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**Final Report**

**May 1988**

# Evaluation of the Performance of Child Restraint Systems



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16. Abstract

The objective of this program was to test all types of booster seats currently on the market in 30 mph sled tests with test dummy occupants that represent nine-month old infants, three-year old, and six-year old children. Another objective was to evaluate different means for measuring pressures imposed by the restraints on the dummy's abdomen during impacts and to use the most promising ones in the evaluation of the performance of these restraints.

Calibration tests were performed on each of the three sizes of dummies for Task I work. Following this effort fifteen baseline sled tests were conducted under Task II. In this series, two basic approaches for determining pressures on the dummy's abdomen were evaluated. One method used a University of Michigan specially designed pressure measuring device installed in the abdominal area of the three-year old and six-year old dummies. The second method was to measure belt loads restraining the dummy and the contact area between the dummy and restraint. The abdominal pressures were then calculated with the estimated loads on the abdomen and the known contact areas. Also, ten different kinds of contact area measuring devices were tried and the most sensitive material found was a contact paper called ACUTRED. The final series of 16 sled tests, under Tasks III and IV, were performed to evaluate the ten types of booster seats available on the market.

The calculated abdominal pressures showed a range from 18.7 psi to 32.8 psi for the infant dummy, from 22.9 psi to 49.8 psi for the three-year old child dummies, and from 31.4 psi to 47.0 psi for the six-year old dummies. The maximim abdominal pressure recorded in the booster seat tests by the dummy special pressure sensors was 14.4 psi for a six-year old dummy.

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# 1.0 INTRODUCTION

At the present time, there is a large number of restraint systems on the market which are being recommended for protection of young and older children in motor vehicle accidents. Child seats are designed for use by toddlers up to the age of approximately four, booster seats are intended for use by older children up to the age of seven or eight, while vehicle belts are considered to be used by the adult population. These different restraint systems are expected to provide optimum protection if used by the age groups for which they were designed. However, with the increased use of child restraints because of various state laws, there has been increased development and use of restraints with questionable protection capability. The type of restraint, which is of particular concern in this program, is the shield-type booster seat.

The first booster seats were introduced in this country in 1979 and were intended for use by older children, using either a vehicle lap belt, a "Y"-type shoulder belt, or a vehicle lap-shoulder belt in conjunction with the seat. At that time, test dummies representing older children were not available to evaluate this type of restraint so the 3-year old test dummies were used employing the procedures specified in the FMVSS No. 213 regulation. This testing with the 3-year old dummies inadvertently allowed the booster seats to be certified for use by a wide range of young and older children. Presently, the seats are recommended for use by children weighing generally from 17 to 70 lbs. The currently available booster seats are secured on a vehicle seat by a lap belt, which usually goes around the shield. Restraint of the child in the forward direction is accomplished by the shield of the booster seat. In addition, some booster seats, when used with older children, are recommended to be used with the lap/shoulder belt combination (3-point belts).

For the shield-type booster seats, a growing concern is whether this restraint can provide adequate protection for a range of children from nine-month old infants to six-year old and older children and whether protection is provided against possible submarining, ejection, or impacts into the vehicle interior. In addition, since almost all restraint is accomplished through loads on the child abdomen and since the restraining surface of some booster seats is not large, there is a concern that the pressure exerted by this small surface area might lead to abdominal injuries.

Accordingly, the objective of this program was to test all types of booster seats currently on the market in 30 mph sled tests with test dummy occupants that represent nine-month old infants, three-year old, and six-year old children. The main purpose was to determine how well different models are performing with the test dummy occupants representing different age and size children. Another objective was to evaluate different means for measuring pressures imposed by the restraints on the dummy's abdomen during impacts and to use the most promising ones in the evaluation of the performance of these restraints. It should be pointed out that this was a research program and not a compliance testing program.

## 2.0 SUMMARY

Three different size child test dummies were employed in this program to test all of the latest child booster seats in 30 mph sled tests. The dummy sizes were: a nine-month old infant, a three-year old child, and a six-year old child.

Calibration tests were performed on each of the three sizes of dummies in Task I. One head and one chest impact were performed on the single infant dummy. Since there is no standard regulation governing the tests of the nine-month old infant dummy, the work was performed according to previous Calspan calibrations of this dummy, which, at that time, was performed in conformance with the procedures specified in the Part 572 Regulation. The four calibration tests conducted on each of two three-year old child dummies, were done according to the standard tests specified in the 49 CFR, Part 572, Subpart C. Finally, five component tests were accomplished on each of the two six-year old dummies. These tests were conducted in a manner similar to the three-year old dummy test series plus one additional impact test was performed on each of the femurs as specified in Part 572, Subpart B.

Baseline sled tests were performed in TASK II at 30 mph with all three sizes of dummies. The objective of this task was to evaluate two basic approaches for determining the pressures imposed by the restraints on the dummy's abdomen in crash tests. One method was to use a specially designed pressure measuring device installed in the dummy's abdomen and the second method was to measure the belt loads (restraining the dummy or its restraint) and the contact area between the restraint and the dummy. In the first method the abdominal pressures were to be measured directly while in the second approach, the pressures were to be calculated from belt load/contact area relationships. The three-year old and six-year old dummies were equipped with special pressure measuring devices in the abdominal areas to directly measure impact pressures, while the nine-month old dummy was too small for this type of installation. Thus, the three-year old and six-year old dummies were used for direct measurement of abdominal pressures, while all three sizes were employed for the belt load/contact area pressure measurements. Evaluation of the abdominal pressure measurement methods was performed with test dummies restrained by lap belts only and by child restraints including 5-point harnesses and stiff and flexible shield type seats. Fifteen sled tests were performed with the dummies in side-by-side seating arrangements. Ten different kinds of contact area measuring devices were tried. The most sensitive material found was a carbon/contact paper called ACUTRED.

In the final series of 16 sled tests, covering the planned work of TASKS III and IV, all types of booster seats available on the market were tested with the three sizes of dummies. There were ten types of booster seats tested. Another type of booster restraint, called Tot-guard, was tested earleir in the TASK II effort. The Acutred contract paper was used to obtain impact areas on the dummies and the restraining loads were measured by load cells mounted on the restraint straps. Abdominal pressures were also measured directly with the special pressure sensing devices installed in the dummy's abdomens.

The measured performance of several booster seats was outside the criteria prescribed by FMVSS No. 213. Five models [1] tested with a three-year old dummy gave head excursions over the 32-inch limit of FMVSS No. 213. There were also nine head displacements of the six-year old dummy exceeding this criterion. In addition, one six-year old dummy in a booster seat used with a 3-point auto harness, indicated a HIC number of 1238. Dummy ejections occurred during the rebound phase from three booster seats for the nine-month old infant dummy, from two booster restraints for the three-year old dummy, and one booster seat for the six-year old dummy.

The calculated abdominal pressures, using measured dummy belt loads and contact areas, showed a range from 18.7 psi to 32.8 psi for the infant dummy, from 22.9 psi to 49.8 psi for the three-year old child dummies, and from 31.4 psi to 47.0 psi for the six-year old dummies. The maximum abdominal pressure recorded in the booster seat tests by the dummy pressure sensors was 14.4 psi for a six-year old dummy.

