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RESULTS FROM TESTS OF THREE PROTOTYPE GENERAL AVIATION SEATS

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SUMMARY

Jungle Aviation and Radio Service (JAARS) provided NASA Langley Research Center with three types of energy absorbing general aviation seats to be dynamically tested and evaluated for crash load attenuation. Two of the seats utilized S-shaped tube front legs that were designed to form plastic hinges and stroke when the design load was exceeded. The other seat used a foam wedge for energy absorption.

On the basis of the static and dynamic test results, it was recommended that the S-leg seats be redesigned to initiate stroking at approximately 12 G's rather than the 20 to 25 G range. A lower density foam was recommended for the foam block seat with more foam beneath the base of the spine.

INTRODUCTION

Jungle Aviation and Radio Service (JAARS), a non-profit organization delivering humanitarian services to remote areas, provided NASA Langley Research Center with three types of energy absorbing general aviation seats to be dynamically tested and evaluated for crash load attenuation. After development these seats are intended for use in the JAARS world-wide aircraft fleet.

One crew seat and two types of passenger seats were tested. The crew seat and one of the passenger seats which was foldable utilized S-shaped tube front legs that were designed to form plastic hinges and stroke when the design load was exceeded. The remaining passenger seat was composed of foam-block cushions.

Crash load attenuation tests conducted on the seats consisted of five dynamic tests which were performed at an impact velocity of 35 ft/sec at various pitch attitudes, and a series of static seat and seat component tests.

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TEST SPECIMENS

The three prototype general aviation aircraft seats, supplied by JAARS for testing at NASA Langley Research Center, are shown in figure 1 and consisted of a crew seat, a folding passenger seat, and a foam block passenger seat. Both the crew seat and the folding passenger seat were constructed of 4130 tubular steel and incorporated S-shaped front legs that were designed to form plastic hinges to limit the load and provide energy absorption (ref. 1). The cushion of the foam block passenger seat was composed of various-density foam layers.

TEST APPARATUS AND METHODS

Static and dynamic tests were performed on the seats and on various seat components. The dynamic tests were performed first, as they were the only tests requested by JAARS. However, in order to interpret the dynamic test data, it became necessary to conduct static and component tests.

The dynamic tests were performed by mounting the seats on a floor inside a steel cylinder and dropping the cylinder from a predetermined height to obtain the desired impact velocity. A photograph of the apparatus is presented in figure 2, and a description of the testing technique is detailed in reference 2. The orientation of the floor inside the cylinder could be changed from 0° to 90° by suspending the cylinder from different points on its rim. The cylinder was equipped with honeycomb and wedges, which impacted into small glass beads thereby tailoring the acceleration pulse transmitted to the seat. Honeycomb was installed to provide an acceleration limit of 35 G's.

A 50th percentile, hybrid II, part 572 anthropomorphic dummy, defined in reference 3, was used throughout the tests and was equipped with a three-point restraint (double shoulder harness and lap belt) provided by JAARS. The shoulder harness was attached to a bracket mounted on the test cylinder. The other ends were connected to the center of the lap belt. In all tests, the angle of the shoulder harness with the floor was no more than 30°. The lap belt was attached to the seat in all tests.

The crew seat was statically tested using the NASA Langley static seat testing apparatus shown in figure 3. Component tests were performed using a conventional Baldwin tension-compression testing machine with 100,000 pound capacity.

INSTRUMENTATION AND DATA REDUCTION

DC accelerometers were used in the dummy, on the seat, and on the floor to obtain a continuous recording of the accelerations during the dynamic tests. Figure 4 is a close-up view of the dynamic test apparatus and shows positive acceleration directions. Load cells were used on the shoulder harness and lap belt to record the tension in the straps. Extensometers were installed on the seat to monitor normal and longitudinal seat displacements. All data were transmitted to a tape recorder through an umbilical cord that was hard-wired to the instrumentation system.

In reducing the data, the analog signals were first digitized at 4000 samples per second, and the digitized accelerometer data were passed through the following digital filters:

Dummy chest	180 Hz
Dummy pelvis	180 Hz
Seat	20 Hz
Floor	20 Hz
Input pulse	20 Hz

Motion pictures were taken at 400 pps during the experiments, and still photographs were taken before and after the tests.

For the static tests, instrumentation consisted of extensometers to measure seat displacement and load cells to measure the forces. All data were recorded on an X, Y plotter.

DESCRIPTION OF TESTS

In preparation for each dynamic test, the test cylinder was raised 19 ft to obtain a free fall velocity of 35 ft/sec. The test numbers and pitch attitudes at impact were as follows:

TEST	JAARS SEAT	ATTITUDE
1	crew	-42° pitch down
2	folding passenger	-30° pitch down
3	foam block passenger	0° pitch (vertical)
4	foam block passenger	-31.5° pitch down
5	crew	-30° pitch down

Because very little damage occurred to the crew seat in test 1, the seat was repaired and tested again at a different pitch attitude in test 5.

The crew seat was statically tested to determine load-deflection characteristics by applying an increasing downward force to the seat through a wooden body block as shown in figure 3. Component tests were performed by compressing specimens in a Baldwin testing machine.

RESULTS AND DISCUSSION

Dynamic Tests

The vertical input acceleration for the tests averaged 20 G's (filtered at 20 Hz) with total pulse duration of 0.088 sec. The pulse shape was approximately trapezoidal with an onset rate of 1800 G's/sec. The unfiltered test cylinder acceleration time history exhibited acceleration spikes of high frequency exceeding 20 G's. However, the spikes were primarily a result of natural elastic vibrations of the cylinder and were considered to have no significant effect on the seat and dummy dynamics.

The first test with the crew seat was performed at 35 ft/sec with the floor pitched down 42° to the horizontal. No significant stroking of the seat was observed during this test; and it was decided, after contacting JAARS, to employ a 30° pitch down configuration for the rest of the tests except for test 3, which was scheduled for zero pitch attitude. For the 30° pitch down cases, the 20 Hz filtered acceleration perpendicular to the floor (normal) averaged 17.8 G's with 0.085 sec duration. The filtered acceleration parallel to the floor (longitudinal) averaged 9.4 G's with 0.090 sec duration. Table I gives a summary of the test cylinder input, floor, seat pan, and dummy pelvis accelerations; and Table II gives the maximum restraint loads as measured in the shoulder harness and seat belts.

JAARS Crew Seat. - Figures 5(a) through 5(e) show pre-test and post-test photographs of the JAARS crew seat for tests 1 and 5. Figures 5(a) and 5(b) show the test set-up (impact position) for the 42° pitch down condition (test 1) and 30° pitch down condition (test 5), respectively. For each test, the seat height adjustment was set in the intermediate notch; the lowest notch setting could not be used because of interference between the seat and the seat rail. The seat back adjustment was also set in the intermediate notch because another interference prevented the seat back from being positioned in the most reclined position.

Figures 5(c) and 5(d) present post-test photographs of test 1 and test 5, respectively. Extensometer data from test 1 indicated a maximum seat displacement of approximately 1 inch during impact in both the normal and longitudinal directions. However, post-test measurements showed that the seat was permanently deformed less than 0.5 inch in either direction. Extensometer data from test 5 indicated negligible displacements, which were confirmed by post-test measurements.

The only significant damage to the seat was a weld failure in test 1. This failure, seen in figure 5(e), occurred on the left bottom side of the seat where the S-tube joins the larger diameter tube. This weld was repaired before the seat was retested in test 5.

Figures 6 and 7 provide the acceleration time histories for tests 1 and 5, respectively. These time histories consist of the test cylinder input pulse accelerations, and the normal and longitudinal accelerations measured at the floor, the seat pan, and the dummy chest and pelvis. Since the seat stroked very little at these input acceleration levels, the dummy accelerations followed or exceeded the floor accelerations. In test 5 the vertical input acceleration to the test cylinder was only 3 G's lower than in test 1; thus, normal accelerations at the floor, seat pan, pelvis, and chest were about the same for the two tests. The longitudinal floor acceleration in test 1 was 13 G's as compared to 9 G's for test 5. Consequently, the lap belt and shoulder harnesses, which must restrain the occupant against longitudinal accelerations, were loaded much higher in test 1 (See Table II). Post-test inspection of the restraint system indicated that the lap belt had been pulled up by the shoulder harness into the abdominal region of the dummy. It would appear that a lap belt-buckle tie-down strap would help prevent the shoulder harness from pulling the lap belt up during impact.

JAARS Folding Passenger Seat. - Figures 8(a) through 8(c) are pre-test and post-test photographs of the JAARS folding passenger seat for test 2. Figure 8(a) shows the pre-test set-up with the apparatus being readied for the 30° pitch down impact attitude, and figures 8(b) and 8(c) are two views of the seat pan failure which occurred during the test.

In this test, the S-shaped leg showed more permanent deformation than that experienced by the crew seat in tests 1 and 5. The attachment of the front S-leg to the seat frame was farther rearward in the case of the folding passenger seat. This produced a larger moment arm between the seat frame and hinge point of the S-leg, thereby causing the leg to stroke at a lower impact loading. The front of the seat collapsed approximately 1.3 inches in the normal direction as measured from the front target (see figure 8(b)). The rear of the seat showed negligible displacement. Due to seat pan failure, the cushions protruded 1.75 inches below the seat frame on the left side, as shown in figure 8(b). Cross stabilizing wires caught the aluminum seat pan and prevented it from failing completely. The two circular cut-outs in the rear of the seat pan, identified in figure 8(c), contributed to the seat pan failure by weakening it at a high load carrying point. As noted in the figure, all rivets were sheared on the left side of the seat pan, and the most rearward rivet was sheared on the right side of the seat pan. On the back of the seat pan, four rivets were sheared on the left side.

Figure 9 presents the acceleration time history of the test cylinder input pulse and the normal and longitudinal acceleration time histories of the floor, seat pan, and dummy chest and pelvis for test 2. Although the front of the seat stroked 1.3 inches, the normal pelvis acceleration (31.4 G's) was slightly higher than that from tests 1 and 5, due perhaps to the rigidity of the back legs which also contributed to the seat pan failure.

JAARS Foam Block Passenger Seat. - Figure 10 presents pre-test and post-test photographs of the JAARS foam block passenger seat for tests 3 and 4. Figures 10(a) and 10(b) show the test set-up (impact position) for the 0° pitch down condition of test 3 and for the 30° pitch down condition of test 4, respectively. Note from the photographs that the dummy's back is more aligned with the vertical input pulse in the 30° pitch down condition (figs. 8(a) and 10(b)) than in the 0° pitch condition, (fig. 10(a)).

As noted in Table II, the restraint loads for test 3 were in the 50 to 60 lbs range and for test 4 extended from 150 to 300 lbs. In test 3, the back of the seat provided a large part of the longitudinal (dummy axes system) stopping force, which caused the seat back to plastically deform as the occupant's upper torso rotated backwards (see figure 10(c)). In test 4 the occupant's upper torso pitched forward, loading the restraint system. As seen in figure 10(d), the shoulder harness pulled the lap belt buckle upward, which is undesirable as submarining of the occupant could occur. The lap belt anchor points are too far rearward for this seat. Negligible crushing of the foam wedge occurred in the tests. Post-test inspection revealed that the foam wedge had cracked in the unsupported area beneath the seat (figures 10(e) and 10(f)).

Figures 11 and 12 present the acceleration time histories of the test cylinder input pulse, and the normal and longitudinal acceleration time histories of the floor, and dummy chest and pelvis for tests 3 and 4, respectively. Maximum normal pelvis acceleration occurred in test 4 (30° pitch down case) since the dummy's spine was more aligned with the vertical input pulse. The maximum longitudinal pelvis acceleration occurred in test 3 (0° pitch down case) because of the dummy's reclined position. In this case, the longitudinal acceleration results from the seat back loading and is in the opposite direction from the other tests (note positive polarity of acceleration trace in figure 11(b)).

Static Tests and Calculations

In order to help interpret dynamic seat test results, a series of static seat and seat-component tests were performed. The objectives of these tests were to determine the loads required to initiate stroking and to determine load-deflection curves.

JAARS Crew Seat. - The JAARS crew seat was tested in the NASA static seat testing apparatus to determine the vertical load at which stroking would occur. The vertical load reached a maximum value of 2640 lbs at which point the front legs began to buckle and then dropped to a minimum of 500 lbs as the legs collapsed (fig. 13(a). Since this seat had been dynamically tested twice (tests 1 and 5), the load of 2640 lbs may be somewhat low for an untested seat. No stroking of the back legs occurred up to the 6700 lb maximum capability of the test machine. If the angle that the back legs make with the vertical is increased, the back legs will collapse at a lower load. The welds at the junction of the front legs with the seat pan failed as can be seen in figures 13(b) and 13(c).

Simple calculations to compute the expected dynamic seat acceleration based on the static load data follow. The effective dummy weight is found by assuming 80 percent of the dummy weight acts on the seat (165 x .80 = 132 lbs). Dividing the maximum static seat load by the effective dummy weight gives an estimate of the dynamic dummy pelvis acceleration (2640/132 = 20 G's). Consequently, to initiate stroking, the dynamic vertical acceleration applied to the seat would need to be 20 G's. The crew seat did not exhibit any stroking in tests 1 and 5 because the peak normal acceleration was below 20 G's. As noted in reference 4, most of the present energy absorbing seats are designed to initiate stroking at approximately 12 G's. The occupant's weight is very important in energy absorbing seat design; since, for a given seat, the acceleration experienced is inversely proportional to the occupant's weight. For example, if this crew seat was designed for a 200 pound occupant with an effective weight of 160 lbs, the expected dynamic acceleration needed to initiate stroking would be 16.5 G's (2640/160). Typically the dummy's pelvis exhibits higher peak G values than estimated from static analysis due to dynamic amplification. In addition, the dummy's "spine" has a higher natural frequency and less damping than that of a human. The higher frequency spikes in the dummy pelvis and chest traces should be interpreted carefully.

<u>JAARS Folding Passenger Seat</u>. - The folding passenger seat base was cut into a left and right half and the components were statically tested. A C-section was cut from the S-leg of the right half of the seat and compressed in the static loading machine. A maximum force of 600 lbs was developed. The left half of the seat was then loaded in the normal direction such that both the front and back legs collapsed together. The maximum force reached 1710 lbs, which would imply that a total force of 3420 lbs would be needed to crush this seat. Dividing the seat force (3420 lbs) by the effective dummy weight of 132 lbs yields 25.9 G's as the estimated acceleration level needed to initiate stroking. Again 12 G's is a more reasonable design value to limit the acceleration experienced by the occupant to within human tolerance (ref. 4).

<u>JAARS Foam Block Passenger Seat</u>. - A static loading test of the 16.5 inch x 13.5 inch foam wedge was performed to determine its crushing load, and the results are presented in figure 14. The figure shows that a crushing plateau starts around 8000 lbs at approximately 1 inch deflection and extends up to about 10,000 lbs at approximately 4 inches deflection. This corresponds to loadings of 36 lb/in^2 to 45 lb/in^2, respectively. Assuming a pelvis contact area of 100 square inches (a conservative estimate) the corresponding force (3600 to 4500 lbs) is considerably greater than desired. Using an effective weight of 132 lbs, these loads correspond to 27.3 and 34.1 G's for a 50th percentile occupant. In addition, a minimum thickness of crushable foam is available under the spine where it is needed the most.

CONCLUDING REMARKS

Five dynamic seat tests at 35 ft/sec impact velocity were performed using three types of seats: (1) an S-leg crew seat, (2) an S-leg folding passenger seat, and (3) a foam block passenger seat. Static tests were performed after the dynamic tests to determine the vertical crushing loads of the seats.

The crew seat was dynamically tested twice and then statically crushed in the vertical direction. The normal dummy pelvis acceleration approached 30 G's in this seat with negligible plastic deformation of the legs. The vertical static test indicated at least 20 G's would be needed to initiate stroking. The seat should be redesigned to stroke at a static load of approximately 12 G's to limit the acceleration experienced by a representative occupant. The back legs are presently designed too strong and resisted stroking in the static test. A larger angle between the back legs and the vertical would allow the seat to deform at a lower load. A smaller diameter tube could also be used. Both welds at the top junction of the front legs and seat pan failed.

The shoulder harness system used was noted to interfere with the seat stroking. Also, the shoulder harness tended to pull the lap belt up into the soft abdominal region. To prevent this behavior for the crew seat, where pilot leg motion must not be restricted, a tie down for the buckle may be more desirable than moving the belt anchor points forward.

The folding passenger seat's aluminum seat pan failed in the dynamic test. The two circular cut-outs in the rear of the seat pan contributed to the pan failure. The front legs stroked approximately 1.3 inches vertically; but again, as in the crew seat, the rear legs did not stroke to lower the dummy pelvis acceleration, which reached 27.8 G's. The lap belt anchor is not properly located in this seat since crushing of the legs would produce slack from the lap belt. For a passenger seat without a buckle tie down strap, the lap belt anchor should be located on the seat pan tube approximately two inches forward of the seat back intersection point. This belt position tends to resist the upward pull of the shoulder harness to prevent submarining.

The vertical static test indicated the folding passenger seat would require 3420 lbs of force to initiate stroking corresponding to a 25.9 G load for a 50th percentile occupant. The desirable maximum static load for a 50th percentile occupant would be 1600 lbs with a 12 G loading.

