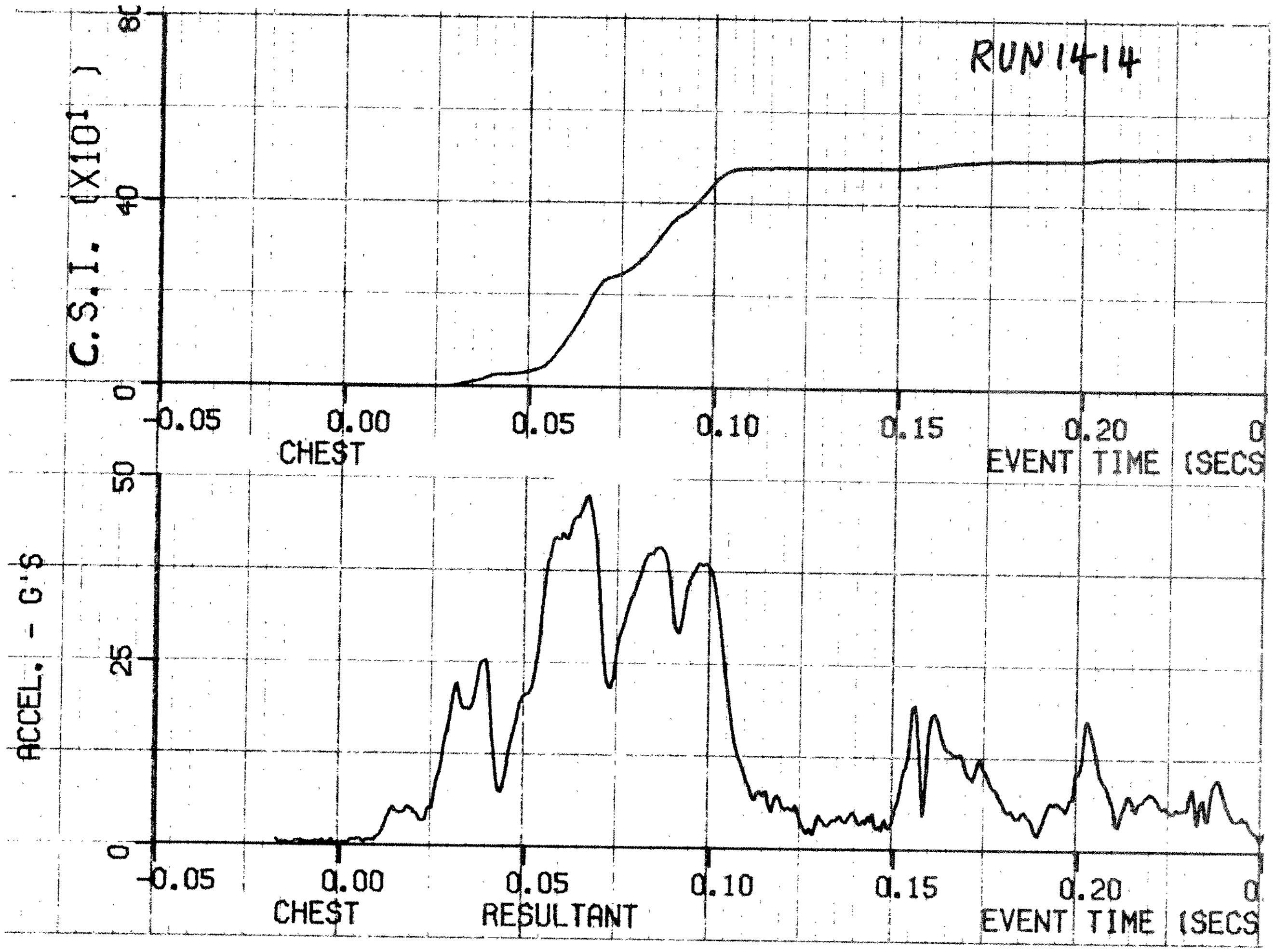




CALMAN 5 HEAD RESULTANT AND HSI



CALMAN 5 CHEST ACCELERATIONS



