Image Cover Sheet

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TITLE

DYNAMIC TESTING OF THE CT114 TUTOR EJECTION SEAT

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DYNAMIC TESTING OF THE CT114 TUTOR EJECTION SEAT

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DEPARTMENT OF NATIONAL DEFENCE - CANADA

TABLE OF CONTENTS

Auxiliary Appendices:

B: Edited 16-mm high-speed movie film of all runs from 3 cameras

C: Two Polaroid Graph-Check prints taken during the impact for each run

D: Slides (35 mm) of pre- and post-test seat configurations for each run

LIST OF FIGURES

TABLE

ABSTRACT

A series of five tests on the Canadian Forces CT114 Tutor aircraft ejection seat was performed at the Impact Studies Facility, using the HyGe crash simulator. These impacts were used to determine the integrity of structural modifications to the lap-belt seat anchorages, and the support structure for the (MA-6) Ballistic Powered Inertial Reel (BPIR) within the headrest, for comparison with relatively recent military specifications for ejection seats. As a secondary objective, the lock-up performance of the BPIR was also observed at high crash severity levels, in both the automatic and locked modes of operation. The tests showed that the seat modifications met the pertinent military specifications, but that the seat itself failed the angle-impact portion of one of the specifications. The BPIR failed to lock-up from the auto mode; and, in the locked mode, failed to remain locked-up for one test out of four, at the relatively high crash severity level (96% cumulative frequency of occurrence) which was employed for all the impacts.

These results prove that the modifications to the seat are adequate from a strength viewpoint, and that the seat performs well, especially since it was designed before dynamic seat specifications had become established. On the other hand, the BPIR is only marginally satisfactory; its use should be re-examined if and when safer, more crash-proof cockpit environments are used in Canadian Forces aircraft.

1. BACKGROUND AND OBJECTIVES

The Ballistic-Powered Inertial Reel (BPIR), which is used on many Canadian Forces (CF) jet aircraft ejection seats, acts on the two shoulder restraint belts behind the point at which they come together at the back of the airman's shoulders. The BPIR and the shoulder belts have several important functions:

(i) to "haul back" the seat occupant in the event of an ejection, so that the occupant is properly positioned to prevent injury during the ejection;

(ii) to provide full and continuous restraint, in order to minimize injury to the seat occupant in the event of a crash; and

(iii) to allow body movements beyond the normal fully-restrained position, at the option of the seat occupant, during relatively-safe aircraft operations, while providing for automatic inertial reel lock-up (which prevents further play-out of webbing) in the event of sudden turbulence or an impact.

Haul back is accomplished by a gas-discharge turbine device which is attached to an (MA-6) inertial reel; it causes the reel to wind up any slack shoulder restraint webbing once seat ejection has been initiated.

During normal flight, the BPIR can function in either of two modes under the control of the seat occupant. In the "locked" mode, the shoulder belt cannot play out of the reel, which satisfies the conditions for function (ii). In the "unlocked" or "auto" mode, the shoulder belt can play out of the reel to its maximum limit under constant tension, which allows the occupant to move in order to reach controls or make observations from unusual positions. In addition, in the "unlocked" mode, the BPIR is designed to automatically lock-up whenever the belt webbing plays out of the reel with an acceleration greater than 1.5 to 3 G's. This provides protection for the occupant in the event of sudden turbulence or impact; it is not intended to provide protection in the event of a seat ejection. The "unlocked" mode therefore meets the requirements of function (iii).

The Impact Studies Facility at DCIEM has previously tested the support structure for, and operation of, the BPIR for the Aerospace Engineering Test Establishment (AETE) on two occasions prior to 1984. The first study, done in 1982, evaluated the structural integrity of the modified support structure for the BPIR on a CT133 seat, which was proven to be sound (1). However, it was observed then that the BPIR failed to lock-up from the automatic mode at high (but potentially survivable) deceleration levels.

In 1983, additional simulated impacts were carried out for AETE, using a CT114 Tutor aircraft seat and the same BPIR, with objectives similar to those of the 1982 test program. That series of tests was prematurely terminated because of structural failure of the seat at the lap-belt attachments. Also, the BPIR again failed to perform well at high impact levels. However, the precise conditions required for failure were not determined, since the test set-up had not been established specifically to study the performance of the retractor. A recommendation was made then to conduct a thorough test program to investigate the lock-up failure of the BPIR, paying particular attention to the installation and operation of the MA-6 inertial reel.

Early in 1984, the Impact Studies Facility began to investigate the effectiveness of the CH135 helicopter restraint system in preventing excessive occupant excursions (2). On the basis of the work done for AETE in 1982 and 1983, this study focussed particularly on the behaviour of the MA-6 retractor, which is used in the CH135, as well as in the BPIR used in the CT114 and CT133 ejection seats. Those tests showed that the MA-6 retractor locked-up from the automatic mode even at the most severe crash which was simulated, which had a cumulative frequency of occurrence (CFO) of 95%.*

Subsequently, in order to repeat the AETE tests which had been prematurely terminated in 1983, AETE modified and strengthened both the lap-belt attachment points at the seat, and the area within the seat headrest in which the BPIR had been relocated. Two CT114 Tutor seats were sent to DCIEM, with the objective of determining the structural integrity of the modified seats; and, as a new objective, to observe the behaviour of the MA-6 retractor within the BPIR at impacts of higher crash severity than those which were employed during the CH135 helicopter seat tests (i.e., with CFO ratings greater than 95%).

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* The Aircraft Crash Survival Design Guide (3) and Crash Survival Design Guide (4) define the CFO as the fraction, expressed as a percentage, obtained by dividing the cumulative total number of crashes which are judged to be potentially survivable, by the cumulative total number of crashes during the studied period, for a specified impact deceleration level and change in velocity. The data in these references were obtained for rotary and light fixed-wing aircraft, and are not directly applicable to a study of jet aircraft restraint systems. However, there is no similar analysis or guideline for ejection seats, nor any other study from which to draw any more applicable data. Also, the CT114 and CT133 BPIR's utilize the same (MA-6) inertial reel which is used in many CF helicopters (e.g., the CH135), to which both References 3 and 4 are directly applicable. Any knowledge gained of the lock-up capability of the BPIR in the CT114 and CT133 is directly applicable, therefore, to the behaviour of the inertial reels used in many CF helicopters.

2. TEST METHODOLOGY

2.1 Equipment and Instrumentation

The tests were performed on the DCIEM 12-inch HyGe (Bendix Corp) impact accelerator, which simulates impact by rapid acceleration, or, as it is commonly referred to, by a "reverse mode" impact. The crash acceleration pulse that was delivered to the test package was programmed by the adjustment of various gas pressures and volumes within the HyGe accelerator; and by the selection of an appropriate profile for an internal metering pin, which determines the precise shape of the acceleration pulse. The test sled, with its payload, was accelerated in a backwards direction to a pre-determined velocity. During this short period of rapid acceleration, the payload on-board the sled experienced the same dynamic loads that would occur during a sudden deceleration impact. After the initial acceleration, the sled was slowly decelerated to a stop.

The two CT114 Tutor aircraft ejection seats that were used in the tests had been modified by AETE with strengthened lap-belt attachment hardware, and strengthened headrest structures for supporting the BPIR. The seats had been subjected to a variety of tests at AETE before being shipped to DCIEM, but had not suffered any structural damage which could be expected to effect the validity of the results obtained from the DCIEM tests. One of these seats is shown mounted on the impact sled in Figure 1.

The occupant of the ejection seat was a 95th-percentile adult anthropomorphic crash-test dummy (Alderson Research Labs, Stamford, Connecticut, U.S.A.; Model VIP-95, Serial No. 158), which conforms to the United States Code of Federal Regulations (5). It was instrumented in the chest and head cavities with Endevco type 7267C-750 triaxial accelerometers in order to monitor chest and head decelerations during the impact. The accelerometers were orientated within the dummy along three orthogonal axes such that positive X was in the direction from the back to the front of the dummy, positive Y was in the direction from the dummy's right side to its left, and positive Z was in the direction from the feet to the head.

The dummy wore a helmet and was clothed in a Canadian Forces summer flying suit provided by the Medical Life Support Division (MLSD) of DCIEM; new seat belt restraint systems were supplied by AETE. Five refurbished, unused, BPIR's were also supplied by AETE, and each run was performed with a different, unused retractor.

The load on the shoulder belt webbing was measured using a Lebow Model 3419 belt load cell. The loads in the direction of impact at each of the four points at which the seat was attached to the sled structure were measured using four customized, strain-gauged support brackets supplied by AETE.

Basic sled acceleration data were monitored using two Setra Model 141 high-output accelerometers, which were mounted directly on the impact sled.

For high-speed filming, three Stalex rotating prism movie cameras, equipped with wide angle (13 mm) lenses and operating at 1000 frames per second, were used. Two of these were mounted on outriggers beside and in front of the seat, to provide lateral and frontal views of the dummy and seat. The third camera was positioned on the laboratory floor, to provide an oblique angle view of the impact.

Two Graph-Check sequence cameras were set up so that "quick-look" photographs of events during the impact were available. These cameras take eight separate photographs at pre-selected equal intervals on a single sheet of Polaroid film, for viewing immediately after the impact.

Before and after each run, photographs were taken of the sled and the seat configuration. The photographs are identified by the last 2 digits of the test run number, which are photographically reproduced within the corner of each frame.

2.2 Selection of the Deceleration Pulse

The CT114 aircraft ejection seat had not been designed to meet any particular dynamic loading specifications. However, AETE wished to test the seat dynamically against a relatively recent seat standard, particularly in view of the structural modifications which were being carried out to relocate the BPIR and strengthen the lap-belt attachment points at the seat.

The two most recent and relevant U.S. military specifications for ejection seats require dynamic testing at a peak acceleration level of 40 G's for frontal and ± 20° impacts, resulting in a change in velocity of 54 MPH, as shown in Figure 2 (6,7). However, since the CT114 seat had not originally been designed to meet this particularly demanding specification, the decision was made to retain the peak acceleration requirement at 40 G's, but to reduce the velocity change from 54 MPH to one that would produce a 40 G deceleration in a typical longitudinal impact. The data from the Crash Survival Design Guides (3,4) were consulted for this purpose, and it was found that a 40 G longitudinal impact deceleration corresponds to a 97% CFO value, which, in turn, requires a velocity change of 36 MPH. Consequently, this was the targeted velocity change for all the impacts in the test program.

Concerning the precise pulse shape, a one-half sinusoid-shaped acceleration profile was used for this test series, following the practice established for the previous AETE test programs. An example of this profile, from run #510, is shown in Figure 3, and is very similar in shape to the triangular-shaped profile recommended in the Crash Survival Design Guides (3,4).

2.3 Data Recording and Processing

The output from the accelerometers was amplified on board the sled, using a series of specially designed, ruggedized, low-noise preamplifiers. The signals were analog-filtered at 5 kHz on board the sled and then transmitted along a low noise, flying-lead umbilical cable to the recording and data reduction area for storage by a multi-channel transient recorder (Datalab, Surrey, UK). The transient recorder equipment digitized the input signal from each channel synchronously with every other channel, at a sampling rate of 20 kHz. The digitizer accuracy was 10 bits (1 part in 1024) and the total recording time of the digitized data was 0.4 seconds, which was sufficient to capture all significant impact and rebound inertial, and belt-load, data. Complete details of the Impact Studies Facility's data acquisition system are available elsewhere (8). The digitizer and recording equipment specifications are more stringent than the requirements established by the Society of Automotive Engineers (SAE), which sets standards for instrumentation for dynmamic test purposes (9).

Immediately after firing the sled, the data were transferred to a computer disk for processing. (The raw data for all runs are being indefinitely retained on magnetic tape in the DCIEM computer centre.) The computer programs first performed digital filtering on the data according to the SAE specifications (9) which detail the specific filtering to be carried out on signals emanating from various sources. For these tests, the sled, chest, and head accelerations were recorded, as well as the belt load and seat support bracket forces. The inertial data were appropriately filtered, as specified, at 60, 180, and 1000 Hz, respectively. The belt load and seat support bracket forces were filtered at 60 and 600 Hz, respectively. The data were then scaled and the resultant head and chest accelerations computed, along with the sled displacement and velocity, by successive integrations of the sled acceleration. Finally, appropriate graphs were produced by a plotter under computer control.

3. RESULTS

For all runs, data from the accelerometers (dummy head and chest), seat support bracket load strain-guages, and the shoulder-belt load-cell, are given in Appendix A in plotted form. The most important data have been summarized and are included in Table 1, along with the objectives for each run and other pertinent test set-up data and conditions. The following notes and observations should be considered along with the tabular results for each run:

Run No. 510

The velocity achieved during this impact was 33 MPH which is 8% below the desired goal of 36 MPH. The CFO value for this velocity is 95%, compared to the desired value of 97%. This error occurred because of a small discrepancy between the expected and actual seat masses, and uncertainties in the set-up of certain other pulse formation parameters. Since there were only two Tutor seats available for the entire program, it was decided to accept this error, which is negligible for practical test purposes, and to conduct all of the remaining tests using the same pulse set-up conditions (i.e., using impacts of 40 G's and 33 MPH).

