Report No. NA-69-5
(DS-69-10)

FINAL REPORT

Project No. 510-002-04X

DYNAMIC TEST CRITERIA FOR AIRCRAFT SEATS

OCTOBER 1969

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
National Aviation Facilities Experimental Center
Atlantic City, New Jersey 08405

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for

AIRCRAFT DEVELOPMENT SERVICE

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ABSTRACT

A series of static and dynamic tests of representative aircraft passenger seats was conducted. The static tests utilized the procedures of Technical Standard Orders C-22 and C-39 which embody the test standards for certifying passenger seats for commercial aircraft. The dynamic tests utilized, in part, test procedures developed specifically for this project and, in part, test procedures developed from experience in the testing of Navy aircrew seats.

A significant difference between static and dynamic test results was found, thus warranting further investigation of the validity of utilizing static tests alone for the type certification of aircraft passenger seats for a dynamic or crash load requirement. The fact that static test results, in themselves, cannot be related to crash environments is demonstrated and cited as a definite limitation of static tests. Dynamic test results are demonstrated as having the capability of being related to crash environments and are considered to be the more meaningful in defining the behavior of seat/occupant systems when subjected to crash phenomena.

Dynamic test criteria for the type certification of aircraft seats were established and used to analyze the static and dynamic test results. A relationship between the static and dynamic test load conditions was devised as part of the criteria. Relatively simple methods for dynamic testing are suggested, and the procedure for analyzing test results is presented.

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INTRODUCTION

Purpose

The purposes of the project reported herein were (1) to establish background for dynamic test criteria for the type certification of aircraft seats and restraint devices, (2) to determine test methods which demonstrate compliance with the dynamic criteria, (3) to express the present static test load requirements for aircraft seats and restraint devices specified in the Federal Aviation Regulations (FAR) in terms of the dynamic criteria, and (4) to relate the static test load requirements to an actual crash environment utilizing the dynamic criteria.

Background

FAR's 25.561 and 25.785, and Technical Standards Orders (TSO) C-22 and C-39 specify design loads for aircraft seats and restraint devices for which the aircraft occupant is to be restrained and protected even though parts of the aircraft would be damaged. These design loads are expressed in static "inertia forces" based on the combined weight of the seat and occupant, with the occupant weight taken as 170 pounds. The specified inertia forces have remained unchanged since 1957, and their values are indicated in the test specifications as 9 g's forward, 6 g's downward, 2 g's upward, and 1.5 g's sideward.

Although seats and restraint devices are designed to withstand these inertia forces, there is no way to relate the forces with the crash environments that would produce them. The dynamic test criteria establish a relationship between inertia forces and crash environments by specifying tests in terms of crash environment inputs, allowing the inertia forces to develop as short-duration response pulses as they would in an actual crash. Utilization of the dynamic test criteria, then, enables the inertia forces on the seat/occupant combination and the seat's capability of restraining the occupant to be expressed in terms of the crash phenomenon, resulting in a more realistic certification procedure.

The dynamic test criteria presented herein can also satisfy the present need for standardization in the aircraft industry in view of the fact that several airlines have for some time required dynamic testing for acceptance of aircraft seats, with the tests being conducted by the seat manufacturers. The test specifications have differed between airlines, and the test methods have differed between manufacturers.

To meet the objectives of the project, it was first necessary to establish a theoretical basis for the dynamic test criteria. The seat types to be tested were then determined along with the test methods which would yield seat response characteristics in a form compatible with the dynamic test theory. Finally, it was necessary to utilize existing crash environment data to relate the results of the dynamic tests with actual crash severity.

Description of Theory for Dynamic Test Criteria: In a static test of a seat, the specified inertia force for the seat/occupant combination provide the input to the seat and are applied at the center of gravity of the seat/occupant combination. The vertical seat leg reactions are a measure of the response of the seat and are directly proportional to the input, or inertia force, from which they can be calculated.

In a dynamic test, the input is the acceleration-time pulse of the sled on which the seat with occupant (dummy) is mounted. An actual crash environment is simulated where the input is the acceleration-time pulse of the aircraft floor in the vicinity of the seat, and the seat/occupant combination is free to respond as a spring-mass system (Figure 1). The vertical seat leg reactions are a measure of the response as they were in the static test. Likewise, the effective inertia force remains proportional to the reactions, but in the dynamic test becomes part of the response and can be calculated from the measured reactions. The direct proportionality between the reactions and the input holds for the dynamic test, as it did for the static test, provided the input is of long duration (Figure 2a). If the input is of short duration, as it is for typical crash environments, the reactions will lag the input and have peak values lower than those indicated by the long-term proportionality (Figure 2b).

Static tests can be related to dynamic tests by utilizing the response level (vertical seat leg reaction level) as a parameter. For a given seat, lap belt, occupant weight, input direction, and peak seat leg reaction level, there exists one static input (inertia force) and an infinite number of dynamic inputs (acceleration-time pulses) which will induce the given peak seat leg reaction level. Since there are an infinite number of dynamic inputs, they can be expressed as a curve, called a sensitivity curve, provided an empirical relationship can be established between the dynamic inputs and the peak seat leg reaction level and provided the dynamic inputs can be expressed in terms of two variables, such as velocity change and average acceleration.

Figure 3 shows a variety of input acceleration-time pulses and their corresponding response curves for a given seat, lap belt, occupant weight and input direction. These response curves can be obtained empirically during the type certification testing of the seat and are the means by which the dynamic inputs and the peak vertical seat leg reaction level can be related. Each seat test produces one point on the curve. Other points are obtained by testing the seat with input pulses of different magnitudes. The response factor C, for each test, can be calculated as follows:

$$C = \frac{g_e}{\bar{G}} \qquad (1)$$

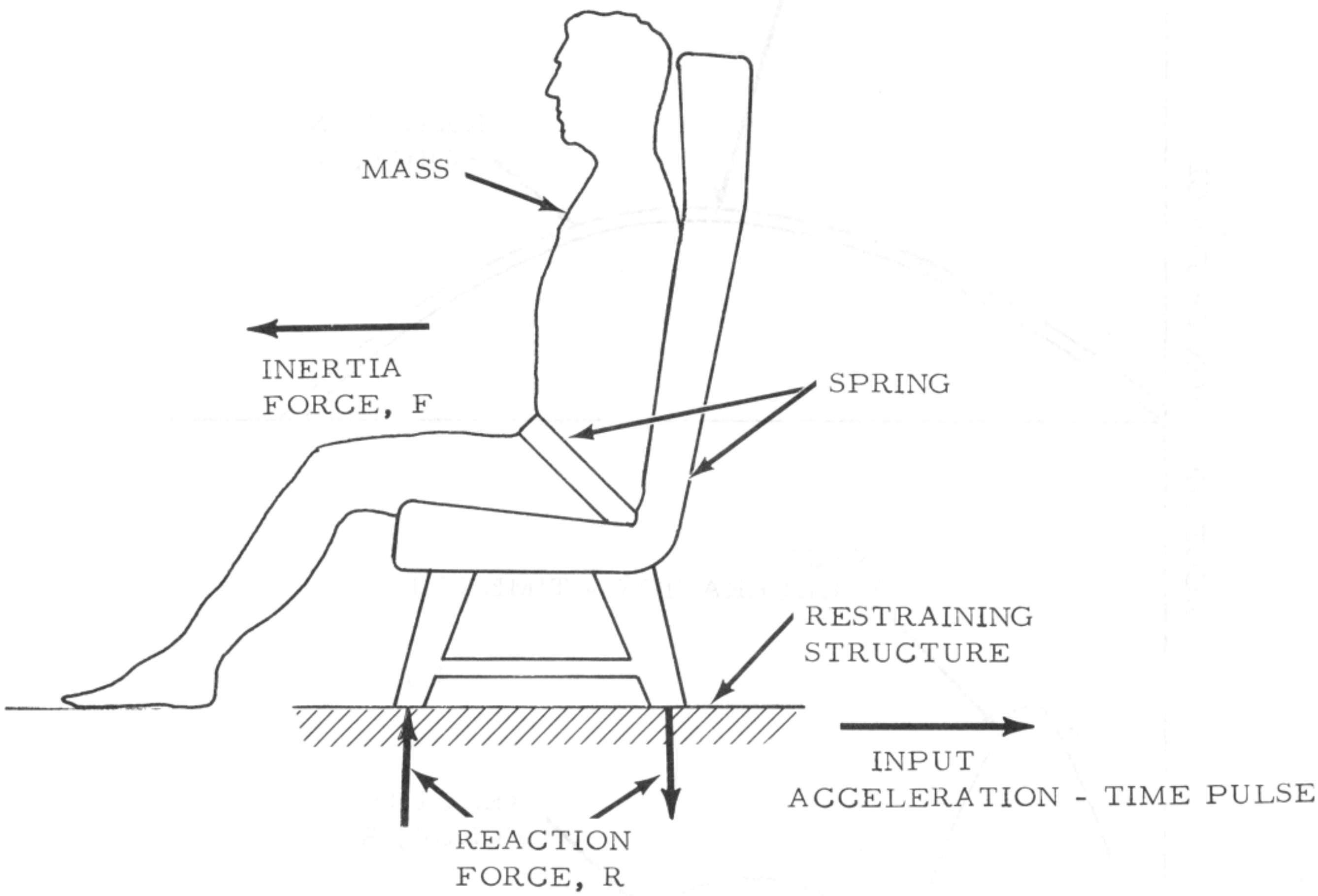


FIG. 1 SEAT/OCCUPANT SPRING-MASS SYSTEM

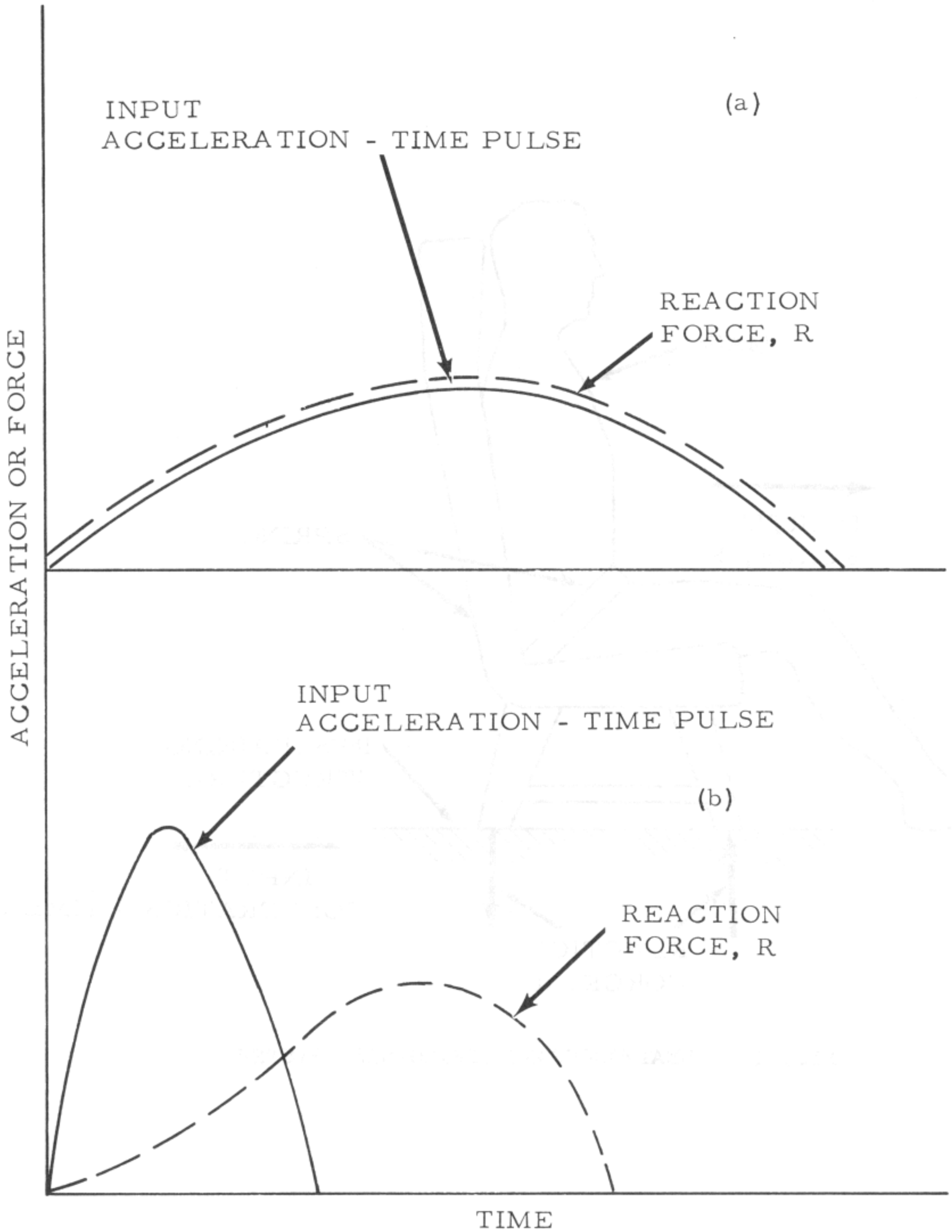


FIG. 2 RELATIONSHIP BETWEEN INPUT PULSE AND REACTION FORCE

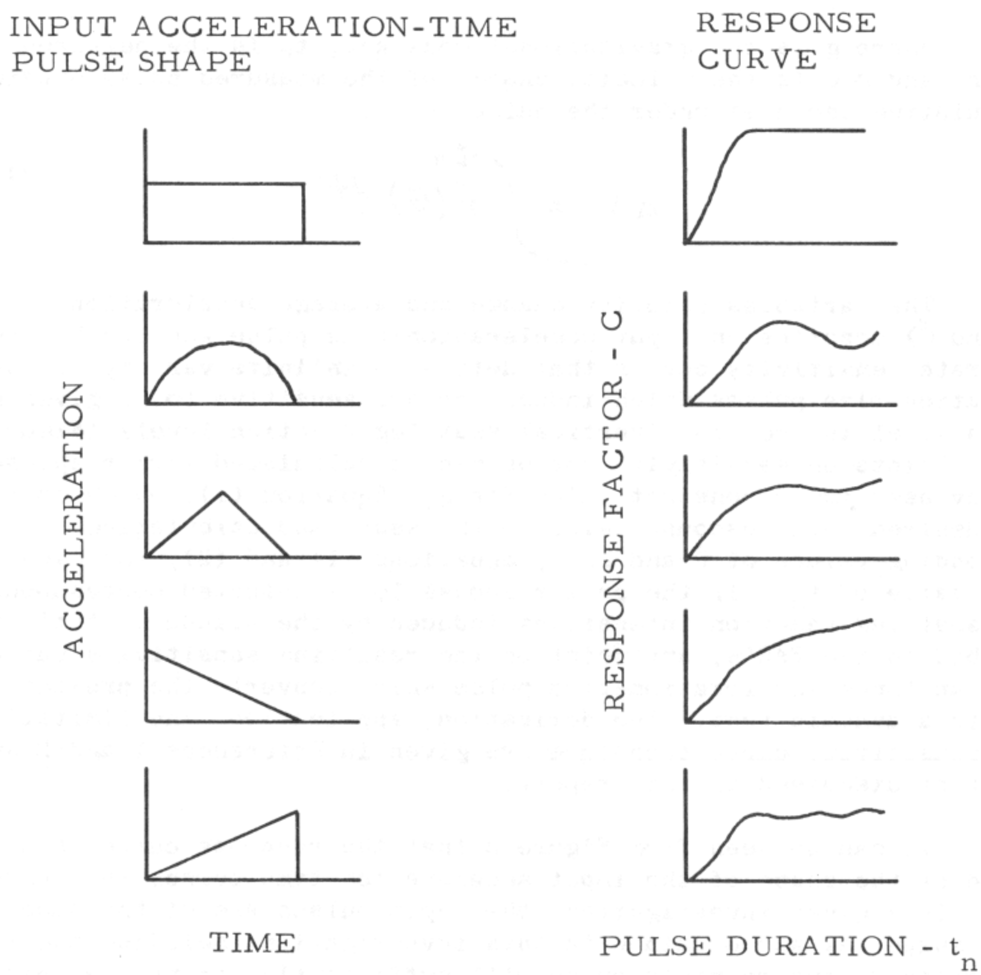


FIG. 3 RESPONSE FACTORS FOR A SIMPLE SPRING-MASS SYSTEM SUBJECTED TO SINGLE PULSES

Where g_e is the effective peak inertia force on the seat/occupant combination calculated from the measured peak vertical seat leg reactions, and $\bar{G}$ is the average acceleration of the input acceleration-time pulse calculated from the measured pulse as follows:

$$\bar{G} = \frac{\Delta V}{g \times t_n} \qquad (2)$$

Where g is the gravitational constant, t_n is the measured pulse duration, and ΔV is the velocity change of the measured pulse obtained by calculating the area under the pulse shape:

$$\Delta V = \int_0^{t_n} f(G)\, dt \qquad (3)$$

The variables velocity change and average acceleration (ΔV and $\bar{G}$) describe an input acceleration-time pulse and can be used to generate sensitivity curves that define an infinite variety of input acceleration-time pulses which induce, or are sensitive to, a given peak response level in the seat (vertical seat leg reaction level) (Figures 4 and 5). Points on sensitivity curves can be calculated from response curves by assuming a constant value for g_e, Equation (1), which corresponds to the desired peak response level in the seat, and calculating the corresponding values of $\bar{G}$ and ΔV, Equations (1) and (2), for each assumed value of t_n. If the peak response level selected corresponds to the seat leg reaction intensities induced by the standard static test prescribed in the FAR's, any point on the resulting sensitivity curve defines an input acceleration-time pulse which converts the present static test into a dynamic test. The derivation, application, and limitations of the sensitivity curve technique are given in References 1 and 2 and will not be discussed in this report.

It can be seen from Figure 3 that the response curve is a function of the shape of the input acceleration-time pulses that produce it. If, in a given investigation, the input pulses are of the same general shape, as was obtained in this investigation including the results in Reference 3, one response curve will sufficiently define the relationship between the input pulses and the peak response level for each seat and loading direction, thus considerably simplifying the dynamic method.

To use this technique to express the present Federal Aviation Administration (FAA) static test load requirements in terms of dynamic criteria, it was necessary to determine the response characteristics of a representative number of aircraft seat/occupant systems to both statically and dynamically applied loads.

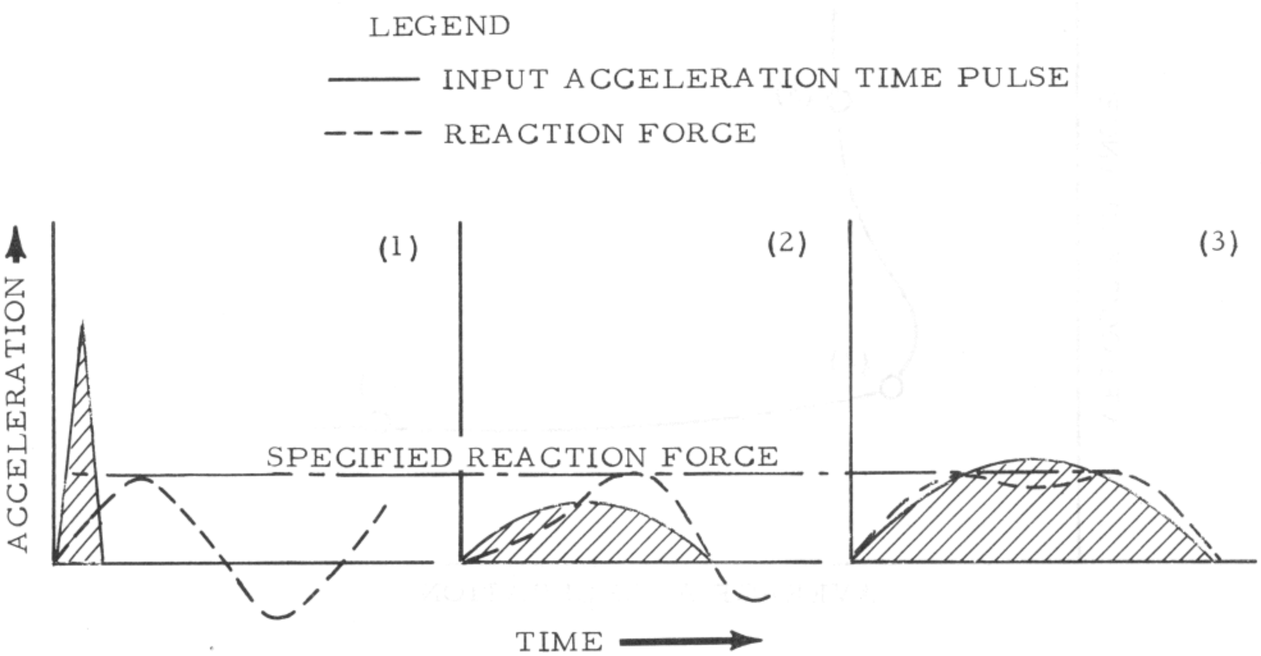


FIG. 4 INPUT PULSES FOR THE SPECIFIED RESPONSE

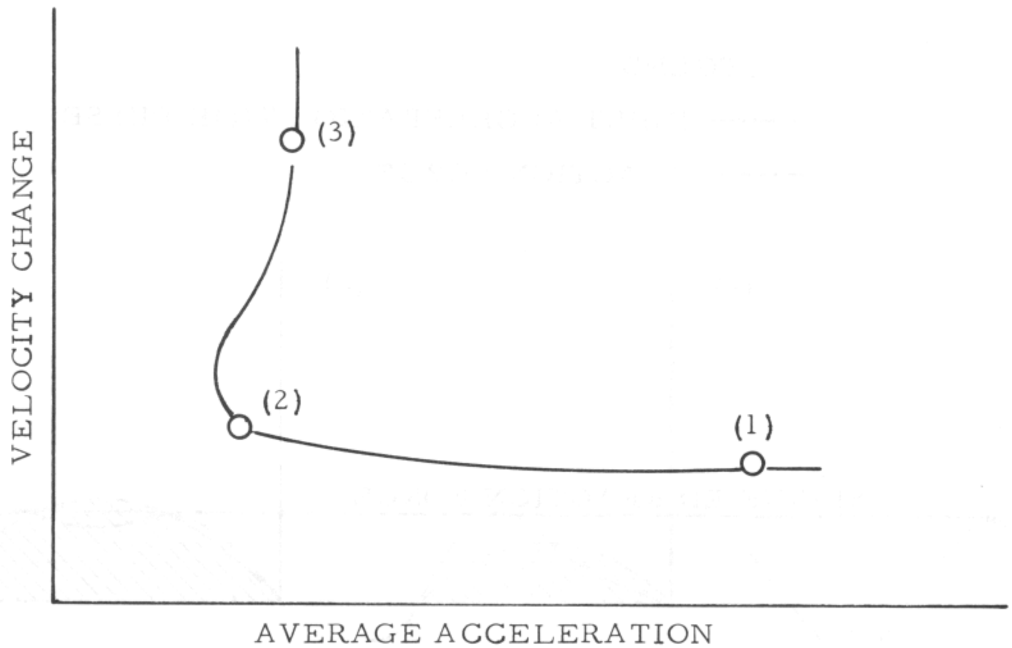


FIG. 5 SENSITIVITY CURVE FOR THE SPECIFIED RESPONSE

Three different types of seats, designated as A, B, and C, were selected to represent the majority of equipment being used by the airlines. All of the seats were three-place tourist class, but differed in construction. Seat A was of tubular construction, floor-mounted; Seat B was of sheet metal construction, floor-mounted; and Seat C was of tubular construction, floor/sidewall mounted (Figures 6, 7, and 8).

The seats were instrumented to measure the data necessary to establish dynamic seat test criteria comparable to the present FAA static test load requirements. It should be noted that these tests were not conducted for the purpose of certifying any particular aircraft seat or to compare static testing with dynamic testing per se. The seat installations on the test facilities simulated, as near as practical, the seat installation in an aircraft, but no attempt was made to simulate the aircraft floor structure because of the difference in the floor construction from aircraft to aircraft. The seat tests were limited to the forward and downward directions only, because of the cost of the test specimens and because these are the most common seat loading conditions which occur in an airplane crash. This, however, did not limit the technique to these particular cases.

Test Methods and Procedures: The static tests were conducted in accordance with the present FAA regulations at the National Aviation Facilities Experimental Center (NAFEC). These tests were conducted to provide load and failure data that could be compared with similar data obtained from the dynamic seat tests. Similarities and differences between the two means of testing were thus noted. The seats were attached to a test stand using instrumented attachment fittings. Body blocks, weighing 170 pounds, were positioned and secured in each seating place with standard airline seat belts. Loads as specified in TSO C-39 were applied to each body block simultaneously by means of hydraulic cylinders. An electrically driven pump supplied the pressure to the hydraulic cylinders, and the load was regulated by a control valve housed in a console. Typical setup positions are shown in Figures 9 and 10.

The input load supplied by the hydraulic cylinders, the seat belt tension, and the reaction forces of the seat attachments were recorded by two oscillographs. Motion picture cameras were positioned to photograph the test from various angles. Time correlation between the cameras and the oscillograph was used. A complete instrumentation description of the static tests is contained in Appendix II.

The horizontal and vertical dynamic tests were conducted under an agreement with the Aerospace Crew Equipment Department (ACED) located at the Naval Air Development Center, Philadelphia, Pennsylvania. Under this agreement, the seats were subjected to several nondestructive dynamic tests where the velocity change was held constant while the average acceleration was varied. The seats were again tested holding the

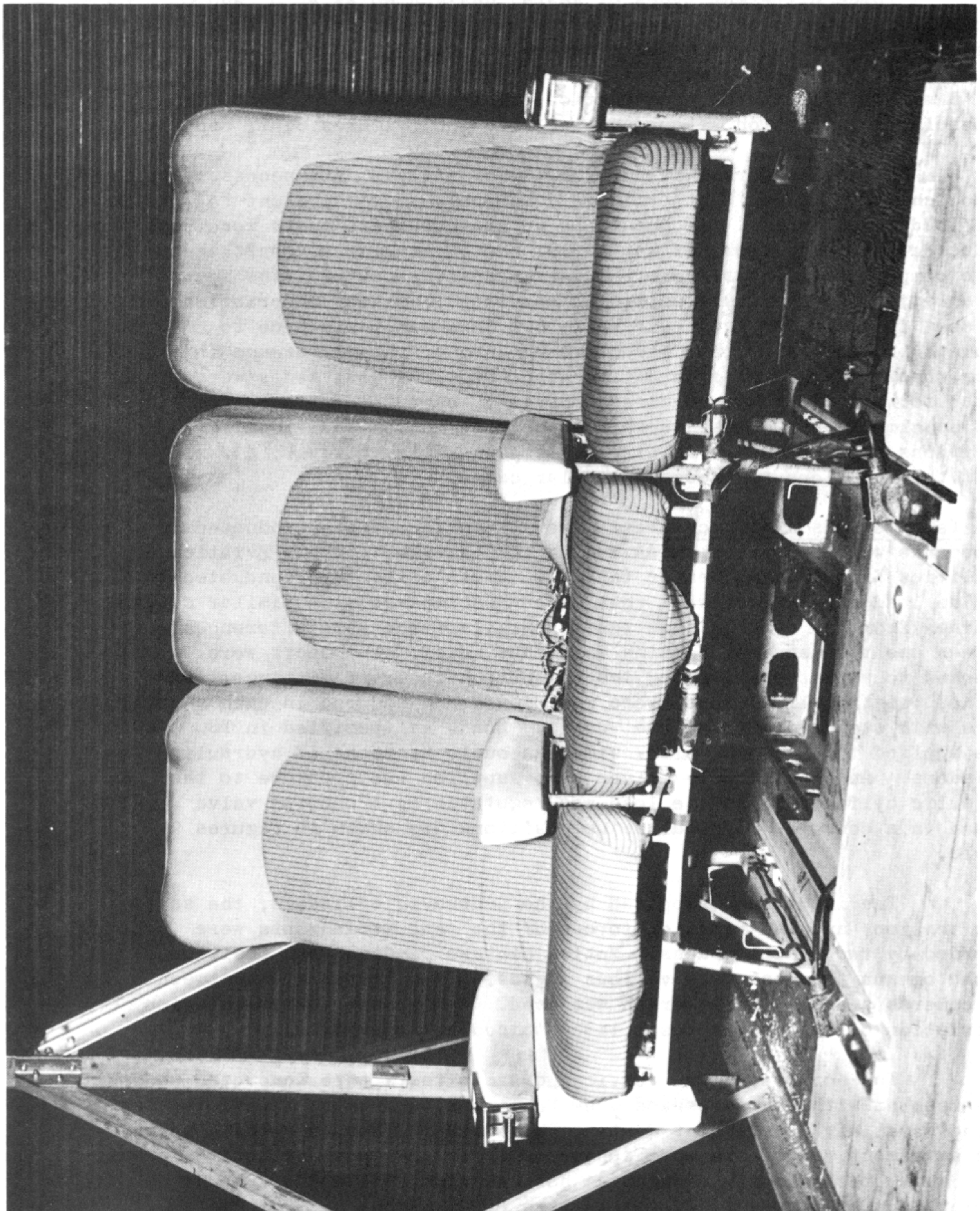


FIG. 6 SEAT A - TUBULAR CONSTRUCTION

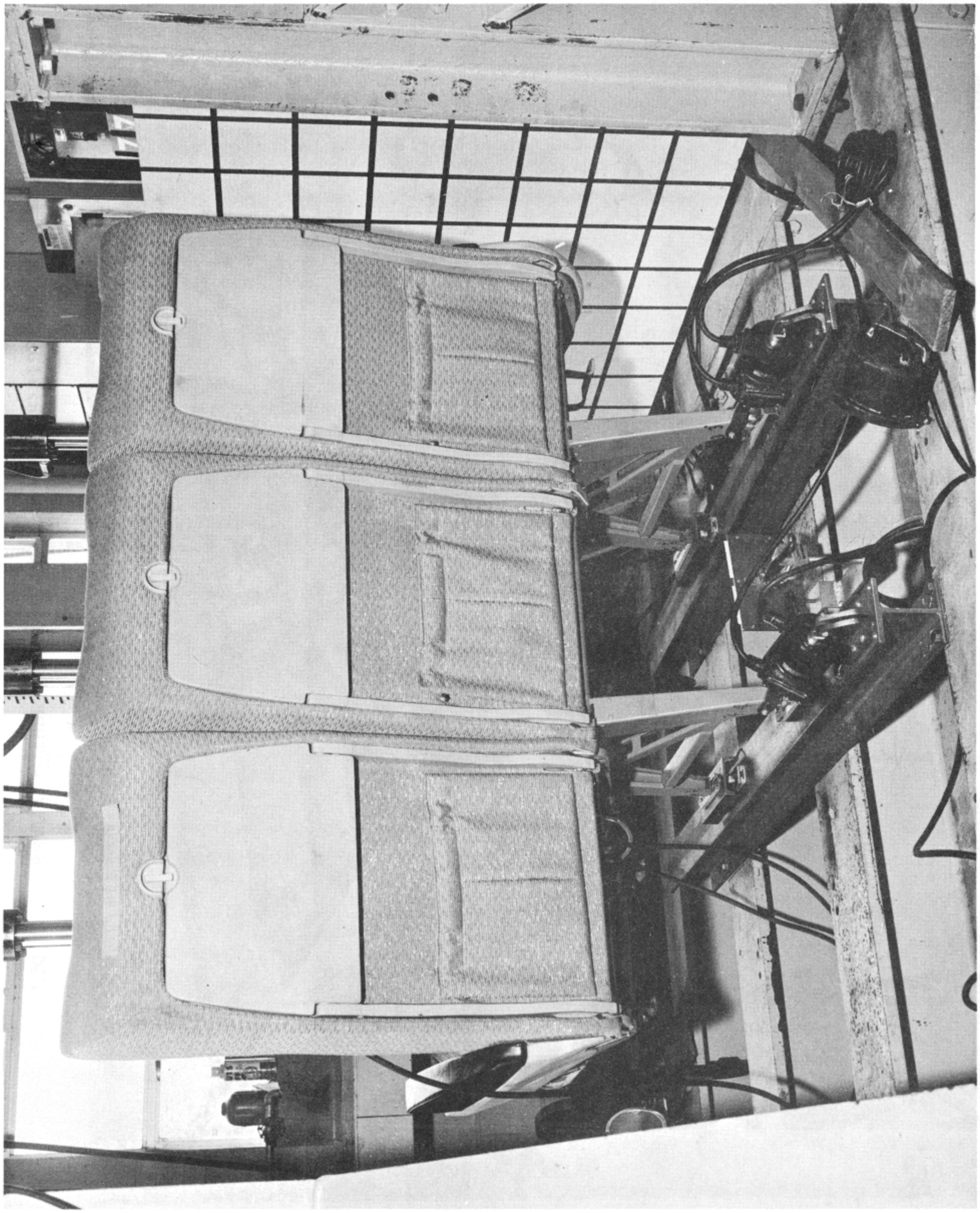


FIG. 7 SEAT B - SHEET METAL CONSTRUCTION

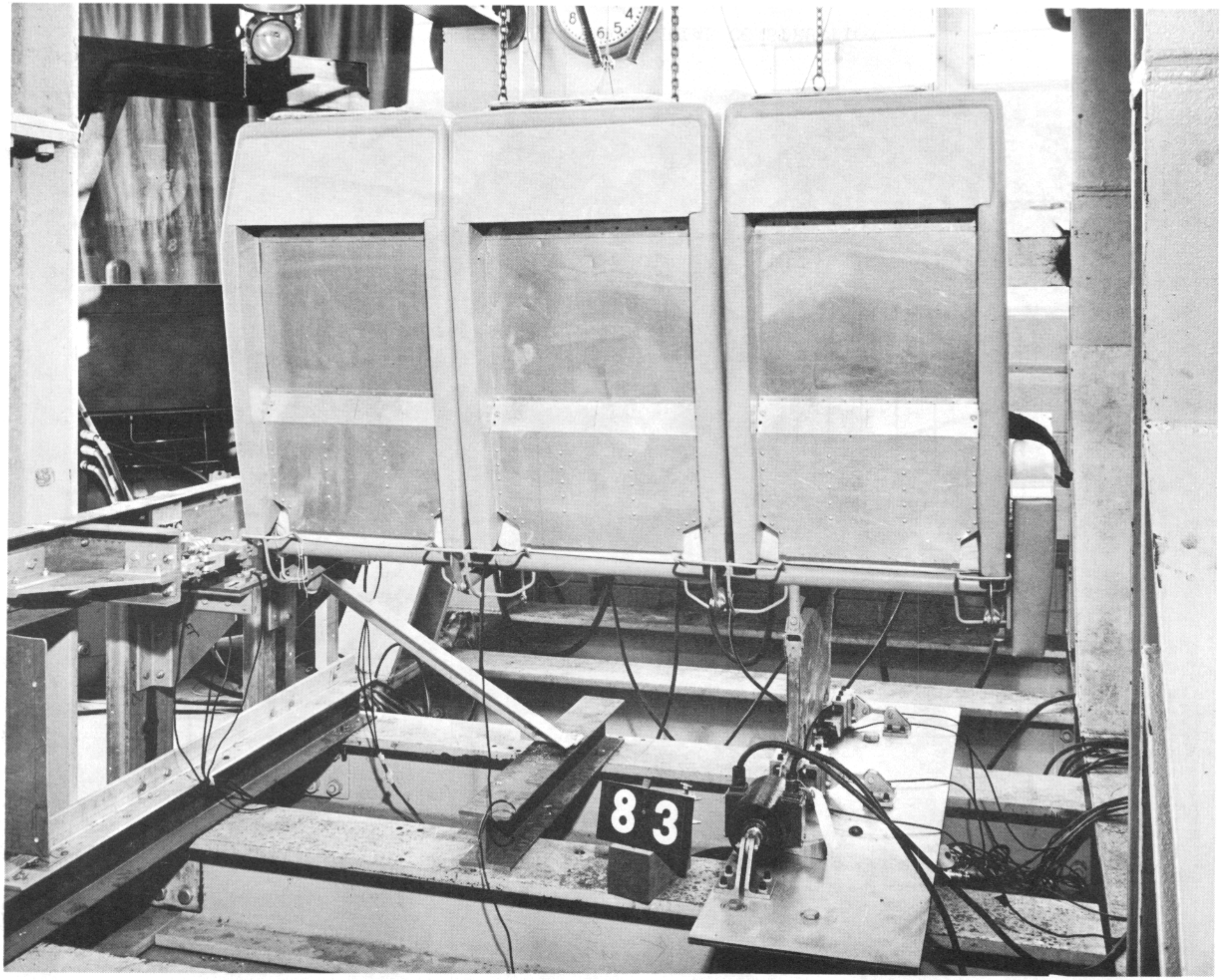


FIG. 8 SEAT C - TUBULAR CONSTRUCTION - FLOOR/SIDEWALL MOUNTED

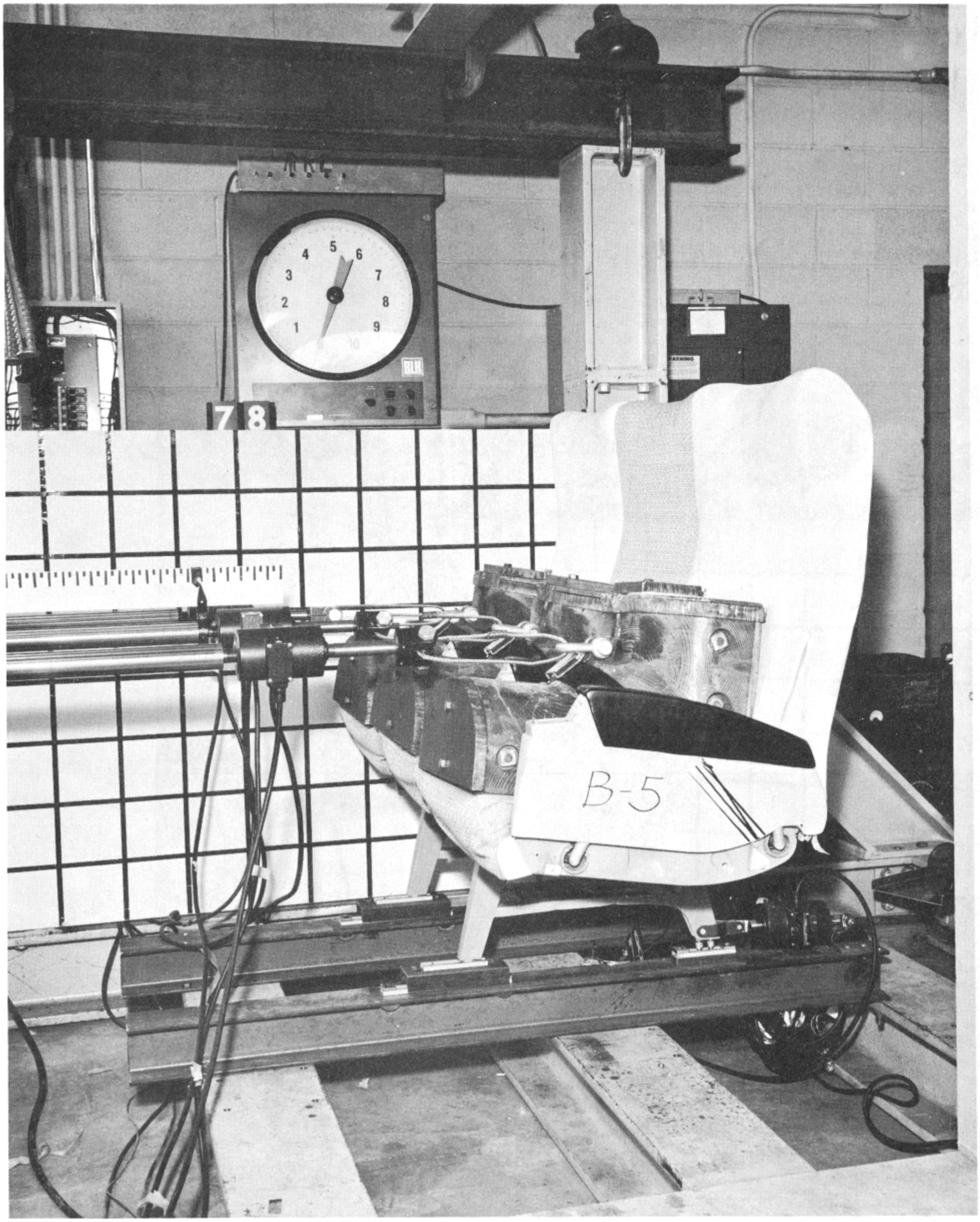


FIG. 9 TYPICAL SEAT SETUP FOR A FORWARD STATIC TEST

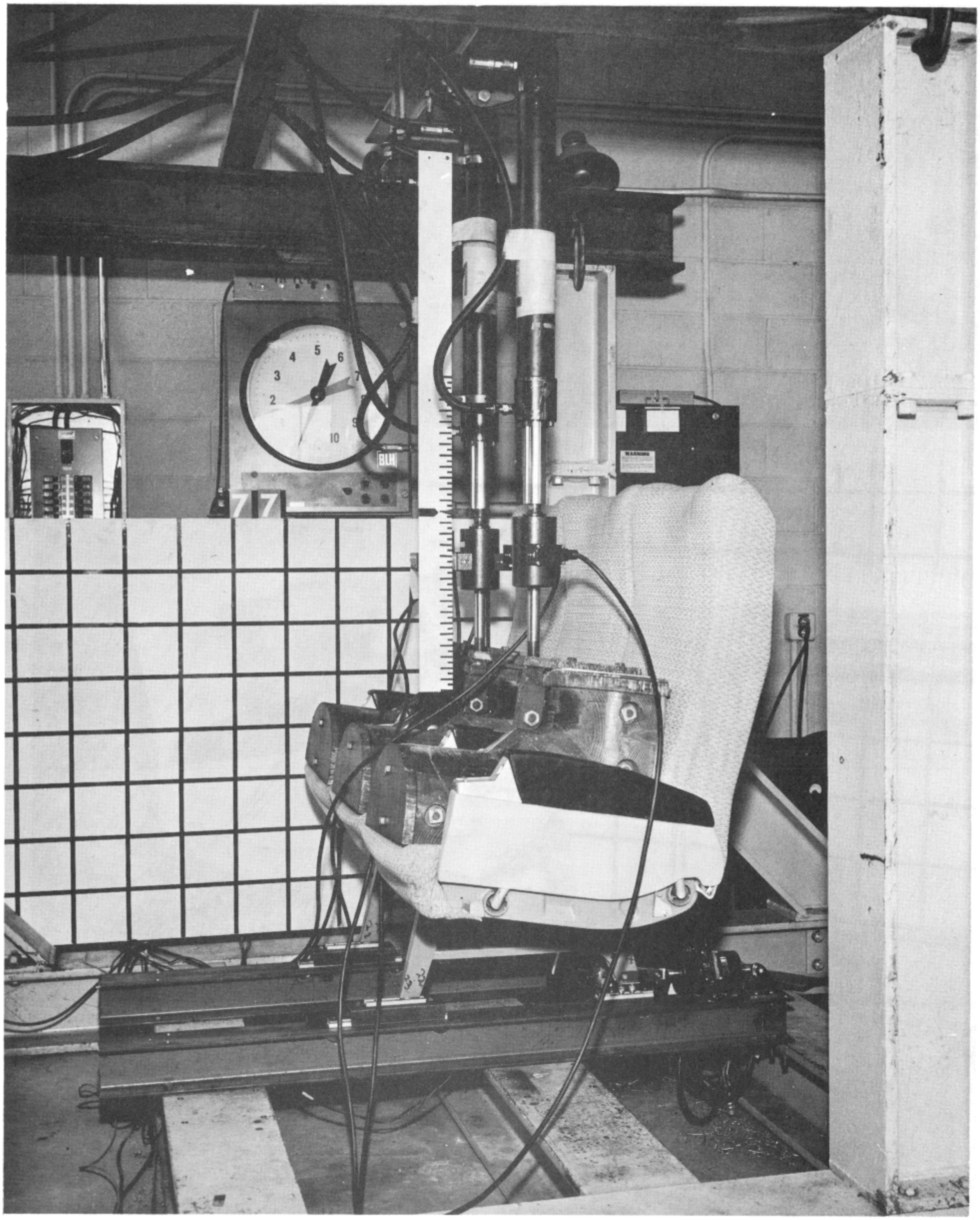


FIG. 10 TYPICAL SEAT SETUP FOR A DOWNWARD STATIC TEST

average acceleration constant and varying the velocity change. Finally each seat was tested, increasing either the velocity change or average acceleration, until the seat was damaged.