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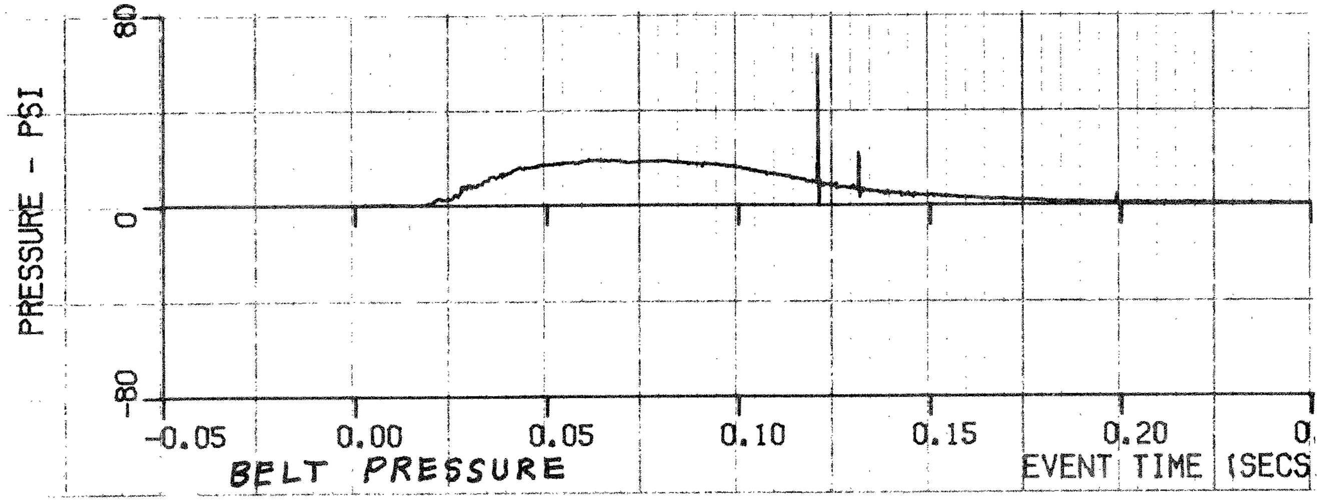
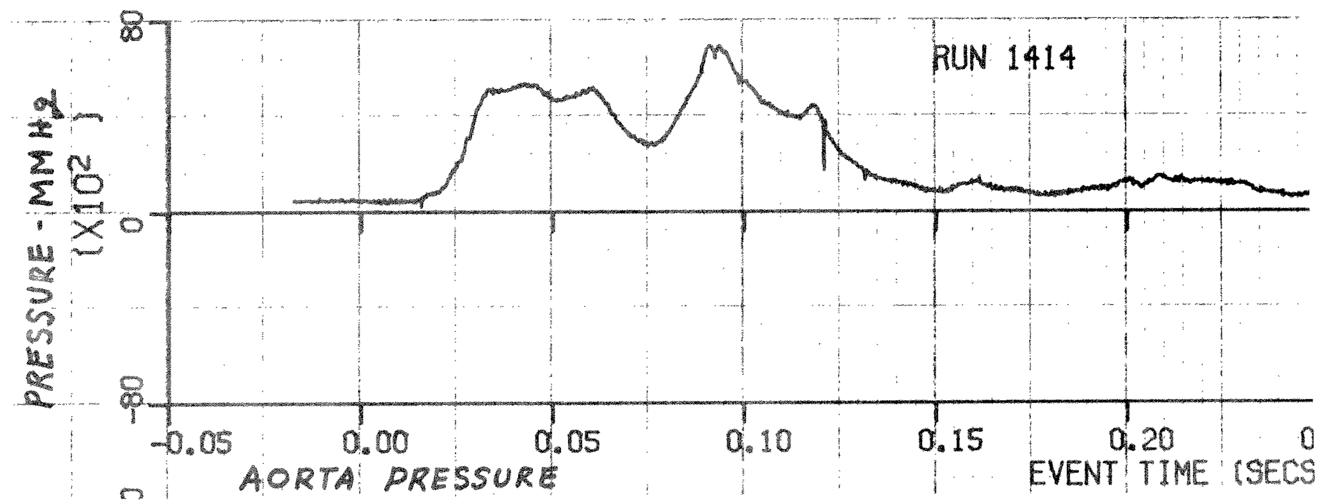