The booster seats showing the lowest calculated abdominal pressues were the Century Commander (18.7 psi) with an infant dummy, and the Evenflo 7-year seat for both the three-year old dummy (22.9 psi) and the six-year old child dummy (31.4 psi).

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1. Ford Tot-Guard tests in TASK II are added to the ten models tested in TASKS III and IV.

## 3.0 CALIBRATION OF TEST DUMMIES, TASK I

### 3.1 GENERAL REMARKS

Five anthropomorphic test dummies were employed in the conduct of this program: (1) one ECE nine-month old infant dummy (developed by Research Institute for Road Vehicles TNO), (2) two SAE 103C three-year old child dummies and (3) two SAE 106C six-year old child dummies. The nine-month old and the six-year old dummies currently have no standard specifications by which they can be calibrated so all tests were peformed as they were in previous NHTSA programs. The dummy calibration methods accomplished in References 1 and 2 were used for the nine-month old and six-year old dummies, respectively The three-year old child dummies were calibrated according to the requirements specified in Part 572, Subpart C regulation, Reference 3. One test was performed on each of the required components of the five dummies.

### 3.2 NINE-MONTH OLD INFANT DUMMY

The nine-month old infant dummy was partially disassembled and inspected before conducting the calibration tests. No visible damage to any part was found during this inspection. One Endevco 7267A triaxial accelerometer was mounted in the head cavity on a teflon block. Since the chest cavity does not have sufficient room for a 7267A transducer, a special mounting block with three single-axis Endevco 2264 accelerometers was installed at that location. This unit was bolted to a steel mounting plate, which was then secured in place in the thorax. All of the dummy joints and the spinal column and neck tensions were adjusted, as the dummy was assembled in accordance with the TNO specifications for this dummy (Reference 4).

The head impact test configuration was similar to that used for the three-year old dummy in a seated position. The backrest was set to 10.3 inches high as measured from the seating surface. The impact probe centerline was aligned to a point on the head 1.54 inches above the head-neck pivot axis or approximately 15.13 inches above the dummy seating surface. Probe impact velocity was approximately 7.0 fps and the resulting data are presented in Table 1. The Part 572 ranges are given in this table only for reference purposes, since they do not apply to the nine-month old infant dummy. As noted in the table, the head peak resultant acceleration was 42 g's and the peak lateral acceration was 4 g's.

Table 1

SUMMARY OF HEAD IMPACT TEST CALIBRATION DATA

CHILD DUMMY I.D. NO. TNO, 9 MONTH OLD INFANT

| | | | |
|---|---|---|---|
| DATE OF CALIBRATION | 4/10/87 | | |
| ROOM TEMPERATURE (66-78°F) | 70 | | |
| ROOM RELATIVE HUMIDITY (10-70%) | 32 | | |
| TEST MEASUREMENTS: | | | PART 572 REQMT. |
| TEST PROBE IMPACT VELOCITY, fps | 7.1 | | 6.86 - 7.14 fps |
| PEAK HEAD RESULTANT ACCEL., g | 42 | | 95 - 118 g |
| PEAK HEAD LATERAL ACCEL., g | 4 | | ≤ 7 g |
| PULSE Δ TIME @ 50 g, ms | -- | | 2 - 3 ms |

For the chest calibration test of the nine-month old infant dummy, the probe centerline was aligned with the thorax at a distance of 8.2 inches above the seating surface. Probe impact velocity was approximately 13 fps and the resulting performance data are shown in Table 2. The thorax exhibited a peak resultant acceleration of 82 g's and a pulse width of 4.3 ms at the 30 g level.

## 3.3 THREE-YEAR OLD CHILD DUMMY

The two SA103C dummies, that were used in this program, were modified with an abdominal pressure measuring device by the University of Michigan (Reference 5). The changes to the dummies are discussed in detail in Section 4.1. Generally, the dummies were in good condition before modification so it was assumed that they were still in that condition after they were received from the University. Two Endevco 7267A triaxial accelerometers were mounted in each dummy, one in the head and one in the chest cavity. Following the external inspection, the head impact calibration test was set up as specified in the Part 572 regulation (Reference 3). One probe impact to the head, at a velocity of approximately 7 fps, was performed on each dummy. The cylindrical aluminum probe was 10.38 pounds in weight and its centerline was positioned at 3.0 inches below the top of the head. A summary of the resulting data is presented in Table 3 along with the Part 572 requirements. The head calibration data were all within the required ranges.

For the neck calibration tests, the head-neck assemblies were mounted on the bottom of a rigid pendulum and the pendulum was impacted into a block of aluminum honeycomb at a velocity of approximately 17 fps. The resulting angular displacement of the head and the chordal displacement of the head center-of-gravity were measured electronically by three potentiometers located on the right side of the head--two rotary type and one linear unit. The velocity of the pendulum at impact was measured with a light-beam speed trap. The performance data are summarized in Table No. 4. Analysis of these tabulated results show that the responses of the two head-neck components were within the Part 572 specifications.

The chest impact tests were performed with a cylindrical aluminum impactor, which was the same probe used for head imapcts. The probe was positioned with its longitudinal centerline at 1.5 inches below the centerline of the bolt attaching the top of the rib cage sternum to the thoracic spine box. Probe impact velocities

Table 2

SUMMARY OF CHEST IMPACT TEST DATA

CHILD DUMMY I.D. NO. TNO, 9 MONTH OLD INFANT

| | | |
|---|---|---|
| DATE OF CALIBRATION | 4/14/87 | |
| ROOM TEMPERATURE (66-78°F) | 75 °F | °F |
| ROOM RELATIVE HUMIDITY (10-70%) | 40 % | % |

| TEST MEASUREMENTS: | | | PART 572 RQMTS. |
|---|---|---|---|
| TEST PROBE IMPACT VELOCITY, fps | 13.1 | | 12.87-13.13 |
| PEAK CHEST RESULT. ACCEL., g | 82 | | 50-70 g |
| PEAK CHEST LATERAL ACCEL., g | 8 | | ≤5 g |
| PULSE Δ TIME @ 30 g, ms | 4.3 | | 2.5-4.0 ms |

Table 3

**SUMMARY OF HEAD IMPACT TEST CALIBRATION DATA**

3 YEAR OLD DUMMY

| CHILD DUMMY I.D. NO. | 38 | 39 | |
|---|---|---|---|
| DATE OF CALIBRATION | 3/16/87 | 3/13/87 | |
| ROOM TEMPERATURE (66-78°F) | 69 | 70 | |
| ROOM RELATIVE HUMIDITY (10-70%) | 25 | 25 | |
| TEST MEASUREMENTS: | | | PART 572 REQMT. |
| TEST PROBE IMPACT VELOCITY, fps | 7.11 | 6.90 | 6.86 - 7.14 fps |
| PEAK HEAD RESULTANT ACCEL., g | 108 | 106 | 95 - 118 g |
| PEAK HEAD LATERAL ACCEL., g | 7 | 5 | ≤ 7 g |
| PULSE △ TIME @ 50 g, ms | 2.4 | 2.2 | 2 - 3 ms |

