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DOT HS-801 719

INFLATABLE BELT DEVELOPMENT FOR SUBCOMPACT CAR PASSENGERS

Contract No. DOT-HS-4-00917

September 1975

Final Report

PREPARED FOR:

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16. Abstract

This report summarizes the analyses, design, and testing that were conducted to develop an airbelt restraint system for the subcompact car capable of protecting the passenger in frontal and frontal oblique crashes up to 50 mph. The result of this work has been the development of a rapidly inflating 3-point airbelt mounted to three stroke efficient energy-absorbing belt anchors. The system ultimately proved capable of protecting subcompact car passengers throughout the adult anthropometric size range at velocities exceeding 50 mph. In addition, the finalized restraint system is constructed of components that are oriented toward eventual mass production.

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1.0 INTRODUCTION

This report documents the work conducted on NHTSA Contract DOT-HS-4-00917 "Inflatable Belt Development for Subcompact Car Passengers."

The objectives of this program were:

1. To design a passively operating inflatable belt restraint capable of protecting the full anthropometric size range of right front passengers in the subcompact vehicle in frontal crashes up to 50 mph.

2. To accomplish these goals with a system that is amenable to mass production.

In this program the injury criteria used to determine attainment of the first objective were:

Head Injury Criterion < 1000
Peak Resultant Chest g's < 60 g's
Femur Loads < 1700 pounds

The crash environment specified for this program consisted of:

1. The standard 1974 Ford Pinto compartment dimensions.

2. The crash pulse typical of a subcompact car structurally modified to prevent excessive compartment intrusion and to crush in a stroke efficient manner. We chose the crash pulse of the modified Pinto developed on NHTSA Contract DOT-HS-113-3-746 to fulfill this requirement (Figure 1.1).

For several reasons, the subcompact car presents a crash environment much more severe than standard size cars. The reasons are:

1. Higher average crash pulse g levels due to the relatively low mass of the subcompact car.

2. Reduced compartment volume which decreases the allowable space the passenger has available in the compartment to come to rest.

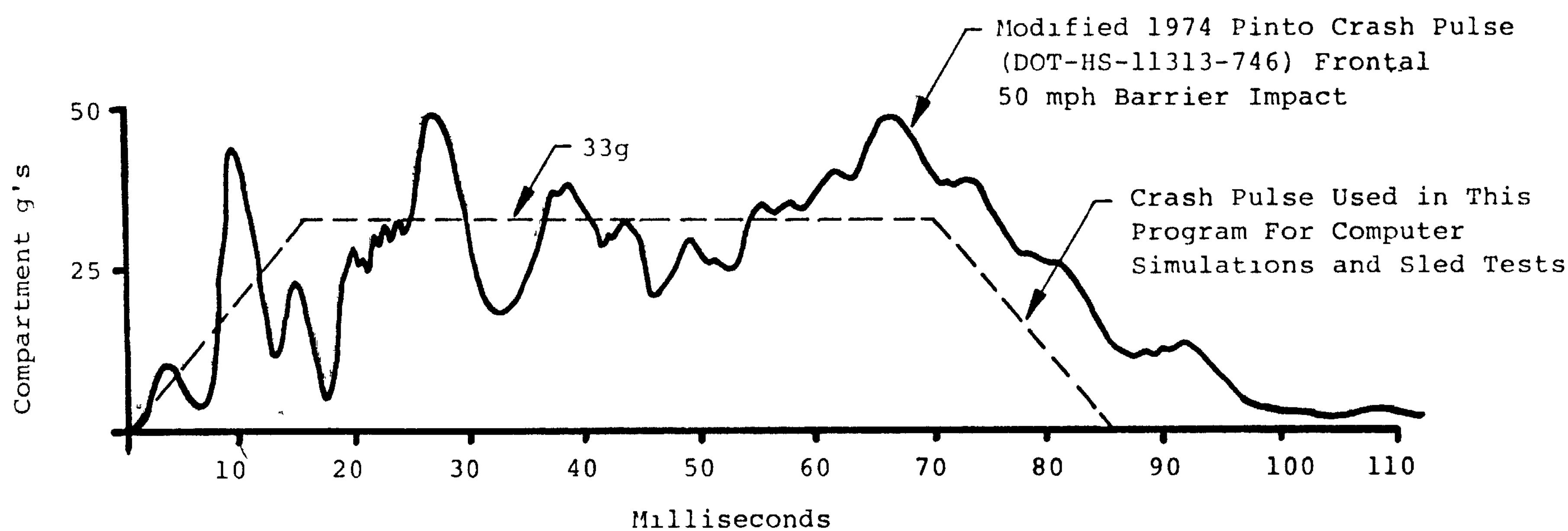


FIGURE 1.1 COMPARTMENT G'S VS. TIME

3. The relatively greater statistical probability of being involved in a high-speed accident. This is due to the fact that in car-to-car accidents, the smaller car has a greater total velocity change than the larger car due to the required momentum exchange between the two unequal mass cars.

In this report we will discuss each of these items in detail and show how the airbelt design we developed overcomes each of these potential problem areas.

However, prior to discussing the details of the studies, analyses, trade-offs, and testing that went into the development of the final airbelt system, it would be informative to discuss a bit of background that will shed light on the desirability of such a system.

Background

As just mentioned, the subcompact car presents special problems in the design of safety restraint systems. In the last restraint program Minicars worked on for NHTSA (Contract DOT-HS-113-3-742 "Development of an Advanced Passive Restraint System for Subcompact Car Drivers"), we dealt exclusively with the subcompact car crash environment. In this program we learned a number of things that are "musts" when designing the restraint for this particular crash environment. Here we will list those that have a bearing on this discussion.

1. Due to the higher crash pulse g levels experienced in a subcompact car, the restraint must exhibit a low amplification factor on crash pulse g's.

2. The restraint must be relatively insensitive to the crash pulse variability that can be experienced in the realm of the traffic mix in which the subcompact car must operate.

3. Due to the limited compartment space available in the subcompact vehicle, the restraint must be extremely "quick," intercepting the occupant before he picks up a high velocity relative to the compartment.

4. The restraint itself must be stroke efficient with rapid onset to the threshold force level of the restraint system. This means a relatively high airbelt pressure is required. This minimizes stroking space required by the occupant by maximizing the percentage of kinetic energy absorbed in the "ride down" mode.

1.1 The Conventional Belt System

For several reasons, conventional 3-point belt systems fall far short of providing adequate protection under these conditions. Evidence in the form of sled tests and car crash data indicates that at impact velocities above 30 mph* the belted passenger exceeds the injury criteria. To understand the function of the airbelt, it will help to look at some of the reasons for this.

Four things can be identified as primary contributors to reducing the effectiveness of the 3-point belt system at high velocities (greater than 30 mph).

1. The relatively small area over which the lap and torso belt loads are distributed.

2. The lack of head support.

3. Non-yielding belt anchors.

4. Belt slack.

We will take a look at each one of these items.

* This is based upon the results of the injury measures experienced in testing conventionally belted dummies in the "other car" of the two-car crash tests reported in Section 6.0, as well as recent sled tests conducted by Minicars for Allstate Insurance Company.

Item 1. The rather small area over which the belt loads are applied to the passenger mean that very high contact pressures are applied at critical points. Since the torso belt passes across mid sternum, high pressures bear directly over the heart. Injuries to the heart and actual crushing of the chest are very common with conventional belt systems in high-speed frontal impacts.

To perform as desired, the lap belt should pass over the hips. Often, due to poor belt placement, the lap belt rides up and presses inward on the soft abdominal cavity so that the only solid point of resistance is the backbone. Abdominal organs are violently squeezed and pushed upward into the thoracic cavity.

Item 2. Critical injury can also result from the unsupported head whipping forward during a frontal impact. Here several injuries are possible. First, the uncontrolled head can impact some exterior surface in the compartment such as the windshield, A-pillar, or dash.

Second, the extremely rapid rotation results in very high centripetal acceleration levels applied to the brain. Even without contact with the compartment, the brain can experience g levels on the order of 120 g's just due to this rotational component.

Third, the chin eventually impacts the sternum -- so hard, in fact, that this impact alone can be enough to impart a fatal concussion to the passenger.

Fourth, the neck must react an extremely high tension load as the head rotates forward. This force is sometimes great enough to break the neck in tension.

Items 3 and 4. Non-yielding anchors and the slack in conventional belts combine to produce inefficient usage of the stopping distance or stroke that is available to decelerate the passenger. There are three primary ways these inefficiencies are introduced.

First, the belt slack that is necessary for user comfort prevents the immediate application of decelerative forces being applied to the passenger undergoing the crash. The time that elapses and the passenger forward travel that is used up before the belt slack is taken up (or before the inertia reel locks up), is lost.

Second, since there is not much "give" in the system due to the fixed anchor points, the force applied to the passenger is very violent and of relatively short duration. The body of the occupant is brought up short so that the remaining compartment space available within which to stop the passenger is wasted.

Third, the non-yielding anchors and the elasticity of the belts combine to produce a devastating rebound effect. Since the anchor points are fixed, "give" in the system comes only from elastic deformation of the belt material. Therefore, most of the passenger's kinetic energy is merely stored in the belts and not absorbed. This stored energy is then returned to the occupant in the form of a violent rebound. He is actually propelled backward at a velocity that can approach the original forward velocity, thus increasing the effective velocity of the accident by a substantial amount.

In order to retain the positive features of a belt system, such as its rollover protection, lower cost (as compared to airbags), and mass production features, and to cope with these difficulties, the airbelt was conceptualized.

1.2 The Force-Limited Airbelt

The airbelt is basically a 2-point or 3-point belt restraint modified to inflate upon impact. The anchor points have also been modified to provide a controlled yielding in the system. In the following, we will show how these features of the airbelt promise to solve the high velocity impact problem typical of the conventional 3-point system.

First of all, the belt inflation itself performs three very important functions.

1. The belt contact area is substantially increased, thereby lowering the probability of fracturing the chest or rupturing internal organs.

2. The head is supported by the inflated torso belt capturing the chin and face, thereby preventing substantial forward head rotation.

3. The rapid inflation of the belt takes all belt slack out of the system.

Further, the belt is force-limited due to the installation of energy absorbing units at the belt anchors. This minimizes the effect vehicle crash pulse has on g levels imparted to the passenger.

The project undertaken by Minicars was to design, develop, and test just such a system so that the resulting design met or exceeded the program objectives listed earlier.

In the following sections of this report, we will describe our total approach toward attaining these objectives, the details of the design evolution, and finally the testing we conducted to attain and verify attainment of these objectives.

2.0 SUMMARY

In this program we conducted the analyses, design, and testing necessary to design a force-limited, passive airbelt restraint system for the right front passenger of a subcompact vehicle which would satisfy the requirements listed in the Introduction. We used computer simulations of the airbelted passenger undergoing specific crash environments to narrow the field of potential restraint designs and to select a preliminary restraint system which we could use to begin the sled test phase of the program. This preliminary design consisted of two separate approaches to meeting the requirements of the contract.

The first approach consisted of a 2-point force-limited airbelt in which the belt portion passed only across the torso of the passenger (Figure 2.1). The upper and lower ends of the inflatable torso belt were connected to force-limited anchors. The lower body kinetic energy was absorbed by a crushable knee restraint.

The second approach was a 3-point version of the airbelt. Here the configuration was much like a conventional 3-point belt system except the torso belt inflates in the crash and each of the three anchors are force limited. In this case, the lower body energy is absorbed by the yielding anchors at each end of the lap belt (Figure 2.2).

The development test series consisted of two phases. Phase I testing had the objective of obtaining a "developmental" design that met the first objective of the program, i.e., minimum injury levels for the range of potential passenger sizes in a sled simulated 50-mph frontal barrier crash.

Phase II testing was structured to take into account those changes mandated by accommodating a passive belt design while, at the same time, maintaining the low injury levels established as possible during the Phase I testing.

We concluded the development sled test phase when we felt the airbelt had been tuned to the greatest degree possible in the sled test crash environment.

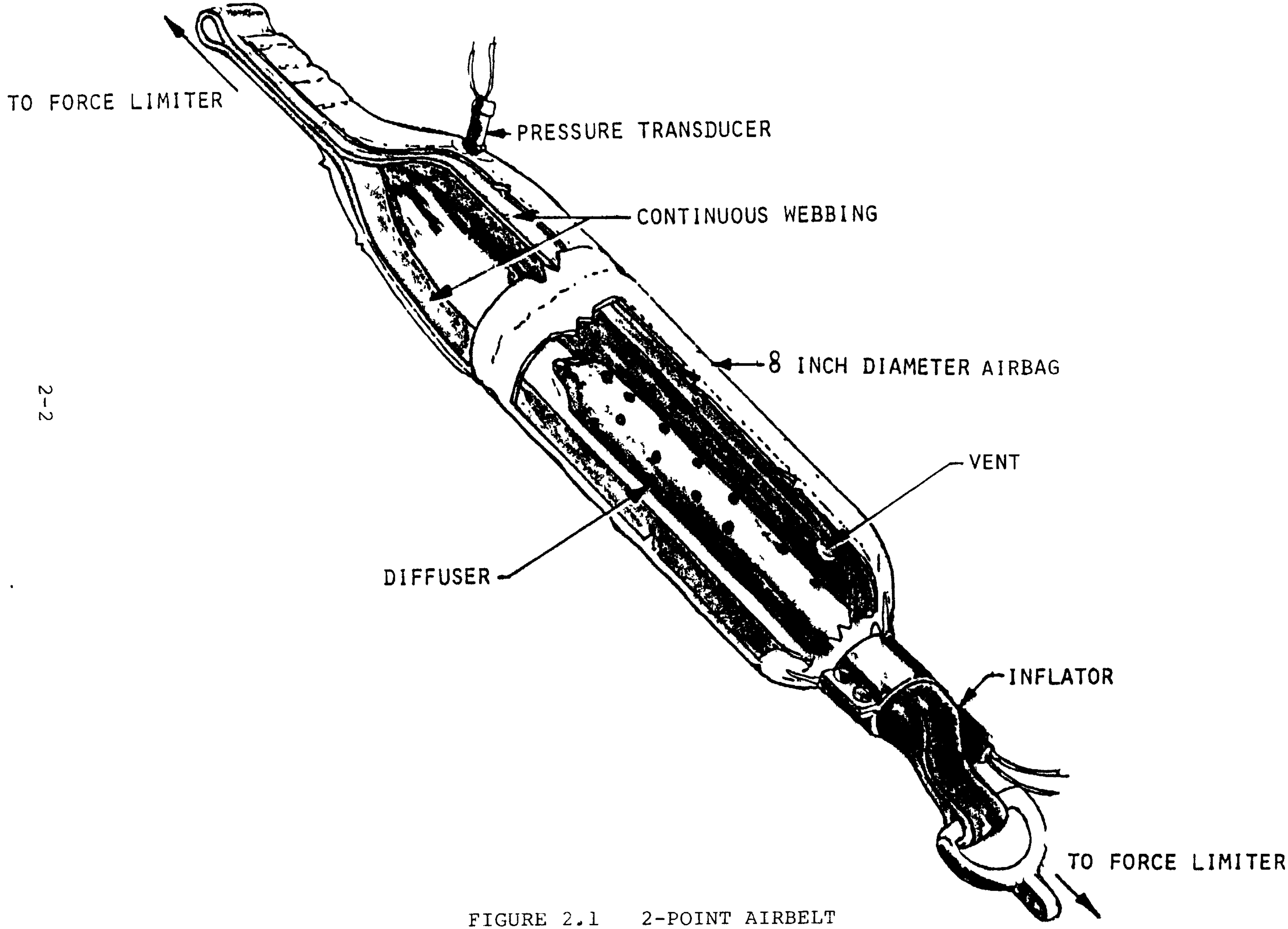


FIGURE 2.1 2-POINT AIRBELT

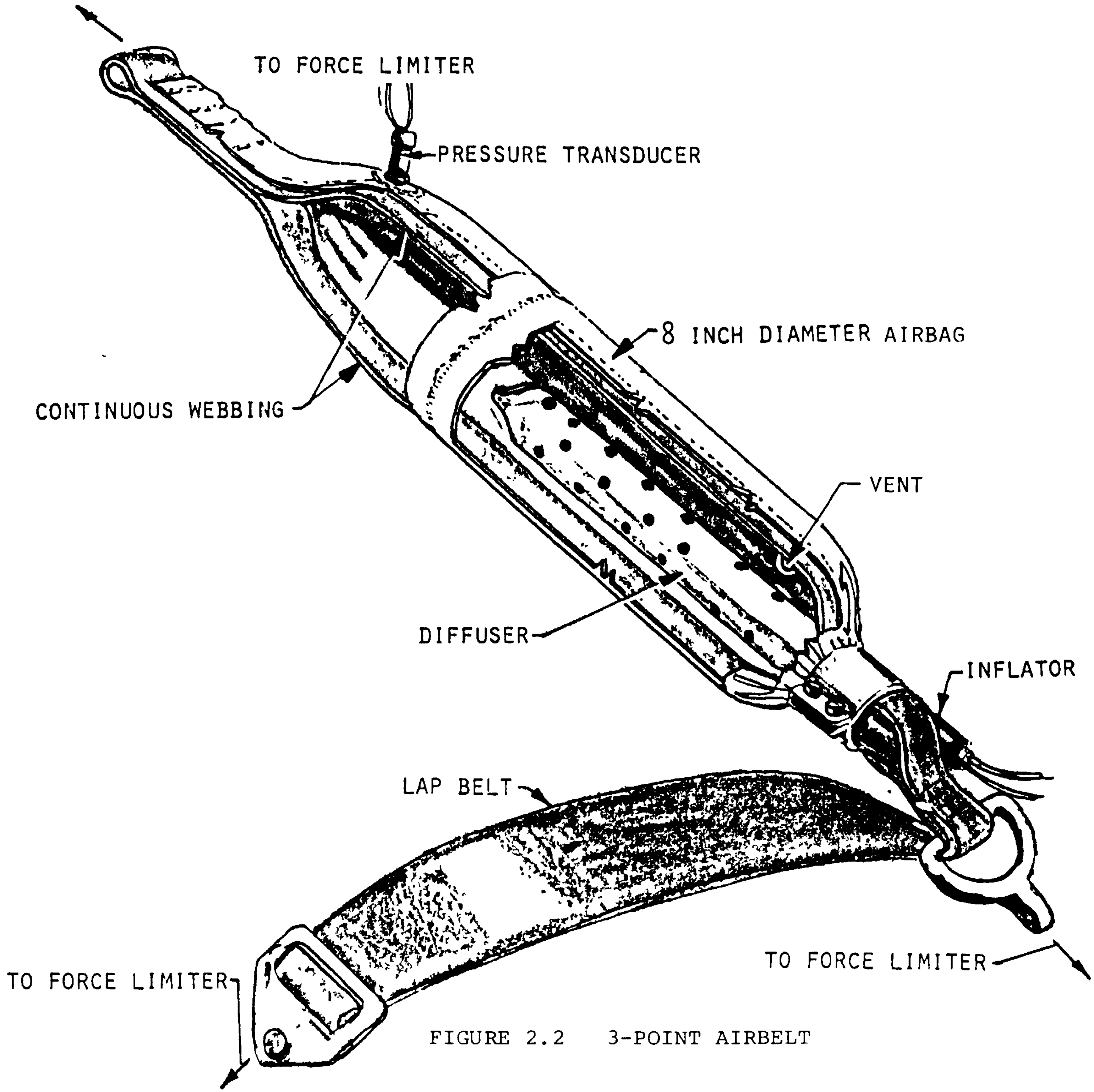


FIGURE 2.2 3-POINT AIRBELT

In order to demonstrate the capability of the finalized restraint to repeatably meet the injury criteria in a variety of crash situations, a series of evaluation tests were conducted.

These evaluation tests were of two basic types. First, a series of sled tests were conducted in which the passenger size, impact velocity, and impact angle were varied. Second, in order to demonstrate restraint performance in an actual crash situation, we installed the airbelt in three structurally modified 1974 Ford Pintos and crashed them in various modes.

Results of the evaluation sled tests are presented in Figures 2.3 through 2.6. From these figures we conclude that the size range from 5th percentile female through 95th percentile male are protected by the airbelt in frontal impacts to impact velocities greater than 50 mph. The six year old child exceeds the allowable criteria at velocities greater than approximately 47 mph.

In oblique impacts, the six year old child, the 50th percentile male, and the 95th percentile male all easily meet the injury criteria. However, the 5th percentile female, for reasons discussed in Section 6.0, slightly exceeded the allowable HIC through head impact with the door window opening.

The three car crash tests are discussed in detail in Section 6.0. The tests are designated as car crashes 1, 2, and 3 in this report.

Crash No. 1 was a car-to-car crash in which a modified Ford Pinto was crashed into a 1974 Ford LTD at a nominal 80-mph closing velocity. The impact was a full frontal impact across the full width of the cars.

Crash No. 2 was a barrier impact in which the modified Ford Pinto impacted a rigid barrier frontally at 42 mph.

Crash No. 3 was the second car-to-car crash, and again the modified Pinto was crashed into a 1974 Ford LTD at a nominal

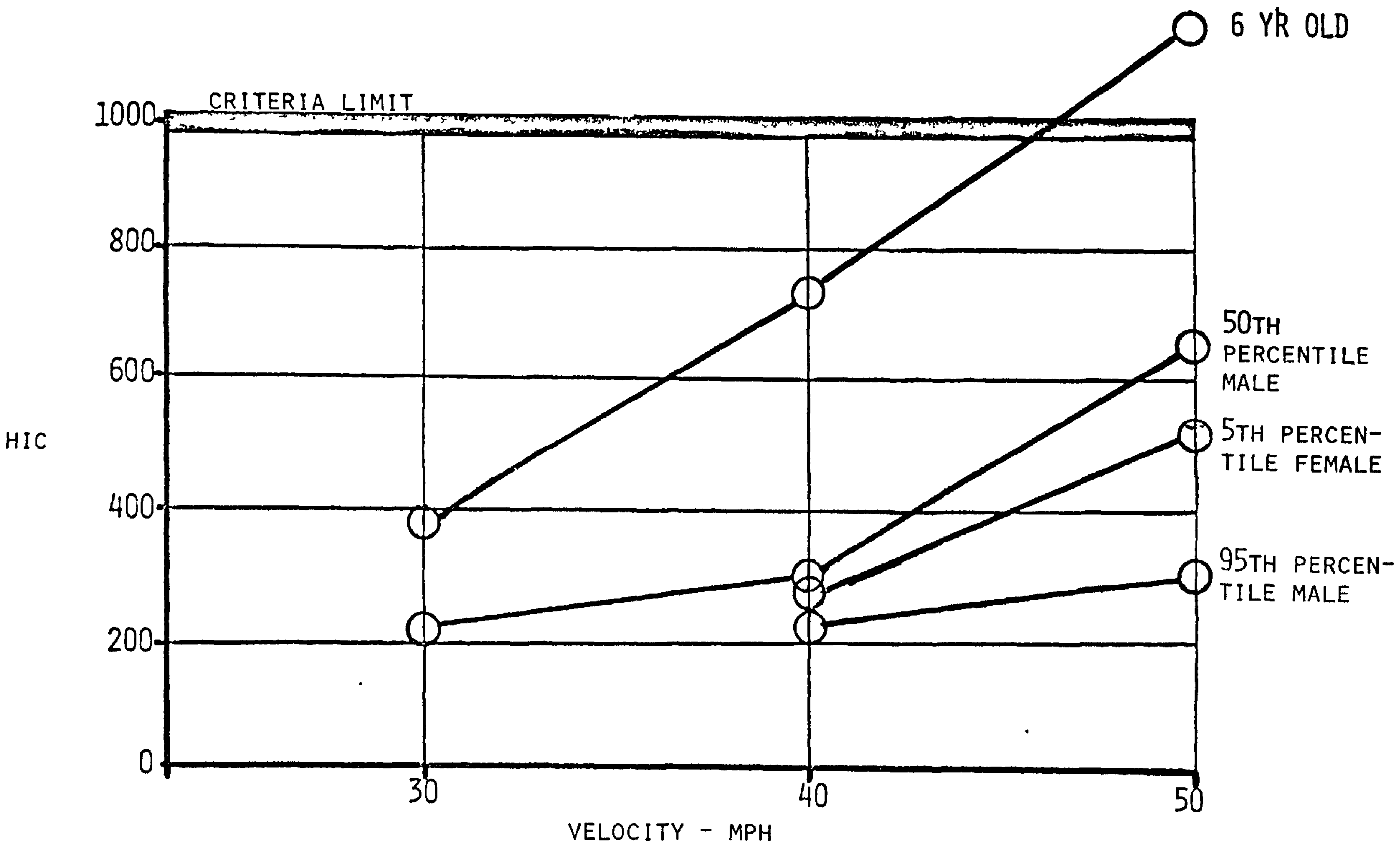


FIGURE 2.3 EVALUATION SLED TEST RESULTS - FRONTAL IMPACT

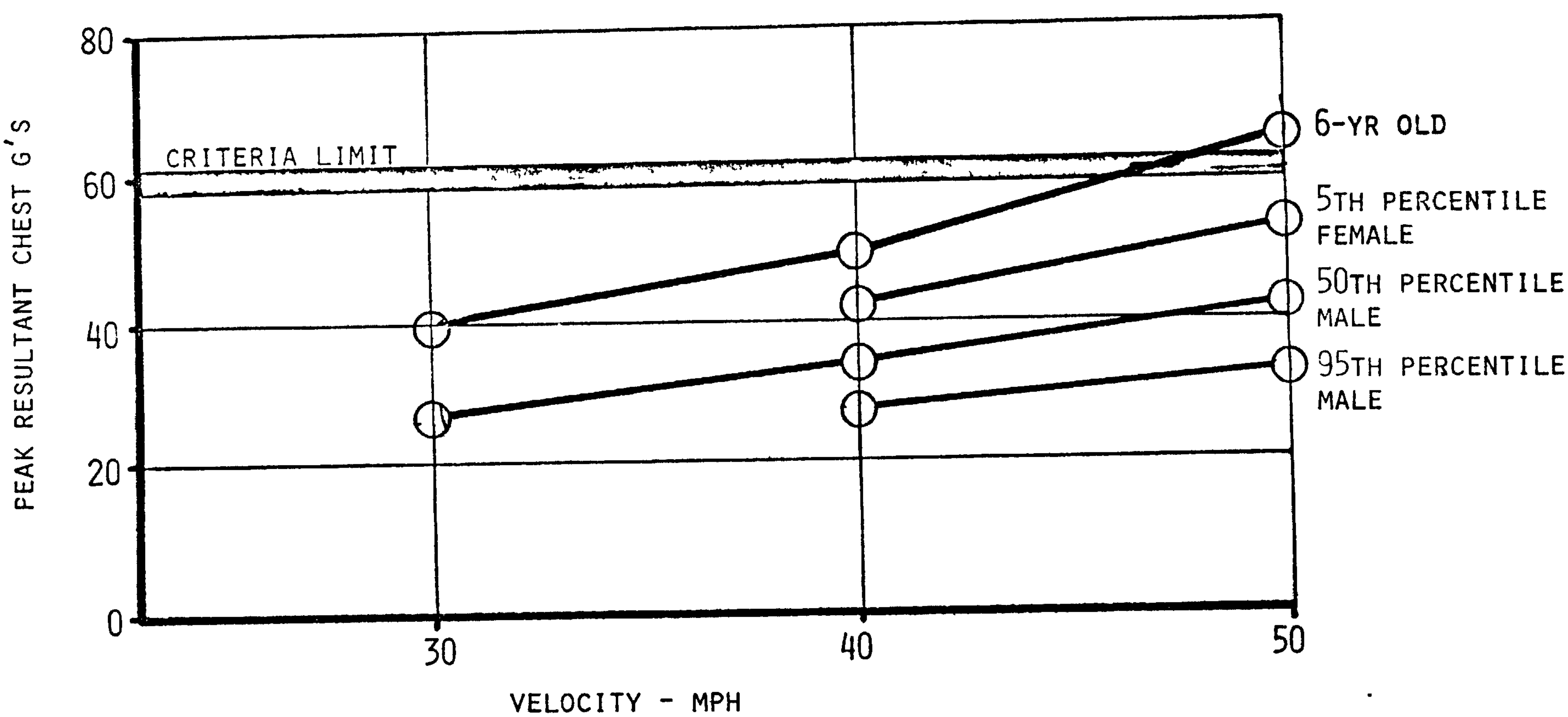


FIGURE 2.4 EVALUATION SLED TEST RESULTS - FRONTAL IMPACT

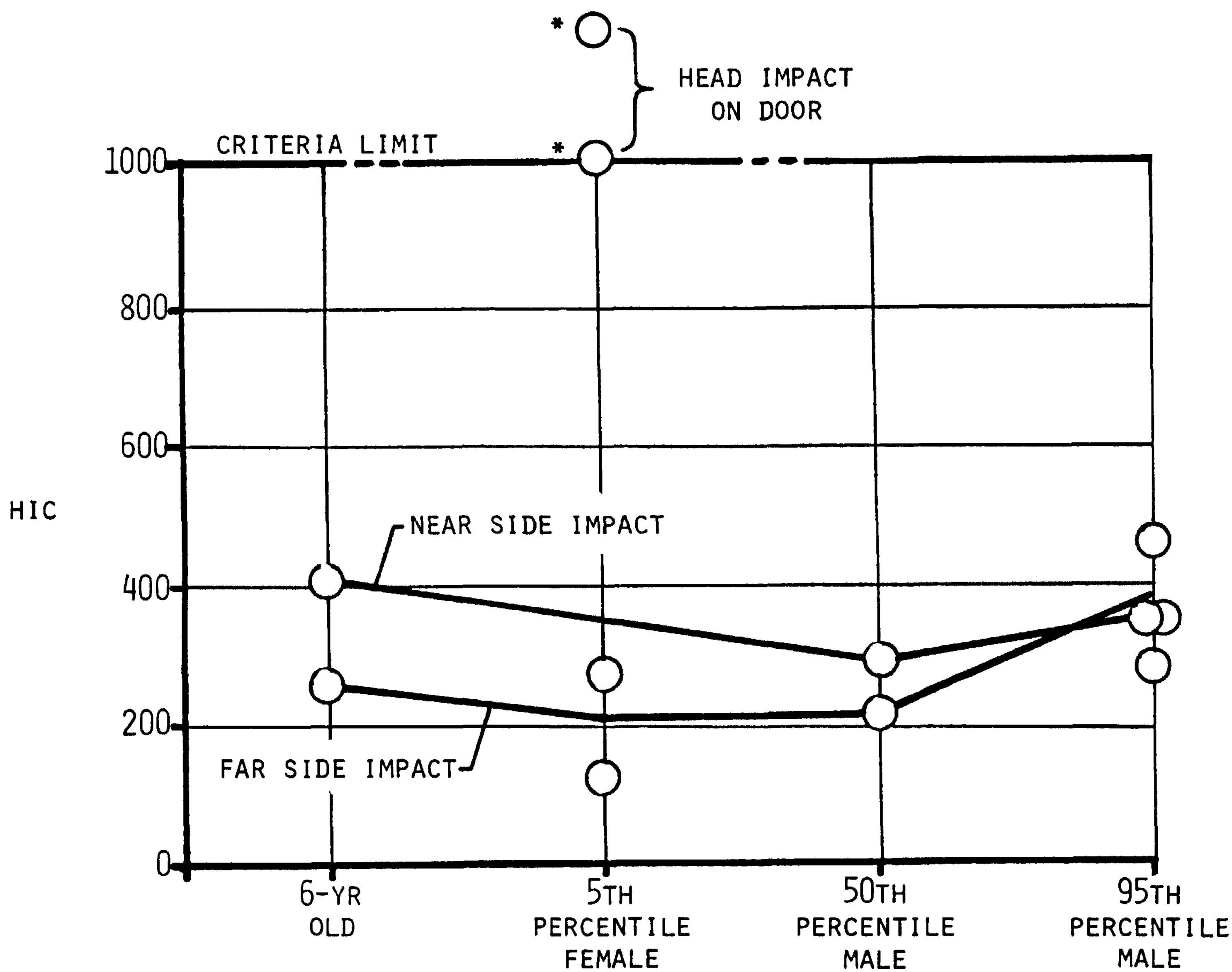


FIGURE 2.5 EVALUATION SLED TEST RESULTS - 38 MPH OBLIQUE IMPACT

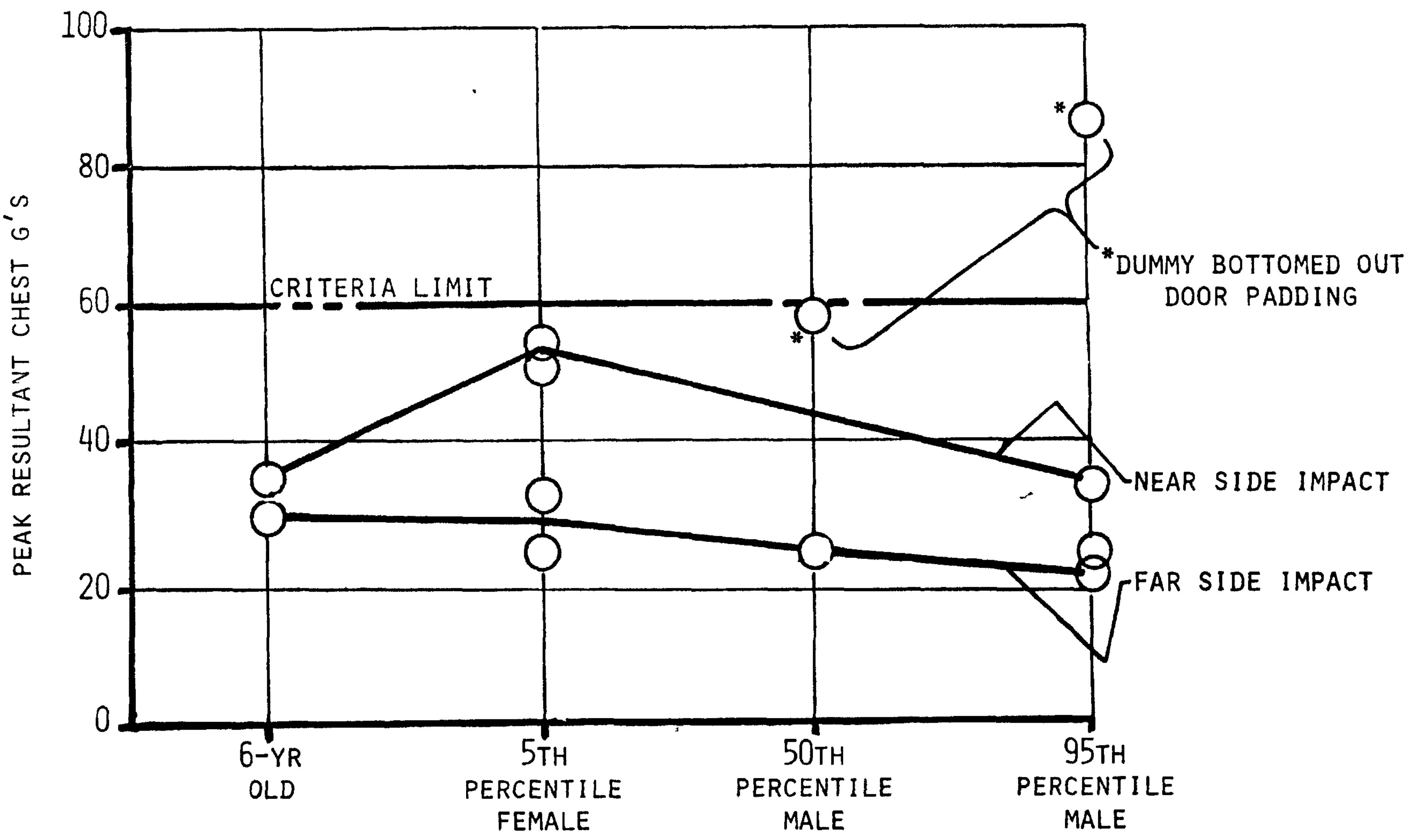


FIGURE 2.6 EVALUATION SLED TEST RESULTS - 38 MPH OBLIQUE IMPACT

80-mph closing velocity. However, this crash was offset frontally so that only one-half of the front of each car contacted the other.

The results of these three tests are shown in Figure 2.7. As can be seen from these results, the airbelted passenger received extremely low injury levels considering the severity of the subcompact car crash environment.

We feel that because of the airbelt's rapid deployment time, its force-limited anchors, and the fact that the inflated torso belt supports the head and results in much lower body contact pressures than conventional belt systems, it has the potential for the lowest injury levels of any restraint system ever developed. We further feel this has been demonstrated by the results obtained in this program.

Figure 2.8 shows the finalized airbelt configuration.

INJURY MEASURE	CRASH NO. 1 FRONTAL CAR-TO-CAR IMPACT ΔV = 55 MPH	CRASH NO. 2 FRONTAL BARRIER IMPACT V = 42 MPH	CRASH NO. 3 OFFSET CAR-TO-CAR IMPACT ΔV = 55 MPH
HIC	549	302	457
PEAK RESULTANT CHEST G'S	44	36	41

FIGURE 2.7 AIRBELT PERFORMANCE - EVALUATION CAR CRASH TESTS

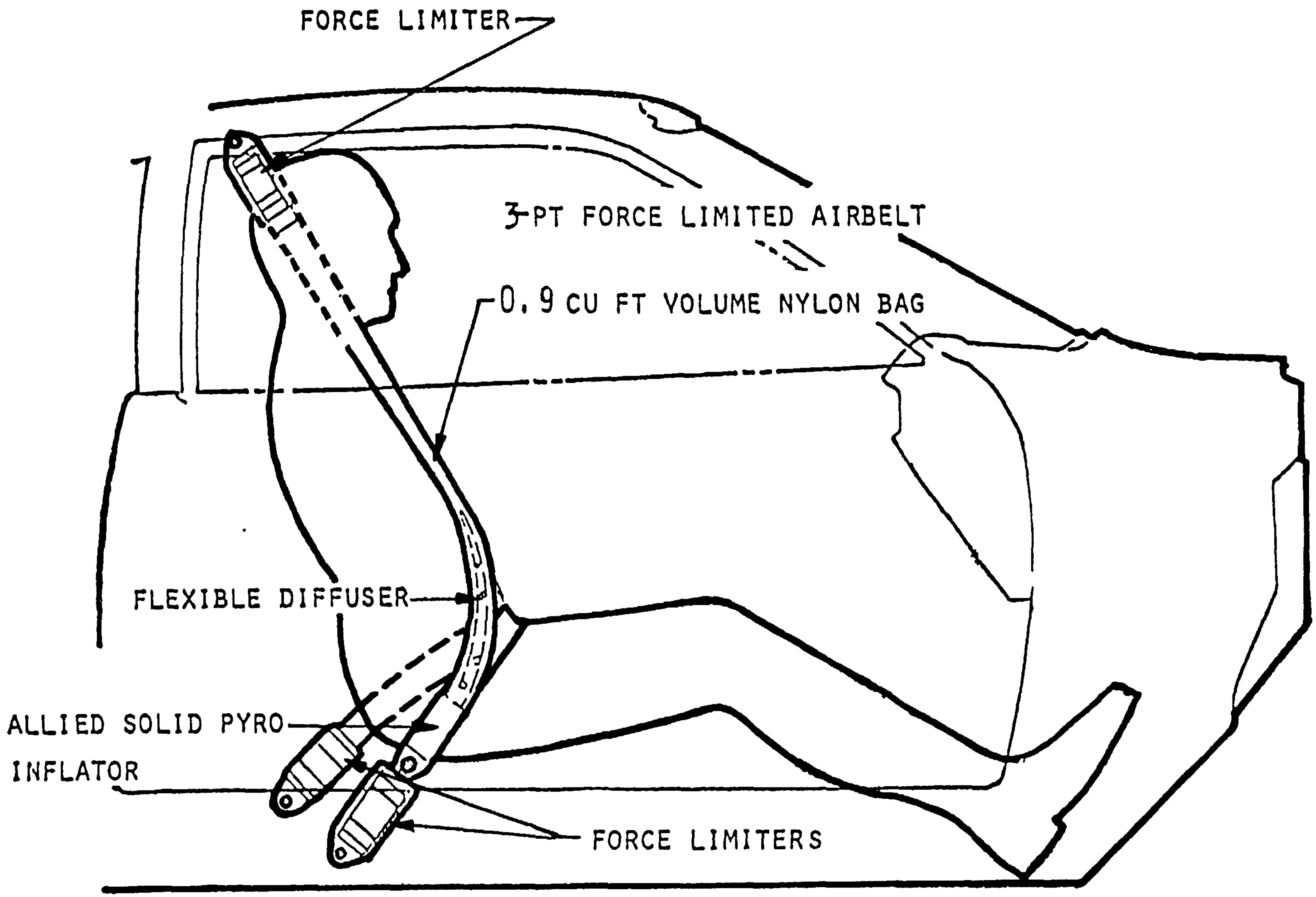


FIGURE 2.8 FINAL DESIGN OF AIRBELT RESTRAINT SYSTEM

3.0 CONCLUSIONS AND RECOMMENDATIONS

During the course of the contract, especially during the test phase, we became progressively conscious of the great potential the airbelt has for reducing the degree of passenger injury and, therefore, societal cost of accidents. First, during the analytical phase of the contract, we began to see that the combination of the rapid inflation, low stroking mass, and force limiting aspects of the belt system had great potential for reducing vehicle occupant injury levels to values lower than any other system with which we were familiar. The reasons for this are discussed in detail in Section 4.2.2. Briefly, they have to do with the fact that the g amplification common to most restraint systems can be virtually eliminated by proper design of the force limiters attached to the airbelt at each anchor point.

Once this had been shown by computer simulation of the crash environment, we were eager to verify the analytical predictions during the sled test phase.

During the test phase and through the remainder of the program, we were able to verify our analytical technique as well as to arrive at certain conclusions regarding the airbelt design, which we will discuss in the following.

3.1 Conclusions

1. The force-limited 3-point airbelt restraint system will meet the injury criteria for the anthropometric size range of passengers from 5th percentile female to 95th percentile male in frontal impacts to velocities substantially greater than the required 50 mph. This is based upon sled test and car crash test results in which the injury measures were well below the criteria limit, with room available in the compartment for additional stroke of the passenger (Figures 2.3, 2.4, and 2.7).

2. The six year old child is protected to approximately 47 mph in frontal impacts. At velocities above 47 mph, both the HIC measure of injury and the peak resultant chest g levels exceed the criteria limits of 1000 and 60 g, respectively (Figures 2.3 and 2.4).

3. The six year old child, 50th percentile male, and 95th percentile male all easily met the injury criteria in 38-mph 30-degree oblique impacts from both the near (1 o'clock) and far (11 o'clock) sides of the vehicle (Figures 2.5 and 2.6). However, the 5th percentile female meets the criteria for far side oblique impact only. In near side impacts, the head rotates toward the door window opening and eventually contacts the door at the point where the window rolls in and out of the door. This phenomenon is peculiar to the 5th percentile female only since the 50th and 95th percentile males sit high enough in the seat that their head does not rotate over far enough to contact the door. In contrast, the six year old child sits low enough in the seat that his head is below the door window opening and, therefore, impacts the padded door so that his injury measures are quite low.

4. The standard seat locations provided in the Ford Pinto are adequate in providing sufficient stroking room to bring the passenger to rest in 50-mph frontal impacts.

   This conclusion is based upon the 95th percentile male in the aftmost seat position having approximately 4 to 6 inches stroking room remaining, the 50th percentile male having approximately 10 to 12 inches remaining from the midseat adjustment position, and the 5th percentile female and six year old child having even greater amounts of available stroking room remaining from any seat position.

5. The standard Pinto anchor points with which we began the program were judged to be inefficient from a stroke efficiency standpoint. We found the angle from horizontal to the line of action of the belt to be too high to provide a major decelerative force to the passenger

in the initial stroking stages of the crash event. We therefore changed the belt anchor locations to obtain a more stroke efficient system (Figure 5.3). This change also substantially reduced the belt forces required to adequately restrain the passenger due to the more favorable belt angles.

6. Both the 2-point and 3-point airbelt restraint systems were capable of meeting the injury criteria. However, the 2-point system was very sensitive to the placement of the belt on the dummy. If the torso belt were not placed on the dummy exactly the same way every time, the dummy would move erratically during the crash -- sometimes rotating almost completely out of the restraint. Since the 3-point system did not exhibit this instability, we judged the 3-point system to be superior to the 2-point system.

7. The finalized airbelt restraint system is entirely producible in quantity by conventional mass production techniques. We base this conclusion on the fact that the components comprising the system are either off-the-shelf items themselves or are of very simple, easily fabricated construction.

8. The energy-absorbing belt anchors (force limiters) attenuate the g levels that otherwise would be transmitted to the passenger through the compartment. G amplification to the passenger through the restraint is very low, with the force limiters acting as filters to prevent crash pulse functions and spurious "g spikes" from reaching the passenger.

   This amplification factor, i.e., the ratio of torso acceleration level to vehicle compartment acceleration level, varies with restraint mass, relative velocity of the driver with respect to the impacted restraint, and the effective spring rate for the airbelt restraint. It is this effective spring rate of the restraint that is reduced by the addition of the force limiters.

9. The restraint system is relatively insensitive to variations in crash pulse. We base this conclusion on the fact that in the frontal sled tests, the oblique sled tests, and the three car crash tests in which different crash pulses were obtained, the restraint system performed very consistently with very similar injury levels measured in these tests (Figures 2.3 through 2.7).

3.2 Recommendations

1. Additional sled testing with some force limiter adjustments are required to lower the injury levels for the six year old child, while maintaining the overall low injury levels for the larger passenger sizes. By increasing the length of the low force regime of the force limiter, it should be possible to meet this objective within a few sled tests.

2. The force-limited, but not inflated, 3-point belt will meet the injury criteria at 50-mph frontal impact (Figure 5.5), but head injury levels and contact pressures are higher with this system than for the airbelt. However, since this version is less expensive than the airbelt, a favorable benefit-cost relationship may be possible. We therefore recommend that a study be initiated to determine which of these two belt systems will result in the greatest overall societal benefits.

3. Although the 3-point airbelt is entirely producible on a mass production basis as it is, we feel there are certain areas where the belt system can be made even more production oriented. Some of these are:

   A. Force limiting methods, besides the type-roller mechanism described in this report, should be investigated to ascertain whether the desired force-stroke relationships can be obtained with an even simpler mass producible system.

B. The passive version of the 3-point airbelt should be tested by a statistical sample of people to ascertain:

1. How well they like the system.

2. How well the system accommodates the anthropometric size range of passengers (we did some work on this, but more work should be done).

3. The potential usage rates.

4. Their suggested improvements.

C. The inflator performs the function of filling the belt with the proper amount of gas in the required time; however, we recommend that additional testing outside the scope of this contract be conducted to verify performance of the inflator in other areas such as:

1. Stability of performance in a variety of environmental conditions.

2. Statistical probability of reproducible performance.

3. Shelf life.

In addition, the inflators used in this program were "work horse" inflators that could be reloaded a number of times. In the interest of making the system less massive and cheaper to produce, a new lightweight, non-reloadable case should be designed.

4.0 TECHNICAL DISCUSSION

In the Introduction of this report, we established what we have attempted to accomplish in the program and the criteria we used to determine the degree to which we accomplished our objectives. In this section we will focus upon how we accomplished these objectives and why we arrived at a certain conclusion or design. However, prior to describing how we proceeded through the program and how each program objective was met, it will be informative for the reader to refer to Figure 4.1 as the program methodology unfolds in the following pages.

4.1 Program Development

Following the approval of the Program Plan submitted to NHTSA by Minicars, we began work to analytically derive the airbelt restraint system that would provide the basis for additional tuning via sled testing. We called this first system our "baseline system." This sytem was largely derived by computer simulations of the airbelt restrained passenger undergoing 50-mph frontal barrier carshes. Here our objective was to analytically trade off various restraint parameters in order to converge to a total system that would be our baseline system. In these simulations we were able to not only converge to a promising design, but were also able to learn a great deal about the restraint parameters that were of greatest importance in governing restraint performance, and then, most importantly, why these parameters interact the way they do in producing a given response of the passenger to a specific crash condition.

Based upon this analytical effort, plus previous experience we had with the inflatable belt concept and the limitations of conventional belt systems, we were able to formulate a total airbelt restraint system for initial sled testing which appeared to best satisfy the program objectives. This system comprised the unit with which we began Phase I sled testing.

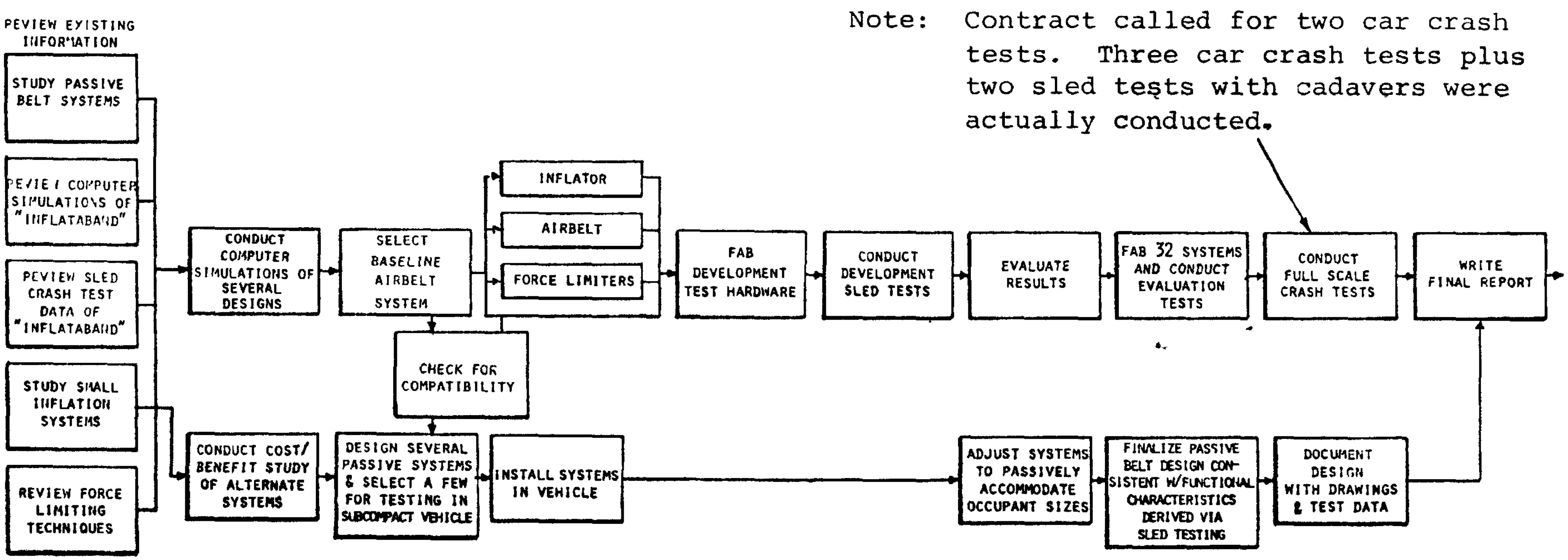


FIGURE 4.1 PROGRAM FLOW CHART

In the Phase I tests, our objective was to carry the baseline design to the point that any further refinements were minor and of a "tuning" nature.

Following the Phase I tests, the results were evaluated and those modifications made that we felt would improve the system performance for the Phase II tests.

During the Phase II development sled tests, further minor changes were made to better accommodate the size range of potential passengers, satisfy the requirements of oblique impacts, and to make the system amenable to passive operation. In this test phase, we also ran a series of tests in which we compared the performance of the force-limited airbelt with the conventional 3-point belt system and with a non-inflated force-limited 3-point belt system.

The finalized version of the airbelt restraint was then installed in a structurally modified 1974 Ford Pinto (NHTSA Contract DOT-HS-113-3-746) for the first of three car-to-car crash tests with 50th percentile male dummies.

Following this first test, the finalized version of the airbelt was futher tested in a series of evaluation sled tests.

In parallel with the test effort, we conducted a study of several potential schemes for making the airbelt system passive. Once we had selected the basic system (following the Phase I sled tests), we proceeded to fabricate the mechanism that would provide the passive belt function.

With the system fabricated and installed in the 1974 Ford Pinto, we adjusted the system to passively accommodate the whole range of possible passenger sizes from 6-year old child to 95th percentile male. A series of movies were made demonstrating the passive operations of the belt system.

Following the passive airbelt development, we conducted two more car crash tests plus two sled tests with a cadaver. The last car crash and the two cadaver tests were not contractually required; however, at the request of NHTSA, we agreed to conduct these additional tests since we judged we had sufficient funds remaining in the contract.

With this general overview of the program in mind, we will now, in detail and in the order established in the foregoing, describe the evolution, testing, and analyses that led to the finalized airbelt design.

4.2 Analytical Derivation of the Baseline Restraint System

As previously mentioned, one of the first things we did at the beginning of the program was to conduct a series of computer simulations of the passenger interacting with the airbelt restraint system. We will now describe the approach and methods we used in conducting these simulations.

One of the things we learned in previous programs was that we could not only analytically predict injury levels and the magnitude of bodily accelerations, but, more importantly, we could know which factors interact to produce a given injury or acceleration. This insight as to what actually causes the degree of injury is the first necessary step to understanding what one can do to minimize the injury, and this is where we have found simulation of the crash event to be invaluable.

Another result of these simulations is that they allow one to observe in a controlled atmosphere -- much like a high-speed movie or barrier crash test -- how each anatomical articulation, loading, and phasing contribute to the degree of occupant injury. These simulations, however, possess an even more powerful potential, one that sled test movies and accelerometer traces lack. Unlike test data which present accelerations versus time, or movies which present the occupant kinematical motion, no question exists as to "where the occupant was" or "what he was doing" when a certain value of acceleration was experienced.

Therefore, a program, once validated, is a powerful tool for obtaining a "feel" for exactly what effect on occupant injury a certain combination of events can produce. One may immediately confirm these suspicions by changing a single parameter in an attempt to improve the situation and then observing in the subsequent simulation, the time-step-by-time-step effect of this change on the injury level to the anatomical area of interest.

4.2.1 The Computer Programs Used

Two computer programs were used in this program to design and tune the passenger restraint to satisfy the objectives stated in the first part of this report. The programs are AIRBLT and ABAG19.

At this point, it would be useful to describe each one of these programs in some detail and show how each program was used in arriving at the baseline design.

4.2.1.1 AIRBLT

AIRBLT is a three mass (head, torso, and lower body) planar model of the passenger that describes the articulated interaction of the various body components and the corresponding injury levels. By inserting a range of force limiter, air-belt, and head support parameters into this program, it is possible to assess the detailed motions, injury levels, accelerations, and other particulars of each part of the modeled anatomy. This makes it possible to design the total restraint system to obtain the lowest injury levels possible for the anthropometric size range of potential passengers. This is done by properly phasing in time the simultaneous interactions of all forces influencing body displacements and accelerations to obtain the best combination of the computer derived value of interst, namely HIC, chest g's, and femur loads. Figure 4.2 shows a schematic of the model.

AIRBLT input:

1. Vehicle crash pulse.
2. Initial position of the passenger relative to the vehicle.

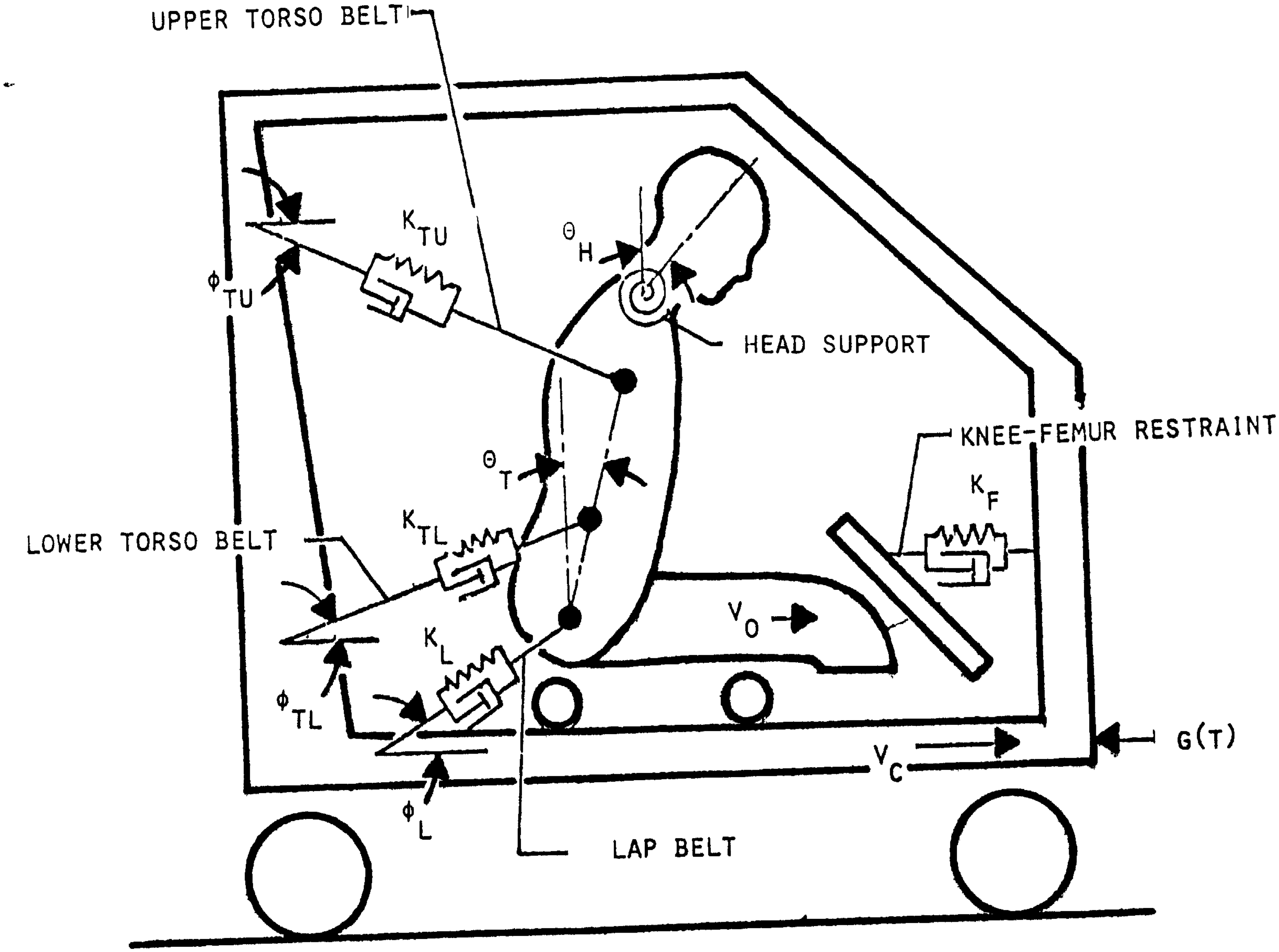


FIGURE 4.2 "AIRBLT" COMPUTER PROGRAM SCHEMATIC

3. Geometry and weight of passenger.
4. Restraint geometry when passenger is in initial position.
5. Airbelt deployment time.
6. Airbelt and force limiter force-deflection properties.
7. Initial velocity of vehicle and passenger.
8. Head support provided by airbelt and neck muscular resistance.

Output is specified by the user and may include time histories and plots of any or all of the following:

1. Vehicle acceleration, velocity, and displacement.
2. Head, torso, and lower body linear and rotational accelerations, velocities, and displacements. These parameters may be calculated with respect to reference point, either stationary or moving. Examples of moving points of reference are the passenger compartment or another part of the anatomy.
3. Force limiter stroke.
4. Head Severity Index.
5. Head Injury Criterion.
6. Chest g time history (A-P and S-I components).
7. Femur loads (if knee restraint force properties are input into the program).

The AIRBLT computer program specified the optimum combination of force limiter properties for each anchor point, as well as giving us the degree of head support required to obtain lowest injury levels for 50-mph frontal impact for each passenger size.

4.2.1.2 ABAG19

The ABAG19 computer program was used to determine the theoretical design parameters that yield the optimum combination of inflator, airbelt volume, and force limiter performance to minimize passenger injury levels. Figure 4.3 shows a schematic of the program.

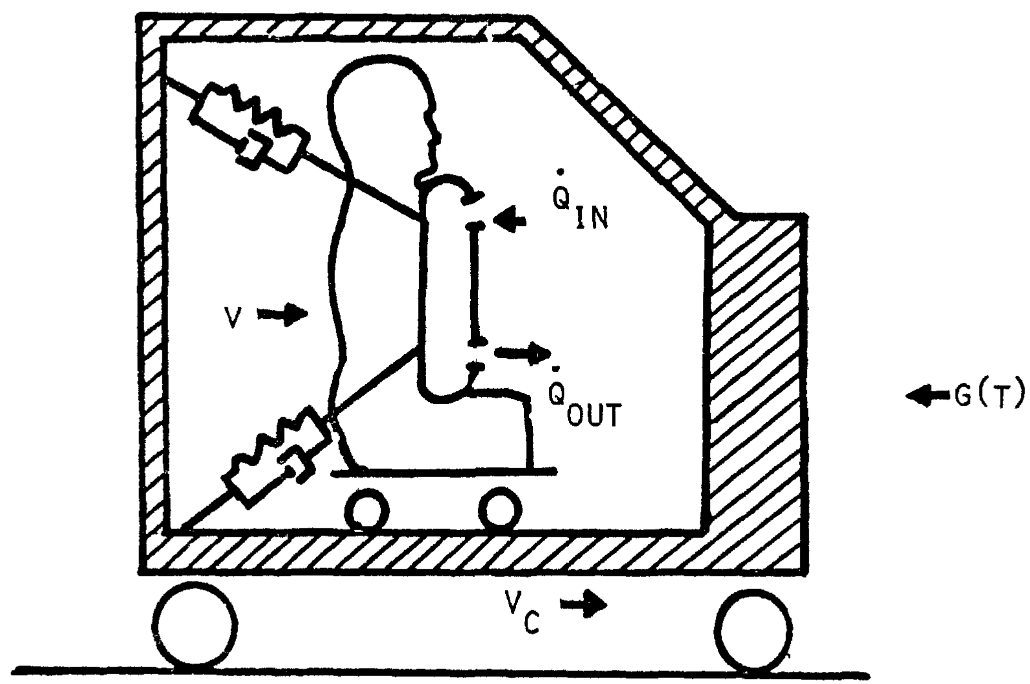


FIGURE 1.3 'ABAG 19" COMPUTER PROGRAM SCHEMATIC

The program is basically a one-dimensional program that can simulate the interaction of the passenger torso with an airbelt that is being simultaneously inflated, vented, and penetrated by the passenger torso while the entire assembly is stroking toward the dash according to the predetermined force characteristics of the force limiters. Typical input to the program is listed below.

Inputs for ABAG 19:

1. Vehicle crash pulse.
2. Airbelt activation time (sensing time plus airbelt deployment time).
3. Venting characteristics.
4. Inflator flow rate into the belt as a function of time.
5. Force-stroke characteristic of force limiters.
6. Initial velocity of vehicle and passenger.
7. Initial position of airbelt relative to passenger.
8. Size and shape of airbelt.
9. Anthropomorphic size of passenger.
10. Type and temperature of gas in airbelt.
11. Allowable stroke of force limiters.

Output from the program includes time histories through rebound (if any) of:

1. Torso g load.
2. Torso velocity.
3. Vehicle velocity.
4. Vehicle crush.
5. Airbelt penetration.
6. Airbelt pressure.
7. Force limiter stroke.
8. Volume of gas in airbelt.
9. Mass or volume rate of flow from airbelt.

As can be seen in the foregoing, the input and output parameters for the airbelt portion of the system are similar to other airbag programs. However, acting in series or in parallel with the airbelt system, the program user may specify the force-deflection properties of an energy-absorbing force limiter.

4.2.2 Computer Derived Airbelt

Before describing in detail the evolution of the baseline airbelt system through computer simulation, we would like to preface this discussion by describing briefly our view of the restraint system and how it fits into the subcompact car crash environment. We will show why the force-limited airbelt has very high potential in operating effectively in this crash environment.

Past experience has shown that the subcompact vehicle operates in a crash environment that dictates an approach to solving the restraint problem that precludes the use of conventional restraints. For the subcompact vehicle, we have a curb weight on the order of 2,500 pounds. This means that the average crash pulse g level is relatively high -- on the order of 35 g's. For a crash pulse such as this, it is extremely important that the restraint itself does not further amplify this g level since the decelerative forces are transmitted directly to the restrained occupant.

Unfortunately, most IORS transmit g levels to the occupant that are 1.5 to 2 times greater than the crash pulse g level. This is due to the nature of the primary restraint mechanism, i.e., the airbag. If one goes through the mathematics of a particular restraint mechanism, it turns out that the degree of amplification varies directly with relative velocity of the occupant with respect to the vehicle, the effective spring rate of the restraint at a particular point in the event, and the ratio of the mass of the restraint to the restrained mass.

There are two basic approaches to reducing the amplification factor.

First Approach. One approach is to reduce the spring rate of the inflated bag or belt. This is commonly done by incorporating a vent of the proper size in the inflated bag. However, this approach has three main drawbacks. First, it only reduces the effective spring rate of the inflated bag; it does not eliminate it. Second, the vent area is usually fixed at some constant area that "best" reduces the average bag spring rate while, at the same time, providing the damping required to reduce the rebound velocity of the occupant to reasonable values. This means the vent is really only the "right" size for a certain design condition that is transient or even non-existent in the real world of crashes. Attempts to provide a variable vent area have proven difficult to implement.

Third, and most importantly, the airbag with a given vent area is really only "right" for the design crash pulse -- any other pulse that deviates from the design pulse affects the performance of the restraint. This is because the required vent area is a strong function of the relative velocity of the occupant with respect to the inflated bag (due to gas compressibility effects) and this relative velocity, in turn, varies with changes in the crash pulse.

Since crash pulse variability is a fact of life due to the variability of front end structural characteristics in the traffic mix, which, in turn, increases the uncertainty involved in predicting the performance characteristics of the "other cars" in two-car accidents, we cannot design the restraint for one particular crash pulse. Rather, we need a restraint that is relatively insensitive to crash pulse variations.

Second Approach. Therefore, we have found a second approach we like better. The best way to reduce the amplification factor and simultaneously reduce the sensitivity of the restraint to crash pulse variations is to approach the problem from a different angle. Rather than attempt to reduce the spring rate of the bag per se, we concentrate on reducing the "effective" spring rate of the total restraint. We do this by placing an energy absorbing device in series with the airbag portion of the restraint. If this device happens to be a constant force device, its spring rate is, by definition, zero. Further, if this device has sufficiently low mass, we are subject to crash pulse amplification only during the portion of the crash event at which the force level applied to the torso is below the threshold stroking level for the force-limiting device, i.e., only whenever the force limiter is not stroking.

This device for the driver restraint, developed by Minicars under NHTSA Contract DOT-HS-113-3-742, is the energy absorbing steering column. With this device we routinely experienced amplification factors (torso g's divided by crash pulse g's from 0.8 to 1.2). This is to be compared with the 1.5 to 2.0 amplification factors commonly experienced with restraint systems in which the airbag is the primary energy absorber. Obviously, this reduction in amplification factor has extremely important implications, especially in reducing injuries and therefore the total societal cost of accidents.

We see, therefore, that the subcompact car crash environment necessitates a new approach to restraint design. For the driver, the solution is easiest -- we merely make use of the existing steering column to provide the necessary force limiting that lowers the restraint's effective spring rate, thereby attenuating the transmissibility and amplification of the crash pulse g's to the driver.

On the right front passenger side, however, there is no ready device to provide the force-limiting function. We can, however, provide a force-limiting device in series with the airbelt that will prevent the undesirable g amplification.

We chose to incorporate this force-limiting device at each anchor point of the belted passenger. Therefore, in the AIRBLT computer simulations we adjusted the force-stroke properties of each belt system independently to obtain the best overall combination that resulted in minimum injury levels. We will now discuss these simulations in detail.

4.2.2.1 AIRBLT Simulations

The purpose of the AIRBLT computer runs were to derive the detailed force-stroke properties for each force limiter and to determine the degree of head support required to achieve minimum injury levels for the anthropometric size range in 50-mph frontal impact. In order to accomplish this and to obtain the necessary input for computer simulation, we

1. Made scale drawings of the 1974 Ford Pinto compartment with the anchor point locations.

2. Positioned anthropometric dummies in the right front passenger position of the 1974 Ford Pinto to obtain the restraint geometry such as belt angles, lengths, centers of gravity of various dummy components relative to the compartment, etc.

3. Input the crash pulse and other pertinent crash parameters for the 50-mph frontal impact.

A significant number of computer runs were made with various degrees of head support, various passenger sizes, seat positions (the Pinto has an adjustable passenger seat), and various force-stroke properties for the belts themselves.