During this impact, the shoulder-harness failed (the two shoulder-belts separated behind the dummy's neck) and the locking pin in the lap-belt buckle also broke. The resultant extreme, unexpected excursion of the dummy caused the head and chest accelerometers, and the shoulder-belt cell to become disconnected: the signals from these transducers were lost. In addition, both lower strain-gauged seat support brackets deflected into their plastic region, which destroyed the strain-guages on these members.

The headrest of the seat showed no significant permanent deflection as a result of the shoulder-belt force acting on the BPIR within the headrest, nor did the new lap-belt hardware at the anchorage points on the seat show any damage. However, it was decided to strengthen the lap-belt buckle and shoulder stitching for all subsequent runs, and to repeat this run in order to ensure that the full peak load could be taken by the BPIR and lap-belt attachment points (see run No. 512).

Run No. 511

This was essentially a repeat of run No. 510, but with the improvements noted above, and with the seat in its lowest position. There was no significant or permanent seat damage, thereby proving the soundness of the modifications for the seat in its lowest position.

Run No. 512

This was a repeat of run #510, but with the improvements noted above. The seat performed very well, as in run No. 511. Although the retractor was initially in the locked mode, the high-speed films showed that the retractor released about 2.5 in. of webbing before actuating, and then suddenly spooled out all of the webbing remaining in the retractor. After the initial impact, the dummy rebounded to the back of the seat, at which time the retractor reeled in the excess shoulder webbing and locked-up.

Run No. 513

This was the only run conducted at an impact angle of -20°. The two screws which attach the seat-rail to the two longer seat support brackets sheared off, and the rail-bracket at the top of the seat fractured, allowing the seat to become separated completely from the sled. Consequently, all load and inertial data were lost for this run.

Run No. 514

This was the only run carried out with the rectractor in the unlocked or "auto" mode. The retractor failed to lock-up during the impact, and spooled out the entire length of webbing on the reel.

4. CONCLUSIONS

The CT114 Tutor ejection seat, and in particular, the modifications by AETE to strengthen the lap-belt anchorage and the support structure for the BPIR, both exceed the requirements set out in Military Specifications MIL-S-9479 B(USAF) and MIL-S-18471 F(AS) for frontal impacts. The seat itself does not meet these requirements for the -20° impact, which is specified. It should be noted that this seat was not originally designed to meet these specifications, and that strengthening of the shoulder-belt portion of the restraint harness, and the lap-belt buckle, were required to complete the tests.

The BPIR remained locked for 3 of the 5 impacts (see Table 1). For the other two, it failed to lock from the auto mode in the only test in which the auto mode was used. In the second test, the BPIR failed to remain locked, even though it was initially put in the locked mode. These impacts are representative of crash severities of about the 96% CFO level (i.e., 97% CFO, based on 40 G's peak acceleration; 95% CFO, based on a velocity change of 33 MPH).

Previous tests at DCIEM with the MA-6 retractor (1), suggested that it failed because the inertial reel control cable was absent during these tests. It appears to be necessary for effective retractor lock-up operation, at least up to crash severities at the 95% CFO level. Subsequent work (2), with a control cable in place, showed no failure up to the 95% CFO level of crash severity. However, it was demonstrated that at higher crash severity levels, the MA-6 retractor, or BPIR, can fail from either the locked or auto modes, depending on other undetermined factors.

Currently, there are no restraint systems on aircraft seats in the Canadian Forces which are designed to withstand crashes with a severity level of 95% CFO. Consequently, the use of the MA-6 retractor and BPIR should not pose a problem for the Canadian Forces, as it is not likely that any aircrew could survive a crash at or above the retractor failure level, even if the retractor were not to fail.

ACKNOWLEDGEMENTS

The author would like to acknowledge the assistance of Capt. D. Urdal and Sgt B. O'Cain, both of AETE, who assisted in the supply of equipment and the set-up of the ejection seat, and the assistance of the following DCIEM staff: Mr. D. Dennison and Mr. G. Thagard, who performed the technical operations required for the set-up of the ejection seat, and the sled firings; Mr. R. Cardin, who provided editorial assistance; and Dawn Gardham, who typed the report.

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7. Military Specification: System, Aircrew Automated Escape, Ejection Seat Type General Specification for MIL-S-18471 F(AS), October 1978.

8. Bowden, T.J., J.K. Reichert, and J.P. Landolt. The Data Acquisition System at the DCIEM Impact Studies Facility, in Passenger Car Meeting, Society of Automotive Engineers, Inc., Warrendale, PA, USA, June 8-12, 1981 (SAE Paper No. 810812).

9. "SAE Recommended Practice J 211 1980 - Instrumentation for Impact Tests", Society of Automotive Engineers Inc., Warrendale, PA, USA, 1980.

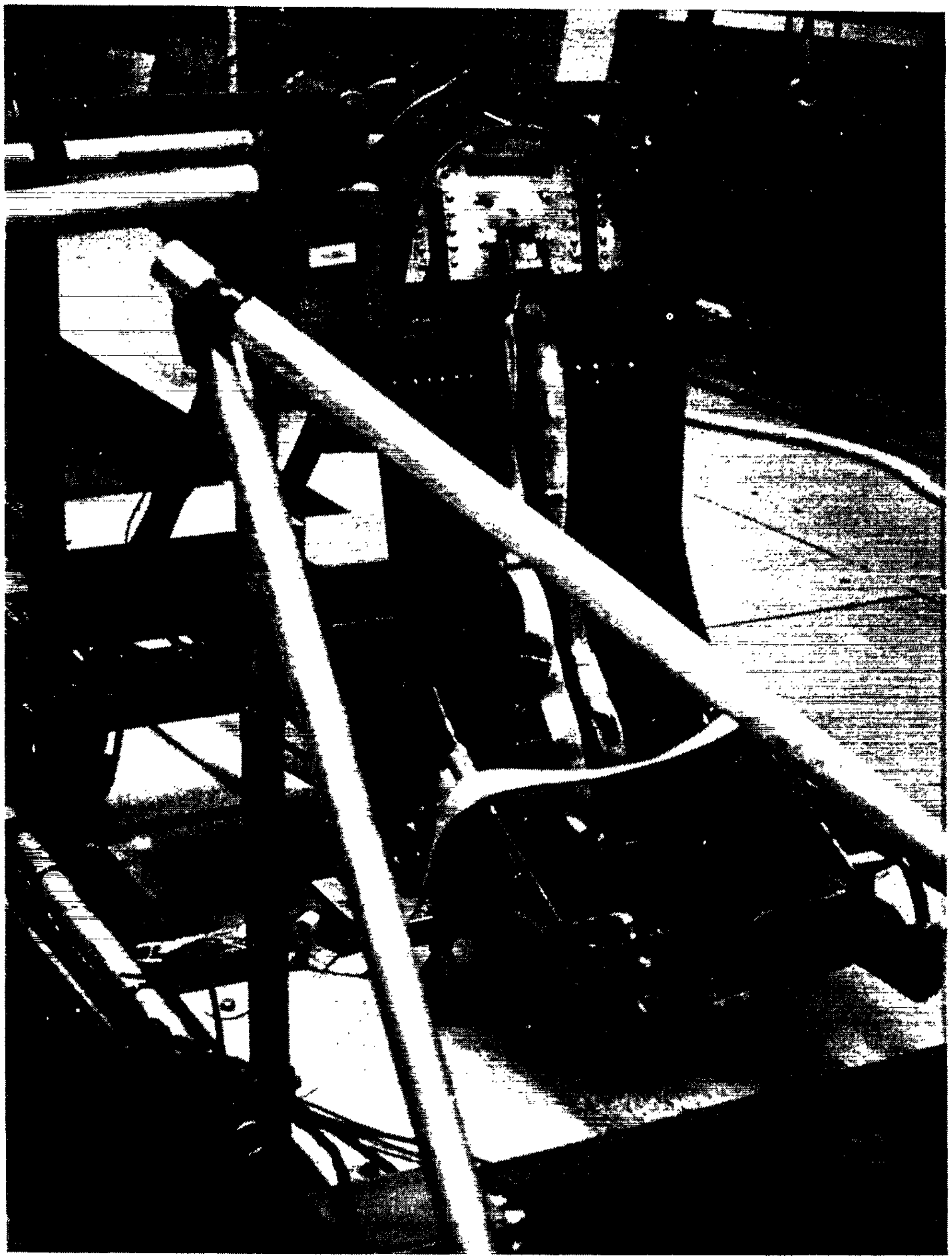

Figure 1. CT114 Tutor Aircraft Ejection Seat Mounted on the Impact Sled

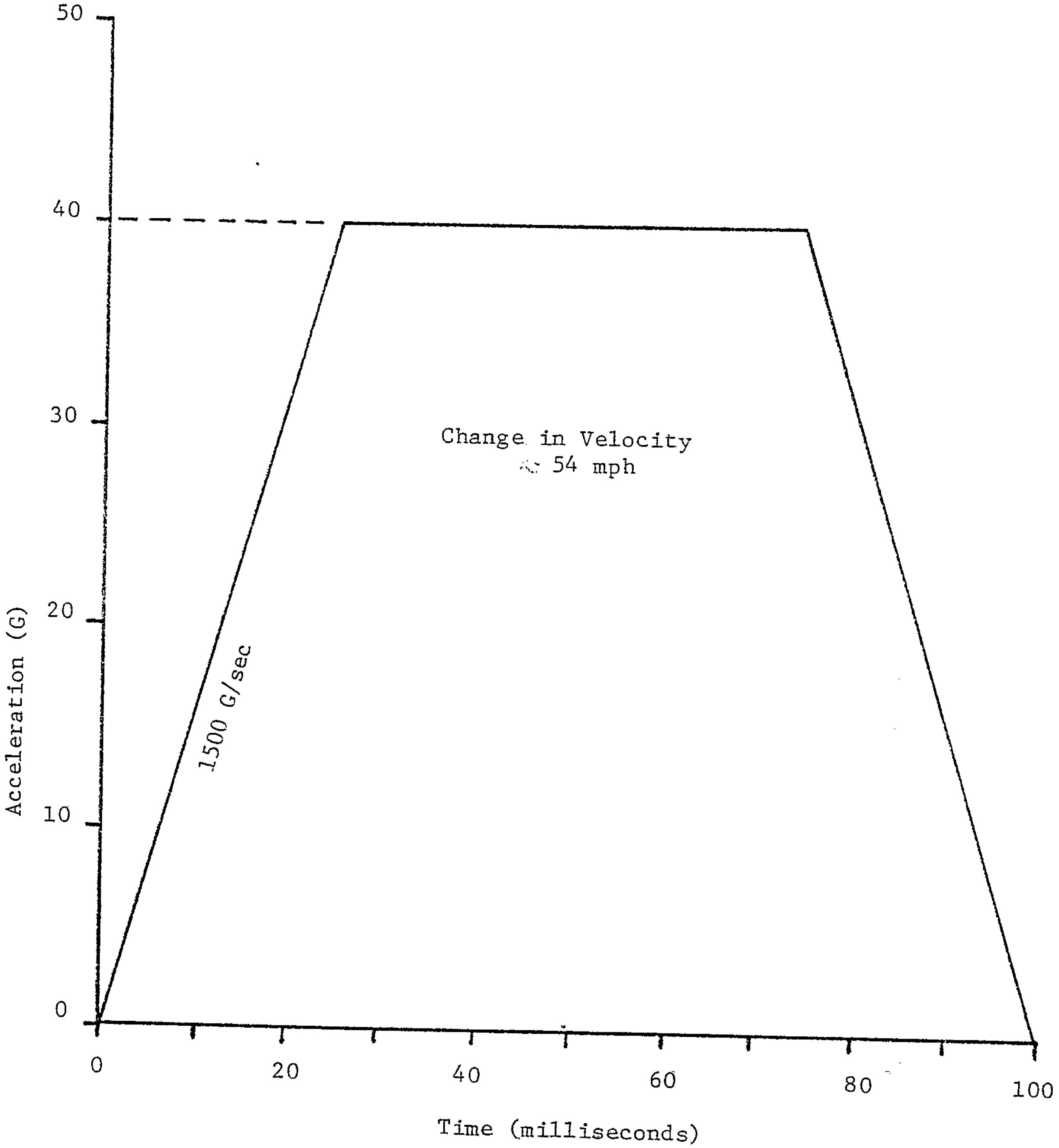

Figure 2: Recommended Longitudinal Design Crash Pulse as per MIL-S-18471F(AS)