**Table 4**

**SUMMARY OF HEAD-NECK PENDULUM TEST DATA**

3 YEAR OLD DUMMY

| CHILD DUMMY I.D. NO. | 38 | 39 | |
|---|---|---|---|
| DATE OF CALIBRATION | 3/16/87 | 3/17/87 | |
| ROOM TEMPERATURE (66-78°F) | 72 °F | 70 °F | |
| ROOM RELATIVE HUMIDITY (10-70%) | 24 % | 24 % | |
| TEST MEASUREMENTS: | | | PART 572 REQMT. |
| PENDULUM IMPACT VELOCITY, fps | 17.4 | 17.7 | 16-18 fps |
| PEND. AVERAGE DECEL. OVER $(t_3 - t_2)$, g | 28 | 27 | 20-34 g |
| PEAK HEAD RESULT. ACCEL., g | 22 | 28 | ≤ 30 g |
| PEND. DECEL. PULSE Δ TIME $(t_2 - t_1)$, ms | 2.0 | 2.0 | ≤ 4 ms |
| PEND. DECEL. PULSE Δ TIME $(t_3 - t_2)$, ms | 20.7 | 20.5 | 18-21 ms |
| PEND. DECEL. PULSE Δ TIME $(t_4 - t_3)$, ms | 3.8 | 3.8 | ≤ 5 ms |
| HEAD ZERO POSITION TIME/ PEND. REVERSAL TIME | 111/118 | 117/124 | —/— |
| HEAD MAX. ROTATION ANGLE, ° | 82 | 86 | 76-92° |
| TIME (ms) @ HEAD ROT. ANGLE: 0° | 0 | 0 | -2 - +2 ms |
| 30° | 24.5 | 24.7 | 17.3 - 24.7 ms |
| 60° | 37.0 | 36.5 | 31.1 - 40.9 ms |
| Max. | 59.0 | 57.3 | 55.0 - 69.0 ms |
| 60° | 83.0 | 88.0 | 81.7 - 100.3 ms |
| 30° | 97.6 | 102.0 | 97.4 - 118.6 ms |
| 0° | 111.4 | 117.0 | 111.2 - 134.8 ms |
| CHORDAL DISPLACEMENT (in) @ HEAD ROTATION ANGLE OF: 0° | 0.0 | 0.0 | -0.8 - +0.8" |
| 30° | 3.0 | 2.9 | 1.4 - 3.0" |
| 60° | 4.7 | 4.4 | 3.5 - 5.1" |
| Max. | 5.7 | 5.5 | 5.0 - 6.6" |
| 60° | 4.5 | 4.2 | 3.5 - 5.1" |
| 30° | 2.7 | 2.6 | 1.4 - 3.0" |
| 0° | 0.0 | 0.0 | -0.8 - +0.8" |

were measured with a light beam speed trap and were within 1% of the specified velocity of 13 fps. The performance data of both dummies are summarized in Table 5 along with the Part 572 specifications. As noted from the tabulated results, all the thorax impacts were within the required ranges.

The lumbar spine flexion test for the two three-year old dummies was performed with a special clamping apparatus which held the pelvic section and upper legs in a rigid position. Force was applied to the upper torso by a cable attached to the neck mounting area. The force in the cable was increased until the torso flexed forward to an angle of 40 degrees from its initial upright position. A small pendulum arm attached to a rotary potentiometer at the dummy shoulder, monitored the torso angle during the test. The loads in the cable were obtained by a load cell. Both the load and the torso flexion angle data were plotted simultaneously on an X-Y plotter so that it could be immediately seen when the torso angle reached the required 40 degrees. The load plotted at this flexion angle was recorded and compared to the Part 572 requirement. The resulting data from the spinal flexion runs are shown in Table 6 for both dummies. All of these data met the Part 572 regulation requirements, and there were no problems associated with conducting these tests.

## 3.4 SIX-YEAR OLD CHILD DUMMY

The two six-year old child test dummies were modified to measure abdominal pressures in approximately the same manner as the three-year old dummies. The only indication that these dummies were modified was the external metal tube mounted to the back of the dummies. The calibration tests of these dummies were performed by using similar procedures as prescribed for the three-year old dummies in the Part 572, Subpart C regulation. Both dummies were instrumented with Endevco Model 2264-2000 accelerometers in the head and chest and GSE model T11654 load cells in the femurs. One test was performed on each of the required components of the dummies.

For head impact tests, the centerline of the 10.38 pound impact probe was set 2.8 inches below the top of the head to insure that the lower edge of the probe did not strike the bridge of the nose before the flat face contacted the forehead. Probe alignment to the head was critical with this dummy because of the shape of the nose. A dummy back support with a height of 12.4 inches above the seating surface

Table 5

**SUMMARY OF CHEST IMPACT TEST DATA**

3 YEAR OLD DUMMY

| CHILD DUMMY I.D. NO. | | 38 | 39 | |
|---|---|---|---|---|
| DATE OF CALIBRATION | | 3/13/87 | 3/13/87 | |
| ROOM TEMPERATURE (66-78°F) | | 71 °F | 71 °F | |
| ROOM RELATIVE HUMIDITY (10-70%) | | 26 % | 26 % | |
| TEST MEASUREMENTS: | | | | PART 572 RQMTS. |
| TEST PROBE IMPACT VELOCITY, fps | | 13.02 | 12.92 | 12.87-13.13 |
| PEAK CHEST RESULT. ACCEL., g | | 52 | 61 | 50-70 g |
| PEAK CHEST LATERAL ACCEL., g | | 5 | 2 | ≤5 g |
| PULSE Δ TIME @ 30 g, ms | | 3.1 | 3.6 | 2.5-4.0 ms |

Table 6

SUMMARY OF LUMBAR SPINE FLEXION TEST DATA

3 YEAR OLD DUMMY

| CHILD DUMMY I.D. NO. | 38 | 39 | |
|---|---|---|---|
| DATE OF CALIBRATION | 3/10/87 | 3/11/87 | |
| ROOM TEMPERATURE (66°-78°F) | 68 °F | 66 °F | |
| ROOM RELATIVE HUMIDITY (10%-70%) | 24 % | 22 % | |
| TEST MEASUREMENT: | | | PART 572 REQMT. |
| FORCE @ 40° FLEXION ANGLE, lbs. | 40 | 41 | 34-47 lbs. |
| SPINAL COLUMN ANGLE @ 3 MIN. POST TEST | 2 | 3 | ≤5° |

was employed in each test and a sheet of teflon was secured to the seating surface under the dummies. Probe impact velocities were 7.0 ± .1 fps. Results of the head impacts are prsented in Table 7 for both dummies. The head peak resultant accelerations were 131 and 133 g's for dummy S/N 121 and 133, respectively which is somewhat less than the preliminary requirement of 140 to 180 g.

