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QUANTIFICATION OF THORACIC RESPONSE AND INJURY:
THE GATHERING OF DATA

FINAL REPORT. CONTRACT DOT-HS-4-00921

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1.0 INTRODUCTION

The purpose of this report is to present methods and results for a series of 84 thorax impact tests using human cadaver subjects. This is the first of a series of four reports from a project addressing itself to the generation of fundamental knowledge to achieve four results:

1. Quantification of the impact response of the human thorax using human cadaver and laboratory animal test subjects;
2. Definition of performance specifications which ensure impact response fidelity between human and surrogate thoraxes;
3. Compilation of analytical functions which relate kinematic response of the thorax to the actual injuries which have been observed in the experimental portion of the project; and,
4. Development of a side impact device matching thoracic response corridors obtained during the project.

The present report is concerned primarily with the first of the four results listed above.

After a discussion of the development of a thorax instrumentation package and the twelve accelerometer concept in Section 2, the test matrix and a description of each type of test are given in Section 3. Both frontal and side impact sled tests are included. Restraints include three-point belts and energy-absorbing steering columns, as well as door structures with and without padding. These tests are complemented by a series of controlled energy pendulum tests where a six-inch diameter piston is directed toward either the front or side of the thorax.

Section 4 presents details of test protocol and methods. As many procedures for the handling, surgery, instrumentation, and care of un-

embalmed cadavers were developed during the project, the details are presented at some length along with liberal illustrations. Also included in Section 4 are details of two specialized tests originally selected to provide information for use in development of analytical models of thoracic deformation during impact. During these tests, geometric information on seated thoracic posture was obtained from stereo x-ray views. Also some ribs were instrumented with strain gages.

Section 5 includes the description of the test subjects. Anthropometric measurements are summarized. Also, strength and geometry measurements on rib samples from the various subjects are included. The section is concluded by a geometric comparison of the location and orientation of accelerometer mounts from one subject to the next.

Two Appendices to the report have been prepared as separate volumes. The first (Appendix A) includes the individual test reports. Individual test descriptions, autopsy results, analog data, and filtered data are all contained in the Appendix. Appendix B contains the data from the rib tests. These include force-deflection curves and photographs of rib cross-sections.

2.0 DEVELOPMENT OF A THORACIC INSTRUMENTATION PACKAGE AND THE TWELVE ACCELEROMETER CONCEPT

The instrumentation package was selected to provide a measure of the physical response of the thorax to blunt impact which could be related to medical measures of injury such as those quantified in the Abbreviated Injury Scale (2.1). Variables associated with the impact event, the subject, the environment, the kinematic and other instrumentation monitors of response, and measures of the injuries themselves were included in the considerations leading to selection of an instrumentation package.

The impact event itself contributes at least the following variables which may influence the pattern of injury:

- a. size and shape of impactor
- b. force delivered by impactor
- c. acceleration and velocity of impactor
- d. the impact point in three dimensions and the path followed by the impactor.

The subject of the impact has numerous biological parameters which may be important. Many of the likely candidates, not necessarily independent, are included in the following list:

- a. species
- b. age
- c. sex
- d. stature
- e. weight
- f. sitting height
- g. chest breadth, depth, and circumference
- h. chest compliance (under dynamic loading from different directions)
- i. time and cause of death (for cadaver test subjects as opposed to live accident victims)
- j. natural frequency of thoracic skeleton, internal organs and other structures
- k. physiological state of musculature, heart, and lungs at the time of impact (state of inflation of lungs and vasculature; time point in pumping cycle of heart)
- l. other physiological measures such as blood chemistry
- m. mass-volume ratio of the thoracic skeleton in relation to the contents.

Environmental variables which are believed to be important include:

- a. seat back and seat cushion physical properties and geometry
- b. subject posture and position in relation to the environment

In order to monitor physical response of the thorax to impact a variety of instrumentation techniques were considered including:

- a. accelerometers mounted on the thorax
- b. displacement transducers
- c. airway and vascular pressure transducers

In that a major objective of the project was the development of injury predictive functions, selection of a quantitative measure of injury was required. The Abbreviated Injury Scale (AIS) offered such a means in that specific injuries are coded on a scale of increasing severity from zero to six as follows:

- | | |
|---------------|----------------------------|
| 0 - no injury | 4 - severe |
| 1 - minor | 5 - critical |
| 2 - moderate | 6 - virtually unsurvivable |
| 3 - serious | |

As the AIS was revised from States original version (2.2), the new versions took precedence as they became available during the project (2.3, 2.4, 2.1). Although the AIS is a numerical scale, no claims are made for equality of the increments between each level of injury. However, until such time as level of injury can be quantified in physical terms the AIS will remain a useful tool in injury prediction.

In developing injury predictive functions, it is desirable to include as many parameters as possible for which data are available. A general formulation, including the variables just presented, is

$$I = f(X_K, X_S, X_E, E_C)$$

where

I are injury measures

f are analytical functions

X_K are kinematic and other responses to impact

X_S are subject descriptors

X_E are environmental descriptors

X_C are impact event descriptors

If the predictive functions are limited to the inclusion of response

variables, as has been a stated objective of the project, the formulation is reduced to

$$I = f_1 (X_K, X_S)$$

Further, if the formulation is reduced to exclude explicit variables of subject definition, as would be the case for predictive functions derived from cadavers but useable with the data gathered from a mechanical surrogate, then the final reduction would be to

$$I = f_2 (X_K)$$

Much of the analysis accomplished during the project used this last formulation. However, a large body of data on all five sets of parameters (I, X_K, X_S, X_E, X_C) has been gathered which is available in a form adaptable to more sophisticated and complete analyses as well as useful for applications beyond development of specifications for mechanical surrogates.

The ultimate goal in selection of a system for measurement of the physical response of a subject to an impact, would be non-invasive instrumentation which monitors stresses and motions at every point within and on the surface of the subject. The "non-invasive" requirement restricted use of kinematic instrumentation to devices which could be attached to the periphery of the thorax and which could monitor acceleration, velocity, or displacement. Accelerometers had great appeal in that they could be securely attached to the bony structures of the thorax, were minimally invasive, and could be monitored with available instrumentation. No suitable velocity or displacement transducers were found to be available. Also, estimates of chest compression had already been developed by other researchers such as Nahum, et al (2.5) leading to the conclusion that reasonable estimates of all three standard kinematic quantities (acceleration, velocity, and displacement) could be derived from accelerometer data.

A ten (later in the project, twelve) accelerometer system was developed to monitor the periphery of the thorax making use of the heuristic argument that knowledge of the kinematics of the periphery of an object (the thorax) could be used to deduce the mechanical responses (injuries) of the interior of the object. The idea behind the system visualizes the thorax as a structure of approximately ellipsoidal shape. The attempt has been to locate accelerometers around the periphery to register different

acceleration signatures from different directions, magnitudes, and durations of impact. The locations of the twelve accelerometers are shown in Figures 2.1 and 2.2.

Supplemental instrumentation was also used. As a supplement to the kinematic data available from the accelerometers, visual targets were attached directly to the subject for use in defining subject position in space, and also for measuring relative motions between various points on the thorax. Two pressure transducers were also used in many of the experiments. The vasculature was pressurized and dynamic pressure measured using a Kulite transducer passed down a carotid artery and located in or near the aortic arch. The lungs were also inflated and held at constant pressure for the tests. A strain gage pressure transducer was inserted into the trachea for measurement of dynamic pressure.

3.0 TEST MATRIX AND DESCRIPTION OF EACH TEST TYPE

3.1 TEST FACILITIES USED

Three facilities were used during the test program: the impact sled, the pneumatically operated impact device (Cannon), and the pendulum impactor. The sled moves on a 45-foot track into a pneumatic decelerator and has the capability of a 75 mph velocity change and a 75 G deceleration. The basic sled is a 975 lb test platform which is 6.5 ft.² The various seating structures and other equipment associated with the tests were bolted directly to the sled or to a structure of steel channels which was then bolted to the sled. The impact sled is driven by a compressed-gas-powered ram, and is stopped by impacting an adjustable pneumatic decelerator. The sled operates on the principle of rebound, achieving the desired velocity change by reversing its direction during the impact with the decelerator. The sled payload is 1,224 lbs. Equipment for acquiring and recording data includes high-speed cameras and a 65,000 watt lighting system. Accelerations, forces, and other physical quantities were transduced and recorded on magnetic tape. All controls were remotely operated, using safety-interlocked electronic sequences. An overview of the impact sled is given in Figure 3.1.

The pneumatically operated impact device was designed to produce a specific velocity to determine the behavior of objects under impact conditions. The machine consists of an air reservoir, and a ground and honed cylinder with two carefully fitted pistons. One, the transfer piston, is propelled by compressed air through the cylinder and transfers its momentum to the impact piston. A striker plate, attached to the impact piston, travels a distance of about four inches before striking an inversion tube which halts piston movement. The machine may be operated over a velocity range of 3 to 60 miles per hour with a 20 pound impact piston. As in the case of the sled, high-speed cameras were used. Dynamic test data were recorded using the same equipment common to all three facilities. The cannon device is illustrated in Figure 3.2.

A pendulum impactor was also used to provide a higher energy with a heavier transfer piston. In this case the energy was provided by the release of a ballasted pendulum which contacted the transfer piston at

the lowest point in its swing. The length of the pendulum from its pivot to the impact point with the transfer piston is 105.8 in. while its unballasted weight is 96.8 lb. Ballasted, the weight is 136.8 lb. The transfer piston has a weight of 51.5 lb. and a maximum stroke of 15.25 in. Its maximum velocity is over 30 ft/sec. Accessory hardware was designed to provide precision positioning capability for test subjects. Dynamic test data were recorded using the same equipment common to all three facilities. The pendulum impactor is illustrated schematically in Figures 3.3 and 3.4 as well as photographically in Figure 3.5.

Figure 3.6 is a schematic of the overall data handling system used on the project. Analog transducer data is digitized and filtered with output review possible at any stage. When required, high speed photographic data were also analyzed.

3.2 TEST MATRIX

Table 3.1 is a summary description of the tests conducted during the project. The first column gives the test number. All tests are listed in chronological order. The test numbers with an A-prefix were conducted between May and December 1975 while those beginning with 76 or 77 were conducted in either 1976 or 1977. All tests after 76T029 are listed, for example, as 76T034(2F,3S). This code actually refers to three tests conducted on the same cadaver. The primary test was 76T034 which has the velocity, type, AIS, etc. listed. The other two were low energy, sub-injury, tap tests with 2F equivalent to 76T032, which was a pendulum tap to the front of the thorax and 3S equivalent to 76T033 which was a pendulum tap to the left side of the thorax.

The second column defines the test velocity in miles per hour. The number in parentheses following the velocity is the sled deceleration in G's.

The third column lists the type of test which was conducted on each subject. The original statement of work required a test matrix which would "adequately characterize the kinematic and kinetic response and resulting injury of the human thorax to most present and anticipated forms of loading encountered in the automotive crash environment, i.e., stylized steering wheel/column, dashboard, air cushion, side door, shoulder belt." Front,

TABLE 3.1 SUMMARY OF TESTS WITH CADAVER SUBJECTS (1 of 3)

Test No.	Velocity(mph)	Test Type	AIS	Sex-Age	Weight (kg)	Stature (cm)
A-867	24.6(10.4)	3-point belts	3	F-67	70.5	164.3
A-868	32.4(20.4)	3-point belts	5	M-46	61.5	178.1
A-876	23.0(10.0)	EA column (no pad)	3	M-73	68.6	176.3
A-877	23.0(9.8)	EA column (no pad)	3	F-76	40.3	149.9
A-880	34.5(20.7)	EA column (no pad)	5	M-74	48.3	171.0
A-883	33.0(19.8)	EA column (no pad)	5	F-74	75.4	156.2
A-884	23.0(10.0)	EA column (padded insert)	4	M-60	90.2	177.3
A-887	23.0(10.0)	EA column (air cushion)	2	M-68	85.5	173.7
A-923	34.8(10.0)	EA column (air cushion)	3	F-69	37	165.6
A-924	33.2(10.0)	EA column (air cushion)	5	M-64	76.5	171.6
A-927	33.0(20.0)	EA column (air cushion)	5	M-72	80.7	163.3
A-928	16.5(10.0)	EA column (soft pad)	2	F-50	56.8	163.5
A-937	23.2(9.8)	EA column (soft pad)	4	F-48	67.7	162.7
76T003	13.5	Rigid wall	2	M-60's	102.1	180.5
76T008	38.9(17)	3-point uncharged inflatabelt	4	F-74	71.1	163.0
76T009	25.8	Rigid wall	5	F-75	44.1	155.5
76T010	19.6	Rigid wall	4	M-84	87.8	162.2
76T011	20.0	Rigid wall	4	M-69	74.9	170.2
76T020	24.4(17.0)	EA column (air cushion)	5	F-78	63.6	158.8

TABLE 3.1 SUMMARY OF TESTS WITH CADAVER SUBJECTS (2 of 3)

Test No.	Velocity(mph)	Test Type	AIS	Sex-Age	Weight (kg)	Stature (cm)
76T021	15.0	Cannon	5	F-55	43.2	160.9
76T022	10.2	Cannon	3	M-85	60.1	164.6
76T024	10.2	Cannon	4	F-75	76.1	169.0
76T025	16.4	Cannon	4	M-66	69.7	174.6
76T029	10.2	Padded door	3	M-67	62.5	167.1
76T034(2F,3S)	19.6	Padded door	4	M-62	59	183.5
76T039(7F,8S)	20	Padded door	3	M-72	73.9	186.8
76T042(0F,1S)	25	Padded door	4	F-58	64.5	177.7
76T050(8F,9S)	9.5	Pendulum (front)	4	M-61	83.7	176.8
76T053(1S,2F)	9.5	Pendulum (front)	0	M-63	105	174.3
76T056(4S,5F)	9.5	Pendulum (front)	0	F-40	70	162
76T059(7S,8F)	10.2	Pendulum (front)	3	M-76	88	184.5
76T062(0F,1S)	9.5	Pendulum (side)	5	M-69	50.1	174.3
76T065(3F,4S)	9.5	Pendulum (side)	1	M-63	94.7	178.9
77T068(6S,7F)	9.8	Pendulum (front)	5	M-52	62.1	174.5
77T071(9F,0S)	9.8	Pendulum (side)	3	M-60	80.2	172.2
77T074(2F,3S)	9.8	Pendulum (side)	2	M-60	54	176.9
77T077(5F,6S)	13.6	Pendulum (side)	4	M-79	73.7	175.5

TABLE 3.1 SUMMARY OF TESTS WITH CADAVER SUBJECTS (3 of 3)

Test No.	Velocity(mph)	Test Type	AIS	Sex-Age	Weight (kg)	Stature (cm)
77T080(8F,9S)	13.6	Pendulum (side)	4	M-64	40.8	170.2
77T083(1S,2F)	13.6	Pendulum (front)	4	F-60	63.8	156
77T086(4S,5F)	13.6	Pendulum (front)	3	F-54	78.4	163
77T089(7F,8S)	20	Rigid wall	5	M-66	55.1	173.5
77T092(0F,1S)	20	Rigid wall	4	F-45	58.3	176.7
77T095(3F,4S)	20	Padded wall	4	M-77	92.8	183.2
77T098(6F,7S)	20	Padded wall	4	M-71	59	168.2

lateral, and oblique impacts were planned. Oblique impacts were later deleted due to shifting emphases within the project. The tests from the beginning of the project until 76T020 were mostly concentrated on realistic seating hardware and were part of a test matrix which varied the test velocity, sled G-level, and contact surface stiffness. As other test series had concentrated on belt systems, they were not the major part of the present program. Also, as virtually no testing had been done with cadavers in lateral impact, it was decided to initiate this phase with a harsh, idealized side-door environment - a rigid flat surface. Other side door test environments were to follow including an idealization of the Minicars RSV structure and padded flat surfaces. After Test 76T020 the emphasis was shifted to controlled energy test procedures similar to those used in qualifying dummy hardware. At first these involved the HSRI pneumatic cannon device, and later, the pendulum impactor. Impacts to both the front and side of the thorax were conducted. Starting with Test 76T034, low energy front and side pendulum taps were added to the test sequence to study comparative thoracic responses at sub-injury impact levels. Details of the test apparatus are given in Sections 3.3-3.9.

The fourth column contains the maximum AIS number obtained for the thorax during autopsy. Higher or lower AIS numbers may have been obtained for other body regions such as the head, abdomen, or extremities. The numbers contained in this column represent the final values obtained as a consensus by a group of trauma surgeons at the University of Michigan Medical Center. Because this final AIS determination was completed after use of the initial estimates, there are some differences between Table 3.1 and data contained in publications such as References 3.1, 3.2, and 3.3 authored or co-authored by the HSRI investigation team. A variety of publications by other authors also made use of preliminary data and hence should be updated. The final values of AIS along with their determination, are included in detail in Appendix A. The fifth, sixth, and seventh column describe the subject population. Sex and age are followed by weight and stature data.

3.3 FRONTAL IMPACT SLED TESTS. BELTS

Figures 3.7 and 3.8 show side and front views of the apparatus and positioning used for the three tests with three-point belt restraints. This seat apparatus was originally developed for and used by the Whole Body Response project at HSRI sponsored by General Motors Corporation (Reference 3.4). The reason for choosing this hardware, other than its availability, was the fact that it represented high-volume American hardware including belt attachment points. Figure 3.9 includes a schematic of the seat surface as developed from real vehicle geometry. Also superimposed are the steering column and anchor point locations. The upper torso belt anchor is located to the left of the centerline by 8.75 inches. Both lap belt anchors are also the same distance from the centerline. The cushion angle is oriented zero degrees with respect to a horizontal surface in keeping with the prior observation that H-point motion is nearly horizontal in tests using belted subjects in soft seats. Current production belt hardware was used for Tests A-867 and A-868.

For Test 76T008 a three-point uncharged inflatable belt, coupled with Minicars energy-absorbing anchor links, was used. The EA links are shown assembled and disassembled in Figures 3.10 and 3.11. The upper left shoulder belt was designed to yield at 1100 lb. and again at 1600 lb. The common lower anchor yielded at 1200 lb. while the single left lap belt anchor yielded at 700-800 lb. The very strong belt element consisted of a double layer of webbing and showed little elongation. In addition, specialized instrumentation included strain gages in ribs, special photographic targets, and stereo x-rays of the subject in position for the test.

3.4 FRONTAL IMPACT SLED TESTS. STEERING COLUMNS.

Figures 3.12 and 3.13 show side and front views of the apparatus and positioning for the seven tests using energy-absorbing steering columns and lap belt restraints. The wheel and column were stock 1974 Ford Maverick hardware. As was the case for the seat buck, this hardware represented a high-volume product. Also, a mounting assembly for this hardware was available from a previous study of dummy chest compliance sponsored by MVMA. The first four of the tests (A-876 through A-883) were conducted

with the basic hardware at two velocities and G-levels. A small EA pad was added to the hub to represent the padding present in the vehicle. A larger diameter of padding, nearly filling the space outlined by the rim, was added for the other three tests (A-884, A-928, A-937). The objective was to observe any effects due to the added area for load distribution on the thorax.

3.5 FRONTAL IMPACT SLED TESTS. COLUMNS WITH AIR CUSHION INSERTS.

Figures 3.14 and 3.15 show side and front views of the apparatus and positioning for the five tests using an energy-absorbing steering column supplemented by an air cushion insert and a lap belt. A schematic of the geometry of the ellipsoidal cushion is shown in Figure 3.16. The cushion was backed up by a wooden plate which is shown along with the rest of the bag/wheel/column components in Figure 3.17. The bag was preinflated by means of a rubber bladder inside the cushion and its pressure was monitored during each test.

For the case of Test 76T020, specialized instrumentation included strain gages on ribs, special photographic targets, and stereo x-rays of the test subject in position before the test. More details on this test are included in Section 4.4.

3.6 FRONTAL IMPACT. AIR-ACTUATED PISTON.

Figure 3.18 shows a side view of the positioning of a subject for testing using the air-actuated piston impact device (cannon). Four tests (76T021-76T025) were conducted producing controlled energy impacts. The subject was positioned so that the thorax was in as vertical a position as possible. The subject was held erect by supporting the arms on a horizontal frame. The head was also held erect. The back of the thorax as well as the piston were targeted for chest deflection measurements in addition to the usual accelerometer matrix.

3.7 FRONTAL IMPACT. PENDULUM.

Figure 3.19 shows a side view of the positioning of a subject prior to a test using the pendulum impactor. Seven high energy (9.5 and 13.6 mph) and twenty low energy (tap) tests were conducted in this mode yielding a large body of data. The transfer piston was faced with a 6 inch

diameter flat disc and weighed 51.5 lb. The arms were positioned on arm rests. Most of the support holding the cadaver erect was provided by a sling on the head. The support ropes holding the cadaver erect were released a few milliseconds before the impact. The cadaver was positioned using the adjustable seat structure so that the center of the impactor would strike as close as possible vertically to the level of the point where the fourth rib enters the sternum.

3.8 SIDE IMPACT. PENDULUM.

Figure 3.20 shows a front view of the positioning of a subject prior to a test using the pendulum impactor to impact the side of the thorax. Six high energy (9.5 and 13.6 mph) and twenty low energy (tap) tests were conducted in this mode. These tests were virtually identical to the frontal pendulum impacts with the exception of subject positioning. In addition to locating the center of the impactor at the level of attachment of the fourth rib to the sternum, it was located midway between the front and back of the subject. The arms were positioned over the head in a manner to expose the chest structure to direct impact.

3.9 SIDE IMPACT SLED TESTS. RIGID AND PADDED SIDE DOORS.

Three types of tests were conducted in this series. The first type - six tests at velocities ranging from 13.5 to 25.8 mph - involved an interaction between the subject and a rigid flat wall. This was intended to be a harsh idealization of an interaction with vehicle side structures. Front and side views of the pre-test setup are shown in Figures 3.21 and 3.22. The second type of test was not as harsh as the first in that the flat wall was padded with energy-absorbing materials. Two tests, with the setup configuration shown in Figures 3.23 and 3.24, were conducted. The third type was designed to simulate the energy-absorbing structures of the Minicars RSV. Four tests at velocities ranging from 10.2 to 25 mph. were conducted. They are illustrated in Figures 3.25 and 3.26.

The sequence of actions which occurs during a test is as follows. The sled buck is first brought up to speed. In order to accomplish this and maintain the proper initial position of the subject, a series of bolsters were placed on the right side of the subject. Next, the sled enters the

deceleration phase. During this phase the sled is stopped and its motion reversed. The total change in velocity generated during this phase represents the target velocity for the interaction between the subject and the side structures. While the sled motion is being reversed, the unrestrained subject begins to slide along the low friction seat surface building up a velocity relative to the sled about equal to the change in velocity generated by the deceleration. The distance between subject and door structures was designed to allow completion of sled change in direction before the interaction.

The padded side door structures (Tests 76T029-76T042) were based on the Minicars RSV door structures (3.5). A cross-section of the structure is shown in Figure 3.27. Non-sculptured padded wall structures were used for Test Nos. 77T095 and 77T098. In the case of 77T095, a 4-inch layer of Ethafoam 220 closed cell polyethylene foam was backed by 2 inches of Scott II open cell foam. For 77T098, the entire 6-inch pad was fabricated from the Scott II open cell foam.

A special technique was developed for measuring a profile of peak deflections in padding used in side impact tests. The technique was used in Tests Nos. 77T095 and 77T098. A matrix of single indicators was mounted rigidly to the side wall as shown in Figure 3.28. The indicators were made from cable wrappers such as Ty-Wraps. The locks were rigidly mounted at the matrix holes as shown. The tie-strips were pushed through guiding holes in the foam. They were then pulled further until the ends were flush with the surface of the foam. Marks were then placed on the strips where they emerge from the locks. Upon impact the tie strips were forced further through the locks. Peak deformation was thus recorded because of the one-way action of the tie-lock combination. The data are included in Appendix A with the test reports.

4.0 TEST PROTOCOLS AND METHODS

4.1 INTRODUCTION

The test protocol and methods used in the Quantification of Thoracic Response and Injury project did not exist when the project began. This absence led to innovations in transducer installation and test methodology. Special thoracic instrumentation mounting hardware had to be developed specifically for this project. Several devices have been routinely used on other projects both here, at HSRI, and at other research installations. Similarly, the surgical procedures for attaching this hardware to the cadaver had to be developed and proven. Special test fixtures, ranging from steering wheel mountable airbags and side impact foam deflection measurement devices to a pendulum driven ram impactor were designed, tested and used successfully in this series of tests.

For human cadaver tests, the protocols and methods can be divided conveniently into two areas: those dealing with the subject (the cadaver) and those involving the laboratory. The subject must be acquired, measured, instrumented and otherwise prepared for the test; tested, then removed from the test fixture and transferred from the laboratory to the anatomy lab for autopsy.

In a parallel process, the laboratory must be prepared, test fixture assembled, data collection electronics and photographics prepared and tested prior to the impact test. After the test, the lab must be cleaned and preliminary data assessments made.

Two distinct protocols were developed, one for each area. Figures 4.1 and 4.2 are sample protocols used in a sled test. Similar protocols were used for pendulum tests and taps and cannon tests.

The discussion which follows will be in two parts and generally follows the protocol sequence. It will elaborate the activities, methods, procedures and hardware used in cadaver tests for the Thoracic Response and Injury project.

4.2 CADAVER HANDLING AND INSTRUMENTATION

The topic of cadaver handling and instrumentation can be divided into the following categories:

- Obtaining the cadaver from the Anatomy Department
- Preliminary activities
- Surgical routines
 - Accelerometer mount installation
 - Pressure transducer preparations
- Post-surgical routines
- Pre-test activities
- Post-test activities
- Autopsy
- Returning the cadaver to the Anatomy Department

Each of these will be discussed in turn.

4.2.1. Subject Acquisition

The first stage of a cadaver test is that of the acquisition of a subject. Cadavers were obtained through the facilities of the Anatomy Department of the University of Michigan Medical School. While the overall design of the test matrix determined the type and sequence of tests, no test could be firmly scheduled until HSRI was notified by the Anatomy Department that a cadaver was available. Only then could a cadaver be obtained and a test firmly scheduled. When the subject arrived at HSRI, it was logged in and identifying numbers were placed on the skin.

When procedures were not being carried out on the subject, it was stored in a large refrigeration unit and kept at or below 4°C to retard

decomposition. In a typical session the cadaver would be taken from the refrigeration unit in the morning of the day of a test, undergo the test, then be returned to storage after the test.

4.2.2. Preliminary Activities

The first procedure performed on the subject after its arrival and logging in was sanitary preparation. During this stage, the cadaver was stripped of any clothing and cleaned as needed. The conclusion of the sanitary preparations was the packing of the anal, nasal and buccal orifices with absorbent material.

For preliminary radiography, small (2mm) lead pellets were taped to the subject at locations near those where accelerometers would be attached, i.e., at the most lateral extent of the fourth and eighth ribs, and over the spines of the first and twelfth thoracic vertebrae. Overlapping films were taken as needed to show the entire bony thorax and neck. They were examined to find whether any reasons existed to reject the cadaver (pre-existing fractures, e.g.) as well as to determine whether the lead markers were located over the proper targets.

The final stage in the preliminary activities was anthropometry. A set of measures (Figure 4.3) was made on each cadaver. The subject was placed in a supine position with the head supported on a flat horizontal surface. A vertical surface, perpendicular to the table and the long axis of the body, was placed against the vertex. All measures which reference the vertex were made with respect to this surface. All depth measures were taken with respect to the table. Breadth and point-to-point measures were made directly, using an anthropometer. Circumferences were measured with a calibrated flexible metal tape. After all possible measures were taken on the anterior aspect, the subject was placed in a prone position,

supported as before, and spinal measures were made. It should be noted that there is no known procedure for correlating measurements made on subjects in these postures with those taken on subjects in standard postures.

Sanitary preparation, initial radiography, and anthropometry constitute the preliminary activities. The anthropometry could precede radiography, depending on the availability of personnel and equipment. When all three were concluded, the surgical procedures could begin.

4.2.3. Surgical Procedures

The surgical procedures for attaching accelerometer mounts and pressure transducer carriers were usually performed in parallel, that is, while one person was attaching mounts to the ribs and sternum, another was inserting tubing into the carotid and trachea. For ease in describing the procedures, they will be considered separately. Hardware mounts for phototargets were also attached at this stage.

4.2.3.1. Accelerometer Instrumentation

A total of fifteen Endevco Series 2264-2000 accelerometers was used in these tests. Four uniaxial accelerometers were located individually on the fourth and eighth ribs bilaterally, maintaining a normal-to-body direction on the fourth ribs, and a parallel-to-body direction on the eighth ribs. Two uniaxial accelerometers were affixed to the sternum, one at the suprasternale and the other at the substernale, with an effort being made to maintain a posterior-anterior orientation. Triaxial configurations were located at T_1 and T_{12} and in the central portion of the posterior pelvis at S2 (Figures 2.1 and 2.2).

Because each location required a separate interface between the anatomical part and the accelerometer, several different mounting platforms were designed and machined at HSRI. Dental acrylic was applied to the

underside of the mounts to furnish a planar surface for the mount while conforming to the contours of the anatomical location (Figure 4.4).

The mounts constructed for the fourth rib provide two grooves which act as channels for stainless steel wire. The wire is wrapped around the mount, securing the mount to the rib. The accelerometer is placed in the slot, and anchored by two 0-80 screws (Figures 4.5 and 4.6).

The eighth rib mounts are designed with similar grooves and fasten in the same manner. Because of the slant of the rib, the accelerometer slot is at an angle to the base. In addition, there is a screw hole into which a phototarget may be attached (Figures 4.7 and 4.8). The left and right mounts are mirror images, compensating for the shape of the thorax (Figure 4.9).

The uniaxial substernale mount is designed with the two screw holes on either side of the accelerometer slot. It is bolted directly into the sternum. The accelerometer is attached using two 0-80 screws. As it may be a location for a phototarget, there is a screw hole at one end into which the target can be placed (Figures 4.10 and 4.11).

The suprasternale mount uses basically the same design as the substernale mount. It is not, however, used as a phototarget (Figures 4.12 and 4.13) base.

The pelvic mount consists of a narrow rectangular platform which spans the posterior superior iliac spines of the pelvis. Two threaded lag bolts are located at either end of the platform, affixing it to the cadaver. The accelerometer mount is attached by a single bolt through its center, over S_2 (Figures 4.14 and 4.15).

The triaxial arrangement used on T_1 and T_{12} requires a mounting platform which is a U-shaped metal support, onto which the accelerometer

mount is then placed. The platform is attached by putting a screw through it and into the end of, and parallel to, the spinous process. It is then bolted down. The accelerometer mount, which is secured to the platform with two 2-56 screws, is constructed with three sections for the accelerometer locations (Figures 4.16, 4.17, and 4.18). It also provides a tapped hole for the insertion of a phototarget.

4.2.3.2. Photographic Targets

The triaxial accelerometers of T_1 and T_{12} are designated by a styrofoam ball having four smaller styrofoam balls at equal intervals around it, and one on top. A flat metal target is located at T_8 (Figure 4.19). A single styrofoam ball is used at the sternal and R_8 locations. At each acromion, a styrofoam ball is attached using a threaded lag bolt. An unspecified number of adhesive fabric phototargets are placed at various points on the body depending on the test.

4.2.3.3. Vascular Pressurization and Equipment

The techniques used for pressurization of the vascular system involve catheter construction, surgical installation, and pressurization methods. A Foley balloon catheter is used. It is composed of three sections, the tip, center tubing, and inlet, which holds the fluid and air input sections (Figure 4.20). The center section, however, is removed and replaced by appropriate lengths of polyethylene tubing which has less flexibility. Two tubes are required, one with a 0.128 in. diameter which transports the pressurization fluid, and the other with a 0.066 in. diameter, which provides for the flow of the air pressure to inflate the occluding balloon. These are inserted into the inlet end of the catheter. The smaller tube is greased and inserted with a wire (Figure 4.21). One end of the large tube is perforated, allowing liquid to flow into the descending aorta.

The opposite end is heated, causing it to flare slightly so that it will not slip out of the catheter (Figure 4.22). Lead targets are used to identify radiographic locations before impact. They are inserted in the perforated end of the tube which is subsequently sealed with epoxy (Figure 4.23). The pressure transducer is prevented from exiting the tube by a small section of tubing which has a narrower tip (Figure 4.24). This procedure is different from those developed by Cromack (4.1), Tarriere (4.2), and Ziperman, et. al. (4.3).

4.2.3.4. Surgical Installation of Catheter

Surgical installation of the catheter consists of locating the carotid artery in the neck and making a short longitudinal incision just long enough to allow the catheter to pass through the artery and into the descending aorta. When it is desired to measure pressure in the ascending aorta, a balloon catheter is inserted through the carotid artery into the descending aorta, just below the level of the heart. A length of additional polyethylene tubing, to act as a pathway for a miniature pressure transducer, is then inserted next to the catheter and into the ascending aorta (Figure 4.25). Once all the tubes have been placed in the appropriate arteries, the carotid incision is sealed with quick-setting plastic to prevent fluid leakage.

4.2.3.5. Respiratory System Surgery and Equipment

The techniques for pressurization of the respiratory system were developed at HSRI. They involve trachea tube construction, surgical installation, and pressurization methods.

The respiratory pressurization equipment consists of a flexible polyethylene tube that is inserted into the trachea. It is wrapped with adhesive tape that can be adjusted to fit the individual trachea (Figure

4.26). The final wraps of tape are applied after the trachea is exposed and measured to ensure a secure fit.

The surgical procedure consists of making a longitudinal incision in the neck above the trachea. The incision is cut so that the trachea can be accessed easily. To allow for intubation, a small x-like incision is made in the trachea just big enough for the trachea tube to pass through. Once the tube has been inserted into the trachea, a length of stainless steel wire is wrapped around the outside of the trachea, covering that part of the tube wrapped with tape. Then it is twisted until the plastic tube cannot be removed.

4.2.4. Post Surgical Procedures

Following surgery, and prior to sealing the carotid catheter with epoxy, radiographs were taken to establish the location of the tip of the catheter. Using the information gained from the radiographs, the catheter was adjusted until it was satisfactorily located. The radiographs also established the locations of the accelerometer mounts.

After the anterior and lateral accelerometer mounts had been attached, and again after attachment of the spinal mounts, a series of mount geometry measures was made (Figure 4.27). A set of six measures was made for each mount: X, Y, and Z, (the distance from the table (supine), the S-I midline, and the vertex, respectively), and the angles about the X, Y, and Z axes. The distances were measured using an anthropometer, as for the anthropometry described previously. The angles were measured using a combined protractor and level.

The final post-surgical activity is clothing the subject. The cadaver is clothed in two-piece honey-comb cotton thermal white underwear (Figure 4.28) covering a "Slim-eze" two-piece vinyl sweatsuit (Figure

4.29), white cotton gloves, and socks. The head is covered and the face obscured with appropriate materials. Holes are cut in the clothing as needed to allow access to transducer mounts.

4.2.5. Pre-Test Activities

The techniques of subject handling will be discussed in this section, along with instrumentation and pressurization. The first step in the routine is to bring the subject into the test laboratory. Accelerometers are then installed in their mounts and the incisions are sutured shut. Pressure transducers are installed in their carriers and secured. The subject is placed in position on the test facility. Phototargets are attached as described in the section on surgical procedures. When the subject has been positioned satisfactorily, the vascular and respiratory systems are pressurized, and the test is performed.

4.2.5.1. Subject Handling

The techniques for handling of human subjects are a modification of ambulance emergency procedures used for extraction of patients from automobiles after an accident.

Once the subject has been clothed and instrumented with both the pressurization equipment and accelerometers, it is necessary to place the subject in an appropriate position prior to the test. For pendulum impact tests, a head stabilizing restraint strap assembly is attached to the head of the subject from an overhead boom. The subject is raised into a sitting position by use of the boom and is placed in a specially constructed chair (Figure 4.30). This chair has the capability of moving in three directions. Up-and-down motions is accomplished by use of a large-threaded rod attached to the platform upon which the subject is seated. The rod screws into a base that is allowed to move freely in the

horizontal plane by riding on two sets of linear bearings (Figure 4.31). Once the subject is in position, all three dimensions are locked.

Positioning for a sled test is accomplished with the use of a Build-A-Board and a scoop stretcher which can be molded around a subject in almost any position and locked to ensure that position of the subject does not change. The subject is placed in the Build-A-Board in approximately the same seated position as will be used on the sled. All target placement and cabling of accelerometer wires are done at this time. The subject is then placed on the sled in a seated position (Figure 4.32), connected to the pressurization, and placed in final position.

4.2.4.2. Vascular Pressurization

Vascular pressurization is created by forcing fluid into the descending aorta through the center section of the catheter until the appropriate pressure is reached in the ascending aorta.

Various pressurization fluids have been used such as water, water and black india ink, and thickening agent with black india ink. The purpose of the ink is to mark ruptures due to impact, while the purpose of the thickening agent is to prevent the fluid from entering the very small blood vessels that communicate with the venous system. By varying the amount of thickening agent in the fluid, the degree of perfusion can be somewhat controlled.

For direct pendulum impact testing, an air hose is connected to a 5-liter fluid-filled container which, in turn, is connected to the catheter inlet tube (Figure 4.33). When air pressure is applied to the container, the fluid is forced into the cadaver. Prior to pressurization,

the catheter balloon is inflated to block off the descending aorta. During pressurization, the air pressure in the air container is increased until the pressure in the cadaver vascular system reaches approximately 75 mm Hg and has become stable as indicated by the pressure transducer. After the desired pressure level is attained, the air tank inlet is shut-off, leaving the air tank to maintain the fluid pressure.

4.2.5.3. Respiratory Pressurization

For direct impact and sled testing, the plastic tracheal tube is connected to a 10-liter, air-filled tank that has been pre-pressurized with enough air to inflate the lungs to a stable 15 mm Hg pressure (approximately 100 mm Hg). Immediately before the test, the tank is opened, pressurizing the respiratory system.

4.2.6 Post-Test Activities

After impact, there is the strong possibility that the subject was injured. The thorax is splinted by the use of various back boards, scoop stretchers and Build-A-Boards. Once placed on a board or in a Build-A-Board, the subject is lowered either by hand or with the help of an overhead crane (Figure 4.35) to a Gurney stretcher. After unloading the subject onto a Gurney, the transducers are disconnected and removed. The subject can then be moved from the test laboratory into the radiology or autopsy areas.

4.2.7. Autopsy

An autopsy was performed on each subject to determine the nature and extent of injuries suffered as a result of the impact test. Particular attention was paid to the thorax, cervical and lumbar spines and abdominal viscera. A thorough examination of each area was performed and any unusual injuries were photographed. As a routine part of the autopsy procedure, a

section of ribs was saved for later analysis. Examples of autopsy recording forms are shown in the various test reports included in Appendix A.

4.2.8. Final Handling of Cadaver Material

At the conclusion of the autopsy, the subject was placed in a suitable container and transferred to a refrigerated storage unit. At a convenient time, it was returned to the Anatomy Department, again following appropriate guidelines.

Materials reserved for later testing were frozen in air tight containers until needed. At the conclusion of this later testing (rib strength, e.g.), all materials were returned to the Anatomy Department for proper handling.

4.3 LABORATORY PROCEDURES

The topic of Laboratory Procedures can be divided into the following categories:

- General preparation
- Test-specific Preparation
 - Resource allocation
 - Electronics testing
 - Lab set up and checkout
- Testing
- Post-test procedures
- Initial test data retrieval

Each of these will be discussed in turn.

4.3.1. General Preparation

When the test matrix was decided upon, laboratory personnel met with the project director to determine the laboratory hardware needed for each type of test. The specific test arrangement, including illustrative drawings and example photographs are given in Section 3, "Test Matrix and Description of Each Test Type," and will not be elaborated here.

In general, however, a test could be performed only after the laboratory had procured and assembled the test equipment and when a cadaver was made available by the Anatomy Department. When both of these conditions were met, a test could be scheduled.

4.3.2. Test-specific Preparations

4.3.2.1. Resource Allocation

When the laboratory was notified of a pending test, it received a packet of forms (Figures 4.36 through 4.42) which specified the test type, instrumentation and photographic coverage required.

The laboratory was then able to select the transducers - accelerometers, pressure transducers, and load cells - required for the test. Once selected, they were checked to ensure proper operation.

At the same time, the test hardware was prepared. For example, if a "Front Sled Airbag" test was called for, a frontal impact buck had to be mounted on the sled. The standard seat was installed, along with lap belts. An energy absorbing steering column was fitted to the buck, and a steering wheel with specially fabricated airbag insert was attached to the column.

Finally, cameras were checked to ensure that the requested photographic coverage could be obtained.

4.3.2.2. Electronics Testing

Transducers were connected to the umbilical cord and tested for continuity and recalibrated as needed. Amplifiers and tape recorders were also checked for proper operation.

4.3.2.3. Lab Set Up and Checkout

Calculations were performed to determine the correct pressures and timing delays for sled firing. Electronic and electromechanical devices needed for running the test were programmed as needed.

Tripods for cameras were positioned, camera bodies attached to them and properly aimed and focussed. Photo lights were tested and burned out bulbs replaced.

4.3.3. Testing

The test phase was begun when the subject was transferred into the test laboratory. Transducers were attached to their mounts and the subject positioned on the test device. Targets were attached at this time, as were any necessary restraints, belts, or tethers.

During this period, the cameras were loaded, their frame rates set, and connections made to triggers and power supplies. For sled tests, a special camera ("Graph-Check") was used. It uses eight lenses to produce multiple images on Polaroid film. After the subject's position was satisfactorily adjusted, photographs were taken to document the positioning (See figures in Section 3).

Following the set up photographs, the test came under the direct control of the Test Director. He insured that all safety precautions were followed, and directed the arming of the test device. One final check of the transducers was made. Analog tapes were positioned and prepared for recording. After a final safety check, the Test Director fired the test.

4.3.4. Post-Test Procedures

Immediately after the test, the following activities occurred: the test device was secured; excess pressures, if any, were bled off. Films were run out of the high speed cameras and packaged for shipment to the processing lab. The Graph-Check photograph was developed and coated. Post-test photos were taken as needed.

The subject was removed from the test device and placed on a Gurney cart, the transducers were dismantled, and the subject was removed from the laboratory.

The laboratory and test fixture were then cleaned and sanitized. Test hardware was either recycled for another test (short term) or returned to storage.

4.3.5. Initial Test Data Retrieval

The analog data tapes were played back and the data written onto a strip chart recorder. These records ("Brushes") were then calibrated with major peaks identified and scaled. They were then mounted in a form which can be reproduced for presentation (See Appendix A for examples).

The Graph-Check was photographed so that copies can be made. All laboratory work sheets, including checklists and test notes, were copied and placed in a permanent file thus concluding the Test Procedures.

4.4 SPECIALIZED THORACIC INSTRUMENTATION AND MEASUREMENTS

Two frontal impacts were conducted which had specialized instrumentation. These were 76T008 and 76T020. The first of these involved a cadaver subject restrained by an uncharged 3-point inflatable belt. Special Mini-cars energy absorbing belt anchor links were also included. In the second impact, the subject was restrained by a lap belt and an energy absorbing steering column with an air cushion insert. Figure 4.43 shows geometric details of the test setup. The purpose of these tests was to provide detailed geometric information for potential use in developing and validating mathematical models of thoracic response to an impact.

Specialized instrumentation and procedures involved installing strain gages on the ribs of the subject in order to measure strain and, perhaps, applied force. Additional visible photographic targets were installed to measure the change in angle of ribs as the thorax deforms during impact. X-rays were taken of the subject while seated on the sled prior to each test. These were taken from both front and side in order to locate the various targets and instrumentation in three dimensional space. A photograph of the x-ray system in place prior to a test is shown in Figure 4.44.

The properties of the column used in Test 76T020 are given in Table 4.1 to provide a measure of the force applied to the subject's chest. The collapse deflection was obtained from film analysis of the targeted column as a function of time. The force was obtained from a column mounted force transducer. The column collapse measured photometrically matched well with the permanent crush measured on the column after the test.

Table 4.2 shows belt anchor elongation data as a function of time for Test 76T008. It had been indicated (4.4) that:

TABLE 4.1. COLUMN FORCE AND COLLAPSE DATA

<u>Time (sec.)</u>	<u>Force (lbs.)</u>	<u>Collapse Deflection (in.)</u>
0.0	0	0
.059	0	0
.078	677	1.4
.084	529	1.59
.096	529	1.59
.100	889	1.57
.105	508	1.52
.109	762	1.47
.115	741	1.40
.121	423	1.25
.132	296	1.25
.140	296	1.25
.144	0	1.25

TABLE 4.2. BELT ANCHOR ELONGATION DATA

Time (ms)	Right Lap Belt (in)	Left Lap Belt (common) (in)	Left Shoulder Harness (in)
0	0	0	0
51	0	0	0
56	0.32	0.29	0.29
61	0.63	0.57	0.57
66	0.95	0.86	0.71
71	1.26	1.00	1.86
76		1.29	2.57
81	1.58	1.43	3.14
86	1.89	2.00	3.71
91	2.21	2.29	4.00
96		2.57	4.29
101		2.86	
106		3.43	
111		3.71	
116		3.43	
121			

1. Left shoulder belt anchor should yield in the range 1100-1600 lb.
2. Common anchor should yield at about 1200 lb.
3. Left lap belt should yield in the range of 700-800 lb.

It was also indicated that 6 inches of elongation or material pull-through might be expected at the anchors. It should be noted for the right lap belt that a peak force of 1700 lb. occurs at approximately 600 ms. Yielding, presumably at 1200 lbs., is already occurring. For the left lap belt, a peak force of 900 lb. is reached at about 50 ms, the point at which yielding appears to begin. For the shoulder harness, some yielding occurs before the peak load of 1200 lb. is reached at about 20 ms. From these peak values, forces either remain constant or drop somewhat before returning to zero as the test subject rebounds. In the case of the right lap belt, elongation ceases well before 116 ms, the point at which the load has dropped to 928 lb. It appears that the 1200 lb. yield load has worked properly. Yielding in the left lap belt did not occur until the load reached 900 lb., a bit higher than expected. However, yielding had stopped before the load had dropped to 623 lb. at 120 ms. In the shoulder belt, which also appears to have worked as predicted, no yielding occurred after the load dropped below 1200 lb.

4.4.1. Initial System Geometry. Test 76T008.

This section reports the initial position of the instrumentation, its relation to the skeletal structure, and the various geometric features of the restraint system. All data are given in a sled-fixed coordinate system where the origin is at the center of the seat at the point where the seat back and seat cushion intersect. The numerical data presented are determined using various techniques from x-ray plates, high-speed motion

pictures, direct measurements on the sled, and direct measurement of anatomical and instrumentation relations. The coordinate system is:

- x - positive to the front of the subject
- y - positive to the right of the subject
- z - positive down

Table 4.3 defines the initial positions of a variety of points. A plot of many of these points is given in Figures 4.43, 4.44.

Figure 4.45 illustrates the interpretation of the Euler Angle and three-dimensional position data obtained from the photometric targets attached to left rib number 9. Differing from the sled-fixed system, the Euler angles for the target cluster are interpreted from an x (forward), y (left) and a z (up) configuration. The order of rotations is ψ , θ , ϕ about the x, y, and z axes. From a plot of the reduced Euler angle data (see Appendix A), it is seen that the seated subject has $\psi \cong 0^\circ$, $\theta \cong 60^\circ$, $\phi \cong -72^\circ$ initially. To interpret the movie data, the $\psi=0$, $\theta=0$, $\phi=0$ position of the three targets is shown by balls in Figure 4.43. After $\psi=0$ and $\theta=-60^\circ$ rotations, the balls assume the position shown in Figure 4.43. Finally, after the $\phi=-72^\circ$ rotations they assume the position visible on the movie and illustrated in Figure 4.43C. It should be noted that the view is looking toward the left side of the subject. Also, it should be

TABLE 4.3 INITIAL POINT LOCATIONS FOR TEST 76T008
IN SLED-FIXED COORDINATES

Point	X (in)	Y (in)	Z (in)
1. Upper sternal accelerometer	6.26	-0.34	-17.12
2. Lower sternal accelerometer	7.78	-0.81	-13.26
3. Right upper rib (5) accelerometer	3.61	4.77	-15.45
4. Left upper rib (6) accelerometer	1.77	-4.99	-15.94
5. Right lower rib (9) accelerometer	3.23	4.59	-11.35
6. Left lower rib (9) accelerometer	3.00*	-5.53	-11.13
7. Biaxial accelerometer mount, T11	0.85	-0.27	-10.5
8. Biaxial accelerometer mount, T2	-1.53	0.42	-19.37
9. Front strain gage (Right 7th rib)	7.04	2.87	-10.5
10. Side strain gage (Right 7th rib)	3.28	4.38	-13.7
11. Rear strain gage (Right 7th rib)	0.53	2.02	-15.31
12. Surface of right rib (9) where visual target sits	3.48	4.43	-10.81
13. Surface of left rib (9) where visual target sits	3.31	-5.22	-11.2
14. Bony top of sternum	5.6	-0.2	-18.1
15. Bony bottom of sternum	7.7	-0.9	-12.7
16. Rib center under right upper rib accelerometer	3.61	4.52	-15.45
17. Rib center under left upper rib accelerometer	1.77	-4.24	-15.94
18. Left lower rib visual target center	3.25*	-6.62	-11.15
19. Right lower rib visual target center	3.03	6.12	-10.63
20. Rib center under right lower rib accelerometer	3.23	4.22	-11.35
21. Rib center under left lower rib accelerometer	3.00*	-5.19	-11.13
22. Rib center under right lower rib visual target	3.48	4.31	-10.8
23. Rib center under left lower rib visual target	3.31*	-5.10	-11.2
24. T2 visual target center	-2.5	0.55	-20.24
25. Center of body of T2	1.30	0.55	-20.12
26. T11 visual target center	-0.54	-0.40	-10.37
27. Center of body of T11	3.83	-0.14	-12.45

TABLE 4.3 INITIAL POINT LOCATIONS FOR TEST 76T008
IN SLED-FIXED COORDINATES - CONT'D

Point	X (in)	Y (in)	Z (in)
28. Shoulder left anchor point	-17.6	-8.8	-33.0
29. Right lap belt anchor point	- 5.1	8.8	10.5
30. Left lap belt anchor point	- 5.1	-8.8	-10.5
31. Most forward point of shoulder belt passing in front of sternum	8.0	0.	-16.0
32. Most forward point of lap belt passing over lap	12.0	0.	- 7.0
33. Point where should belt leaves contact with subject	4.0	-4.0	-19.5
34. Point at side where left lap belt leaves contact with subject	5.0	-8.0	0.
35. Point at side where right lap belt leaves contact with subject and where connection is made with shoulder belt	5.0	7.0	0.

noted that a plane defined by the three target points is approximately perpendicular to the axis of the rib at the target attachment point.

Little non-planar motion was observed in the spinal mounts. Analysis was limited to planar motion. The initial position is shown in Figure 4.46. The initial position, from a planar point of view, is also given for the right lower rib target. The view is looking at the right side of the subject. Examination of x-rays showed that the spinal mounts were actually placed on the second and eleventh thoracic vertebrae.

Figures 4.47 and 4.48 show the geometry and mount locations on the sternum. These measurements were made on the cadaver at autopsy. For analytical modeling purposes, this should allow a rather accurate location of the attachment of rib elements to the sternum.

Figure 4.49 shows a front view of the relation of the upper rib accelerometer mounts to the skeletal elements underneath. Both ribs have the accelerometer attached at a point estimated by palpation to be the most lateral point. The accelerometer element is oriented approximately normal to the thorax. The center of the rib underneath the target was determined in occupant seated posture directly from the frontal and side calibrated x-rays which clearly showed the mount. Measurements of the relation of the mount to the underlying bone were obtained directly at autopsy. Similar combinations of photometric measurements, three-dimensional x-ray measurements, and direct measurements of tissue/mount combinations were used to determine the remainder of the bony structure locations given in Table 4.3. In determining motions of the bony thorax from these initial positions, it is recommended that the assumption of a rigid linkage between bone, accelerometers, and visual target be made.