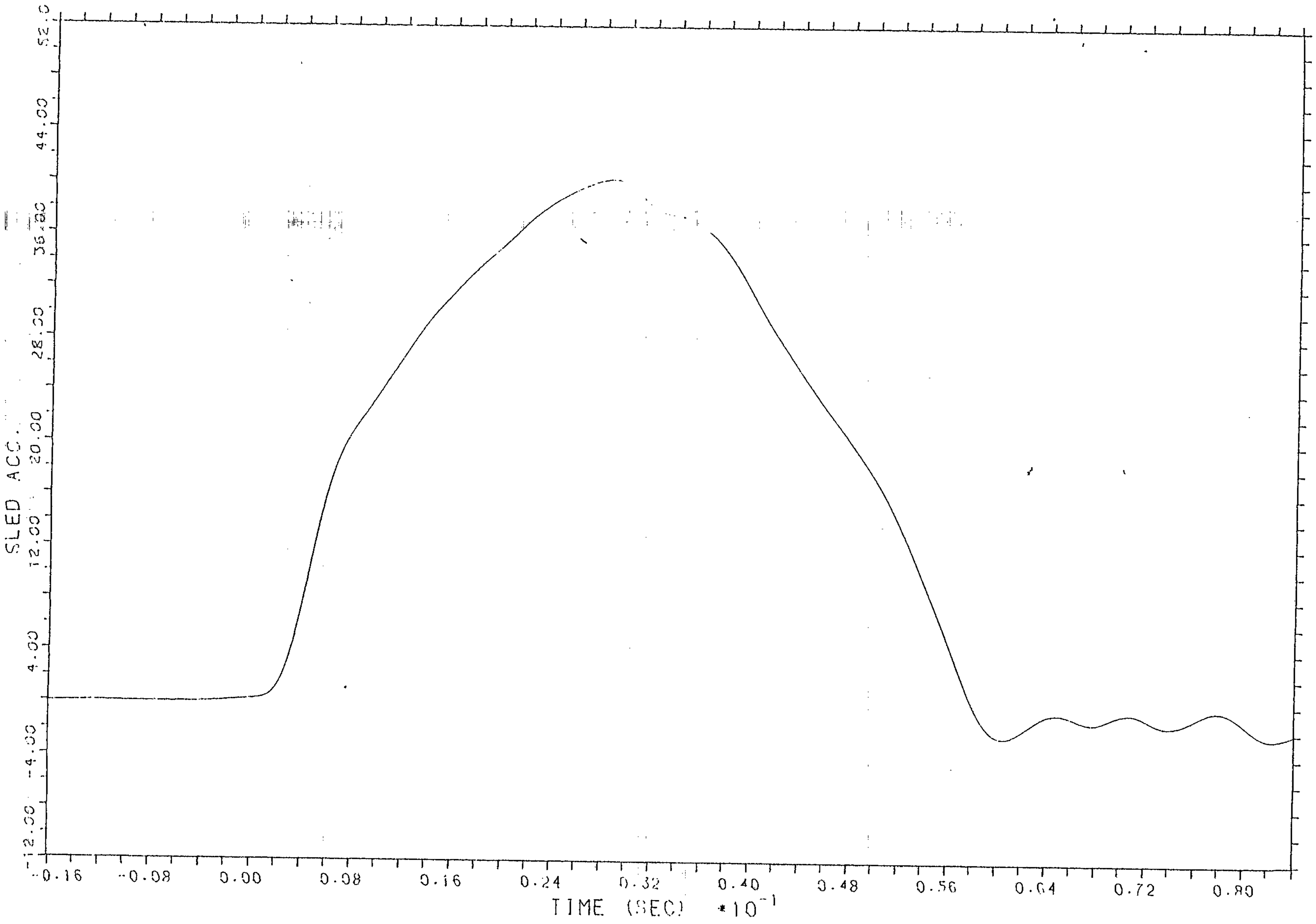

Figure 3. Simulated Crash Pulse Used for All Test Runs

Table 1. Summary of Objectives, Test Conditions, and Results

Objective	Run No.	Direction of Impact	Seat Position on Rails	Peak Acc. (G's)	Velocity (MPH)	Retractor Condition		Peak Shoulder-Belt-Load (lbs)
						Initial	During Impact	
To determine integrity of seat modifications	510	frontal	up	40	33	locked	locked	-----
	511	frontal	down	40	32	locked	locked	3960
	512	frontal	up	40	32	locked	unlocked	3970
	513	-20°	down	40	34	locked	locked	----
To observe retractor lock-up capability	514	frontal	mid point	44	34	unlocked (auto)	unlocked	-----

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APPENDIX A:

Seat Support Bracket Forces and Belt Loads, and Inertial Data

The data are grouped in chronological order by run number: on the plot pages the run number is given by the 3 digits on the second line of the heading on the first page of each set. The same number can also be found at the top left corner of all subsequent pages of plots for the same run: e.g., the "page 1" with the second line reading "DK:TUT510.DAT" is the first page of the data for run No. 510. For each run, the plots are presented in the following order:

Page 1, sled displacement, velocity, and acceleration

Page 2, head acceleration in the X-direction
head acceleration in the Y-direction
head acceleration in the Z-direction
resultant head acceleration

Page 3, chest acceleration in the X-direction
chest acceleration in the Y-direction
chest acceleration in the Z-direction
resultant chest acceleration

Page 4, upper left seat support bracket load
upper right seat support bracket load
lower left seat support bracket load
lower right seat support bracket load

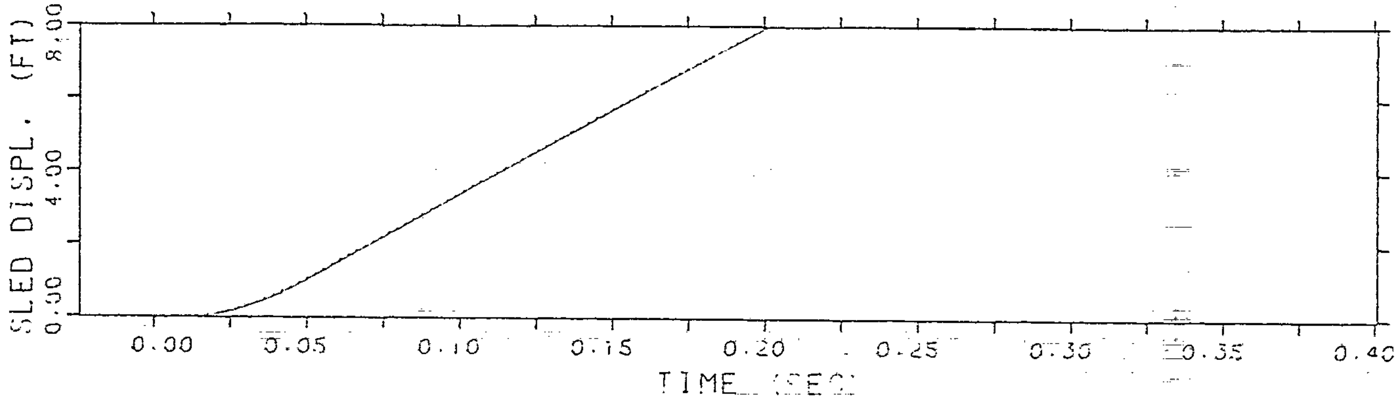
Page 5, shoulder belt load

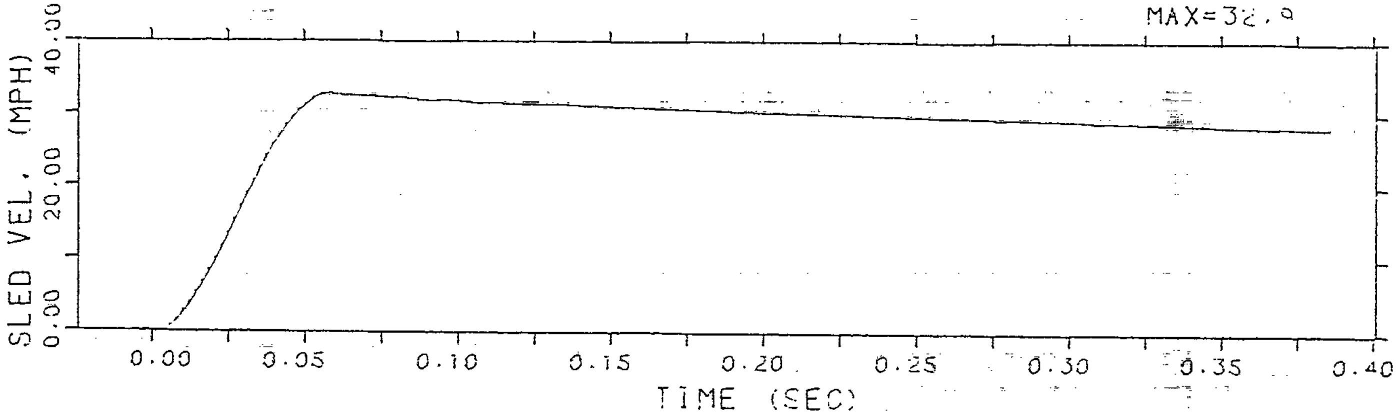
The maximum value of each plot is printed above, and at the right side of each plot. Note that, when the dummy experienced excessive movements during some of the runs, certain of the data was lost due to disconnection of the transducer cabling, and subsequent signal loss.

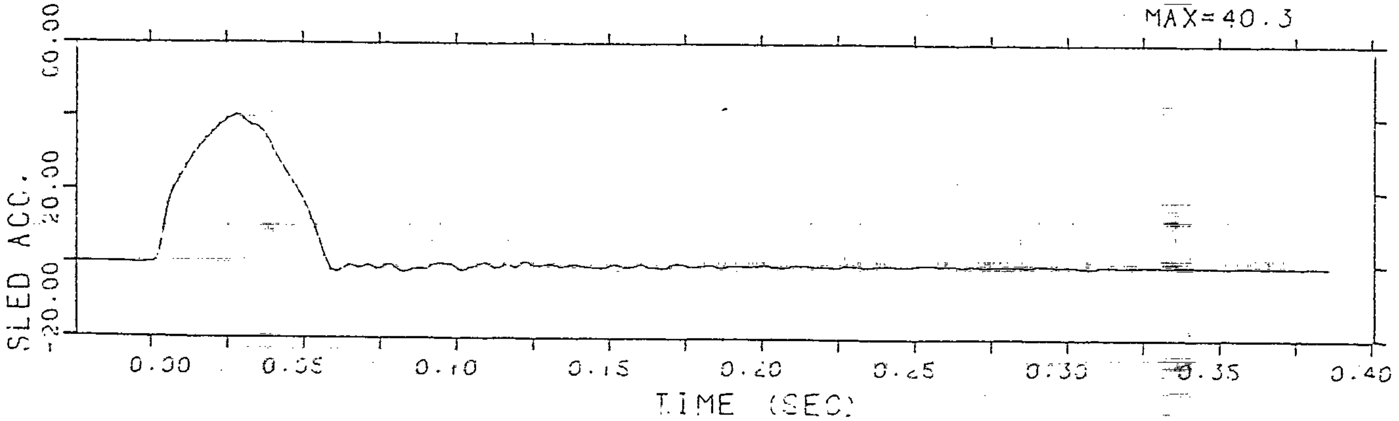
DCIEM IMPACT STUDIES FACILITY

DK:TUT510.DAT

14-AUG-84







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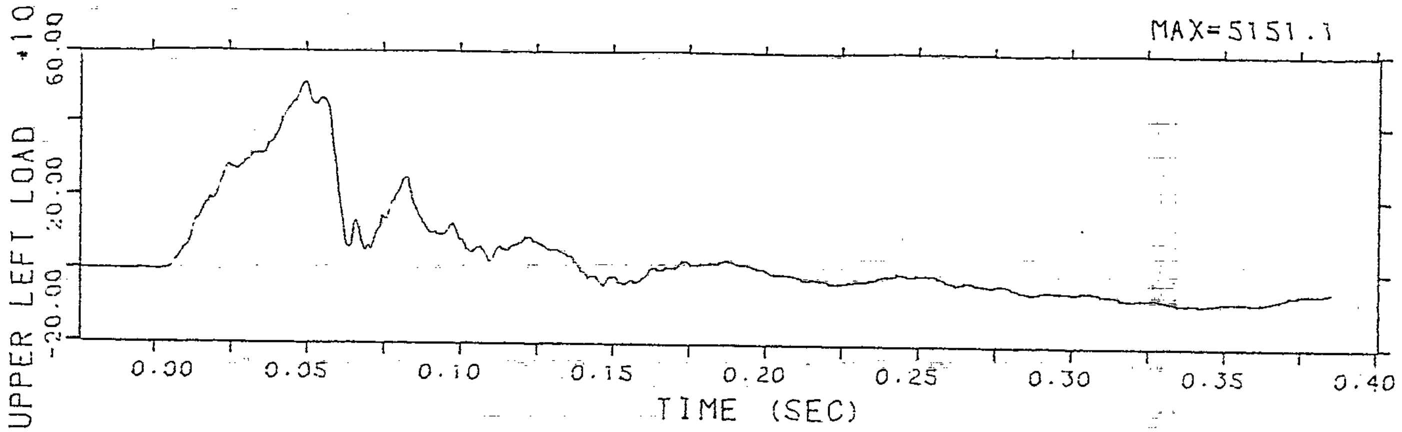