The head-neck calibration tests employed the same pendulum apparatus as used for the three-year old dummies. The head-necks were mounted to the bottom of a rigid pendulum which was swung into a decelerator at a velocity of approximately 17.5 fps. A summary of the test results is shown in Table 8. An analysis of these data show that dummy S/N 121 produced calibration values very similar to dummy S/N 133. For instance, the head peak resultant accelerations were both equal at 19 g's and the head maximum rotation angles were 88 and 89 degrees for dummy 121 and 133, respectively.

The chest impact calibration tests were performed according to the Part 572 Subpart C procedures. The cylindrical impactor was the same one used for the head tests and this probe was positioned with its centerline 2.25 inches below the center of the clavical retainer screw or approximately 12 inches up from the seating surface. Before each impact, the dummy torsos were angled forward approximately 2.5 degrees from the vertical to insure that the No. 3 rib was horizontal at the time of impact. Probe impact velocities were controlled to 20 ± .3 fps and each dummy was impacted once. The thorax test results are shown in Table 9 for the two dummies. It can be seen from these results that the chest peak resultant accelerations were similar for each dummy - 55 g's for dummy 121 and 52 g's for dummy 133.

The procedure employed for the lumbar spine flexion tests of the six-year old child dummies was taken from Part 572 Subpart C regulation. The test setup uses only the dummy torso and upper legs. In this procedure a dummy was secured to a flat metal platform by a 0.5 inch diameter bolt, which fastened into the bottom of the lower torso section. A flat steel bar was also clamped down over the top of the knees for additional support. A three-inch diameter pulley was mounted in front of the dummy with its center 23 inches from the center of the main bolt and 1.87 inches up from the seating surface. In order to exert a forward pull force on the upper torso, a cable was fastened to the top of a metal neck section, guided around the pulley and

Table 7

SUMMARY OF HEAD IMPACT TEST CALIBRATION DATA

6 YEAR OLD DUMMY

| CHILD DUMMY I.D. NO. | 121 | 133 | |
|---|---|---|---|
| DATE OF CALIBRATION | 4/16/87 | 4/16/87 | |
| ROOM TEMPERATURE (66-73°F) | 72 | 72 | |
| ROOM RELATIVE HUMIDITY (10-70%) | 38 | 38 | |
| TEST MEASUREMENTS: | | | PRELIMINARY REQUIREMENT |
| TEST PROBE IMPACT VELOCITY, fps | 6.9 | 7.0 | 6.9 to 7.1 fps |
| PEAK HEAD RESULTANT ACCEL., g | 131 | 133 | 140 to 180 g |
| PEAK HEAD LATERAL ACCEL., g | 3 | 4 | ≤ 7 g |
| PULSE △ TIME @ 50 g, ms | 1.4 | 1.4 | 2 - 3 ms |

Table 8

SUMMARY OF HEAD-NECK PENDULUM TEST DATA

6 YEAR OLD DUMMY

| CHILD DUMMY I.D. NO. | 121 | 133 | |
|---|---|---|---|
| DATE OF CALIBRATION | 4/15/87 | 4/15/87 | |
| ROOM TEMPERATURE (66-78°F) | 75 °F | 75 °F | |
| ROOM RELATIVE HUMIDITY (10-70%) | 40 % | 40 % | |
| TEST MEASUREMENTS: | | | PRELIMINARY REQUIREMENT |
| PENDULUM IMPACT VELOCITY, fps | 17.8 | 17.1 | 16-18 fps |
| PEND. AVERAGE DECEL. OVER $(t_3 - t_2)$, g | 26 | 25 | 20-34 g |
| PEAK HEAD RESULT. ACCEL., g | 19 | 19. | ≤ 30 g |
| PEND. DECEL. PULSE Δ TIME $(t_2 - t_1)$, ms | 2.0 | 2.0 | ≤ 4 ms |
| PEND. DECEL. PULSE Δ TIME $(t_3 - t_2)$, ms | 22.0 | 21.0 | 18-22 ms |
| PEND. DECEL. PULSE Δ TIME $(t_4 - t_3)$, ms | 4.5 | 5.0 | 0-6 ms |
| HEAD ZERO POSITION TIME/ PEND. REVERSAL TIME | 147/151 | 142/144 | -/- |
| HEAD MAX. ROTATION ANGLE, ° | 88 | 89 | 76-92° |
| TIME (ms) @ HEAD ROT. ANGLE: 0° | 0 | 0 | -2 to +2 |
| 30° | 26.5 | 26.5 | 19.2 - 26.8 |
| 60° | 39.5 | 37.0 | 32.9 - 43.0 |
| Max. | 71.5 | 72.0 | 60.6 - 75.4 |
| 60° | 108.5 | 104.0 | 90.0 - 110.0 |
| 30° | 128.0 | 124.5 | 109.3 - 132.7 |
| 0° | 146.5 | 141.5 | 126.8 - 153.2 |
| CHORDAL DISPLACEMENT (in) @ HEAD ROTATION ANGLE OF: 0° | 0.0 | 0.0 | -.8 to +.8 |
| 30° | 2.7 | 2.3 | 1.7 - 3.3 |
| 60° | 4.5 | 3.9 | 3.7 - 5.3 |
| Max. | 6.2 | 5.9 | 5.2 - 6.8 |
| 60° | 4.3 | 3.9 | 3.7 - 5.3 |
| 30° | 2.2 | 1.7 | 1.7 - 3.3 |
| 0° | 0.0 | 0.0 | -.8 to +.8 |

Table 9

SUMMARY OF CHEST IMPACT TEST DATA

6 YEAR OLD DUMMY

| CHILD DUMMY I.D. NO. | 121 | 133 | |
|---|---|---|---|
| DATE OF CALIBRATION | 4/16/87 | 4/15/87 | |
| ROOM TEMPERATURE (66-78°F) | 72 °F | 75 °F | |
| ROOM RELATIVE HUMIDITY (10-70%) | 38 % | 40 % | |
| TEST MEASUREMENTS: | | | PRELIMINARY REQUIREMENT |
| TEST PROBE IMPACT VELOCITY, fps | 19.7 | 20.0 | 19.7 to 20.3 fps |
| PEAK CHEST RESULT. ACCEL., g | 55. | 52 | 36 to 90 g |
| PEAK CHEST LATERAL ACCEL., g | 3 | 4 | ≤5 g |
| PULSE Δ TIME @ 30 g, ms | 4.6 | 5.5 | 2.5-4.0 ms |

connected to a hand crank mechanism. A load cell was mounted in series with the cable to monitor the spinal flexion loads. The flexion 'angle of the upper torso was monitored by a rotary potentiometer attached to a bracket on the shoulder clevis of the dummy. A small pendulum arm, attached to this potentiometer, provided a constant vertical reference. During the test, the force and angle transducer signals were simultaneously recorded on a X-Y plotter. The torso flexion rate was approximately 1 degree/second.

A summary of the spinal flexion tests is presented in Table 10. Also shown, along with the force levels measured at the 40 degree flexion angles, are the forces at 20 degrees flexion to indicate the smoothness of the loading curves. Dummy S/N 121 indicated forces of 45 pounds and 25 pounds obtained at the 40 degree and 20 degree angles, respectively. The second dummy contained a somewhat stiffer lumbar spine, showing 55 lbs at 40 degrees of flexion and 30 lbs. at 20 degrees.