The horizontal tests of Seats A, B, and C and vertical tests of Seat A were conducted on the ACED Horizontal Linear Accelerator. This facility is a hydraulically controlled, pneumatically driven catapult device incorporating a test sled and 386 feet of track. The seats, facing opposite to the direction of acceleration, were mounted to the sled by means of instrumented attachment fittings. Instrumented anthropomorphic dummies, each weighing 170 pounds, were secured in each seating place with standard airline seat belts. Typical test arrangements are shown in Figures 11 and 2-3.

The sled was accelerated by a piston which receives its energy from the expansion of a fixed air mass entrapped in an accumulator. The sled, seat, and dummy accelerations, seat belt tension, and the reaction forces of the seat/floor attachments were transmitted by direct line from the sled and recorded by two oscillographs during the acceleration stroke. Motion picture cameras were positioned on and around the sled to photograph the tests from various angles. A complete instrumentation description of these dynamic tests is contained in Appendix II.

The vertical dynamic tests for Seats B and C were conducted on the ACED 150-Foot Vertical Drop Tower (Figure 12). This facility is a 150-foot tower incorporating a 10- by 10-foot test car which can be dropped from any height up to 112 feet and is arrested by metal straps. Mounting techniques similar to those used on the catapult were incoporated for the installation of the seats on the drop tower test car. Again, anthropomorphic dummies were secured in each seating place with standard airline seat belts.

The car was raised to the desired height then dropped and arrested by the controlled bending of the metal straps. The sled, seat, and dummy accelerations, seat belt tension, and the reaction forces of the seat attachments were transmitted by telemetry to a ground station and recorded on magnetic tape. The tests were photographed from various angles by motion picture cameras mounted on and around the test facility. Refer to Appendix II for instrumentation details of these tests.

Selection of the Acceptable Dynamic Test Methods: To determine methods of testing aircraft seats and occupant restraint devices to show compliance with dynamic seat test criteria, a study was made of existing seat test facilities, both static and dynamic. Since seat testing is primarily conducted by the manufacturer, consideration had to be given to the amount, complexity, and cost of the test equipment and facilities required to certify an aircraft seat under dynamic conditions.

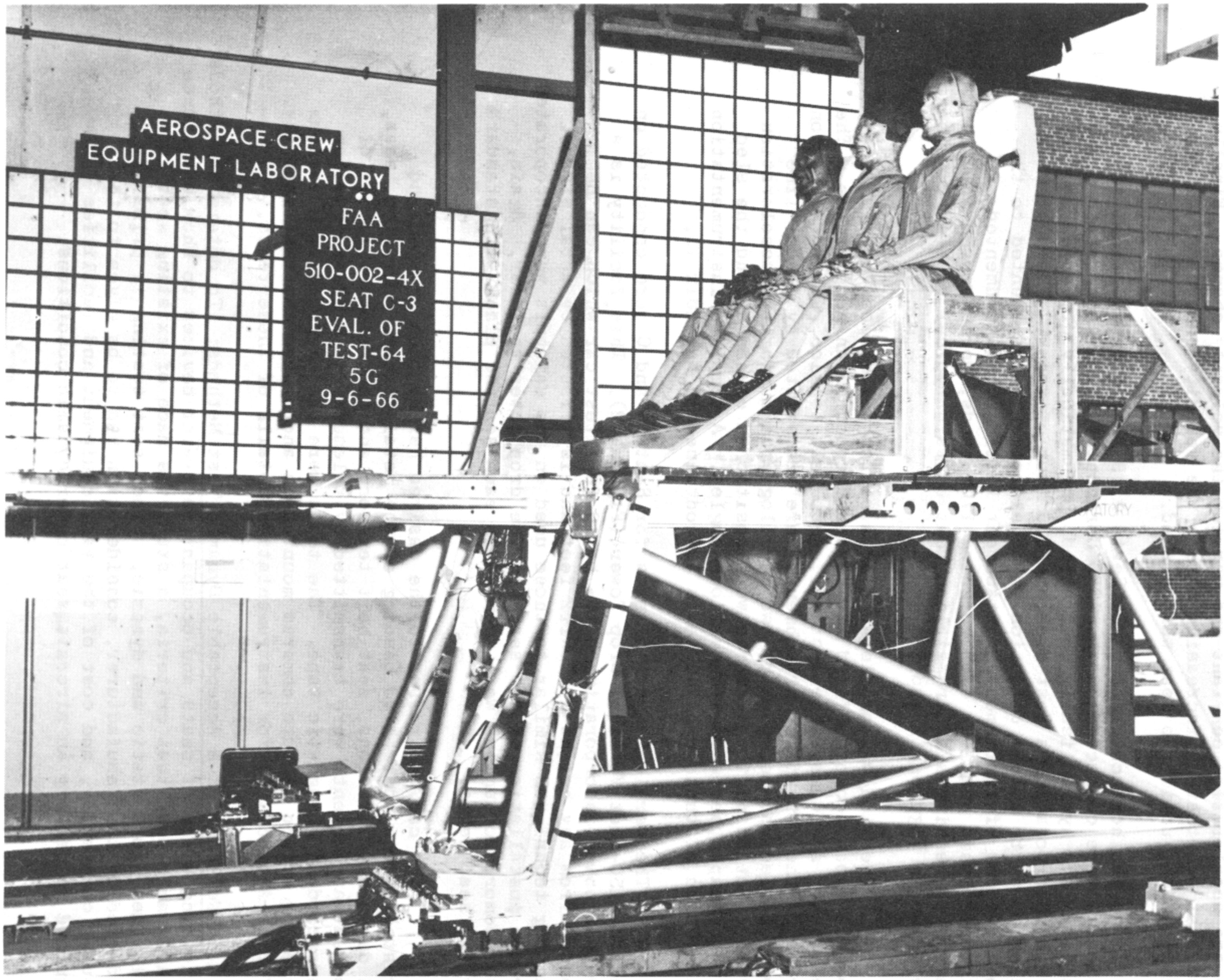


FIG. 11 TYPICAL SEAT TEST SETUP ON THE ACED HG-1 CATAPULT

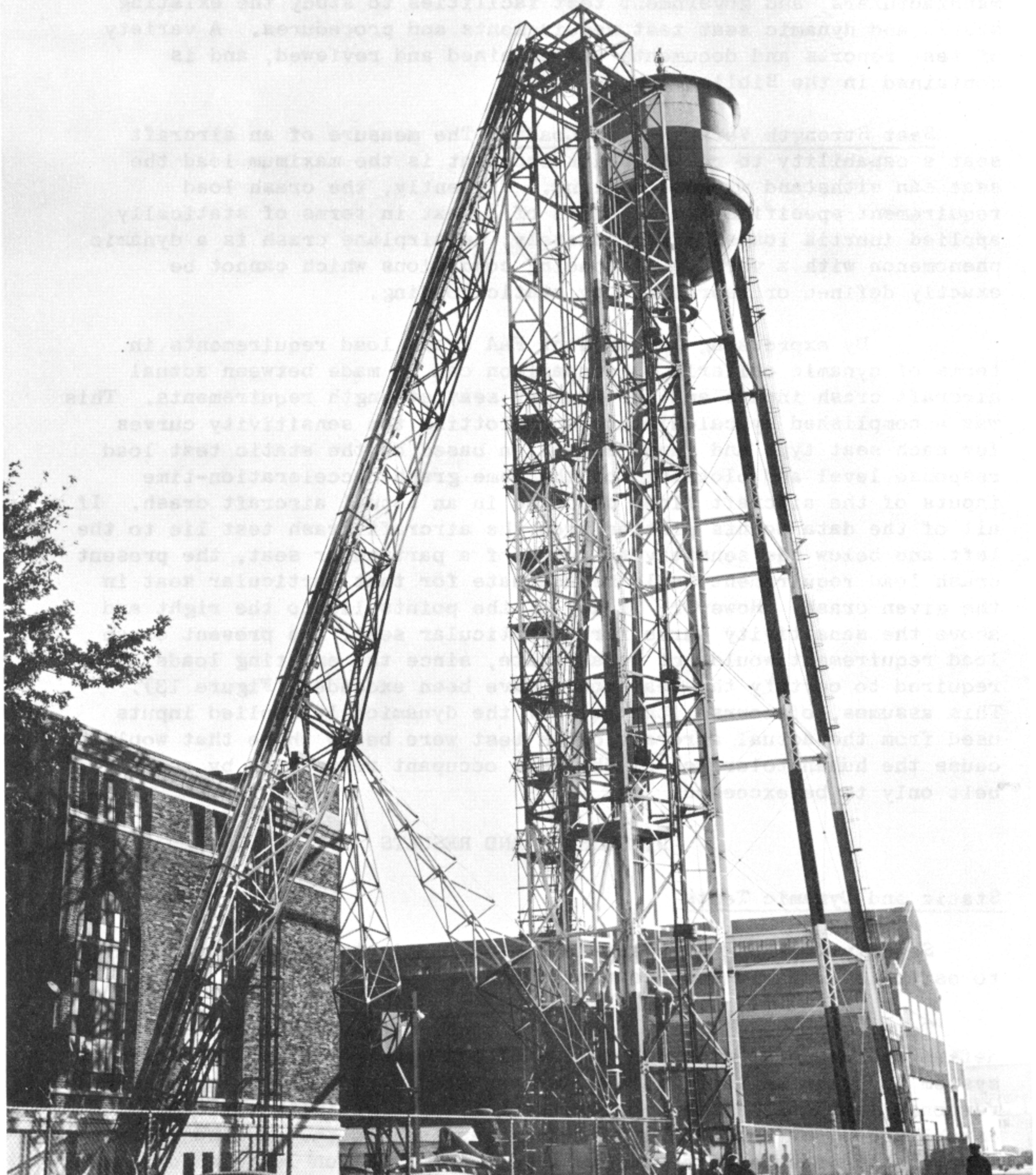


FIG. 12 ACED 150-FOOT VERTICAL DROP TOWER

Visits were made to airlines, seat manufacturers, airframe manufacturers, and government test facilities to study the existing static and dynamic seat test requirements and procedures. A variety of test reports and documents was obtained and reviewed, and is contained in the Bibliography.

Seat Strength Versus Crash Loads: The measure of an aircraft seat's capability to restrain its occupant is the maximum load the seat can withstand without failing. Presently, the crash load requirement specifies the strength of a seat in terms of statically applied inertia loads. Unfortunately, an airplane crash is a dynamic phenomenon with a variety of loading conditions which cannot be exactly defined or reproduced by static loading.

By expressing the present FAA crash load requirements in terms of dynamic criteria, a comparison can be made between actual aircraft crash inputs and the present seat strength requirements. This was accomplished by calculating and plotting the sensitivity curves for each seat type and input direction based on the static test load response level and plotting, on the same graph, acceleration-time inputs of the aircraft floor produced in an actual aircraft crash. If all of the data points plotted from the aircraft crash test lie to the left and below the sensitivity curve of a particular seat, the present crash load requirement would be adequate for that particular seat in the given crash. However, if any of the points lie to the right and above the sensitivity curve for a particular seat, the present crash load requirement would not be adequate, since the existing loads required to certify the seat would have been exceeded (Figure 13). This assumes, of course, that all of the dynamically applied inputs used from the actual aircraft crash test were below those that would cause the human tolerance of the seat occupant restrained by a lap belt only to be exceeded.

DISCUSSION AND RESULTS

Static and Dynamic Tests

Seventy-four dynamic tests and nine static tests were conducted to establish dynamic seat test criteria.

To use the sensitivity curve approach, it was first necessary to define the response characteristics of each seat/occupant, spring-mass system in both the longitudinal and vertical directions. Knowing the response characteristics for each system, a sensitivity curve was established (for each direction) that represented the applied dynamic inputs that produced the same peak seat leg reaction level as did the FAA-required static test load.

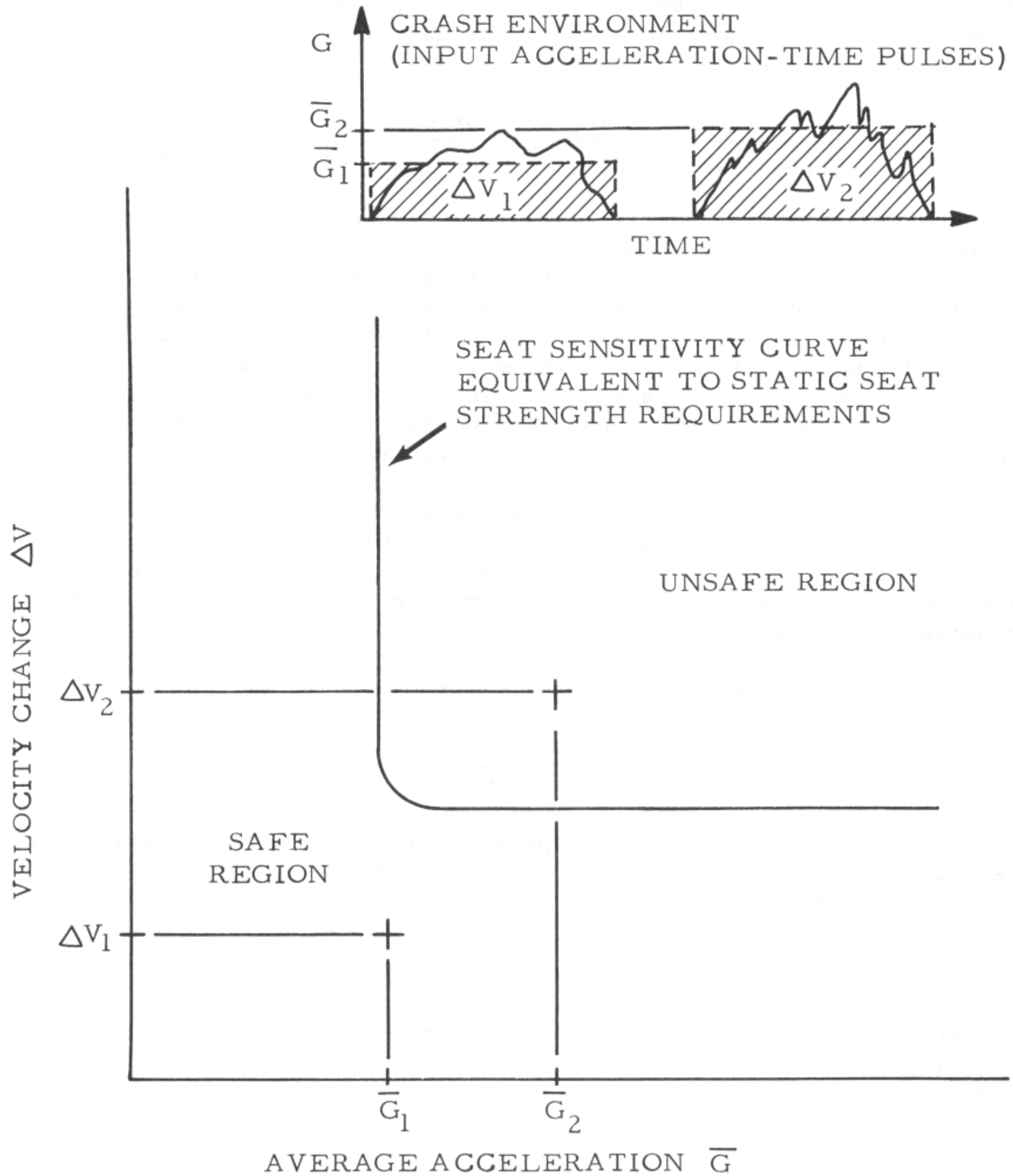


FIG. 13 SAMPLE SENSITIVITY CURVE RELATING STATIC SEAT STRENGTH REQUIREMENTS TO CRASH ENVIRONMENT

The spring response characteristics of each seat were defined in terms of the effective peak inertia force on the seat/occupant combination, g_e, and the average acceleration of the input acceleration-time pulse, $\bar{G}$, and were expressed as response factor C. Dynamic response curves were plotted for each seat/occupant system in terms of the response factor, C, versus the input acceleration-time pulse duration, t_n, whereas in Equation (1), Page 2:

$$C = \frac{\text{Effective Peak Inertia Force}}{\text{Effective Weight* X } \bar{G}} = \frac{Wt \times g_e}{Wt \times \bar{G}} = \frac{g_e}{\bar{G}}$$

and where the effective peak inertia force was calculated from the recorded reaction loads. Examination of these response curves, shown in Figures 14 through 19, indicates that each seat has different spring characteristics and that the spring characteristics can change with loading history; i.e., response level. This was most evident in the vertical dynamic tests of Seat A where the anthropomorphic dummy bottomed out on the aft stress tube (Figures 15 and 20). Seat C, because of its unique energy-absorbing design, established two longitudinal response curves as shown in Figure 18.

To derive the sensitivity curves for each seat comparable to the present static load requirements, the values of $\bar{G}$ and ΔV were calculated for a specified statically applied load; i.e., 9 g's forward, using the respective response curves for each seat to determine the appropriate response factor C.

To calculate $\bar{G}$, Equation (1) was expressed as:

$$\bar{G} = \frac{g_e}{C}$$

where C is determined drom the response curve for an arbitrarily selected pulse duration, t_n. The velocity change corresponding to the same duration, t_n, was then determined from Equation (3), Page 6:

$$\Delta V = \bar{G} \times g \times t_n$$

* Effective weight is the weight of the seat plus that weight of the anthropomorphic dummies on the seat. In some cases, the dummies' legs were partially supported by the floor, and the effective weight was correspondingly reduced.

