Report No. NA-68-24
(DS-68-23)

FINAL REPORT

Project No. 530-003-03X

EVALUATION OF EXPERIMENTAL FLIGHT DATA RECORDERS IN AN AIRCRAFT CRASH ENVIRONMENT

NOVEMBER 1968

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

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for

AIRCRAFT DEVELOPMENT SERVICE

November 1968

DEPARTMENT OF TRANSPORTATION
Federal Aviation Administration
National Aviation Facilities Experimental Center
Atlantic City, New Jersey 08405

ABSTRACT

Two types of experimental 20-channel flight data recorders were evaluated to determine their resistance to an aircraft crash environment. This crash environment was simulated by a series of four tests: a shock test, a crushing test, a penetration test, and a fire test. The first flight data recorder tested was an oscillographic recorder enveloped in a 1/2 ATR (Air Transport Radio) case; the recording medium being stainless steel tape. This recorder survived all the tests except the shock test in the longitudinal direction. A minor modification to the recorder would correct this fault. The second type of recorder was a magnetic tape recorder. This recorder was also destroyed in the longitudinal shock test. A major redesign would be required for this recorder to survive this test. It was concluded that the series of four crash survivability tests are poorly defined and recommendations are made herein to correct this problem.

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INTRODUCTION

Purpose

The purpose of this project was to evaluate two 20-channel experimental flight data recorders to determine their resistance to an aircraft crash environment.

Background

All turbine-powered civil air carrier aircraft are currently required by Federal Aviation Administration (FAA) to carry crash survivable five-channel flight data recorders. This regulation has been in effect since 1958. The data from these recorders are utilized in the investigation of aircraft accidents and incidents.

Since 1958, instances have been experienced where flight data records were rendered unreadable by a severe aircraft accident. The National Transportation Safety Board (NTSB), formerly the Civil Aeronautics Board, requested the FAA to investigate the possibility of revising TSO C51 (Technical Standard Order which lists hardware and software requirements for flight data recorders). The NTSB was particularly interested in updating the crash survivability requirements and increasing the number of parameters to be recorded. Updated specifications for a multichannel flight data recorder are described in FAA Engineering Requirement (ER) 605-001 dated October 9, 1963. The crash survivability portion of ER-605-001 is as follows:

1. Half-sine-wave impact shocks applied in each of the three main orthogonal axes and having a peak acceleration magnitude of 1000g with a time duration of 5 milliseconds.

2. A static crushing force of 4000 pounds applied continuously but not simultaneously to each of the three main orthogonal axes for a test period of 5 minutes.

3. An impact shearing force equal to a 500-pound steel bar which is dropped from a height of 10 feet to strike each side of the enclosure. The point of contact of the bar shall have a cross-sectional area that is no greater than a cylindrical rod one-fourth inch in diameter. The longitudinal axis of the bar shall be vertical at the time of impact.

4. An exposure to flames of open fire at 1100° C for a continuous and uninterrupted period of 30 minutes in which the flames envelop at least 50 percent of the outside area.

The selected parameters that are recorded for a typical two-engine aircraft are:

1. Altitude
2. Airspeed
3. Heading
4. Acceleration
5. Time
6. Angle of Attack

7. Pitch Rate
8. Yaw Rate
9. Roll Rate
10. Angle of Bank
11. Pitch Angle
12. Ambient Air Temperature
13. Control Wheel Position
14. Rudder Pedal Position
15. Control Column Position
16. Exhaust Gas Temperature 1
17. Exhaust Gas Temperature 2
18. Engine Torque 1
19. Engine Torque 2
20. Wing Flap Position

Nos. 1, 2, 3, 4, and 5 above are recorded on current flight data recorders.

Description of Recorders

Two distinct types of flight data recorders were procured by the FAA, Aircraft Development Service, under Contract Nos. FA65WA-1067 and FA65WA-1056 for this project. In this report the recorder purchased under Contract No. FA65WA-1067 will be called Recorder A and the remaining recorder will be called Recorder B.

Recorder A: Recorder A (Figure 1) is an airborne recording system which provides an oscillogrpahic record of selected parameters with respect to time. This recording system consists of three basic parts; a 1/2 ATR (Air Transport Radio) case containing the recorder and electronics, a remote control panel (optional) with the selected transducers. The record is made by engraving lines with scribes into a high nickel content stainless steel tape (Figure 2). This stainless steel tape will allow approximately 400 hours of recording time. The recorder weighs 29.5 pounds. This includes the stainless steel tape and the integral protective armor plating.

Recorder B: Recorder B (Figure 3) is a digital magnetic tape system capable of continuously recording airborne data in digital computer language. The recording system consists of five basic elements; the tape recorder, the crash housing for the recorder (Figure 4), the recorder electronics (Figure 5), and the transducers. The record medium in this case is the normal mylar magnetic tape and a new development, stainless steel magnetic tape. The system records parallel tracks on this 1/2-inch magnetic tape compatible with IBM gapless format. The approximate weights of the major system elements are as follows: Recorder - 40 pounds, Recorder Electronics - 60 pounds, Crash Housing - 120 pounds.

DISCUSSION

It was not required in the definition of the shock, penetration, and crushing tests that one recorder survive each of these tests in all three axis, only in the most critical axis. Rather than trying to estimate