The location of the strain gage rosettes at the beginning of the test is given in Table 4.3 and illustrated in Figures 4.43-4.44. The orientation of the gages in the rosette is given in Figure 4.50. At the time of the test, the strain gages on the ribs were strained beyond the value for which the bridges and amplifiers were built to balance. This must have occurred by the movement of the subject from supine to sled-seated posture. After a change of instrumentation, the test 76T008 was continued. It seems likely that the change in strain was caused by a change in loads transmitted to the ribs while the subject was moved from the preparation lab to the impact sled.

4.4.2. Initial System Geometry. Test 76T020.

The principles used in determining initial geometry were the same for Test 76T020 as they were for Test 76T008. The initial plane angles for the four visual target clusters are shown schematically in Figure 4.51. Table 4.4 gives the coordinates of various initial point location while Figures 4.52 and 4.53 show front and side views of various points.

4.4.3. Results of Photometric Analyses.

The following data were obtained as a function of time for Test 76T008:

- left lower rib visual target center displacement
- left lower rib visual target center Euler angles
- sled motion (inertial)
- T2 visual target cluster displacement
- T2 visual target plane angular motion
- T11 visual target plane angular motion
- T11 visual target center displacement
- right lower rib visual target displacement
- right lower rib visual target plane angular motion

TABLE 4.4 INITIAL POINT LOCATIONS FOR TEST 76T020
IN SLED-FIXED COORDINATES

Point	X	Y	Z
1. T1 Accelerometer mount	0.8	0.1	-14.4
2. T11 Accelerometer mount	2.8	-0.8	- 8.6
3. T1 Body	3.8	0.2	-20.3
4. T1 Visual Target	-0.3	0.2	-20.2
5. T11 Body	4.7	-0.7	- 9.7
6. T11 Visual Target	1.5	-0.7	- 8.5
7. Right Lower Rib (9) Accelerometer Mount	7.6	4.8	-10.1
8. Left Lower Rib (8) Accelerometer Mount	5.4	-5.3	-11.9
9. Right Lower Rib (9) Center Under Mount	7.6	4.4	-10.1
10. Left Lower Rib (8) Center Under Mount	5.4	-4.9	-11.9
11. Right Lower Rib (9) Visual Target Center	6.3	5.7	-10.6
12. Left Lower Rib (8) Visual Target Center	4.9	-6.5	-12.4
13. Right Lower Rib (9) Center Under Visual Target	6.6	4.4	-10.5
14. Left Lower Rib (8) Center Under Visual Target	4.8	-5.1	-12.2
15. Upper Sternal Accelerometer Mount	6.1	-0.3	-17.1
16. Lower Sternal Accelerometer Mount	8.2	-0.6	-14.4
17. Bony Top of Sternum	5.5	-0.3	-17.7
18. Bony Bottom of Sternum	9.3	-0.8	-12.3
19. Right Upper Rib (5) Accelerometer Mount	4.8	4.0	-14.3
20. Left Upper Rib (4) Accelerometer Mount	3.4	-4.8	-15.5
21. Right Upper Rib (5) Center Under Mount	4.8	3.7	-14.3
22. Left Upper Rib (4) Center Under Mount	3.4	-4.5	-15.5
23. Right Seat Belt Anchor	-5.1	8.8	10.5

TABLE 4.4 INITIAL POINT LOCATIONS FOR TEST 76T020
IN SLED-FIXED COORDINATES - CONT'D

Point	X	Y	Z
24. Left Seat Belt Anchor	-5.1	-8.8	10.5
25. Left and Right Lap Belt Contact Points	8.0	+6.,-7.	- 3.0
26. Lap Belt Center on Lap	10.0	0.	- 6.0
27. Bottom Center of Steering Wheel Rim	12.0	0.	- 8.7

It is possible, using these data, plus the variety of initial skeletal geometry information, to determine the skeletal displacement as a function of time at various points on the sternum, spine, and ribs. A limited amount of data on rib properties for the test subjects is given in Section 5 of the report. The time plots for this test are included in Appendix A with the accelerometer, strain gage, autopsy, and the remainder of the test data.

Similarly, the following data were obtained and are presented for Test No. 76T020:

- left lower rib visual target plane angle
- right lower rib visual target plane angle
- T1 visual target plane angle
- T11 visual target plane angle
- T1 visual target translational displacement
- T11 visual target translational displacement
- left lower rib visual target translational displacement
- right lower rib visual target translational displacement
- sled motion (inertial)

5.0 SUBJECT DESCRIPTIONS. ANTHROPOMETRY, RIB STRENGTH, AND ACCELEROMETER PLACEMENT

5.1. ANTHROPOMETRY

The set of measures shown in Figure 4.3 was made on each cadaver. The subject was placed in a supine position with the head supported so that the nose pointed upward. A vertical surface, perpendicular to the table and the long axis of the body, was placed against the vertex. All measures which reference the vertex were made with respect to this surface. All depth measures were taken with respect to the table. Breadth and point-to-point measures were made directly, using an anthropometer. Circumferences were measured with a calibrated flexible metal tape. After all anterior measures were taken, the subject was placed in a prone position and spinal measures were made. It should be noted that there is no known procedure for correlating measurements made on cadaver subjects in these postures with those taken on living subjects in standard postures.

Some comments are required with respect to definitions of anthropometric quantities. Stature is measured with the cadaver supine on the autopsy table. The distance is from the vertex to a plane defined by the bottom of the feet when flat against a vertical board. Supine torso length is measured from the top of the head to the inferior margin of the pubic symphysis. The left and right acromion measurements refer to the distance from the top of the head, parallel to the body centerline, to the acromion. Head circumference is measured roughly in a plane passing through the most prominent part of the brow and the rearmost portion of the head (assuming head in a Frankfurt plane orientation). The axilla is on the side and reflects the level of the front crease of the armpit. Axilla chest depth, breadth, and circumference were measured at this level. The head to C7

measurement is the distance from the top of the head to the process of C7 in the prone subject. The suprasternale and substernale were measured from the vertex to the palpable bony landmark. Acromion to tip of finger refers to a stretched out arm and hand and uses the longest finger. Vertex to 12th rib is intended to define the lowest extent of the rib cage and refers to a measurement from the top of the head to the farthest palpable point which is part of the rib cage. Upper arm circumference was measured with the arm extended at the junction of the triceps and biceps.

Table 5.1 is a tabulation of the measurements which were made on the entire subject population. A few measurements were incorrectly recorded or not recorded and are listed as -0.

5.2. RIB PROPERTIES

After completion of test procedures, specimens of undamaged (if available) ribs were saved and frozen for later specialized testing. Bending tests were conducted to failure and dimensional data recorded for each specimen. Bone ash determinations were made for a limited number of specimens while torsional strength data were determined for two specimens.

The bending test was based on the similar procedure of Granik and Stein (5.1). Six inch samples of hard frozen ribs, from which nearly all the attached tissue and periosteum had been removed, were brought to room temperature and placed curving upward (unstable) so as to span supports four inches apart (Figure 5.1). The test fixture was placed in an Instron testing machine and loaded at midspan at a 0.1 inch/min. crosshead rate. A force versus time plot was obtained for each specimen (Figure 5.2) which could be converted into a force-deflection plot using the knowledge of crosshead and strip chart speeds.

TEST#	AGE	WEIGHT (kg)	SEX	STATURE (cm)	TORSO LENGTH (cm)	RT. ACROM (cm)	LT. ACROM (cm)	HEAD CIRC.(cm)	ACROM TO FINGER (cm)	ARM CIRC. (cm)
A-867	67.0	70.5	F	164.3	81.0	22.2	20.6	53.2	70.2	30.6
A-868	46.0	61.5	M	178.1	85.4	26.5	26.7	57.3	78.0	25.8
A-876	73.0	68.6	M	176.3	86.9	23.7	23.9	56.1	78.0	19.3
A-877	76.0	40.3	F	149.9	72.9	23.8	21.2	52.1	62.8	19.7
A-880	79.0	48.3	M	171.0	80.3	24.8	29.2	54.6	75.2	21.9
A-883	74.0	75.4	F	156.2	79.4	19.0	19.7	56.5	69.2	31.8
A-884	60.0	90.2	M	177.3	85.9	24.7	25.7	59.8	77.1	30.9
A-887	68.0	85.5	M	173.6	85.5	21.8	22.0	58.4	77.0	29.0
A-923	69.0	37.2	F	165.6	79.3	25.5	22.8	51.4	74.5	13.0
A-924	64.0	76.5	M	171.6	83.3	25.1	23.0	58.2	75.8	26.2
A-927	72.0	80.7	M	163.3	78.3	22.3	22.3	58.3	75.0	31.2
A-928	55.0	56.8	F	163.5	82.6	24.1	22.8	54.9	72.0	26.4
A-937	48.0	67.7	F	162.7	82.8	19.0	18.5	56.1	68.2	22.8
76T003	53.0	102.1	M	180.5	87.6	25.3	25.5	62.1	80.0	32.2
76T008	74.0	71.1	F	162.9	79.1	24.6	21.1	55.7	72.7	26.5
76T009	75.0	44.1	F	155.5	77.2	27.4	-0.	54.2	67.2	18.9
76T010	84.0	87.8	M	162.6	85.1	23.1	22.9	58.4	69.5	31.2
76T011	69.0	74.9	M	170.0	81.6	24.1	24.8	58.7	78.7	30.5
76T020	78.0	66.8	F	158.8	71.8	22.4	22.8	53.7	70.2	26.0
76T021	55.0	43.2	F	160.8	78.7	22.9	22.2	52.8	70.1	20.6
76T022	85.0	60.1	M	164.7	76.8	21.9	19.3	50.5	75.2	28.3
76T024	75.0	76.1	F	169.0	80.7	21.4	21.2	56.0	72.9	31.8
76T025	66.0	69.7	M	174.6	81.6	21.8	21.9	56.2	76.4	24.2
76T029	67.0	62.5	M	167.1	-0.	20.9	20.3	55.9	74.1	23.5
76T034	62.0	59.0	M	183.5	84.9	23.5	22.9	57.1	84.8	21.8
76T039	72.0	73.9	M	186.8	90.5	25.0	25.4	59.0	85.3	26.6
76T042	58.0	64.5	F	177.7	86.0	25.8	25.8	54.8	78.1	24.2
76T050	61.0	83.7	M	176.8	85.0	23.6	23.7	59.0	75.2	34.0
76T053	63.0	105.0	M	174.3	83.7	20.8	20.7	60.5	77.2	38.1
76T056	40.0	69.9	F	162.0	80.7	23.9	23.9	56.7	71.0	29.8
76T059	76.0	87.7	M	184.5	83.5	23.0	23.2	58.2	85.3	29.5
76T062	69.0	50.1	M	174.3	84.1	25.5	25.4	54.5	79.8	22.8
76T065	63.0	94.7	M	178.9	90.6	23.3	24.4	58.5	74.5	31.1
77T068	52.0	62.1	M	174.5	84.7	24.0	23.2	57.2	76.2	36.5
77T071	60.0	80.7	M	172.2	-0.	22.9	22.5	-0.	76.1	31.8
77T074	60.0	53.6	M	176.9	-0.	25.4	25.4	56.0	76.2	22.5
77T077	79.0	73.7	M	175.5	84.7	22.9	23.2	59.4	77.8	27.6
77T080	64.0	40.8	M	170.2	81.8	23.2	23.0	56.5	74.4	20.2
77T083	60.0	63.9	F	153.6	79.2	22.5	24.0	53.8	62.2	28.8
77T086	54.0	78.4	F	163.0	78.7	22.6	22.8	56.5	71.5	25.2
77T089	66.0	55.1	M	173.5	85.2	26.1	26.2	55.4	74.3	25.5
77T092	45.0	58.3	F	177.4	84.8	25.2	25.0	57.1	75.0	20.0
77T095	77.0	92.8	M	183.2	86.8	24.0	24.1	62.1	82.1	31.9
77T098	71.0	59.0	M	168.2	81.3	24.6	24.0	60.0	75.2	26.0

TABLE 5.1. SUBJECT ANTHROPOMETRY (1 of 2)

5.4

TEST #	AXILLA			SUBSTERNALE			HEAD TO	SUPERSTERNAL	SUBSTERNAL	VERTEX TO
	DEPTH(cm)	WIDTH(cm)	CIRC(cm)	DEPTH(cm)	WIDTH(cm)	CIRC(cm)	C7 (cm)	HEIGHT(cm)	HEIGHT(cm)	12TH RIB(cm)
A-867	20.1	30.8	87.9	22.0	30.4	89.9	23.2	30.6	47.3	59.4
A-868	16.5	29.3	82.8	17.5	30.1	84.3	26.2	33.6	55.1	65.8
A-876	19.3	27.0	88.7	21.5	32.5	94.0	25.6	30.7	50.5	65.9
A-877	16.4	24.9	70.7	18.3	24.1	70.6	24.7	28.1	44.9	53.0
A-880	21.8	26.2	87.4	22.9	31.5	87.1	27.5	30.1	52.9	62.5
A-883	17.8	29.2	102.3	21.0	31.8	96.5	18.4	28.6	44.4	58.4
A-884	24.8	34.8	114.7	27.5	32.4	101.5	25.0	31.2	52.0	64.4
A-887	21.5	31.4	104.4	27.1	34.8	107.1	22.8	28.0	49.0	61.1
A-923	13.5	24.2	67.0	15.4	26.7	72.5	23.6	31.9	49.0	58.1
A-924	19.8	30.4	98.1	24.2	35.0	100.5	21.6	32.0	53.4	61.9
A-927	21.0	31.8	109.7	28.6	33.6	103.1	23.0	28.8	48.3	61.1
A-928	18.5	27.8	87.3	18.9	28.2	80.0	23.2	30.0	49.6	58.5
A-937	17.1	21.1	86.7	21.8	33.7	93.6	20.3	27.6	46.2	55.7
76T003	22.4	31.0	102.7	25.2	33.2	104.6	24.9	31.2	52.7	67.0
76T008	18.9	27.1	94.6	21.0	28.5	82.8	23.7	47.6	28.7	59.8
76T009	18.8	24.2	73.2	18.9	26.2	75.6	25.0	30.4	49.7	59.3
76T010	23.3	30.3	109.2	27.2	32.7	105.1	23.3	28.9	49.9	62.1
76T011	20.3	33.0	101.6	24.1	34.9	99.7	24.1	30.8	57.8	61.6
76T020	17.9	26.2	84.8	21.4	29.1	86.5	24.4	28.6	46.3	55.4
76T021	16.1	25.9	65.1	16.8	26.2	72.6	25.3	29.2	46.7	58.7
76T022	20.1	25.2	87.1	25.8	29.0	91.5	23.3	20.9	50.1	54.4
76T024	18.9	30.0	97.0	20.8	30.8	91.8	25.7	28.2	48.8	61.6
76T025	17.5	30.2	95.9	20.8	28.7	86.3	22.4	30.9	50.6	59.4
76T029	15.7	30.4	93.9	21.0	29.4	97.9	22.1	28.7	64.5	65.1
76T034	19.7	29.0	83.2	23.2	30.7	90.5	23.5	32.6	54.0	62.9
76T039	20.9	29.7	96.7	22.0	31.2	92.8	27.3	34.2	59.4	69.4
76T042	18.4	24.3	76.1	19.6	27.5	83.8	24.6	31.6	53.1	64.1
76T050	22.0	30.0	106.0	25.7	34.0	103.0	23.6	31.6	53.5	65.7
76T053	25.6	35.7	111.8	30.2	36.2	108.2	24.9	29.1	53.3	62.8
76T056	18.1	27.5	89.5	21.7	29.3	90.4	24.6	29.7	48.8	60.7
76T059	23.9	30.0	99.9	29.0	34.9	108.1	28.1	31.4	55.7	62.6
76T062	19.9	30.1	89.9	21.6	29.7	87.1	24.3	54.4	33.3	64.2
76T065	21.9	35.5	105.4	24.5	34.5	103.8	25.5	31.5	54.0	68.3
77T068	15.8	33.3	93.5	21.0	31.5	89.2	23.0	32.4	52.1	63.9
77T071	17.7	34.9	101.5	24.2	33.0	98.5	21.9	30.9	53.2	63.5
77T074	18.5	24.8	78.9	21.8	26.3	80.5	25.8	32.1	51.3	65.1
77T077	20.4	29.2	93.9	25.2	31.8	95.9	28.1	30.1	51.3	62.7
77T080	17.0	26.0	77.7	18.7	28.4	79.9	26.4	28.5	48.6	60.5
77T083	18.8	27.5	88.5	21.2	26.9	88.8	24.7	29.2	46.0	62.1
77T086	17.9	29.6	87.5	22.1	29.3	90.6	26.1	28.5	46.5	54.5
77T089	19.3	31.9	88.4	21.7	31.0	90.5	26.9	32.5	55.4	67.7
77T092	16.0	30.4	84.5	17.6	26.8	81.4	25.0	33.3	49.4	64.0
77T095	20.1	36.2	102.5	25.6	36.0	103.9	27.0	32.0	53.0	64.9
77T098	18.9	32.0	93.4	23.6	29.1	91.9	27.0	31.0	47.3	58.2

TABLE 5.1. SUBJECT ANTHROPOMETRY (2 of 2)

For the majority of ribs, the initial part of the test resulted in simple bending, during which the recorded force increased quite uniformly toward a maximum. Then, depending on the rib, localized crushing and buckling of the upper half of the cortical bone into the spongy center coincided with a leveling off and decrease in recorded force. The load continued to decrease as the rib was further loaded. Usually it was only quite late in the loading (well after the peak load) that any kind of fracturing or snapping of the rib occurred. Even then the load dropped to zero in only about 50% of the cases. Figure 5.3 illustrates four regions of the typical test curve. Test curves for all rib samples are included in Appendix B.

In order to compare rib geometry of subjects, a detailed study was made of cross sections of the tested samples. First the rib was cut and a photograph taken of the cut end (Figure 5.4). Tracings were then made outlining the exterior and edge of the compact interior of the bone cross-section (Figure 5.5). Due to the spongy material inside the bone, some judgement was necessary in drawing an outline of the core. The inside and outside outlines were digitized and the two peripheries analyzed for enclosed area. The area of compact bone could thus be computed. Also, the peripheries were fit to an ellipse to allow an estimation of major and minor axes. Cross-section photographs for all rib samples are included in Appendix B.

Table 5.2 is a summary of all the data derived from the rib tests. The second column identifies the test while the third identifies the side from which the rib is taken (left=1, right=2). The fifth and sixth columns give maximum force in lbs. and peak displace in inches. The rest of the columns are self-explanatory and have units of centimeters or centimeters squared.

CASE#	TEST#	SIDE	RIB#	MAX FORCE (lbs)	DSP ϕ PEAK (in)	TOTAL AREA (cm ²)	RIM AREA (cm ²)	CORE AREA (cm ²)	R/T RATIO	C/T RATIO	R/C RATIO	MAJOR AXIS (cm)	MINOR AXIS (cm)	M/M RATIO
1	A-868	R	7.	55.0	.100	.9182	.2897	.6284	.6844	.4610	.3155	1.320	1.018	1.296
2	A-883	R	7.	36.0	.230	.4352	.2028	.2323	.5339	.8731	.4661	1.221	.482	2.532
3	A-937	L	6.	63.0	.170	.3960	.2106	.1854	.4682	1.1360	.5318	1.163	.451	2.579
4	A-937	L	7.	64.0	.180	.4344	.2608	.1736	.3996	1.5026	.6004	1.278	.421	3.034
5	A-937	R	6.	54.0	.140	.3954	.2069	.1885	.4767	1.0979	.5233	1.095	.449	2.440
6	A-937	R	7.	40.0	.110	.6896	.2222	.4674	.6778	.4753	.3222	1.246	.672	1.855
7	A-937	R	7.	40.0	.110	.4004	.2459	.1545	.3858	1.5919	.6142	1.163	.418	2.784
8	76T003	L	6.	45.0	.020	.7129	.2323	.4807	.6742	.4832	.3258	1.408	.646	2.180
9	76T003	L	7.	36.0	.007	.5947	.2144	.3803	.6395	.5638	.3605	1.258	.611	2.060
10	76T003	R	6.	60.0	.100	.5986	.3539	.2447	.4088	1.4463	.5912	1.100	.734	1.499
11	76T003	R	7.	36.0	.090	.6952	.2268	.4684	.6737	.4843	.3263	1.258	.678	1.856
12	76T008	R	7.	21.5	.100	.9042	.2672	.6370	.7045	.4194	.2955	1.479	.782	1.891
13	76T009	L	6.	13.8	.125	.4260	.1498	.2761	.6482	.5426	.3517	.911	.613	1.486
14	76T009	L	6.	13.8	.125	.4479	.1561	.2918	.6514	.5351	.3486	1.020	.483	2.112
15	76T010	R	6.	-0.	-0.	.7662	.2330	.5331	.6958	.4371	.3042	1.391	.659	2.112
16	76T011	R	5.	15.5	.140	.7738	.1706	.6032	.7795	.2829	.2205	1.588	.606	2.621
17	76T020	L	7.	20.7	.107	.4649	.1988	.2661	.5724	.7471	.4276	1.150	.514	2.236
18	76T021	R	6.	22.5	.167	.5065	.1589	.3476	.6863	.4572	.3137	1.049	.632	1.661
19	76T021	R	7.	18.5	.127	.5011	.1478	.3533	.7051	.4183	.2949	1.156	.533	2.168
20	76T022	L	3.	16.2	.133	.4682	.1823	.2860	.6107	.6374	.3893	1.269	.552	2.300
21	76T024	L	7.	19.5	.133	.8198	.1608	.6590	.8039	.2440	.1961	1.617	.692	2.336
22	76T024	L	8.	16.0	.133	.8488	.1670	.6819	.8033	.2448	.1967	1.556	.780	1.994
23	76T024	R	6.	12.1	.137	.7454	.1493	.5962	.7998	.2504	.2002	1.379	.666	2.070
24	76T024	R	7.	9.2	.202	.7052	.2834	.4218	.5981	.6719	.4019	1.607	.591	2.720
25	76T024	R	8.	15.8	.193	.8081	.1574	.6507	.8053	.2418	.1947	1.579	.663	2.380
26	76T024	R	9.	14.4	.133	.6274	.1371	.4903	.7815	.2795	.2185	1.582	.490	3.231
27	76T025	L	6.	21.4	.110	.7005	.1986	.5019	.7165	.3957	.2835	1.358	.660	2.056
28	76T025	L	7.	18.5	.085	.6634	.2028	.4607	.6944	.4401	.3056	1.155	.624	1.850
29	76T025	L	8.	20.8	.108	.5521	.1899	.3622	.6560	.5243	.3439	1.320	.546	2.419
30	76T025	R	6.	21.9	.150	.6276	.1725	.4552	.7252	.3789	.2748	1.491	.516	2.889
31	76T025	R	7.	18.2	.134	.7385	.2281	.5105	.6912	.4468	.3088	1.362	.738	1.846
32	76T025	R	8.	16.1	.100	.5426	.2271	.3155	.5815	.7196	.4185	1.354	.660	2.051
33	76T029	R	5.	28.3	.183	.4966	.2139	.2827	.5693	.7566	.4307	1.239	.506	2.450
34	76T029	R	6.	33.9	.177	.5573	.2409	.3164	.5677	.7614	.4323	1.143	.593	1.926
35	76T029	R	7.	29.6	.100	.6127	.2842	.3284	.5361	.8655	.4639	1.238	.628	1.971
36	76T029	R	8.	37.6	.107	.6995	.2832	.4163	.5951	.6803	.4049	1.451	.601	2.415
37	76T039	L	6.	30.5	.137	1.1279	.2454	.8825	.7824	.2780	.2175	1.713	.847	2.023
38	76T039	L	7.	43.2	.147	1.2271	.2492	.9779	.7969	.2549	.2031	1.425	1.167	1.220
39	76T050	L	6.	44.0	.120	.7159	.2595	.4564	.6375	.5686	.3625	1.222	.721	1.695
40	76T050	L	7.	33.0	.168	.7251	.3363	.3888	.5362	.8649	.4638	1.630	.624	2.612
41	76T050	L	8.	38.0	.127	.6986	.2665	.4321	.6186	.6167	.3814	1.409	.673	2.093
42	76T053	R	5.	32.0	.150	.6409	.1938	.4470	.6975	.4336	.3025	1.420	.569	2.495
43	76T053	R	6.	29.8	.115	.7188	.2195	.4993	.6946	.4396	.3054	1.348	.726	1.856
44	76T053	R	7.	43.5	.131	.6739	.2016	.4723	.7009	.4268	.2991	1.351	.677	1.996
45	76T053	R	8.	47.2	.117	.7332	.2502	.4830	.6587	.5181	.3413	1.294	.734	1.764
46	76T059	L	5.	13.4	.205	.5933	.1565	.4368	.7362	.3582	.2637	1.729	.415	4.169
47	76T059	L	6.	20.4	.133	.6244	.1262	.4982	.7978	.2534	.2022	1.256	.654	1.922
48	76T059	L	7.	20.1	.095	.7594	.1341	.6253	.8235	.2144	.1765	1.312	.757	1.732
49	76T059	L	8.	31.2	.131	.7262	.1887	.5375	.7401	.3511	.2599	1.394	.694	2.010

5.6

TABLE 5.2. SUMMARY OF RIB BENDING TEST AND CROSS-SECTION DATA (1 of 2)

CASE#	TEST#	SIDE	RIB#	MAX FORCE (lbs)	DSP @ PEAK (in)	TOTAL AREA (cm ²)	RIM AREA (cm ²)	CORE AREA (cm ²)	R/T RATIO	C/T RATIO	R/C RATIO	MAJOR AXIS (cm)	MINOR AXIS (cm)	M/M RATIO
50	76T056	L	4.	40.0	.217	.4959	.2253	.2706	.5456	.8329	.4544	1.010	.666	1.518
51	76T056	L	5.	31.4	.250	.3982	.1676	.2306	.5791	.7269	.4209	.952	.525	1.811
52	76T056	L	6.	43.8	.217	.4863	.2106	.2758	.5670	.7636	.4330	1.041	.558	1.866
53	76T056	L	7.	37.7	.134	.5514	.2884	.2630	.4770	1.0966	.5230	1.227	.591	2.077
54	76T056	L	8.	43.6	.217	.4734	.2711	.2023	.4273	1.3400	.5727	1.331	.487	2.734
55	76T062	R	5.	-0.	-0.	.5493	.1774	.3719	.6770	.4771	.3230	1.390	.486	2.860
56	76T062	R	6.	25.0	.167	.6147	.1239	.4908	.7984	.2524	.2016	1.238	.624	1.985
57	76T062	R	6.	25.0	.167	.6168	.1360	.4808	.7795	.2829	.2205	1.266	.613	2.065
58	76T062	R	7.	37.0	.133	.7206	.2079	.5128	.7116	.4054	.2884	1.226	.783	1.567
59	76T065	L	5.	47.6	.192	.6890	.2084	.4806	.6976	.4335	.3024	1.110	.789	1.407
60	76T065	L	6.	34.0	.233	.7161	.2228	.4933	.6889	.4516	.3111	1.434	.618	2.320
61	76T065	L	7.	61.9	.160	.8274	.2876	.5399	.6524	.5327	.3475	1.403	.781	1.797
62	76T065	L	8.	43.0	.192	.6717	.2365	.4352	.6479	.5434	.3521	1.405	.585	2.403
63	76T068	L	4.	46.2	.135	.8163	.2203	.5960	.7301	.3697	.2699	1.371	.777	1.765
64	77T068	L	5.	48.4	.133	.5757	.1806	.3951	.6863	.4571	.3137	1.231	.631	1.953
65	77T068	L	6.	45.6	.093	.7843	.2103	.5740	.7318	.3664	.2681	1.305	.739	1.777
66	77T071	L	4.	40.7	.250	.5991	.2448	.3542	.5913	.6912	.4087	1.282	.620	2.068
67	77T071	L	5.	46.7	.217	.6137	.2136	.4001	.6519	.5339	.3481	1.037	.830	1.250
68	77T071	L	6.	55.9	.135	.7047	.2377	.4671	.6628	.5086	.3371	1.035	.958	1.080
69	77T074	L	4.	25.5	.200	.6447	.2349	.4098	.6356	.5732	.3644	1.626	.508	3.199
70	77T074	L	5.	30.8	.109	.8393	.2417	.5977	.7120	.4045	.2880	1.470	.787	1.868
71	77T074	L	6.	66.5	.167	.9251	.3705	.5545	.5994	.6682	.4006	1.463	.808	1.810
72	77T077	R	4.	41.4	.233	.8341	.2404	.5937	.7118	.4050	.2882	1.436	.783	1.834
73	77T077	R	5.	32.5	.167	.7207	.2108	.5098	.7074	.4135	.2925	1.424	.662	2.151
74	77T077	R	6.	37.6	.130	.8951	.2358	.6592	.7365	.8958	.2635	1.502	.699	2.151
75	77T080	R	4.	15.3	.283	.5779	.1365	.4414	.7738	.3093	.2362	1.210	.668	1.812
77	77T080	R	5.	16.2	.217	.7280	.1337	.5943	.8163	.2250	.1837	1.315	.730	1.800
77	77T080	R	6.	25.5	.155	.8397	.1988	.6408	.7732	.3103	.2368	1.523	.693	2.197
78	77T080	R	7.	20.9	.101	.7303	.1705	.5598	.7765	.3047	.2335	1.272	.807	1.577
79	77T083	R	6.	22.1	.150	.4644	.1591	.3053	.6574	.5212	.3426	1.072	.562	1.907
80	77T083	R	7.	16.5	.120	.4251	.1634	.2617	.6157	.6241	.3843	1.039	.531	1.956
81	77T083	R	8.	32.1	.103	.4915	.2170	.2745	.5586	.7903	.4414	.928	.633	1.467
82	77T086	L	4.	17.8	.150	.4106	.1389	.2716	.6616	.5114	.3384	.988	.533	1.852
83	77T086	L	5.	18.0	.167	.4321	.1418	.2903	.6718	.4886	.3282	1.034	.518	1.997
84	77T086	L	6.	14.6	.167	.4153	.1937	.2216	.5337	.8738	.4663	1.163	.408	2.855
85	77T089	R	4.	27.0	.233	.7023	.1934	.5089	.7246	.3800	.2753	1.352	.753	1.796
86	77T089	R	5.	31.0	.150	.7827	.2042	.5785	.7391	.3530	.2609	1.296	.778	1.666
87	77T089	R	6.	40.0	.200	.8930	.2373	.6557	.7343	.3619	.2657	1.530	.787	1.943
88	77T089	R	7.	54.0	.183	.9004	.3279	.5725	.6358	.5727	.3642	1.520	.749	2.029
89	77T092	R	6.	41.1	.183	.5055	.2340	.2715	.5370	.8620	.4629	1.159	.607	1.911
90	77T092	R	7.	-0.	-0.	.5431	.2152	.3279	.6037	.6564	.3963	1.112	.611	1.821
91	77T092	R	8.	25.5	.158	.5671	.2410	.3261	.5750	.7391	.4250	1.369	.540	2.533
92	77T095	R	5.	27.8	.108	.9873	.2723	.7150	.7242	.3808	.2758	1.613	.823	1.960
93	77T095	R	6.	35.4	.150	1.0173	.2743	.7429	.7303	.3692	.2697	1.730	.788	2.195
94	77T095	R	7.	-0.	-0.	1.0134	.3033	.7100	.7007	.4272	.2993	2.063	.605	3.409
95	77T098	R	5.	15.8	.128	.5944	.2049	.3895	.6553	.5260	.3447	1.597	.502	3.180
96	77T098	R	6.	-0.	-0.	.6233	.1877	.4356	.6989	.4309	.3011	1.301	.673	1.935
97	77T098	R	7.	17.3	.050	.7562	.2055	.5507	.7282	.3732	.2717	1.525	.723	2.108
98	77T098	R	8.	8.3	.083	.7095	.1739	.5356	.7549	.3246	.2451	1.337	.753	1.774

5.7

TABLE 5.2. SUMMARY OF RIB BENDING TEST AND CROSS-SECTION DATA (2 of 2)

Table 5.3 is a summary of bone ash determinations made at the University of Michigan Nutrition Labs. The test and rib number are given along with the wet sample weight, the percent dry mass, and the percent of ash from the dry mass.

Torsion tests were done for the two specialized tests, 76T008 and 76T020. Figure 5.6 shows the test apparatus. Strain rosette data are plotted in Figures 5.7 and 5.8 for two specimens while torque-angle plots are given in Figures 5.9 and 5.10.

5.3. ACCELEROMETER PLACEMENT

Data were obtained on accelerometer placement for each mount at the time the mounts were installed during surgery. This procedure was conducted after completion of anthropometry and used some of the same equipment. A set of six measurements (Figure 4.27) was made for each location.

These were:

- Distance from the table (supine), X-coordinate
- Distance from the body midline, Y-coordinate
- Distance from the vertex, Z-coordinate
- Angle about X-axis
- Angle about Y-axis
- Angle about Z-axis

The distances were measured using an anthropometer while the angles were measured using a combined protractor and level.

Table 5.4 contains the position and angular orientation for each mount for each test which was conducted. The first column in each table contains the test identification while the next three columns give the X, Y, and Z coordinate locations in inches. Following this are the estimations of angular orientation about each axis as projected on the plane. For example, the rotation in degrees about the x-axis should be viewed as

TABLE 5.3 BONE ASH DATA

Test No.	Sample	Wet Weight (gm.)	% dry mass	% Ash
A-868	R7	0.7658	77.60	63.21
76T008	R7	0.9482	73.60	95.17
76T009	L7	0.6180	75.10	62.41
76T011	R5	0.7861	64.82	94.10
76T022	L3	0.5555	69.52	62.51
76T024	R6	1.0979	61.00	54.22
76T025	L6	0.5084	68.59	72.65
76T039	L7	1.6067	68.40	54.98
76T050	L6	0.9092	74.40	91.98
76T053	R6	1.0686	68.25	81.41
76T056	L7	0.7067	65.20	56.56
76T059	L7	0.6091	66.13	89.30
76T062	R7	0.8403	70.50	60.55
76T065	L7	1.3405	72.90	84.34
77T068	L6	0.6489	67.01	69.55
77T071	L6	1.1321	74.23	86.55
77T074	L5	1.1094	74.10	89.50
77T077	R6	0.7605	74.00	62.71
77T080	R7	0.5385	68.52	67.24

RIGHT LOWER RIBS

TEST #	X	Y	Z	<X	<Y	<Z	RATING
A-867	3.50	6.25	18.25	7.00	5.00	25.00	.791
A-868	4.75	6.25	20.25	5.00	-17.00	-10.00	.967
A-876	5.25	7.00	20.00	-10.00	-18.00	-17.00	.975
A-877	3.30	5.25	16.75	0.	0.	10.00	.933
A-880	4.13	6.00	17.38	-10.00	-7.00	2.00	.985
A-883	4.13	7.00	18.88	-10.00	-8.00	0.	.991
A-884	5.50	6.50	19.75	-9.00	-9.00	-8.00	.999
A-887	5.50	7.00	17.25	-12.00	-5.00	-10.00	.992
A-923	3.75	5.25	18.50	-11.00	-35.00	-10.00	.902
A-924	-0.	-0.	-0.	-0.	-0.	-0.	-0.
A-927	5.25	6.75	20.25	0.	-3.00	0.	.976
A-928	4.00	5.50	19.25	-15.00	-26.00	-15.00	.943
A-937	4.75	6.00	17.75	-20.00	-14.00	-5.00	.973
76T003	4.50	7.00	21.00	5.00	-10.00	8.00	.942
76T008	3.25	6.00	18.88	2.00	-1.00	-28.00	.912
76T009	4.90	4.50	18.63	-27.00	-20.00	-16.00	.917
76T010	3.50	6.00	21.00	0.	3.00	24.00	.826
76T011	5.38	5.50	21.75	0.	-45.00	0.	.803
76T020	5.00	5.00	18.90	-16.00	-8.00	-8.00	.989
76T021	4.00	5.13	18.75	-25.00	-30.00	-18.00	.880
76T022	6.00	5.00	19.25	-9.00	-5.00	-16.00	.985
76T024	6.50	4.00	19.50	-8.00	-16.00	-8.00	.994
76T025	5.25	5.00	20.00	-15.00	-8.00	-20.00	.967
76T029	5.00	5.50	18.90	-20.00	-13.00	0.	.967
76T034	5.50	5.50	20.50	-4.00	-9.00	-10.00	.997
76T039	4.00	7.00	20.50	0.	-12.00	8.00	.956
76T042	4.00	5.50	18.50	0.	-17.00	-7.00	.984
76T050	4.33	6.69	22.09	-10.00	-15.00	-10.00	.994
76T053	6.50	6.30	20.39	-7.00	-3.00	-5.00	.992
76T056	5.75	5.50	20.00	-3.00	-4.00	-17.00	.978
76T059	7.76	5.91	20.31	-20.00	0.	-10.00	.961
76T062	6.38	5.35	20.35	-5.00	0.	-25.00	.938
76T065	5.39	5.91	21.02	-20.00	-9.00	-15.00	.967
77T068	2.02	6.42	18.03	0.	-3.00	-18.00	.967
77T071	5.20	5.87	18.39	-9.00	-15.00	0.	.988
77T074	4.69	5.08	20.20	0.	0.	0.	.969
77T077	6.73	5.28	20.20	0.	0.	-25.00	.931
77T080	4.76	5.91	18.31	0.	-4.00	-13.00	.981
77T083	4.96	4.76	18.23	-10.00	-10.00	-10.00	.998
77T086	4.53	5.47	18.31	0.	0.	-3.00	.974
77T089	3.86	5.79	20.43	-15.00	-7.00	0.	.982
77T092	4.17	5.12	18.66	0.	-10.00	-6.00	.991
77T095	5.55	7.09	20.83	-10.00	-5.00	-7.00	.996
77T098	5.51	5.59	20.70	-13.00	-8.00	-20.00	.971

5.10

TABLE 5.4. ACCELEROMETER PLACEMENT DATA (1 of 9)

RIGHT UPPER RIBS

TEST #	X	Y	Z	<X	<Y	<Z	RATING
A-867	-0.	-0.	-0.	-0.	-0.	-0.	-0.
A-868	4.00	5.25	15.00	-0.	-0.	-0.	-0.
A-876	6.50	5.75	13.75	-25.00	-24.00	-10.00	.966
A-877	3.50	4.50	13.00	0.	-37.00	20.00	.867
A-880	5.75	5.00	15.00	-10.00	-15.00	-18.00	.946
A-883	4.00	6.00	14.75	0.	-25.00	0.	.968
A-884	5.75	5.50	15.25	-13.00	-19.00	-3.00	.978
A-887	4.75	5.50	13.50	-22.00	-8.00	-13.00	.905
A-923	3.88	4.75	14.00	-11.00	-60.00	-20.00	.847
A-924	-0.	-0.	-0.	-0.	-0.	-0.	-0.
A-927	3.75	5.25	16.00	0.	-25.00	10.00	.932
A-928	3.75	5.25	15.00	-12.00	-57.00	-15.00	.885
A-937	4.25	5.25	13.75	-10.00	-38.00	-6.00	.991
76T003	4.50	5.88	17.25	7.00	-34.00	0.	.938
76T008	3.75	5.50	14.50	-3.00	-39.00	-35.00	.863
76T009	4.50	5.25	14.50	-22.00	-45.00	-11.00	.950
76T010	3.50	5.50	16.25	-5.00	-34.00	16.00	.912
76T011	3.88	4.63	17.00	-5.00	-14.00	18.00	.863
76T020	4.00	5.00	14.00	-16.00	-28.00	13.00	.936
76T021	4.00	4.75	14.00	-12.00	-35.00	-9.00	.996
76T022	5.25	4.50	15.00	-10.00	-35.00	-4.00	.995
76T024	5.50	3.75	14.50	-15.00	-22.00	0.	.980
76T025	4.75	4.50	14.75	-19.00	-30.00	-15.00	.982
76T029	4.30	5.00	13.80	-25.00	-37.00	-6.00	.966
76T034	4.50	4.75	14.75	-6.00	-40.00	-19.00	.960
76T039	4.00	5.50	14.75	-12.00	-35.00	0.	.989
76T042	4.00	4.50	14.25	-6.00	-40.00	-20.00	.956
76T050	2.48	5.91	16.06	-20.00	-25.00	18.00	.893
76T053	4.72	4.06	13.86	-20.00	-32.00	-10.00	.988
76T056	4.50	4.50	13.50	0.	-30.00	-15.00	.970
76T059	5.04	5.16	14.21	-9.00	-33.00	-13.00	.992
76T062	4.80	5.00	14.45	-12.00	-27.00	-15.00	.989
76T065	1.77	5.98	16.02	-20.00	-26.00	-11.00	.984
77T068	4.61	5.12	12.40	-32.00	-32.00	-18.00	.920
77T071	5.08	5.59	14.45	-20.00	-23.00	-4.00	.980
77T074	4.88	4.29	14.92	-8.00	-12.00	-15.00	.938
77T077	5.24	4.57	14.06	-5.00	-20.00	-15.00	.968
77T080	4.76	4.65	13.19	-23.00	-24.00	-20.00	.950
77T083	3.58	3.94	13.31	-22.00	-27.00	-5.00	.981
77T086	4.41	4.72	14.61	0.	-37.00	12.00	.920
77T089	4.53	4.69	15.51	-5.00	-30.00	-10.00	.992
77T092	3.90	5.27	14.76	-9.00	-45.00	-10.00	.965
77T095	5.55	5.94	15.16	-6.00	-25.00	-20.00	.965
77T098	4.09	5.23	15.67	-15.00	-22.00	-10.00	.986

5.11

TABLE 5.4. ACCELEROMETER PLACEMENT DATA (2 of 9)

LEFT LOWER RIBS

TEST #	X	Y	Z	<X	<Y	<Z	RATING
A-867	4.00	5.50	20.00	4.00	-5.00	-11.00	.949
A-868	4.25	6.25	19.25	10.00	-11.00	3.00	.997
A-876	4.75	6.38	20.50	5.00	-30.00	10.00	.934
A-877	3.00	4.50	13.00	-10.00	5.00	3.00	.921
A-880	5.63	5.50	18.50	10.00	5.00	10.00	.965
A-883	3.75	5.00	18.13	15.00	-4.00	-13.00	.931
A-884	4.75	6.50	20.63	-4.00	-29.00	-9.00	.890
A-887	6.25	6.50	17.75	18.00	-5.00	9.00	.980
A-923	4.75	5.13	18.50	22.00	-15.00	6.00	.964
A-924	-0.	-0.	-0.	-0.	-0.	-0.	-0.
A-927	5.00	6.25	19.00	12.00	0.	5.00	.983
A-928	3.13	5.50	18.50	7.00	-31.00	-4.00	.915
A-937	4.38	5.50	16.00	-17.00	-13.00	-4.00	.893
76T003	4.13	5.88	18.75	13.00	-3.00	-15.00	.921
76T008	3.25	5.50	19.38	-4.00	-7.00	20.00	.951
76T009	3.90	5.60	20.00	7.00	-22.00	2.00	.974
76T010	4.25	6.25	20.38	10.00	3.00	-15.00	.908
76T011	4.50	6.38	20.75	16.00	-15.00	-7.00	.958
76T020	5.25	5.25	17.50	0.	-10.00	-12.00	.941
76T021	4.13	5.00	18.00	24.00	-17.00	17.00	.935
76T022	5.00	6.00	17.50	14.00	-25.00	13.00	.951
76T024	7.00	3.50	18.75	0.	-12.00	0.	.984
76T025	4.50	4.75	19.75	14.00	-15.00	27.00	.926
76T029	5.40	5.70	19.00	12.00	-9.00	5.00	.997
76T034	5.50	7.00	19.75	8.00	-15.00	15.00	.984
76T039	4.25	7.00	21.50	0.	-10.00	4.00	.990
76T042	3.75	5.50	17.00	10.00	-20.00	14.00	.974
76T050	4.41	6.30	22.05	3.00	-3.00	5.00	.990
76T053	7.36	5.20	20.43	0.	-5.00	10.00	.986
76T056	5.50	5.75	19.75	5.00	-5.00	18.00	.975
76T059	10.24	4.72	19.91	6.00	-15.00	22.00	.958
76T062	6.54	5.39	21.46	3.00	-3.00	20.00	.962
76T065	7.24	5.94	20.39	18.00	-4.00	35.00	.859
77T068	2.14	6.02	19.29	6.00	0.	20.00	.958
77T071	5.98	5.79	19.10	8.00	-7.00	10.00	.997
77T074	4.53	5.00	20.12	5.00	0.	8.00	.985
77T077	5.98	5.91	19.37	5.00	0.	5.00	.985
77T080	4.65	5.75	18.31	10.00	-11.00	9.00	.998
77T083	3.39	5.83	19.09	0.	-6.00	-4.00	.973
77T086	3.15	4.41	18.46	23.00	0.	18.00	.931
77T089	4.09	5.67	21.14	25.00	-15.00	17.00	.934
77T092	3.58	5.59	18.70	0.	-10.00	-7.00	.964
77T095	5.62	6.73	22.05	15.00	-8.00	10.00	.989
77T098	4.96	5.27	20.47	0.	-8.00	5.00	.991

5.12

TABLE 5.4. ACCELEROMETER PLACEMENT DATA (3 of 9)

LEFT UPPER RIBS

TEST #	X	Y	Z	<X	<Y	<Z	RATING
A-867	-0.00	5.00	14.75	-0.00	-0.00	-0.00	-0.00
A-868	4.00	5.25	15.00	20.00	-20.00	19.00	.970
A-876	6.00	4.50	16.20	0.00	-37.00	0.00	.946
A-877	3.50	4.75	14.50	10.00	-4.00	30.00	.865
A-880	6.00	4.00	14.50	0.00	-20.00	0.00	.963
A-883	4.38	5.75	15.50	3.00	-7.00	0.00	.929
A-884	5.00	5.00	12.50	34.00	-12.00	14.00	.901
A-887	5.00	5.00	12.75	14.00	-47.00	0.00	.918
A-923	3.50	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00
A-924	-0.00	5.00	15.00	7.00	-30.00	-5.00	.966
A-927	3.25	5.00	13.50	12.00	-64.00	-14.00	.721
A-928	3.25	5.25	13.75	-17.00	-18.00	10.00	.863
A-937	3.75	5.88	15.50	9.00	-22.00	-4.00	.975
76T003	3.75	5.50	14.75	-5.00	-16.00	8.00	.942
76T008	1.75	4.50	13.25	14.00	-34.00	1.00	.980
76T009	3.25	5.50	14.75	12.00	-22.00	-23.00	.855
76T010	3.50	4.25	15.50	16.00	-8.00	0.00	.945
76T011	3.88	5.00	12.75	3.00	-26.00	8.00	.986
76T020	3.50	5.25	14.00	5.00	-21.00	10.00	.988
76T021	3.75	5.00	14.00	7.00	-35.00	10.00	.980
76T022	5.00	3.75	13.75	20.00	-25.00	7.00	.991
76T024	6.00	4.50	14.75	0.00	-32.00	8.00	.969
76T025	3.00	5.00	13.80	25.00	-25.00	5.00	.975
76T029	4.90	5.50	13.75	25.00	-27.00	12.00	.973
76T034	4.50	5.50	15.50	12.00	-30.00	14.00	.991
76T039	4.75	5.50	13.00	-4.00	-5.00	35.00	.803
76T042	4.50	5.51	15.16	13.00	-19.00	-15.00	.915
76T050	3.46	6.34	14.09	12.00	-4.00	8.00	.933
76T053	6.34	4.75	13.50	27.00	-25.00	30.00	.898
76T056	5.00	5.04	14.21	30.00	-29.00	21.00	.927
76T059	5.71	4.84	14.80	9.00	-16.00	20.00	.964
76T062	5.16	5.91	15.98	7.00	-28.00	10.00	.954
76T065	4.65	5.12	13.50	32.00	-32.00	20.00	.915
77T068	4.72	5.28	15.67	25.00	-25.00	7.00	.976
77T071	5.16	4.29	14.76	20.00	-18.00	14.00	.979
77T074	5.00	5.47	13.82	10.00	-30.00	15.00	.988
77T077	5.12	4.65	12.99	25.00	-25.00	20.00	.955
77T080	4.57	5.12	13.98	7.00	-27.00	5.00	.993
77T083	4.37	3.90	14.61	11.00	-33.00	0.00	.980
77T086	3.15	4.65	15.67	22.00	-32.00	12.00	.977
77T089	4.21	4.88	14.76	27.00	-45.00	18.00	.896
77T092	3.62	6.02	15.16	6.00	-30.00	0.00	.980
77T095	4.33	4.17	15.00	7.00	-22.00	0.00	.984
77T098	9.13	4.17	15.00	7.00	-22.00	0.00	.984

TABLE 5.4. ACCELEROMETER PLACEMENT DATA (4 of 9)

UPPER STERNALS

TEST #	X	Y	Z	<X	<Y	<Z	RATING
A-867	8.00	0.	12.50	0.	20.00	0.	.996
A-868	6.50	0.	14.25	0.	27.00	0.	.999
A-876	8.75	0.	13.50	10.00	27.00	-5.00	.983
A-877	6.00	0.	11.50	-10.00	35.00	3.00	.966
A-880	7.75	0.	11.75	0.	23.00	-3.00	.999
A-883	6.00	0.	12.00	0.	25.00	0.	1.000
A-884	8.00	0.	12.75	0.	34.00	-2.00	.987
A-887	7.50	0.	11.50	0.	51.00	0.	.896
A-923	6.00	0.	13.00	0.	0.	0.	.908
A-924	-0.	-0.	-0.	-0.	-0.	-0.	-0.
A-927	7.50	0.	12.50	0.	37.00	-6.00	.974
A-928	6.50	0.	13.63	3.00	16.00	-15.00	.960
A-937	6.25	-.63	11.63	-8.00	13.00	-6.00	.966
76T003	7.75	-.88	13.75	-5.00	29.00	-14.00	.970
76T008	6.75	0.	12.50	6.00	48.00	0.	.914
76T009	6.90	0.	12.50	-16.00	28.00	4.00	.955
76T010	7.00	0.	12.75	0.	40.00	0.	.964
76T011	7.25	0.	13.00	-5.00	28.00	0.	.994
76T020	6.50	0.	11.50	6.00	24.00	-8.00	.988
76T021	-0.	-0.	-0.	-0.	-0.	-0.	-0.
76T022	-0.	-0.	-0.	-0.	-0.	-0.	-0.
76T024	-0.	-0.	-0.	-0.	-0.	-0.	-0.
76T025	-0.	-0.	-0.	-0.	-0.	-0.	-0.
76T029	7.90	0.	12.50	-3.00	27.00	3.00	.995
76T034	8.25	0.	13.75	0.	23.00	0.	.999
76T039	8.50	0.	14.25	10.00	15.00	0.	.971
76T042	7.50	0.	13.25	4.00	15.00	3.00	.980
76T050	7.68	0.	12.83	0.	27.00	0.	.999
76T053	9.13	0.	11.81	-6.00	38.00	0.	.967
76T056	7.00	0.	12.50	-3.00	30.00	-3.00	.994
76T059	8.54	0.	12.28	0.	27.00	-2.00	.999
76T062	7.48	0.	13.66	5.00	25.00	-10.00	.986
76T065	8.31	0.	13.39	4.00	14.00	0.	.980
77T068	6.81	0.	13.39	0.	15.00	5.00	.979
77T071	6.57	0.	12.73	0.	22.00	0.	.998
77T074	7.09	0.	12.83	0.	30.00	0.	.995
77T077	7.76	0.	12.40	0.	17.00	-4.00	.990
77T080	6.50	0.	12.40	0.	20.00	0.	.996
77T083	7.24	0.	12.32	0.	15.00	0.	.985
77T086	6.10	0.	12.52	14.00	20.00	7.00	.957
77T089	7.32	0.	13.35	3.00	15.00	-4.00	.983
77T092	5.75	0.	13.58	-10.00	20.00	0.	.981
77T095	7.17	0.	13.27	0.	20.00	0.	.996
77T098	6.73	0.	13.03	5.00	25.00	-5.00	.995