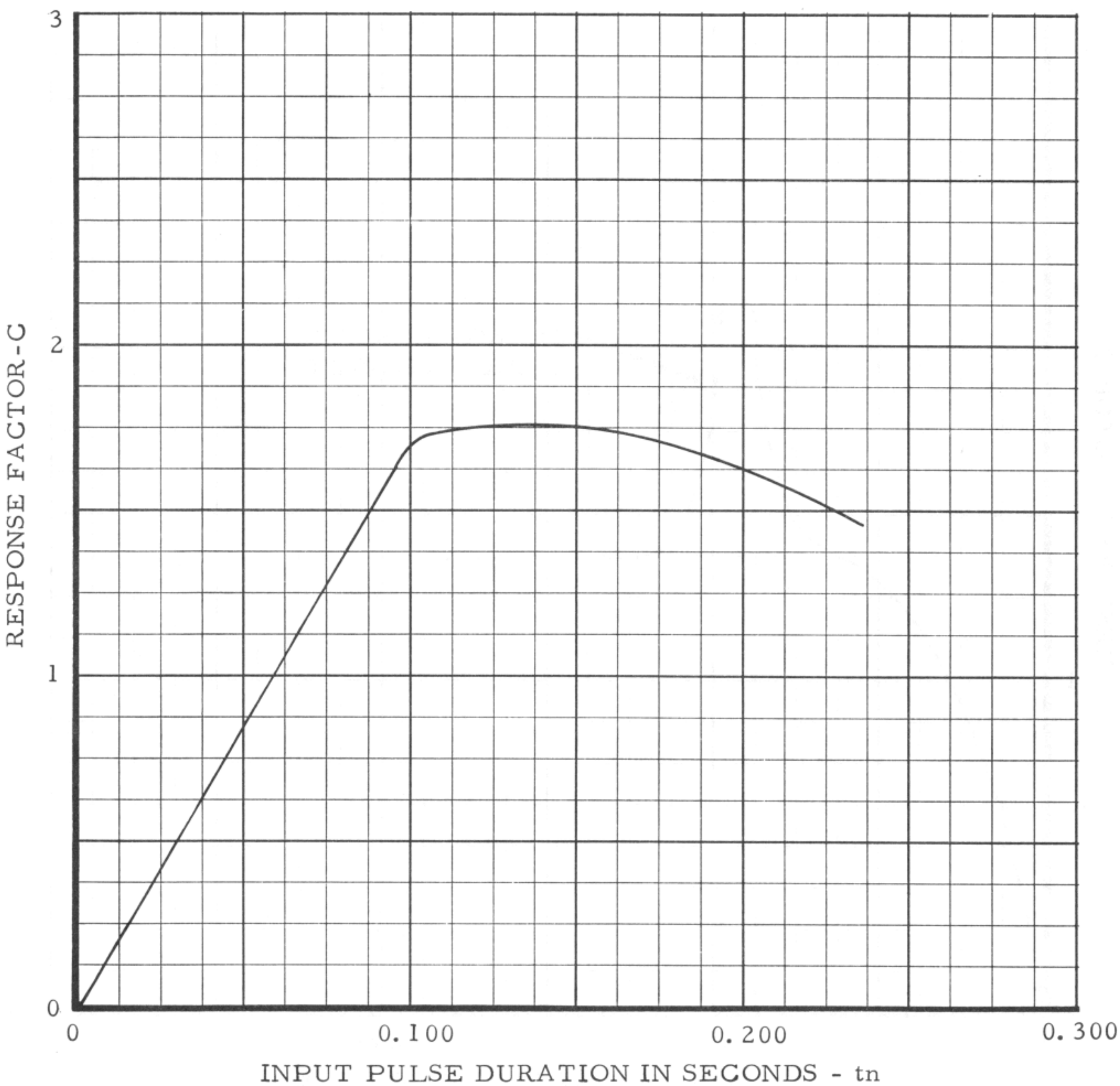


FIG. 14 LONGITUDINAL RESPONSE CURVE FOR SEAT A

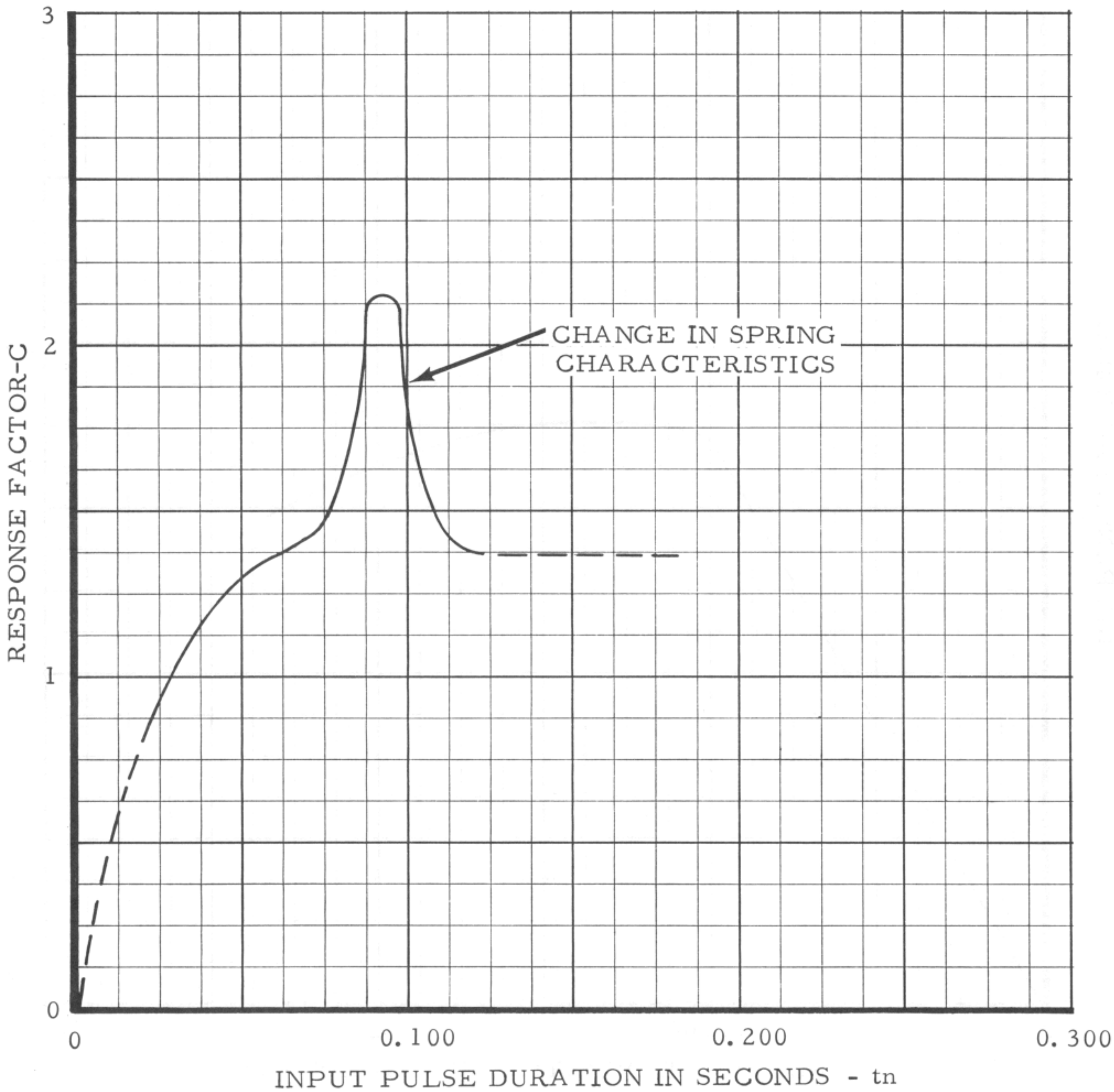


FIG. 15 VERTICAL RESPONSE CURVE FOR SEAT A

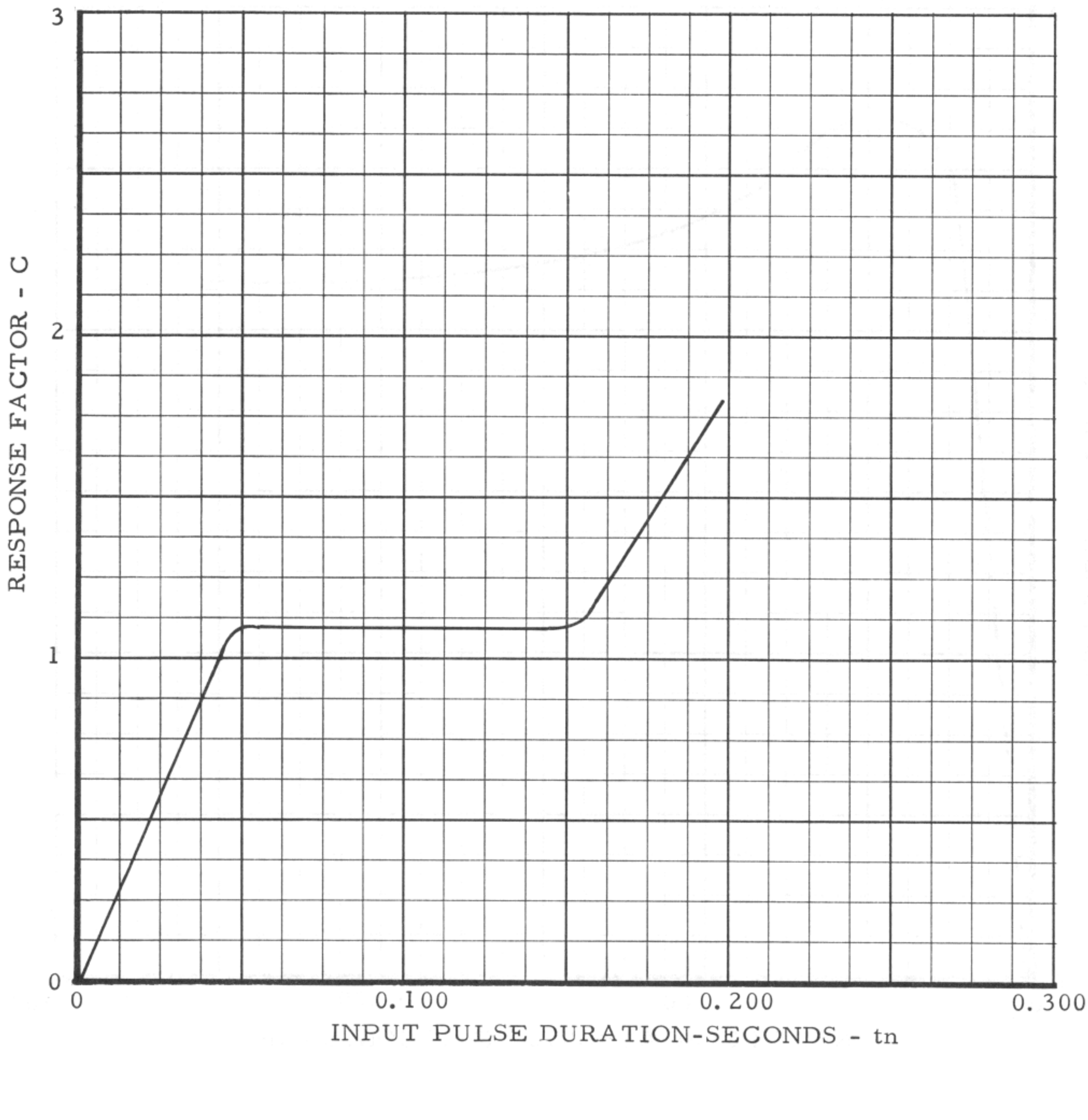


FIG. 16 LONGITUDINAL RESPONSE CURVE FOR SEAT B

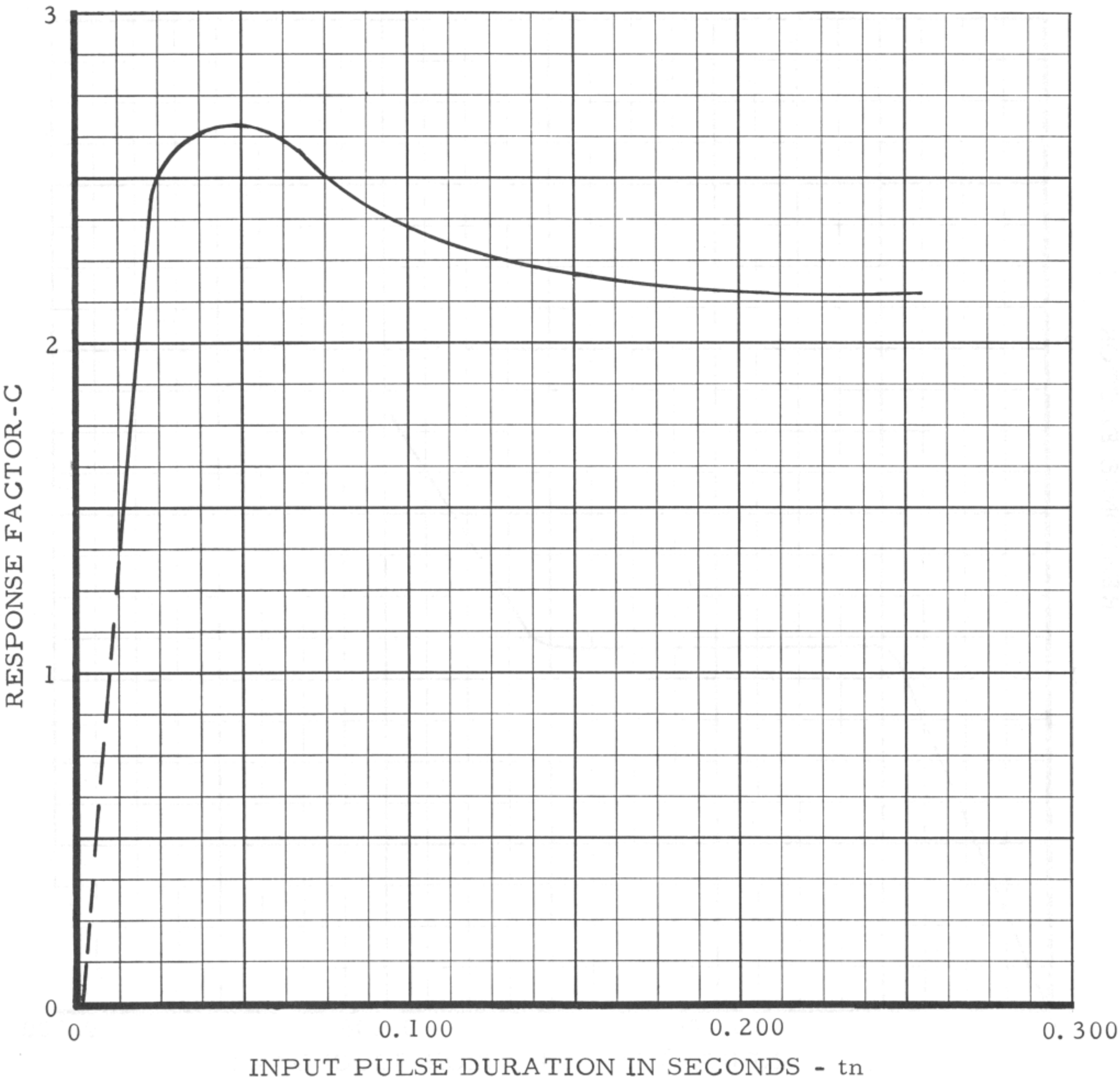


FIG. 17 VERTICAL RESPONSE CURVE FOR SEAT B

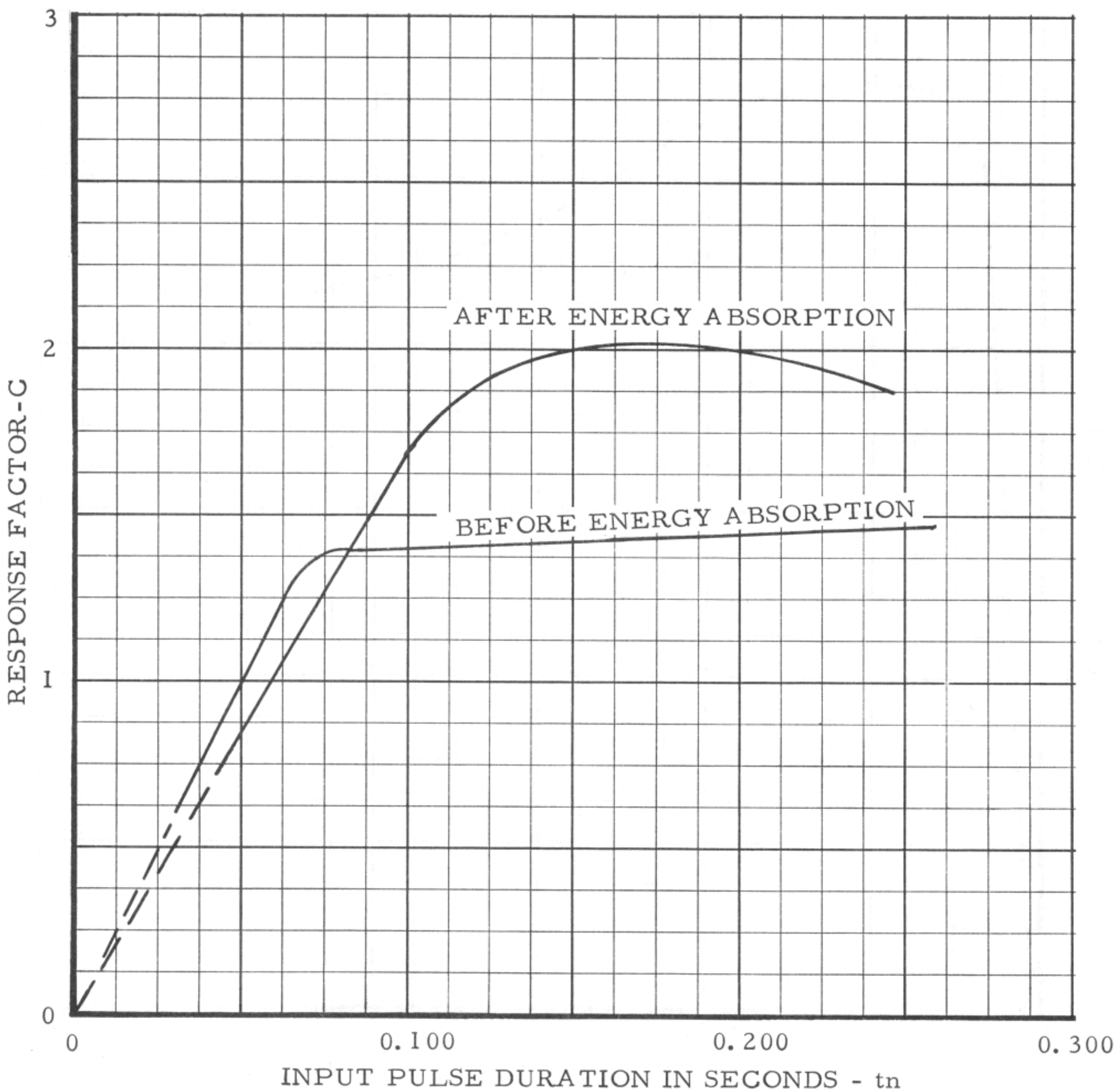


FIG. 18 LONGITUDINAL RESPONSE CURVE FOR SEAT C

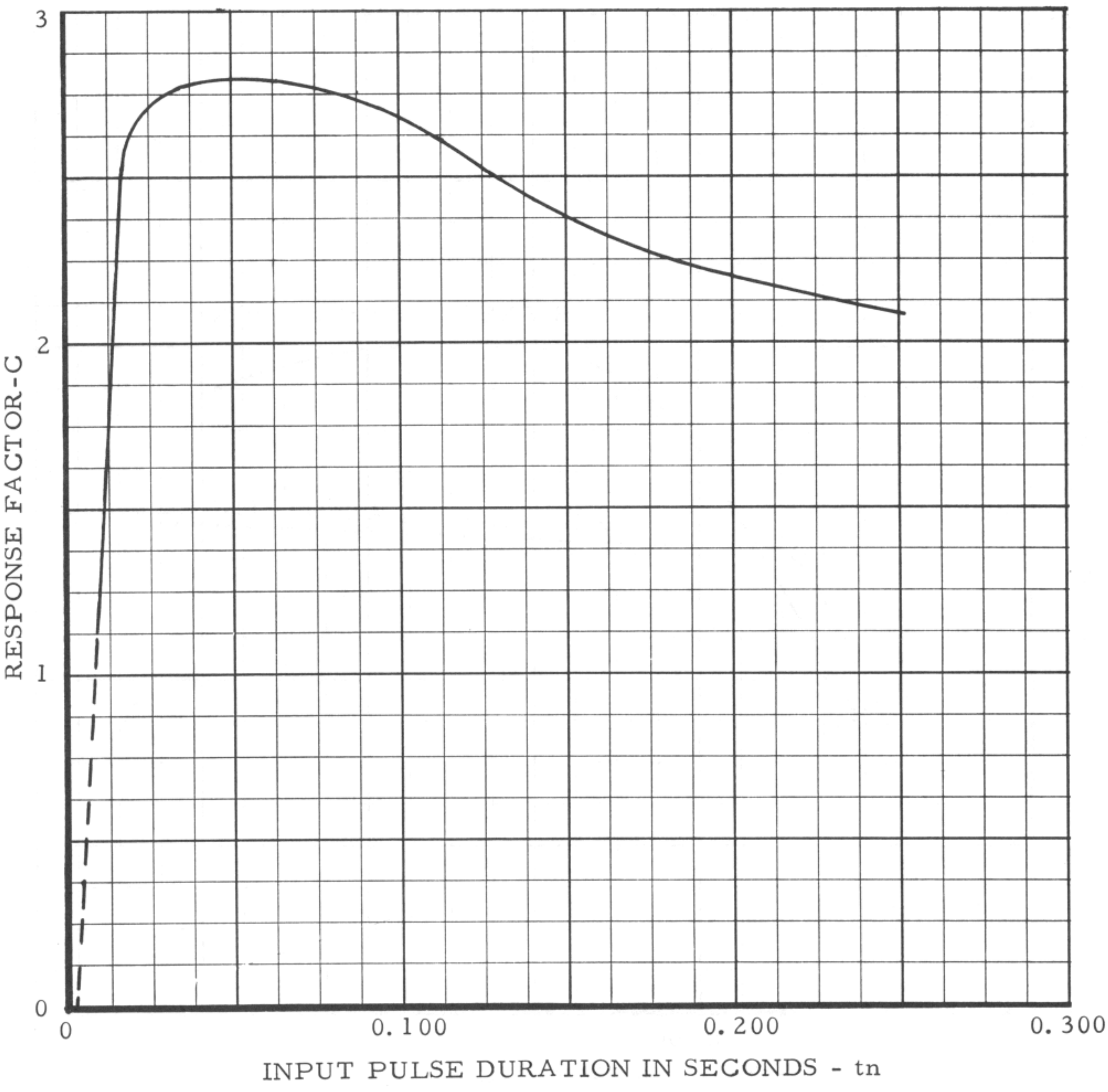


FIG. 19 VERTICAL RESPONSE CURVE FOR SEAT C

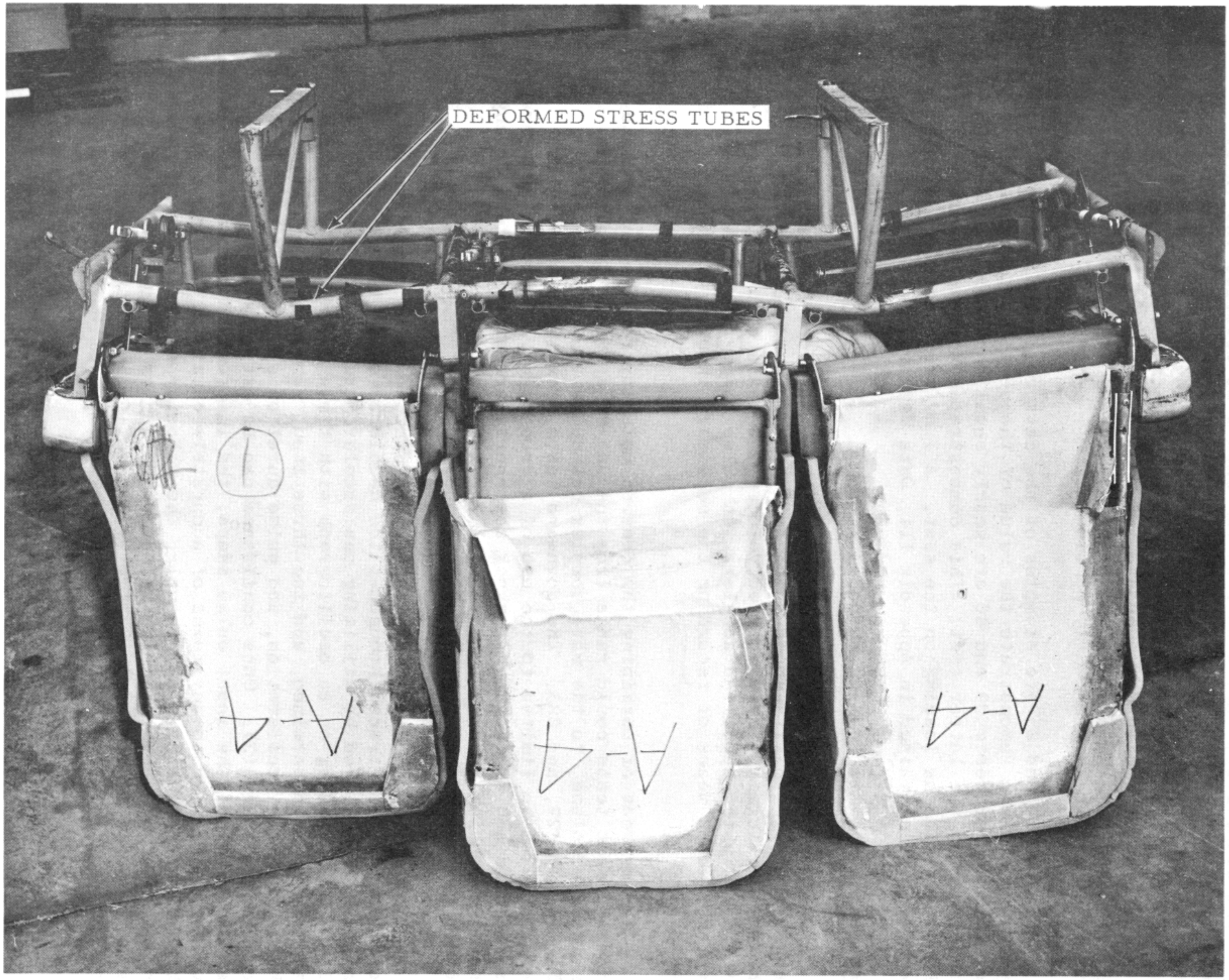


FIG. 20 BACK VIEW OF SEAT A AFTER VERTICAL DYNAMIC TESTING

The sensitivity curves derived for each seat describe the input acceleration-time pulses which induce the same peak seat leg reaction level as the applied static loads specified in the FAR's. Inspection of Figures 21, 22, and 23 shows clearly that seats certified for the same applied static loads responded quite differently to the same dynamic inputs. This is evident since the spring characteristics of each seat differ as previously mentioned.

Figures 24 and 25 are examples of the data collected from the dynamic tests and demonstrate the value of the sensitivity curve. Note that $\bar{G}$ for Tests 39 and 40 are nearly equal; however, the seat failed during the latter test. This demonstrates how the velocity change affects the loading on the seat. All of the data used in this reported are contained in Appendix III, Data Summary.

Acceptable Dynamic Testing Methods

Dynamic test methods and instrumentation need not be elaborate. The basic test facility would only require a means of accelerating the test article to the specified velocity, a means of decelerating it to obtain the specified acceleration pulse shape and acceleration average, and a means of recording the necessary input and response variables.

The methods of obtaining the desired velocity for the forward and sideward seat tests could range from the use of a simple pendulum or an inclined plane, to the more complex catapults and rocket sleds (Figures 26, 27, and 28). The downward tests, for the best results, were found to be limited to the use of a drop tower. Adequate deceleration can be obtained by the use of shock absorbers, arresting cables, or any energy-absorbing technique which will provide the desired average acceleration and acceleration pulse shape.

Ideally, the instrumentation of the input would be a continuous acceleration-time trace throughout the deceleration or impact cycle. This can be achieved by utilizing one accelerometer, mounted on the test sled, and recording on an oscillograph with timing. The pulse shape can readily be determined, and the three input variables, velocity change, average acceleration, and pulse duration can readily be calculated, Equations (2) and (3). Once confidence can be established in the repeatability of the input pulse shape, the instrumentation can be further simplified to any means of accurately obtaining any two of the three input variables. For example, the velocity change could be reduced to some means of obtaining the velocity just prior to impact. This velocity would represent the velocity change if the seat/occupant system comes to rest at the end of the impact cycle.

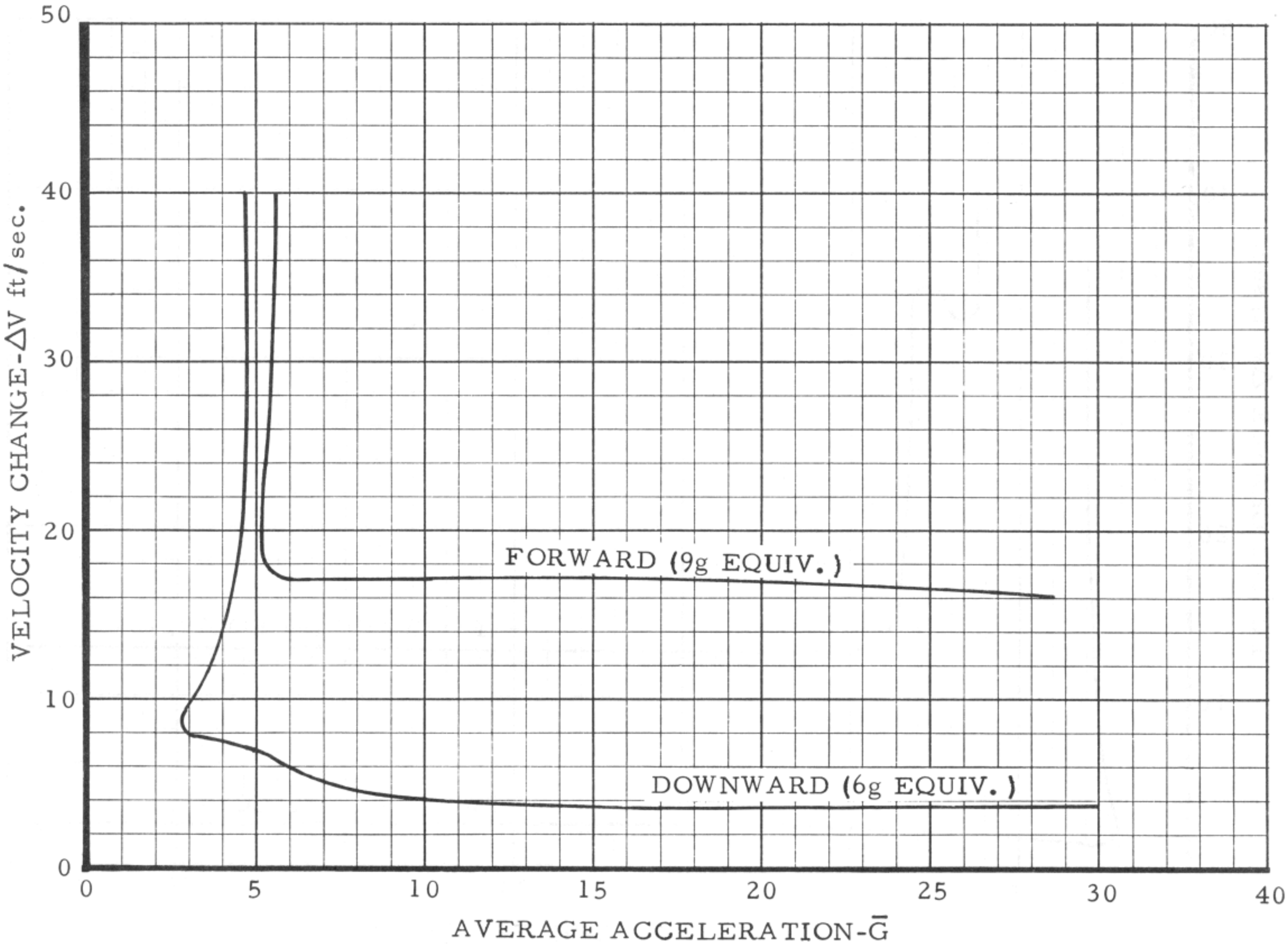


FIG. 21 SENSITIVITY CURVE - SEAT A

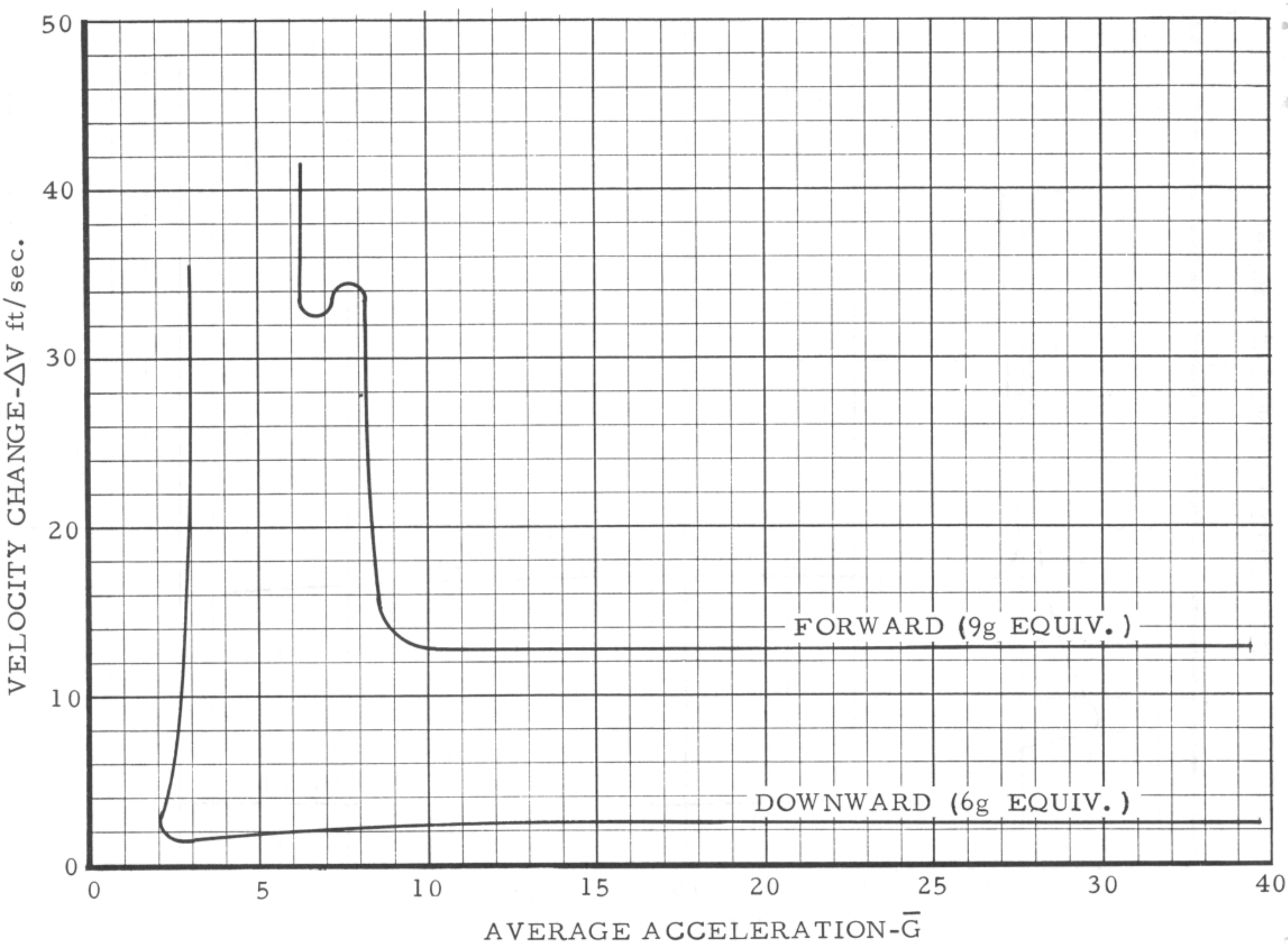


FIG. 22 SENSITIVITY CURVE - SEAT B

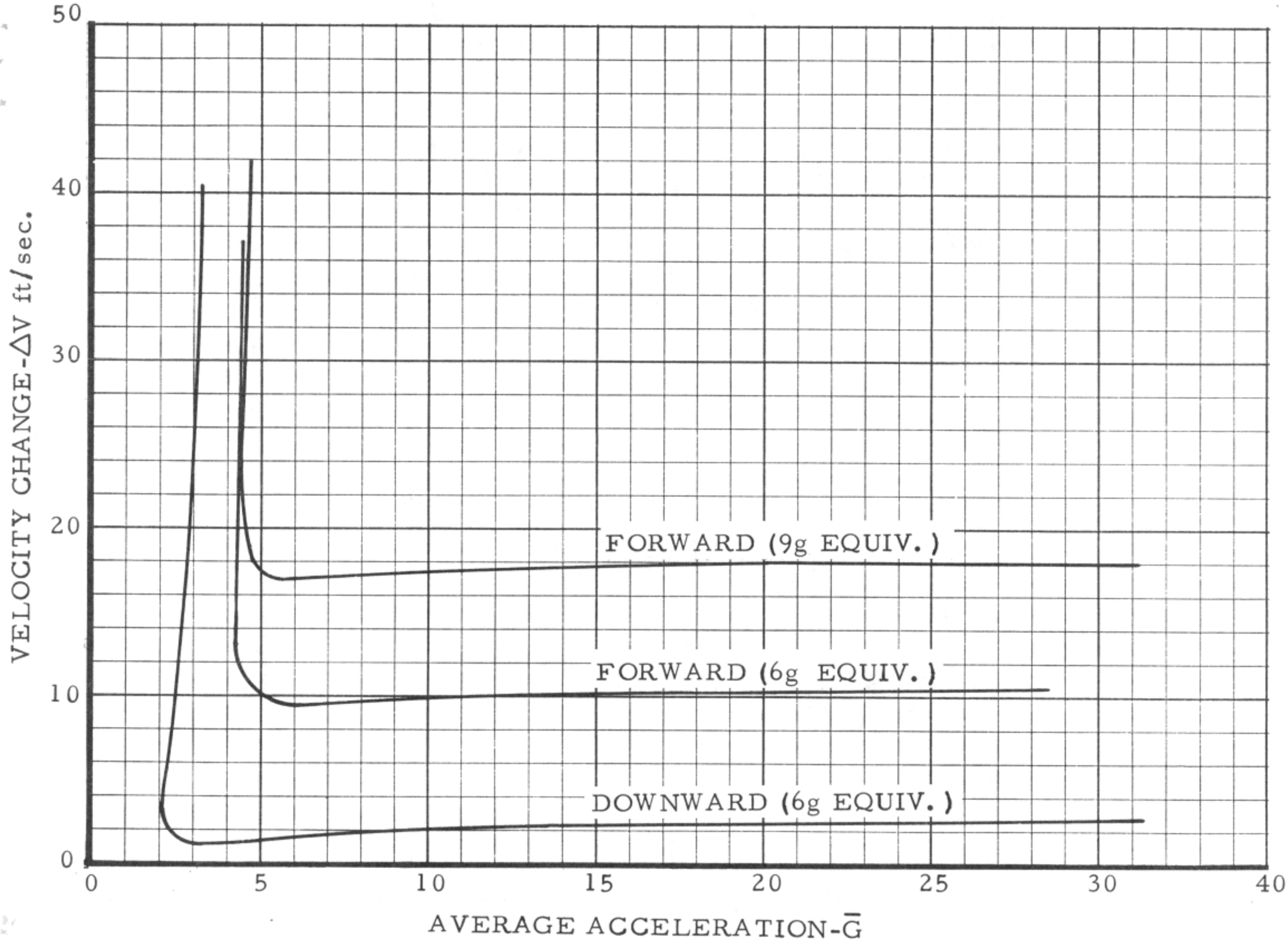
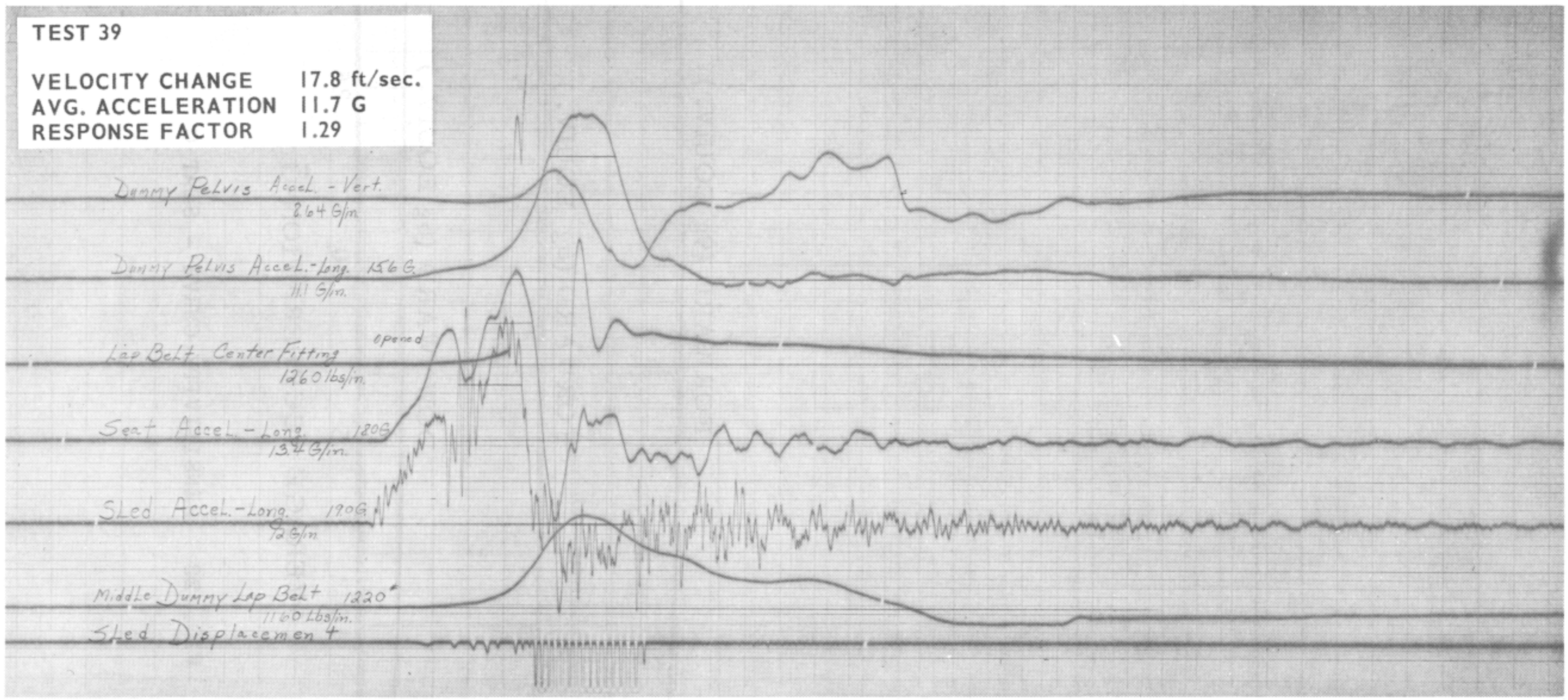
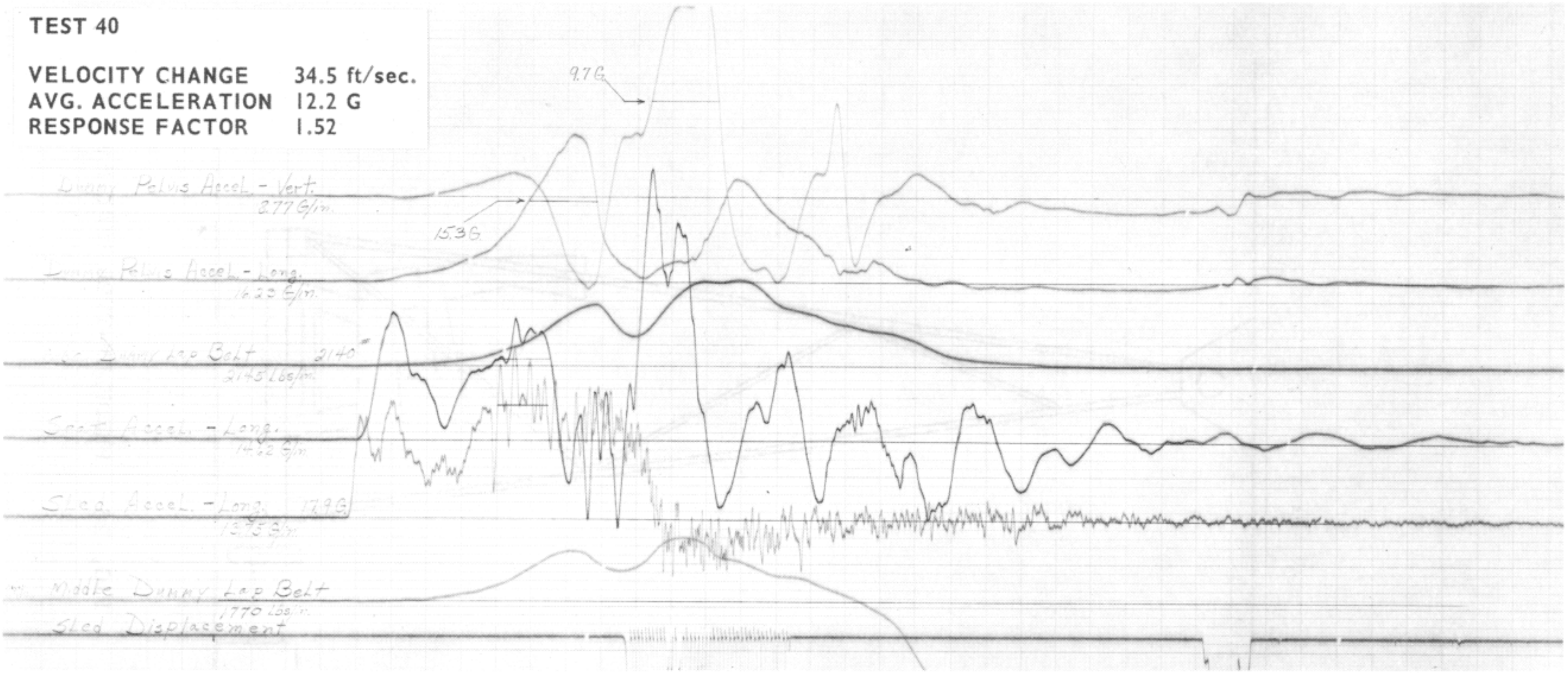


FIG. 23 SENSITIVITY CURVE - SEAT C



NOTE – NOT TO SCALE

FIG. 24 DYNAMIC TEST DATA COLLECTED FOR TEST NO. 39



NOTE – NOT TO SCALE

FIG. 25 DYNAMIC TEST DATA COLLECTED FOR TEST NO. 40

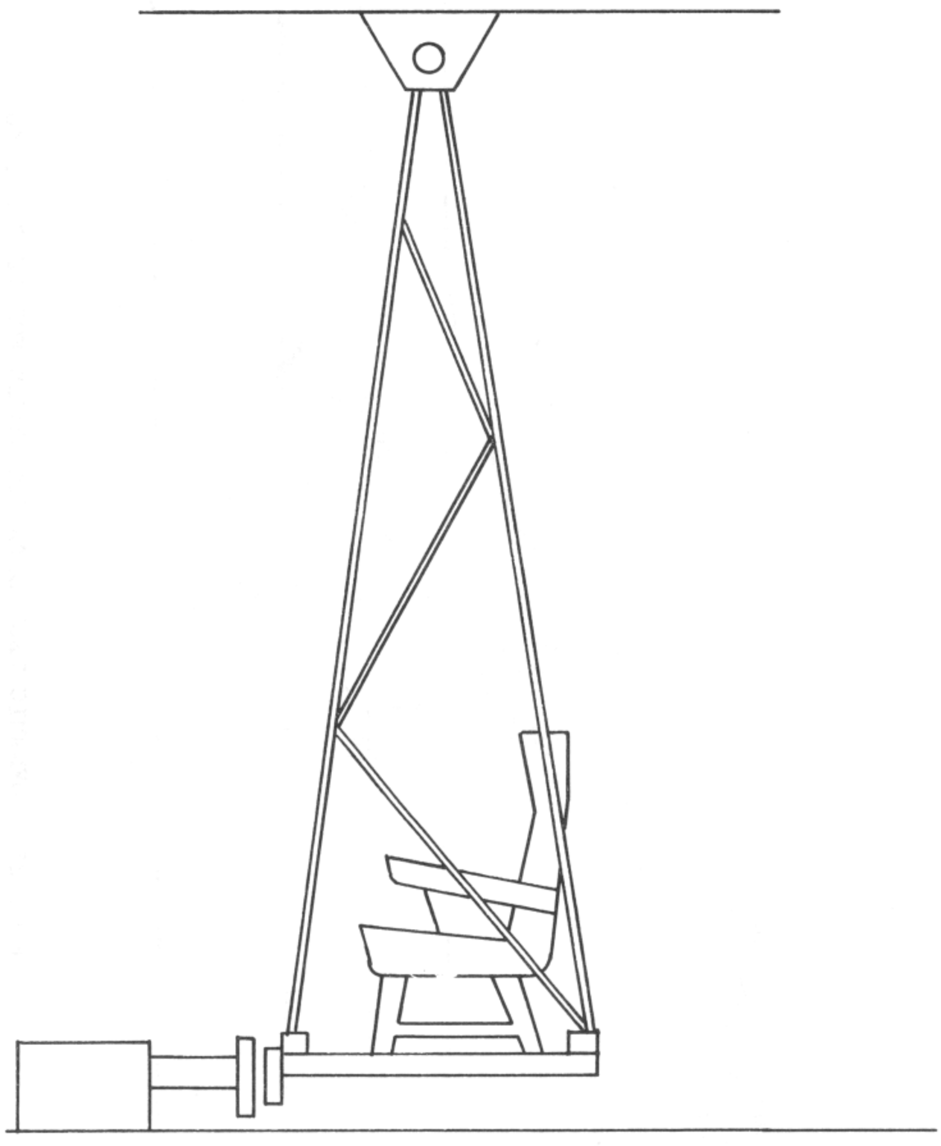


FIG. 26 PENDULUM-TYPE TEST FACILITY

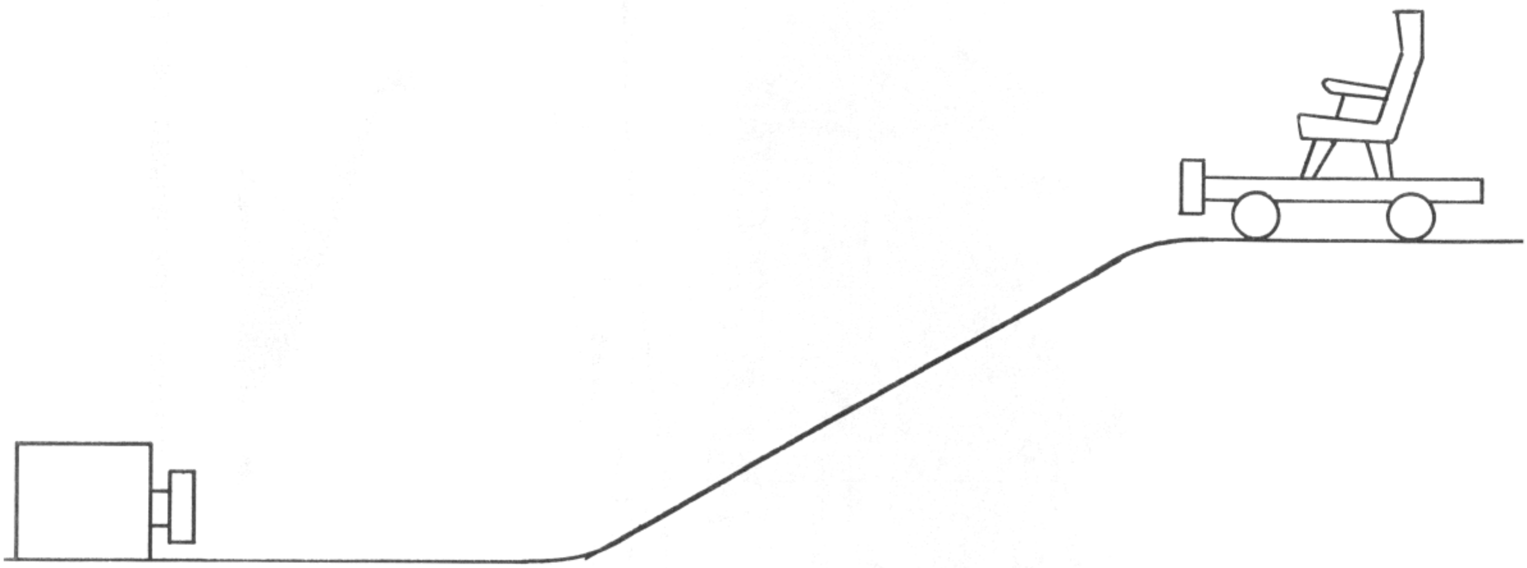


FIG. 27 INCLINED PLANE-TYPE TEST FACILITY

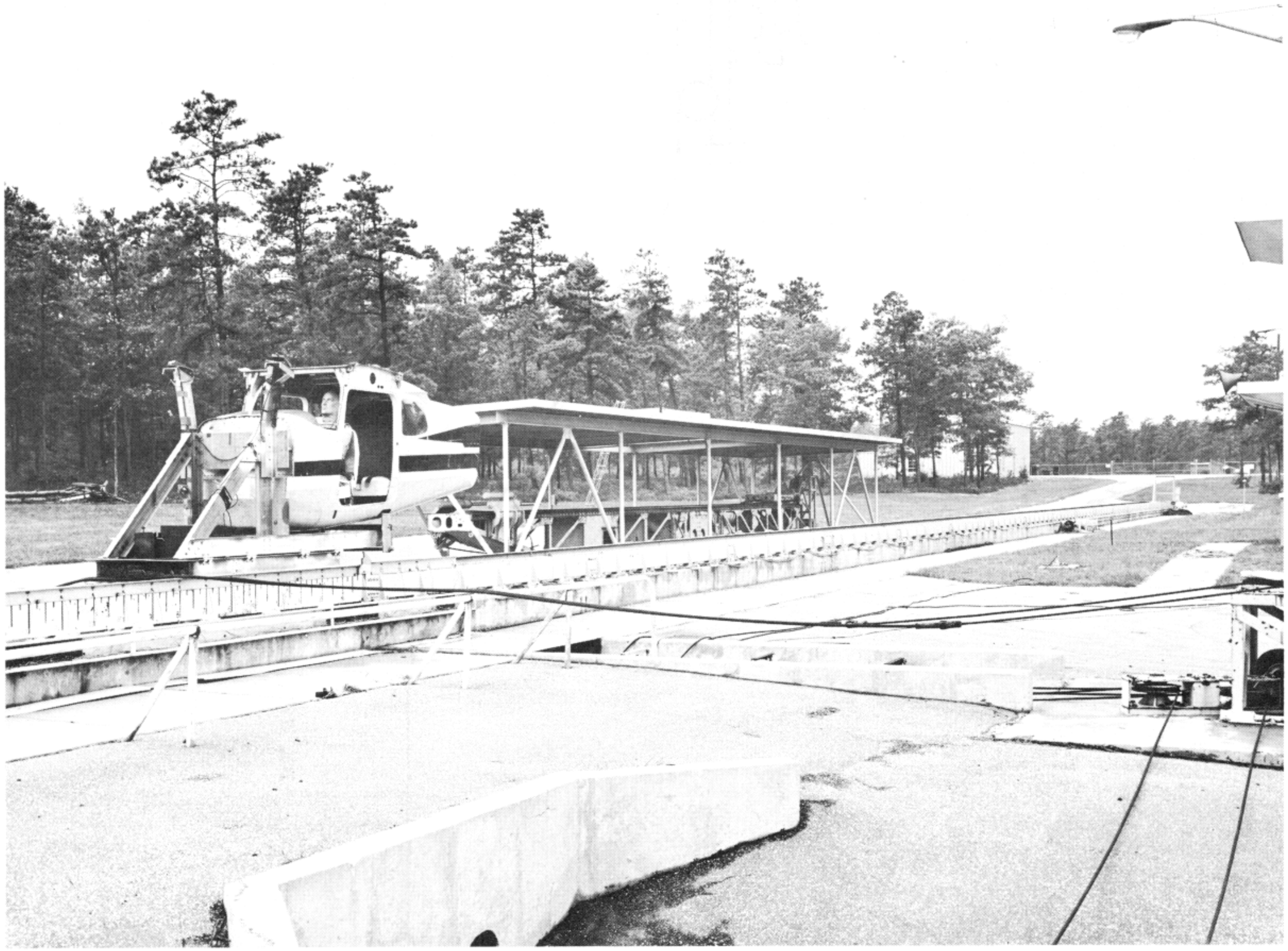


FIG. 28   CATAPULT-TYPE DYNAMIC TEST FACILITY

Instrumentation for the response of the seat/occupant system involves the recording of only the peak seat leg reactions. Continuous traces of the reactions throughout the deceleration cycle are not required. Peak reactions are required for all four legs in the downward and upward tests. For the forward and sideward tests, peak reactions are required for only the two legs subjected to tension. The tension legs are selected to minimize the random effect that occupant rebound may have on the response characteristics of the seat/occupant system. Occupant rebound is otherwise important in the evaluation of human survivability, ultimate damage to the seat, and the restraint capabilities of the seat. The tension legs are the two aft legs for the forward tests, and the aft leg and forward leg on the side opposite to the direction of the inertia force for the sideward tests.

An acceptable method of recording input data would be the use of high-speed photography. This technique would probably be more desirable to the seat manufacturer since it would provide him with a visual account of the test, along with the required data, using a minimum amount of equipment. For this method to be acceptable, time and the required distances must be recorded on the film.

In conducting a dynamic test, the test setup should be similar to that used in the test portion of this project with the exception of the elaborate instrumentation. The seat should be mounted to a rigid test bed using the same tiedowns (track and floor fittings) planned for the seat installation in operational aircraft. A rigid test bed is recommended in lieu of the simulated aircraft floor structure for several reasons:

1. Even though it would be desirable, it is doubtful whether or not the structural response of an aircraft floor could be simulated since such a small portion is required for the seat test installation.

2. The floor response characteristics will vary from aircraft to aircraft and from seat location to seat location in any given aircraft. For example, the transverse beams which support the seat tracks in one aircraft have a spacing of 20 inches. The seat spacing used by most airlines is 34 inches. Since 20 is not a multiple of 34, it is obvious that some seats will be mounted directly over the transverse beams providing a comparatively more rigid installation than those seats straddling the beams.

3. A rigid floor structure will usually create the most severe test condition for a seat and will insure test consistency for better seat evaluation.