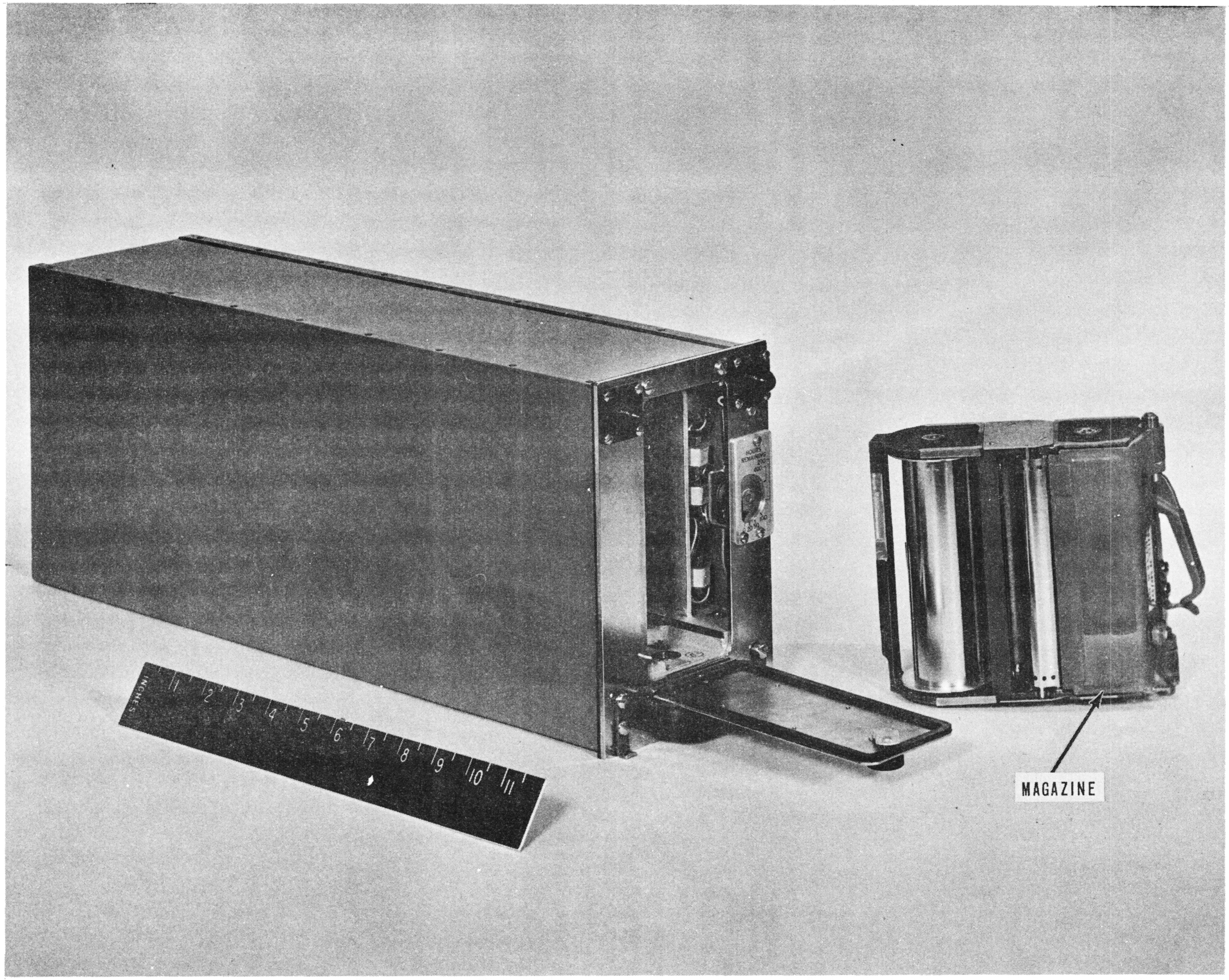

FIG. 1 RECORDER A

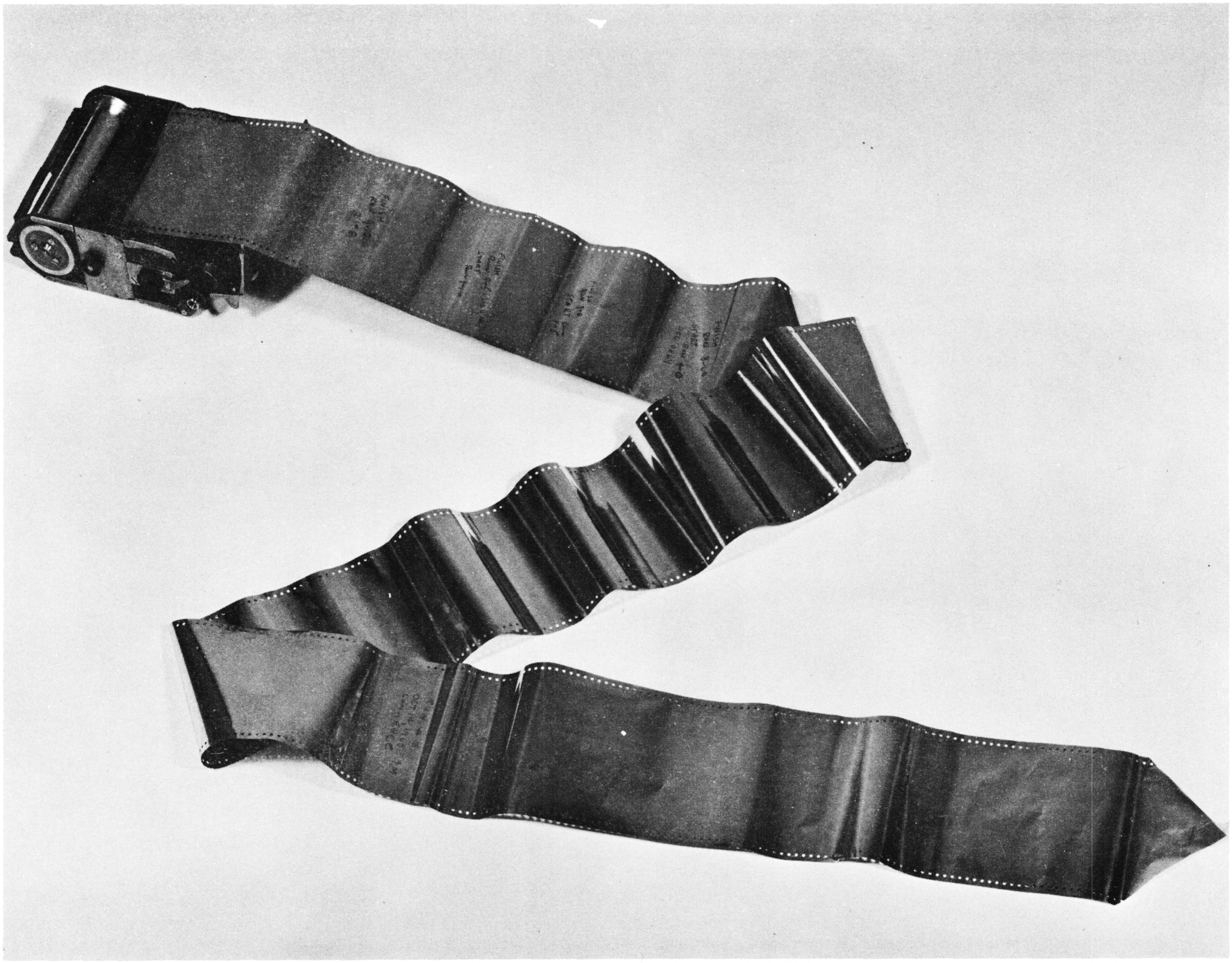

FIG. 2 RECORDER A, MAGAZINE AND RECORDING TAPE

FIG. 3 RECORDER B, TAPE TRANSPORT

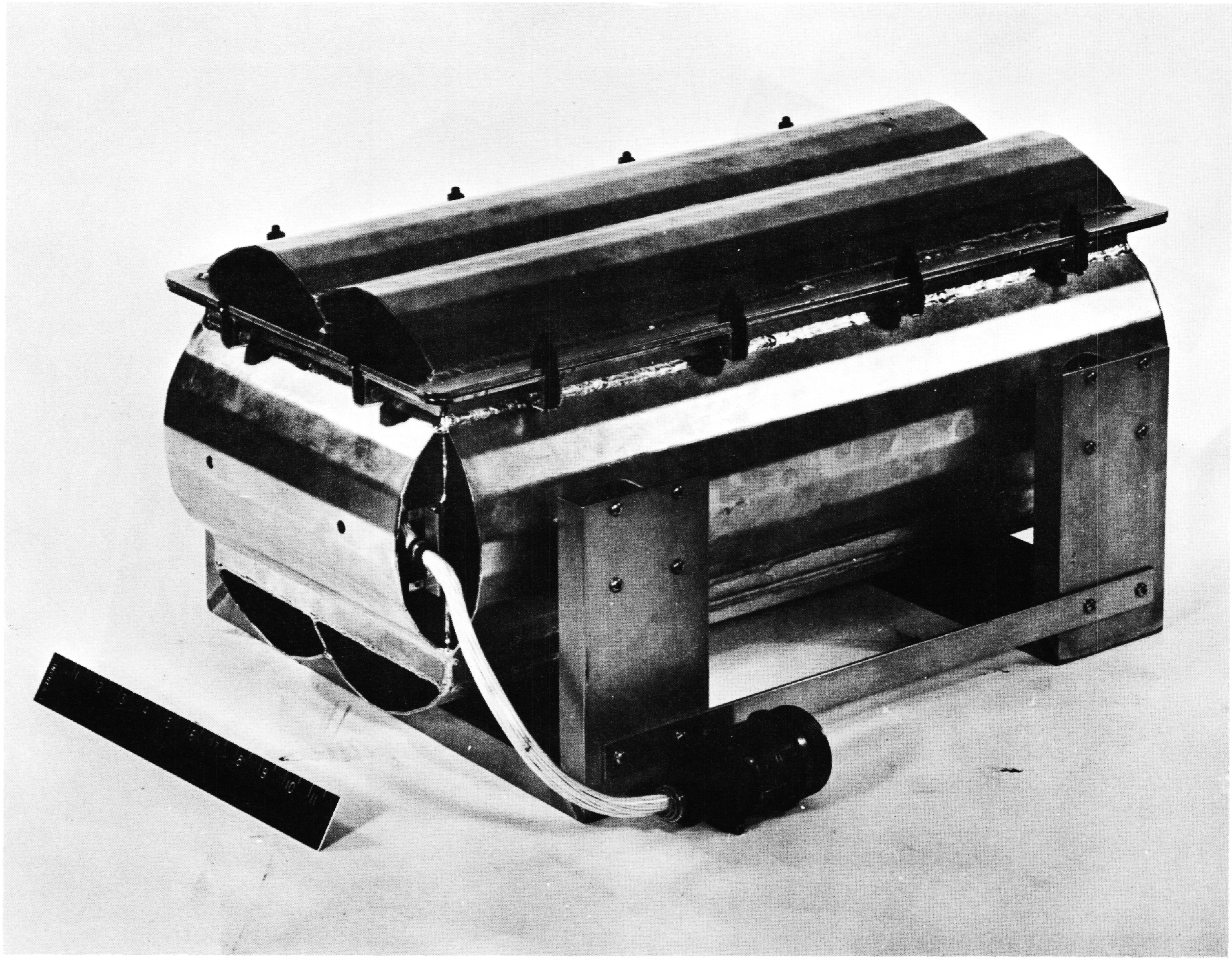

FIG. 4 RECORDER B, CRASH HOUSING

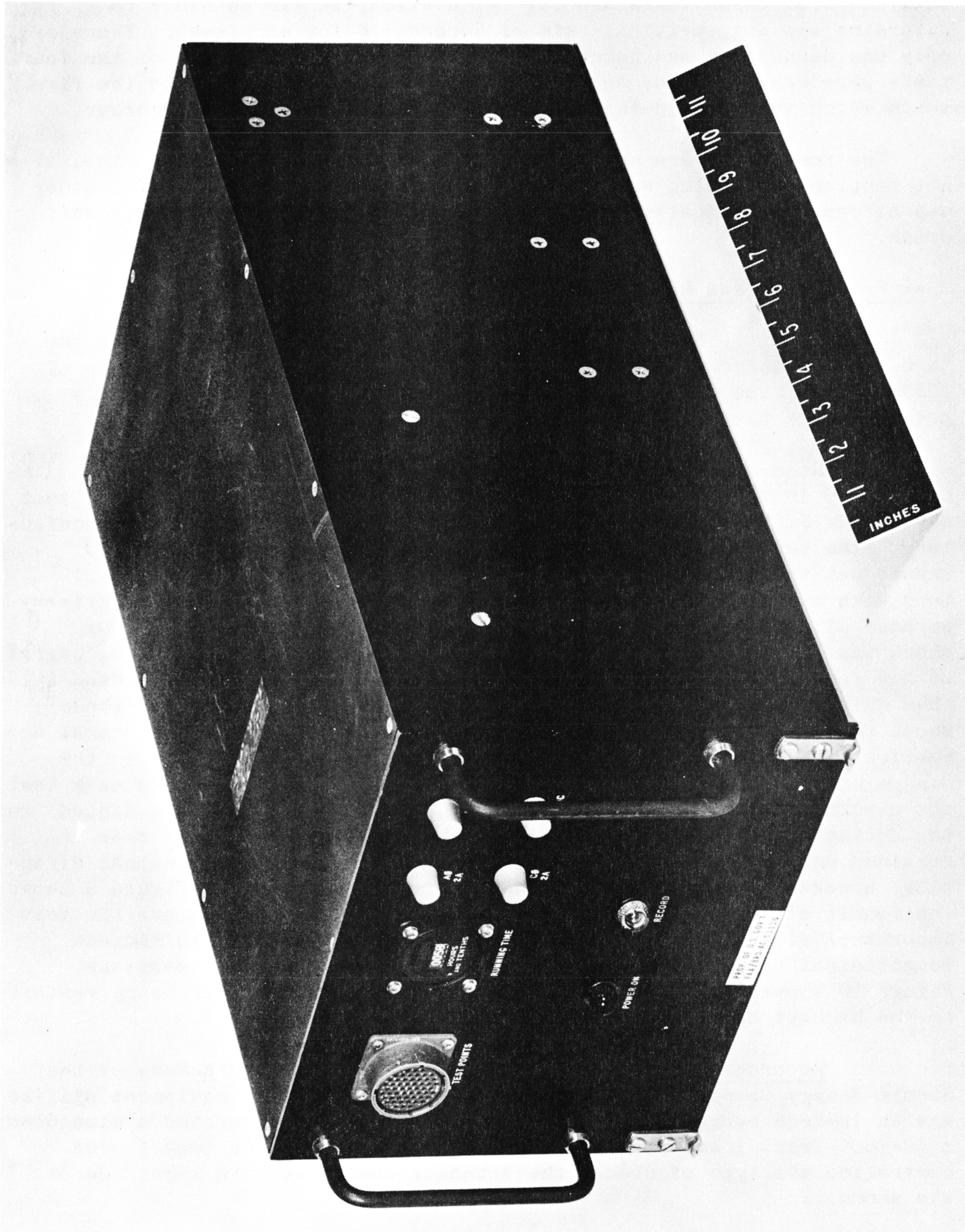

FIG. 5 RECORDER B, ELECTRONICS

the most critical axis, three Recorders A were purchased. The series of four tests was performed on Recorder A first. From the information obtained from these tests and our calculation, it was possible to determine the most critical axis of Recorder B for each test. Therefore, only one Recorder B was purchased for these tests. Only two of the four tests were scheduled for Recorder B. These were the shock and the fire tests which were considered most critical for this type of recorder.