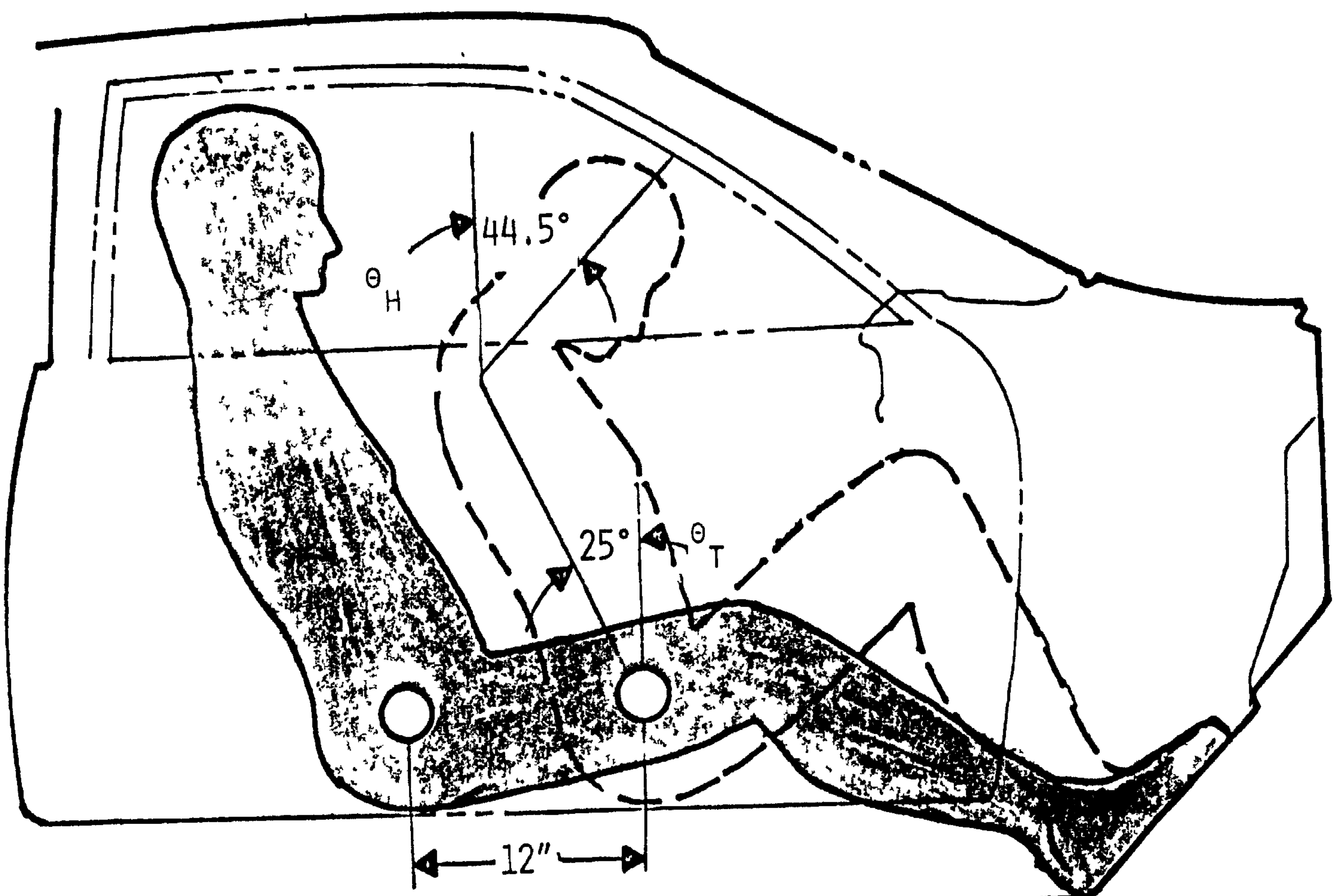
Figures 4.4 through 4.6 show the forward-most position of the various passenger sizes for the final computer iteration on airbelt parameters. This iteration yielded the best overall performance (lowest injury levels consistent with stopping the various passenger sizes within the compartment with the seat in the standard Pinto positions). The total airbelt system that accomplished this became the system which we selected for further computer analysis with the ABAG19 computer model.

The purpose of running the ABAG19 program was to determine the inflator gas flow history required to obtain the degree of head support derived as optimum in the AIRBLT computer simulations.

Figure 4.7 shows the belt properties that produced the results shown in Figure 4.4 through 4.6. These values were obtained for the crash pulse shown in Figure 1.1 and for the stock Pinto anchor positions. With the belt force-stroke properties and the degree of head support established by the AIRBLT runs, we were now in a position to size the inflator.

PASSENGER SIZE	HIC	PEAK CHEST G'S	CSI	CHEST ONSET RATE
50TH	832	48.6	726	1352

50 MPH FRONTAL IMPACT

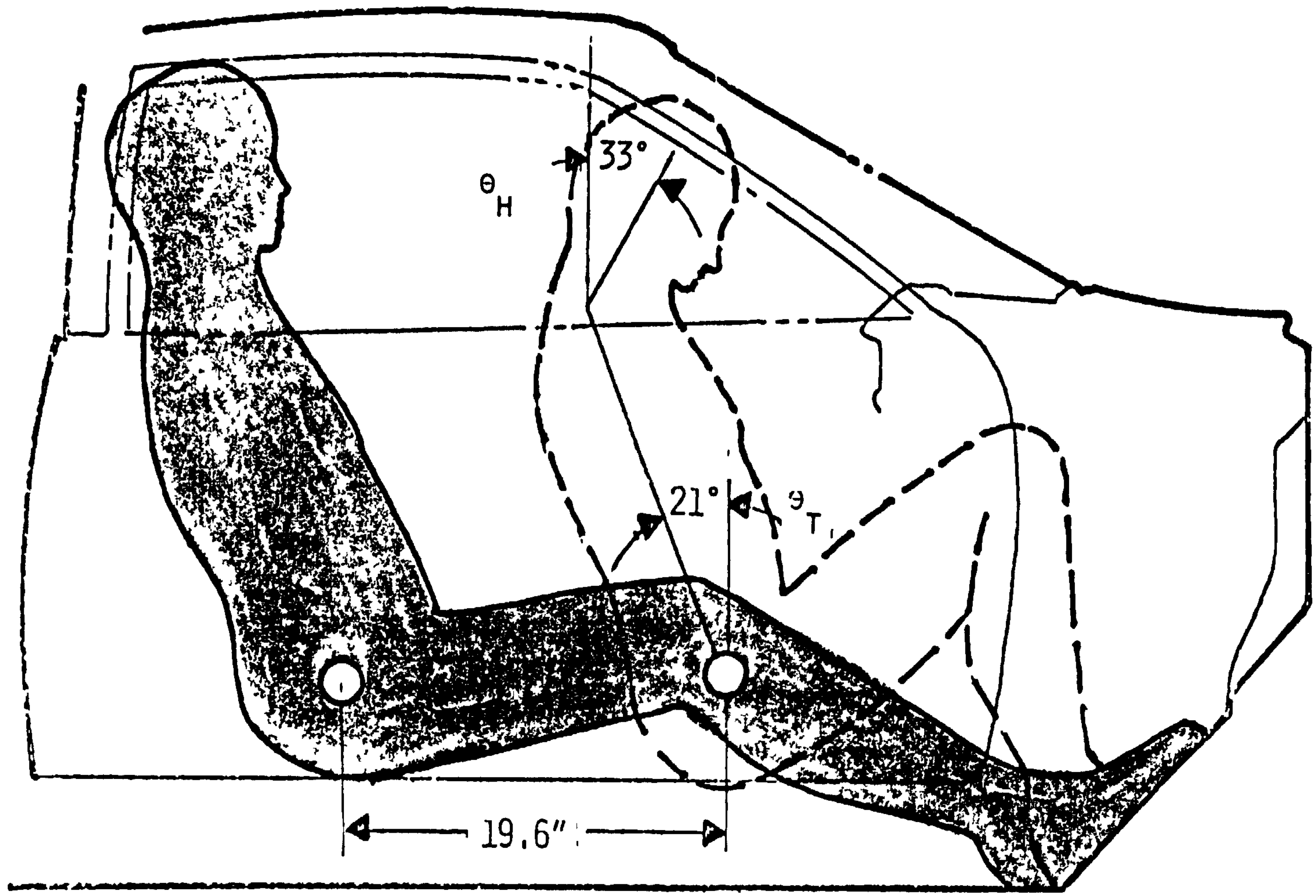


"H" POINT STROKE

FIGURE 4.4 "AIRBLT" SIMULATION RESULTS - 50th PERCENTILE MALE

PASSENGER SIZE	HIC	PEAK CHEST G'S	CSI	CHEST ONSET RATE
95TH	535	39.6	517	1057

50 MPH FRONTAL IMPACT



"H" POINT STROKE

FIGURE 4.5 "AIRBLT" SIMULATION RESULTS - 95th PERCENTILE MALE

PASSENGER SIZE	HIC	PEAK CHEST G'S	CSI	CHEST ONSET RATE
5TH	804	66.1	775	2040

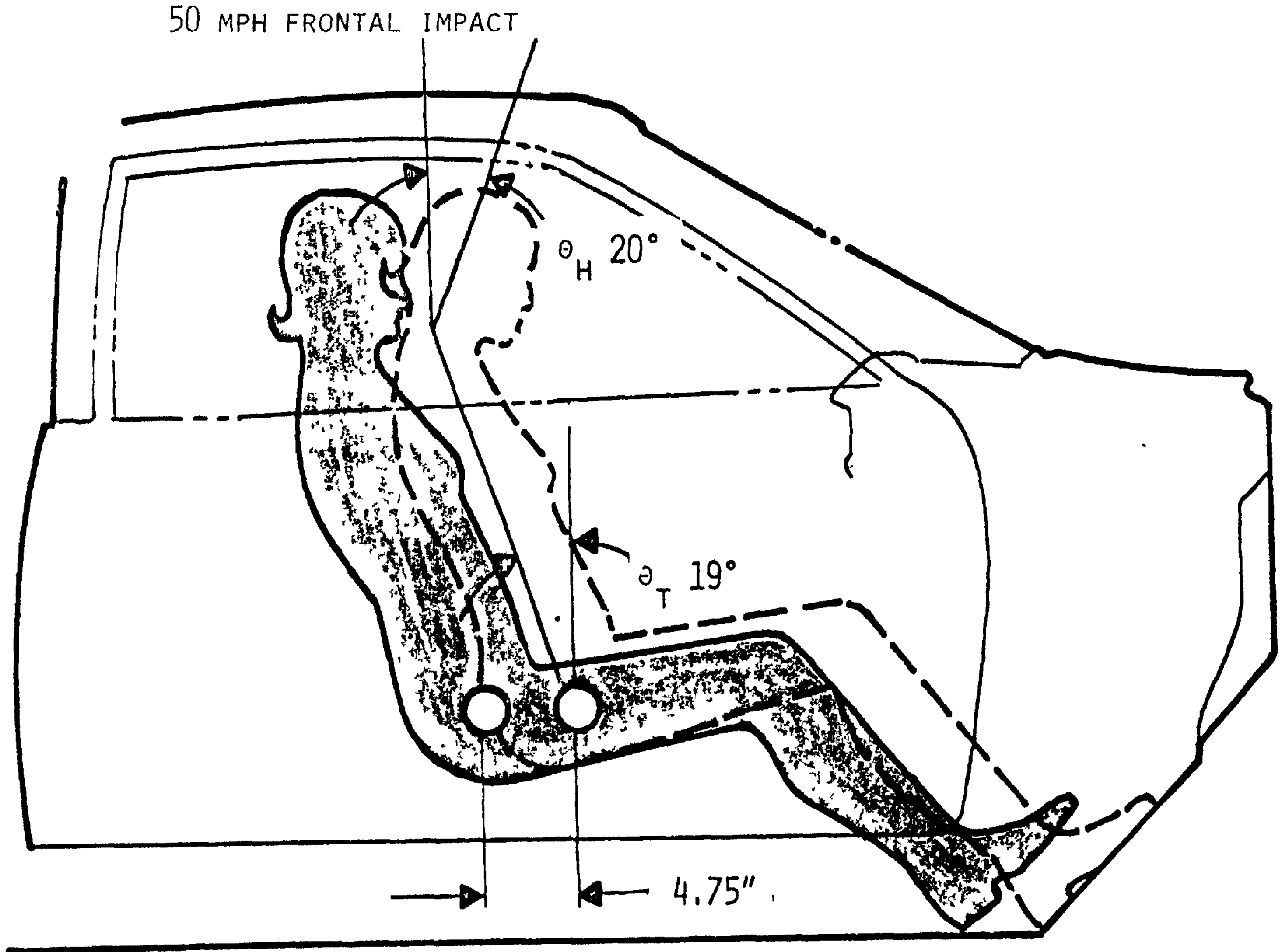
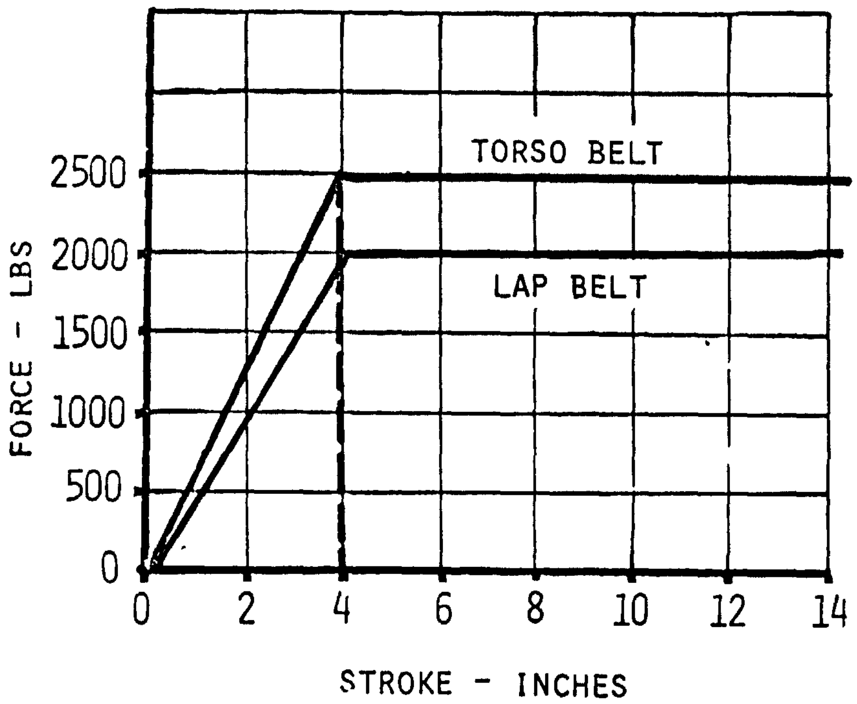


FIGURE 4.6 "AIRBLT" SIMULATION RESULTS - 5th PERCENTILE FEMALE

BELT FORCE-STROKE PROPERTIES



HEAD SUPPORT REQUIREMENTS

Note: A positive head rotation is forward.

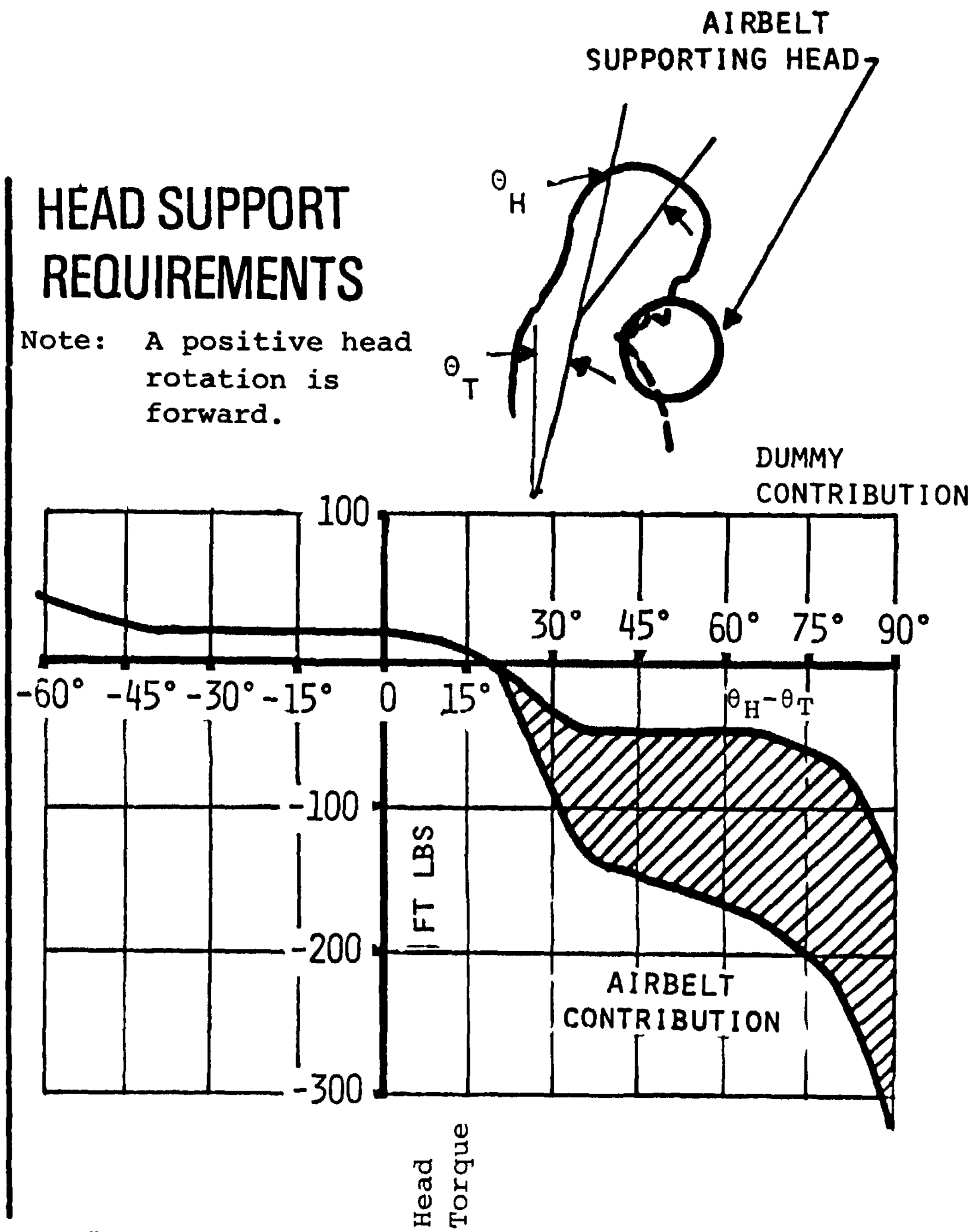


FIGURE 4.7 "AIRBLT" COMPUTER RESULTS

4.2.3 Computer Derived Inflator

The information summarized in Figure 4.7 gave us valuable data regarding the actual amount of head retardation that is required to reduce injury levels to lowest values. The question then is, "what do these retarding head torques mean in terms of airbelt related parameters such as gas flow into the airbelt, belt pressure, required belt volume, etc."

To obtain the answer to this question, we ran several computer simulations with the ABAG19 computer program. In this program we input the belt force-stroke properties derived in the AIRBLT computer runs, as well as the other necessary data described in Paragraph 4.2.1.2. The results of these simulations showed that the inflator Allied Chemical Company had preliminarily selected for our use would not have sufficient gas capacity to fill the bag to the pressure required to provide the degree of head support we had derived as necessary in the AIRBLT computer simulations. We gave the information to Allied and they redesigned the inflator to increase the gas producing capability of the inflator to obtain the required head support.

Subsequent sled testing with the new increased capacity inflator showed the actual measured head support to be almost identical to the value derived in the computer runs.

We feel the value of computer simulations was demonstrated rather graphically by this example. The early simulations of the crash event showed the need for an increased inflator capacity. Since this need was highlighted prior to sled testing, no time or money was wasted trying to make an underdesigned system work successfully on the sled.

4.2.4 Baseline Airbelt for Sled Testing

In the preceding, we have discussed in detail the role that computer simulations played in obtaining the design characteristics of various components that comprise the total airbelt system. In this section, we will summarize the total airbelt system that we call our "baseline system" which was the system with which we began the Phase I development sled testing.

There were two basic design approaches that were compatible with the computer derived component characteristics previously discussed.

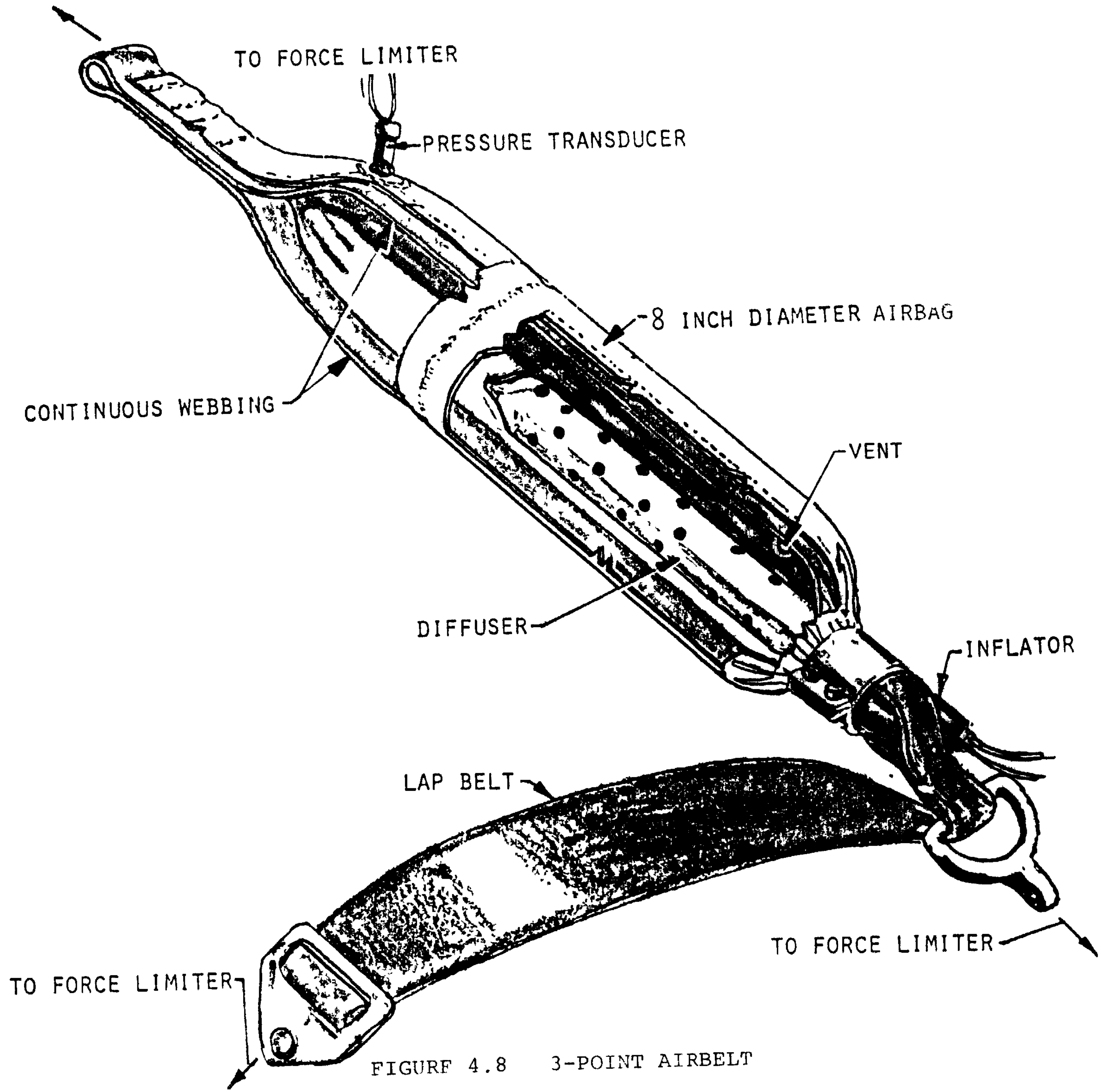
Design 1 - A 3-point airbelt consisting of a non-inflating lap belt plus an inflatable torso belt (Figure 4.8). The 3-point belt had energy absorbing force limiters at each anchor point (we will discuss these in more detail later). The anchor points chosen to begin testing were the standard Pinto anchor positions.

Design 2 - A 2-point airbelt. Here we eliminated the lap belt and replaced it with a knee restraint. The design is exactly equivalent to the 3-point version except for this substitution (Figure 4.9). The knee restraint chosen was DB styrofoam made by Dow Chemical Company (Figure 4.10).

Preliminary cost estimates showed the 2-point airbelt to be slightly less costly than the 3-point version -- primarily due to the ease with which it could be made passive and the fact that only two force limiters and anchors were required rather than three as in the 3-point version.

We considered inflating the lap belt in the 3-point version; however, after constructing some test hardware and running some static inflation tests, it became apparent that the additional gas generating capacity required of the inflator would be substantial. We felt the additional production cost that the system would accrue for dual inflators (one for the torso belt and one for the lap belt) or the cost for the manifolding required for a single large inflator would not be justified by substantially increased benefit. This, we felt, was due to the fact that even though contact pressures across the abdomen could be reudced somewhat by lap belt inflation, the contact pressures were already very low due to the force limiting nature of the belts themselves. We therefore judged that further benefits accruing due to lap belt inflation would be low and not justified by the additional cost of the system.

The force limiter we chose for sled testing is shown by Figure 4.11. Put very simply, the force limiter absorbs



FIGURF 4.8 3-POINT AIRBELT

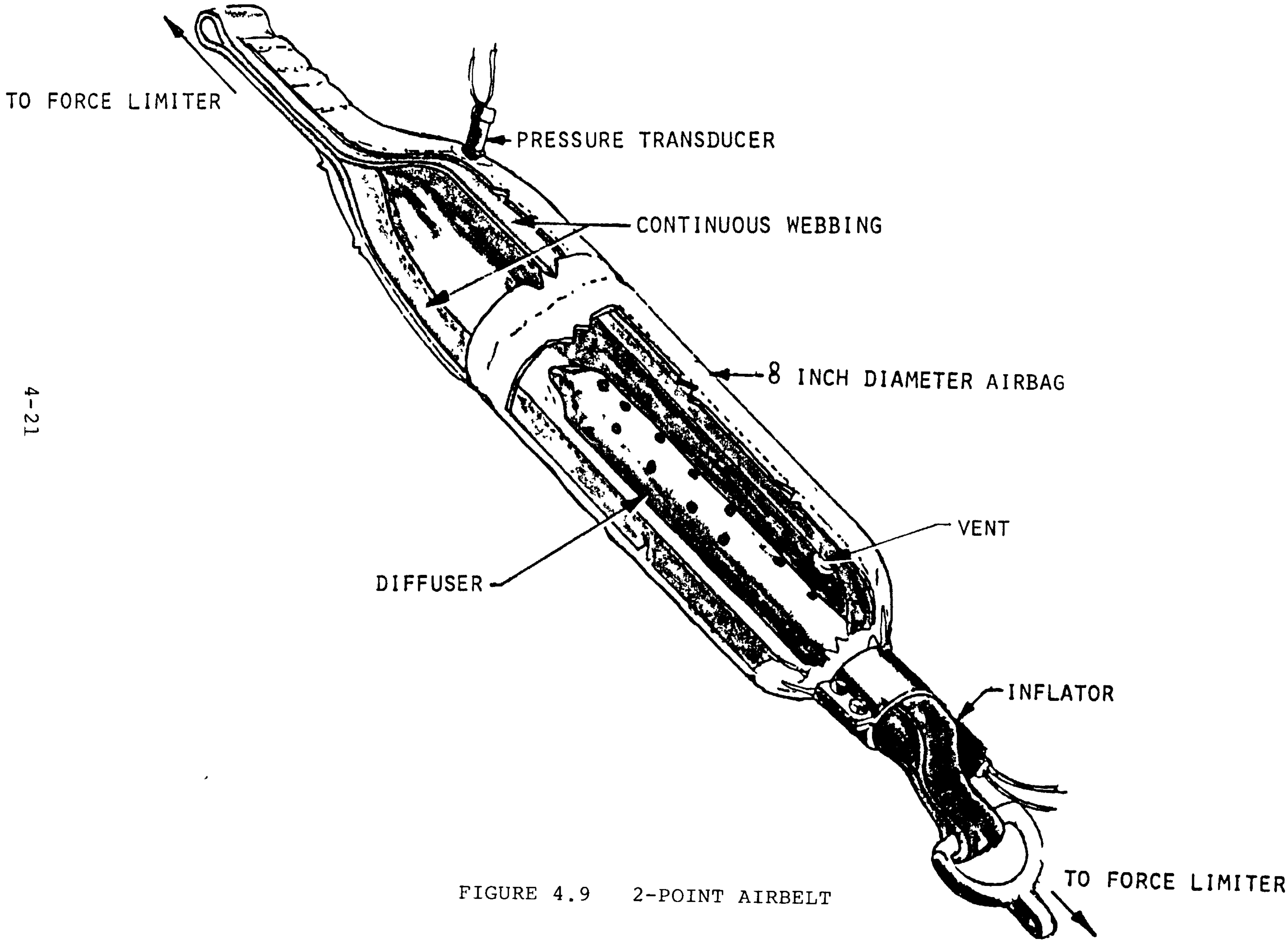


FIGURE 4.9 2-POINT AIRBELT

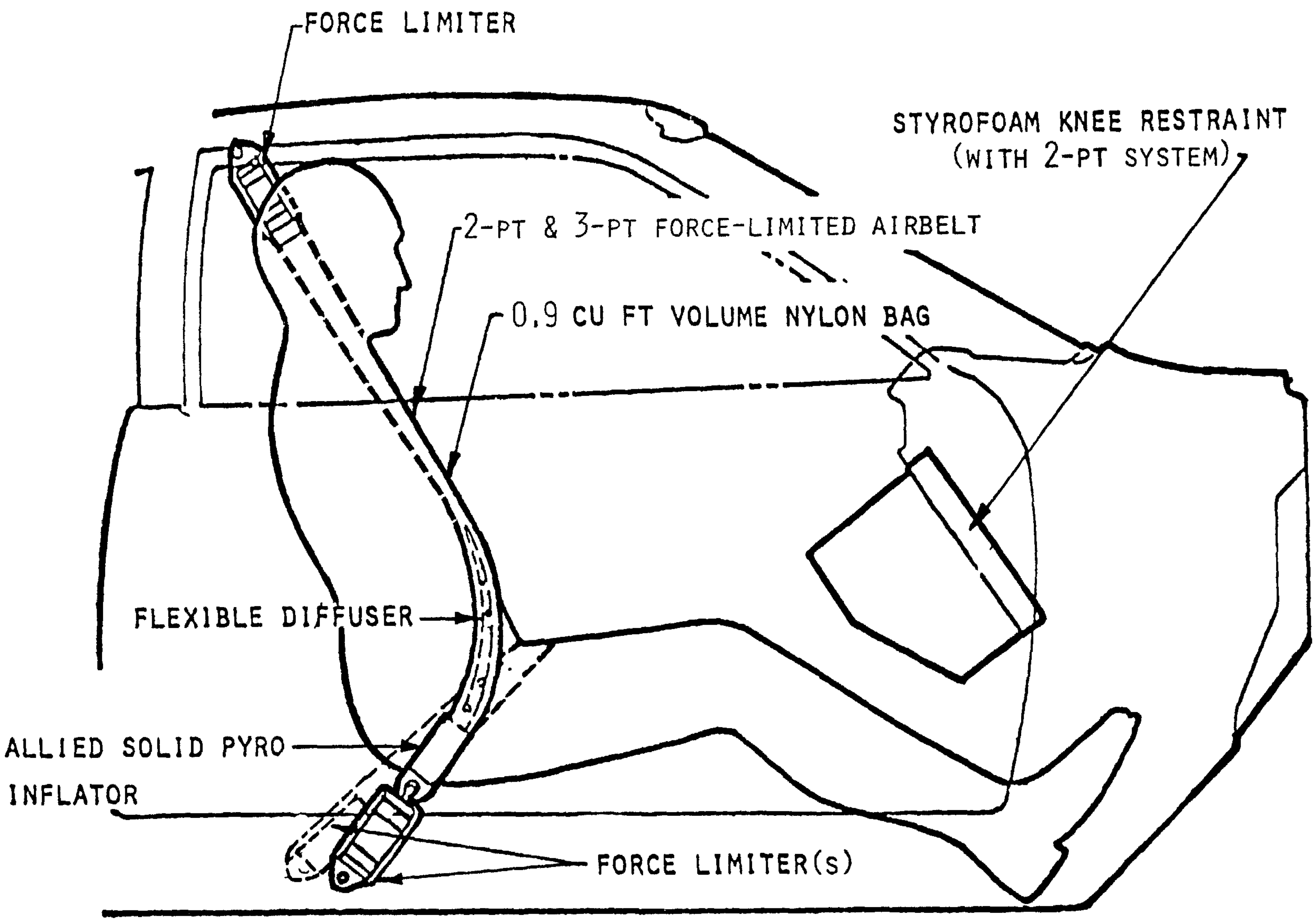


FIGURE 4.10 THE BASELINE AIRBELT RESTRAINT SYSTEMS

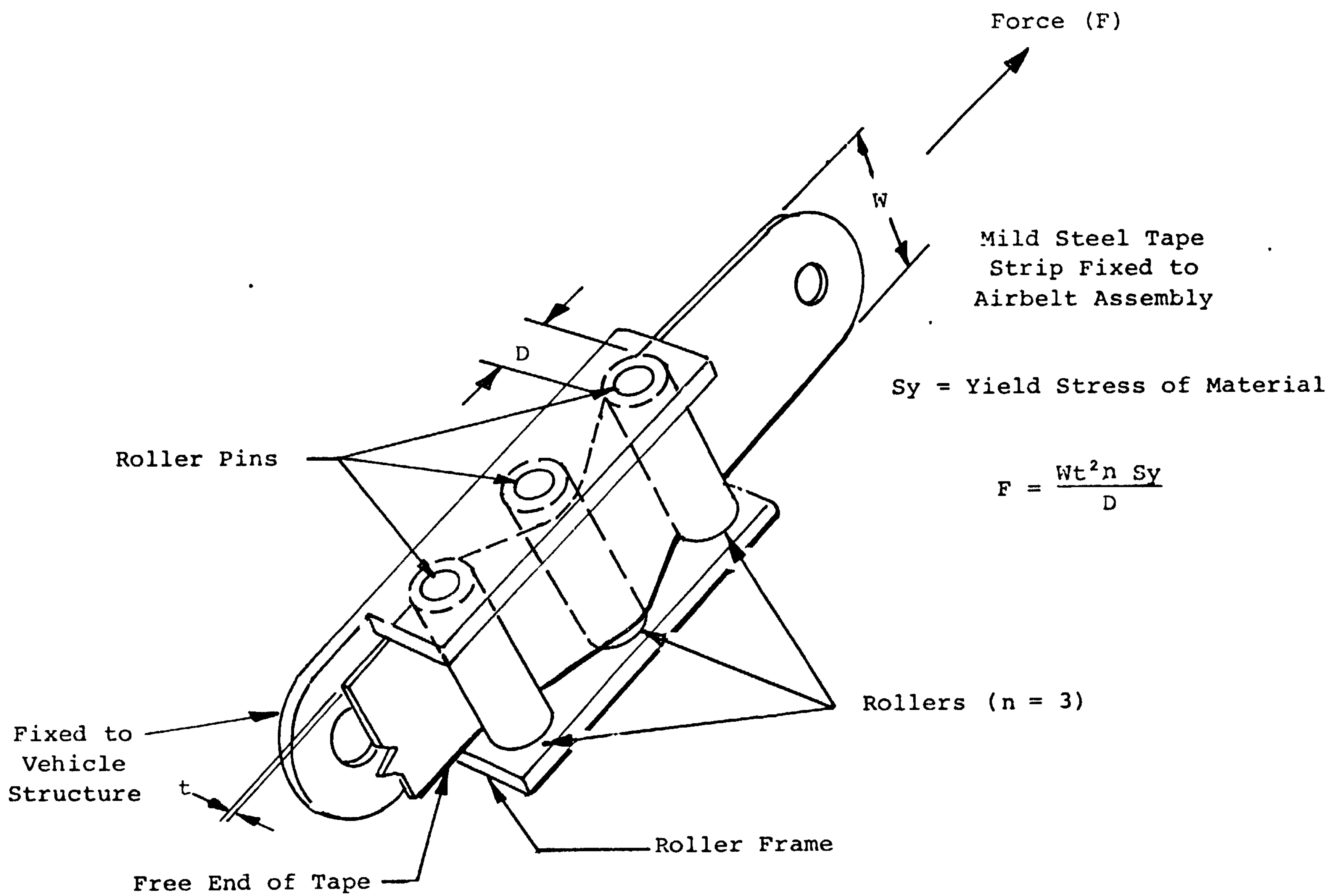


FIGURE 4.11 FORCE LIMITER

the kinetic energy of the decelerating passenger by pulling the metal tape across the roller arrangement shown in the figure. As the metal tape passes over the rollers, the tape is plastically deformed, resulting in a very efficient energy absorption process since the kinetic energy of the passenger is absorbed by the system rather than stored in the system, as would be the case for conventional belt webbing without these force limiters. This means the passenger rebound velocity and crash pulse amplification is substantially reduced over conventional systems by virtue of the force limiters at the belt anchors.

We fabricated the inflatable bag portion of the airbelt systems of a double layer of nylon. The particular specifications of this nylon are shown in Appendix A.

These components were assembled into the basic configuration shown in Figure 4.10 and the Phase I development sled tests began.

5.0 DEVELOPMENT SLED TESTS

With the baseline design determined by the procedure described in the previous sections, we procured the necessary materials, airbelts, inflators, etc. for Phase I development sled tests. We had as our objectives those set out in the beginning of this report -- namely, to meet the injury criteria for the entire size range of potential passengers in "barrier equivalent" frontal crashes up to 50 mph, and to accomplish this with a system that would lend itself to mass production.

The test phase, then, was to, first, verify our analytical techniques, and, then, to further tune and adjust the system for the anomalies that we couldn't account for in the analytical phase previously described.

5.1 Test Facilities and Instrumentation

5.1.1 Decelerating Sled

The bulk of the testing for this program took place on Minicars' high-speed decelerating sled. Figure 5.1 shows a time lapse photograph of a typical sled run in this program. The sled employs two 6-inch diameter cylinders stroking over a distance of 23-1/2 feet as the primary accelerator powered by a storage tank containing up to 250 psig air pressure. Additionally, a booster cylinder 10 inches in diameter is employed to double the acceleration pulse over the first 10 feet of the run.

The impact pulse at the end of the run is generated by impacting a beam probe into a band of mild steel which is then drawn over a series of steel rollers, generating forces of up to 60,000 pounds. Force levels may be set by adjustment of the rollers; variance in the width, thickness, and yield strength of the steel impact band; as well as adjustments in the impact probe. Using these variables, virtually any pulse may be generated.

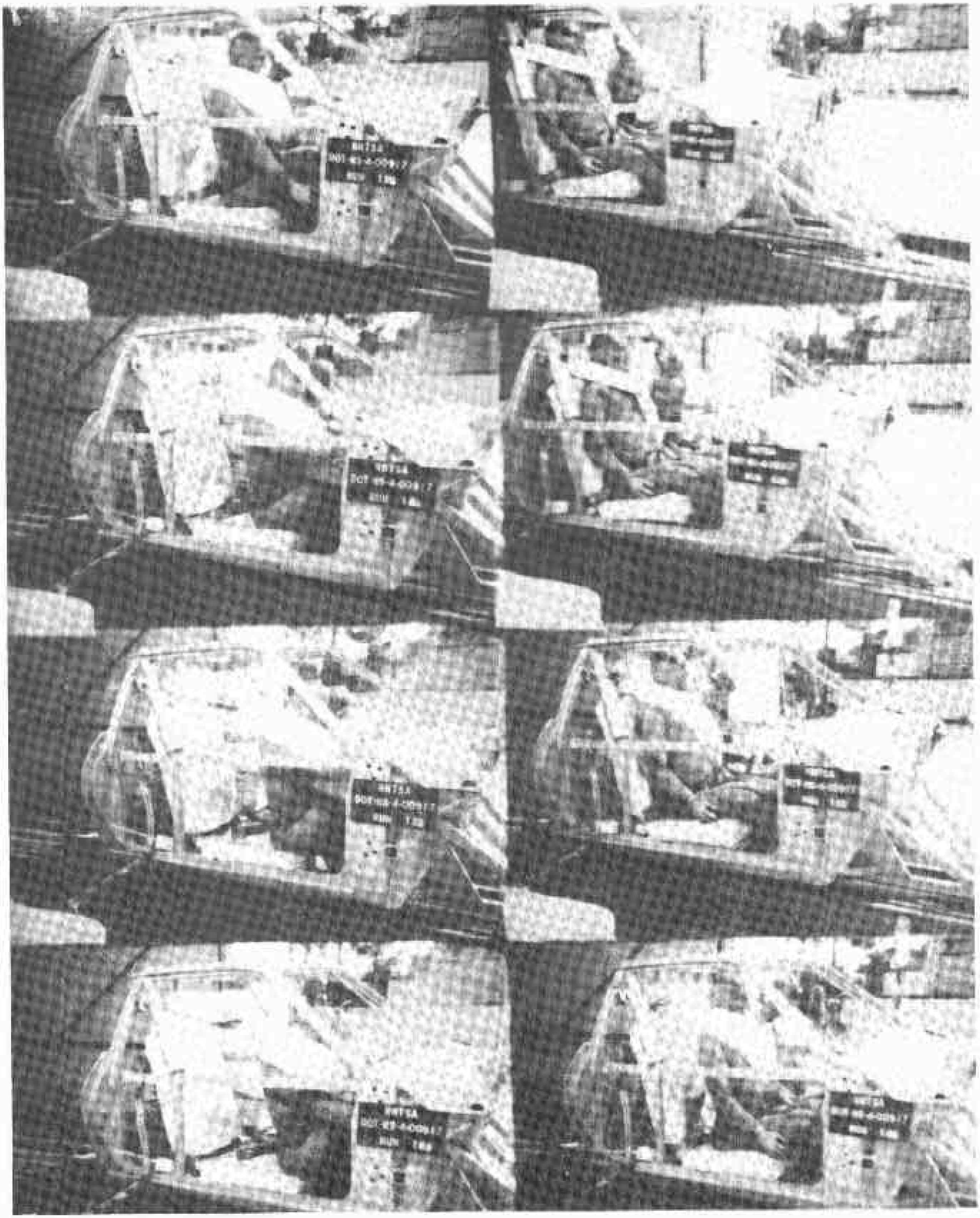


FIGURE 5.1 TIME LAPSE PHOTO OF SLED RUN 18

The sled has the ability to simulate up to 60-inch long crush strokes and has the added capability of accelerating actual vehicles into a barrier or other cars.

The compartment chosen for sled testing was a 1972 Ford Pinto compartment which was structurally modified to withstand the repeated simulation of high-speed barrier impacts. Figure 5.2 shows the compartment as mounted on the sled.

5.1.2 Instrumentation - Transducers

In order to measure the values of head and chest accelerations and the femur loads to be compared with the allowable injury criteria, we chose the following transducers from our inventory of test equipment.

Dummy - Head and chest triaxial accelerometers (model Endevco 7232C-750); femur load cells (strain gauge type, model GSE 2430).

Airbelt- Pressure transducer (model Endevco 8503A-100).

Sled - Accelerometer to determine sled pulse (model A6-100-350).

5.1.3 Instrumentation - Recording

1. Ampex FR-100, 14-channel, 60 inch/second FM/FM magnetic tape recorder.
2. CEC oscillograph, model 5-124.
3. Crystal controlled speed trap.
4. Sierra dummies, Models 805, 1095; GM Hybrid 50th percentile male; and Humanoid 50th percentile male.
5. 6-channel brush recorder.
6. 3 Photosonic 1-B high-speed 16 mm cameras with f/1.5 lens utilizing 7241 Kodak color film.
7. Electronic and visual event marker.
8. Instrumentation calibration.
   A. Calibrations are checked before and after each test by the following methods: Immediately prior to and after a test run, the gain of the amplifier/recording instrument is checked. The strain-gauge-type transducer channels are checked by the standard bridge unbalance method wherein a known value of

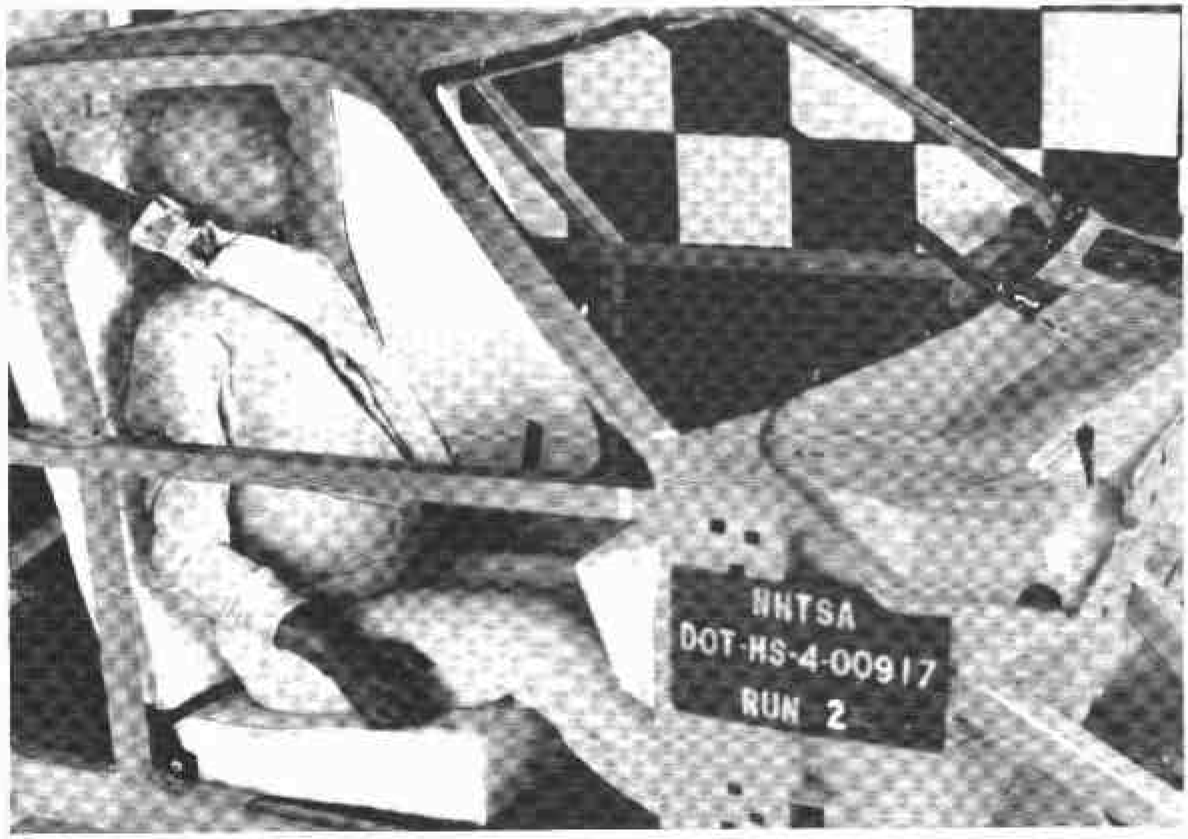


FIGURE 5.2 FORD PINTO COMPARTMENT AND AIRBELT RESTRAINED DUMMY PRIOR TO SLED RUN

resistance is used to unbalance the transducer bridge, providing a reference input signal to the remaining circuitry. In the case of the piezo-electric transducers, a known voltage is inserted in place of the transducer.

B. Accelerometer shake table is used to completely recalibrate accelerometers periodically.

9. Filters - SAE Class 1000 for head accelerometers, SAE Class 600 for femur load cells, SAE Class 180 for chest accelerometers.

5.2 Test Procedures

There are, of course, numerous things that are closely checked before each sled test -- many of these purely of a precautionary measure and several that have to do with the quality of data derived from the test. In the following, we will list only those procedures which are directly pertinent to the objective of the program.

5.2.1 Pre Test

1. Polaroid pictures are taken both pre and post impact.
2. Dummy is adjusted to 1 g and located in compartment in standard position relative to restraint system.
3. Measurements are taken to document dummy pre and post impact position.
4. Sled decelerator band is selected and recorded.
5. Anchor point energy absorber characteristics are checked and recorded.
6. Restraint system is checked to verify readiness for test.
7. Movie cameras and high-speed Polaroid camera are checked for ready.

5.2.2 Post Test

1. Velocity is recorded.
2. Total compartment deceleration stroke is recorded. This is equivalent to vehicle crush distance.
3. Dummy post impact position is recorded.
4. Force limiter strokes are recorded.
5. Knee target penetration is recorded (for 2-point system only).
6. Dummy injury measures are calculated, i.e., femur loads, HIC, and chest peak resultant g's.

7. Data is run off and evaluated.
8. High-speed Polaroid photograph is studied.
9. Movies are evaluated.
10. Plans for next run are made.

5.3 Phase I Development Sled Tests

The development sled tests began on November 19, 1974. The approach we took in the sled test program was, in Phase I, to derive a "developmental" restraint that was tuned to the point that:

1. The passenger trajectory consisted of pure rigid body motion in order to minimize HIC and peak chest g's (refer to DOT Report No. DOT-HS-801 528 to obtain an explanation of why this type of motion minimizes injury levels).

2. The available interior stroke was almost entirely used.

3. Little improvement in either injury level reduction and/or stroke efficiency could be realized by additional tests.

In this first test phase, emphasis was given to performance rather than producibility of the system except in cases where performance would not be sacrificed for an increase in producibility. In contrast, the Phase II tests were structured so that any changes to the system were geared to make the system more production oriented as well as to make those changes that the incorporation of the passive function of the belt requires. We planned to do this while, at the same time, maintaining the injury levels as close as possible to the lower bound values established in the Phase I tests.

Sled tests 1 through 18 constituted the Phase I sled tests. In these tests, we evaluated the performance of the restraint system in protecting the anthropometric size range of potential drivers from 5th percentile female through 95th percentile male for 50-mph frontal impacts in the subcompact vehicle crash environment. In these tests (summarized in Table 5.1), we established the following things:

1. The force-limited airbelt restraint system is capable of meeting the injury criteria for the anthropometric size range of passengers from 5th percentile female through 95th percentile male in frontal impacts to velocities substantially greater than 50 mph.

   In fact, both the 2-point and 3-point airbelt restraint systems were capable of easily meeting the injury criteria at 50-mph frontal impact velocities. However, the 2-point system was very sensitive to belt placement on the dummy, i.e., if the torso belt were not adjusted carefully so that it passed over the shoulder in exactly the same place each time, the dummy would perform erratically, sometimes rotating almost out of the restraint. Therefore, we judged the 3-point system to provide a more stable restraint for the variety of accident modes likely to be encountered in real world accidents. Consequently, we selected the 3-point system over the 2-point system for the Phase II development sled tests.

2. The seat positions in the standard (unmodified) Ford Pinto were located far enough aft in the compartment to prevent dummy penetration of the windshield plane for the 5th and 50th percentile dummies. The 95th percentile male was marginal in not exceeding the allowable compartment stroke from the Pinto aft-most seat adjustment position.

   We found a seat back angle (as measured from vertical) of 18 to 25 degrees to be in the range of seat back angle required for best airbelt performance. This is to be compared to the standard seat back angle in the Pinto of approximately 20 degrees.

3. The standard Pinto anchor points with which we began the test series were judged to be inefficient from a stroke efficiency standpoint. We found the angle from horizontal to the line of action of the belt to be too high to provide a major decelerative force to the

TABLE 5.1 PHASE I DEVELOPMENT SLED TESTS

Sled Run	Date	Passenger Size (Percentile)	Velocity mph	Crush in.	Sled g's Avg/Pk	Peak Resultant Chest g's (-3 msec)	HIC	Maximum Femur Load lbs Left	Maximum Femur Load lbs Right	Force Limiter Stroke -in Upper	Force Limiter Stroke -in Lower	Maximum Belt Pressure psi	Remarks
1	11-19-74	50th	36	22-3/4	30/35	57	1782	880	1080	3/8	0	21	Bag portion of belt seam ripped in two.
2	11-21-74	50th	42	24-1/2	36/41	126	2006	1200	2150	0	1/8	17	Reinforced belt seam. This time bag fabric burned and the bag came apart due to failure of the diffuser.
3	11-27-74	50th	41	27-3/8	30/35	34	671	940	1020	12-1/4	5/8	30	Fabricated new, stronger belt with continuous webbing. Softened force limiter. 3/4" dia. vent, 8" dia. belt
4 2-pt	12- 2-74	50th GM	40	26-3/4	27/38	52	1961*	1120	1150	3-1/4	4	40	1/2" dia. vent., 7" dia. belt. Softened lower force limiter; made upper harder. Submarine, head hit seat hard in rebound.
5-L 3-pt	12- 6-74	50th GM	42	24-1/2	32/42	58	491	1500	750	8-3/8	5-5/8 - 3-1/8	-	3-pt. belt, torso inflated, lap and torso force limited. Tibia transmitted load thru femurs when legs hit floorboard. 1/2" dia. vent.
5-R 2-pt	12-11-74	50th GM	42	24-1/2	32/42	49	470	1000	900	8-1/8	5-5/8	36	2-pt. belt, top tore out of bag late in event. 1/2" dia. vent.
6-L 3-pt	12-11-74	50th GM	45	29	35/46	53	501	630	580	11-7/8	8-5/8 - 2-1/4	26	Enlarged vent to 5/8" dia., softened force limiters, large amount of head rotation in R-L direction.
6-R 2-pt	12-11-74	50th GM	45	29	35/46	55	899	1380	1370	12-1/2	5-1/2	-	Enlarged vent to 5/8" dia., softened force limiters
7-L 3-pt	12-13-74	50th GM	47	28-1/4	35/48	57	478	1120	1040	11-1/2	12-1/4	-	Softened force limiters slightly.
7-R 2-pt	12-13-74	50th GM	47	28-1/4	35/48	49	529	1300	810	14-1/2	7-3/4	30	Softened force limiters slightly.
8-L 2-pt	1- 7-75	5th	46	28-1/2	33/47	52	468	1400	1030	4-3/4	9-3/8		Used larger volume belt (.95 cu. ft. instead of .8 cu. ft.) 5/8 in. dia. vent.
8-R 2-pt	1- 7-75	95th	46	28-1/2	33/47	60	1035	1280	1980	22-1/2	10-5/8		Moved seat 1" rearward, used larger volume belt (.95 cu. ft. instead of .8 cu. ft.) 5/8 in dia. vent. Tape pulled completely through upper force limiter. Head strike on plenum.

* Rebound g-spike.

TABLE 5.1 PHASE I DEVELOPMENT SLED TESTS (continued)

Sled Run	Date	Passenger Size (Percen-tile)	Velocity mph	Crush in.	Sled g's Avg/Pk	Peak Resultant Chest g's (-3 msec)	HIC	Maximum Femur Load lbs Left	Maximum Femur Load lbs Right	Force Limiter Stroke -in Upper	Force Limiter Stroke -in Lower	Maximum Belt Pressure psi	Remarks
9-L 2-pt	1- 9-75	5th	47	28-1/2	34/44	51	422	900	1140	4-1/2	9-1/4		Repeat of Run No. 8. Good run.
9-R 2-pt	1- 9-75	95th	47	28-1/2	34/44	61	643	-	-	21	11-1/2		Upper force limiter bands made "harder" in last several inches of stroke. Chest g's a little high. Femurs struck knee restraint support beam.
10-L 2-pt	1-14-75	95th	48	29-1/2	35/44	57	790	-	-	18-3/4	6-3/8		Moved 95th rearward to aftmost seat position in stock Pinto. Adjusted forte limiter for upper torso. Femurs struck knee restraint upper support beam. Will relocate beam.
10-R 2-pt	1-14-75	5th	48	29-1/2	35/44	57/130	1548	950	1700	4-3/16	7		Rotated seat back fwd a little, upper torso force limiter buckle caught on seat support limiting stroke. 130 g resultant chest acceleration on rebound.
11-L 3-pt	1-20-75	95th	48	30-1/2	33/38	53	938	-	-	22	9-7/8-8-1/8		Head SI and RL components high. No load cells in femurs so we can check out new support beam.
11-R 3-pt	1-20-75	5th	48	30-1/2	33/38	66	1183	630	900	6-7/8	6-1/2-2-3/8		Spike in chest g's; rebound g spike on head.
12-L 2-pt	2- 6-75	50th GM	47	27	36/51	49	670*/840	1160	920	15-1/4	2-1/4	17	Used new airbelt "head wing" to pre-vent head rotation in R-L direction. Slightly stiffened lower torso F.L. and softened upper torso F.L. to get a little less submarine. Good test-no R-L head rotation.
12-R 2-pt	2- 6-75	50th GM	47	27	36/51	38	598	920	1430	15	2-1/2	29	Same force limiter adjustments as above, no "head wing." Speedometer malfunction. Sled velocity obtained by integrating acc. trace. Good run-very low injury levels.
13-L 3-pt	2-12-75	50th GM	51	28	38/63	52	413	600	1650	14	10-3/4-8-7/8	13	Airbelt with head wing, wing rotated away from head so that head rotated in R-L direction. Large spike in crash pulse.
13-R 3-pt	2-12-75	50th GM	51	28	38/63	44	446	840	840	12-3/8	14-9 [illegible]	24	Regular airbelt configuration. Head rotated in -L direct[illegible]n, seems more severe with 3-pt system.

* Rebound g-spike

TABLE 5.1 PHASE I DEVELOPMENT SLED TESTS (continued)

Sled Run	Date	Passenger Size (Percentile)	Velocity mph	Crush in.	Sled g's Avg/Pk	Peak Resultant Chest g's (-3 msec)	HIC	Maximum Femur Load lbs Left	Maximum Femur Load lbs Right	Force Limiter Stroke-in Upper	Force Limiter Stroke-in Lower	Maximum Belt Pressure psi	Remarks
14-L 2-pt	2-14-75	50th GM	49	29	36/49	75**	661	650	1230	17-1/2	4-1/2	30	Airbelt without head wing (same as RFP, Run 12). Quite a bit of R-L rotation of dummy.
14-R 2-pt	2-14-75	50th Humanoid	49	29	36/49	53	951	1000	1620	16-3/8	4-3/4	21	Airbelt with head wing higher on belt than in Runs 12 & 13. Fair amount of fwd head rotation. Seat back collapse caused limp belt for substantial duration.
15-L 2-pt	2-19-75	50th GM	48	28	35/46	36	1532	670	1560	13	--	33	Eliminated lower force limiter, firmed up upper force limiter. Substantial R-L roation of dummy. Dummy came partially out of restraint.
15-R 2-pt	2-19-75	50th Humanoid	48	28	35/46	51	1377	1040	1370	14-1/2	3	--	Firmed up upper force limiter, some R-L rotation of dummy. Dummy looks unstable in 2-pt system.
16-L 2-pt	2-21-75	50th GM	47	31-1/2	30/35	48	1158*/1697	1100	2000	13-3/4	3-1/2	26	R-L rotation again. Very sensitive to belt placement on torso. Rebound g's high due to exposed unpadded surface impact.
16-R 3-pt	2-21-75	50th Humanoid	47	31-1/2	30/35	43	420	882	865	13-5/8	10-3/4-7-7/8	27	Good trajectory. Rebound g levels fairly high due to head impact with seat frame on rebound. 3-pt sys. looks best.
17-L 3-pt	2-25-75	50th GM	46	31-1/2	29/36	39	344	500	680	12	12-1/4-6-1/2	26	Same set up as RFP last run (16). Good run. Some R-L rotation of dummy due to unequal stroke of lap force limiters, dummy staying on seat.
17-R 3-pt	2-25-75	50th Humanoid	46	31-1/2	29/36	39	237	1390	900	9-1/2	11-1/2-9-5/8	28	Softened upper force limiter slightly. Good run. Short in chest traces at 60 msec, some R-L rotation of dummy for same reason as LFP, heads hit each other during rebound.
18-L 3-pt	2-26-75	50th GM	50	33	29/38	44	408*/582	320	260	15	9-7/8-9-1/4	29	Good run.
18-R 3-pt	2-26-75	50th Humanoid	50	33	29/38	40	373	2220	730	13-1/2	10-7/8-6-5/8	26	Left foot hit sled transmission tunnel flat surface.

* HIC without rebound effects. All other values without asterisk include rebound effects.
** Dummy came part way out of restraint due to seat back collapse on sled acceleration. Dummy hit dash.

passenger in the initial stroking stages of the event. We therefore changed the belt anchor locations somewhat to obtain a more stroke efficient system (Figure 5.3). This change also substantially reduces the belt forces required to adequately restrain the passenger due to the more favorable belt angles.

4. The dummy head tends to rotate in a right-left direction due to the direction the head and torso are loaded by the asymmetric torso belt (Figure 5.4). Injury levels were not increased due to this phenomenon; however, we did try unsuccessfully to eliminate this effect (refer to Appendix B for an excerpt from the February progress report). We suspected that this effect was aggravated by dummy neck construction. A later cadaver test tended to verify this supposition. This test is reported in Section 6.0. In this test, there was substantially less head rotation.

5. The energy-absorbing belt anchors (force limiters) attenuate the g levels that otherwise would be transmitted to the passenger through the compartment. G-amplification to the passenger through the restraint is very low with the force limiters acting as filters to prevent crash pulse fluctuations and spurious "g spikes" from reaching the passenger.

6. The computer selected pure pyrotechnic inflator works extremely well. The inherent flow characteristics of a pure pyro inflator are ideal for providing the peak gas flow rate at the time it is needed, i.e., when the head begins to pitch forward.

5.4 Phase II Development Sled Tests

We began the Phase II sled tests on March 19, 1975, with Run 19. Once we chose the 3-point airbelt restraint system as our preferred restraint system, we began finalizing the details of making the 3-point belt system passive. The details of the design of the passive 3-point belt system are presented in Section 7.0; however, one implication of

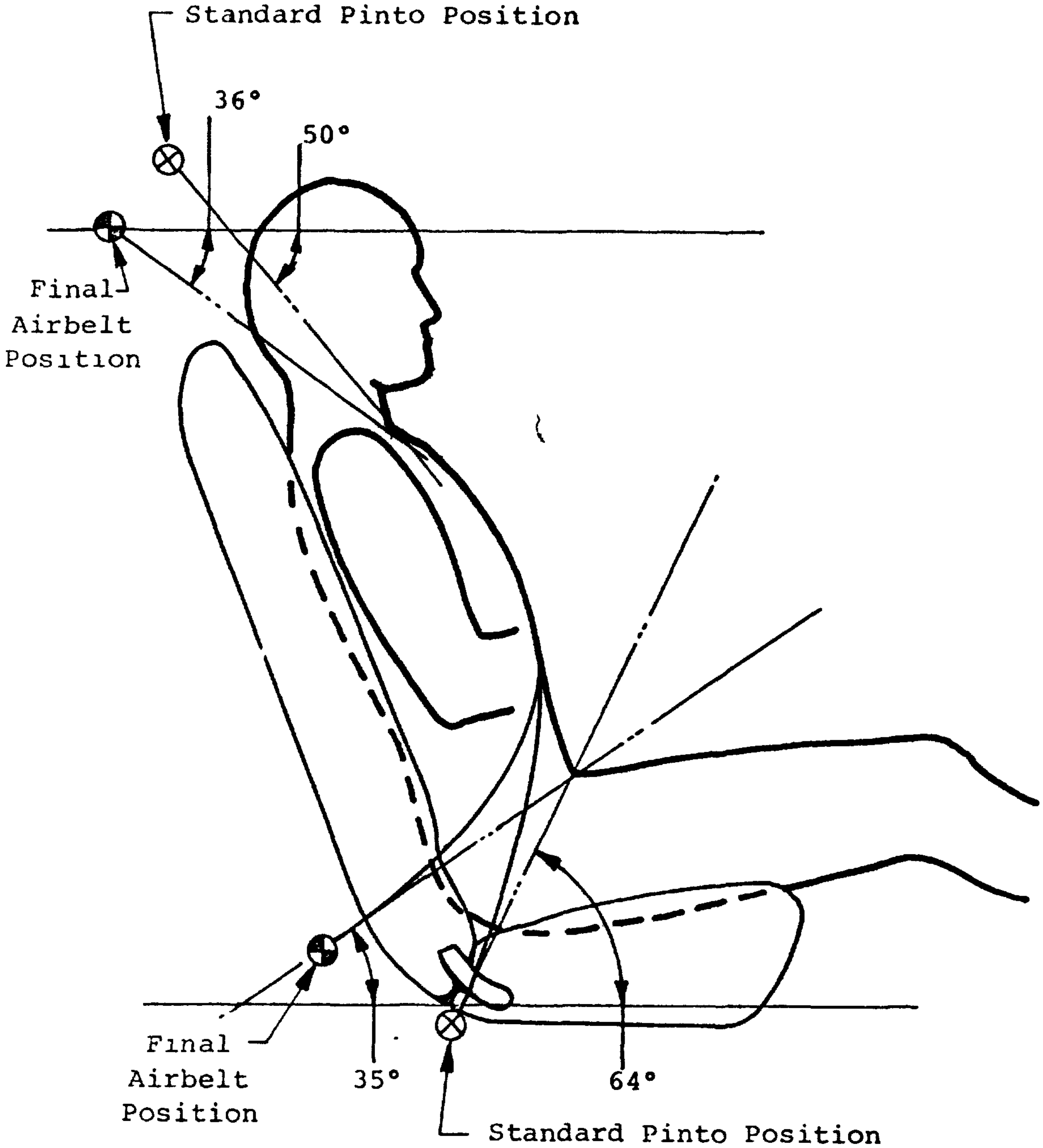


FIGURE 5.3 ANCHOR POSITION RELOCATION

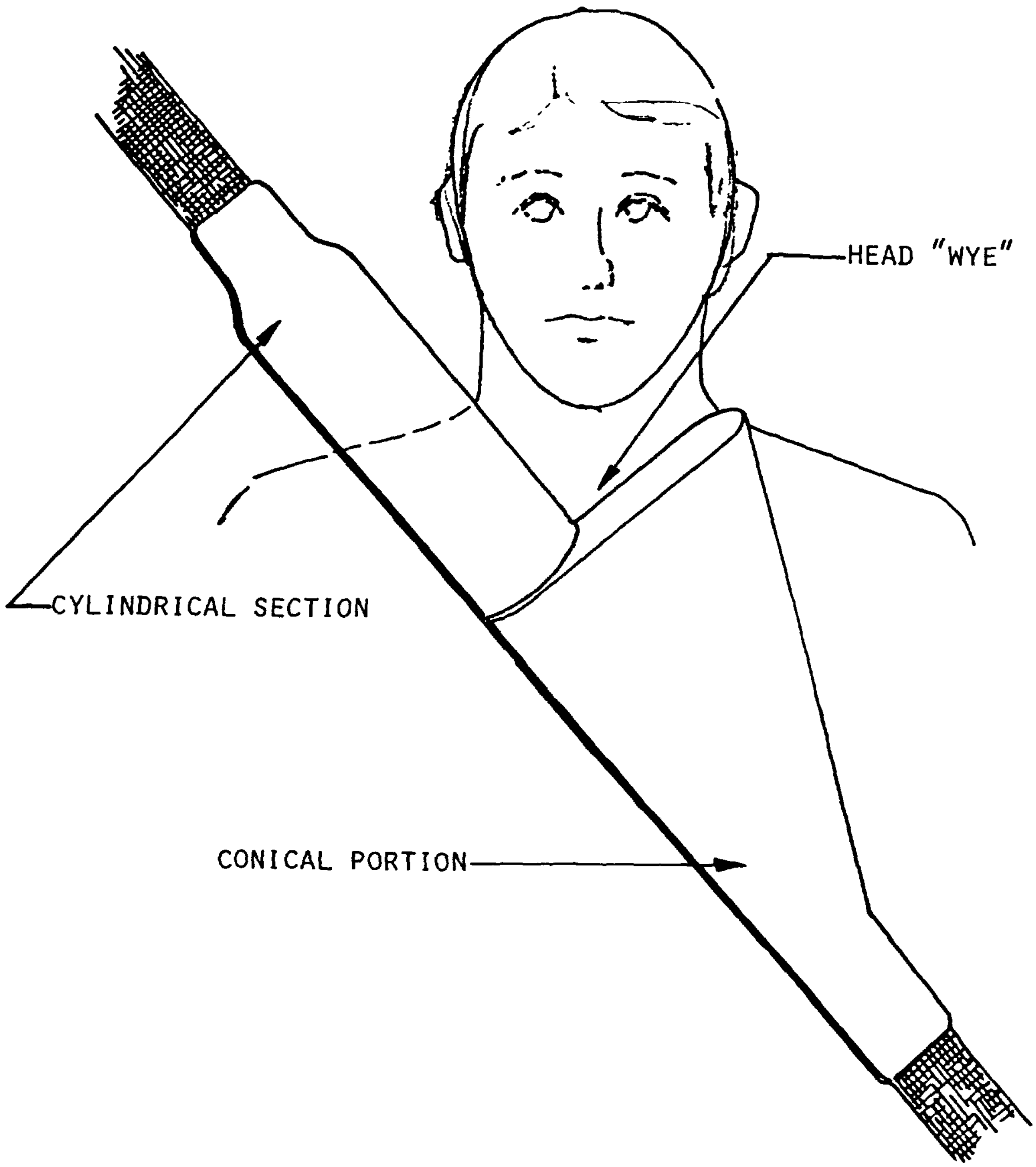


FIGURE 5.4 ATTEMPTED SOLUTION TO THE HEAD ROTATION PROBLEM

this design affected a change in the design to be tested in the Phase II development sled tests and it is this change we will now discuss.

For reasons discussed in Section 7.0, the upper anchor position was moved from the B-pillar area to the center roof position in the car. The change was minor as far as passenger kinematics were concerned since the lower anchor points were not changed and since the upper anchor position had virtually the same relationship with the left side of the passenger, as was previously true with the passenger right side. Thus the torso belt came across the chest at exactly the same angle as before, only this time it passed across the passenger left shoulder rather than the passenger right shoulder, as was the case when the upper anchor was in the B-pillar area.

As a consequence of this change, we continued the development sled testing with Run 19 with the upper anchor changed to the position that would facilitate the later introduction of the passive belt design.

During the Phase II tests, we introduced oblique tests into the test sequence for the first time. We continued to test the 3-point system in both frontal and oblique modes with various passenger sizes with the objective of fine tuning the system to the point where we were confident that further design modifications would not result in significant performance improvements. Table 5.2 summarizes the results of the Phase II development sled tests.

Once we had largely finalized the design of the 3-point version of the force-limited airbelt, we set up a series of sled tests with conventional 3-point belts, as well as force limited -- but not inflated -- 3-point belts. The reason for these additional tests was to compare the performance of the airbelt with these other systems so we could ascertain the degree of improvement the airbelt offered over these systems. Figure 5.5 summarizes the results of these comparative tests.