The foam block seat was dynamically tested at 0° and 30° pitch. No significant stroking of the foam wedge could be measured post-test. The maximum normal pelvis acceleration for the tests was 29.0 G's for the 30° pitch down test in which the seat back is closely aligned with the vertical input acceleration. For the 0° pitch case, the restraints carried only 50 to 60 lbs of load because the seat back was heavily loaded and deformed plastically as the occupant rotated backward. The lap belt anchor points for this seat should also be moved forward two inches from the seat back intersection with the pan to prevent submarining.

The 16.5 inch x 13.5 inch foam wedge was crushed statically and developed 10,000 lbs force at a 3 inch deflection. In order to keep the force more constant and independent of the pelvis contact area, an aluminum seat pan might be desirable between the cushion and the wedge. A foam should be chosen to crush at approximately 1600 lbs to limit the occupant acceleration to a reasonable value within human tolerance. In addition, more foam thickness is desirable under the spine.

REFERENCES

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2. Alfaro-Bou, Emilio; Fasanella, Edwin L.; and Williams, M. Susan: Determination of Crash Test Pulses and Their Application to Aircraft Seat Analysis. SAE Paper 810611, April 1981.

3. U. S. Code of Federal Regulations, Title 49, Chaper 5, Part 572: Anthropomorphic Test Dummy. Government Printing Office, Washington, D.C., (Rev.) 1978.

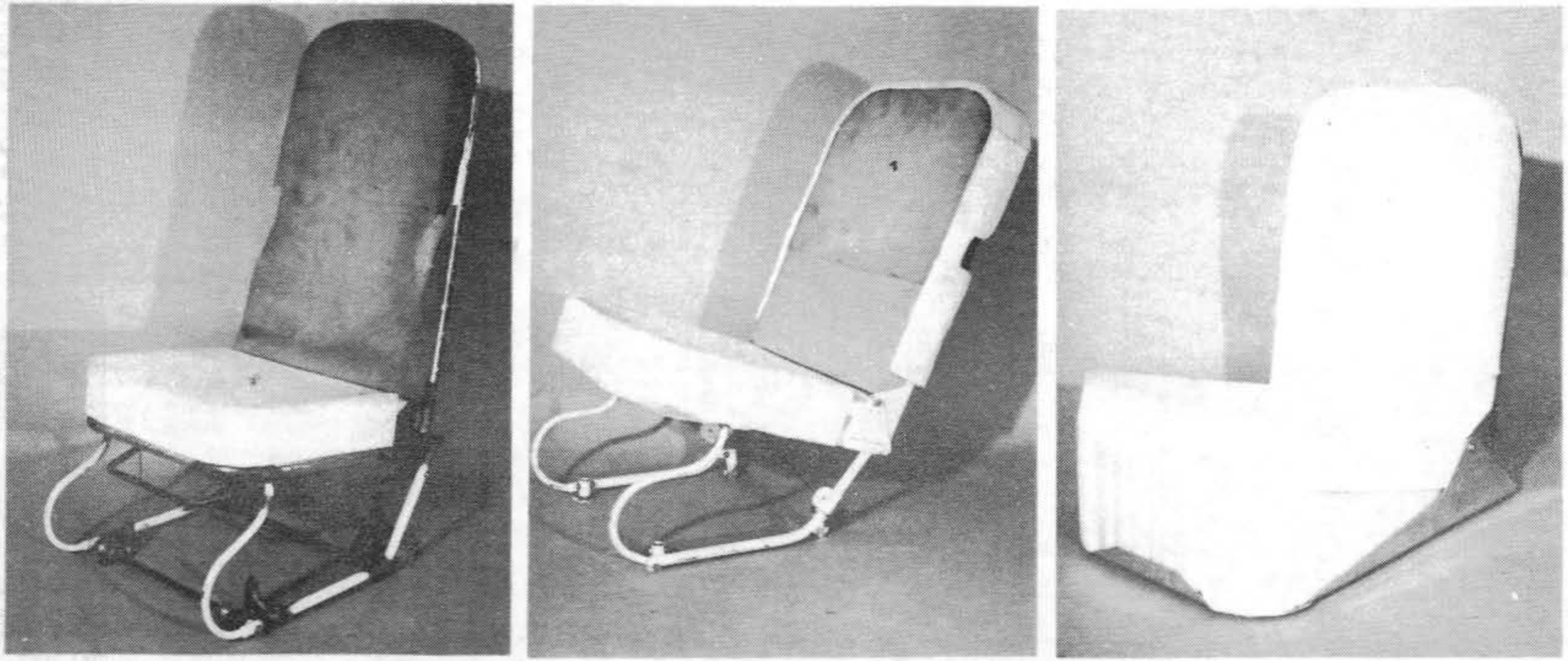
4. Desjardins, S. P.; and Laananen, D. H.: Aircraft Crash Survival Design Guide. USARTL 79-22A, B, C, D, and E, 1980.

TABLE I. - JAARS DYNAMIC SEAT TESTS

JAARS Seat Test	Vertical Input Acceleration		Floor N		Floor L		Seat Pan N		Seat Pan L		Pelvis N		Pelvis L	
	G_{max}	ΔT (sec)	G_{max}	ΔT (sec)	G_{max}	ΔT (sec)	G_{max}	ΔT (sec)	G_{max}	ΔT (sec)	G_{max}	ΔT (sec)	G_{max}	ΔT (sec)
1	-21.6	.093	-15.9	.088	-13.2	.092	-17.1	.083	-17.0	.091	-27.8	.070	-14.9	.093
2	-22.1	.087	-20.1	.088	- 9.9	.092	-22.5	.091	- 7.1	.096	-31.4	.077	-13.5	.054
3	-20.7	.084	-21.5	.080	+ 1.5	.049	-	-	-	-	-25.7	.083	+18.3	.074
4	-18.6	.086	-16.4	.083	- 9.6	.089	-	-	-	-	-29.0	.069	- 4.5	.035
5	-18.2	.088	-16.8	.085	- 8.6	.089	-17.1	.084	-10.4	.087	-27.8	.068	-10.1	.063

TABLE II. - MAXIMUM RESTRAINT LOADS

JAARS TEST	LEFT SHOULDER HARNESS (LBS)	RIGHT SHOULDER HARNESS (LBS)	LEFT LAP BELT (LBS)	RIGHT LAP BELT (LBS)
1	640	630	310	220
2	-	350	200	110
3	67	56	54	56
4	300	170	150	160
5	340	250	76	130



CREW SEAT

FOLDING PASSENGER SEAT

FOAM BLOCK PASSENGER SEAT

Figure 1.- JAARS seats.

Figure 2.- Test cylinder in release position.

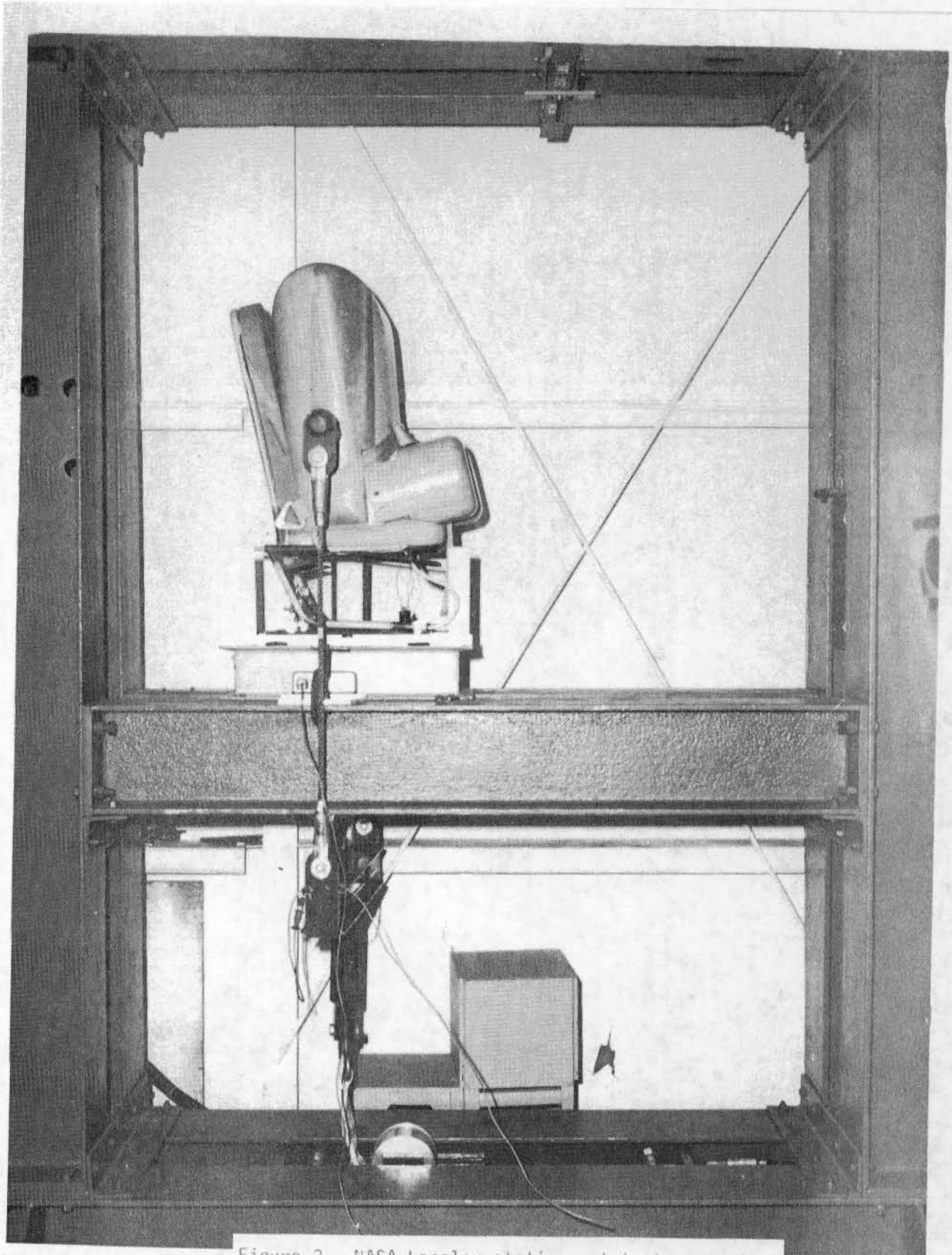


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Figure 3.- NASA Langley static seat test apparatus.

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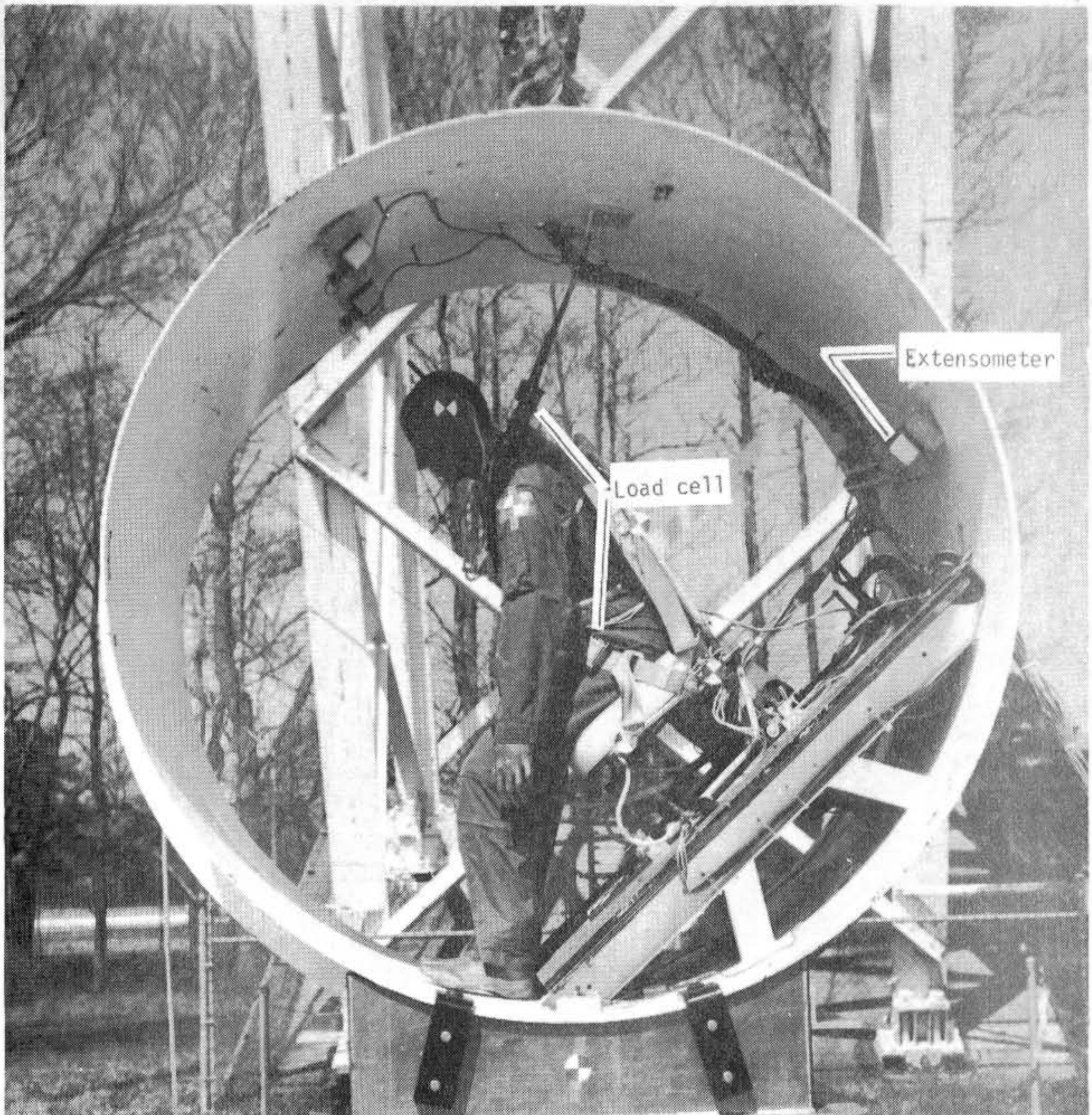
L-82-2,690

Figure 4.- Dynamic test apparatus.



(a) Pre-test set-up for test 1.

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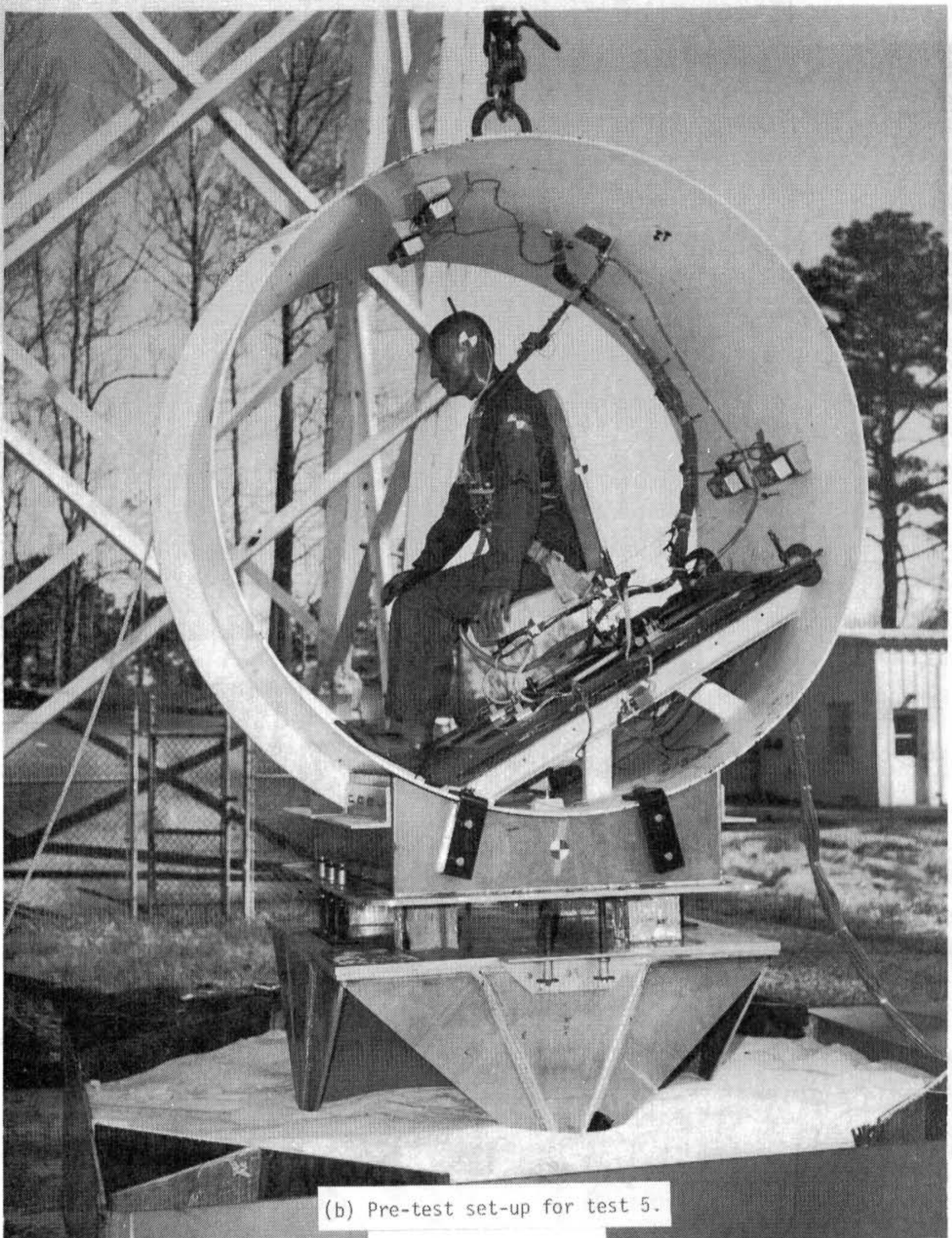
Figure 5.- Pre-test and post-test photographs of tests 1 and 5.