The four tests are not adequately defined in ER-605-001. Also, it was not mentioned in which order the tests were to be conducted. The order was determined logically by analyzing the forces in a typical aircraft crash.

Test Procedures and Results

Shock Test: "Half-sine-wave impact shocks applied in each of the three main orthogonal axes and having a peak acceleration magnitude of 1000g with a time duration of 5 milliseconds." Figure 6 graphically presents this test.

Recorder A - Recorder A was tested at the Naval Ordnance Laboratory in White Oak, Maryland. The equipment utilized for this test was the U. S. Navy's 26-inch diameter air gun. This air gun was manufactured from two 16-inch U. S. Navy gun barrels fastened together and reamed out to 26 inches. This air gun is 90 feet long and weighs 212 tons with a maximum accelerating force of 5,300,000 pounds. The primary purpose of this gun is the testing of full-size weapons. The 1000g shock was obtained by mounting the test article on a piston in the barrel of the gun. The piston was held while air pressure was built behind it, then quickly released. Figures 7, 8, and 9 show the results of these shock tests. The results of the shock tests performed in the lateral and vertical direction (Figures 7 and 8, respectively) are similar in the damage noted. Both of these tests show very little damage. In each test, the electronics broke loose inside; the outside dust cover was dented; and the access door latch was broken; but the magazine and record tape remained undamaged and intact. The shock test in the longitudinal direction, however, completely destroyed the recorder package. Figure 9 shows the result clearly. The last 17 minutes of the tape (which are the most important) were destroyed. Failure occurred because of insufficient longitudinal strength between the electronics and magazine sections. Figure 10 shows the condition of the cassett and tape after being restored to the highest degree possible.

Recorder B - Recorder B was tested at the Sandia Base of the Atomic Energy Commission, Albuquerque, New Mexico. The equipment utilized was an 18-inch hydraulic actuator. This actuator accelerated a sled down a 40-foot track into the impact area. The design of the impact area controlled the type of shock; the actuator controlled the magnitude of the shock.