The femur impacts tests were performed according to the methodology presented in Part 572 Subpart B (tests of the 50th percentile male dummy), but the smaller 10.38 pound impact probe was employed instead of the large unit. The centerline of the probe was aligned with the centerline of the upper leg metal tubes (femurs) and load cells. The dummy was seated on a flat horizontal metal plate with its feet positioned on a flat lower support. The knee-angle centerline of the lower leg was aligned vertically and the distance between the front edge of the dummy's seat and the back of the lowerleg was set to approximately 3.1 inches.

One impact was performed on each knee of both dummies using probe velocities of approximately 7.0 fps. Table 11 presents the results of the femur impact runs. As indicated, the maximum loads on the femurs of dummy S/N 121 were almost identical - 830 lbs. on the left and 820 lbs. on the right leg. Dummy S/N 133 indicated more spread in these loads with 1000 lbs. being the maximum on the right leg.

In addition to the loads, femur impact pulse time - increments were read at the 400 lb. level and these data indicated, to some extent, the consistency of the pulse shapes between the runs. All these time increments were recorded as one millisecond in length which is less than the preliminary requirement of 1.7 milliseconds.

Table 10

SUMMARY OF LUMBAR SPINE FLEXION TEST DATA

6 YEAR OLD DUMMY

| CHILD DUMMY I.D. NO. | | 121 | 133 | |
|---|---|---|---|---|
| DATE OF CALIBRATION | | 3/20/87 | 3/20/87 | |
| ROOM TEMPERATURE (66°-78°F) | | 72 °F | 72 °F | |
| ROOM RELATIVE HUMIDITY (10%-70%) | | 25 % | 25 % | |
| TEST MEASUREMENT: | | | | PRELIMINARY REQUIREMENT |
| FORCE @ 40° FLEXION ANGLE, lbs. | | 45 | 55 | 42 to 54 lbs. |
| SPINAL COLUMN ANGLE @ 3 MIN. POST TEST | | 3.8 | 3.7 | ≤5° |
| FORCE @ 20° FLEXION ANGLE, LBS. | | 25 | 30 | 18 to 30 lbs. |

## Table 11

## SUMMARY OF FEMUR IMPACT TEST CALIBRATION DATA

6 YEAR OLD DUMMY

CHILD DUMMY I.D. NO. 121

DATE OF CALIBRATION 4/20/87

ROOM TEMPERATURE (66-78°F) 76

ROOM RELATIVE HUMIDITY (10-70%) 38

| TEST MEASUREMENTS: | LEFT FEMUR | RIGHT FEMUR | PRELIMINARY REQUIREMENT |
|---|---|---|---|
| PROBE IMPACT VELOCITY, ~fps | 7.1 | 7.0 | 6.9 to 7.1 fps |
| FEMUR IMPACT FORCE, MAX. ~lbs. | 830 | 820 | 900 to 1100 lbs. |
| PULSE Δ TIME @ 400 LBS., ~ms | 1.0 | 1.0 | ≥ 1.7 |

CHILD DUMMY I.D. NO. 133

DATE OF CALIBRATION 4/20/87

ROOM TEMPERATURE (66-78°F) 76

ROOM RELATIVE HUMIDITY (10-70%) 38

| TEST MEASUREMENT | LEFT FEMUR | RIGHT FEMUR | PRELIMINARY REQUIREMENT |
|---|---|---|---|
| PROBE IMPACT VELOCITY, ~fps | 7.0 | 7.1 | 6.9 to 7.1 fps |
| FEMUR IMPACT FORCE, MAX ~lbs. | 830 | 1000 | 900 to 1100 lbs. |
| PULSE Δ TIME @ 400 LBS., ~ms | 1.0 | 1.0 | ≥ 1.7 |

The six-year old child dummy calibration results for both of these dummies indicated very similar acceleration and load levels compared to the values obtained for the same dummies in Reference 2.

## 4.0 BASELINE SLED TESTS, TASK II

The objective of this task was to develop a method (or methods) for measurement of the pressures imposed by the restraints on the dummy's abdomen in crash tests. Two basic methods were used. One method invovled a specially developed pressure measuring device installed in the dummy's abdomen to provide direct pressure measurements during impacts. The second method involved a measurement with load cells of the forces on the belts restraining either the dummy or its booster restraint. In addition, the contact area between the dummy and its restraint were measured. A calculation of the measured belt load divided by the contact area provides an average abdominal pressure measurement. These two methods were employed concurrently where possible so that the validity of the obtained results could be judged on a comparative basis. In the evaluation of the abdominal pressure measuring methods, the following restraint systems were used:

(1) Dummies restrained by a lap belt of the Standard Seat, where the lap belt loads and belt contact area were measured.

(2) Dummies restrained by a 5-point harness of a child seat, where the harness lap belt load and its contact area were measured.

(3) Dummies restrained by a shield booster seat, where the load of the Standard Seat lap belts restraining the booster seat and the dummy/booster seat contact area were measured.

(4) Dummies restrained by a shield-harness type restraint, where the loads of the Standard Seat lap belts restraining the child seat, the loads in the straps supporting the shield, and the dummy/shield contact area were measured.

These four types of restraints were used. In addition to providing different environments for evaluation of the abdominal pressure measuring methods, these tests also provided baseline information on the magnitude of abdominal pressures produced by different types of restraint systems.

In the TASK II baseline sled testing series three dummies were employed: a nine-month old infant, a three-year old child, and a six-year old child dummy. The three-year and six-year old dummies were instrumented with a special device for direct measurement of abdominal pressures and were used for both direct pressure measurements and load/contact area pressure calculations. The nine-month old dummy, shown in Figure 1, was not instrumented with the pressure measuring device, therefore, this dummy was used only for the load/contact area measurements.

## 4.1 DUMMY MODIFICATION FOR DIRECT ABDOMINAL PRESSURE MEASUREMENTS

Two SAE 103C three-year old child dummies and two SAE 106C six-year old child test dummies were instrumented with a special device developed at the University of Michigan for the measurements of impact pressures during child restraint sled tests (Reference 5). A sketch of the inserted hardware in the three-year old dummy and two photographs are presented in Figure 2. As shown in the drawing, a length of fiber-reinforced rubber tubing (0.40 in I.D.) was coiled around the lumbar spine with six overlapping loops. The two ends of the tube terminated as the bottom of the spine and were connected to a 0.5 inch copper tubing Y-manifold that connected to a vertically oriented piston/cylinder along the back of the dummy. The coiled rubber tubing and metal cylinder, below the piston, were filled with water. The volume above the piston, in the tube, was filled with air. The upper end of the cylinder was capped with a port for pre-pressurizing the air above the piston and another port for continuously monitoring the air pressure with an Endevco 8510-B-100 piezoresistive transducer. As indicated in the sketch, the sensitive area of the abdomen that measured pressure was approximately 2.6 inches in length extending along the lumbar spine from 5.3 inches to 7.9 inches above the seating surface.