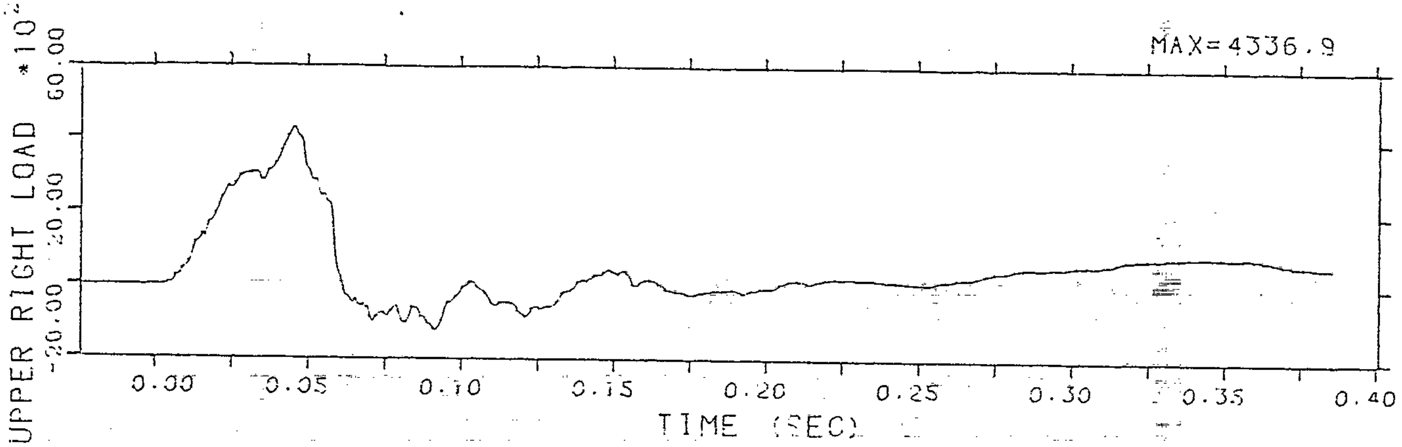

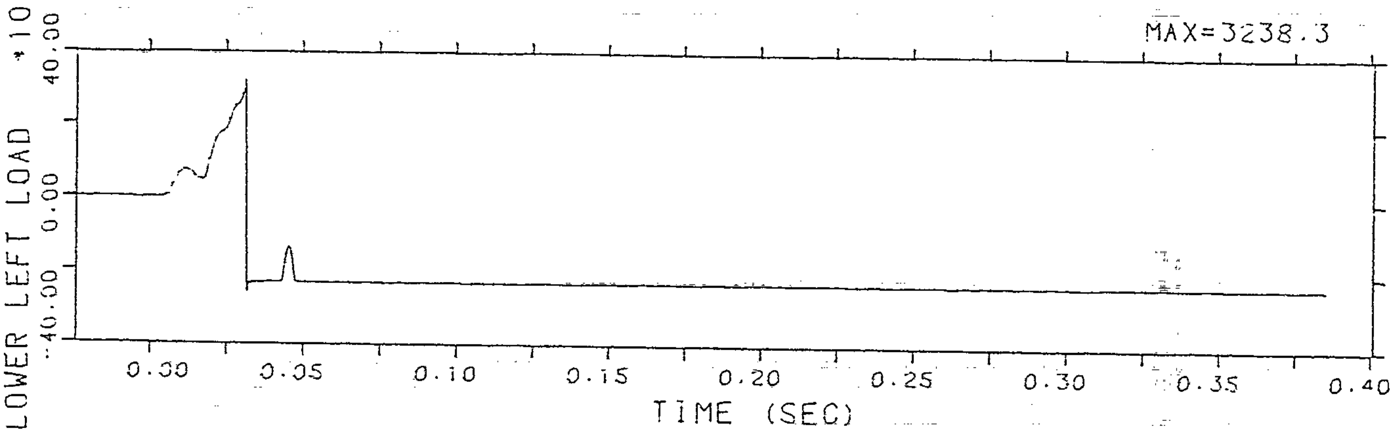

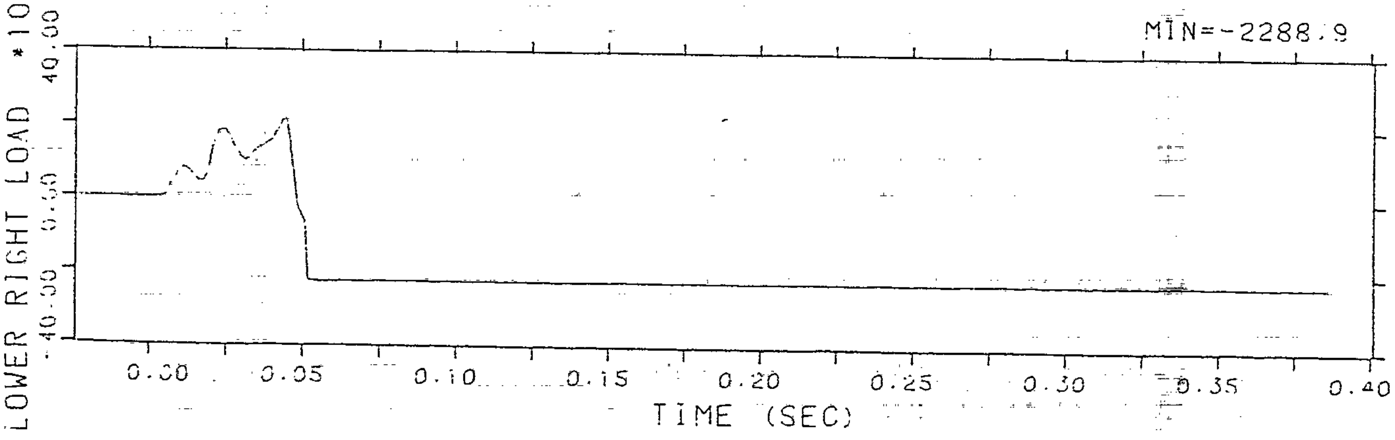

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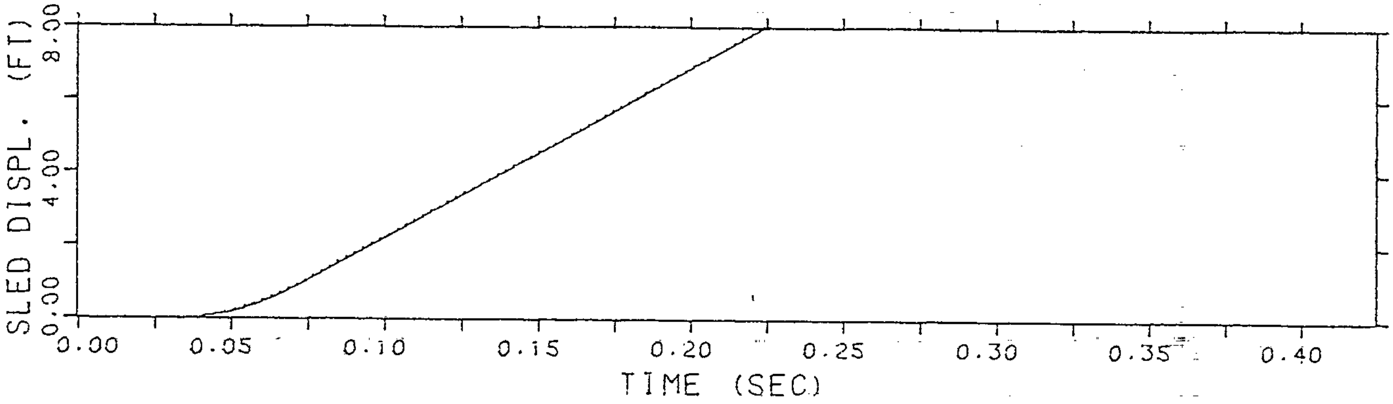