The use of anthropomorphic dummies was found to provide more realistic test results because their response and seat pan impression were more representative of that of a human than the body blocks prescribed in the present FAA requirements (TSO-C-39). The most representative human response simulation available is necessary to accurately evaluate a seat. It was found during the many dynamic tests conducted in this project that many of the forces experienced by the seats were not considered in the initial seat design. For example, a forward seat leg attachment came loose from the floor track due to the dummies' rebound from the initial acceleration inducing a tension force on the attachment (Figure 29). Since all the test conditions for forward facing seats prescribed in the FAR, with the exception of the sideward and upward loads which are comparatively low, places the front legs in compression, it is logical, therefore, that any sizeable tension load in the forward leg could be overlooked.

Another condition which can best be evaluated by use of an anthropomorphic dummy is the possibility of the seat occupant "bottoming out" on the seat's basic frame. Many back injuries have been experienced in aircraft accidents in which high sink rates or vertical decelerations have caused the seat occupant to bottom out on the seat structure. This is especially true of crew members whose seats were mounted on a pedestal. The anthropomorphic dummy provides a more realistic seat pan impression and provides more accurate seat load distribution. The body blocks presently specified have a large seat imprint. Examination of Figures 20 and 30 shows the difference between the results of tests using dummies and those using body blocks.

Seat Sensitivity Versus Crash Loads

Having established sensitivity curves for Seats A, B, and C comparable to the present FAA static crash load requirements, a comparison of these requirements was made with actual airplane crash inputs and the realism of the present seat strength requirements determined.

The actual crash inputs used for the comparison were those taken from the crash test of a Lockheed 1649A aircraft. The data and a detailed description of the test are reported on in Reference 3. The data used in this report were those longitudinal and vertical acceleration-time histories measured at Fuselage Stations (FS) 195 and 685 when the aircraft impacted a 6^{o} and 20^{o} slope (Figures 31 and 32).

The most severe longitudinal acceleration-time pulse for each impact was reduced to terms of velocity change and average acceleration. These quantities were then plotted on a composite of each seat's sensitivity curve comparable to a 9-g forward static load. Inspection of the composite plot which is shown in Figure 33 indicates that the present crash load test requirement was not adequate in this crash for most type-certified seats had they been mounted in the crew compartment area, FS 195. However, the requirement was definitely adequate for such seats mounted at the aircraft's center of gravity, FS 685, and aft during the impact with both the 6^{o} and 20^{o} slopes. Although the horizontal floor acceleration obtained

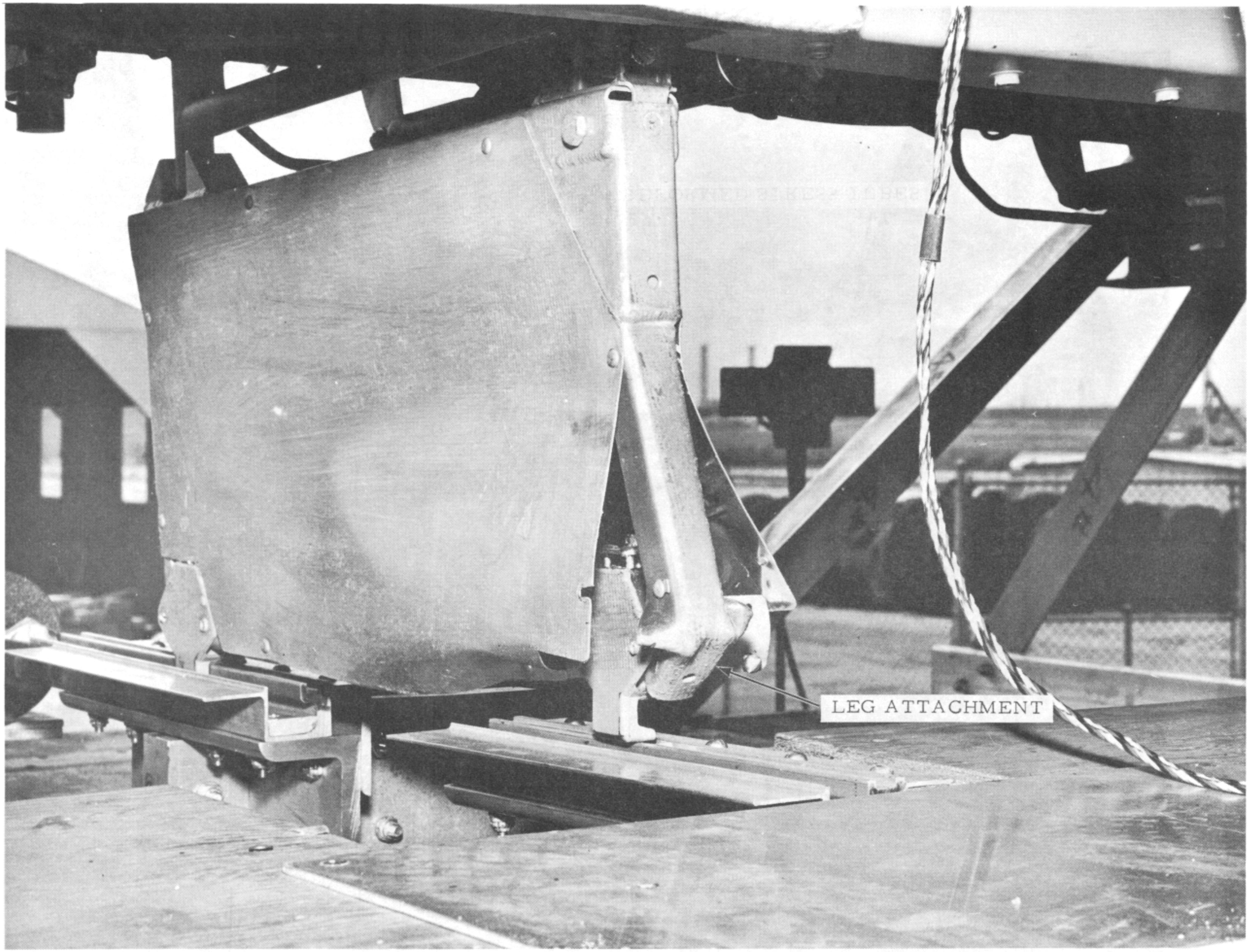


FIG. 29 FORWARD LEG OF SEAT C FOLLOWING FORWARD DYNAMIC TEST

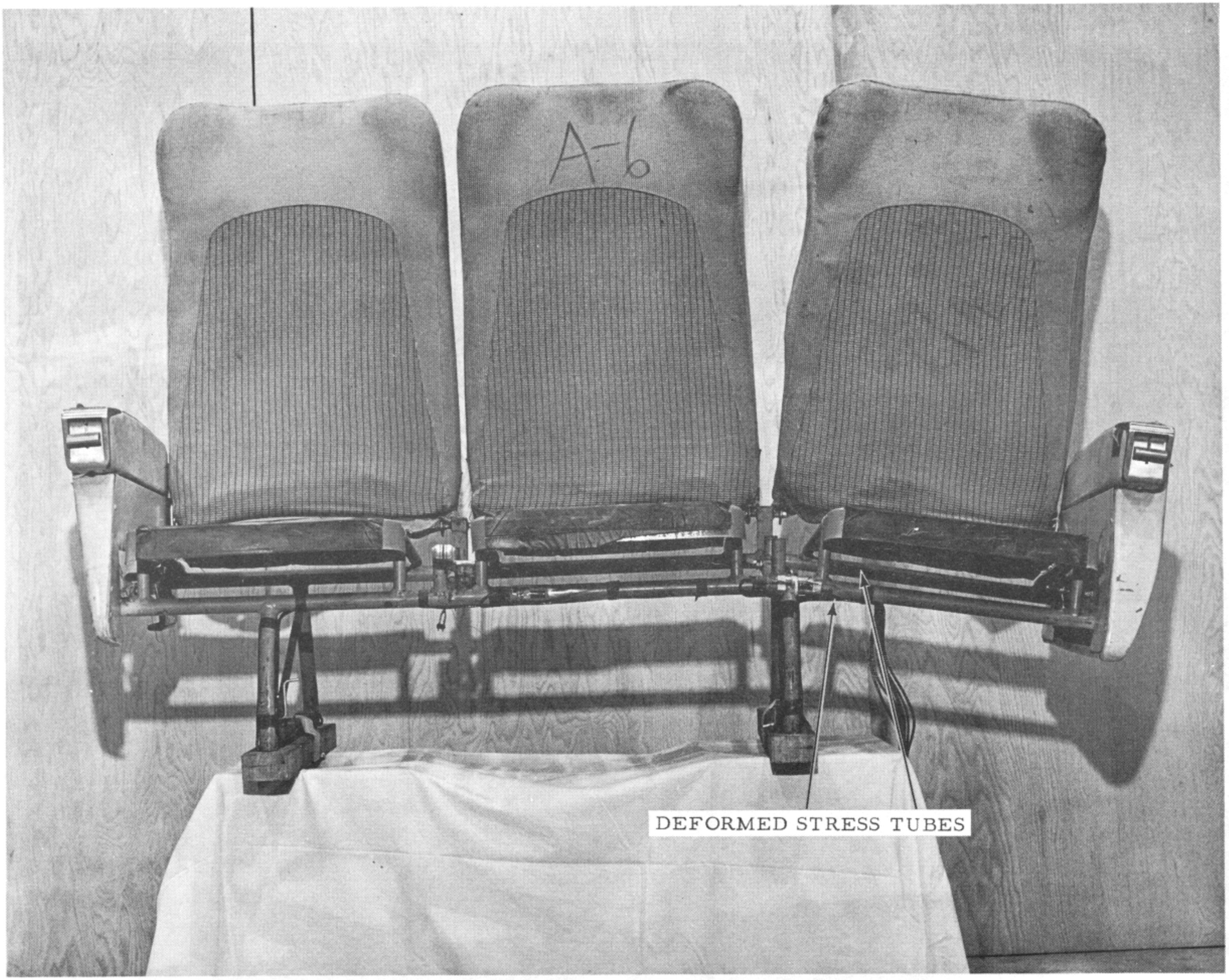


FIG. 30 FRONT VIEW OF SEAT A AFTER VERTICAL STATIC TESTING

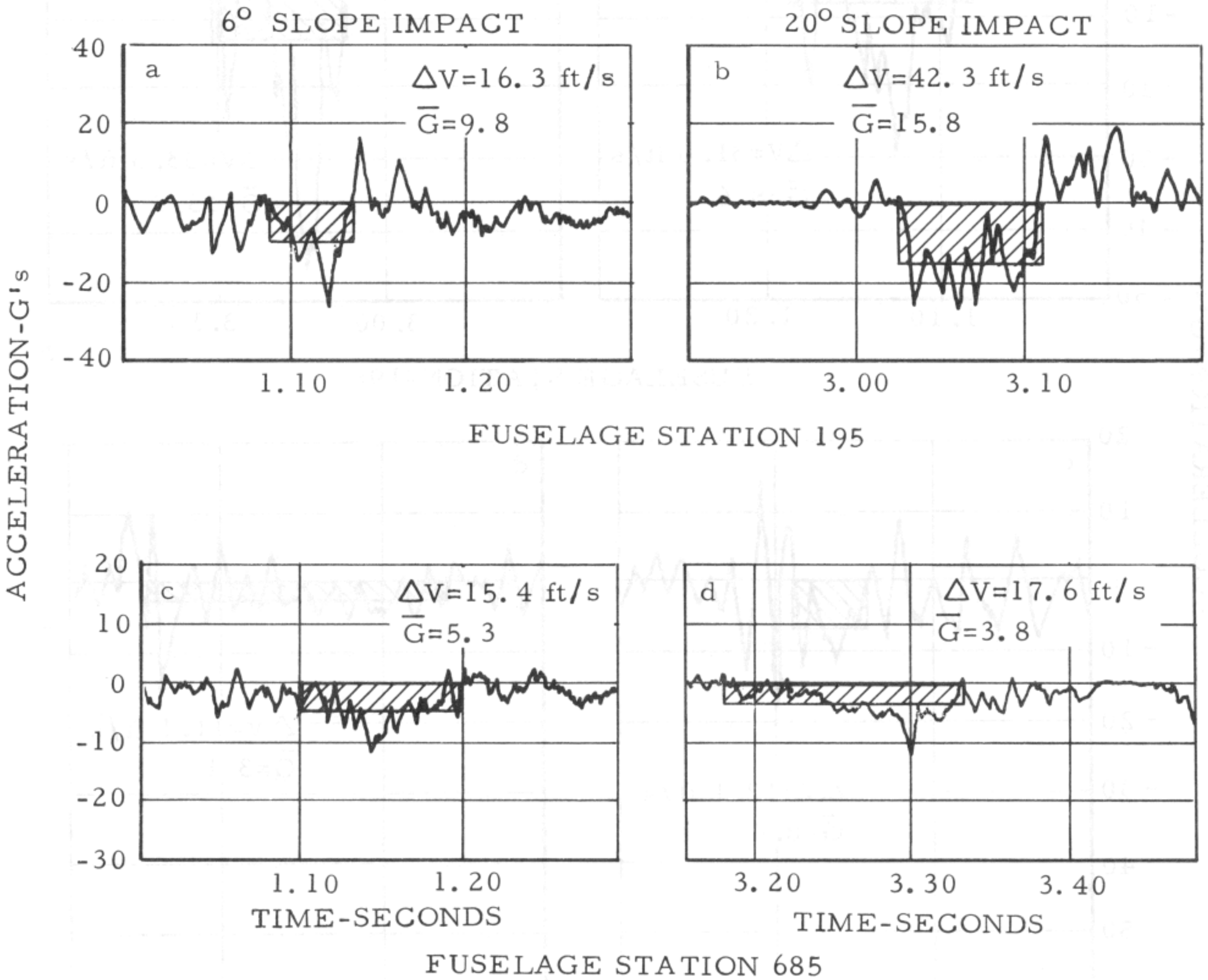


FIG. 31 LOCKHEED 1649A AIRCRAFT LONGITUDINAL FLOOR ACCELERATIONS

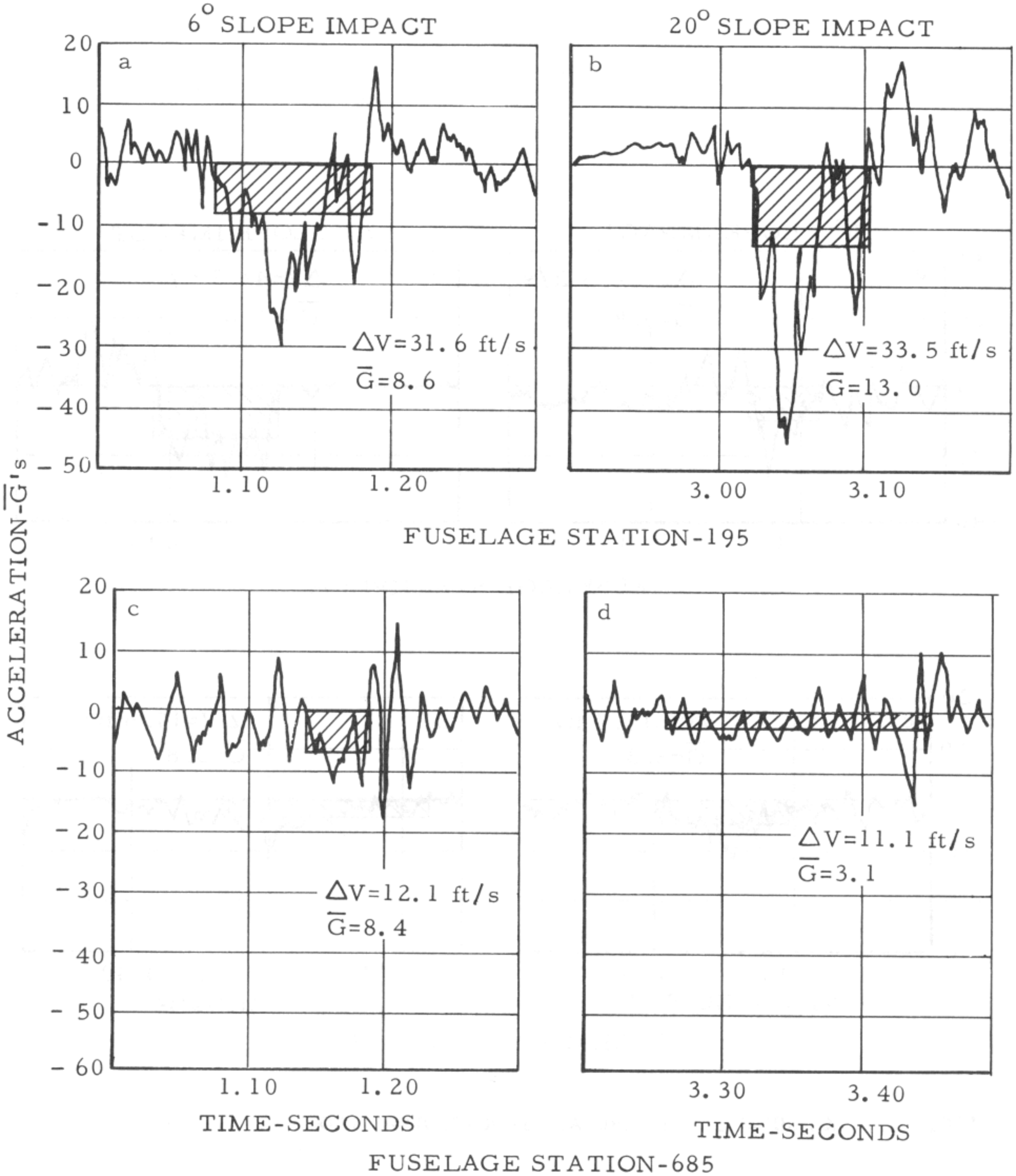


FIG. 32 LOCKHEED 1649A AIRCRAFT VERTICAL FLOOR ACCELERATIONS

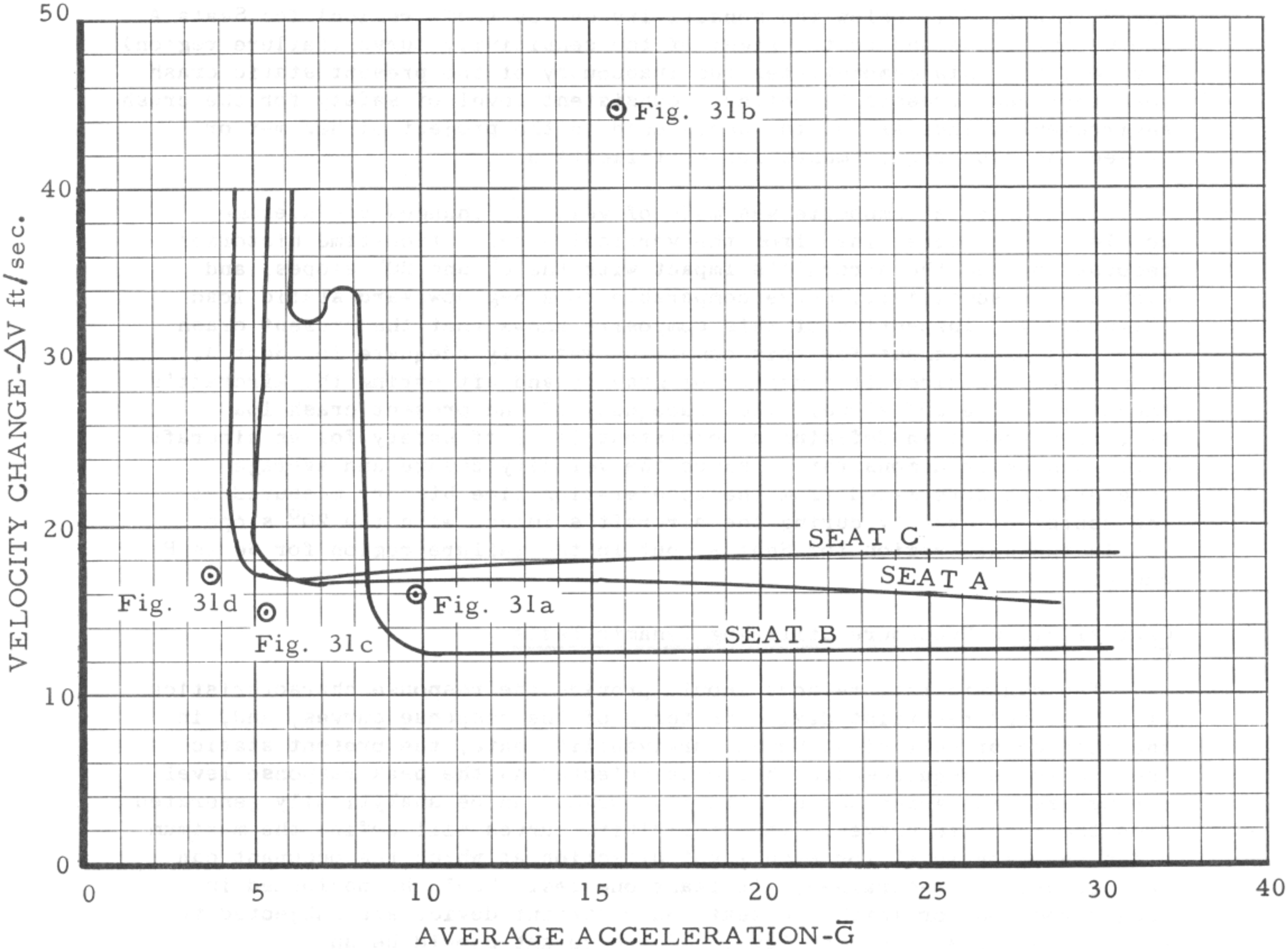


FIG. 33 LONGITUDINAL 9-g SENSITIVITY CURVES

at FS 460 was not analyzed, the fact that a Seat A configuration containing dummy passengers and located at FS 417 did not fail horizontally indicated that the present requirement was probably adequate for type-certified seats had they been mounted anywhere a few feet aft of FS 380 where a complete fuselage break occurred. It should be noted that the velocity change and average acceleration determined from the acceleration-time history, measured on the crew compartment floor, FS 195, during the aircraft's impact with the 6^{o} slope, fell below the sensitivity curves (safe region) for Seats A and C, but above and to the right of the sensitivity curve (failure region) for Seat B. This demonstrates the inadequacy of the present static crash load test requirements to define a consistent level of safety for the crash environment, since all of the seats used in the project either met or exceed the test requirements for certification.

Similarly, a composite was made of velocity changes and average accelerations, determined from the vertical acceleration-time histories recorded during the aircraft's impact with the 6^{o} and 20^{o} slopes, and each seat's sensitivity curve comparable to a 6-g downward static load (Figure 34). Inspection of this composite shows that the present crash load test requirement for this condition was only adequate for Seat A, mounted at the aircraft's center of gravity and aft during the aircraft's impact with the 20^{o} slope. The inadequacy of the present crash load test requirement in defining a consistent level of safety for an aircraft crash was again demonstrated, since the velocity change and average acceleration determined from the acceleration-time history measured at the center of gravity during the aircraft's impact with the 20^{o} slope was in the safe region for Seat A, but in the failure region for Seats B and C.

Certification Procedure Utilizing Dynamic Tests

The dynamic test methods should provide the response characteristics of a seat and restraint device in terms of the response curves, and, in the absence of sufficient human survivability data, the present static inertia force requirements should be selected as the peak response level parameters with which the sensitivity curves can be analytically generated from the response curves. The sensitivity curves will define the maximum crash severity level for each input direction at which the occupant can be successfully restrained. At least one test should be performed in each direction for which the seat and restraint device are subjected to the maximum crash severity level. The occupant should be an anthropomorphic dummy equal in weight to the present occupant weight requirement for the static tests (170 pounds).

The test methods should be such that the response curves reflect the effect of the parameters; input pulse shape and response level.

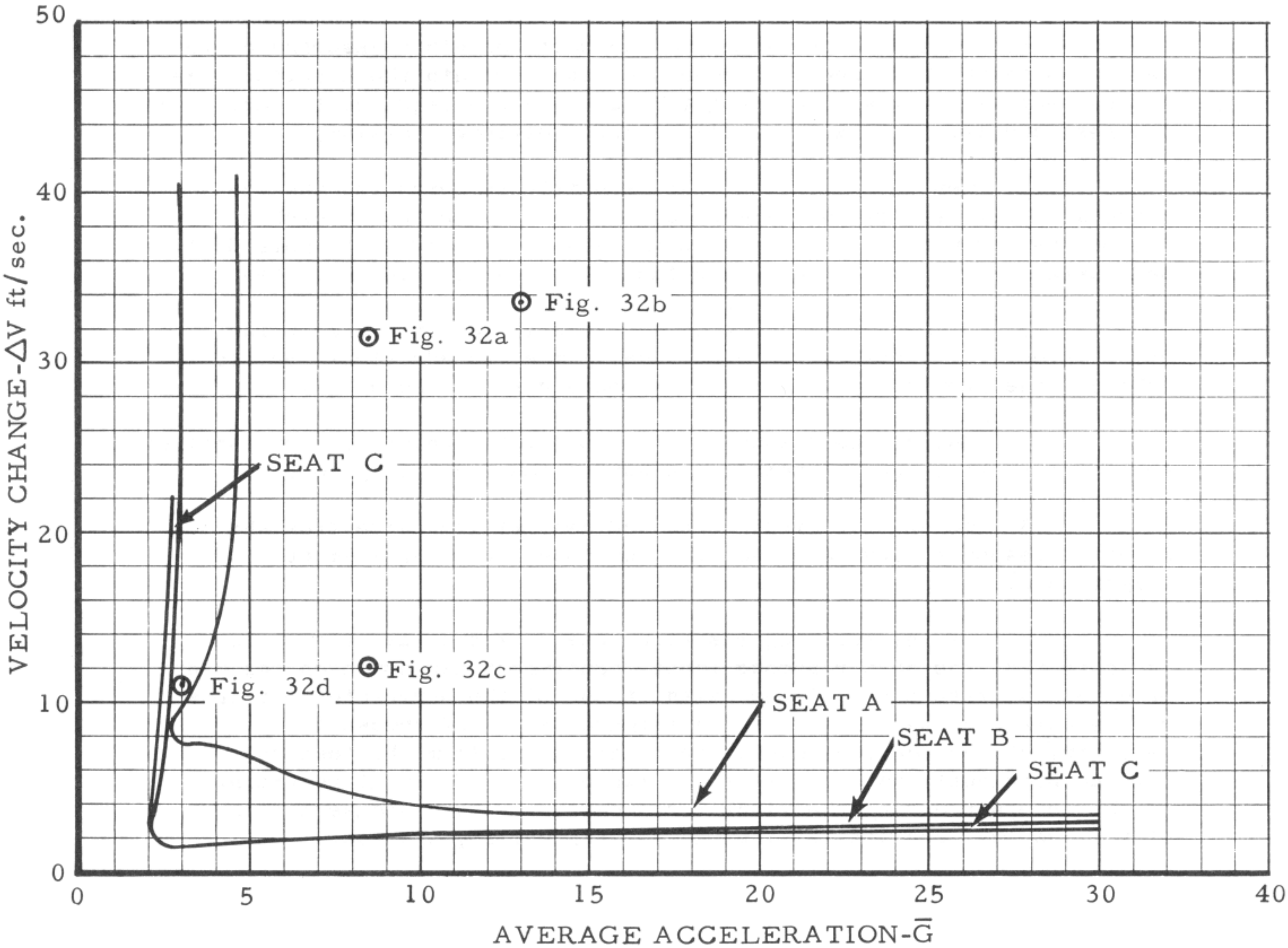


FIG. 34 VERTICAL 6-g SENSITIVITY CURVES

Pulse shapes approximating those encountered in actual crash environments, Reference 3, should be used, and tests producing response levels close to the peak response level requirements should ultimately determine the response curves.

In order to embody the above recommendations, the certification test procedure for each seat/lap belt combination for each input direction should be as follows:

1. Utilizing one seat and lap belt, obtain a response curve using inputs which induce peak response levels within the elastic range of the seat/lap belt system. About five tests are required (Figure 35a). The seat and lap belt can be utilized for additional testing.

2. Generate an approximate sensitivity curve for the peak response level requirement (Figure 35b). Select two inputs each at one of the "asymptote" locations on the sensitivity curve (Figure 35c), and, using two different seats and lap belts, perform two more tests.

3. Permanent deformation characteristics of the seat/lap belt system will probably be noted causing the two additional points to fall off the previously determined response curve (Figure 35d).

4. Adjust the response curve moving the upper portion parallel to itself so that the two points are now on the curve (Figure 35d).

5. Generate a final corrected sensitivity curve from the adjusted response curve for the peak response level requirement (Figure 35e).

6. If the seat leg reaction data from the last two tests indicate that the peak response level requirement had not been reached or exceeded, retest one of the seats at one of the asymptote locations on the corrected sensitivity curve (Figure 35f). If successful restraint of the occupant cannot be obtained, perform the test on a new and previously untested seat and lap belt. Successful restraint of the occupant during the final test together with a documentation of the response and sensitivity curves will certify the seat.

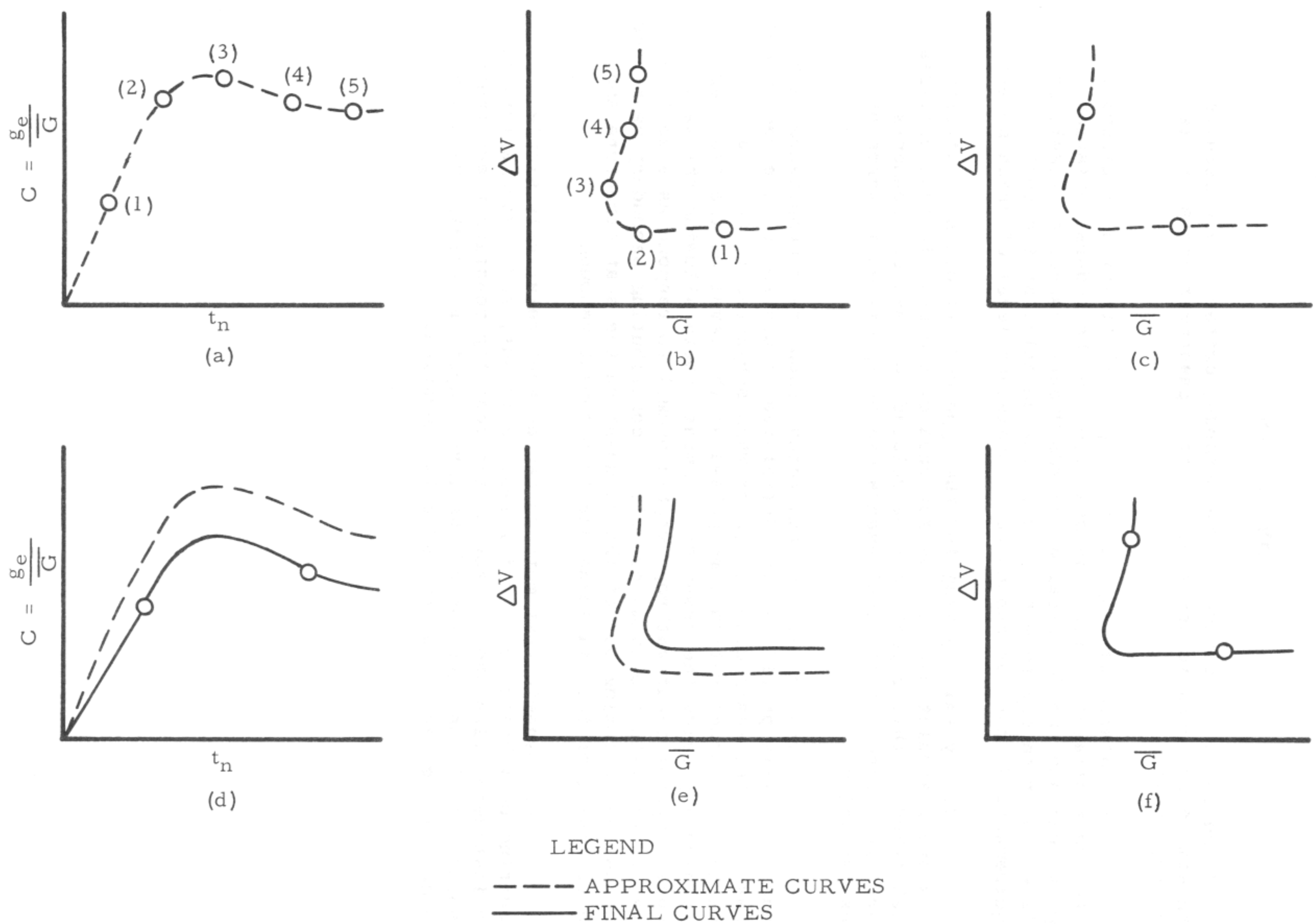


FIG. 35 RESPONSE AND SENSITIVITY CURVES FOR THE TYPE CERTIFICATION OF AIRCRAFT SEAT/LAP BELT SYSTEMS

CONCLUSIONS

Based on an evaluation of the methods, criteria, and results of both static and dynamic tests of aircraft passenger seats, it is concluded that:

1. Static testing for the type certification of aircraft seats and restraint devices, as specified in the Federal Aviation Regulations and the Technical Standards Orders, cannot of itself be related to crash environments, and, consequently, static test requirements do not correspond to a consistent level of crash severity.

2. Dynamic testing for the type certification of aircraft seats and restraint devices, as governed by the dynamic test criteria established in this report, can be related to crash environments; therefore, dynamic test requirements can be specified in terms of crash severity.

3. Dynamic test methods which demonstrate compliance with dynamic criteria provide a more definitive simulation of the mechanical behavior of the seat/occupant system when subjected to the crash environment. Acceleration-time pulses at the level of the seat leg attachments provide the crash environment inputs allowing the seat/occupant system (seat-anthropomorphic dummy) to respond as a spring-mass system, with the dummy capable of contributing secondary responses such as the bottoming out of the occupant on the seat structure and the reversing of inertia loads due to occupant rebound.

4. Dynamic test methods can be kept relatively simple requiring only basic test facilities, equipment, and instrumentation. The instrumentation should provide the seat leg reaction peaks (peak response level) and any two of the three input variables: velocity change, average acceleration and pulse duration.

RECOMMENDATIONS

Based on an evaluation of the dynamic test criteria of aircraft passenger seats, it is recommended that:

1. Dynamic testing in accordance with the criteria and procedure established in this report be considered for the type certification of aircraft seats and restraint devices.

2. Additional data be obtained from a study of the crash test, Reference 3. Data are available for further studies of crash environment severity, crash environment input pulse shapes, and response characteristics of seat/occupant systems when subjected to crash environments.

3. Further effort be expended to establish the applicability of the dynamic test criteria and procedure to the certification of other cabin components such as litters, pallets, oxygen bottles, galleys, etc.

4. Ideally, dynamic test criteria and certification procedures for aircraft seats and restraint devices be such that the seat and restraint device, of necessity, be designed with response characteristics that would enable the crash environment severity, which produces the human tolerance response pulse on the occupant, to be a maximum. The absence of sufficient data on human tolerance of seat occupants restrained by lap belt only precludes the possibility of establishing such criteria at the present time.

APPENDIX I

GLOSSARY OF TERMS

This Appendix is provided to define terms used in this report

C = response factor = $g_e/\bar{G}$

F = force in pounds

g = gravitational constant in ft/sec^2 or units of inertia force based on multiple of W_t

g_d = dummy pelvic acceleration

g_e = effective peak inertia force in g's

g_s = seat acceleration

$\bar{G}$ = average acceleration of input acceleration time pulse in g's

$$\frac{\Delta V}{g \quad t_n}$$

l = distance between the front and rear seat legs, at the attachments, in inches

L = distance from the seat leg attachment to the center of gravity of the seat occupant combination in inches

M = mass in pounds sec^2/ft.

R = reaction force in pounds

R_A = rear leg peak reaction force in pounds

R_F = front leg peak reaction force in pounds

s = distance from the seat occupant combination's center of gravity to the point about which the moments are taken in inches

S = longitudinal peak shear load at the seat attachments in pounds

t = time in sec

t_n = input acceleration time pulse duration in sec

V = velocity in ft/sec

ΔV = change in velocity in ft/sec

W_d = effective weight of the seat occupant in pounds. The effective weight is that weight which is acting on the seat. In some cases the legs of the seat occupants were supported by the floor.

W_s = weight of the seat in pounds

W_t = total effective weight in pounds $W_d + W_s$

APPENDIX II

Instrumentation Summary

This appendix contains descriptions of the sensing transducers, their locations and the equipment used to record the test data.

To measure the seat reaction forces (R) the standard leg fittings were replaced by enlarged studs in order to allow the application of strain gages to this relatively small area (Figure 2-1). Two Budd, Model EC6-124-350, Strain Gages were cemented to each stud in such a manner as to eliminate bending forces which might be introduced under the test conditions. Dummy gages to insure temperature compensation of the bridge circuit were not used because of the lack of available space on the stud. However, the gage material was of a "selected melt" with an adjusted temperature coefficient for minimum response to temperature change and was bonded to the steel used to manufacture these studs. Therefore, the bridge circuits were completed with 1 percent wire-wound precision 350 ohm resistors. It should also be noted that temperature compensation of these bridges was not of the utmost importance in tests of this nature since the load was applied dynamically; i.e., over a short-pulse duration of approximately 100 milliseconds.

The studs measuring the aft leg reaction forces on Seat B were replaced by two BLH, Model U-1, SR-4 Load Cells with a range of 5,000 pounds for the dynamic vertical test. This was done to reduce the total number of data channels recorded. The same make and model load cells were used to measure the longitudinal shear forces (V) at the seat attachments (Figure 2-2). The two shear-force channels were omitted in Tests 14 to 20, inclusive, because of the change in the seat's position (Figure 2-3). Lap belt forces (T) were measured by means of load links, also strain-gaged with Budd, Model ED6-124-350, Strain Gages (Figure 2-4). Complete bridges were cemented on these links since the space available was ample. Thus, these links were temperature-compensated with "dummy gages," as well as being compensated with the proper selection of gage to metal temperature coefficient. Bending is electrically compensated by the application of "back-to-back" gages. In addition, self-alignment was achieved by attaching the links with flexible cables on both ends to the seat attachment location. Seat accelerations (g_s) were measured with a CEC, Type 4-202, Strain Gage Accelerometer on the vertical seat axis. The mounting bracket was attached to one of the seat braces (Figure 2-5). The dummy accelerations of the anthropomorphic dummy (g_d) were also measured with CEC, Type 4-202, Strain Gage Accelerometers mounted with respect to the dummy's vertical (spinal) and longitudinal axis, respectively. Pelvic location of the two transducers is approximately 4¼ inches from the back, and 10½ inches from the buttock, and centered laterally.