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(b) Pre-test set-up for test 5.

Figure 5.- Continued.

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(c) Post-test view of test 1.

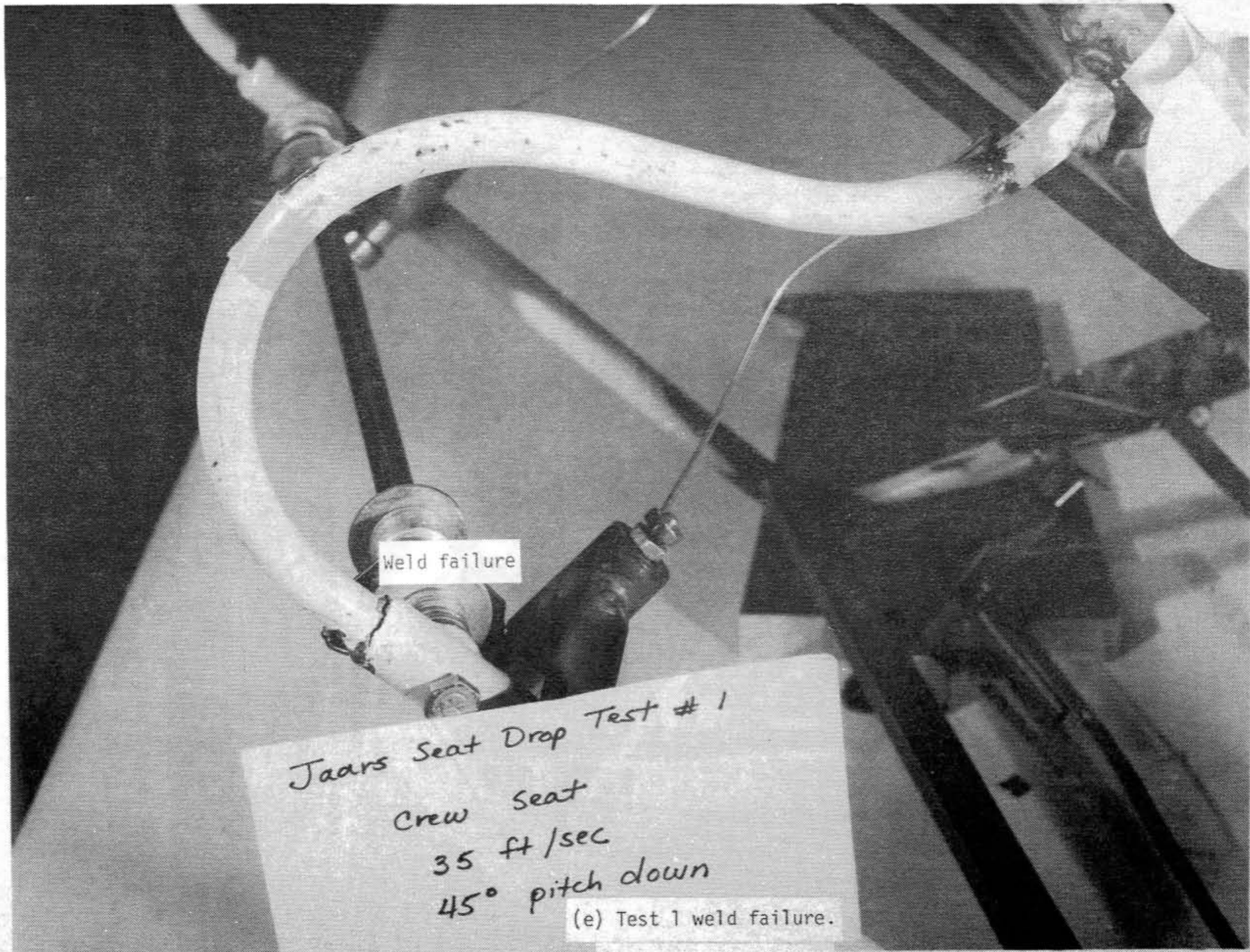
Figure 5.- Continued.

(d) Post-test view of test 5.

Figure 5.- Continued.

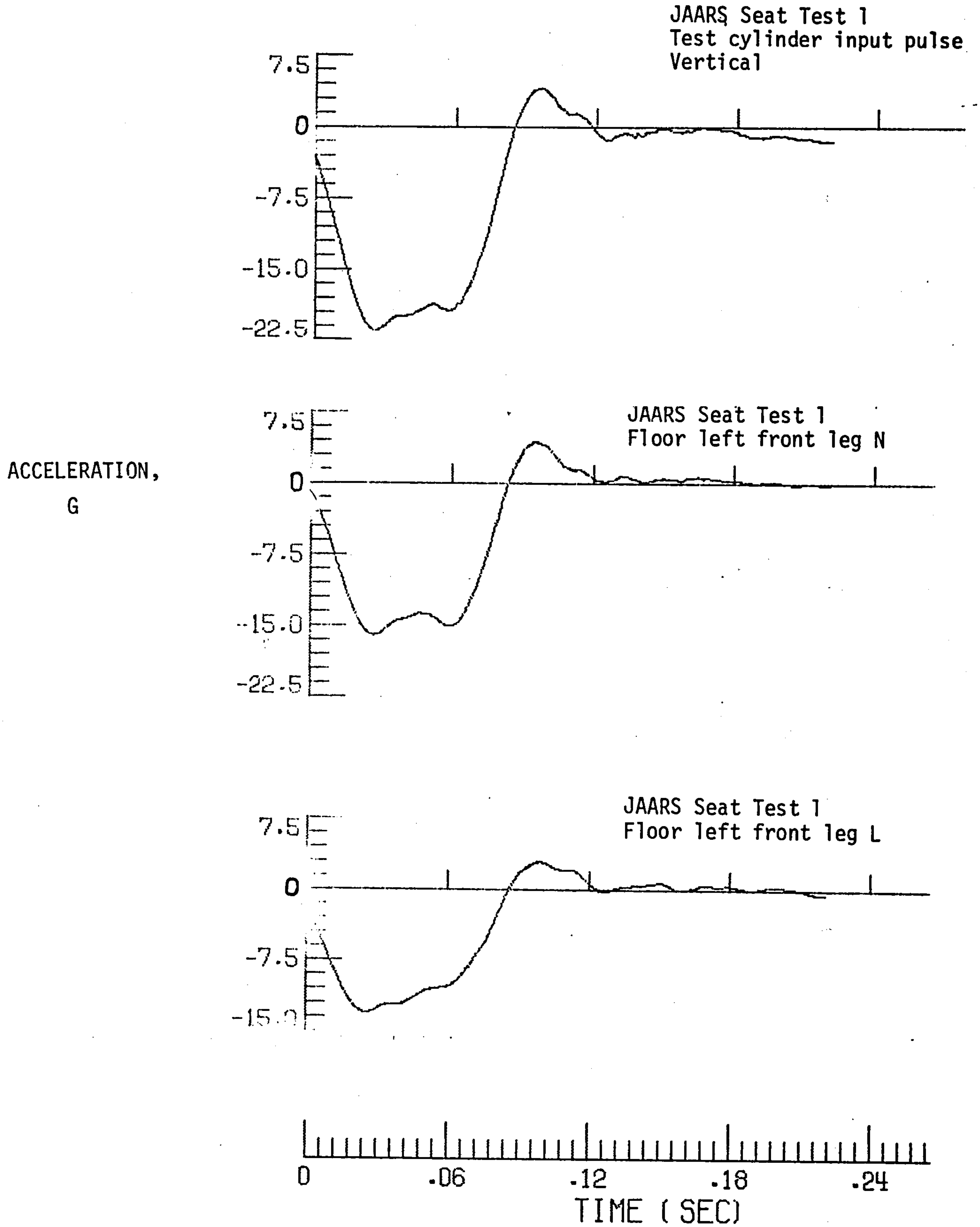
NASA
L-82-3,084

NASA
L-82-2,874



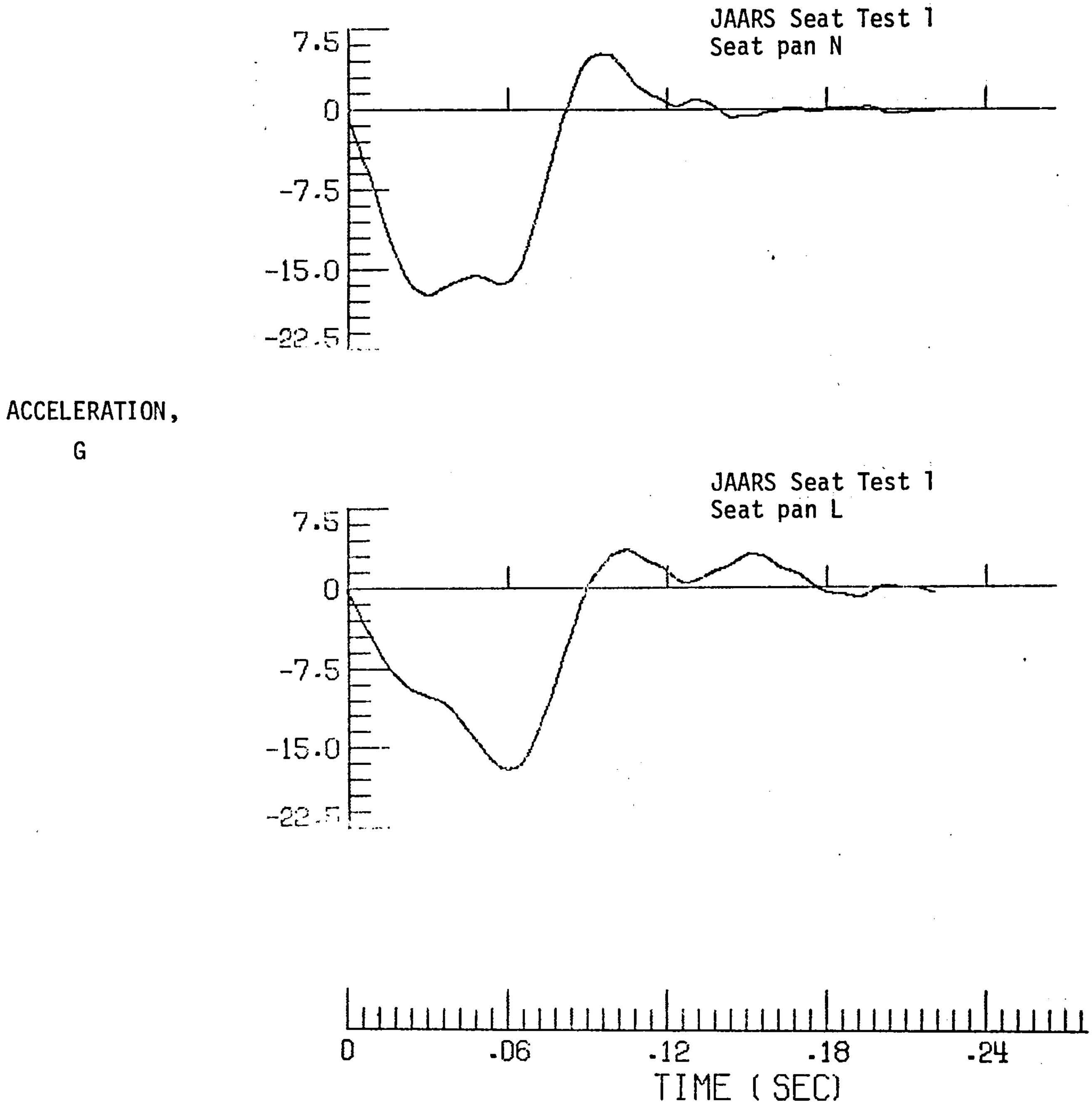
(e) Test 1 weld failure.

Figure 5.- Concluded.



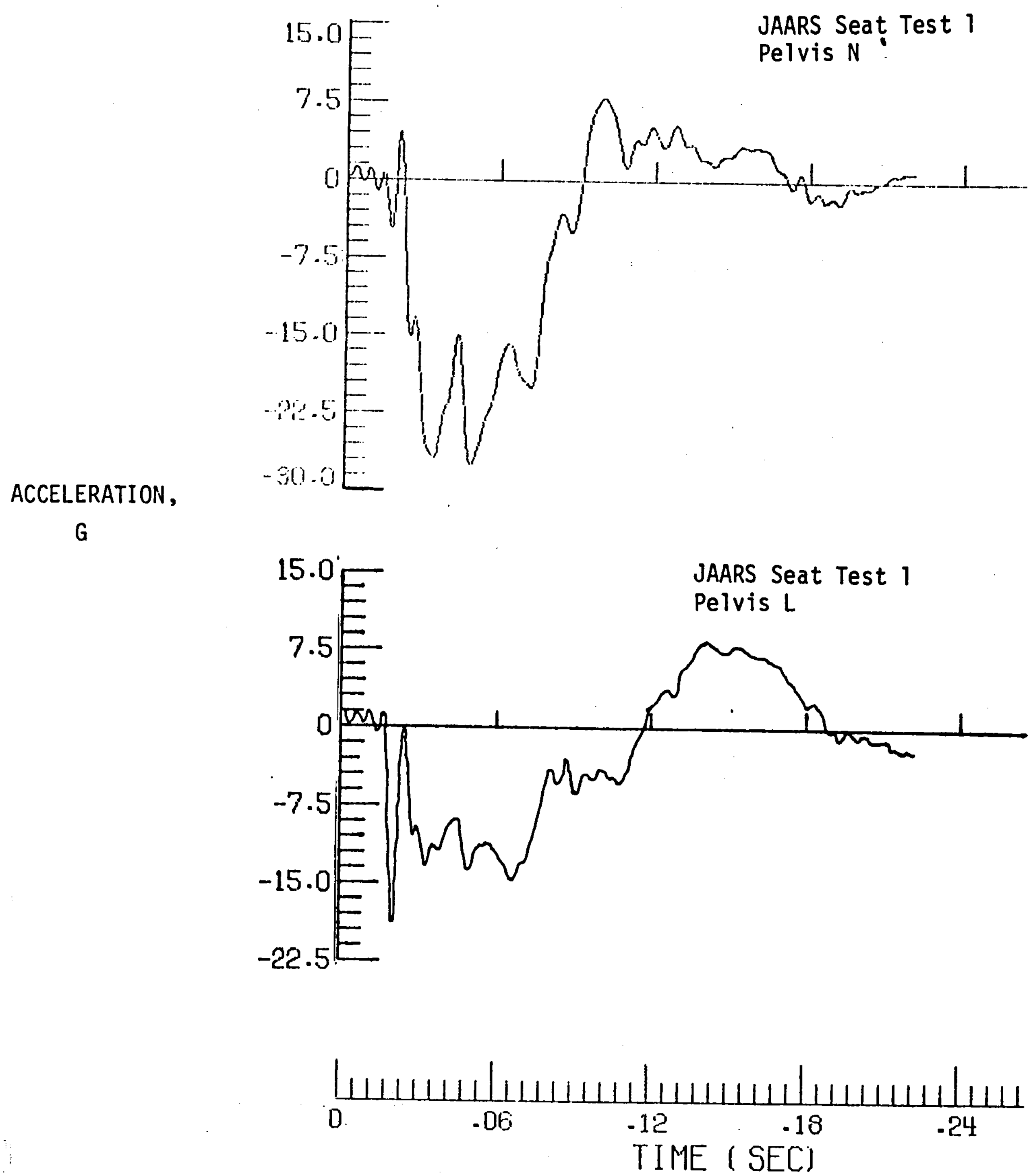
(a) Input pulse and floor accelerations.

Figure 6.- Acceleration time histories for test 1.