The principle of operation of the transducer relies upon the general inextensibility of the fiber-reinforced rubber tubing. As the tubing is squeezed between the lumbar spine and the intruding surface, the water in the tubing is forced to flow into the cylinder and move the piston against the air-pressure chamber. The response of the pressure transducer to an impact load applied to the abdomen was determined by (1) the bending stiffness of the tubing wall, (2) the volume extensibility of the tubing, (3) the flow resistance through the tubing and plumbing into the cylinder, (4) the

Figure 1 9-MONTH OLD INFANT DUMMY

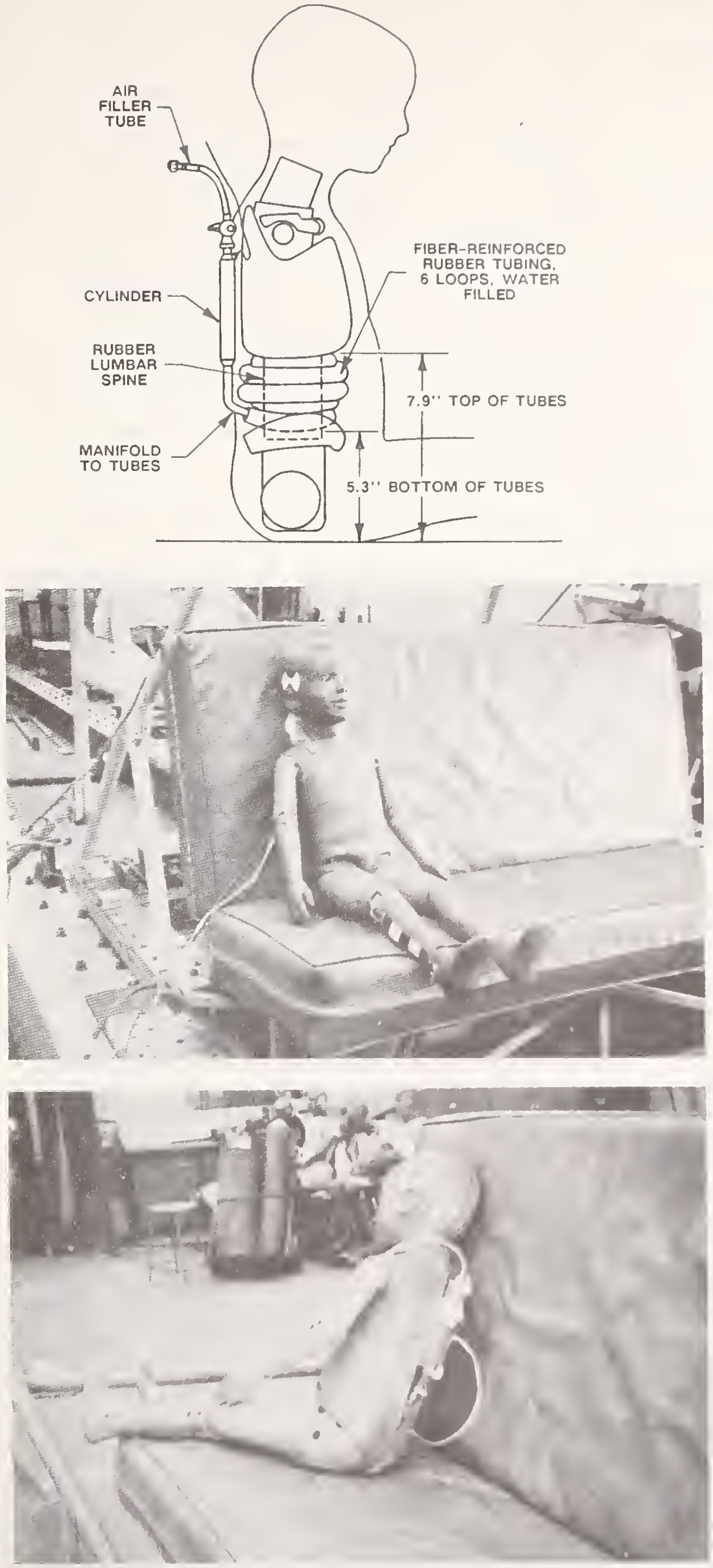



**Figure 2** 3-YEAR OLD CHILD DUMMY ABDOMINAL MODIFICATION

threshold pressure level acting on the sensor piston, and (5) the mechanical characteristics of the dummy abdominal foam overlay. The standard three-year old dummy abdominal foam covering was used without modification. This standard cover, in combination with the added tubing coils, resulted in an increase in abdominal depth from 5 inches to the new dimension of 6 inches. The test weights of the two modified three-year old child dummies, S/N 38 and 39, were 34.1 lbs. and 33.7 lbs., respectively.

The SAE 106C six-year old child dummy was modified in the abdominal area in a manner similar to that used for the three-year old dummy. Figure 3 depicts the modification along with two photographs of the actual dummy. The principle of operation of the pressure system was the same for both types of dummies. With this larger dummy, the rubber tubing was coiled around the lumbar spine which terminated with the copper manifold at the bottom of the spine. The only difference was that the six-year old child abdominal area contained four crescent-shaped spacers, made from hard rubber, mounted on the front side of the lumbar spine. The rubber tubing was looped over these spacers. In front of the tubing coils there was a one-inch thick foam pad and a piece of 0.25 inch thick Ensolite. This thicker padding on the front side of the lumbar spine was required to fill out the abdomen area because the standard abdominal sac had been removed. The pressure sensitive area in the six-year old dummy measured approximately 6.3 inches to 9.3 inches up from the seating surface. The test weights, after modification, of dummy S/N 121 and 133 were 45.7 lbs. and 45.3 lbs., respectively.

## 4.2 BELT LOAD/CONTACT AREA METHOD FOR MEASUREMENT OF ABDOMINAL PRESSURE

One of the first parameters which had to be obtained in determining dummy abdominal pressures was the contact area between the dummy and the restraint. The measurement of well-defined dummy contact areas, during impact, was a difficult problem. Many variables came into play in the dynamic tests such as the soft padding in the abdominal areas and on the restraints, the "roping" of the belt webbing against the soft abdomen, the possible initial sliding of the dummy over the restraint surfaces, and variable pressures over the total contact surface. All of these factors tended to obscure a clean "print" of the dummy impact which was required to determine contact areas and hence, abdominal pressure.