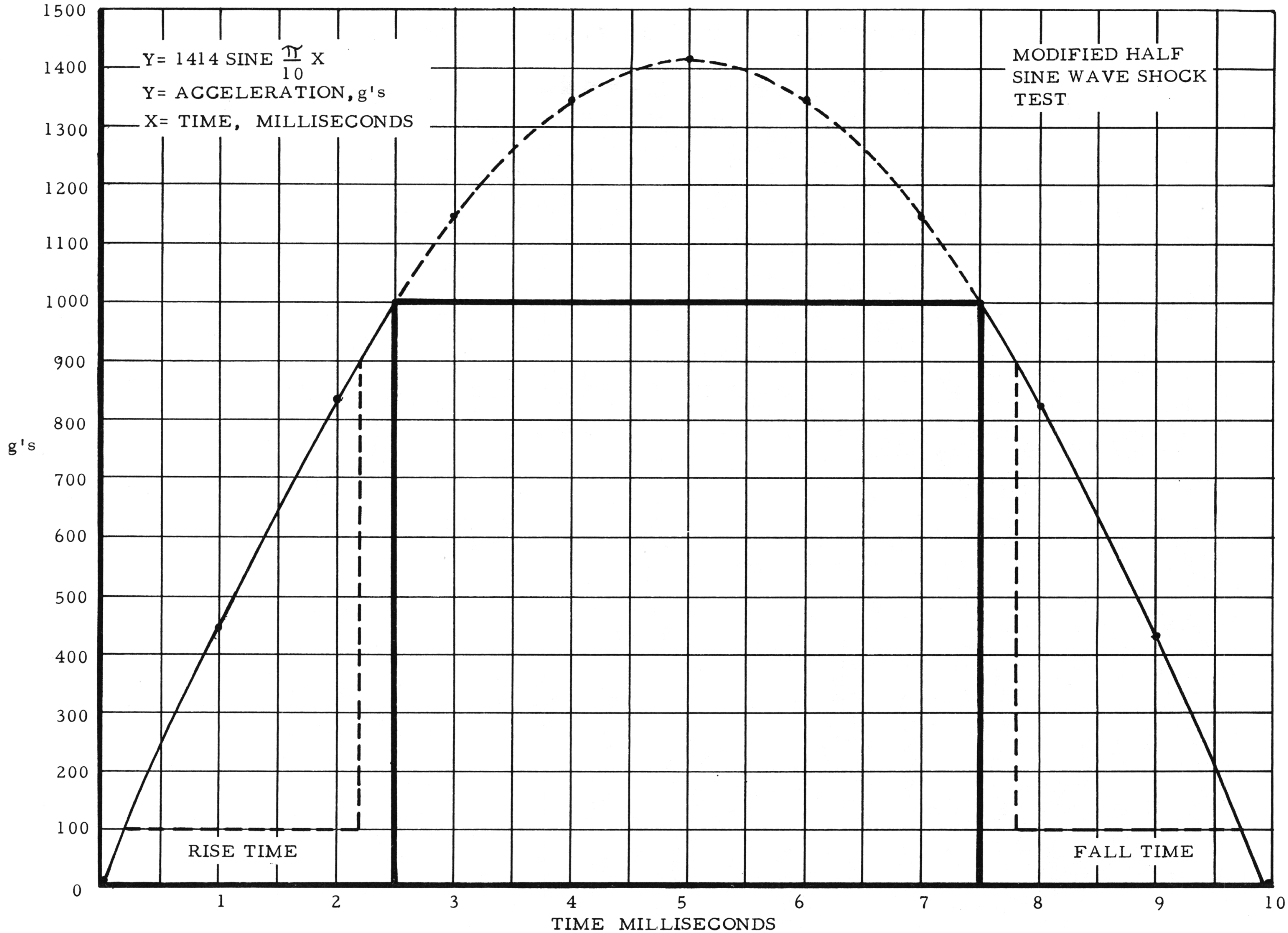

FIG. 6 GRAPHICAL PRESENTATION OF SHOCK TEST

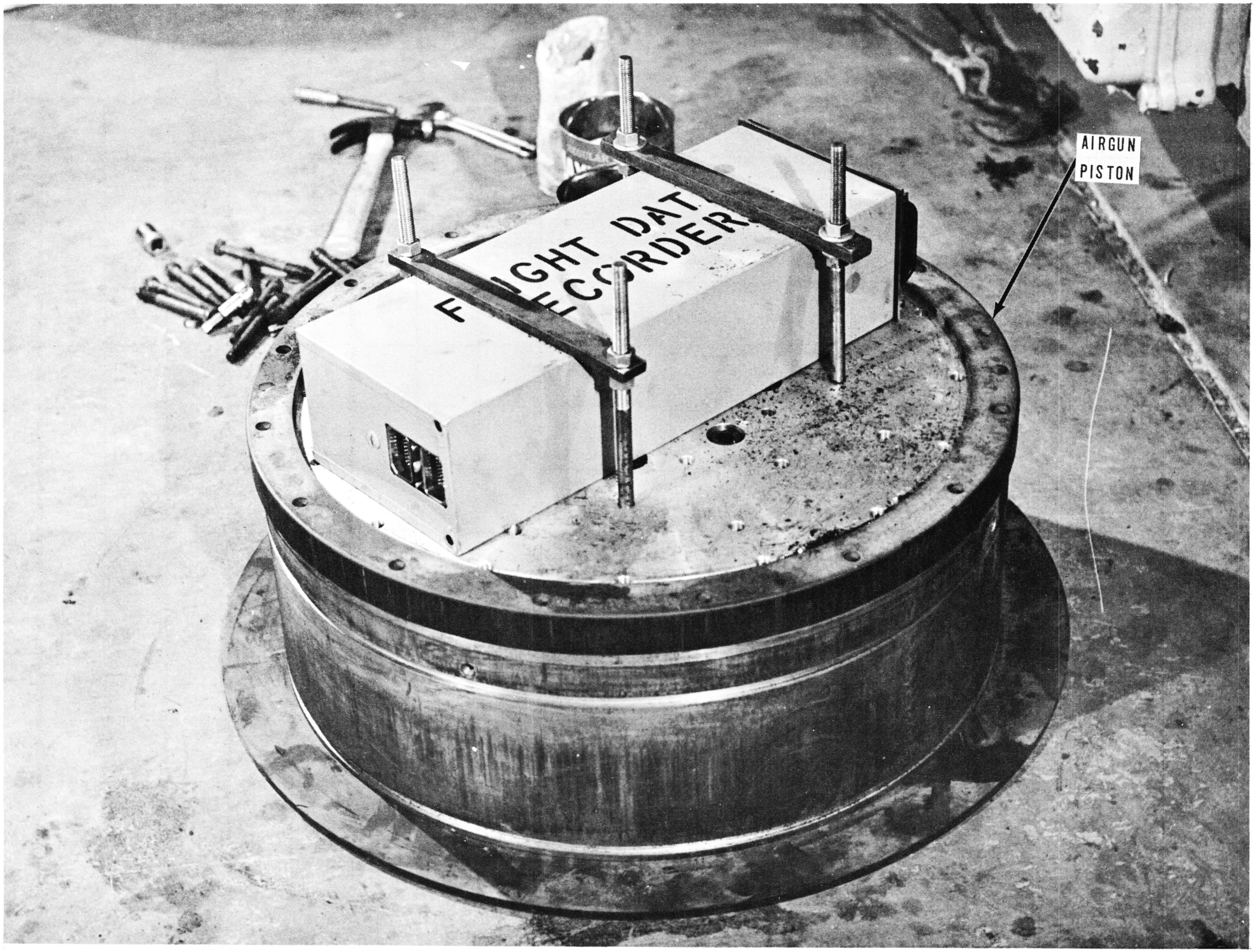

FIG. 7 RESULT OF SHOCK TEST IN LATERAL AXIS

FIG. 8 RESULT OF SHOCK TEST IN VERTICAL AXIS

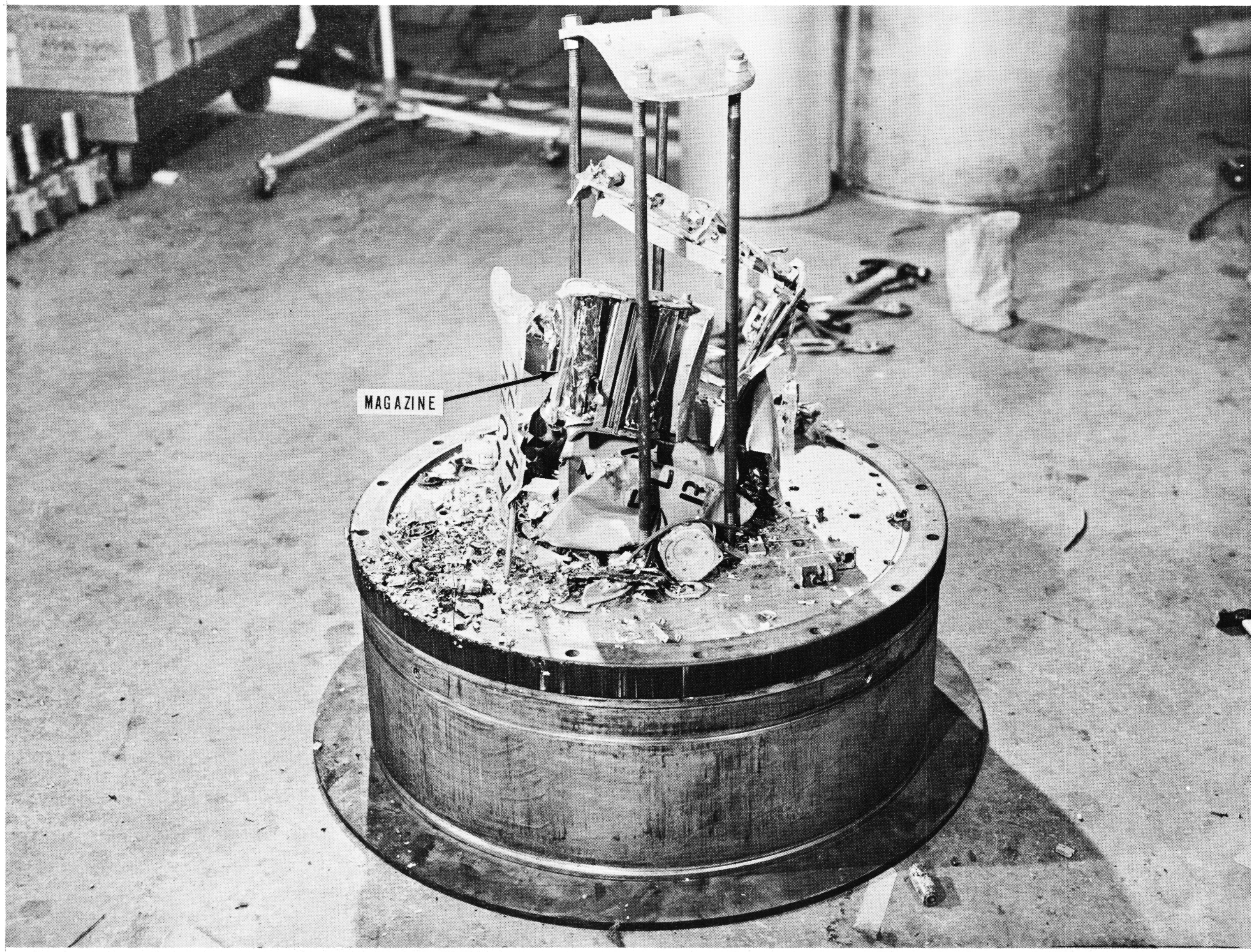

FIG. 9 RESULT OF SHOCK TEST IN LONGITUDINAL AXIS

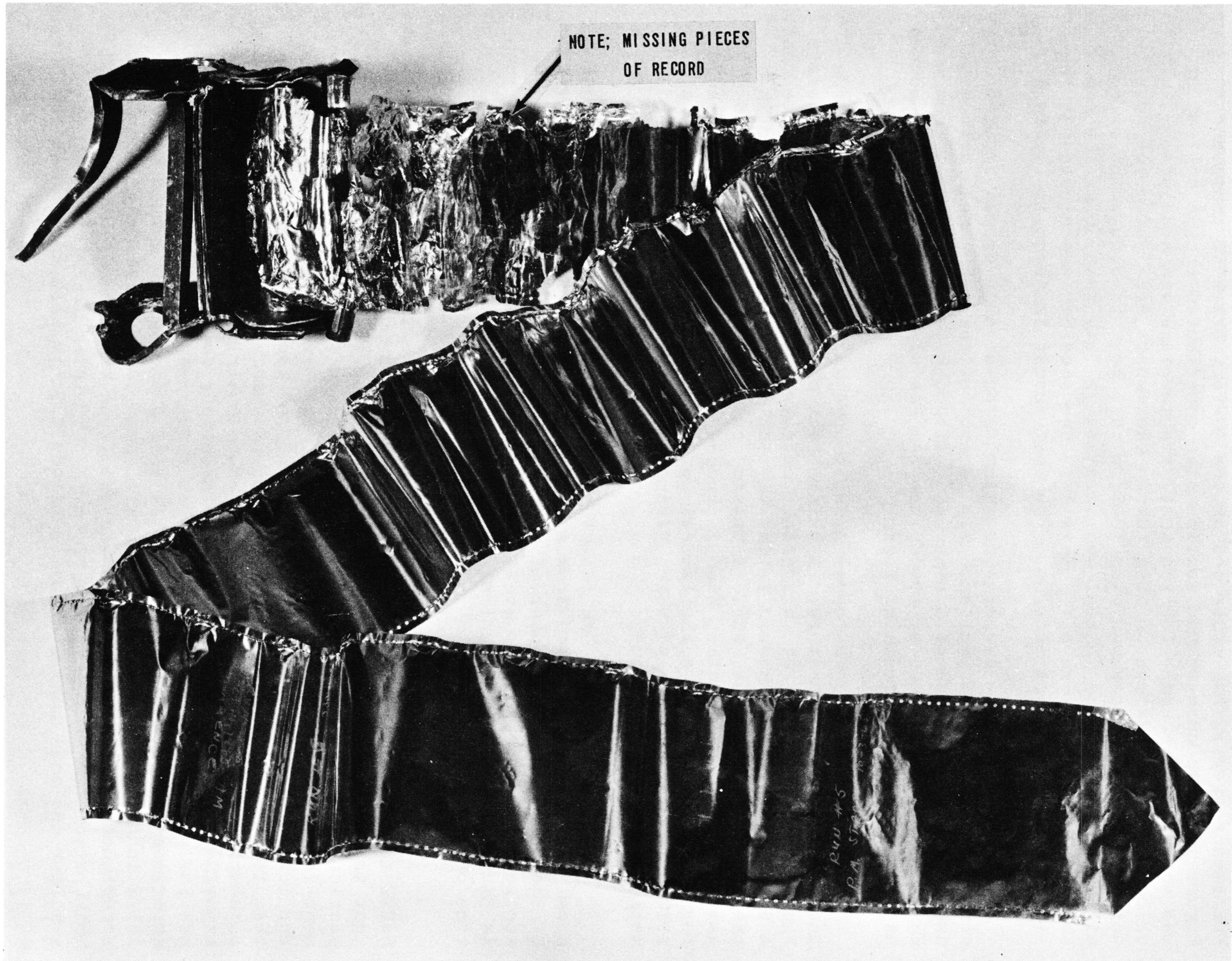

FIG. 10 MAGAZINE AND RECORDING TAPE AFTER SHOCK TEST

Figure 11 shows the test setup with the recorder attached to the actuator carriage or sled. Note the honeycomb triangular section filled with styrofoam. This structure controls the shock pulse shape. The impact area at the other end of the 40-foot track is shown in Figure 12. The cube-shaped section also contributed to the control of the shock pulse shape. For the test, the carriage was accelerated to a velocity with a maximum of 550g toward the impact area where the resultant deceleration shock would be 1000g with a peak time duration of 5 milliseconds. During initial acceleration at less than 550g, the top of the crash housing broke off. This left the recorder unprotected at the time of the 1000g deceleration. The test result is shown in Figure 13.

Crushing Test: "A static crushing force of 4000 pounds applied continuously but not simultaneously to each of the three main orthogonal axes for a test period of 5 minutes." Although the above quote from the ER indicate 4000 pounds of force, the FAA has since suggested 5000 pounds as a more realistic crushing force.

Recorder A - Recorder A was tested at NAFEC in the Standards and Calibrations Laboratory. A Rhiele test machine was used to generate the 5000-pound load. At this point, only two recorders were left to test. A recorder that was shocked in the vertical direction was crushed in the vertical direction, etc. A static crushing force of 4000 pounds was applied for 5 minutes, then increased to 5000 pounds and again held for 5 minutes. In both the lateral and vertical tests, other than a slight bowing of the case which disappeared with the release of the weight, there was no damage.

Penetration Test: "An impact shearing force equal to a 500-pound steel bar which is dropped from a height of 10 feet to strike each side of the enclosure. The point of contact of the bar shall have a cross-sectional area that is no greater than a cylindrical rod one-fourth inch in diameter. The longitudinal axis of the bar shall be vertical at the time of impact."