TABLE 5.4. ACCELEROMETER PLACEMENT DATA (5 of 9)

LOWER STERNALS

TEST #	X	Y	Z	<X	<Y	<Z	RATING
A-867	-0.	-0.	16.83	-0.	-0.	-0.	-0.
A-868	7.50	0.	18.50	0.	-3.00	0.	.974
A-876	9.25	-1.50	18.30	-8.00	-9.00	-5.00	.933
A-877	7.25	0.	15.00	0.	5.00	0.	.996
A-880	9.00	0.	16.63	0.	14.00	-7.00	.991
A-883	6.88	0.	15.25	5.00	15.00	0.	.993
A-884	10.00	0.	17.50	-1.00	9.00	-2.00	.999
A-887	9.75	0.	16.25	0.	20.00	0.	.985
A-923	6.25	0.	15.75	0.	0.	8.00	.974
A-924	-0.	-0.	-0.	-0.	-0.	-0.	-0.
A-927	10.00	0.	15.75	0.	26.00	10.00	.945
A-928	6.50	0.	16.13	5.00	-7.00	6.00	.947
A-937	7.00	0.	15.38	0.	12.00	-7.00	.993
76T003	9.00	0.	17.50	-10.00	24.00	0.	.955
76T008	8.25	0.	16.75	-10.00	11.00	15.00	.948
76T009	7.50	0.	16.50	0.	5.00	-12.00	.977
76T010	9.00	0.	17.13	5.00	11.00	-3.00	.996
76T011	8.50	0.	16.75	-10.00	15.00	0.	.980
76T020	8.00	0.	15.00	10.00	20.00	-8.00	.963
76T021	-0.	-0.	16.38	-0.	-0.	-0.	-0.
76T022	-0.	-0.	16.38	-0.	-0.	-0.	-0.
76T024	-0.	-0.	17.13	-0.	-0.	-0.	-0.
76T025	-0.	-0.	17.90	-0.	-0.	-0.	-0.
76T029	9.60	0.	17.30	4.00	25.00	0.	.964
76T034	9.25	0.	18.75	0.	0.	6.00	.978
76T039	9.75	0.	19.75	0.	6.00	0.	.997
76T042	7.75	0.	17.25	0.	0.	0.	.985
76T050	9.09	0.	18.54	6.00	6.00	0.	.990
76T053	11.65	0.	16.34	0.	22.00	-5.00	.975
76T056	7.75	0.	16.75	0.	7.00	0.	.999
76T059	10.24	0.	18.35	5.00	18.00	-2.00	.987
76T062	8.98	0.	18.15	0.	2.00	0.	.990
76T065	8.90	0.	18.94	-5.00	-13.00	-5.00	.914
77T068	7.68	0.	18.62	-5.00	0.	0.	.980
77T071	8.86	0.	16.81	5.00	15.00	0.	.993
77T074	8.39	0.	17.44	5.00	5.00	-4.00	.991
77T077	8.90	0.	16.77	0.	12.00	-7.00	.993
77T080	7.24	0.	16.81	-3.00	4.00	4.00	.990
77T083	8.62	0.	16.34	0.	20.00	5.00	.980
77T086	7.68	0.	16.50	9.00	14.00	0.	.986
77T089	8.58	0.	20.87	4.00	15.00	6.00	.988
77T092	6.26	0.	17.60	-5.00	15.00	0.	.992
77T095	9.13	0.	18.15	5.00	20.00	-6.00	.977
77T098	8.94	0.	17.09	0.	20.00	-5.00	.982

TABLE 5.4. ACCELEROMETER PLACEMENT DATA (6 of 9)

UPPER SPINALS

TEST #	X	Y	Z	<X	<Y	<Z	RATING
A-867	- .50	0.	11.25	0.	-5.00	0.	.975
A-868	-1.00	0.	12.25	0.	-3.00	0.	.967
A-876	0.	0.	8.50	0.	-11.00	0.	.993
A-877	0.	0.	9.75	0.	-24.00	0.	.994
A-880	0.	0.	10.00	5.00	-50.00	-12.00	.824
A-883	0.	0.	11.50	2.00	-4.00	10.00	.956
A-884	0.	0.	12.25	-1.00	-1.00	-2.00	.957
A-887	0.	0.	9.75	0.	-21.00	0.	.998
A-923	0.	0.	11.00	-2.00	0.	0.	.952
A-924	-0.	-0.	-0.	-0.	-0.	-0.	-0.
A-927	0.	0.	9.00	10.00	-28.00	-5.00	.966
A-928	-0.	-0.	-0.	-0.	-0.	-0.	-0.
A-937	- .50	0.	10.38	0.	-22.00	-4.00	.995
76T003	0.	0.	9.25	10.00	-25.00	7.00	.970
76T008	- .50	0.	9.75	-2.00	-21.00	-2.00	.997
76T009	- .50	0.	8.90	0.	-32.00	10.00	.954
76T010	0.	0.	9.75	0.	-34.00	0.	.960
76T011	0.	0.	9.50	3.00	-32.00	0.	.968
76T020	0.	0.	8.75	-13.00	-21.00	-12.00	.951
76T021	- .50	0.	10.10	-4.00	-41.00	-4.00	.914
76T022	0.	0.	9.50	0.	-10.00	-4.00	.989
76T024	0.	0.	9.25	0.	-8.00	0.	.986
76T025	0.	0.	11.00	3.00	-29.00	-8.00	.970
76T029	0.	0.	9.40	0.	-35.00	0.	.955
76T034	0.	0.	9.75	-20.00	-45.00	0.	.834
76T039	0.	0.	11.25	0.	-15.00	4.00	.996
76T042	0.	0.	12.50	0.	-10.00	0.	.991
76T050	0.	0.	9.72	-7.00	-30.00	-10.00	.955
76T053	0.	0.	8.74	-3.00	-29.00	-2.00	.979
76T056	0.	0.	10.00	3.00	-30.00	-2.00	.975
76T059	0.	0.	11.00	7.00	-15.00	-5.00	.988
76T062	0.	0.	10.31	6.00	-10.00	5.00	.982
76T065	0.	0.	10.75	0.	-2.00	0.	.963
77T068	0.	0.	8.98	-4.00	-5.00	0.	.973
77T071	0.	0.	9.80	0.	-8.00	6.00	.980
77T074	0.	0.	9.65	-4.00	-15.00	0.	.996
77T077	0.	0.	9.65	7.00	-5.00	10.00	.954
77T080	0.	0.	10.04	0.	-5.00	-8.00	.966
77T083	0.	0.	9.45	0.	-7.00	0.	.983
77T086	0.	0.	9.17	0.	-8.00	4.00	.983
77T089	0.	0.	10.43	0.	-30.00	0.	.977
77T092	0.	0.	10.31	0.	0.	4.00	.950
77T095	0.	0.	10.87	0.	-10.00	10.00	.976
77T098	0.	0.	9.96	12.00	-8.00	10.00	.950

5.16

TABLE 5.4. ACCELEROMETER PLACEMENT DATA (7 of 9)

LOWER SPINALS

TEST #	X	Y	Z	<X	<Y	<Z	RATING
A-867	-.50	0.	19.75	0.	25.00	0.	.957
A-868	-1.00	0.	22.25	0.	7.00	0.	.999
A-876	0.	0.	21.75	0.	9.00	0.	1.000
A-877	0.	0.	19.25	0.	7.00	0.	.999
A-880	0.	0.	22.50	0.	18.00	0.	.985
A-883	0.	0.	19.75	-3.00	-7.00	15.00	.937
A-884	0.	0.	23.00	-4.00	17.00	5.00	.984
A-887	0.	0.	19.00	0.	-2.00	5.00	.982
A-923	0.	0.	19.75	0.	0.	0.	.989
A-924	-0.	-0.	-0.	-0.	-0.	-0.	-0.
A-927	0.	0.	21.55	0.	13.00	0.	.996
A-928	-0.	-0.	-0.	-0.	-0.	-0.	-0.
A-937	-.50	0.	21.50	0.	6.00	0.	.999
76T003	0.	0.	22.88	0.	8.00	7.00	.995
76T008	-.50	0.	19.25	1.00	9.00	-2.00	.998
76T009	-.50	0.	19.25	1.00	10.00	15.00	.971
76T010	0.	0.	24.50	0.	0.	0.	.989
76T011	0.	0.	22.50	12.00	13.00	11.00	.961
76T020	0.	0.	20.13	-2.00	4.00	8.00	.990
76T021	-.50	0.	21.00	1.00	0.	3.00	.989
76T022	0.	0.	21.50	0.	4.00	0.	.997
76T024	0.	0.	22.00	0.	0.	-8.00	.976
76T025	0.	0.	26.00	5.00	6.00	-4.00	.991
76T029	0.	0.	20.20	-4.00	13.00	4.00	.993
76T034	0.	0.	20.50	0.	11.00	-9.00	.982
76T039	0.	0.	24.00	0.	5.00	0.	.998
76T042	0.	0.	22.00	0.	0.	5.00	.988
76T050	0.	0.	24.02	3.00	5.00	0.	.997
76T053	0.	0.	22.13	-2.00	15.00	-2.00	.991
76T056	0.	0.	21.38	0.	5.00	-4.00	.994
76T059	0.	0.	23.00	2.00	0.	-10.00	.969
76T062	0.	0.	21.73	0.	12.00	0.	.998
76T065	0.	0.	23.82	-2.00	0.	8.00	.983
77T068	0.	0.	21.85	0.	10.00	2.00	.999
77T071	0.	0.	20.47	0.	6.00	5.00	.997
77T074	0.	0.	21.30	-4.00	20.00	-10.00	.957
77T077	0.	0.	21.54	8.00	0.	0.	.979
77T080	0.	0.	20.39	0.	19.00	-7.00	.972
77T083	0.	0.	19.57	-5.00	15.00	5.00	.988
77T086	0.	0.	19.61	-5.00	8.00	0.	.996
77T089	0.	0.	22.71	0.	7.00	0.	.999
77T092	0.	0.	21.06	-4.00	18.00	4.00	.982
77T095	0.	0.	21.06	-4.00	20.00	5.00	.975
77T098	0.	0.	20.24	0.	10.00	8.00	.993

5.17

TABLE 5.4. ACCELEROMETER PLACEMENT DATA (8 of 9)

PELVIS

TEST #	X	Y	Z	<X	<Y	<Z	RATING
A-867	-0.	-0.	-0.	-0.	-0.	-0.	-0.
A-868	-0.	-0.	-0.	-0.	-0.	-0.	-0.
A-876	-0.	-0.	-0.	-0.	-0.	-0.	-0.
A-877	-0.	-0.	-0.	-0.	-0.	-0.	-0.
A-880	-0.	-0.	-0.	-0.	-0.	-0.	-0.
A-883	-0.	-0.	-0.	-0.	-0.	-0.	-0.
A-884	-0.	-0.	-0.	-0.	-0.	-0.	-0.
A-887	-0.	-0.	-0.	-0.	-0.	-0.	-0.
A-923	-0.	-0.	-0.	-0.	-0.	-0.	-0.
A-924	-0.	-0.	-0.	-0.	-0.	-0.	-0.
A-927	-0.	-0.	-0.	-0.	-0.	-0.	-0.
A-928	-0.	-0.	-0.	-0.	-0.	-0.	-0.
A-937	-0.	-0.	-0.	-0.	-0.	-0.	-0.
76T003	-0.	-0.	-0.	-0.	-0.	-0.	-0.
76T008	-0.	-0.	-0.	-0.	-0.	-0.	-0.
76T009	-0.	-0.	26.00	-0.	-0.	10.00	.989
76T010	-0.	-0.	-0.	1.00	-0.	-0.	-0.
76T011	-0.	-0.	29.25	7.00	-0.	6.00	.992
76T020	-0.	-0.	-0.	-0.	-0.	-0.	-0.
76T021	-0.	-0.	-0.	-0.	-0.	-0.	-0.
76T022	-0.	-0.	-0.	-0.	-0.	-0.	-0.
76T024	-0.	-0.	-0.	-0.	-0.	-0.	-0.
76T025	-0.	-0.	-0.	-0.	-0.	-0.	-0.
76T029	-0.	-0.	-0.	-0.	-0.	-0.	-0.
76T034	0.	0.	29.00	0.	0.	4.00	.998
76T039	0.	0.	31.50	0.	0.	0.	.999
76T042	0.	0.	30.00	0.	0.	0.	.999
76T050	-0.	-0.	-0.	-0.	-0.	-0.	-0.
76T053	-0.	-0.	-0.	-0.	-0.	-0.	-0.
76T056	-0.	-0.	-0.	-0.	-0.	-0.	-0.
76T059	-0.	-0.	-0.	-0.	-0.	-0.	-0.
76T062	-0.	-0.	-0.	-0.	-0.	-0.	-0.
76T065	-0.	-0.	-0.	-0.	-0.	-0.	-0.
77T068	-0.	-0.	-0.	-0.	-0.	-0.	-0.
77T071	-0.	-0.	-0.	-0.	-0.	-0.	-0.
77T074	-0.	-0.	-0.	-0.	-0.	-0.	-0.
77T077	-0.	-0.	-0.	-0.	-0.	-0.	-0.
77T080	-0.	-0.	-0.	-0.	-0.	-0.	-0.
77T083	-0.	-0.	-0.	-0.	-0.	-0.	-0.
77T086	-0.	-0.	-0.	-0.	-0.	-0.	-0.
77T089	-0.	0.	30.43	-0.	-0.	-0.	-0.
77T092	0.	0.	30.35	4.00	7.00	0.	.994
77T095	0.	0.	30.51	0.	5.00	0.	.997
77T098	0.	0.	27.76	0.	0.	-8.00	.986

as the rotation visible in the Y-Z plane about the x-axis. Entries labeled with "-0." were either not obtained or incorrectly recorded.

The last column is indication of the comparative angular orientation of the mounts at the time they were installed. For each mount location, the mean value of each of the three angular orientations was computed. The difference between the angle measured for the individual test and the mean was then computed. This difference in angle then was defined as the comparative "error" for the particular mount for the rotation about the particular coordinate. When the "error" is zero, the cosine of this error angle is 1.0. When there is a non-zero error, the cosine is less than 1.0. A quality indicator, the last column in Table 5.4, was computed by multiplying the three cosine quantities for each mount location together for each test subject.

Over 75% of the mounts have a rating in excess of 0.95 indicating a reasonable accuracy with respect to the comparative orientation of the various mounts. No mount has a rating less than 0.79.

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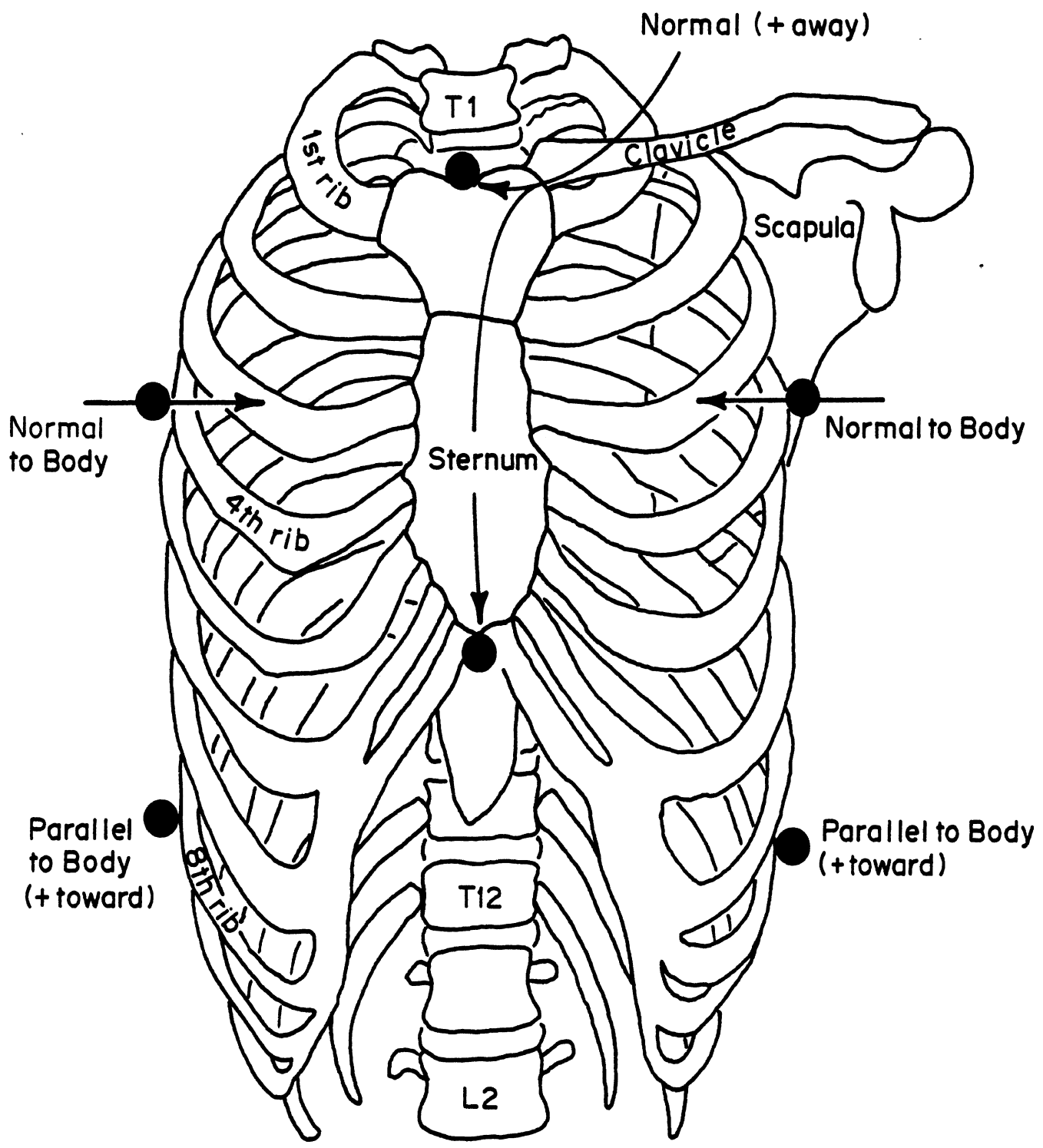


Figure 2.1. Accelerometer locations (front view).

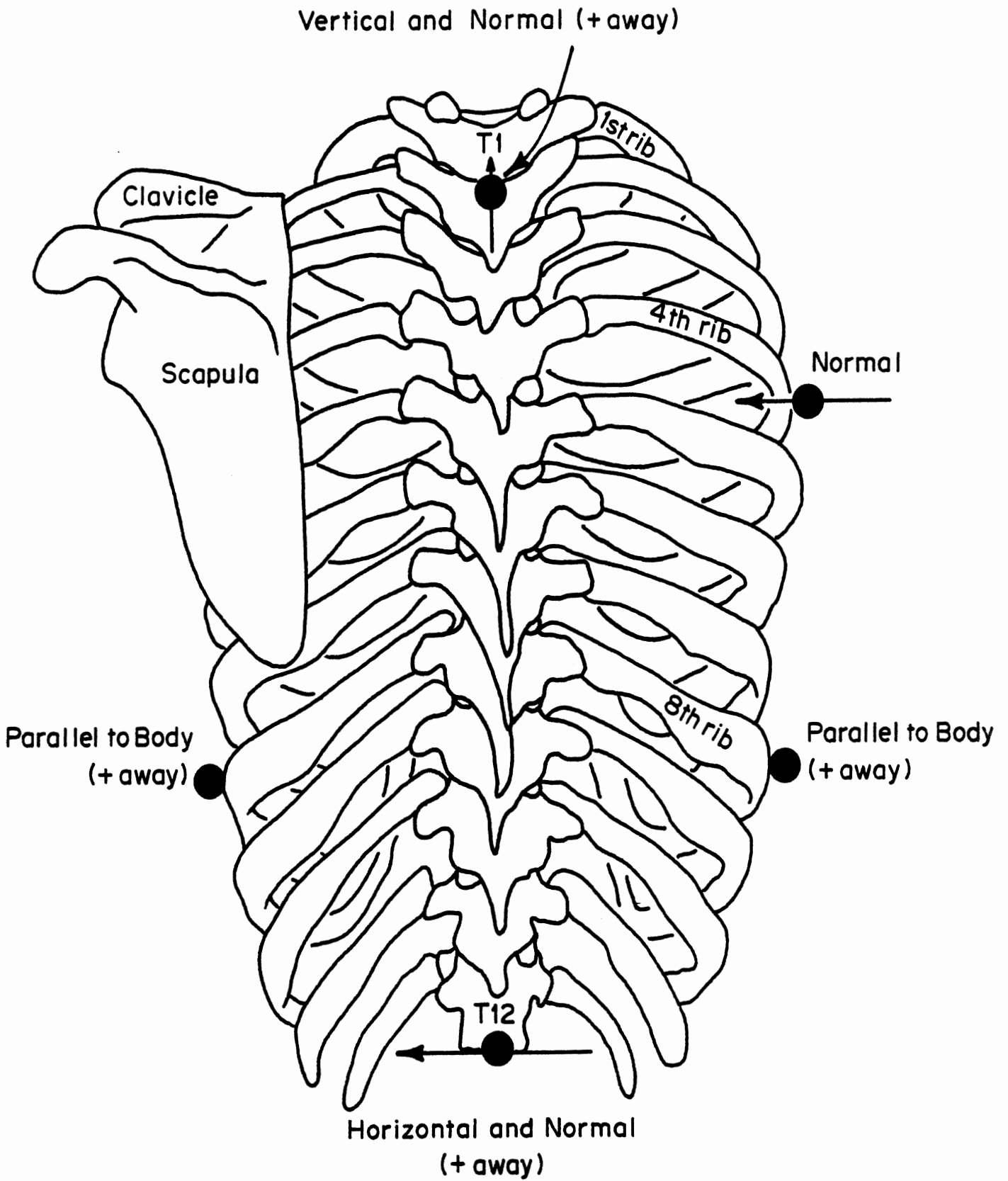


Figure 2.2 Accelerometer locations (back view).



Figure 3.1. HSRI impact sled.

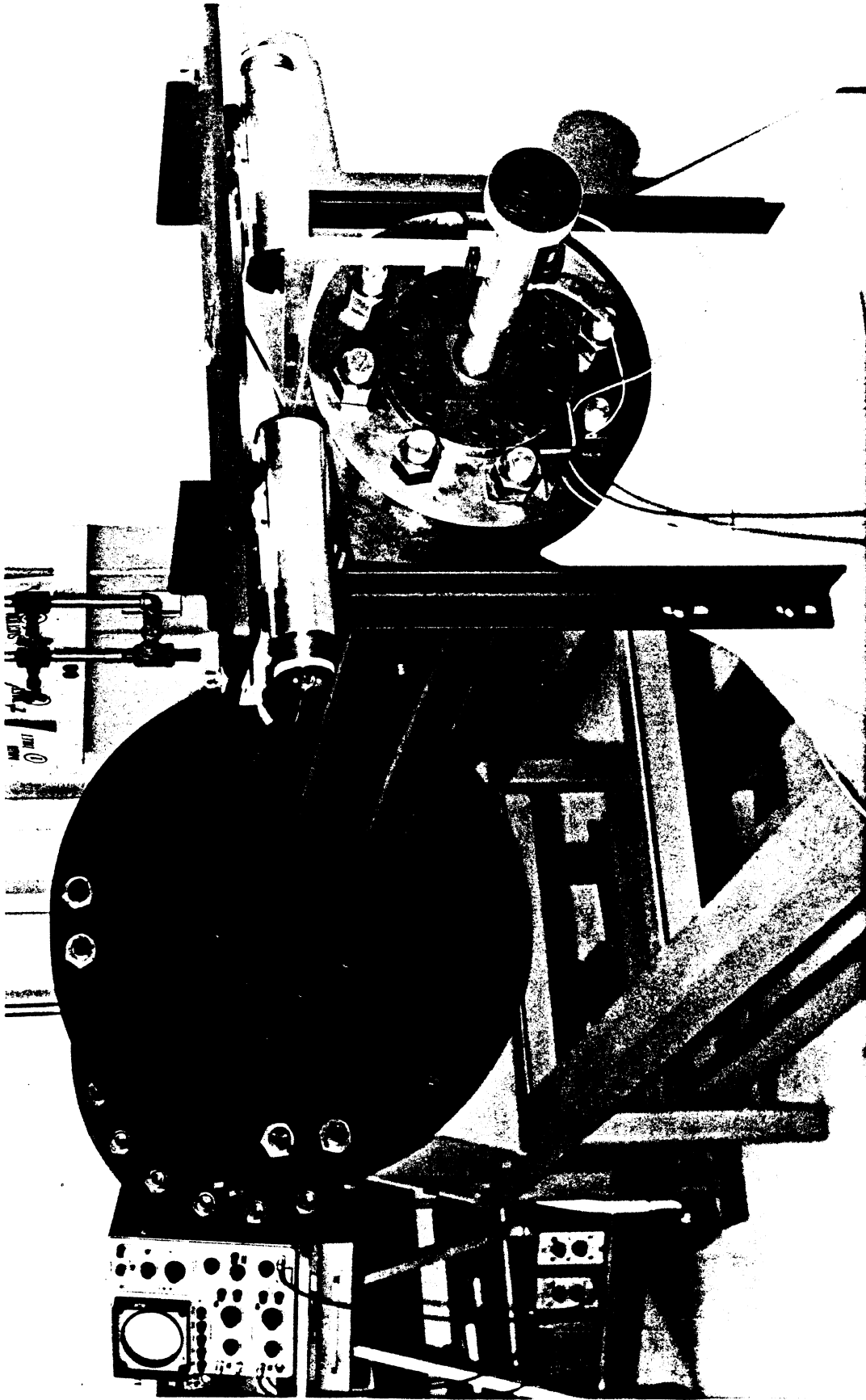
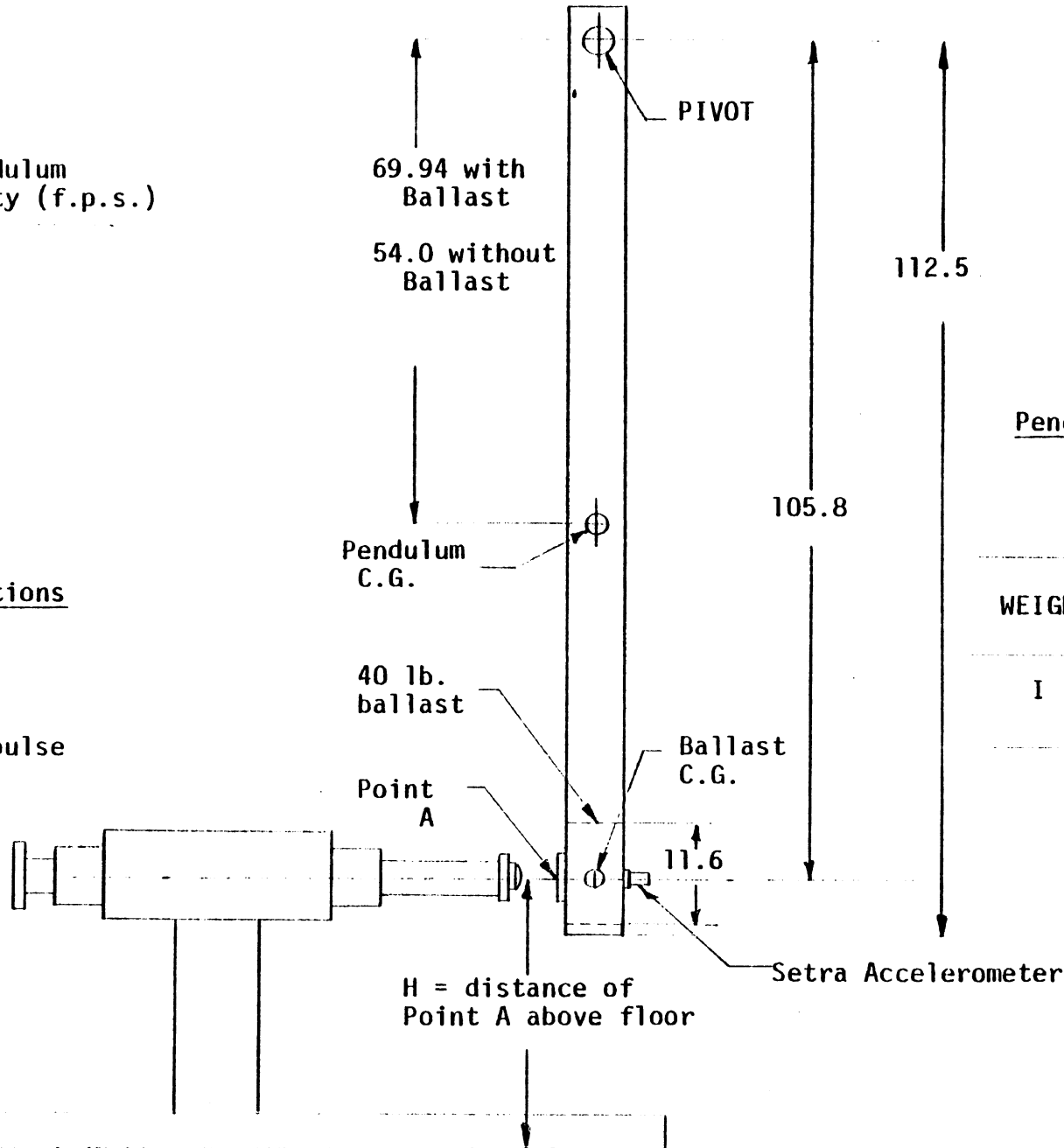


Figure 3.2 Pneumatically operated testing machine (Cannon).

H (inches)	Ballasted Pendulum Piston Velocity (f.p.s.)
53.6	7.0
55.0	7.5
80.0	12.9
89.5	14.1
91.0	14.6
141.6	20.8

Transfer Piston Specifications

2.500 in. diameter
 36 in. length
 15.25 in. max. stroke
 51.5 lb. weight
 .352 in. per velocity pulse



Pendulum specifications

	WITH BALLAST	WITHOUT BALLAST
WEIGHT	136.8#	96.8#
I	185 lb. ft. sec ²	88 lb. ft. sec ²

Figure 3.3. Pendulum impactor and transfer piston.

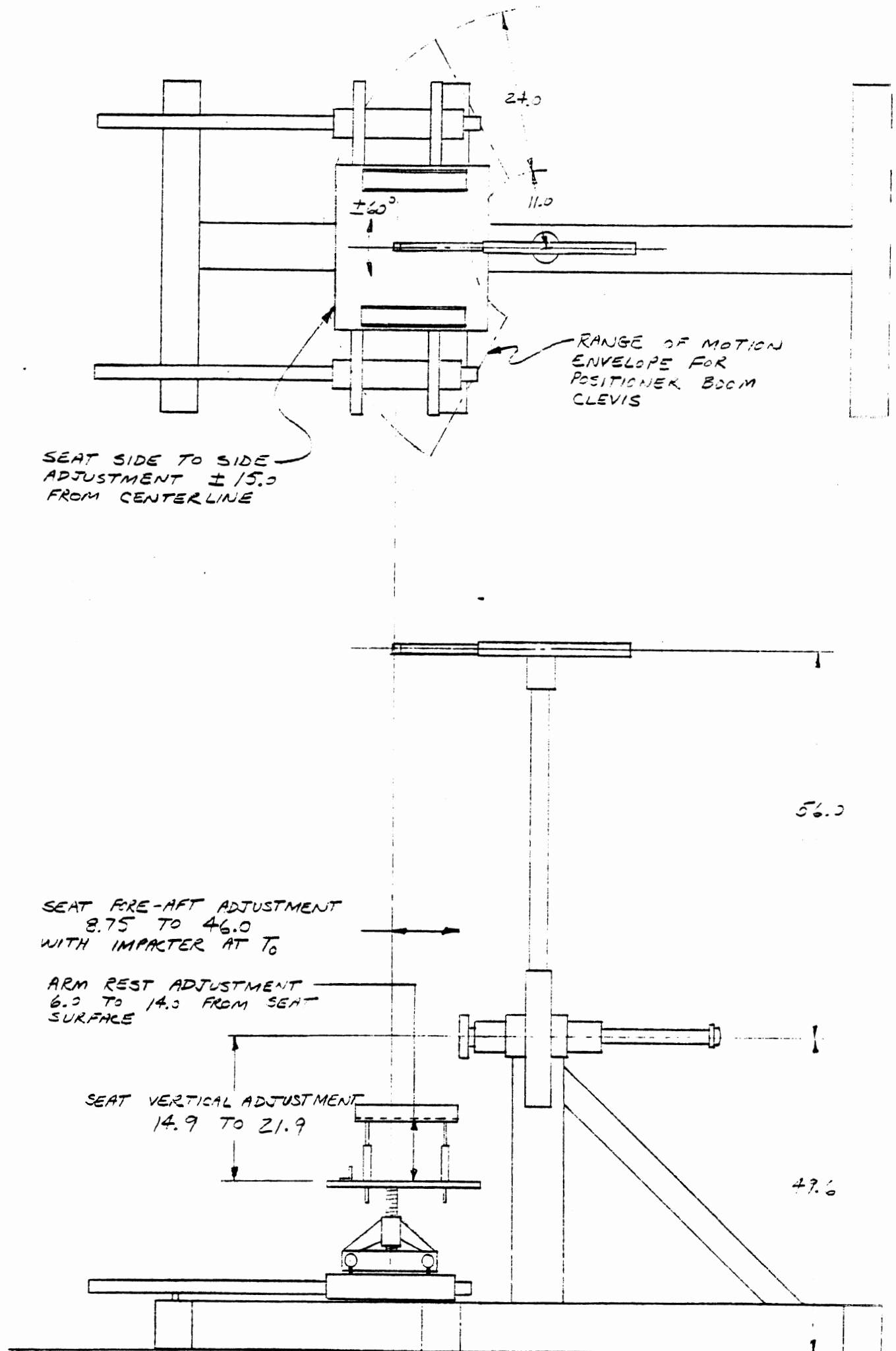


Figure 3.4. Pendulum impactor subject positioning hardware. 1/20 SCALE 3.14

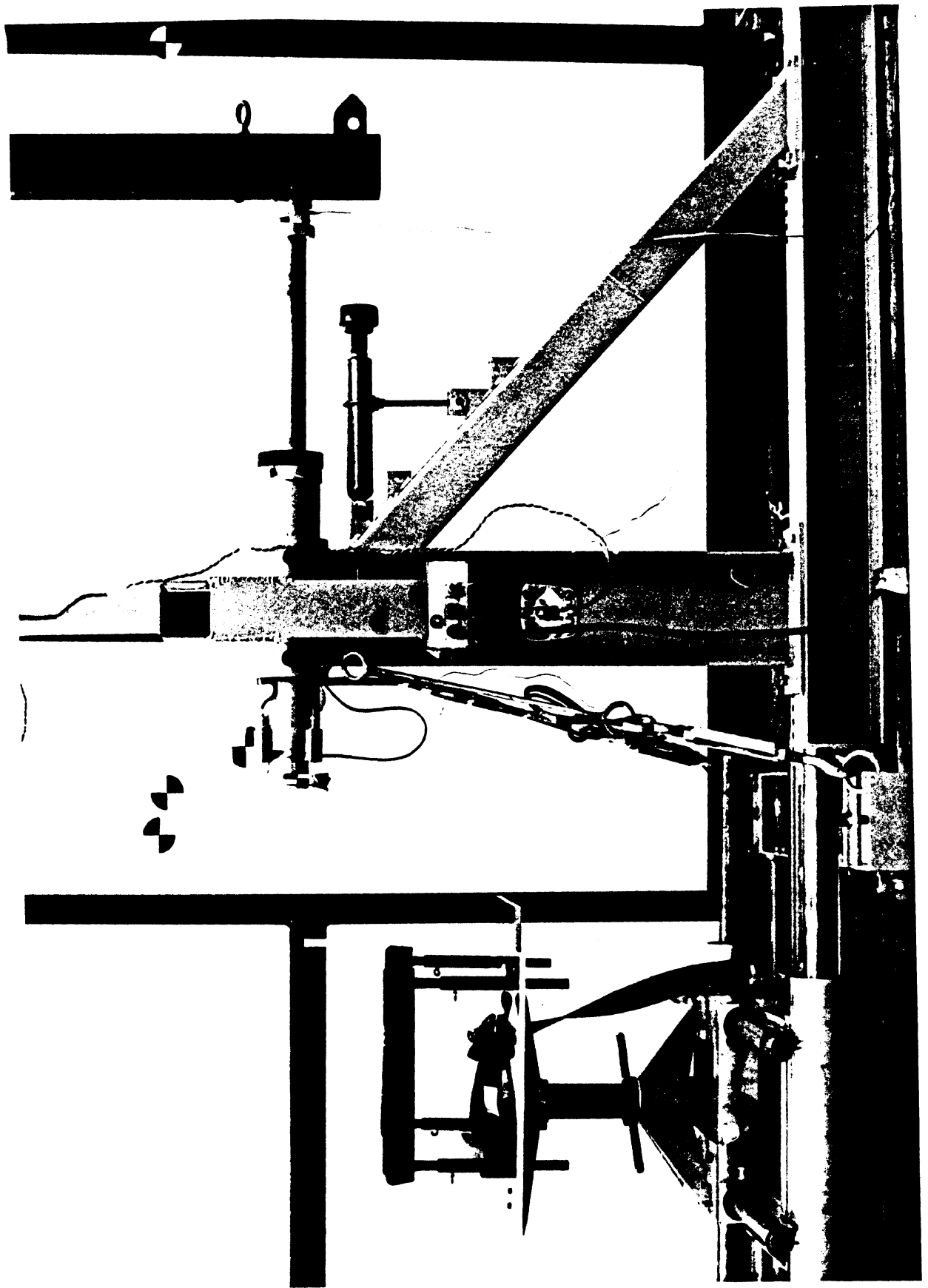


Figure 3.5. Pendulum impactor.

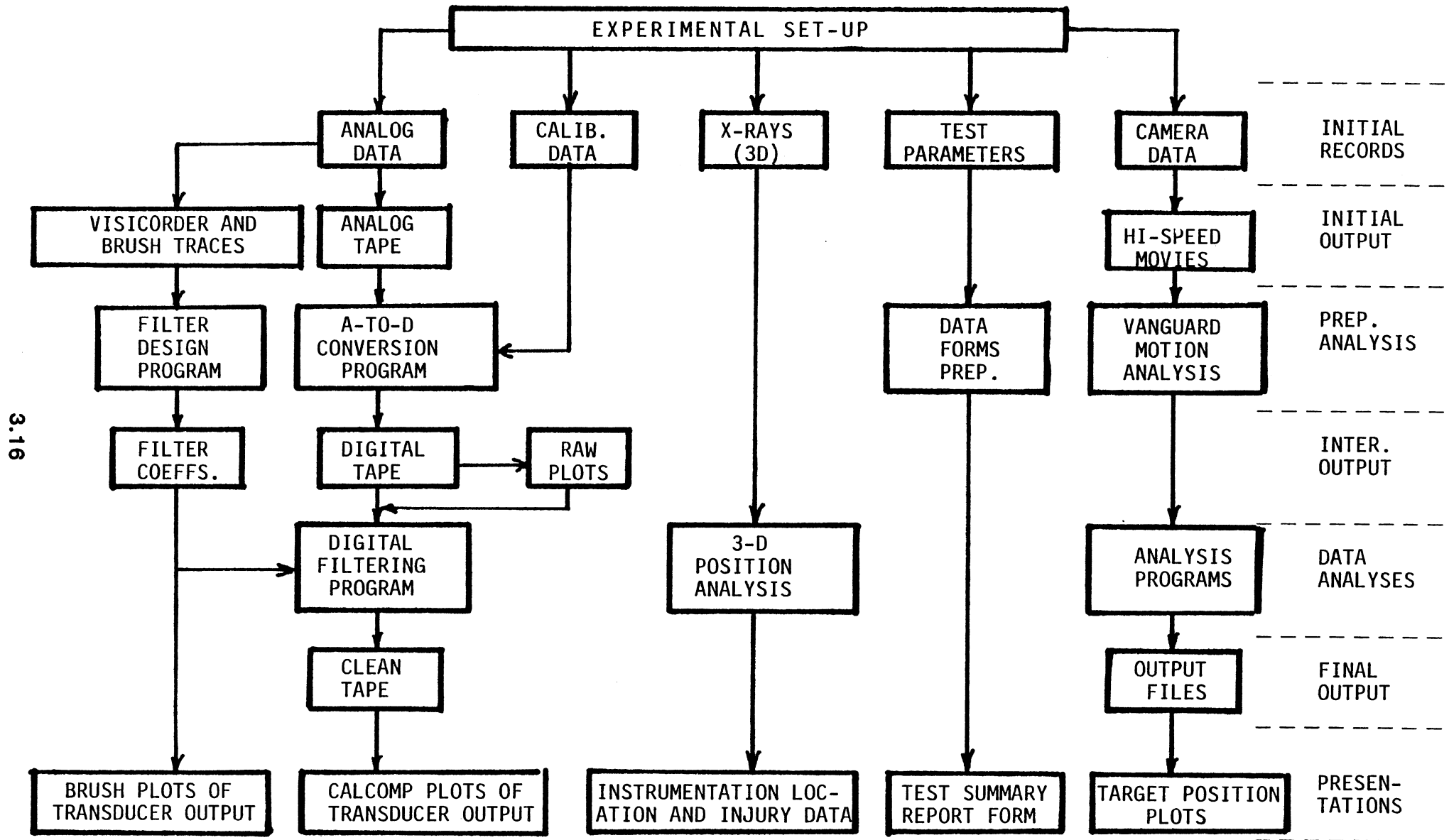


FIGURE 3.6 HSRI DATA HANDLING SYSTEM

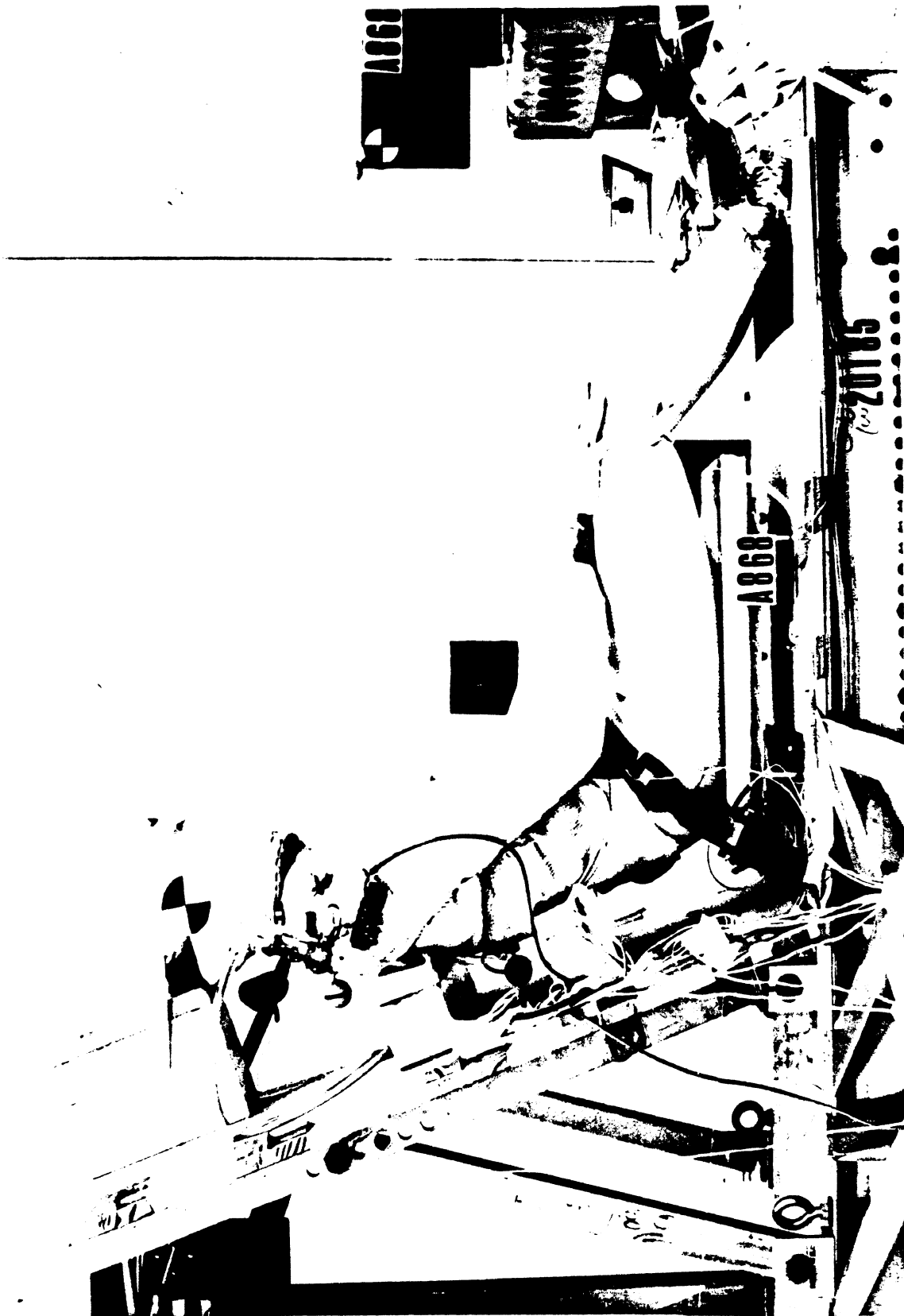


Figure 3.7. Test setup. Frontal impact with 3-point belts . Side view.

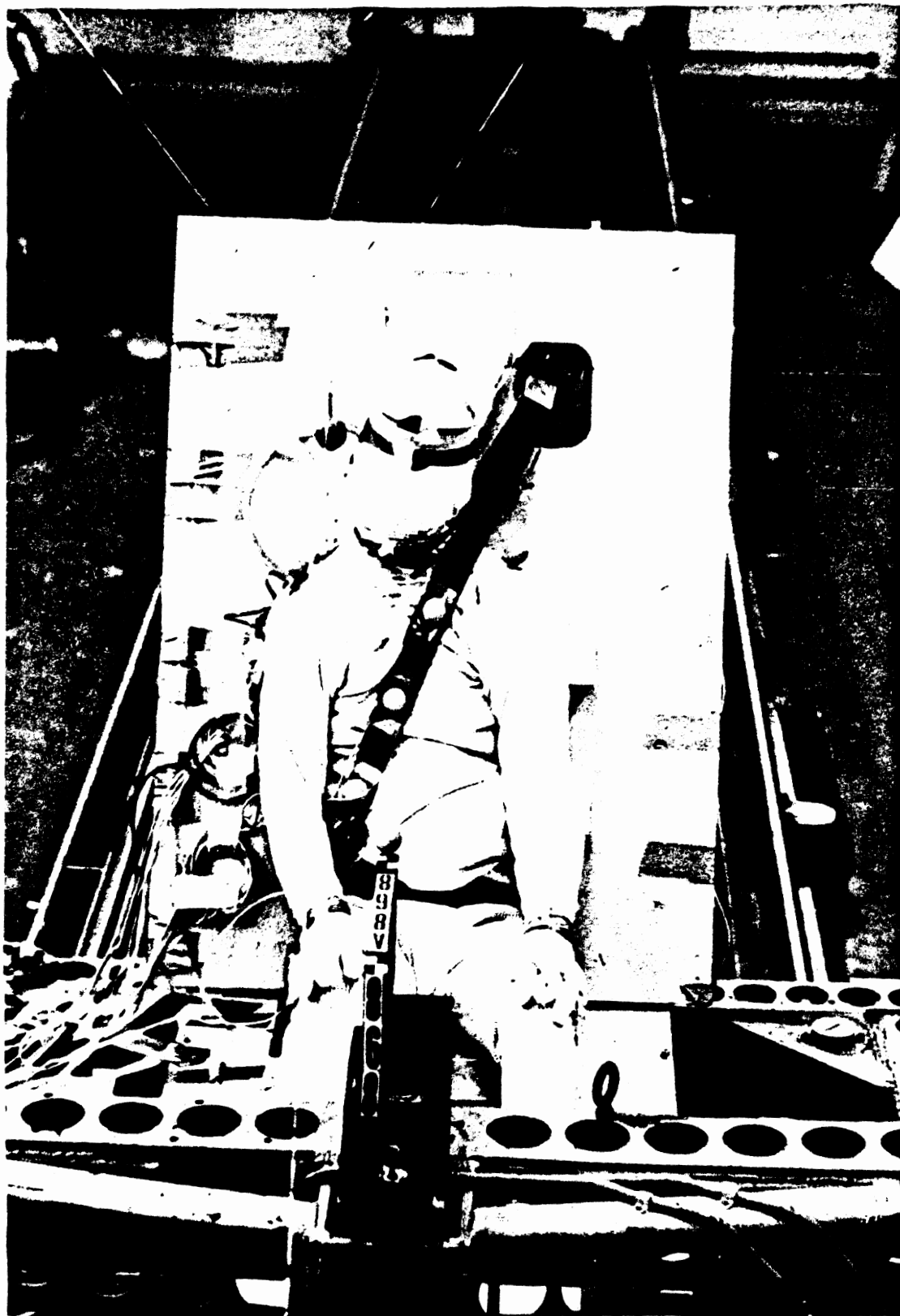


Figure 3.8. Test setup. Frontal impact with 3-point belts. Front view.