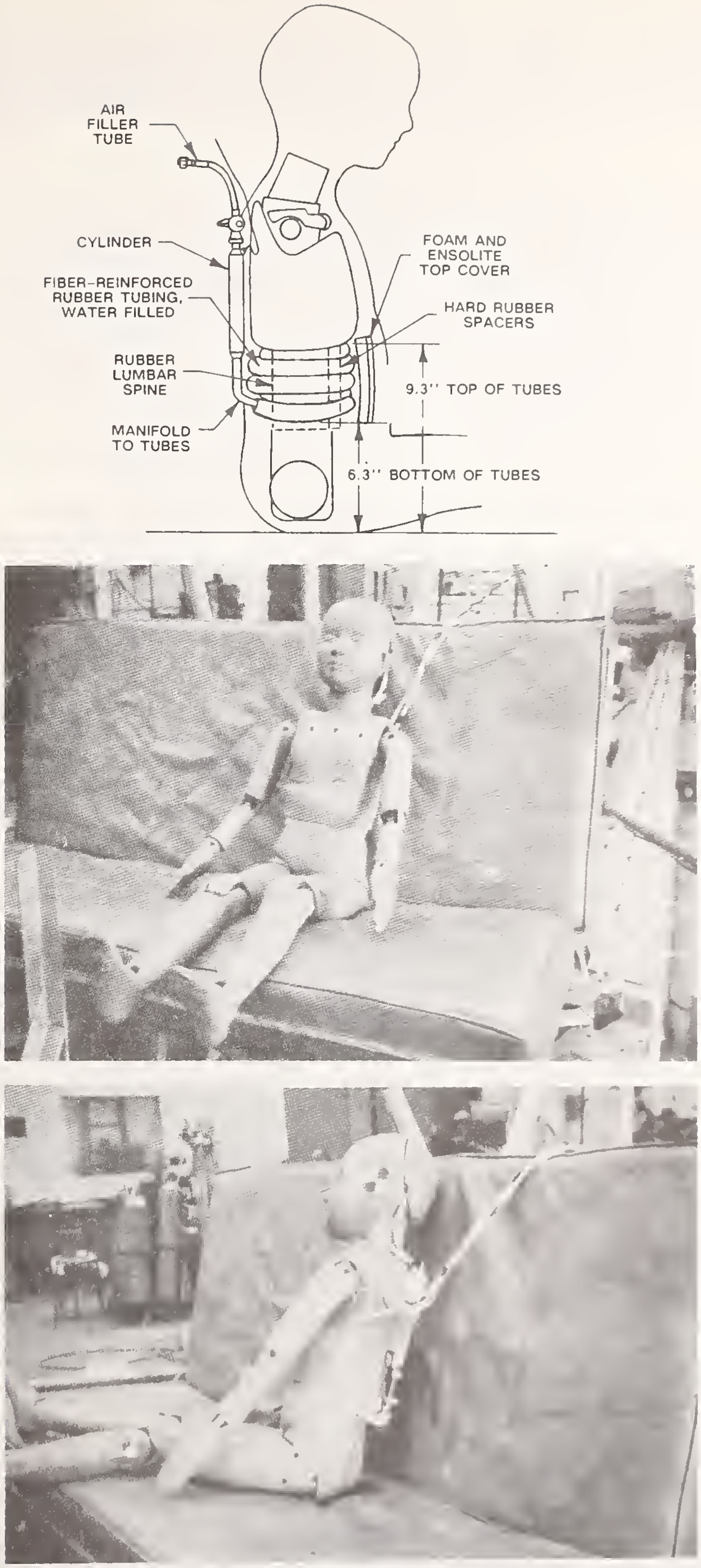



**Figure 3** 6-YEAR OLD CHILD DUMMY ABDOMINAL MODIFICATION

There were ten different methods investigated in an attempt to obtain a sharply defined contact area between the dummy and restraint. These are listed below:

1. Acutred Contact Paper
2. Plastic Bubble Pac, 3/8 x 3/16" cell size
3. Plastic Bubble Pac, 3/8 x 1/8" cell size
4. Plastic Bubble Pac, 1" x 1/2" cell size
5. Blue Chalk on Dummy Torso
6. White Cloth and Paper Carbon Sheet
7. White Cloth and Plastic Carbon Sheet
8. Stiff White Cloth and Plastic Carbon Sheet
9. Stiff White Cloth and Paper Carbon Sheet
10. Denim Cloth and Plastic Carbon Sheet

The Acutred contact paper is a very sensitive (somewhat sticky) paper used in conjunction with a thin carbon sheet. These two papers are bonded together at the top edge with a non-sensitive paper between them. Immediately prior to conducting the test, the intermediate sheet is removed which exposes the carbon sheet to the sensitive sticky paper. The Acutred contact paper, manufactured in California, is generally used in the automobile tire industry for mapping tire tread patterns. It produces good contact traces and even indicates, to some degree, various pressure levels over the contact area. For use in dummy testing, the only significant problem is that it is difficult to place around compound curves.

The three different sizes of plastic Bubble Pac material did not work well in this application because the small cells were not sufficiently sensitive to the levels of pressures developed in these tests. For instance, during lap belt runs, some of the platic bubbles would rupture under the belt and some bubbles would not. In addition, this material was difficult to analyze for contact areas because each cell had to be closely inspected to see if it had ruptured.

The chalk method of obtaining contact traces worked well with those tests where the restraint was not initially in contact with the dummy, such as with the Tot-Guard shield restraint. If chalk was used on lap belts, there would be too much chalk transfer initially when setting up the belts before the test. In addition, the chalk method was difficult to handle in that chalk transferred to any surface that brushed against it.

The white cloth and carbon paper method was tried in several tests because the cloth can be formed more easily around various curves. This method worked well with high loads and pressures, such as with lap belt restraints, but was not sufficiently sensitive in dummy versus shield runs. This was true for all the cloth and carbon sheet methods. The denim cloth and plastic carbon sheet combination was the least sensitive method and did not produce good, readable traces.

The objective of finding a method which would produce a well-defined contact area between dummy and restraint was to use this area in conjunction with measured restraint loads to calculate contact pressures. Lap belt loads were measured directly with Lebow load cells on each webbing. For 5-point harness tests, a Strolee 610 restraint seat was modified with a 0.25" thick steel plate welded to the bottom steel support tubes. The left and right lap straps of the 5-point harness were attached directly to the plate under the seat. Since the Strolee 610 restraint had sufficient room under the plastic seat shell, Lebow load cells were attached to the lap straps in these areas. The slots in the plastic seat, through which the lap straps passed, were elongated to minimize strap binding during the test. The automobile passenger lap belt was placed in the standard position around the Strolee rear tubes so that both the restraint and dummy experienced standard kinematics. Strap loads in the auto lap belt were also measured.

The modification of the Century 100 restraint was much less extensive than the Strolee seat for the 5-point harness runs. The Century seat was used only with the six-year old child dummies because it could accommodate the larger occupants. Lebow load cells were attached to the child lap straps on each side of the seat where the straps attached to the lower support tubes.

The Century 200 restraint was employed for the nine-month-old infant and three-year-old child dummies. This seat is designed with a moveable shield in front of the dummy, which is attached to two upper torso straps and a lower crotch strap. To measure seat strap loads, load cells were placed on one upper torso strap (behind the shoulder) and on the crotch strap beneath the seat. In addition, loads in the main auto lap strap were monitored with Lebow load cells on each side of the seat.

In the determination of abdominal pressures, all of the measured peak strap loads were corrected for weight effects of the child seats in the calculations for those cases where the Standard Seat lap belts were the sole dummy restraint of the seats (i.e., shield/booster seats). For the cases of the moveable shield restraints (Century 200), the forces in the straps supporting the shield (two upper straps and one crotch strap) were resolved into horizontal components at the shield. Once these forces were calculated at the shield, the loads on the dummy abdomen were known and the contact pressures could be obtained.