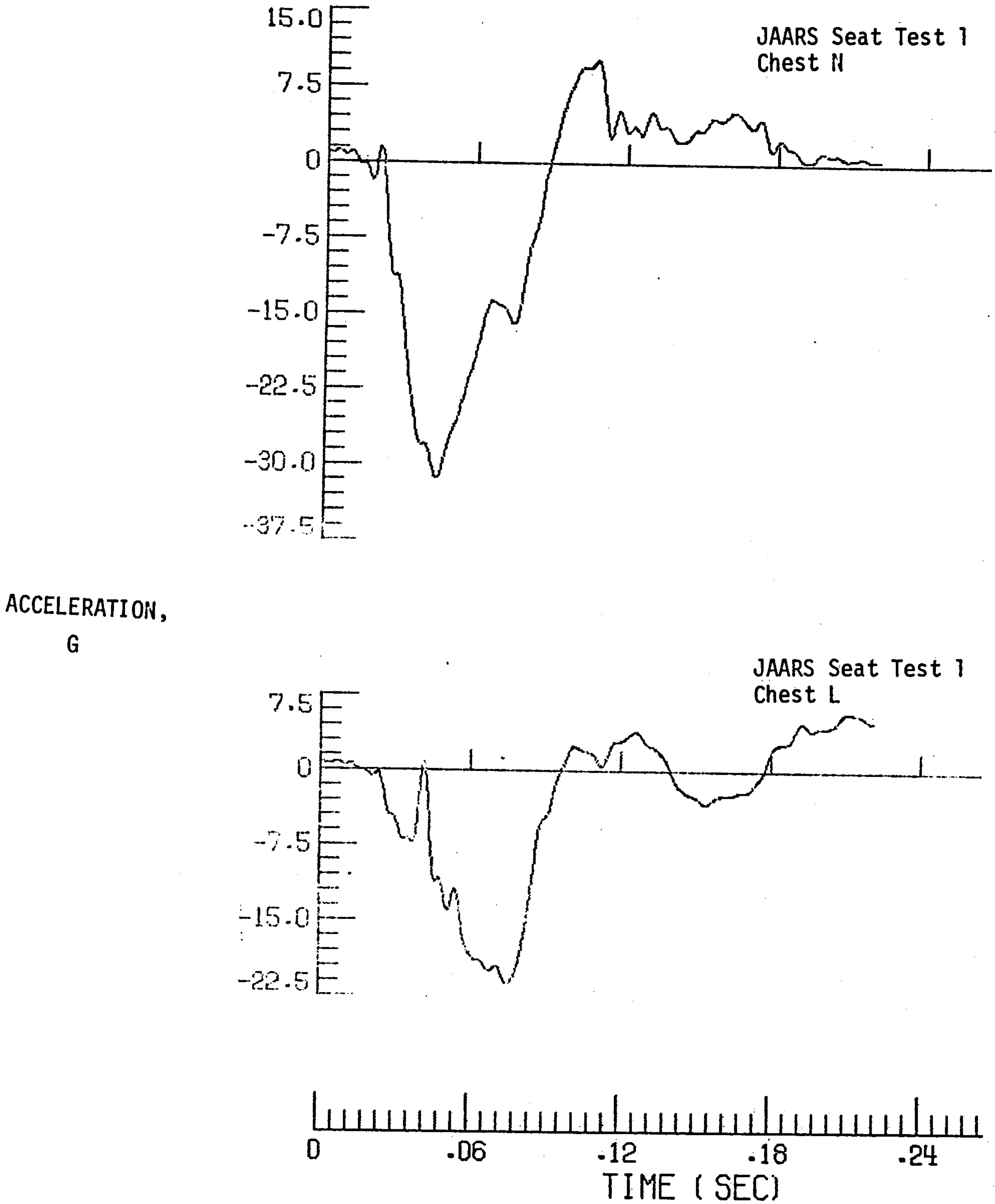
(b) Seat pan accelerations.

Figure 6.- Continued.



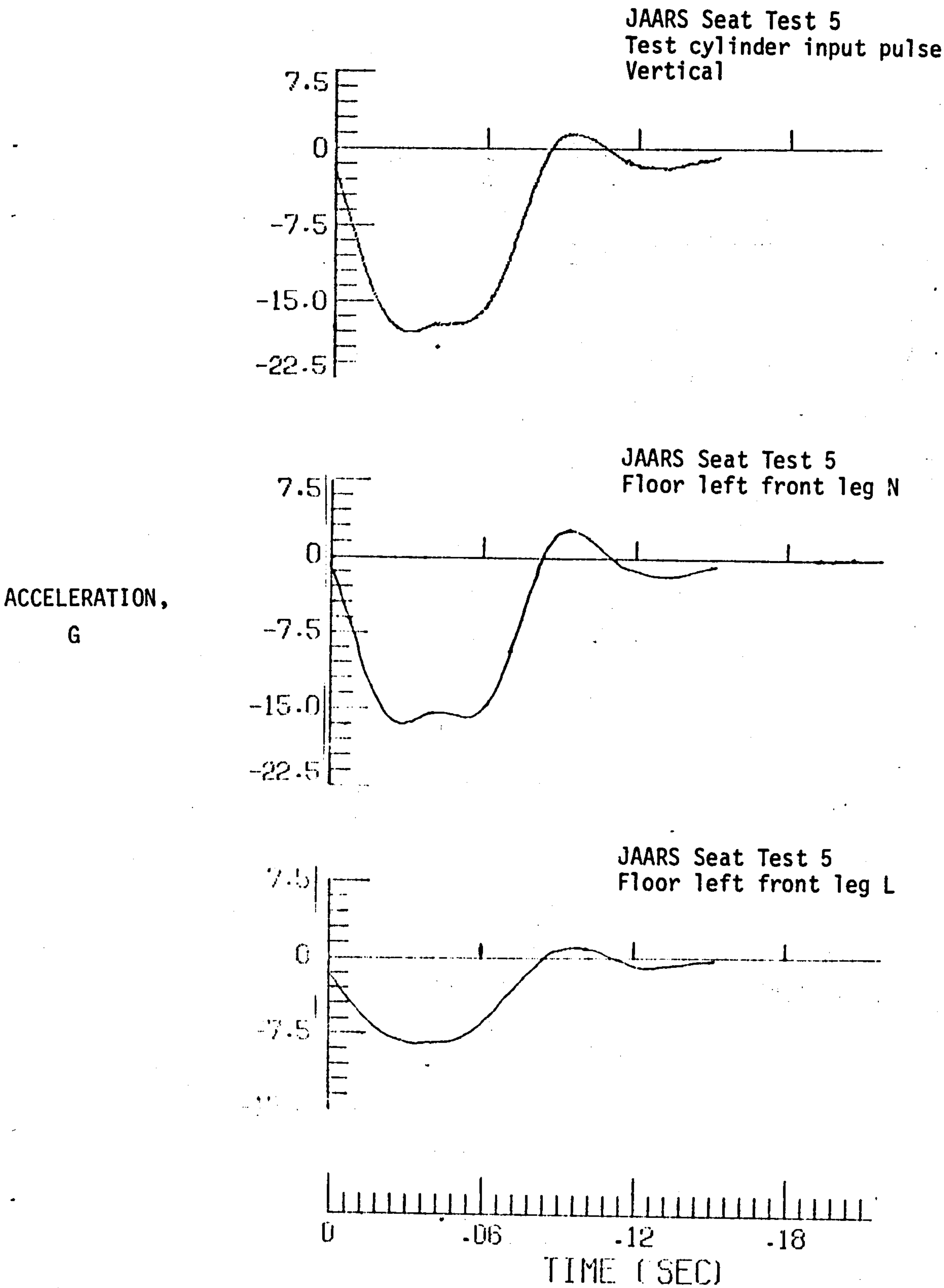
(c) Pelvis accelerations.

Figure 6.- Continued.



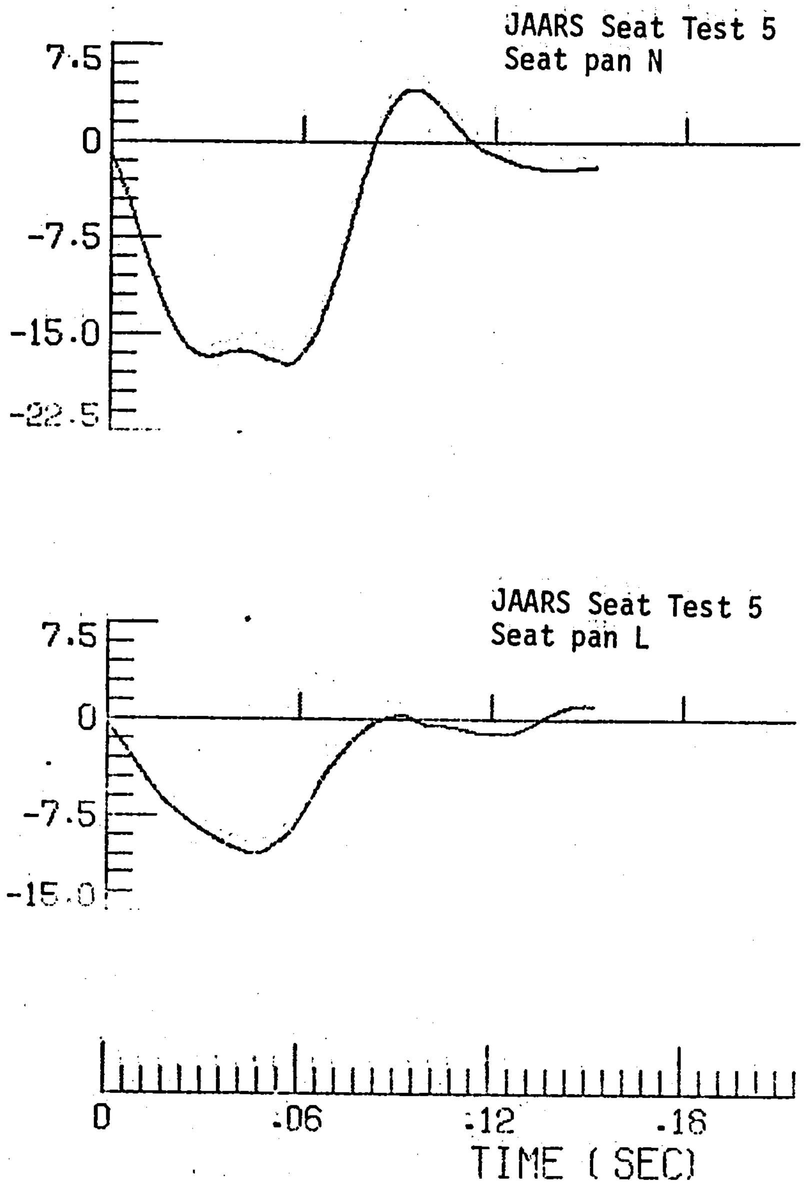
(d) Chest accelerations.

Figure 6.- Concluded.



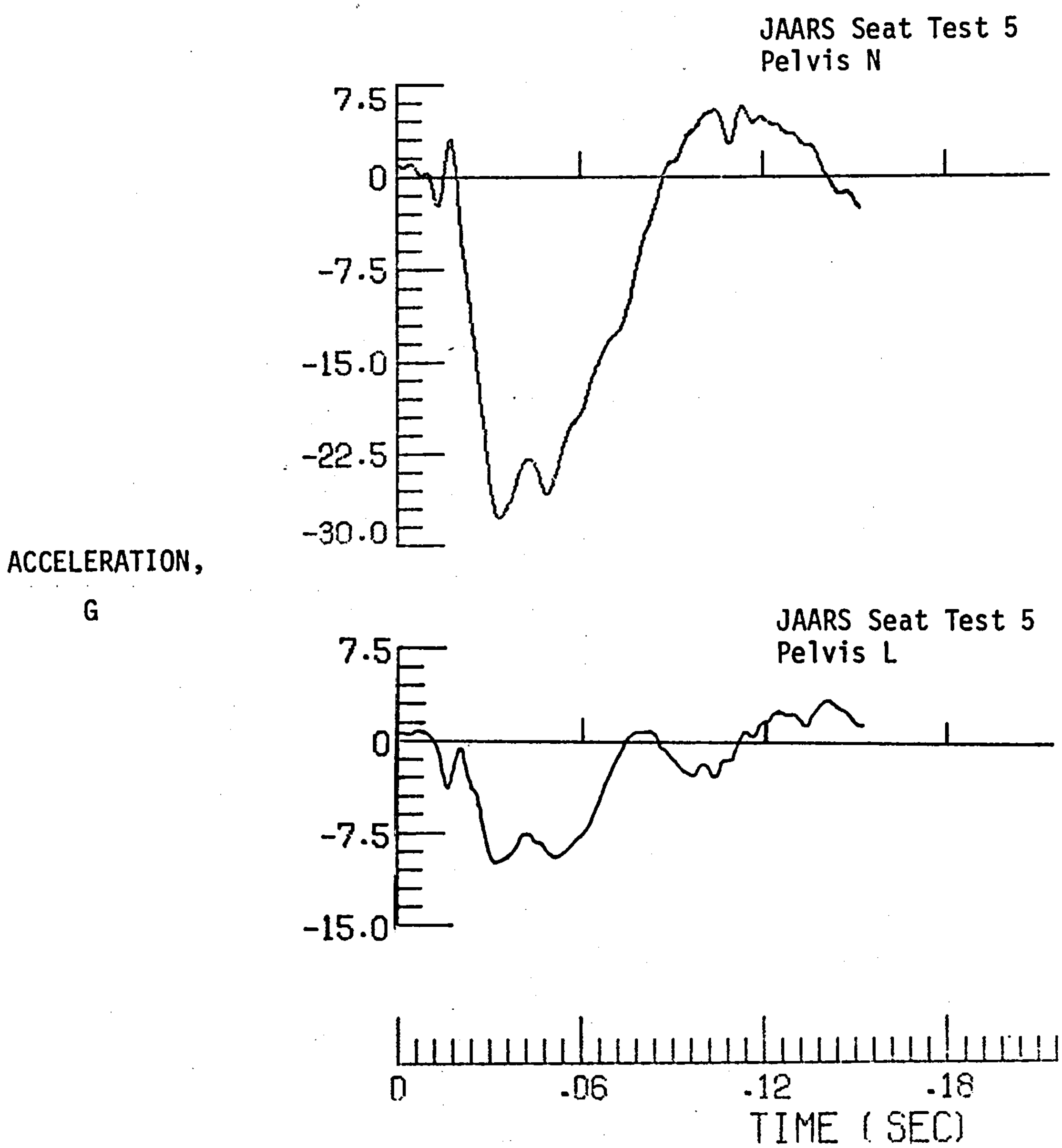
(a) Input pulse and floor accelerations.

Figure 7.- Acceleration time histories for test 5.



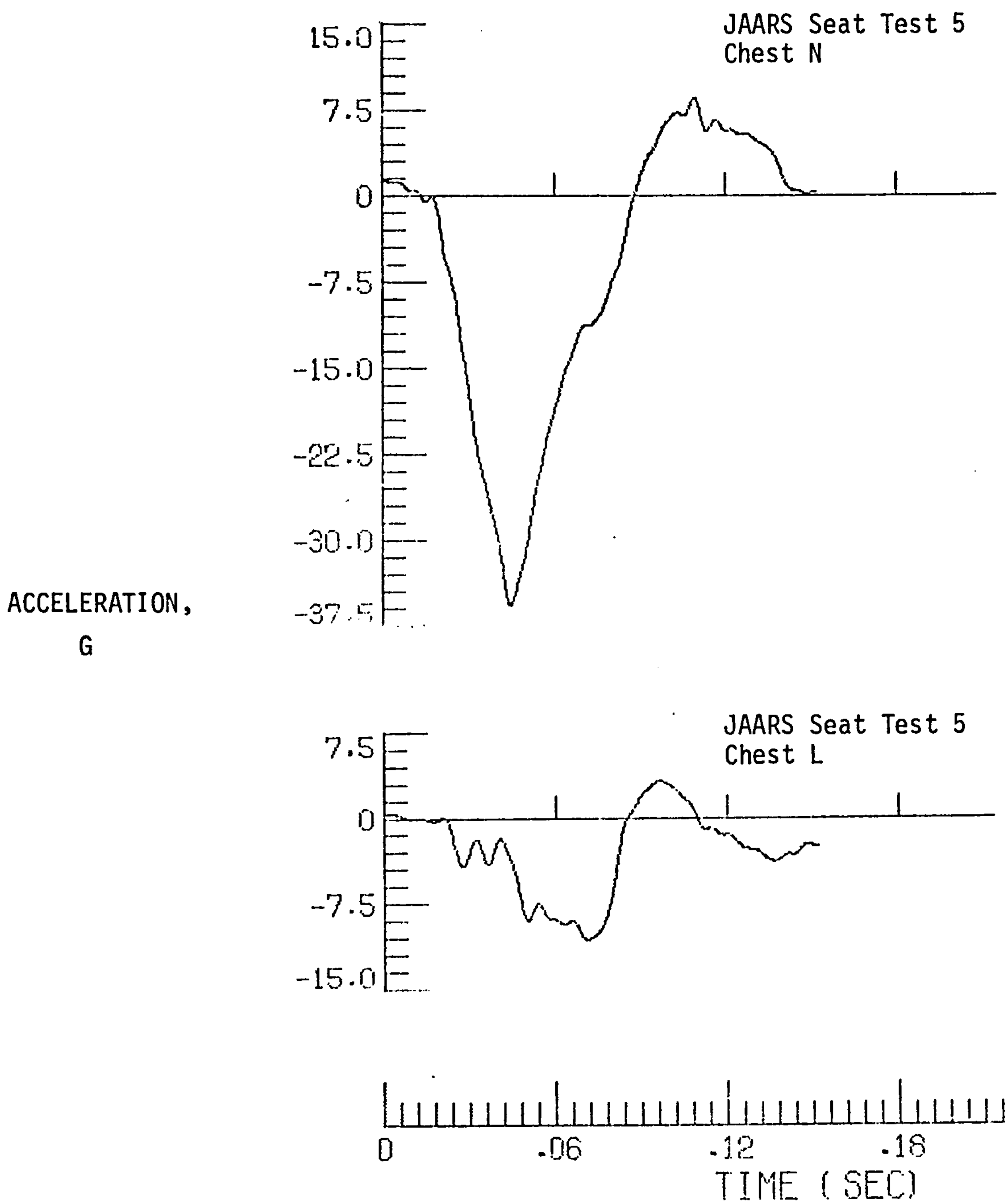
(b) Seat pan accelerations.

Figure 7.- Continued.



(c) Pelvis accelerations.

Figure 7.- Continued.



(d) Chest accelerations.

Figure 7.- Concluded.

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(a) Pre-test set-up.

Figure 8.- Pre-test and post-test photographs of test 2.