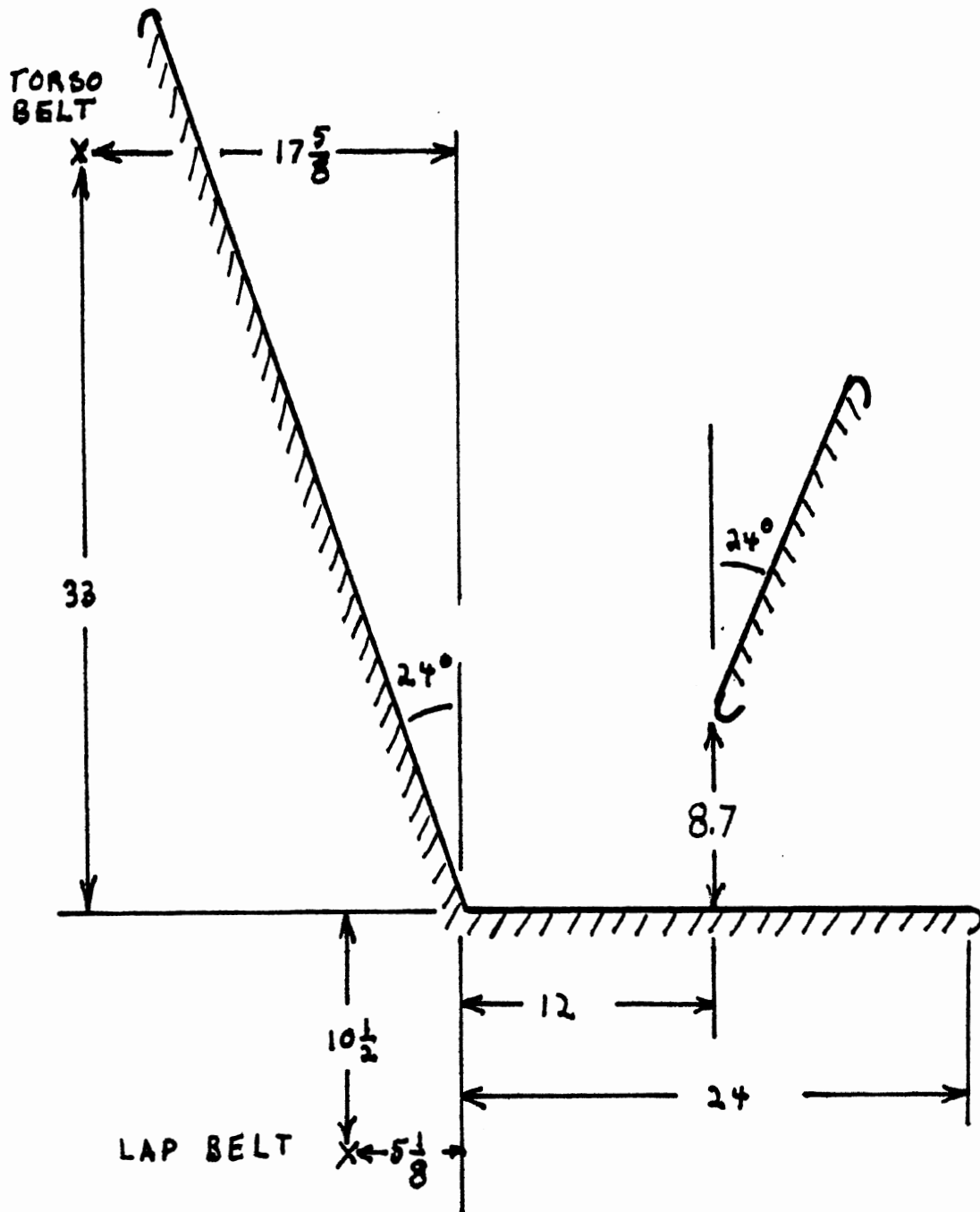


Figure 3.9. Seat buck schematic for frontal impact sled tests.

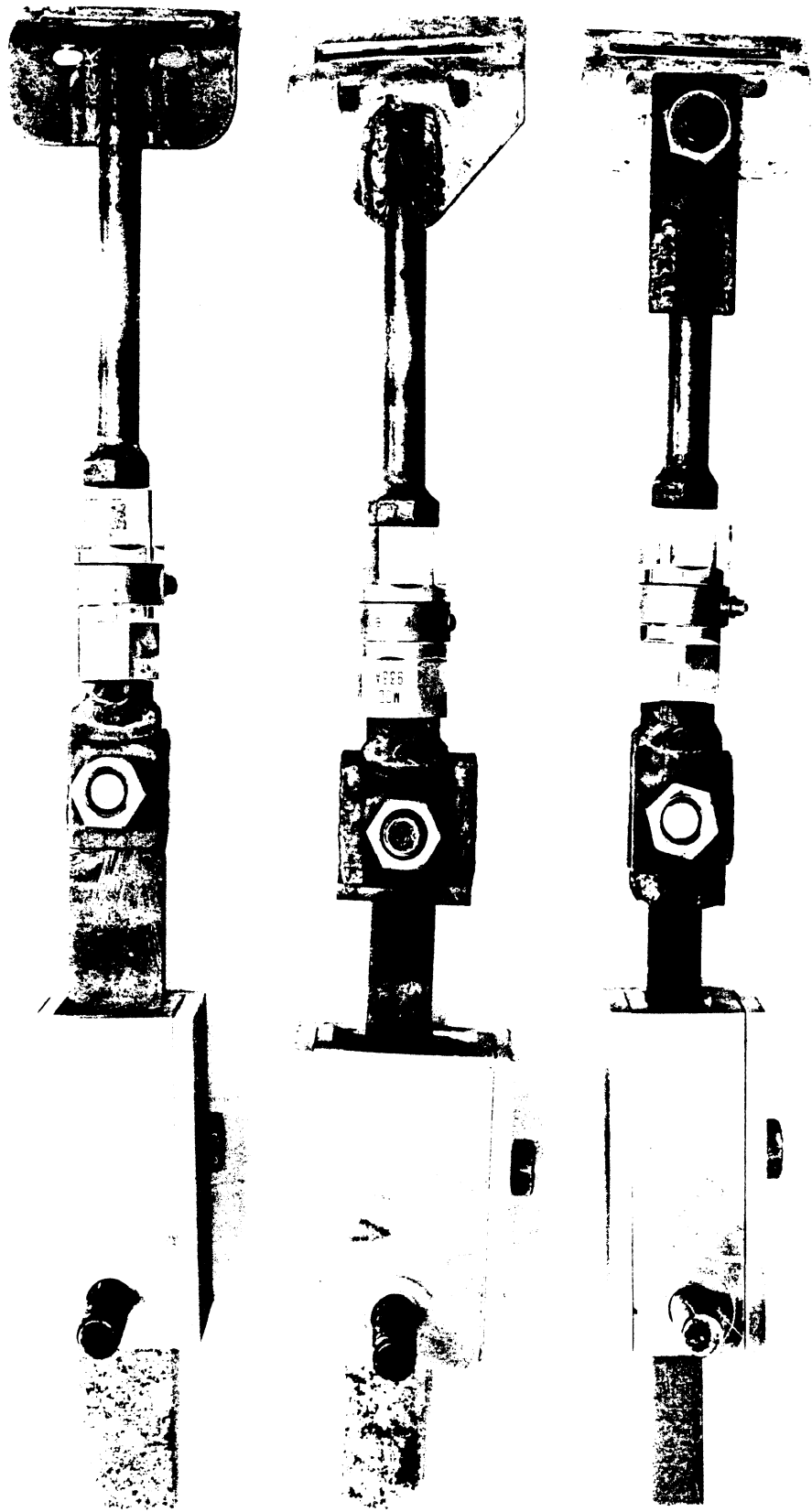
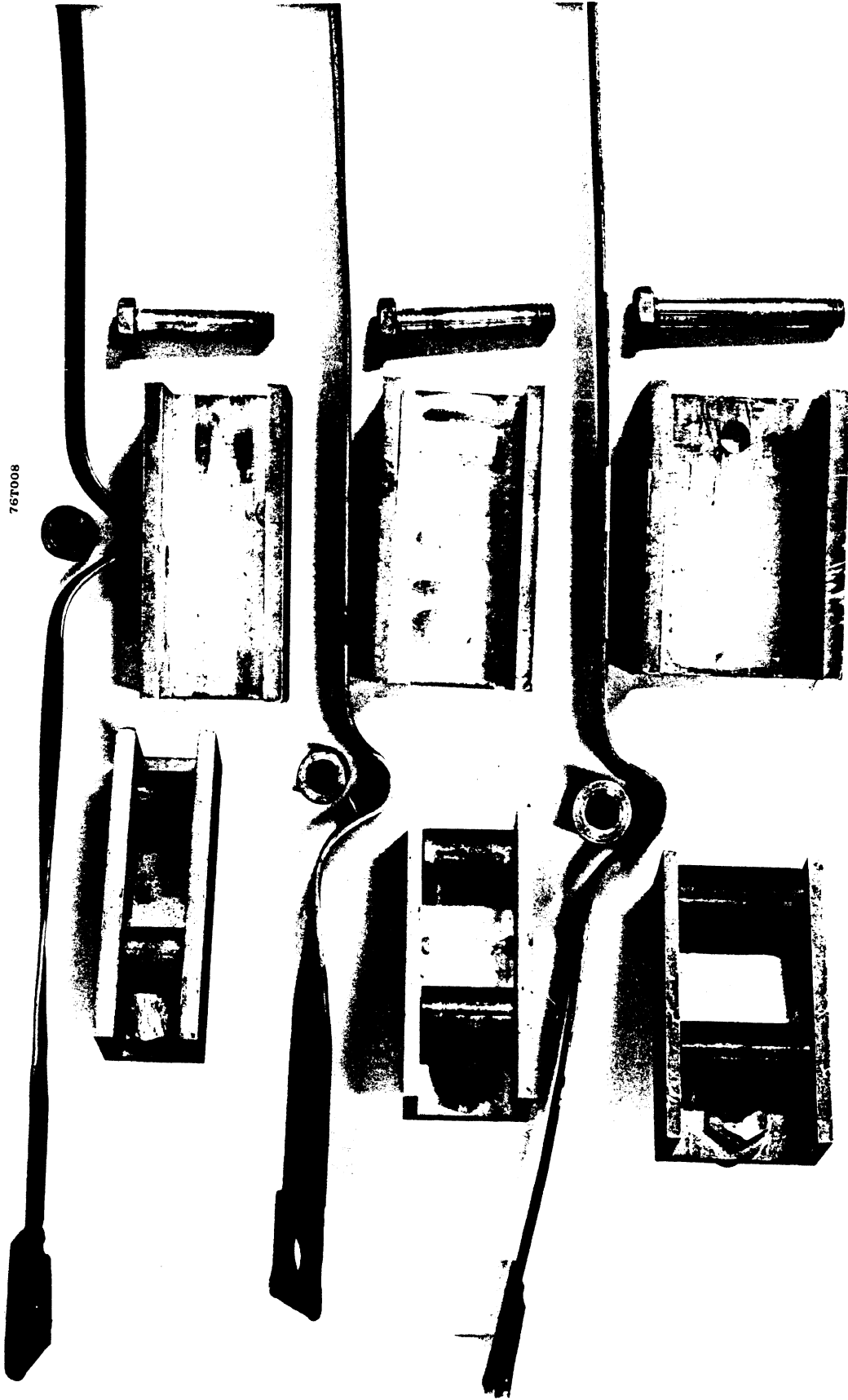


Figure 3.10. Yielding belt anchor assembly.



76T008

Figure 3.11. Yielding belt anchor. Disassembled.

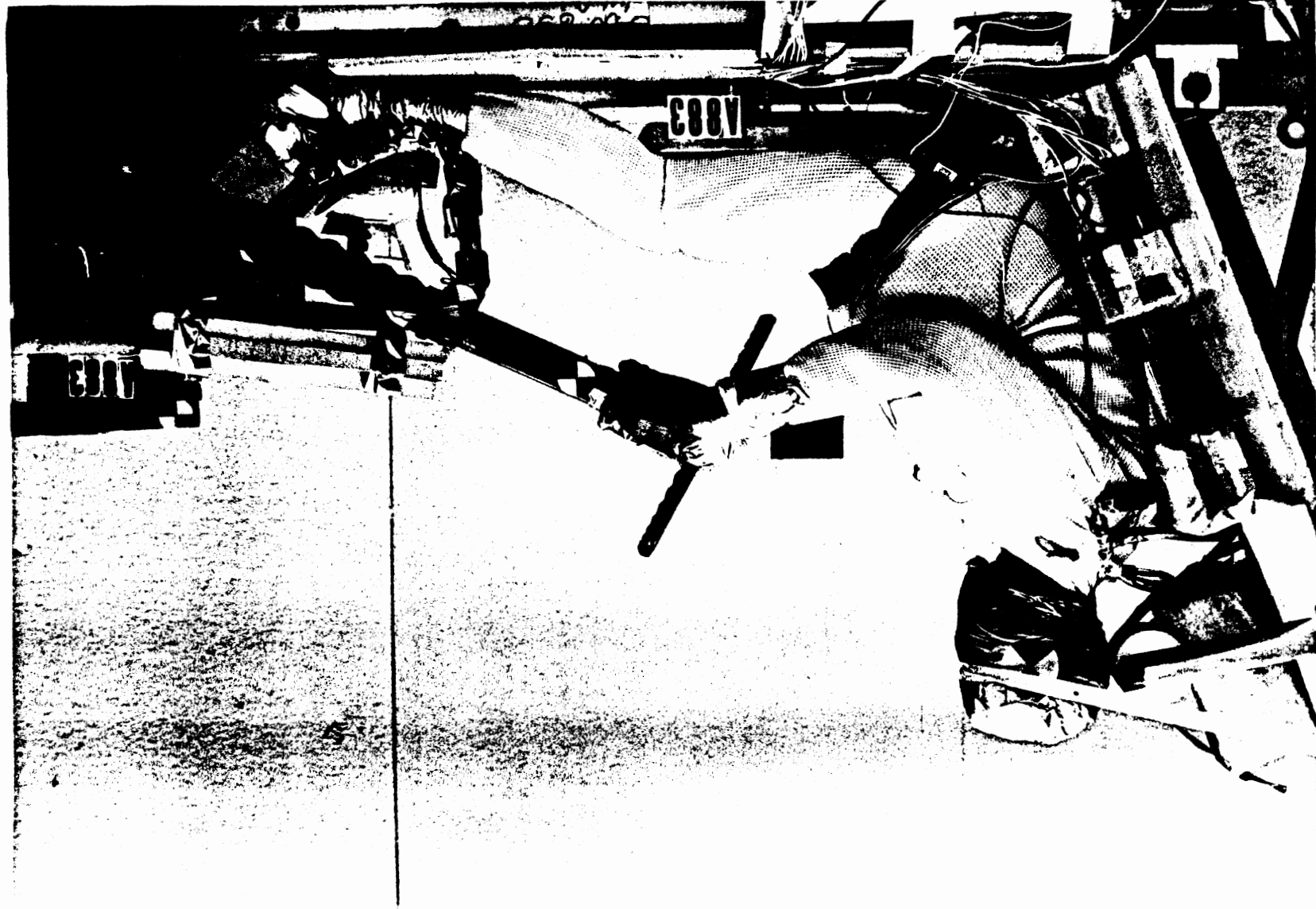


Figure 3.12. Test setup. Frontal impact using EA column and lap belt. Side view.

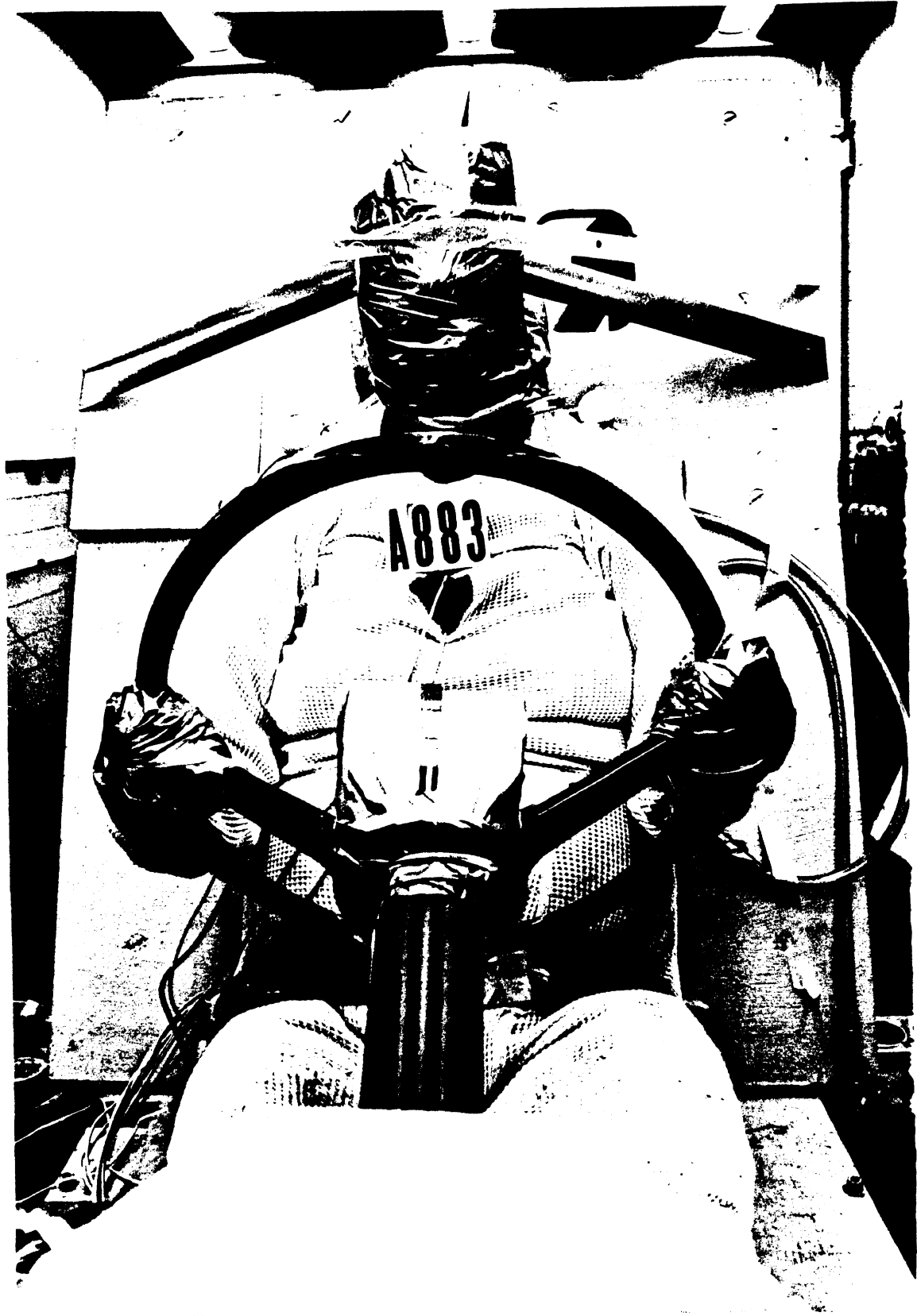


Figure 3.13. Test setup. Frontal impact using EA column and lap belt.
Front view.

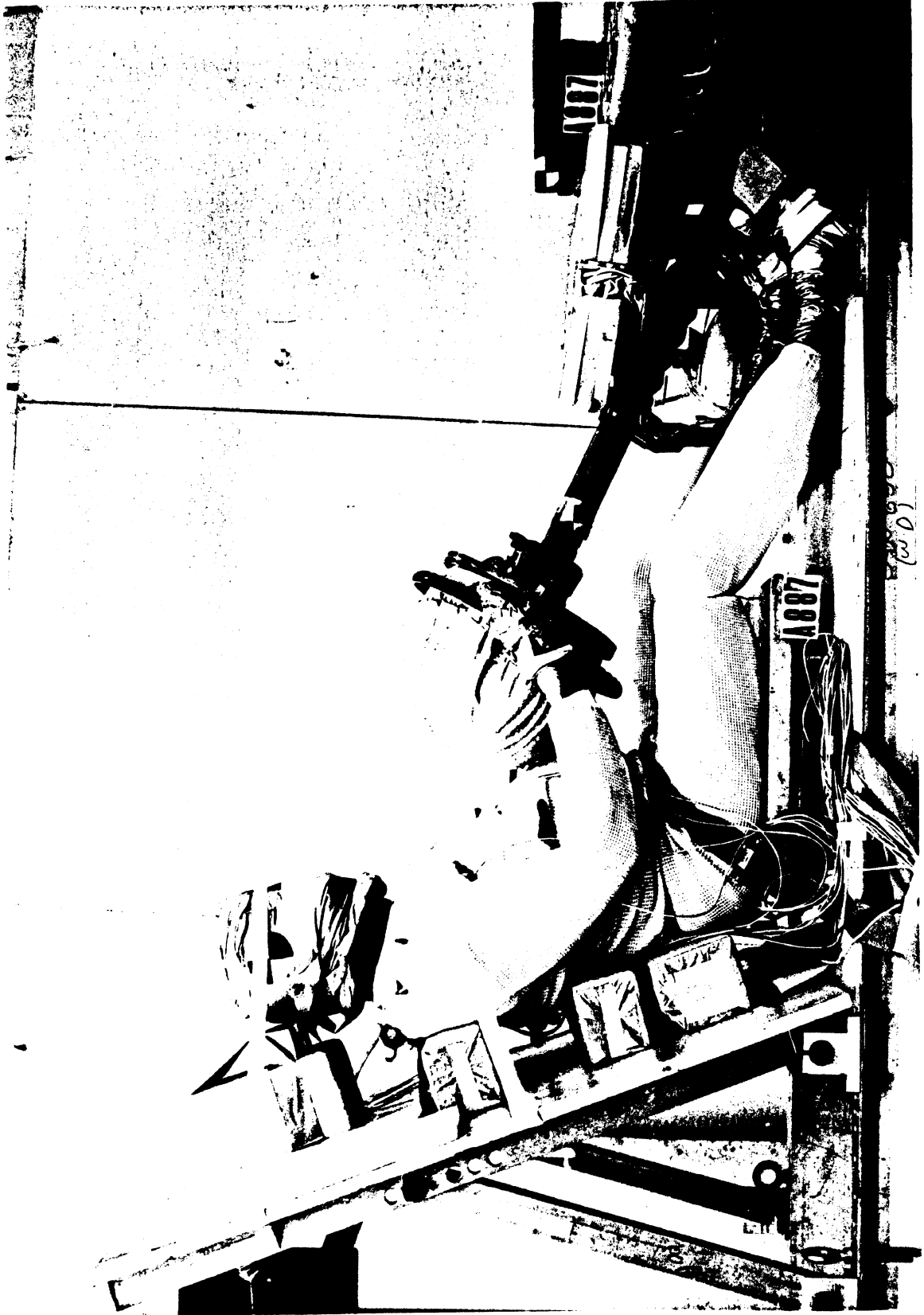


Figure 3.14. Test setup. Frontal impact using EA column with air cushion inserts. Side view.

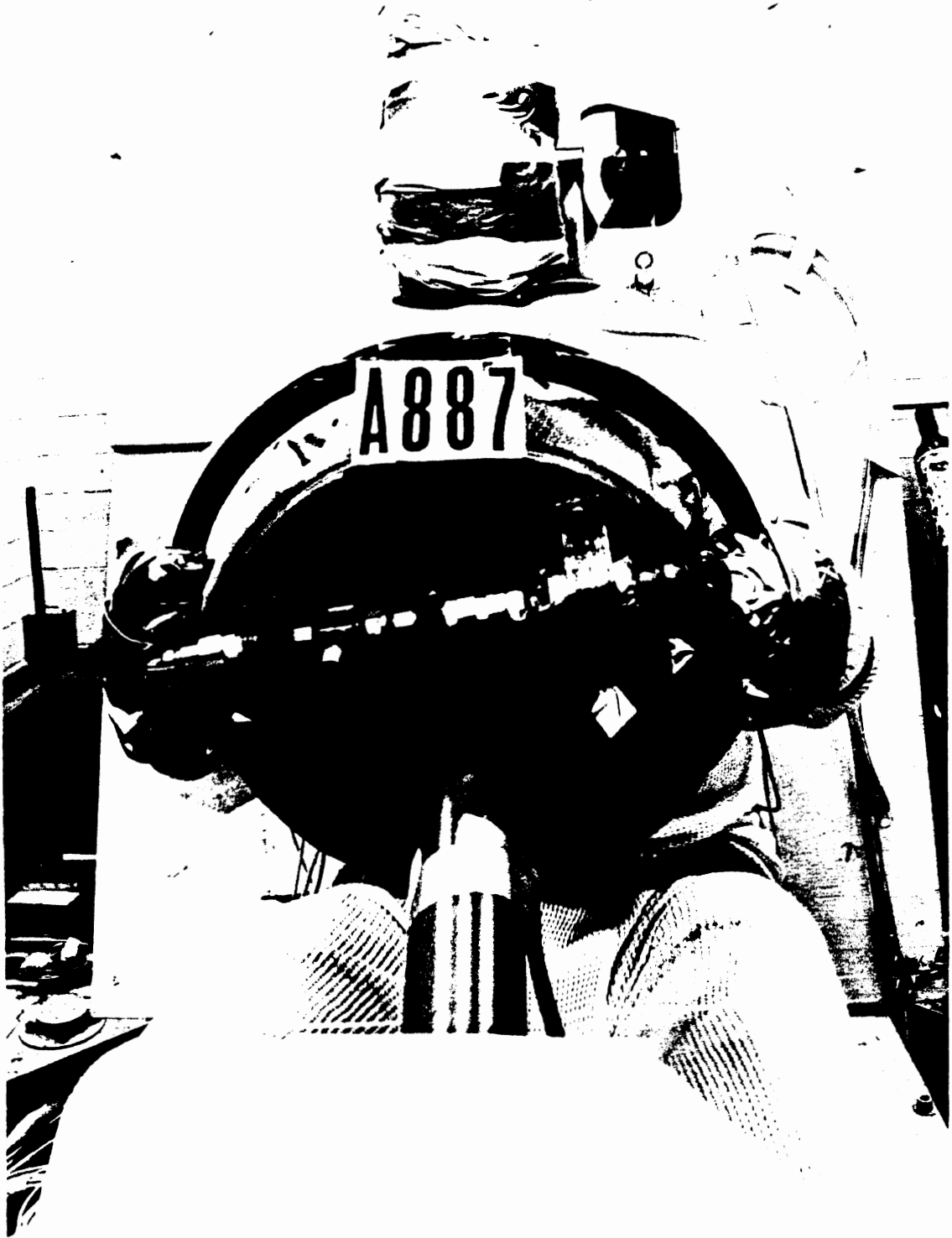


Figure 3.15. Test setup. Frontal impact using EA column with air cushion inserts. Front view.

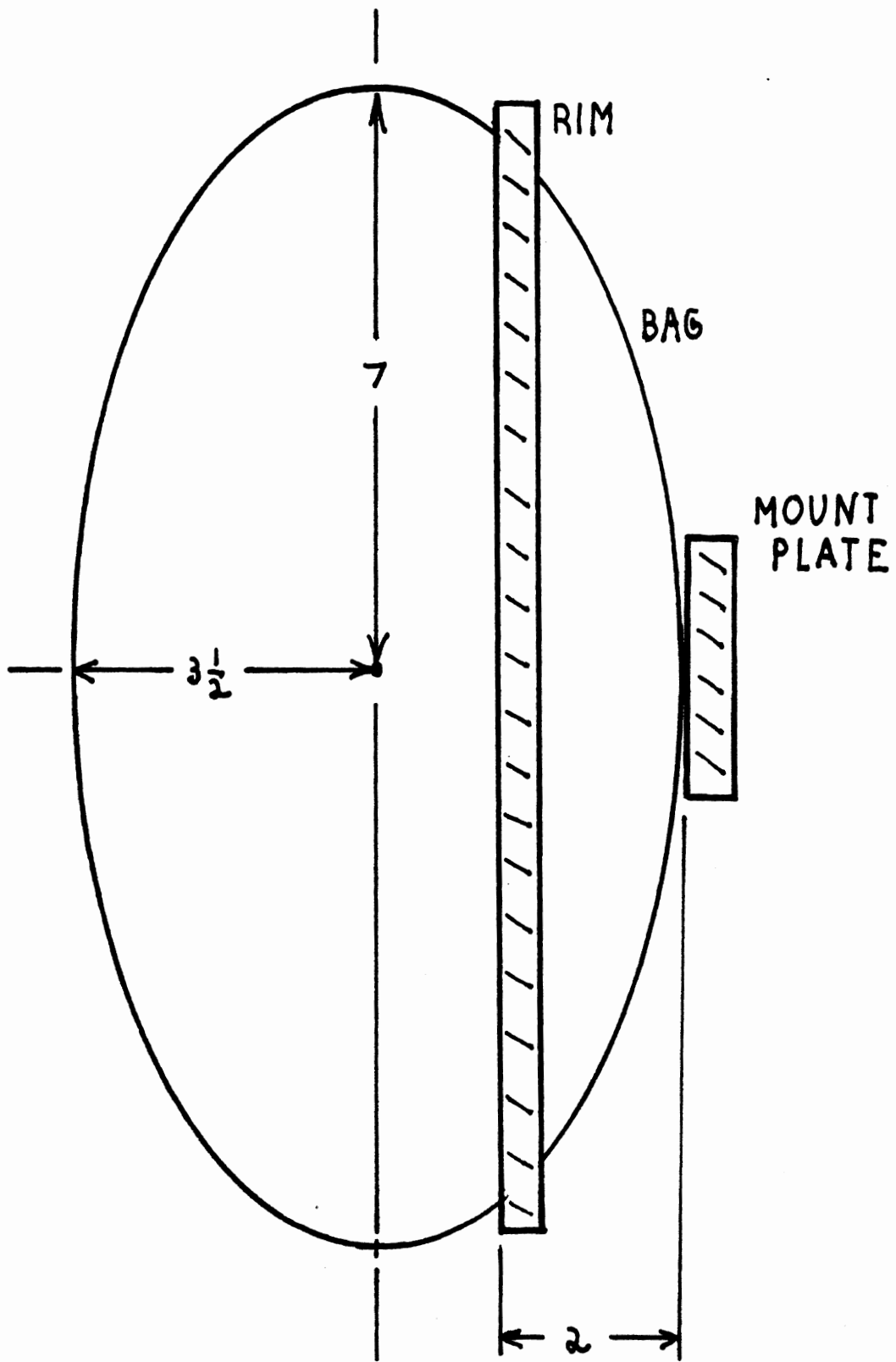
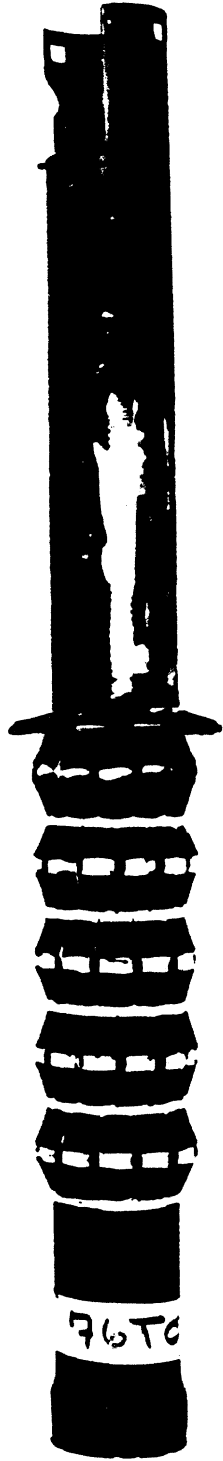
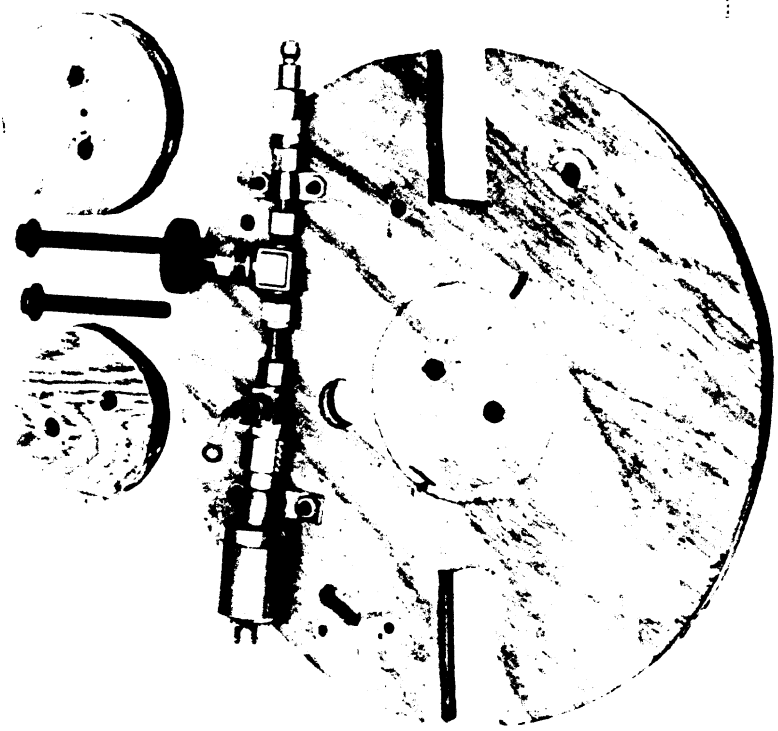
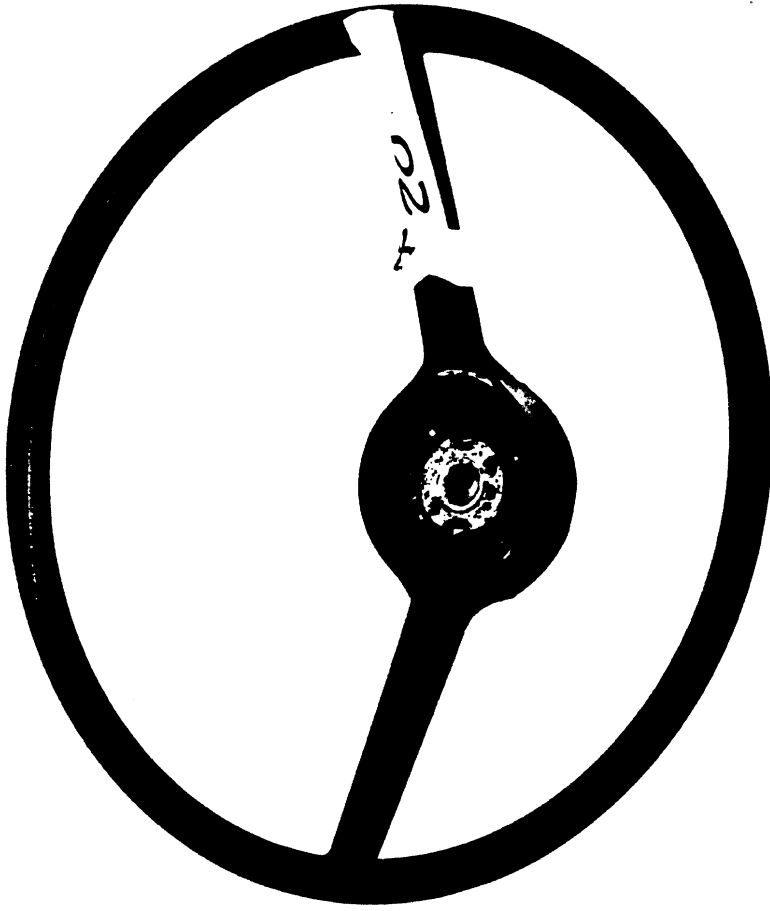


Figure 3.16. Geometry of preinflated air cushion.



6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34

Figure 3.17. Photograph of rim, column, and air cushion support hardware.

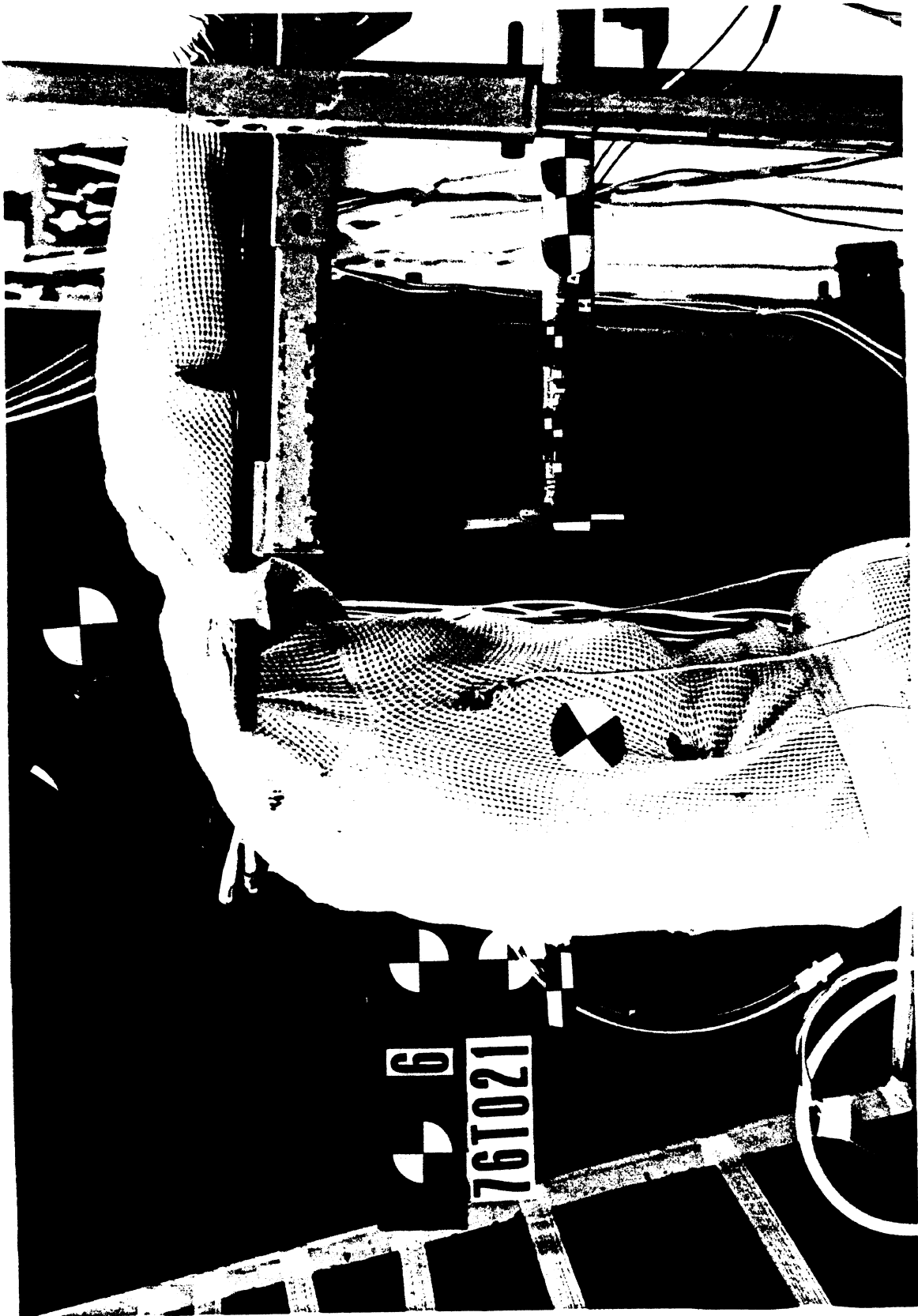


Figure 3.18. Test setup. Frontal impact using air-actuated piston impactor.

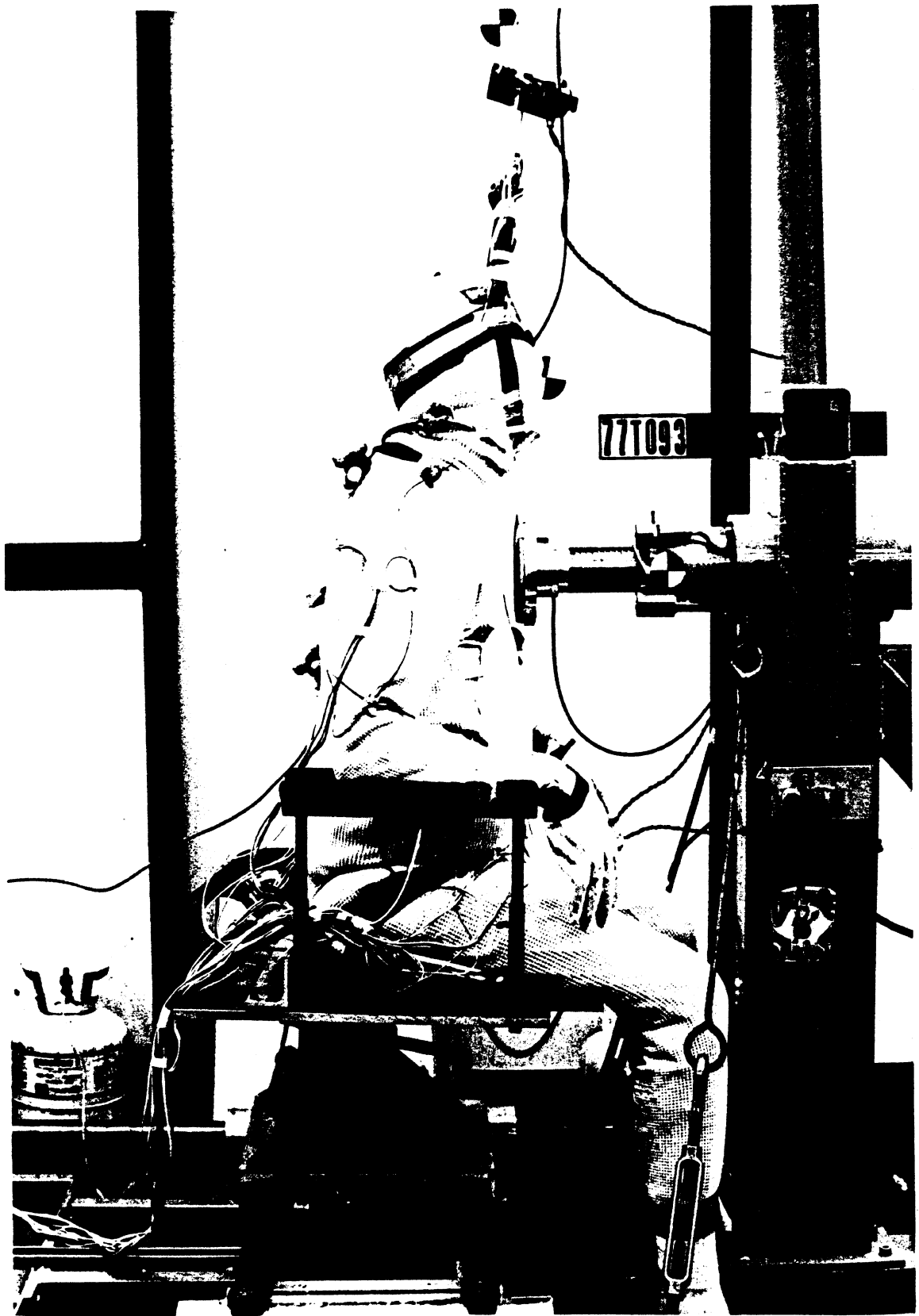


Figure 3.19. Test setup. Frontal impact using pendulum impactor.

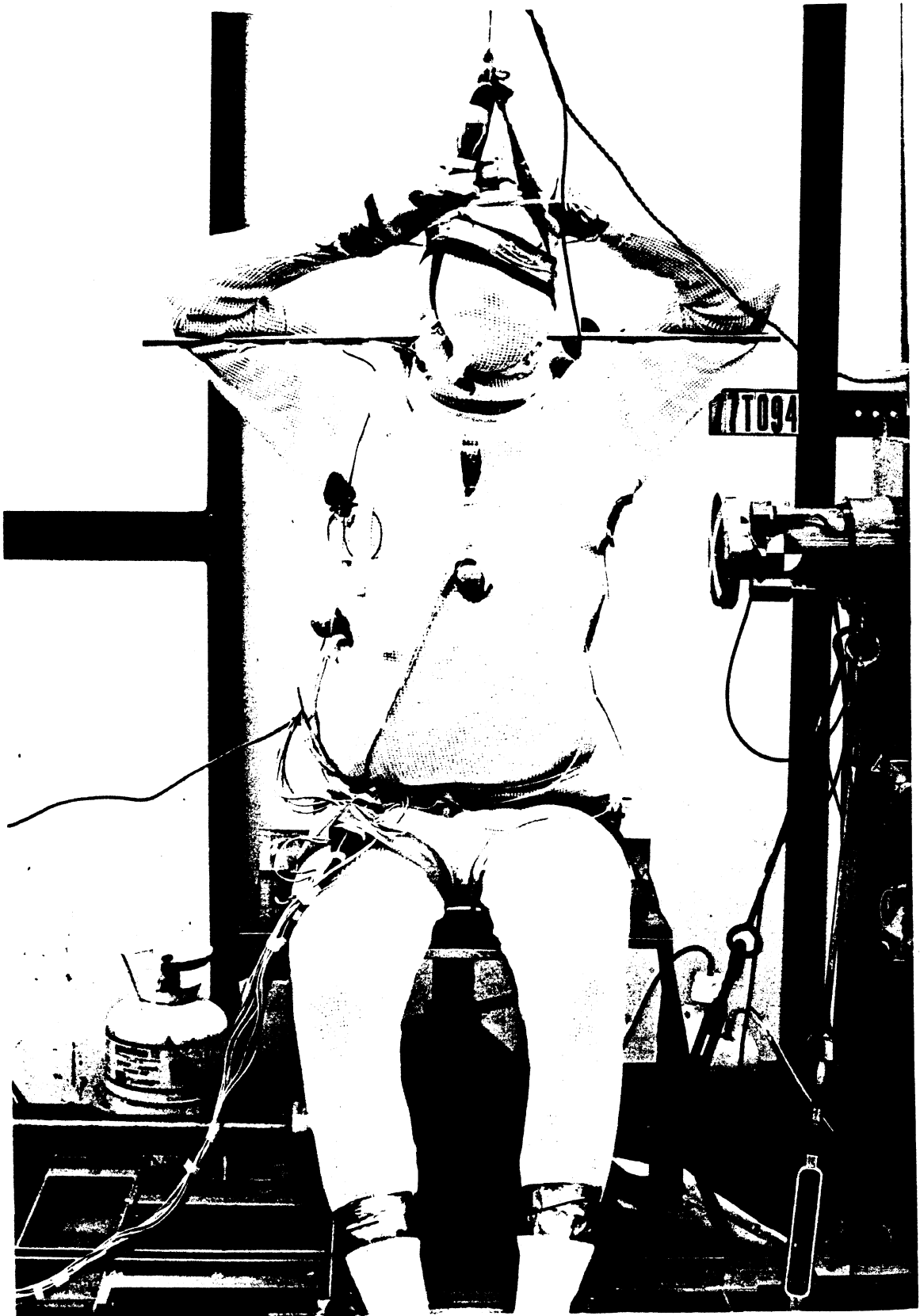


Figure 3.20. Test setup. Side impact using pendulum impactor.



Figure 3.21. Test setup. Rigid door side impact test setup. Front view.

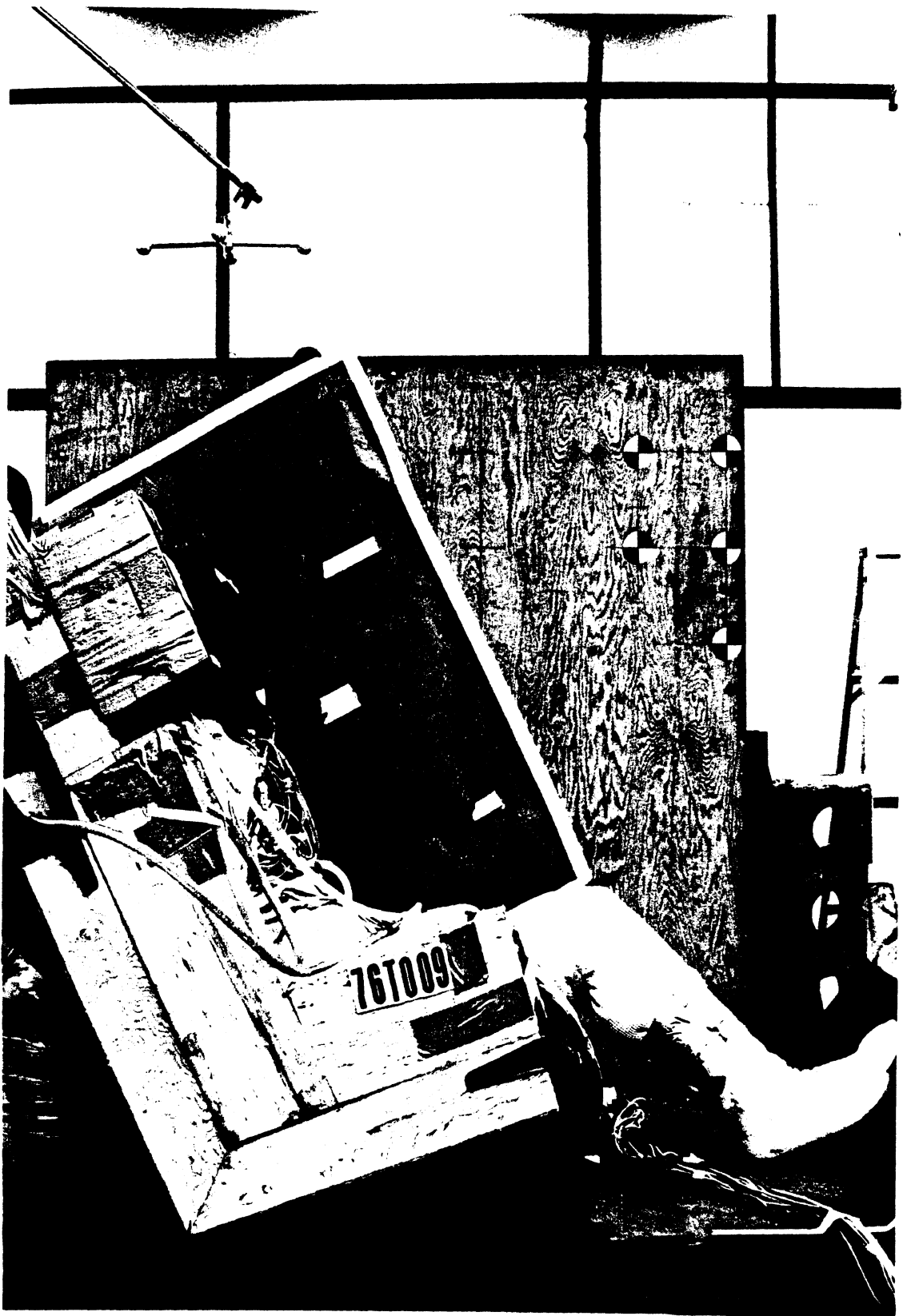


Figure 3.22. Rigid door side impact test setup. Side view.

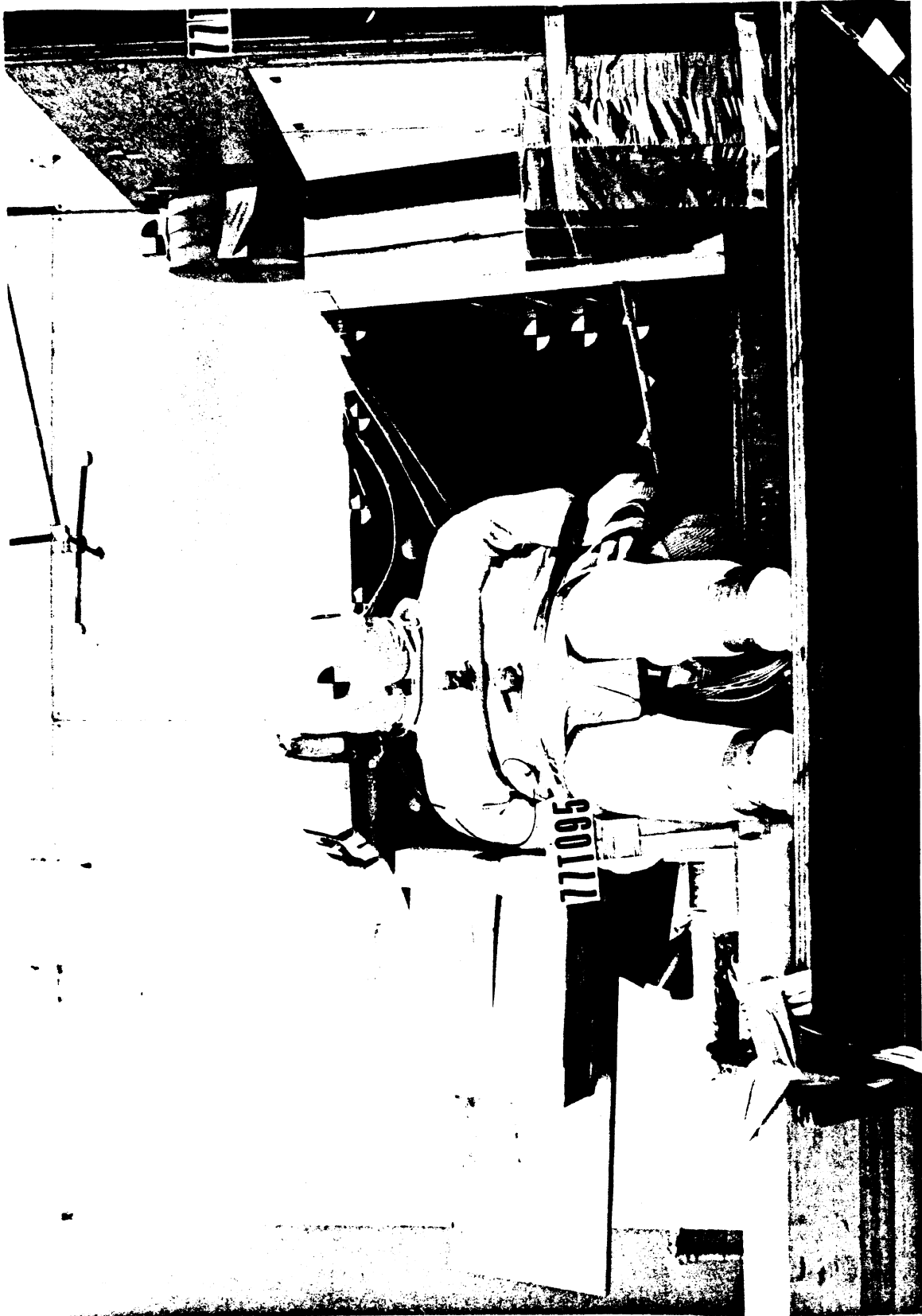


Figure 3.23. Test setup. Padded door side impact test setup. Front view.