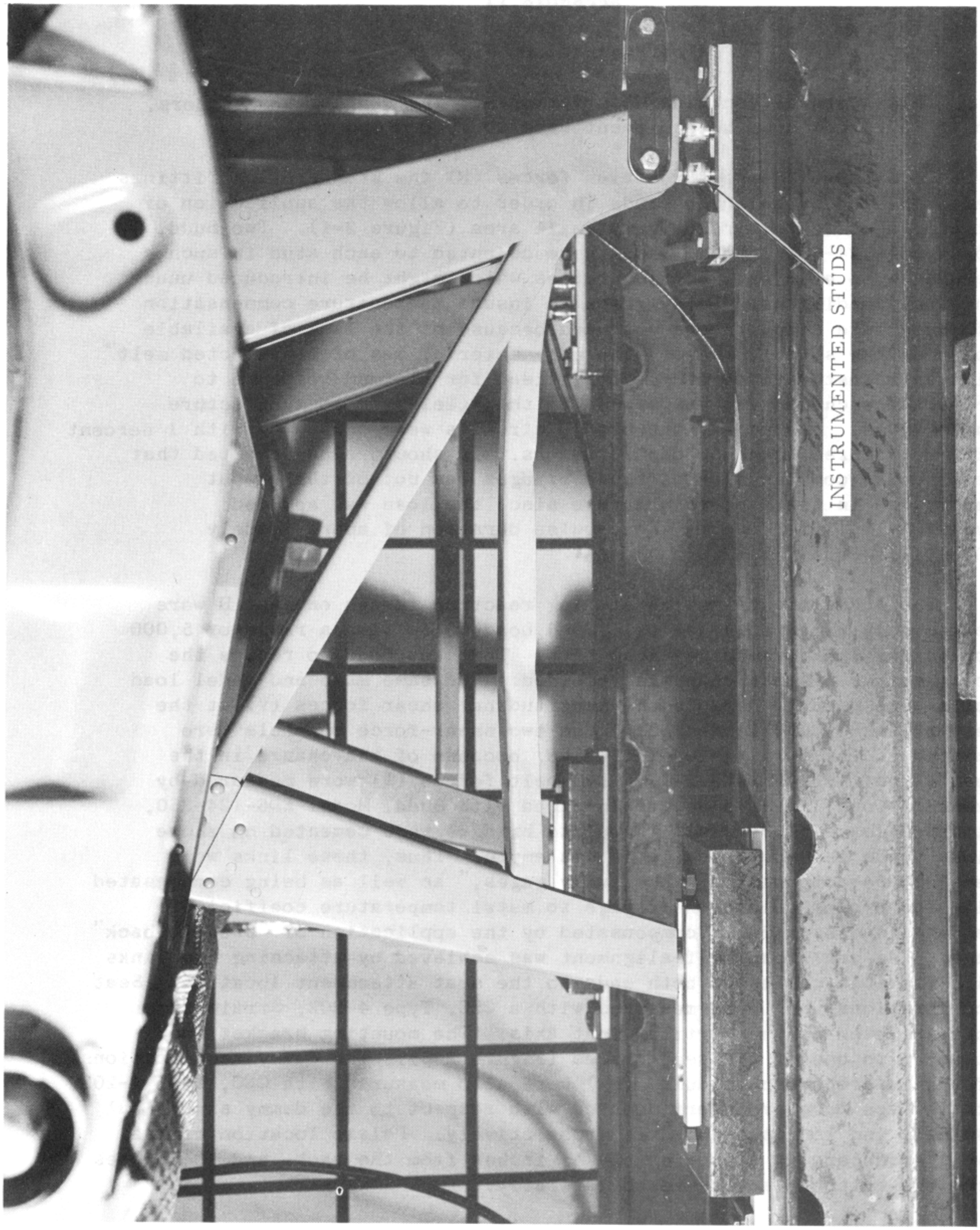


FIG. 2-1 INSTRUMENTED LEG FITTINGS

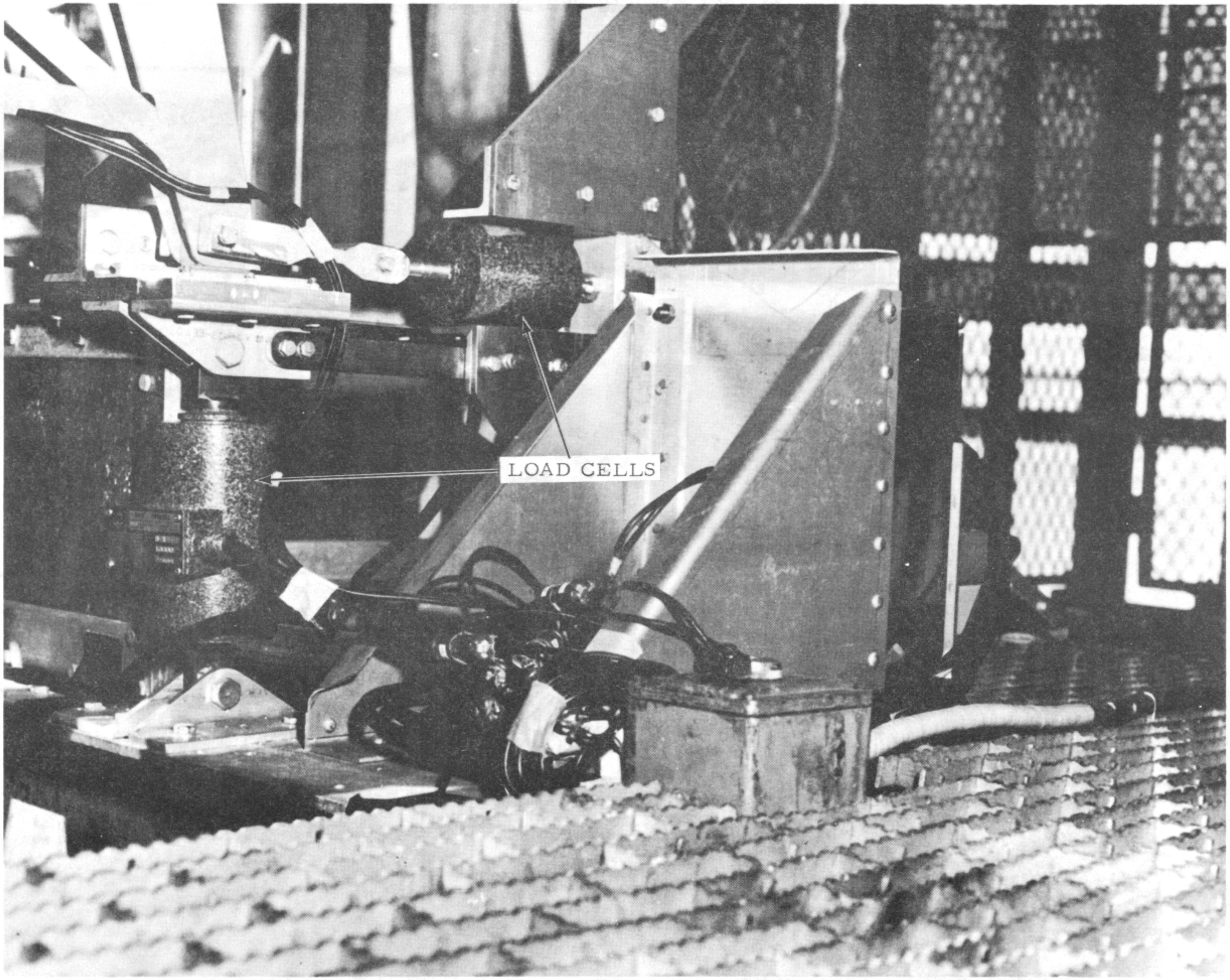


FIG. 2-2 LOAD CELLS TO MEASURE LEG ATTACHMENT VERTICAL AND LONGITUDINAL LOADS

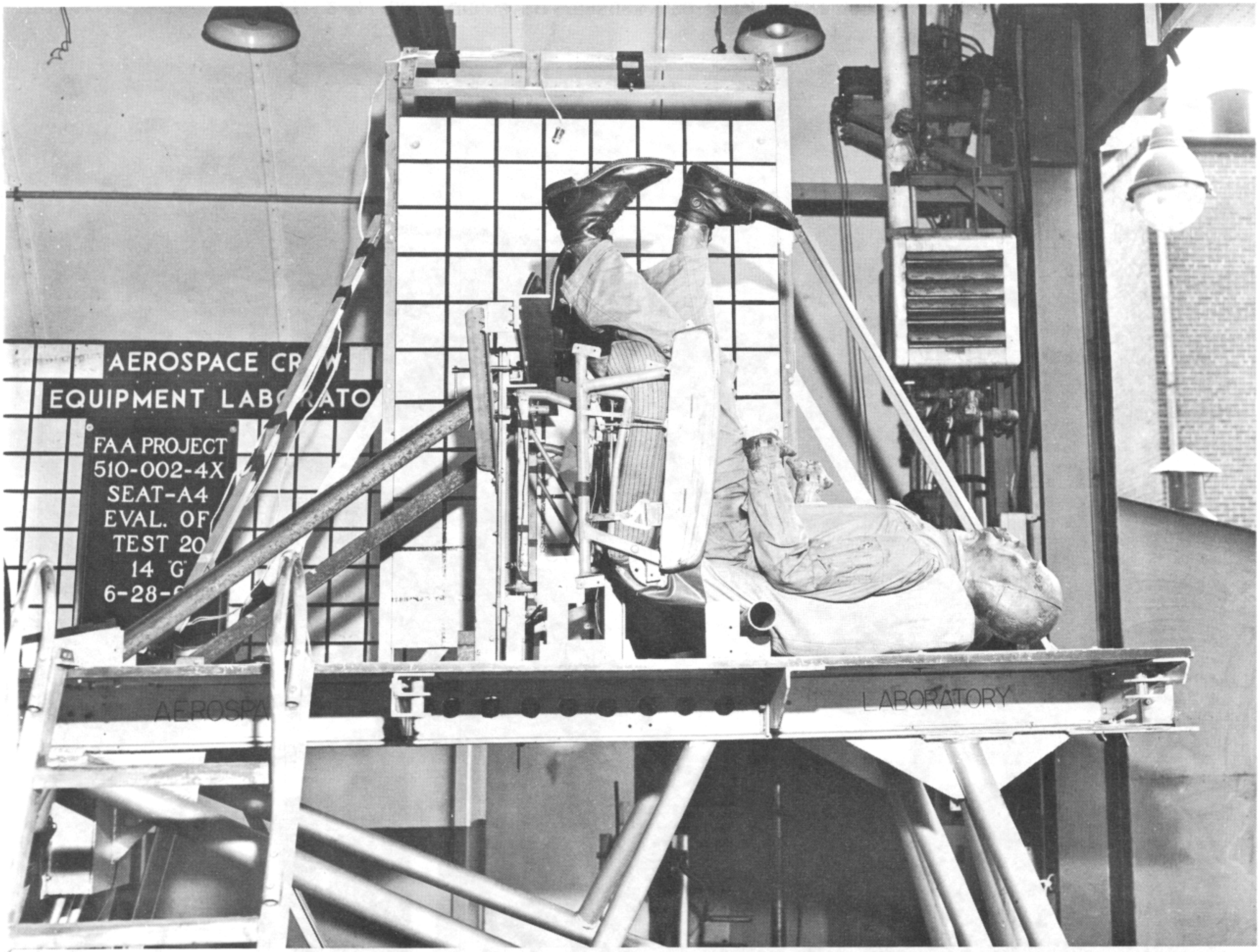


FIG. 2-3 VERTICAL DYNAMIC TEST OF SEAT A

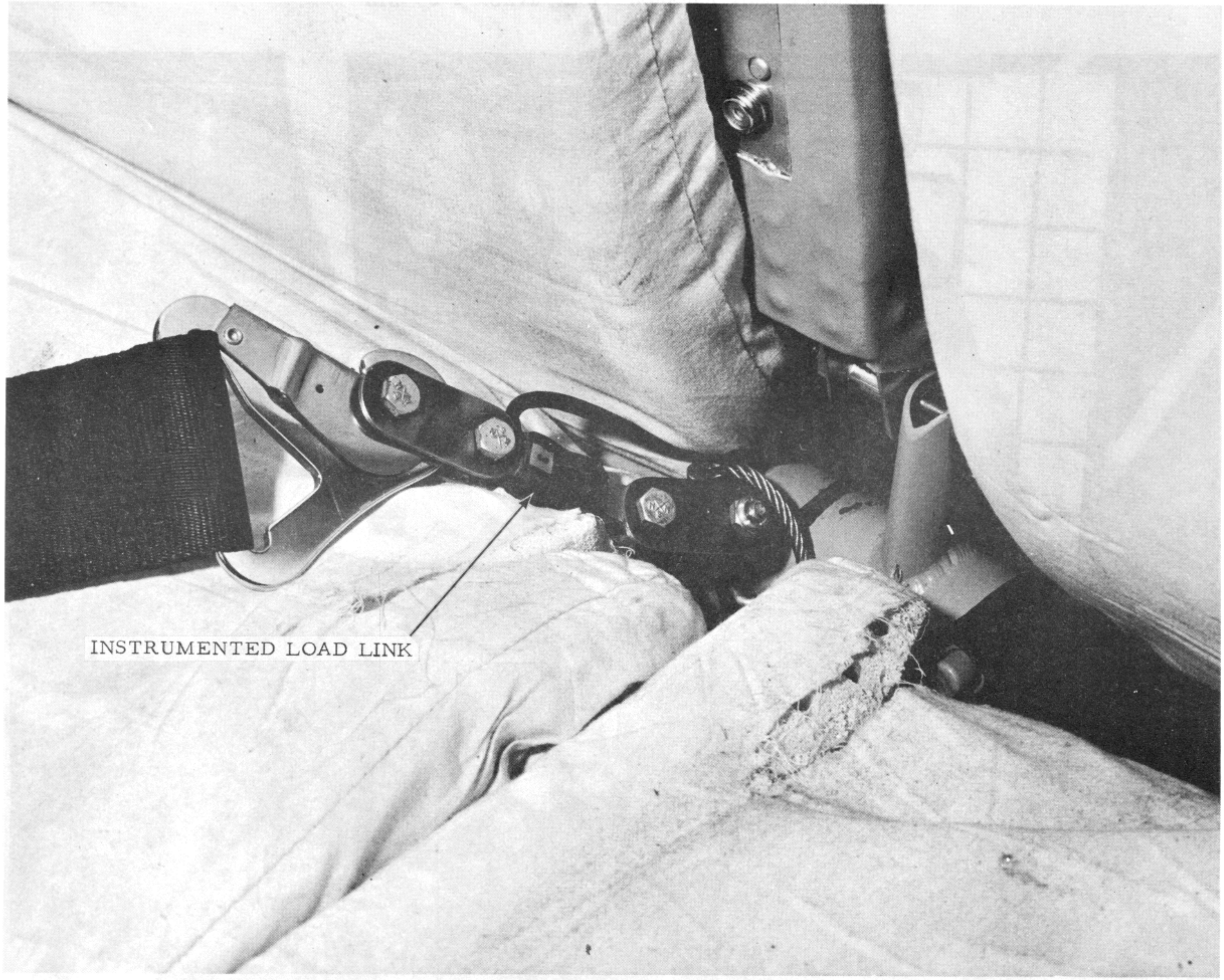


FIG. 2-4 LAP BELT LOAD LINK

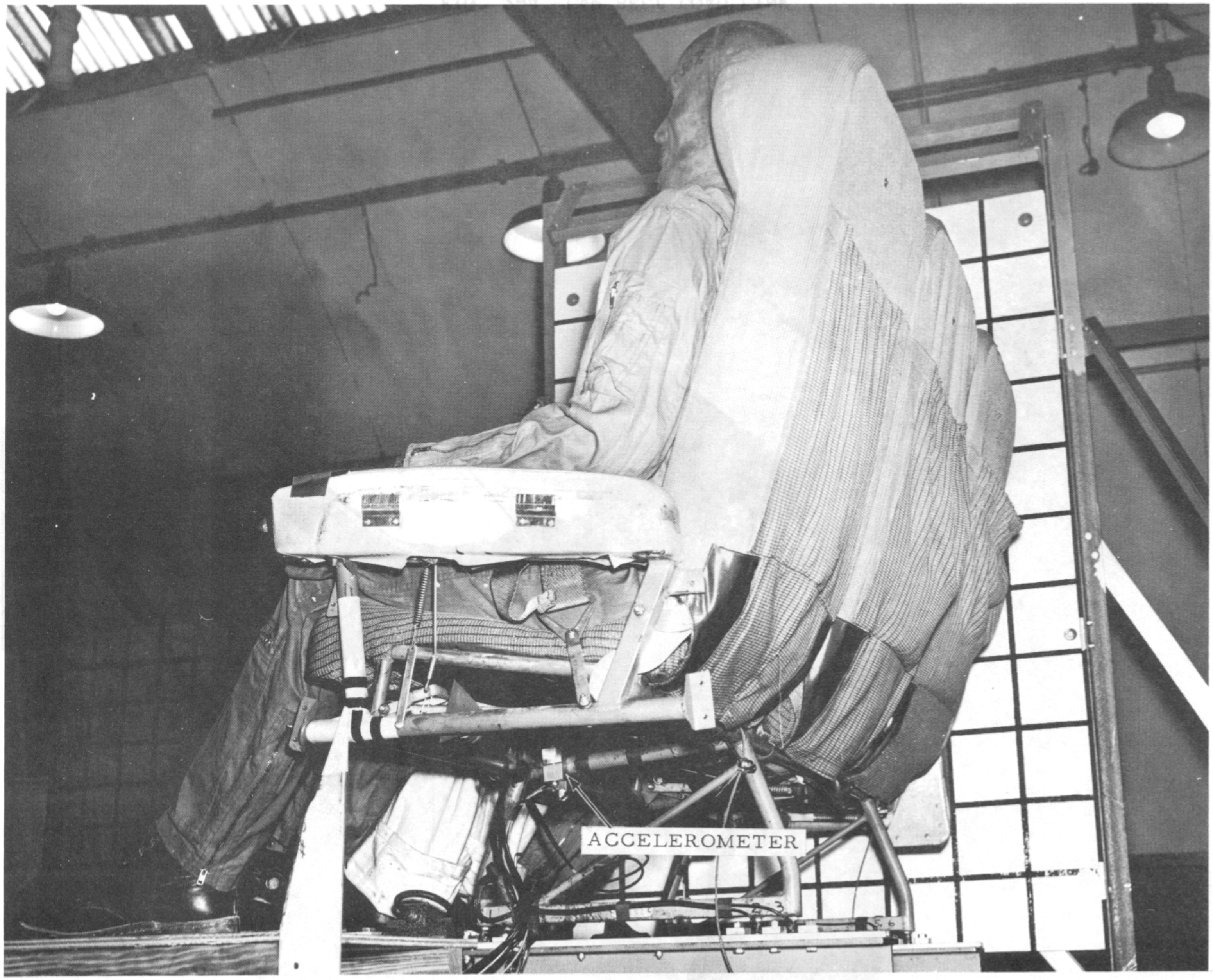


FIG. 2-5 SEAT ACCELEROMETER INSTALLATION

The longitudinal sled acceleration (G_h) of the horizontal accelerator was measured with a CEC, 4-202, Strain Gage Accelerometer mounted at a location close to the piston attachment. Sled final velocity was supplied by measuring the time required for the sled to travel an interval of 6 inches at the end of the required power stroke and recorded on an HP 522B Electronic Counter.

Sled displacement over the variable power stroke is measured by passing an Electro-Products, Model 3010, Magnetic Pickup over a series of sharp metal surfaces spaced according to a set pattern. The first group of pulses are spaced at one-half inch intervals followed by a 2-inch "group separation" interval, followed by a group of pulses spaced at 1-inch intervals. The number of pulses seen on the record for the first group will be dependent upon the length of the power stroke. This displacement trace is recorded on both oscillograph records for each test and, thus, can be used as a reference trace for time correlation.

The vertical acceleration (G_V) of the drop tower test car was measured with a CEC, 4-202, Accelerometer mounted near the center of the car.

The static test input loads (F) were measured with three BLH, Model U-3G2SP-4, Loads Cells rated at 5,000 pounds each. The load cells were attached between the end of the hydraulic cyclinder pistons and the body blocks (Figure 2-6). A steel cable was used to attach the load cells to the body blocks to eliminate binding due to seat bending.

The data sensed by the transducers at the Horizontal Accelerator Facility were transmitted by a direct-wire system to two Honeywell Visicorder Oscillographs, Models 1508 and 1012. The data were recorded on direct-wire light sensitivity paper which was later photographed for presentation in this report (Appendix III).

Telemetry was used to transmit the data measured at the Drop Tower Facility to a ground station located in the adjacent building. The data were transmitted in the Inter-Range Instrumentation Group (IRIG) format, using frequency bands 7 through 18, and recorded on a Precision Instrument Tape Recorder, Model PS207A. The tape was then played back through 12 DCS-DFG-3 Discriminators and recorded on a Honeywell Oscillograph at the Horizontal Accelerator Facility.

The data measured during the static tests were transmitted by a direct-wire system to two CEC Oscillographs, Model 5-125. The data were recorded on direct-wire light sensitive paper.

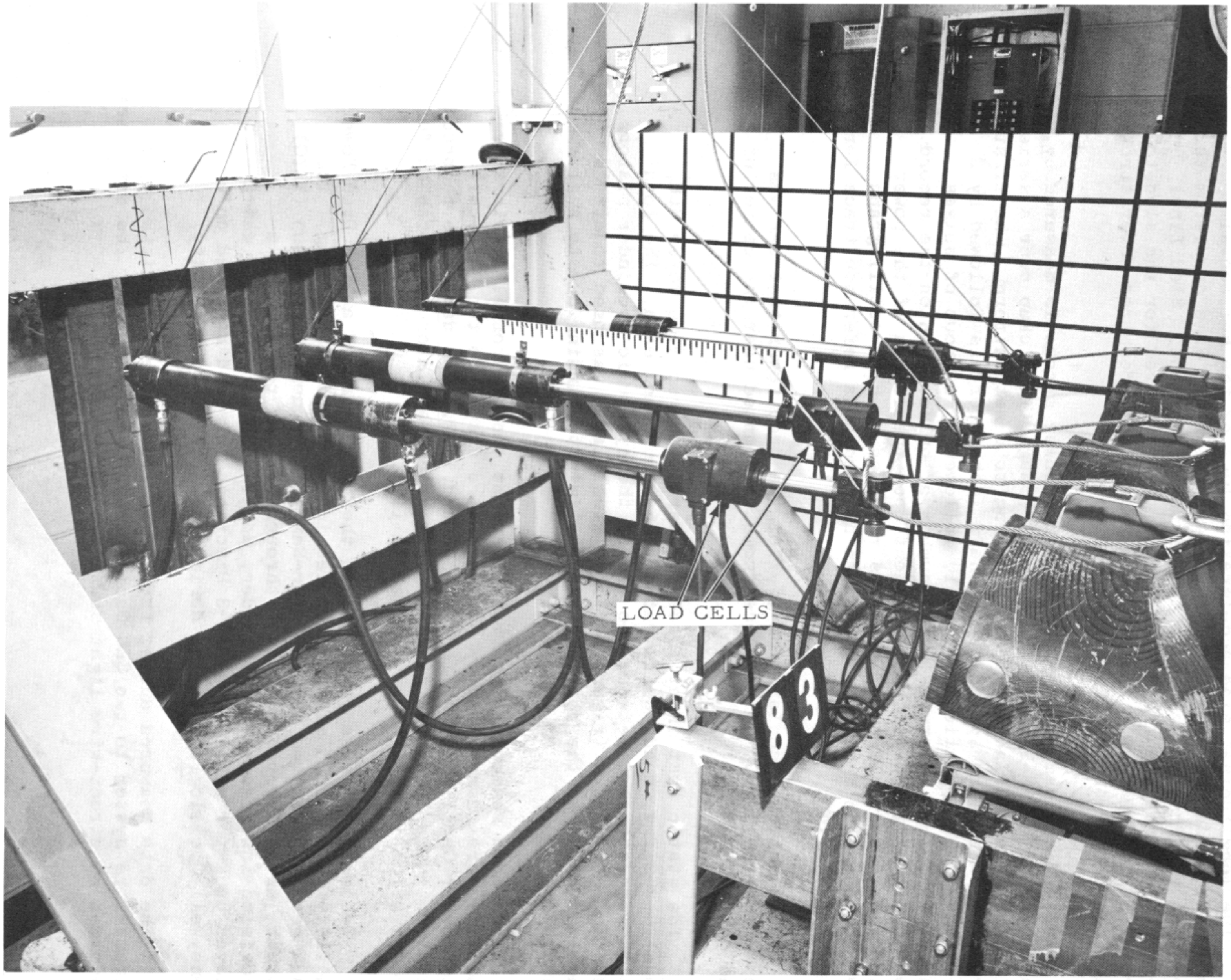


FIG. 2-6 LOAD CELL INSTALLATION TO MEASURE INPUT STATIC LOADS

APPENDIX III

Data Summary

This appendix contains the data collected in the test phases of the project. These data are presented in both oscillogram and tabulated form. Also included are examples of how the data were used in deriving the response and sensitivity curves for the three types of seats tested. These three types were designated as Seats A, B, and C.

Seat A: Seat A was a three-place, floor-mounted, tubular-constructed seat and is shown in Figure 6 of this report. Five of these seats were tested to provide the data necessary to determine the respective longitudinal and vertical response curves.

Tests Numbers 1 through 10 were longitudinal acceleration tests with the seat and dummy facing to the rear as shown in Figure 3-1, thus effecting forward inertial forces on the system. Test No. 5 data used as an example in this appendix is shown in Figure 3-2. Test No. 71 was a static longitudinal test and a typical test setup is shown in Figure 3-3. The data collected from this test are shown in Figure 3-4 in oscillogram form. The pertinent data anlyzed are shown in tabulated form in Table 3-I. Photographs of some of the types of damage or failures are shown in Figure 3-5 through 3-8.

The response curve as primarily defined is a plot of the response factor C versus the applied dynamic pulse duration t_n. To determine the longitudinal response factor for Seat A, Equation (1) from Page 2 of this report:

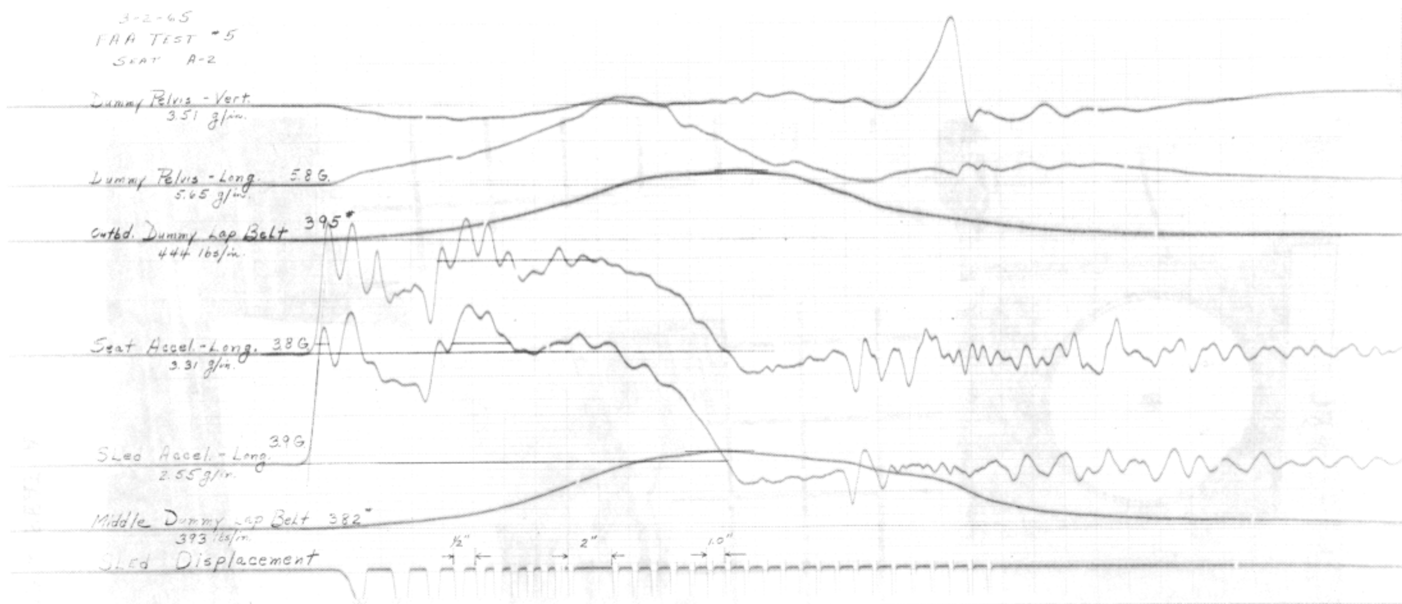
$$C = \frac{\text{Effective Peak Inertia Force}}{\text{effective weight x average input acceleration}}$$

or

$$C = \frac{g_e \times Wt}{W_t \times \bar{G}}$$

was applied.

FIG. 3-1 TYPICAL DYNAMIC LONGITUDINAL TEST SETUP - SEAT A



NOTE – NOT TO SCALE

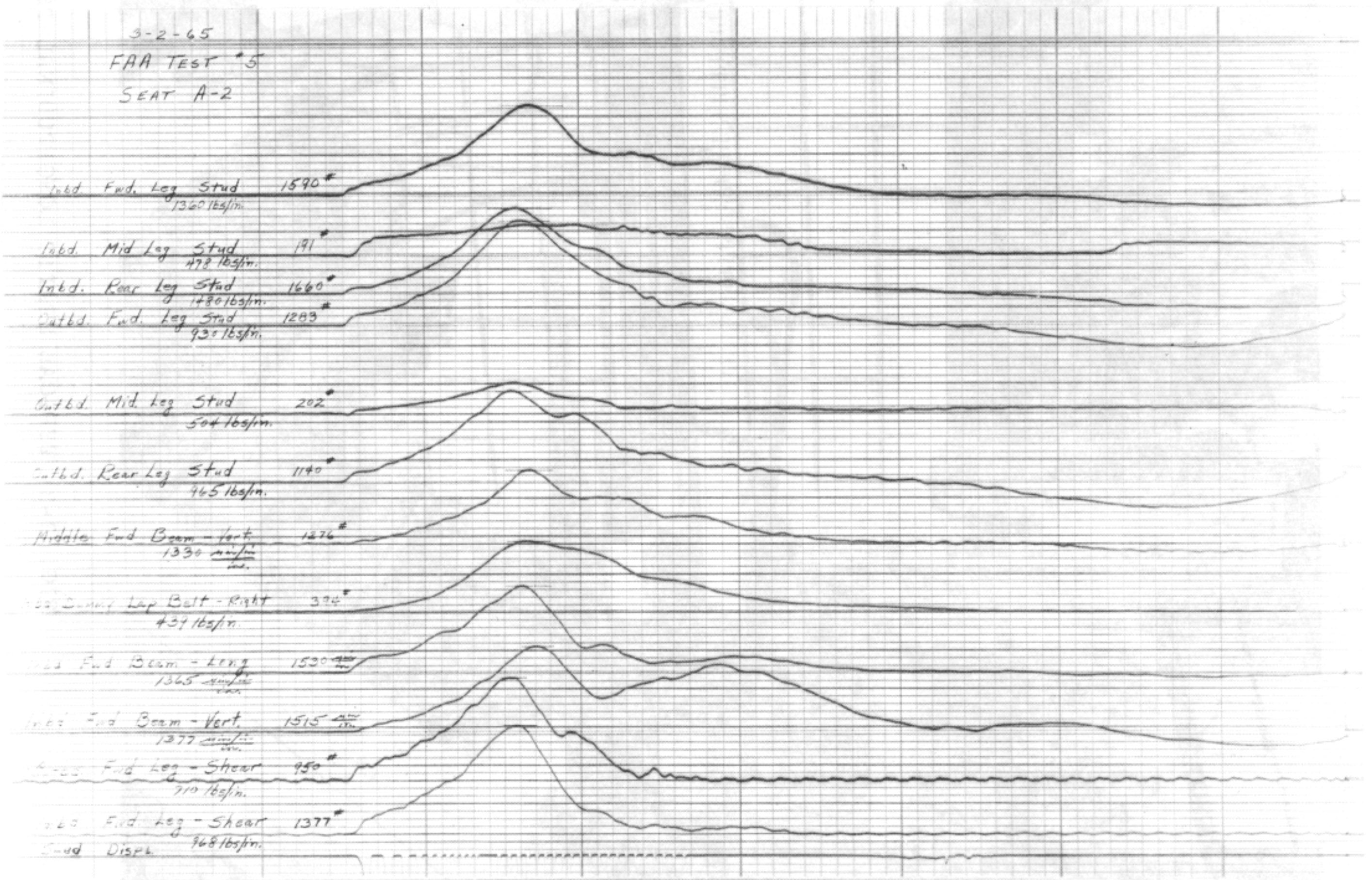


FIG. 3-2 TEST NO. 5 RECORDED DATA

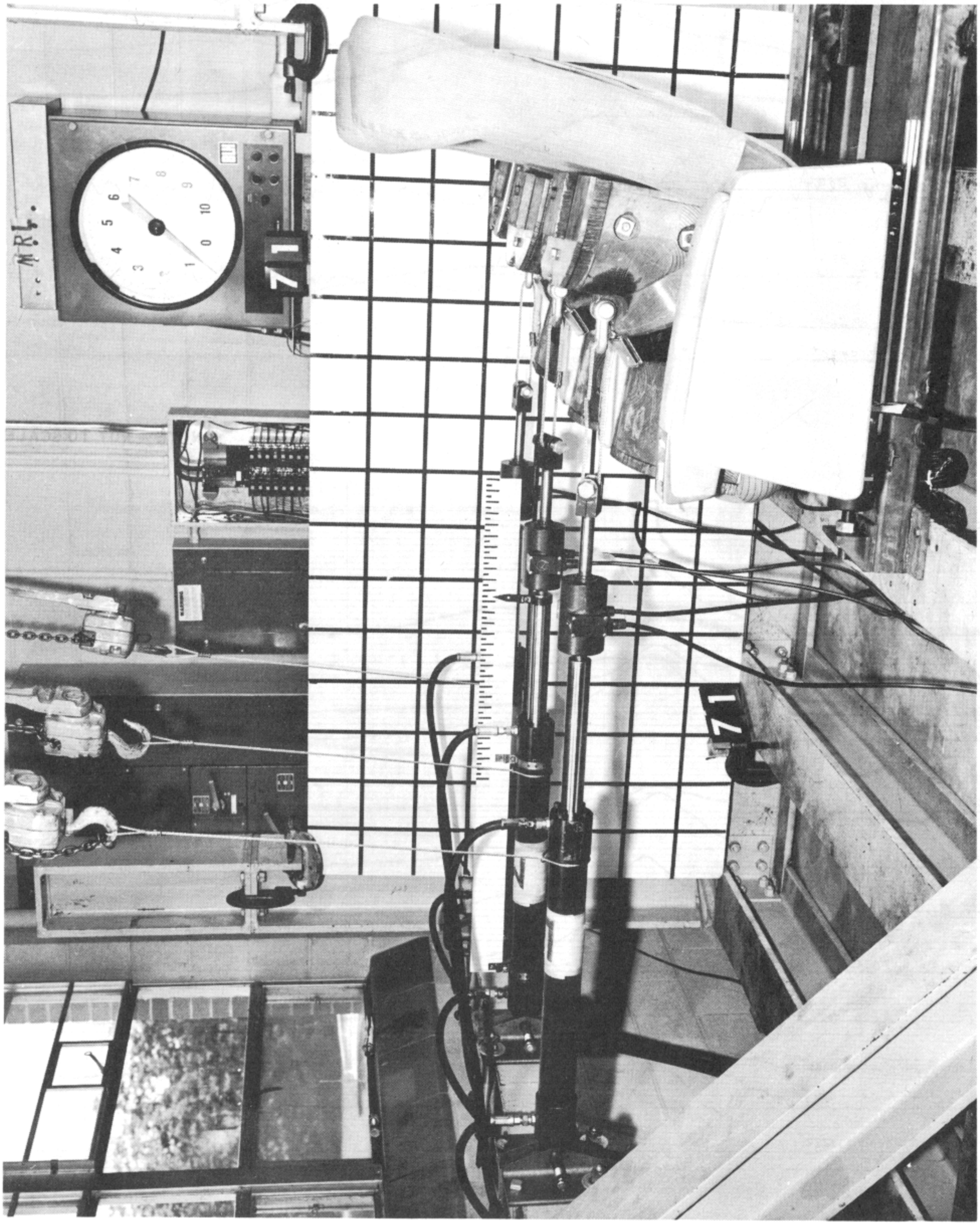


FIG. 3-3 TYPICAL STATIC LONGITUDINAL TEST SETUP - SEAT A

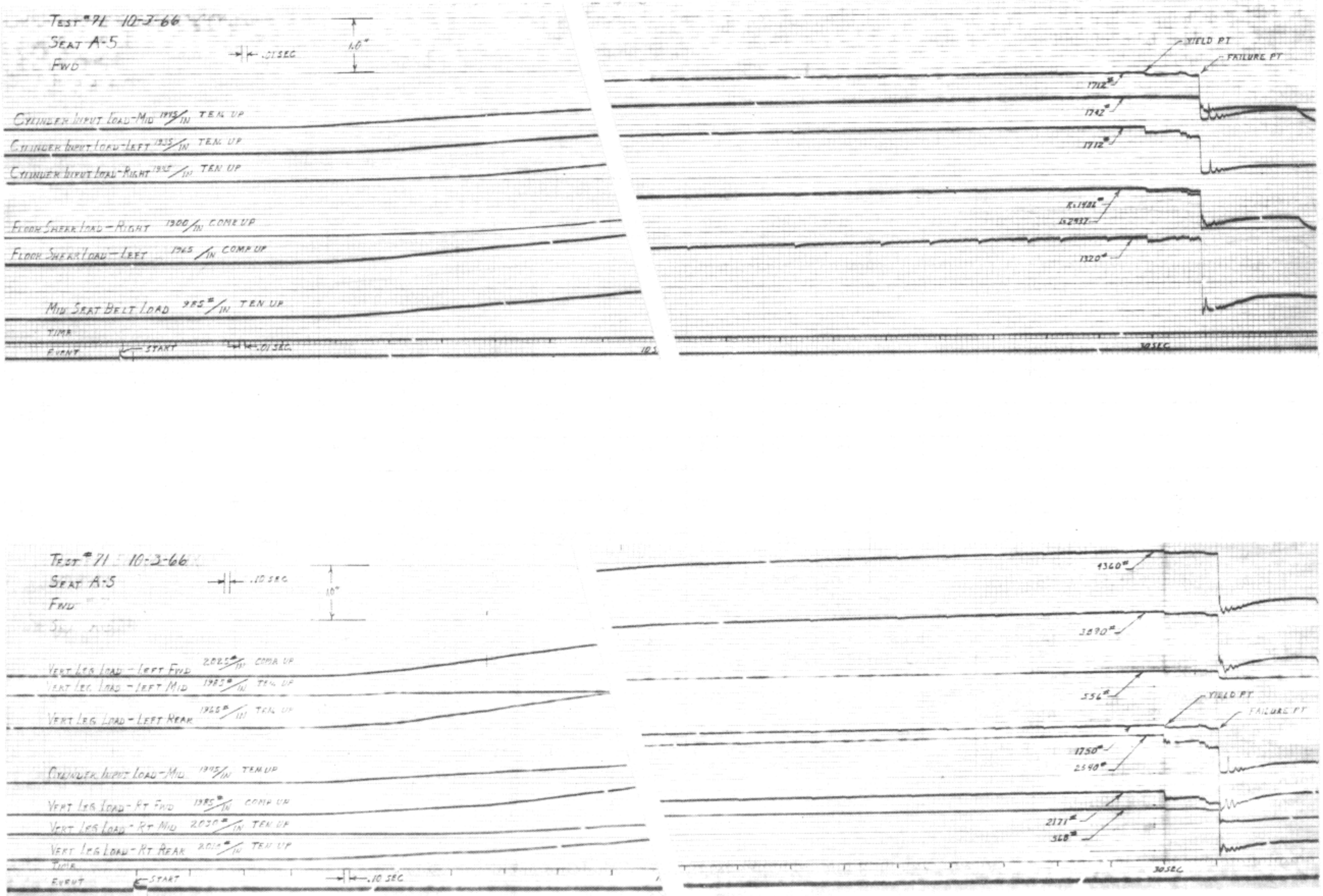


FIG. 3-4 STATIC TEST NO. 71 RECORDED DATA

TABLE 3-I

SEAT A - LONGITUDINAL DYNAMIC AND STATIC TEST DATA

Test No.	Seat No.	Velocity Change ft/Sec	Input Time Pulse Sec	Average Input Accel. $\frac{ft/Sec^2}{32.2}$	Left Fwd. Vert. Reaction lb	Right Fwd. Vert. Reaction lb	R_1+R_4 lb	Left Mid Vert. Reaction lb	Right Mid Vert. Reaction lb	Left Aft Vert. Reaction lb	Right Aft Vert. Reaction lb	R_2+R_5 and R_3+R_6 lb	Left Horiz. Shear lb	Right Horiz. Shear lb	S_L+S_R lb	Peak Dummy Accel. $\frac{ft/sec^2}{32.2}$	Effect Weight lb	REMARKS (Dynamic Tests)
		ΔV	t_n	$\bar{G}$	R_1	R_4	R_F	R_2	R_5	R_3	R_6	R_A	S_L	S_R	S	g	W	
1	A-1	12.5	.238	1.63	662 828	538 448	1200 1276	151 200	112 101	728 672	420 630	1411 1609	499 394	289 279	788 673	2.84 2.46	393 [3] 587	
2	A-1	17.7	.163	3.37	[2]	1510 1258		361 446	140 135	1954 1704	1207 1158	3662 3443	1335 704	889 525	2224 1229	7.36 3.10	472 [3]	Shear Load Sensors Relocated
3	A-1	25.8	.150	5.34	11,233 [1]	5344 [1]		707	412	2721	1844	5684	2486	1507	3993	11.93	472 [3]	Seat Pan Frame Failed..Fig. 3-5
4	A-2	13.3	.136	3.04	1369	1058	2427	193	200	1653	1128	3174	1318	902	2220	5.99	472 [3]	
5	A-2	13.3	.137	3.02	1591	1264	2855	191	191	1657	1158	3197	1355	951	2306	6.38	472 [3]	
6	A-2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Data System Failure
7	A-2	13.0	.100	4.03	2033	1628	3661	248	273	2208	1555	4284	1897	1303	3200	9.03	472 [3]	
8	A-2	14.8	.098	4.68	2541	1803	4344	311	343	2648	1751	5053	2251	1451	3702	10.39	472 [3]	
9	A-2	17.9	.095	5.85	2673	2152	4825	351	404	3004	1980	5739	2567	1696	4263	12.43	472 [3]	
10	A-2	18.6	.095	6.08	3273	2300	5573	458	510	3360	2172	6500	3072	1928	5000	13.39	472 [3]	Same As Seat A-1. Test No. 3
		Left Input Load lb	Mid Input Load lb	Right Input Load lb												Total Input Load lb		(Static Test)
		F_L	F_M	F_R												F		
71	A-5	1742	1712	1712	4360	2500	6900	556	563	3890	2171	7185	2437	1406	3843	5166	587	Ultimate Load Did Not Reach 9g (5283#). Seat Belt Attachment Failed. Figures 3-7 and 3-8

NOTES:
1. Transducer did not return to zero; data questionable.
2. Trace went off the oscillograph paper.
3. Static weight determined from film.