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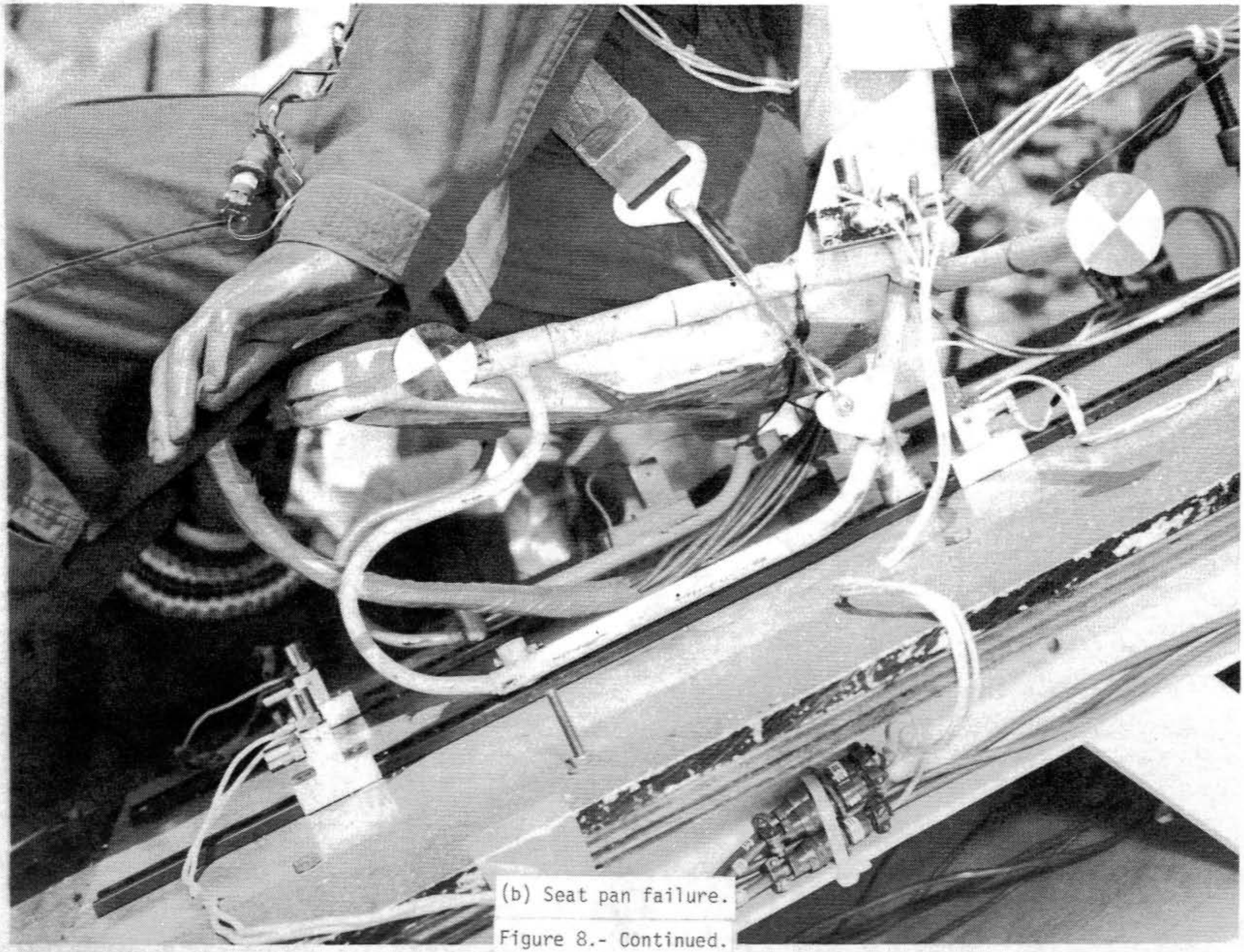

(b) Seat pan failure.

Figure 8.- Continued.

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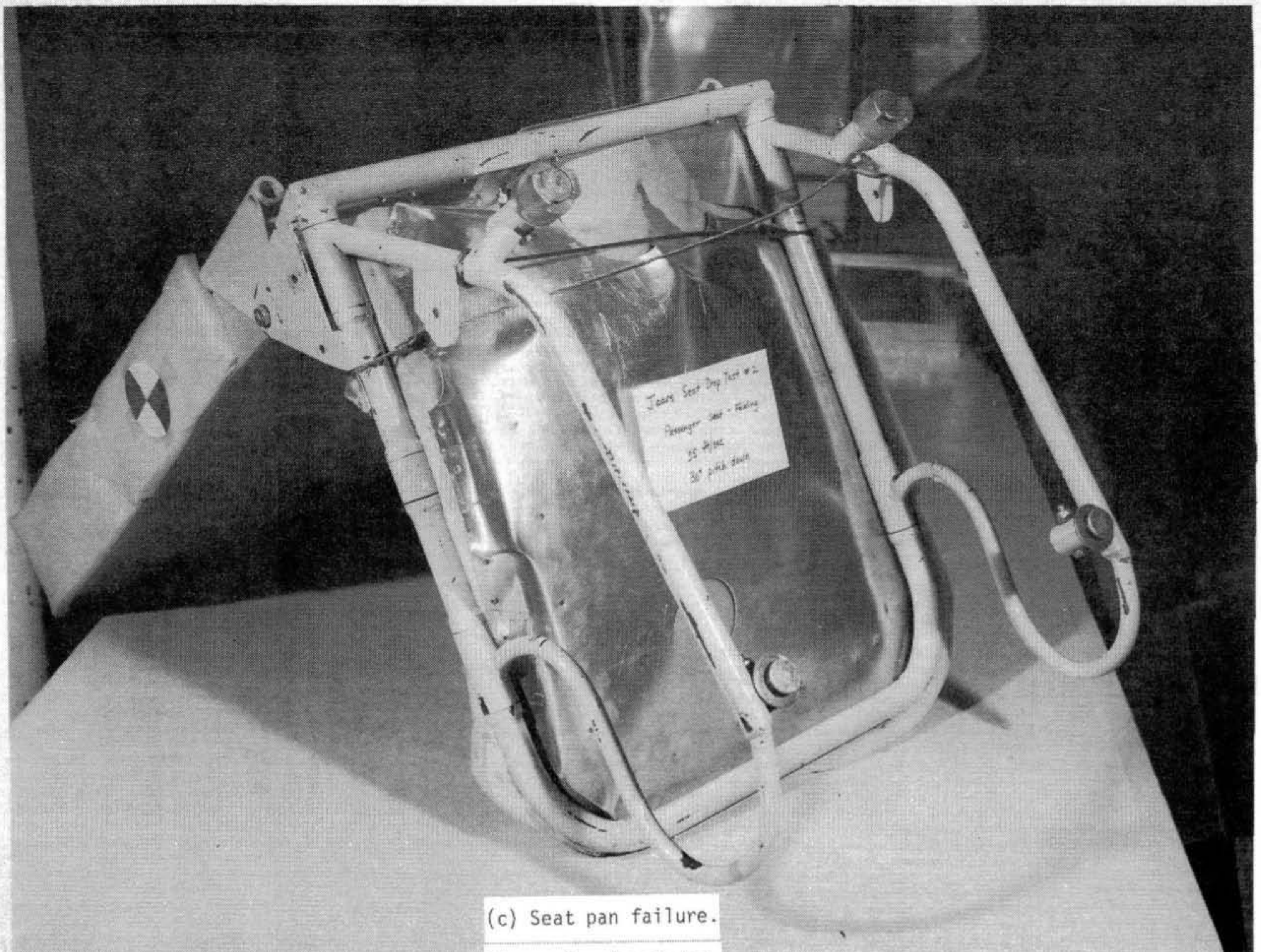
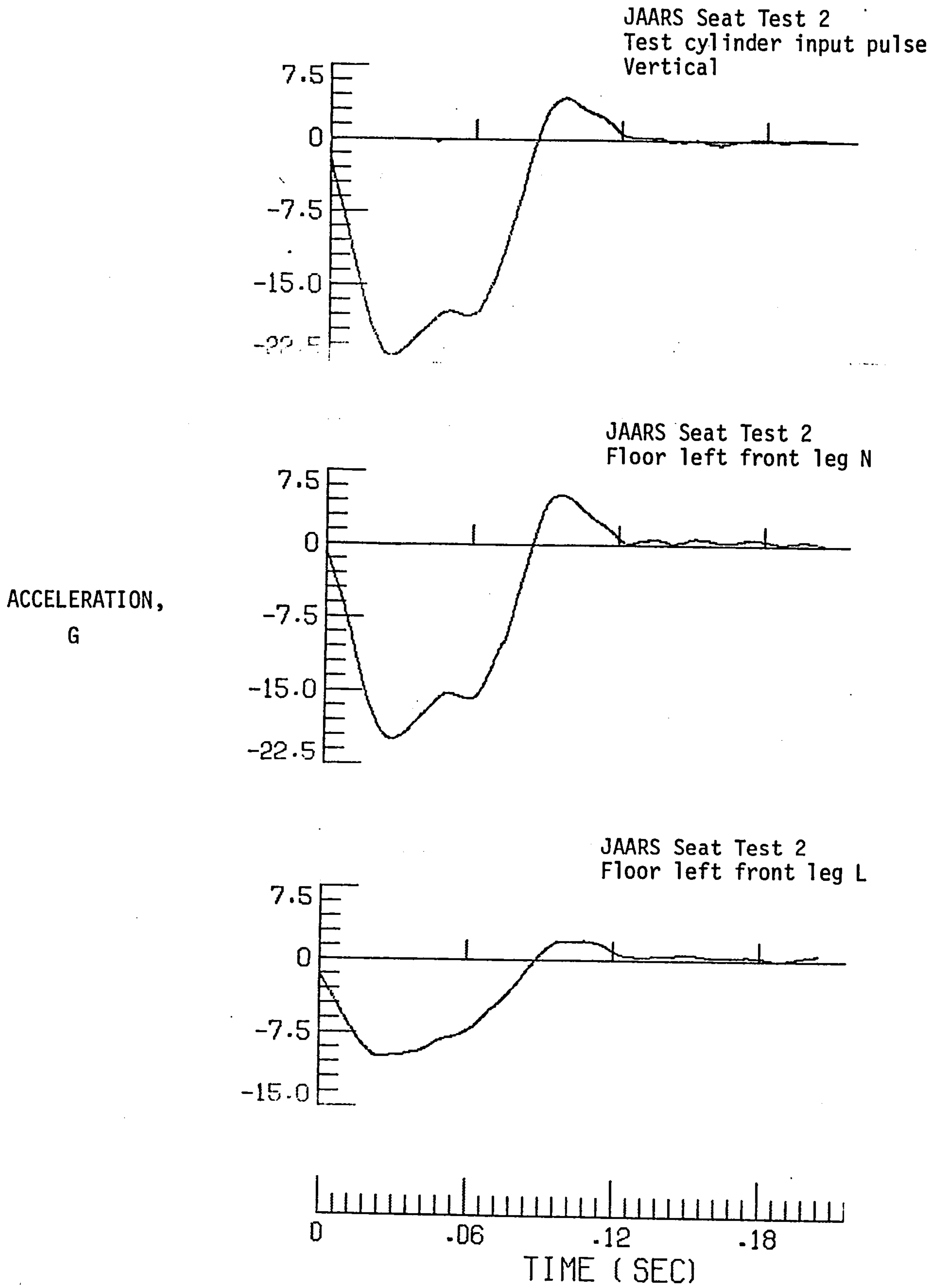


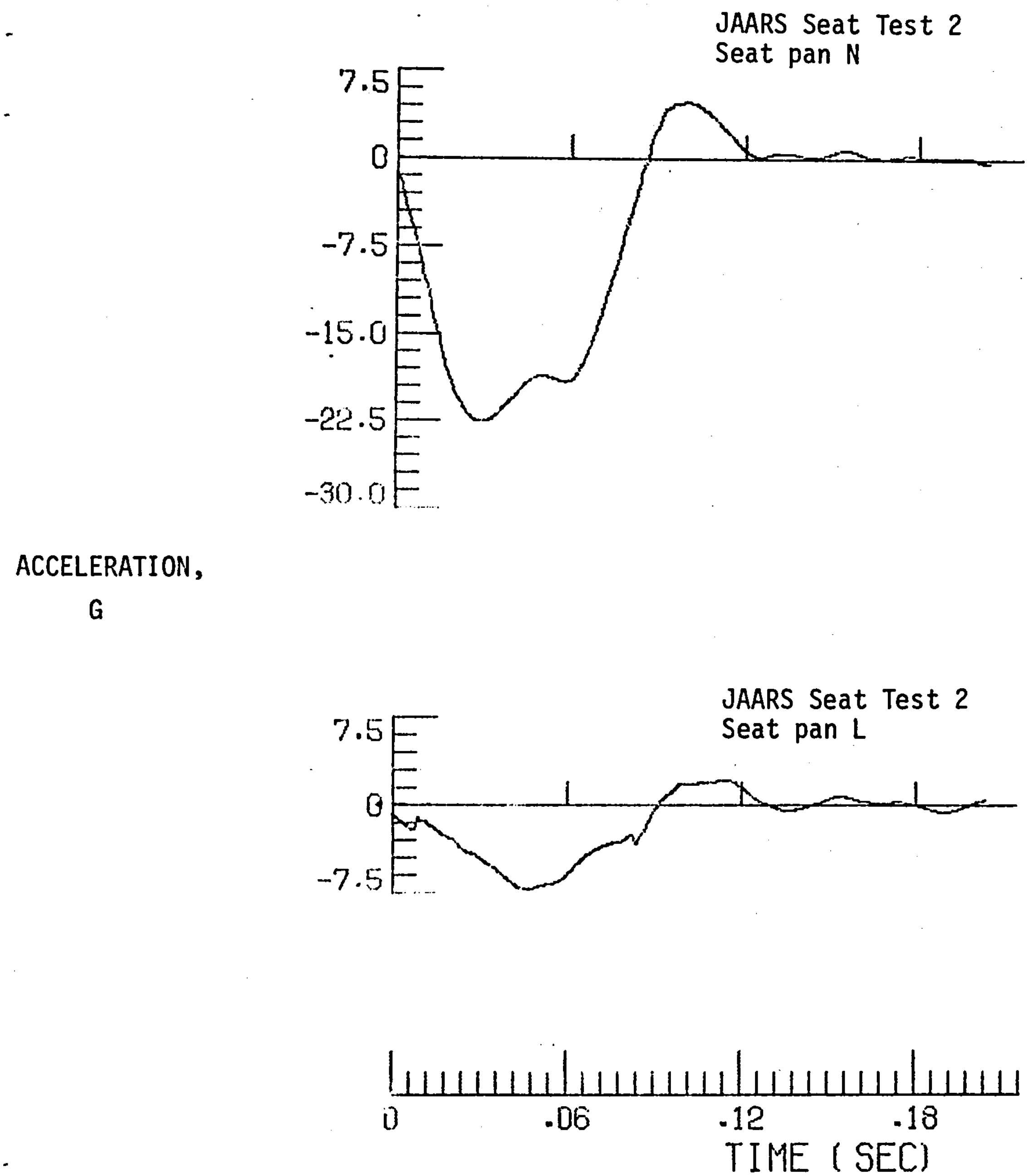
(c) Seat pan failure.

Figure 8.- Concluded.



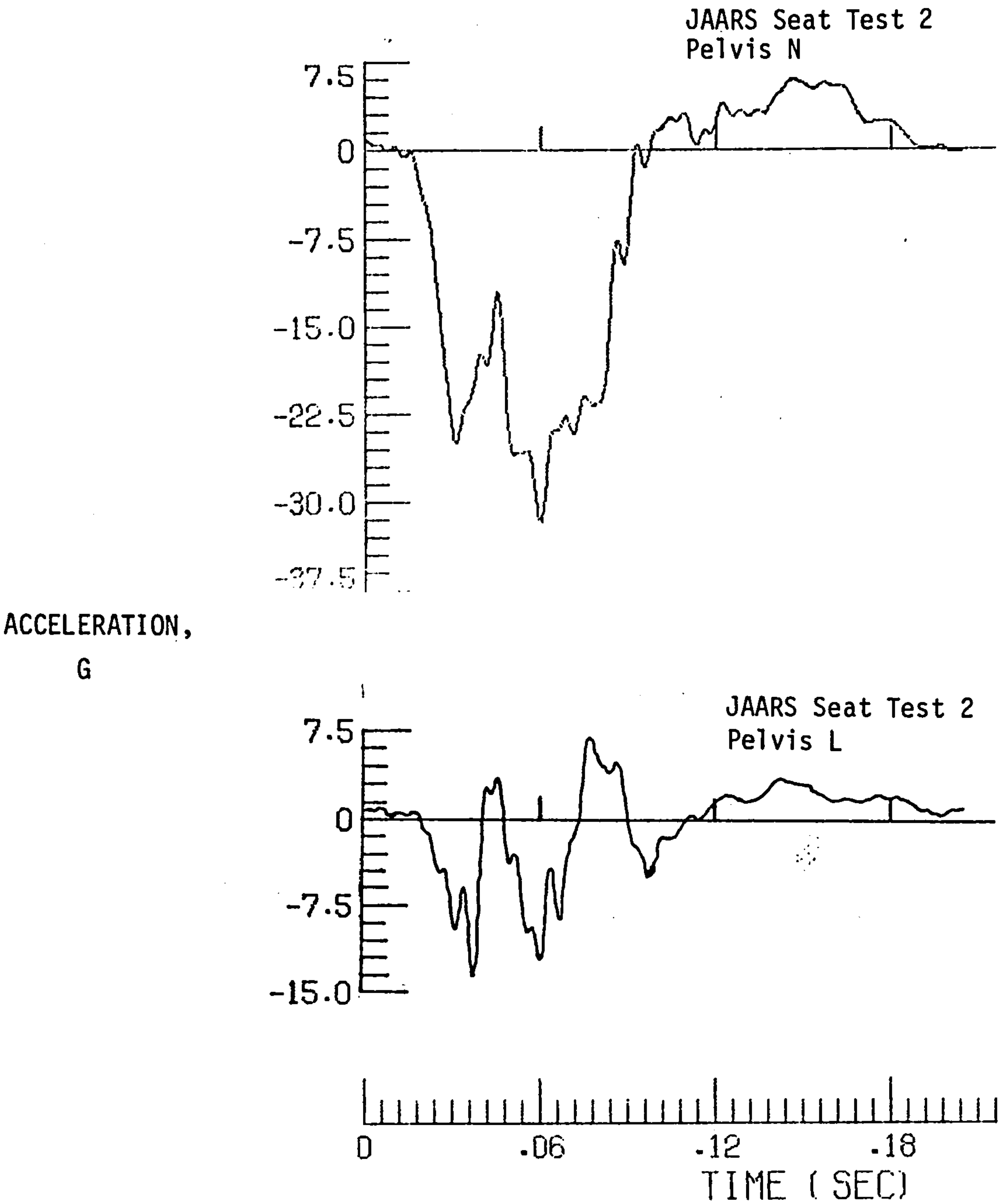
(a) Input pulse and floor accelerations.