Figure 3.24. Test setup. Padded door side impact test setup. Side view.

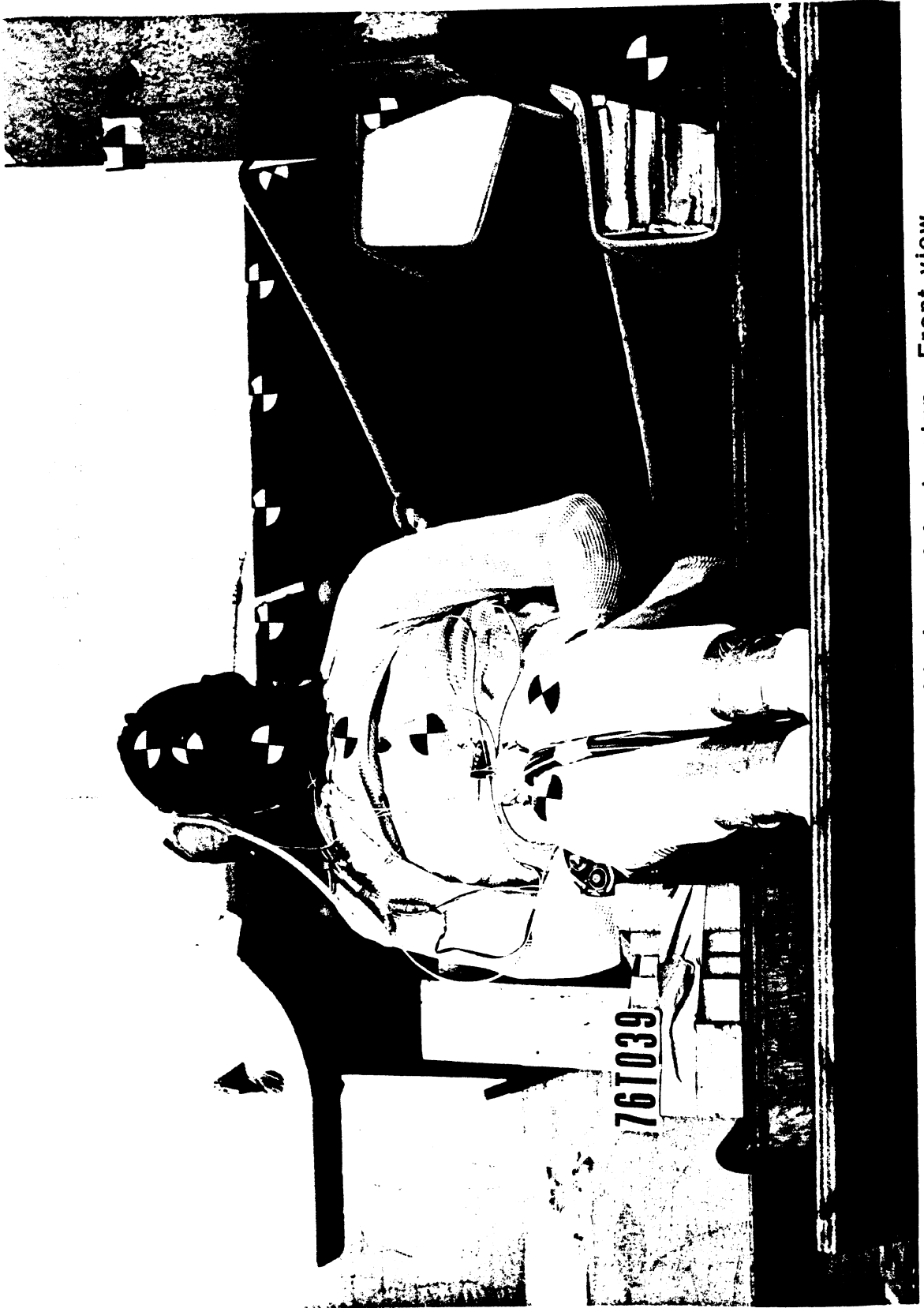


Figure 3.25. Simulated RSV door side impact test setup. Front view.

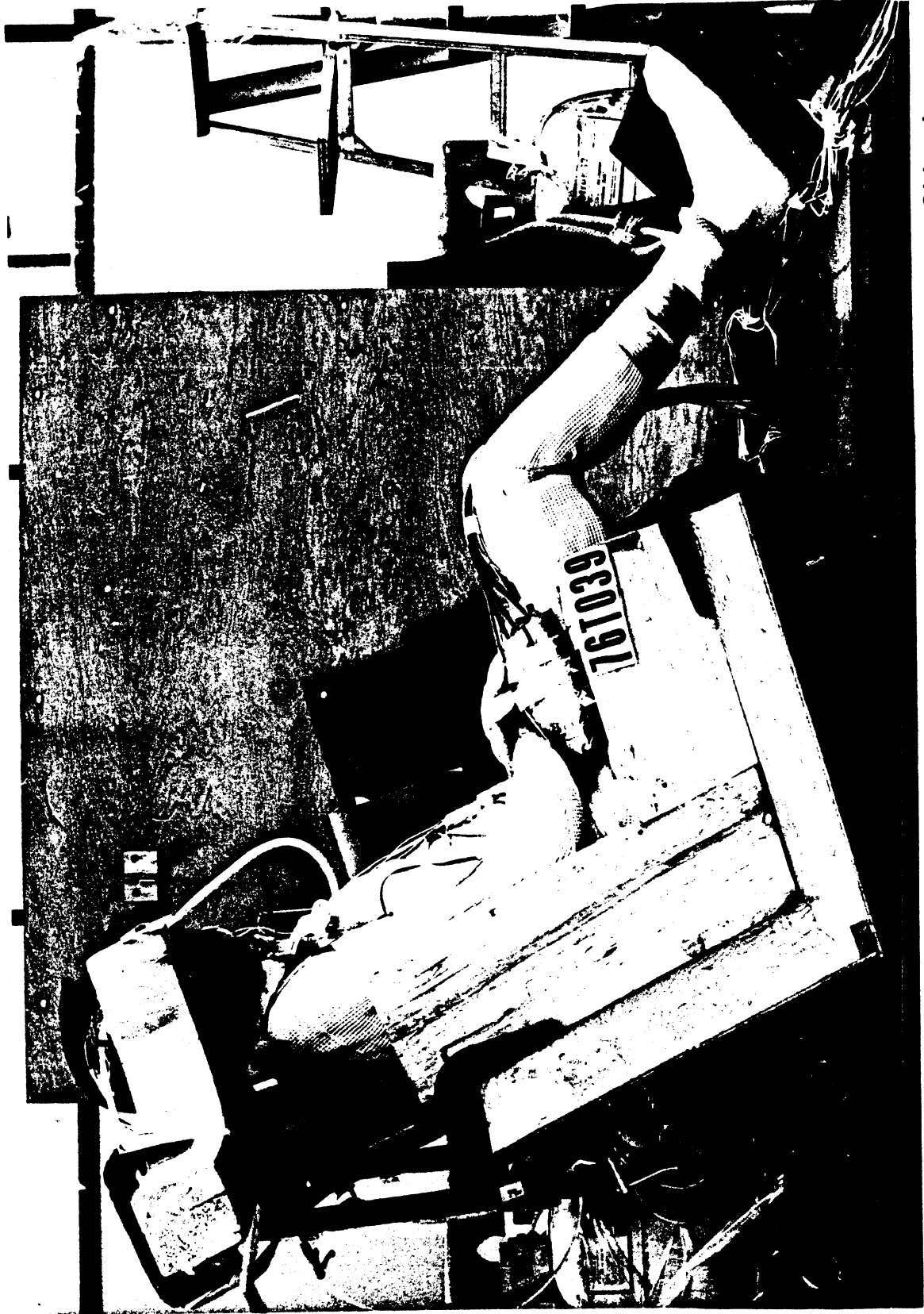


Figure 3.26. Test setup. Simulated RSV door side impact test setup. Side view.

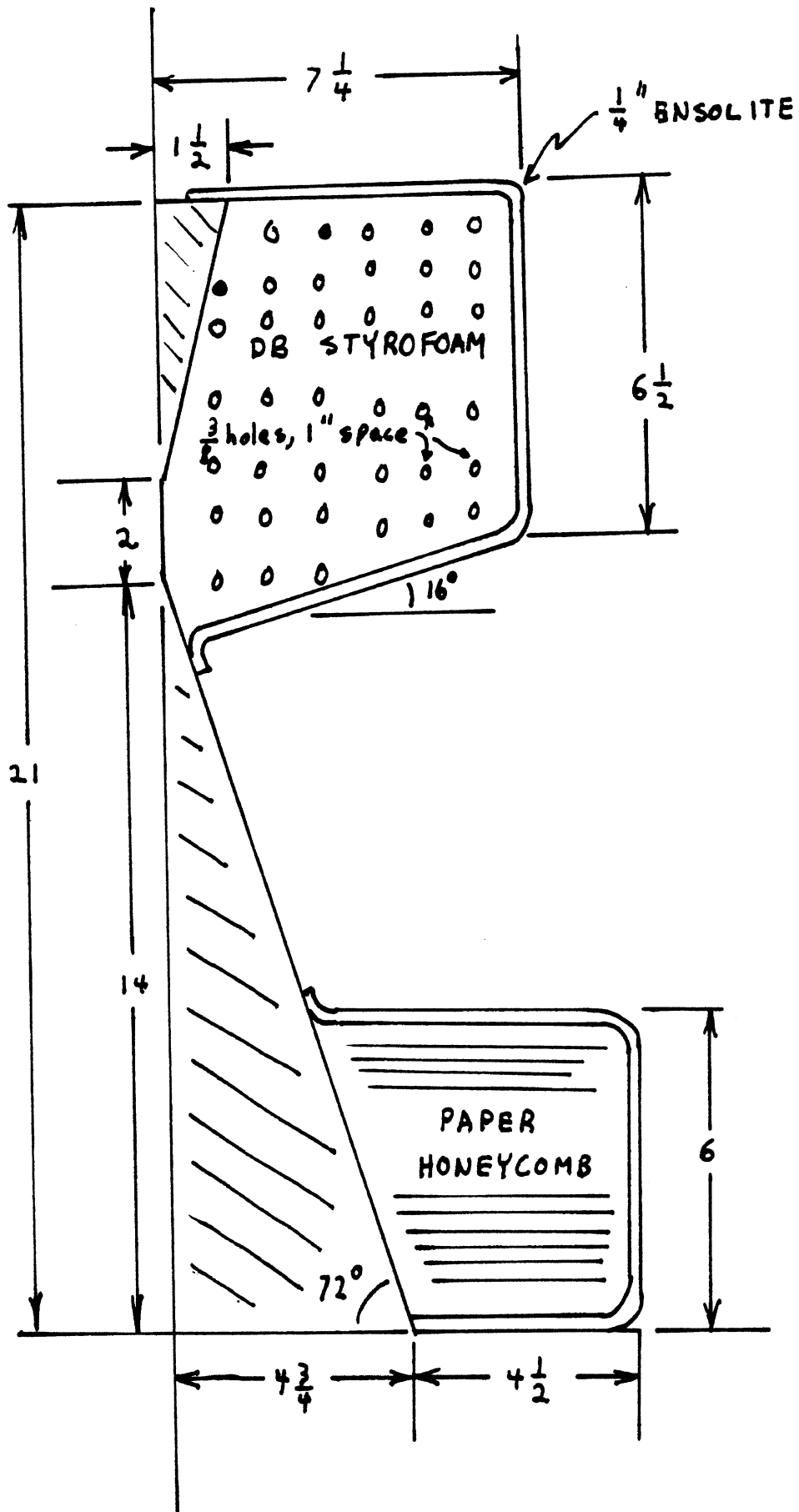


Figure 3.27. Cross section of padded door structure.

DISPLACEMENT TRANSDUCER
 GEOMETRY (77T045, 10/11/77)

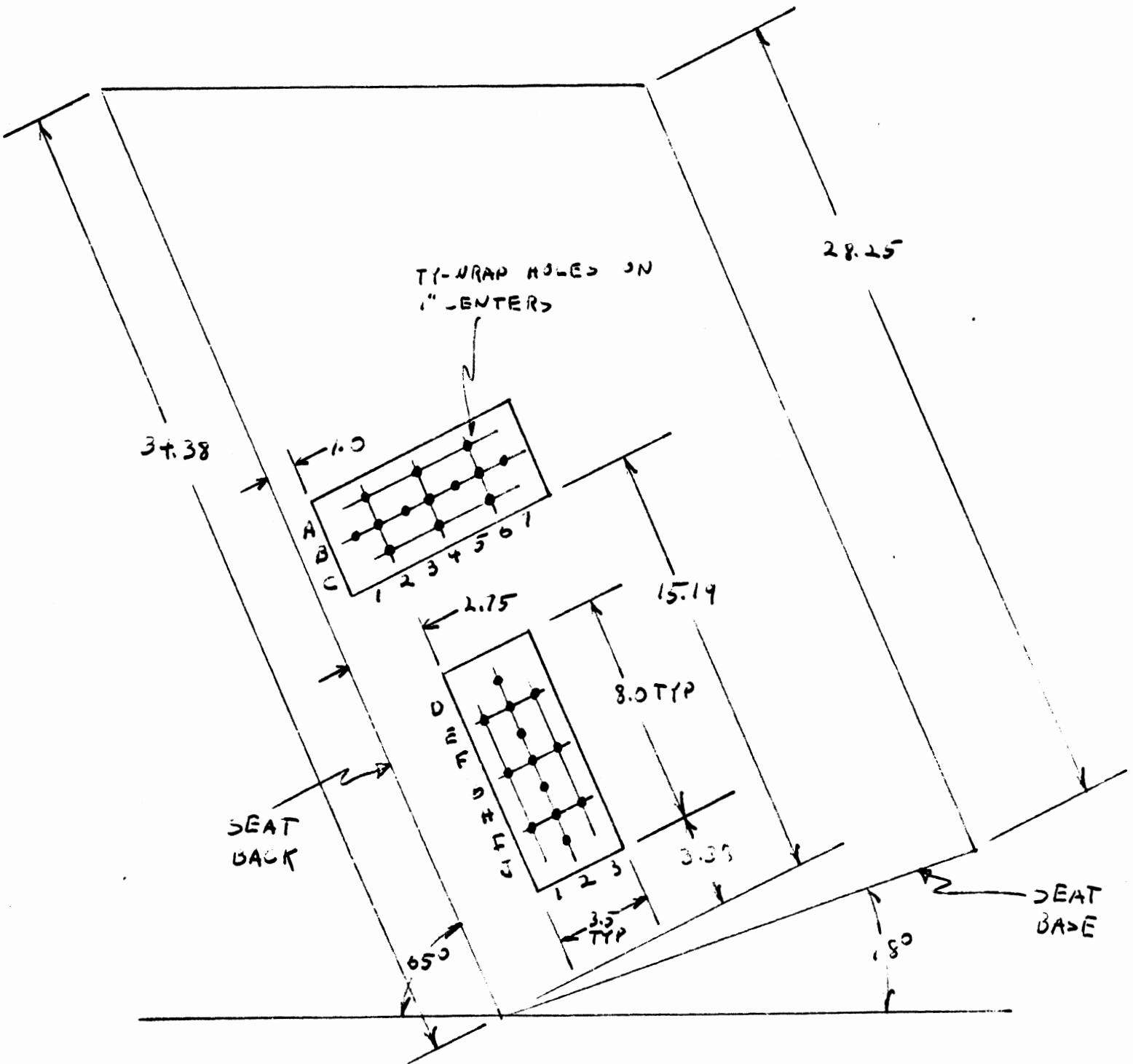


Figure 3.28. Foam padding deflection transducer matrix.

THORACIC IMPACT PROJECT SCHEDULE PART 2: (SLED LAB)

TEST No. _____ CADAVER No. _____

PROJECT DIRECTOR: _____

ITEM (and Description)	TIME REQ'D	DATE & TIME	No. of PERSONS REQUIRED	PERSONNEL ASSIGNED	WHEN COMPLETED, INITIAL HERE
1. Specify all apparatus needed for test					
2. Obtain or fabricate those items needed but not on hand.					
3. Prepare Sled and Lab for test as per test requirements: a. assemble and integrate electronics b. assemble and otherwise prepare sled c. compute pressures, etc., using form provided					
4. Test all electronic devices: if any fail, replace or resort to alternative plans					
5. Prepare lab for test firing: a. Cadaver (see cadaver forms) b. Sled (see sled checklist) c. Cameras (see camera checklist) d. Electronics					
6. Fire sled					
7. Secure sled & initiate post-test activities: a. Photographic b. Visicorder c. Sled/Cadaver					
8. Clean sled and all contaminated places					
9. Make direct Brush recordings of raw data					

4.28

Figure 4.1 (4.38). Test lab protocol.

THORACIC IMPACT PROJECT SCHEDULE PART 1: CADAVER

TEST No. _____ CADAVER No. _____ PROJECT DIRECTOR: _____

ITEM	TIME REQ'D	DATE & TIME	No. of Persons Required	PERSONNEL ASSIGNED	WHEN COMPLETED, INITIAL HERE
1. Obtain cadaver from Anatomy Dep't (See Memo, JMW, 17 Oct. 75)	1 1/2		3		
2. Initial Anthropometry -- (includes marking ID number on cadaver)	1/2		2 + 1		
3. Initial Radiography	3/4		1 + 2		
4. Sanitary Preparations	1/2		1 + 2		
5. Attach accelerometer mounts and insert plumbing	2		1 + 1		
a. Rib mounts	1/2		1 + 1		
b. Sternal Mounts	1		1 + 1		
c. Tracheal intubation	1		1 + 1		
d. Femoral Catheter	1		1 + 1		
e. Carotid Catheter	1		1 + 1		
6. Frontal Instrumentation Geometry	1/2		1 + 1		
7. Attach Spinal Accelerometer mounts	1 1/2		1 + 1		
8. Spinal instrumentation geometry	1/2		1 + 1		
9. Post-surgical Radiology	3/4		1 + 2		
10. Dress cadaver	1		3		
11. Transport cadaver to sled lab	1/4		2 + 1		

Figure 4.2. Biomedical protocol. (1 of 2)

TEST No. _____ CADAVER No. _____

1-2

ITEM	TIME REQ'D	DATE & TIME	No. of Persons Required	PERSONNEL ASSIGNED	WHEN COMPLETED, INITIAL HERE
11. Insert pressure transducer through carotid catheter	1/4		1 + 1		
12. Attach rib and sternal accelerometers	1		1 + 1		
13. Hoist cadaver to sitting position and attach spinal accelerometers	1/2		2 + 1		
14. Transfer cadaver to sled and secure	1/4		3 + 1		
15. Attach targets to cadaver: spinal, acromion, head	1/2		1 + 1		
16. Connect tracheal pressure transducer and junction block	1/2		1 + 1		
17. Adjust position of cadaver to final pre-test condition. (Includes setting belt tensions)	1/2		2 + 1		
18. Pressurize lungs, vasculature (and other items, as needed)	1/4		1 + 1		
19. Fire sled					
20. Disconnect cadaver from sled and transfer to table; make notes re. test results	1/2		3 + 1		
21. Remove accelerometers from cadaver	1/2		2		
22. Autopsy (save 6-inch rib specimen)	2		2 + 1		Rib saved? _____
23. Prepare cadaver & return it to Anatomy Department	2		3		

4.29.a

Figure 4.2. Biomedical protocol (2 of 2)

PROTOCOL I: QUANTIFICATION OF THORACIC RESPONSE
AND INJURY

CADAVER DIMENSIONS AND INITIAL DESCRIPTION (April 25, 1976)

1. Cadaver I.D. _____
2. Date _____
3. Data Gathered By _____
4. Cause of Death _____
5. Age _____
6. Weight _____
7. Sex _____
8. Stature _____
9. Supine Torso Length (Vertex-Symphysion) _____
10. Acromion (Right _____, Left _____)
11. Head Circumference _____
12. Axilla Chest Depth _____
13. Axilla Chest Breadth _____
14. Axilla Chest Circumference _____
15. Substernale Chest Depth _____
16. Substernale Chest Breadth _____
17. Substernale Chest Circumference _____
18. Head to C7 _____
19. Suprasternale _____
20. Substernale _____
21. Acromion to Tip of Finger _____
22. Vertex to 12th Rib _____
23. Upper Arm Circumference _____

Figure 4.3. Cadaver anthropometry.
4.00

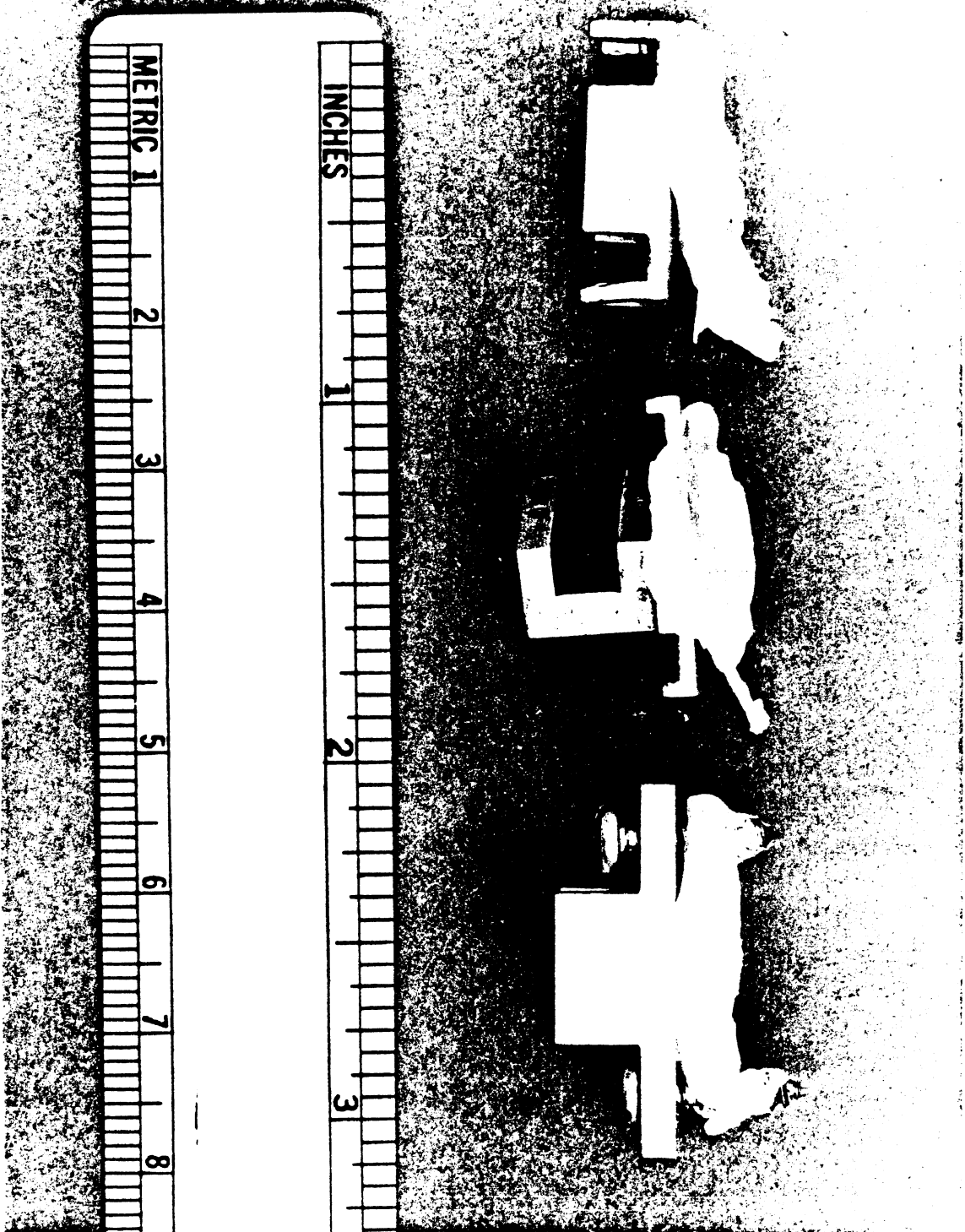


Figure 4.4. Dental acrylic on rib mounts.

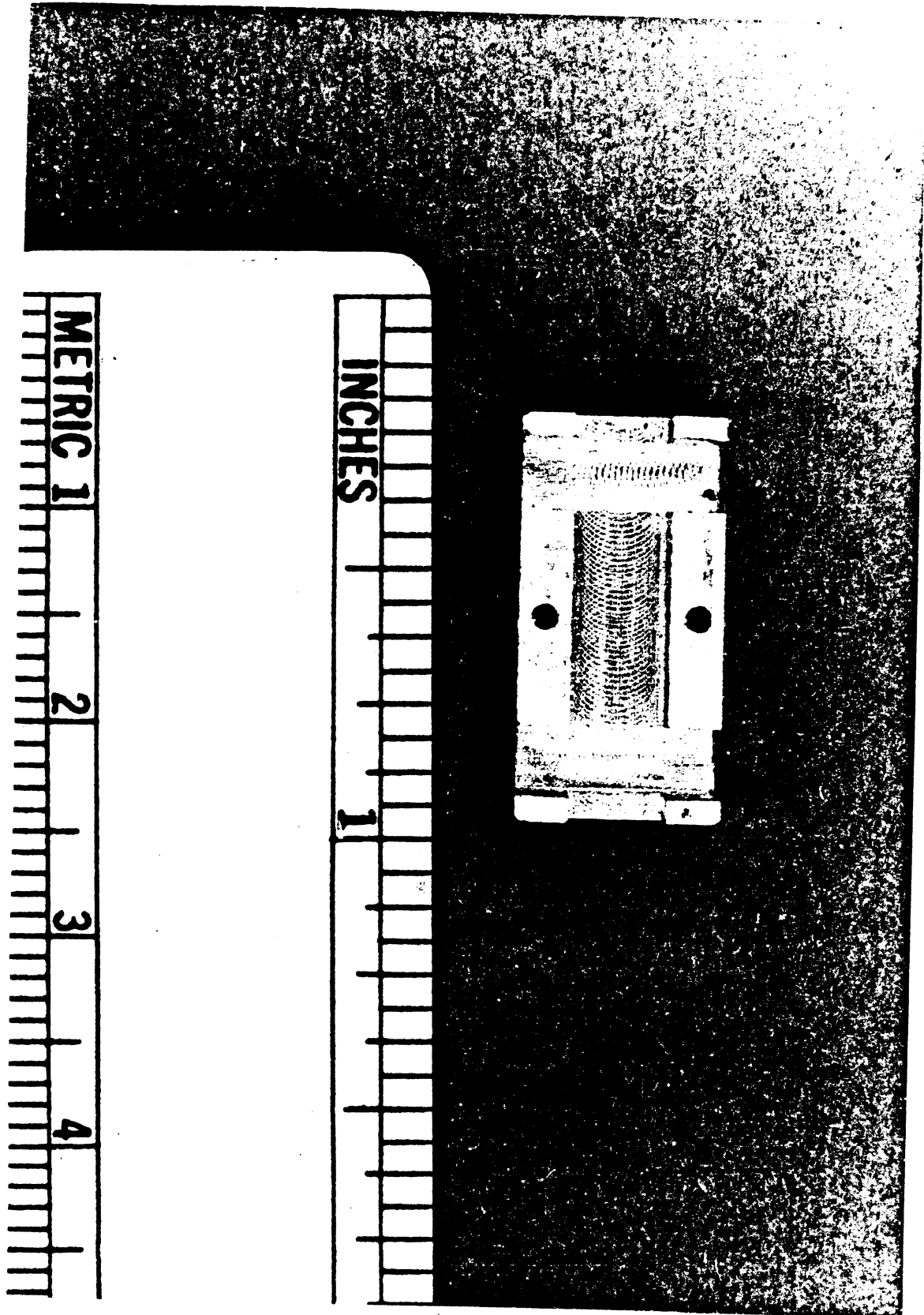


Figure 4.5. Fourth rib accelerometer mounts. (Photo).

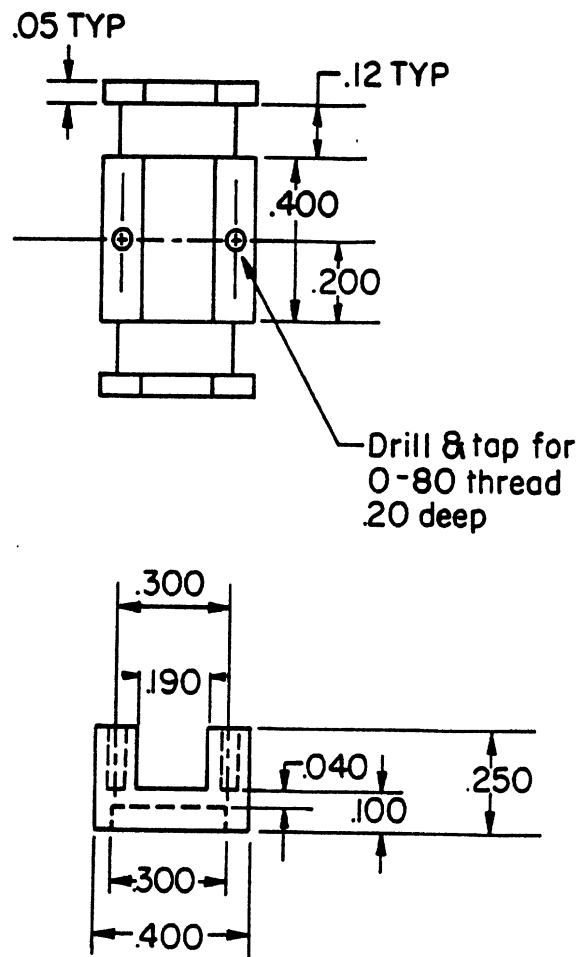


Figure 4.6. Fourth rib accelerometer mounts. (Dimensions).

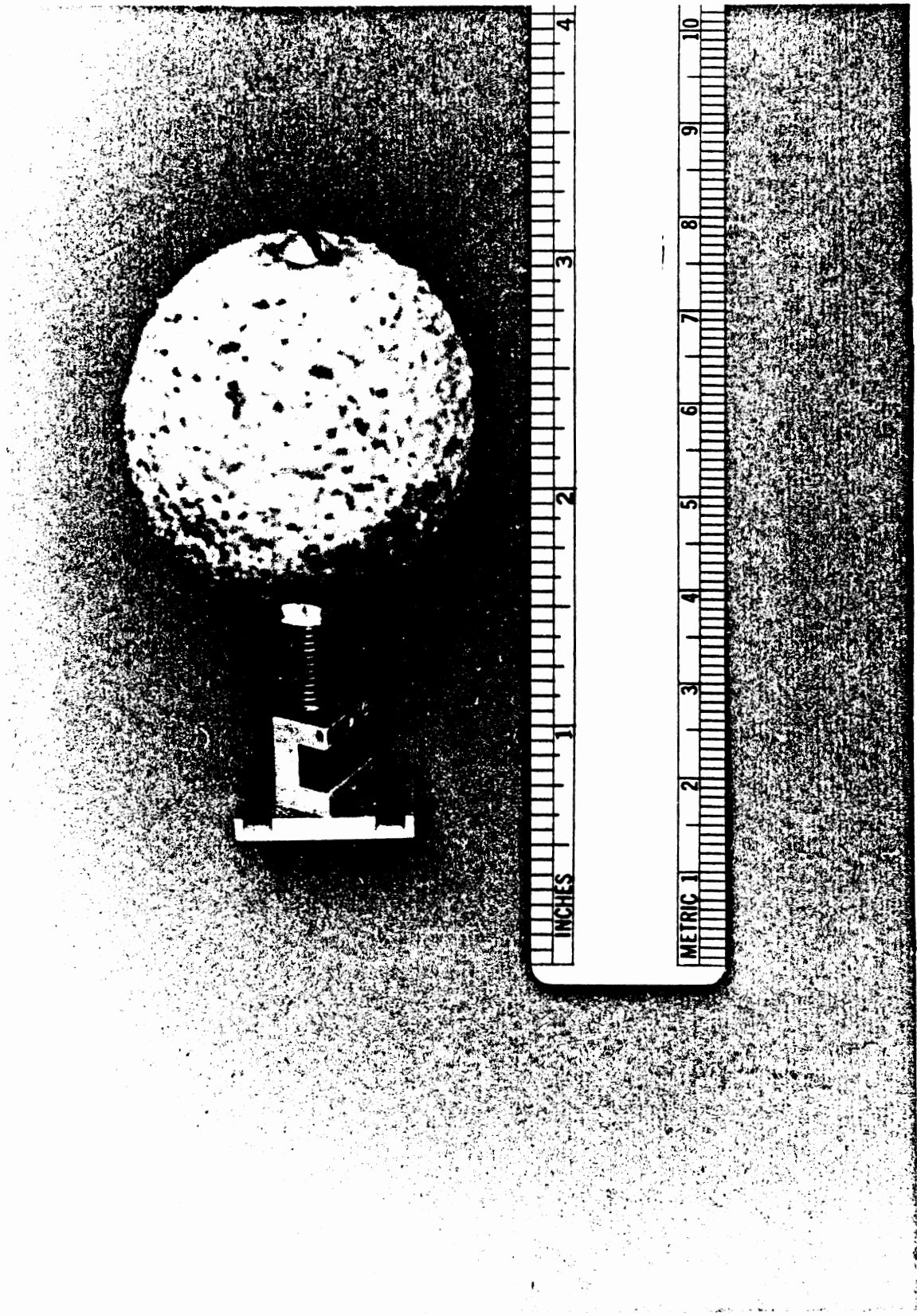


Figure 4.7. Eighth rib accelerometer mount with visible target. (Photo).

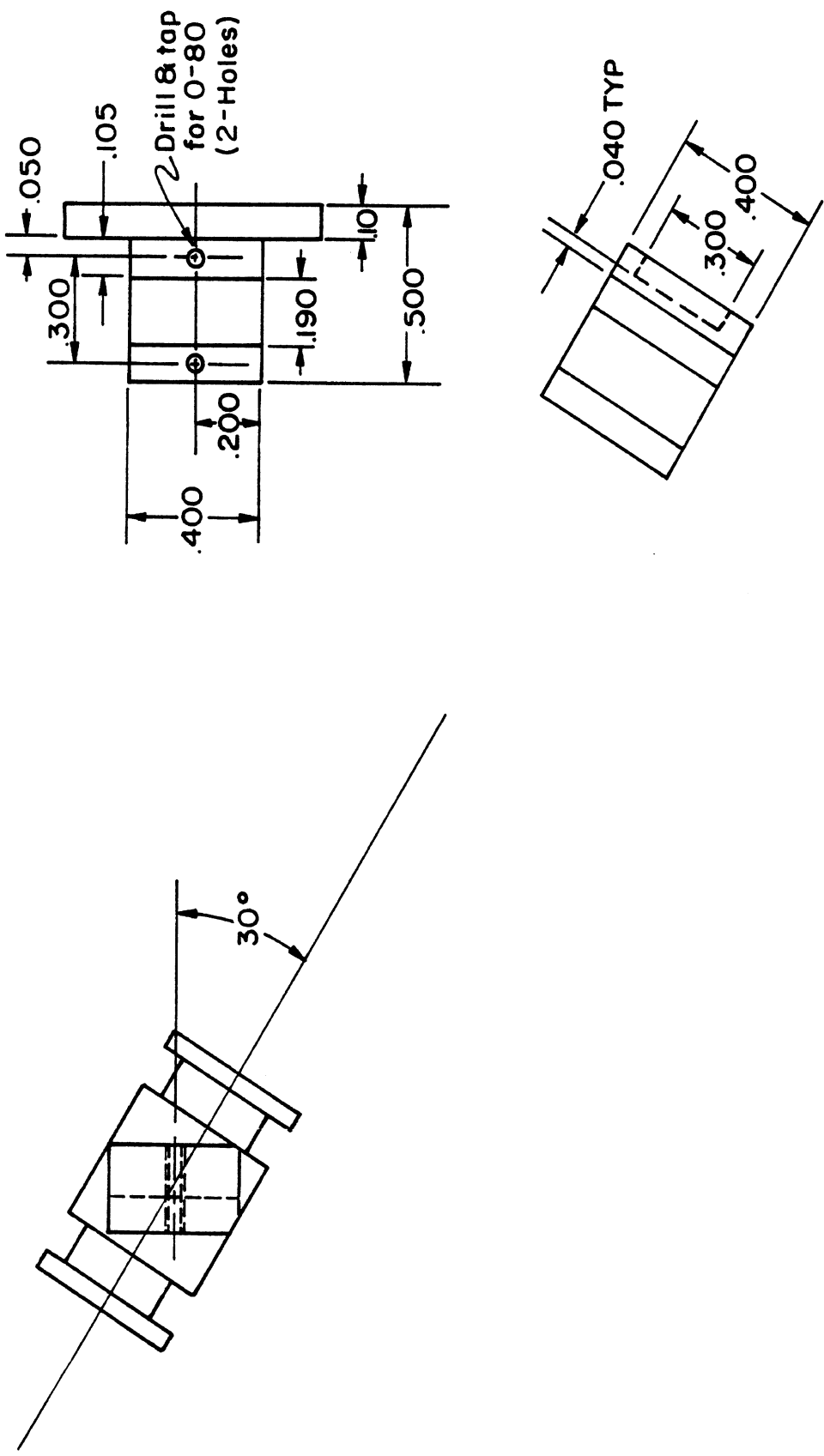


Figure 4.8. Eighth rib accelerometer mounts. (Dimensions).

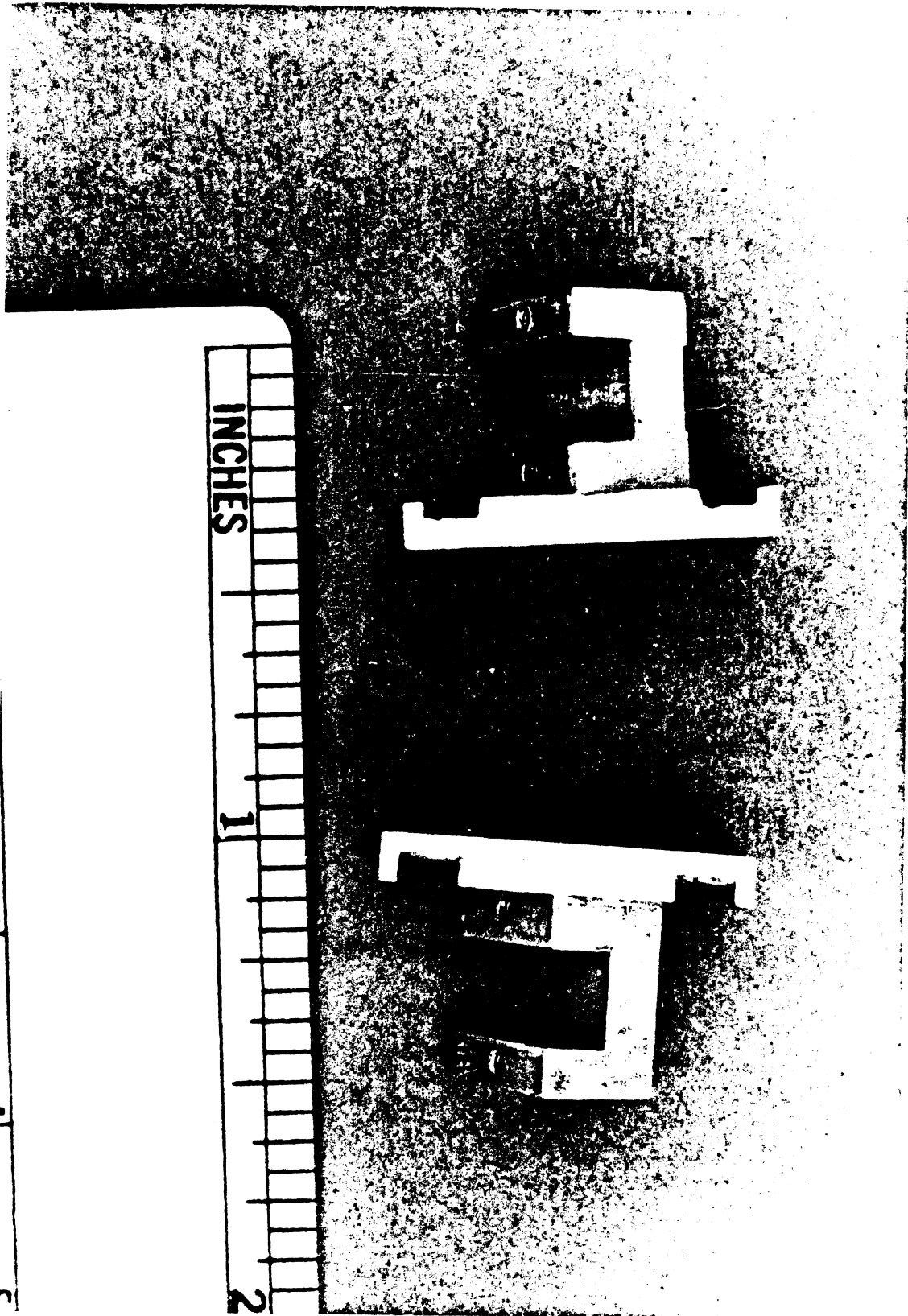


Figure 4.9. Eighth rib accelerometer mounts. (Left-right mirror symmetry).

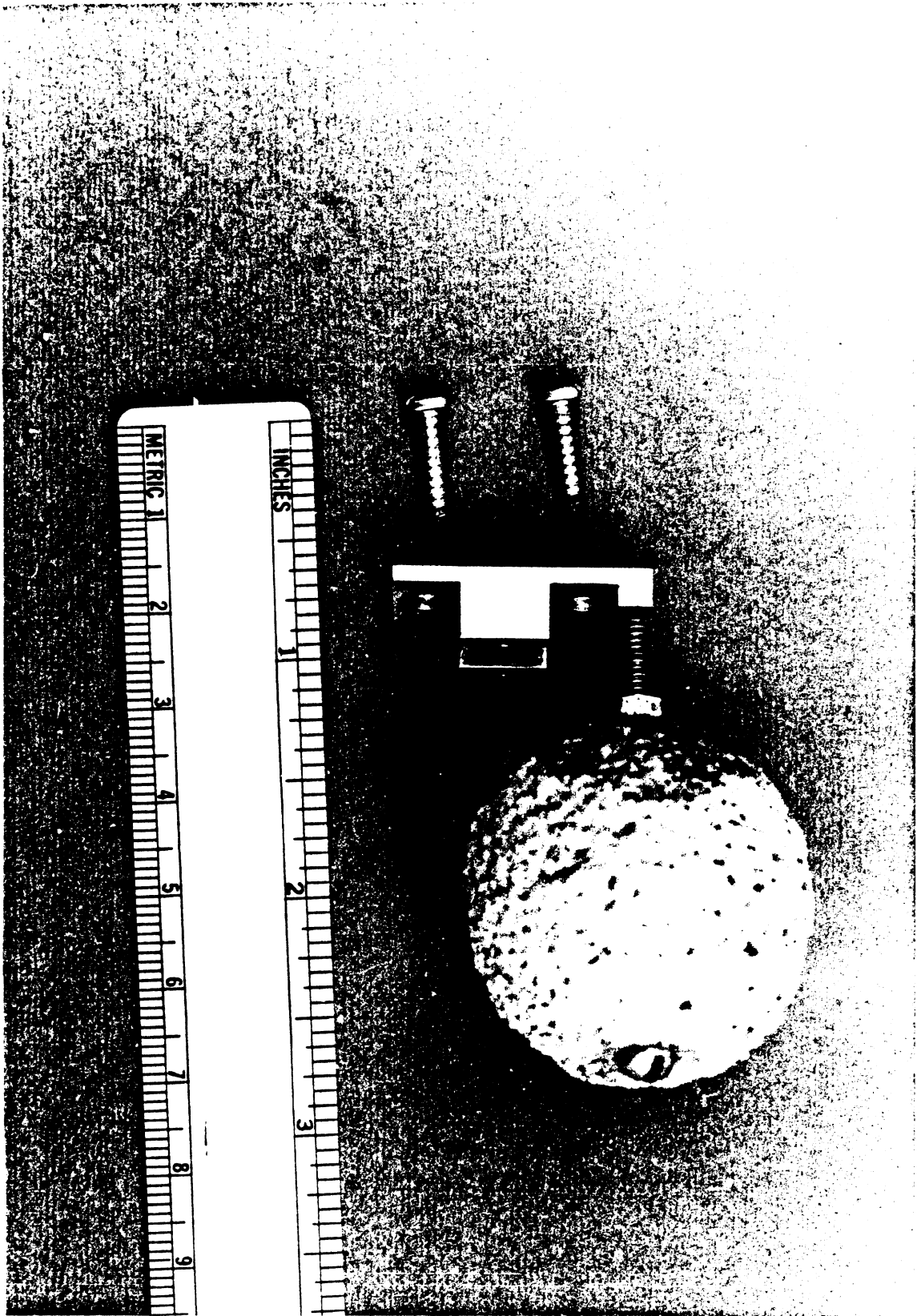


Figure 4.10. Substernale accelerometer mount with visible target. (Photo).

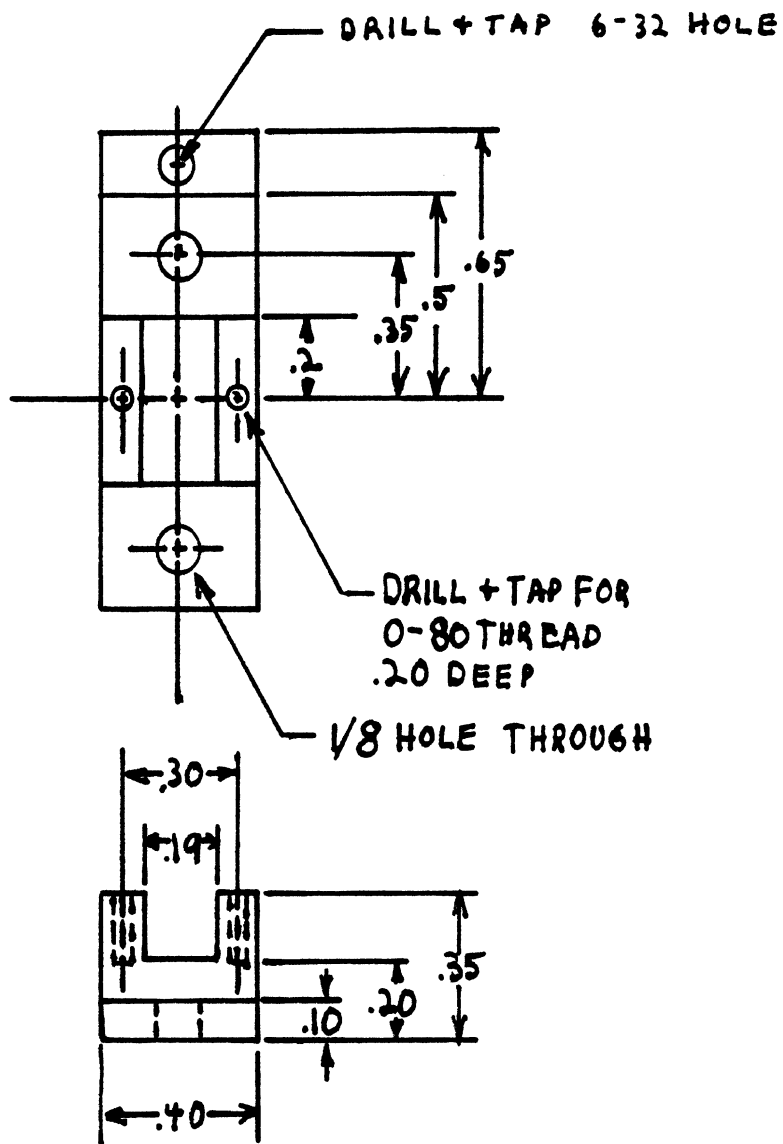


Figure 4.11. Substernale accelerometer mount with visible target. (Dimensions).

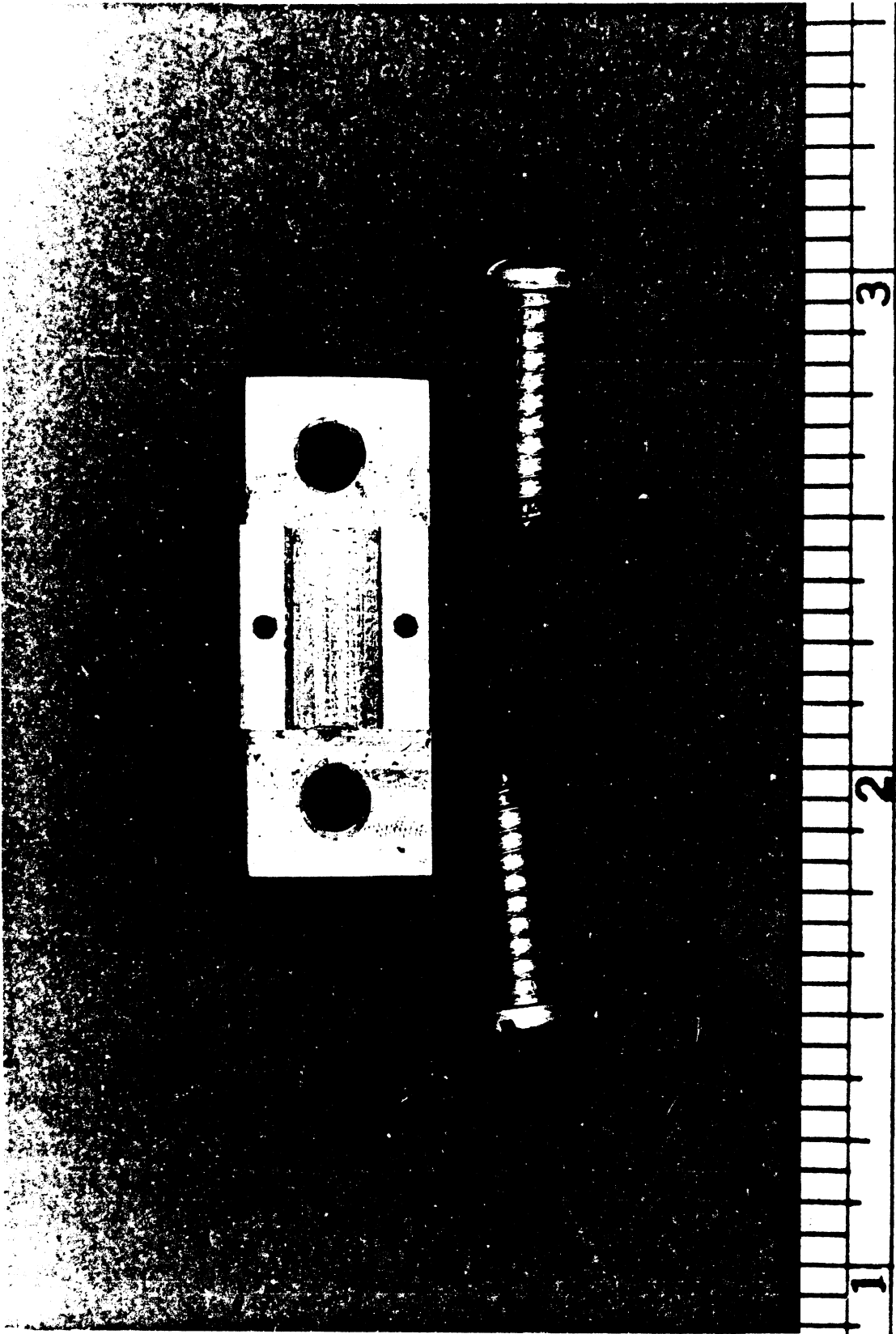


Figure 4.12 . Suprasternal accelerometer mount. (Photo).