The striking thing about these tests is the huge reduction in HIC that is realized by the airbelt as compared to the

TABLE 5.2 PHASE II DEVELOPMENT SLED TESTS

Sled Run	Date	Passenger Size (Percentile)	Velocity mph	Compartment Rotation Degrees	Crush in.	Sled g's Avg/Pk	Peak Resultant Chest g's (-3 msec)	HIC	Maximum Femur Load lbs Left	Maximum Femur Load lbs Right	Force Limiter Stroke-in Upper	Force Limiter Stroke-in Lower	Maximum Belt Pressure psi	Remarks
19-L	3-19-75	50th GM	46	0	31	31/38	44	489	1700	1700	12-3/4	7-10	24	Changed upper anchor to center of compartment. High femur loads caused by foot impacting toeboard.
19-R	3-19-75	50th GM	46	0	31	31/38	47	528	1500	1500	11	8-3/4-11-1/4	27	High initial femur spikes for same reason as above. Tried outboard lower anchor further back in compartment to cut down amount of R-L head rotation.
20-L	3-20-75	50th	38	30	34	20/31	high	high	*	*	3-1/2	6-0	20	1st oblique test. Due to insufficient door padding, the dummy bottomed out on the door structure. The welds attaching dummy head also broke and the dummy head impacted the door structure.
20-R	3-20-75	50th GM	38	30	34	20/31	27	222	*	*	7	2-1/2-6	-	Airbelt did not inflate due to wiring error; however force limiter stroked.
21-L	3-27-75	50th GM	35	30	27-1/2	20/37	26	334	*	*	1-1/2	1-1/2	21	Reconstructed door with additional padding. The corrected high chest and head g levels seen in previous run.
21-R	3-27-75	50th GM	35	30	27-1/2	20/37	20	225	*	*	1/2	1/4-2	22	Left side head initially retarded by inflated belt. Head then slips under belt. Does not appear to be a bad thing; in fact, the initial head retardation keeps head from reaching high rotational velocity in R-L direction.
22-L	3-27-75	50th GM	39	30	34	20/34	32	464	*	*	1	2-1/2-1/2	19	Repeat of Run 21, except slightly higher velocity. Good run.
22-R	3-27-75	50th GM	39	30	34	20/34	22	244	*	*	3/4	2-5	22	Repeat of Run 21. Good run.
23-L	4-1-75	95th GM	46	30	34	21/31	40	421	*	*	5	6-1/2-1-1/2	21	1st oblique test with 95th percentile male.
23-R	4-1-75	50th Sierra	41	30	34	21/31	25	203	*	*	3/4	1-1/2-5	**	
24-R	4-8-75	95th Sierra	45	0	25	35/57	40	461	907	606	19	17-12-1/2	25	Increased stroke from the force limiters over the 50th percentile dummy. Low injury levels.
25-R	4-10-75	95th Sierra	50	0	31	30/40	42	428	--	591	15	14-15	25	Left knee of dummy bottomed out on support structure in firewall through knee bolster causing load cell on left femur to go off scale.

* All femur loads are tension loads in the oblique tests.
**Pressure transducer malfunction.

TABLE 5.2 PHASE II DEVELOPMENT SLED TESTS (continued)

Sled Run	Date	Passenger Size (Percentile)	Velocity mph	Compartment Rotation Degrees	Crush in.	Sled g's Avg/Pk	Peak Resultant Chest g's (-3 msec)	HIC	Maximum Femur Load lbs Left	Maximum Femur Load lbs Right	Force Limiter Stroke-in Upper	Force Limiter Stroke-in Lower	Maximum Belt Pressure psi	Remarks
26-L	4-14-75	50th GM Hybrid	54	0	35	28.4/41	67	1698	1089	1467	None		--	Conventional belt system without force limiters. Very high head and chest injury levels.
26-R	4-14-75	50th GM Hybrid	54	0	35	28.4/41	46	693	1439	646	15-3/4	9-1/8 -9	--	Airbelt without inflator. (Force limited 3-pt. belt)
27-L	4-15-75	50th GM Hybrid	53	0	34	30/38	65	1741	--	693	None		--	Conventional belt system without force limiters. Malfunction in left femur load cell.
27-R	4-15-75	50th GM Hybrid	53	0	34	30/38	45	301	2737	1731	8-1/2	4-1/2 -3	29	Airbelt became perforated during inflation. Femurs bottomed out on knee restraint support structure. The dummy submarined with the lap belt coming up under the ribs. Lap belt was too high on abdomen.
28-L	5-14-75	50th	54	0	34	34/47	71	3023*	1696	1792	-	-	-	Conventional 3-pt system. Head accelerometer malfunction.
28-R	5-14-75	50th	54	0	34	34/47	49	551	847	617	11-3/8	10-3/4-11	27	Dummy was restrained by full airbelt system. It submarined slightly but had low injury levels.
29	5-20-75	6-yr-old	30	0	20	22/25	37	854	-	-	1	1 - 1/2	17	No load cells in femurs. The child dummy was sitting on a foam pad which raised it 6". Dummy appeared to behave about same as it did without pad.

* HIC computed from SI trace alone.

	CONVENTIONAL 3-PT BELT			FORCE LIMITED 3-PT BELT	FORCE LIMITED 3-PT AIR BELT	
SLED RUN	26	27	28	26	27	28
HIC	1698	1741	3023*	693	301	551
PEAK RESULTANT CHEST G'S	67	65	71	46	45	49
REMARKS	SEVERE HEAD ROTATION. VERY HIGH BELT LOADS. HIGH REBOUND VELOCITY.			MODERATE HEAD WHIP. HEAD VERY CLOSE TO WINDSHIELD AND DASH.	VIRTUALLY NO FORWARD HEAD ROTATION. A LOT OF CLEARANCE BETWEEN HEAD AND WINDSHIELD.	

LOST ONE HEAD CHANNEL - HIC CALCULATED WITH VERTICAL HEAD COMPONENT ONLY

FIGURE 5.5 RESTRAINT SYSTEM COMPARISONS - 54 MPH FRONTAL SLED TEST conventional 3-point belt. This, of course, is made possible by the head rotational restraint provided by the airbelt over conventional belt systems. In all the comparative tests we conducted, a reduction in HIC of approximately a factor of 6 is realized. This shows very graphically the strong dependence of HIC on the rotational velocity of the head. Eliminate head rotation and you eliminate virtually all the up-down head acceleration component.

Although not as graphic, the peak resultant chest g's are reduced in the airbelt design as compared to the conventional system. Here the reduction of approximately 50 percent is primarily due to the incorporation of force limiters in the airbelt design.

We therefore see that use of the airbelt has the potential for tremendous reductions in injury level and, therfore, societal cost as compared to conventional belt systems.

The airbelt also results in an injury level reduction as compared to force-limited 3-point belt systems (Figure 5-5). Here the reduction is not as great as was the case with the conventional 3-point belt system. The chest g levels for the two systems are virtually the same, due to the fact that identical force limiters were used in the comparative tests. However, here again the head injury, as measured by the HIC values, is slightly lower for the airbelt. There is a surprising reduction in HIC realized by the mere incorporation of force limiters in the design, as shown in the figure when the conventional system is compared to the force-limited (but not inflated) system. This indicates the potential properly-phased force limiters have on reducing head injury. The reason for this is that head rotational velocities are greatly reduced by:

1. Allowing the passenger to stroke further relative to the compartment.

2. Absorbing energy in the force limiters as opposed to storing energy in the belt webbing. This reduces the the effective crash velocity for the passenger since rebound velocities are much reduced.

5.5 The Finalized System

During the development sled test series, we have described how we evolved and then finalized the design of the airbelt system from a crash performance standpoint. Remaining to be demonstrated were:

1. The passive operation of the derived 3-point airbelt system.

2. The demonstration in a series of evaluation sled tests and evaluation car crash tests that the finalized system would repeatably meet the injury criteria.

Section 6.0 of the report will address the evaluation tests and Section 7.0 will deal with the passive version of the airbelt.

At this point, we will summarize the finalized version of the airbelt.

5.5.1 The Airbag

The airbag portion of the airbelt is that portion that inflates upon impact. In the case of the finalized version of the Minicars' airbelt design, only the torso belt inflates. This inflated section is 30 inches long by 8 inches in diameter and is constructed of two layers of nylon material (Appendix A). Figure 5.6 shows a schematic of the airbag portion of the airbelt. Running longitudinally along two sides of the inflated cylinder are strips of conventional seat belt webbing. This webbing is continuous, as shown in the figure, and eventually joins and is sewn together as a double layer to form the lap belt and the connecting webbing to the upper force limiter and belt anchor.

Located in the airbag portion of the airbelt is a 5/8-inch diameter vent which attenuates rebound by dissipating a portion of the stored compressive energy in the gas. Inside the airbag and attached to the inflator is a diffuser. The

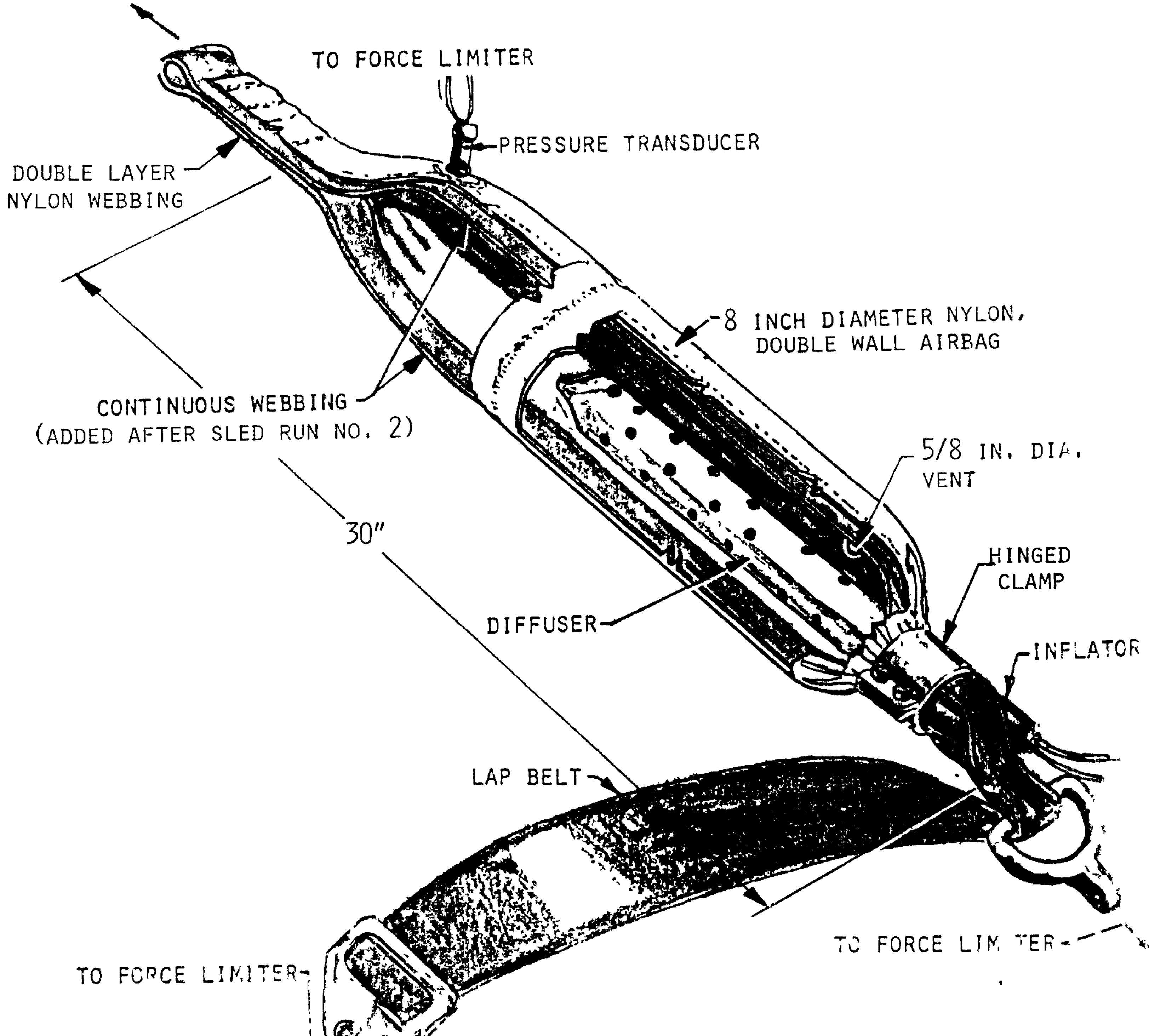


FIGURE 5.6 FINAL VERSION OF AIRBELT

purpose of the diffuser is, of course, to distribute the incoming gas to various areas of the bag in order to prevent a large local hot gas jet from burning a hole in the bag. The diffuser is constructed of radiator hose, 1-3/4 inches inside diameter and 16-1/2 inches long with 3/8 inch diameter holes punched on 2-inch centers. One end of the hose fits over the inflator nozzles, while the other end is pinched with a rivet so that two holes are formed in the end of the tube.

5.5.2 The Inflator

The inflator selected for use in this program was a pyrotechnic inflator as opposed to a stored gas inflator. The reason for this selection was discussed extensively in the proposal Minicars prepared prior to the award of this contract.

Very briefly, the reasons were twofold. First, a stored gas system is prone to gas leakage, especially so since the required gas pressures are so high (approximately 4500 psig). Second, the combined effect of the inflator's high pressure and low volume make the flow duration of a stored gas system very short. In fact, approximately 10 milliseconds after the initiation of gas flow, the gas flow rate has already decreased to practically nothing. After this time, the gas is venting from the bag with no additional flow coming in so that the bag contains less and less total gas. This effect reduces the gas available for supporting the head when the head begins to rotate forward significantly at approximately 50 to 60 milliseconds into the crash event. Thus, for a stored gas system, the flow into the bag is not phased well since there is no gas flow when the gas is actually needed.

In contrast, the pyrotechnic system reaches its maximum rate of gas flow later in the event when the gas pressure in the inflator case reaches its maximum value. For the inflator and propellant chosen for the airbelt in this contract, this occurs approximately 40 milliseconds after squib initiation. Therefore, the pyrotechnic inflator gas flow is more nearly synchronized with the passenger requirements than is the case with a purely "blowdown" system, i.e., the stored gas inflator.

Section 4.0 describes additional details of the role of computer simulations of the crash event in determining the gas flow capacity required for the pure pyrotechnic inflator.

Figure 5.7 shows a photograph of the inflator. The inflator itself is 4 inches long and 1-3/4 inches in diameter, containing 60 grams of propellant.

5.5.3 Force Limiters

The primary energy absorbers in the restraint system are the force limiters -- one at each of the three belt anchor positions. Figure 5.8 shows a general sketch of the force limiters, while Figure 5.9 shows the dimensions of the three energy absorbing metal tapes that are matched with the appropriate force limiter at each anchor position. The roller diameters for the lap belt force limiters are 5/8 inch, while the roller diameter for the upper anchor is 3/4 inch. There are three rollers in each of the three force limiters.

The force-stroke properties of the finalized force limiters are shown in Figures 5.10 through 5.12. The reason the force at the lower outboard location is higher than the force at the lower inboard location is due to the fact that the lower outboard force limiter must react not only a portion of the lap belt load, but also the force transmitted through the lower part of the torso belt.

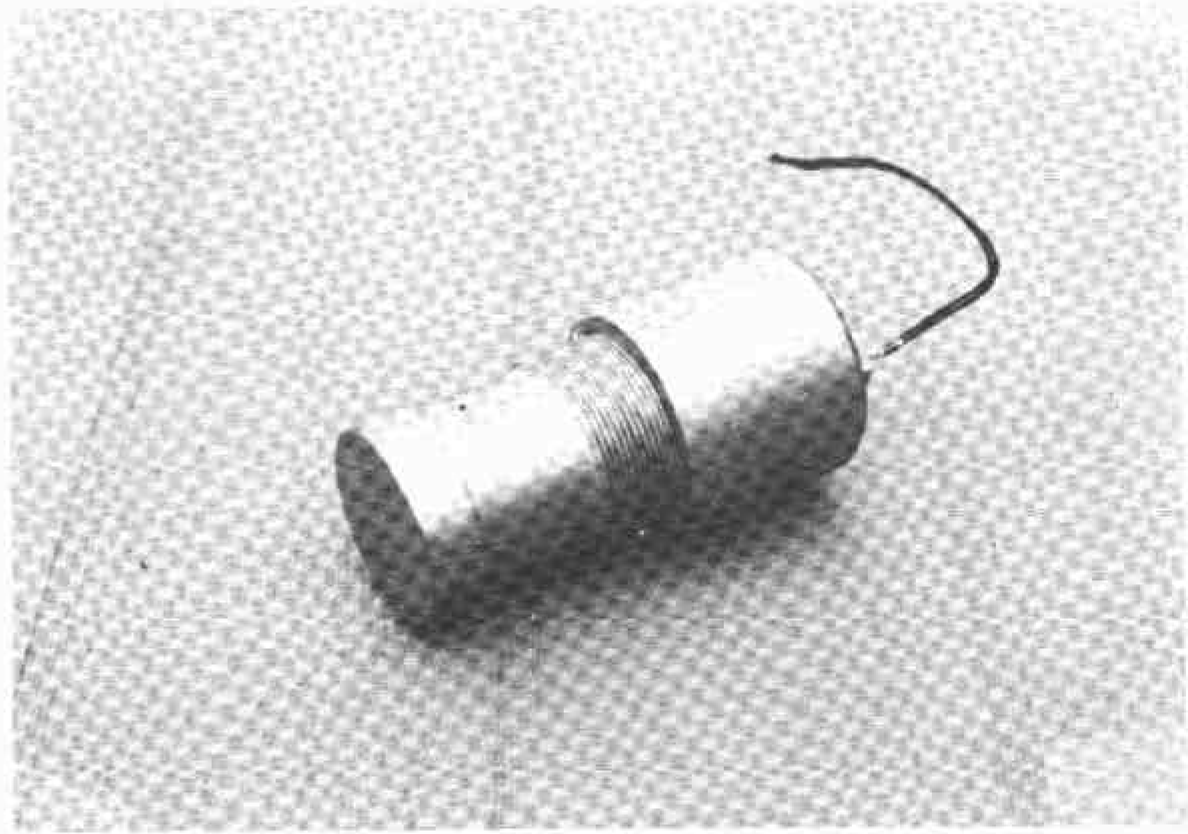
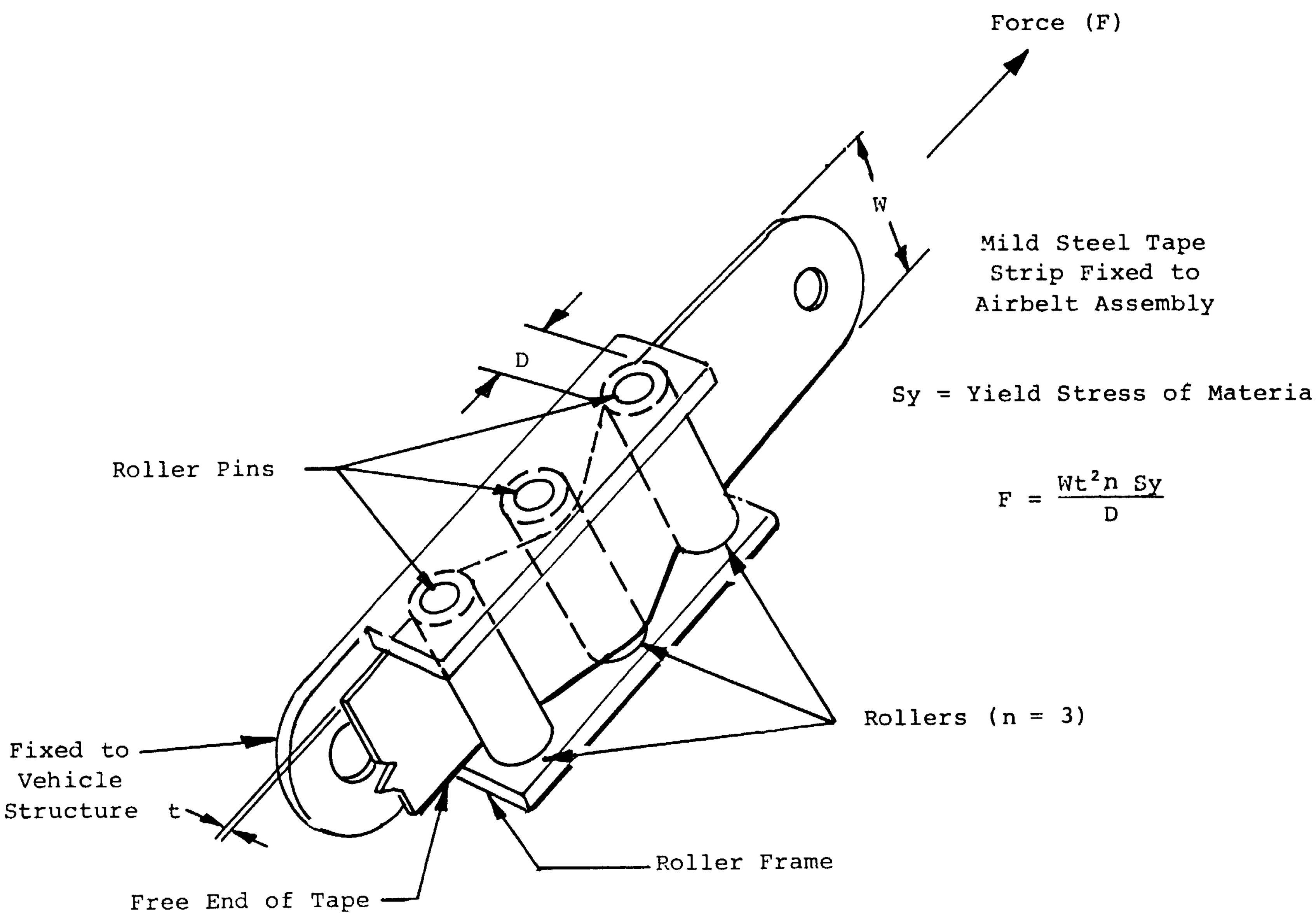
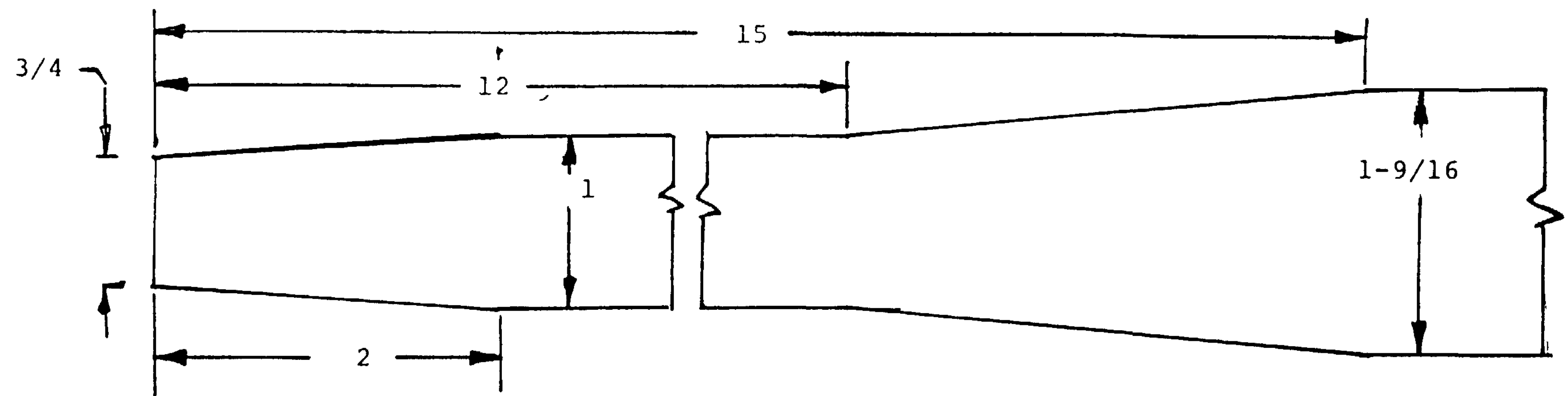


FIGURE 5.7   AIRBELT INFLATOR



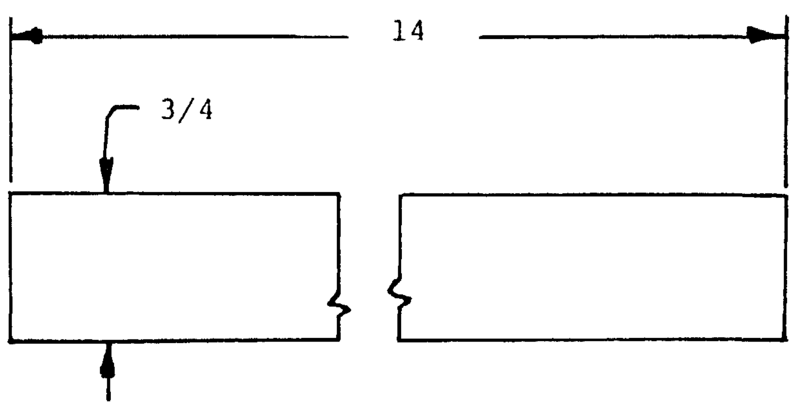
$$F = \frac{Wt^2 n\,Sy}{D}$$

FIGURE 5.8 FORCE LIMITER

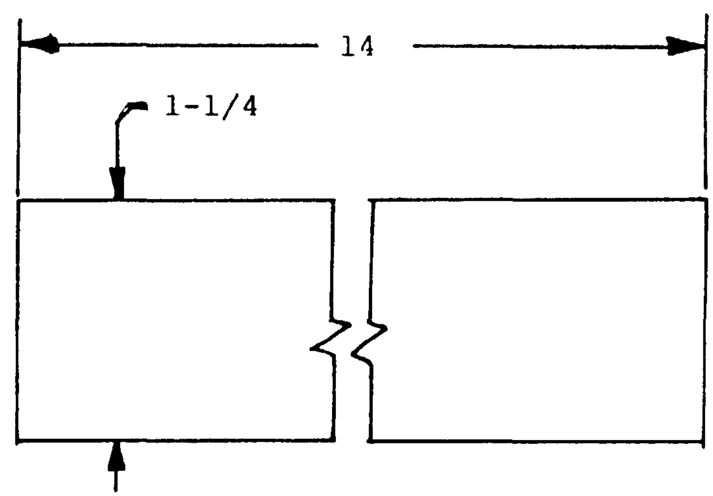


Upper Force Limiter Tape

Note: All three tapes are .075 inches thick.



Lower Inboard Force Limiter Tape



Lower Outboard Force Limiter Tape

FIGURE 5.9 FORCE LIMITER METAL TAPES

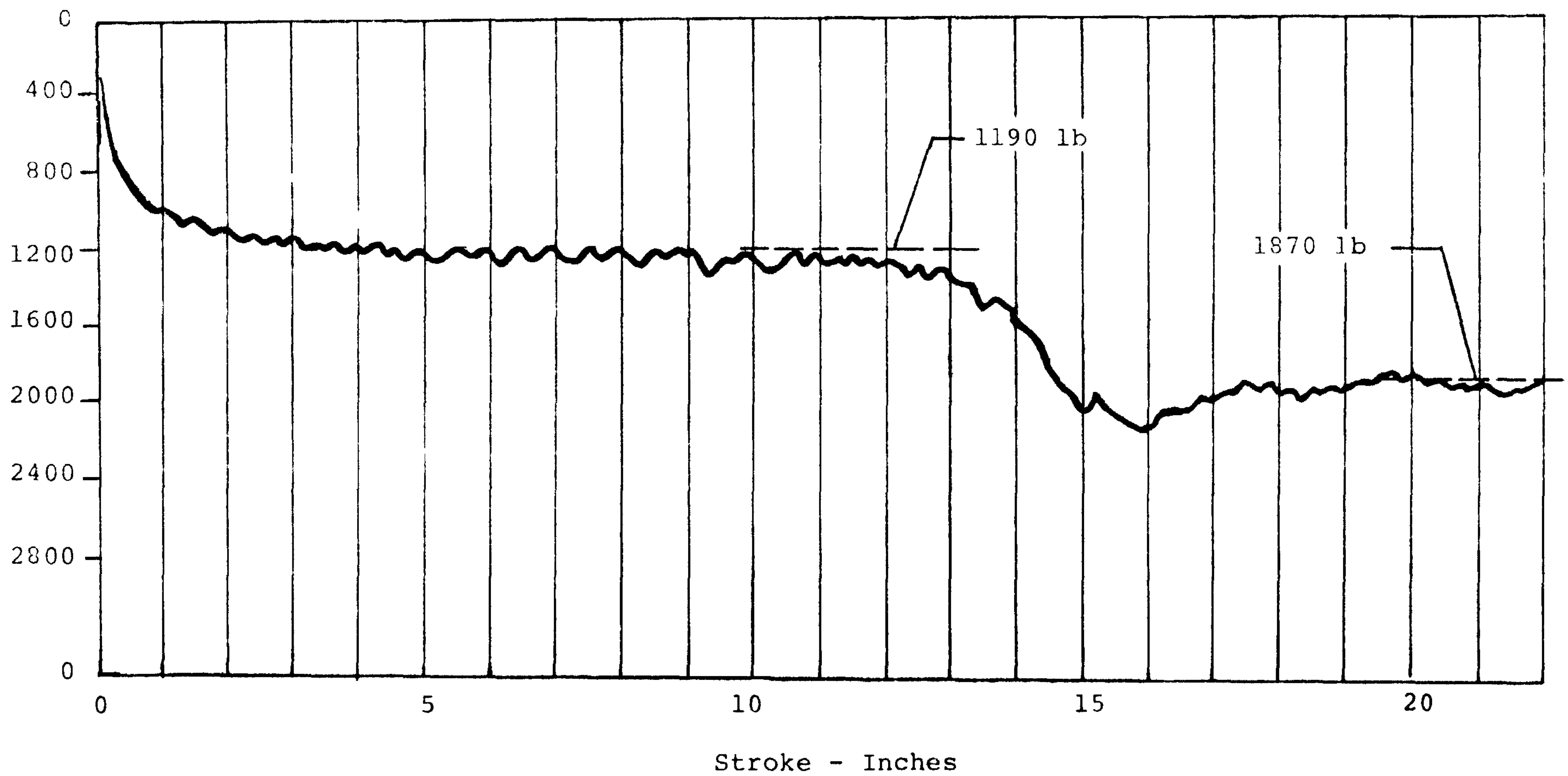


FIGURE 5.10 FORCE-STROKE CHARACTERISTIC - UPPER FORCE LIMITER

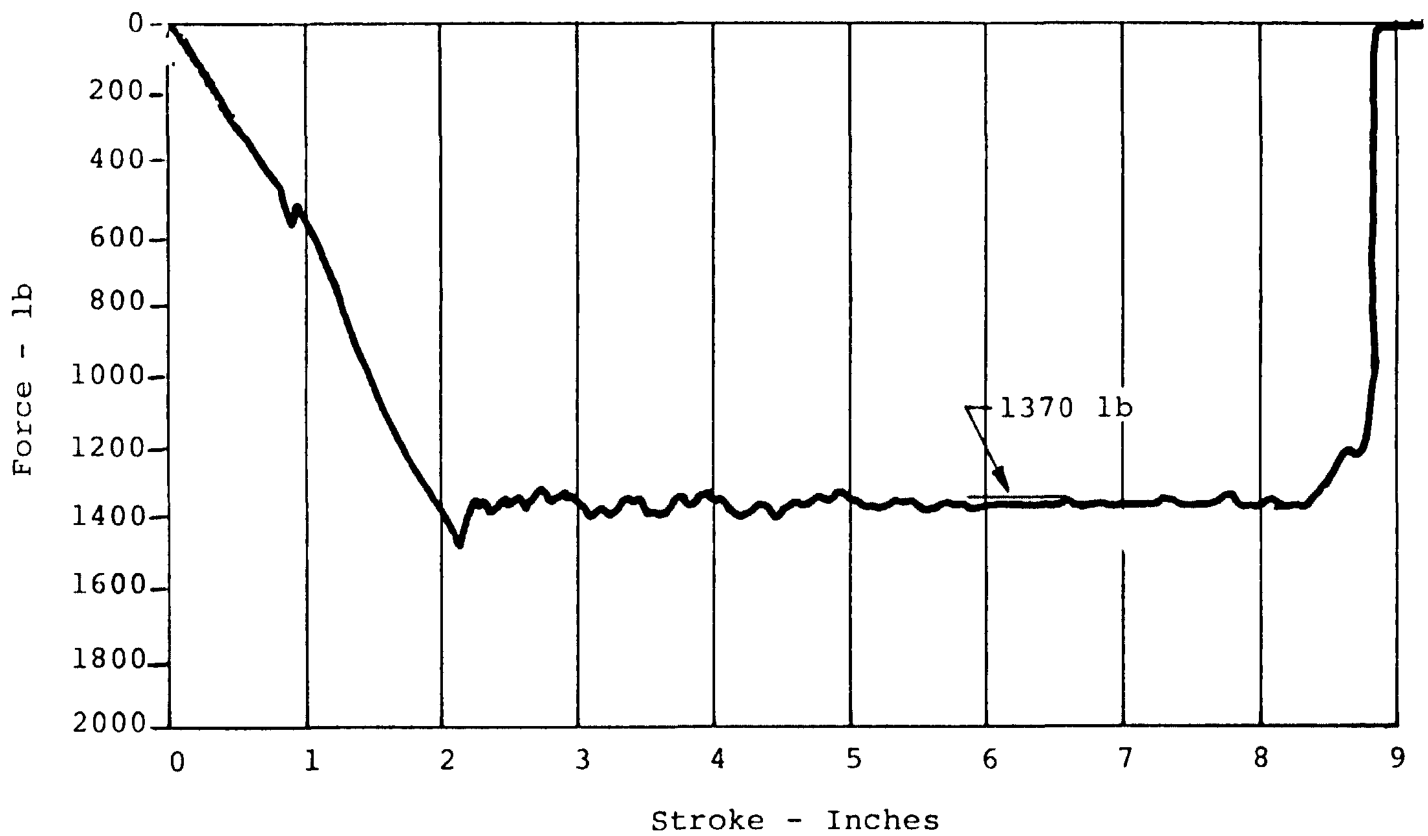


FIGURE 5.11 FORCE-STROKE CHARACTERISTIC - LOWER OUTBOARD FORCE LIMITER

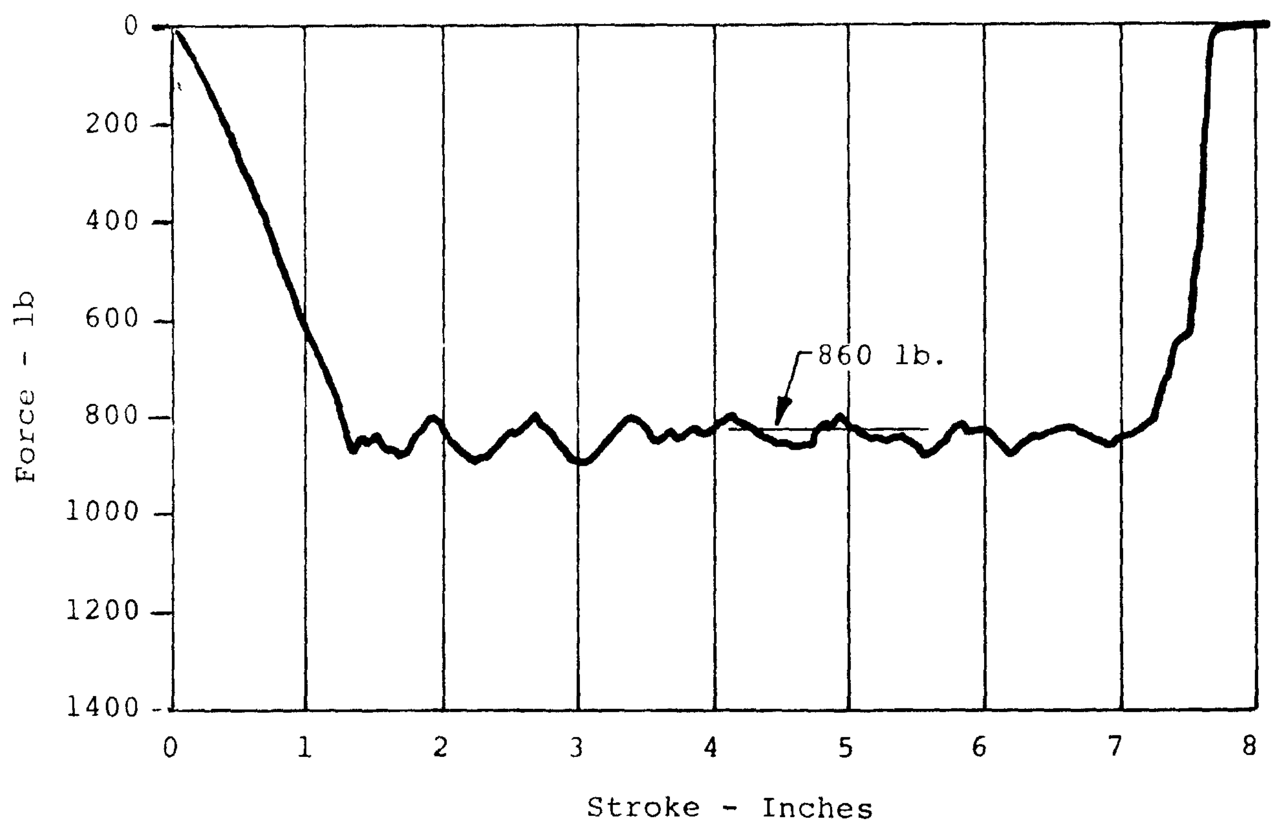


FIGURE 5.12 FORCE-STROKE CHARACTERISTIC - LOWER INBOARD FORCE LIMITER

6.0 EVALUATION TESTS

The purpose of the evaluation tests was to demonstrate the capability of the finalized airbelt design to meet a variety of test conditions which included:

1. Sled testing with various size passengers from six year old child to 95th percentile male in frontal and frontal oblique crashes at various impact velocities.

2. Three car crash tests representing various accident modes. These tests were conducted with a structurally modified Ford Pinto.

3. Two sled tests with cadavers.

In the following, we will discuss these tests.

6.1 Evaluation Sled Tests

The evaluation sled tests for the airbelt were carried out to determine the effectiveness of the finalized restraint to protect passengers in various crash conditions. In these tests the impact velocities, impact angle, and dummy sizes were varied.

Four sizes of dummies were used in testing: the 95th percentile male, the 50th percentile male, the 5th percentile female, and the six year old child.

Altogether, there were 16 evaluation sled tests. Tests 1 through 5 and 12 through 16 were in the frontal impact mode, while Tests 6 through 11 were at 30 degrees obliquity, which simulate car-to-car crashes where the striking car approaches from the 11 o'clock and 1 o'clock positions. All of the evaluation tests were run with two dummies in order to complete the tests in a time and cost efficient manner.

The airbelts were arranged symmetrically to simulate the right front passenger position of a subcompact car in both the left and right side of the sled compartment. In this way, near side oblique impacts (where the striking object impacts on the side nearest to the passenger of interest) were simulated on one side of the compartment, while far side oblique impacts were simulated on the other side of the compartment.

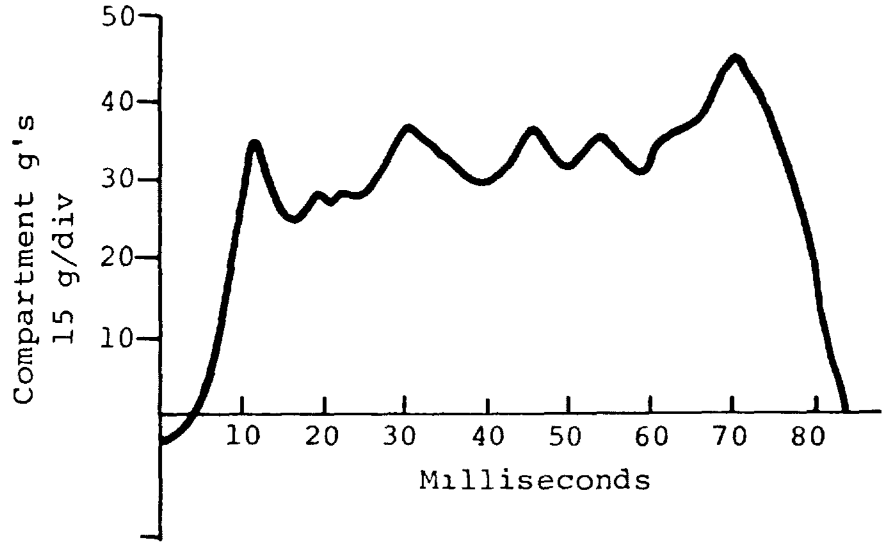
Typical crash pulses used for both the frontal and the oblique tests are shown in Figure 6.1. Peak and average sled accelerations for each test are recorded in Table 6.1. (The actual sled pulse and individual data traces in the individual tests can be found in Appendix C.)

6.1.1 Frontal Impacts

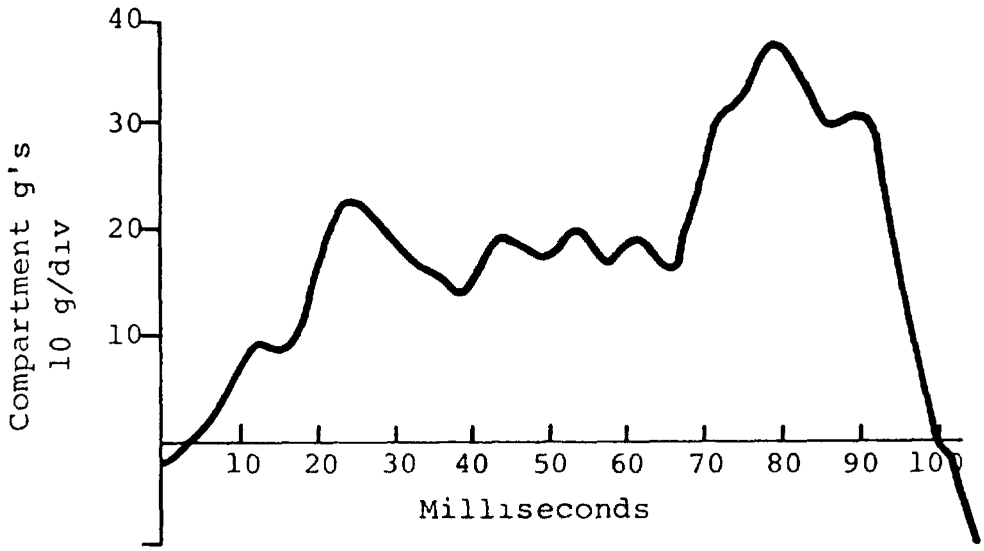
Frontal impact tests were made at nominal velocities of 30, 40, and 50 miles per hour using each of the four dummy sizes. Generally speaking, and as expected, the injury levels became greater as the size and weight of the dummies became smaller. This was evident in both the HIC and chest peak resultant g measurements. Since the force applied to the dummy is independent of the dummy size due to the inherent characteristics of the force limiters, Newton's second law of motion would predict higher accelerations for the smaller passengers.

The chart in Figure 6.2 summarizes the HIC levels for each of the dummy sizes as a function of velocity. Adequate protection to the head, as defined by an HIC of less than 1000, was provided at speeds up to and greater than 50 mph, with the exception of the six year old child. It appears from the figure that the HIC for the child would reach 1000 at about 47 miles per hour.

Peak chest resultant g's followed the same trend as the HIC, with the higher values found in the tests with the smaller dummies (see Figure 6.3). In all cases except one, the airbelt satisfied the chest injury criteria of being less than 60 g's. The exception was the six year old child where, based upon interpolation of the data in the figure, it appears the peak chest g's would exceed the allowable value at approximately 47 mph. Interestingly, this was the



(a) Typical Frontal Impact Sled Test Pulse
(Evaluation Test 5, Velocity = 51 mph)



(b) Typical Oblique Impact Sled Test Pulse
(Evaluation Test 10, Velocity = 37 mph)

FIGURE 6.1 TYPICAL EVALUATION SLED TEST PULSES

TABLE 6.1 EVALUATION SLED TESTS

Sled Run	Date	Passenger Size (Percentile)	Velocity mph	Compartment Rotation Degrees	Crush in.	Sled g's Avg/Pk	Peak Resultant Chest g's (-3 msec)	HIC*	Maximum Femur Load lbs Left	Maximum Femur Load lbs Right	Force Limiter Stroke -in Upper	Force Limiter Stroke -in Lower	Maximum Belt Pressure psi	Remarks
1-L	5-19-75	6-yr-old	35	0	16-3/4	33/39	53	1539/1478	-	-	5/8	3/4 - 1-3/4	22	Deceleration pulse too high for 30 mph
1-R	5-19-75	50th	35	0	16-3/4	33/39	39	310	371	257	6	6 - 8	24	Good run.
2-L	5-22-75	6-yr-old	31	0	21	19/23	39	383	-	-	1/4	1/4 - 5/8	21	Softened pulse slightly.
2-R	5-22-75	50th	31	0	21	19/23	27	245/224	388	163	2-1/4	1-1/4 - 3-1/8	-	Malfunction in airbelt pressure measurement. Good run otherwise.
3-L	5-23-75	6-yr-old	41	0	23-1/2	29/34	47	1117/727	-	-	1/2	1/2 - 2	21	Very high RL component of head pulse in rebound since head hit padded brace on compartment
3-R	5-23-75	50th	41	0	23-1/2	29/34	35	550/305	371	392	6	6-1/2 - 8-1/4	21	Good run.
4-L	5-27-75	6-yr-old	51	0	28-1/2	33/52	69	1737/1068	-	-	1-1/2	1 - 4-1/2	21	Head hit padded brace again during rebound.
4-R	5-27-75	50th	51	0	28-1/2	33/52	42	688/469	941	1028	8-1/2	7 - 14-3/4	26	Good run.
5-L	5-27-75	6-yr-old	51	0	32-1/2	32/44	59.5	1842/1213	-	-	1-3/4	1/2 - 3	23	Same as E4-L.
5-R	5-27-75	50th	51	0	32-1/2	32/44	40	627/584	1152	694	9-3/4	10-1/8 - 9	29	The lower force-limiter tapes were widened by 1/8", since force-limiter tapes were running a little low in thickness.
6-L	5-27-75	6-yr-old	39	30	33	20/37	36	415	-	-	0	3/8 - 1/2	20	Good run.
6-R	5-27-75	50th	39	30	33	20/37	24	212	315	275	3/4	1-1/4 - 5	22	Good run.
7-L	5-29-75	50th	38	30	31	19/39	58	288	259	340	1/2	3 - 3/4	17	Spike occurred in chest RL direction when dummy came up against brace in door on sled.
7-R	5-29-75	6-yr-old	38	30	31	19/39	30	256	-	-	0	0 - 1/2	20	Good run.
8-L	6-2-75	95th	39	30	28	21/42	87	352	191	354	3-3/8	5-1/2- 1-1/4	19	The dummy impacted an edge of the door which was not padded. This produced a high spike of 83 g's in the RL chest trace.
8-R	6-2-75	5th	39	30	28	21/42	25	128	227	149	1-1/4	1/2-1	34	Good run.

*HIC with rebound/HIC without rebound.

TABLE 6.1 EVALUATION SLED TESTS (continued)

Sled Run	Date	Passenger Size (Percentile)	Velocity mph	Compartment Rotation Degrees	Crush in.	Sled g's Avg/Pk	Peak Resultant Chest g's (-3 msec)	HIC	Maximum Femur Load lbs Left	Right	Force Limiter Stroke-in Upper	Lower	Maximum Belt Pressure psi	Remarks
9-L	6-2-75	5th	40	30	28	22/42	52	1206	239	223	3/8	2-1/4-1	20	Dummy head hit the lower edge of the door window opening.
9-R	6-2-75	95th	40		28	22/42	22	289	136	248	3	8-1/2-11-1/2	26	Good run.
10-L	6-3-75	5th	37	30	28	20/37	55	1008	71	71	0	1-3/4-3/4	20	Same head strike as E8-L.
10-R	6-3-75	95th	37	30	28	20/37	24	459	110	78	2-1/8	8-1/8-11-3/8	21	
11-L	6-4-75	95th	38	30	29	22/41	33	606/349	147	191	3	5-1/2-1	18	Good run.
11-R	6-4-75	5th	38	30	29	22/41	33	277	483	31	1/4	2-1/4-1/2	20	Good run.
12-L	6-4-75	5th	55	0	35	30/47	54	519	172	145	1/2	4-1/4-9-1/2	25	Good run.
12-R	6-4-75	95th	55	0	35	30/47	33	310	1062	452	8	16-1/2-15-1/2	25	Good run.
13-L	6-5-75	5th	40	0	34	21/28	48	623	182	169	3-1/4	2-3/4	-	Airbelts did not fire. The squib was not connected correctly.
13-R	6-5-75	95th	40	0	34	21/28	22	270	515	347	11	13-9	-	
14-L	6-5-75	5th	41	0	33	22/27	43	270	212	72	1/4	1/2-1	22	Good run.
14-R	6-5-75	95th	41	0	33	22/27	28	237	255	185	3-1/4	8-3/4-8-1/2	24	Good run.
15-L	6-5-75	5th	51	0	37	28/40	48	1066	146	42	4	3-3/4-4-1/4	-	Loose wire on squib caused airbelts to fire prematurely.
15-R	6-5-75	95th	51	0	37	28/40	36	506	589	468	15-1/2	14-1/4-15-1/2	-	
16-L	6-5-75	5th	51	0	34	31/55	58	675	606	262	2	6-6-1/4	23	Good run.
16-R	6-5-75	95th	51	0	34	31/55	35	428	284	549	12-1/4	16-1/4-17	27	Good run.

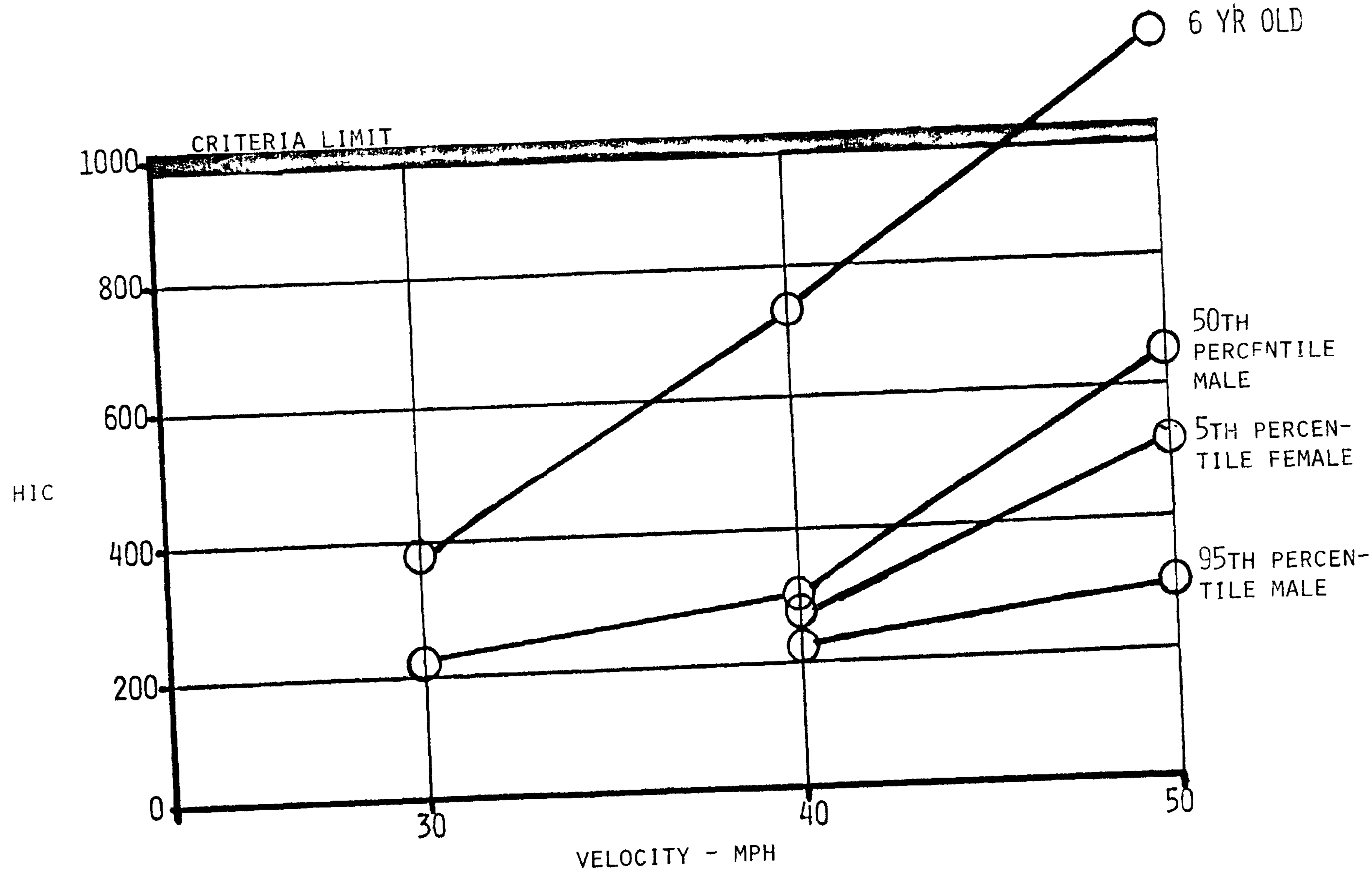


FIGURE 6.2   EVALUATION SLED TEST RESULTS - FRONTAL IMPACT

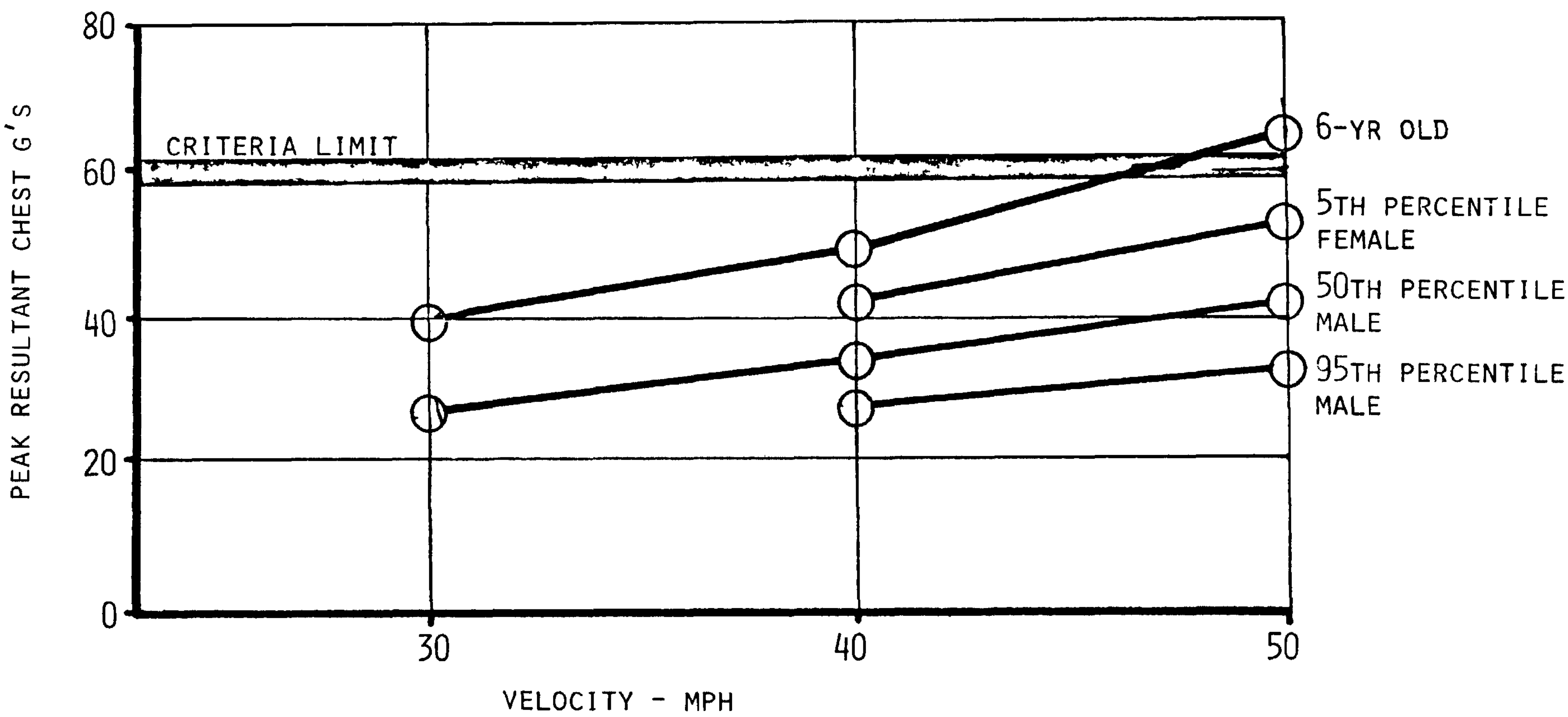


FIGURE 6.3 EVALUATION SLED TEST RESULTS - FRONTAL IMPACT

same velocity at which the HIC value is predicted to exceed the allowable value of 1000 for the child.

Meeting the femur load criteria was a matter of adjusting the force limiters so that the knees of the dummies would not collide with structure in the sled buck. Once this adjustment was made, compressive femur loads were due only to the load transmitted from the toeboard, through the tibia, and into the femur. These loads were generally well below the allowable limit of 1700 pounds.

6.1.2 Oblique Impacts

Since studies of accident statistics show that the only oblique impacts that contribute heavily to societal cost are vehicle-to-vehicle crashes, we placed the sled compartment on the sled track at a 30-degree angle from the subcompact vehicle centerline. The velocity of impact decided upon for the tests was 38 mph, which corresponds approximately to the same injury societal benefit that would accrue from attaining 50-mph protection in the frontal direction.

At speeds of 38 mph, it was found that the airbelt more than met the injury criteria for the entire range of passenger sizes. HIC levels were, for the most part, between 200 and 400 for the entire range of passenger sizes (Figure 6.4). Two tests were run in which the HIC was over 1000. This occurred in the tests with the 5th percentile female. Both tests were near side impacts in which the head rotated to the side and impacted the door where the window slides into the door. This problem was not experienced with the six year old child dummy since he was shorter and impacted the side of the door. Similarly, no problem was experienced with the 50th and 95th percentile dummies since they were sufficiently tall to prevent the head from rotating sideways far enough to impact into the area where the 5th percentile dummy head impacted.

HIC and peak chest g's were both higher for the near side impacts than for far side impacts. This is reasonable because the near side impact involves the second collision

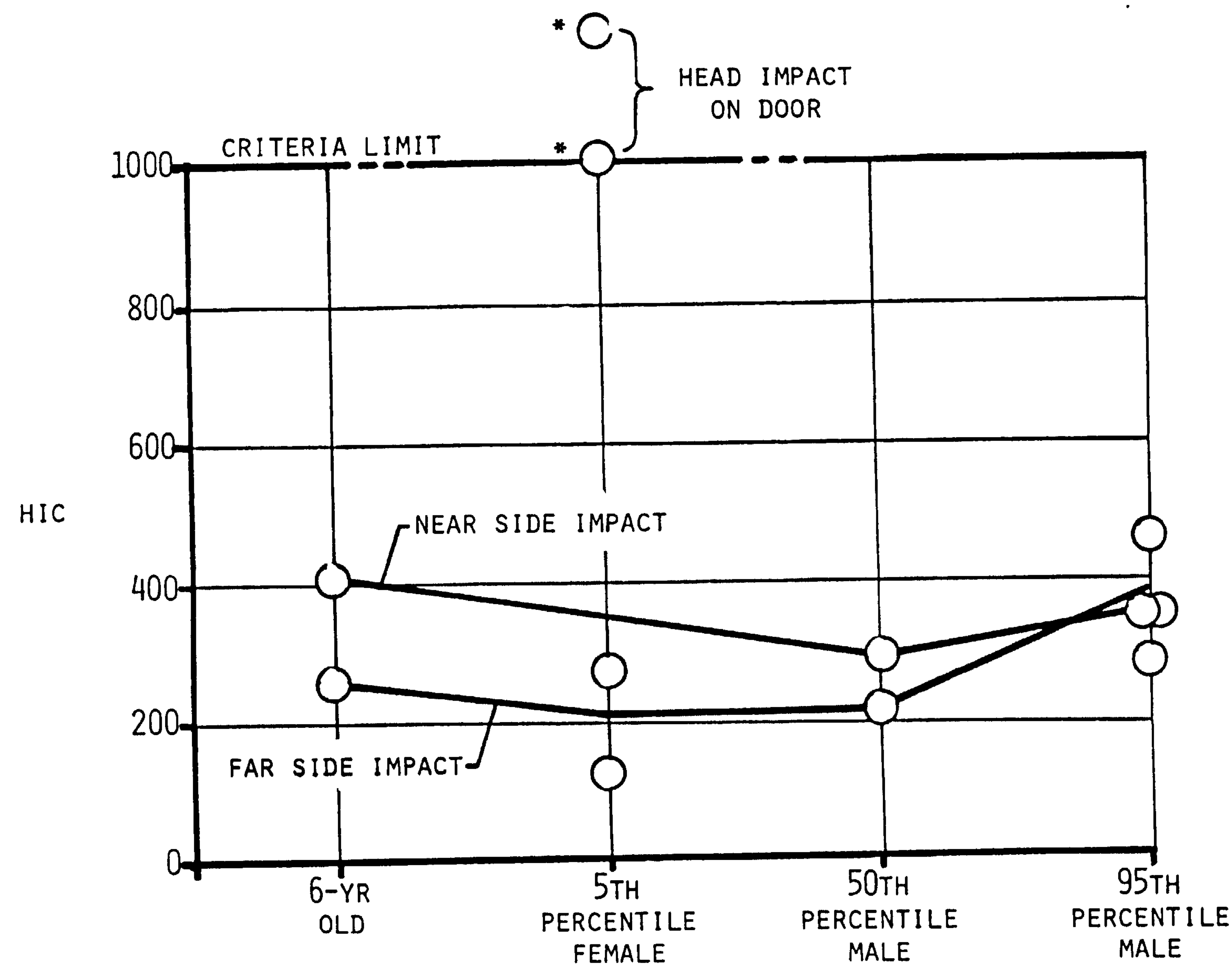


FIGURE 6.4 EVALUATION SLED TEST RESULTS - 38 MPH OBLIQUE IMPACT

of the dummy and the door with less total stroke available to come to rest. In contrast, the far side passenger generally moved a greater distance across the compartment prior to coming to rest. Figures 6.4 and 6.5 summarize the HIC and peak resultant chest g's for the oblique tests.

There was one test where the airbelt did not inflate (Run E-13) due to a wiring error, and one test (Run E-15) where the airbelt inflated too early due to a premature switch closure on the firing circuit. Since these tests were obvious anomalies, the results were not included in the charts in Figures 6.2 and 6.3; however, for completeness, Table 6.1 does include these results.

Further, the value for HIC in the charts for the six year old child did not include rebound effects since a sled compartment reinforcing member was immediately adjacent to the dummy head and impacted the head during the rebound phase of dummy motion. We felt that to include this effect in the charts would detract from the obvious trend established by the airbelt performance. Again, Table 6.1 includes the rebound effect.

6.2 Car Crash Tests

During the course of the contract, we conducted three car crash tests with the airbelt. Two tests were car-to-car crash tests at Dynamic Science in Phoenix, Arizona, and one was a barrier crash test conducted at Calspan Corporation. All three tests had certain things in common. The dummy restrained by the airbelt was, in all cases, a 50th percentile male, and the vehicle in which the airbelt was installed was a Ford Pinto structurally modified to the specifications and configuration established in NHTSA Contract DOT-HS-113-3-746 "Crashworthiness of Subcompact Vehicle."

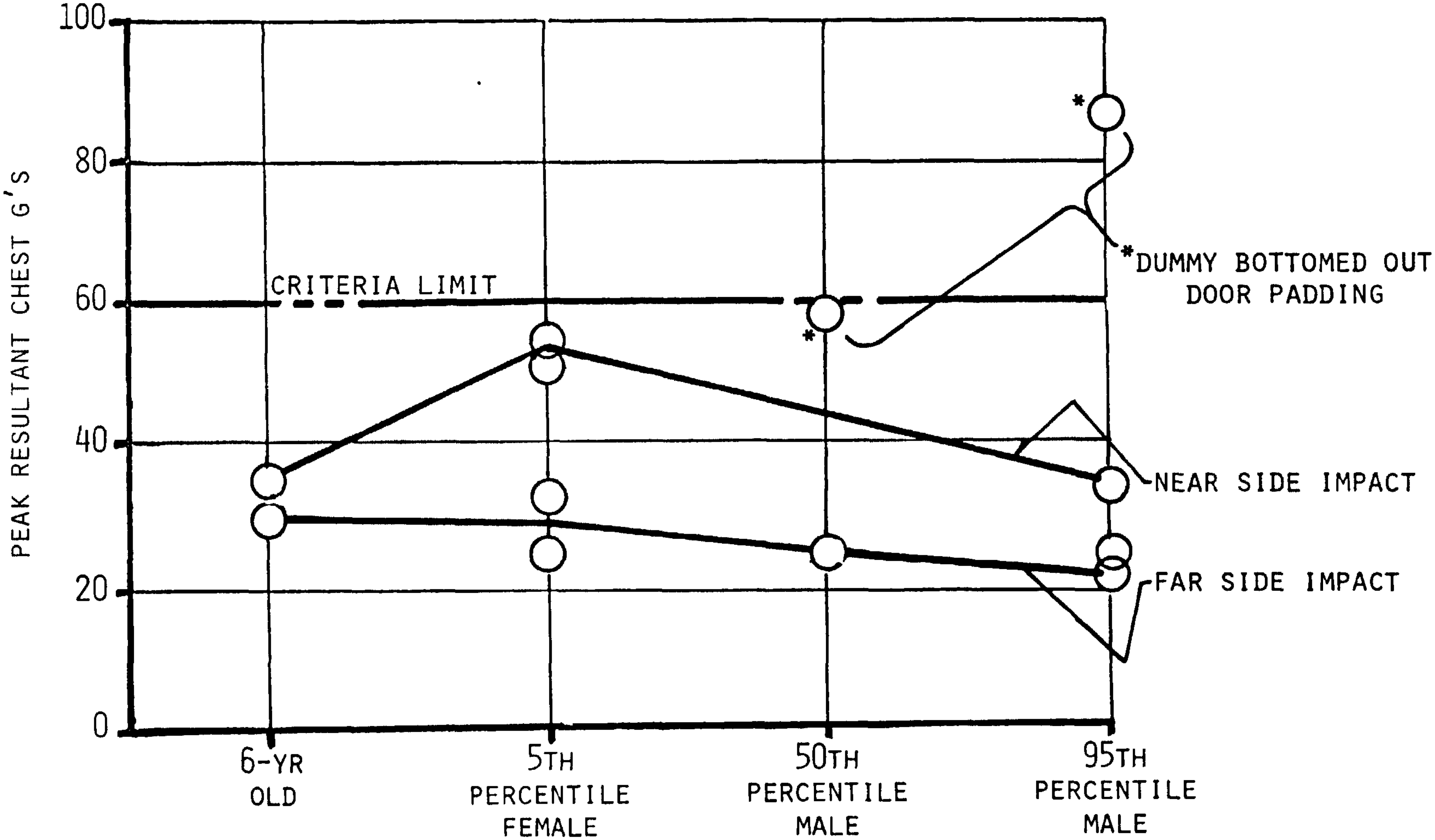


FIGURE 6.5 EVALUATION SLED TEST RESULTS - 38 MPH OBLIQUE IMPACT

6.2.1 Crash Test No. 1 (Test E-25 of DOT-HS-113-3-746)

On April 18, the airbelt system was tested in a full-scale car-to-car (modified Pinto and 1974 Ford LTD) frontal impact at 79 mph closing velocity (80 mph nominal) at Dynamic Science in Phoenix, Arizona. The change in velocity for the modified Ford Pinto was 54 mph and for the Ford LTD it was 35 mph. The airbelt was installed in the right front passenger position in the modified Pinto. The airbelt restrained a 50th percentile male dummy that was sitting 3 inches aft of the stock Pinto midseat position. The sensing time for the airbelt inflator was set for 5 milli-seconds after bumper-to-bumper contact took place.

During impact, the upper force limiter stroked 5 inches, the lower outboard limiter stroked 7-1/2 inches, and the lower inboard limiter stroked 3-1/2 inches, all slightly less than was experienced during sled testing. The rest of the data for the test, including HIC and peak chest g's, are summarized in Figures 6.6 through 6.9. Some of the data for the 50th percentile dummy in the driver's seat is also included. The driver was restrained with the Minicars' driver restraint system developed under NHTSA Contract DOT-HS-113-3-742 "Development of an Advanced Passive Restraint System for Subcompact Car Drivers." It is interesting to note that the results are very similar for both restraint systems.

As can be seen from the data, all measured injury levels for dummies in the Pinto are well below the criteria injury limits. However, in the Ford LTD, the HIC for the conven-tionally belted dummy on the passenger side was 1441, while for the conventionally belted dummy on the driver side it was 956. Figures 6.10 through 6.12 show pre and post test photos of the test setup.