Figure 9.- Acceleration time histories for test 2.



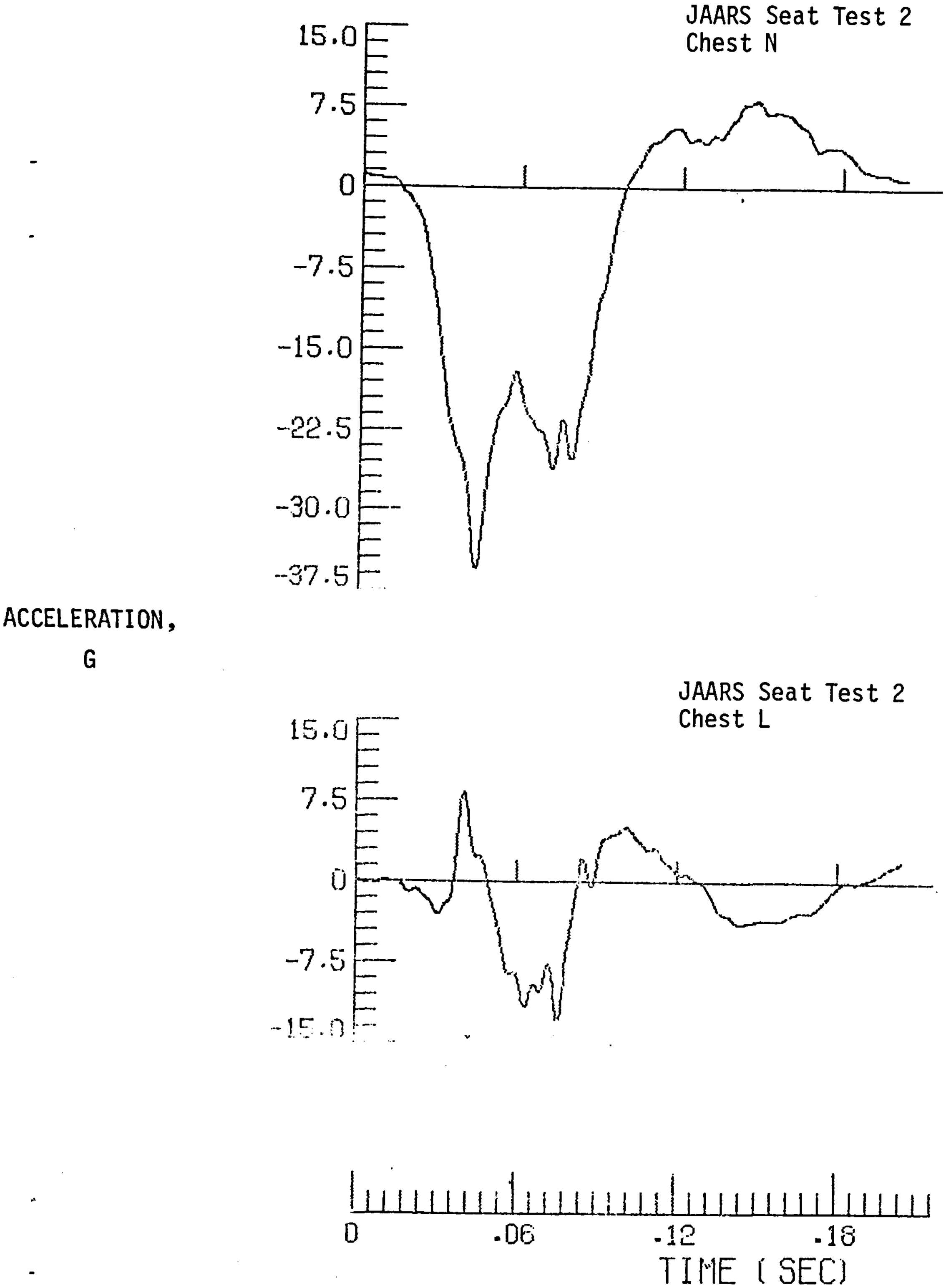
(b) Seat pan accelerations.

Figure 9.- Continued.



(c) Pelvis accelerations.

Figure 9.- Continued.



(d) Chest accelerations.

Figure 9.- Concluded.

(a) Pre-test set-up for test 3.

Figure 10.- Pre-test and post-test photographs of tests 3 and 4.

(b) Pre-test set-up of test 4.

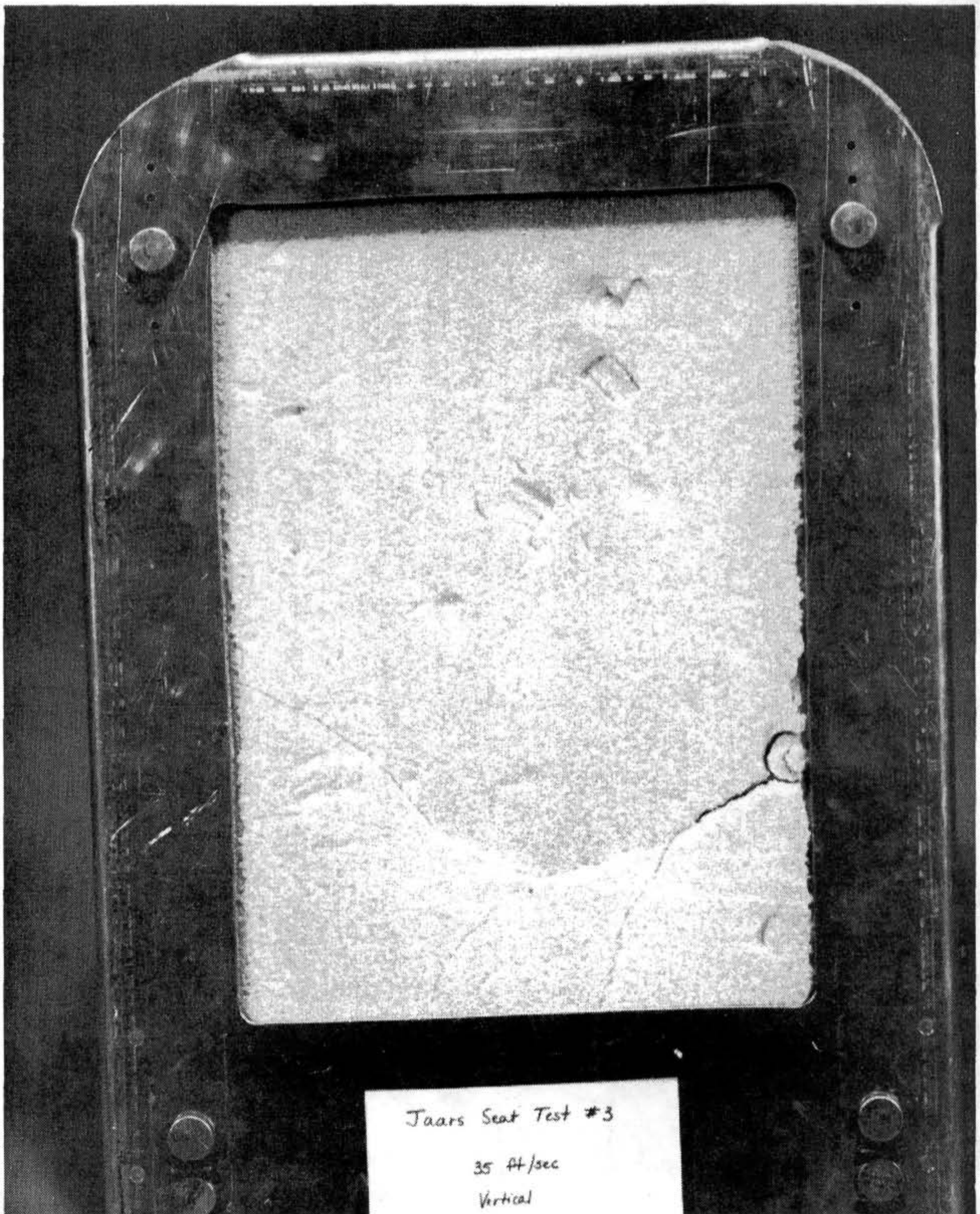
Figure 10.- Continued.

(c) Test 3 post-test.

Figure 10.- Continued.

(d) Test 4 post-test.

Figure 10.- Continued.



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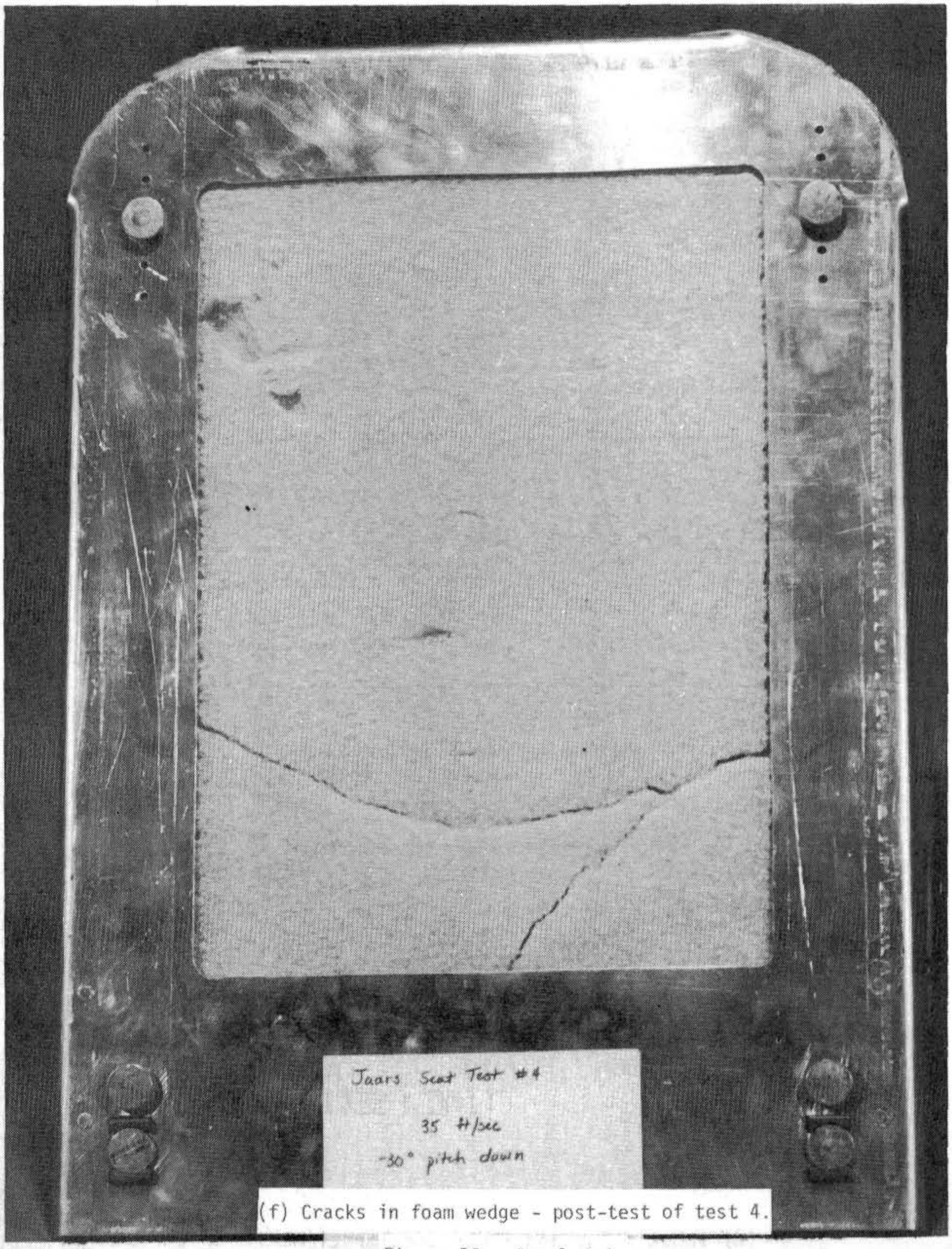
L-82-2,958

(e) Cracks in foam wedge - post-test of test 3.

Figure 10.- Continued.



(f) Cracks in foam wedge - post-test of test 4.

Figure 10.- Concluded.

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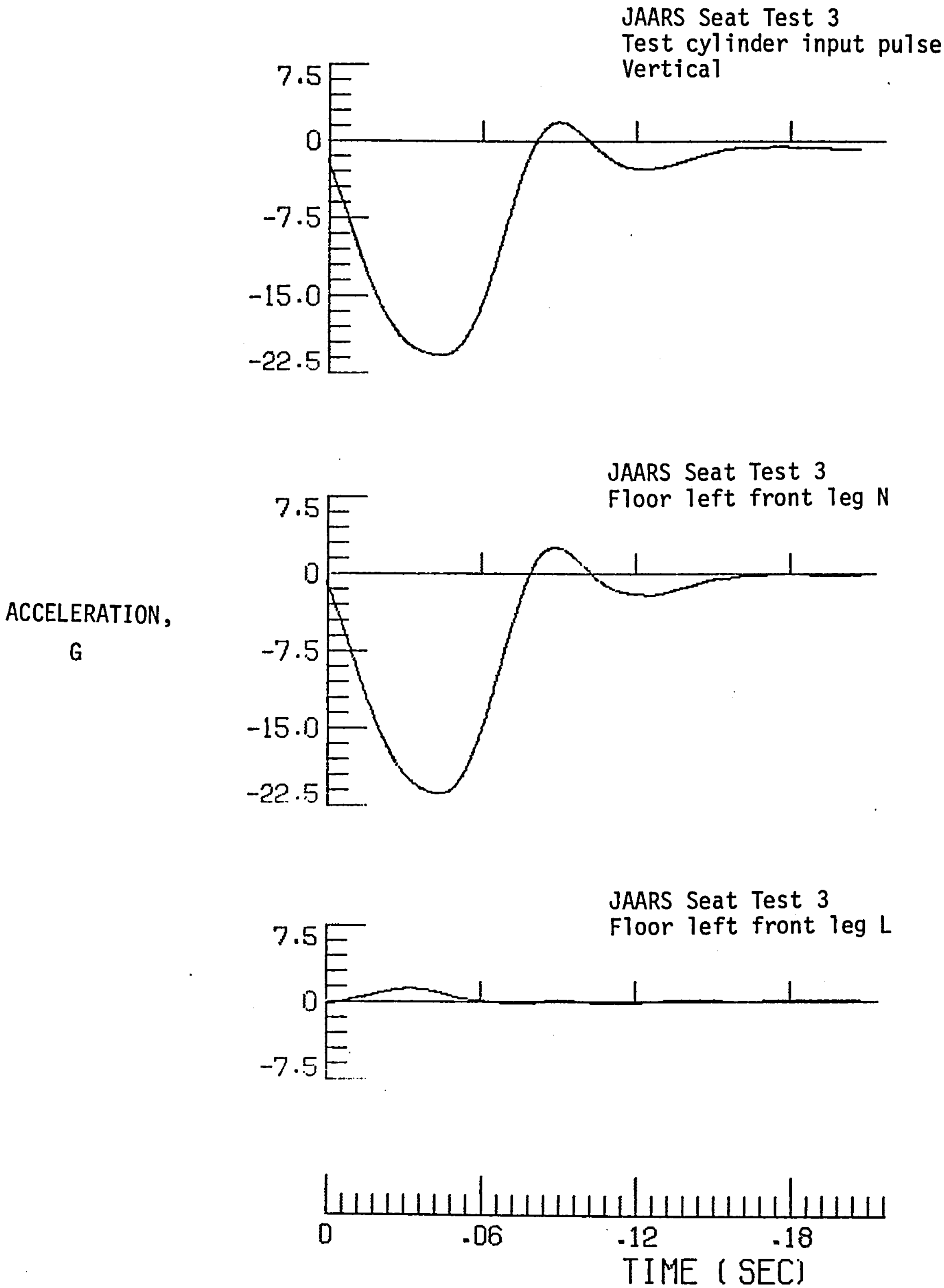
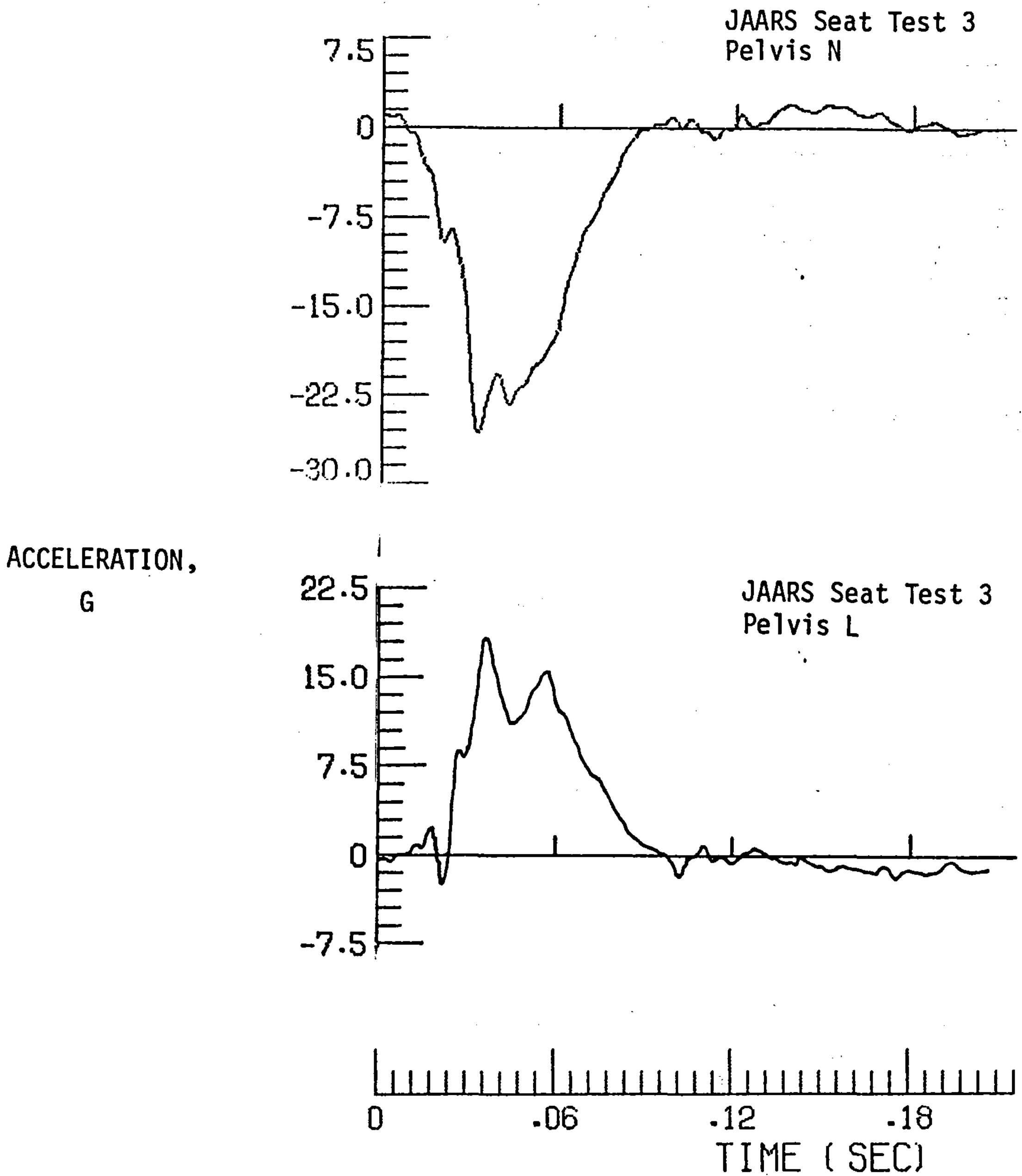