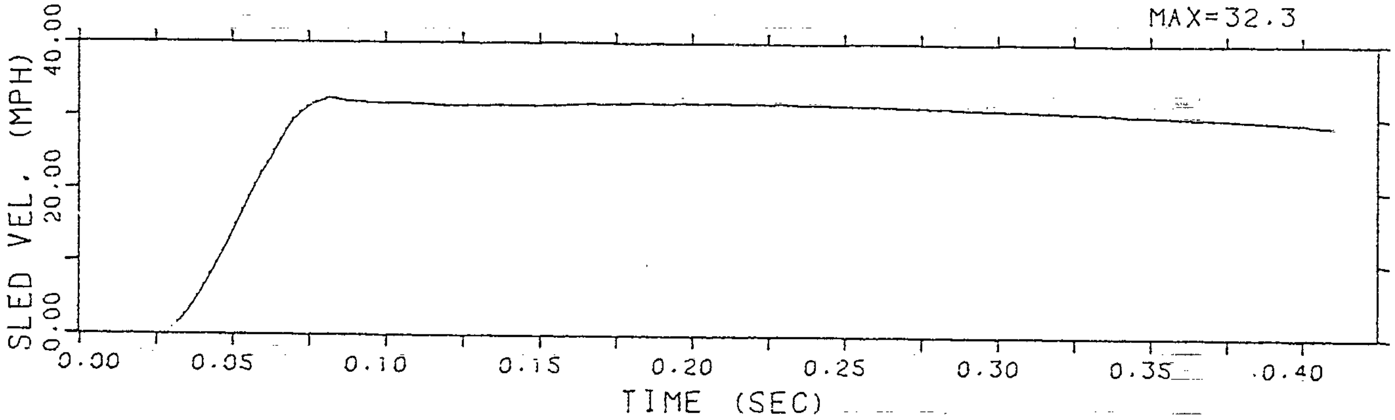

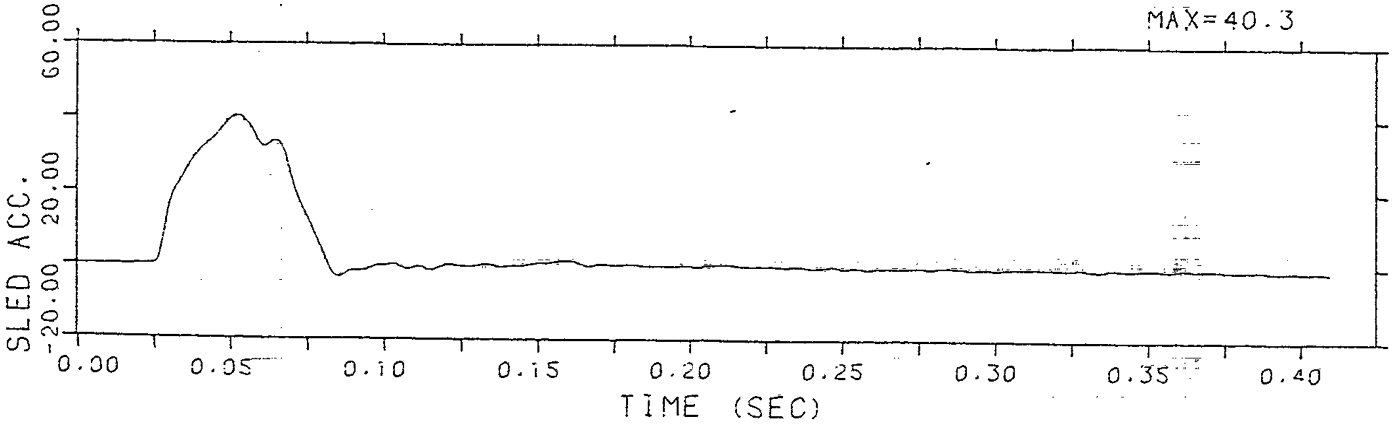

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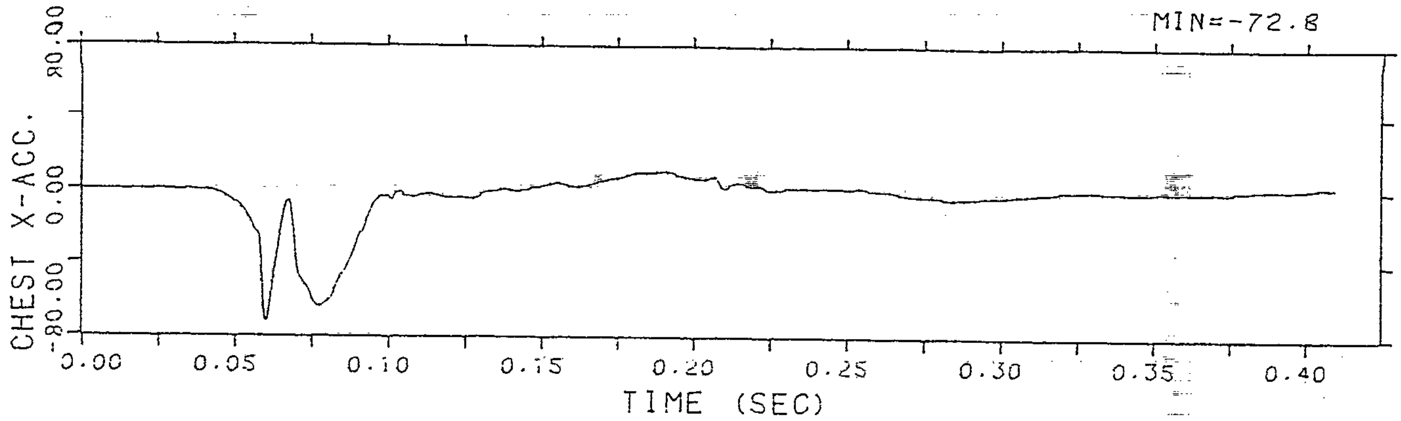
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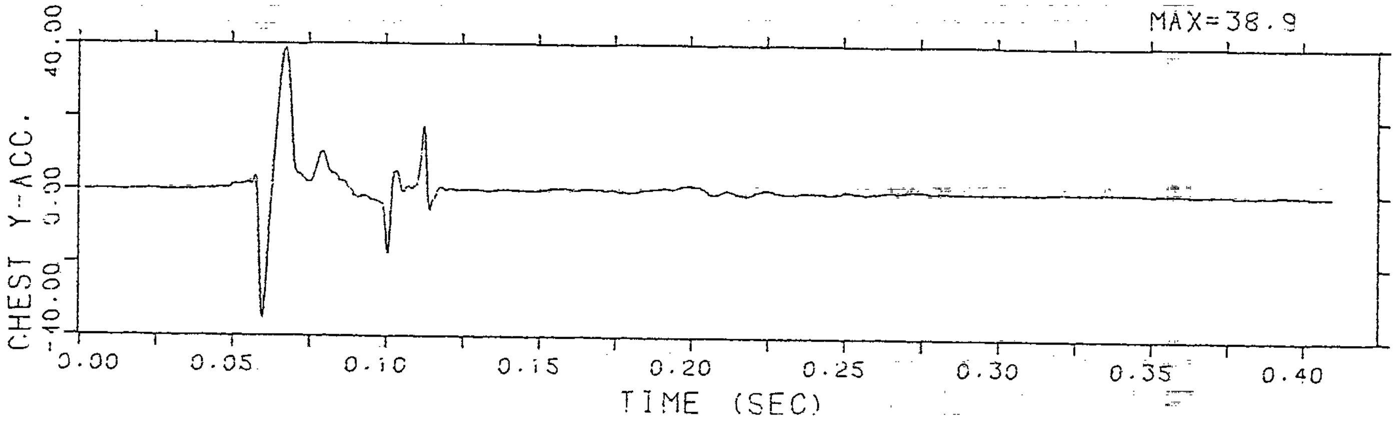
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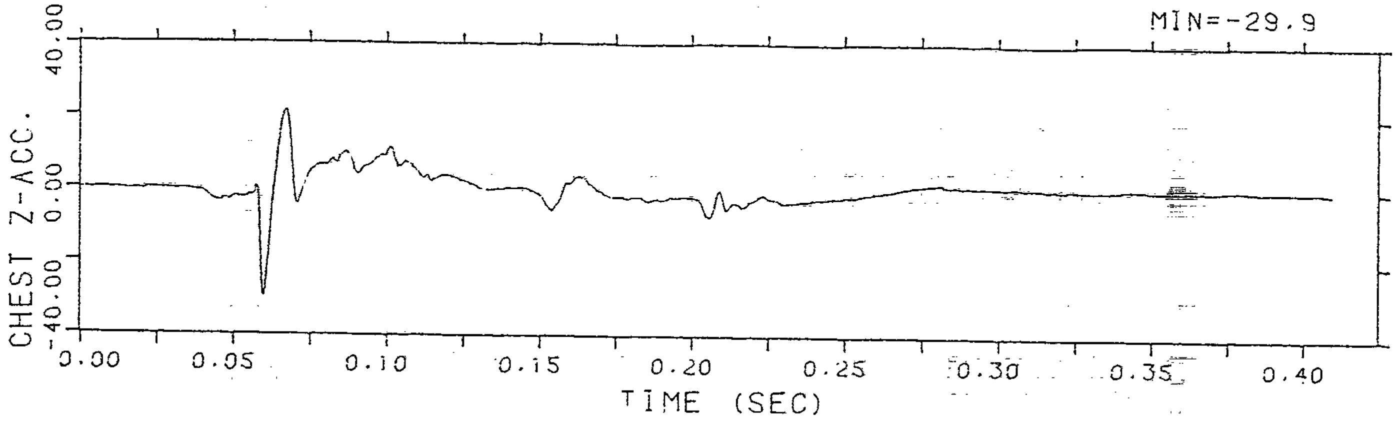
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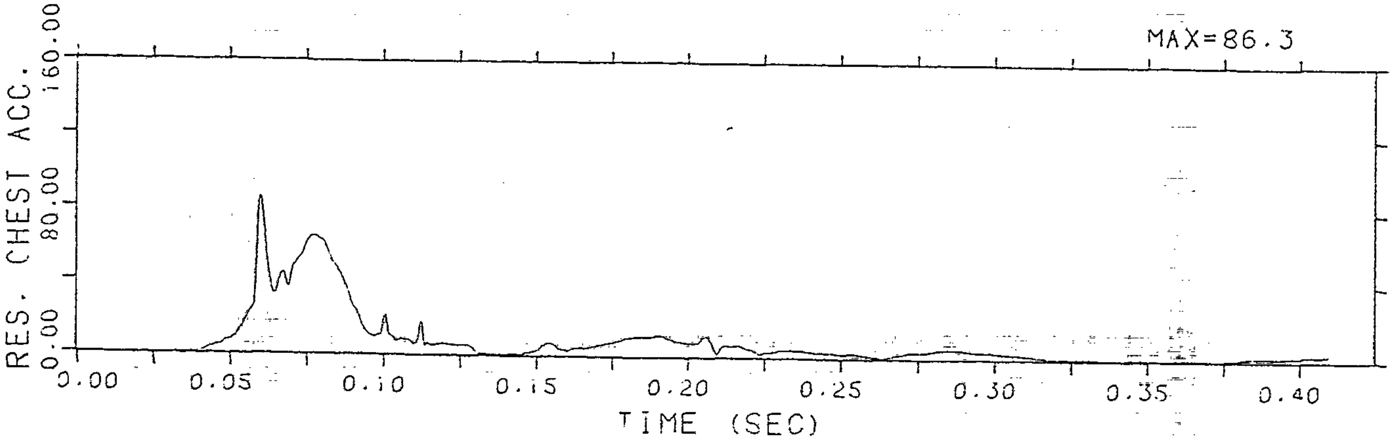
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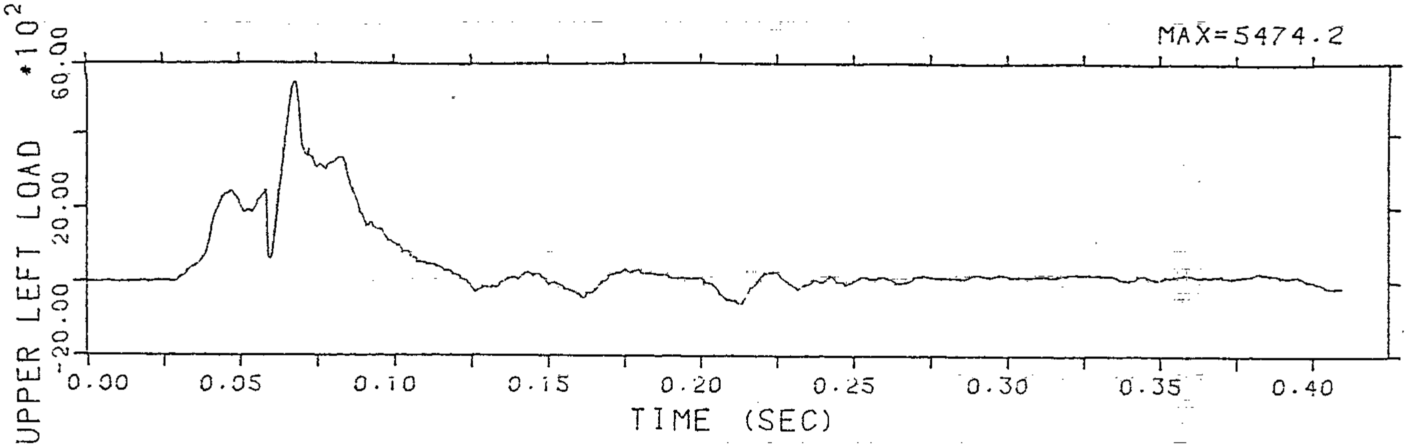
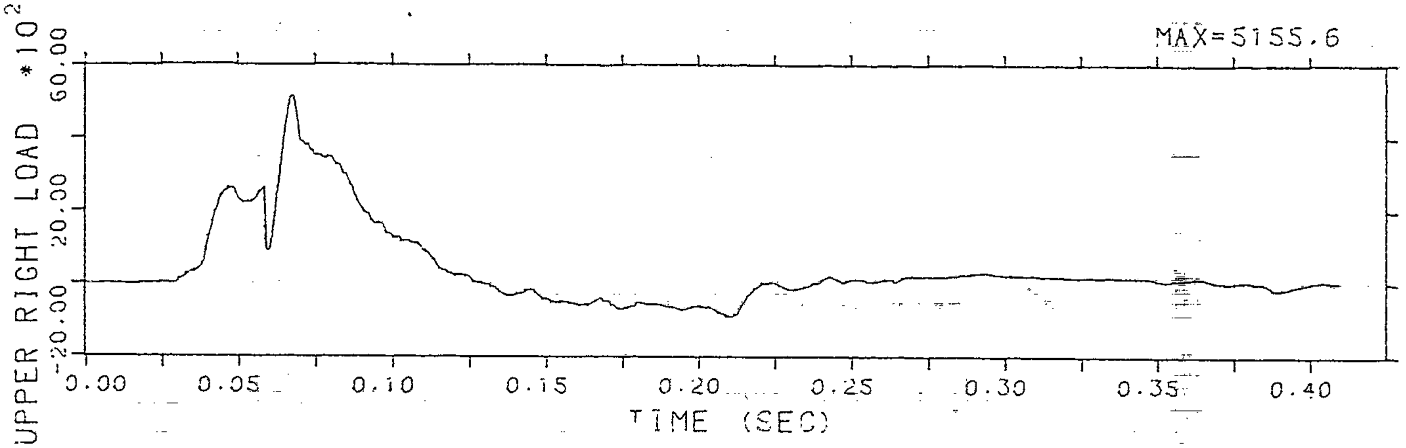
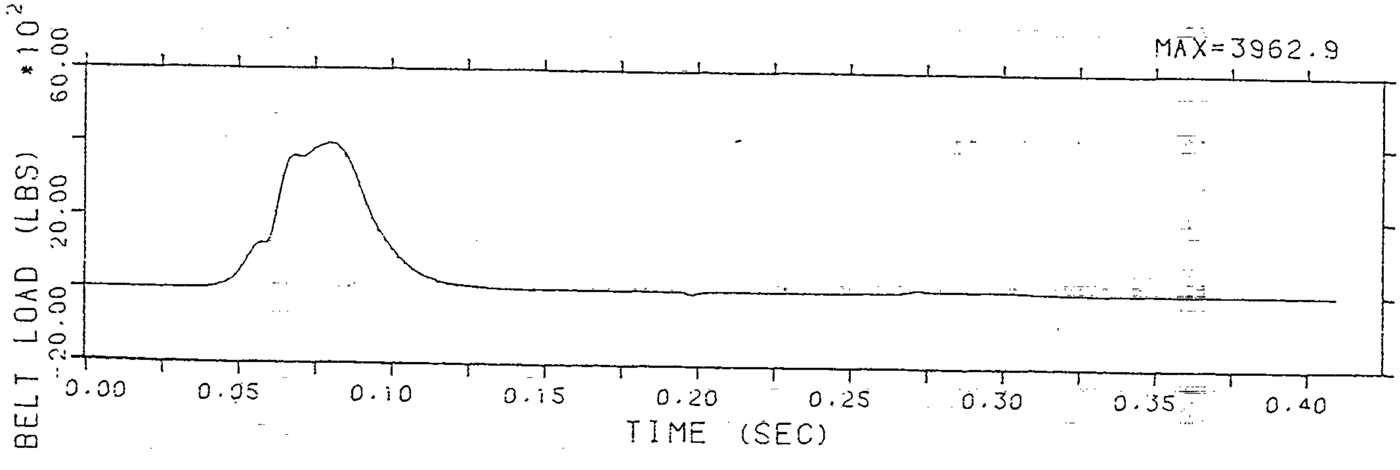
DK:TUT511.DAT SEAT LOADS (LBS)