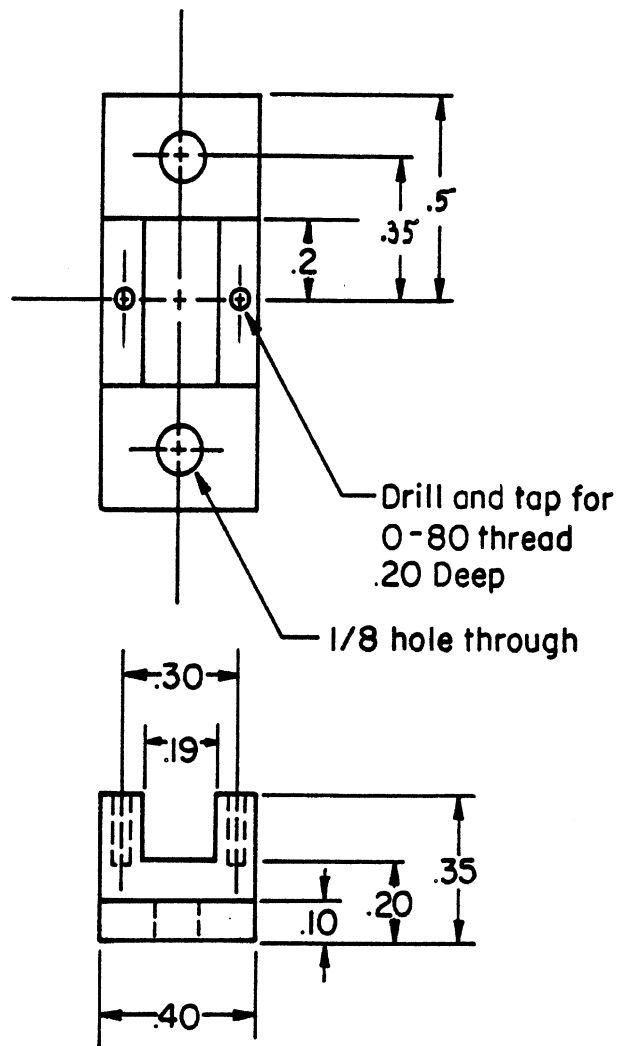


Figure 4.13. Suprasternale accelerometer mount. (Dimensions).

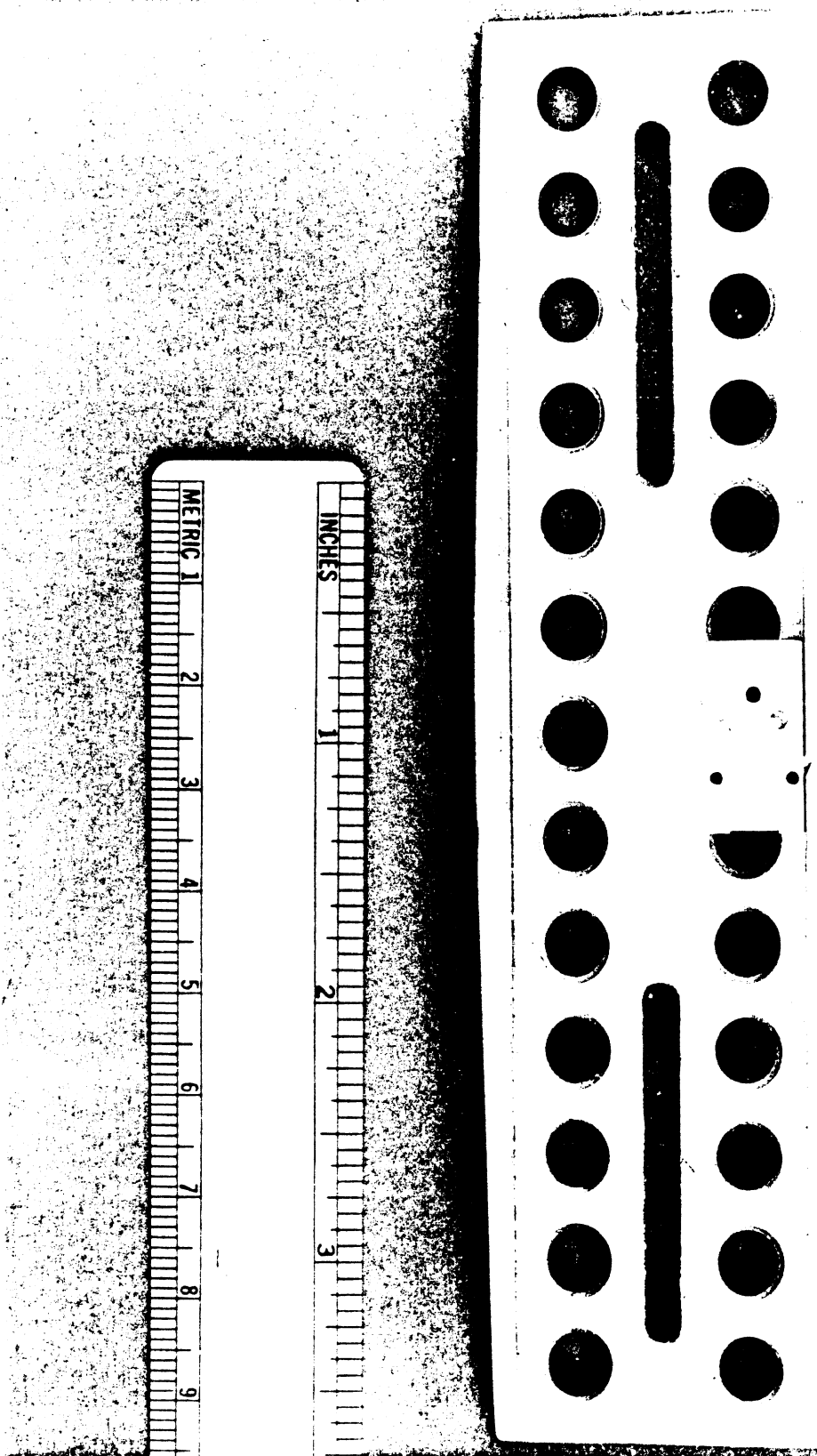


Figure 4.14. Pelvic accelerometer mount. Mount on platform.

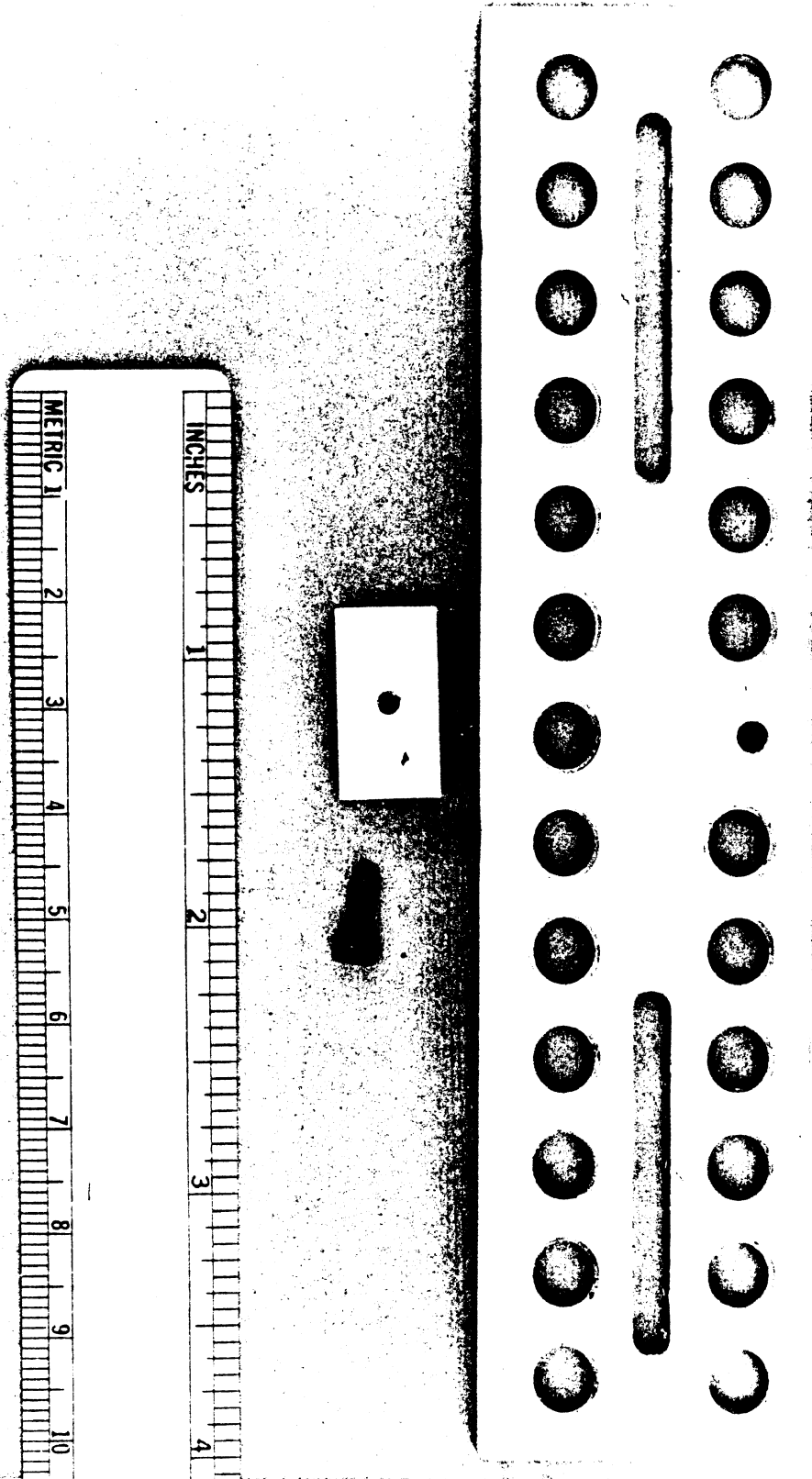


Figure 4.15. Pelvic accelerometer mount. Disassembled.

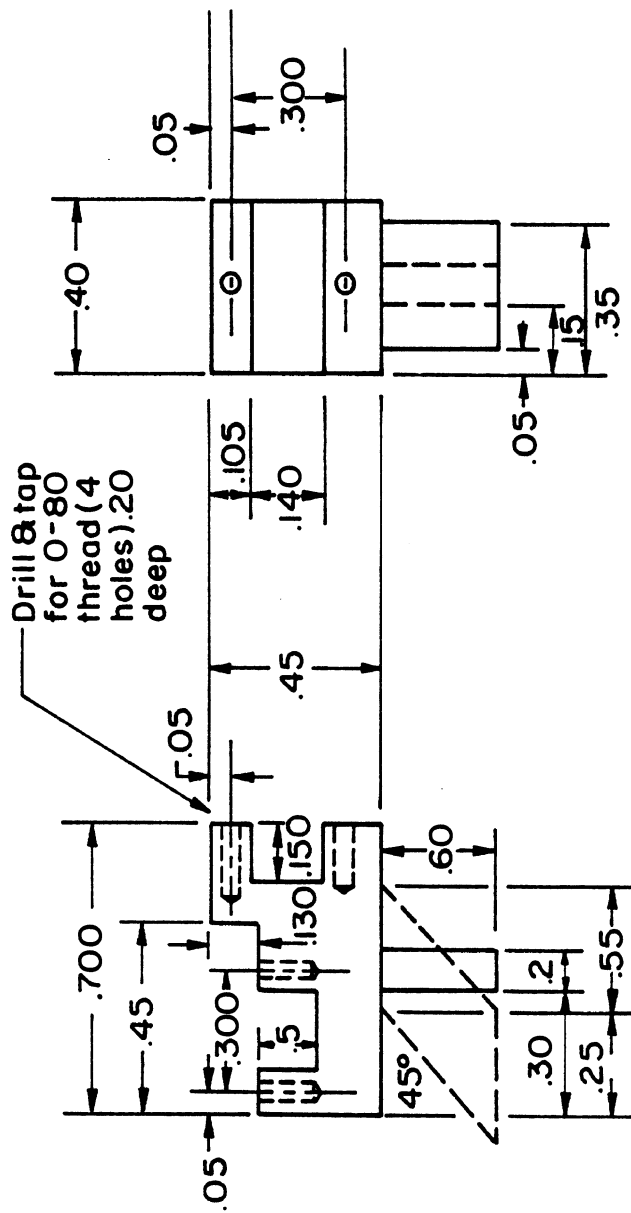


Figure 4.16. T-1 and T-12 accelerometer mounts. (Dimensions).

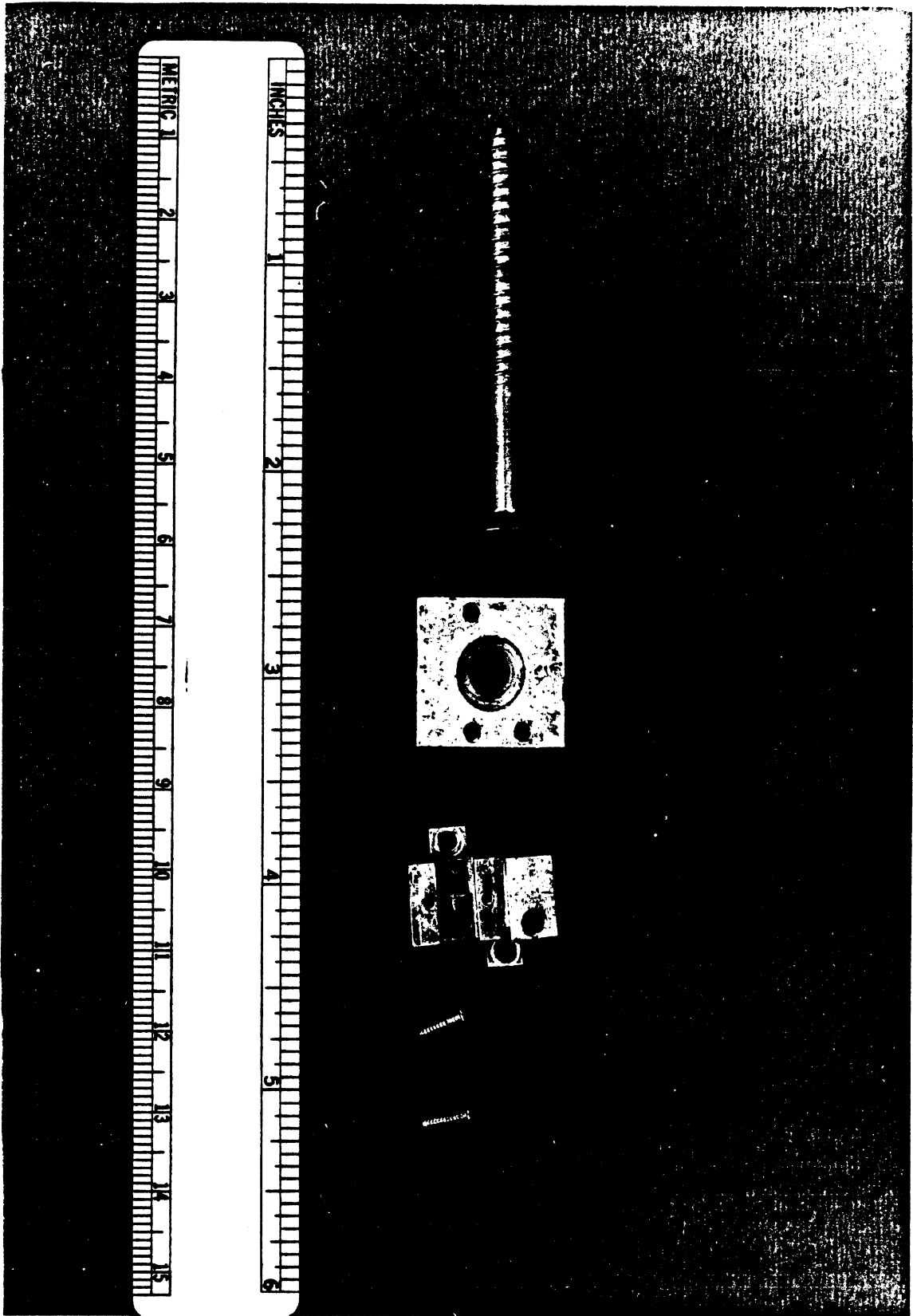


Figure 4.17. T-1 and T-12 accelerometer mounts. (Disassembled).

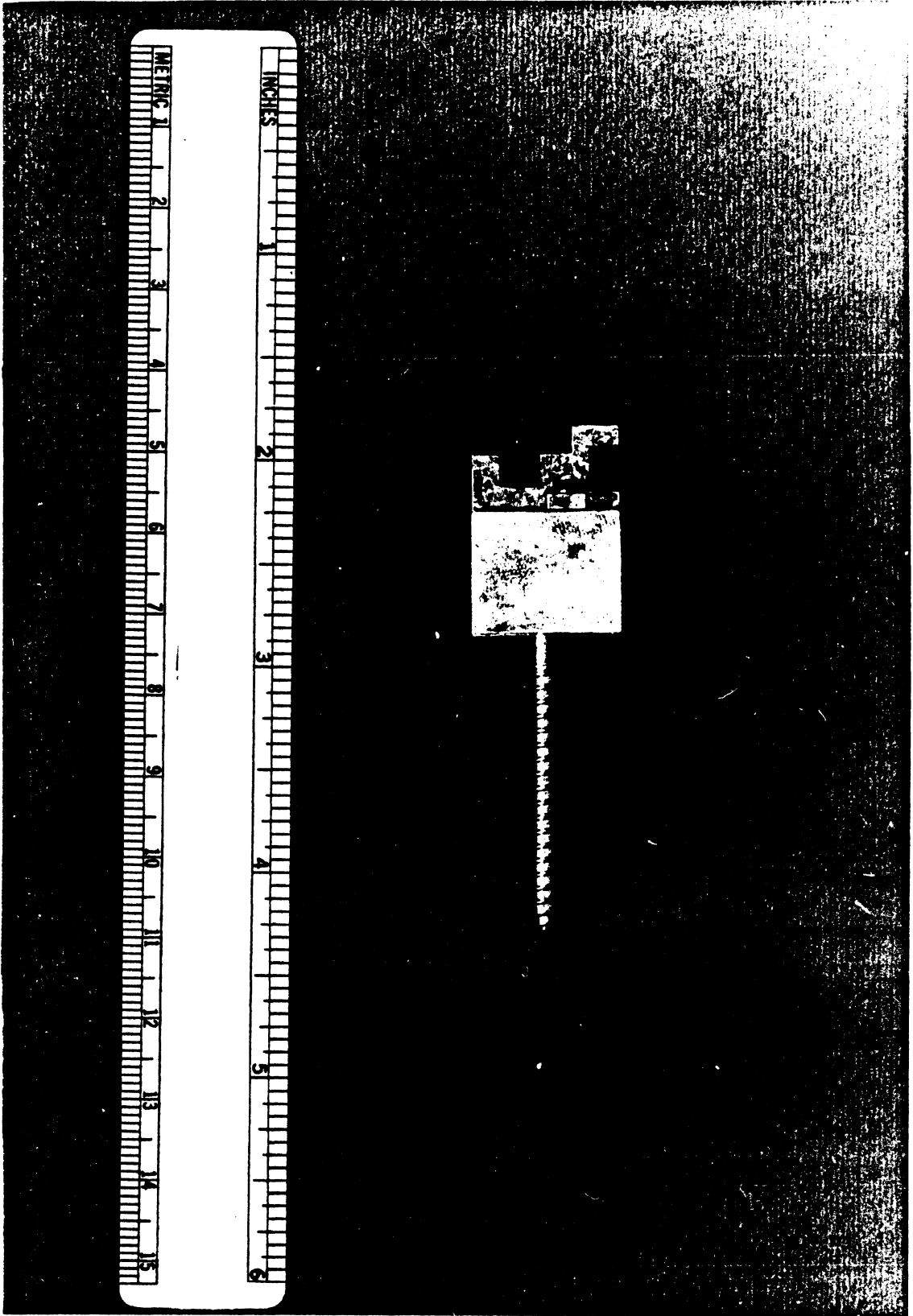


Figure 4.18. T-1 and T-12 accelerometer mounts. (Assembly photo).

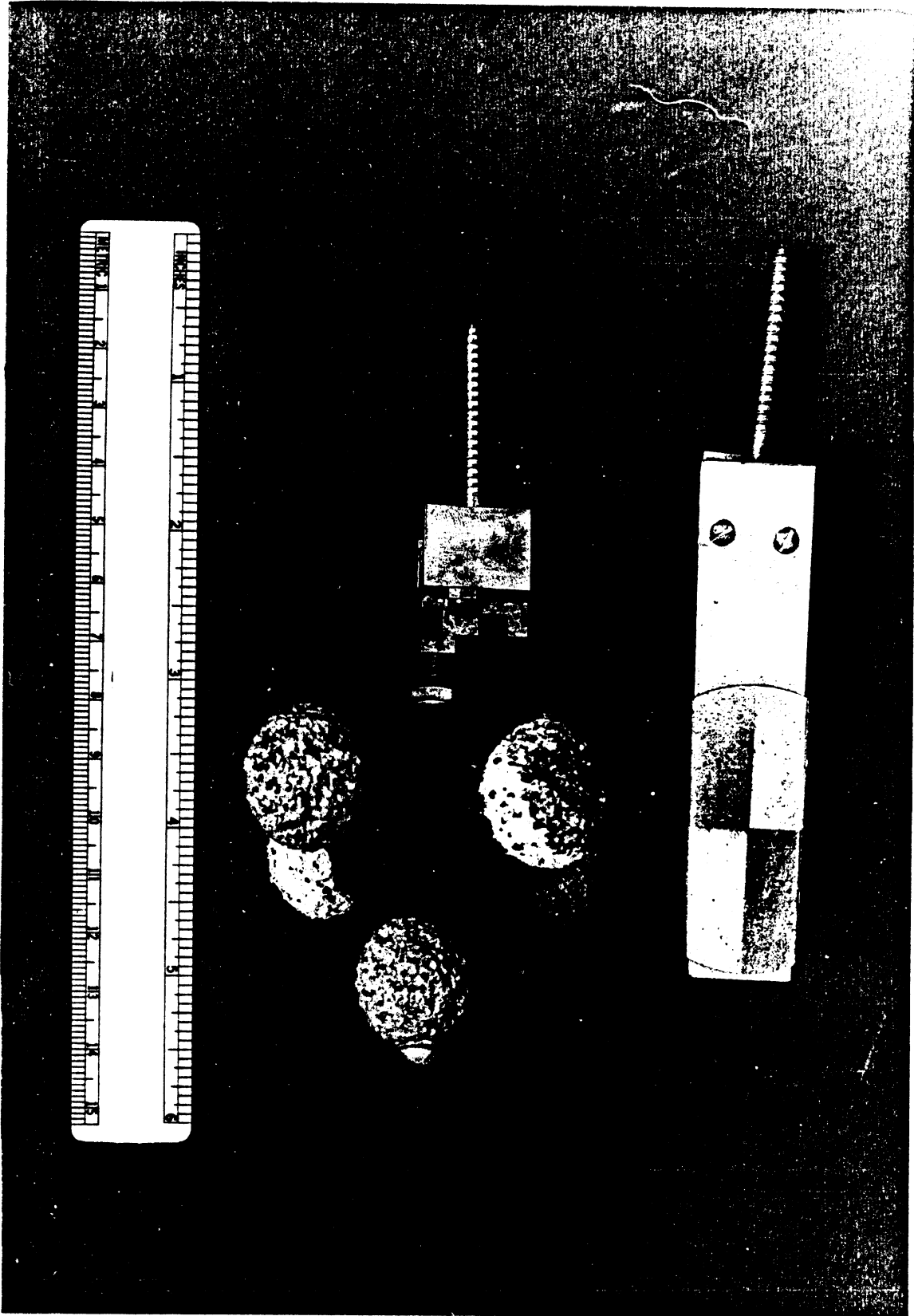


Figure 4.19. Spinal photographic targets.

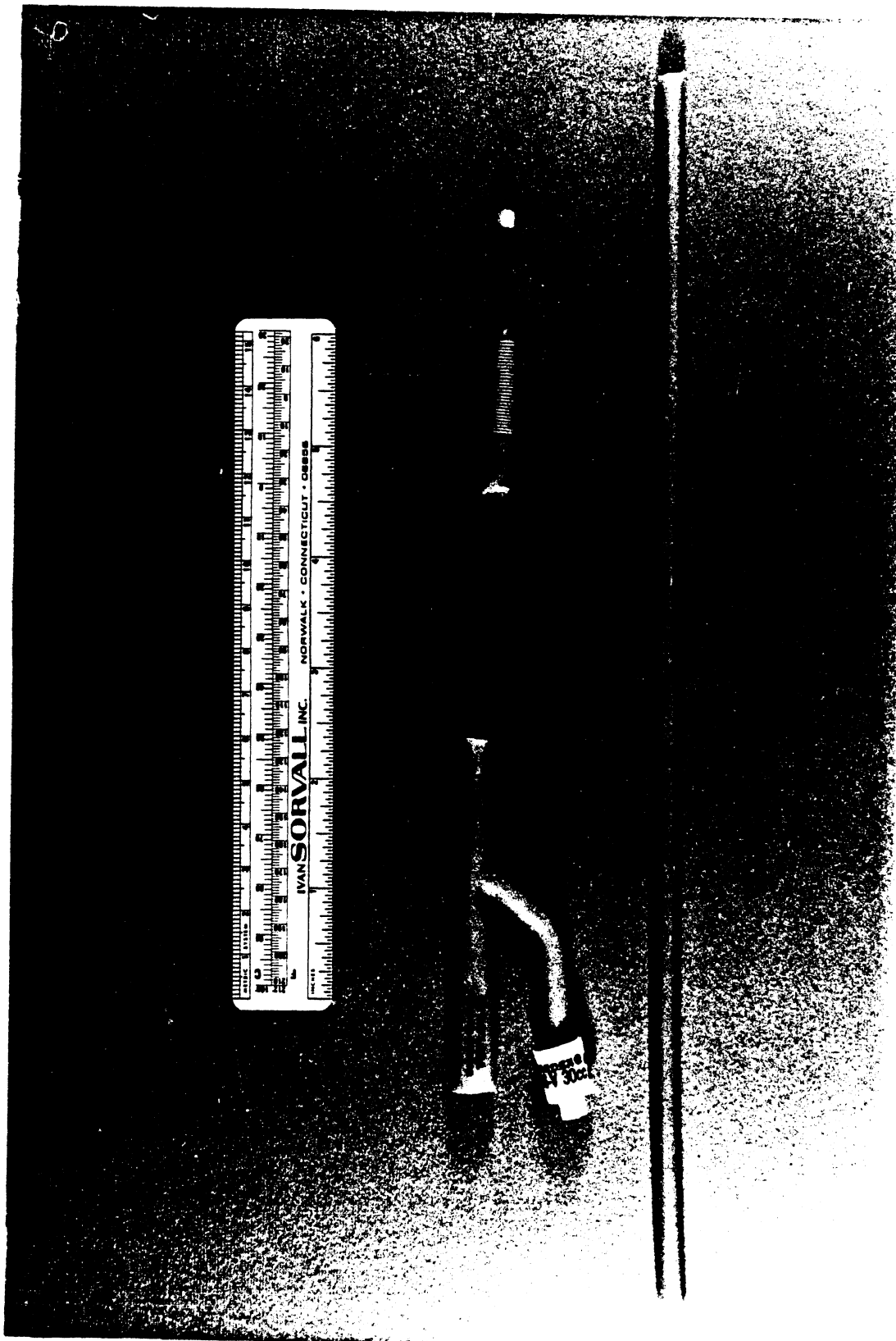


Figure 4.20. Modified Foley balloon catheter for vascular pressurization.

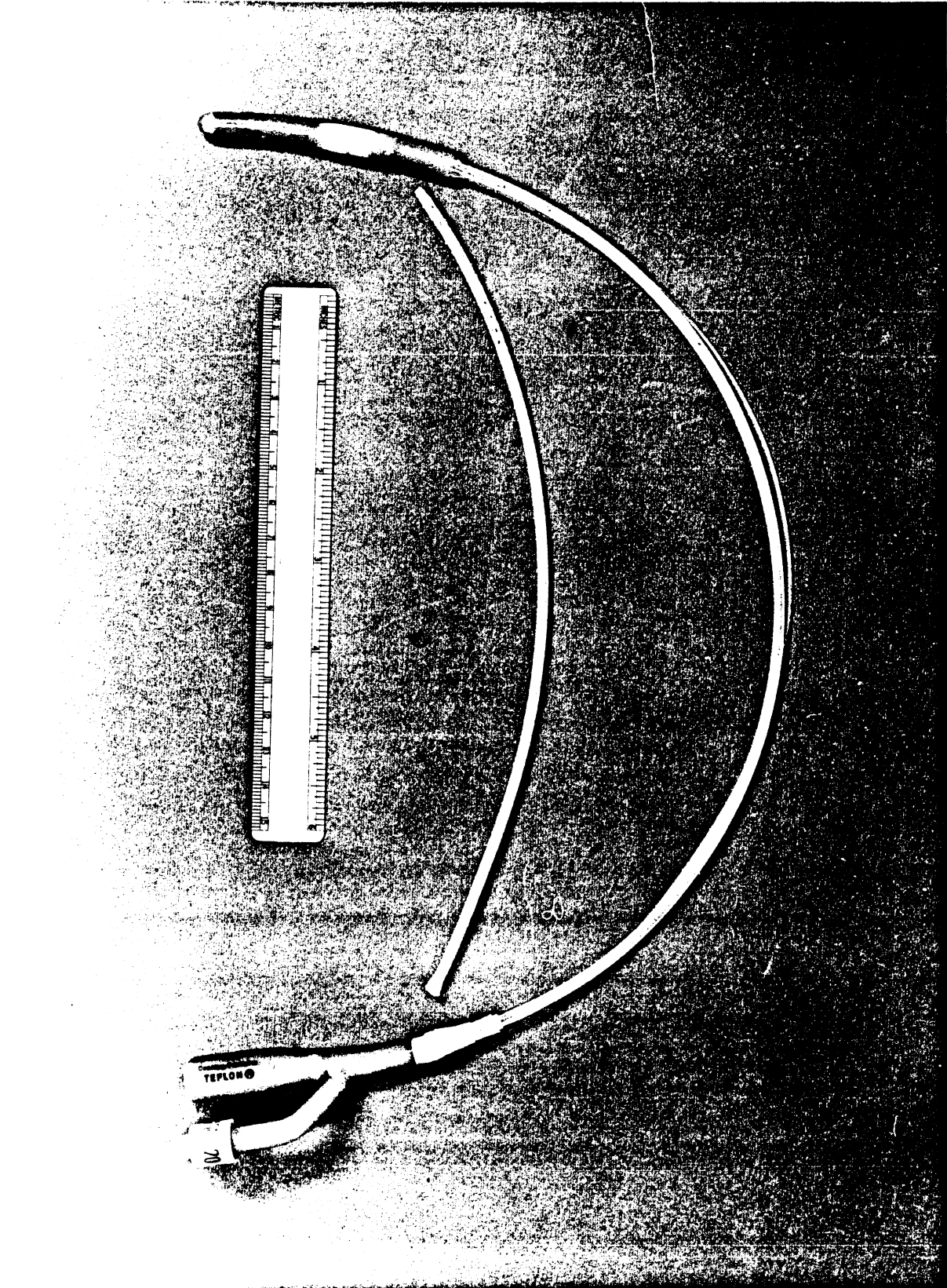


Figure 4.21. Partially constructed catheter assembly.

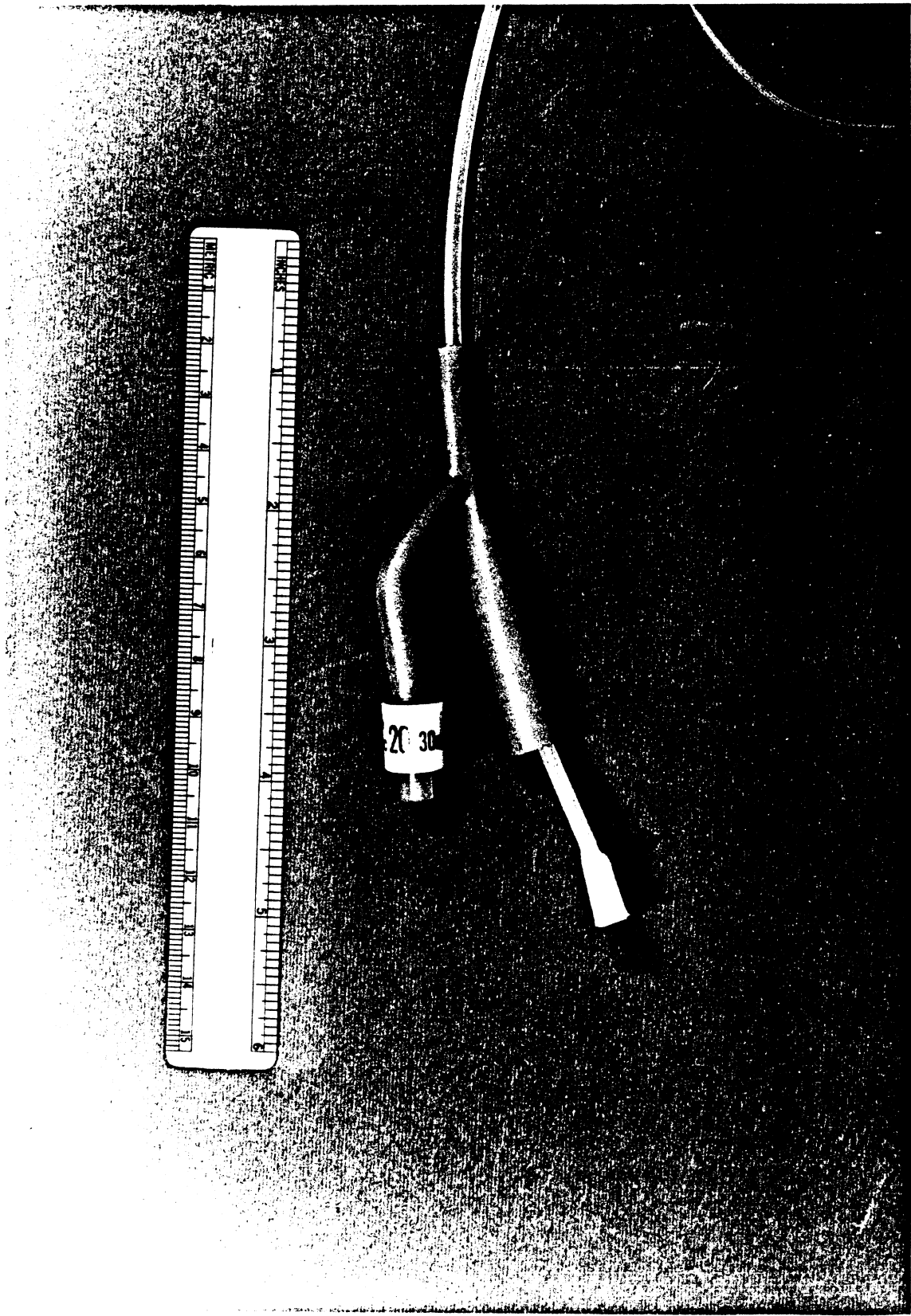


Figure 4.22. Flared end of catheter insert tube.

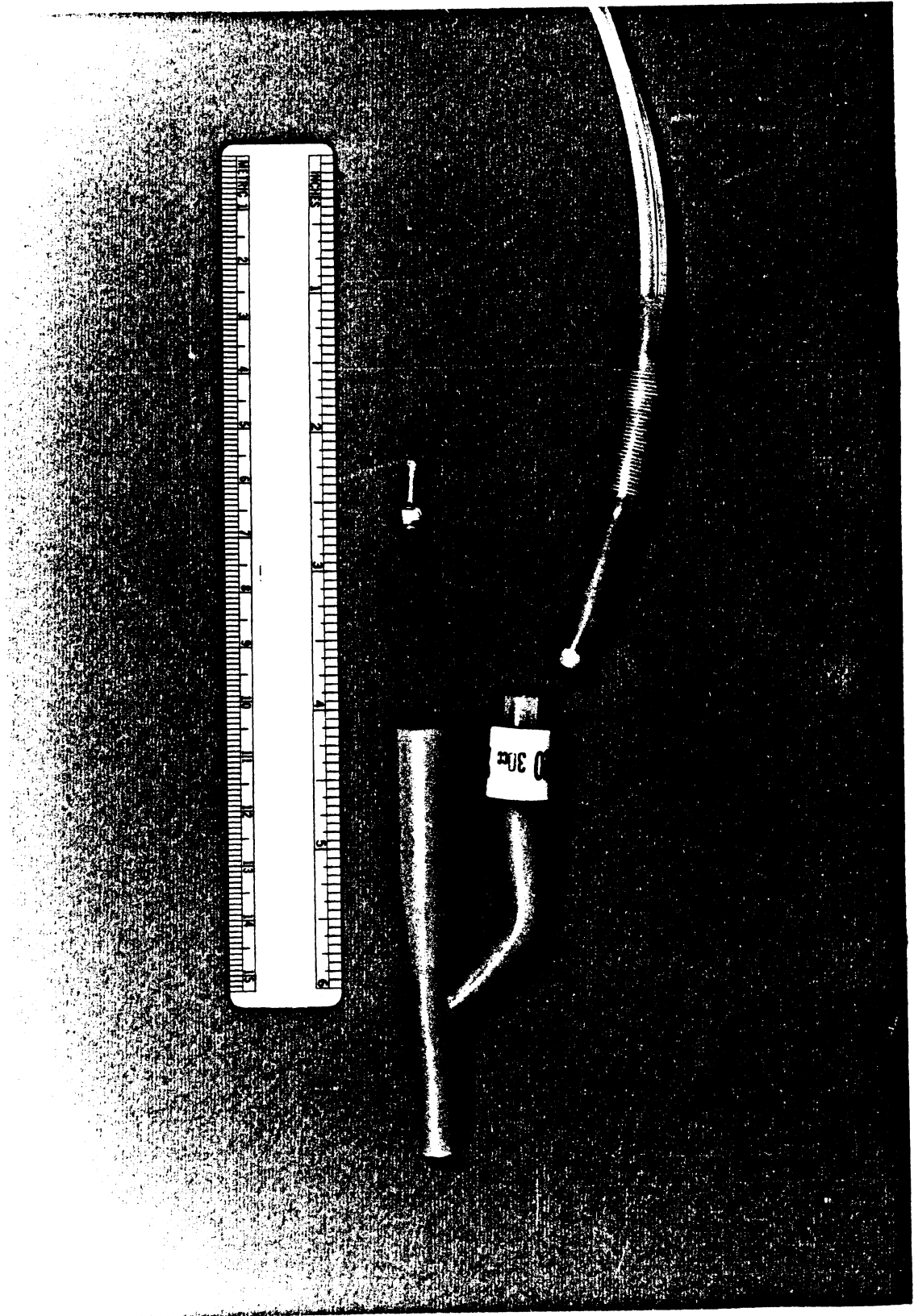


Figure 4.23. Lead targets for end of catheter tube.

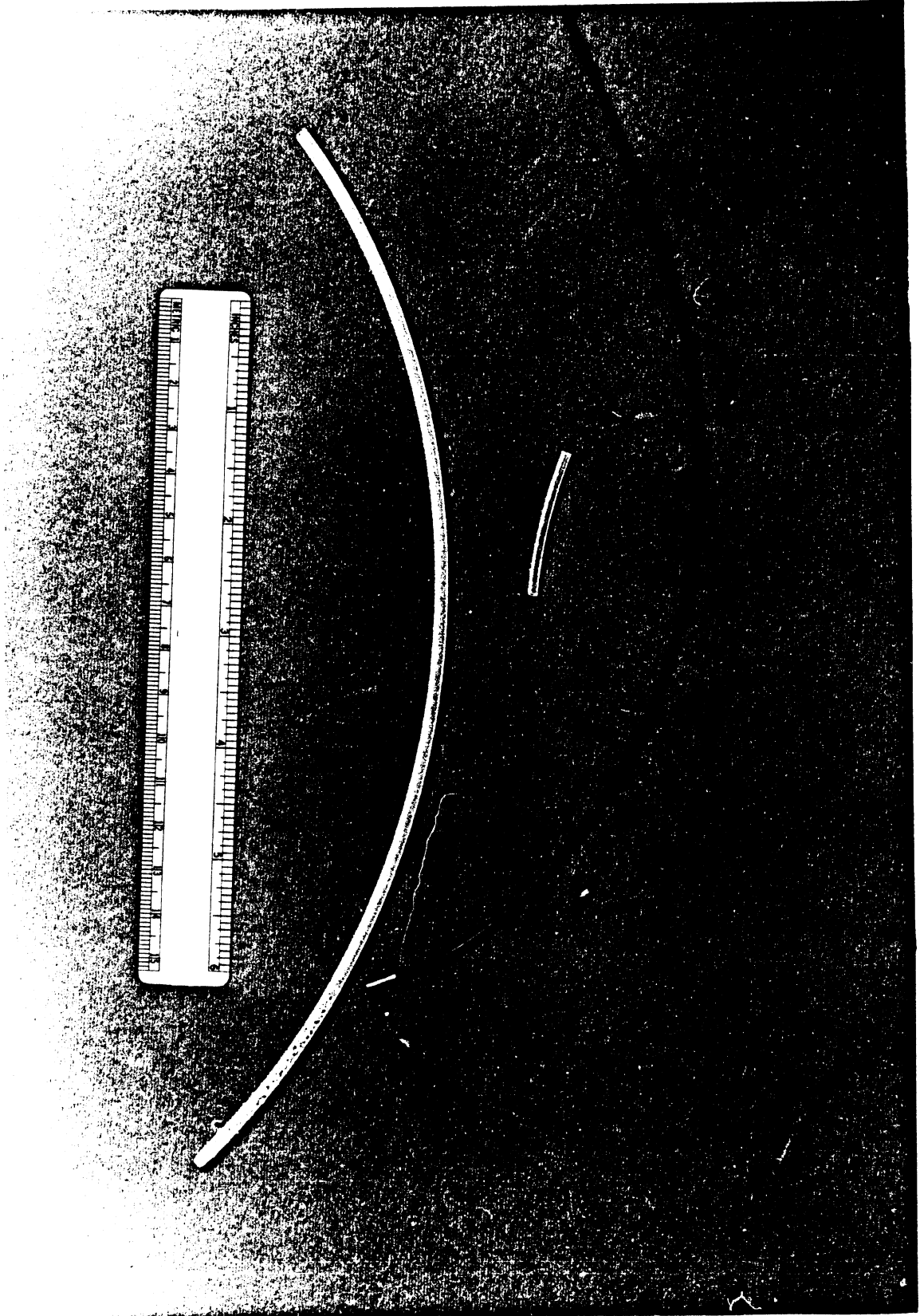


Figure 4.24. Vascular pressure transducer.

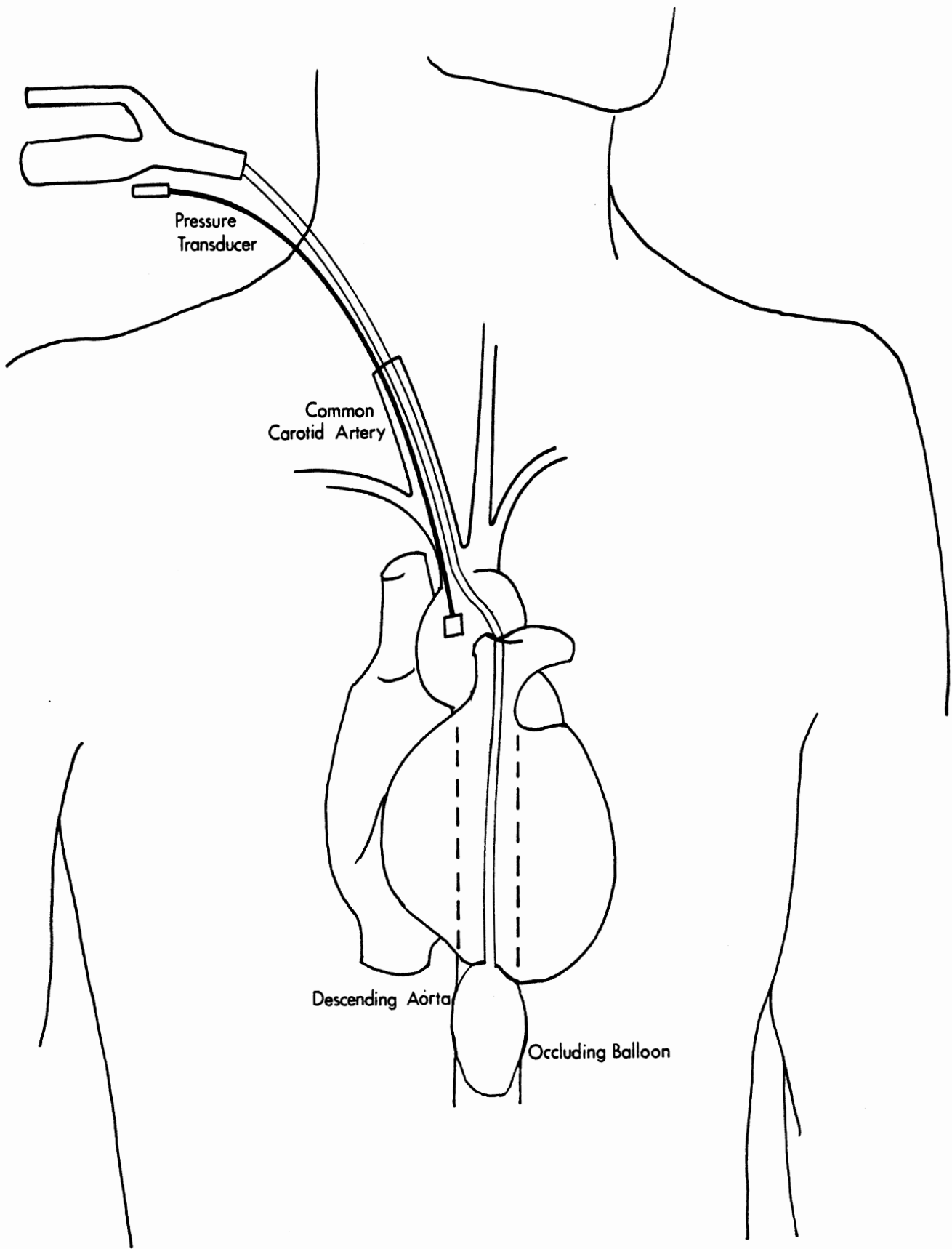


Figure 4.25. Schematic of vascular pressurization equipment in place.

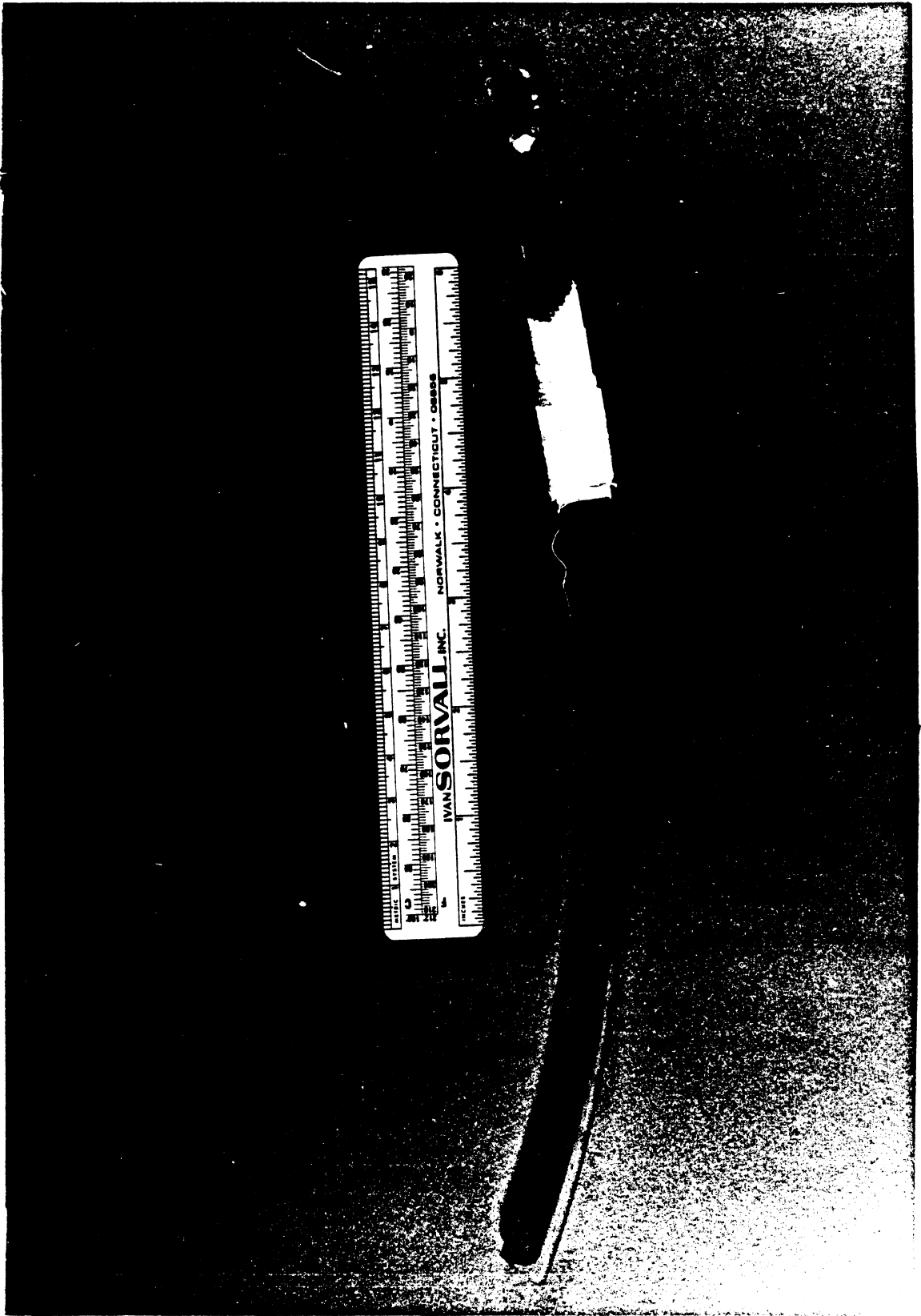


Figure 4.26. Respiratory pressurization tube.