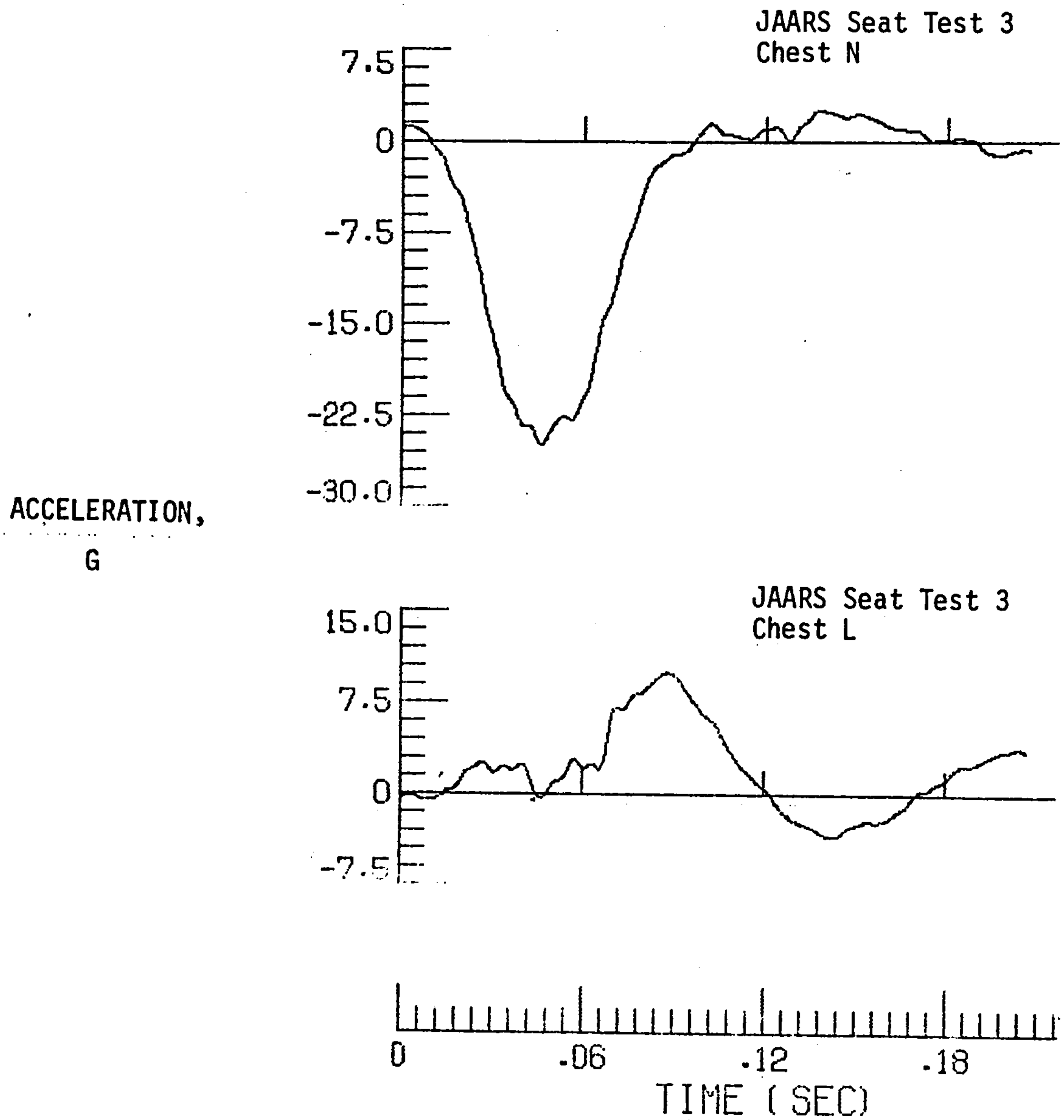
(a) Input pulse and floor accelerations.

Figure 11.- Acceleration time histories of test 3.



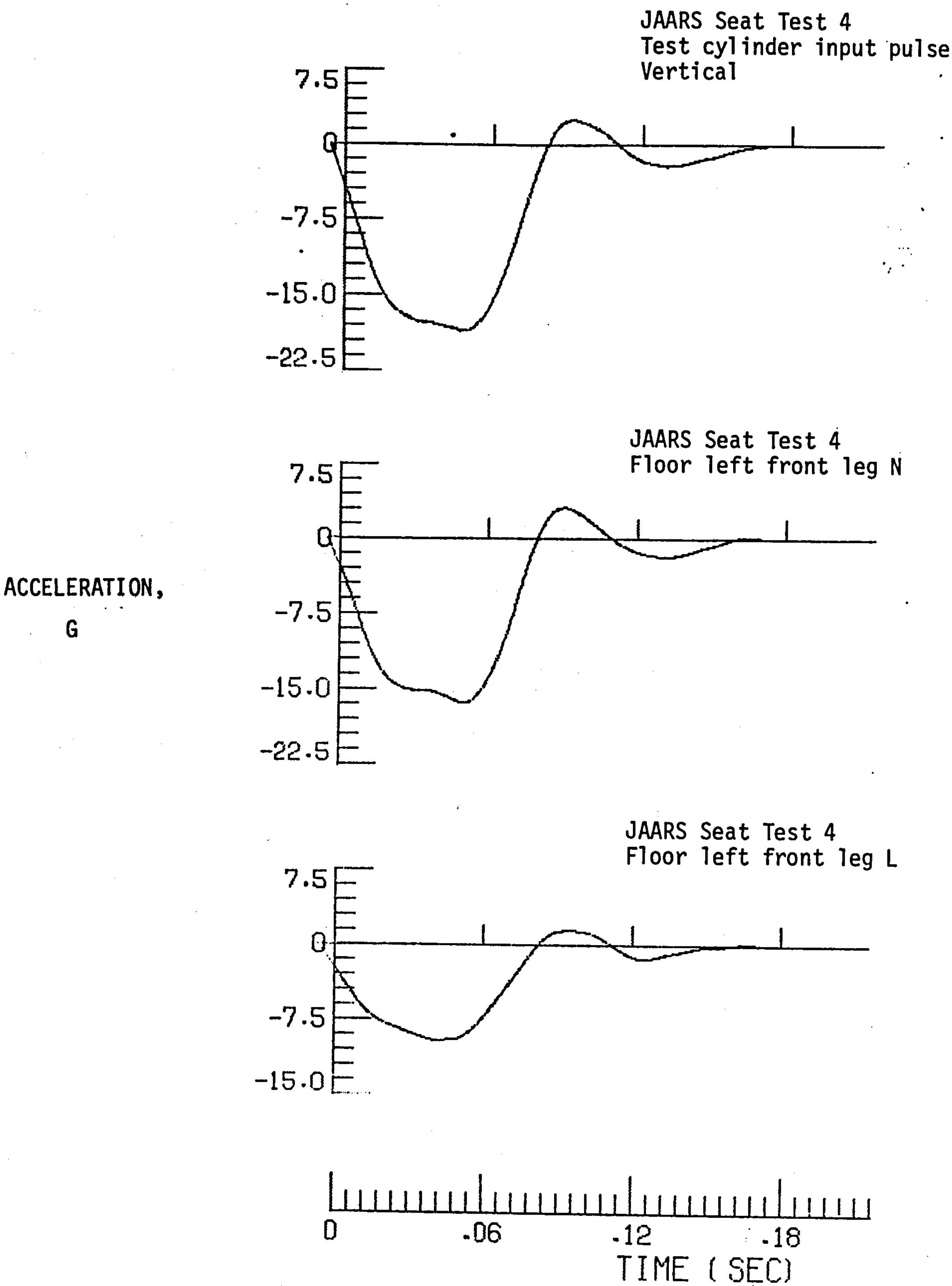
(b) Pelvis accelerations.

Figure 11.- Continued.



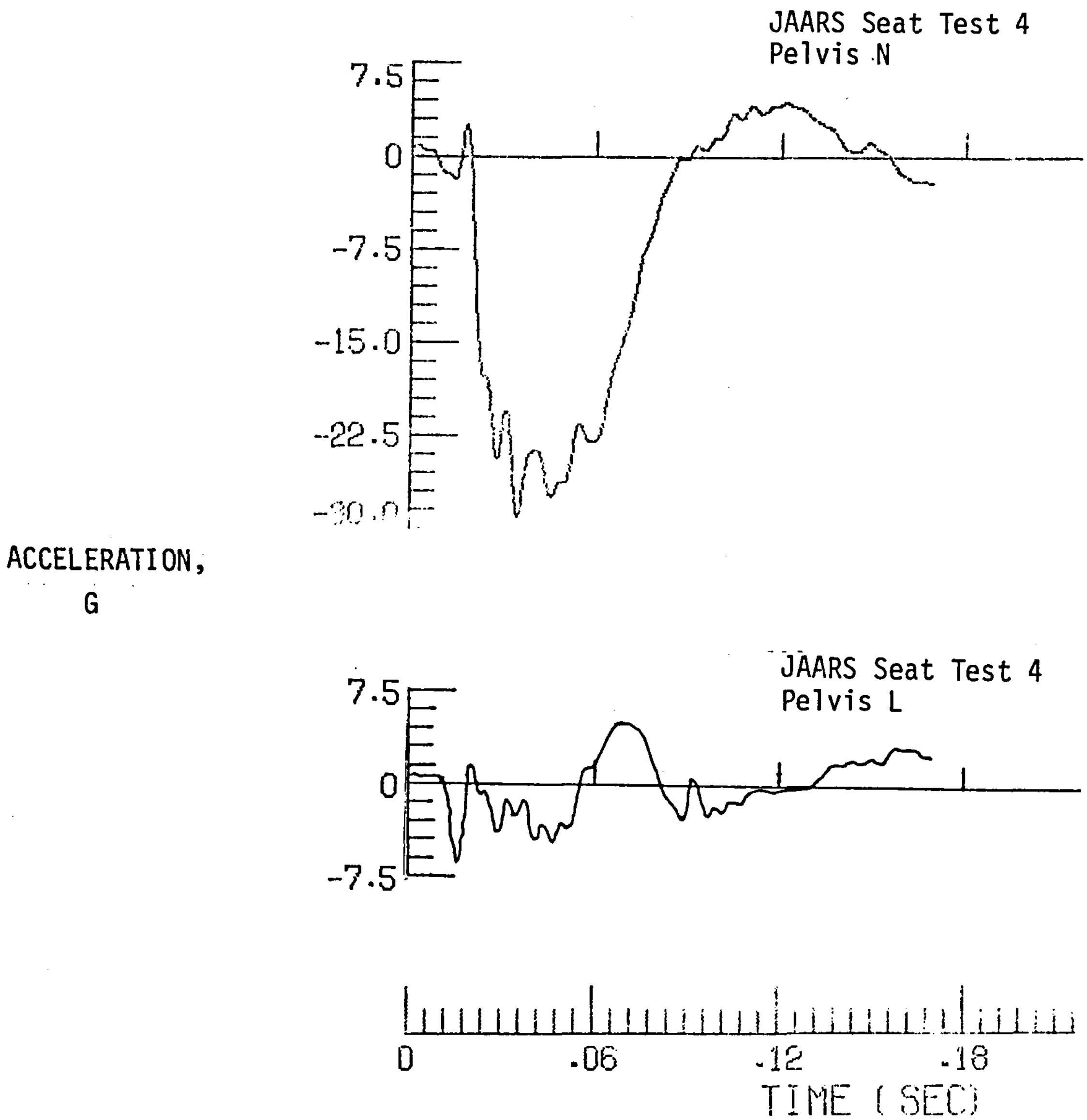
(c) Chest accelerations.

Figure 11.- Concluded.



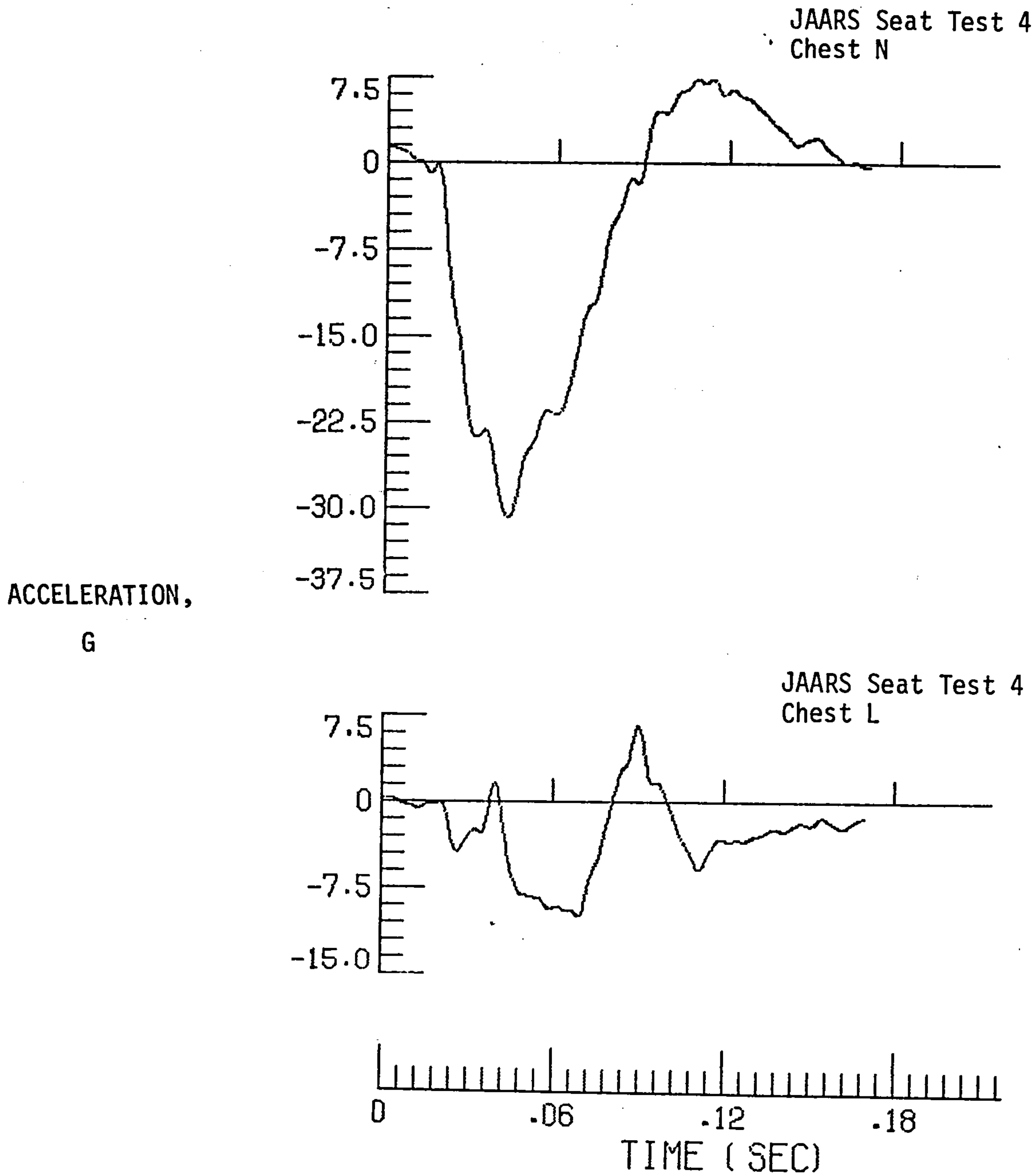
(a) Input pulse and floor accelerations.