6.2.2 Crash Test No. 2

Crash Test No. 2 with the airbelt restraint was conducted at Calspan Corporation on June 4, 1975, as a "piggyback" test with the Calspan right front passenger restraint. The airbelt was installed on the left side of the vehicle

	Modified Pinto	Airbag Restrained Driver	Airbag Restrained Passenger
Peak Longitudinal g's	54	39*	41*
Peak Resultant g's	55	45*	44*
CSI		677	658
HIC		563	549
Peak Femur Loads (lbs) (Left-Right)		1288-1263	-- **

* Chest Acceleration
** Data Not Taken

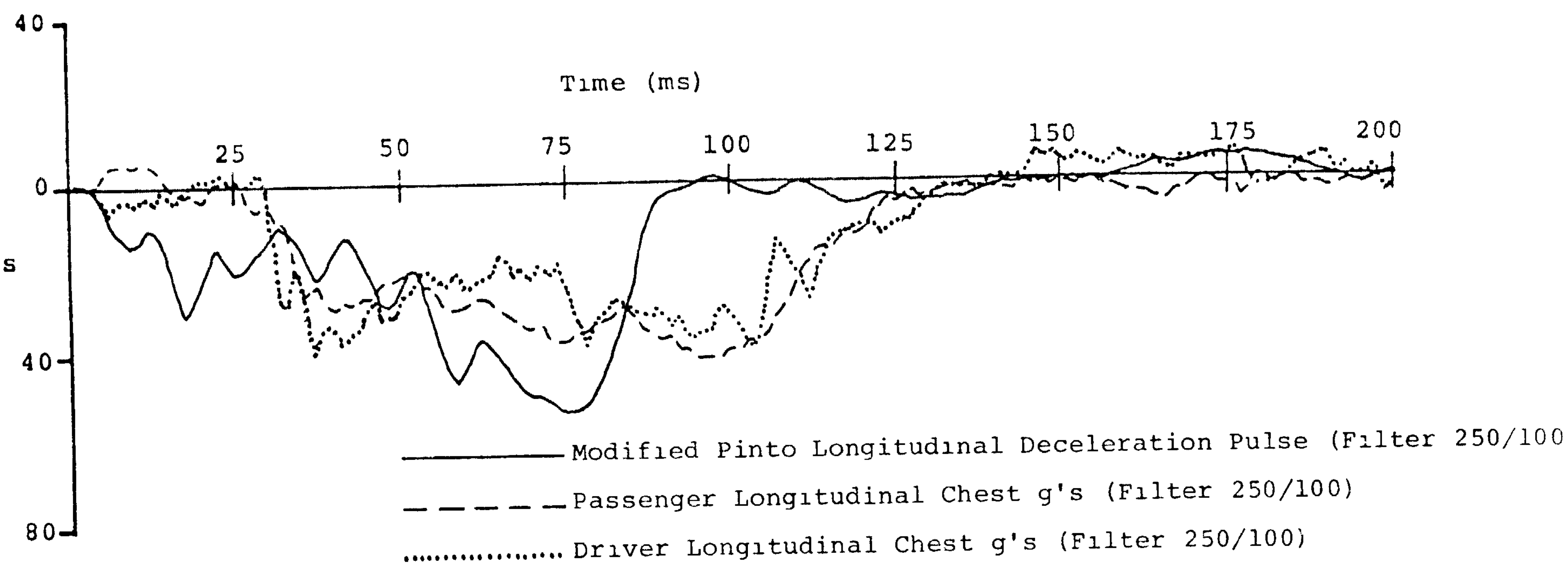
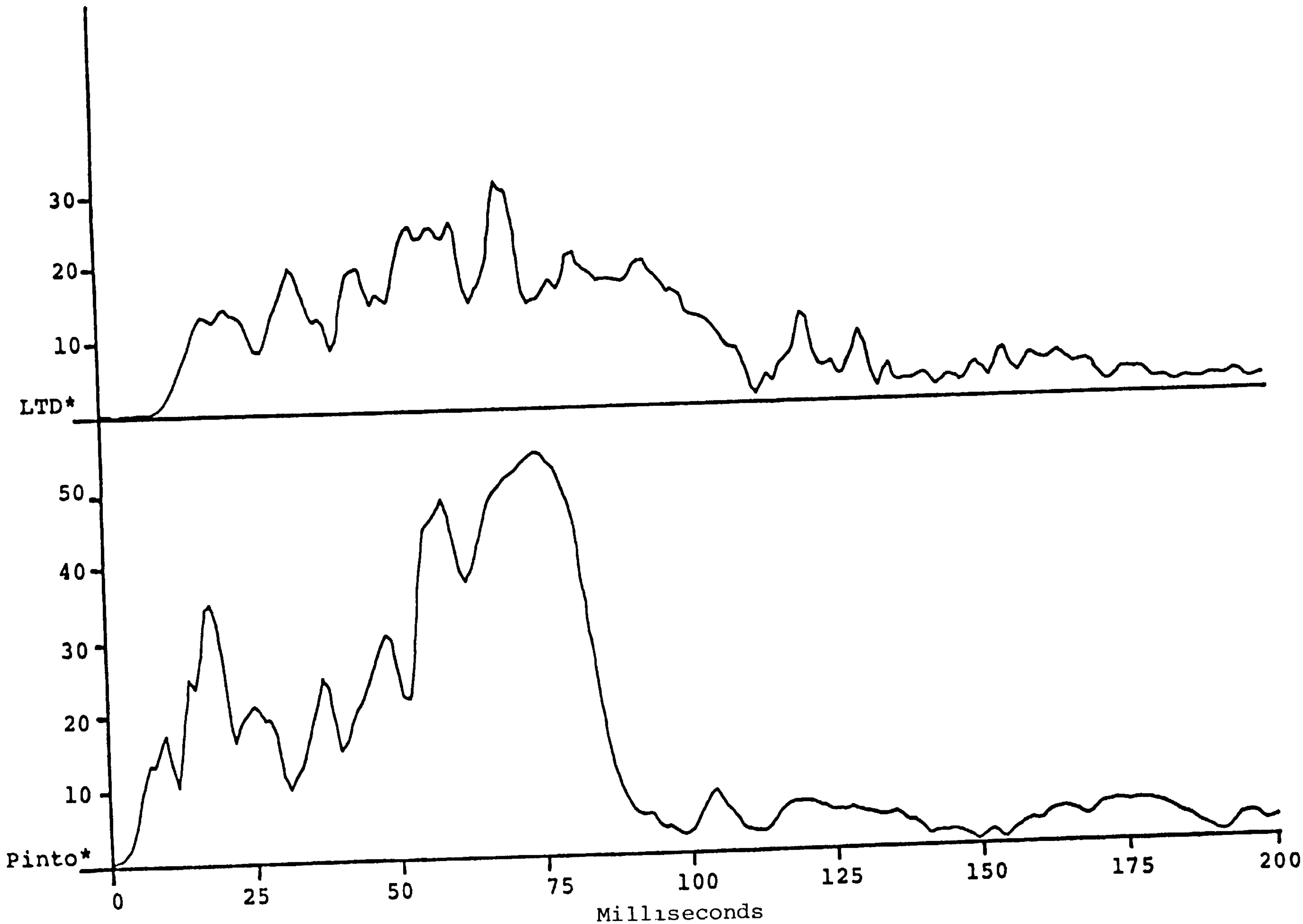


FIGURE 6.6 SUMMARY OF DATA FROM CRASH TEST NO. 1



*Accelerometer located in mid-trunk

FIGURE 6.7 LTD AND MODIFIED PINTO RESULTANT DECELERATION PULSES
CRASH TEST NO. 1 FILTER 250/100

FIGURE 6.8 PASSENGER RESULTANT HEAD ACCELERATION
CRASH TEST NO. 1 FILTER 4000/1650

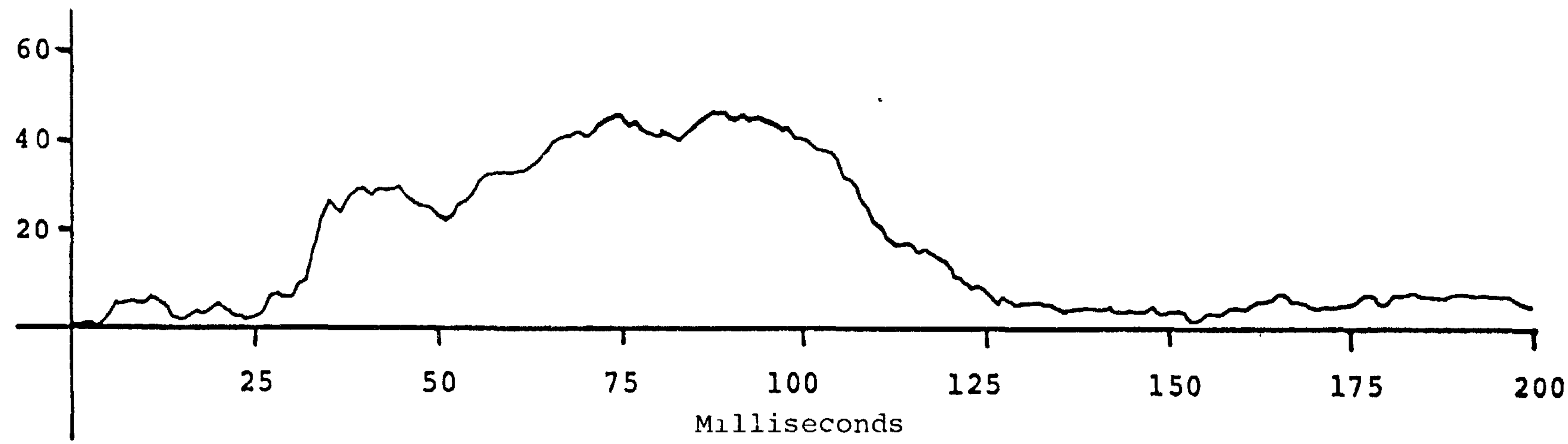
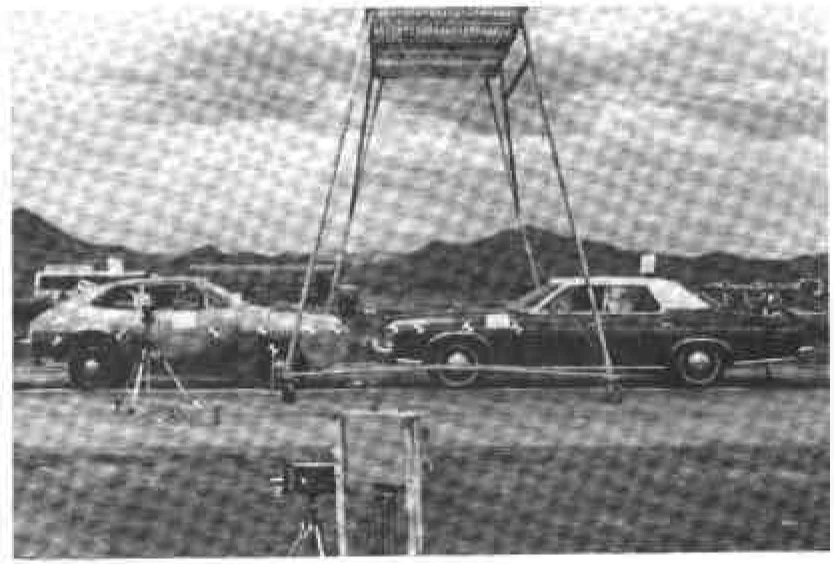


FIGURE 6.9 PASSENGER RESULTANT CHEST ACCELERATION
CRASH TEST NO. 1 FILTER 4000/1650

Modified Ford Pinto



Modified Ford Pinto and Ford LTD

FIGURE 6.10   TEST VEHICLES - CRASH TEST NO. 1

Passenger Airbelt Restraint

Driver Airbag Restraint

FIGURE 6.11 RESTRAINT SYSTEMS INSTALLED FOR CRASH TEST NO. 1

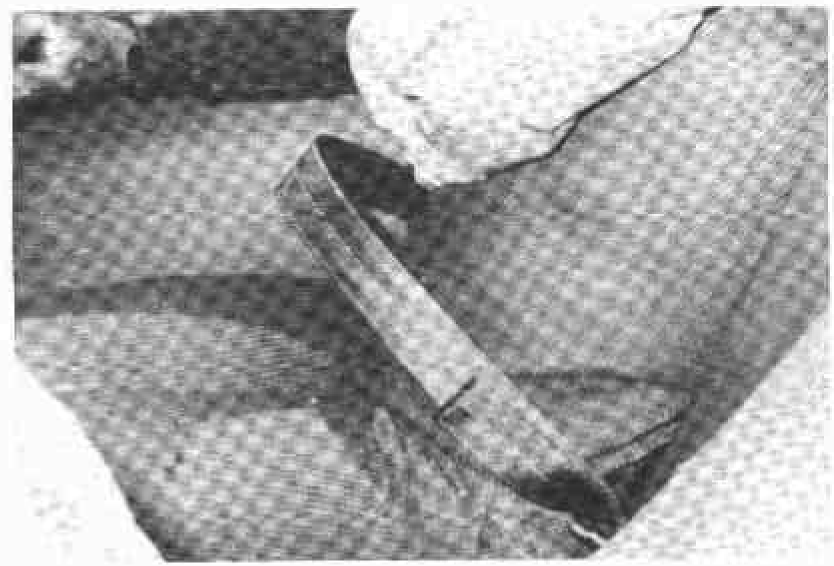


FIGURE 6.12 POST TEST CONFIGURATION OF DUMMY AND AIRBELT RESTRAINT
CRASH TEST NO. 1

in the Pinto standard midseat position. The steering column had been removed so that as far as the airbelt restrained dummy was concerned, he experienced the same crash environment as he would on the right side of the compartment. Installed in the right front passenger position was the Calspan right front passenger airbag-crushable bolster restraintdeveloped under NHTSA Contract DOT-HS-4-00972. As in Crash Test No. 1, this test was conducted with the modified Ford Pinto. However, it was crashed frontally into a rigid barrier at 41.5 mph. The test velocity was chosen by Calspan Corporation. Here again the injury levels were low for the airbelt restrained dummy. Figure 6.13 summarizes the dummy injury levels, while Figures 6.14 through 6.16 contain the data traces from the test.

6.2.3 Crash Test No. 3 (Test E-21 of DOT-HS-113-3-746)

The third and final car crash test conducted with the airbelt restraint system occurred on July 8, 1975. Again, as in the first test, a car-to-car impact was conducted at Dynamic Science. Again, the modified 1974 Ford Pinto impacted a 1974 Ford LTD. However, in this case, the crash mode was somewhat different. In the first test both vehicles impacted frontally along the full frontal width of the vehicles. In this test, the vehicles were offset so that only one-half of the front of each car would impact the other. Here again the driver was restrained by an airbag restraint developed by Minicars for NHTSA under Contract DOT-HS-113-3-742. The driver and passenger in the LTD were restrained by the conventional lap and shoulder belts that come with the car.

The closing velocity between the vehicles at impact was 80.8 mph. The Ford Pinto change in velocity was measured to be 55 mph. Table 6.2 summarizes the results of this test. Again, the airbelted passenger in the Pinto received very low injury levels. Figure 6.17 through 6.27 are the individual data traces for the airbelt restrained passenger in the Pinto.

Incidentally, both dummies in the Ford LTD restrained by conventional belts exceeded the allowable value for HIC (Driver HIC = 1182, Passenger HIC = 1274). The change in velocity for the Ford LTD was 35 mph.

VEHICLE - MODIFIED FORD PINTO

VELOCITY - 41.5 MPH

INJURY MEASURES

HIC	302
PEAK RESULTANT CHEST G'S	36 G

FIGURE 6.13 MEASURED INJURY LEVELS - CRASH TEST NO. 2

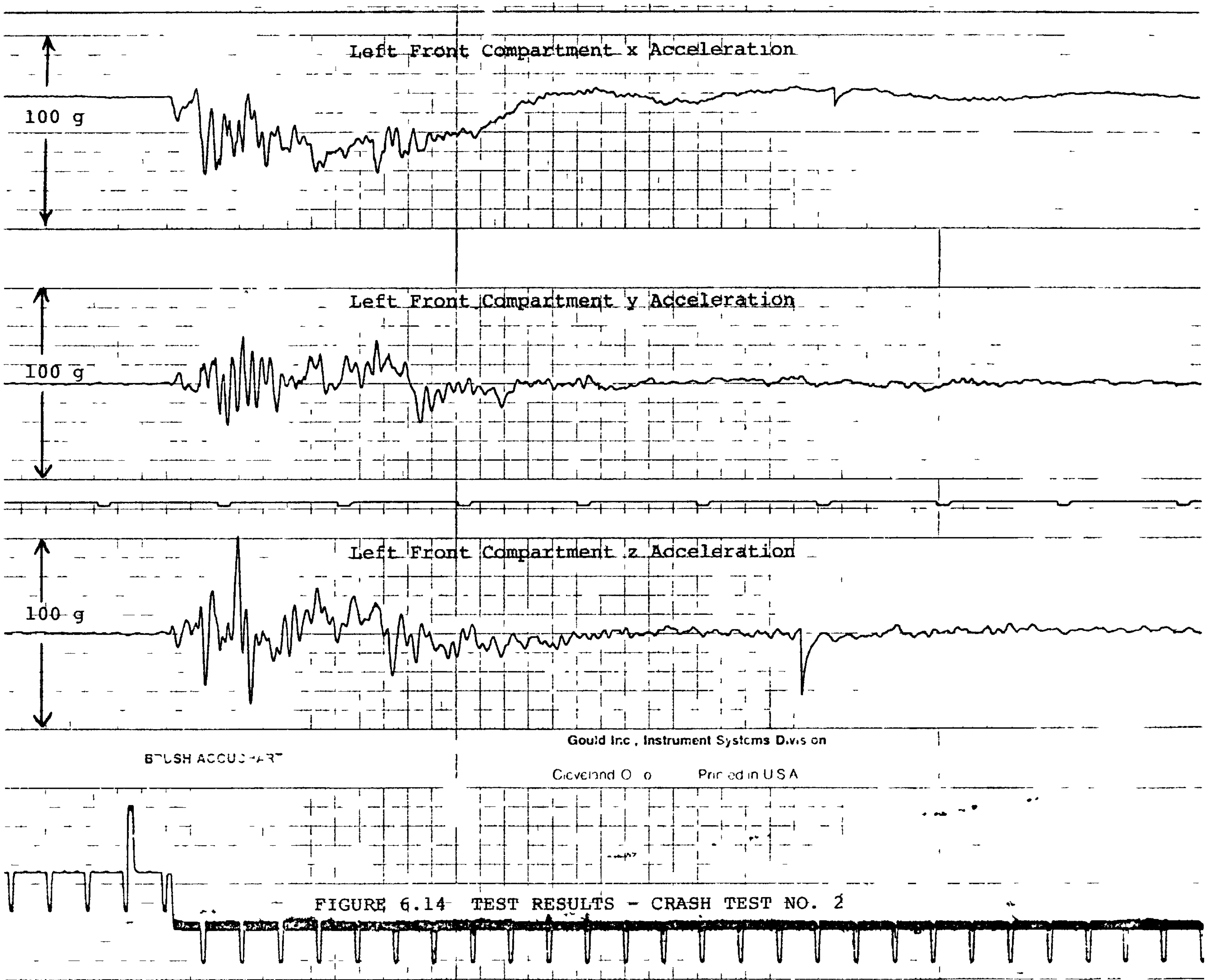


FIGURE 6.14 TEST RESULTS - CRASH TEST NO. 2

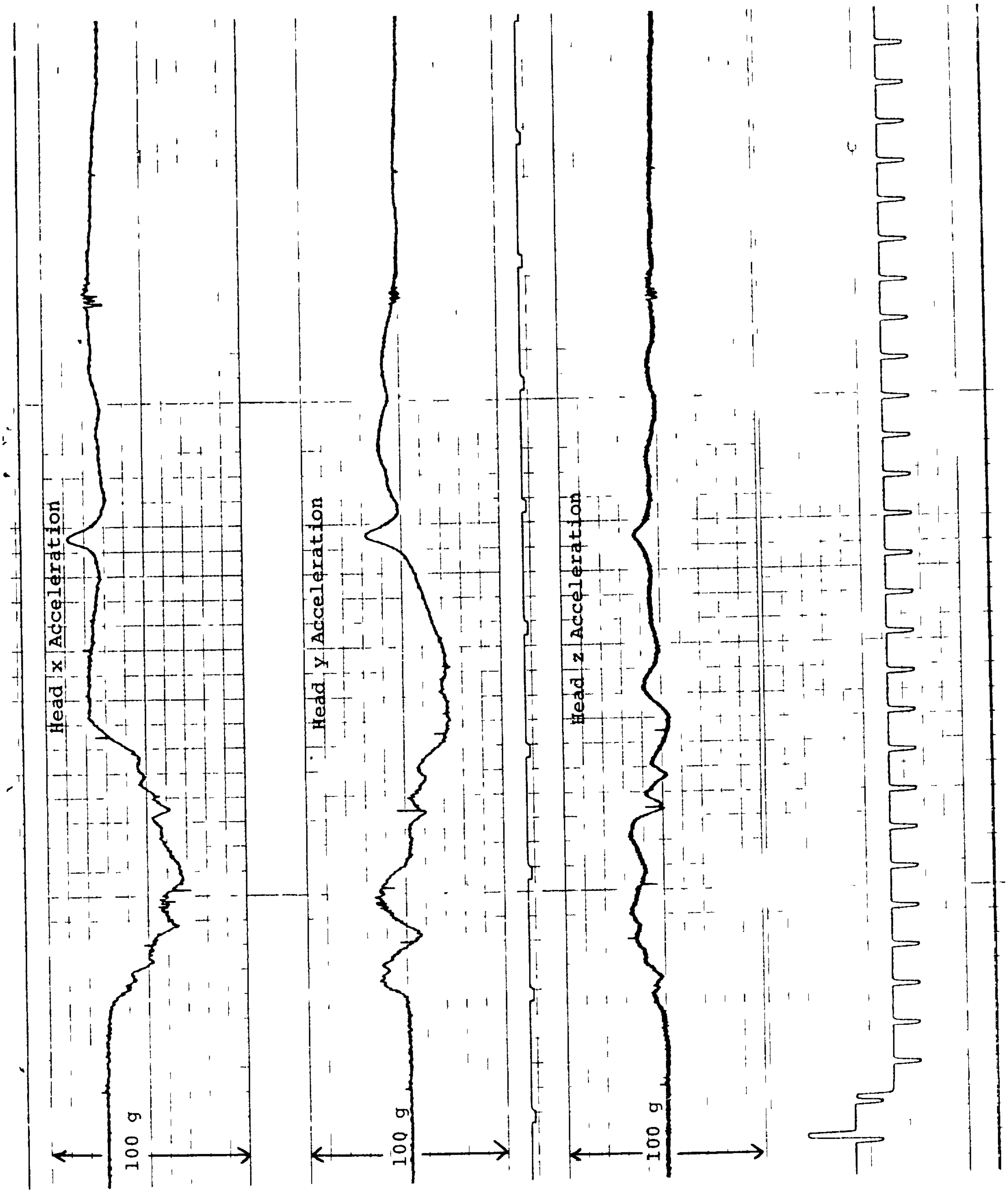


FIGURE 6.15 TEST RESULTS - CRASH TEST NO. 2

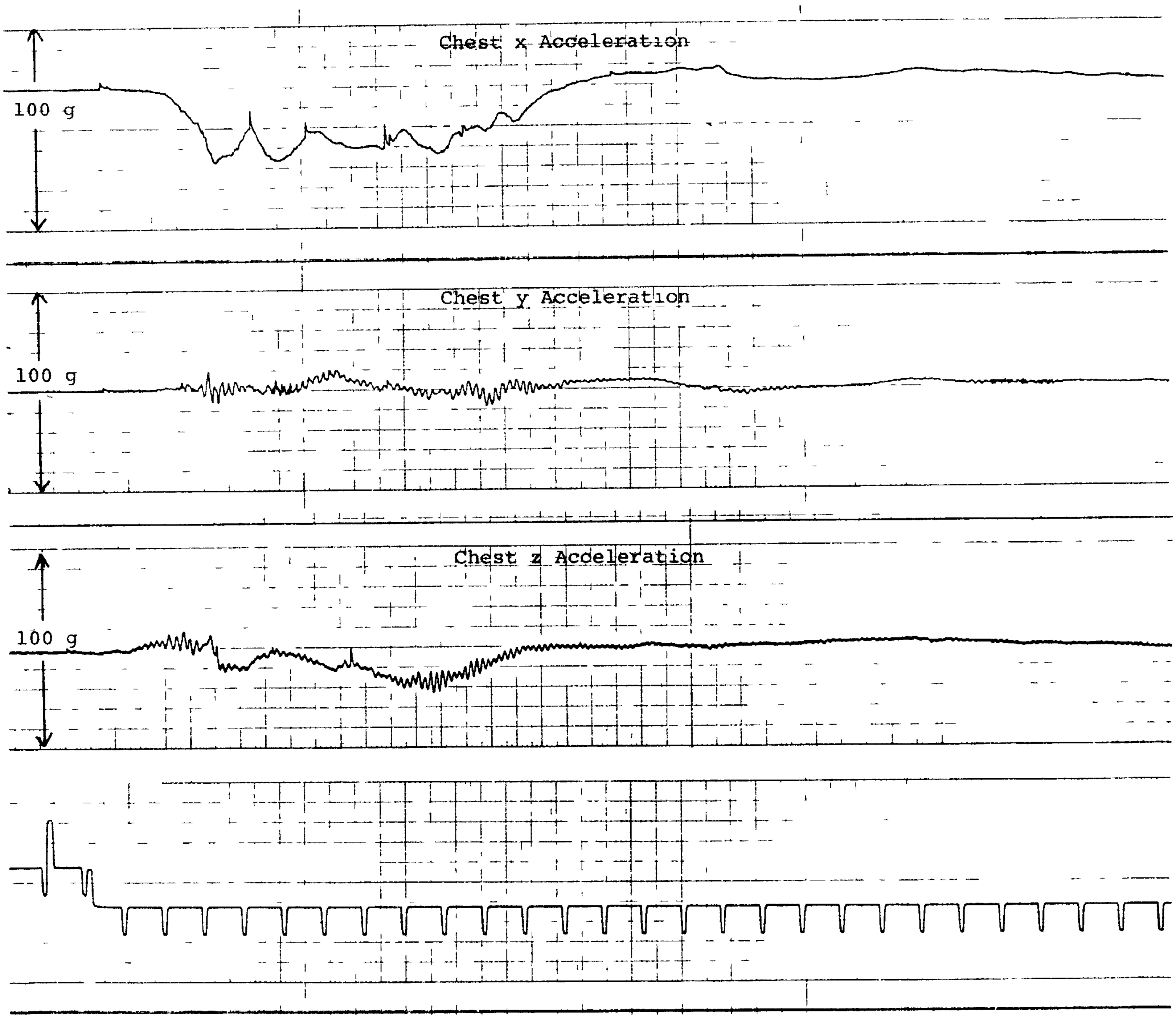


FIGURE 6.16 TEST RESULTS - CRASH TEST NO. 2

TABLE 6.2 MEASURED INJURY LEVELS
CRASH TEST NO. 3

	Chest Peak Resultant g's (-3ms)	HIC	Maximum Femur Loads Left	Maximum Femur Loads Right	Peak Bag Pressure
Pinto Driver	43.2	924	684	735	18.7
Pinto Passenger	40.7	457	326	142	24.6
LTD Driver	49.2	687	*	*	N/A
LTD Passenger	48.6	1274	*	*	N/A

* Data Not Taken

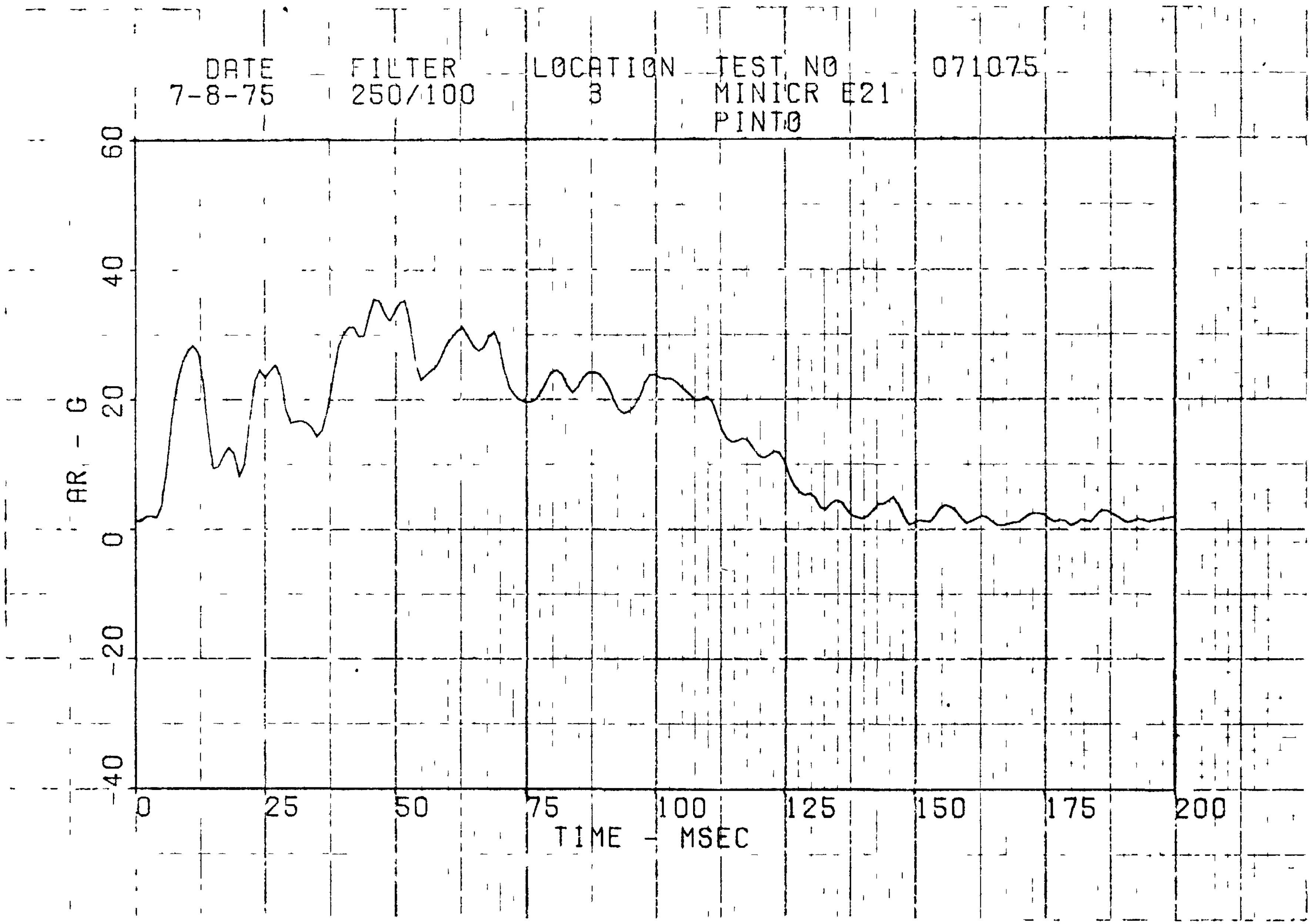


FIGURE 6.17 MODIFIED PINTO CRASH PULSE - CRASH TEST NO. 3

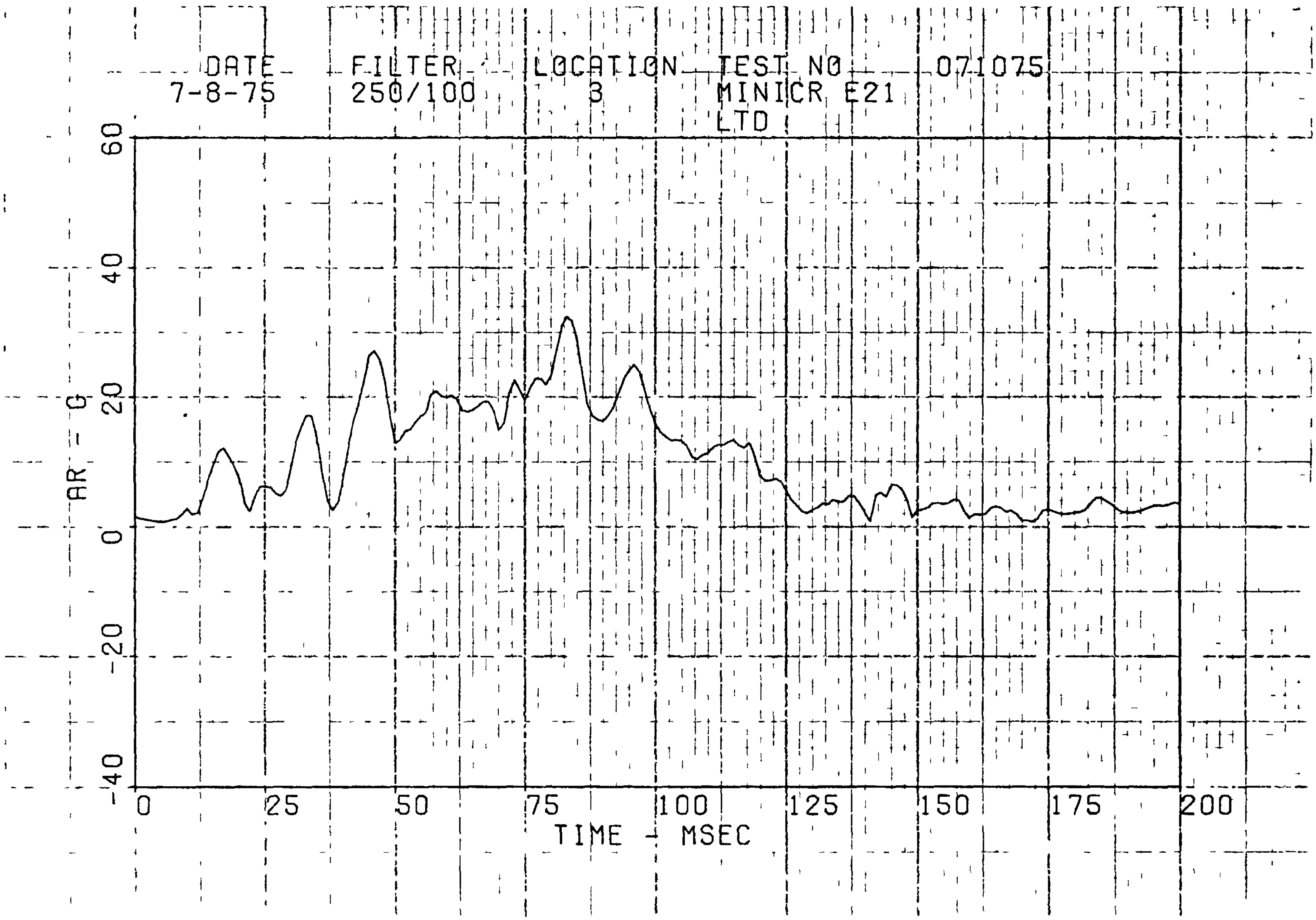


FIGURE 6.18 FORD LTD CRASH PULSE - CRASH TEST NO. 3

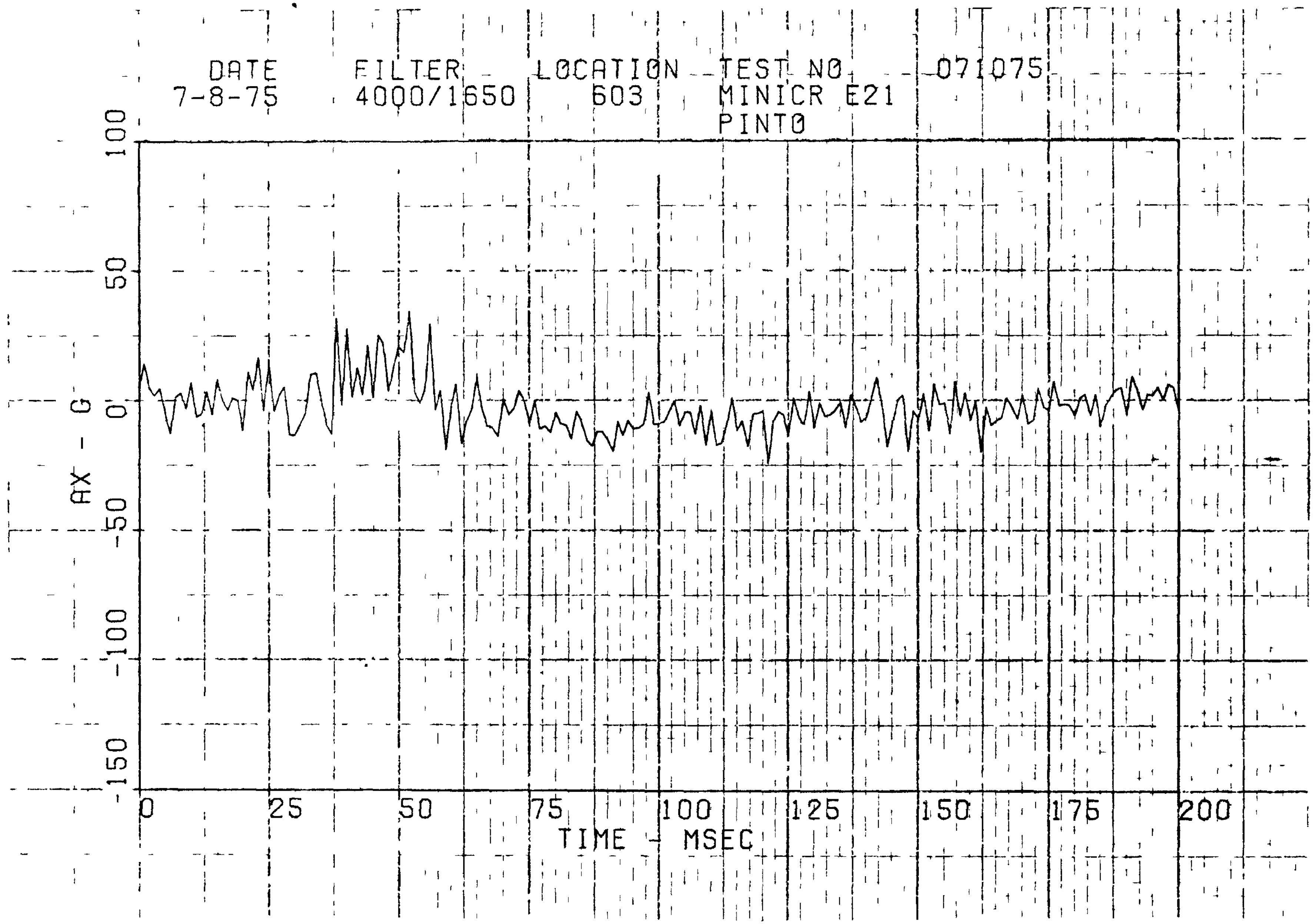


FIGURE 6.19 PASSENGER HEAD ACCELERATION -X COMPONENT - CRASH TEST NO. 3

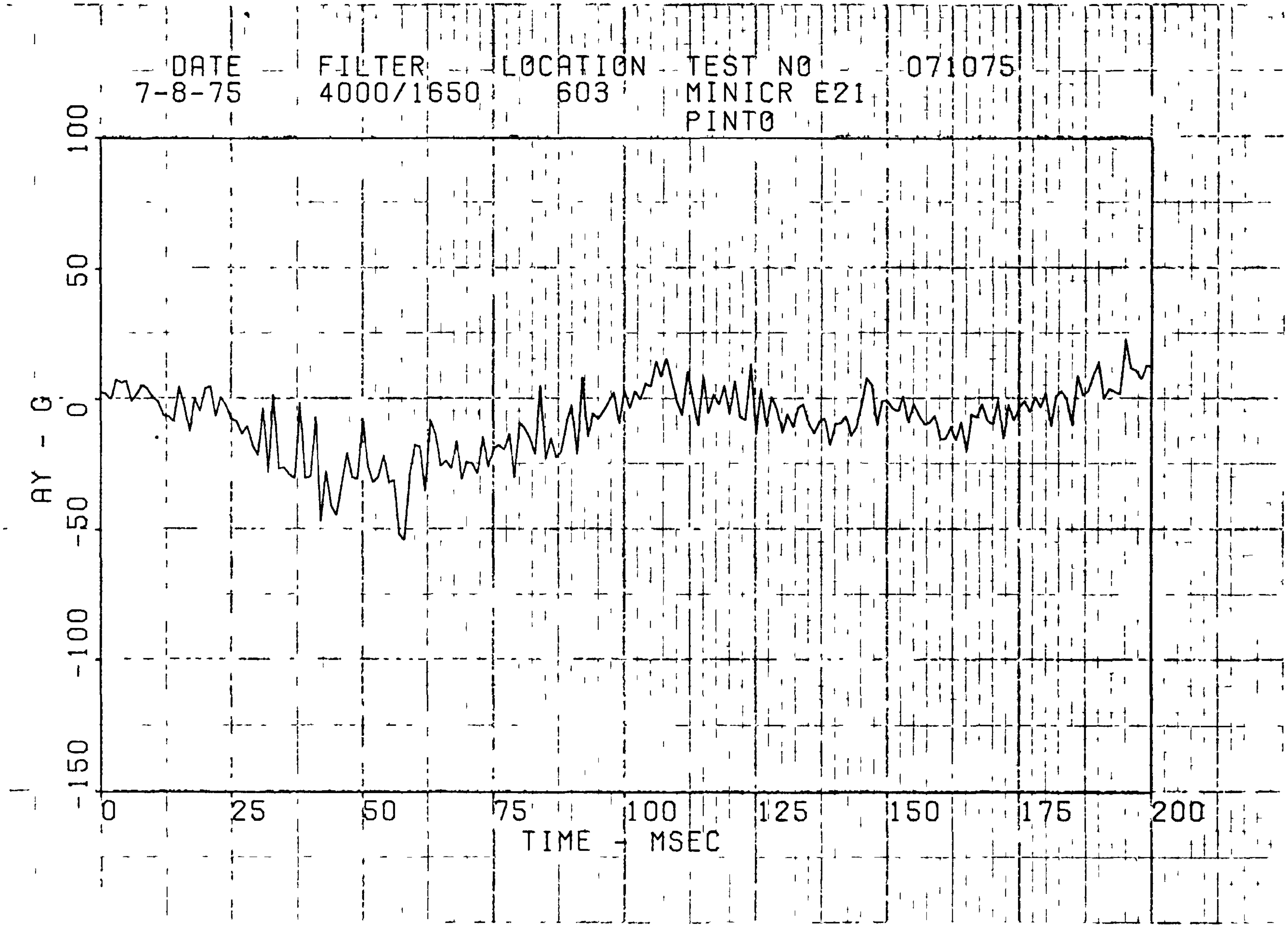


FIGURE 6.20 PASSENGER HEAD ACCELERATION -Y COMPONENT - CRASH TEST NO. 3

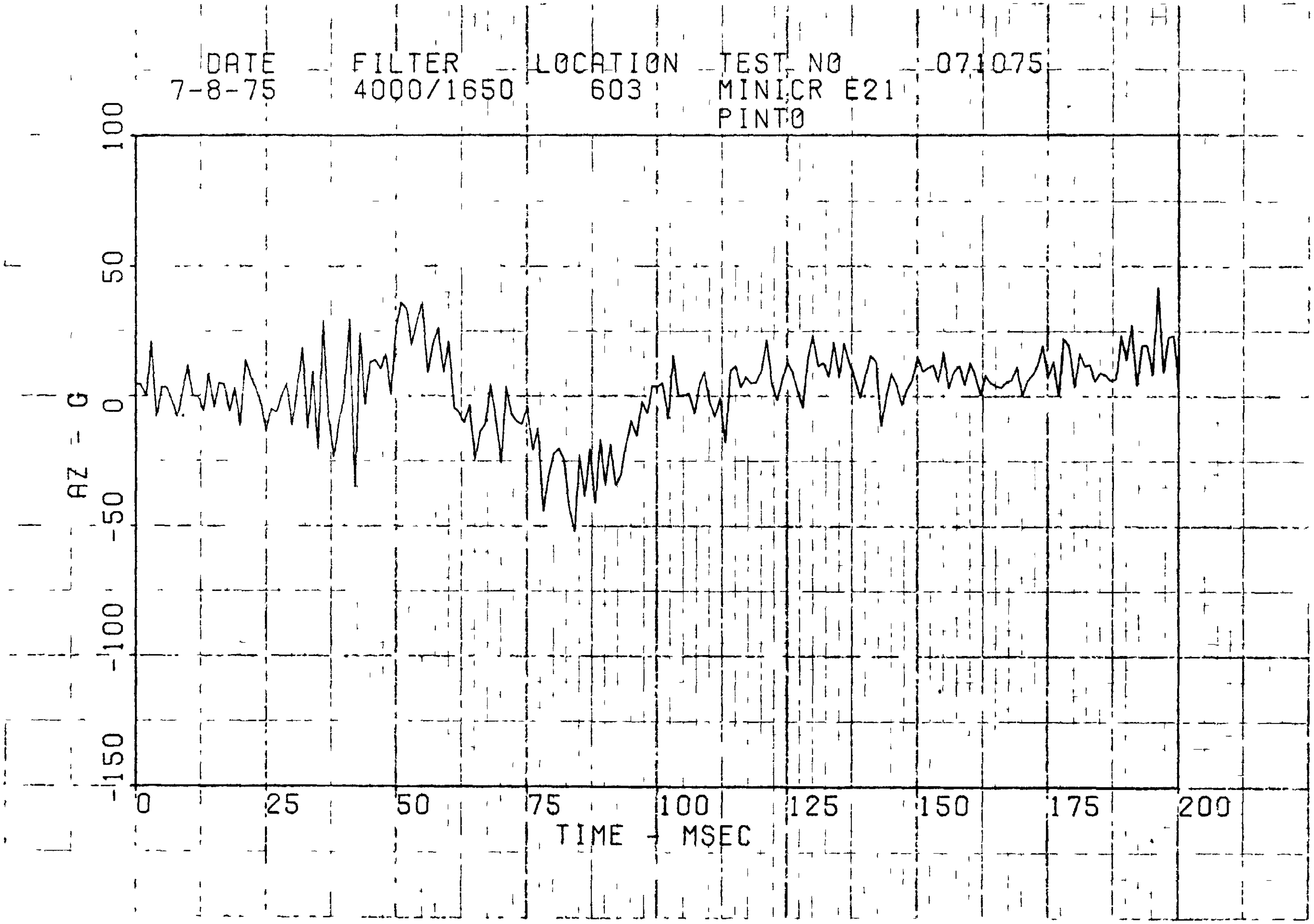


FIGURE 6.21 PASSENGER HEAD ACCELERATION -Z COMPONENT - CRASH TEST NO. 3

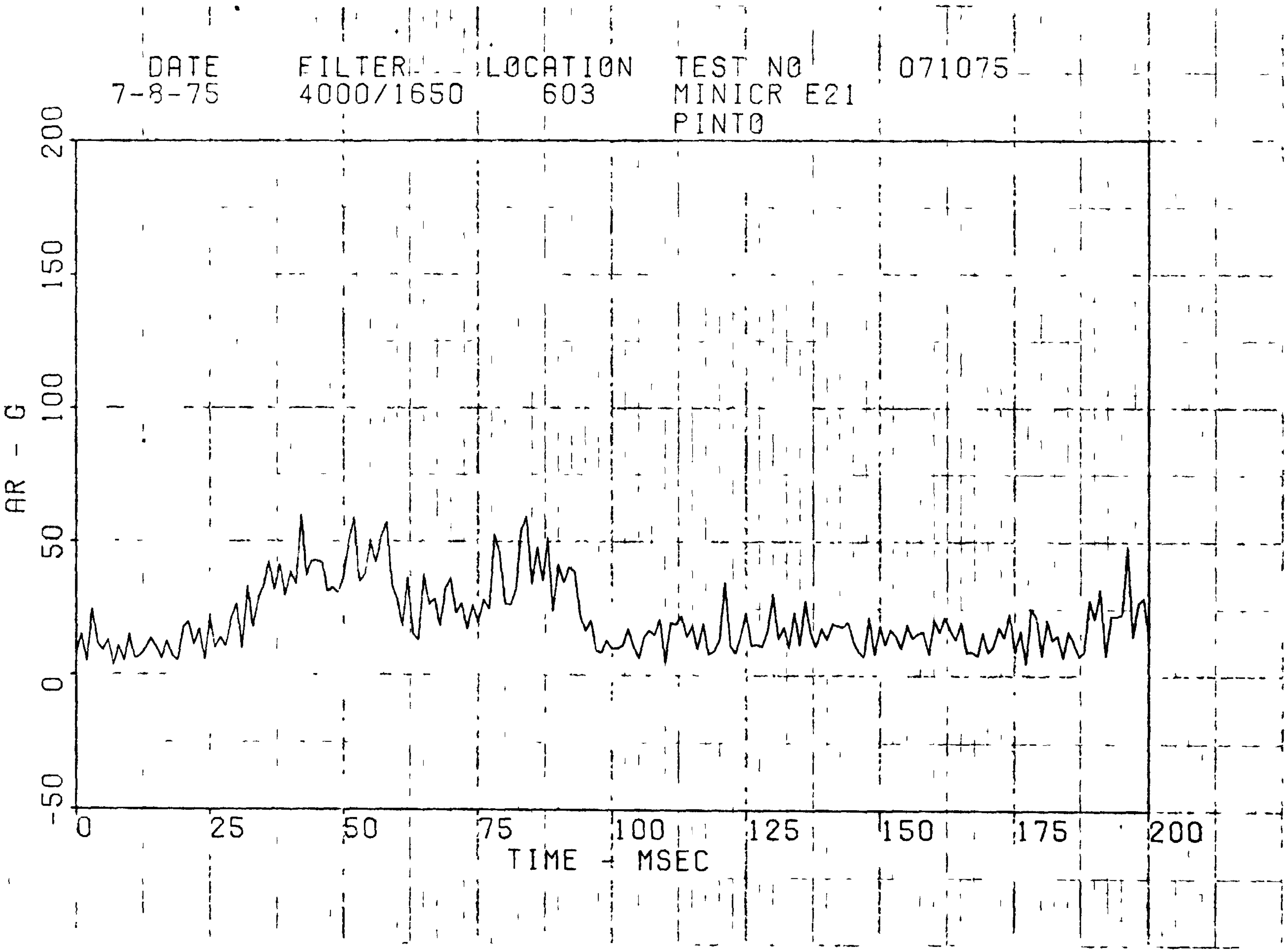


FIGURE 6.22 PASSENGER RESULTANT HEAD ACCELERATION - CRASH TEST NO. 3

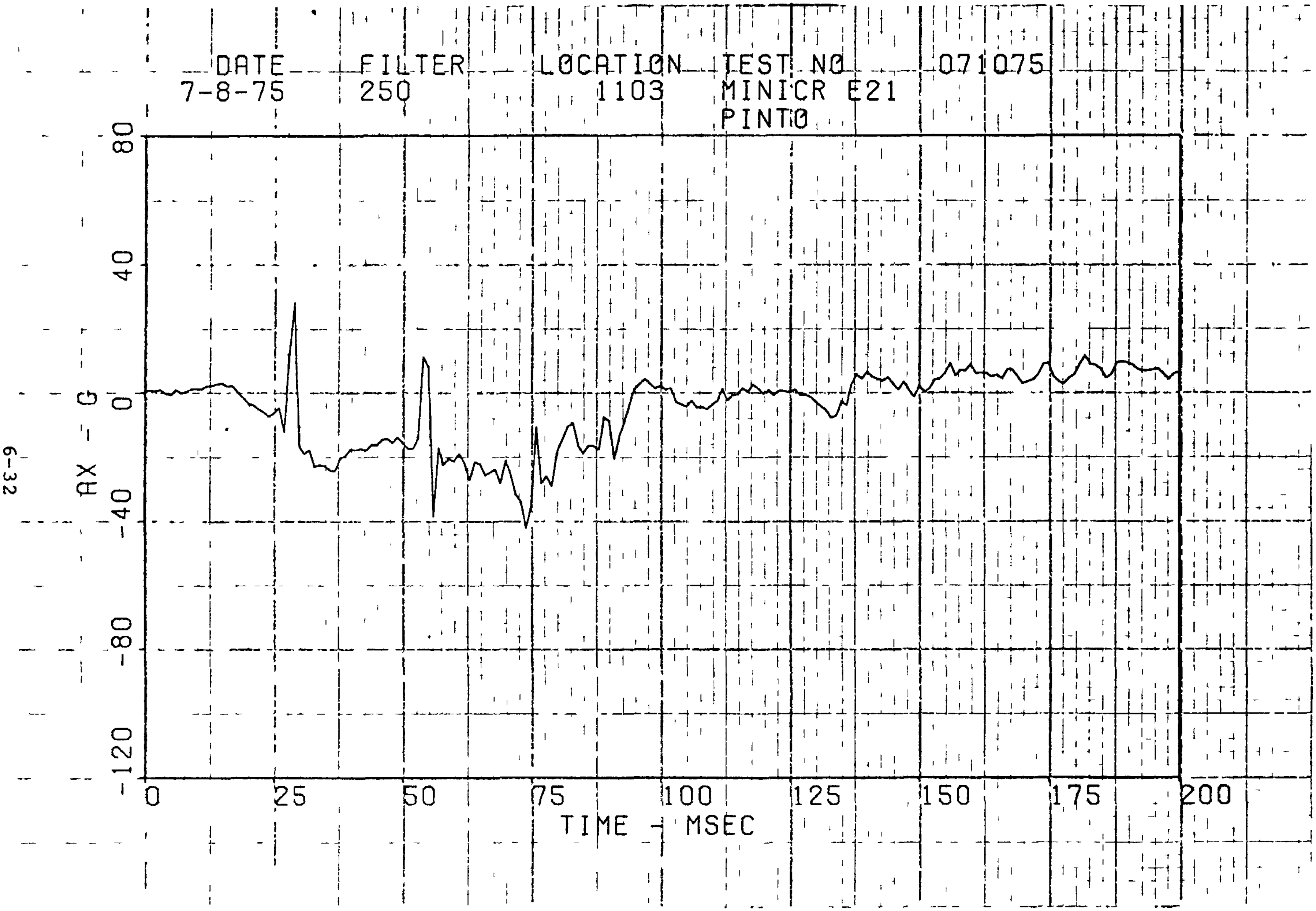


FIGURE 6.23 PASSENGER CHEST ACCELERATION -X COMPONENT - CRASH TEST NO. 3

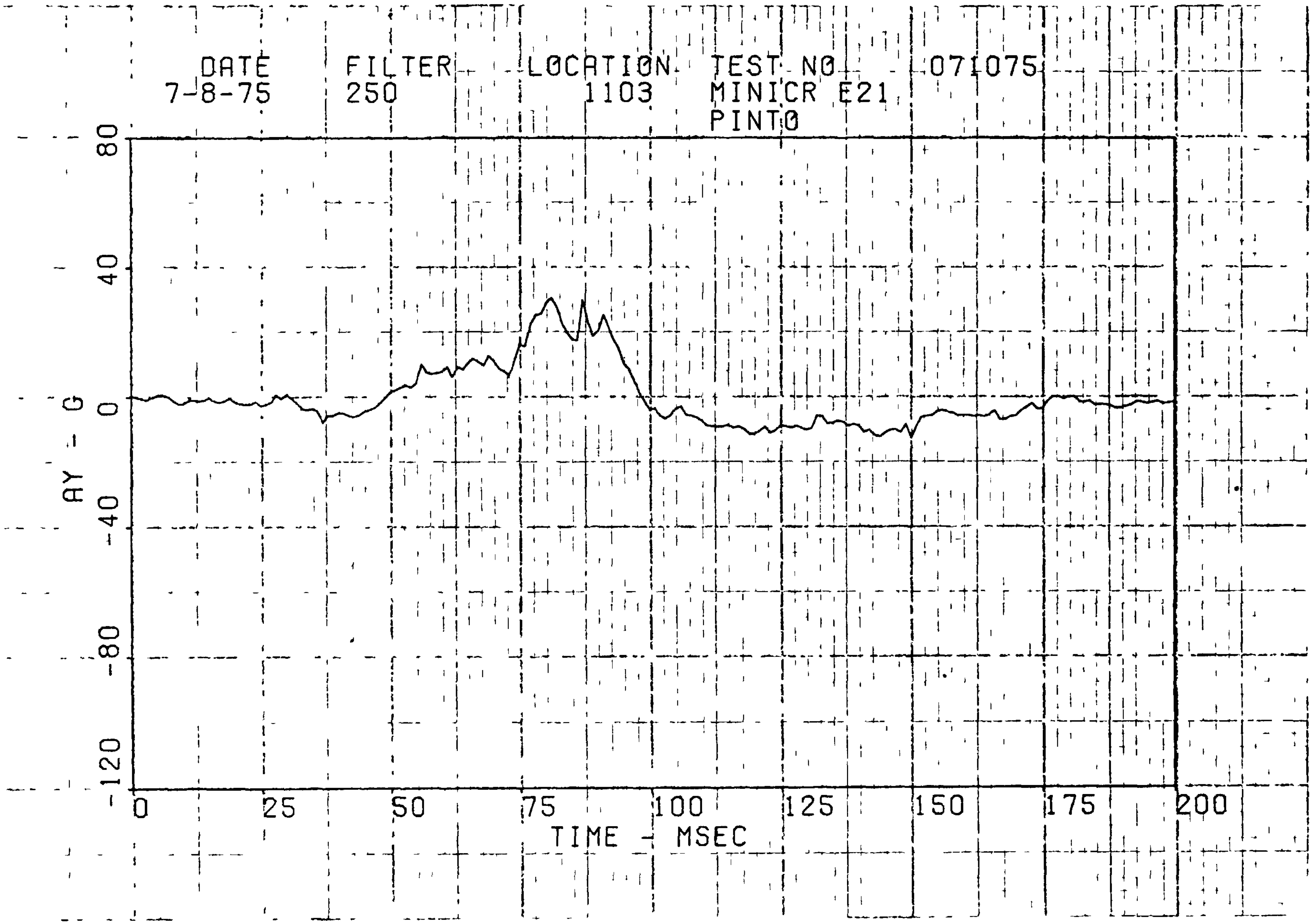


FIGURE 6.24 PASSENGER CHEST ACCELERATION -Y COMPONENT - CRASH TEST NO. 3

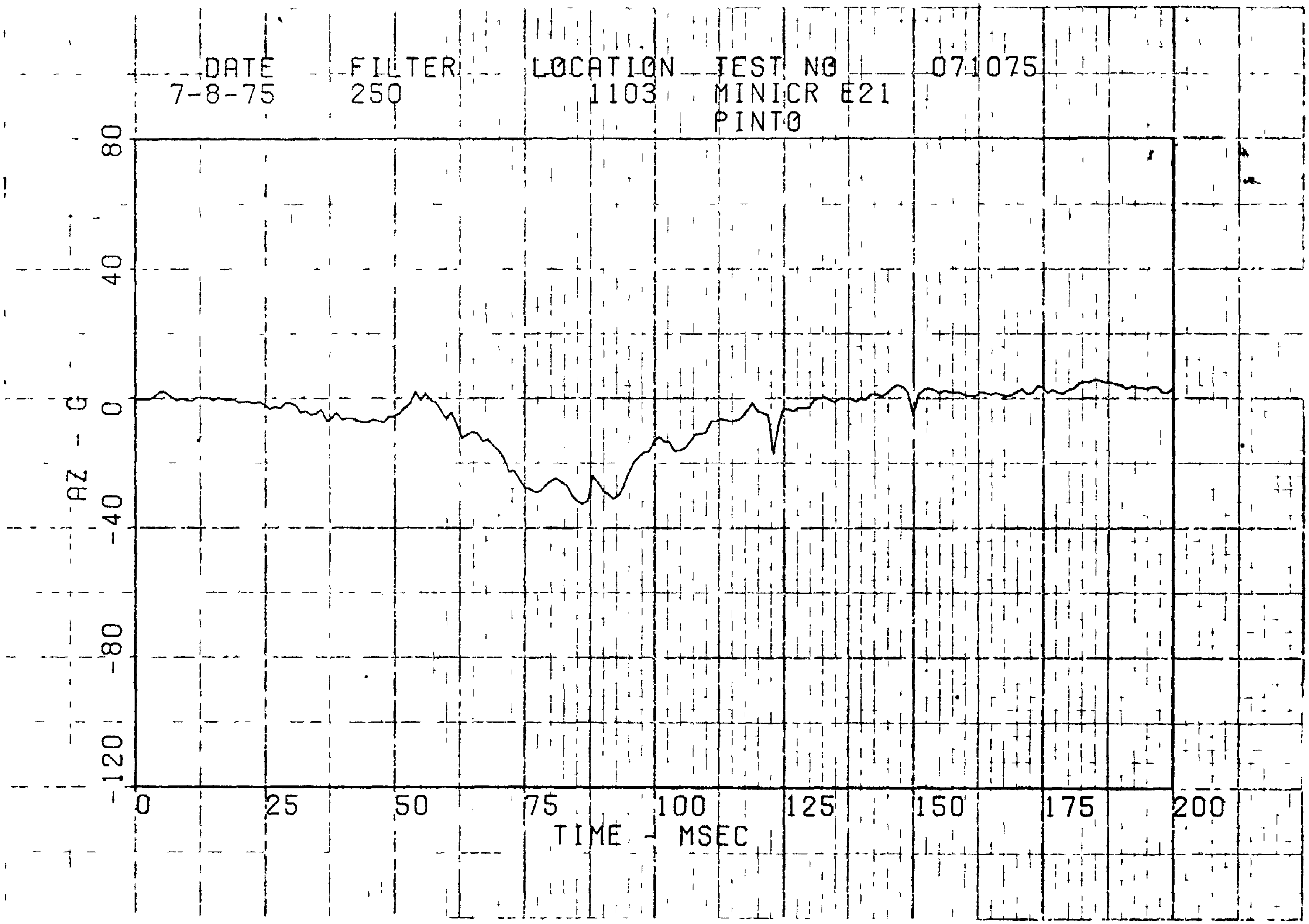


FIGURE 6.25 PASSENGER CHEST ACCELERATION -Z COMPONENT - CRASH TEST NO. 3

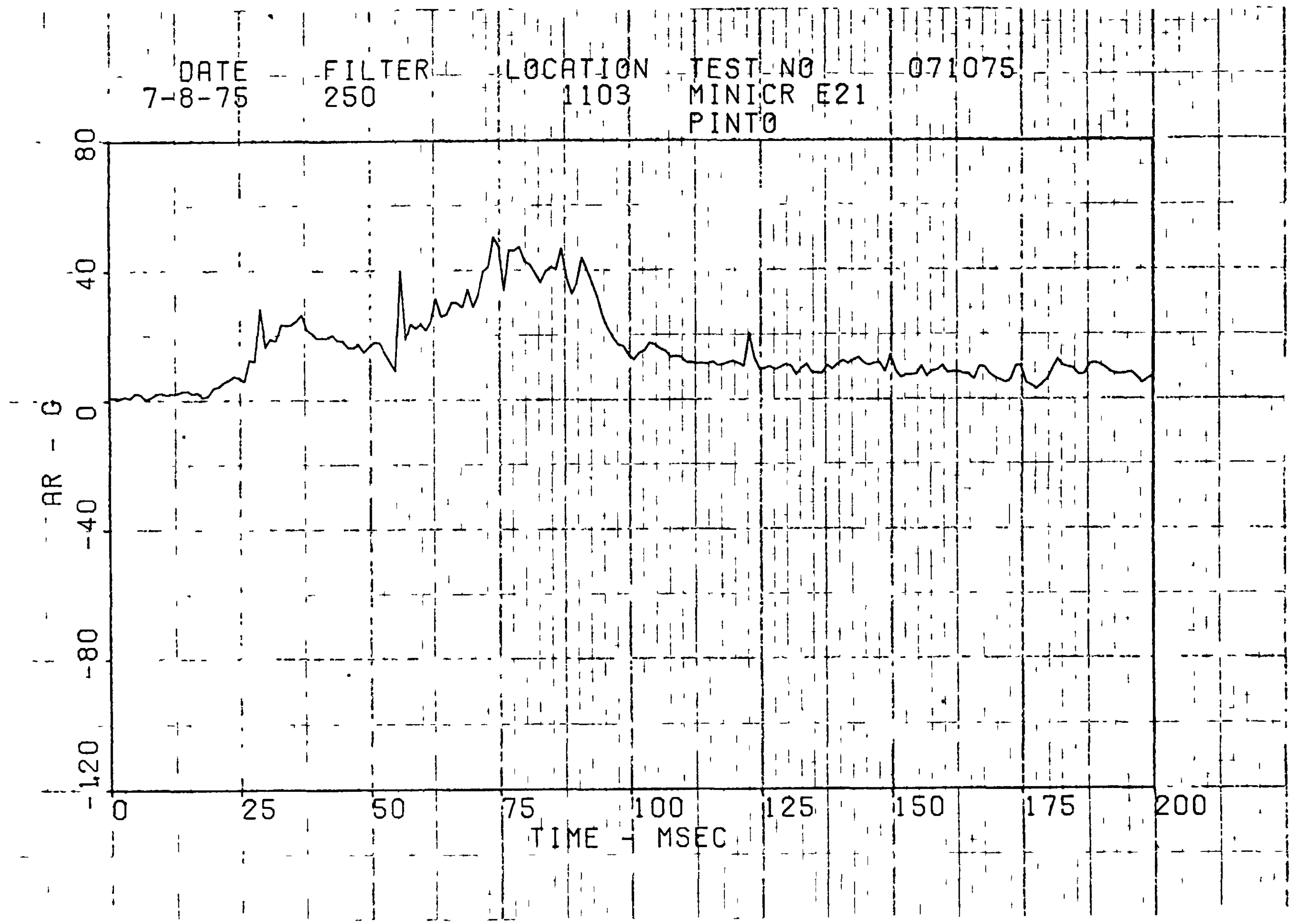


FIGURE 6.26 PASSENGER CHEST ACCELERATION - CRASH TEST NO. 3

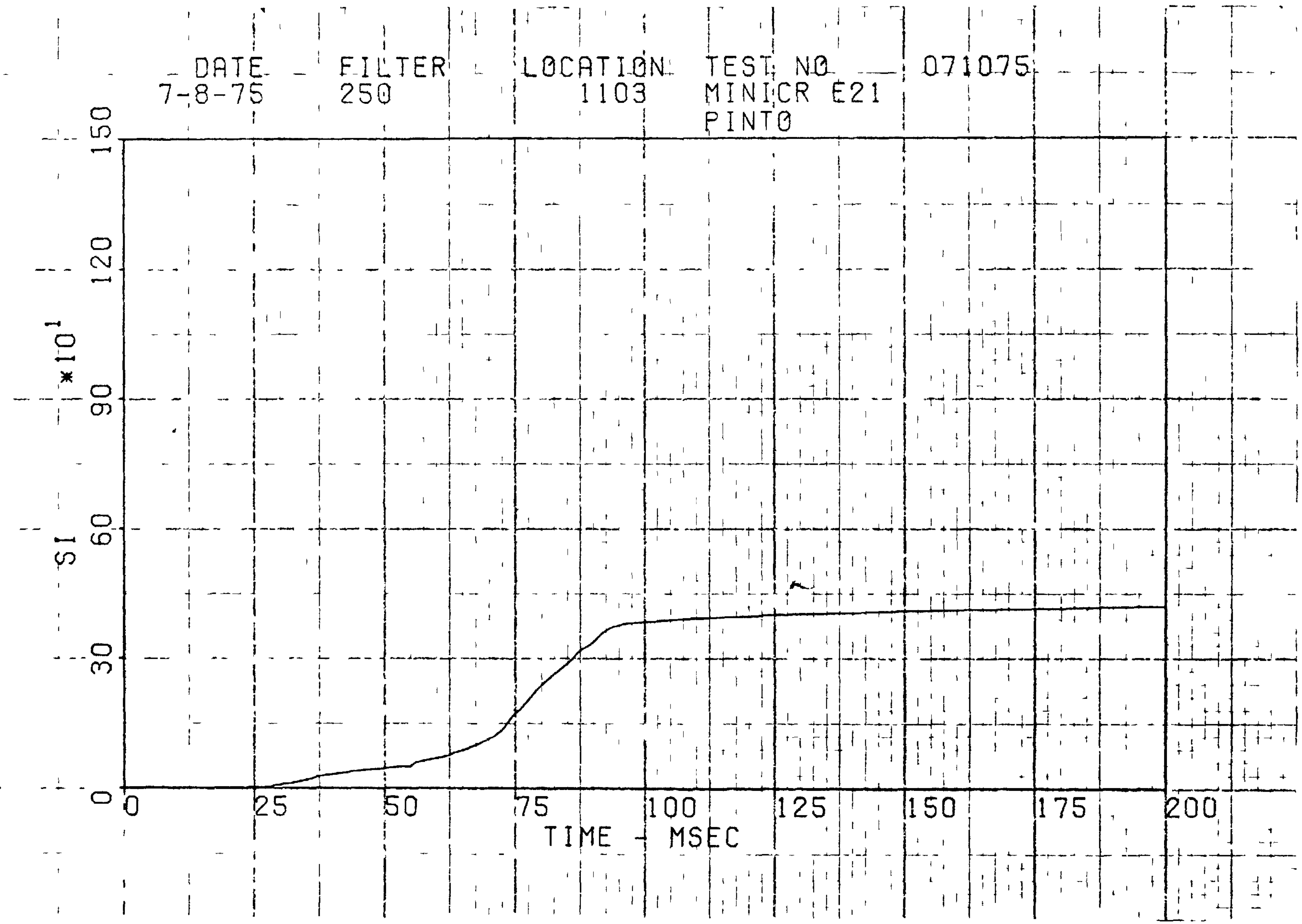


FIGURE 6.27 PASSENGER CHEST SEVERITY INDEX - CRASH TEST NO. 3

7.0 MAKING THE AIRBELT PASSIVE

Once we chose the 3-point airbelt as the finalized airbelt restraint system, we began to finalize the passive version of the airbelt. We first conducted a study of previous work that had been done in developing passive belt systems. One thing seemed to be universally true of all the 3-point passive versions we studied. They were very complex and, therefore, costly, requiring servo motors, moving anchors, and wide open doors for proper activation. Even with these complex systems, none of them worked very well.

We decided that we were not likely, in the amount of time and the funding available on this contract, to be able to improve upon systems in which vast amounts of time and money had already been spent, i.e., by foreign and domestic seat belt and auto manufacturers. For this reason, we decided upon a fresh approach. Preliminary layouts showed the feasibility of making the 3-point system passive in a relatively straightforward manner if the upper belt anchor were moved inboard to the center of the car. Furthermore, the inboard location of the upper anchor would provide the much needed restraint in side and oblique impacts where the impact was on the driver side of the car. This would prevent the passenger from moving across the car and impacting the driver or steering wheel.

With these considerations in mind, we began the detailed design of the passive version of the airbelt.

7.1 The Basic Design

Our objectives in designing a passive version of the airbelt were to make it deploy in a totally automatic fashion and to be as inoffensive to the user as is possible with a 3-point torso-lap belt restraint configuration. Early in this effort, we decided that the simplest way to accomplish these objectives would be to fix the upper and the lower inboard belt anchor points and let the lower outboard belt move up and down along a diagonal slot in the door (see Figures 7.1 and 7.2.