A special test rig (Figure 14) was designed and manufactured at NAFEC to fit the requirements of this test. The description of this test in the specification lacks many important requirements. Three particularly important areas were investigated thoroughly: (a) requirement for 1/4-inch diameter pin strength, (b) requirement for pin length, and (c) elimination of the crushing force of the 500-pound weight since this is not a crushing test. Discussions were scheduled with appropriate personnel to obtain regulatory background material needed in setting up experiments which would provide the necessary technical data to more precisely define the penetration test requirements. It was discovered, experimentally, that the optimum 1/4-inch diameter pin should be 1-1/2 inches long. (A longer pin will bend, not penetrate.) Also, the experiments indicated that the pin should be between 190,000 to 210,000 psi tensile strength for best penetration. (A harder pin will shatter; a softer one will bend.) A common aircraft hinge bolt was chosen for the

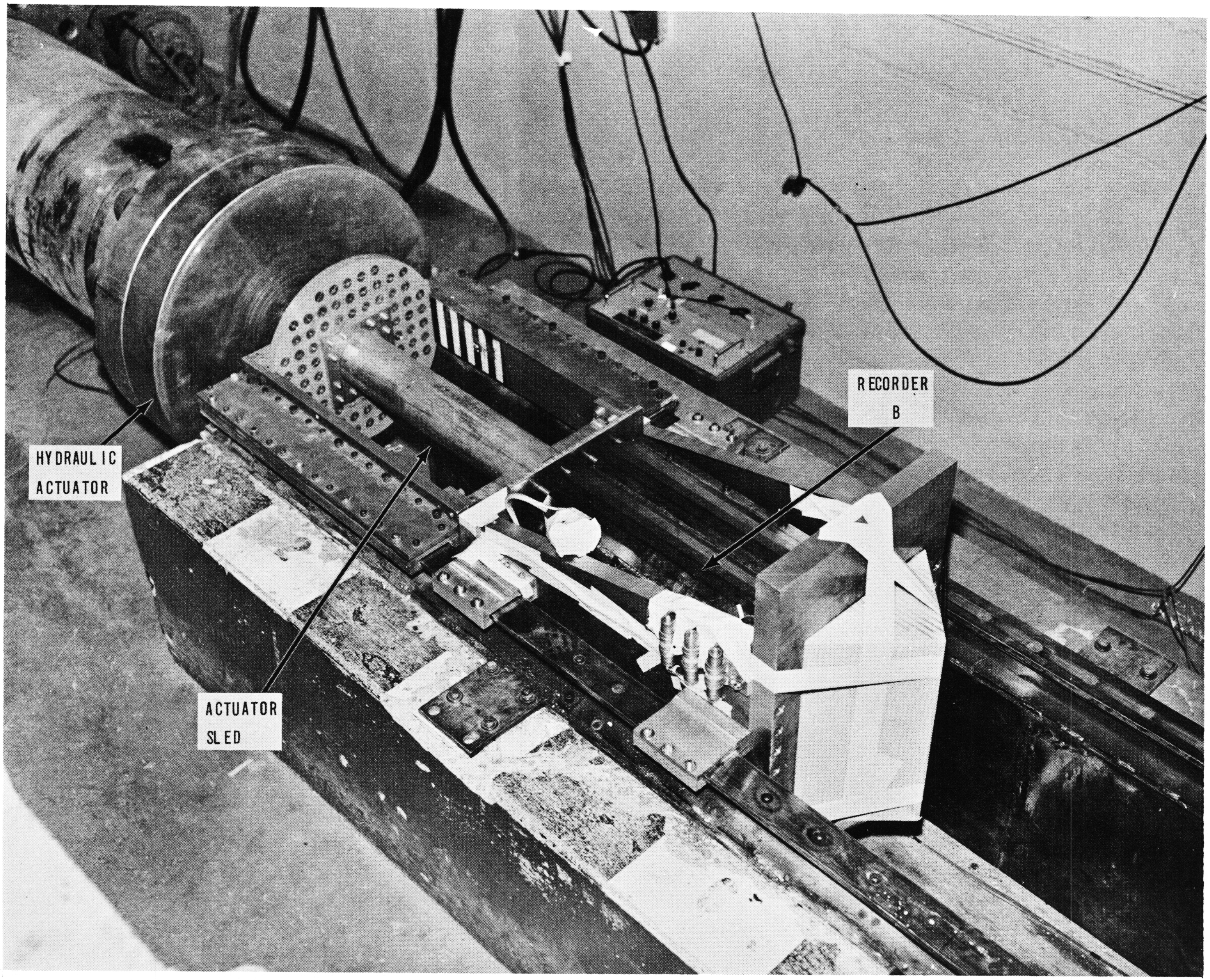

FIG. 11 RECORDER B MOUNTED ON SHOCK TEST SLED

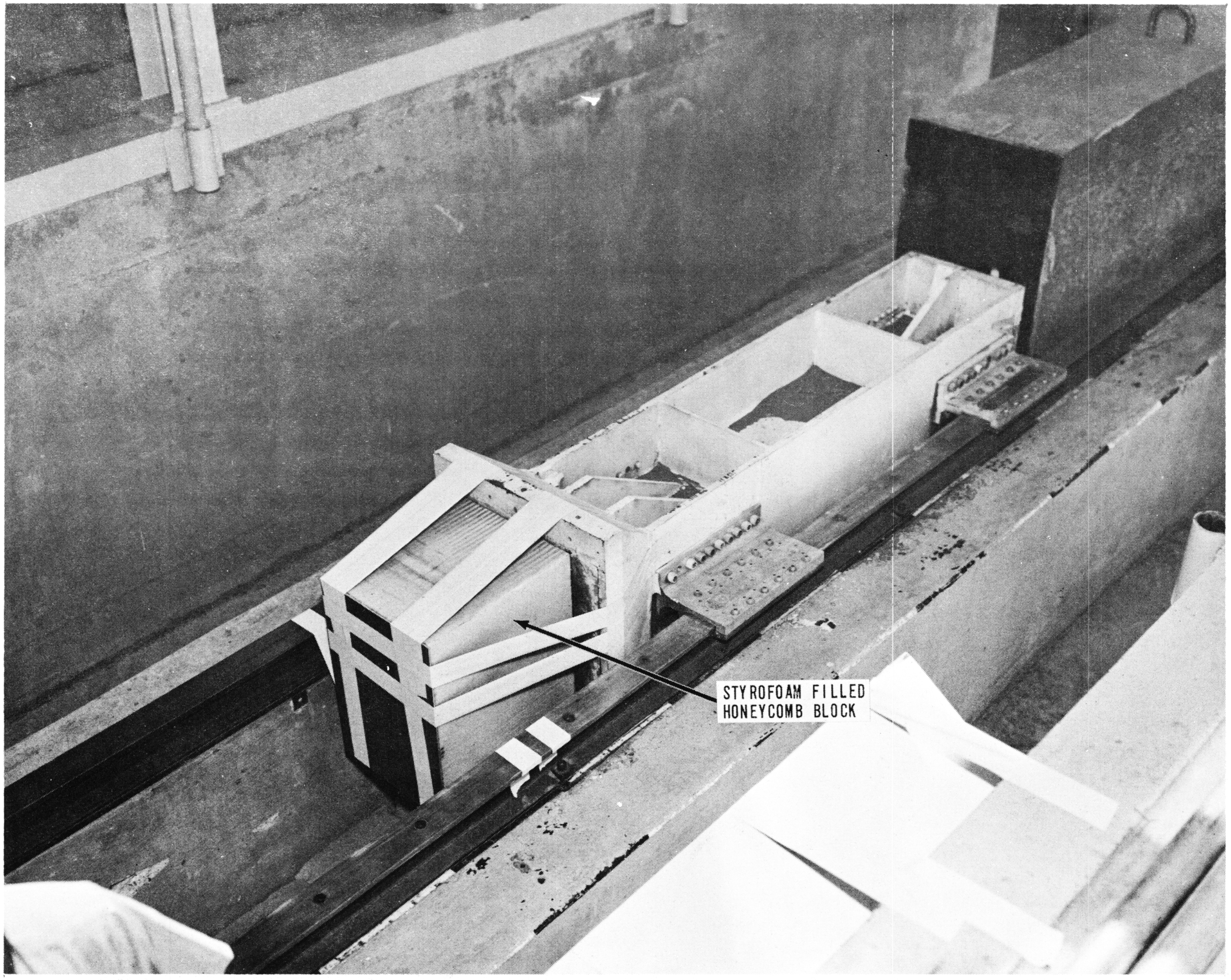

FIG. 12 SHOCK TEST IMPACT AREA

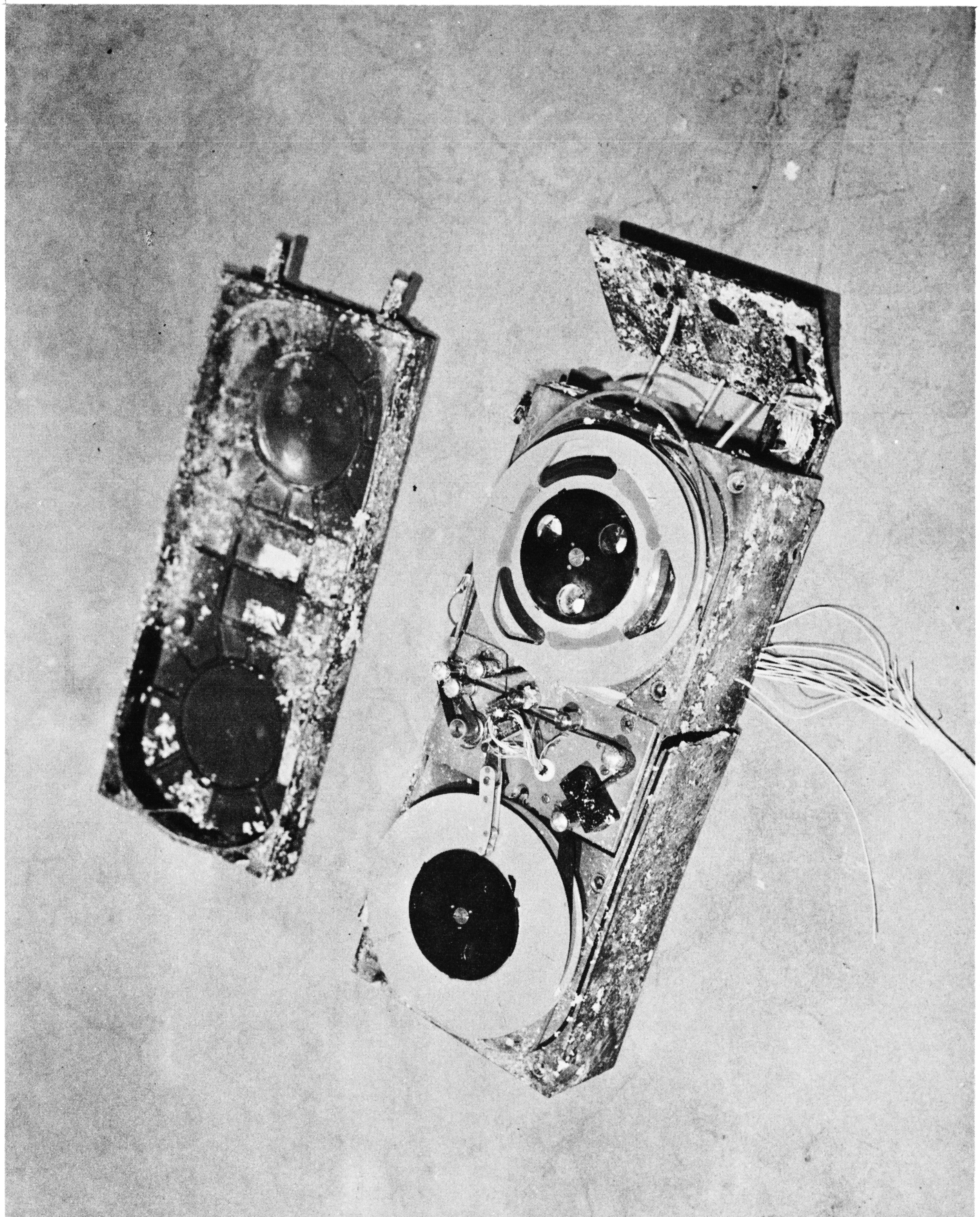

FIG. 13 RESULT OF SHOCK TEST - RECORDER B

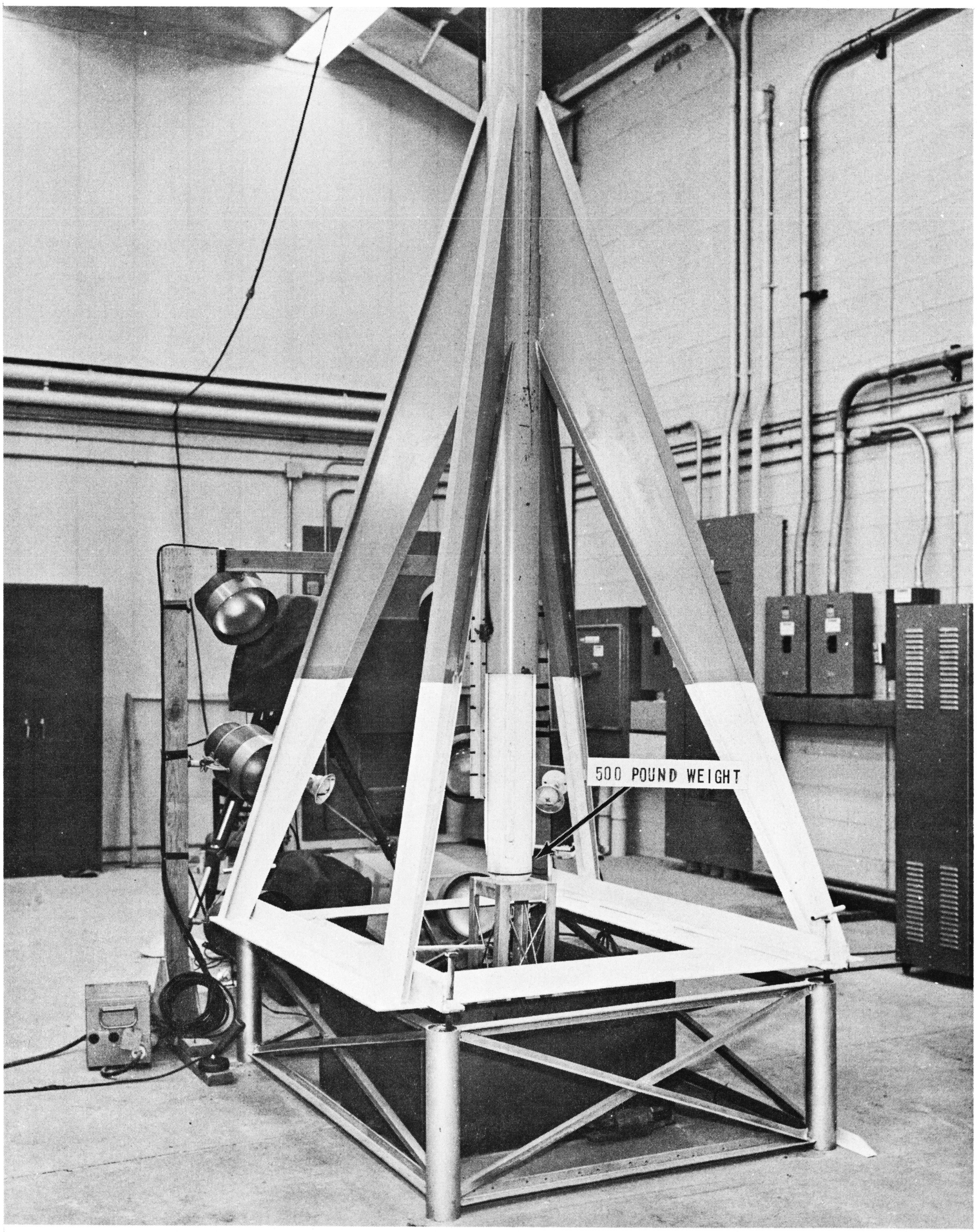

FIG. 14 PENETRATION TEST SETUP

pin - PSN-624-48. It was also found that supporting the test article on 18 inches of fine (65 mesh) sand eliminated the crushing force of the 500-pound weight dropped from 10 feet.

Recorder A - Since only two recorders were left, only four sides, two vertical and two lateral, were tested. These four sides tested, however, were the most vulnerable. Figures 15 and 16 show the typical damage incurred in the vertical and lateral directions, respectively. In each of the four tests, the pin did penetrate to the magazine, but did not damage the stainless steel record tape.