PROTOCOL J: INSTRUMENTATION POSITION AND ORIENTATION DATA SHEET

Accelerometer Location	Distance from Body Center (Y)	Distance from Table (X)	Distance from Vertex (Z)
Rt. Lo. Rib			
Rt. Up. Rib			
Lt. Lo. Rib			
Lt. Up. Rib			
Lt. Frt. Rib			
Up. Stern.			
Lo. Stern.			
T1			
T12			
	Angle about Y	Angle about X	Angle about Z
Rt. Lo. Rib			
Rt. Up. Rib			
Lt. Lo. Rib			
Lt. Up. Rib			
Lt. Frt. Rib			
Up. Stern.			
Lo. Stern.			
T1			
T12			

Date:

Measurer:

Cadaver ID:

Figure 4.27. Instrumentation Position and Orientation Sheet

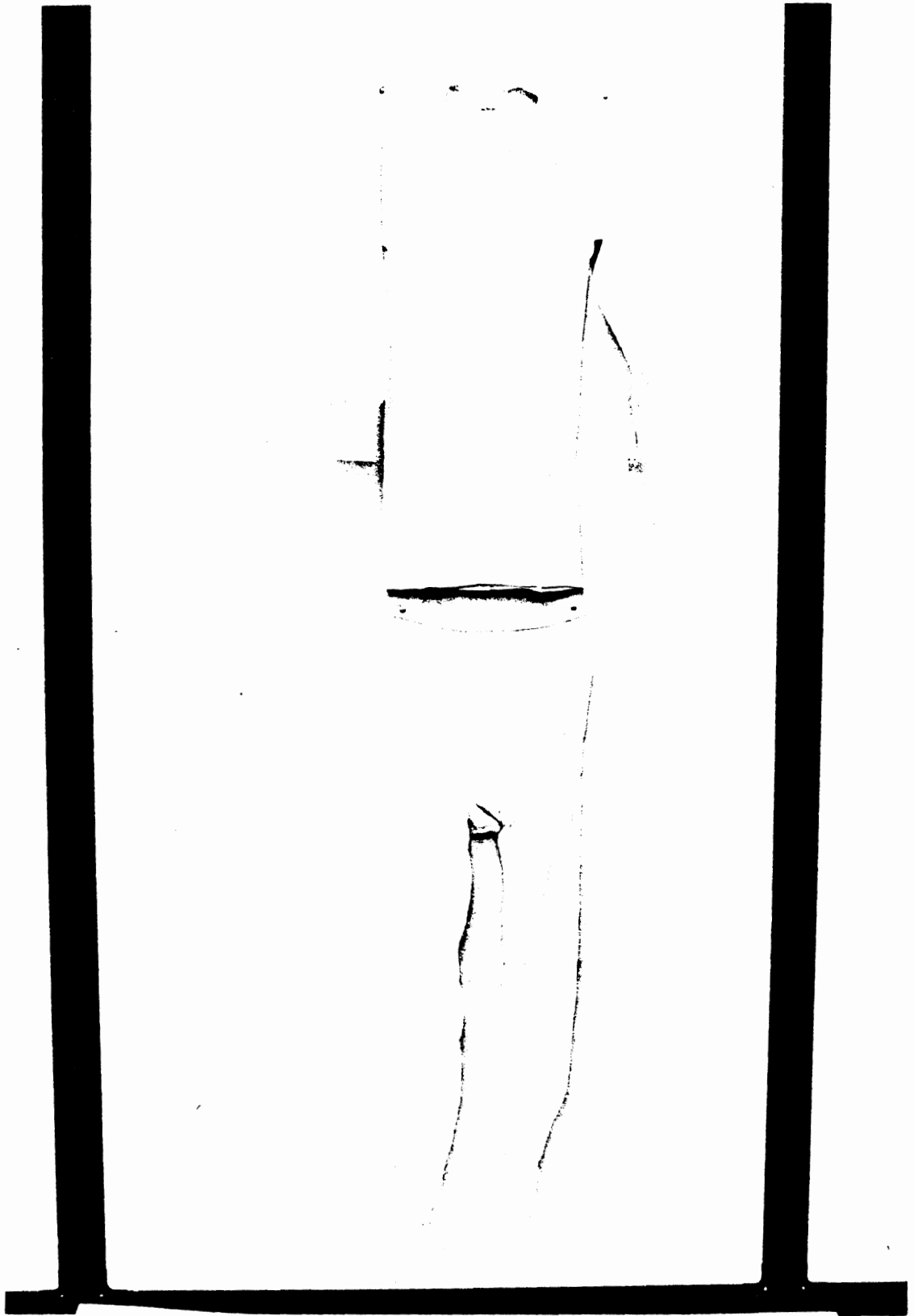


Figure 4.28. Test subject outer clothing.



Figure 4.29. Test subject underclothing.

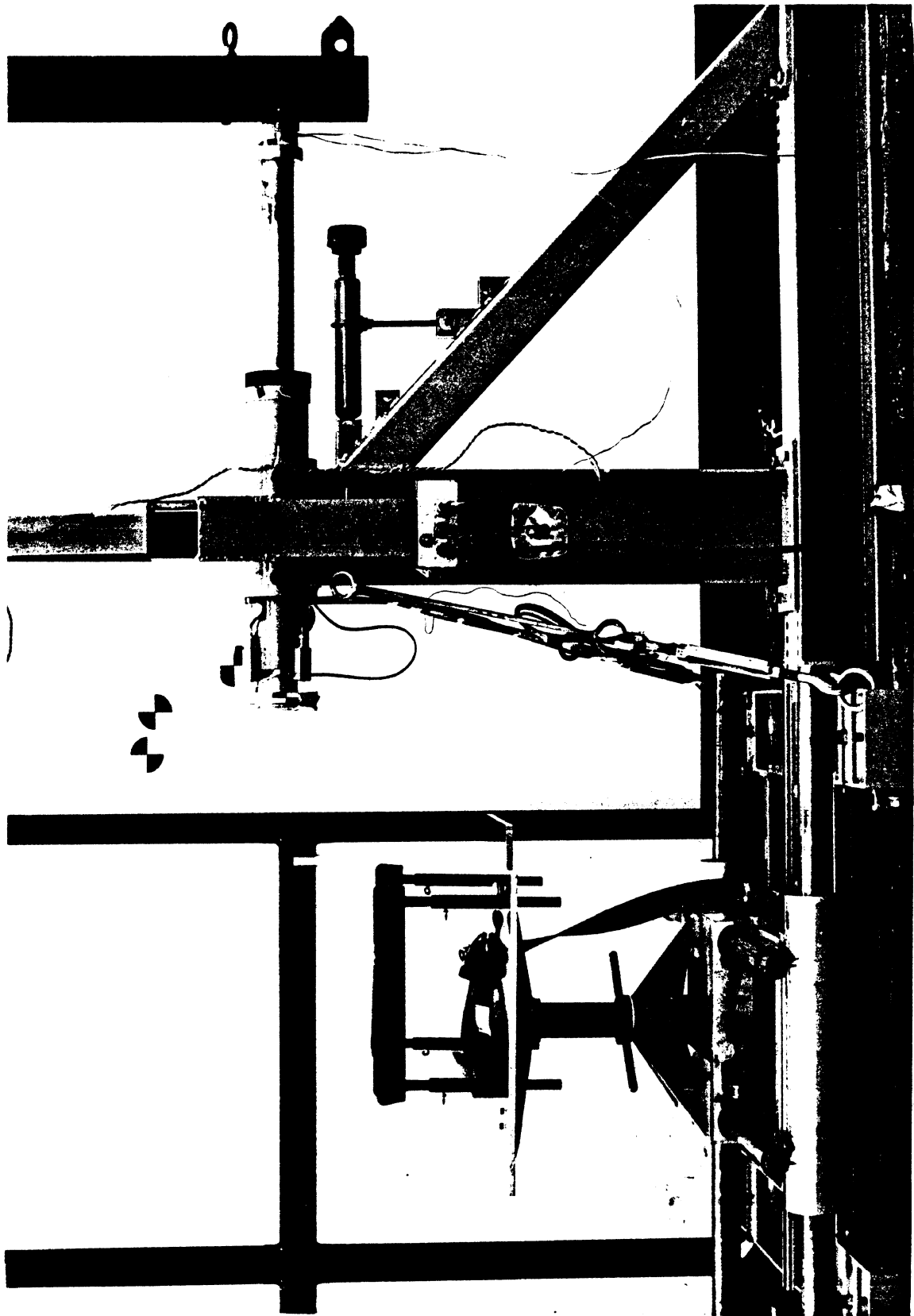


Figure 4.30. Positioning chair for pendulum impacts.

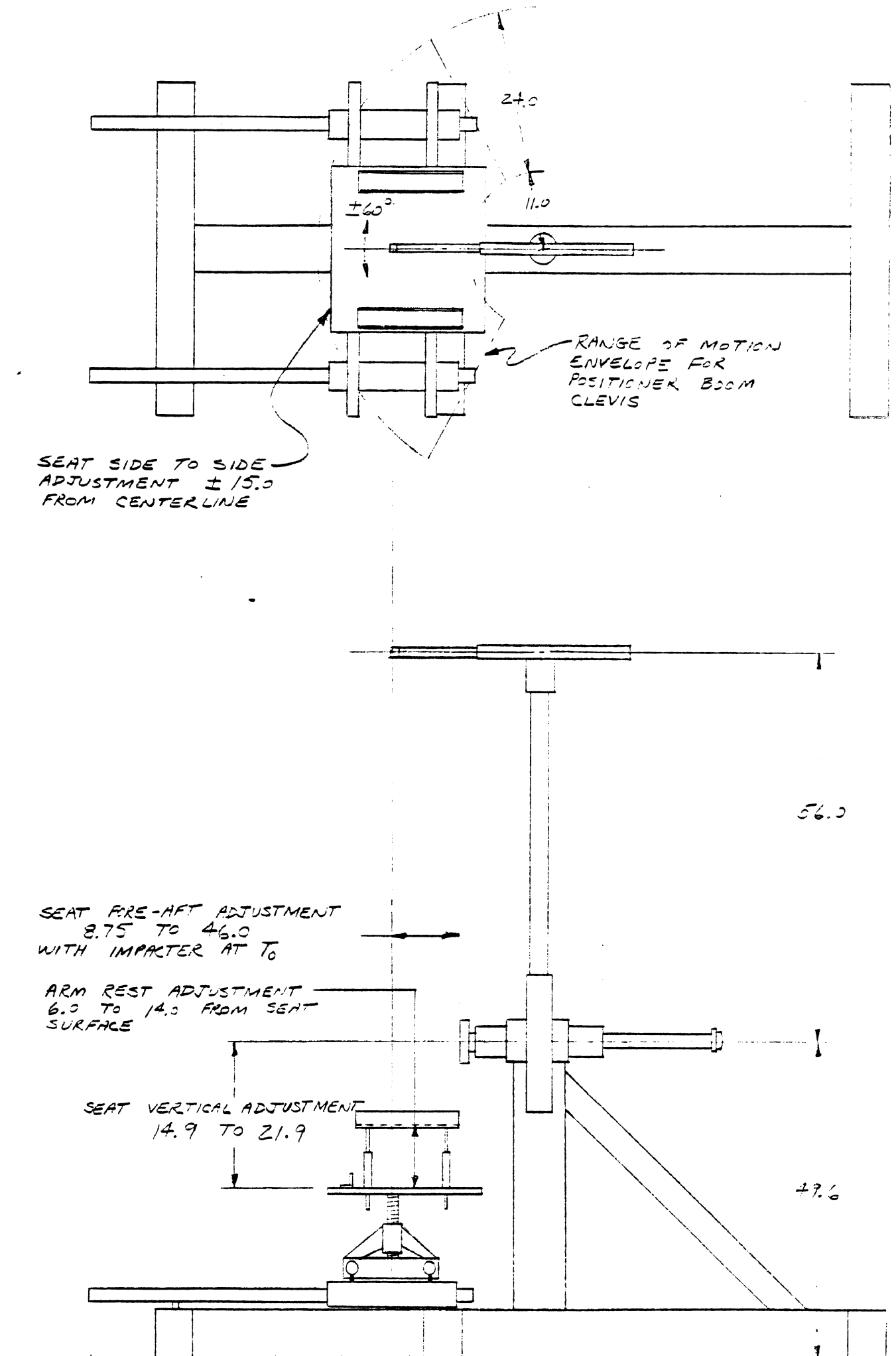
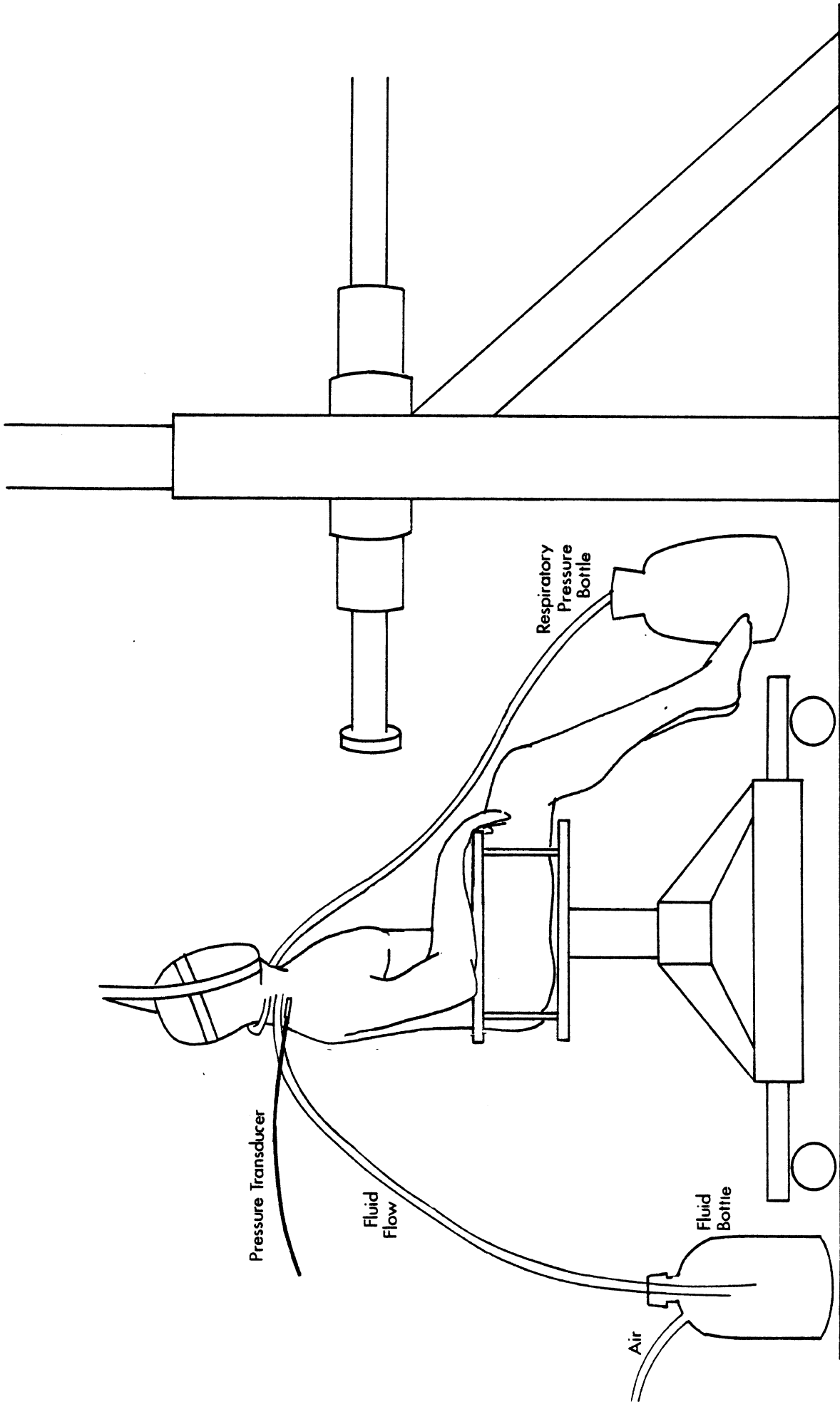


Figure 4.31. Positioning chair adjustments. (Schematic). $\frac{1}{20}$ SCALE 4.58

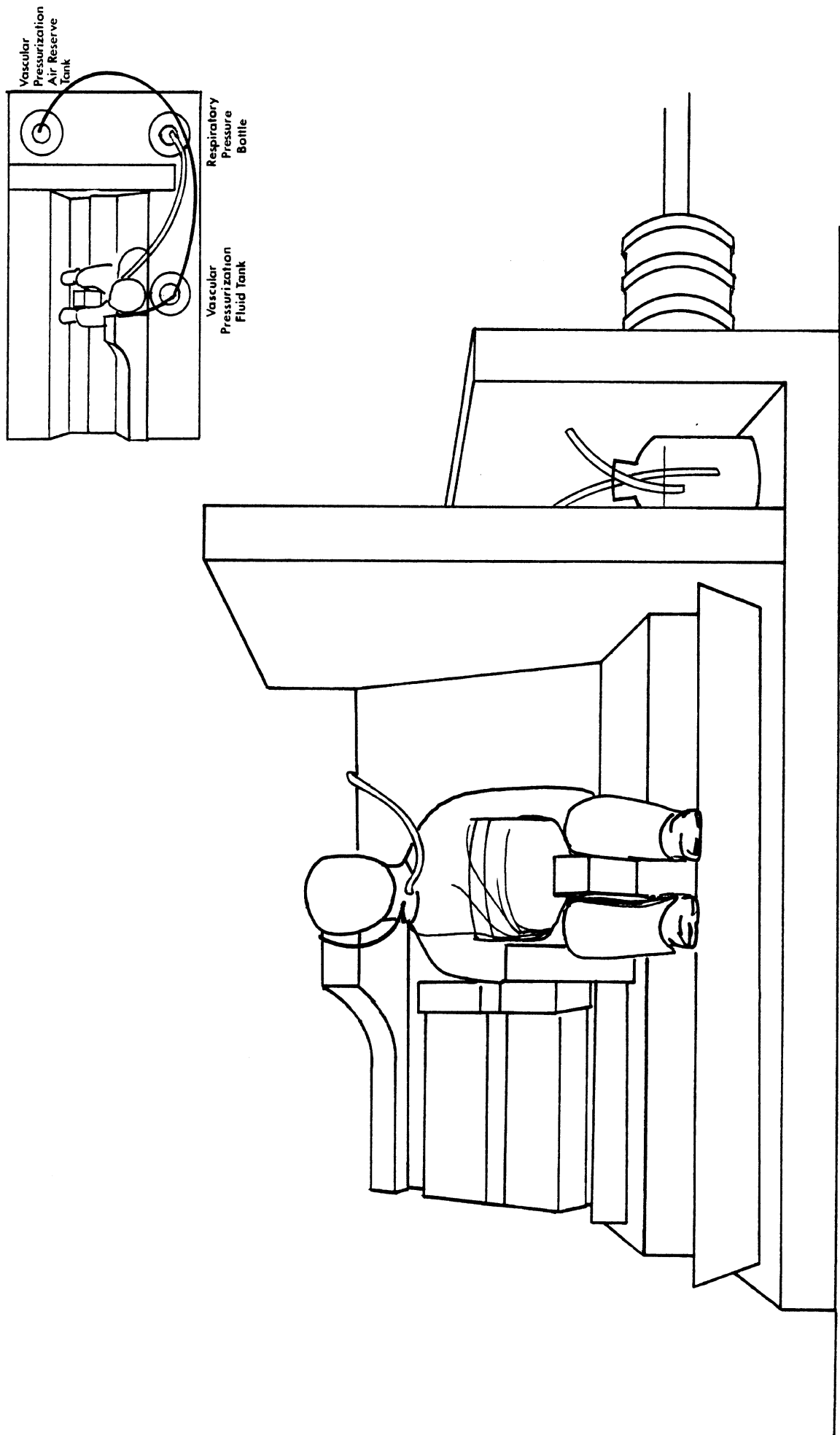


Figure 4.32. Build-A-Board hardware in use.



PENDULUM SET-UP

Figure 4.33. Schematic of pressurization hardware. Pendulum impactor.



SLED SET-UP

Figure 4.34. Schematic of pressurization hardware. Impact sled.

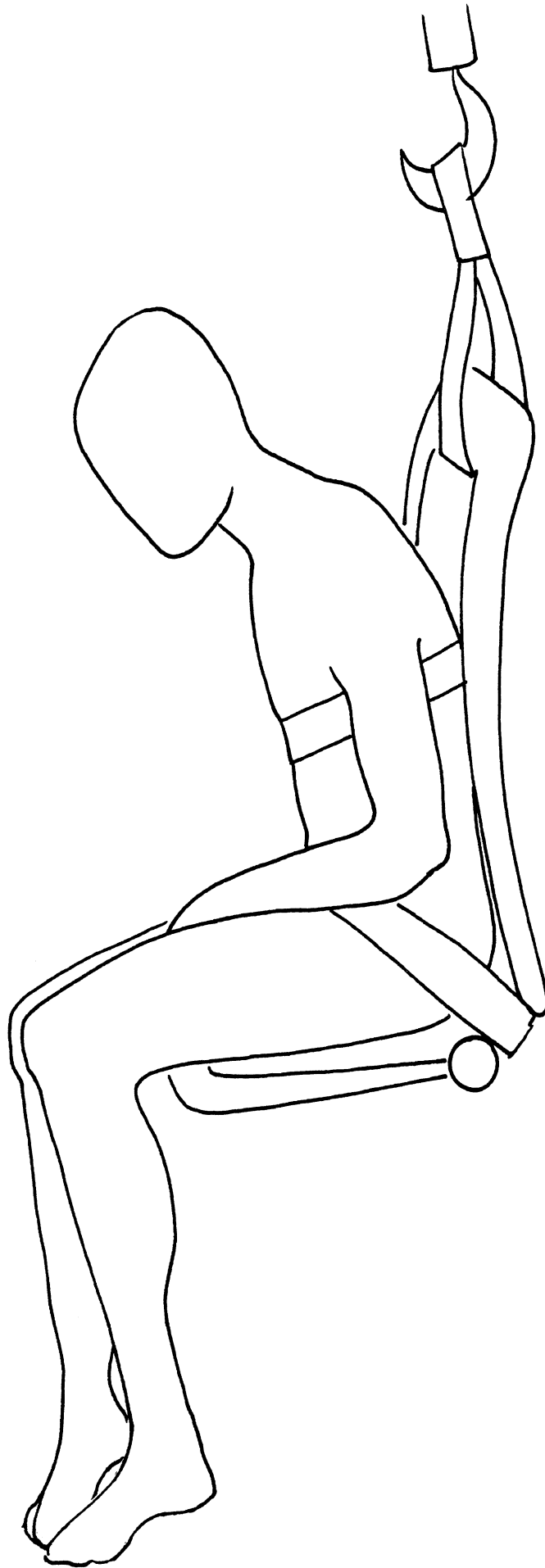


Figure 4.35. Subject immobilized after test. Schematic.

THORACIC IMPACT PROJECT

CADAVER NUMBER _____

TEST RUN NUMBER _____ (PREVIOUS RUN NUMBER _____)
(most recent thorax test)

DATE OF ARRIVAL _____

DATE OF IMPACT _____

DATE OF AUTOPSY _____

SUBJECT STATURE _____

SUBJECT WEIGHT _____

SUBJECT AGE _____

SUBJECT SEX: M _____ F _____

RESTRAINT SYSTEM TYPE _____

VELOCITY _____

DECELERATION _____

NOTE: UPON COMPLETION OF TEST, THE SLED LAB DOCUMENTS MUST BE COPIED (XEROX):
THE ORIGINALS TO BE RETAINED IN THE SLED LAB FILES; THE COPY GOING INTO DR. ROBBINS'
FILES. THIS IS THE RESPONSIBILITY OF THE TEST DIRECTOR, WHO WILL INITIAL HERE
UPON COMPLETION OF COPYING. _____

TEST MODIFICATIONS AND CHANGES IN PROTOCOL:

THORACIC IMPACT PROJECT

INSTRUMENTATION CHECKLIST

Cadaver Number _____

The following instrumentation shall be used in this test

Accelerometers

Left Lower Rib _____	Lower Sternum _____
Left Upper Rib _____	Upper Sternum _____
Right Lower Rib _____	T1 Biaxial _____
Right Upper Rib _____	T12 Biaxial _____
Others _____	

Other Transducers

Tracheal Pressure _____

Intrathoracic Pressure _____

Others _____

Targets

Acromion Targets (2) _____

T1 Target (Ping Pong ball) _____

T12 Target (Ping Pong ball) _____

Rib Accelerometers _____

Shoulder Belt _____

Flat Targets over Ears _____ Top of head _____

Sled

Accelerometer _____

Restraint System _____

Figure 4.37. Sled lab protocol. Instrumentation check list.

THORACIC IMPACT PROJECT SCHEDULE PART 2: (SLED LAB)

TEST No. _____ CADAVER No. _____

PROJECT DIRECTOR: _____

ITEM (and Description)	TIME REQ'D	DATE & TIME	No. of PERSONS REQUIRED	PERSONNEL ASSIGNED	WHEN COMPLETED, INITIAL HERE
1. Specify all apparatus needed for test					
2. Obtain or fabricate those items needed but not on hand.					
3. Prepare Sled and Lab for test as per test requirements: a. assemble and integrate electronics b. assemble and otherwise prepare sled c. compute pressures, etc., using form provided					
4. Test all electronic devices: if any fail, replace or resort to alternative plans					
5. Prepare lab for test firing: a. Cadaver (see cadaver forms) b. Sled (see sled checklist) c. Cameras (see camera checklist) d. Electronics					
6. Fire sled					
7. Secure sled & initiate post-test activities: a. Photographic b. Visicorder c. Sled/Cadaver					
8. Clean sled and all contaminated places					
9. Make direct Brush recordings of raw data					

Figure 4.1 (4.38). Test lab protocol.

THORACIC IMPACT PROJECT

Test Setup

Cadaver No. _____

1. System Weight

_____	975	lbs.	Basic Sled
_____		lbs.	Test Buck
_____		lbs.	Test Subject
_____		lbs.	Misc. Hardware
_____		lbs.	Other _____
_____		lbs.	TOTAL

2. Programming Data

Nominal ΔV = _____ MPH (x 1.467) = _____ ft/sec

Programmer Pressure = _____ PSIG for _____ G's

C_R = Coeff. of Restitution = _____ estimated or from graph

$V_E = \Delta V / (1 + C_R) = (\text{_____}) / (\text{_____}) = \text{_____} \text{ MPH} \times 1.467 = \text{_____} \text{ ft/sec}$

Accel Pressure = _____ PSIG

3. Calculate Actual Impact Parameters (P.S. = Paper Speed in in/sec)

(Dist. = Distance between first and last velocity pulse peaks in inches)

$V_E = \frac{2.0454 \text{ (P.S.)}}{\text{DIST.}} = \frac{2.0454 (\text{_____})}{(\text{_____})} = \text{_____} \text{ MPH} \times 1.467 \text{ _____} \text{ ft/sec}$

$V_R = \frac{2.0454 \text{ (P.S.)}}{\text{DIST.}} = \frac{2.0454 (\text{_____})}{(\text{_____})} = \text{_____} \text{ MPH} \times 1.467 \text{ _____} \text{ ft/sec}$

ACTUAL TEST VELOCITY = ΔV = _____ MPH or _____ ft/sec

ACTUAL SLED DECELERATION = _____ G's

Figure 4.39. Sled Lab Protocol. Setup Parameters.

THORACIC IMPACT PROJECT

Photography Checklist

Cadaver No. _____

A. Photosonics

	Right Side	Left Side	Overhead	Frontal
Frame/Sec.	<u>1000</u>	<u>1000</u>	<u>1000</u>	<u>1000</u>
Film	<u>7242</u>	<u>7242</u>	<u>7242</u>	<u>7242</u>
Film Type	<u>Color</u>	<u>Color</u>	<u>Color</u>	<u>Color</u>
Distance from Subject	<u>18' 5"</u>	<u>8' 2"</u>	<u> </u>	<u>Variable</u>
Camera Height	<u>63-1/2"</u>	<u>60-1/2"</u>	<u> </u>	<u>71"</u>
Shutter Opening	<u>5 = 72°</u>	<u>2.5 = 144°</u>	<u>5 = 72°</u>	<u>5 = 72°</u>
f-stop	<u>3.5</u>	<u>4.0</u>	<u>3.5</u>	<u>2.8</u>
Position, Aim & Focus	<u> </u>	<u> </u>	<u> </u>	<u> </u>
Film in Magazine	<u> </u>	<u> </u>	<u> </u>	<u> </u>
No Binding in Film Drive	<u> </u>	<u> </u>	<u> </u>	<u> </u>
Ready Light ON	<u> </u>	<u> </u>	<u> </u>	<u> </u>
Correct Voltage	<u> </u>	<u> </u>	<u> </u>	<u> </u>
Magazine Switch Correct	<u> </u>	<u> </u>	<u> </u>	<u> </u>
Lens Cap Removed	<u> </u>	<u> </u>	<u> </u>	<u> </u>
Timing Light Functioning	<u> </u>	<u> </u>	<u> </u>	<u> </u>

B. Graph-Check

- Trigger Pulse _____ msec
- Time Delay Setting _____
- Position Correct _____
- Sequence Dial Setting _____
- Battery Connected _____
- Function Checked _____
- Film Loaded _____
- Shutter Cocked _____
- Film Shield Pulled Down _____

C. Take Set-Up Photos: _____

D. Obstructions

All Cameras Have Clear View of Impact Area: _____

E. Targets

All Targets on Subject Visible to Cameras: _____

Figure 4.40. Sled Lab Protocol. Photography Checklist

THORACIC IMPACT PROJECT

Preparation Checklist

Cadaver No. _____

INSTRUMENTATION

- All Cables in Correct Location _____
- Calibrate Electronics _____
- Check Continuity in Data Channels _____
- All Filter Switches in Correct Position

Check Connection: Batteries on Sled

CHECK TIMING

- a. Photosonic Run time _____ msec
- b. Photosonic Relay At _____ for
before
_____ msec delay after Jamesbury
- c. Visicorder Relay at _____ for
_____ msec delay
- d. Caliper Time Delay at .6 for 30
MPH or 1.0 for 20 MPH

VISICORDER READY

- a. Paper Supply _____
- b. Amplifiers (Gain & Mode Settings)

- c. Paper Speed & Length _____
- d. Control Buttons _____
- e. "Auto Rec" Reset _____
- f. Lamps on _____
- g. Galvos Aimed _____

TAPE RECORDERS READY

- a. Controls Set Correctly _____
- b. Tape Speed Correct _____
- c. Test No. and Footage Marked on Reels

- d. Tape Heads Cleaned _____
- e. CEC Remote Connected _____

SLED

- Charge Accelerator _____ PSI
- Charge Programmer _____ PSI
- Subject Positioned _____
- Target Visibility _____
- Restraint Tightness _____
- Photosonics Ready _____
- Graphcheck Ready _____
- Invertube on Ram _____
- Chalk on steering wheel rim and hub
or airbag _____
- Check Floodlight Operation _____
- Check Run Number _____
- Check for Loose Material on Sled _____
- Check for Items Around Rails & Sills

- Rails Oiled _____
- Brake Charged to _____ PSI
- Connect Batteries _____
- Pressurize Cadaver _____
- Turn flood and timer on _____
- Open valve after pressurizing _____
- Check run gains for proper settings

- Lock All Doors into Sled Lab _____
- Check Function of Caliper Brakes _____
- Check Function of Emergency Backstop

- Install Trigger Switch Wires _____
- Check Brake Systems _____
- Check that no items overlooked _____

Checked by _____

Date _____

Figure 4.41. Sled Lab Protocol. Preparation and Safety Protocol.

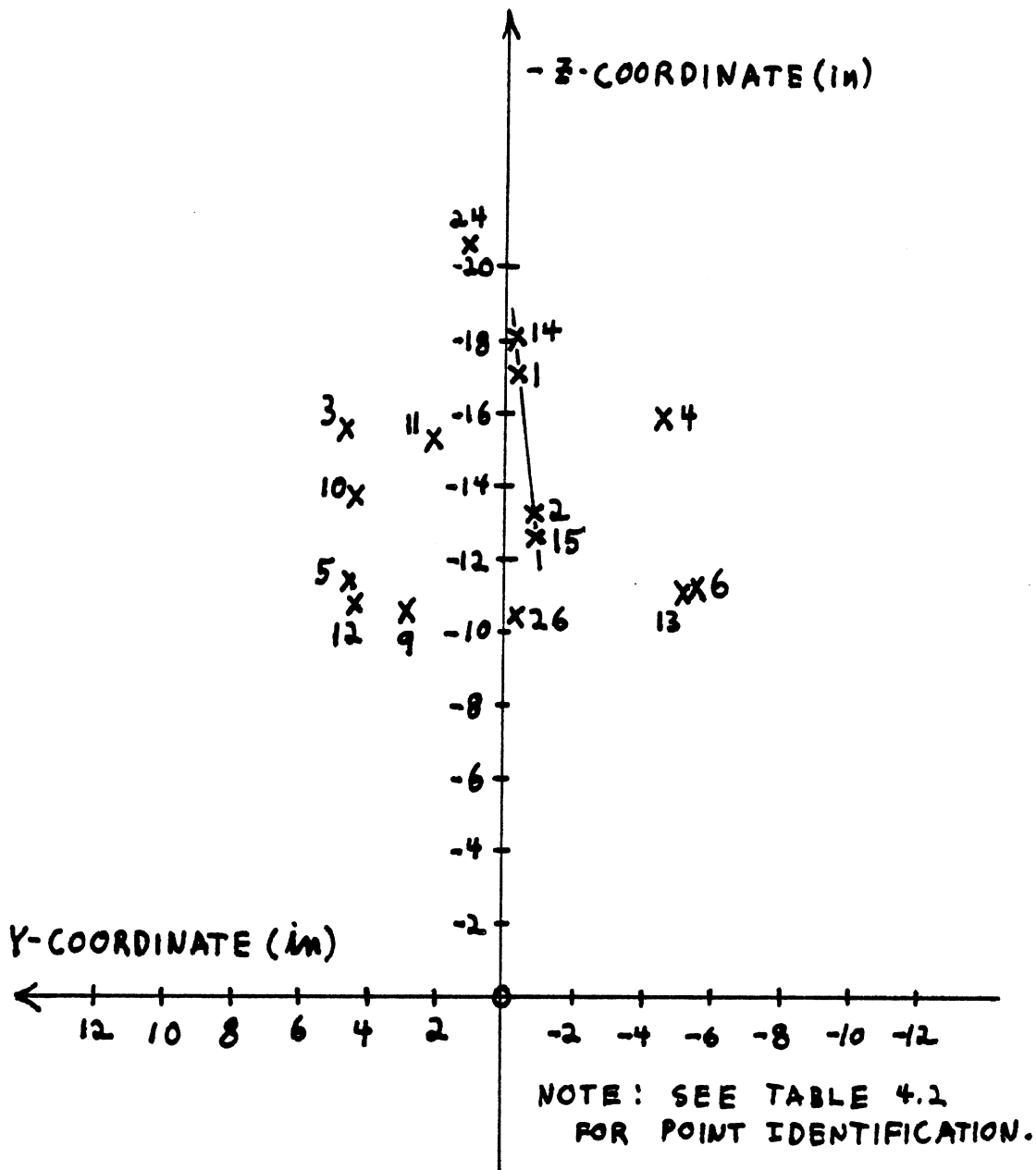


Figure 4.43. Target locations. Front view. Test 76T008.

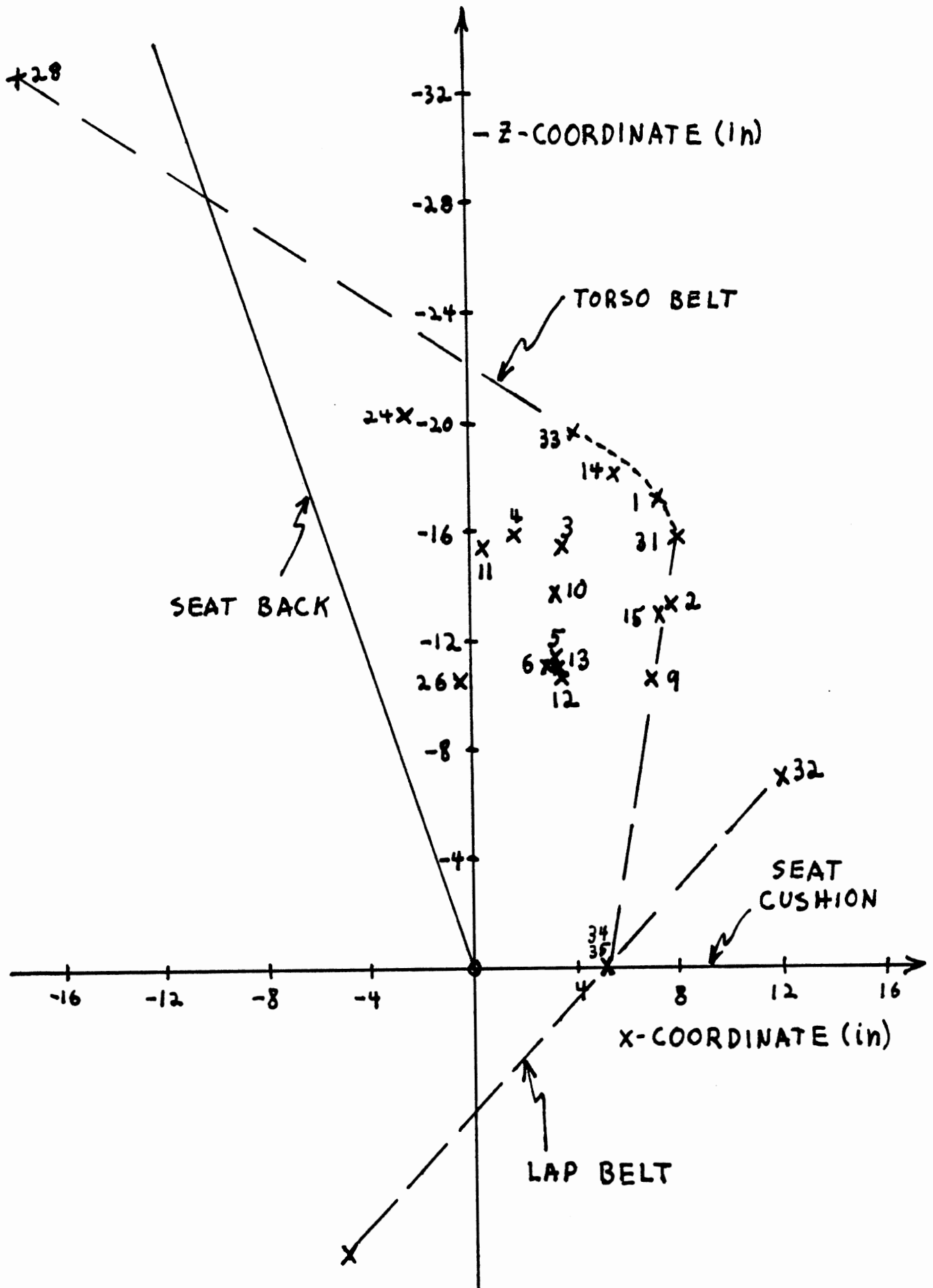


Figure 4.44. Target locations. Side view. Test 76T008.

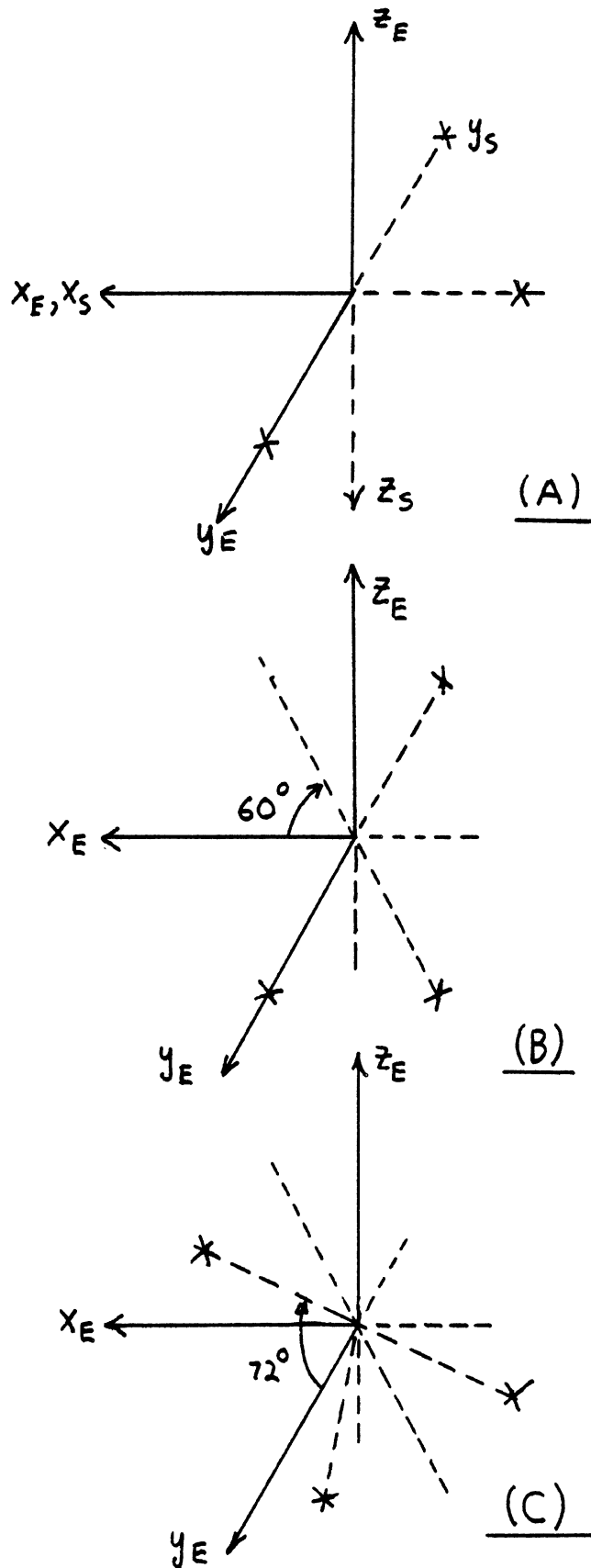
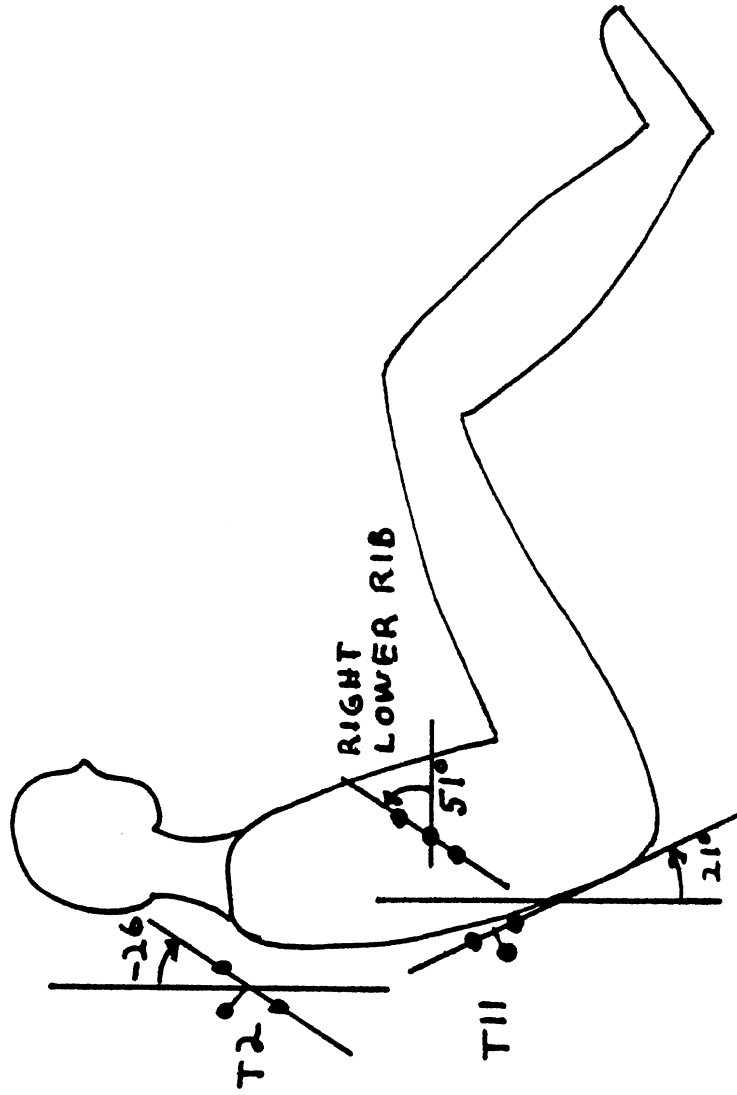


Figure 4.45. Euler angle definitions. Left rib number 9. Test 76T008.



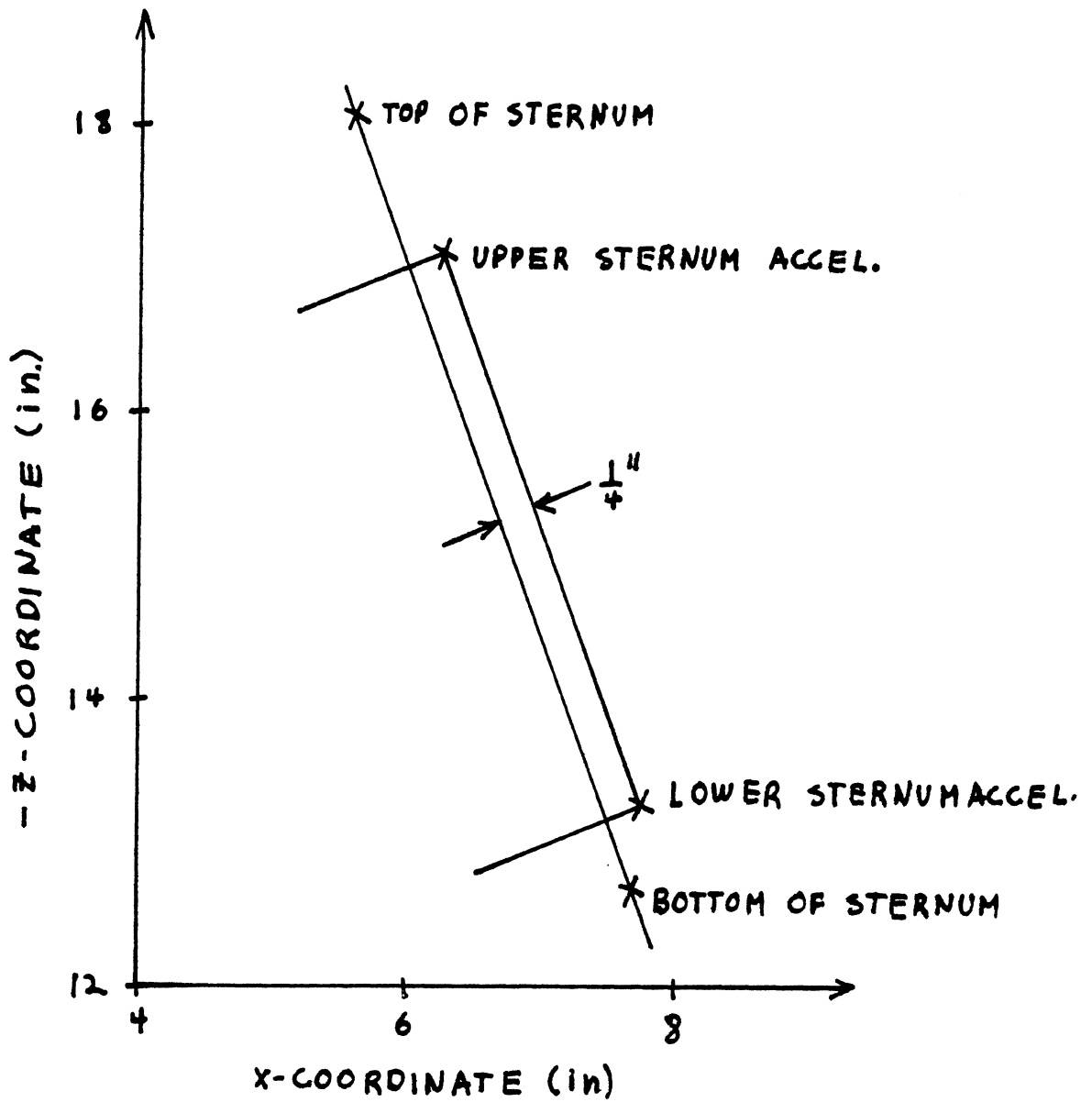


Figure 4.47. Sternum. Side view. Test 76T008.

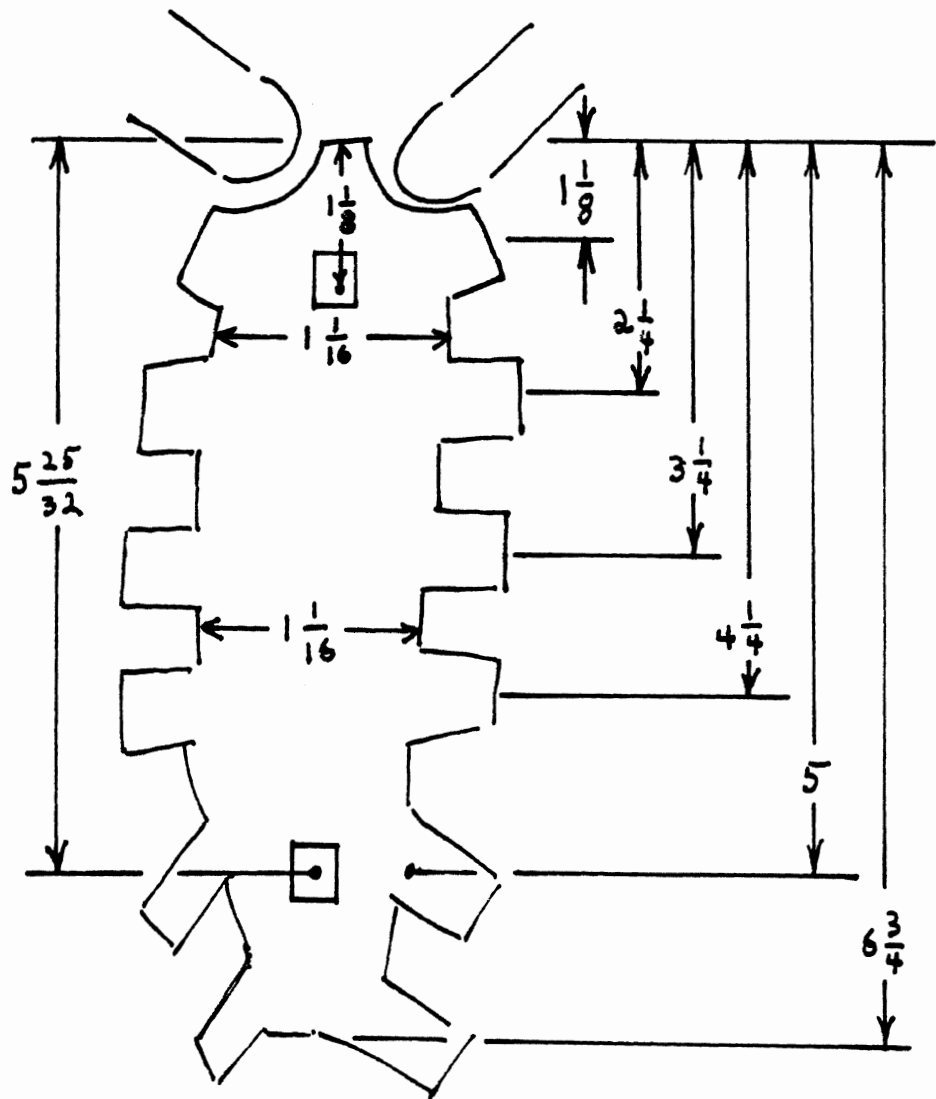


Figure 4.48. Sternum. Front view. Test 76T008.