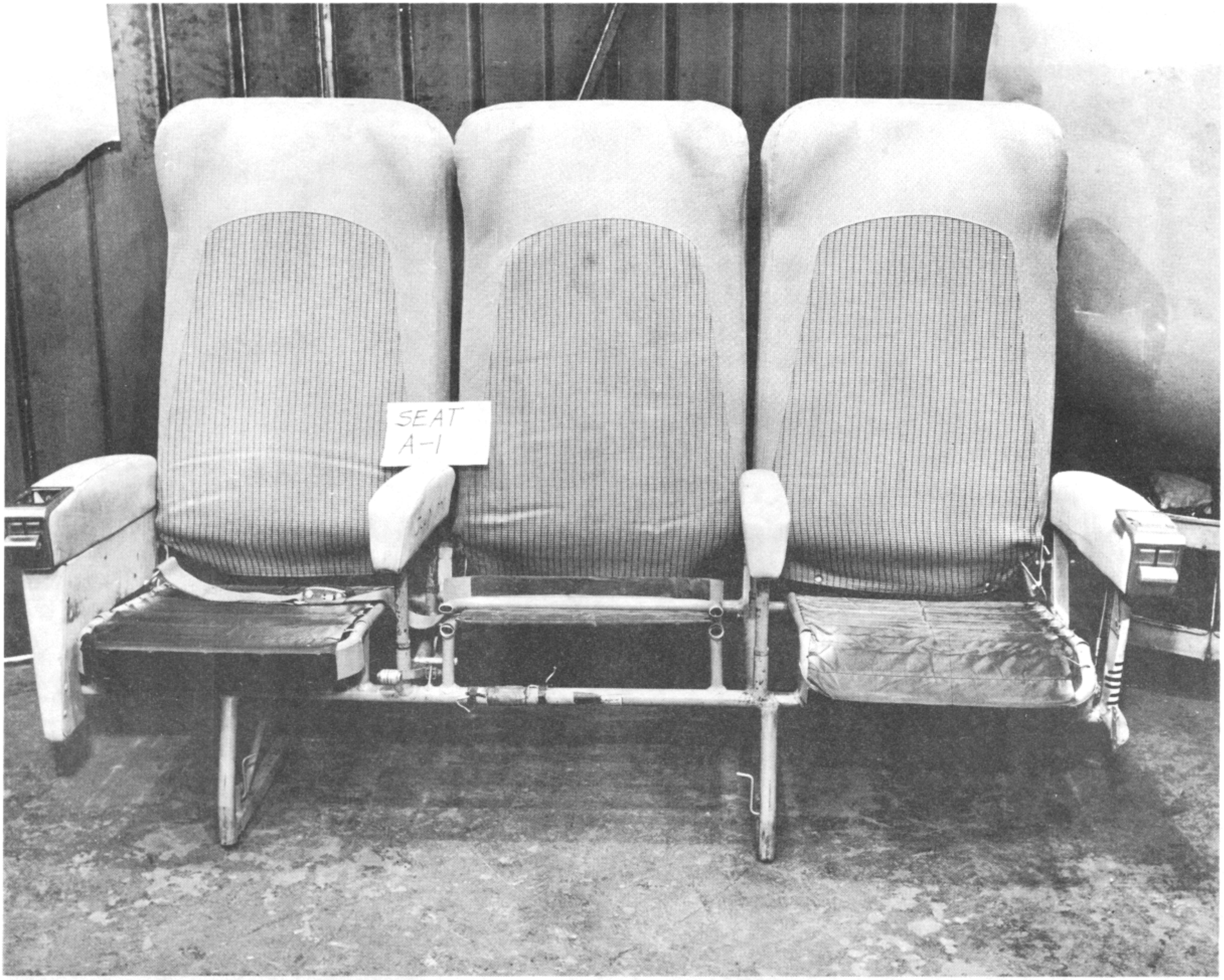


FIG. 3-5 SEAT A-1 AFTER TEST NO. 3

FIG. 3-6 LEFT MIDBOTTOM SUPPORT - SEAT A-1 AFTER TEST NO. 3

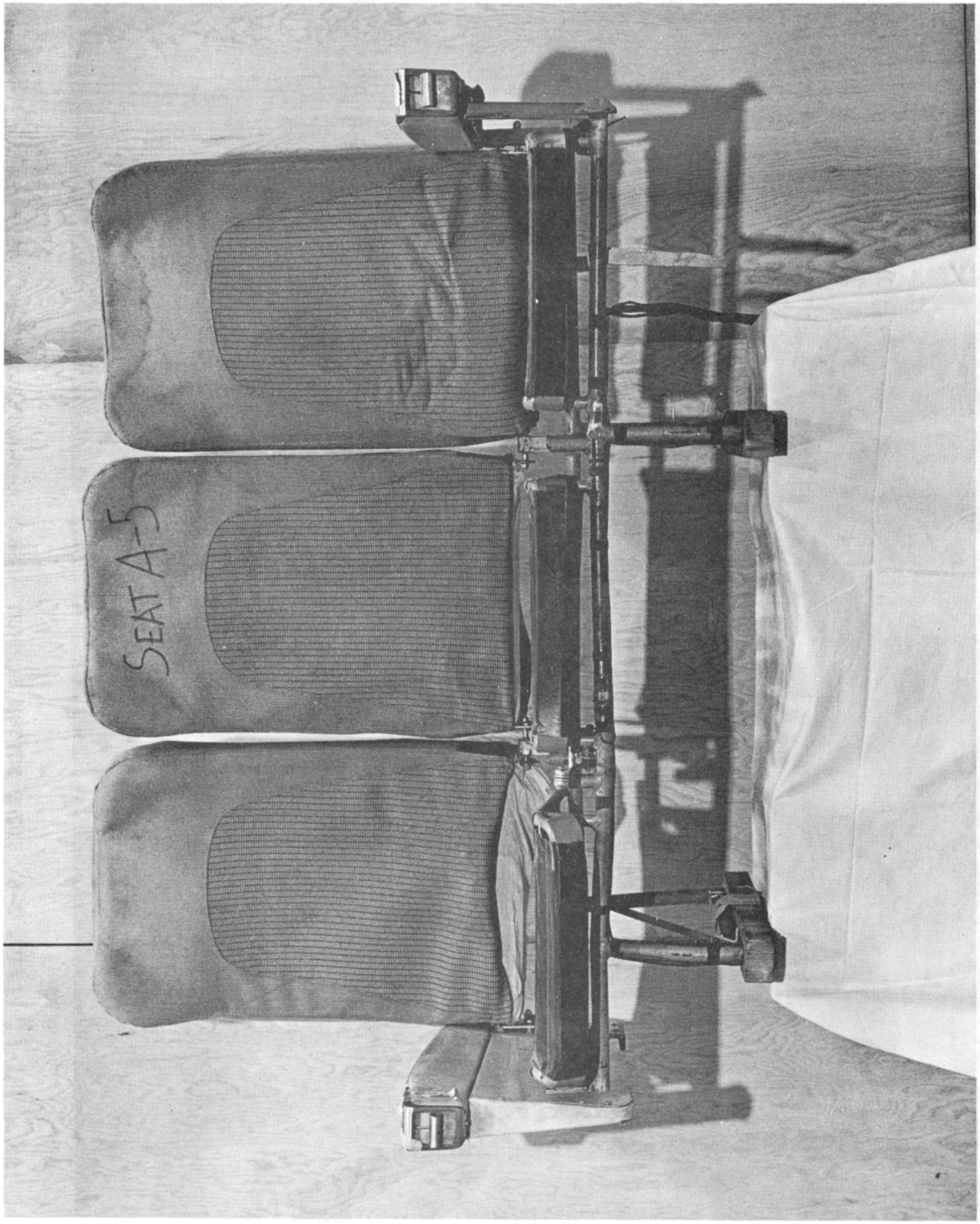
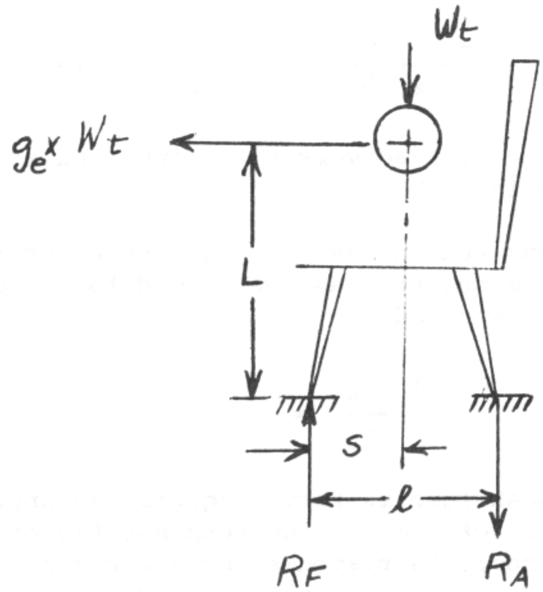


FIG. 3-7 SEAT A-5 AFTER STATIC TEST NO. 71

FIG. 3-8 RIGHT BOTTOM SUPPORT - SEAT A-5 AFTER TEST NO. 71

The technique is illustrated in the following example:



The following values were taken from Table 3-I for Test No. 5.

W_t = 472 lbs., R_A = 3197 lbs., L = 24 inches

l = 17 inches s = 8 inches

= 13.3 ft/sec and t_n = .37 sec for the sled

Solving for the effective peak inertia force, moments are taken about R_F

$$M_{RF} = (g_e \times W_t \times L) - (W_t \times s) - (R_A \times l) = 0$$

$$g_e = \frac{(W_t \times s) + (R_A \times l)}{W_t \times L}$$

$$g_e = \frac{(472 \times 8) + (3197 \times 17)}{24 \times 472} = 5.12$$

To solve for the average input acceleration, $\bar{G}$, Equation (2) Page 6 of this report was applied.

$$\bar{G} = \frac{\Delta V}{g \quad t_n}$$

$$= \frac{13.3}{32.2 \times .137} = 3.02$$

Thus the response factor, C, equals

$$C = \frac{W_t \times g_e}{W_t \times \bar{G}} = \frac{5.12}{3.02} = 1.69$$

This value is then plotted versus the input pulse duration, t_n, which in this case equals .137 sec.

To derive the longitudinal sensitivity curve for Seat A, Equation (1), Page 2 of this report, was rearranged to solve for average input acceleration expected

$$\bar{G} = \frac{g_e \times W_t}{C \times W_t} = \frac{g_e}{C}$$

when g_e or the effective peak inertia force, equals the present FAA static test load requirement of 9 g's. The response factor C, is then selected from the appropriate response curve for various values of t_n. For example, for a value of t_n equal to .100 sec, the value of C from the response curve, Figure 14 of the report, equals 1.70. Solving for $\bar{G}$

$$\bar{G} = \frac{9 \text{ g's}}{1.70} = 5.3 \text{ g's}$$

The corresponding velocity change

$$\Delta V = \bar{G} \times 32.2 \text{ ft/sec}^2 \times t_n \text{ sec}$$

or substituting the previously derived figures

$$\Delta V = 5.3 \times 32.2 \times .100 = 17.1 \text{ ft/sec}$$

This process is then repeated for various t_n's until enough values of $\bar{G}$ and ΔV are obtained to plot the sensitivity curve, Figure 21 of this report.

Tests Numbers 14 through 20 were conducted to collect the necessary data to establish the vertical response curve for Seat A. A typical test setup is shown in Figure 2-3 for a vertical dynamic test on the ACED Horizontal Linear Accelerator. A typical static test setup is shown in Figure 3-9. The tabulated data for Vertical Static Test No. 72 are shown in Table 3-II. Photographs of some of the test results are shown in Figures 29 and 30 of this report.

The technique used for deriving the vertical response and sensitivity curves is identical to that used to derive those for the longitudinal inertial forces except for the method of calculating

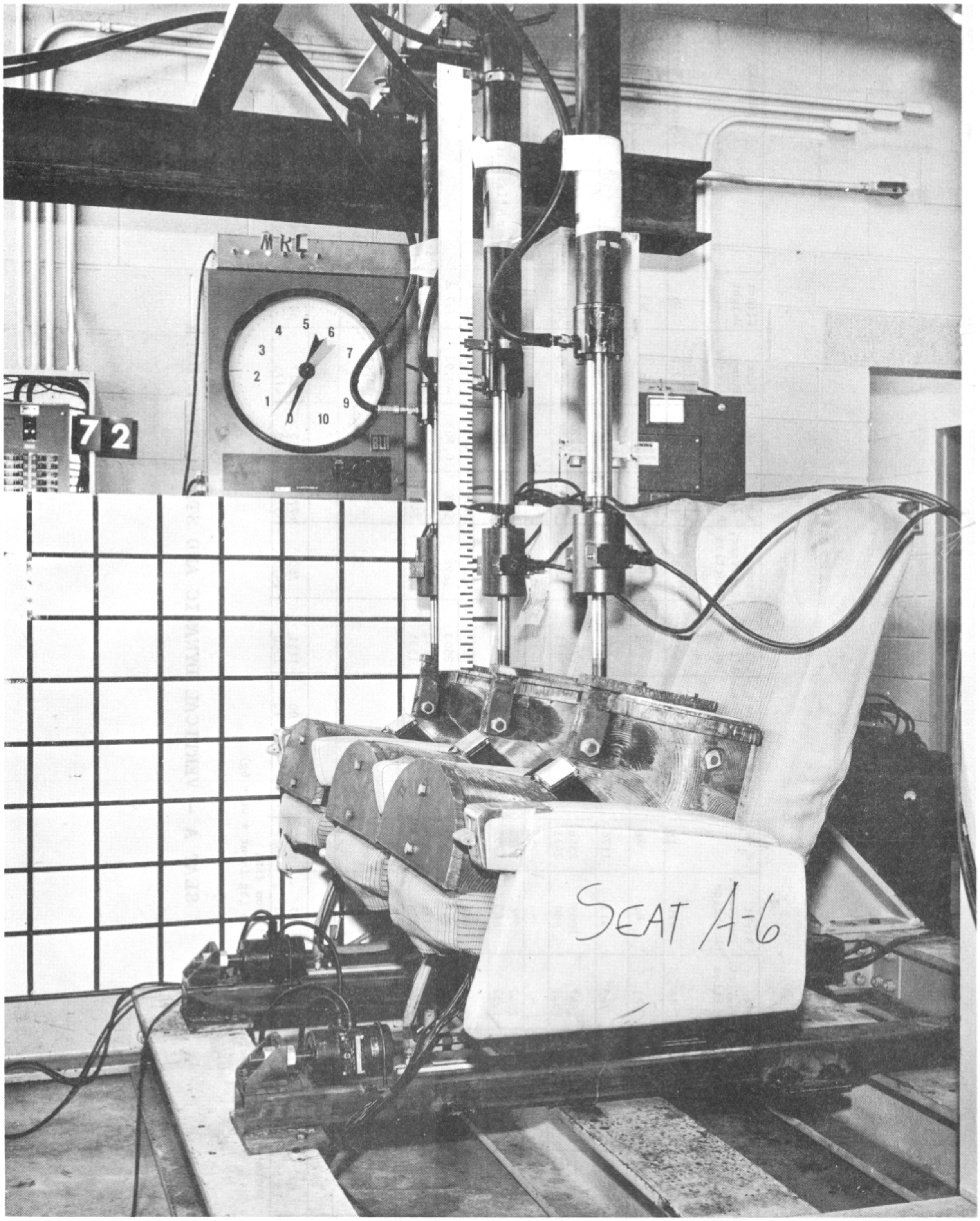


FIG. 3-9 TYPICAL STATIC VERTICAL TEST SETUP - SEAT A-6

TABLE 3-II

Test No.	Seat No.	Velocity Change ft/Sec	Input Time Pulse Sec	Average Input Accel. $\frac{ft/Sec^2}{32.2}$	Left Fwd.Vert. Reaction lb	Right Fwd.Vert. Reaction lb	R_1+R_4 lb	Left Mid Vert. Reaction lb	Right Mid Vert. Reaction lb	Left Aft Vert. Reaction lb	Right Aft Vert. Reaction lb	R_2+R_5 and R_3+R_6 lb	Total Reaction Load lb	Peak Dummy Accel. $\frac{ft/Sec^2}{32.2}$	Effect Weight lb	REMARKS (Dynamic Tests)
		ΔV	t_n	$\bar{G}$	R_1	R_4	R_F	R_2	R_5	R_3	R_6	R_A	R_T	g	W	
14	A-4	10.5	.112	2.91	763	413	1176	255	95	470	354	1174	2350	3.94	587 [1]	
15	A-4	17.5 11.8	.102 .085	5.33 4.29	1587 1531	1009 880	2596 2411	185 185	76 76	1757 1684	606 494	2624 2428	5220 4839	9.24	587 [1]	Lower - Partial Data
16	A-4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Data System Failure
17	A-4	18.9 8.8	.090 .051	6.52 5.34	2042 1332	1276 663	3318 1995	84 186	38 29	2796 1398	1088 558	4006 2171	7324 4166	26.10 8.04	587 [1]	Lower - Partial Data
18	A-4	22.1	.094	7.32	2575	1610	4185	37	57	3052	1624	4770	8955	34.05	587 [1]	
19	A-4	25.6	.095	8.38	3146	1837	4983	- 28	47	3503	1898	5420	10,403	40.92	587 [1]	
20	A-4	31.8 7.2	.098 .026	10.09 8.60	3303 1696	2331 846	5724 2542	- 9 111	95 29	3142 1535	2030 821	5258 2496	10,982 5,038	44.04 9.25	587 [1]	Seat Severely Damaged. Fig. 20 Lower - Partial Data
		Left Input Load lb	Mid Input Load lb	Right Input Load lb										Total Input Load lb		(Static Test)
		F	F	F										F		
72	A-6	882 1385	978 1685	952 1705	707 1050	407 632	1114 1682	-100 - 20	00 12	1111 2000	760 1420	1771 3521	2885 5203	2812 4775	587	Upper Figures - 5g Input Load Lower Figures - Final Load

NOTES: 1. Static weight determined from film
2. Weight electronically zero (5g input + wt = 6g)

SEAT A - VERTICAL DYNAMIC AND STATIC TEST DATA

the vertical peak inertia force. Since in this case all forces act in the same direction, a summation of vertical forces will yield the inertia force. This also holds true for Seats B and C. See Table 3-II for Seat A vertical dynamic test data.

Seat B: Seat B was a three-place, tourist class, sheet metal and tubular-constructed seat (Figure 7 of report). Testing was conducted on six of the seats to collect the data required to determine the respective longitudinal and vertical response curves.

Tests numbered 21 through 40 were dynamic longitudinal tests. Tests numbered 82 and 83 were longitudinal static tests. The data values obtained from these tests are shown in tabular form in Tables 3-III and 3-IV. Photographs of some of the damage or failures are shown in Figures 3-10, 3-11, 3-12, 3-13, 3-14, 3-15, 3-16, and 3-17.

Vertical dynamic tests, numbered 65 through 70, were conducted to obtain the data necessary to establish the vertical response curve for Seat B. A typical test setup is shown in Figure 3-18 on the ACED 150-foot Vertical Drop Tower. For a tabular presentation of all of the vertical test data, see Table 3-V. Photographs of some of the damage and failures are shown in Figures 3-19, 3-20, 3-21, 3-22, and 3-23.

Seat C: Seat C was a three-place, tourist class, tubular-constructed, floor/sidewall-mounted seat (Figure 8 of the report).

Because of the seat's sidewall mounting, an energy absorption technique was designed into the inboard leg which would allow the forward leg to collapse at approximately 6 g's static load (Figure 3-24). Tests were conducted on seven of these seats to collect the necessary data to derive the respective longitudinal and vertical response curves.

Tests numbered 41 through 64 were dynamic longitudinal tests. A typical test setup for the floor/sidewall seat configuration is shown in Figure 11 of the report. Figure 3-25 shows a typical longitudinal test setup for Static Tests Numbers 84 and 85 conducted on Seat C. The tabulated data of both dynamic and static tests conducted are shown in Table 3-VI. Photographs of some of the damage and failures which occurred are shown in Figures 29 of the report, 3-26, 3-27, 3-28, 3-29, 3-31, 3-32, and 3-33.

Vertical dynamic tests, numbered 73 through 79, were conducted and the necessary data to establish the vertical response curve were obtained for Seat C. The vertical dynamic tests for Seat C were conducted on the ACED Vertical Drop Tower. The vertical static test was recorded as Test No. 85. Table 3-VII contains the data from the dynamic and static tests. Some of the seat damage and failures are shown in Figures 3-34, 3-35, 3-36, 3-37, and 3-38.

TABLE 3-III

Test No.	Seat No.	Velocity Change	Input Time Pulse	Average Input Accel.	Left Fwd.Vert. Reaction	Right Fwd.Vert. Reaction	R_1+R_4	Left Mid Vert. Reaction	Right Mid Vert. Reaction	Left Aft Vert. Reaction	Right Aft Vert. Reaction	R_2+R_5 and R_3+R_6	Left Horiz. Shear	Right Horiz. Shear	S_L+S_R	Peak Dummy Accel.	Effect Weight	REMARKS
		ft/Sec	Sec	$\frac{ft/Sec^2}{32.2}$	lb	lb	lb	lb	lb	lb	lb	lb	lb	lb	lb	$\frac{ft/Sec^2}{32.2}$	lb	(Dynamic Tests)
		ΔV	t_n	$\bar{G}$	R_4	R_1	R_F	R_5	R_2	R_6	R_3	R_A	S_L	S_R	S	g	W	
21	B-1	16.5	.105	4.88	2466	1605	4071	1499	1059	530	767	3855	1463	693	2156	5.01	588	
22	B-1	15.3	.085	7.94	3763	4573	8336	2003	1404	673	895	4975	1593	933	2526	13.54	472	
23	B-1	16.0	.075	8.02	4013	3969	7982	2063	1371	741	852	5027	1724	978	2702	15.70	472	
24	B-1	16.6	.063	8.80	4668	4526	9194	2234	1433	911	958	5536	1903	1043	2946	18.21	472	
25	B-1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Data System Failure
26	B-1	12.6	.043	8.35	5180	4149	9329	2001	1370	912	959	5242	1662	945	2607	15.28	472	
27	B-1	15.6	.055	8.43	5135	4301	9436	2029	1385	962	915	5292	1783	913	2696	17.34	472	
28	B-1	14.1	.125	4.54	2720	1919	4636	1069	800	379	501	2749	861	492	1353	6.48	472	
29	B-1	18.5	.123	6.59	3209	3752	6961	1481	1171	667	774	4093	1296	639	1935	10.64	472	
30	B-1	19.6	.118	6.53	3894	3650	7634	1404	1201	688	758	4051	1304	799	2103	10.34	472	
31	B-1	22.3	.135	7.27	4363	4511	8874	1778	1180	806	774	4538	1448	645	2093	12.15	472	
32	B-1	25.1	.143	7.59	4389	3675	8064	1622	1280	779	703	4384	1504	780	2284	11.98	472	Two Data Peaks Observed For
					3752	3593	7345	2063	1450	617	561	4691	931	404	1335			Several Reactions
33	B-1	26.3	.155	7.99	4567	4337	8904	1591	1170	801	720	4282	1381	664	2045	12.01	472	Two Data Peaks Observed For
					3823	3923	7746	2173	1430	725	624	4952	1019	356	1375			Several Reactions
34	B-1	27.8	.165	5.22	5168	4514	9682	1669	1252	860	739	4520	1447	805	2252	12.21	588	Two Data Peaks Observed For
					4814	4305	9119	2369	1555	860	518	5302	1102	378	1480			Several Reactions
35	B-1	31.2	.177	5.46	5027	4573	9600	1796	1263	909	687	4655	1504	751	2255	12.79	588	Two Data Peaks Observed For
					5062	4861	9923	2436	1717	963	706	5822	1328	607	1935			Several Reactions
36	B-1	33.4	.200	5.18	5841	3749	9590	1779	1212	903	697	4591	1504	747	2251	12.33	588	Two Data Peaks Observed For
					6372	3255	9627	2756	1888	1131	977	6752	1648	843	2491			Several Reactions
37	B-1	41.5	.180	7.14	6776	4830	11606	2318	1727	816	787	5648	1987	1201	3188	15.46	588	Two Data Peaks Observed For Several Reactions - Seat Buckle Failed, Fig. 3-10, Fig. 3-11, Fig. 3-12.
					6406	5152	11558	3334	2283	1071	854	7542	3128	963	4091			

SEAT B - LONGITUDINAL DYNAMIC TEST DATA

TABLE 3-IV

Test No.	Seat No.	Velocity Change ft/Sec	Input Time Pulse Sec	Average Input Accel. $\frac{ft/Sec^2}{32.2}$	Forward Vert. Reaction L - F 1b	Forward Vert. Reaction L - A 1b	Forward Vert. Reaction R - F 1b	Forward Vert. Reaction R - A 1b	R_1+R_2 and R_5+R_6 1b	Aft.Vert. Reaction L - F 1b	Aft.Vert. Reaction L - A 1b	Aft.Vert. Reaction R - F 1b	Aft.Vert. Reaction R - A 1b	R_3+R_4 and R_7+R_8 1b	Left Horiz. Shear 1b	Right Horiz. Shear 1b	S_L+S_R 1b	Peak Dummy Accel. $\frac{ft/Sec^2}{32.2}$	Effect Weight 1b	REMARKS (Dynamic Tests)
		ΔV	t_n	$\bar{G}$	R_1	R_2	R_5	R_6	R_F	R_3	R_4	R_7	R_8	R_A	S_L	S_R	S	g	W	
38	B-2	9.0	.068	4.10	447	751	219	473	1890	751	554	503	320	2128	855	333	1188	4.73	472	
39	B-2	17.8	.047	11.74	1611	2127	1341	2145	7224	2807	1782	1903	1348	7840	2725	1921	4646	20.87	472	
40	B-2	34.5	.088	12.16	2067	2313	3000	1144	8524	2968	2131	2208	1653	8960	3023	2461	5484	27.59	472	Leg Cross Channels Failed, Figures 3-13 and 3-14

Test No.	Seat No.	Left Input Load 1b	Mid Input Load 1b	Right Input Load 1b														Total Input Load 1b		REMARKS (Static Tests)
		F_L	F_M	F_R	R_1	R_2	R_5	R_6	R_F	R_3	R_4	R_7	R_8	R_A	S_L	S_R	S	F		
82	B-5	1762 2356	1755 2115	1831 2189	1495 1915	2410 1675	1070 1520	1895 2170	6870 7280	2700 2575	1385 1365	1840 2375	1055 1300	6980 7615	1264 1422	2480 2800	3744 4222	5348 6660		Seat Designed To Fail Progressively, Thus Two Sets of Figures.
83	B-6	1751 1811	1764 2025	1744 2140	1376 1376	2276 1491	1040 1600	1714 2108	6406 6575	2136 2075	1810 1412	1467 2050	1465 1872	6878 7409	909 1010	1940 2280	2849 3290	5259 5976		Seat Belt Attachment Failed at 9g. See Figures 3-15, 3-16, 3-17.