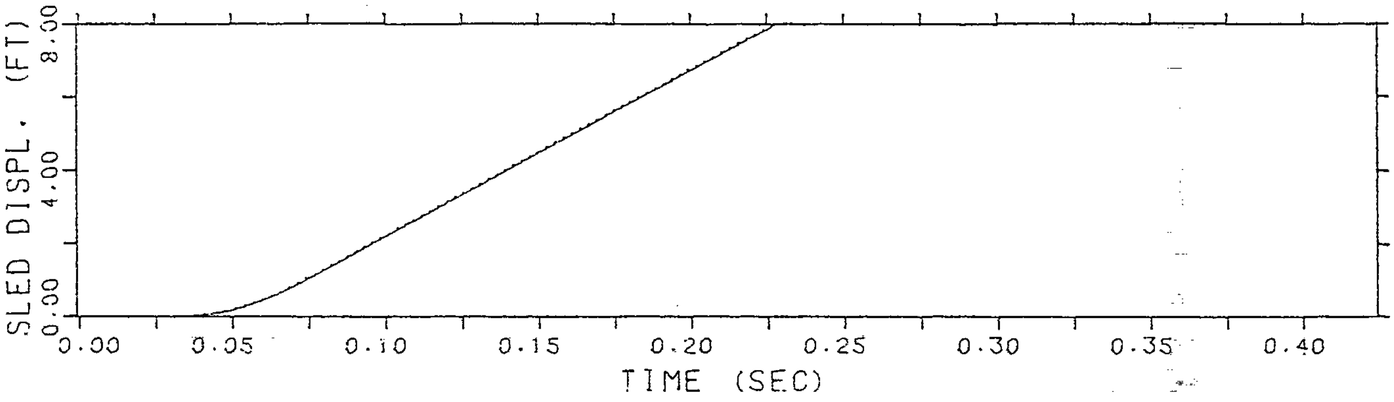


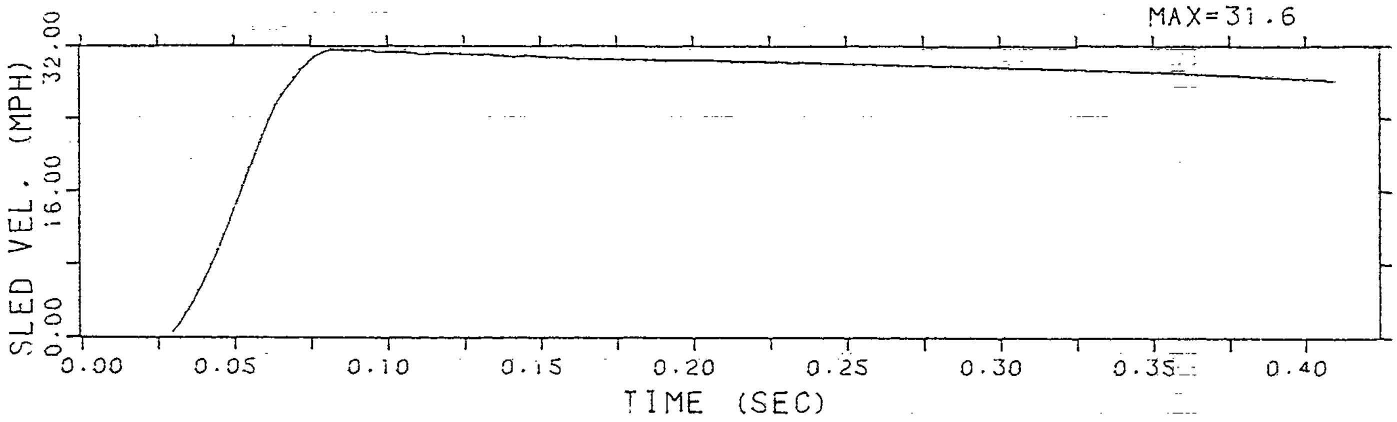

MAX=3962.9
*10²
60.00
20.00
-20.00
BELT LOAD (LBS)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
TIME (SEC)