Fire Test: "An exposure to flames of open fire at 1100° C for a continuous and uninterrupted period of 30 minutes in which the flames envelop at least 50 percent of the outside area."

The fire test was conducted at NAFEC in a fire test cell. A modified gun-type oil burner using JP-4 fuel produced the flame required for this test. Twelve gallons of JP-4 per hour were used. The flame temperatures were monitored by chromel-alumel thermocouples. The positioning of these thermocouples and the flame pattern was developed by conducting preliminary fire tests on a mockup.

Recorder A - Fire tests were conducted on the two remaining recorders. Figure 17 shows the flame pattern around the recorder during the test. The typical results of this test are shown in Figure 18. Figure 19 shows the tape extended. Most of the two recorders were melted during this test. All that remained were the magazine and tape, the armor plate protection, and various piles of melted metal. The record tapes were in good condition and all data readable.

Recorder B - To maintain 1000° C for 30 minutes with flames covering 50 percent of the area of Recorder B, two burners were required. The test was performed without incident and the recorder survived. Figure 20 shows the recorder and crash housing opened up after the test. The mylar and stainless steel magnetic tape retained all of the simulated data.

SUMMARY OF RESULTS

Both recorders were destroyed in the longitudinal shock test phase of the series of four crash survivability tests. Recorder A would require a minor modification of some column strength in the longitudinal direction to survive this shock. Recorder B, however, would require a major redesign of the crash housing to survive this test. Also, Recorder B never did record or operate. An attempt was made to determine the cause of the malfunction of Recorder B. FAA technical personnel as well as the manufacturer's representative could not determine the cause of the malfunction to get the recorder operable during these tests.