SEAT B - LONGITUDINAL DYNAMIC AND STATIC TEST DATA

FIG. 3-10 SEAT B-1 AFTER TEST NO. 37

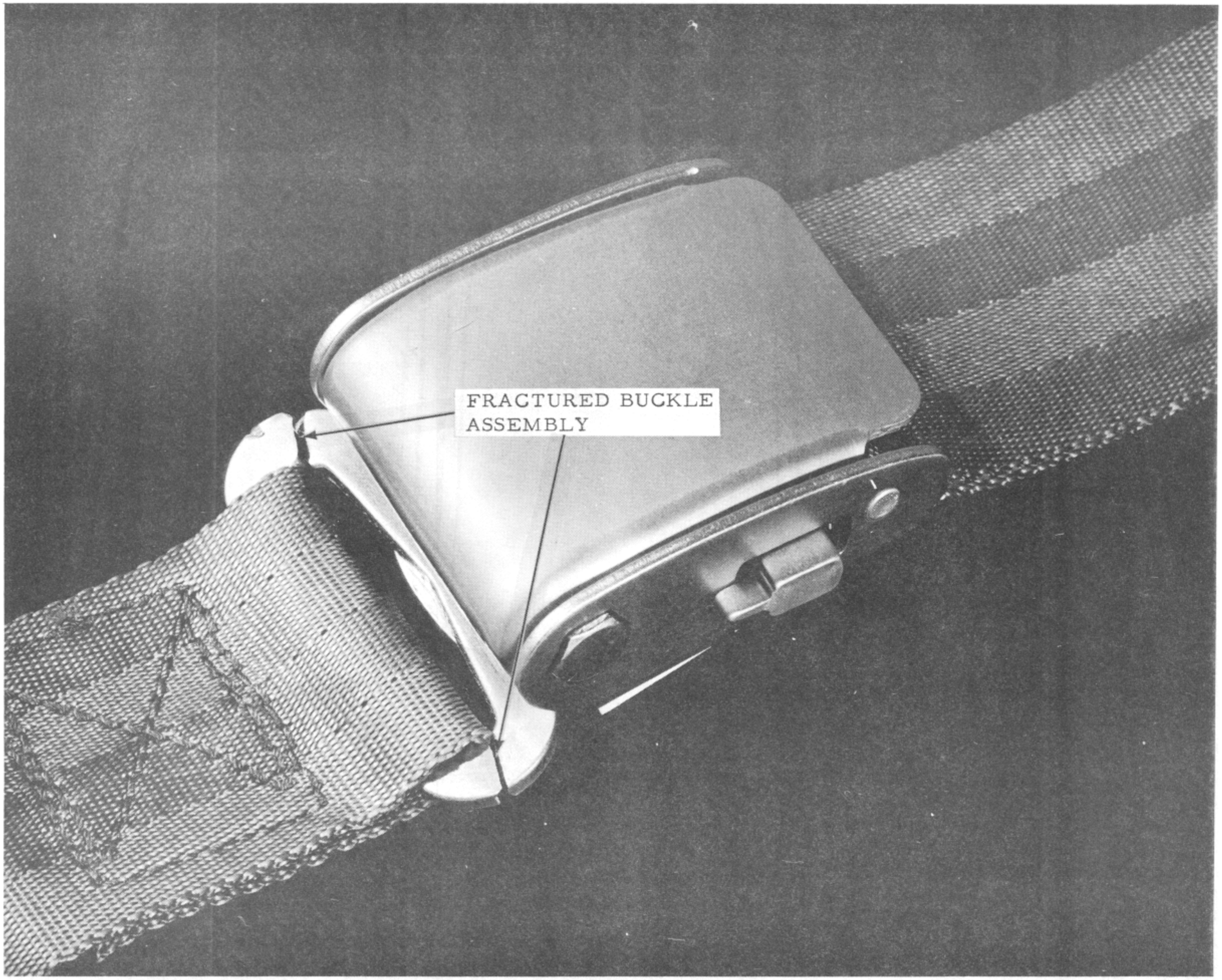


FIG. 3-11 SEAT B-1 INBOARD SEAT BELT AFTER TEST NO. 37

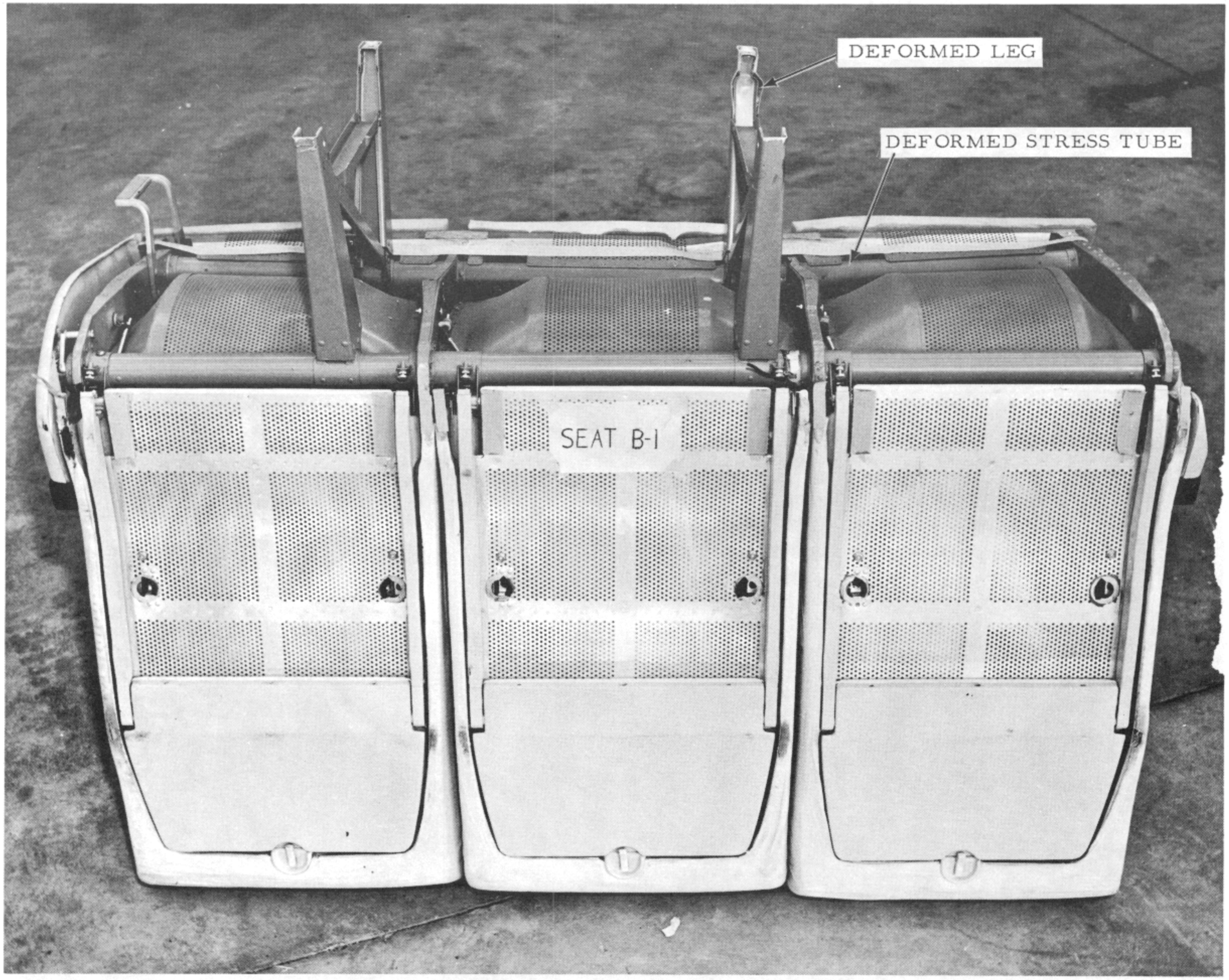


FIG. 3-12 REAR VIEW OF SEAT B-1 AFTER TEST NO. 37

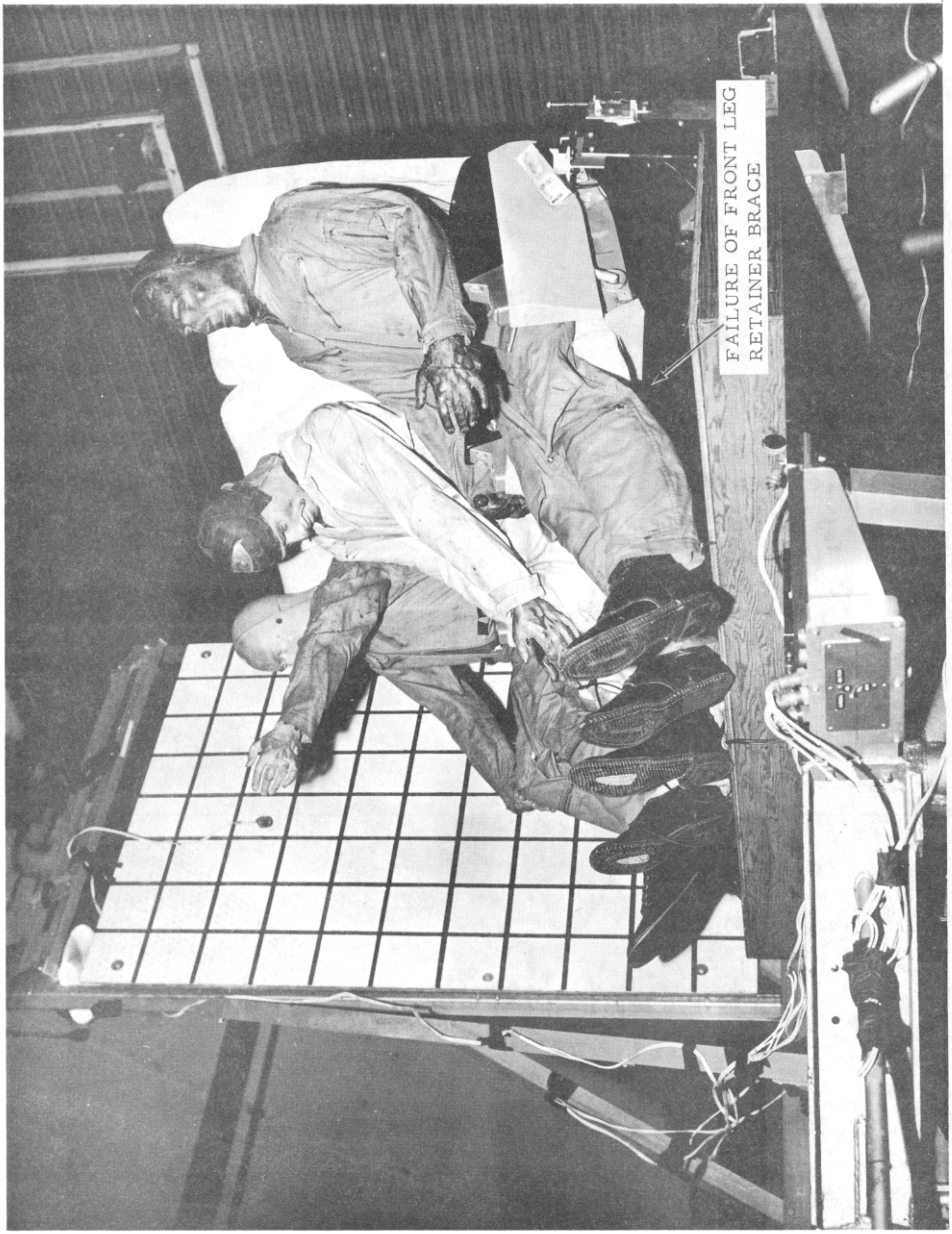


FIG. 3-13 SEAT B-2 AFTER TEST NO. 40

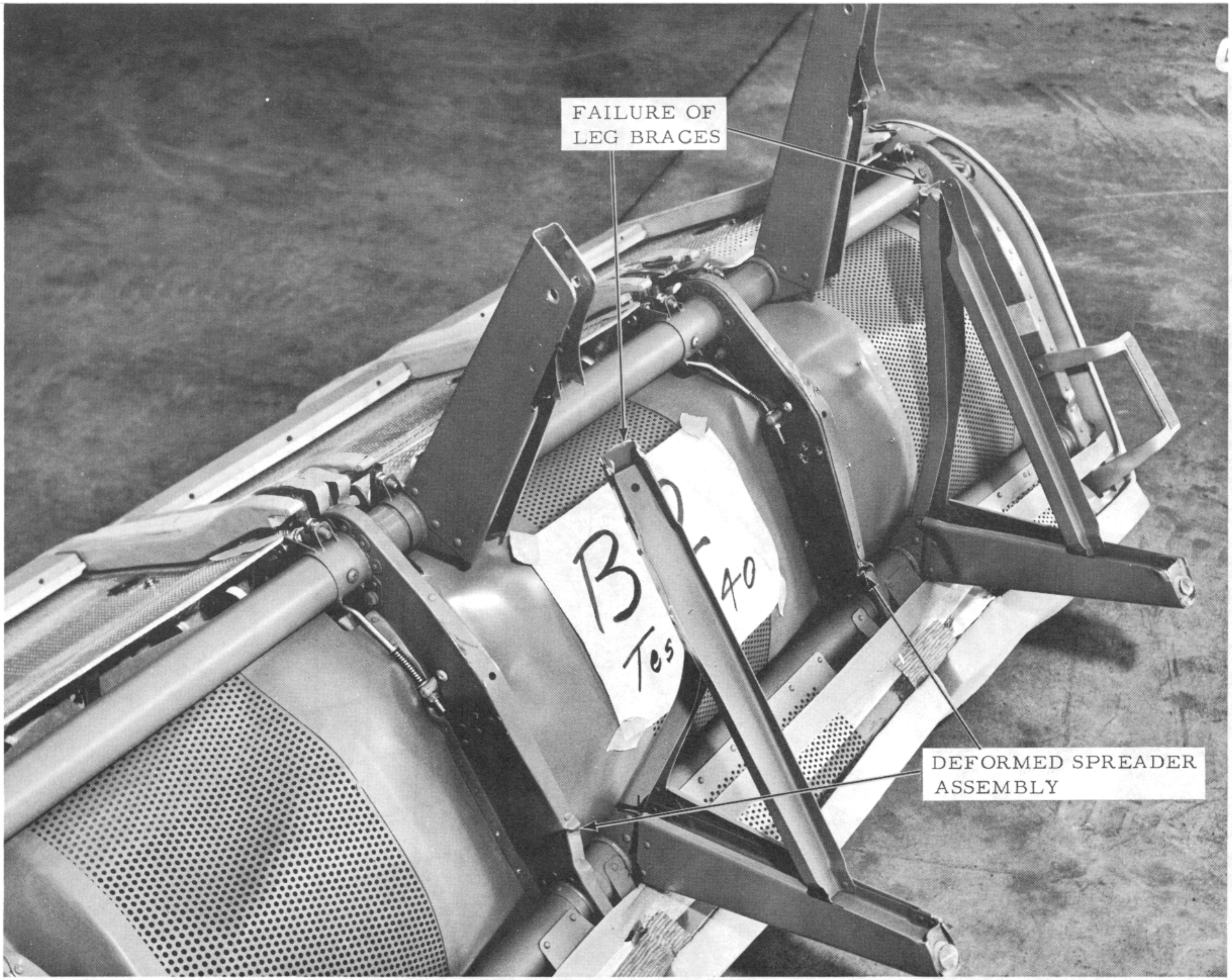


FIG. 3-14 BOTTOM VIEW OF SEAT B-2 AFTER TEST NO. 40

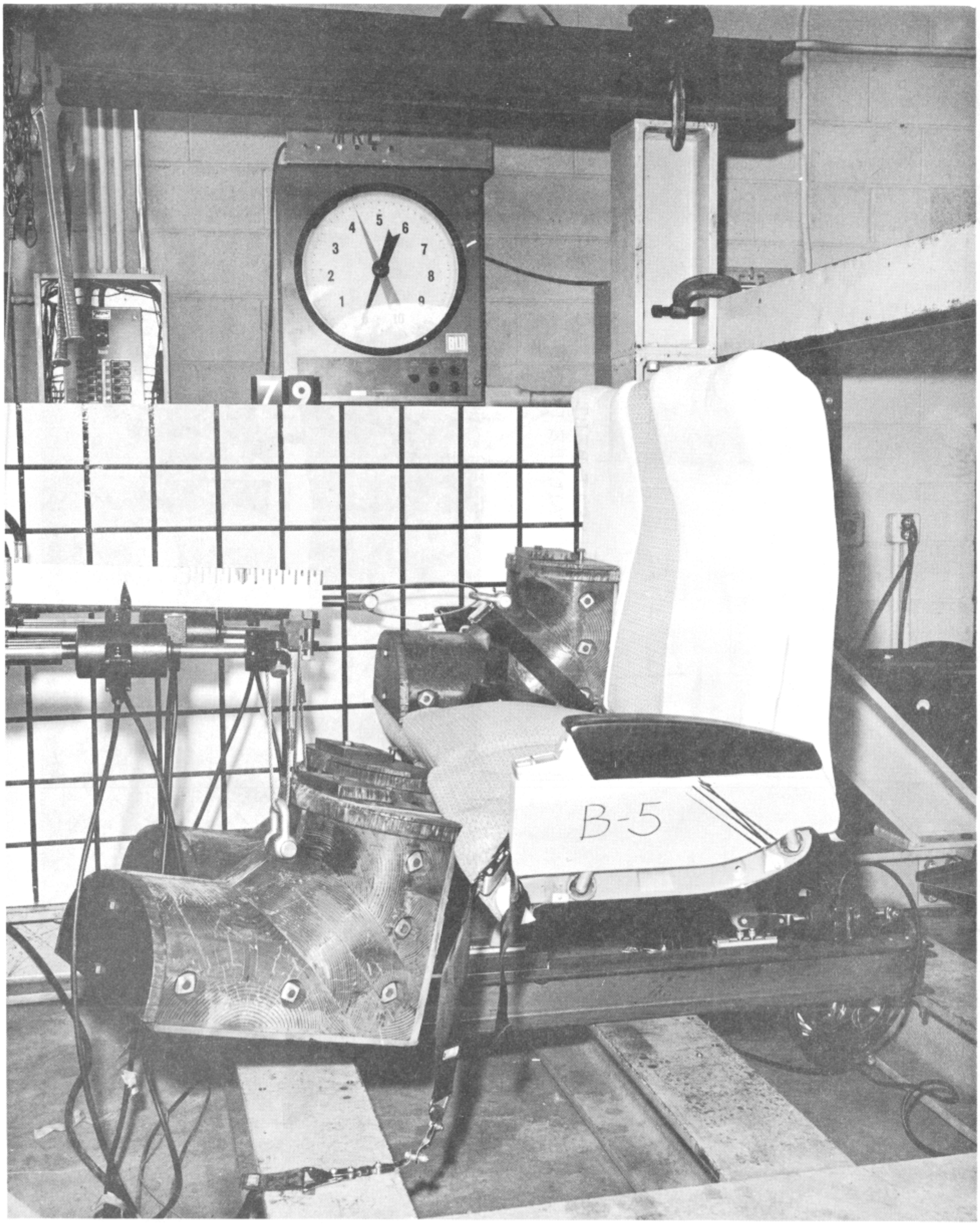


FIG. 3-15 SEAT B-5 AFTER TEST NO. 82 SHOWING THAT SEAT BELT ATTACHMENT FAILED

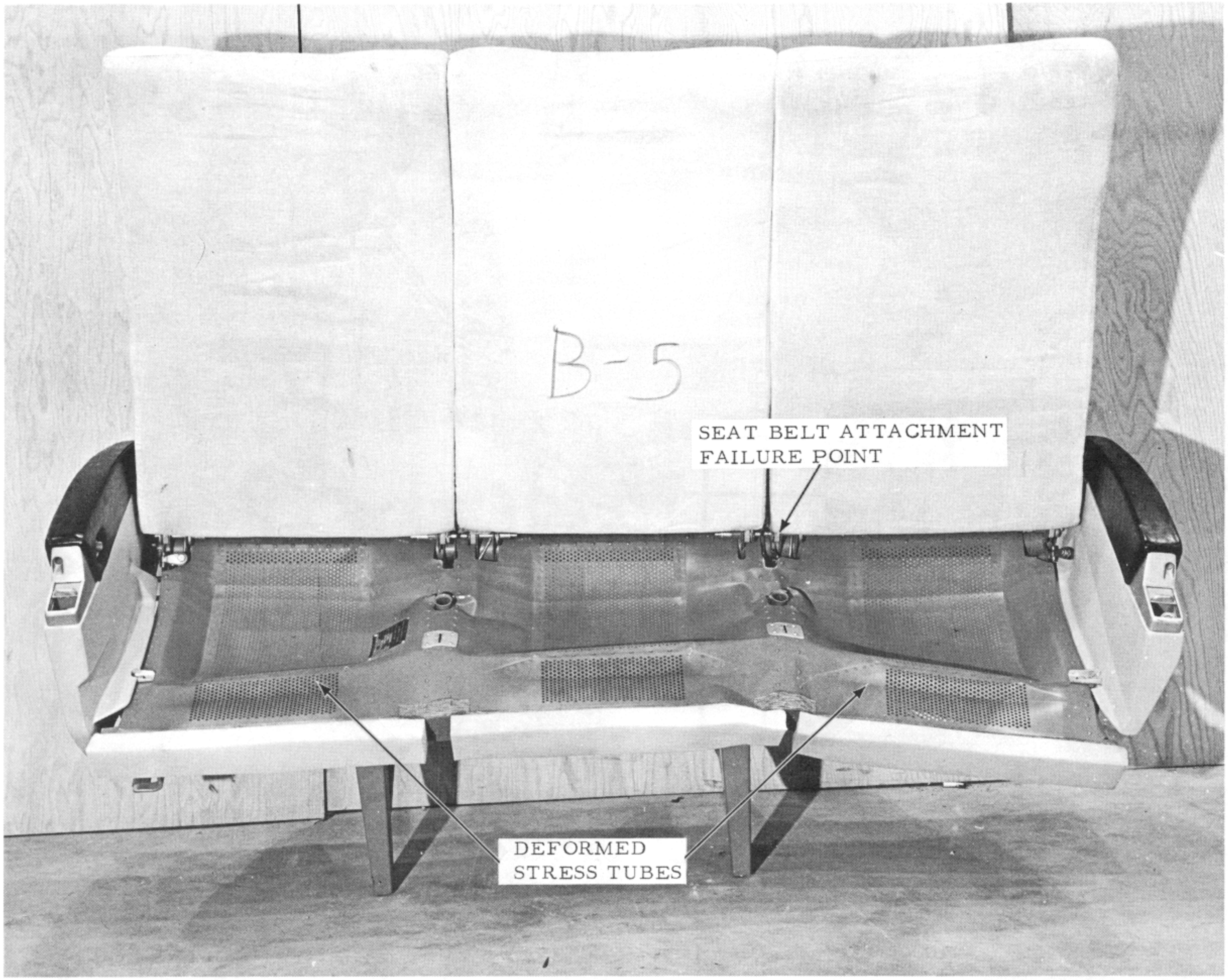


FIG. 3-16 FRONT VIEW OF SEAT B-5 AFTER TEST NO. 82

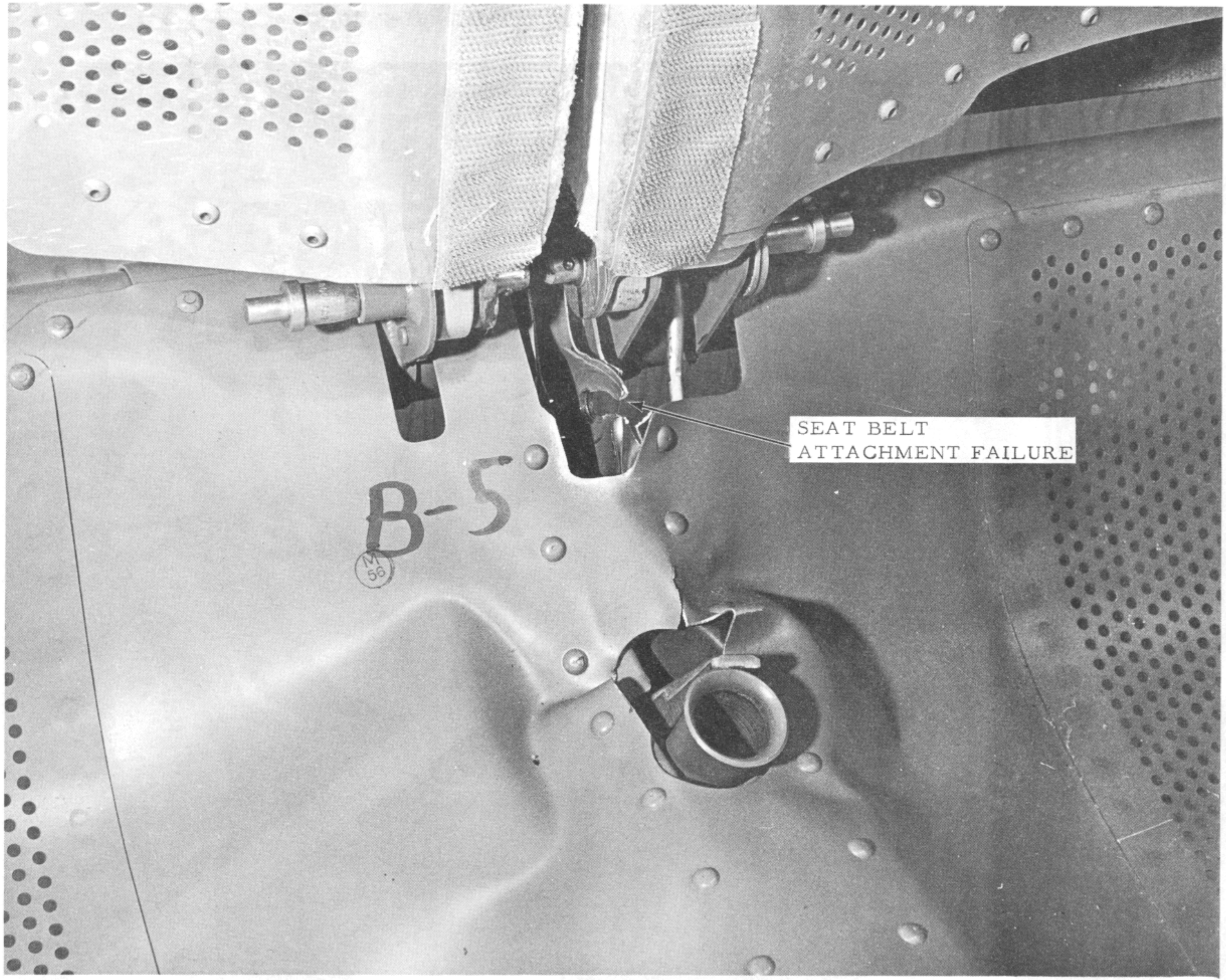


FIG. 3-17 CLOSEUP OF SEAT B-5 AFTER TEST NO. 82

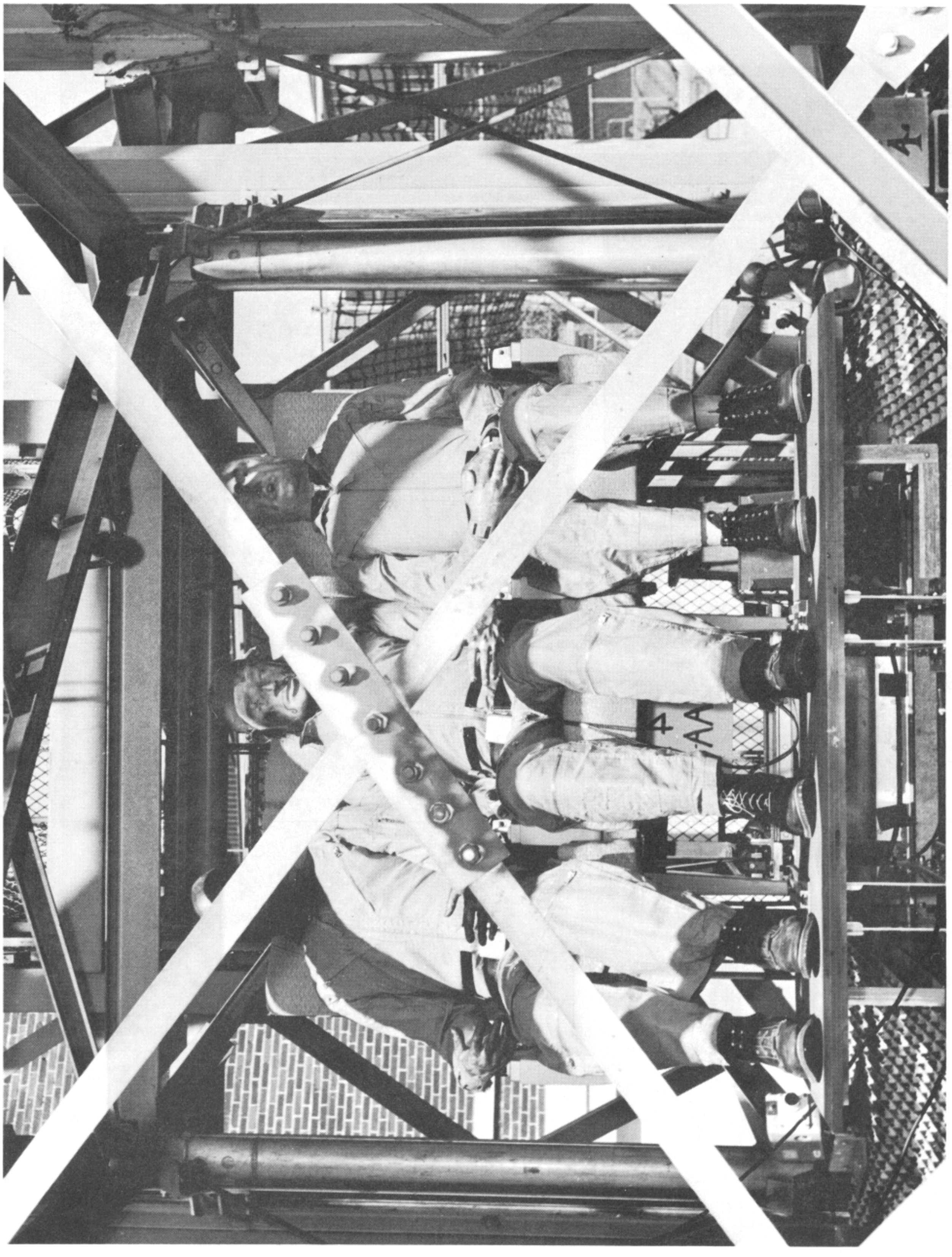


FIG. 3-18 TYPICAL DYNAMIC VERTICAL TEST SETUP - SEAT B

TABLE 3-V

Test No.	Seat No.	Velocity Change	Input Time Pulse	Average Input Accel.	Left Fwd.Vert. Reaction Pos. - 1	Right Fwd.Vert. Reaction Pos. - 1	Left Fwd.Vert. Reaction Pos. - 2	Right Fwd.Vert. Reaction Pos. - 2	R_1+R_2 and R_3+R_4	Left Aft Vert. Reaction Pos. - 1	Right Aft Vert. Reaction Pos. - 1	Left Aft Vert. Reaction Pos. - 2	Right Aft Vert. Reaction Pos. - 2	R_5+R_6 and R_7+R_8	R_A+R_F	Peak Dummy Accel.	Effect Weight	REMARKS
		ft/Sec	Sec	ft/Sec^2 32.2	lb	lb	lb	lb	lb	lb	lb	lb	lb	lb	lb	ft/Sec^2 32.2	lb	
		ΔV	t_n	$\bar{G}$	R_1	R_2	R_3	R_4	R_F	R_5	R_6	R_7	R_8	R_A	R_T	g	wt	(Dynamic Tests)
65	B-3	9.3 4.6	.127 .080	2.27 1.78	156 104	123 123	550 465	472 472	1301 1164	756 492	338 242	-	-	1094 734	2395 1898	666 5.20	472	Data For The Overall Time Pulse Lower - Partial Data
66	B-3	16.3	.179	2.83	65	64	666	546	1341	804	726	-	-	1530	2871	7.28	472	
67	B-3	26.4	.248	3.51	168	141	980	691	1980	812	600	-	-	1412	3392	7.66	472	
68	B-3	25.4	.133 .020	5.93 2.79	266 53	224 112	1702 561	1214 613	3406 1339	1720 732	1424 706	- -	- -	3144 1438	6550 2777	14.38 4.11	472	Data For The Overall Time Pulse Lower - Partial Data
69	B-3	26.1	.085 .045	9.52 7.31	507 295	428 309	2748 2291	2166 1768	5849 4663	2825 2632	2233 2048	- -	- -	5058 4680	10,907 9,343	28.04 15.32	472	Data For The Overall Pulse - Aft Leg Lower - Partial Data /Buckled
70	B-3	40.2	.109	11.45	488	532	2850	3028	6898	1163	3902	-	-	5065	11,963	33.32	472	Left Leg Collapsed - Stress Tubes Bent
		Left Input Load lb	Mid Input Load lb	Right Input Load lb												Total Input Load lb		
		F_L	F_M	F_R												F		(Static Tests)
80	B-4	950 2025	978 2133	954 2133	179 776	198 486	696 1672	478 1191	1551 4125	556 1468	99 279	176 390	269 248	1100 2385	2651 6510	2882 6291	588	5g Load Ultimate Load - Stress Tubes Bent

SEAT B - VERTICAL DYNAMIC AND STATIC TEST DATA

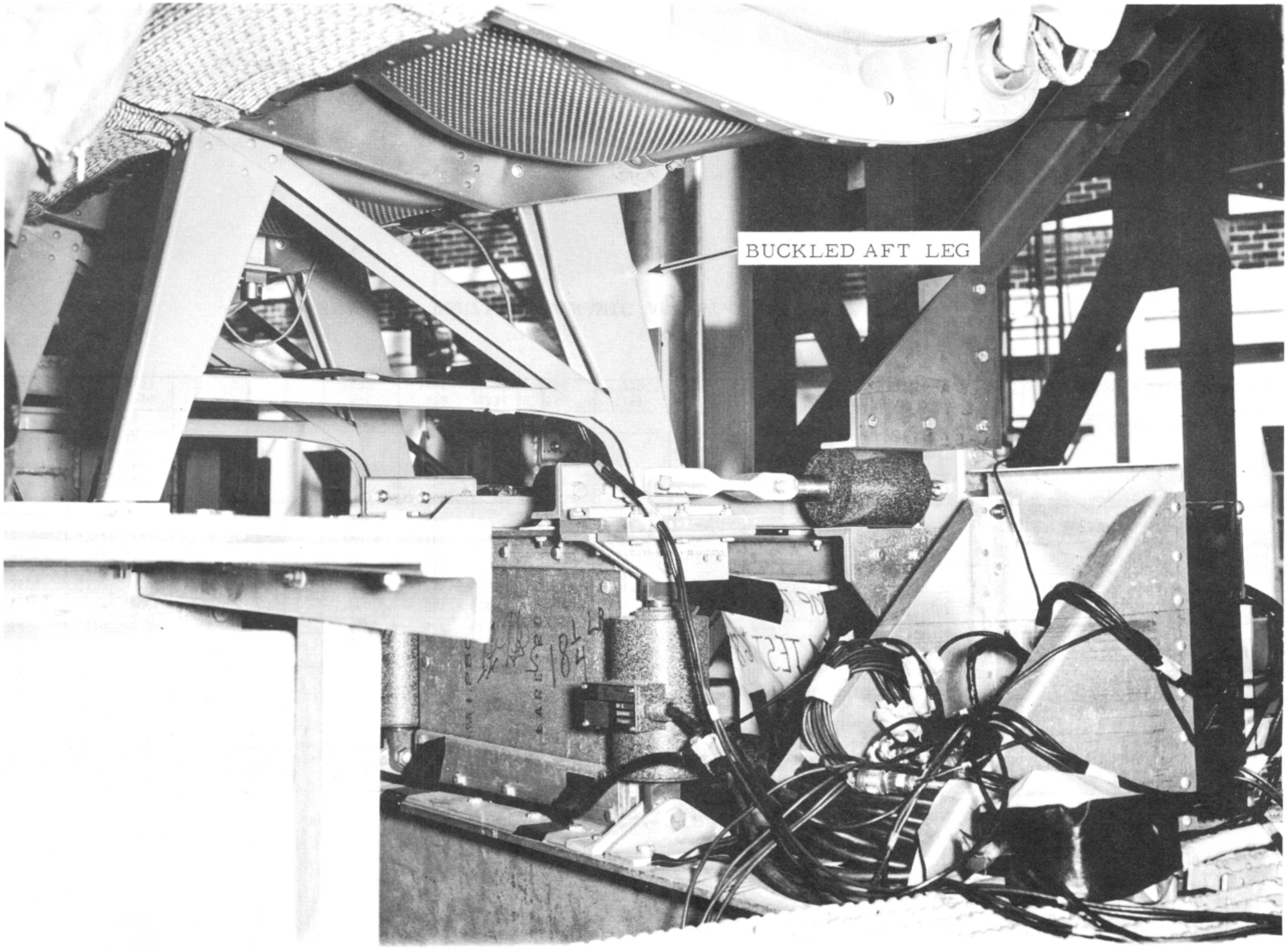


FIG. 3-19 SEAT B-3 AFTER TEST NO. 69

FIG. 3-20 SEAT B-3 AFTER TEST NO. 70 SHOWING BASIC STRUCTURE FAILURE

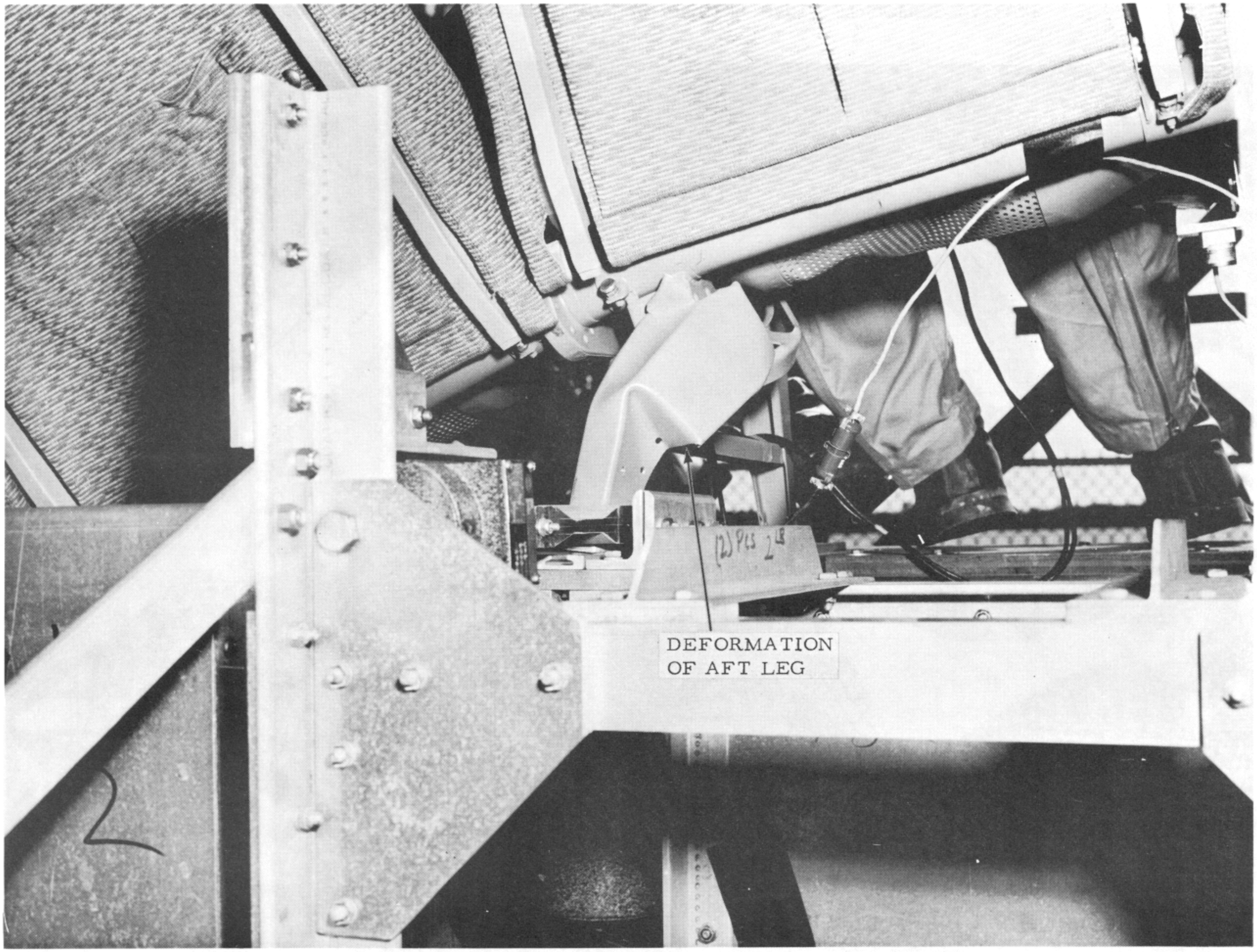


FIG. 3-21 REAR VIEW OF SEAT B-3 AFTER TEST NO. 70

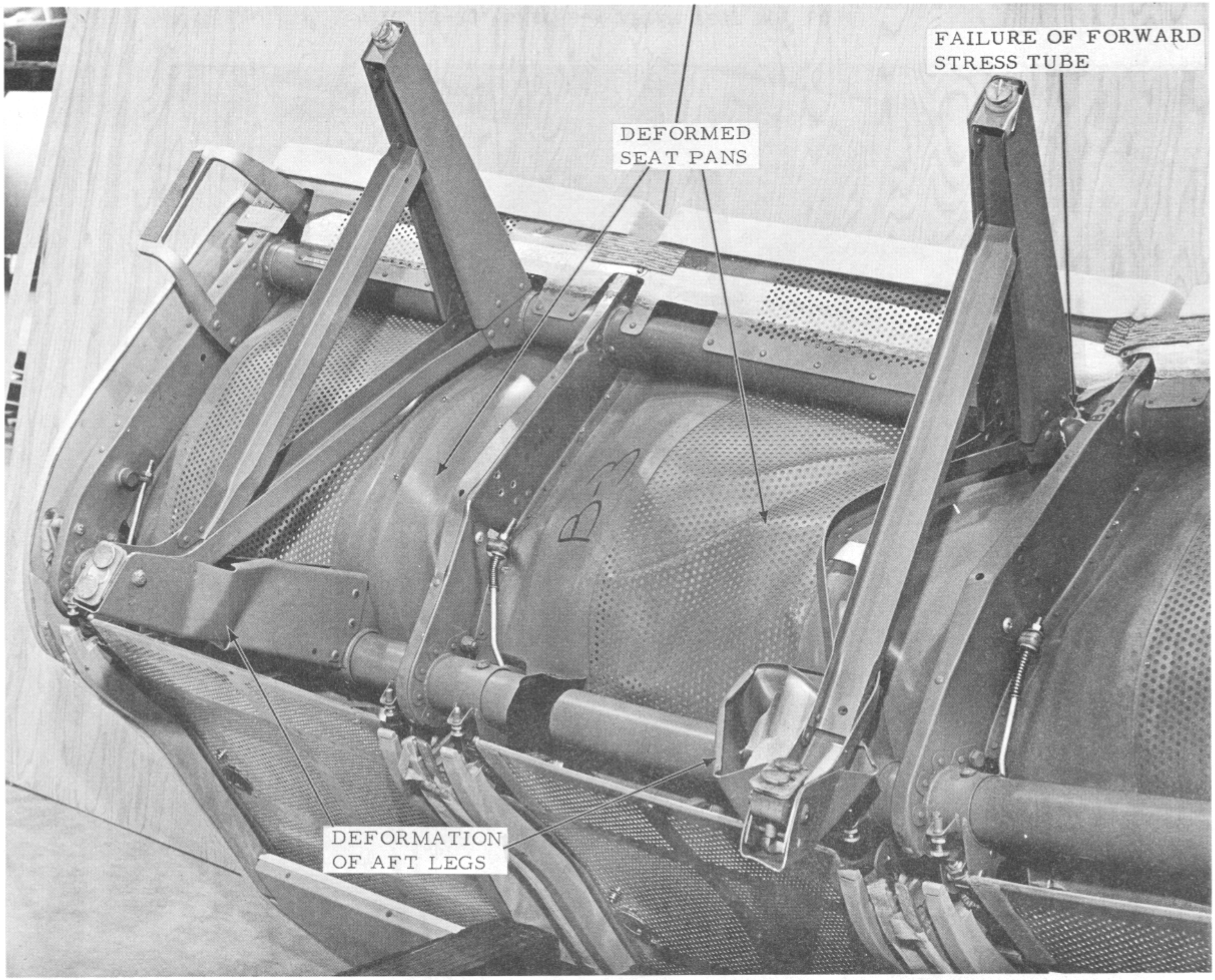


FIG. 3-22 BOTTOM VIEW OF SEAT B-3 AFTER TEST NO. 70

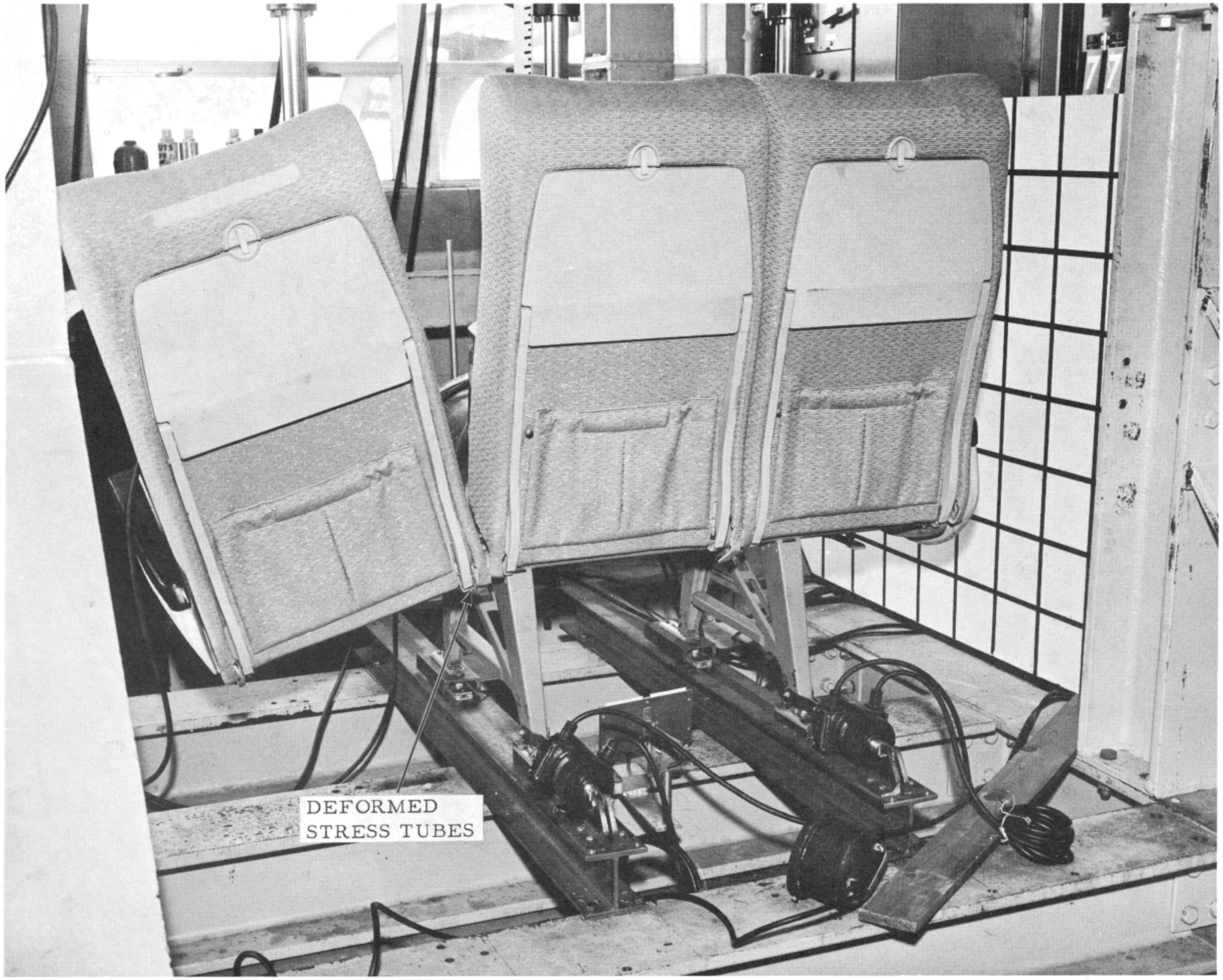


FIG. 3-23 SEAT B-4 AFTER TEST NO. 80

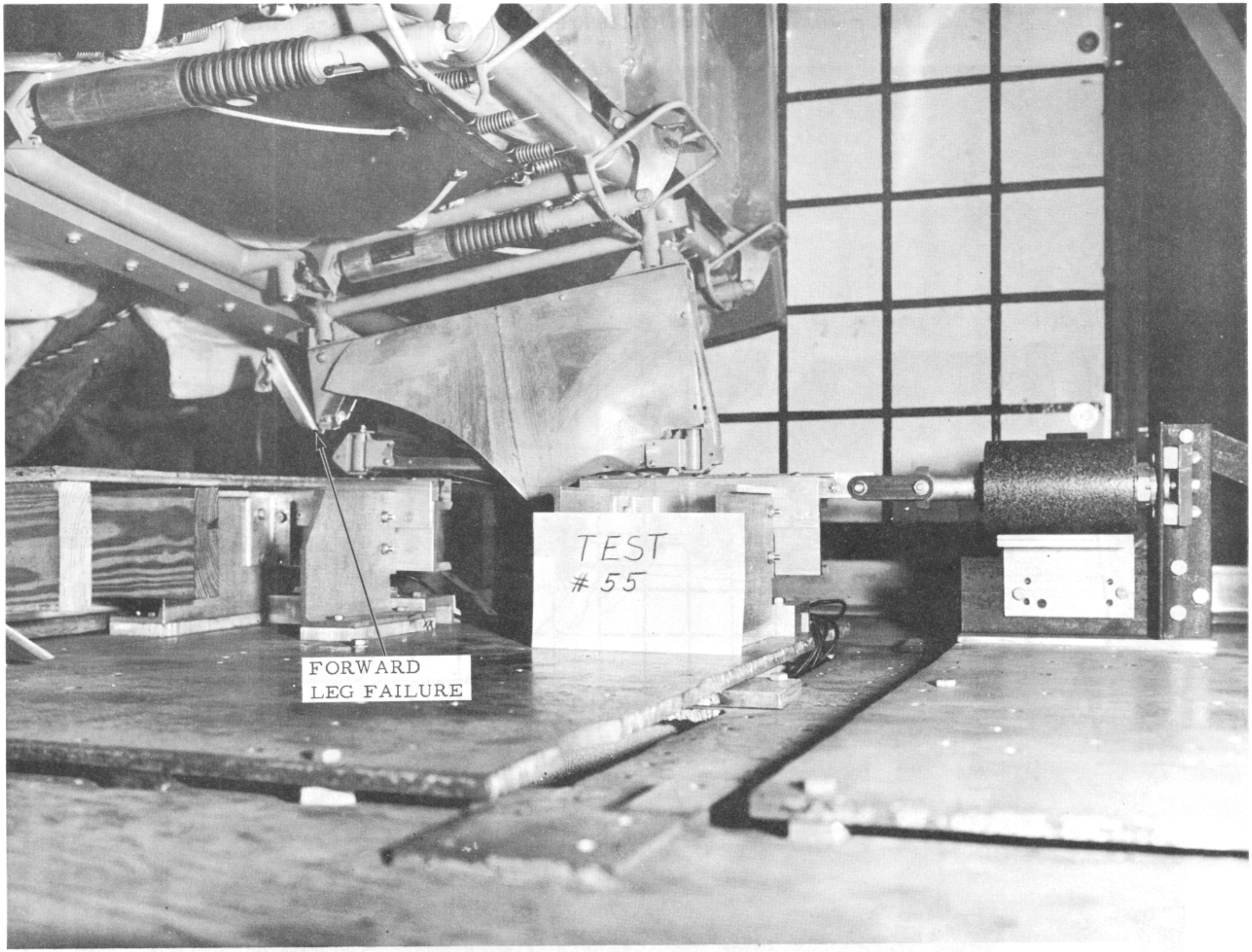


FIG. 3-24 SEAT C-1A AFTER TEST NO. 55

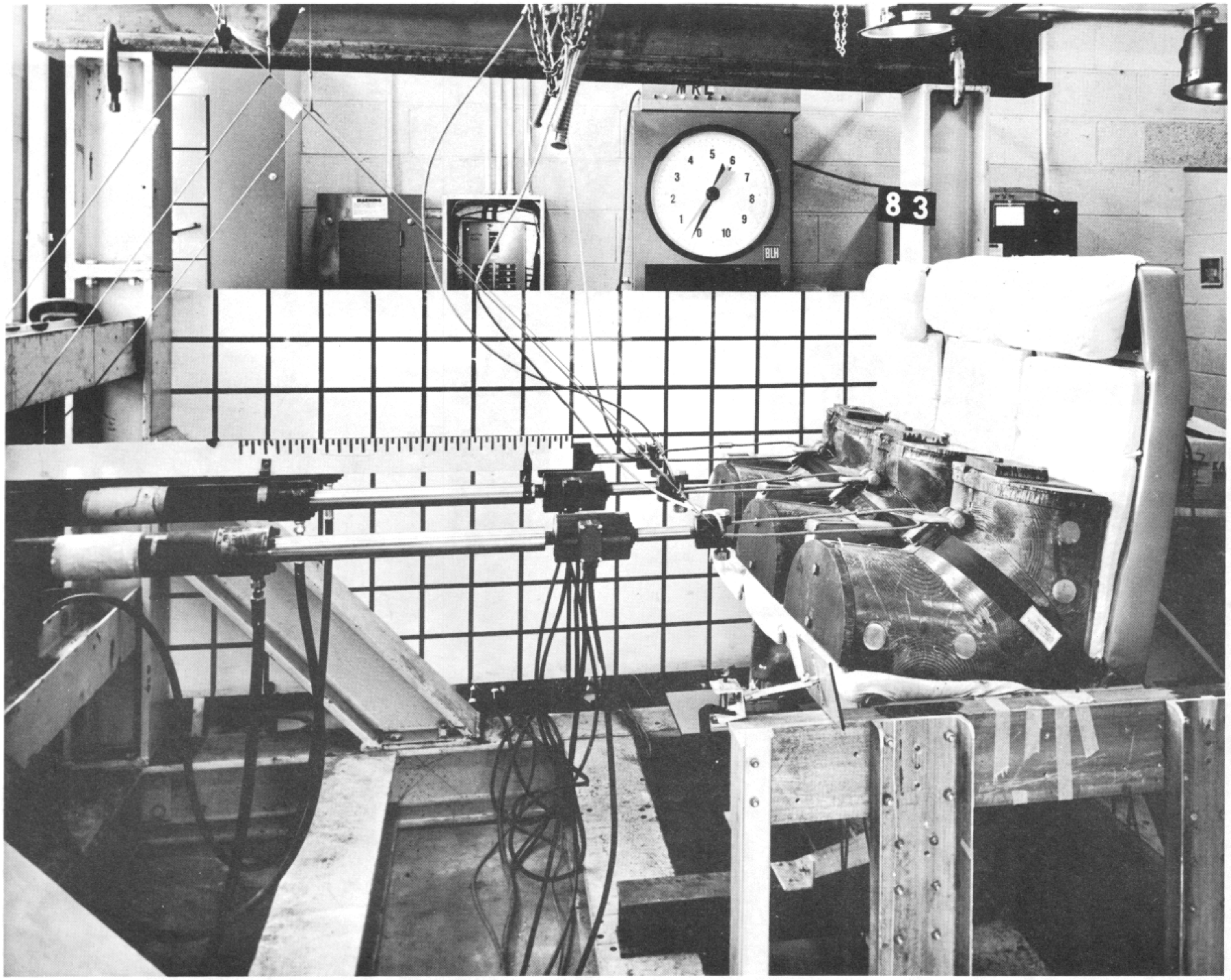


FIG. 3-25 TYPICAL STATIC LONGITUDINAL TEST SETUP - SEAT C

TABLE 3-VI

Test No.	Seat No.	Velocity Change	Input Time Pulse	Average Input Accel.	Left Horiz. Shear Reaction	Right Horiz. Shear Reaction	S_L+S_R	Peak Dummy Accel.	Effect Weight	REMARKS
		ft/Sec	Sec	g	lb	lb	lb	g	lb	(Dynamic Tests)
		V	t_n	$\bar{G}$	S_L	S_R	S	g	Wt	
41	C-1	12.5	.145	2.68	839	1651	2490	5.49	573	Wall Attachment Torqued. Lateral Load Link Failed.
42	C-1	12.4	.148					7.39	573	Leg Collapsed & Foot Freed From Track - Lost Data
43	C-1	11.4	.172	2.06	485	1185	1670	4.28	573	Leg Replaced
44	C-1	10.2	.150	2.11	455	1240	1695	4.16	573	
45	C-1	7.6	.130	1.82	349	1107	1456	3.97	573	
46	C-1	5.0	.090	1.72	245	819	1064	3.39	458	
47	C-1	7.0	.070	3.10	451	1461	1912	5.95	458	
48	C-1	5.2	.056	2.77	837	1019	1356	3.33	458	
49	C-1	5.9	.052	3.52	411	1285	1696	4.26	458	
50	C-1	7.4	.044	5.22	619	1927	2546	6.39	458	Leg Collapsed Testing Continued
51	C-1	13.8	.115	3.74	895	2302	3197	8.05	458	
52	C-1	11.3	.237	1.48	619	983	1602	4.34	573	
53	C-1	12.5	.144	2.59	1012	1836	2848	7.42	573	
54	C-1	13.1	.105	3.87	1177	1562	2739	6.36	458	
55	C-1	12.1	.052	8.37	1254	1840	3094	8.50	458	