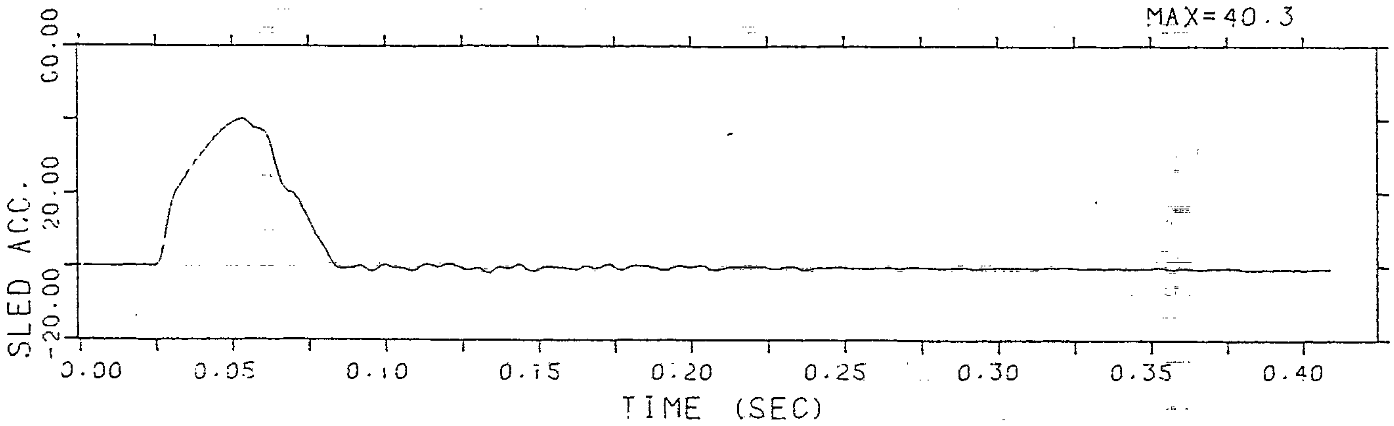
DCIEM IMPACT STUDIES FACILITY

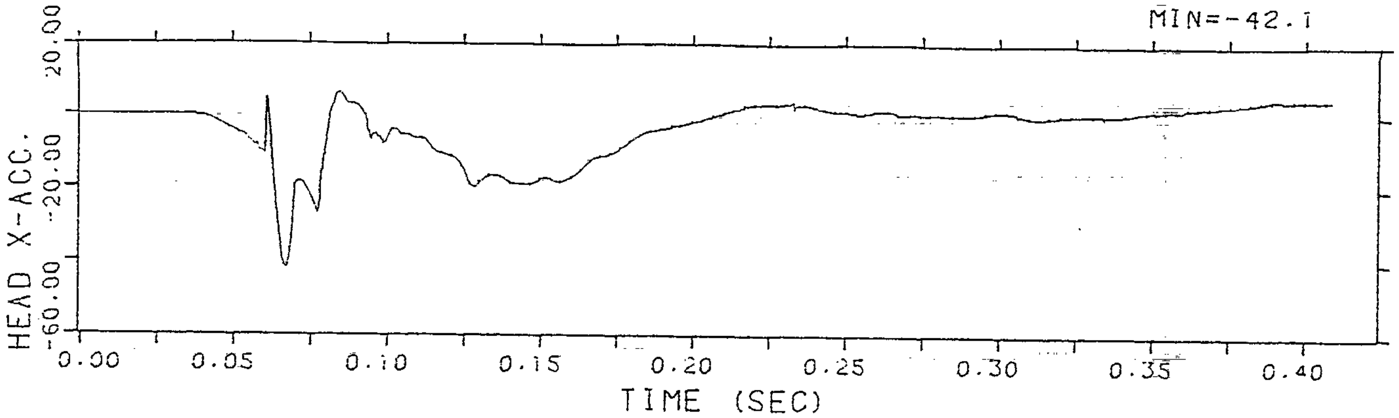
DK:TUT512.DAT

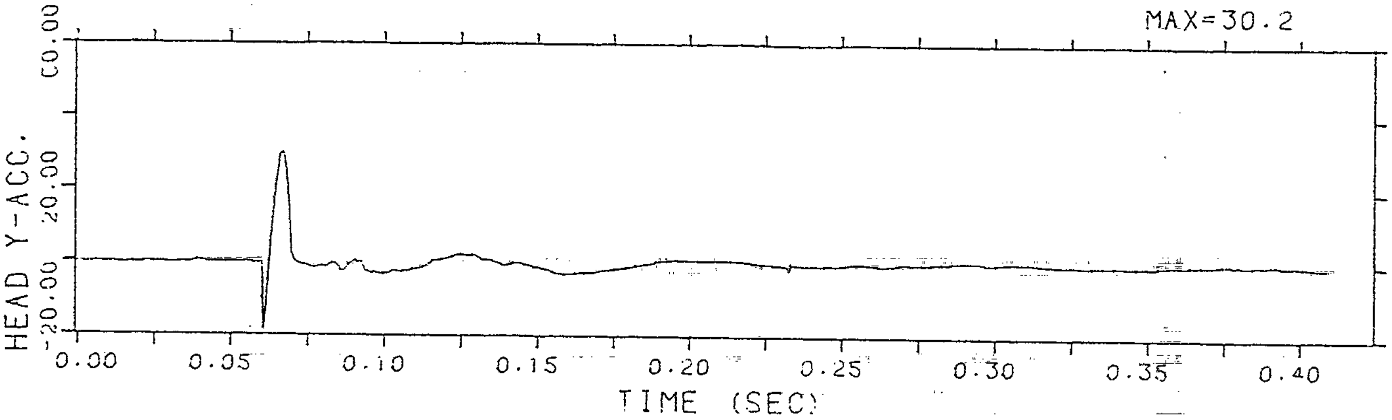
16-AUG-84

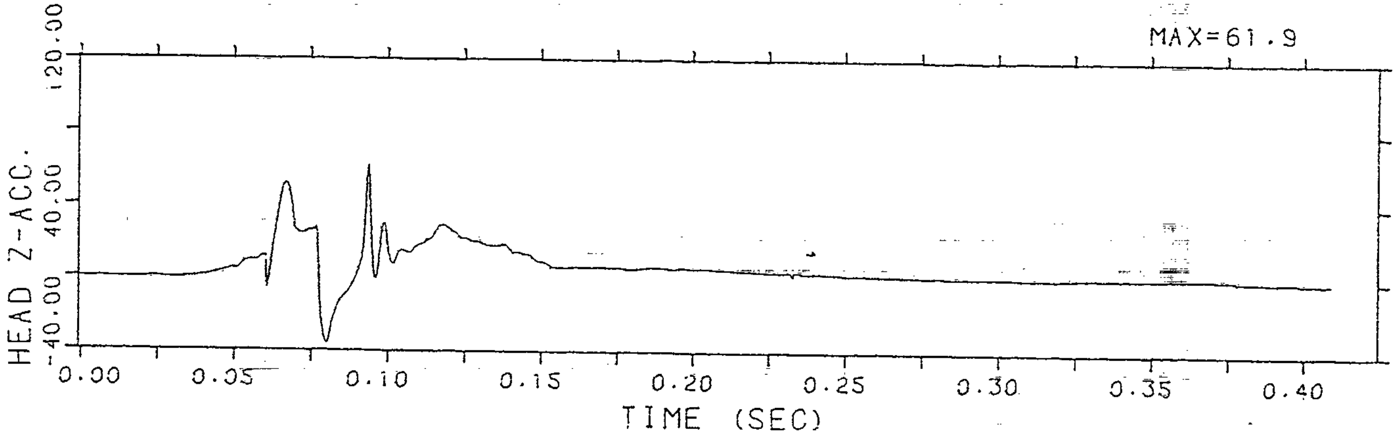


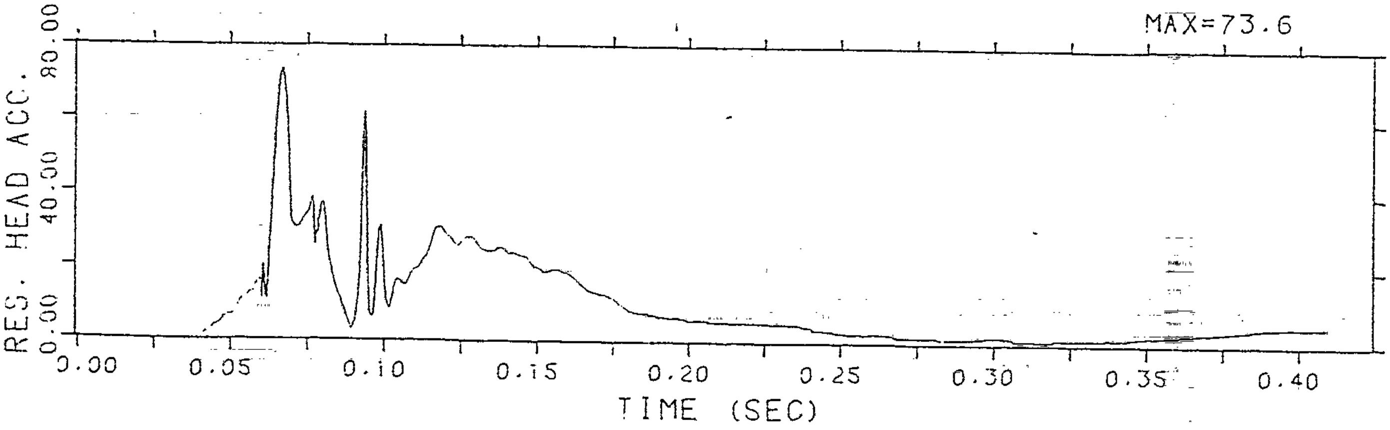


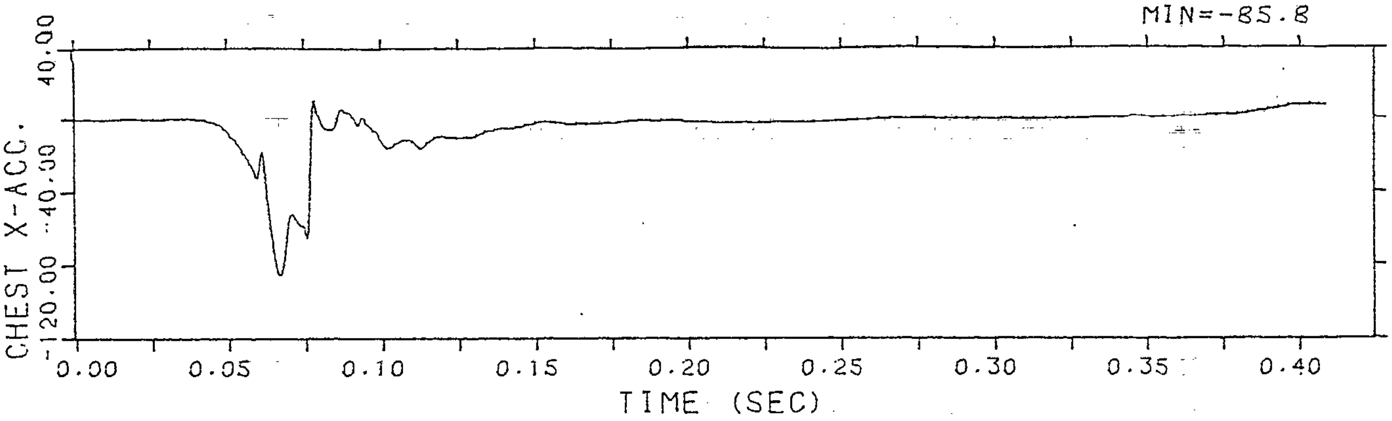


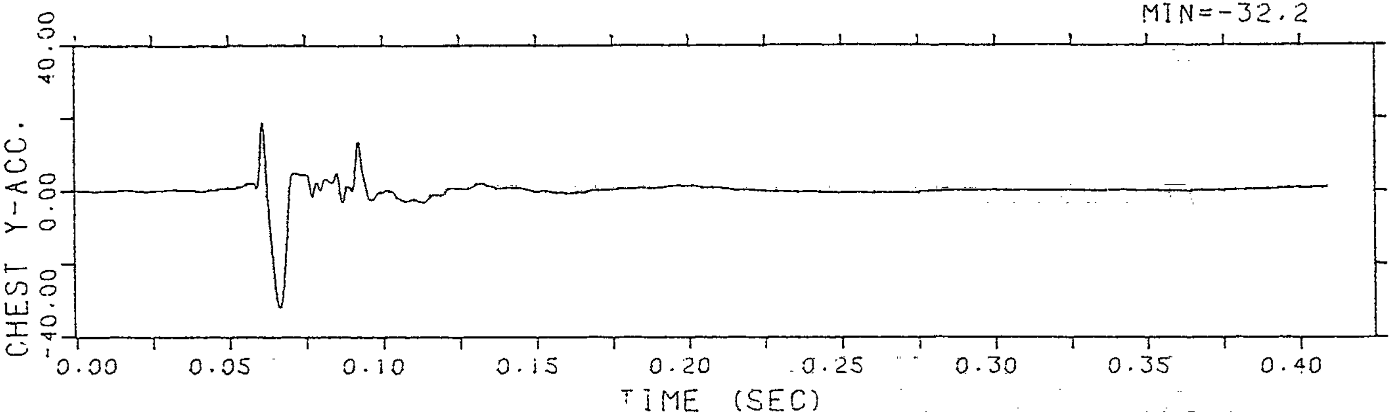

MIN=-42.1
HEAD X-ACC.
20.00
-20.00
-60.00
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
TIME (SEC)

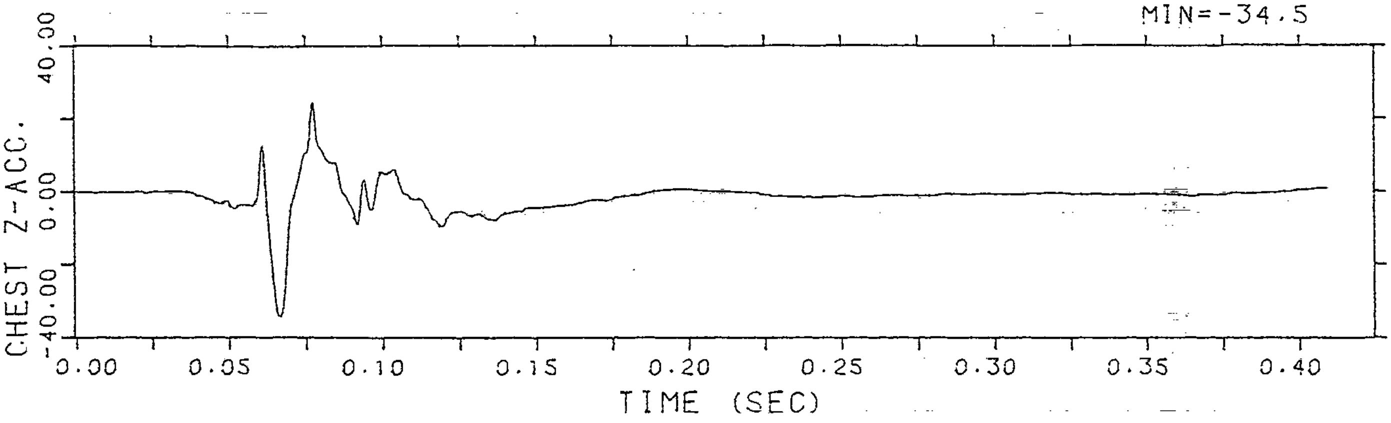

MAX=30.2
HEAD Y-ACC.
60.00
20.00
-20.00
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
TIME (SEC)

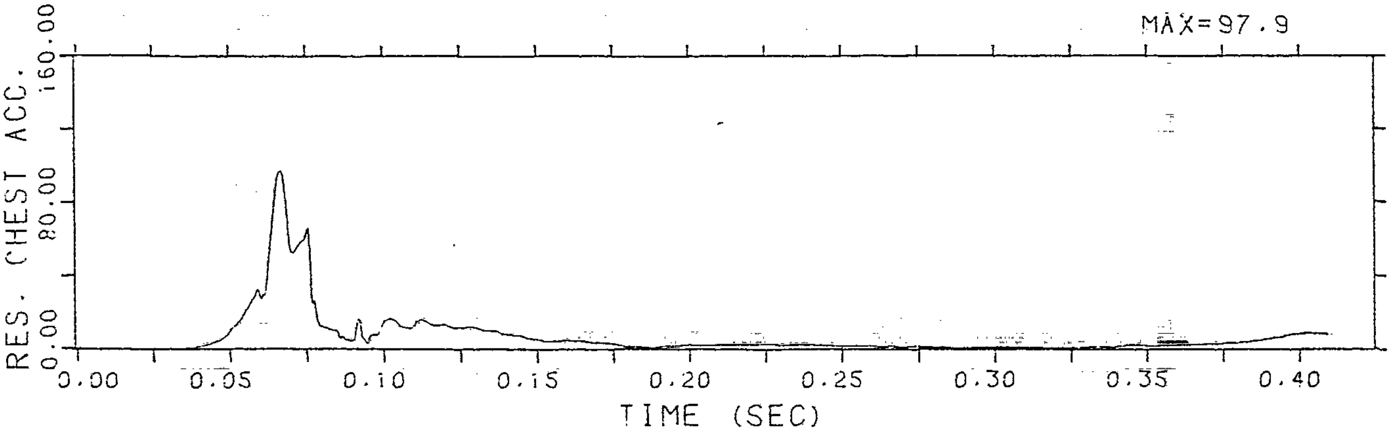

MAX=61.9
HEAD Z-ACC.
120.00
40.00
-40.00
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
TIME (SEC)


MAX=73.6
RES. HEAD ACC.
80.00
40.00
0.00
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
TIME (SEC)

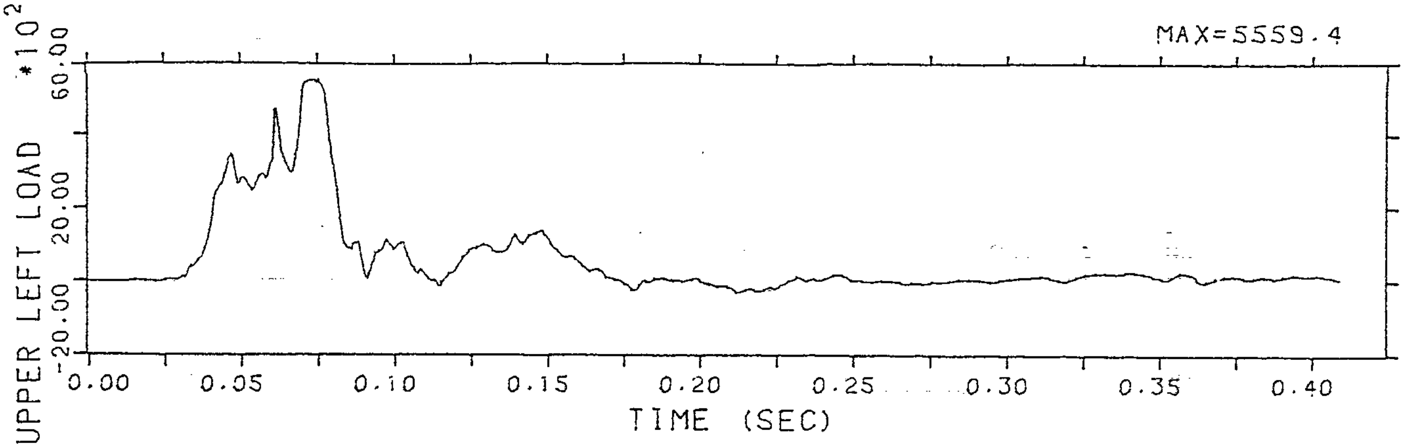

MIN=-85.8
CHEST X-ACC.
40.00
-40.00
-120.00
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
TIME (SEC)

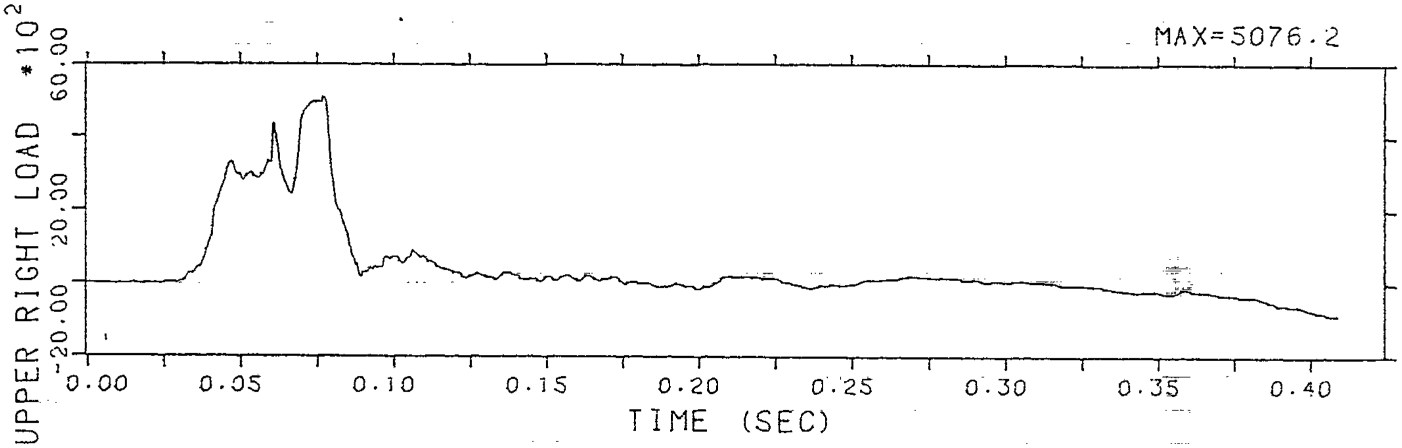

MIN=-32.2
CHEST Y-ACC.
40.00
0.00
-40.00
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
TIME (SEC)