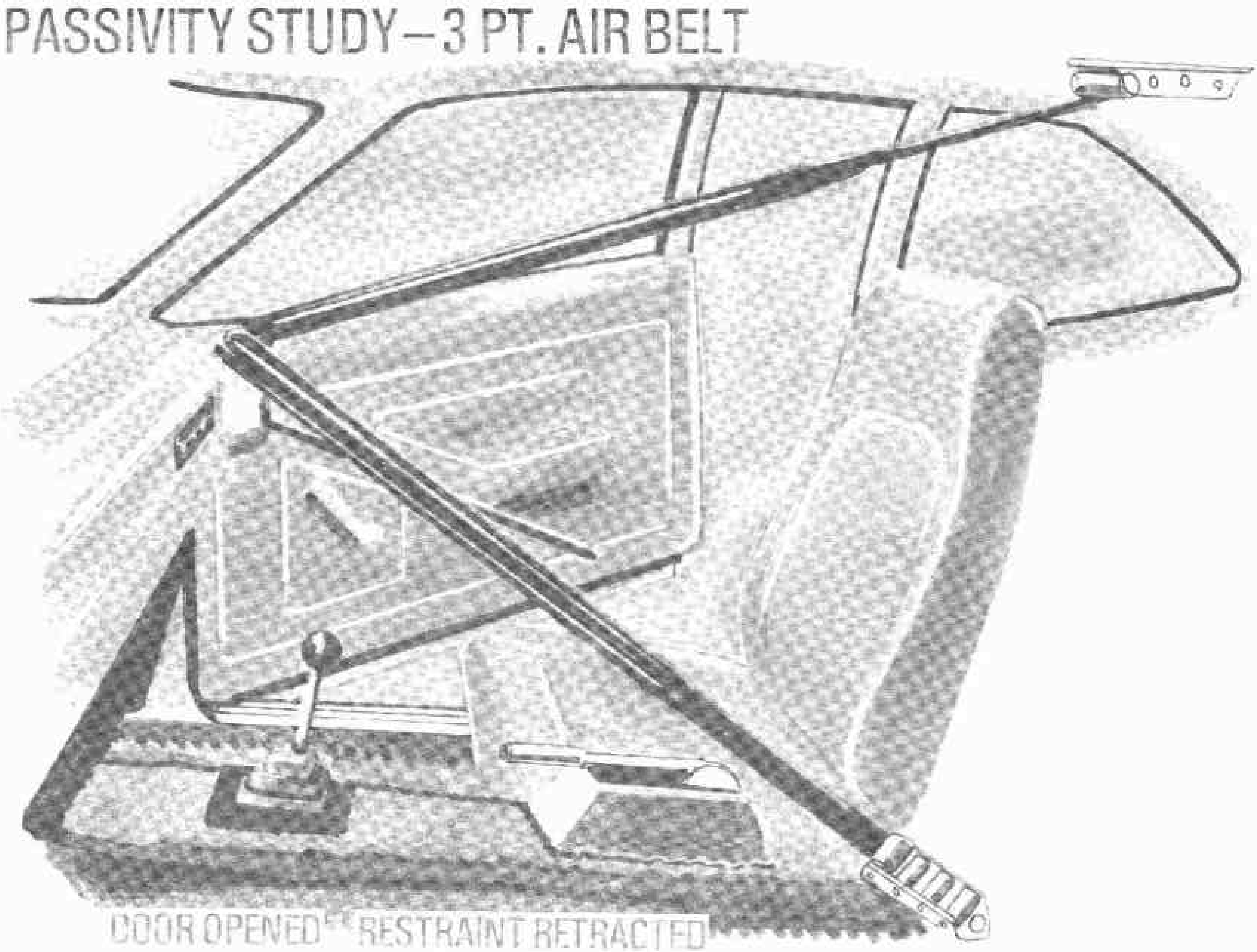


FIGURE 7.1 PASSIVE RESTRAINT RETRACTED

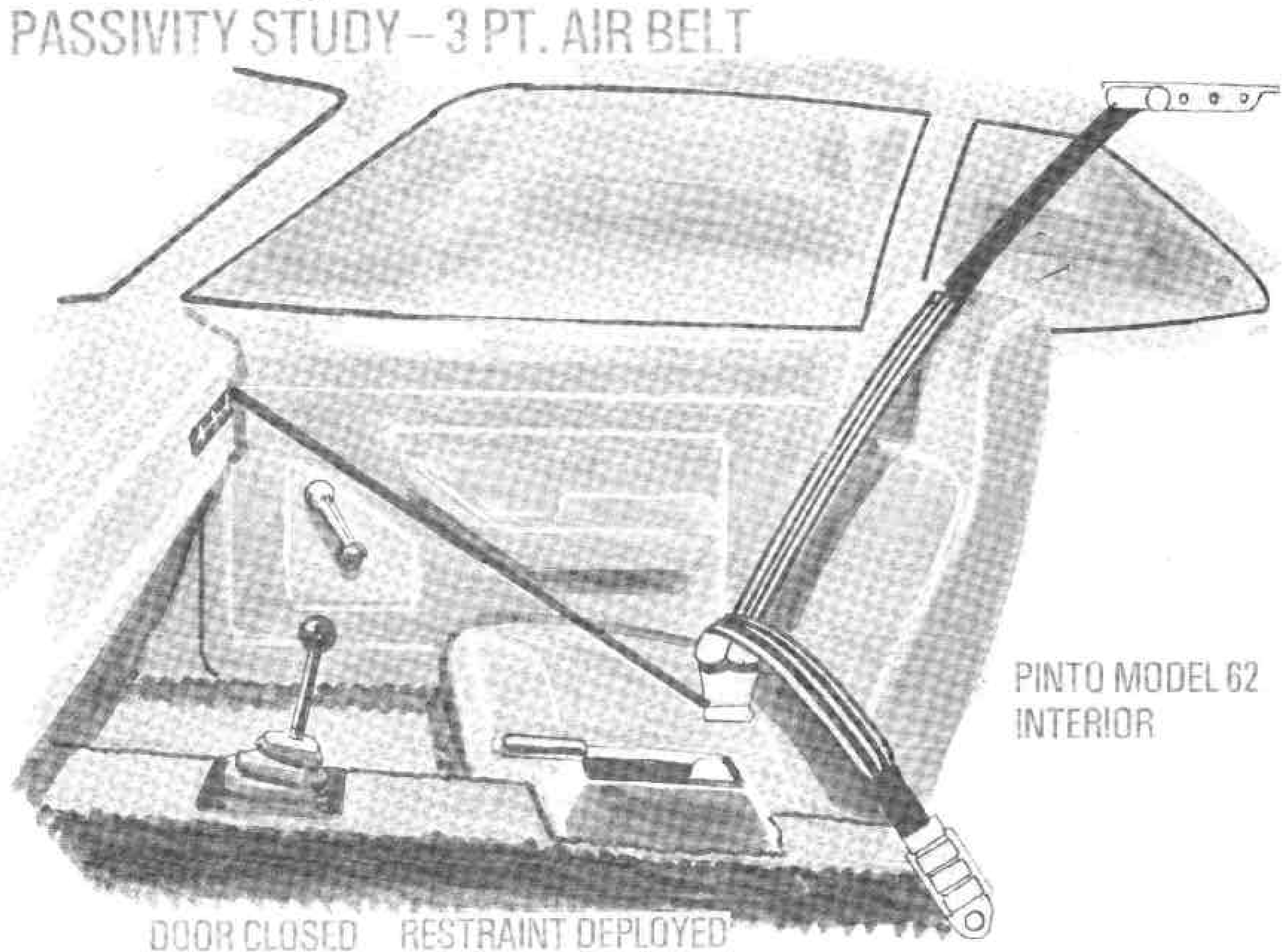


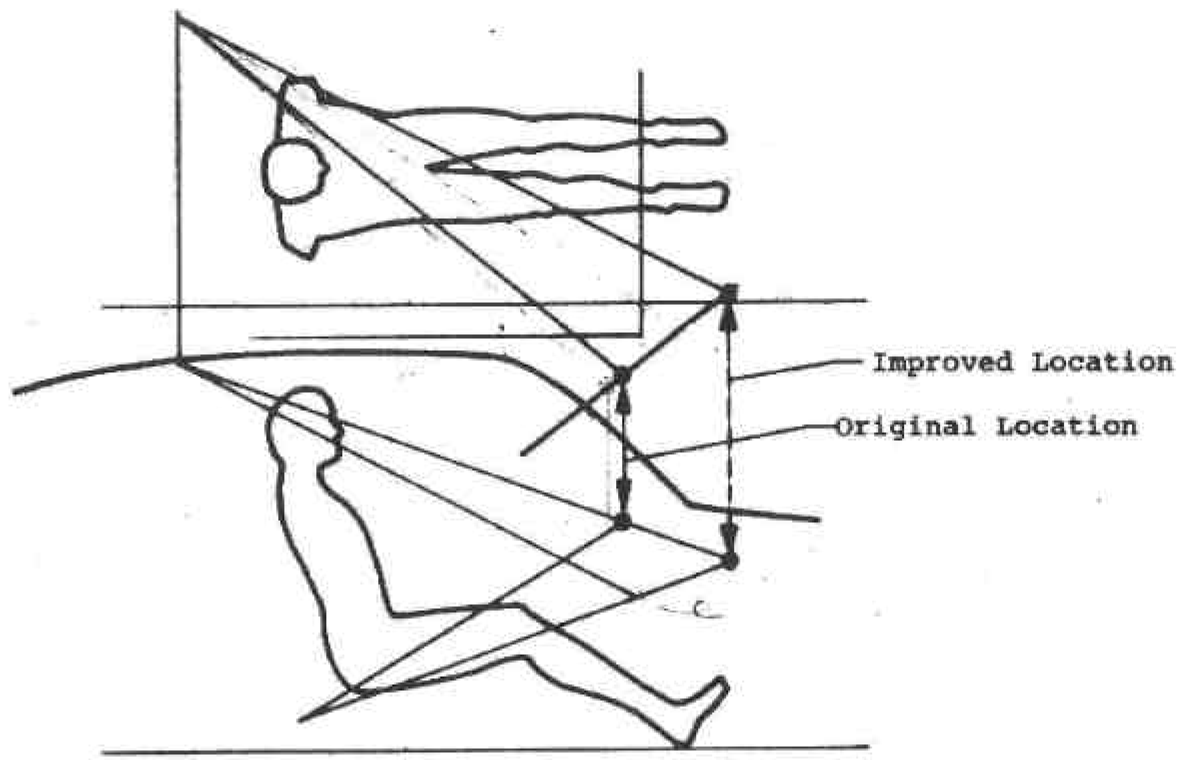
FIGURE 7.2 PASSIVE RESTRAINT DEPLOYED

As mentioned previously, the final configuration we selected required moving the upper anchor point from near the door to the center of the car in the roof, and to make the torso belt and lap belt of one continuous piece passing through a D-ring assembly in the door. During deployment, the D-ring assembly is transported down the diagonal slot in the door. To retract the restraint, the belt travels up the slot in the door. Many different variations of this passive system are possible. Later, we will discuss a few of these alternate designs.

Locating the upper anchor point of the torso belt in the center of the roof helped to prevent the torso belt from draping into the passenger's face during entrance and egress. When retracted, both the torso belt and the lap belt extend from the D-ring in the upper-forward corner of the door away from the passenger as he stands outside of the automobile. This presents a much less formidable appearance than if the upper anchor point of the torso belt were in the standard position near the B-pillar.

We found it was also important to locate the position of the movable anchor point in the door as high and as far forward as is possible when the belt is retracted to prevent the belt from encroaching upon the space that the passenger requires to enter the car. We found that by proper location of this position, as well as proper location of the upper anchor point, the airbelt would not drape into the face of the passenger and left ample space for the motions required by the passenger for entering into and exiting from the vehicle (Figure 7.3).

The airbelt restraint deploys only when the door is shut tight and travels in the slot below the passenger's right arm as he closes the door. The door handle is relocated to an area where the arm can comfortably lie on an arm rest as the belt deploys (Figure 7.4). If the passenger drops his hand from the armrest before the system is fully deployed, his arm can be trapped underneath the torso and lap belt. This would cause no real problem because the arm can be easily disentangled due to the slack available in the inertia reel.



Note: Placing the movable D-ring as far forward and as high as possible when retracted keeps the torso belt out of the passenger's face while he is entering or exiting the vehicle.

FIGURE 7.3 METHOD USED TO REDUCE BELT INTERFERENCE DURING INGRESS

(a) Restraint Not Deployed

(b) Restraint Deploying

(c) Restraint Fully Deployed

FIGURE 7.4 PASSIVE DEPLOYMENT OF THE RESTRAINT

The restraint releases the passenger as soon as the door is unlatched and is fully retracted in approximately 1 to 2 seconds. If the occupant would happen to open the door too rapidly for the transport mechanism to retract the restraint before the door is open, webbing is drawn from the inertia reel to compensate.

Unfortunately, the airbelt is no more comfortable to wear than the conventional 3-point torso-lap belt. There does not seem to be much that can be done to improve this situation but, compared to other passive belt systems, we feel that greater convenience of entrance into and egress from the car is realized by shifting the upper anchor point to the center of the roof.

Figure 7.5 shows the total passive belt mechanism.

7.1.1 Anchor Points

All three anchor points are force limited, which makes it possible to absorb a great deal of the kinetic energy of the passenger, as well as to phase and control the body kinematics during vehicle deceleration.

The upper anchor point is located in the center of the roof of the car slightly aft of the front seats. The airbelt inflator is inside the upper portion of the torso belt at the point where the belt attaches to the force limiter located in the head liner next to the car roof. Therefore, the inflator is carried within the belt during impact.

At the lower inboard anchor point, the force limiter is slightly aft of the front seat and located on the top of the driveline tunnel. (It could also be attached to the side of the driveline tunnel.) An inertia reel is attached between the force limiter and the belt itself. The lap belt moves in and out from the inertia reel as the belt is retracted and deployed. Since the torso and lap belts are constructed in one continuous piece, the inertia reel must keep the torso and lap belt snug when the system is deployed (Figure 7.5).

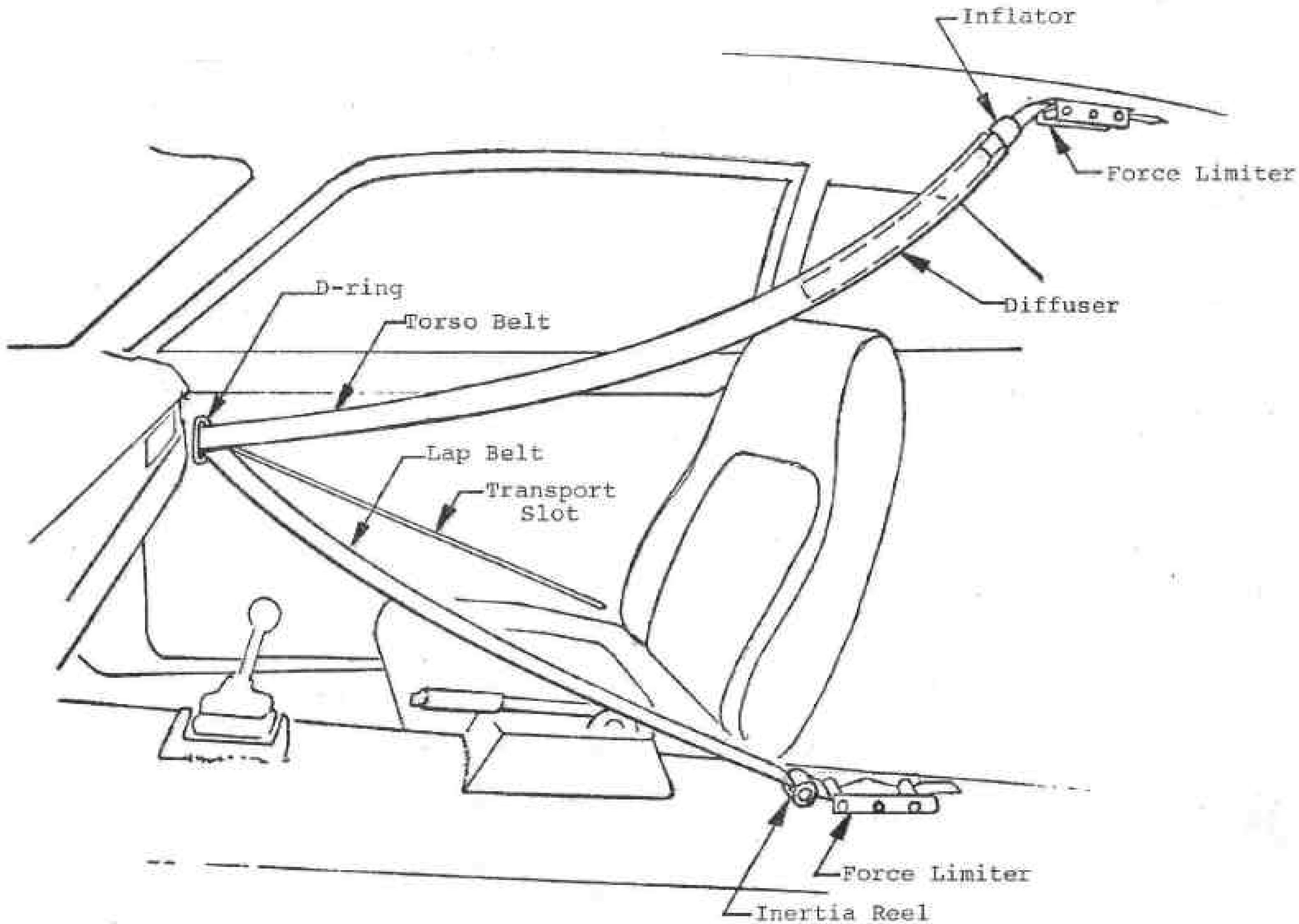


FIGURE 7.5 PASSIVE AIRBELT DESIGN

7.1.2 The Transport Mechanism

The retract and deploy transport mechanism consists of a carriage which slides up and down on a slide rail. A 12-volt Ford electric window motor at one end of the slider moves the carriage by means of a cable and pulley system, as shown in Figure 7.6. The motor powers the lower pulley. The only purpose this mechanism serves is to transport the D-ring, through which the airbelt passes, up and down the diagonal slot on the inside of the door. A latch assembly holds the D-ring and rides with the carriage. The latch attaches the belt to the lower outboard force limiter located inside the door, as shown in Figure 7.7. The key to the latch design is that force applied to the D-ring from the belt will not release the latch, but force applied to the latch by the carriage as it begins to move up the slider releases the latch very easily. In the event of an impact, the latch tears away from the carriage so that the belt is not constrained to move along the slider but, rather, can assume a line of action that is the shortest point between the lap of the passenger and the lower outboard anchor. The working of the latch is illustrated in Figure 7.8.

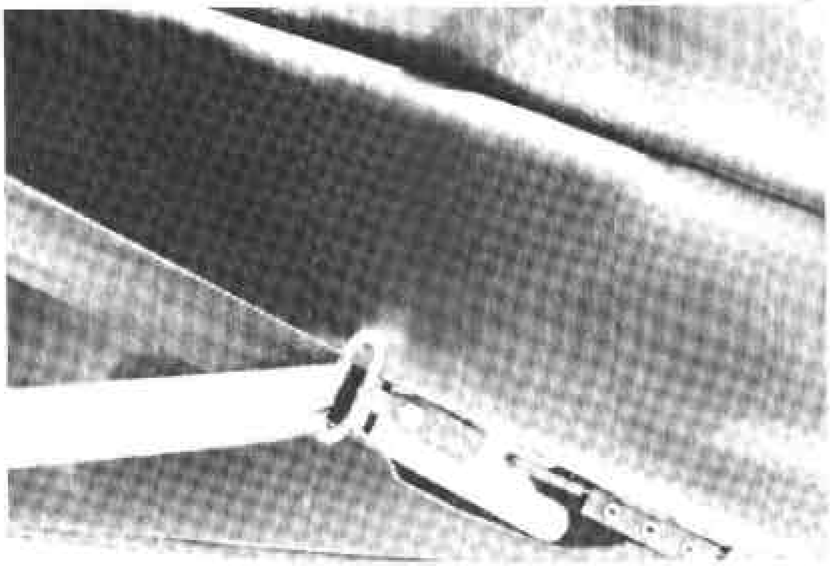
7.1.3 Electrical Activation Circuit

The circuit logic that automatically starts and stops the deployment mechanism is very simple (Figure 7.9). It requires only three switches and two diodes. The door switch senses when the door is closed and when it is open. Our experience has shown that the two states that the door switch must be able to sense are:

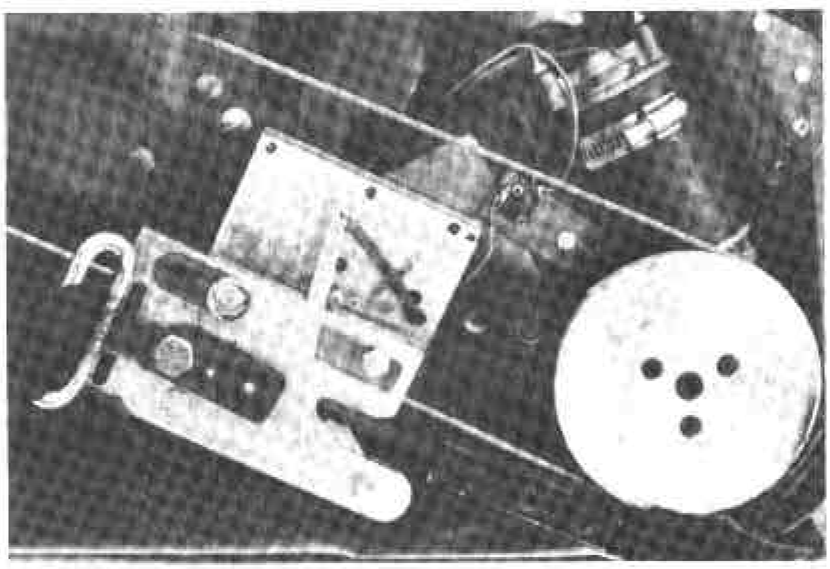
1. When the door is shut tight and latched.
2. When it is open or only partially closed.

The function of the door switch is to reverse the polarity of the electric supply to the 12-volt motor and thereby reverse the direction of pulley rotation. The end result is that when the door is fully closed, the motor can only

FIGURE 7.6   BELT TRANSPORT MECHANISM

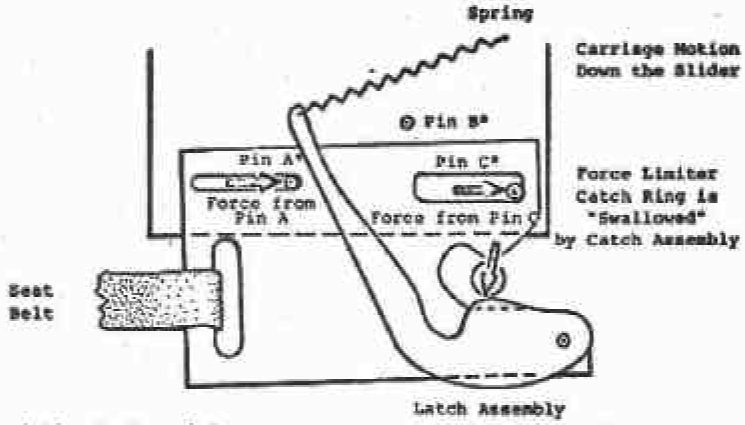


(a) Latch with Door Panel in Place



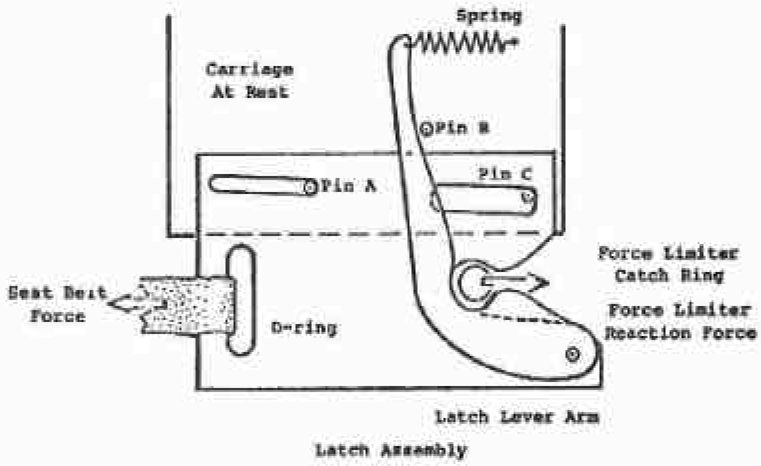
(b) Latch with Door Panel Removed

FIGURE 7.7 LATCH MECHANISM WITH THE AIRBELT DEPLOYED

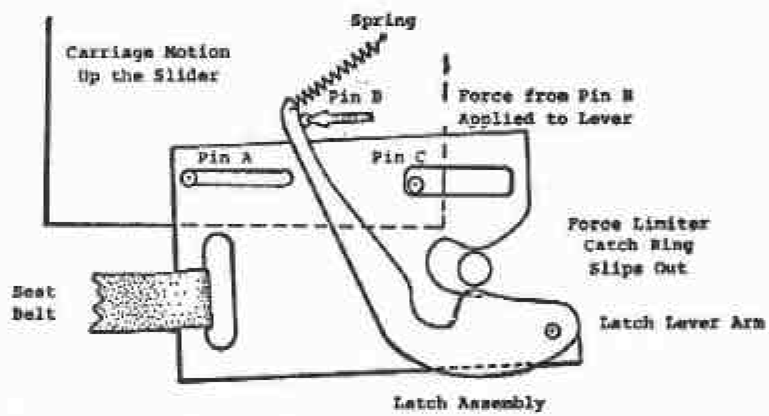


* Pins A, B, and C are
Anchored to the Carriage

(a) Latching Process. The force from Pins A and C move the latch assembly down to the force limiter catch ring. The catch ring tilts the latch assembly upward and pushes into the latch past the lever arm.



(b) Latched. Seat belt latch assembly and carriage latched to force limiter catch ring.



(c) Unlatching Process. As the carriage moves up the slider, Pin B pushes against the lever arm releasing the force limiter catch ring. Pins A and C slide freely in the grooves in the latch assembly.

FIGURE 7.8 LATCH MECHANICS

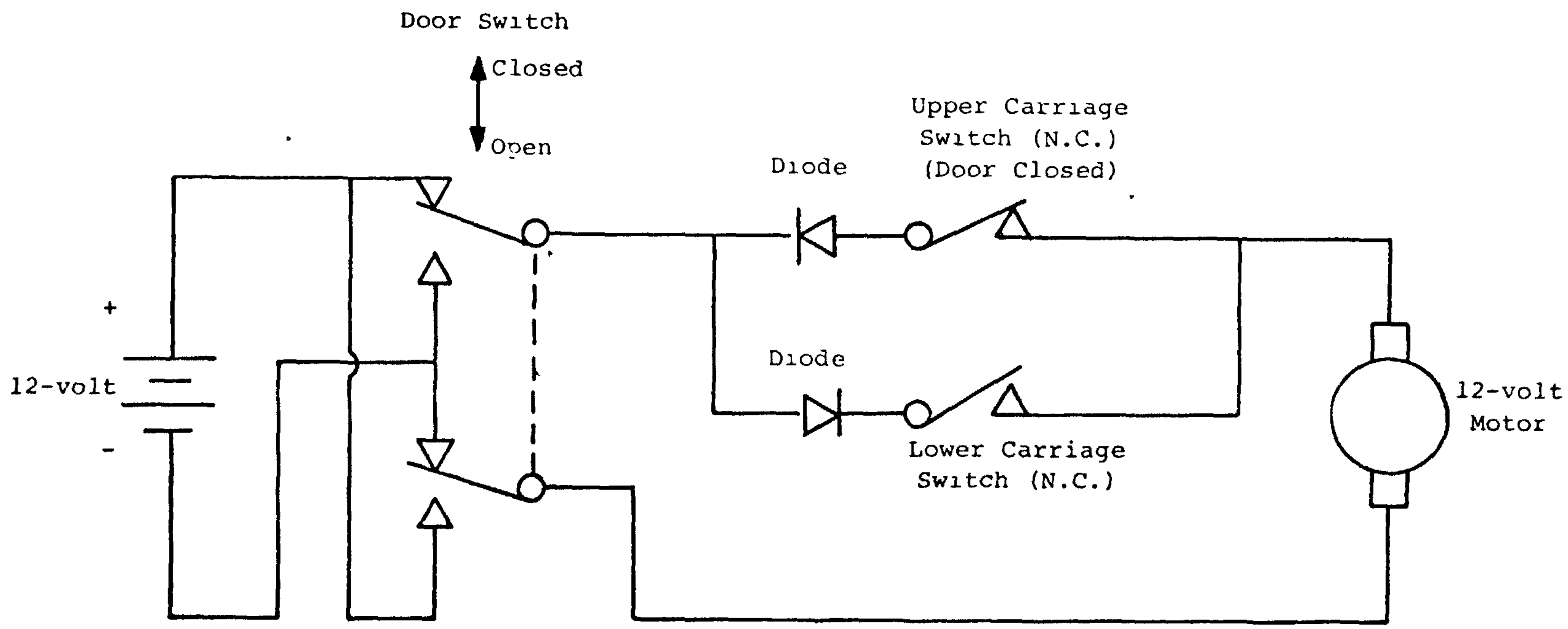


FIGURE 7.9 CIRCUIT DIAGRAM - TRANSPORT MECHANISM

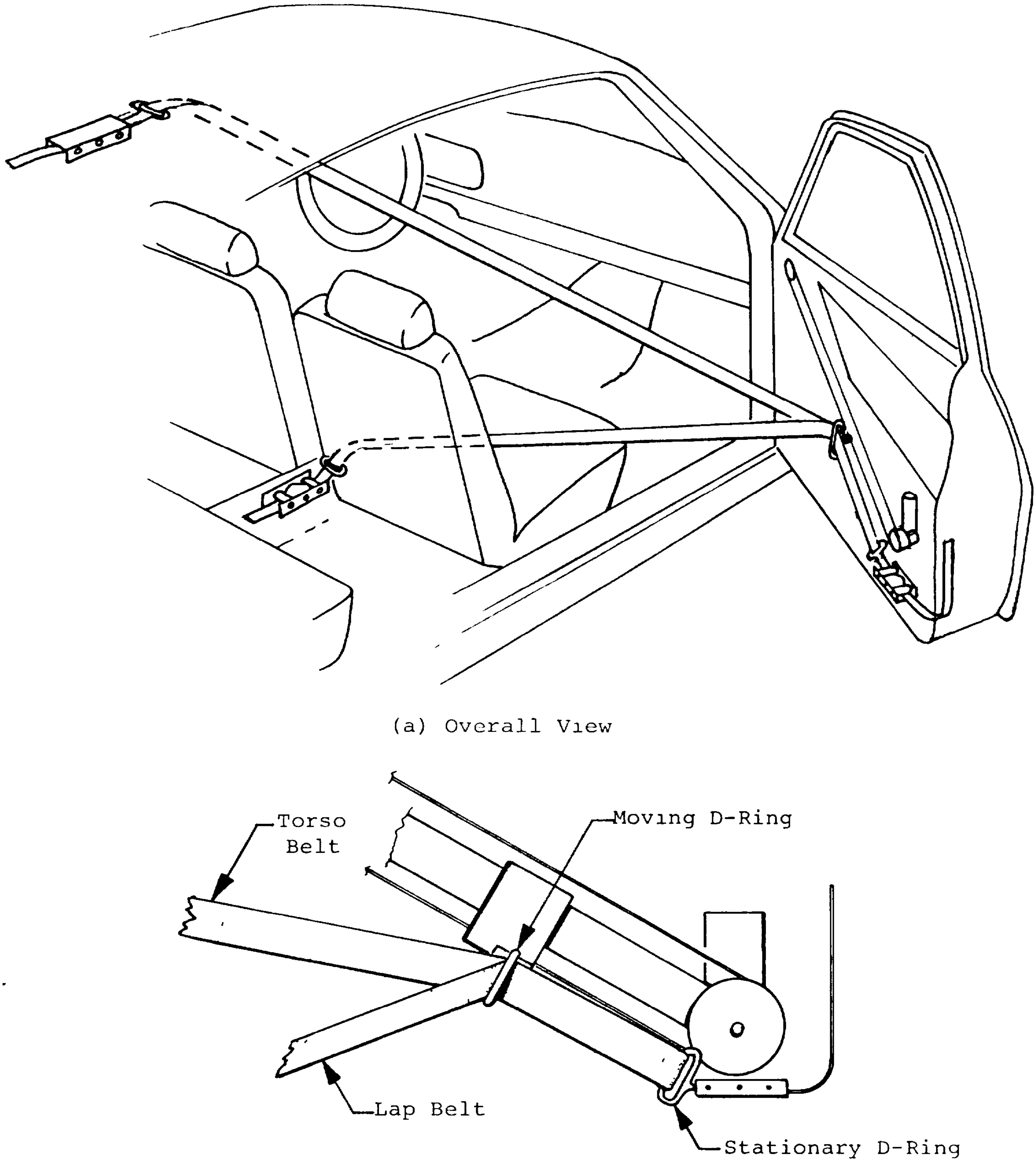
transport the carriage down and engage the restraint system. With the door open or only partially latched, the motor can only transport the carriage up the slider and release the passenger from the restraint.

The other two switches are limit switches for halting the carriage motion at the correct position. One switch senses when the carriage is down, the other when it is up. Since these sensing switches are both normally closed, one or both of them are always closed. We had to include two diodes in the circuit so that only one switch would be active at a time, depending on the polarity of the electrical supply across this leg of the circuit.

The original design of the electrical circuit included a seat switch so that the restraint would only deploy when the door was shut if a passenger occupied the right front seat. We decided to eliminate this feature because when the passenger seat was not occupied, the retracted airbelt would obstruct the vision of the driver along the right side of the automobile.

7.2 Alternate Designs

As was mentioned previously, many variations of this passive design are possible. With one alternate design, it would be possible to eliminate the latching mechanism on the carriage. The lap and torso belts could be fixed to the force limiter in the door and then pass through a D-ring affixed to the carriage. This configuration is shown in Figure 7.10. With the take-up reel in the position between the seats, it would be necessary to run the belt through two D-rings, one attached to the end of the force limiter and the other on the carriage. The torso belt would pass through the movable D-ring on the carriage, run inside the door to the stationary D-ring on the force limiter in the door, back through the door to the movable D-ring, and then across the passenger's lap. A high torque inertia reel would be needed to overcome the extra friction arising from the belt passing through the two D-rings.



(a) Overall View

(b) Detail of Mechanism

FIGURE 7.10 ALTERNATE DESIGN THAT ELIMINATED THE LATCH MECHANISM

A second alternate system could solve the friction problem by placing two reels in the door and attaching them to the force limiter. This would eliminate the stationary D-ring as a friction point and would also eliminate some of the friction from the belt sliding across the passenger as it tightens (Figure 7.11).

A third alternate passive belt design that we have developed lends itself to placing the torso belt anchor point in the outboard position where it is in conventional 3-point belt active systems. The torso belt forms an independent 2-point system similar to that of the passive system in the Volkswagen "Rabbit" with the upper anchor point right on the door, as shown in Figure 7.12. The lap belt is then anchored to the force limiter in the door and is manipulated as in our passive system by a D-ring on a sliding carriage. The major disadvantages of this system are the necessity of strengthening the door frame to accommodate the upper anchor point, the torso belt falling into the passenger's face upon entry into the vehicle, its inherent complexity, and the fact that the belt is totally retracted only when the door is wide open. This would make it difficult to enter the car in all situations where there was insufficient room to open the door all the way, such as parking lots, diagonal parking zones, etc.

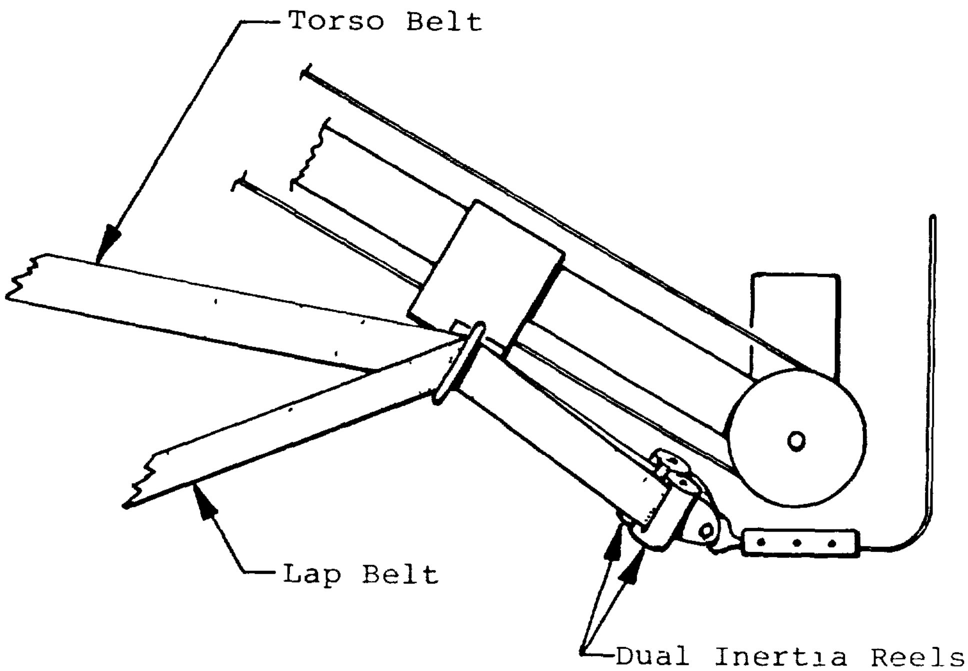


FIGURE 7.11 ALTERNATE DESIGN USING DUAL INERTIA REELS TO REDUCE BELT FRICTION ON THE D-RING

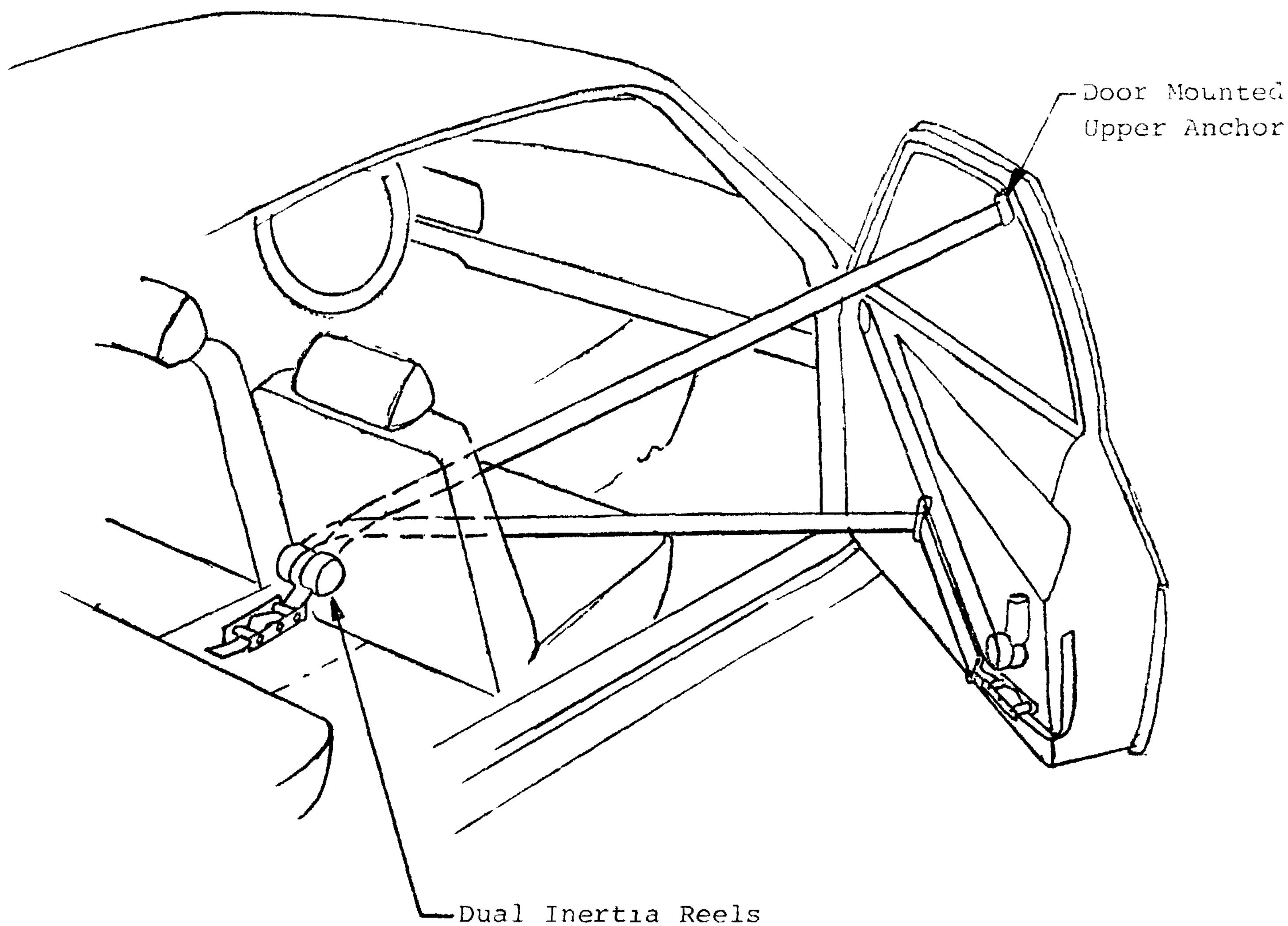


FIGURE 7.12 ALTERNATE DESIGN - UPPER ANCHOR ON DOOR

APPENDIX A

APPENDIX A

AIRBELT AIRBAG FABRIC

The physical properties of the low permeability plain weave 840 denier Nylon 6 air cushion fabric are listed below:

Construction (Threads/Inch)	W	35.5
(in 2 perpendicular directions)	F	32.4
Weight (oz/sq yd)		8.4
Permeability at 0.5" H_2O	CFM/ft^2	2.0
Grab Tensile (pounds)	W	781
	F	710
Trapezoid Tear (pounds)	W	223
	F	207
Tongue Tear (pounds)	W	66
	F	56

APPENDIX B

MINICARS, INC.

35 La Patera Lane • Goleta, California 93017 • Phone (805) 964-6271

March 4, 1975

Mr. John Morris
Department of Transportation
National Highway Traffic
Safety Administration
400 Seventh Street, S.W.
Washington, D.C. 20590

Dear Mr. Morris:

Progress Report for February 1975
Inflatable Belt Development
for Subcompact Car Passengers
Contract No. DOT-HS-4-00917

The effort this month has been directed toward two primary tasks.

1. To complete the evaluation of the 2-point and 3-point airbelt restraints, and then choose the version that will be carried forward for the remainder of the program.

2. To design the passive version of the chosen airbelt system for installation in the subcompact Ford Pinto.

Task 4.4 Development Sled Tests

This month we conducted a total of seven sled tests with two 50th percentile male dummies installed in the Pinto compartment for each test. As pointed out in previous reports, the reason for testing two dummies at once for each test is to gain additional information from each test so as to ultimately arrive at the most finely tuned system possible with the airbelt type restraint.

As we discussed last month, there has been a tendency to experience a large amount of head rotation in the right-left direction. This is caused by the asymmetric torso belt inflating on one side of the head and then pushing the head in the opposite direction.

Although the conventional injury levels measured during these tests are substantially below the allowable limits, we were interested in eliminating this problem if at all possible. In order to support the head in a more symmetric manner, we came up with the design shown in Figure 1.

We tested this version of the belt in Runs 12 and 13 on the left side of the compartment and in Run 14 on the right side of the compartment. In these tests the conventional airbelt without the "head wing" was used on the other side of the compartment. Since in all tests 50th percentile male dummies were tested, we had a good base from which to compare the performance of the new belt with the "head wing" in supporting the head (see Table 1).

In Run 12, the head wing worked well, virtually eliminating the right-left head rotation. However, the resulting increased volume of the bag caused lower belt pressures with reduced head support in the fore-aft direction. In addition, this was the only test where the belt worked as designed. In the other runs (13 and 14) the sensitivity of the wing to up-down and right-left placement on the dummy was in evidence.

In Run 13, the wing deployed across the chest and then abruptly rotated 90° so that the wing stood out in front of the chest rather than across the chest. This, of course, prevented the head from being supported in the "wye" of the belt as planned.

In Run 14, the increased volume of the belt with the head wing allowed a little more forward rotation and somewhat higher HIC values than we liked.

TABLE 1 - DEVELOPMENT SLED TESTS

Sled Run	Date	Passenger Size (Percentile)	Velocity mph	Crush in.	Sled g's Avg/Pk	Peak Resultant Chest g's (-3 msec)	HIC	Maximum Femur Load lbs Left	Maximum Femur Load lbs Right	Force Limiter Stroke-in Upper	Force Limiter Stroke-in Lower	Maximum Belt Pressure psi	Remarks
12-L 2-pt	2- 6-75	50th GM	47	27	36/51	49	670*/840	1160	920	15-1/4	2-1/4	17	Used new airbelt "head wing" to prevent head rotation in R-L direction. Slightly stiffened lower torso F L. and softened upper torso F L. to get a little less submarine. Good test-no R-L head rotation.
12-R 2-pt	2- 6-75	50th GM	47	27	36/51	38	598	920	1430	15	2-1/2	29	Same force limiter adjustments as above, no "head wing." Speedometer malfunction. Sled velocity obtained by integrating acc. trace. Good run-very low injury levels.
13-L 3-pt	2-12-75	50th GM	51	28	38/63	52	413	600	1650	14	10-3/4- 8-7/8	13	Airbelt with head wing, wing rotated away from head so that head rotated in R-L direction. Large spike in crash pulse.
13-R 3-pt	2-12-75	50th GM	51	28	38/63	44	446	840	840	12-3/8	14- 9-7/8	24	Regular airbelt configuration. Head rotated in R-L direction, seems more severe with 3-pt system.
14-L 2-pt	2-14-75	50th GM	49	29	36/49	75**	661	650	1230	17-1/2	4-1/2	30	Airbelt without head wing (same as RFP, Run 12). Quite a bit of R L rotation of dummy
14-R 2-pt	2-14-75	50th Humanoid	49	29	36/49	53	951	1000	1620	16-3/8	4-3/4	21	Airbelt with head wing higher on belt than in Runs 12 & 13. Fair amount of fwd head rotation. Seat back collapse caused lump belt for substantial duration.
15-L 2-pt	2-19-75	50th GM	48	28	35/46	36	1532	670	1560	13	--	33	Eliminated lower force limiter, firmed up upper force limiter. Substantial R-L rotation of dummy, Dummy came partially out of restraint
15-R 2-pt	2-19-75	50th Humanoid	48	28	35/46	51	1377	1040	1370	14-1/2	3	--	Firmed up upper force limiter, some R-L rotation of dummy. Dummy looks unstable in 2-pt system
16-L 2-pt	2-21-75	50th GM	47	31-1/2	30/35	48	1158*/1697	1100	2000	13-3/4	3-1/2	26	R-L rotation again. Very sensitive to belt placement on torso. Rebound g's high due to exposed unpadded surface impact.
16-R 3-pt	2-21-75	50th Humanoid	47	31-1/2	30/35	43	420	882	865	13-5/8	10-3/4- 7-7/8	27	Good trajectory. Rebound g levels fairly high due to head impact with seat frame on rebound
17-L 3-pt	2-25-75	50th GM	46	31-1/2	29/36	39	344	500	680	12	12-1/4- 6-1/2	26	Same set up as RFP last run (16). Good run. Some R-L rotation of dummy due to unequal stroke of lap force limiters, dummy staying on seat
17-R 3-pt	2-25-75	50th Humanoid	46	31-1/2	29/36	39	237	1390	900	9-1/2	11-1/2- 9-5/8	28	Softened upper force limiter slightly. Good run. Short in chest traces at 60 msec, some R-L rotation of dummy for same reason as LFP, heads hit each other during rebound
18-L 3-pt	2-26-75	50th GM	50	33	29/38	44	408*/582	320	260	15	9-7/8- 9-1/4	29	Pre evaluation test run. Good run
18-R 3-pt	2-26-75	50th Humanoid	50	33	29/38	40	373	2220	730	13-1/2	10-7/8- 6-5/8	26	Pre evaluation test run. Left foot hit sled transmission tunnel flat surface

* HIC without rebound effects. All other values without asterisk include rebound effects

** Dummy came part way out of restraint due to seat back collapse on sled acceleration. Dummy hit dash. (See body of report for explanation.)

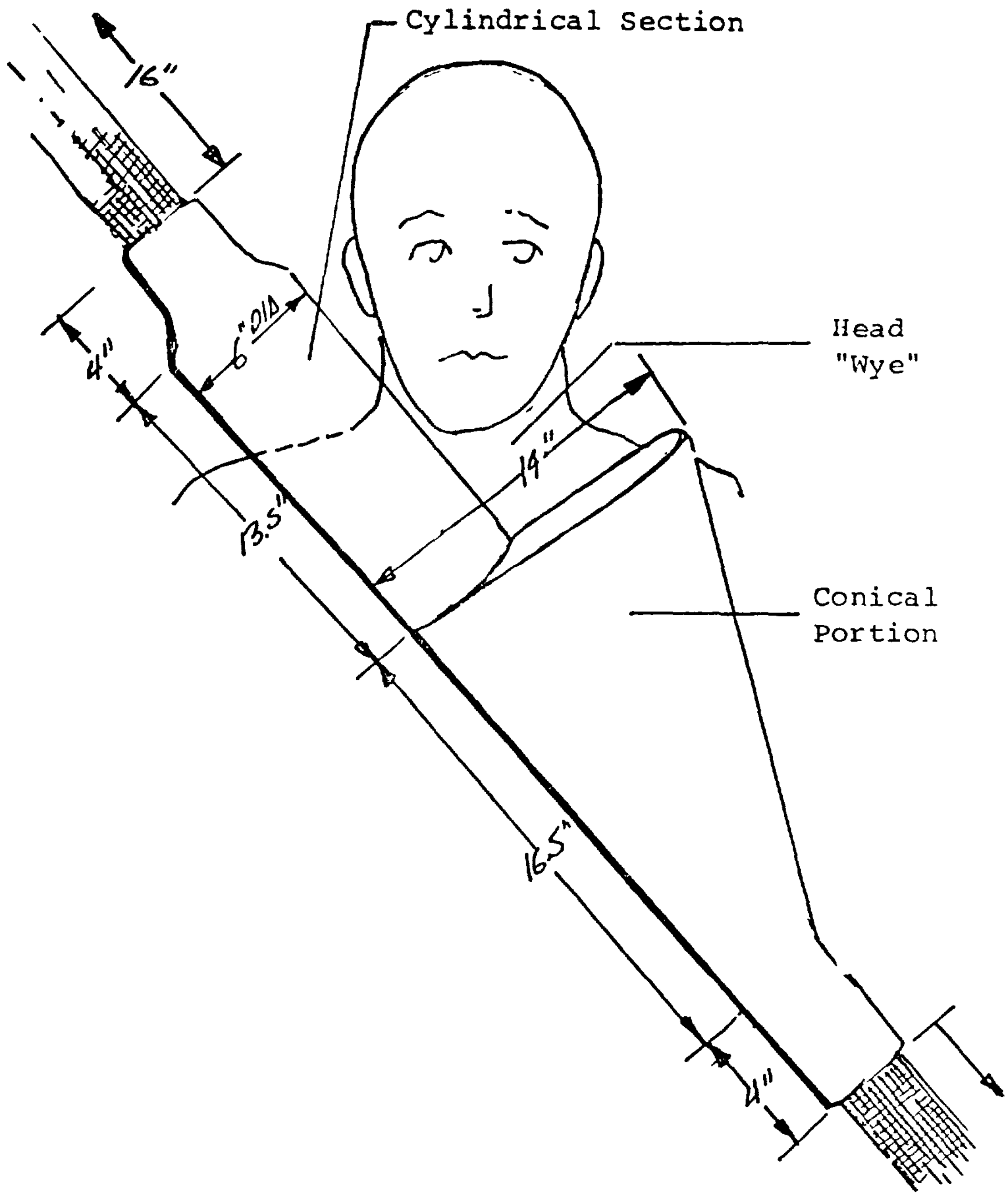
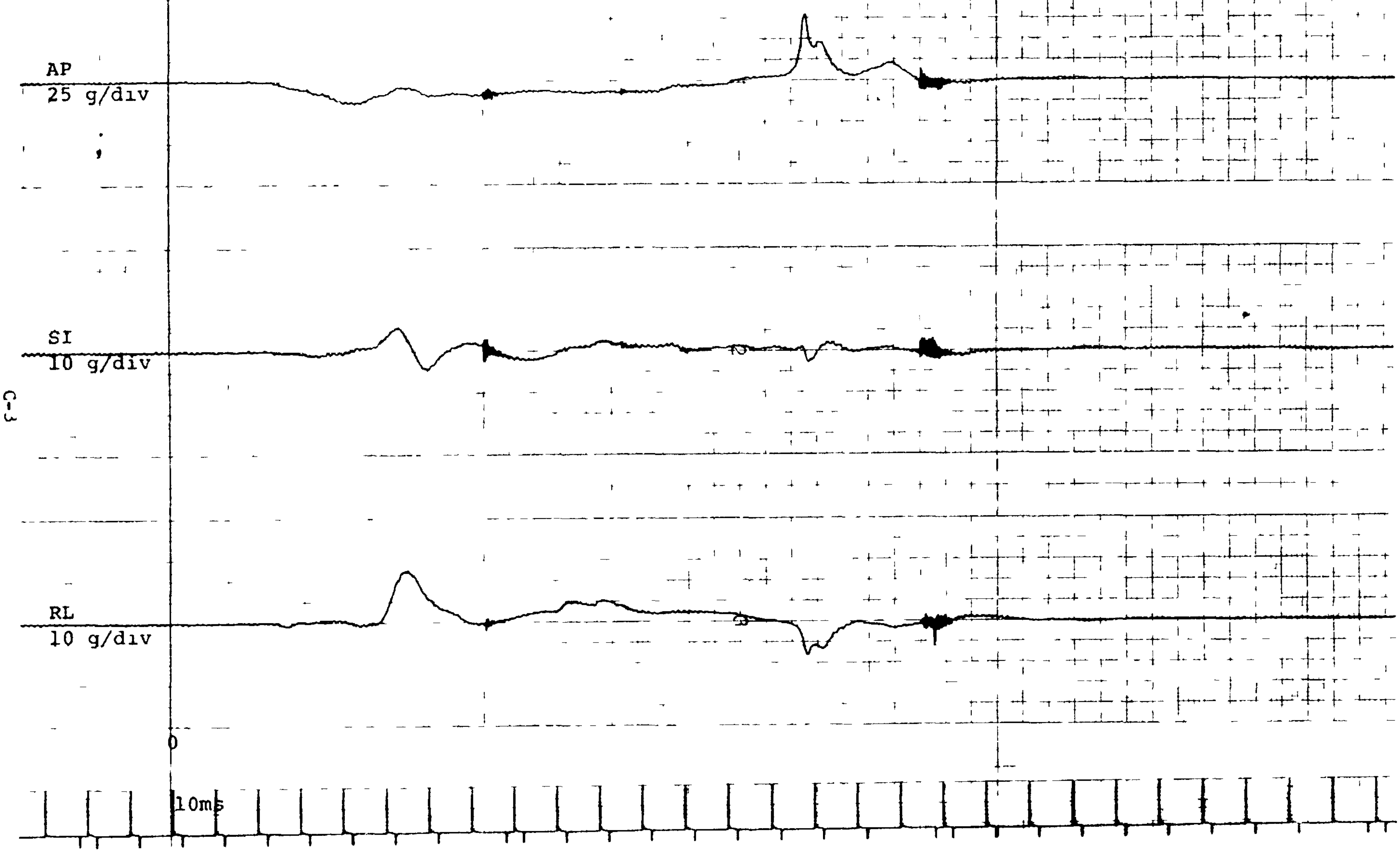


FIGURE 1 PROPOSED SOLUTION TO HEAD ROTATION PROBLEM

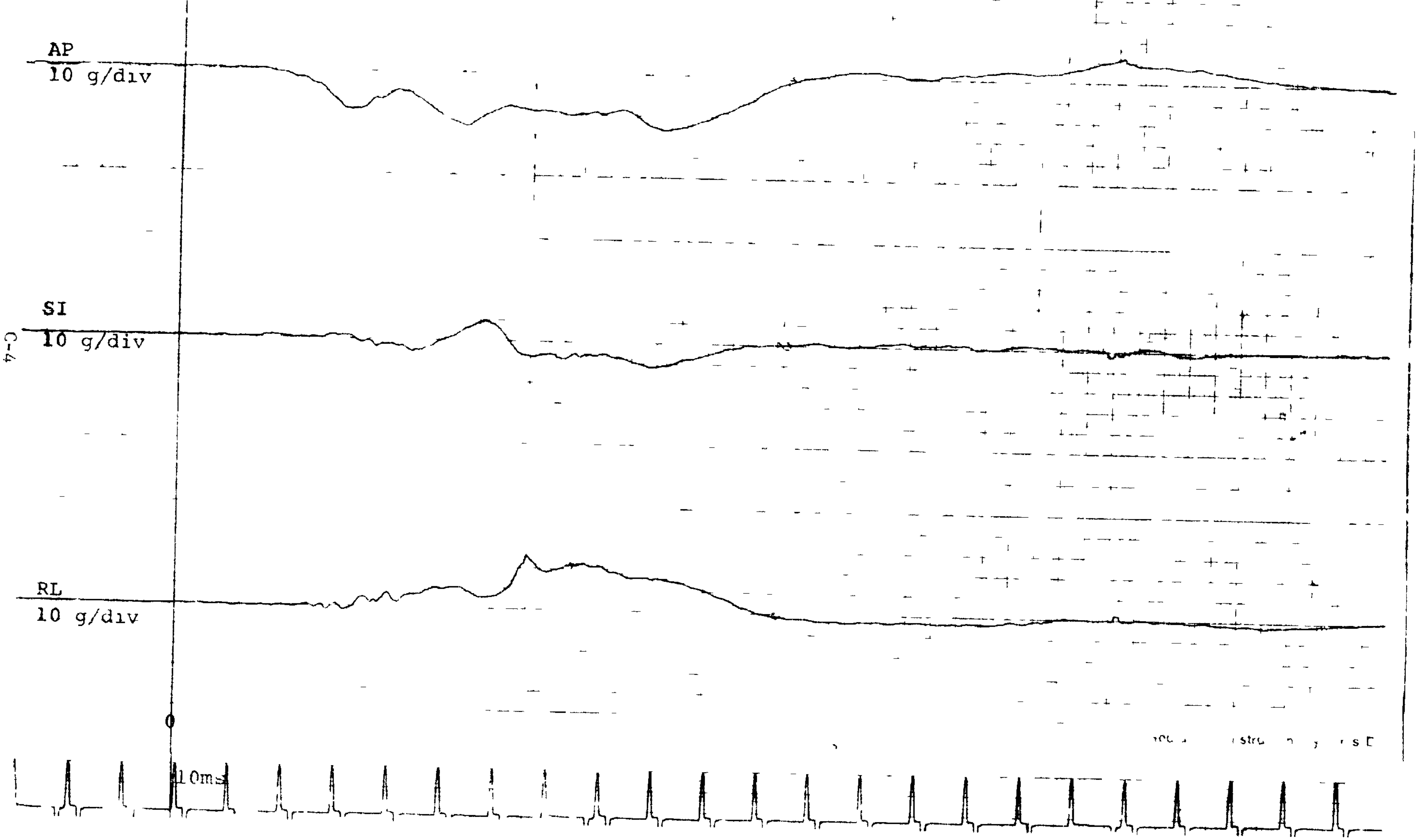
Therefore, for the combined reasons of the belt placement sensitivity and what we considered inadequate fore-aft head support, we eliminated the head wing airbelt from further consideration.

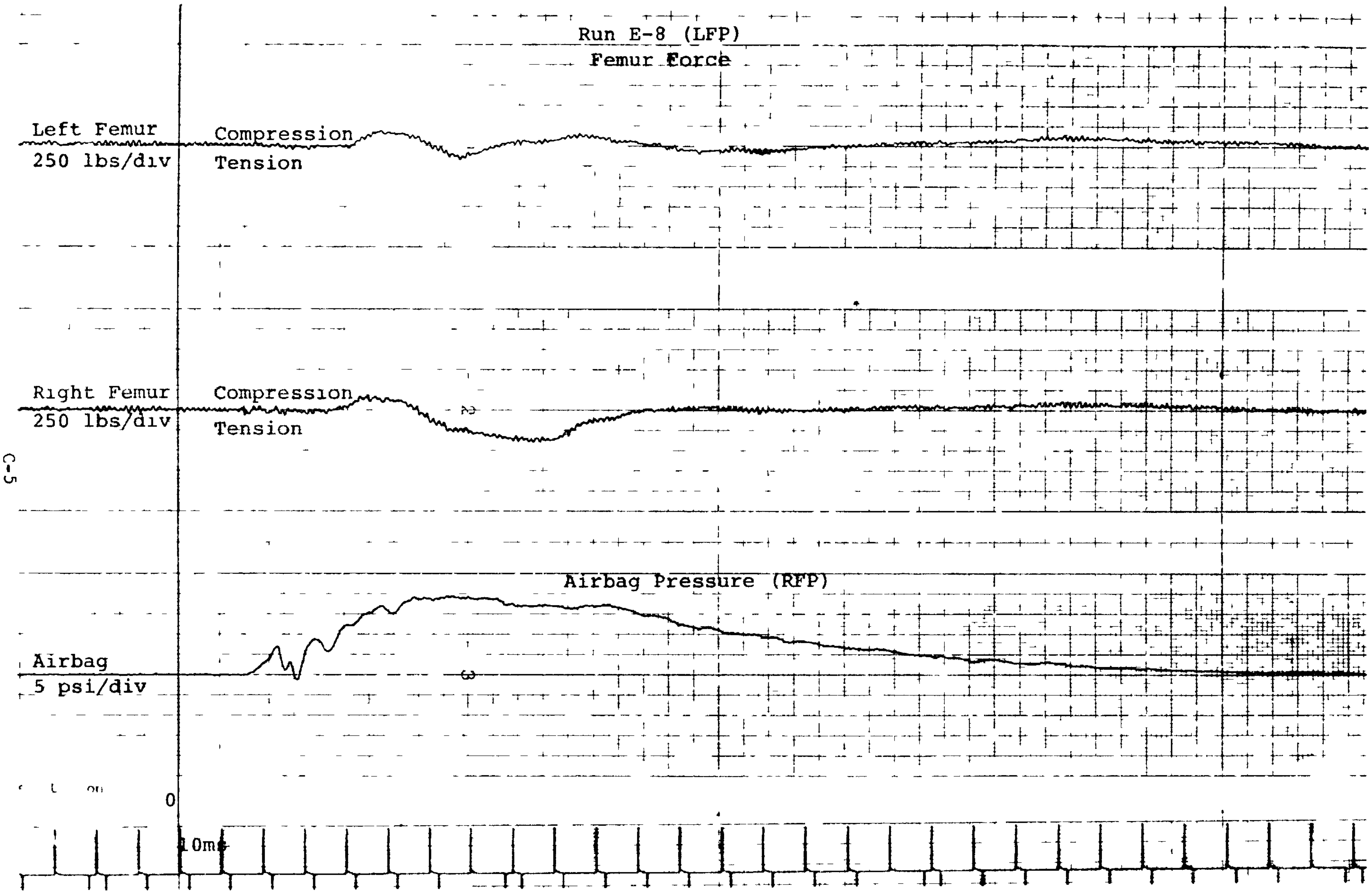
APPENDIX C

Run E-8 (LFP)
Head Accelerations

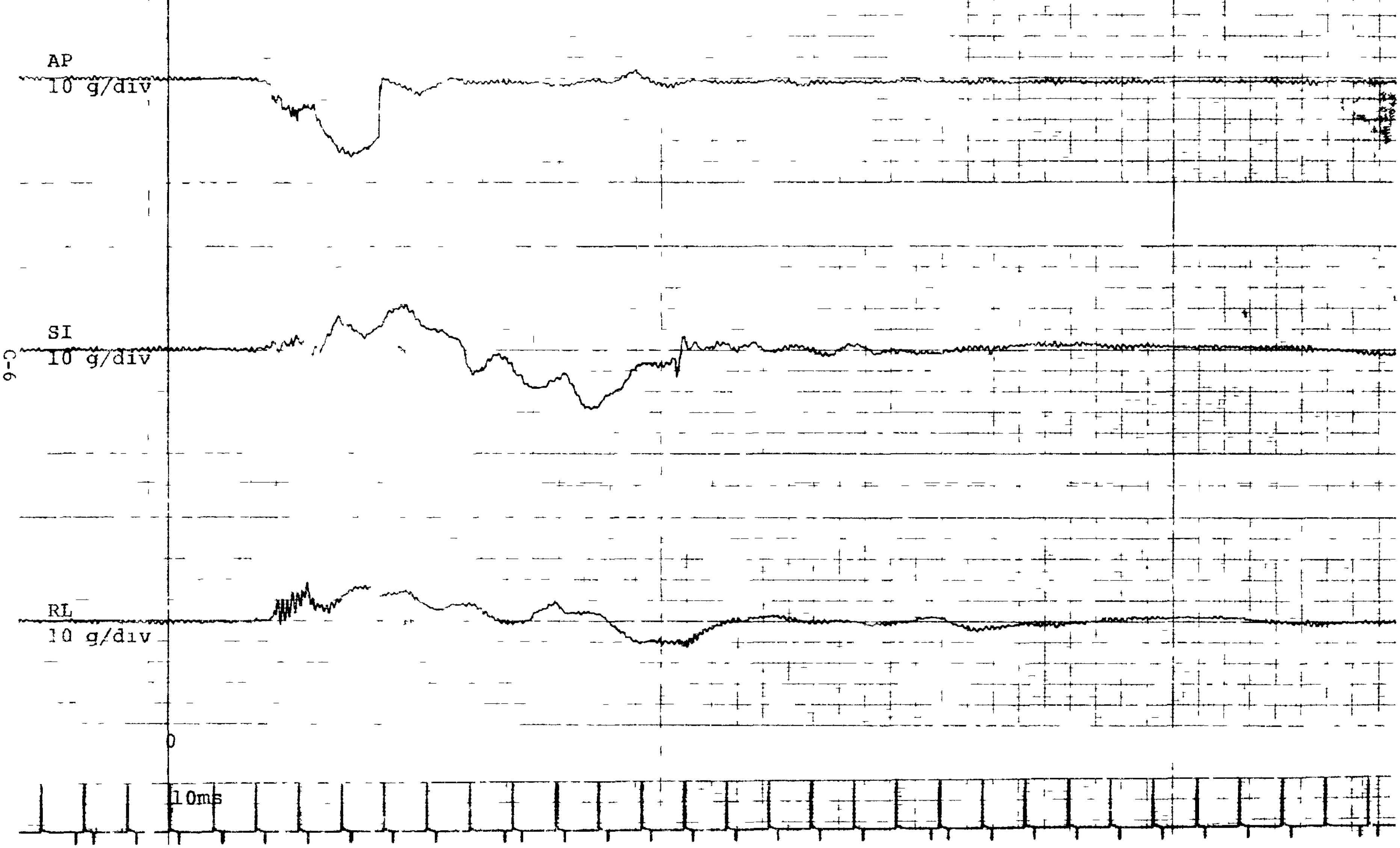


Run E-8 (LFP)
Chest Accelerations

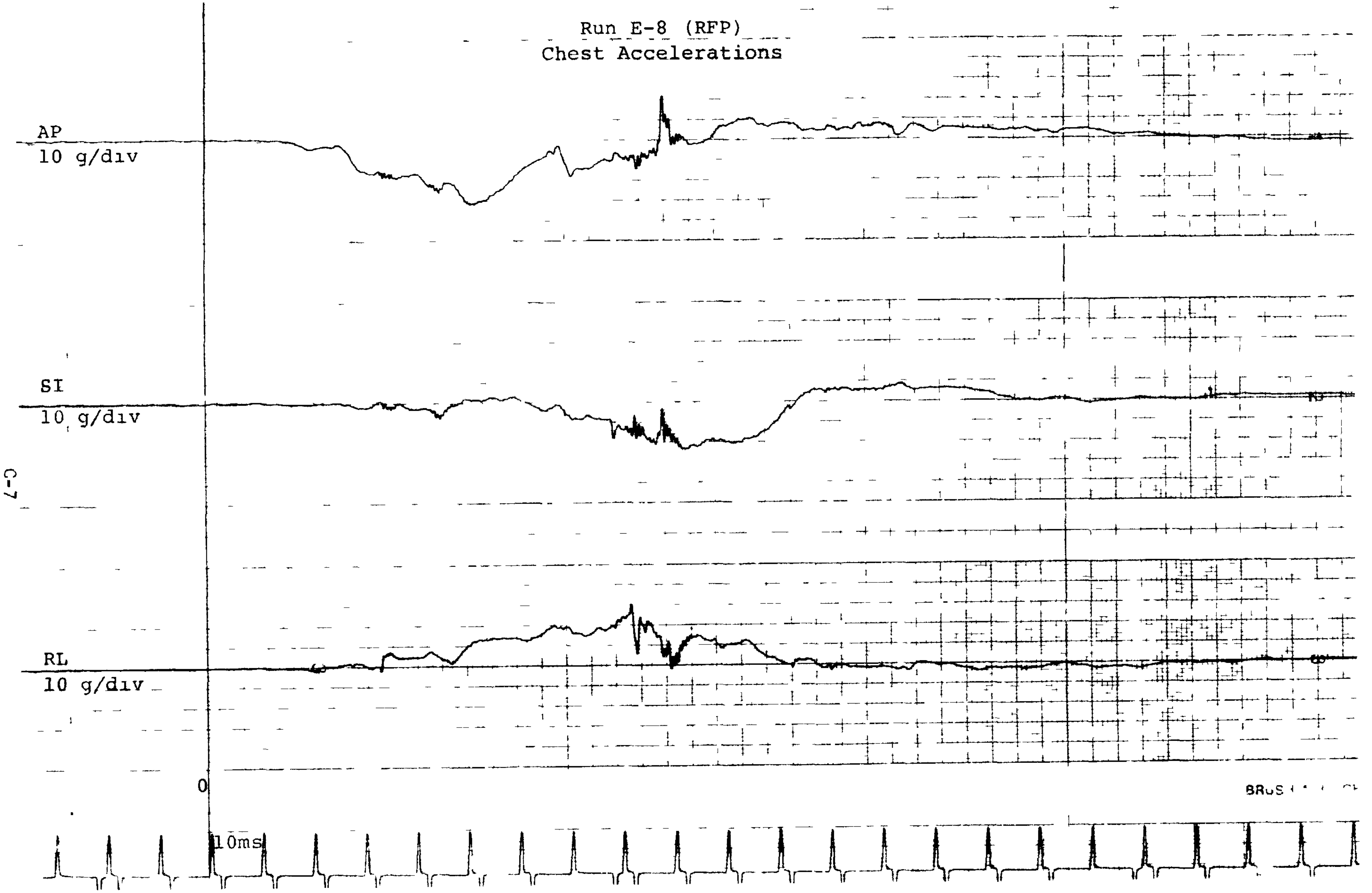


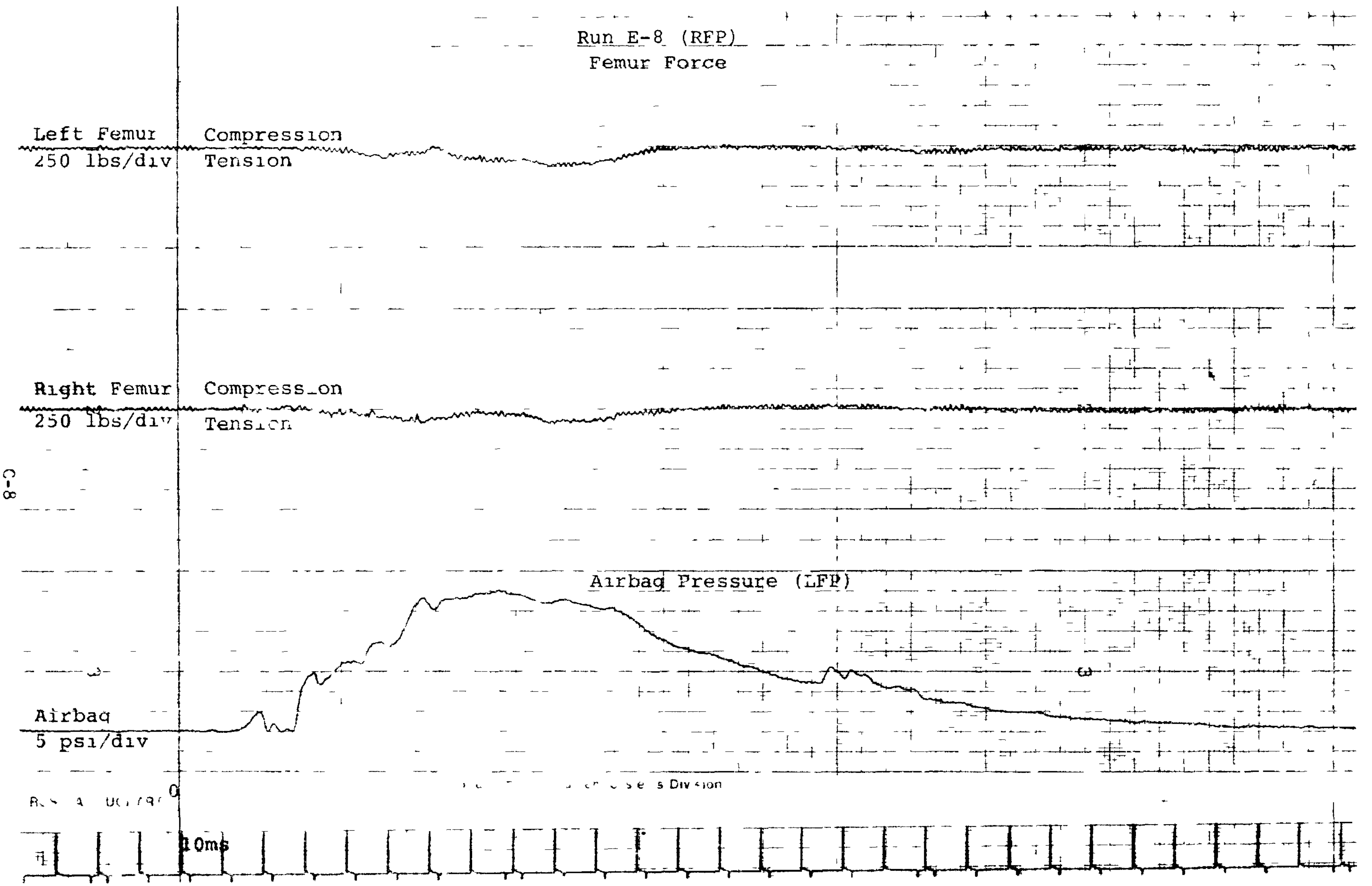

Run E-8 (LFP)
Femur Force
Left Femur
250 lbs/div
Compression
Tension
Right Femur
250 lbs/div
Compression
Tension
Airbag Pressure (RFP)
Airbag
5 psi/div
0
10ms