Figure 12.- Acceleration time histories of test 4.



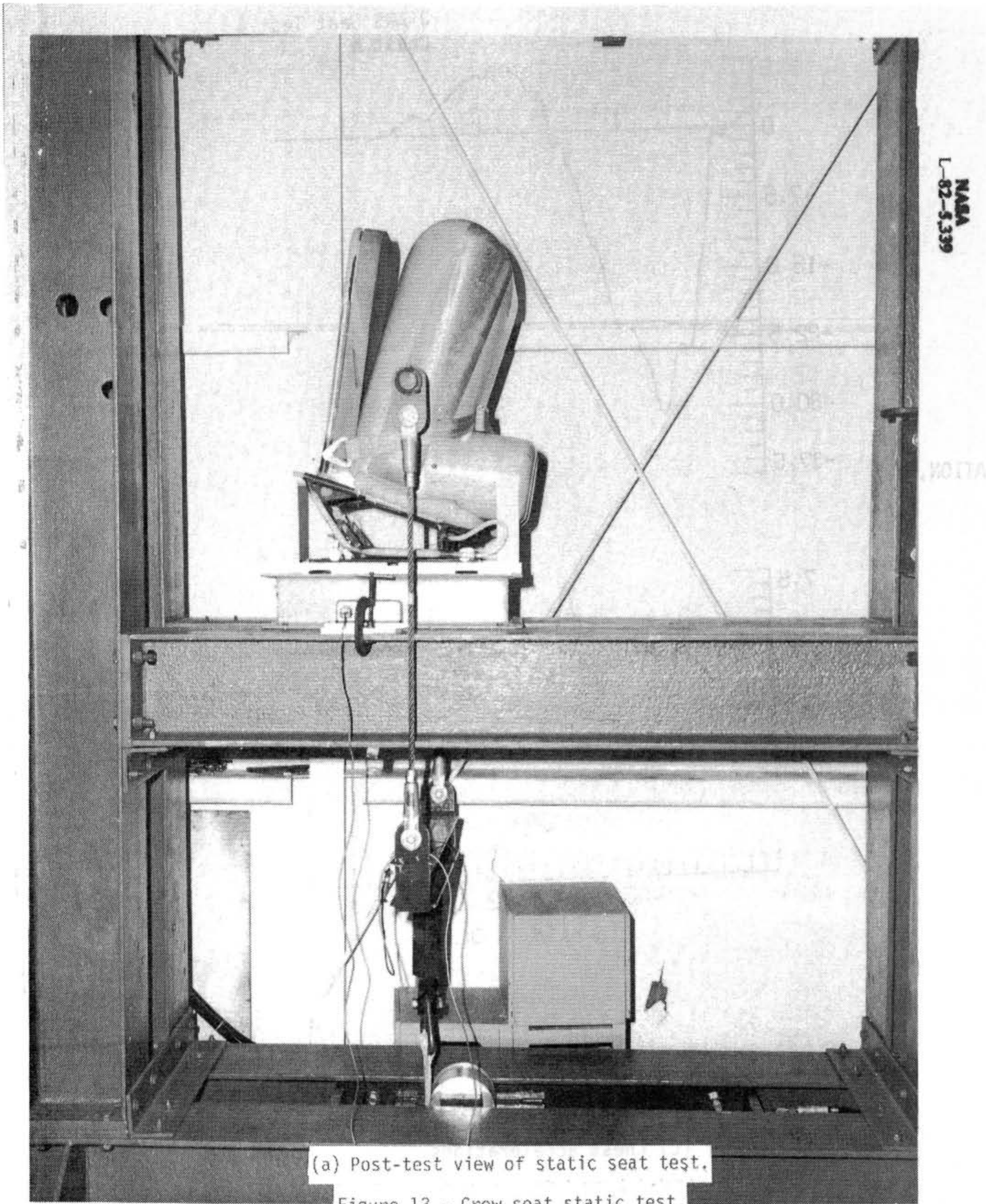
(b) Pelvis accelerations.

Figure 12.- Continued.



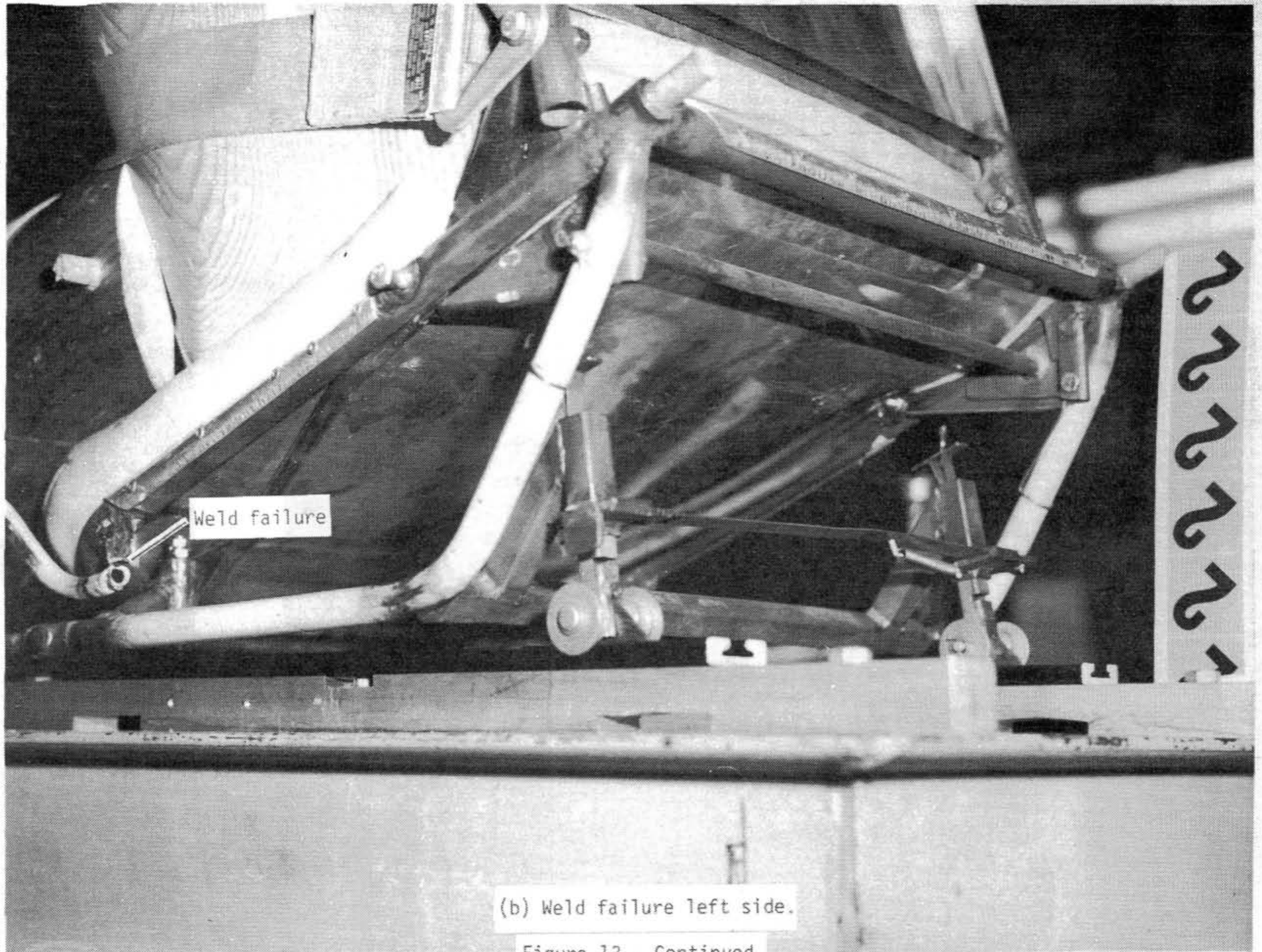
(c) Chest accelerations.

Figure 12.- Concluded.



(a) Post-test view of static seat test.

Figure 13.- Crew seat static test.



(b) Weld failure left side.

Figure 13.- Continued.

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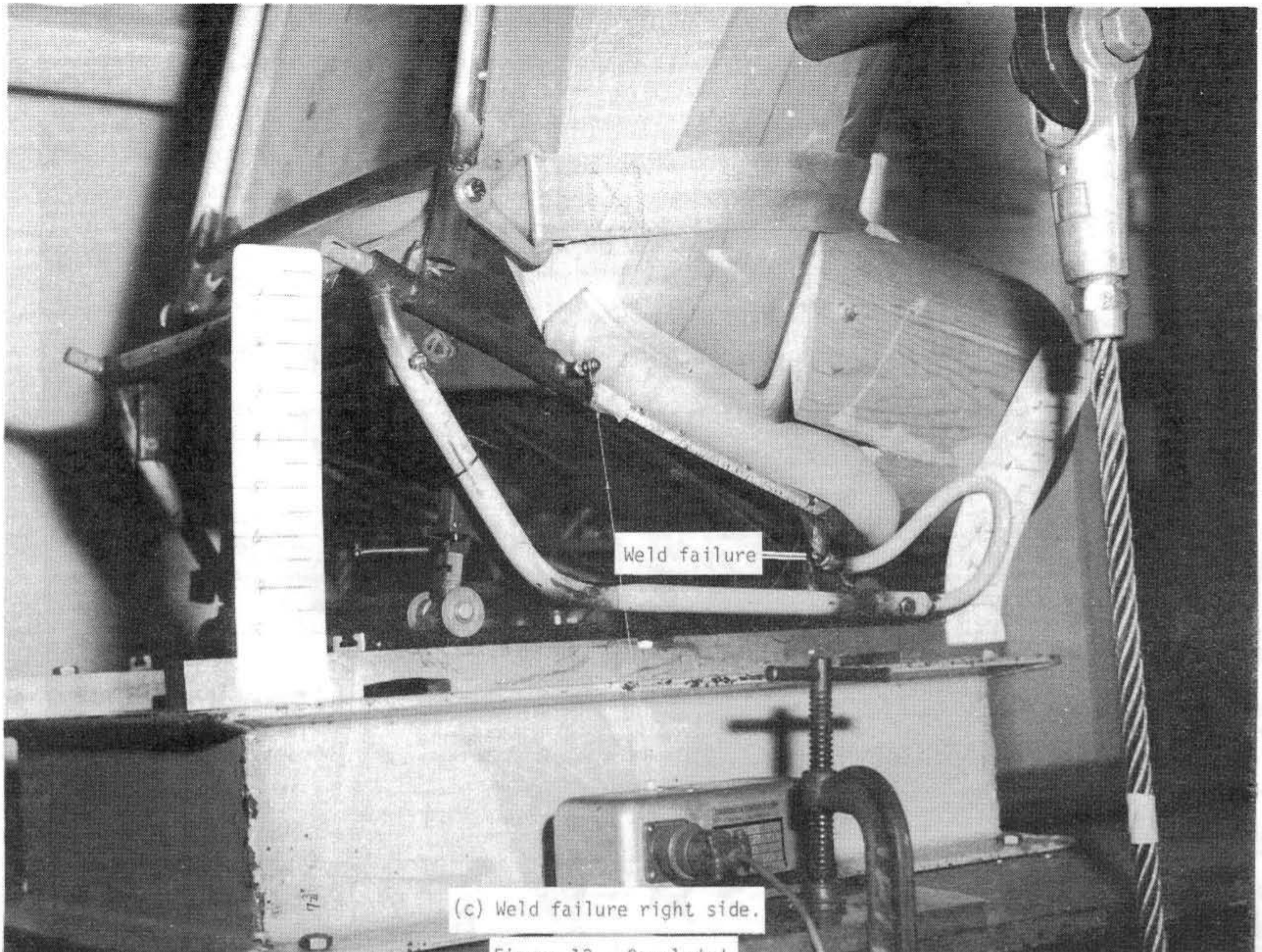

(c) Weld failure right side.

Figure 13.- Concluded.

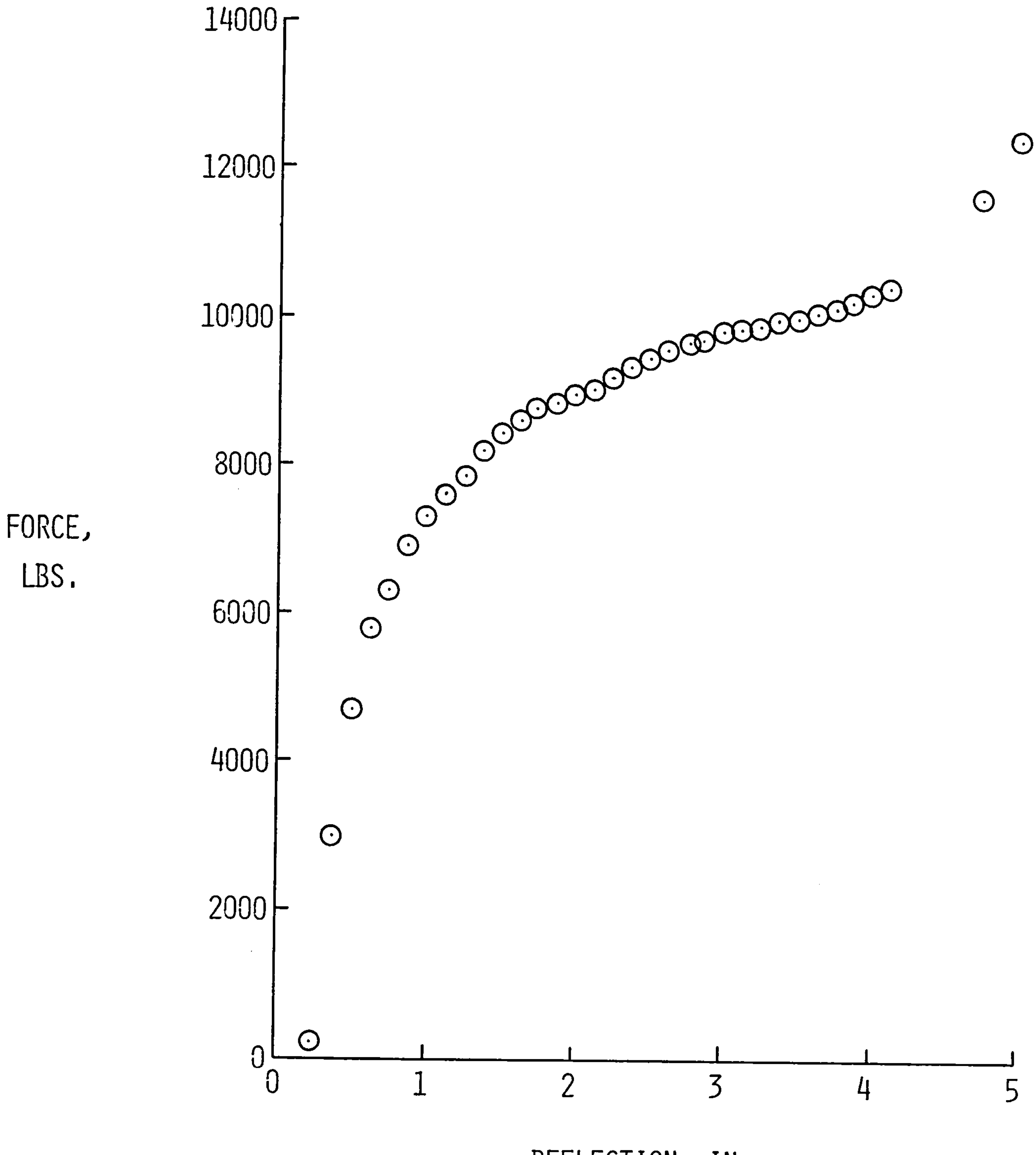

Figure 14.- Foam-block load-deflection data.

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16. Abstract

Jungle Aviation and Radio Service (JAARS) provided NASA Langley Research Center with three types of energy absorbing general aviation seats to be dynamically tested and evaluated for crash load attenuation. On the basis of the static and dynamic test results, it was recommended that the tubular frame seats be redesigned to initiate stroking at approximately 12 G's rather than the 20 to 25 G range. Lower density foam was recommended for the foam wedge passenger seat.

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