FIG. 15 RESULT OF PENETRATION IN VERTICAL AXIS

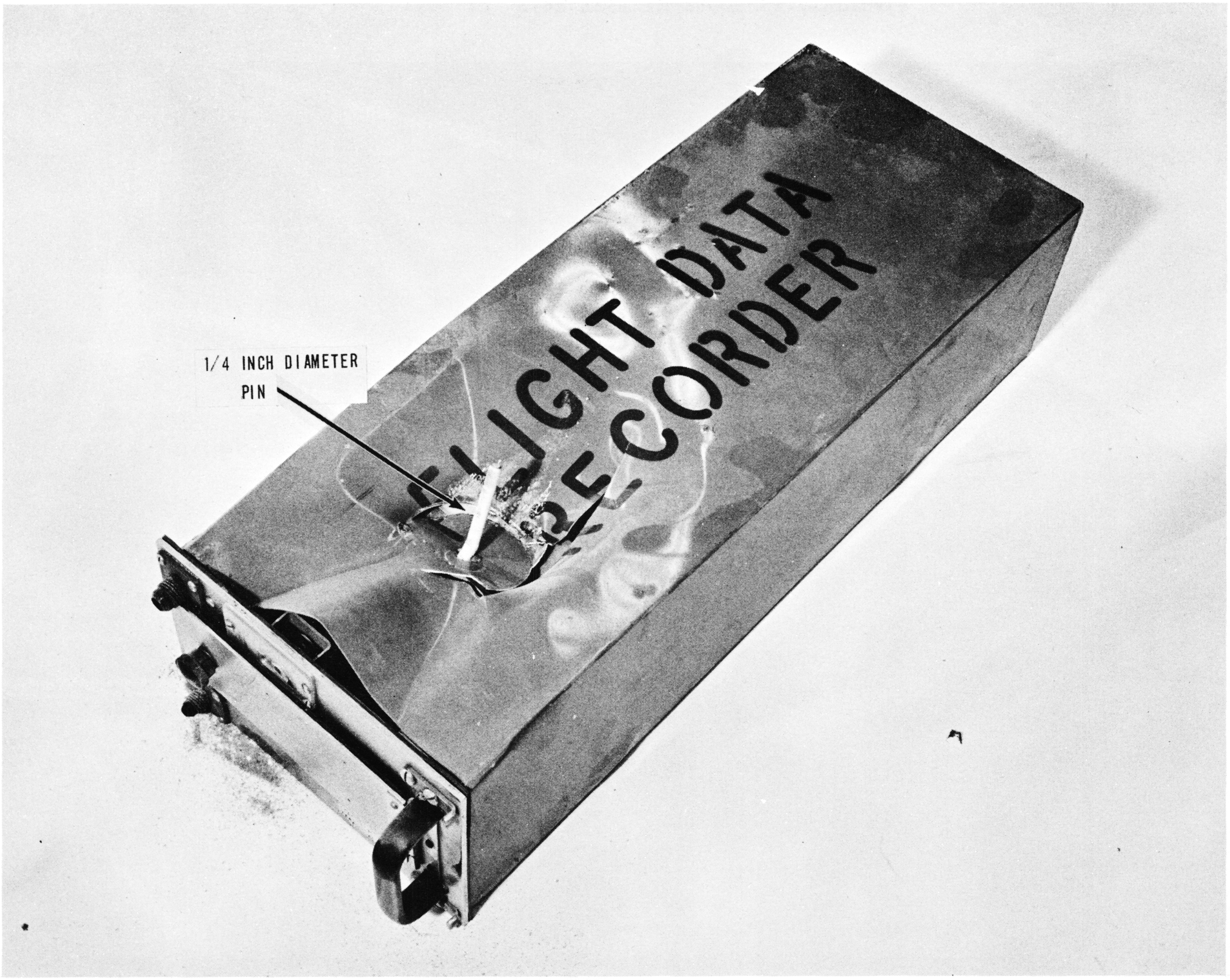

FIG. 16 RESULT OF PENETRATION IN LATERAL AXIS

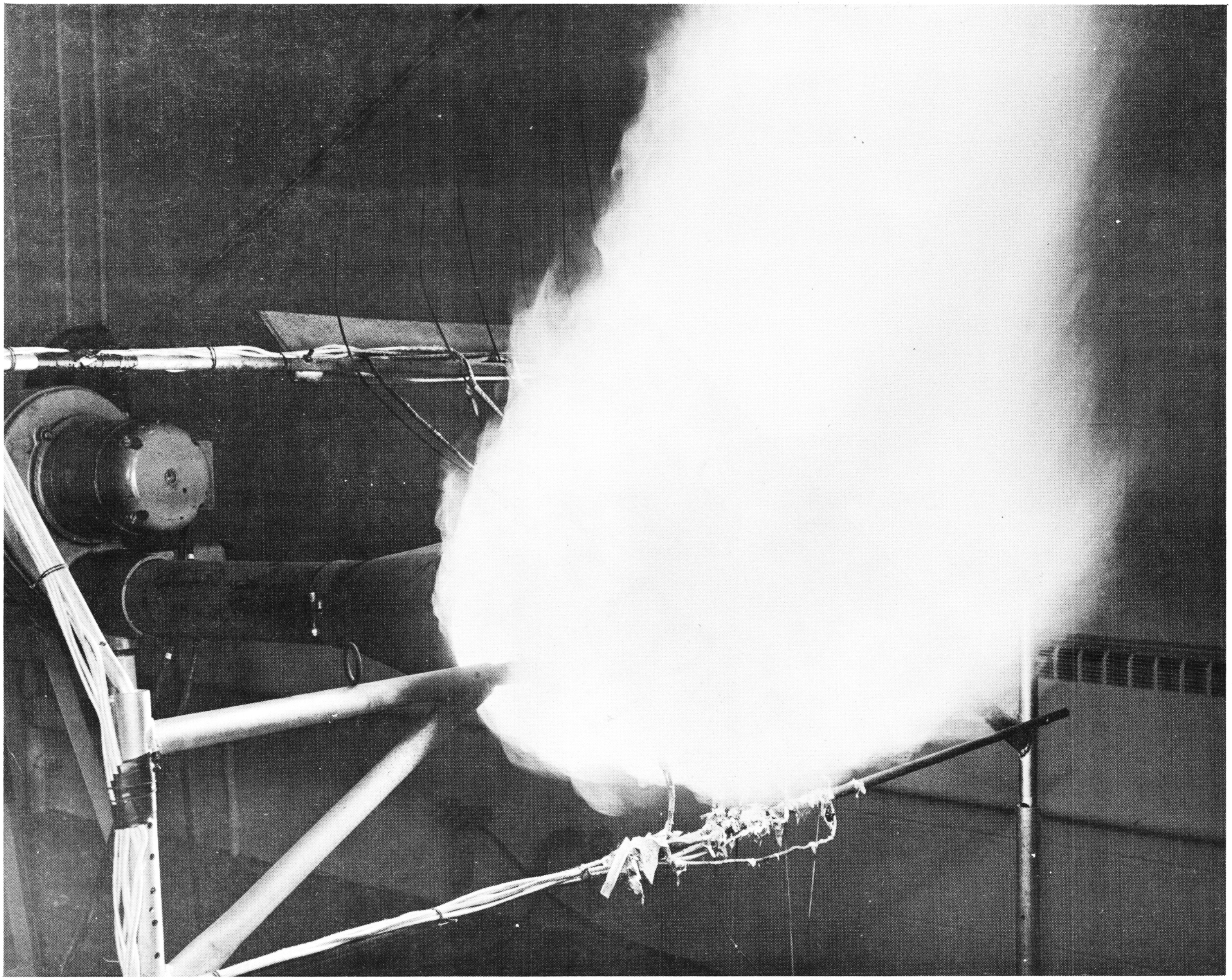

FIG. 17 FIRE TEST IN PROGRESS (TYPICAL)