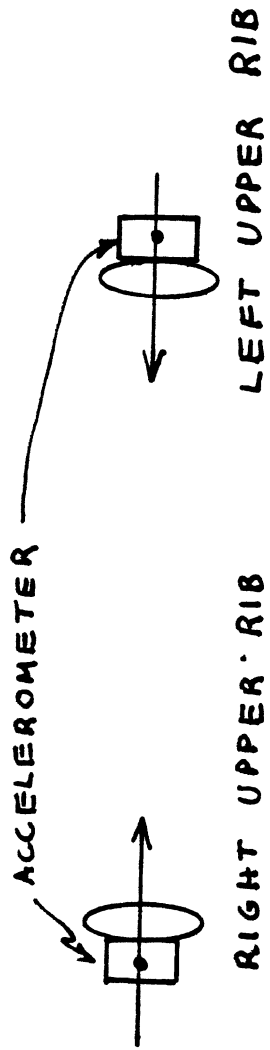


Figure 4.49. Front view of upper rib mounts on ribs. Test 76T008.

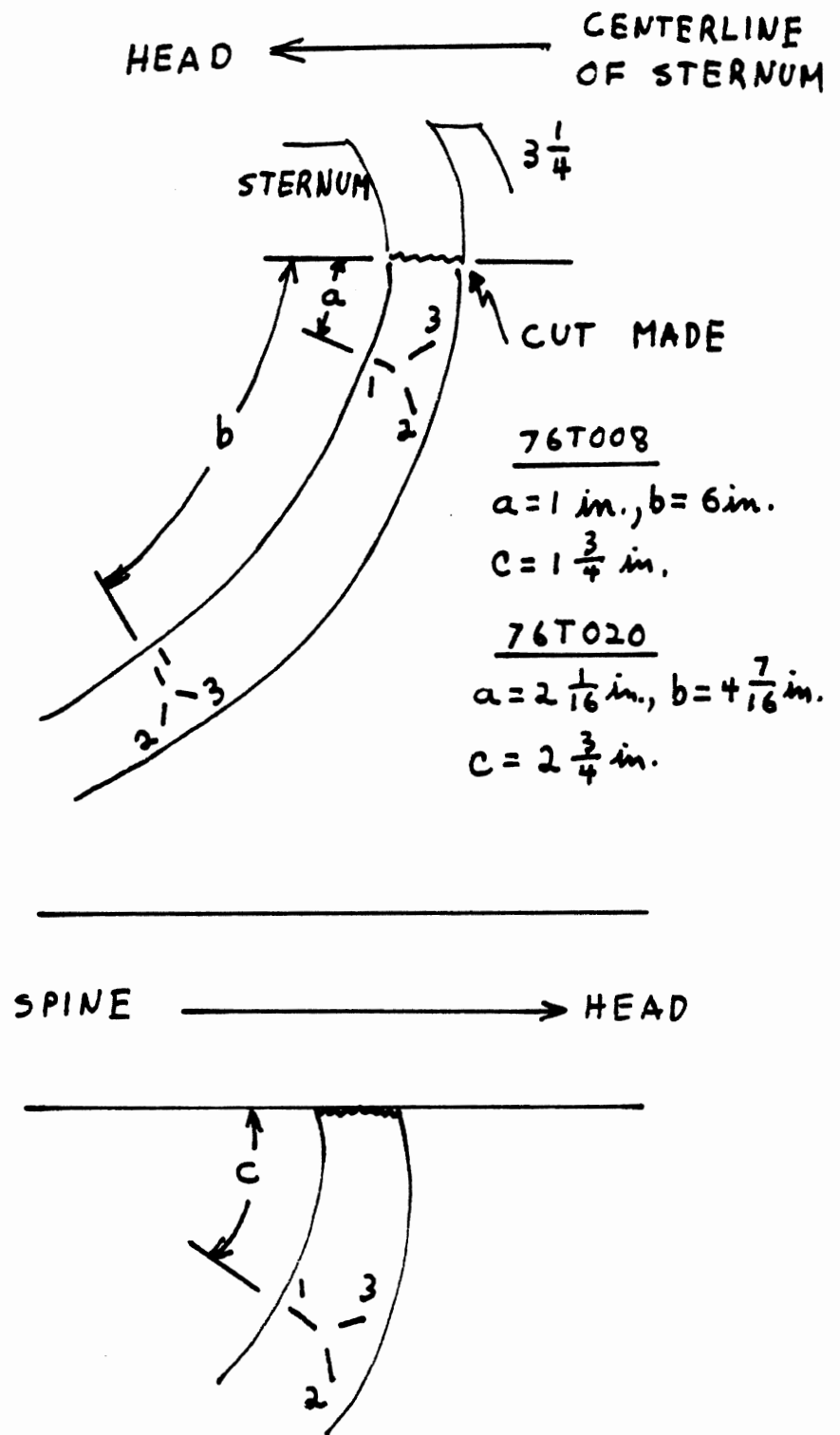


Figure 4.50. Strain gage rosette orientations.

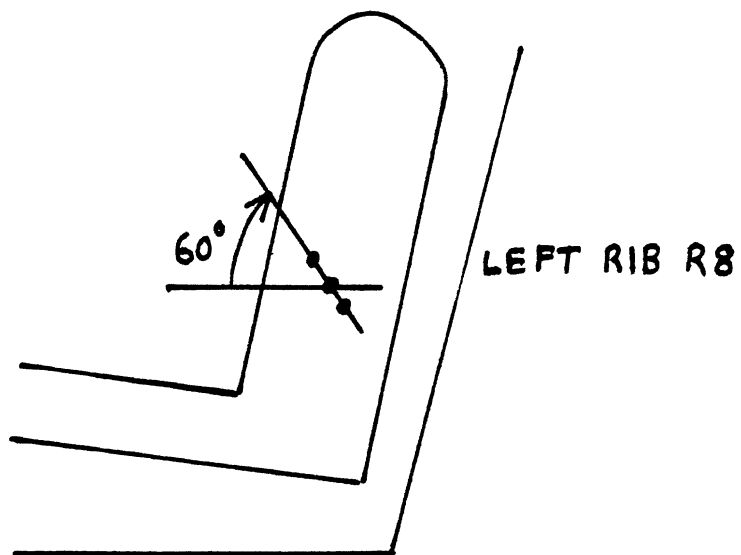
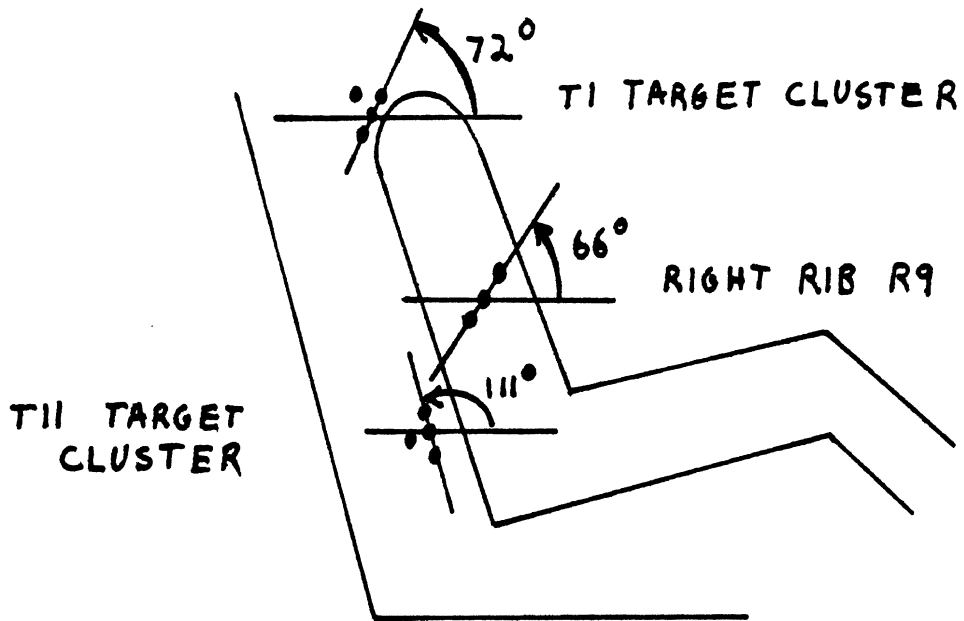


Figure 4.51. Visual target clusters. Test 76T020.

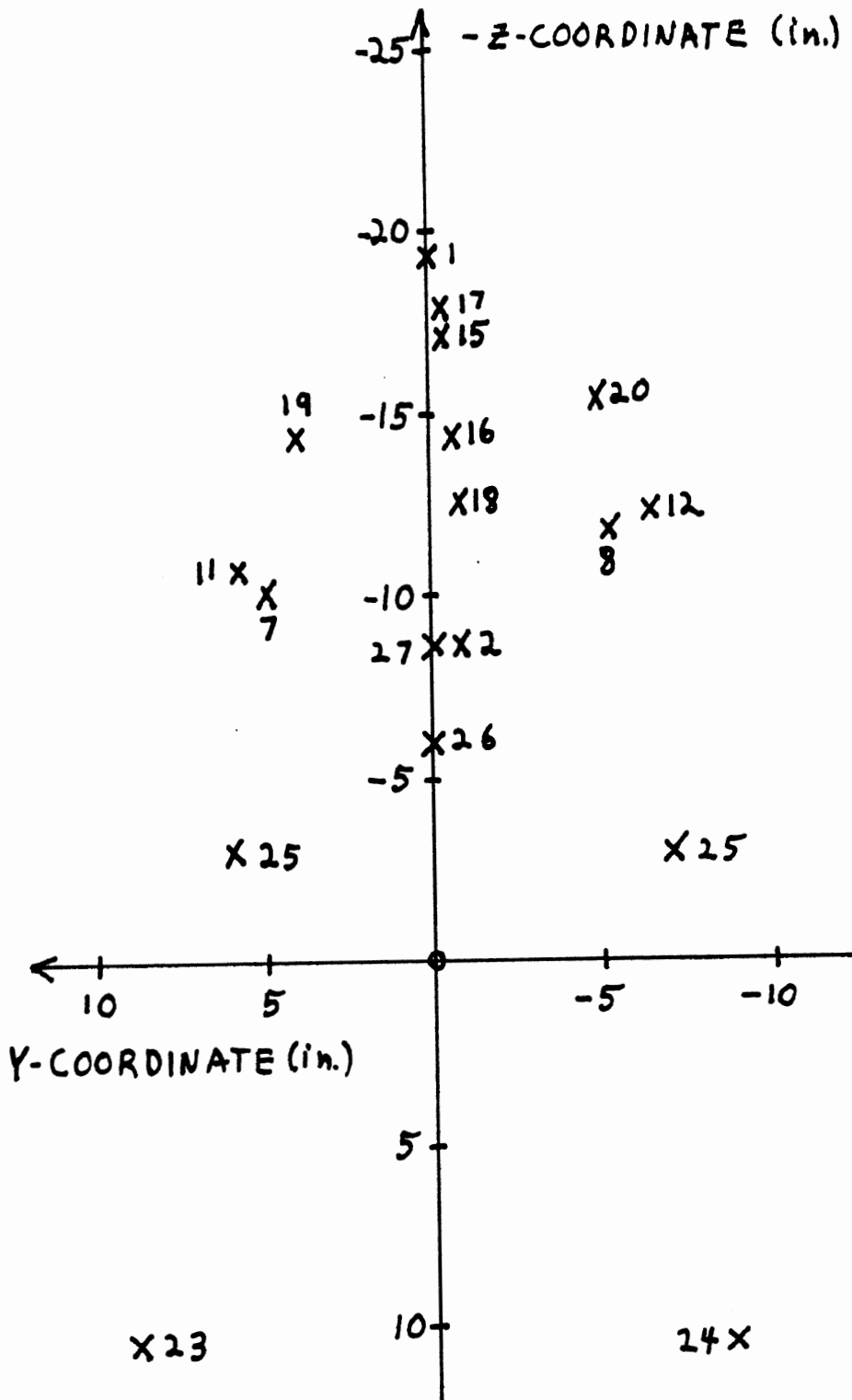


Figure 4.52. Target locations. Front view. Test 76T020.

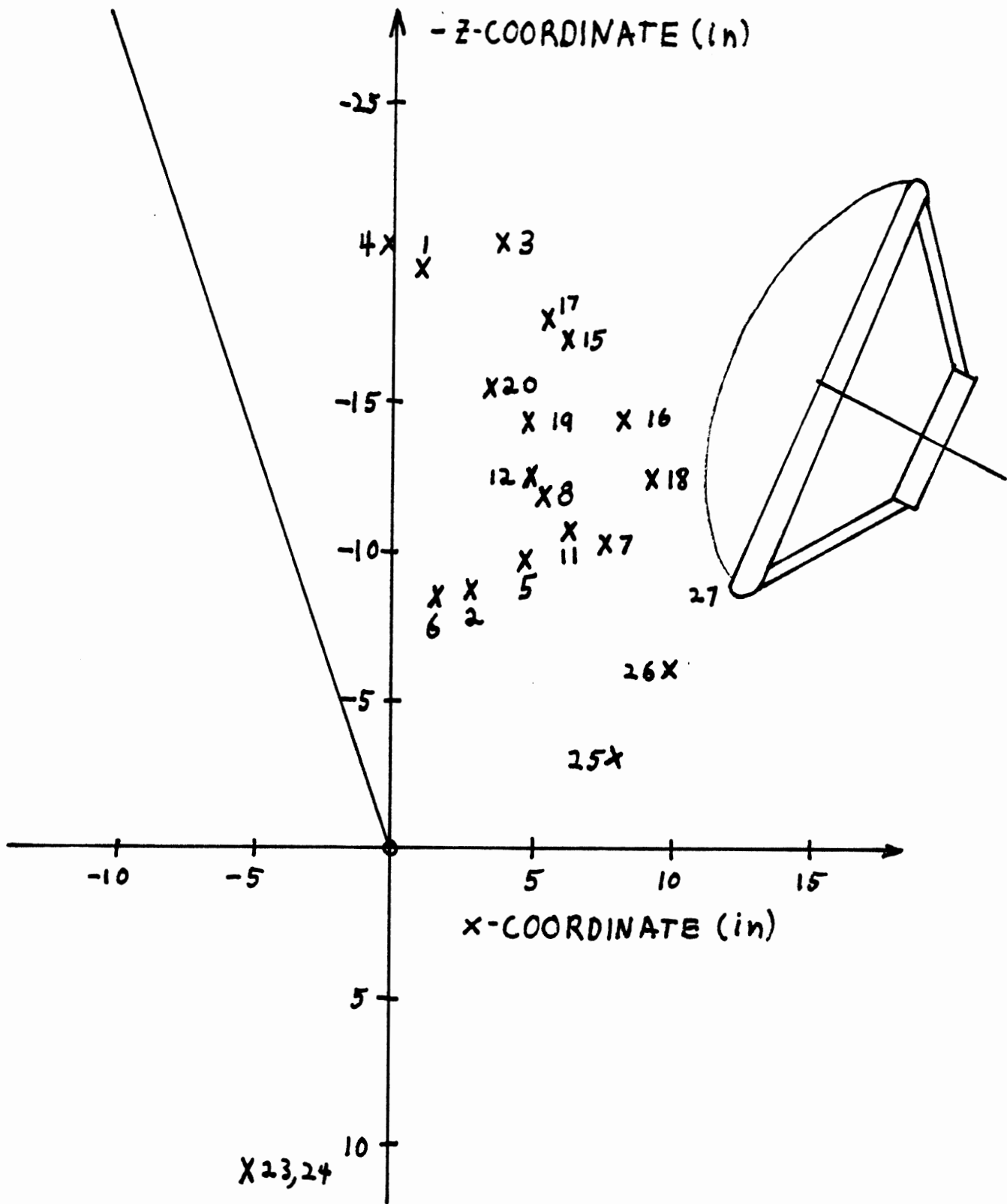


Figure 4.53. Target locations. Side view. Test 76T020.

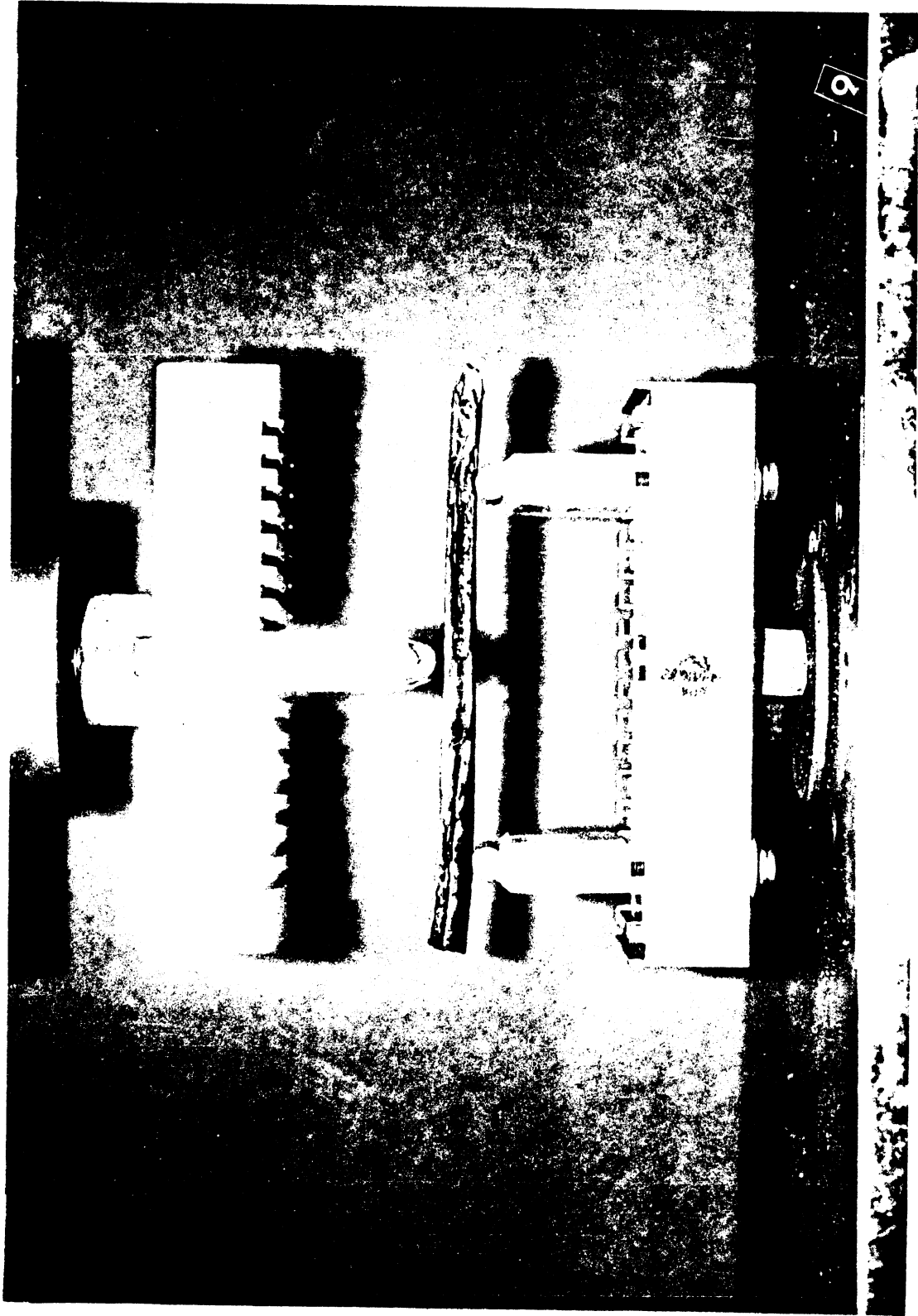
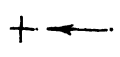


Figure 5.1. Bending test apparatus.



Subject 20616
Sample L5

→ 1/3 inch ←

↓ 10# ↑

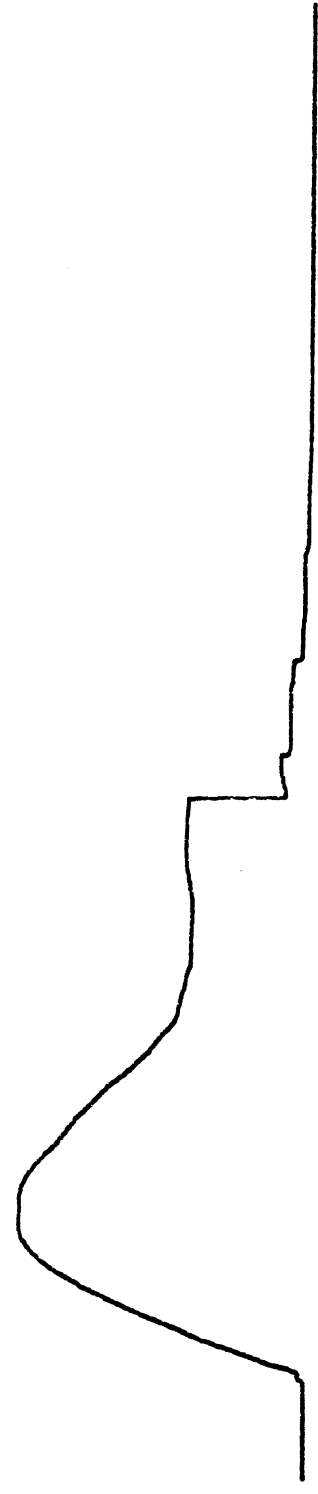


Figure 5.2. Bending test. Force vs. time plot.

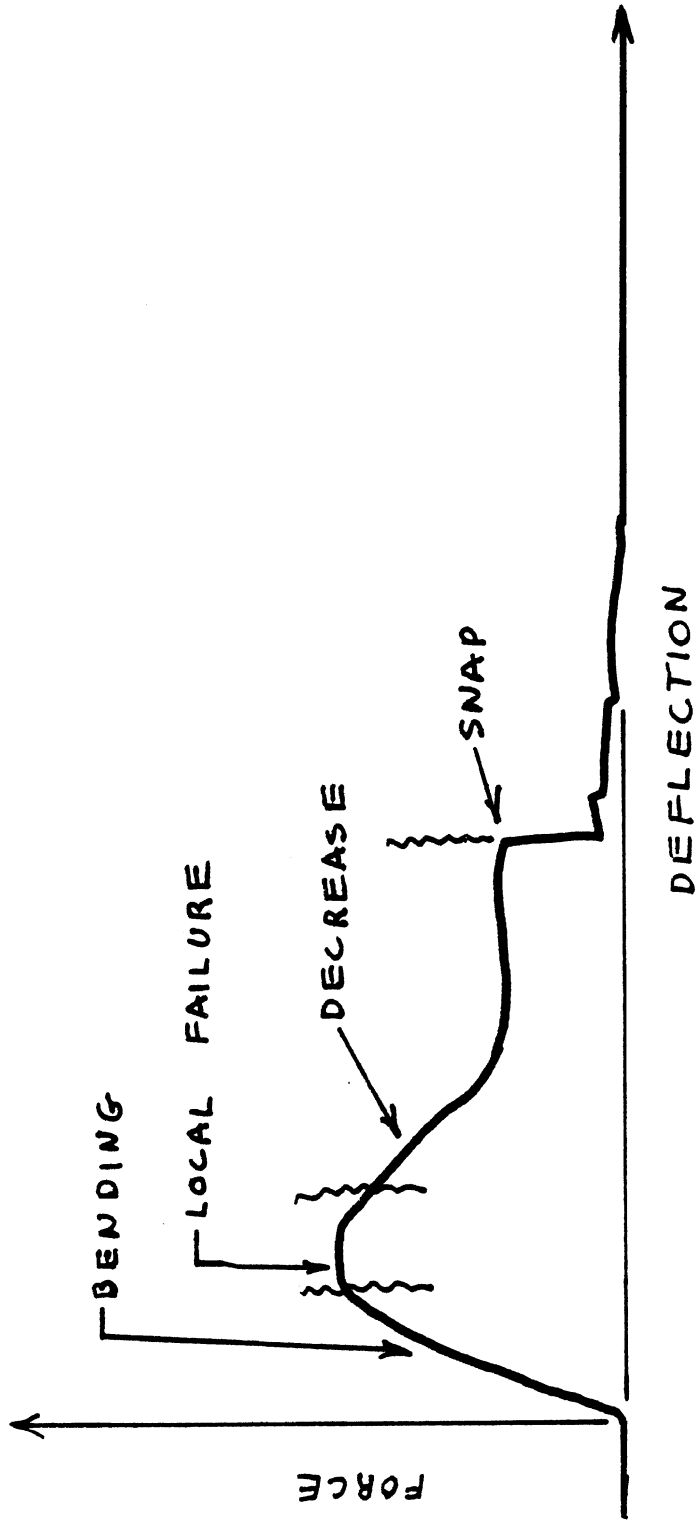


Figure 5.3. Schematic of force-time plot showing regions of breakdown.

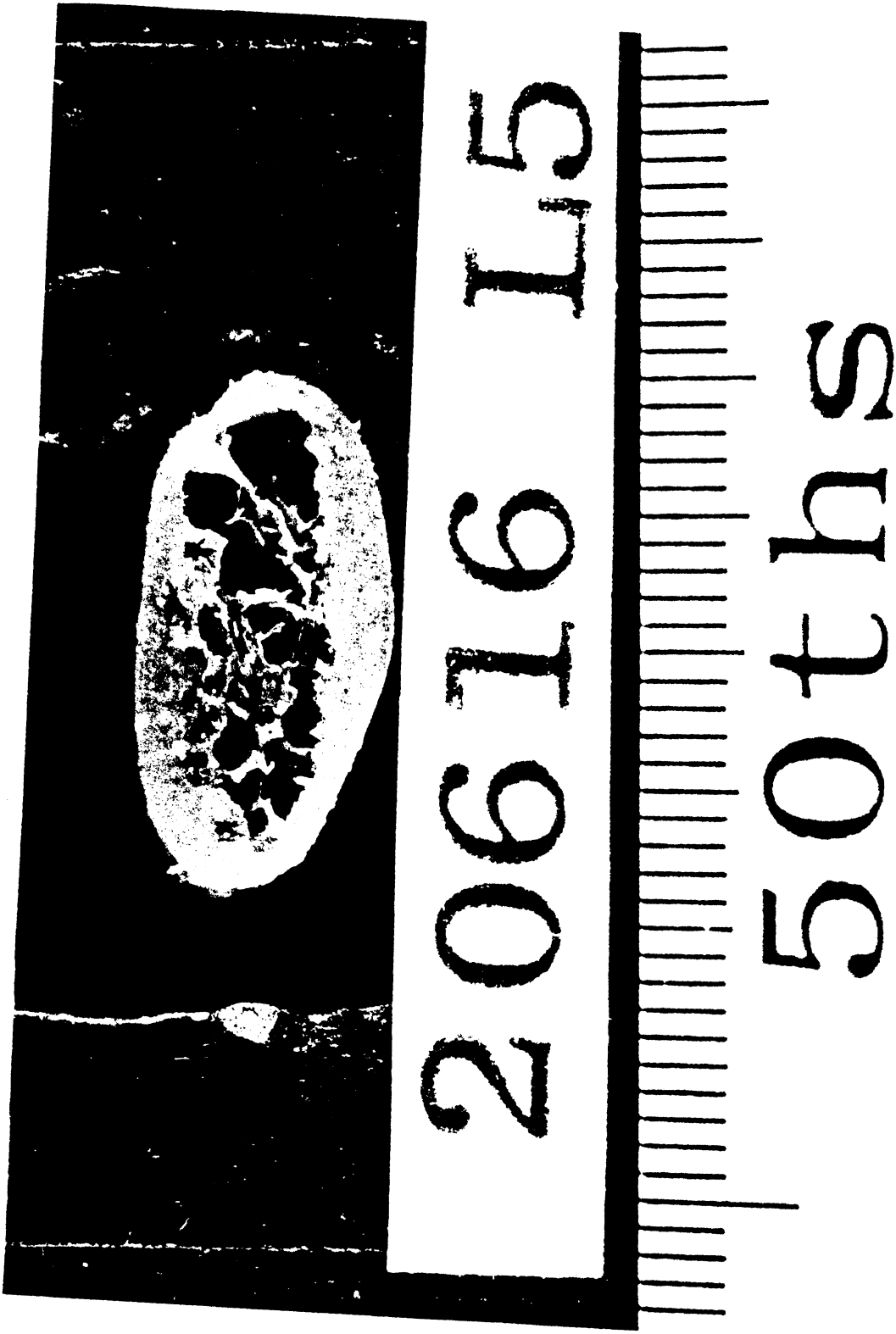


Figure 5.4. Bone cross-section photograph.

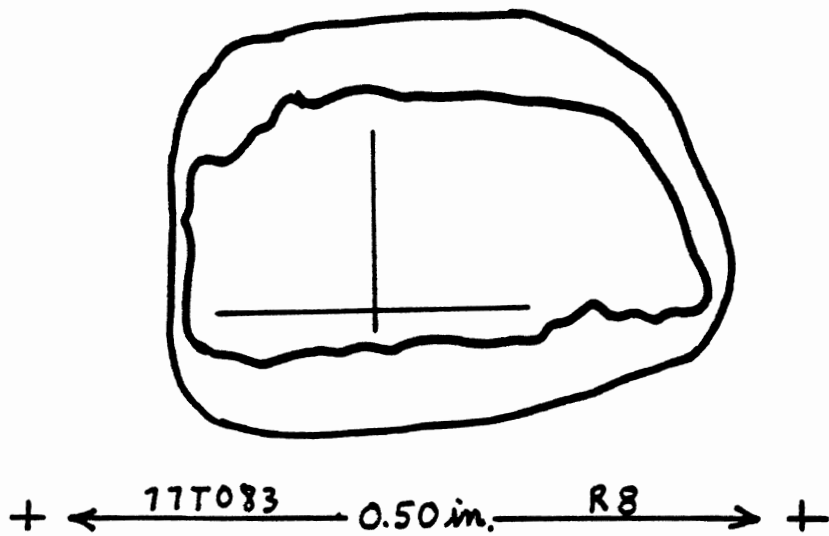
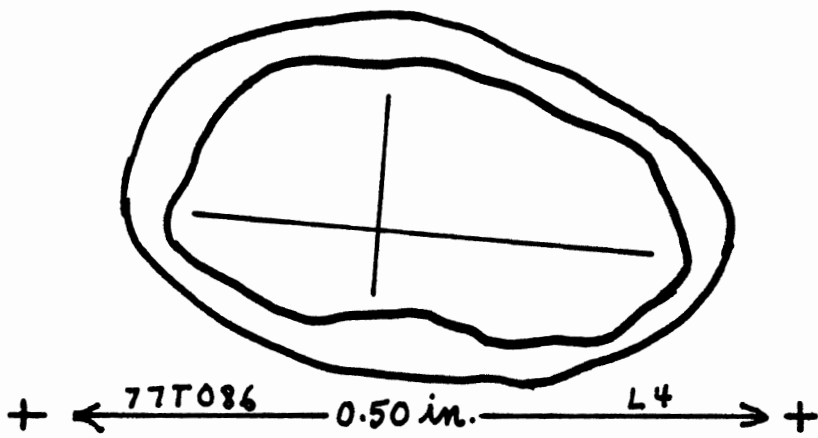
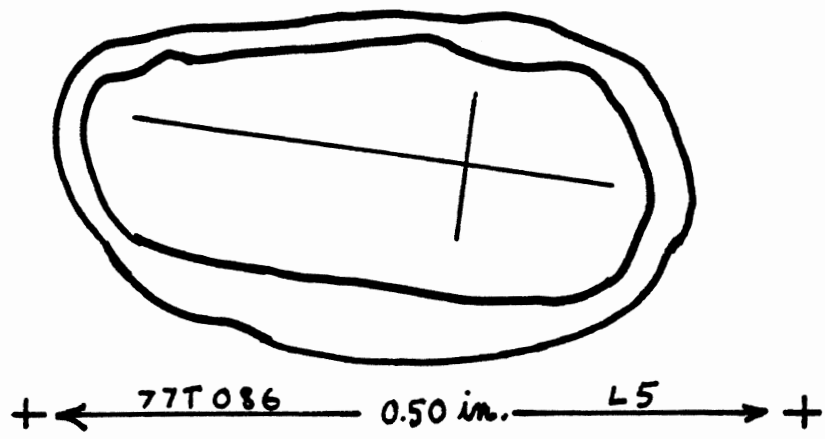


Figure 5.5. Tracings of rib rim and core perimeters.

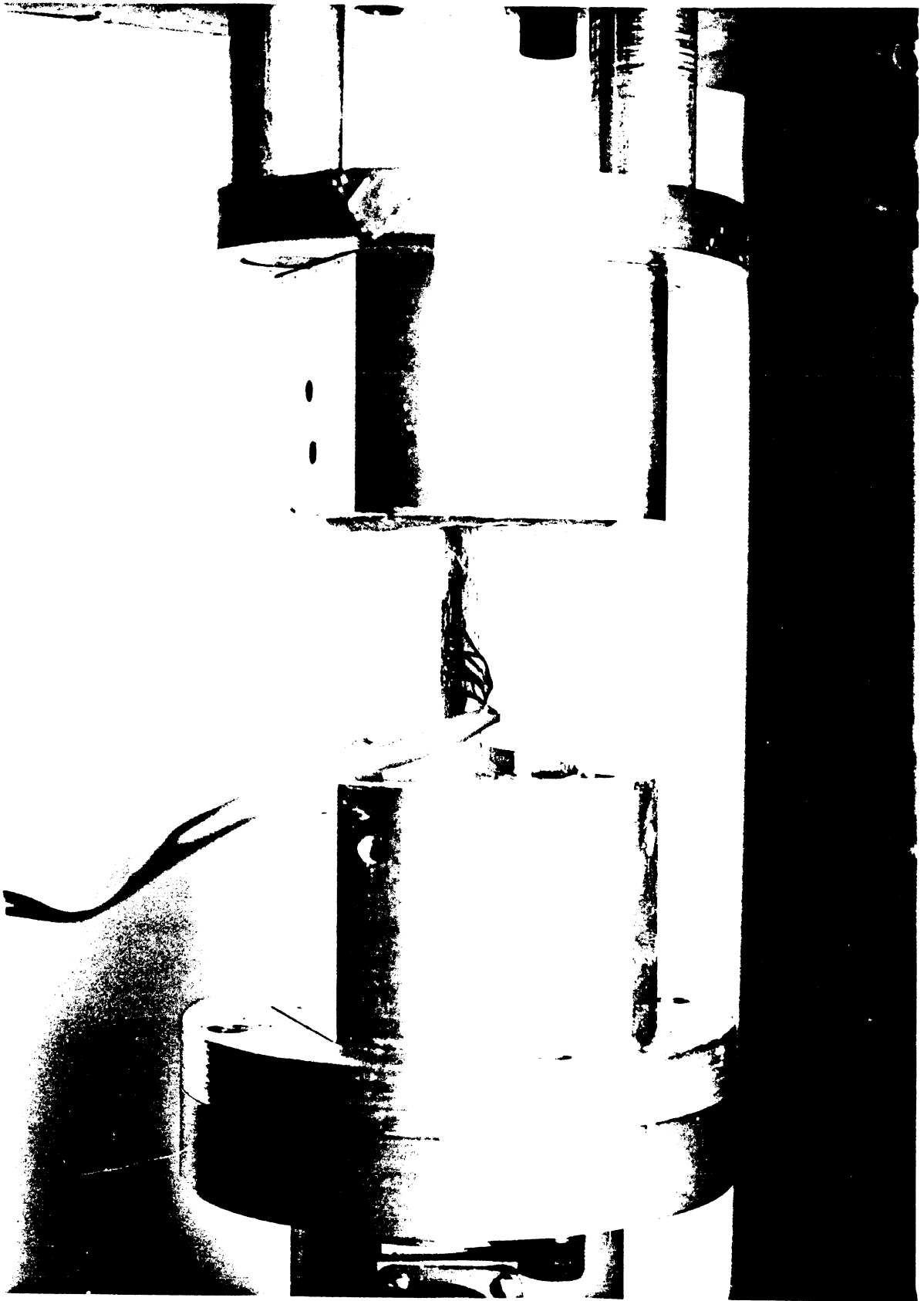


Figure 5.6. Photograph of torsion test apparatus.

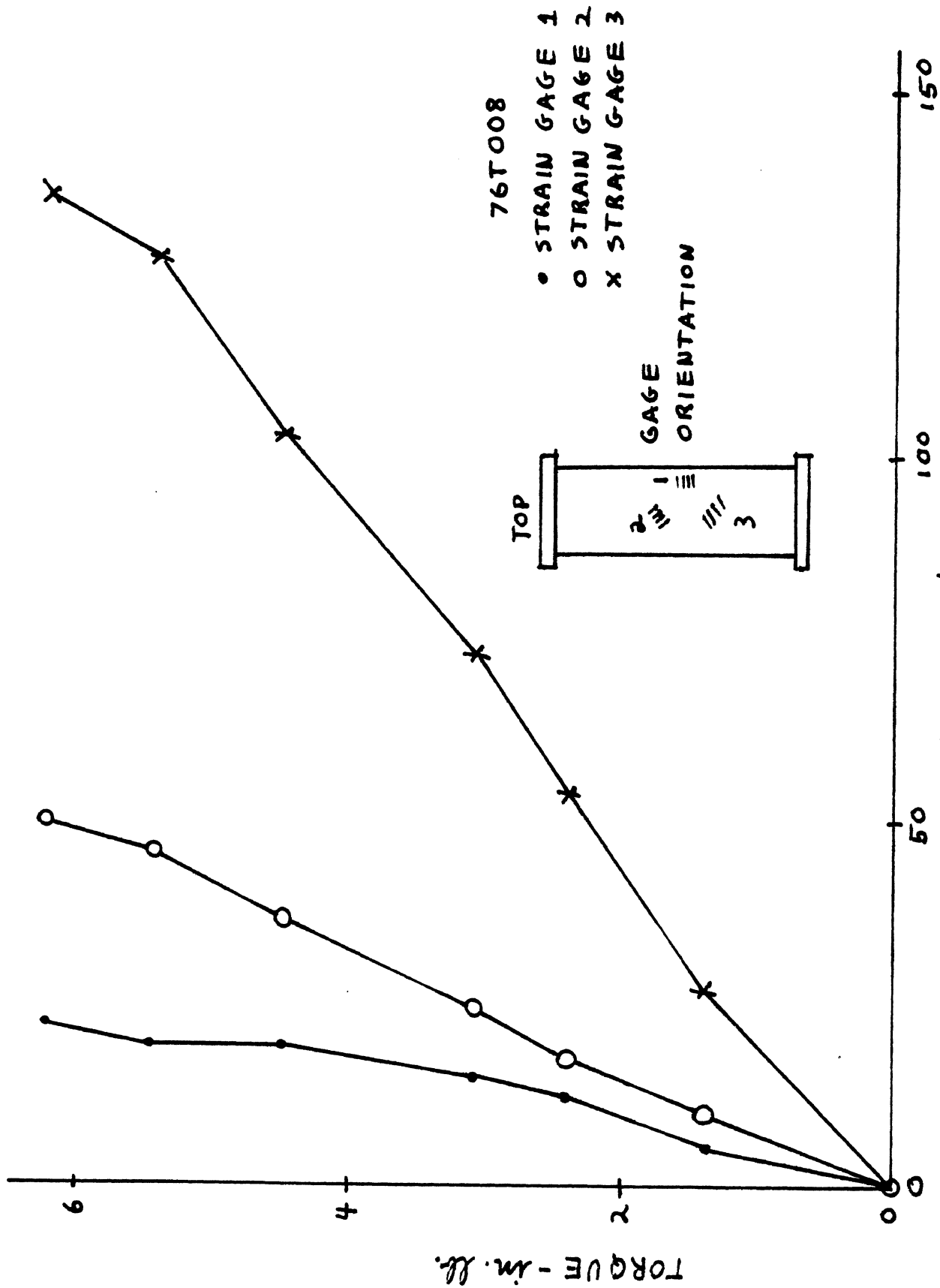


Figure 5.7. Strain rosette data. Test 76T008.

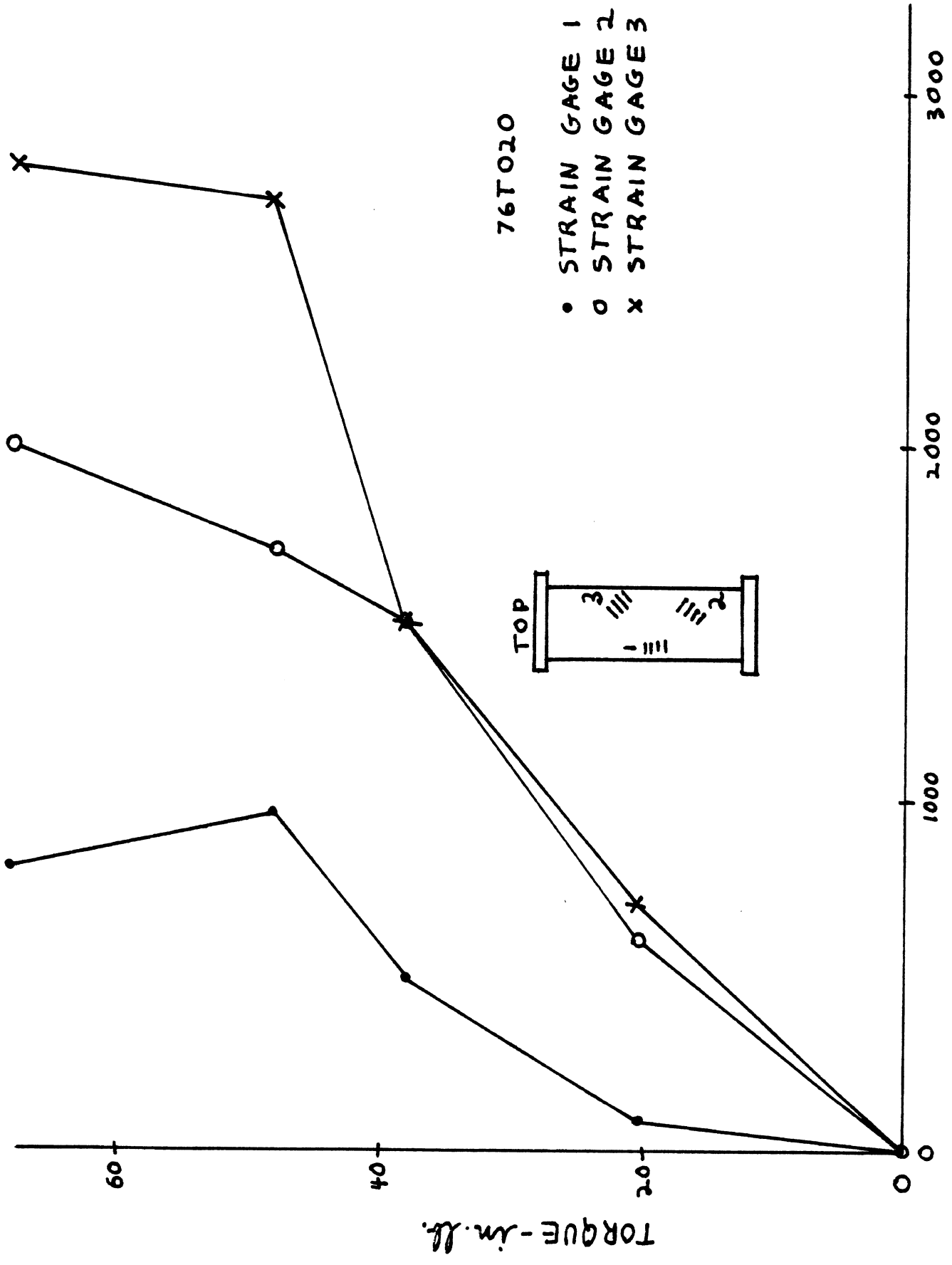


Figure 5.8. Strain rosette data. Test 76T020.

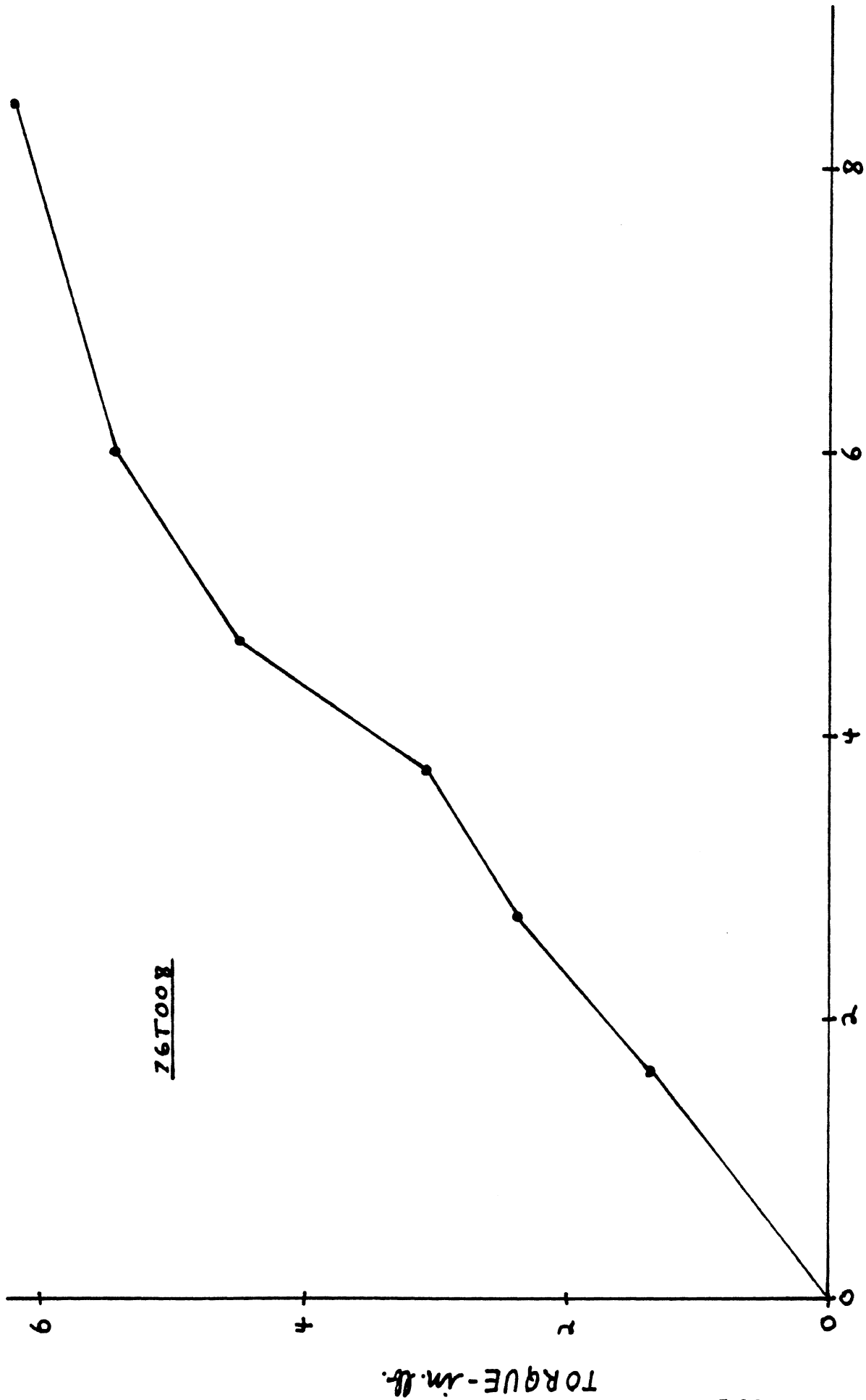


Figure 5.9. Torque/angle data. Test 76T008.

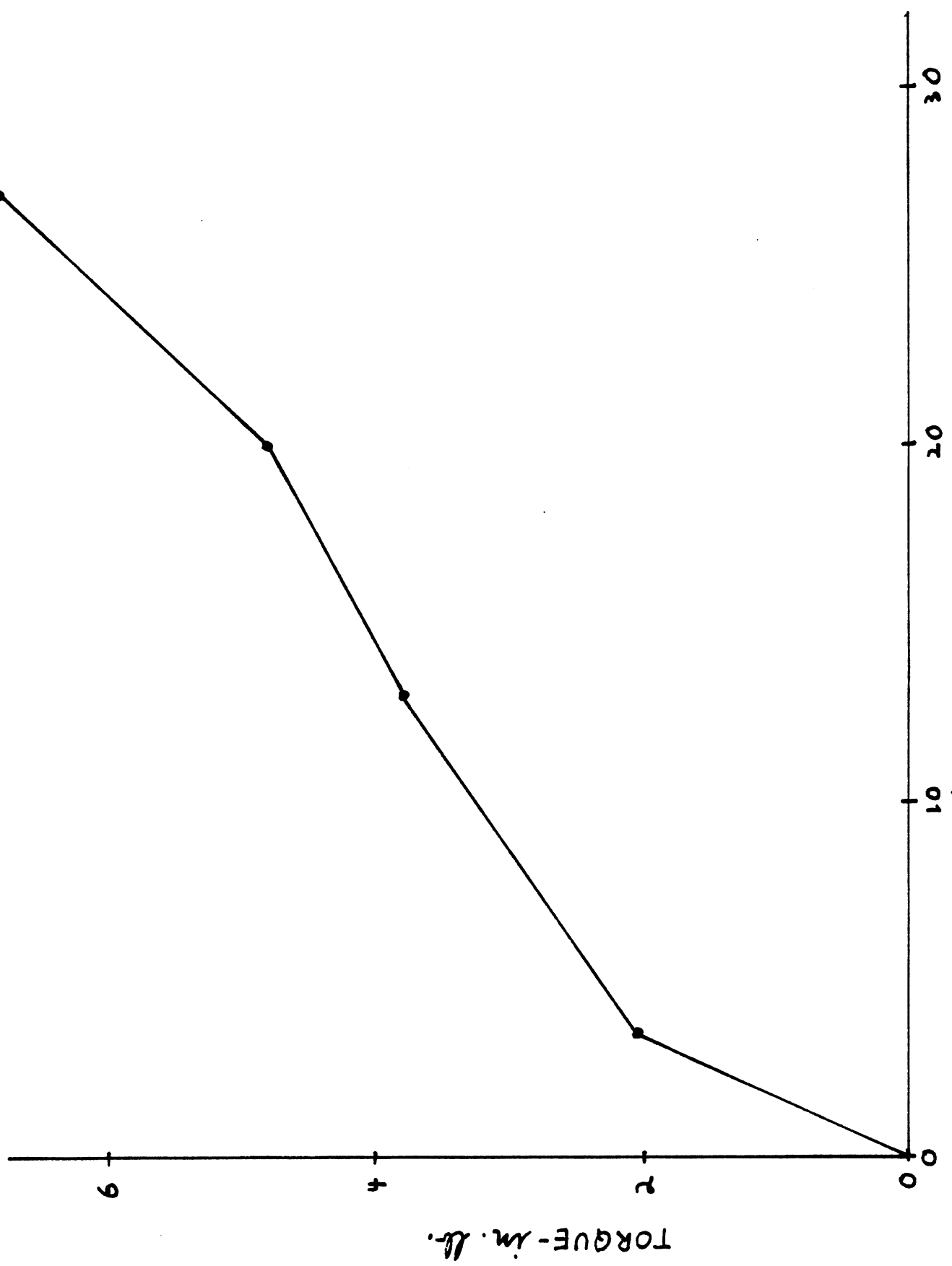


Figure 5.10. Torque/angle data. Test 76T020.