Test No.	Seat No.	Velocity Change	Input Time Pulse	Avg. Input Accel.	Left Horiz. Shear Reaction	Right Horiz. Shear Reaction	S_L+S_R	Peak Dummy Accel.	Effect Weight	REMARKS
		ft/Sec	t_n	g	lb	lb	lb	g		(Dynamic Tests)
		V	t_n	$\bar{G}$	S_L	S_R	S	g	Wt	
56	C-1	38.10	.183	6.47	2087	3542	5629	14.16	458	Seat Separated From Sled. Inb'd. Leg Failed First. Fig. 3-26 and 3-27.
57	C-2	5.7	.058	3.27	505	1272	1777	4.30	458	
58	C-2	10.4	.110	2.93	854	2019	2873	5.71	573	Forward Leg Buckled. Testing Continued.
59	C-2	12.3	.145	2.63	986	1475	2461	5.32	573	
60	C-2	7.1	.043	5.10	899	1109	2008	4.12	458	
61	C-2	11.8	.098	3.84	1659	1825	3484	7.54	458	Leg Failed Completely. Figures 3-28, 29 and 30.
62	C-3	24.4	.308	2.50	778	2262	3040	5.77	573	
63	C-3	13.1	.110	3.71	959	2398	3357	7.68	573	Forward Leg Buckles Testing Continued.
64	C-3	16.5	.172	3.01	1291	2223	3514	8.48	573	Seat Deformed; Testing Halted
Test No.	Seat No.	Left Input Load	Mid Input Load	Right Input Load	Left Horiz. Shear Reaction	Right Horiz. Shear Reaction	V_L+V_R	Total Input Load	Effect Weight	
		lb	lb	lb	lb	lb		lb	lb	(Static Tests)
		F_L	F_M	F_R	V_L	V_R	V	F	Wt	
84	C-5	1012	782	734	860 1796	1313 1810	2173 3606	2528	573	Figs. 3-31, 3-32 and 3-33.
86	C-7	856	727	690	720	1125	1845	2273	573	

SEAT C - LONGITUDINAL DYNAMIC AND STATIC TEST DATA

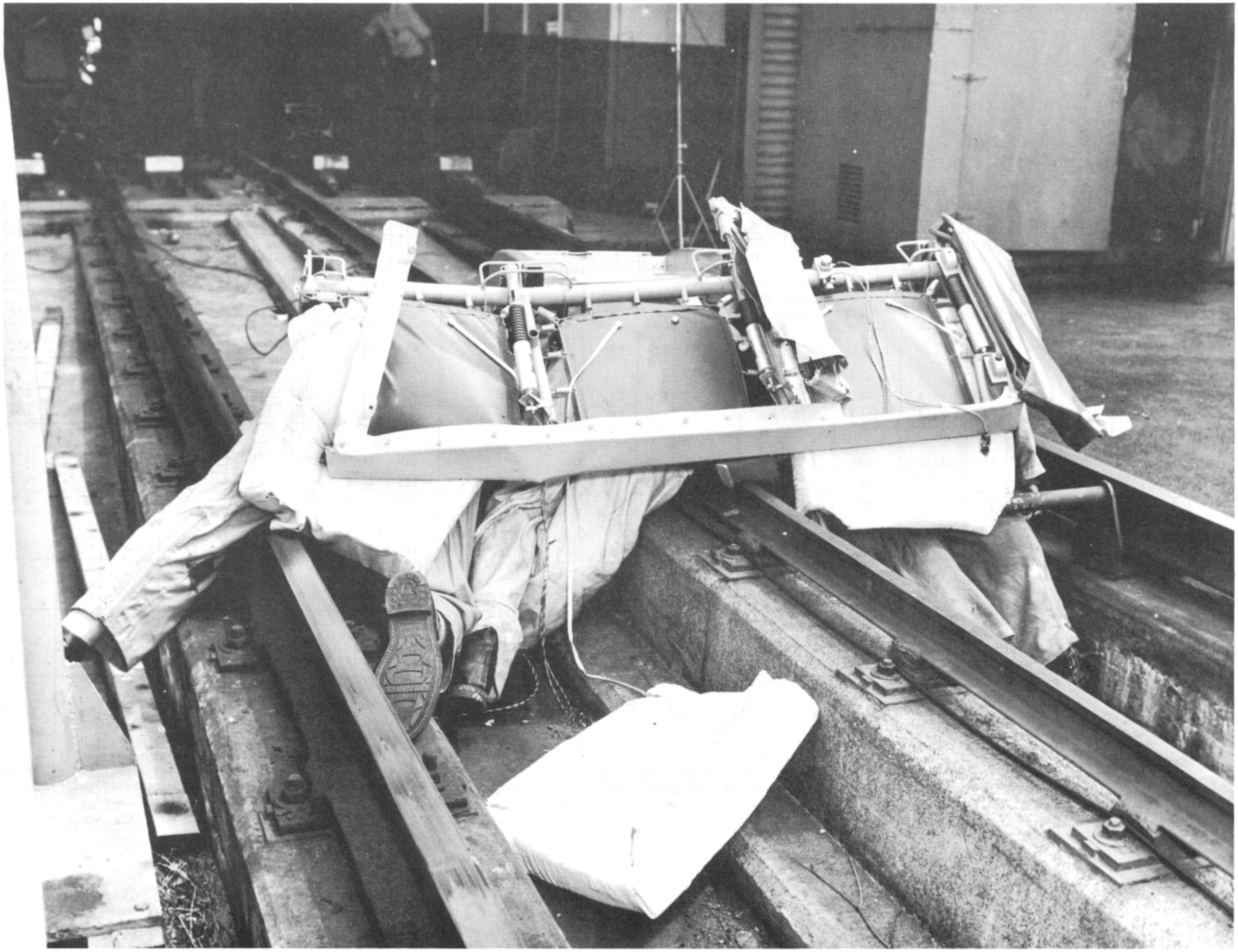


FIG. 3-26 SEAT C-1A AFTER TEST NO. 56 - LEG FAILED FIRST

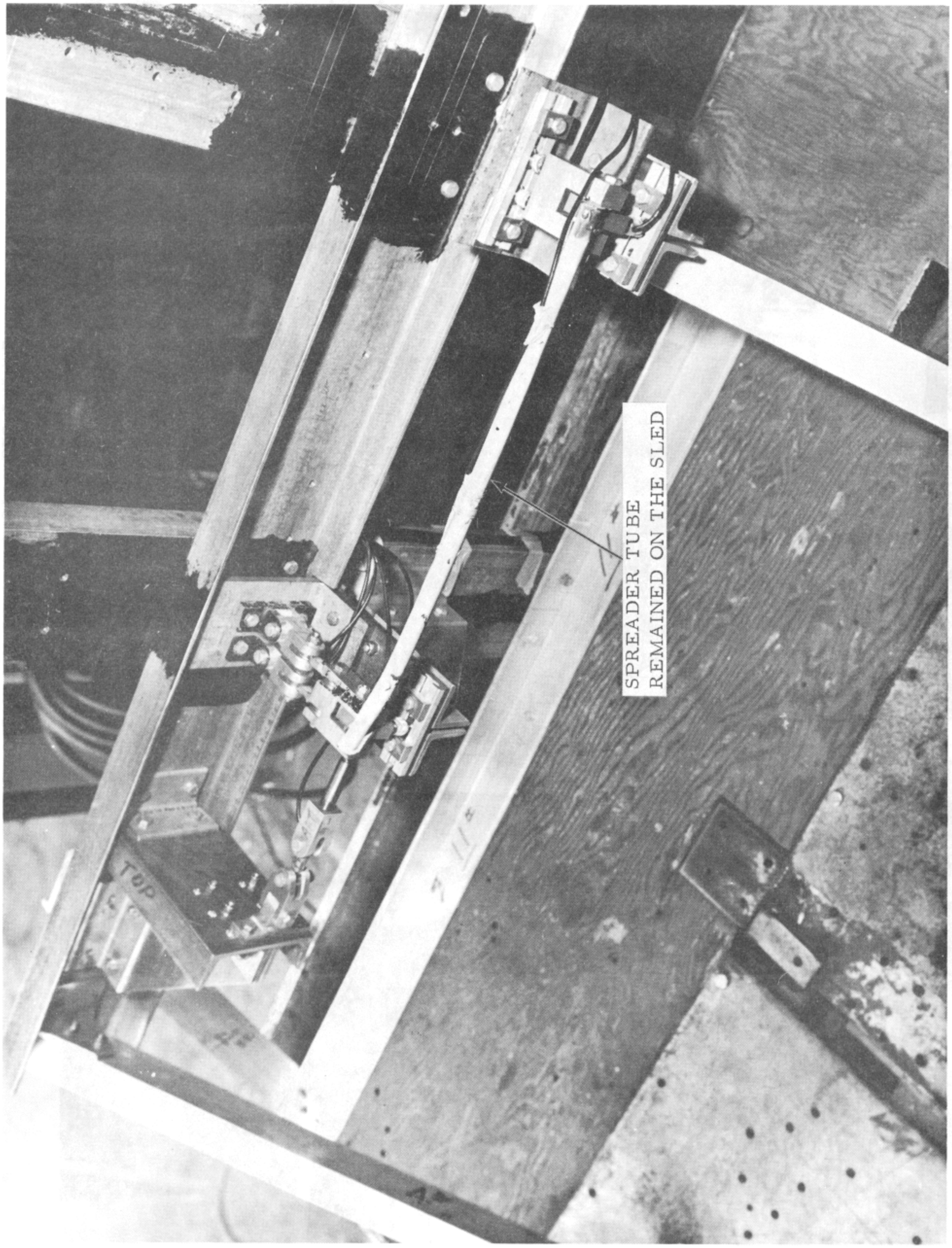


FIG. 3-27 SEAT C-1A AFTER TEST NO. 56

FIG. 3-28 SEAT C-2 AFTER TEST NO. 61 - LEG FAILED

FIG. 3-29 UNDERSIDE VIEW OF SEAT C-2 AFTER TEST NO. 61

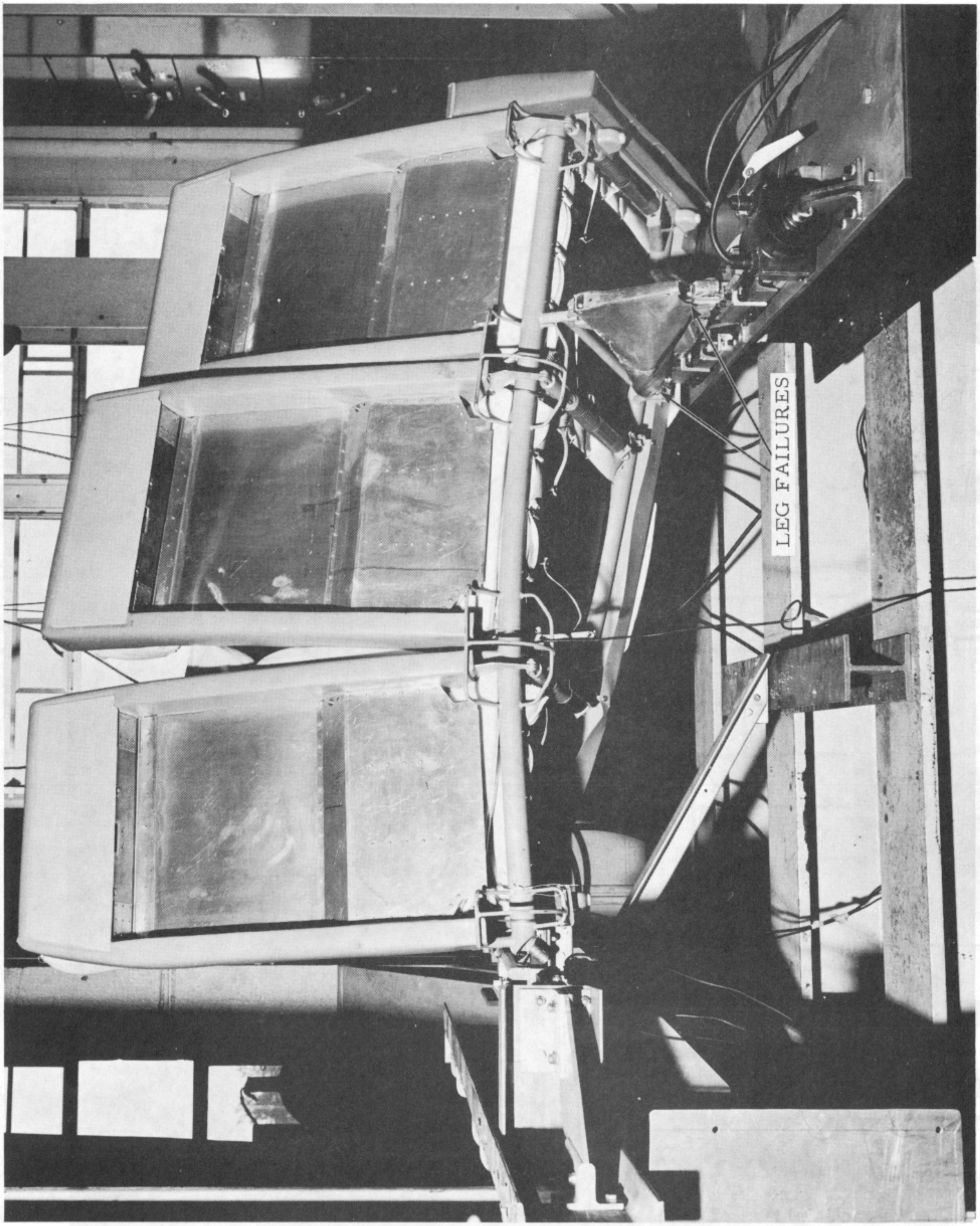


FIG. 3-32 REAR VIEW OF SEAT C-5 AFTER TEST NO. 84

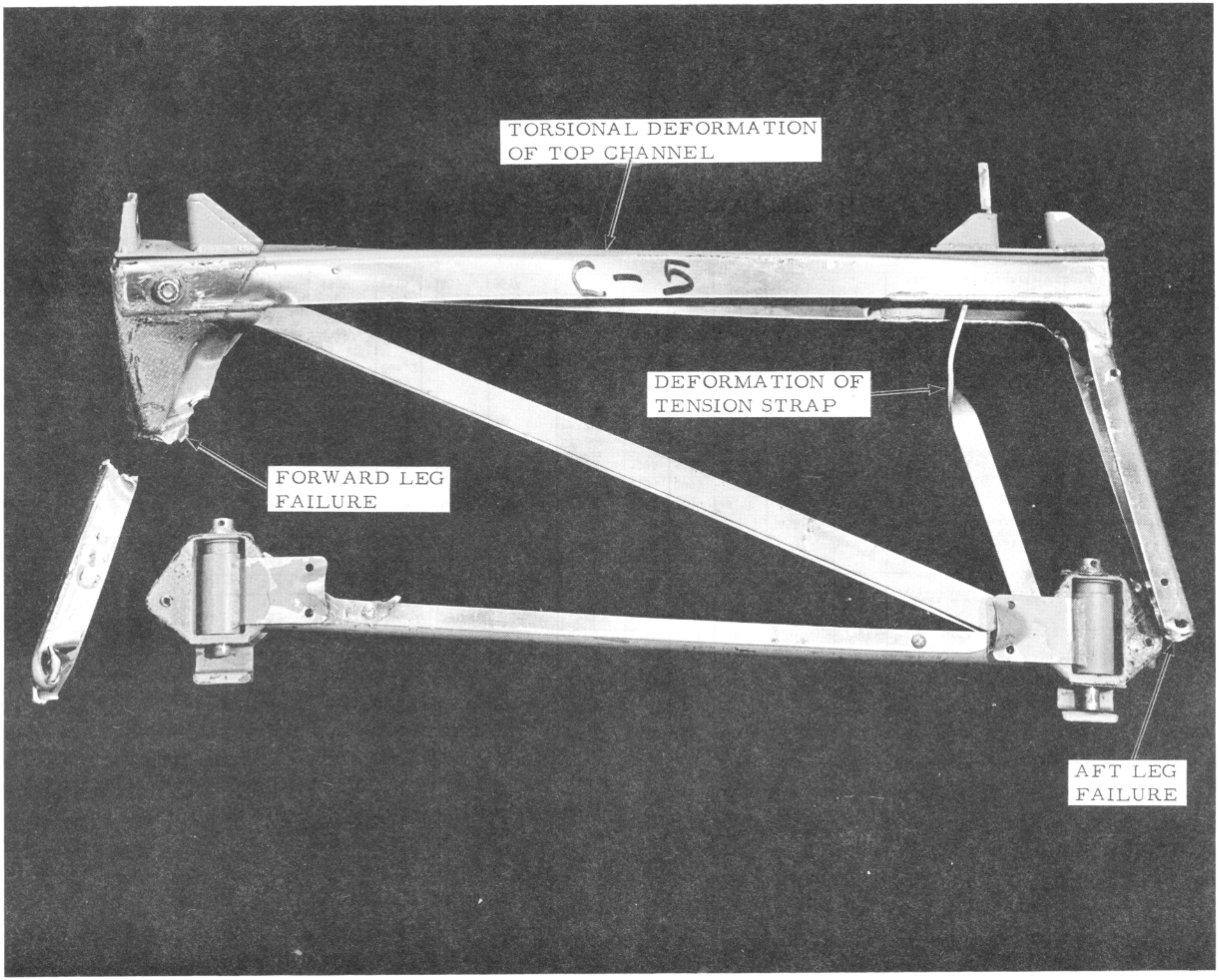


FIG. 3-33 LEG FRAME OF SEAT C-5 AFTER TEST NO. 84

TABLE 3-VII

Test No.	Seat No.	Velocity Change	Input Time Pulse	Average Input Accel.	Left Forward Vertical Reaction	Right Forward Vertical Reaction Pos. - 1	Right Forward Vertical Reaction Pos. - 2	$R_1+R_2+R_3$	Left Aft Vertical Reaction	Right Aft Vertical Reaction Pos. - 1	Right Aft Vertical Reaction Pos. - 2	$R_4+R_5+R_6$	R_A+R_F	Peak Dummy Accel.	Effect Weight		REMARKS
		ft/Sec	Sec	g	lb	lb	lb		lb	lb	lb			g	lb		(Dynamic Tests)
		V	t_n	$\bar{G}$	R_1	R_2	R_3	R_F	R_4	R_5	R_6	R_A	R_T	g	Wt		
73	C-4	10.40 2.49	.127 .055	2.54 1.41	302 242	52 139	307 138	661 519	518 242	624 580	831 332	1973 1154	2634 1673	6.32 3.11	458 458		 Lower - Partial Data
74	C-4	16.04	.176	2.83	585	236	459	1280	828	847	352	2027	3307	11.38	458		
75	C-4	18.12 1.14	.182 .022	4.08 1.61	544 181	261 87	450 348	1255 616	600 247	1058 937	511 142	2169 1326	3424 1942	11.70 2.25	458		 Lower - Partial Data
76	C-4														458		No Data - Instrumentation Breakdown
77	C-4	7.85	.120	2.03	390	226	372	988	684	790	238	1712	2700	8.58	458		
78	C-4	25.72	.252	3.18	391	160	340	891	560	1010	534	2104	2995	6.48	458		
79	C-4	23.85	.123	6.02	680	832	649	2161	1050	1182	972	3204	5365	9.88	458		Inboard Legs Failed, Figures 3-34 and 3-35
Test No.	Seat No.	Left Forward Vertical Reaction	Right Fwd. Vert. Reaction Pos.1	Right Fwd. Vert. Reaction Pos.2	$R_1+R_2+R_3$	Left Aft Vertical Reaction	Right Aft Vertical Reaction Pos. - 1	Right Aft Vert. Reaction Pos.2	$R_4+R_5+R_6$	R_A+R_F	Effect Weight						
		lb	lb	lb		lb	lb	lb			lb						(Static Tests)
		R_1	R_2	R_3	R_F	R_4	R_5	R_6	R_A	R_T	Wt						
85	C-6	490 765	300 362	302 520	1092 1647	495 960	700 1339	577 1110	1772 3409	2864 5056	573						See Figures 3-36, 3-37 and 3-38. Weight Was Electronically Zeroed (6g = 5g + Wt)

SEAT C - VERTICAL DYNAMIC AND STATIC TEST DATA

FIG. 3-34 REAR VIEW OF SEAT C-4 AFTER TEST NO. 79

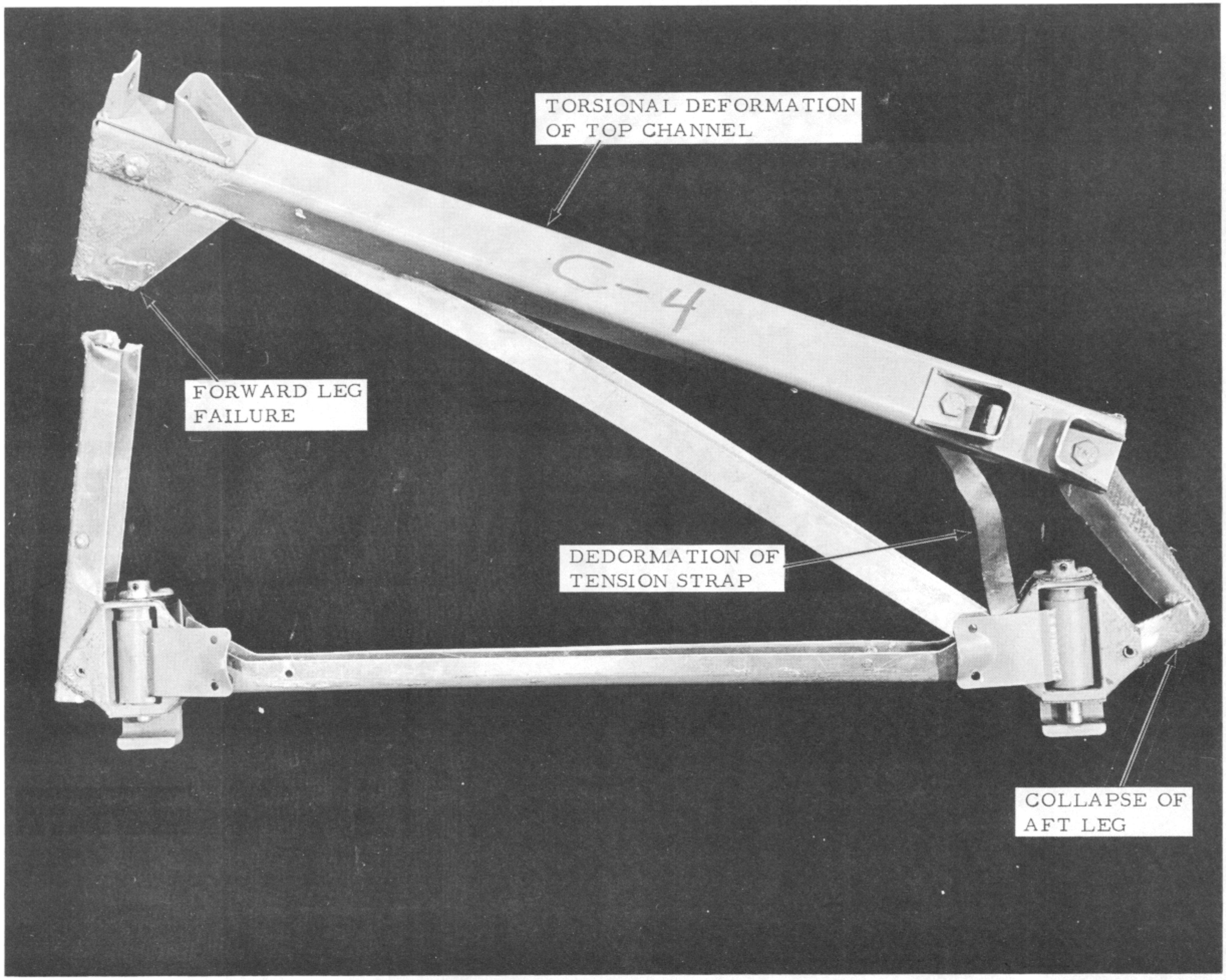


FIG. 3-35 LEG FRAME OF SEAT C-4 AFTER TEST NO. 79

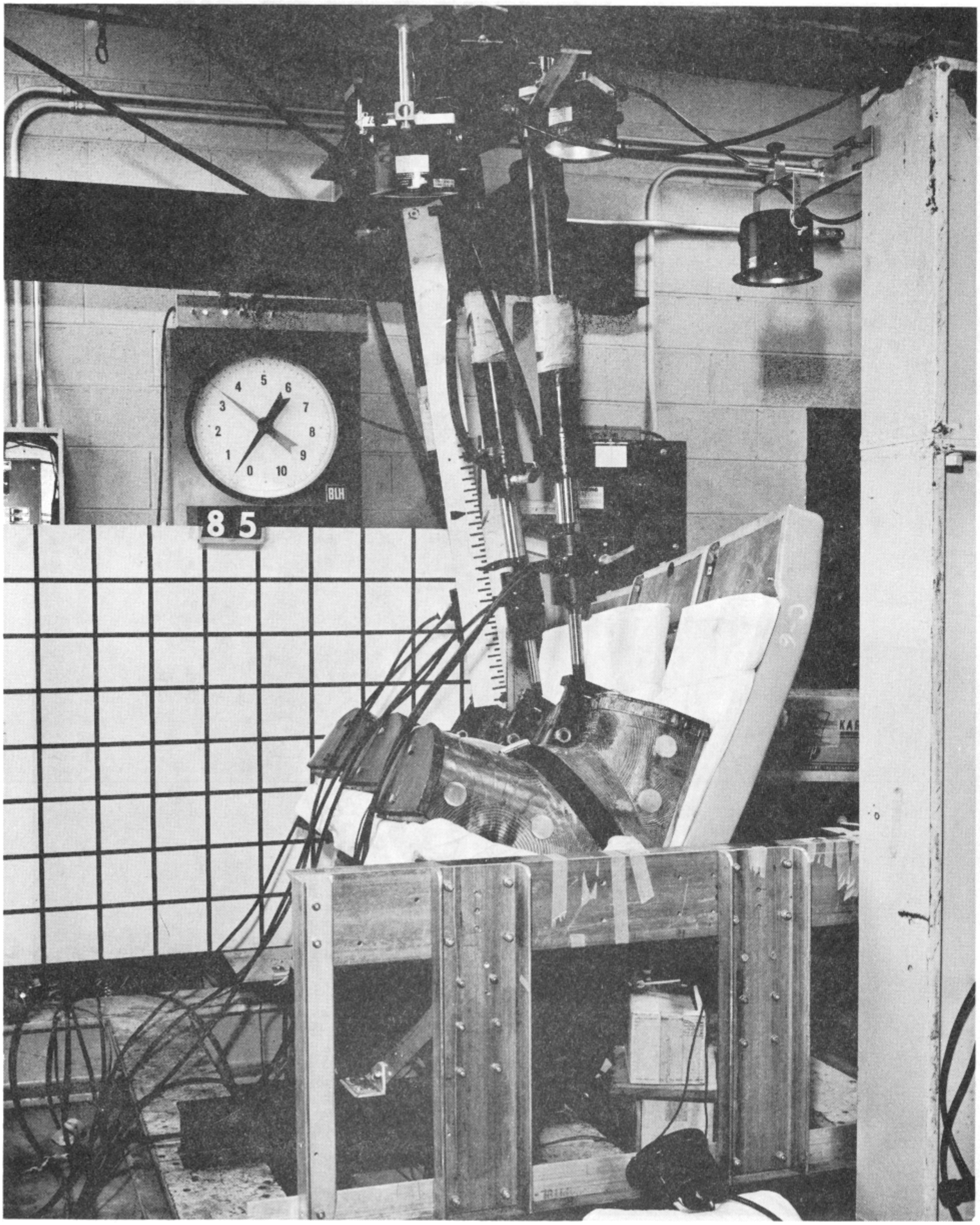


FIG. 3-36 SEAT C-6 AFTER STATIC TEST NO. 85

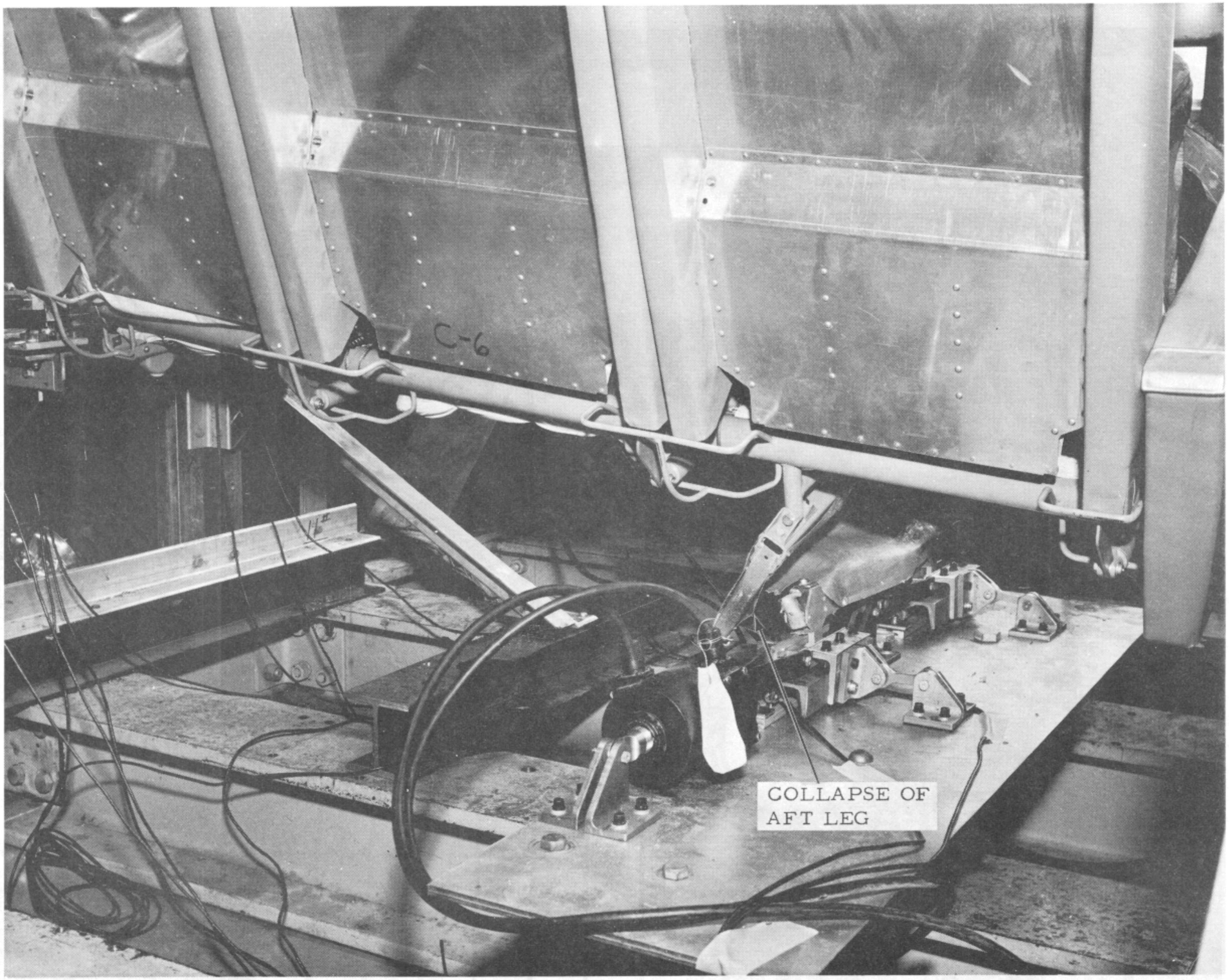


FIG. 3-37 REAR VIEW OF SEAT C-6 AFTER STATIC TEST NO. 85

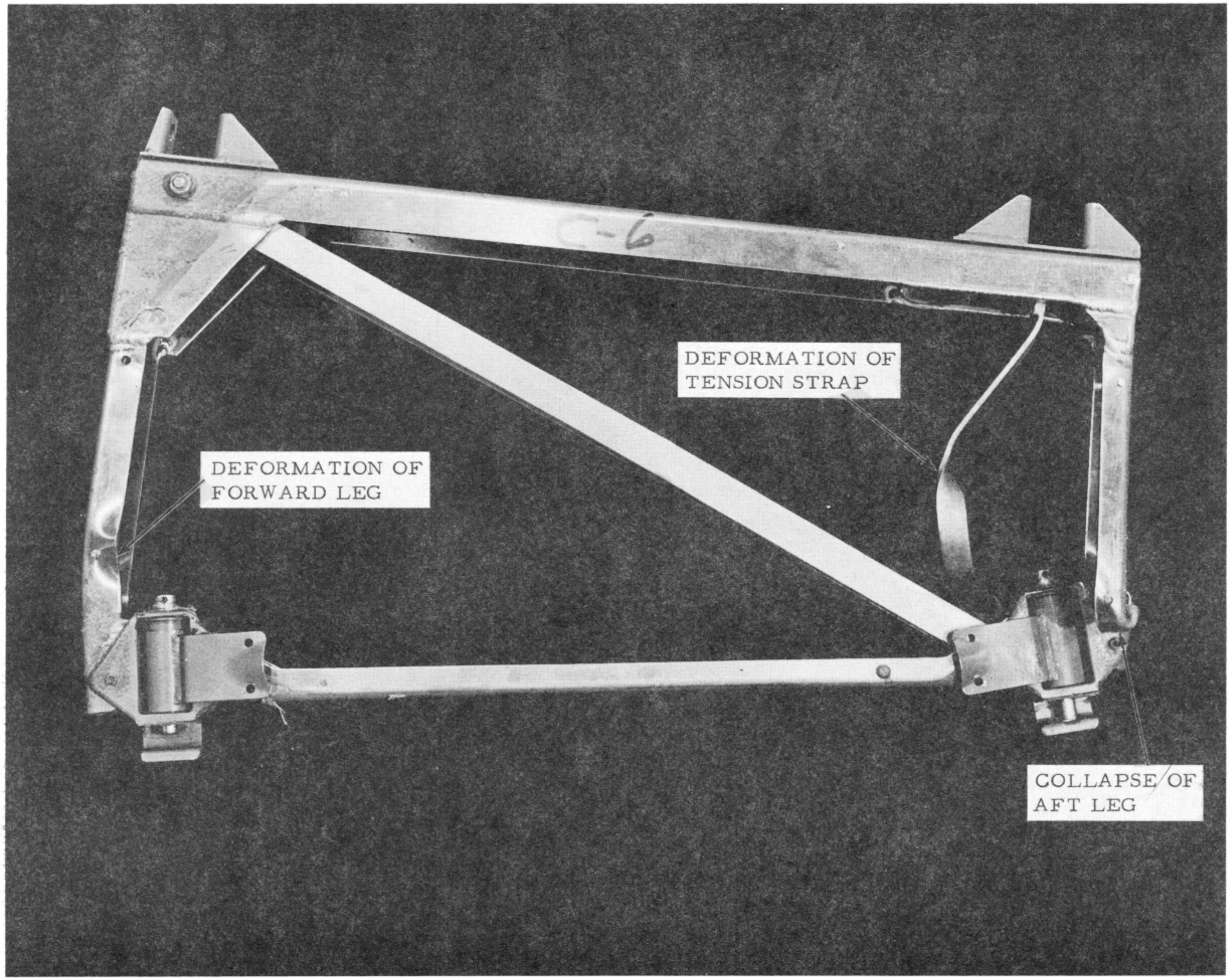


FIG. 3-38 LEG FRAME OF SEAT C-6 AFTER STATIC TEST NO. 85