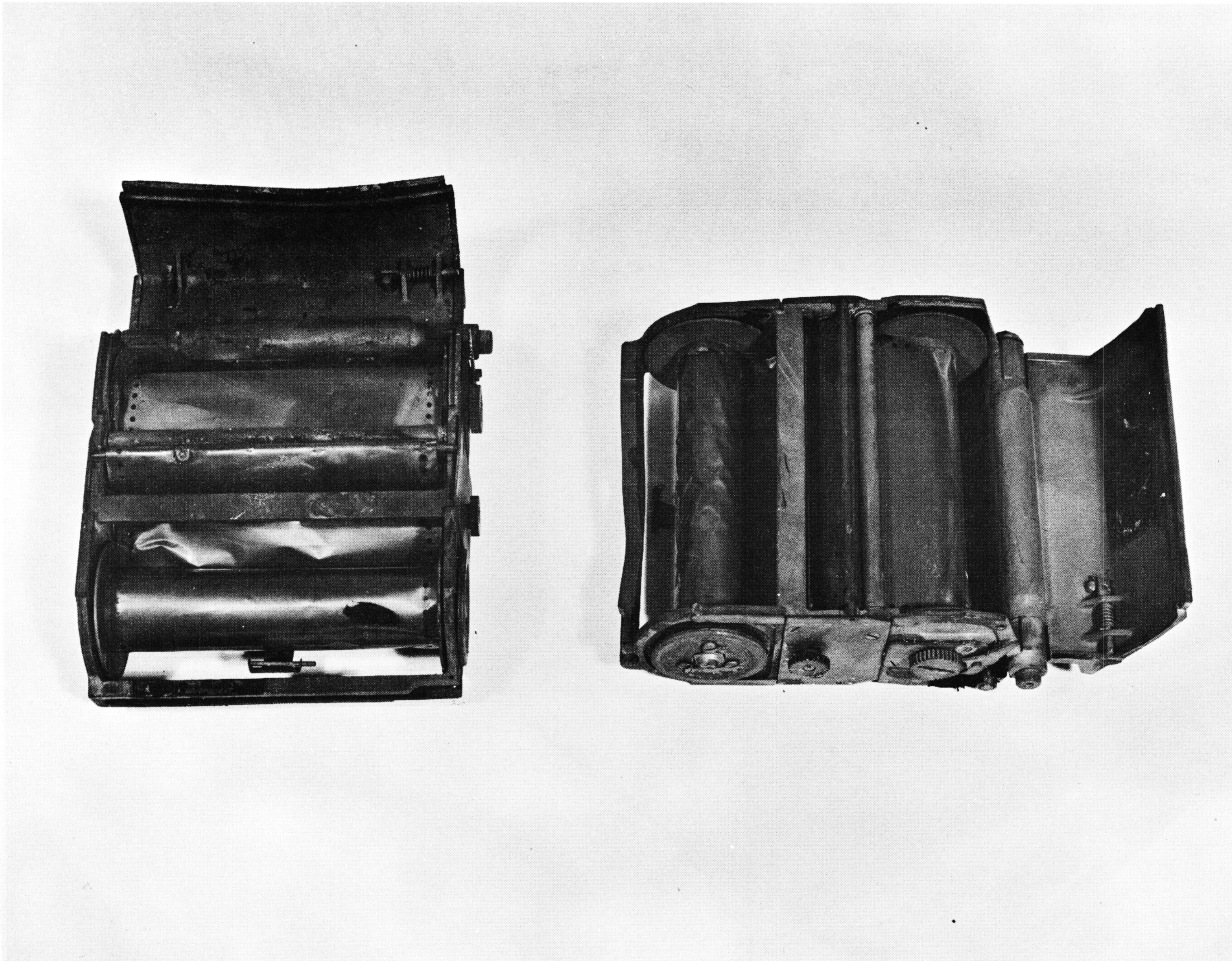

FIG. 18 MAGAZINES AND RECORDS AFTER FIRE TEST

FIG. 19 EXTENDED VIEW OF RECORD

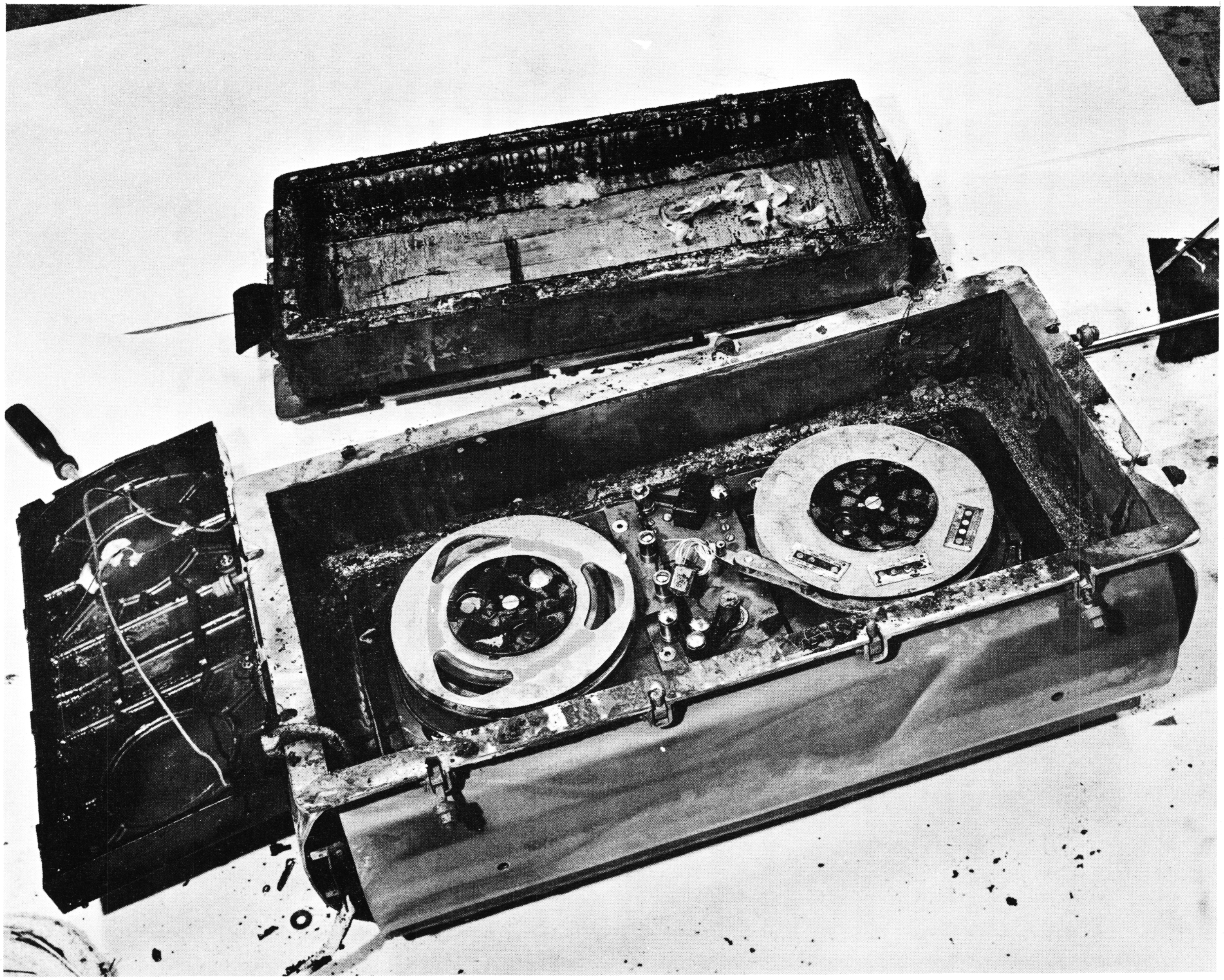

FIG. 20 RESULT OF FIRE TEST - RECORDER B

The four crash survivability tests are ambiguous and poorly defined. It is suggested that the following points be taken into consideration in the definition of the tests:

Shock Test

The shock test defined in Figure 6 is misleading. This curve seems to indicate the 5-millisecond duration at 1000g is the damaging part of a shock pulse. This is not true. The most damaging part of a half-sine-wave shock pulse is the rise time or fall time. This drastic change in velocity over a short period of time causes the damage. Therefore, in this case, Figure 21 shows the most realistic shock test pulse. The rise and fall times are the same as those in Figure 6 (1000g), but the delay at 1000g for 5 milliseconds is eliminated. Accuracies in meeting this pulse rise-fall time should be within $\pm$ 15 percent.

Crushing Test

The crushing test is quite well defined. One point that is not brought out, but is logically assumed, is the area over which the 5000 pounds are to be distributed. It is therefore suggested that a phrase be added to the crushing test indicating that the 5000-pound crushing force be distributed over the area of each side of the enclosure tested.

Penetration Test

The penetration test was developed under this project. One of the first innovations necessary was the addition of a bed of sand to offset the crushing force of the 500-pound weight. This bed was made of fine sand (i.e., be able to pass through a 65 mesh screen) with a length and width of not less than 3 by 3 feet but not greater than 6 by 6 feet. It was also found that it is very important to specify exactly what type of material is to be used for the 1/4-inch diameter pin and how long this pin should be. It was found that the ideal pin should be 190,000 psi tensile strength protruding 1-1/2 inches from the bar. The pin that was used in these tests was PSN-624-48. The longitudinal axis of this pin and bar should be within 1° of vertical at time of impact. It was also noted that it is important for the diameter and length of the 500-pound weight to be roughly defined.

Fire Test

A separate project is being conducted at NAFEC to more thoroughly define the fire test.

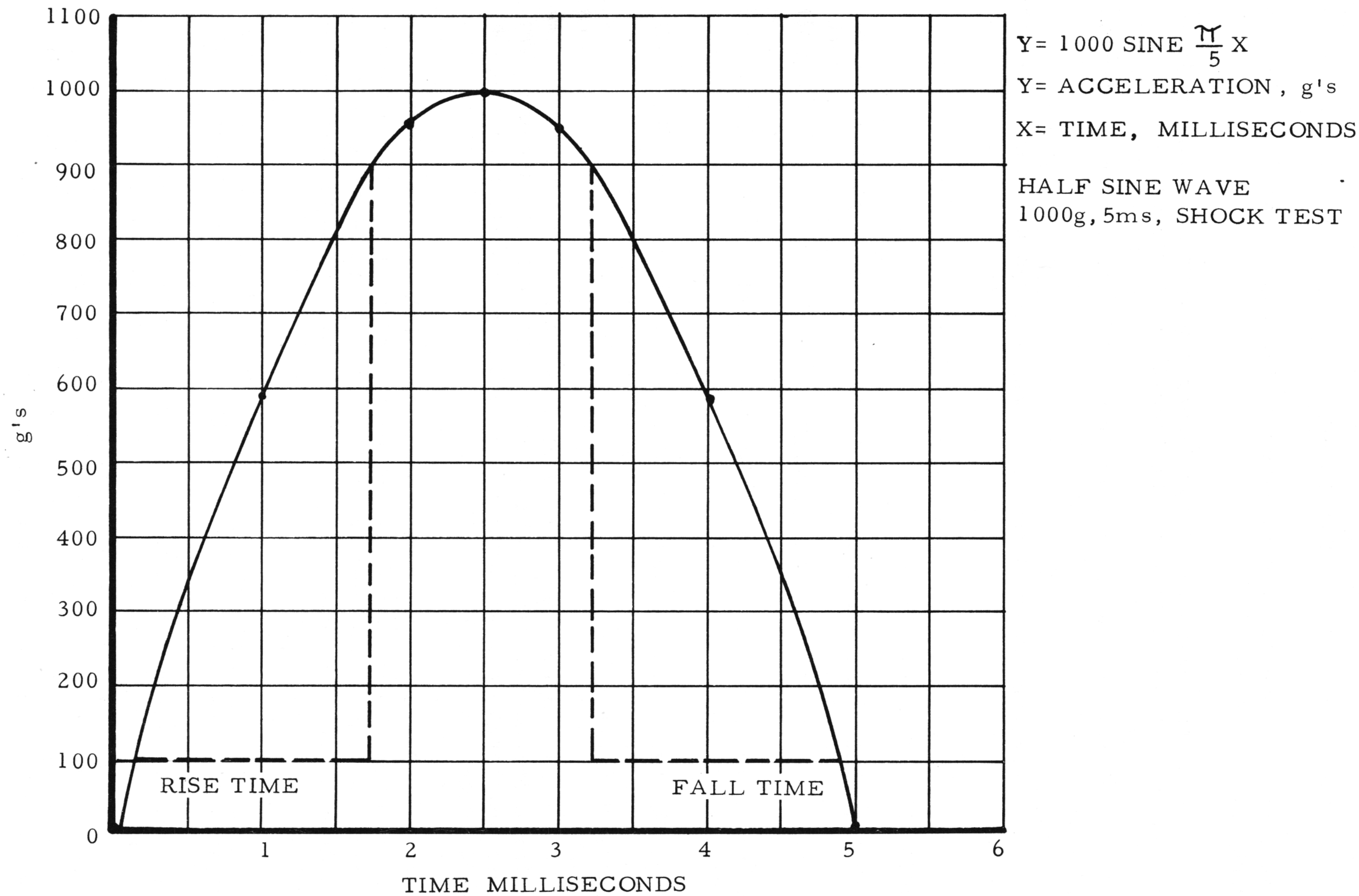

FIG. 21 PROPOSED SHOCK TEST

CONCLUSIONS

Based on the results of evaluation of two experimental flight data recorders, it is concluded that:

1. Neither Recorder A nor Recorder B is of a design capable of withstanding the shock test in the longitudinal direction.

2. Recorder A would require a minor modification to survive the shock test.

3. Recorder B would require a major redesign to survive the shock test.

4. Flight data recorders can be produced to survive the updated crash survivability tests.

5. The crash survivability tests are inadequately defined.

RECOMMENDATIONS

Based on the results of evaluation of two experimental flight data recorders, it is recommended that:

The evaluation of the two experimental flight data recorders indicates that the crash survivability tests should be defined more clearly as follows:

1. Shock Test - A 1000g shock shall be applied in each of the three orthogonal axes. This shock shall be half-sine-wave in shape and shall have a rise time of 1.85 milliseconds $\pm$ 15 percent and a peak of 1000g $\pm$ 5 percent.

2. Crushing Test - A static crushing force of 5000 pounds shall be applied continuously but not simultaneously to each of the main orthogonal axes for a test period of 5 minutes. The 5000-pound force shall be distributed over the area of the side of the enclosure perpendicular to each orthogonal axis.

3. Penetration Test - A 500-pound steel bar shall be dropped from a height of 10 feet to strike each side of the enclosure. The point of contact of the bar shall have cylindrical rod 0.25 inch in diameter, extending 1.5 inches from the bar. The pin should be PSN-624-48. The longitudinal axis of the bar shall remain essentially straight and be within 1° of vertical at time of impact. The recorder shall be positioned on a bed of fine (65 mesh) sand, 18 inches deep, at least 3 by 3 feet, but not greater than 6 by 6 feet. The test shall be designed so that the recorder enclosure will sustain the 500-pound load after impact.

ACKNOWLEDGMENT

Appreciation is expressed to Mr. O. E. Patton of the NTSB for his assistance and advice on the data reduction of the damaged records.

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Descriptors

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Environmental Tests

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Department of Transportation, Federal Aviation Administration, National Aviation Facilities Experimental Center, Atlantic City, N.J.

EVALUATION OF EXPERIMENTAL FLIGHT DATA RECORDERS IN AN AIRCRAFT CRASH ENVIRONMENT BY Paul M. Rich, Final Report. November 1968, 29pp. incl. illus.
(Project No. 530-003-03X, Report No. NA-68-24)
(DS-68-23)

UNCLASSIFIED REPORT

Two types of experimental 20-channel flight data recorders were evaluated to determine their resistance to an aircraft crash environment. This crash environment was simulated by a series of four tests: a shock test, a crushing test, a penetration test, and a fire test. The first flight data recorder tested was an oscillographic recorder enveloped in a 1/2 ATR (Air Transport Radio) case; the recording medium being stainless steel tape. This recorder survived all the tests except the shock test in the longitudinal direction. A minor modification to the recorder would correct this fault. The second type of recorder was a magnetic tape
(over)

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