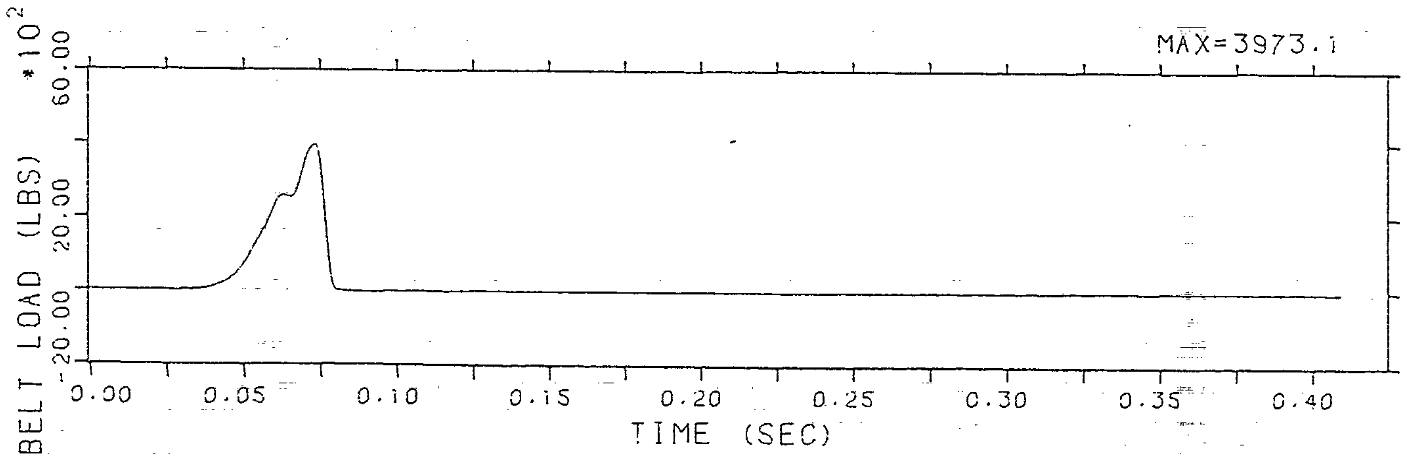

MIN=-34.5
CHEST Z-ACC.
40.00
0.00
-40.00
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
TIME (SEC)


MAX=97.9
RES. CHEST ACC.
160.00
80.00
0.00
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
TIME (SEC)

DK:TUT512.DAT SEAT LOADS (LBS)



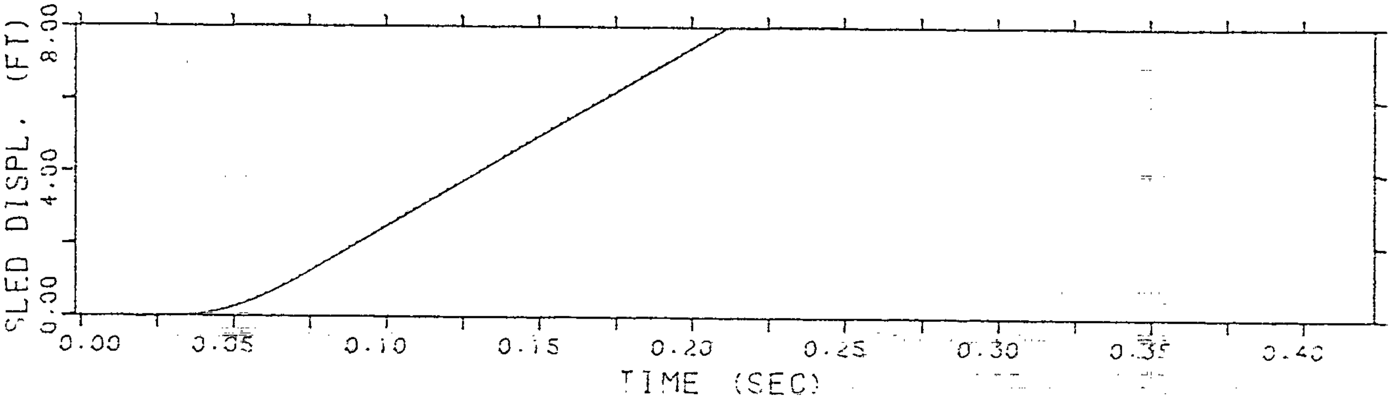


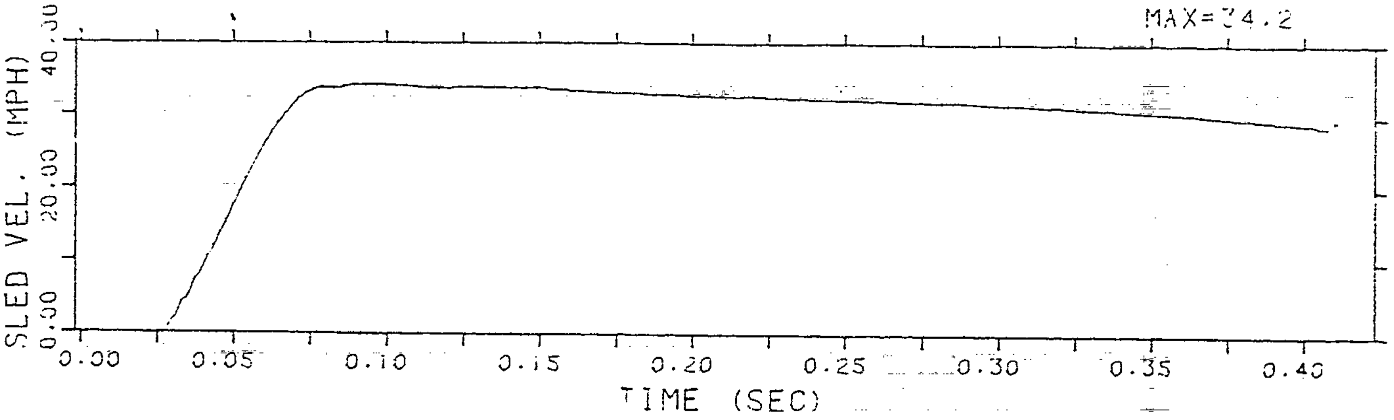

MAX=3973.1
*10²
60.00
20.00
.00
-20.00
BELT LOAD (LBS)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
TIME (SEC)

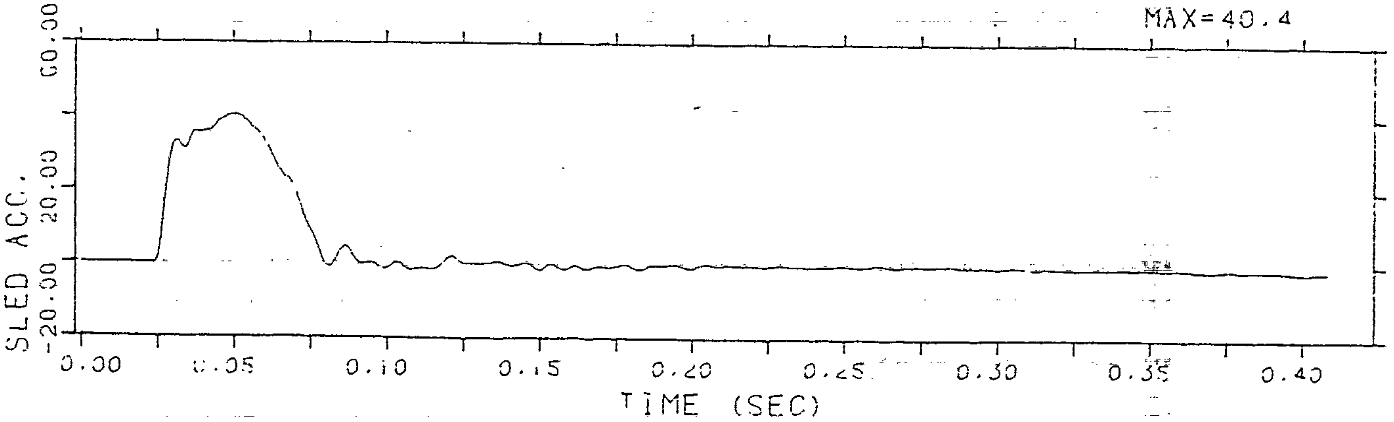
DCIEM IMPACT STUDIES FACILITY

DK:TUT513.DAT

23-AUG-84



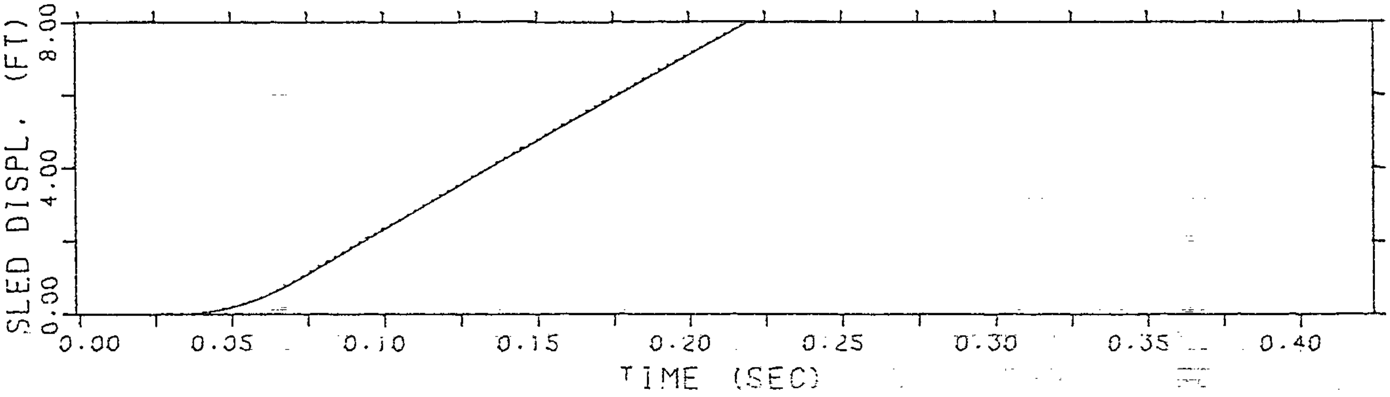


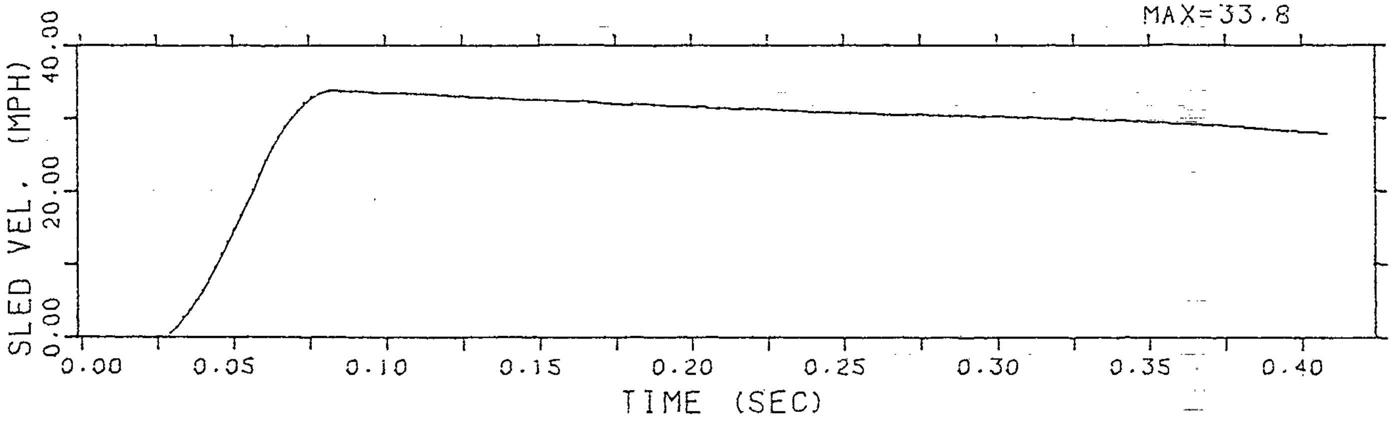


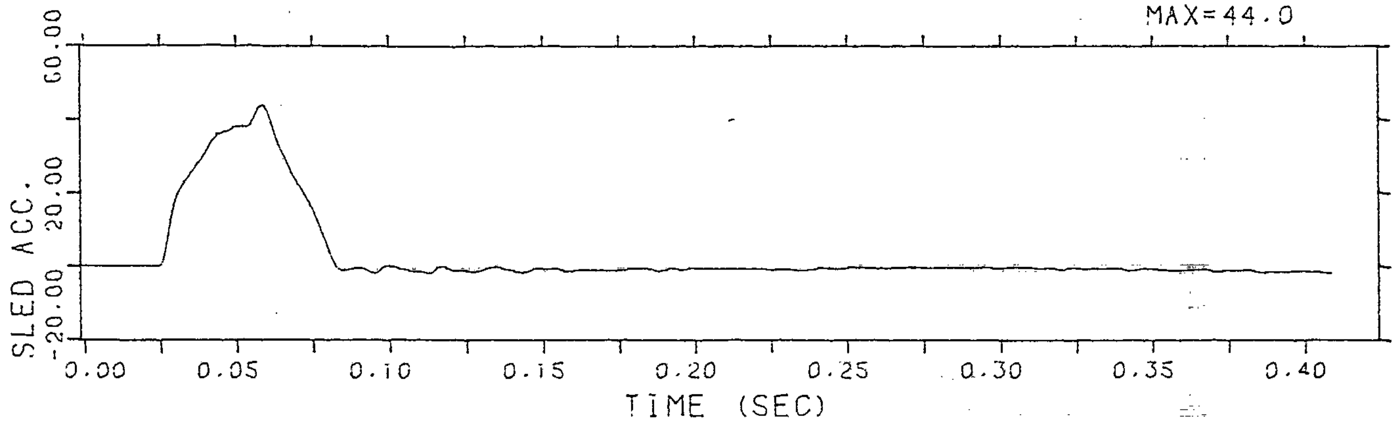
DCIEM IMPACT STUDIES FACILITY

DK:TUT514.DAT

24-AUG-84







#45552

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