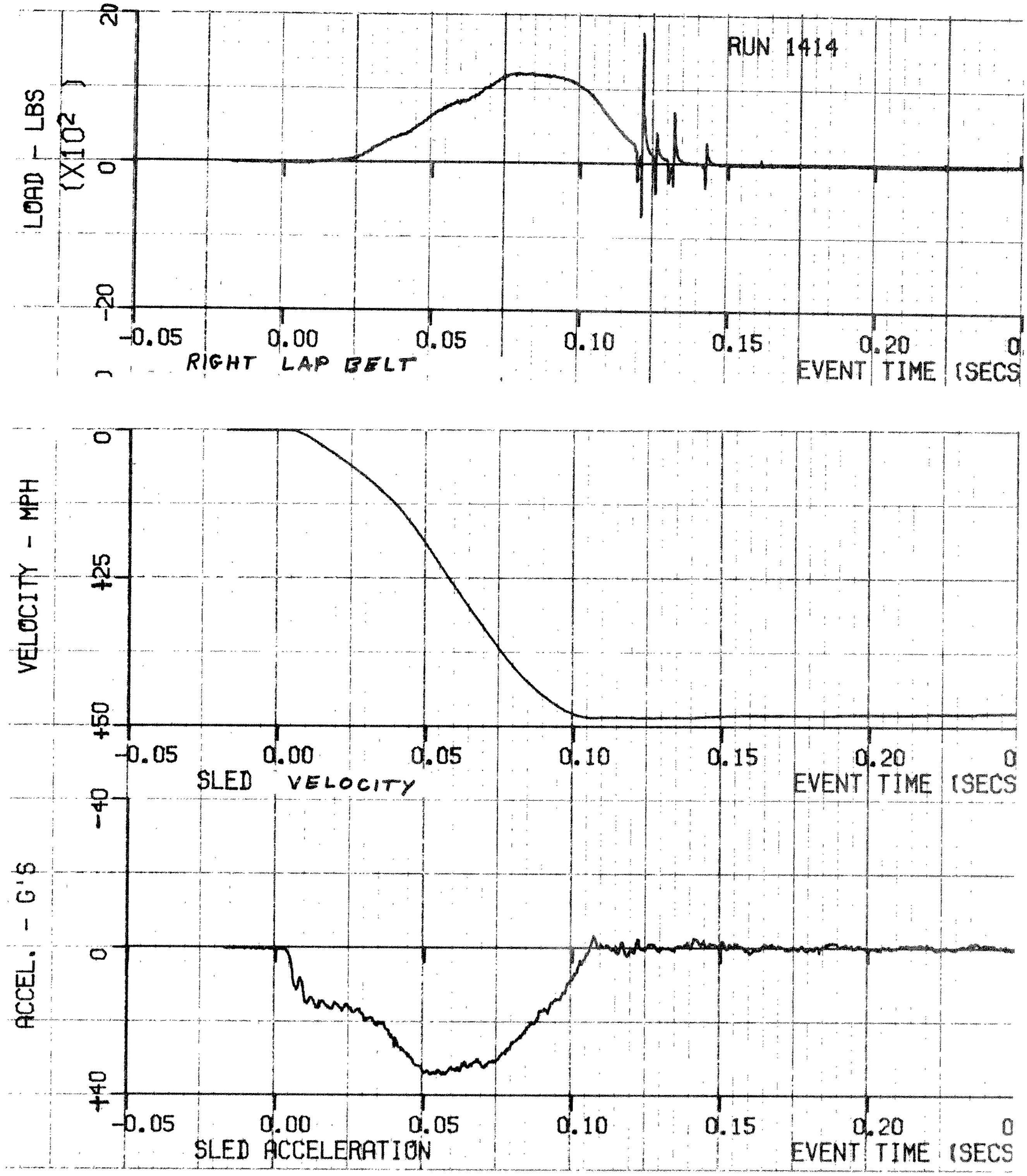




CALMAN 5 AORTA PRESSURE AND BELT PRESSURE



CALMAN 5 SLED AND LAP BELT LOAD