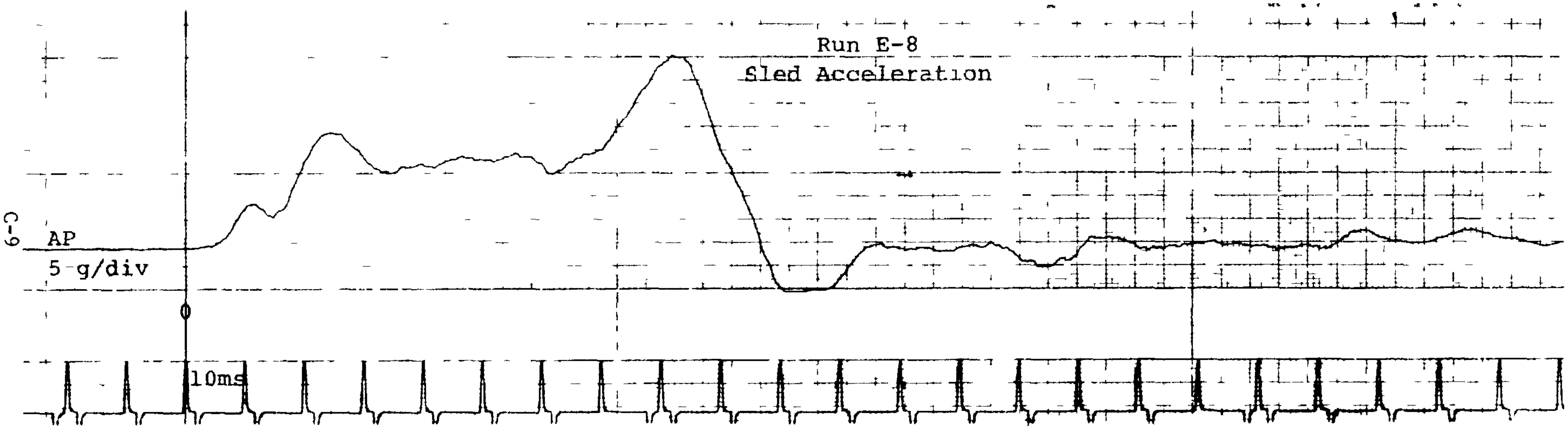
Run E-8 (RFP)
Head Accelerations



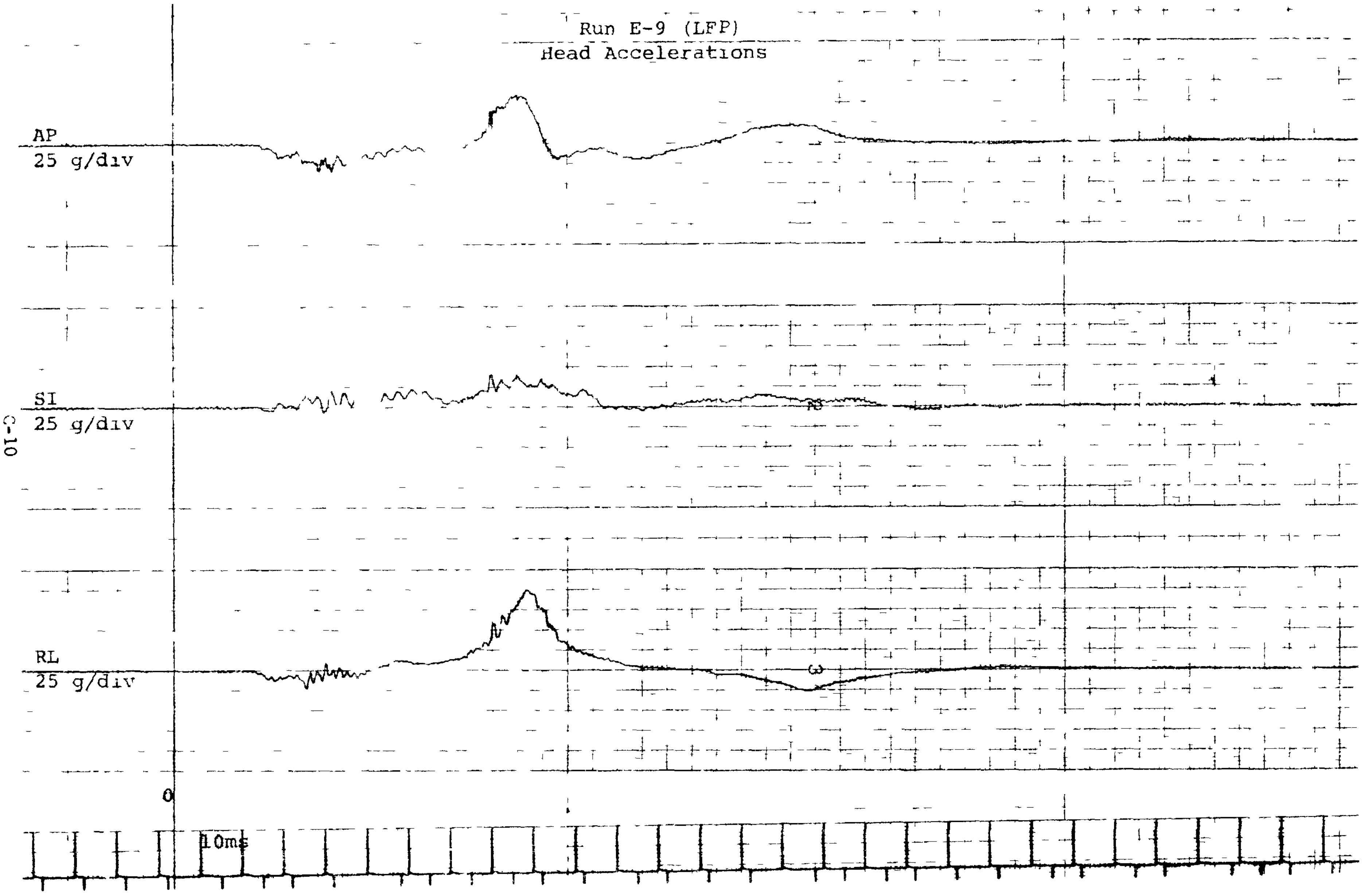
Run E-8 (RFP)
Chest Accelerations

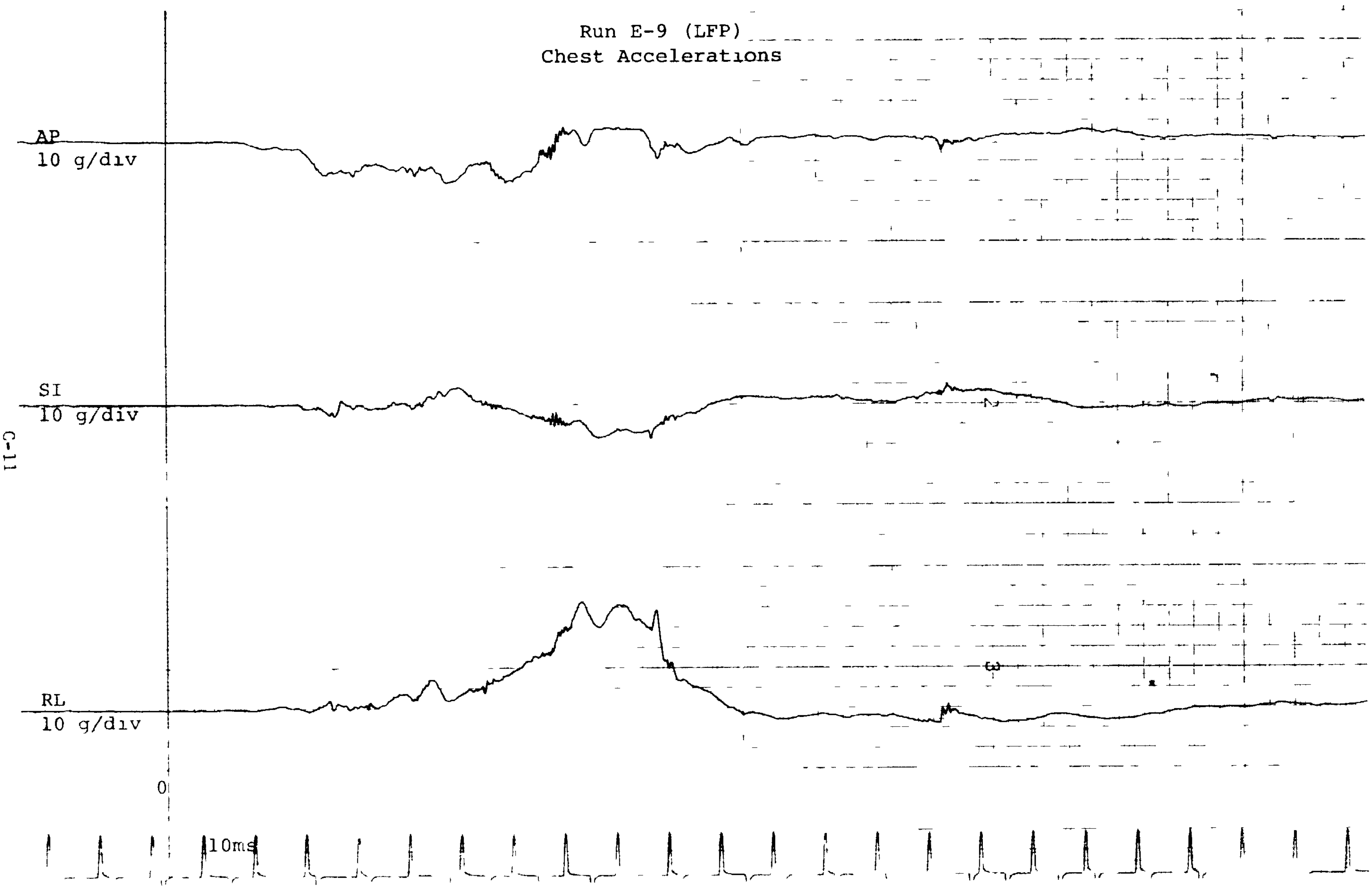



Run E-8 (RFP)
Femur Force
Left Femur
250 lbs/div
Compression
Tension
Right Femur
250 lbs/div
Compression
Tension
Airbag Pressure (LFP)
Airbag
5 psi/div
0
10ms

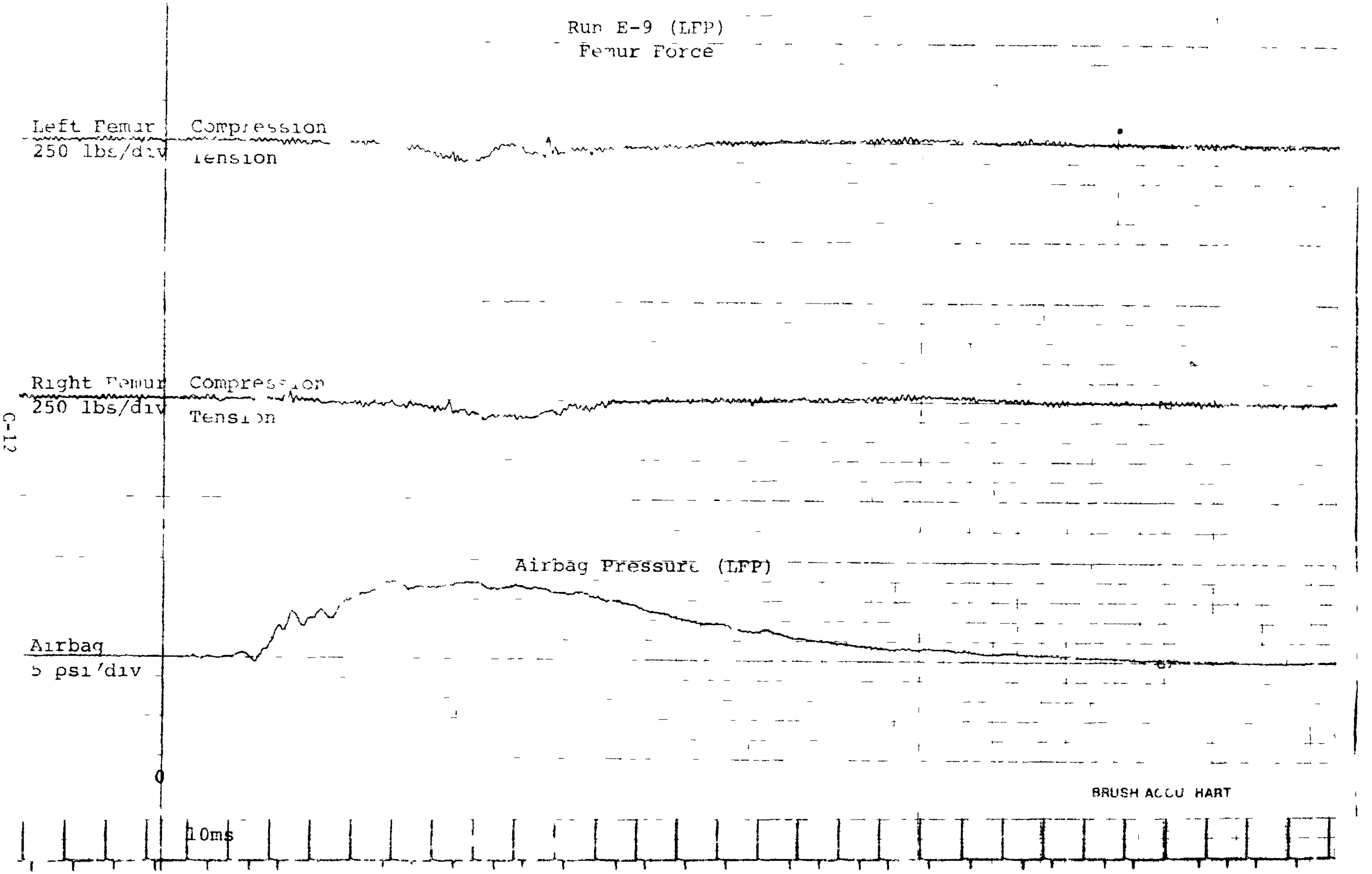

Run E-8
Sled Acceleration
AP
5 g/div
0
10ms

Run E-9 (LFP)
Head Accelerations

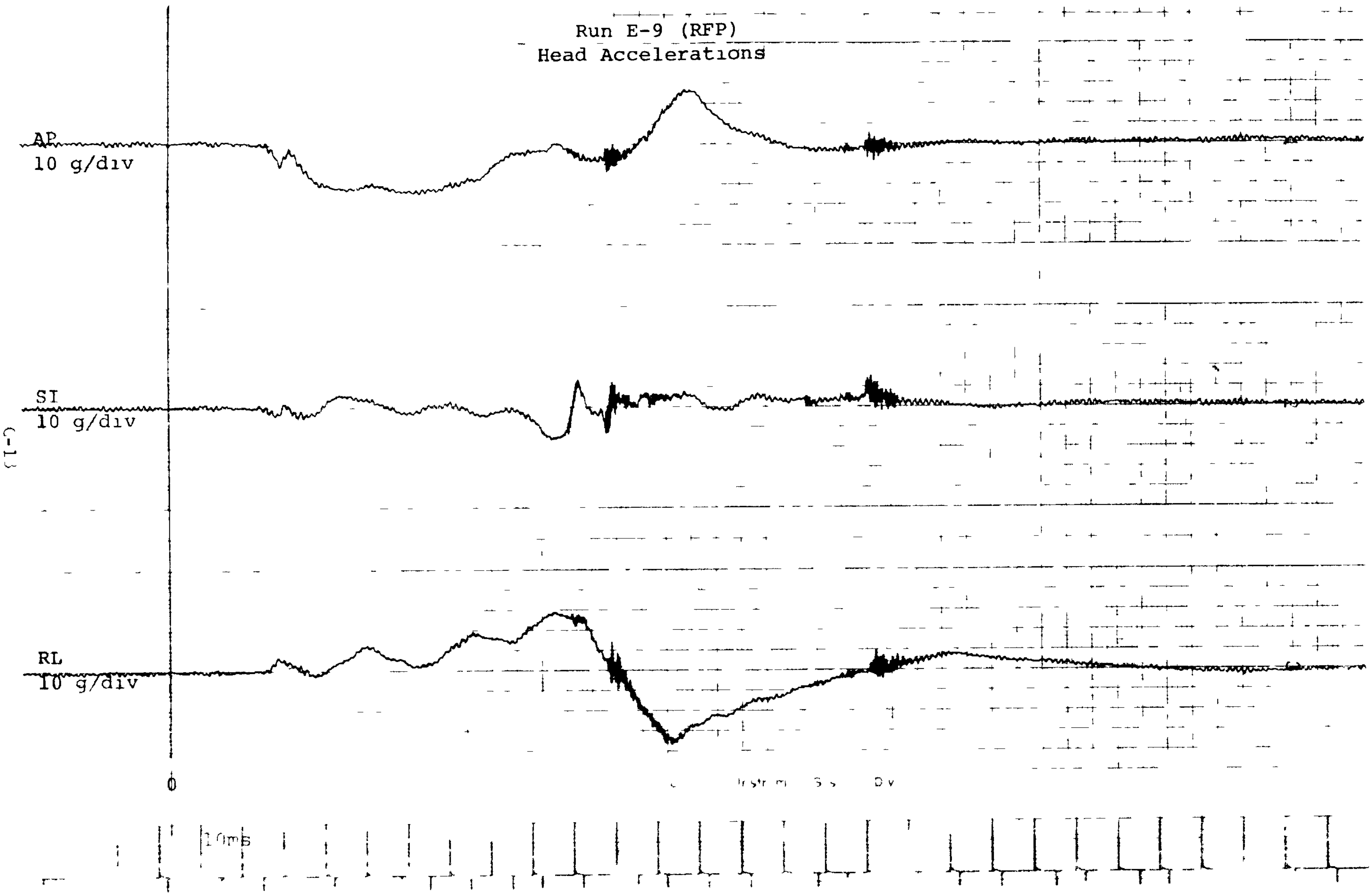




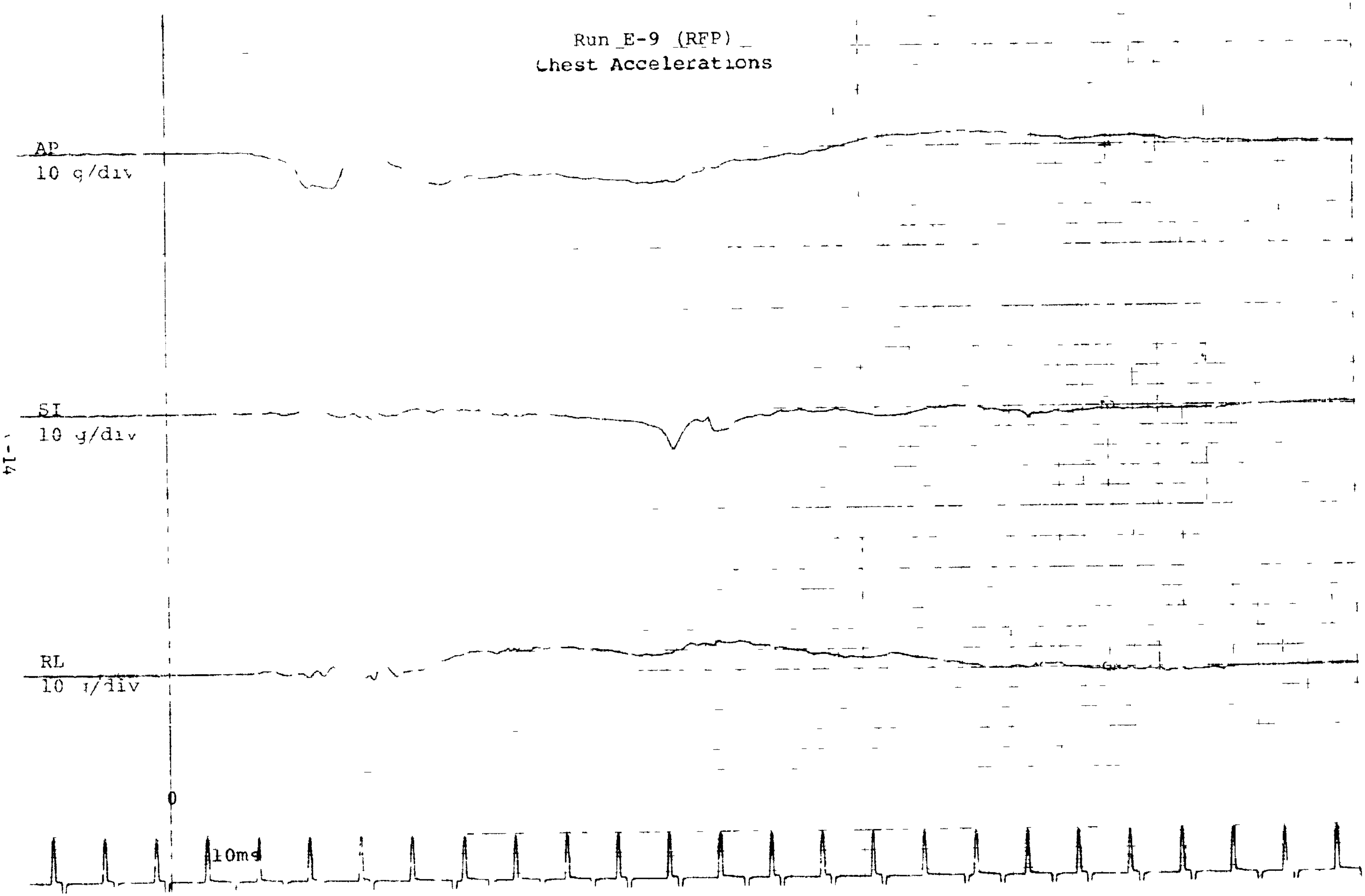
Run E-9 (LFP)
Chest Accelerations

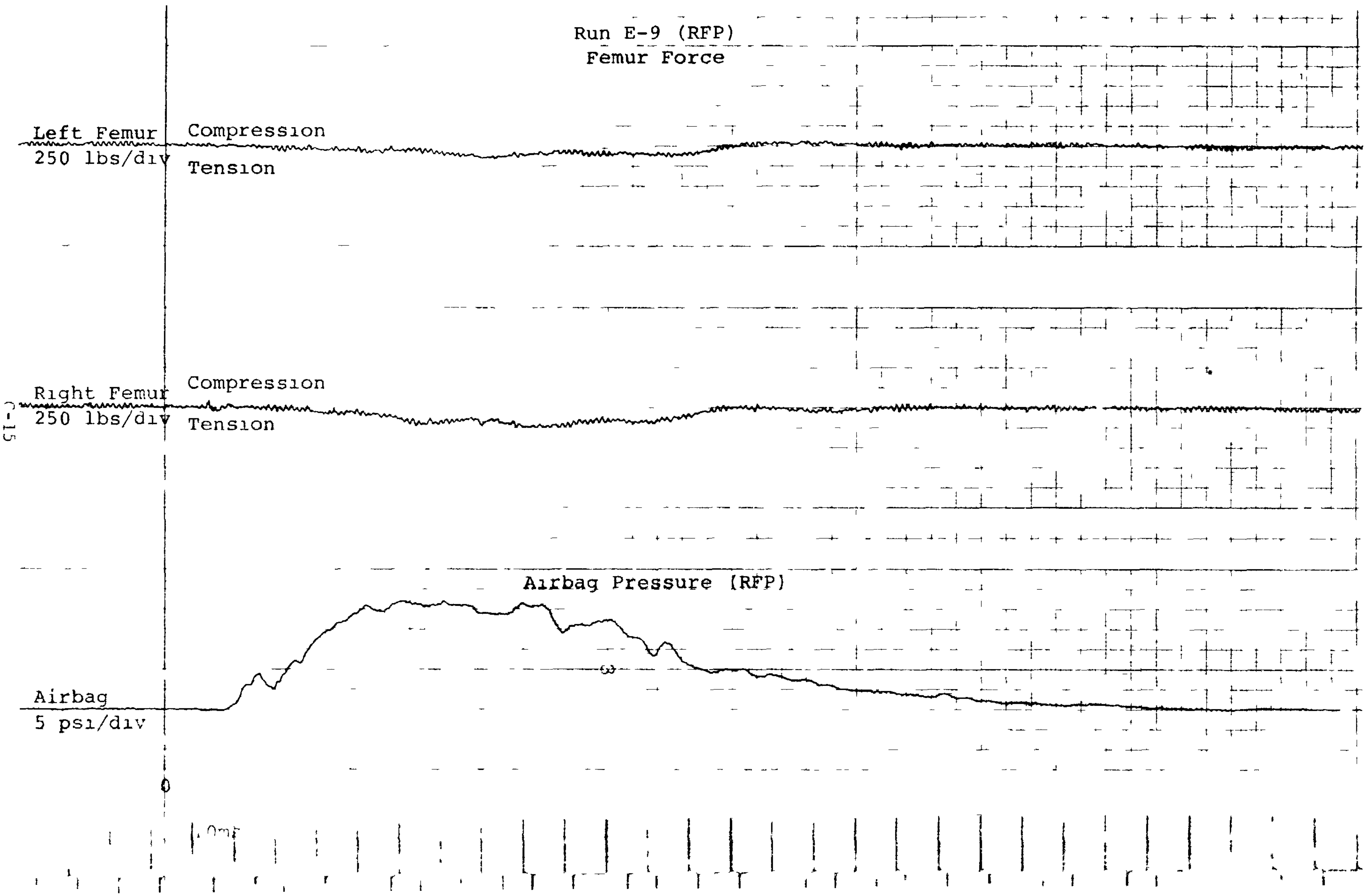

Run E-9 (LFP)
Femur Force
Left Femur
250 lbs/div
Compression
Tension
Right Femur
250 lbs/div
Compression
Tension
Airbag Pressure (LFP)
Airbag
5 psi/div
0
10ms
BRUSH ACCU HART

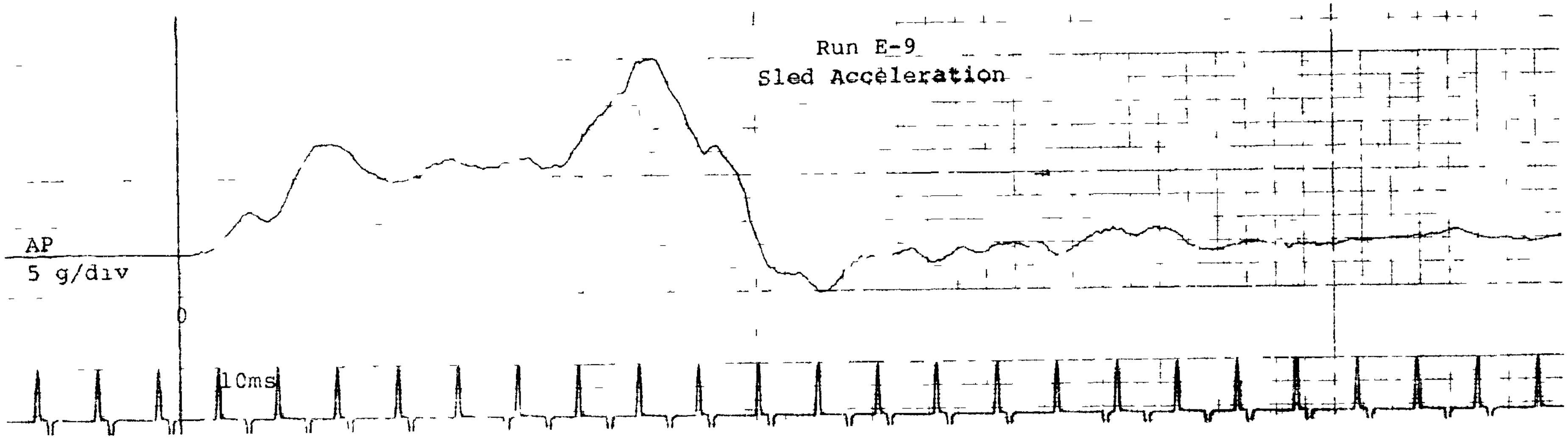
Run E-9 (RFP)
Head Accelerations

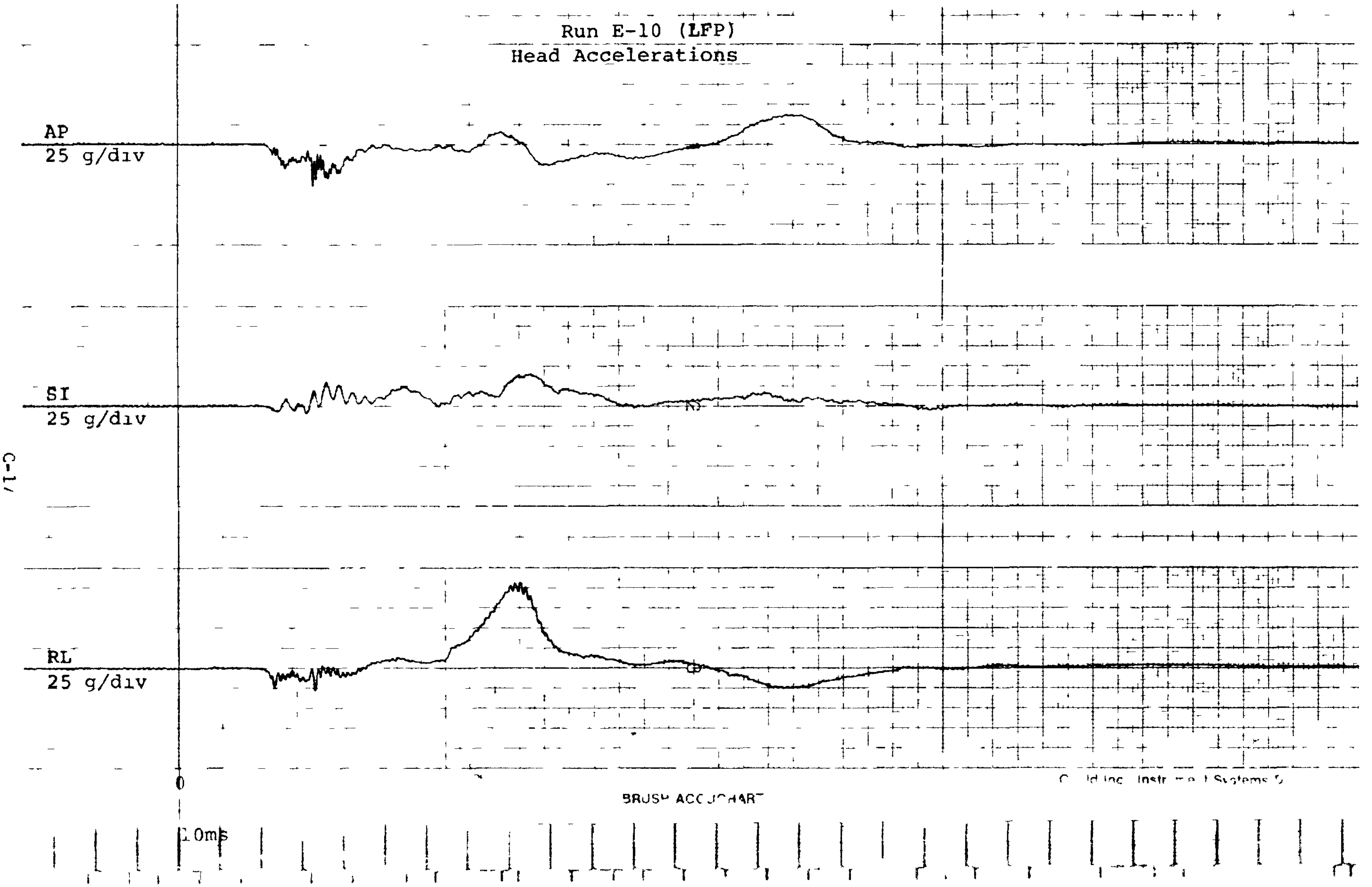


Run E-9 (RFP)
Chest Accelerations

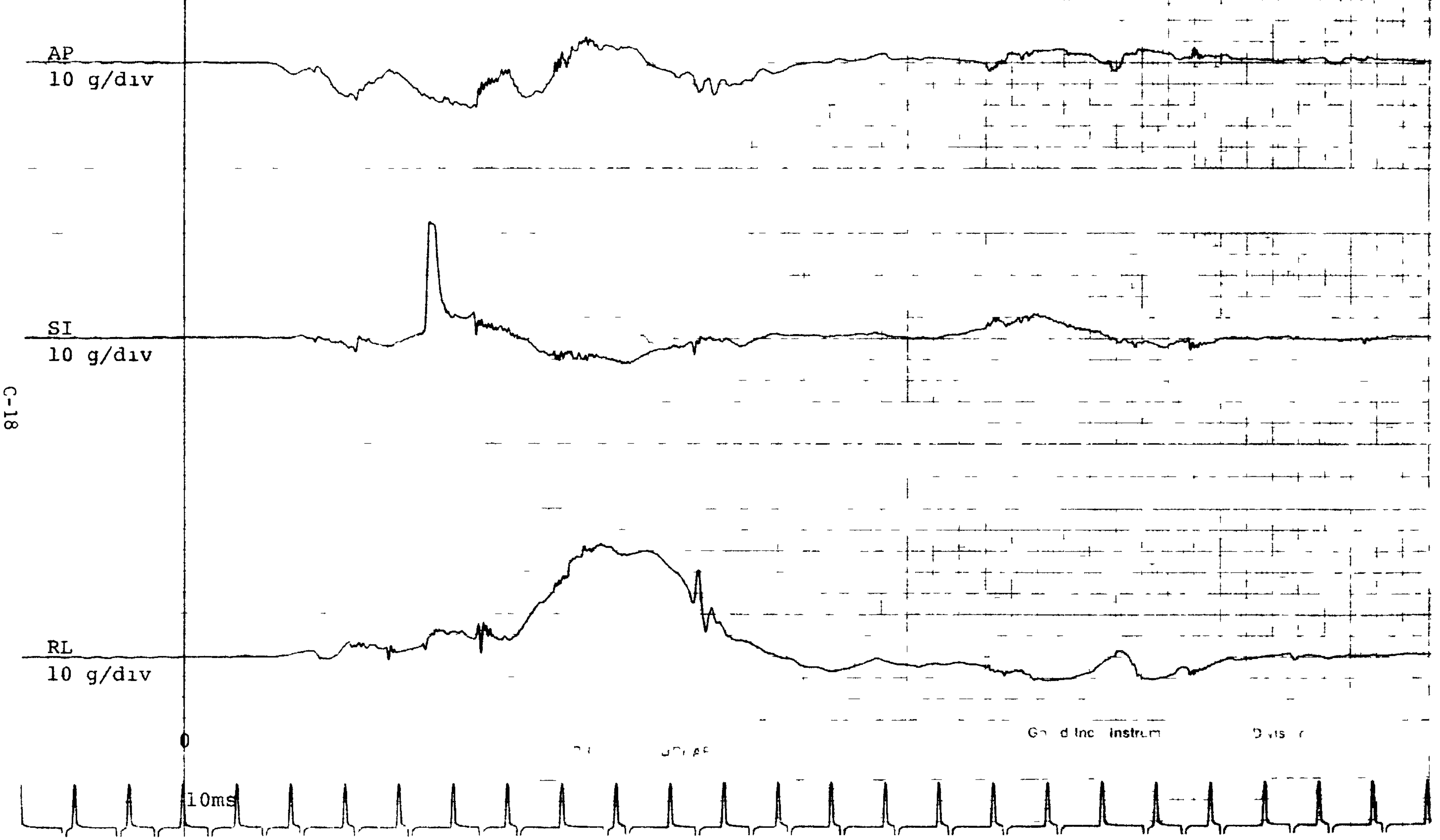


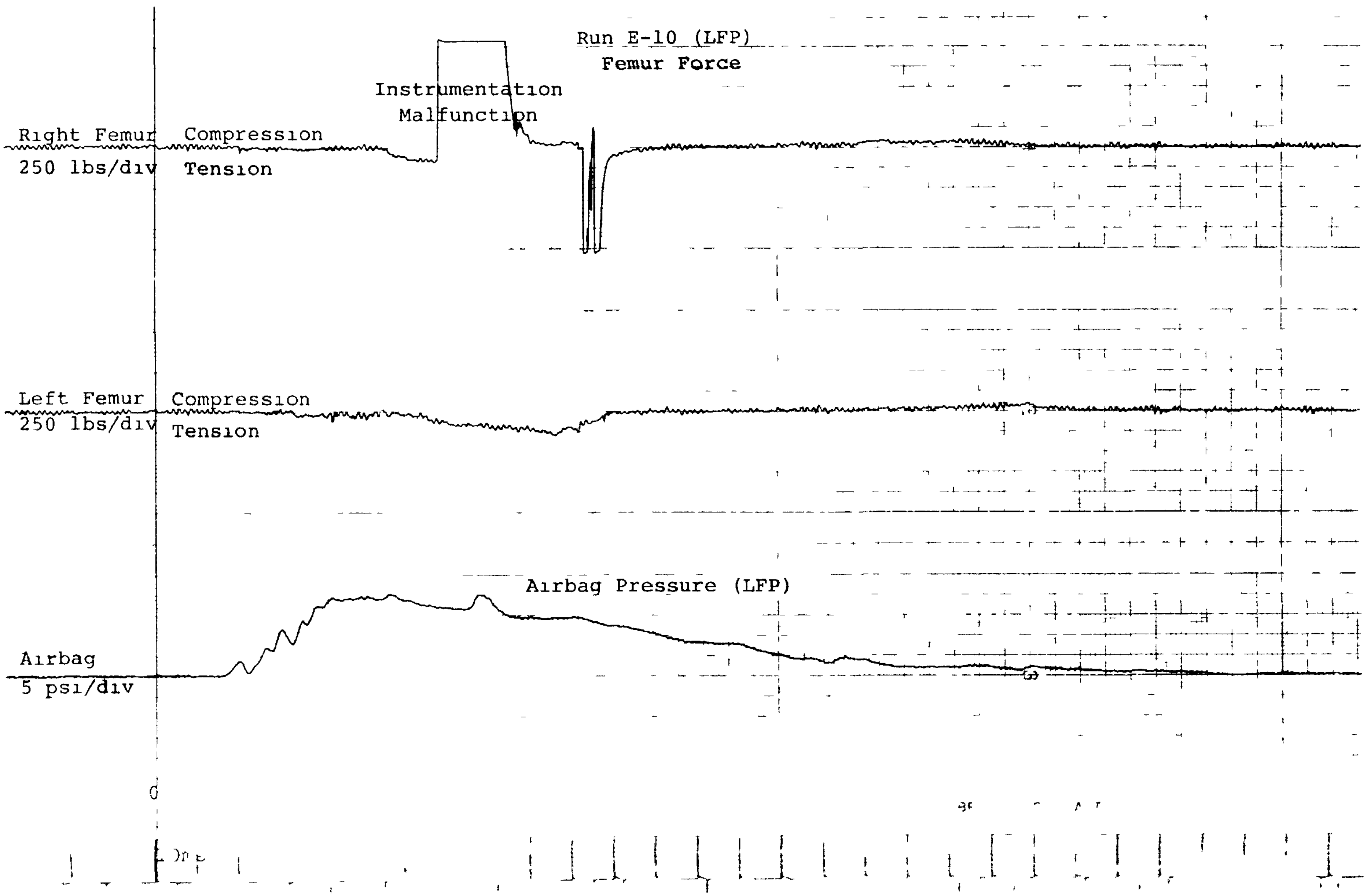

Run E-9 (RFP)
Femur Force
Left Femur
250 lbs/div
Compression
Tension
Right Femur
250 lbs/div
Compression
Tension
Airbag Pressure (RFP)
Airbag
5 psi/div
0


Run E-9
Sled Acceleration
AP
5 g/div
0
10ms

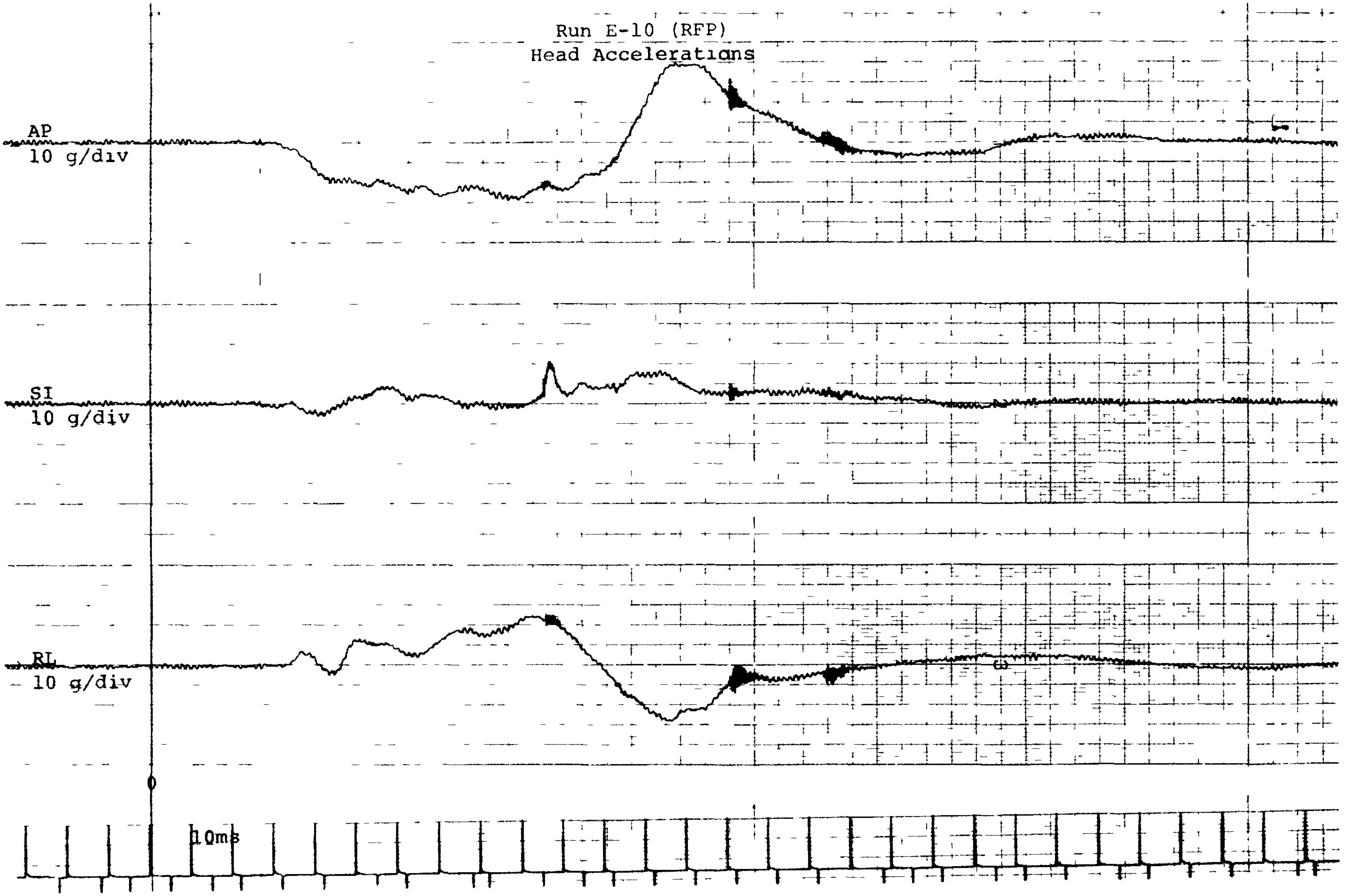

Run E-10 (LFP)
Head Accelerations
AP
25 g/div
SI
25 g/div
RL
25 g/div
0
10ms
BRUSH ACCUCHART

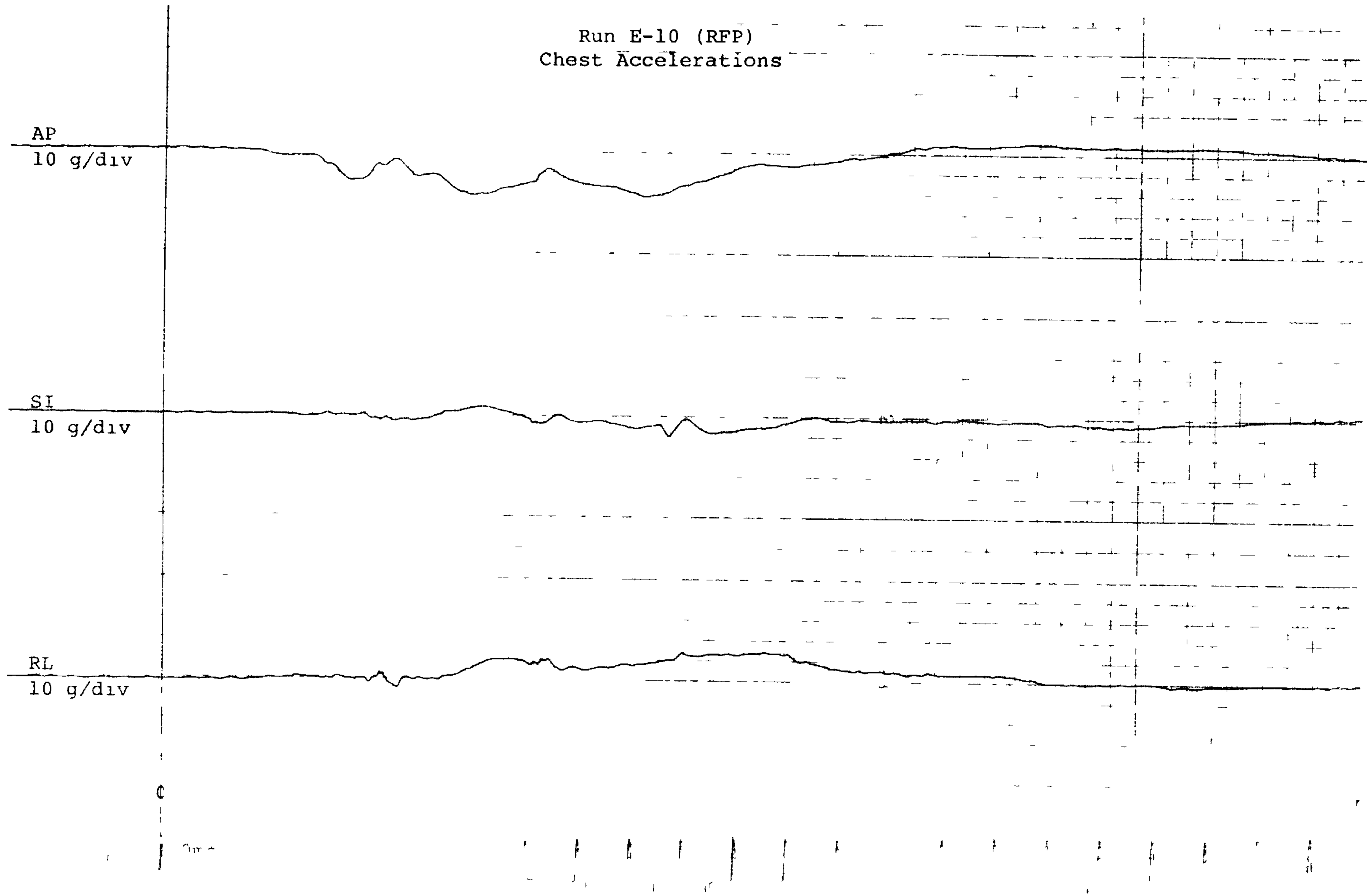
Run E-10 (LFP)
Chest Accelerations

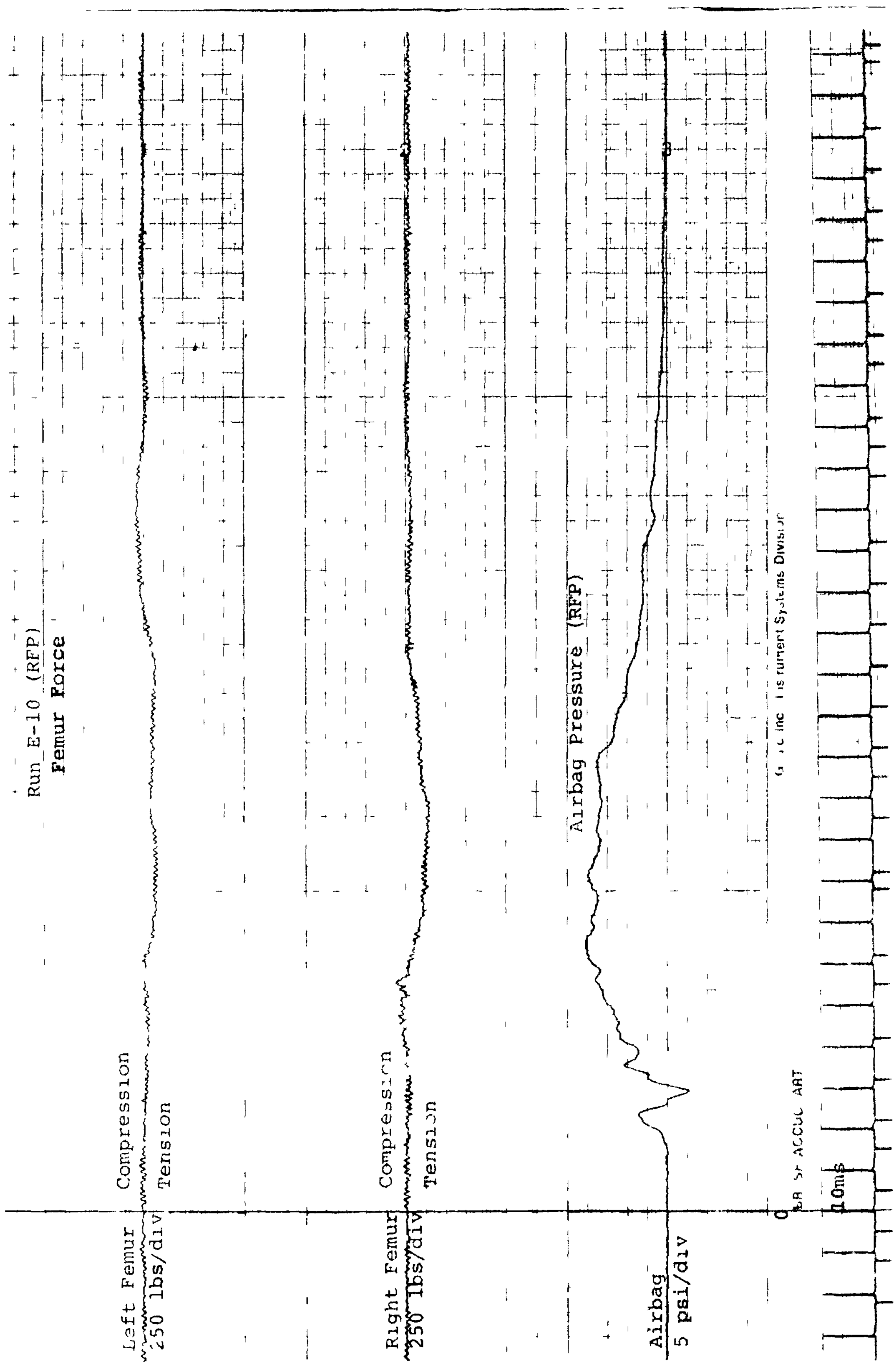


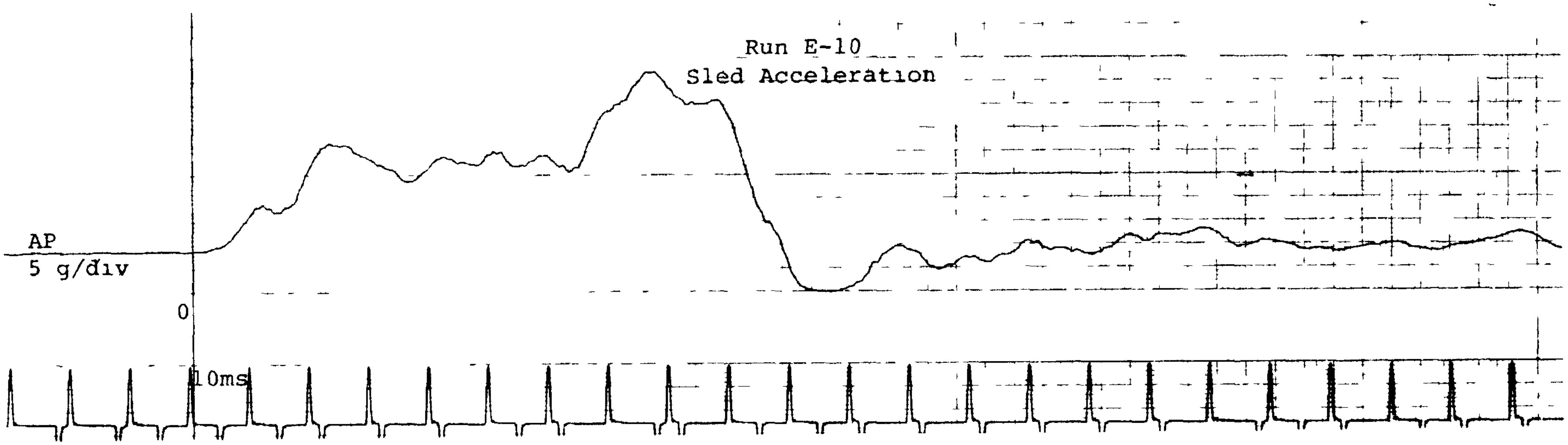

Run E-10 (LFP)
Femur Force
Instrumentation
Malfunction
Right Femur
250 lbs/div
Compression
Tension
Left Femur
250 lbs/div
Compression
Tension
Airbag Pressure (LFP)
Airbag
5 psi/div

Run E-10 (RFP)
Head Accelerations

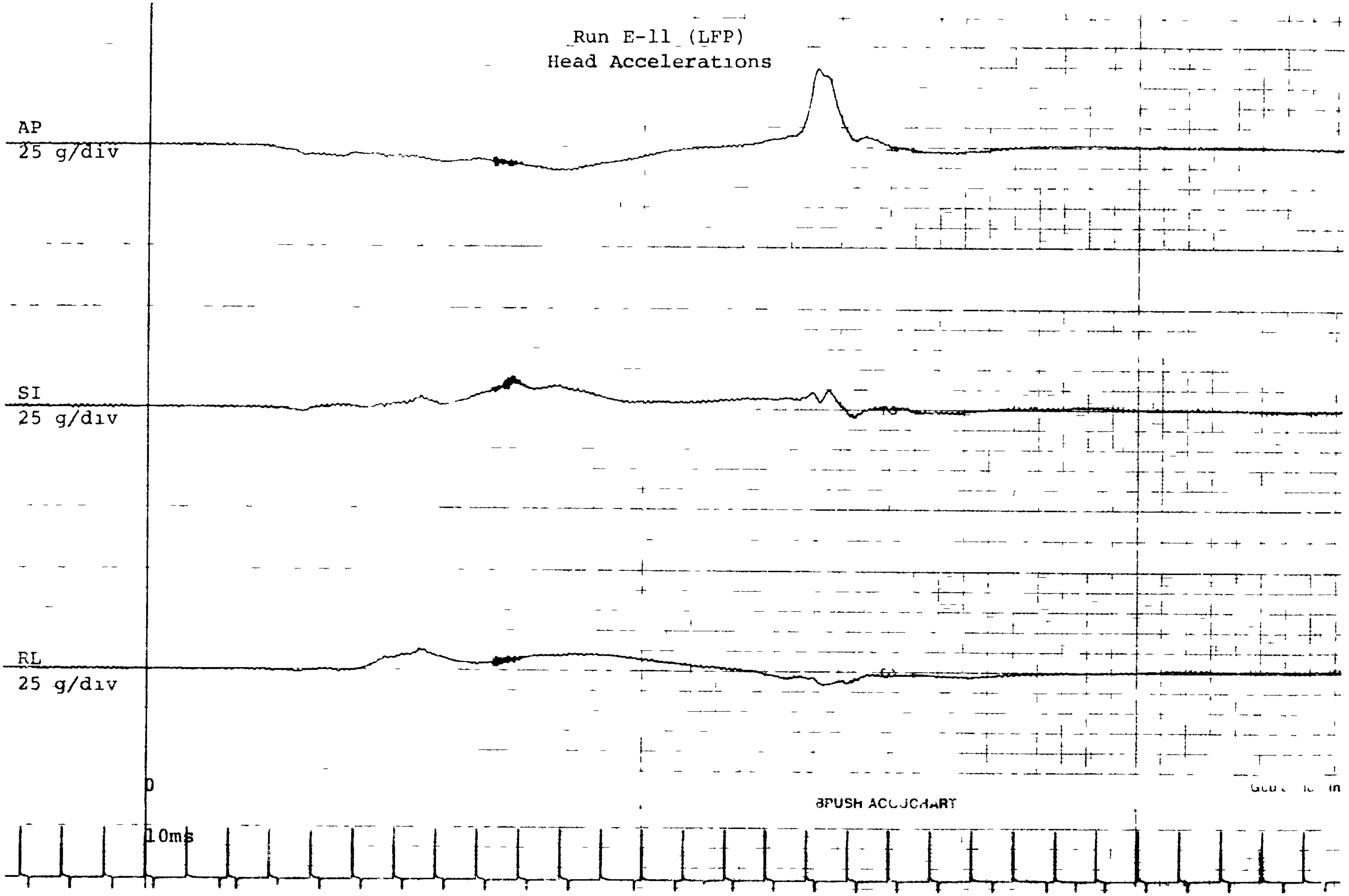


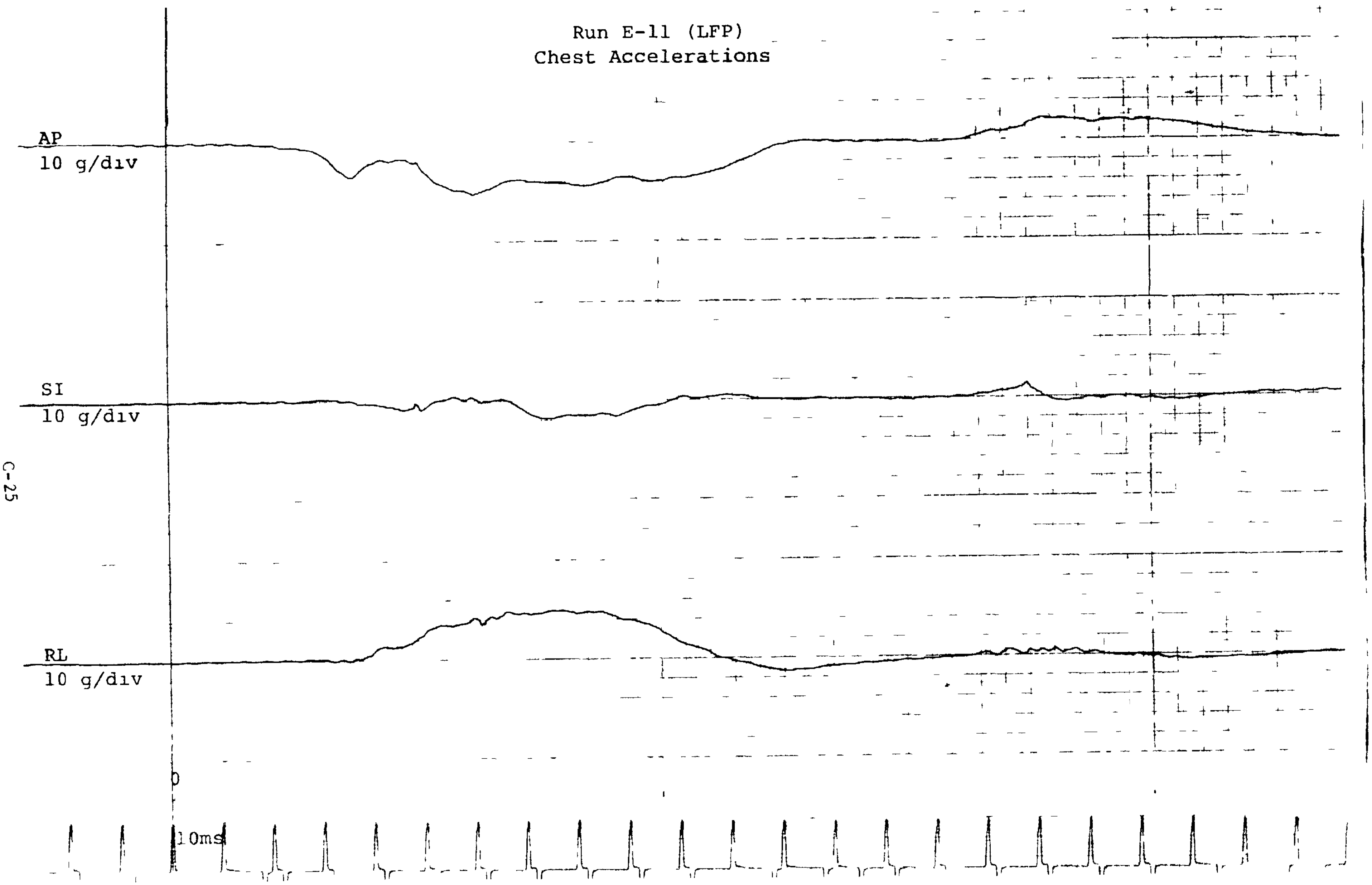

Run E-10 (RFP)
Chest Accelerations
AP
10 g/div
SI
10 g/div
RL
10 g/div

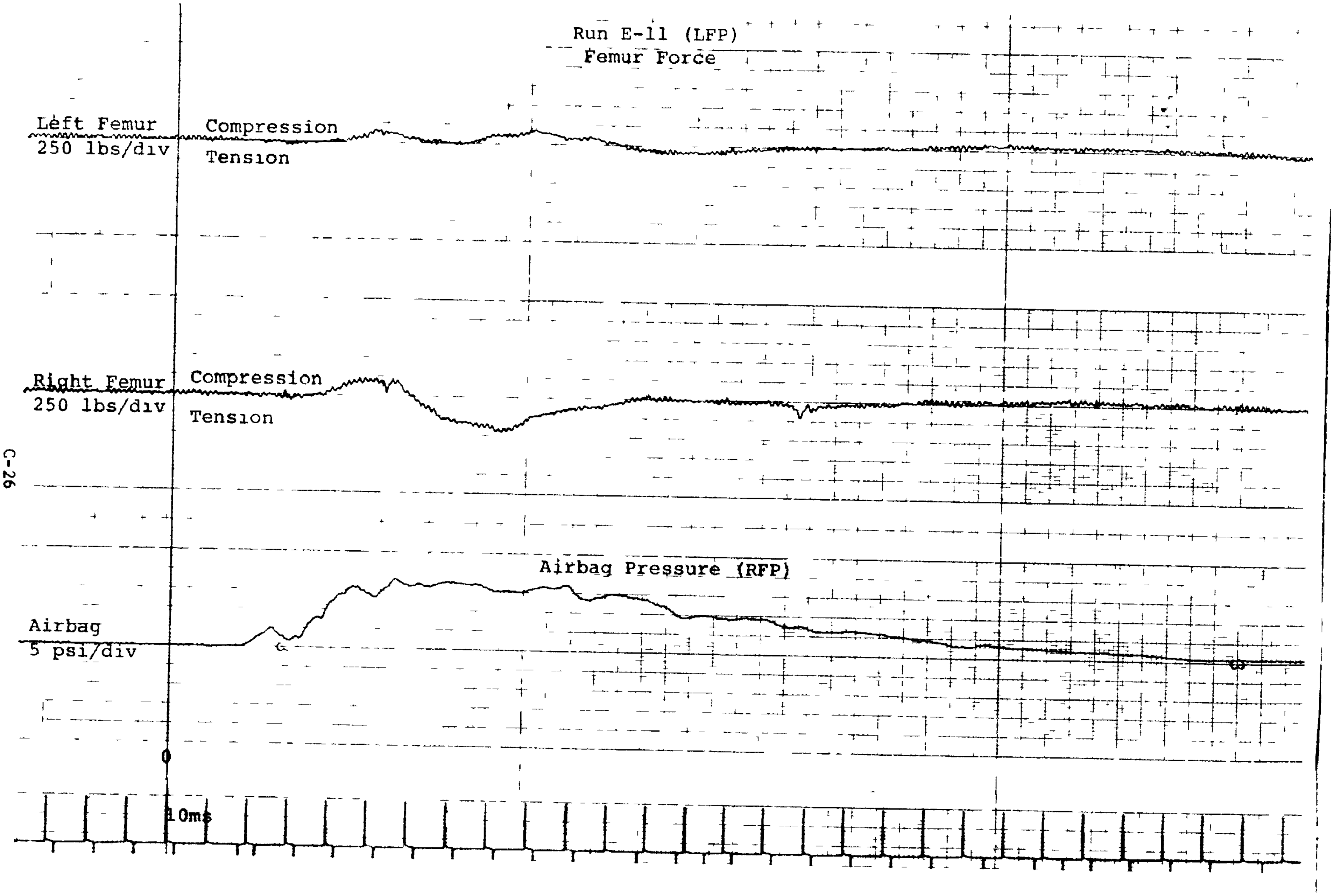

Run E-10 (RFP)
Femur Force
Left Femur
250 lbs/div
Compression
Tension
Right Femur
250 lbs/div
Compression
Tension
Airbag
5 psi/div
Airbag Pressure (RFP)
0
10ms

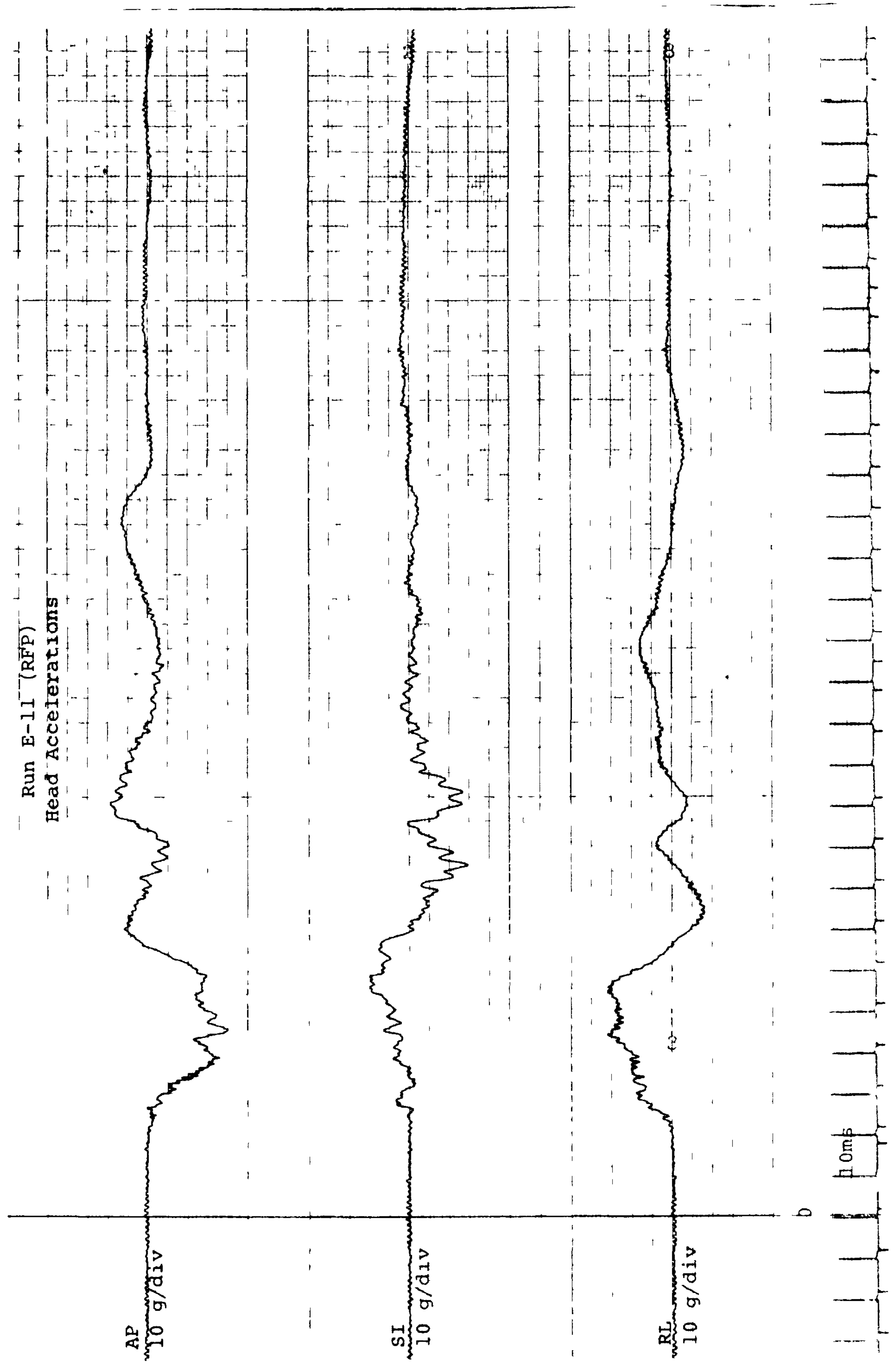

Run E-10
Sled Acceleration
AP
5 g/div
0
10ms

Run E-11 (LFP)
Head Accelerations

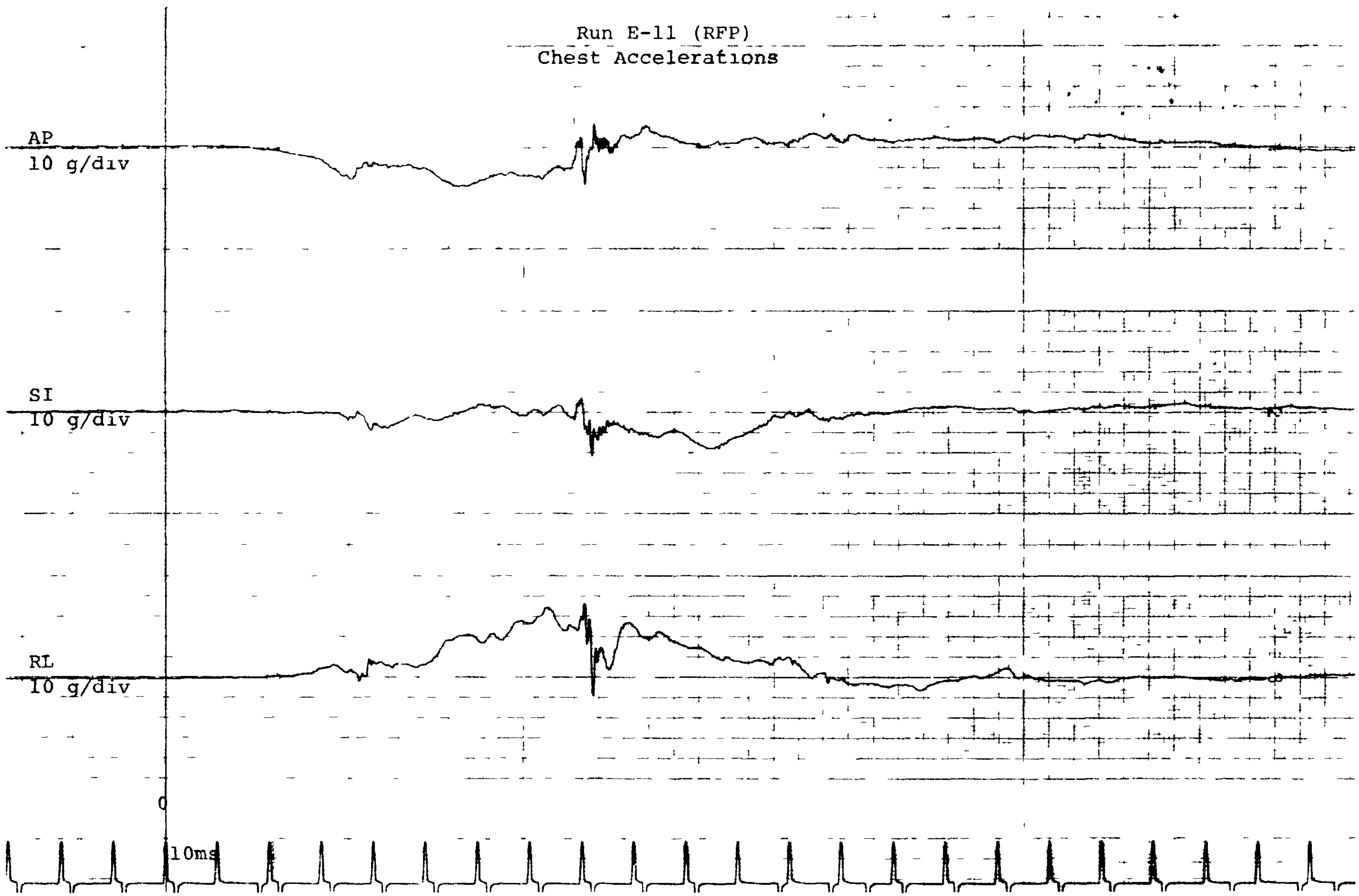


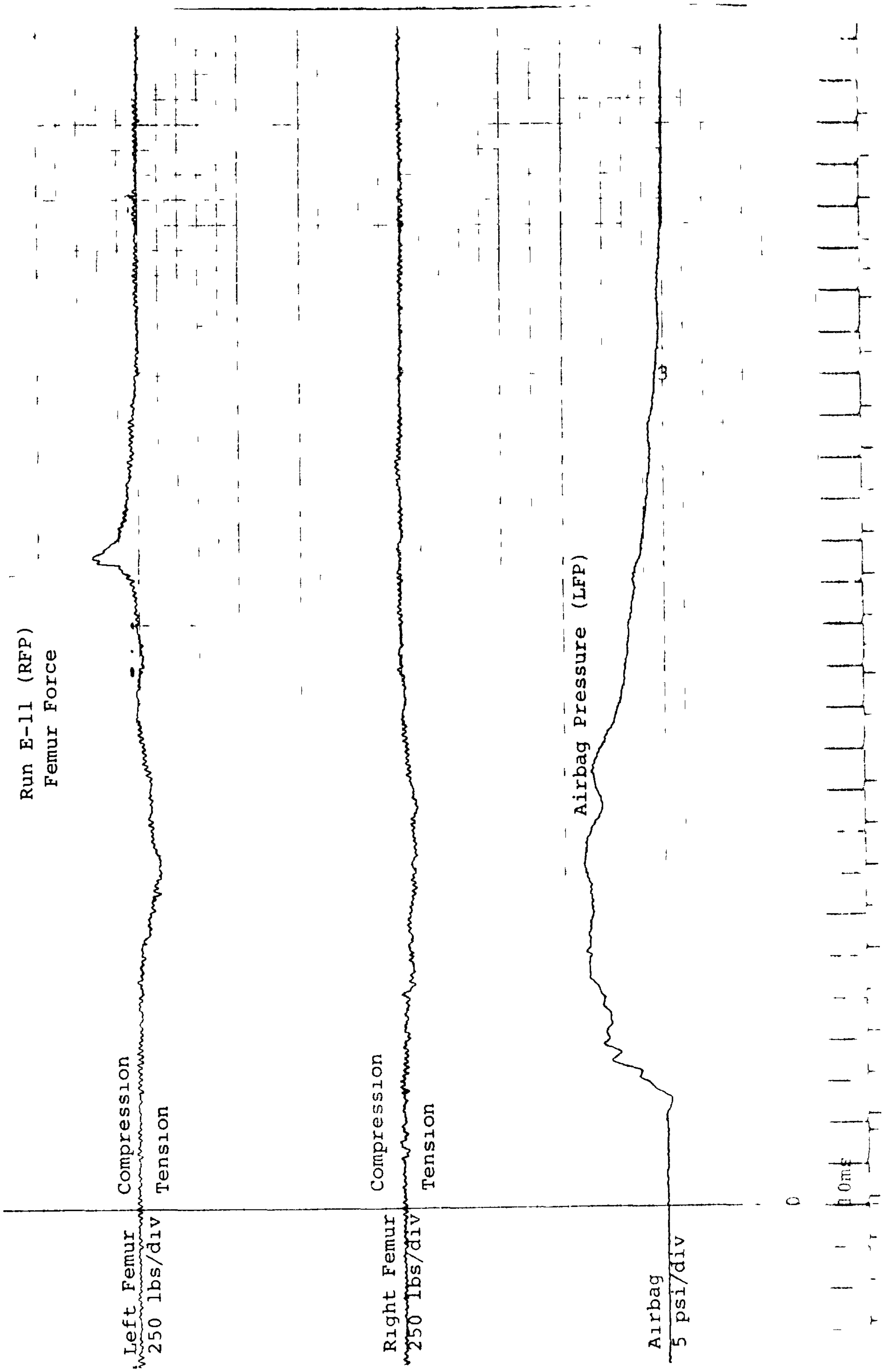

Run E-11 (LFP)
Chest Accelerations
AP
10 g/div
SI
10 g/div
RL
10 g/div
0
10ms

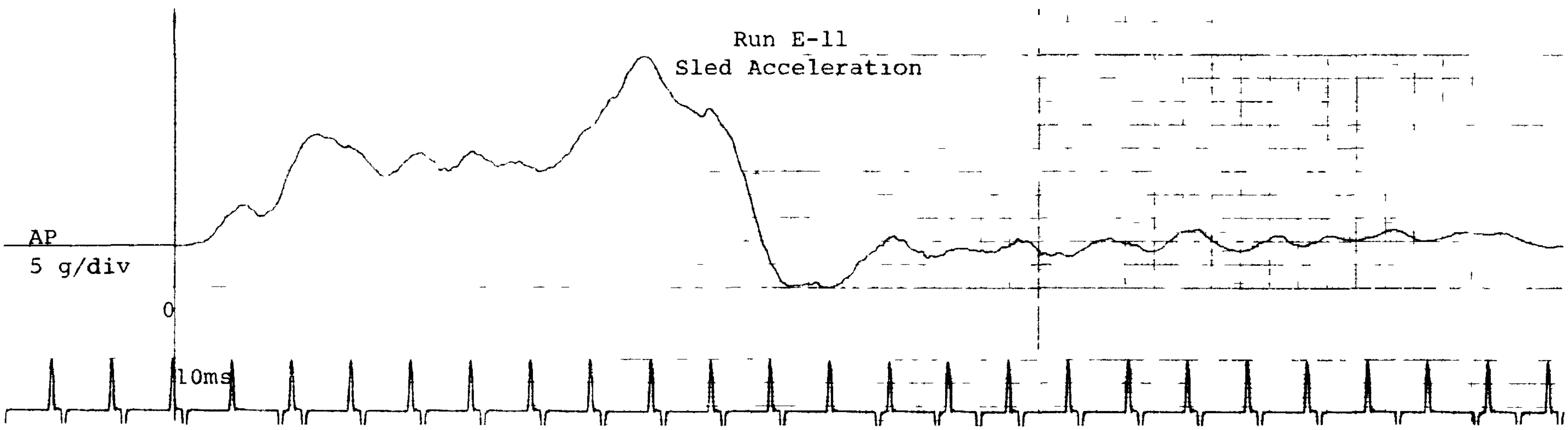

Run E-11 (LFP)
Femur Force
Left Femur
250 lbs/div
Compression
Tension
Right Femur
250 lbs/div
Compression
Tension
Airbag Pressure (RFP)
Airbag
5 psi/div
0
10ms

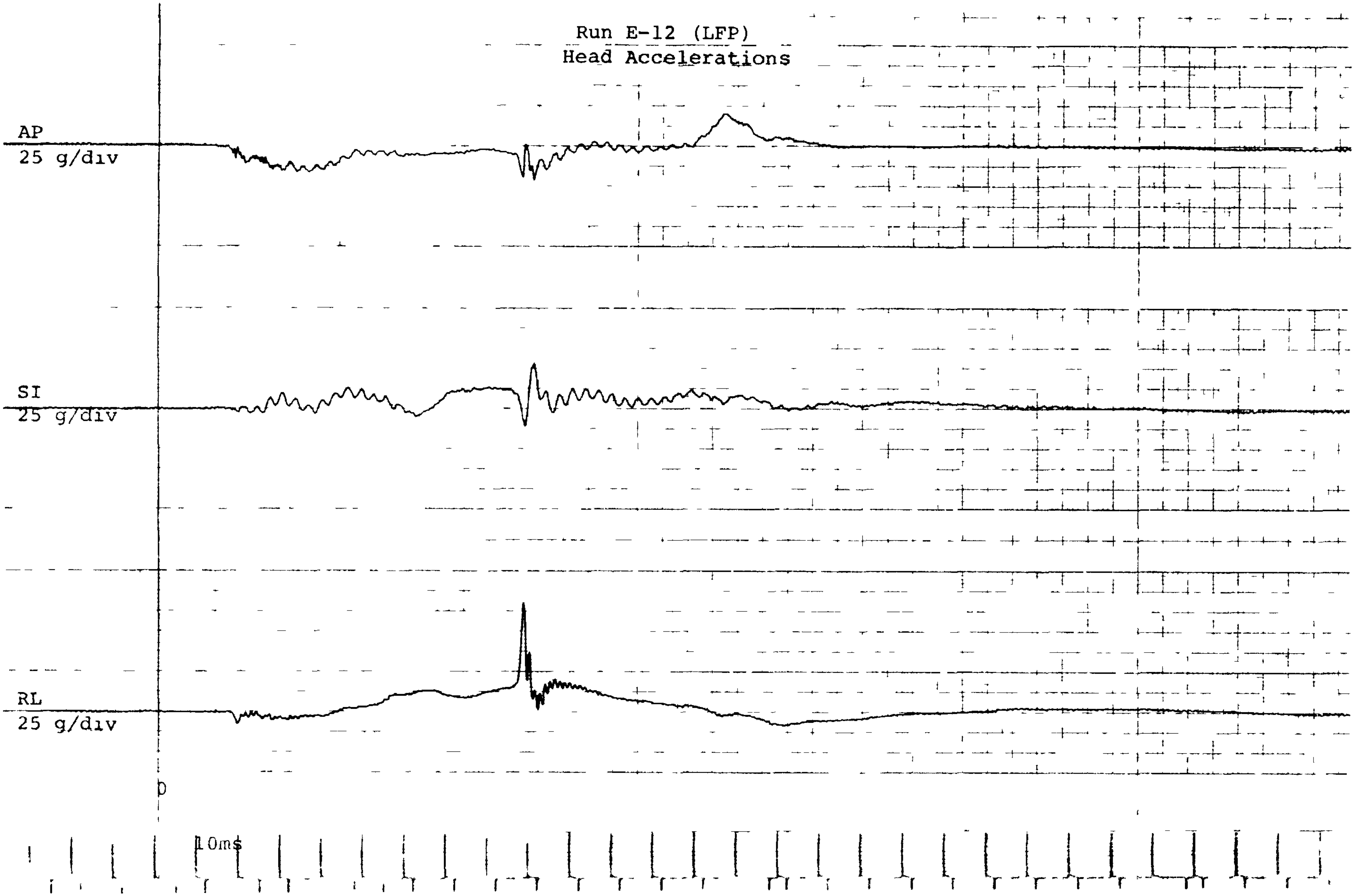

Run E-11 (RFP)
Head Accelerations
AP 10 g/div
SI 10 g/div
RL 10 g/div
10ms

Run E-11 (RFP)
Chest Accelerations

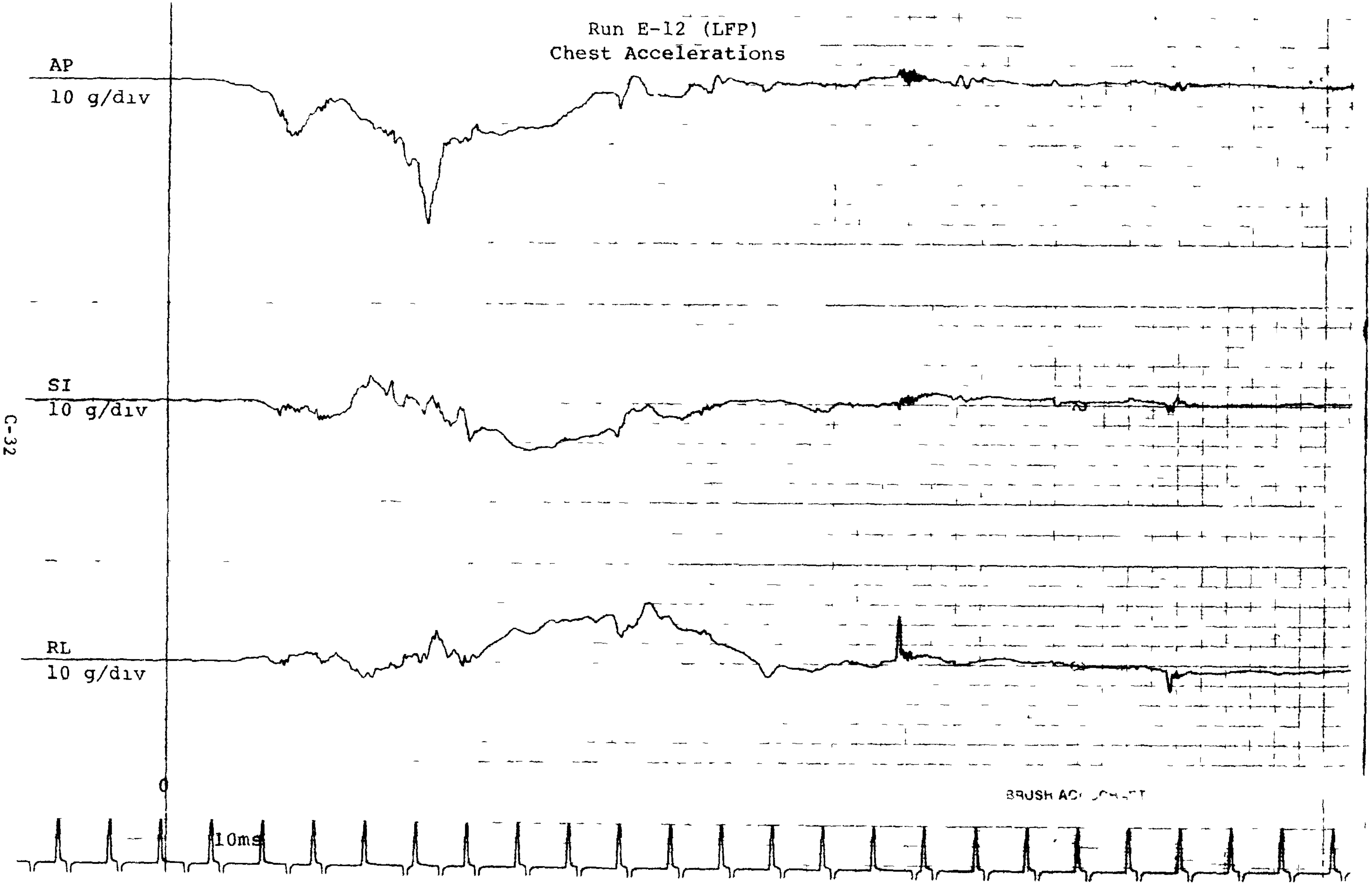


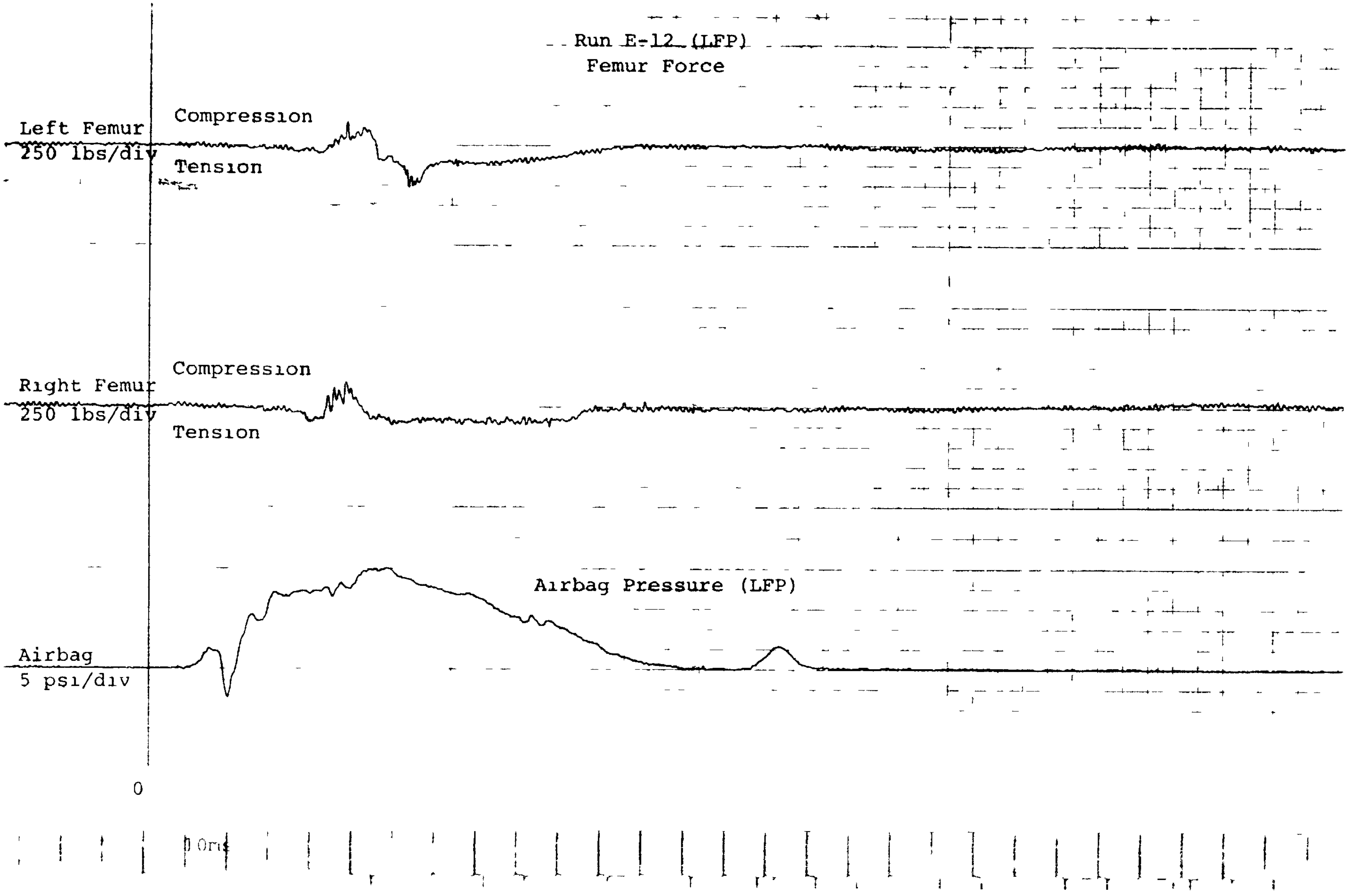

Run E-11 (RFP)
Femur Force
Left Femur
250 lbs/div
Compression
Tension
Right Femur
250 lbs/div
Compression
Tension
Airbag
5 psi/div
Airbag Pressure (LFP)
0
10ms


Run E-11
Sled Acceleration
AP
5 g/div
0
10ms

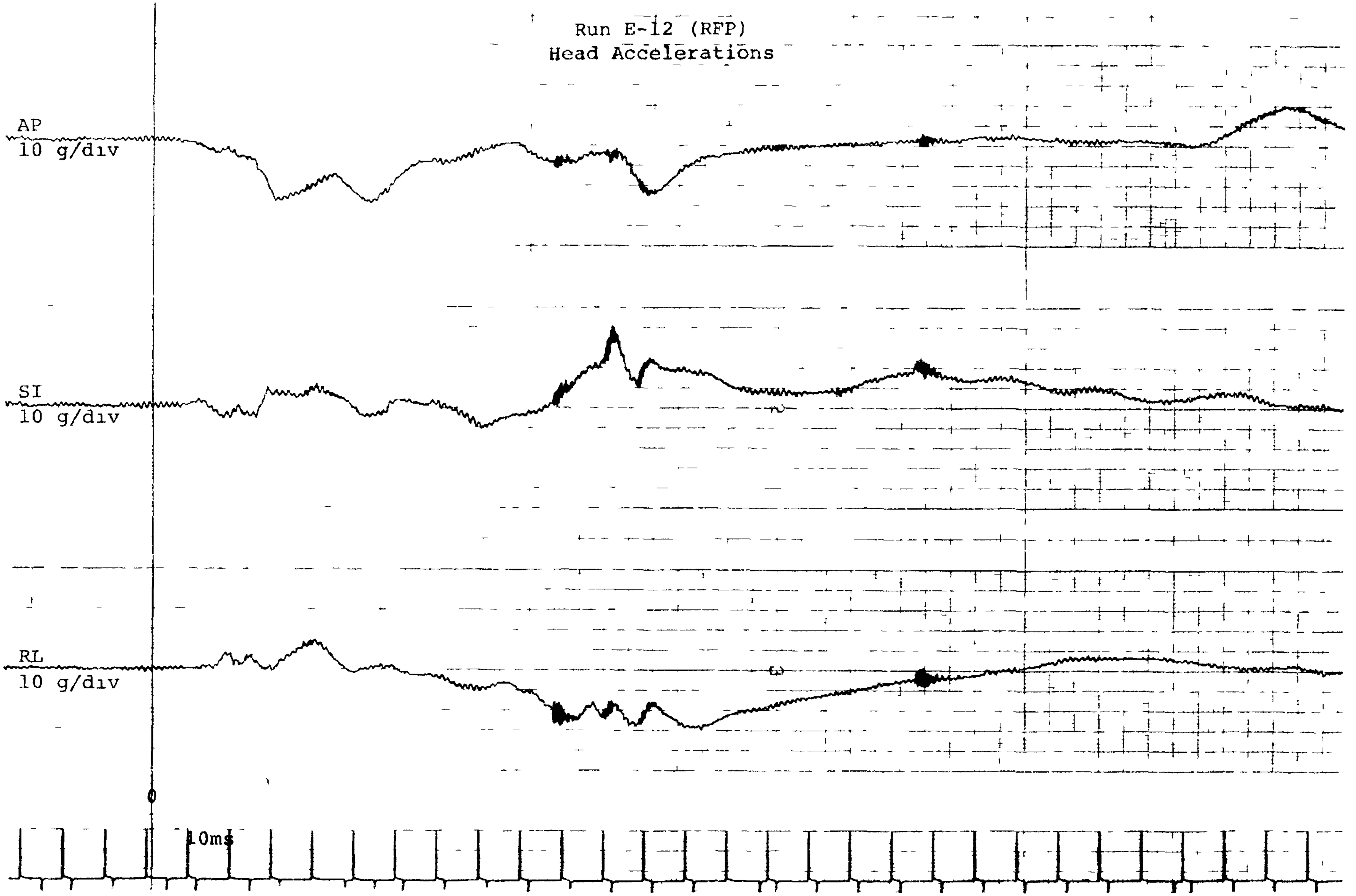

Run E-12 (LFP)
Head Accelerations
AP
25 g/div
SI
25 g/div
RL
25 g/div
0
10ms

Run E-12 (LFP)
Chest Accelerations

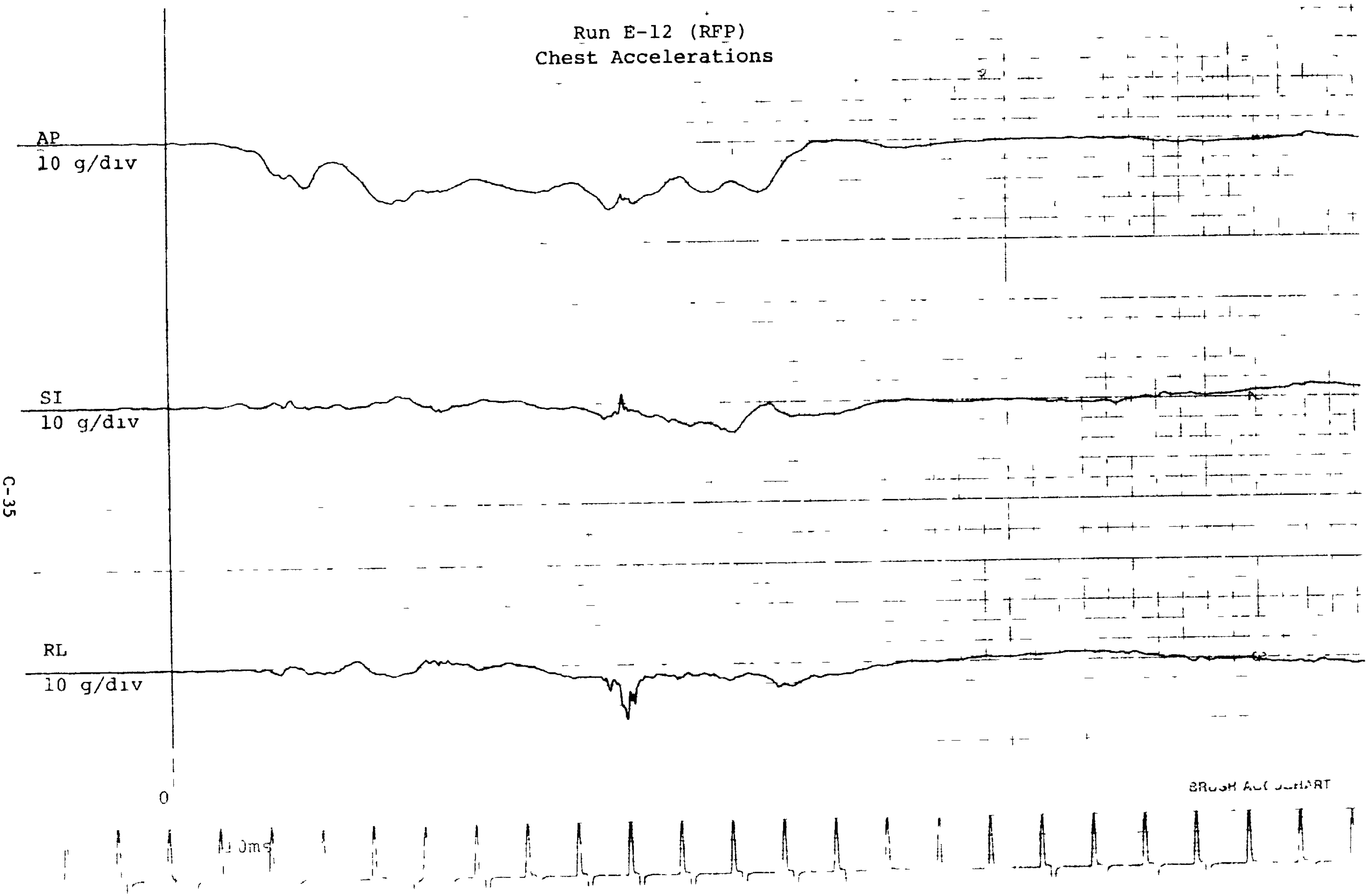


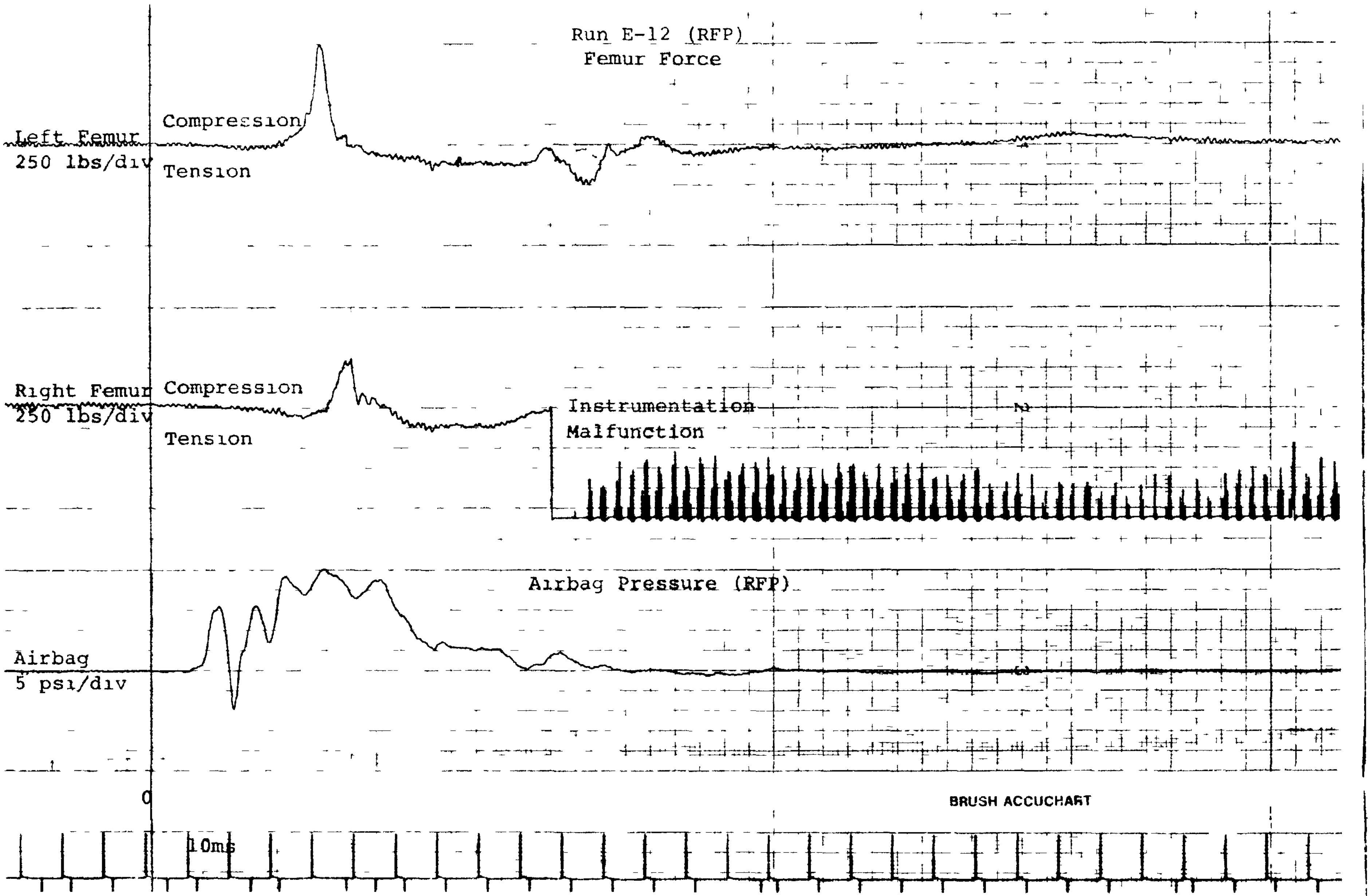

Run E-12 (LFP)
Femur Force
Left Femur
250 lbs/div
Compression
Tension
Right Femur
250 lbs/div
Compression
Tension
Airbag Pressure (LFP)
Airbag
5 psi/div
0

Run E-12 (RFP)
Head Accelerations

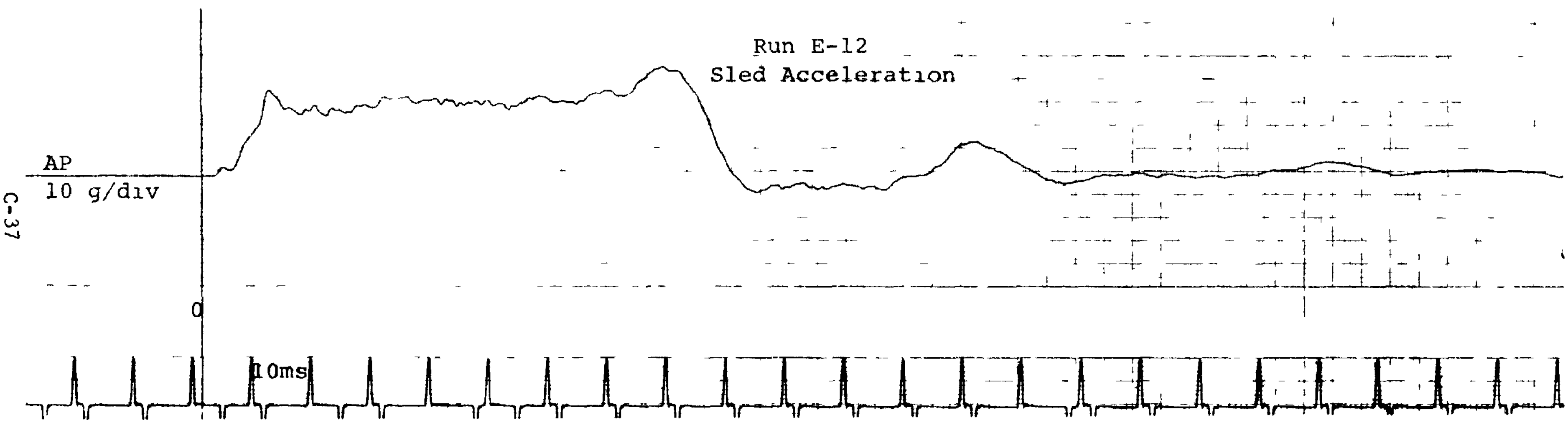


Run E-12 (RFP)
Chest Accelerations

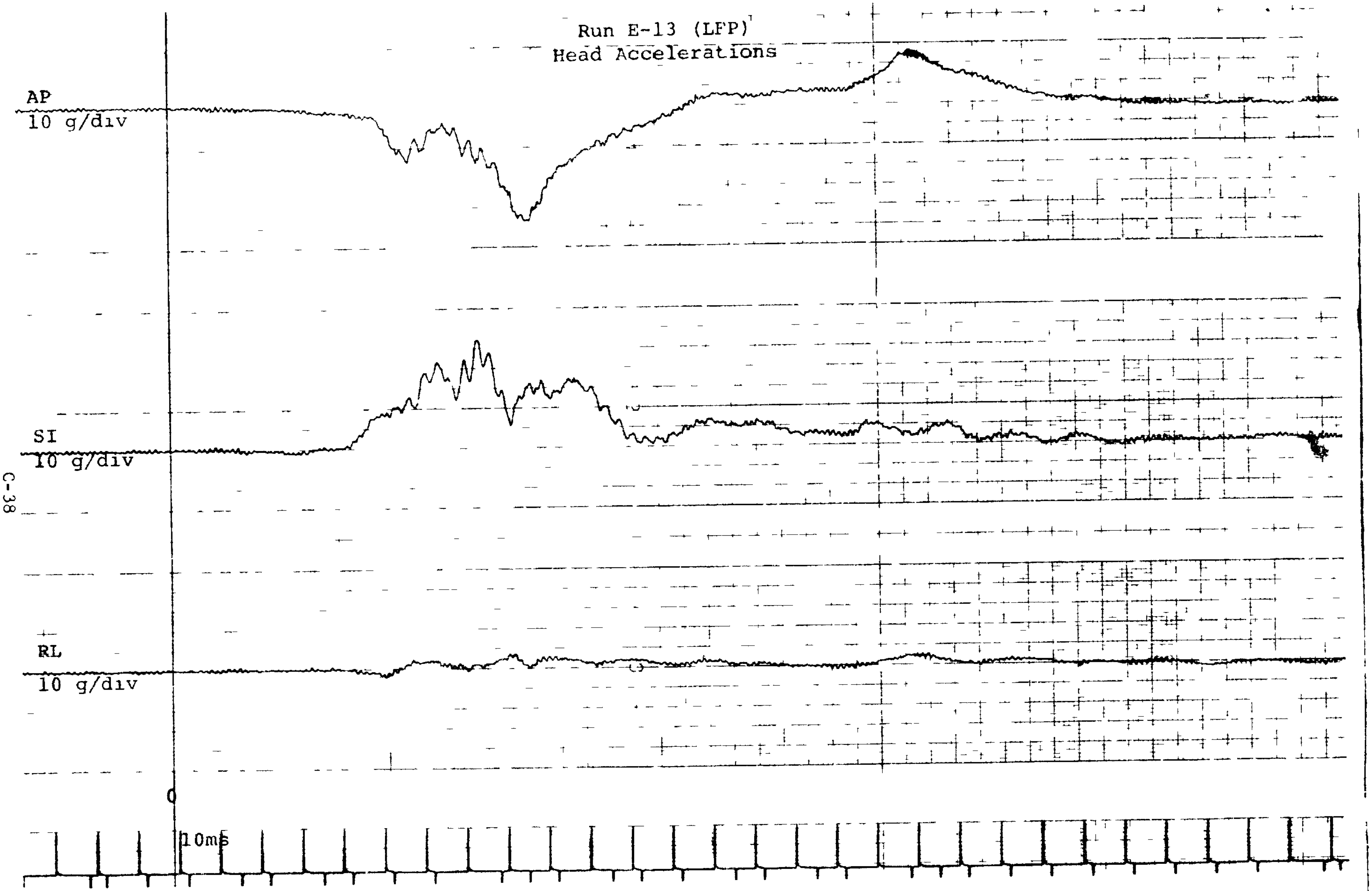


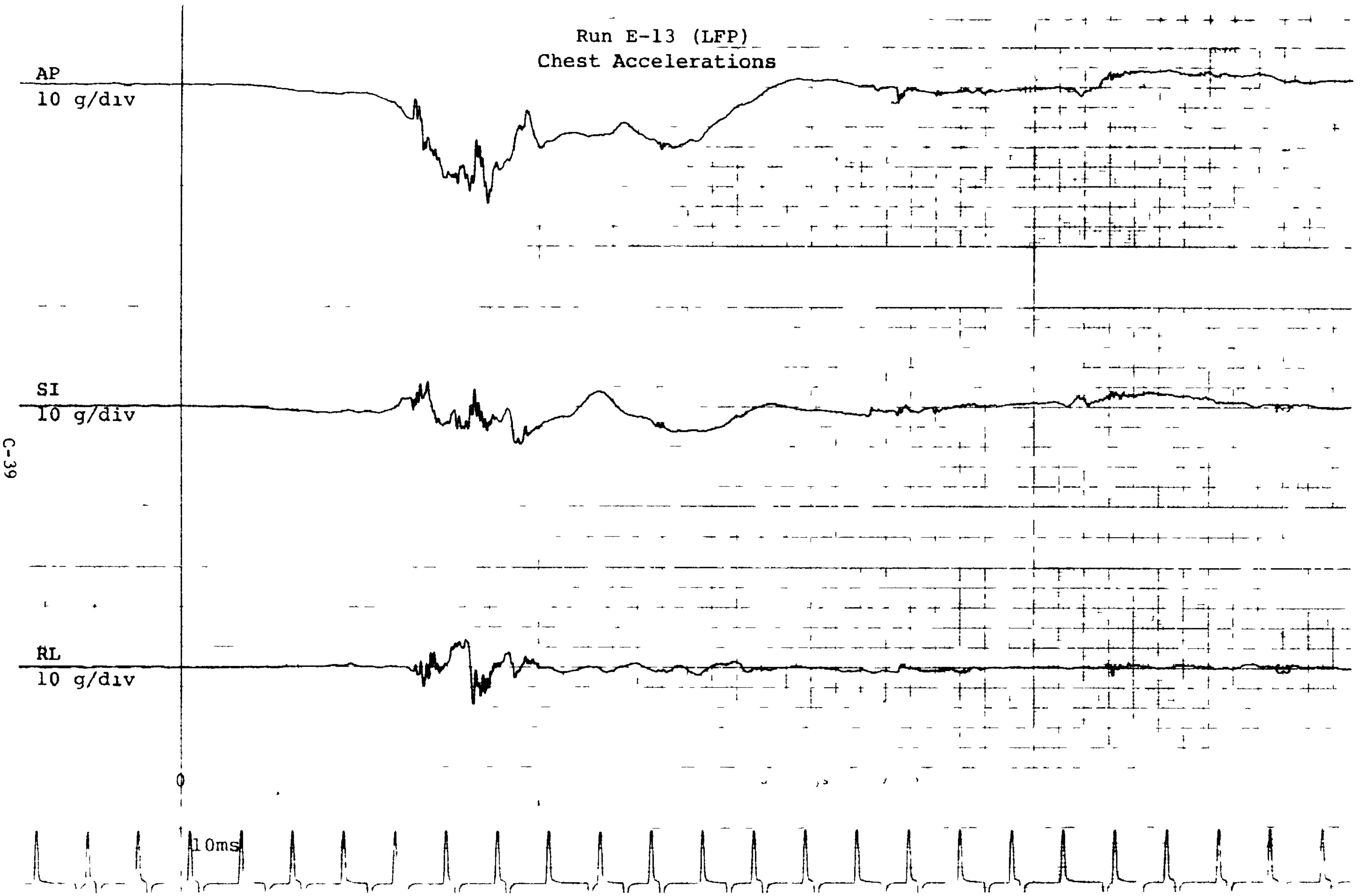

Run E-12 (RFP)
Femur Force
Left Femur
250 lbs/div
Compression
Tension
Right Femur
250 lbs/div
Compression
Tension
Instrumentation
Malfunction
Airbag Pressure (RFP)
Airbag
5 psi/div
0
10ms
BRUSH ACCUCHART

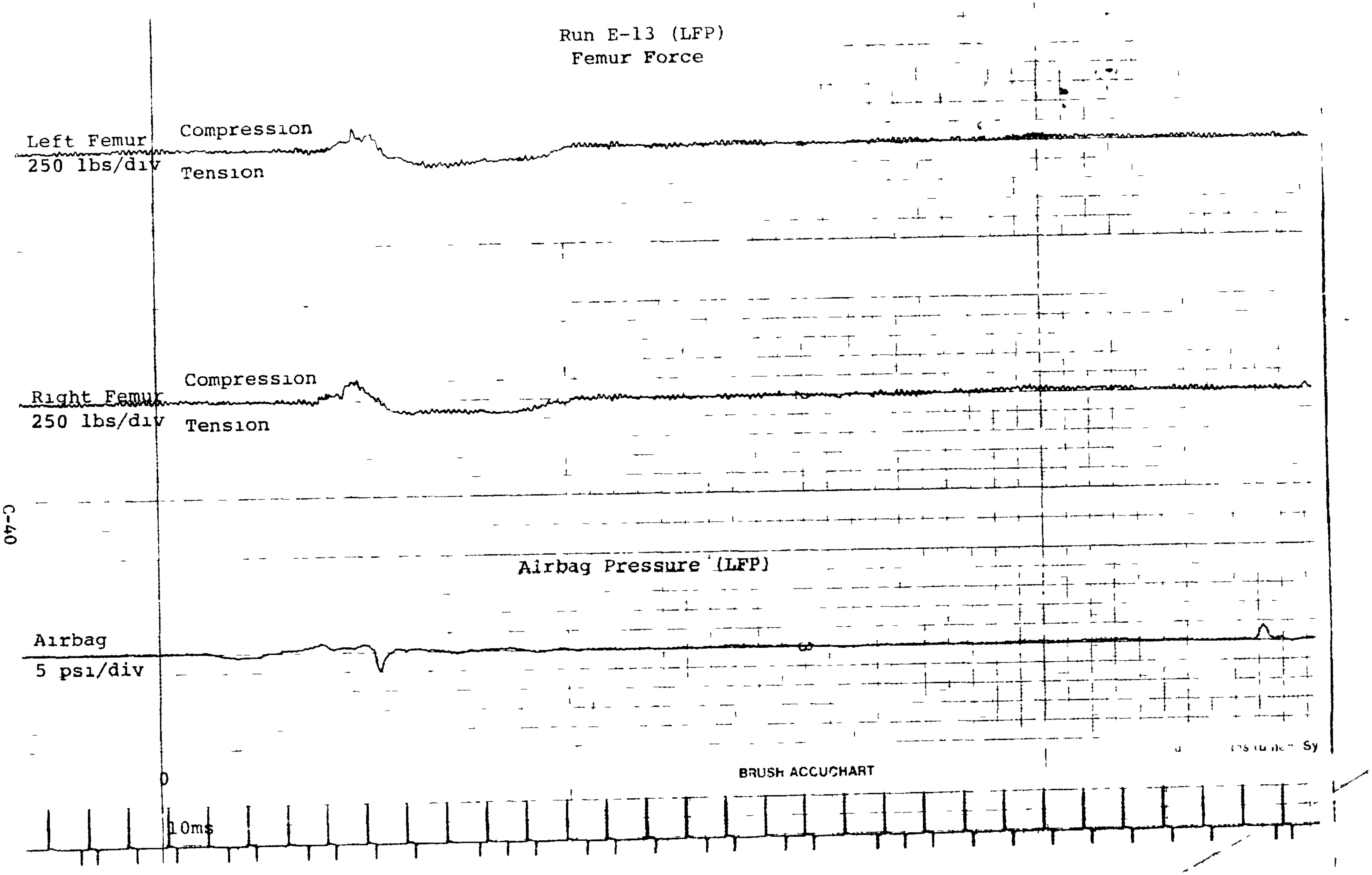
Run E-12
Sled Acceleration



Run E-13 (LFP)
Head Accelerations

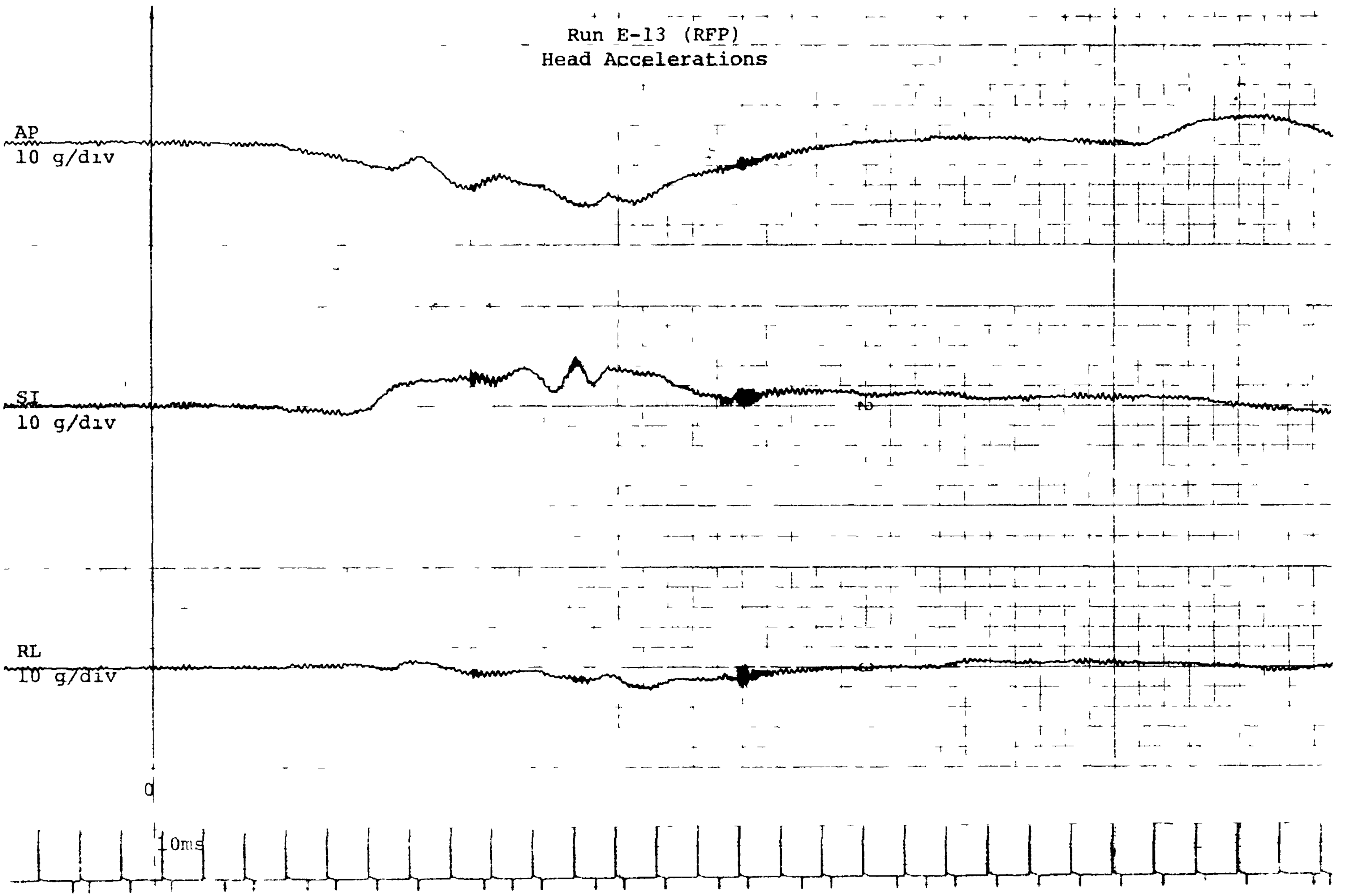



Run E-13 (LFP)
Chest Accelerations
AP
10 g/div
SI
10 g/div
RL
10 g/div
0
10ms

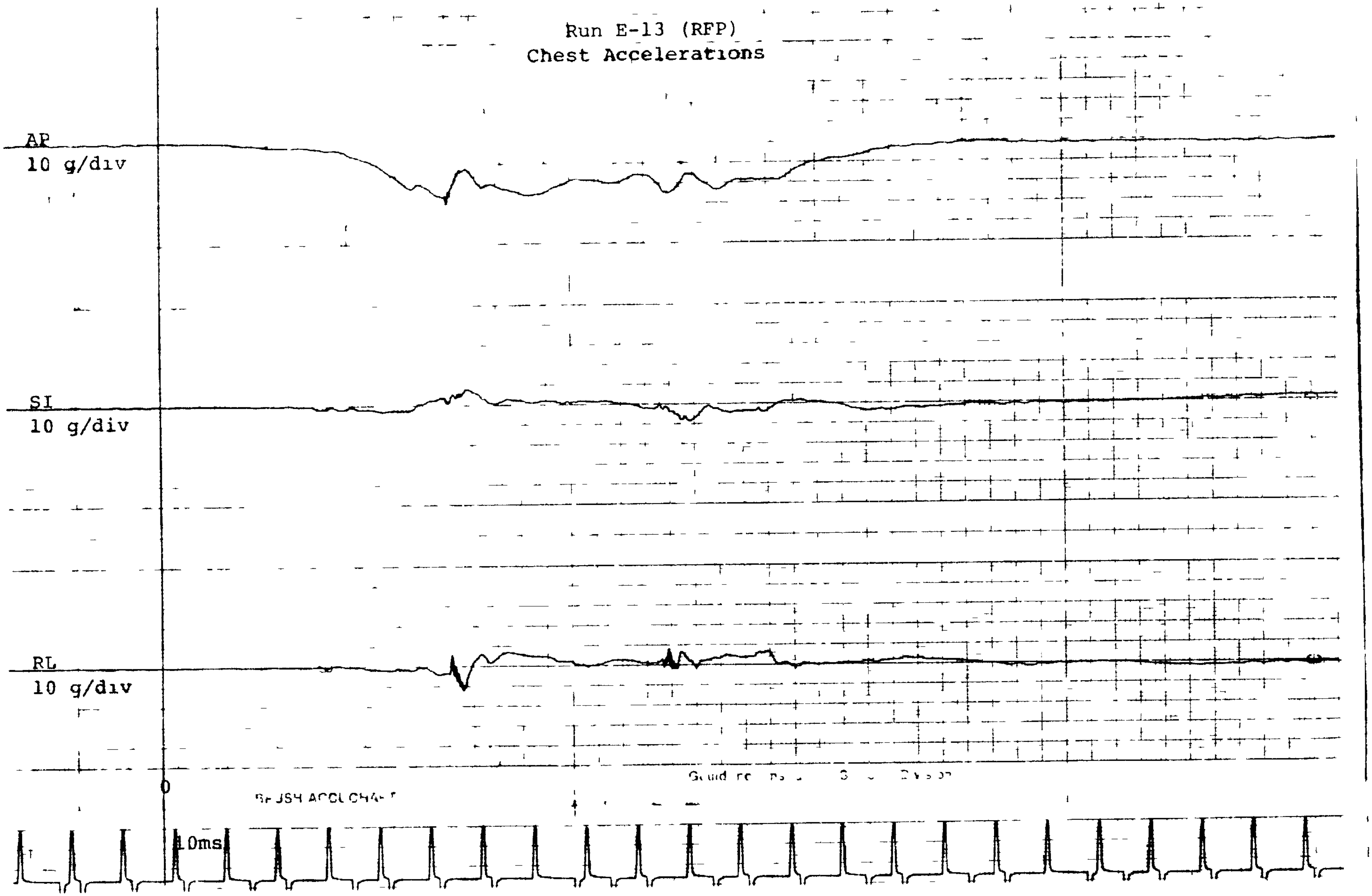


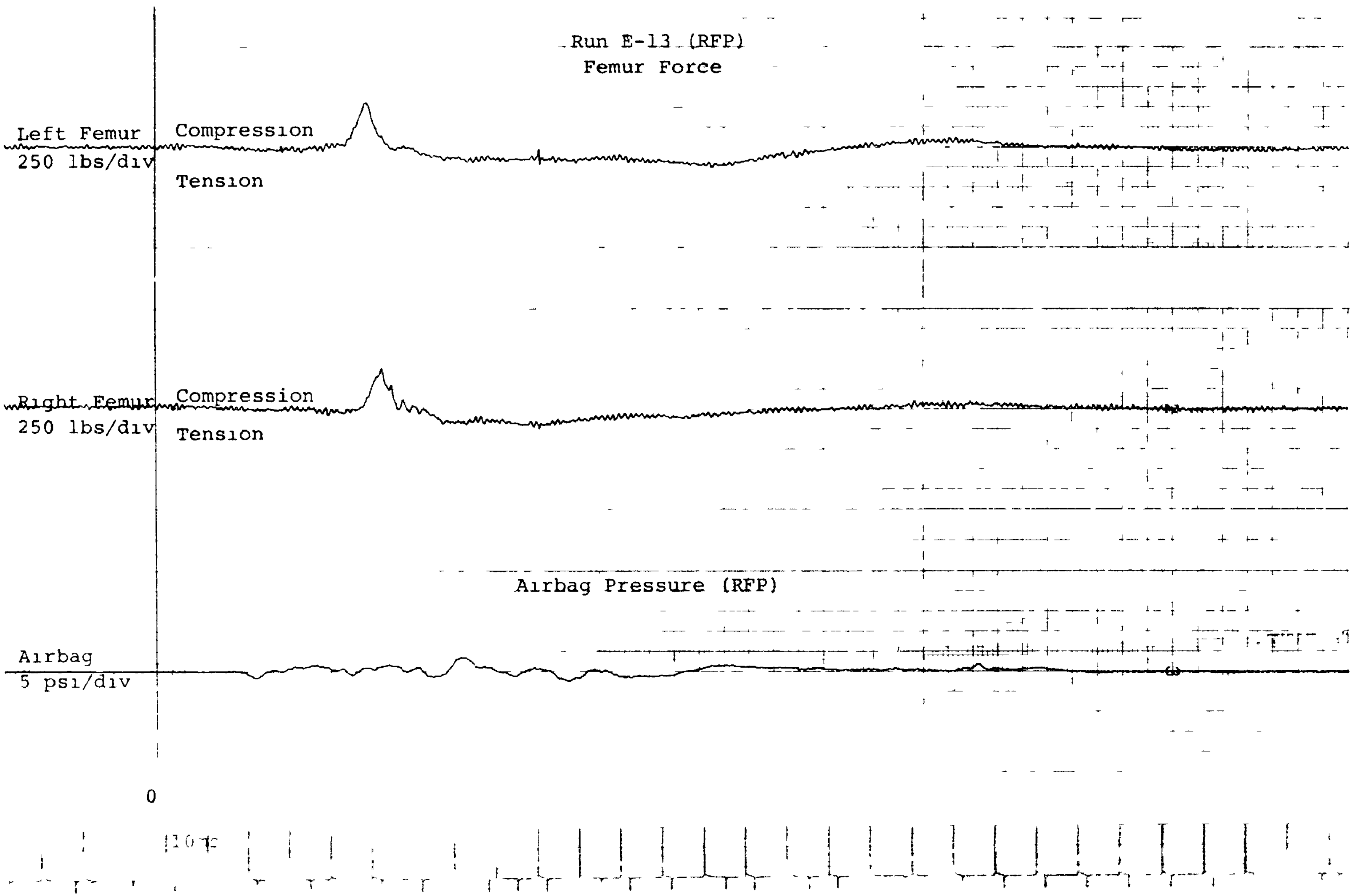
Run E-13 (LFP)
Femur Force
Left Femur
250 lbs/div
Compression
Tension
Right Femur
250 lbs/div
Compression
Tension
Airbag Pressure (LFP)
Airbag
5 psi/div
0
10ms
BRUSH ACCUCHART

Run E-13 (RFP)
Head Accelerations

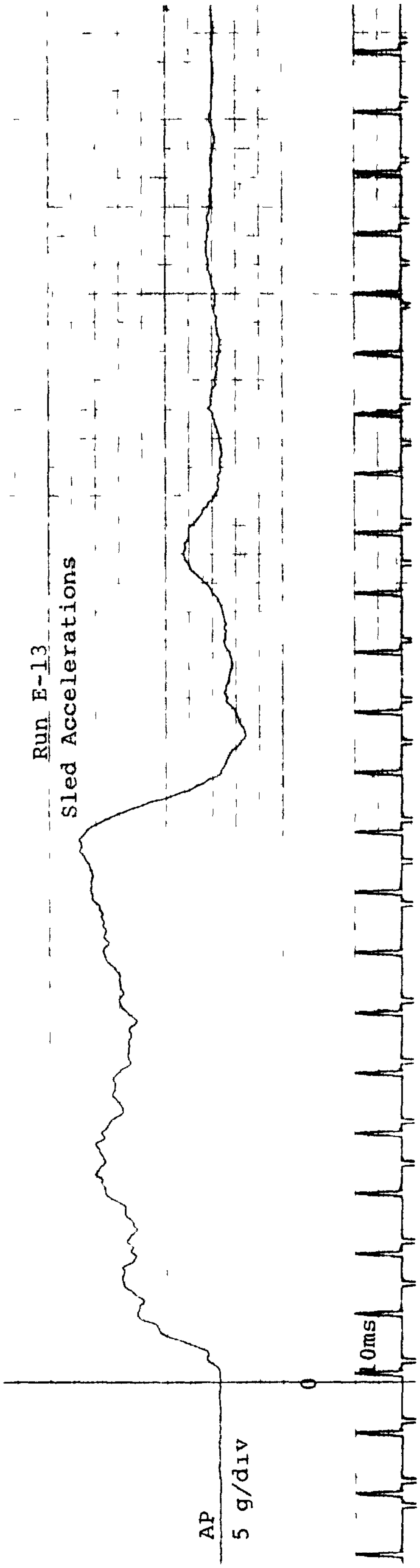


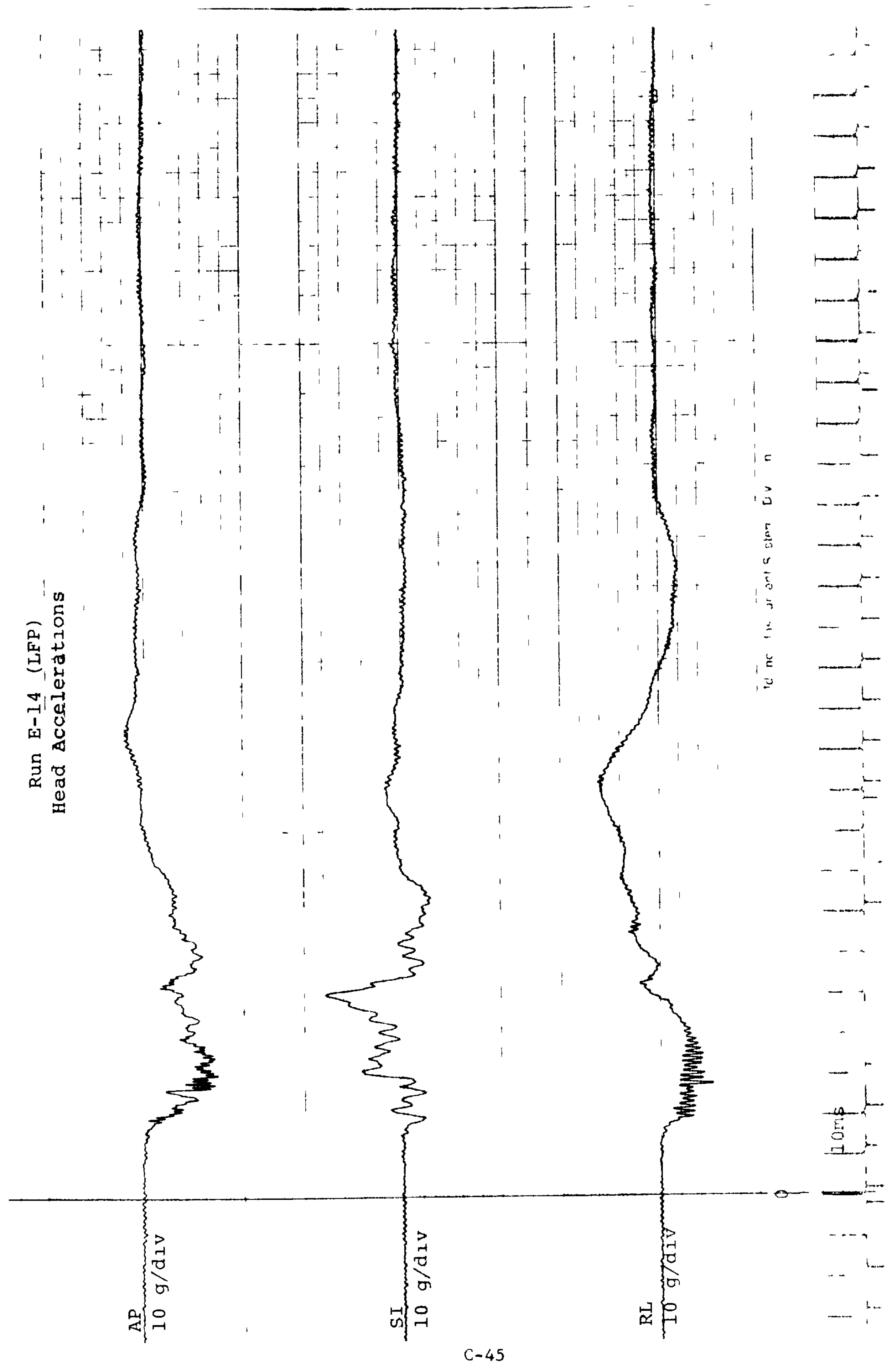
Run E-13 (RFP)
Chest Accelerations





Run E-13 (RFP)
Femur Force
Left Femur
250 lbs/div
Compression
Tension
Right Femur
250 lbs/div
Compression
Tension
Airbag Pressure (RFP)
Airbag
5 psi/div
0

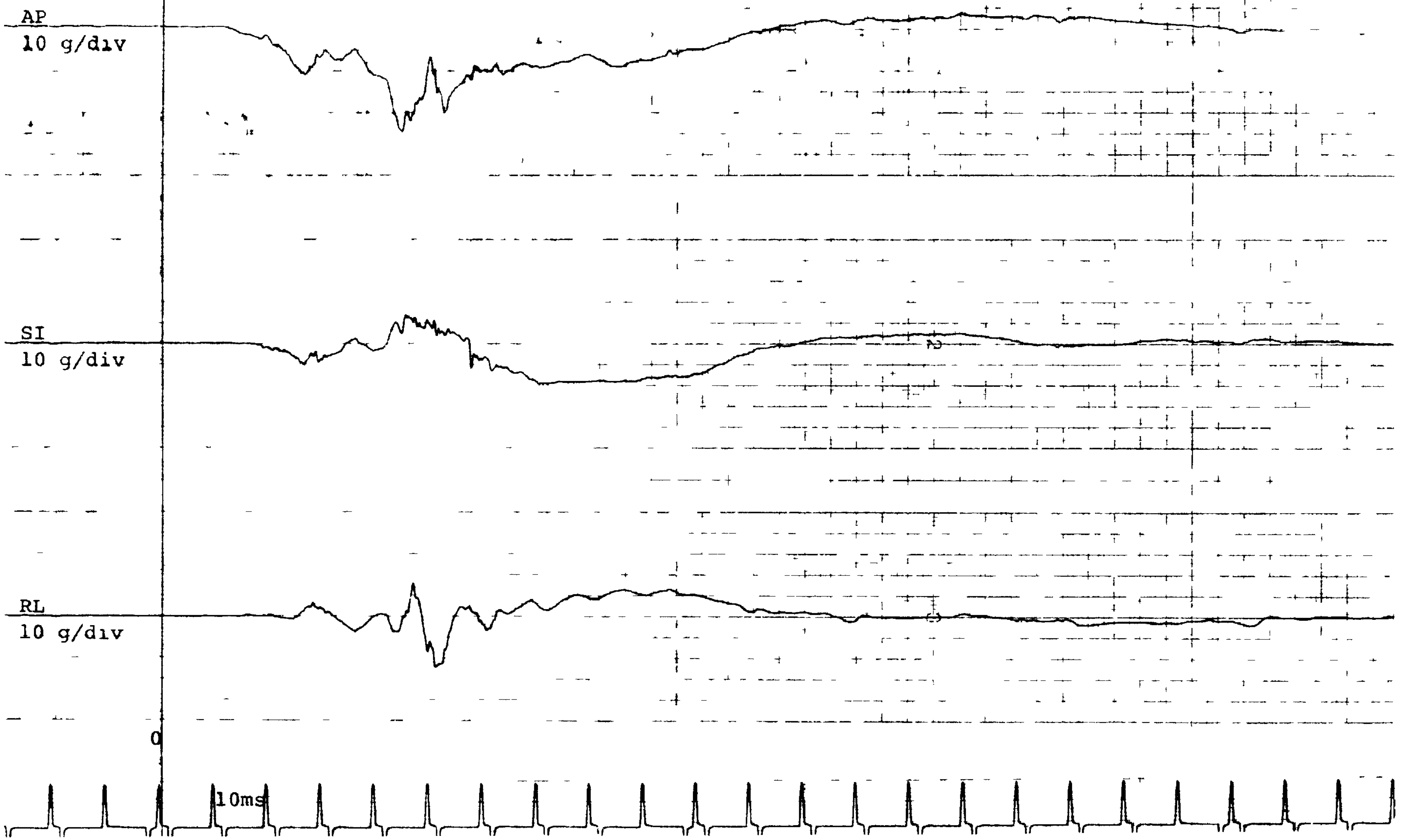

Run E-13
Sled Accelerations
AP
5 g/div
0
10ms

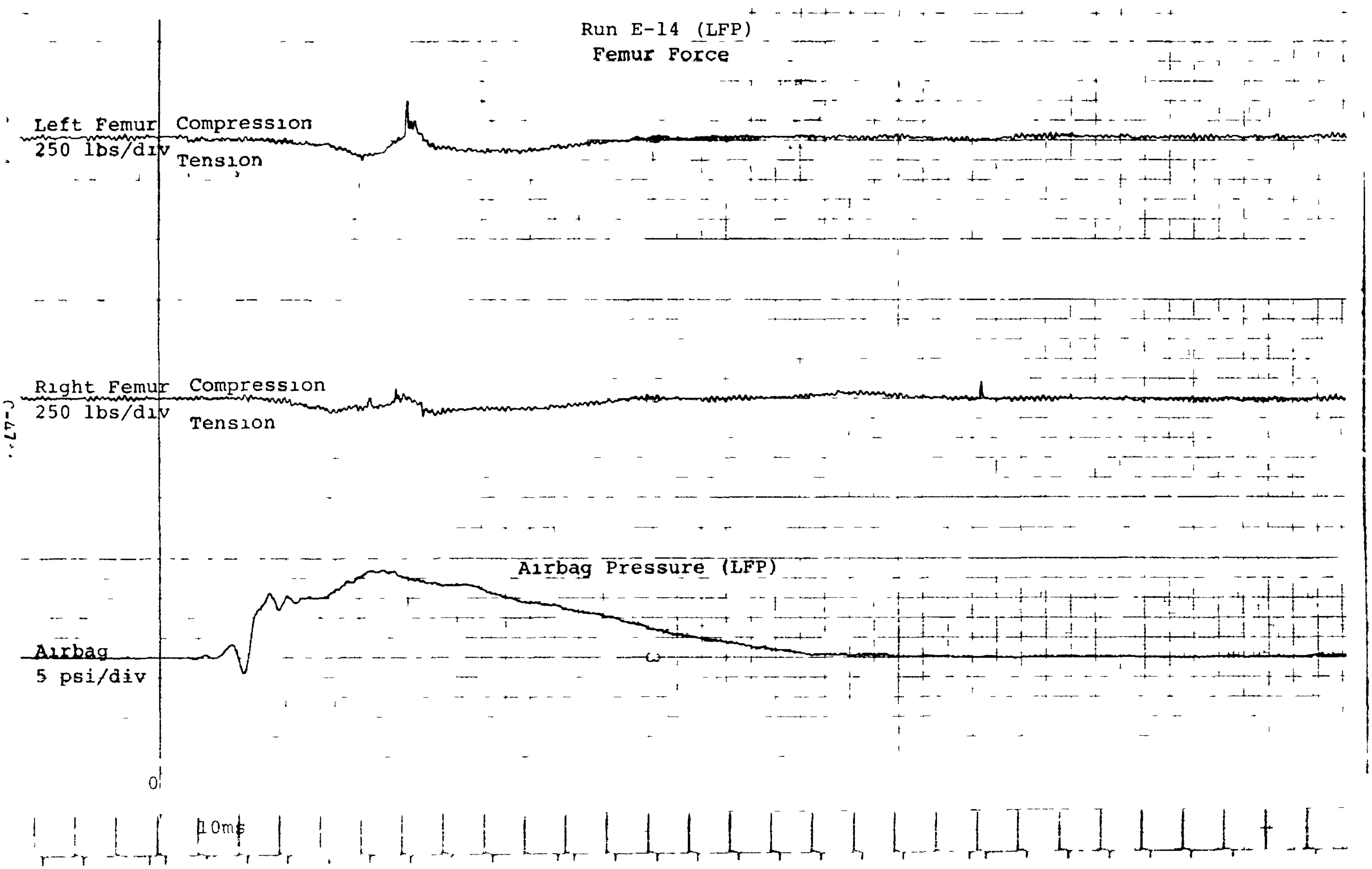


Run E-14 (LFP)
Head Accelerations
AP
10 g/div
SI
10 g/div
RL
10 g/div
10ms

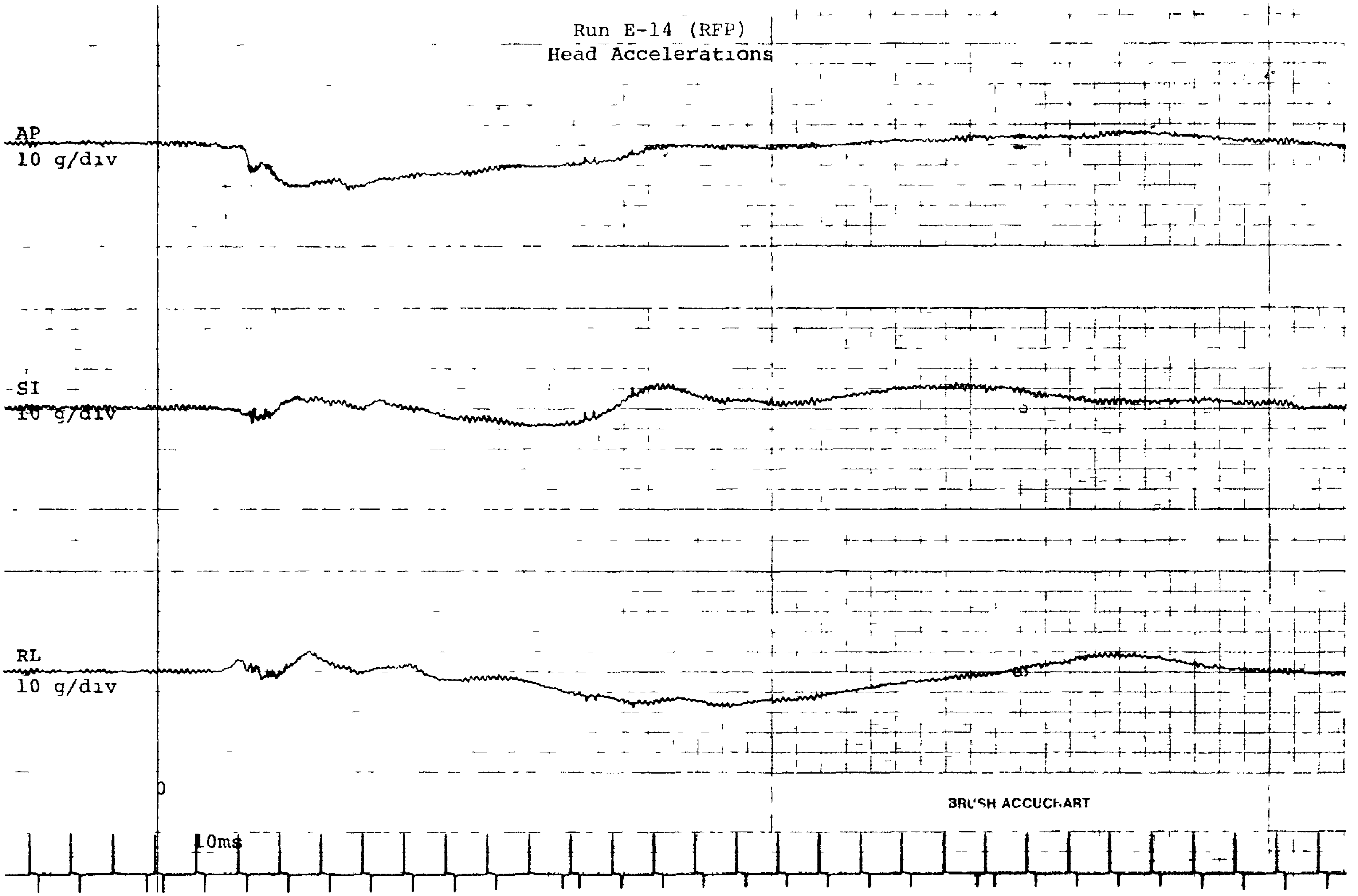
Run E-14 (LFP)

Chest Accelerations

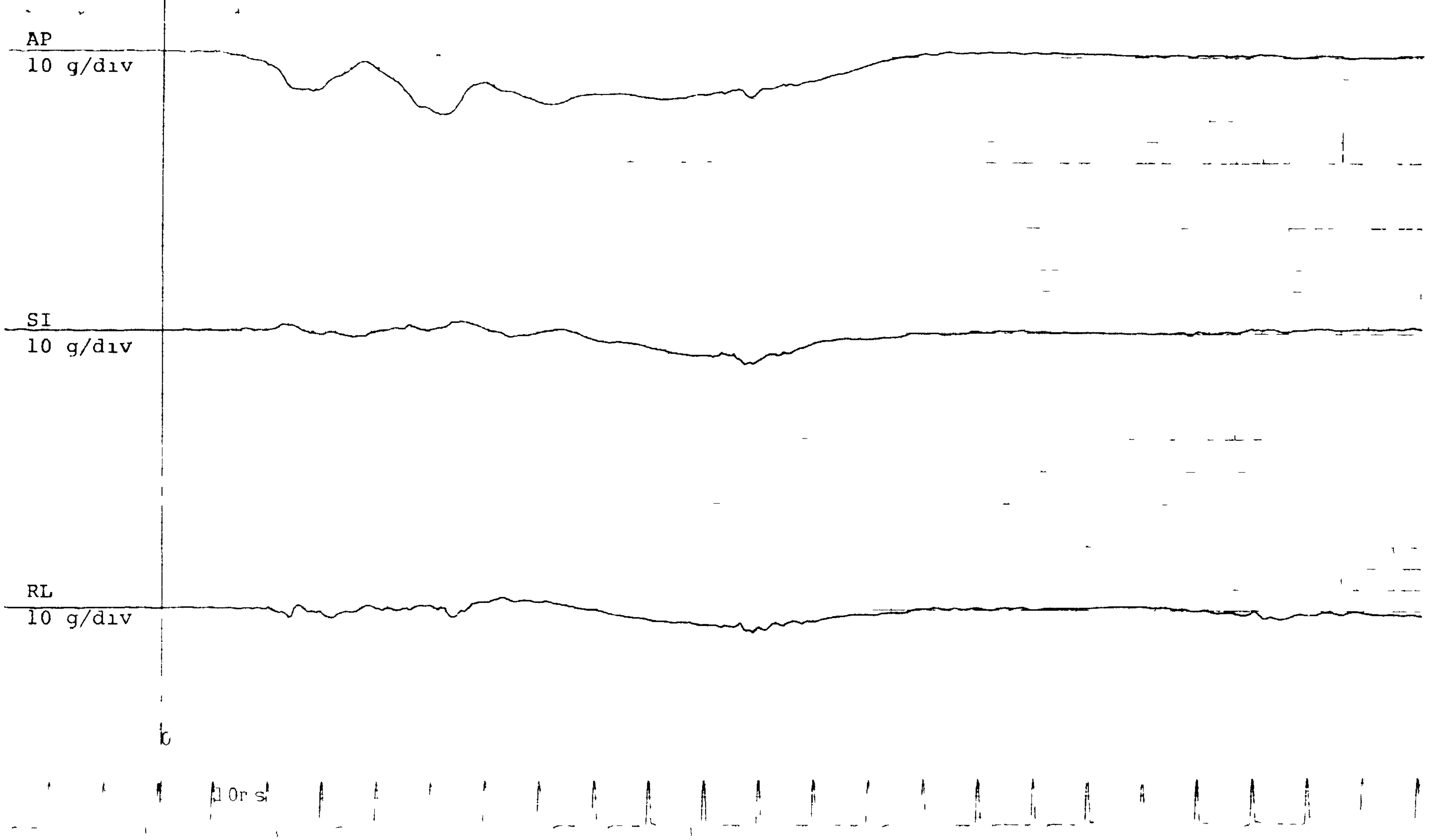


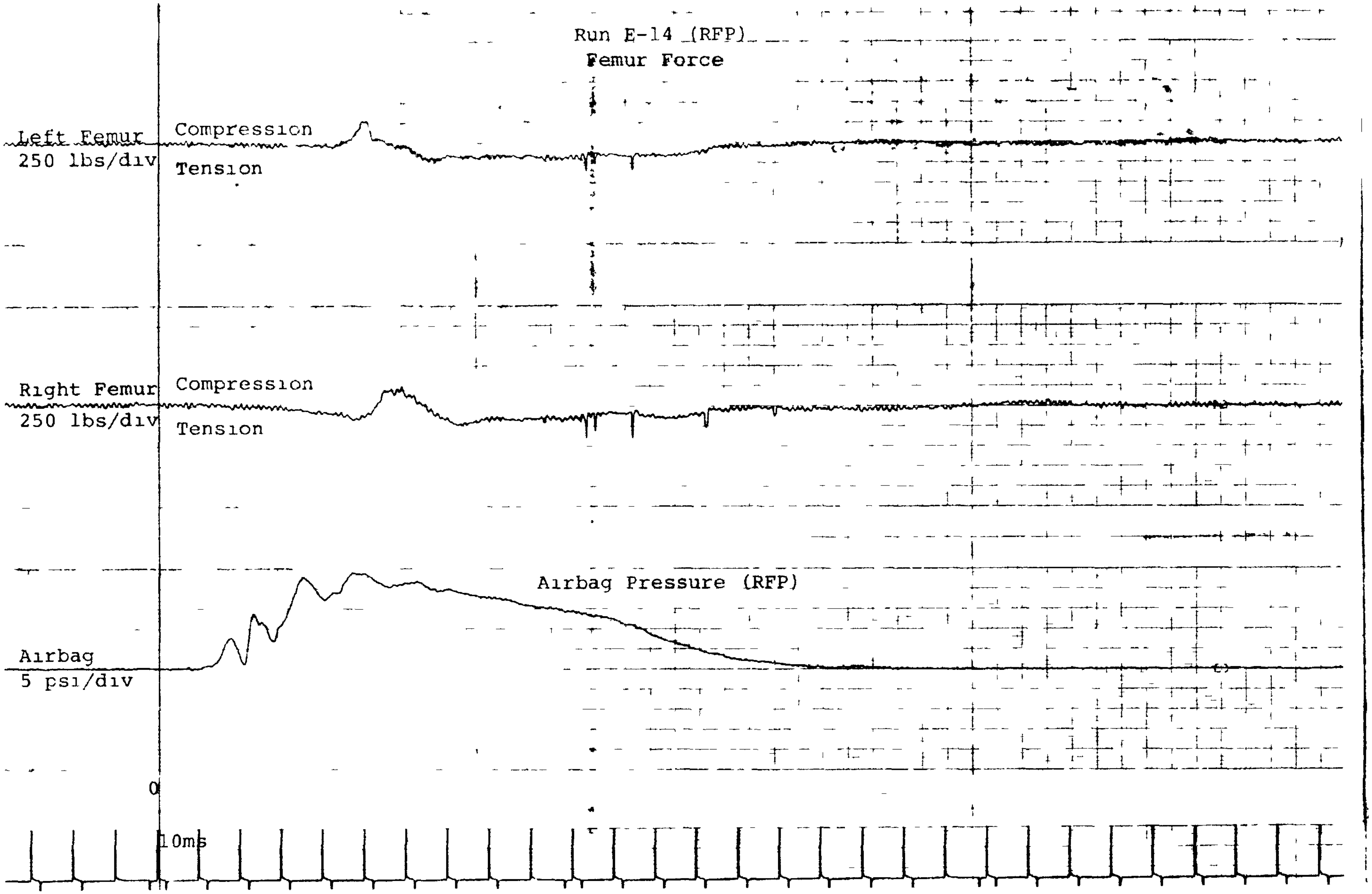

Run E-14 (LFP)
Femur Force
Left Femur
250 lbs/div
Compression
Tension
Right Femur
250 lbs/div
Compression
Tension
Airbag Pressure (LFP)
Airbag
5 psi/div
0
10ms

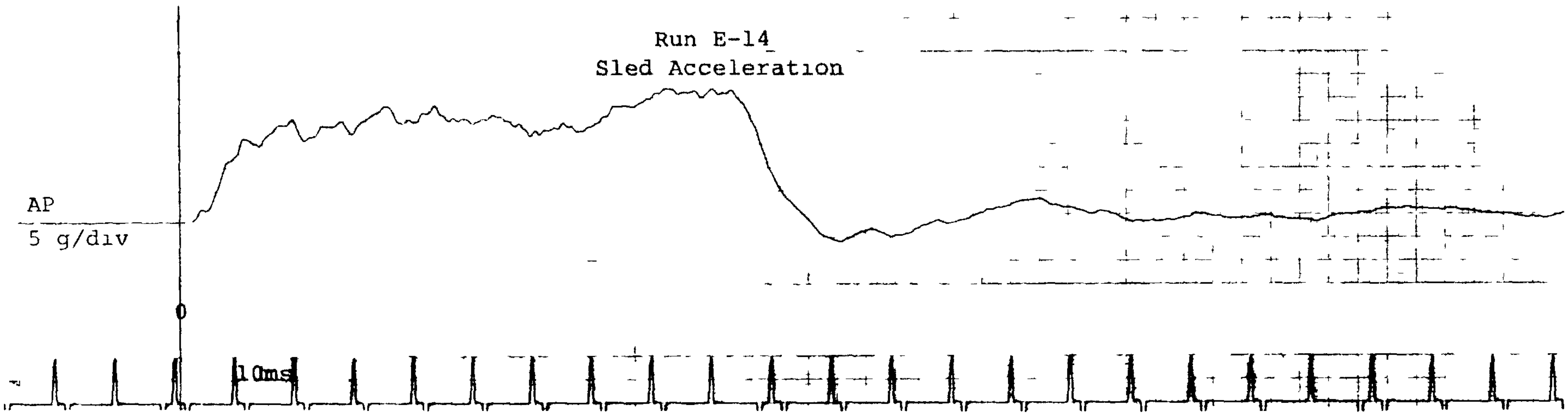
Run E-14 (RFP)
Head Accelerations



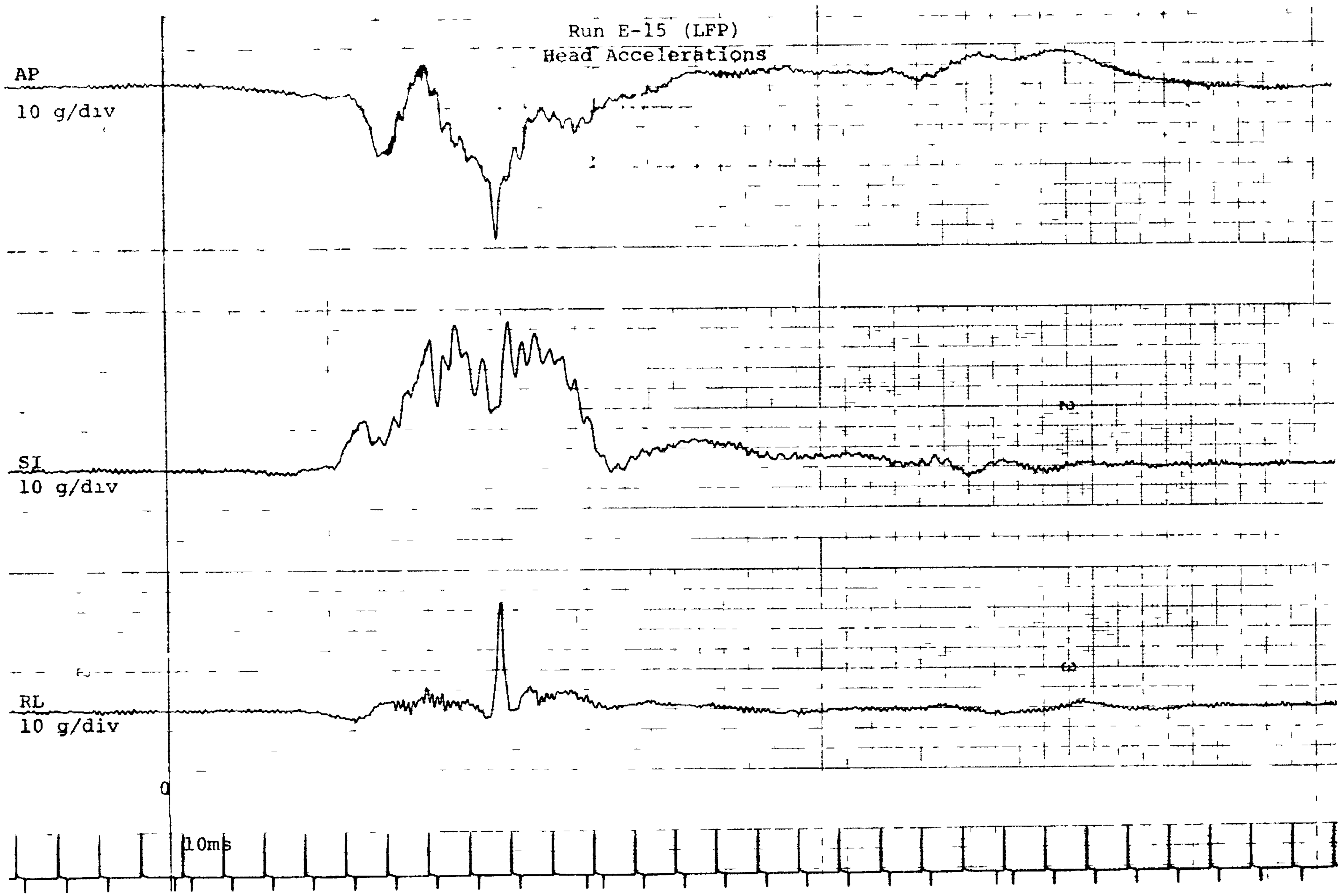
Run E-14 (RFP)
Chest Accelerations

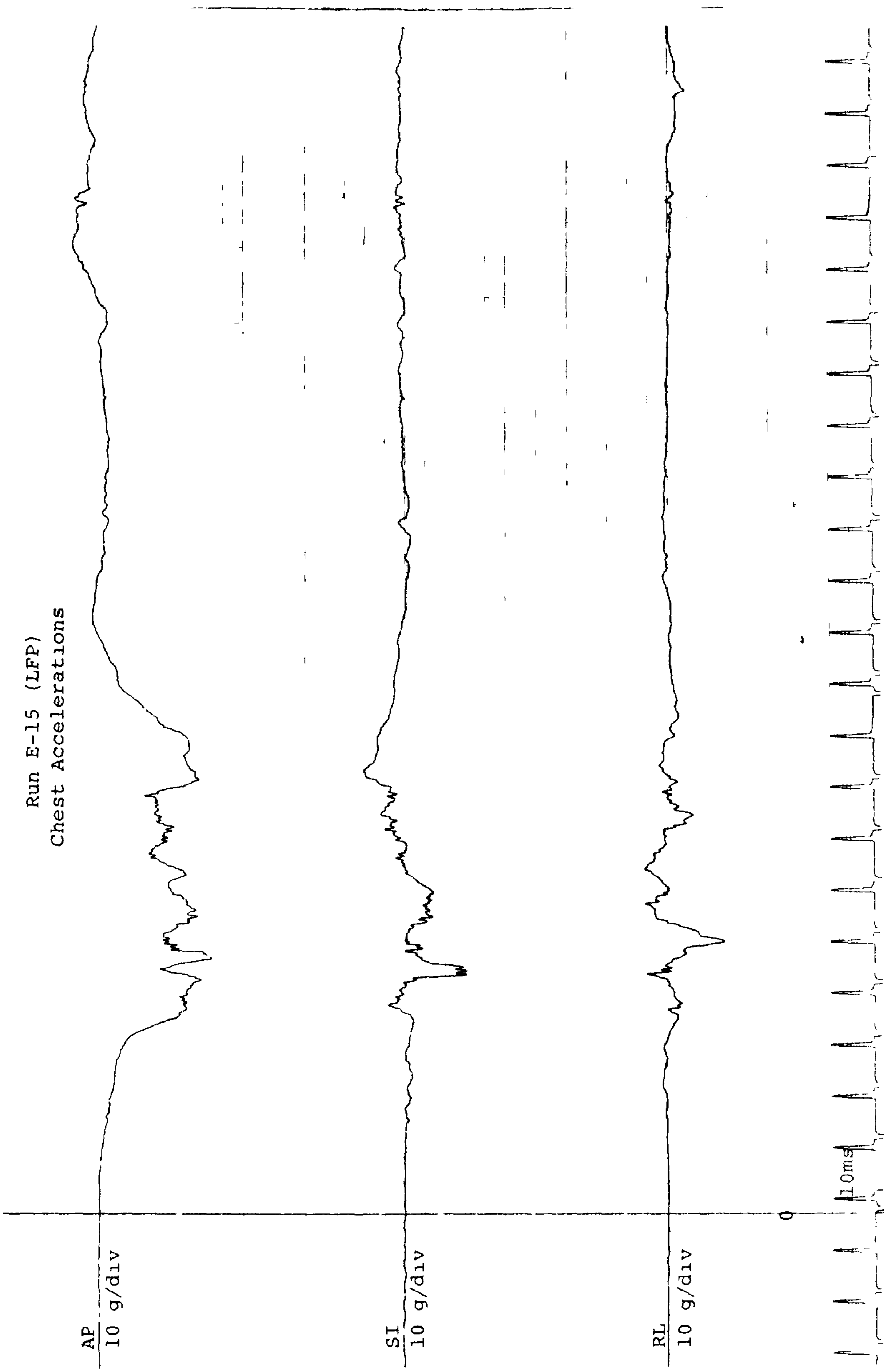



Run E-14 (RFP)
Femur Force
Left Femur
250 lbs/div
Compression
Tension
Right Femur
250 lbs/div
Compression
Tension
Airbag Pressure (RFP)
Airbag
5 psi/div
0
10ms

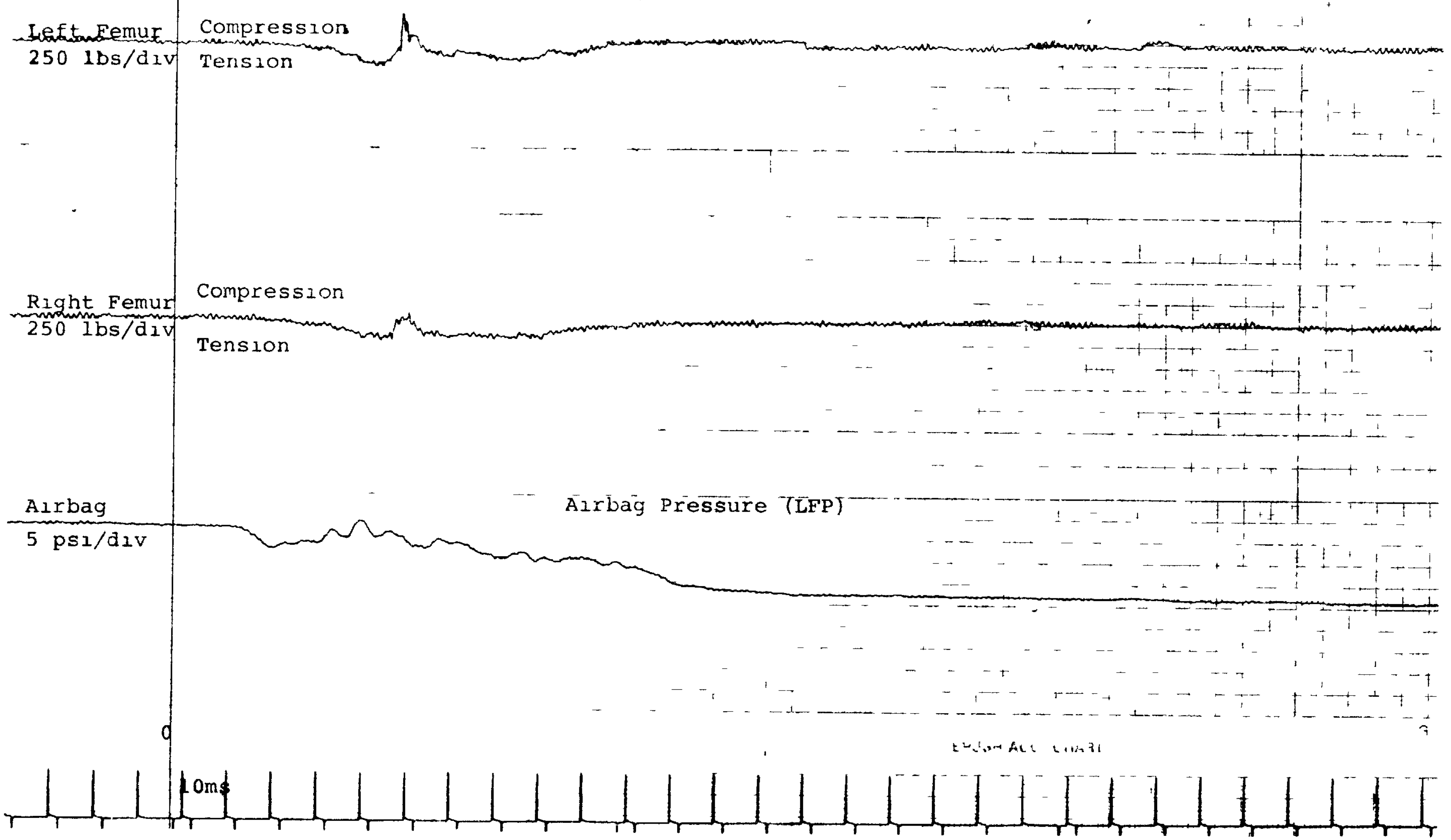


Run E-14
Sled Acceleration
AP
5 g/div
0
10ms

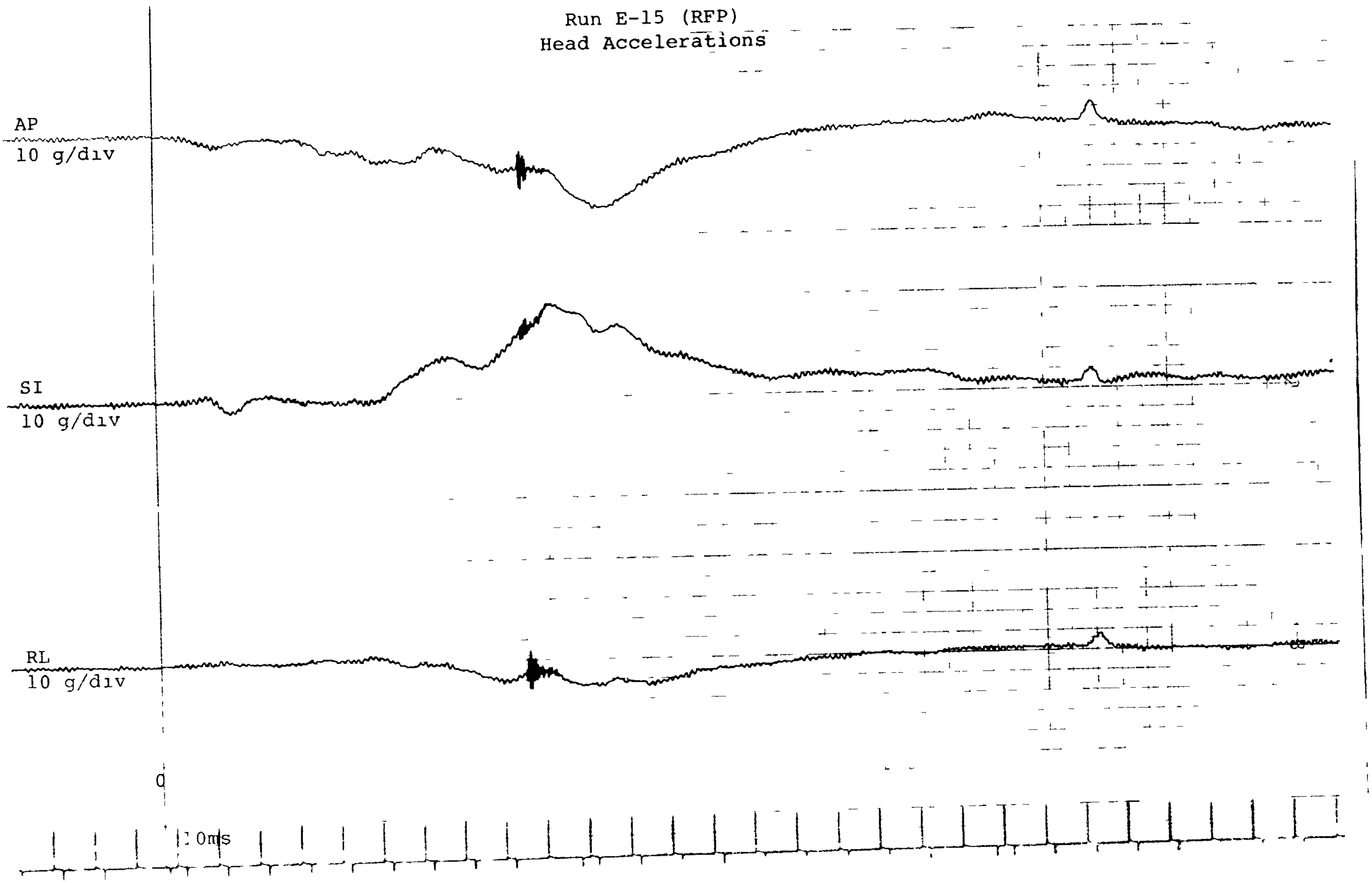

Run E-15 (LFP)
Head Accelerations
AP
10 g/div
SI
10 g/div
RL
10 g/div
0
10ms


Run E-15 (LFP)
Chest Accelerations
AP
10 g/div
SI
10 g/div
RL
10 g/div
0
10ms

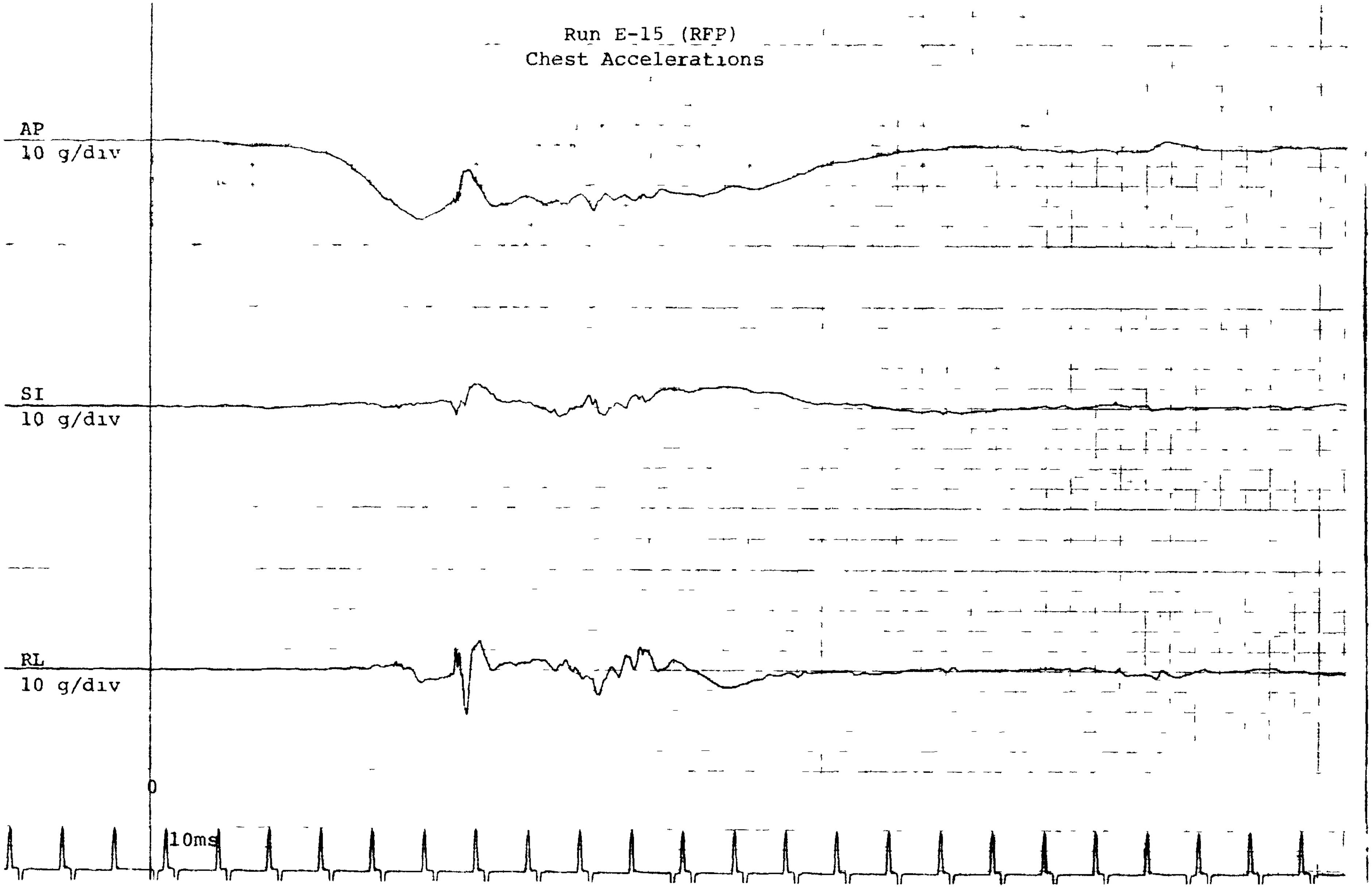
Run E-15 (LFP)
Femur Force

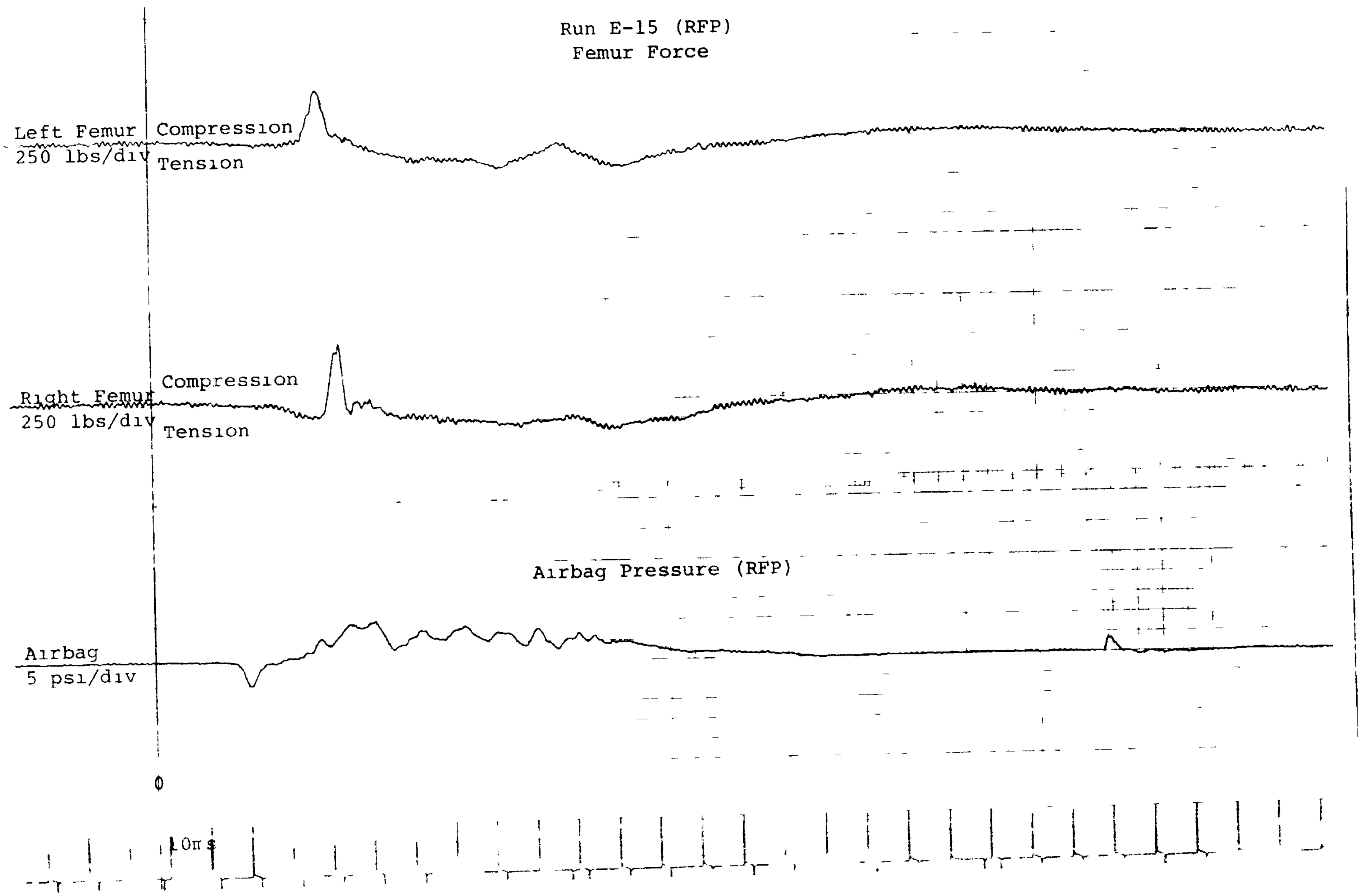


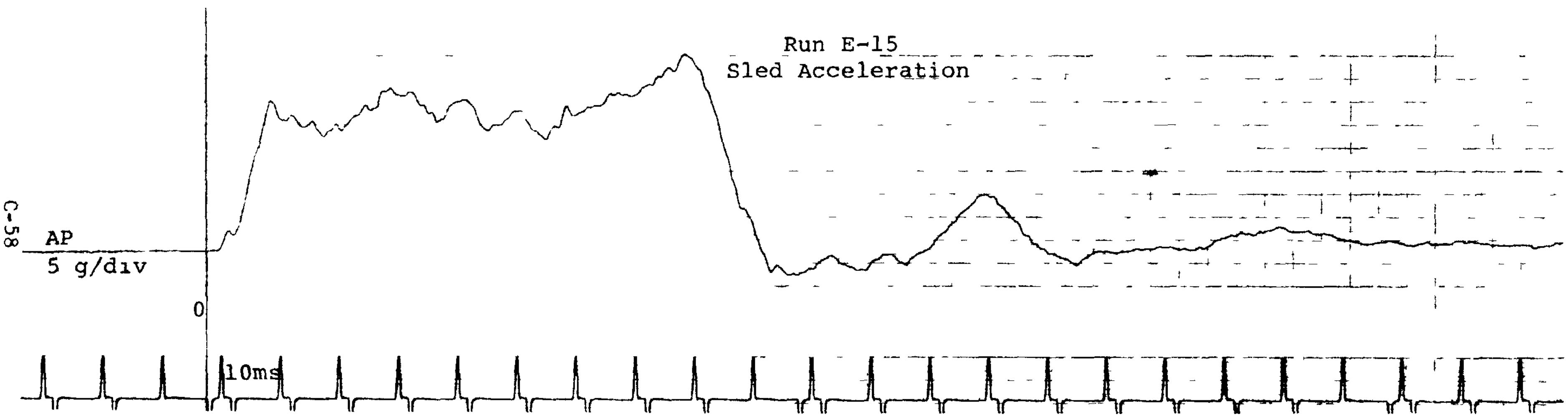
Run E-15 (RFP)
Head Accelerations



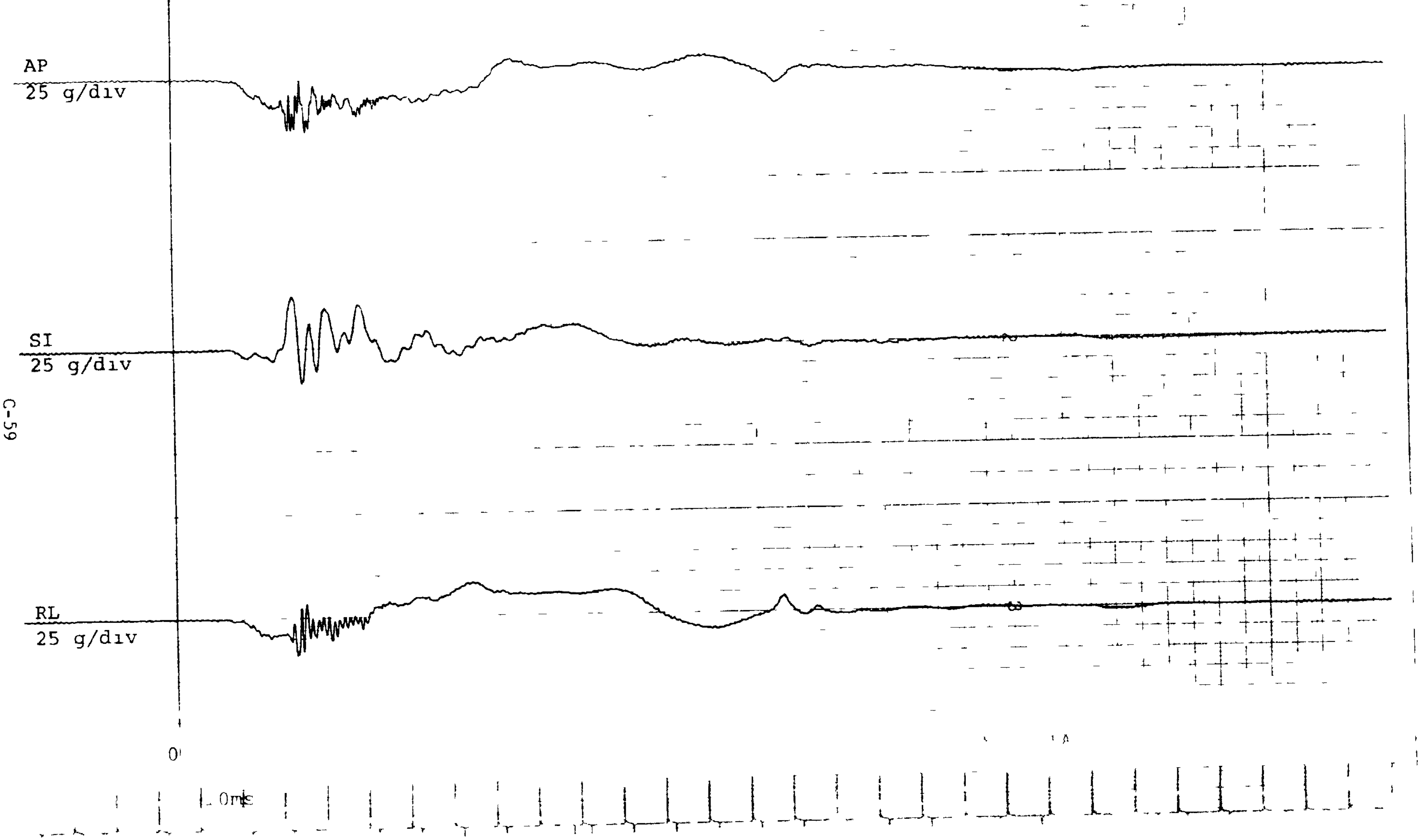
Run E-15 (RFP)
Chest Accelerations



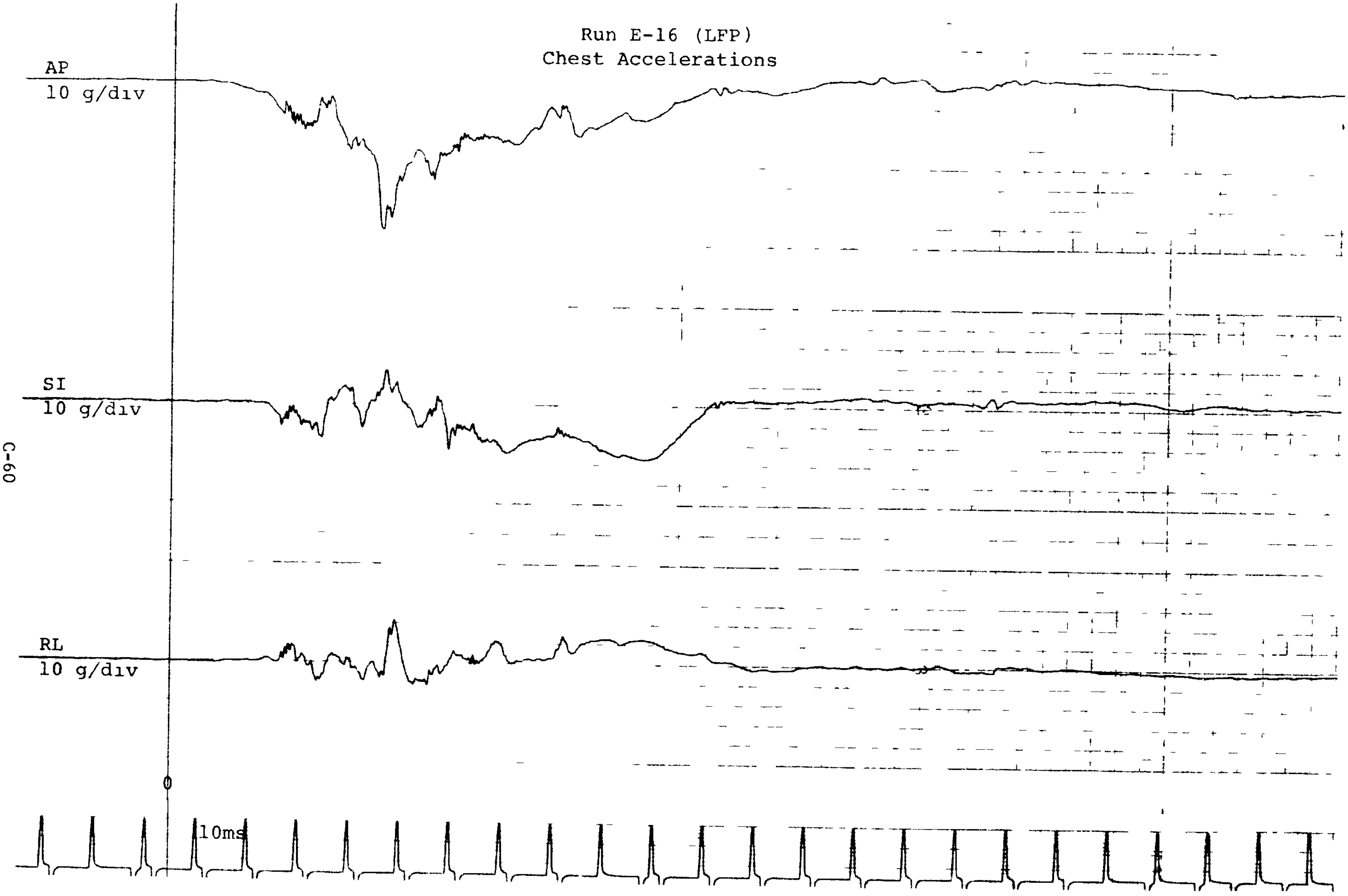

Run E-15 (RFP)
Femur Force
Left Femur
250 lbs/div
Compression
Tension
Right Femur
250 lbs/div
Compression
Tension
Airbag Pressure (RFP)
Airbag
5 psi/div
0
10ms

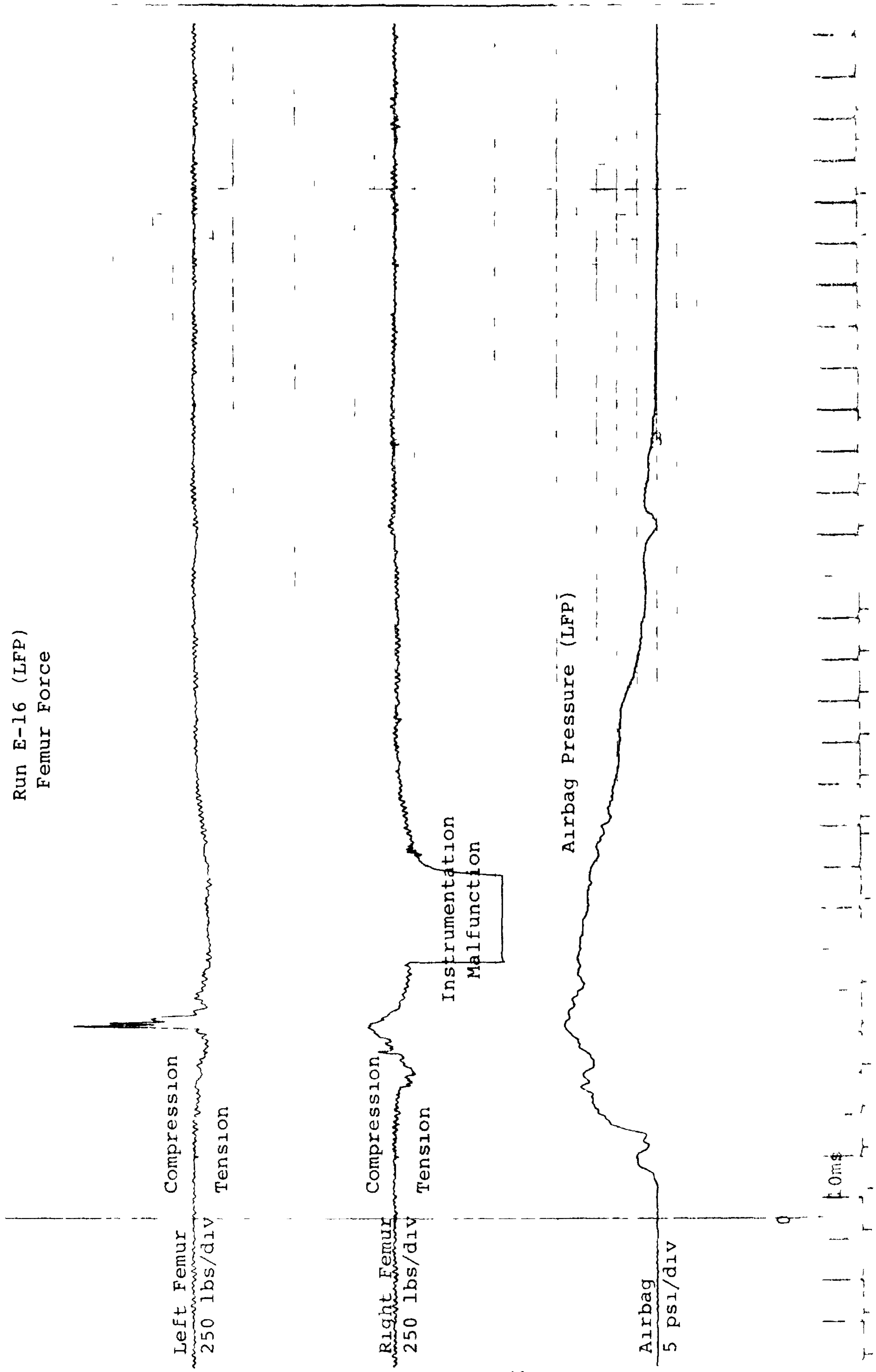

Run E-15
Sled Acceleration
AP
5 g/div
0
10ms

Run E-16 (LFP)
Head Accelerations

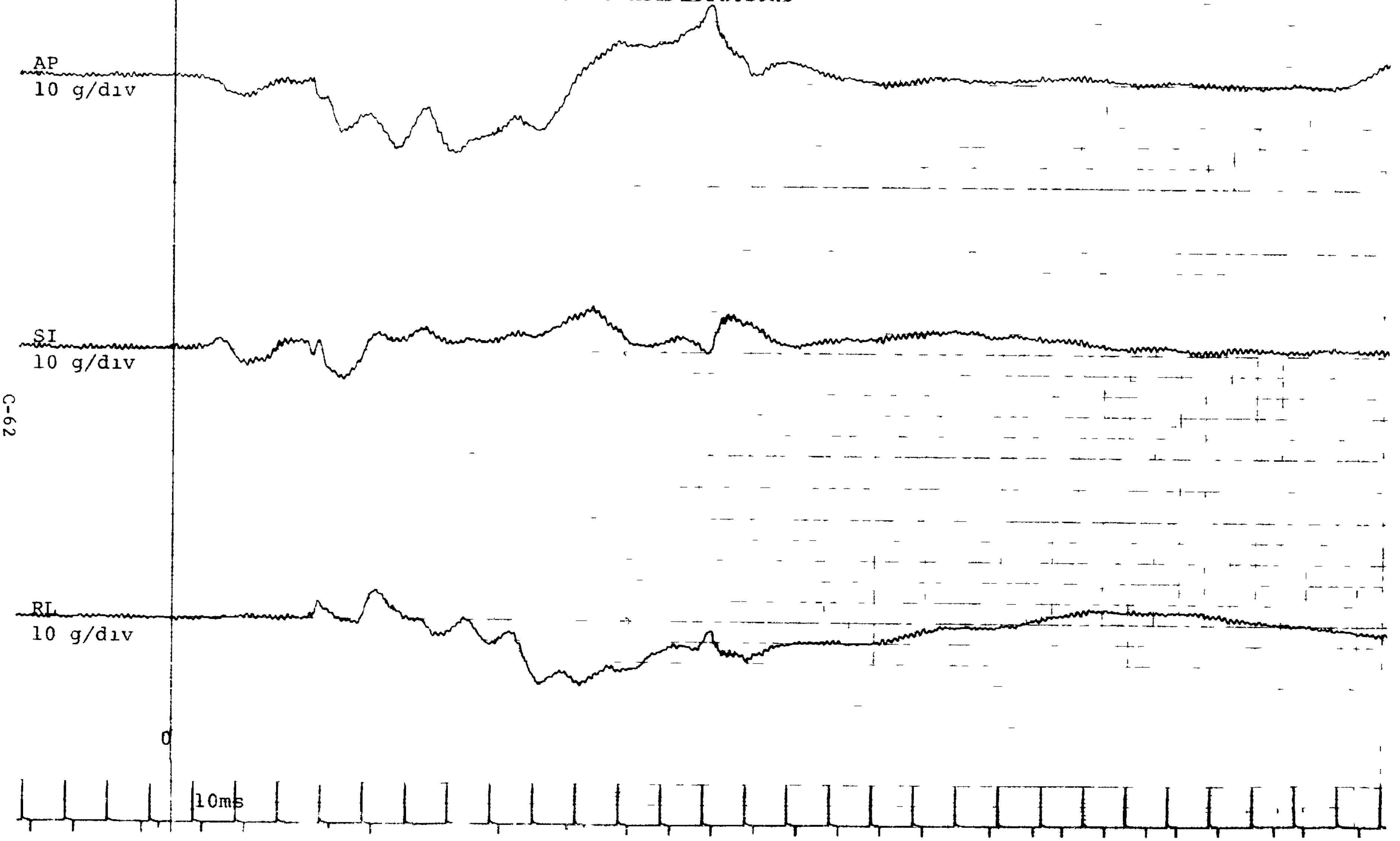


Run E-16 (LFP)
Chest Accelerations

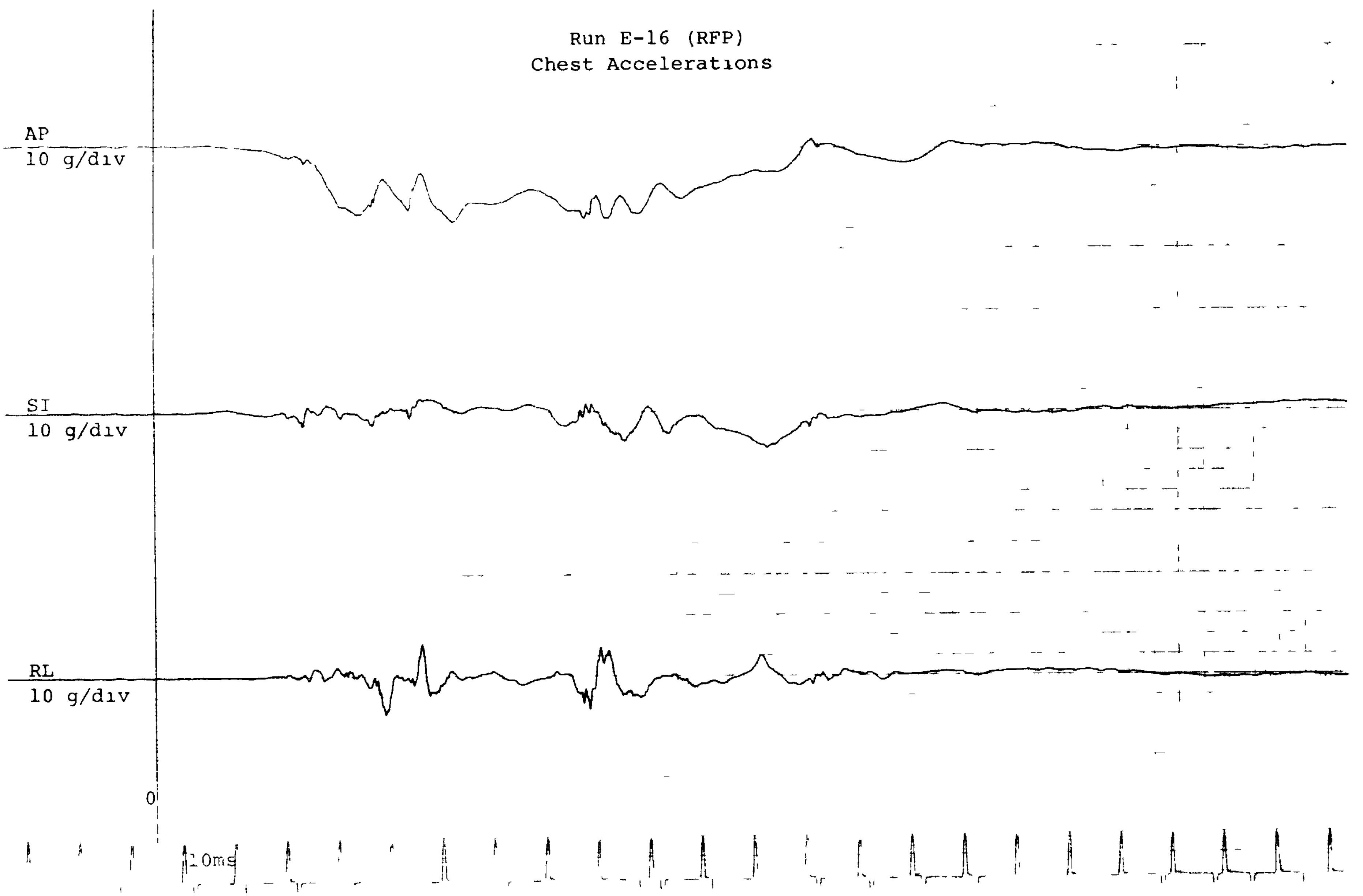


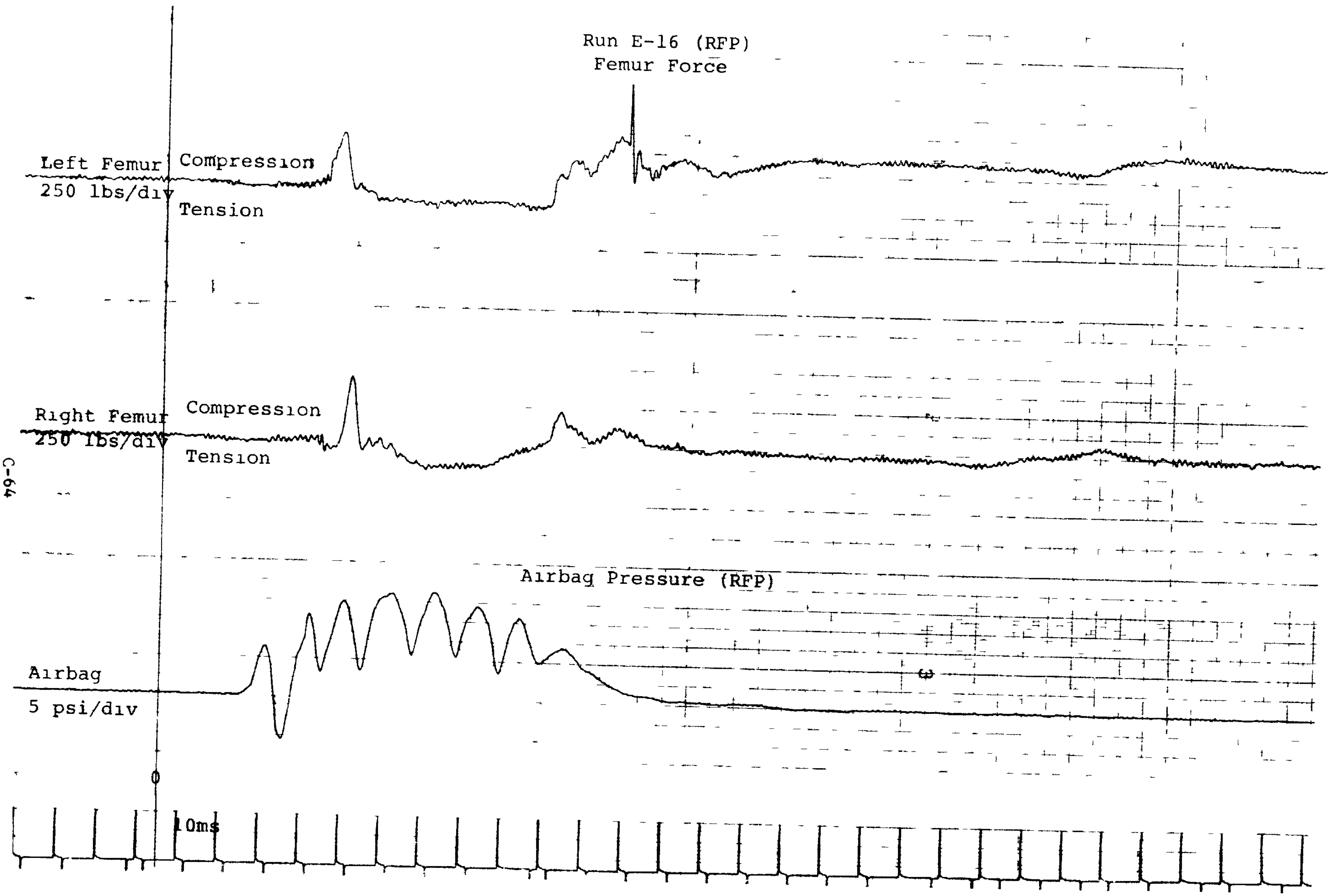

Run E-16 (LFP)
Femur Force
Left Femur
250 lbs/div
Compression
Tension
Right Femur
250 lbs/div
Compression
Tension
Instrumentation
Malfunction
Airbag
5 psi/div
Airbag Pressure (LFP)
0
10ms

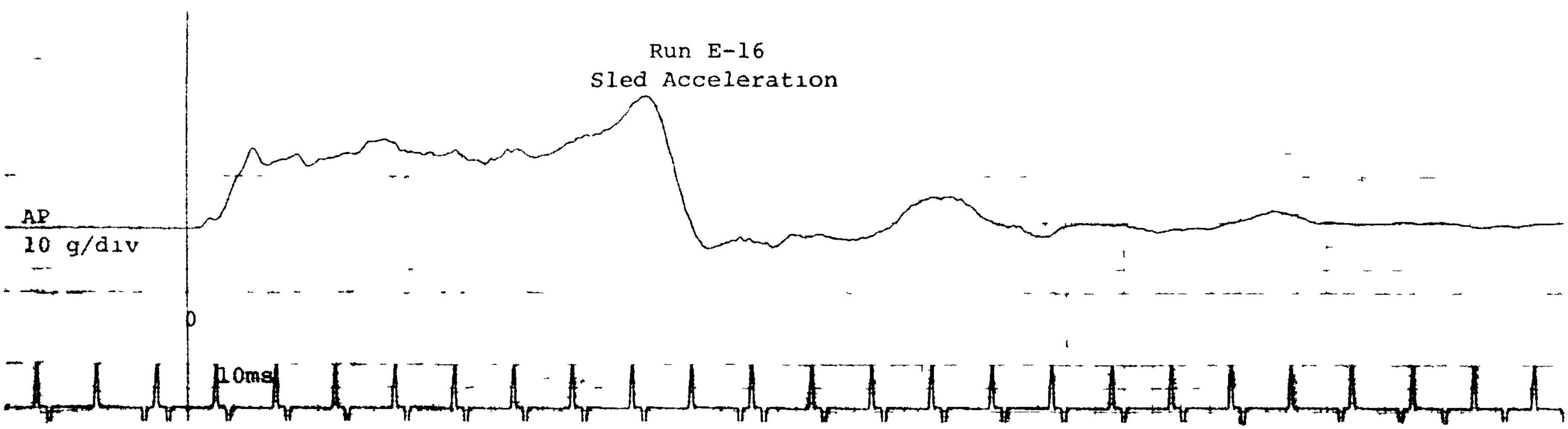
Run E-16 (RFP)
Head Accelerations



Run E-16 (RFP)
Chest Accelerations




Run E-16 (RFP)
Femur Force
Left Femur
250 lbs/div
Compression
Tension
Right Femur
250 lbs/div
Compression
Tension
Airbag Pressure (RFP)
Airbag
5 psi/div
0
10ms



C-65