## 4.3 SLED TEST METHODOLOGY

The child restraint testing was accomplished on the Calspan HYGE accelerator sled using the Square-Wave No. 2 metering pin to control the acceleration time pulse. The 30 mph tests with this pin produce a very repeatable sled pulse, showing peak accelerations of approximately 23 g's and pulse durations of about 80 milliseconds. Figure 4 presents a typical sled acceleration time history of the tests performed in this program. The acceleration level of the pulses are all within the specifications set by the current FMVSS No. 213.

The sled tests were performed using the Standard Seat Assembly specified in FMVSS 213. The standard bench seat assembly was designed specifically as a durable and repeatable test platform for child restraint testing. The seat contains four replacement polyurethane foam inserts for the cushion and the seat backrest. The moveable seat backrest was locked in position for this program to insure better consistency between the various types of child restraints that were tested.

The testing in Task II consisted of 15 simulated 30 mph frontal impact sled tests using a side-by-side dummy seating configuration. The test conditions and procedures followed those presented in FMVSS No. 213 where possible. The objective of this Task II was to find an accurate method of obtaining dummy contact area during dynamic tests while testing representative types of child restraints in current use. These data would be combined with measured restraint loads on the dummies to produce calculated abdominal pressures. In addition, special devices installed in the three-year-old and six-year-old dummies were to be tested for pressure measuring ability.

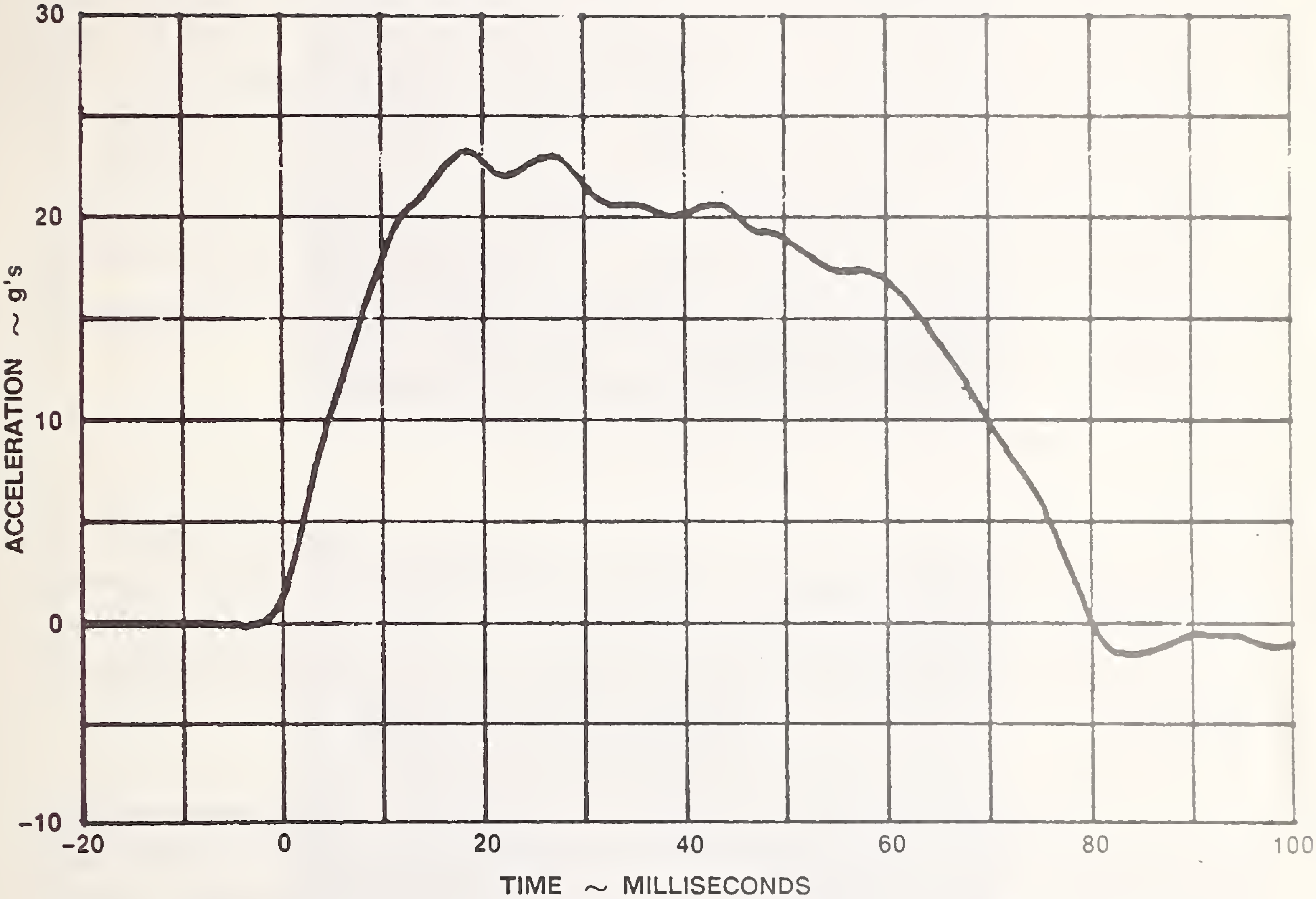



Figure 4 TYPICAL SLED ACCELERATION-TIME HISTORY FOR VELOCITY OF 30 MPH

The first restraint configuration tested was the single lap belt around the abdomen of the three-year-old child dummies, shown in Figure 5. Under the belts, the Acutred contact paper was used to obtain the impact area of the webbing on the dummy. All lap belts around dummies were set to approximately 5 lbs. tension and about 12 lbs. around the child seats. As shown in the photograph, the lap belts were placed slightly higher up on the abdomen, approximately 5.5 inches up from the seat, in order to obtain readable pressures from the special pressure sensing device. The following test series employed shield-type Ford Tot-Guard seats, shown in Figure 6, followed by the Strolee 610 restraints with 5-point harnesses, presented in Figure 7. The final configuration tested was the harness/shield type (Century 200) which contained a moveable shield connected to the child seat straps - Figure 8. During all of these tests, various methods were tried in an attempt to determine dummy contact areas and to measure child restraint strap loads.

## 4.4 TEST MEASUREMENTS AND INSTRUMENTATION

The required test measurements, which were provided for each of the child restraint tests, are summarized in Table 12. The manufacturers and model numbers of the various transducers and cameras are also given in this table. Those transducers used only with the three-year-old dummies or only with the six-year-old dummies are indicated.

Head and knee displacements of the dummy were checked photographically with three high-speed movie cameras. All of these cameras were mounted on the sled, perpendicular to the sled acceleration vector, and in the following positions: one on the right (south) side, one on the left (north) side, and one overhead. Photographic grids in the same vertical planes as the seated dummies were shot in the two side camera views before the tests in order to obtain accurate measurements of head and knee displacements following the tests. In addition to the high-speed movie cameras, a Graphcheck sequence camera was utilized for rapid checks of the dummy and seat motions immediately following each test.

The measurement of tension in the restraint straps, both in the Standard Seat lap belts and in the child restraint webbing was accomplished with Lebow load cells mounted on each of the straps, where possible.

3 YEAR OLD DUMMY

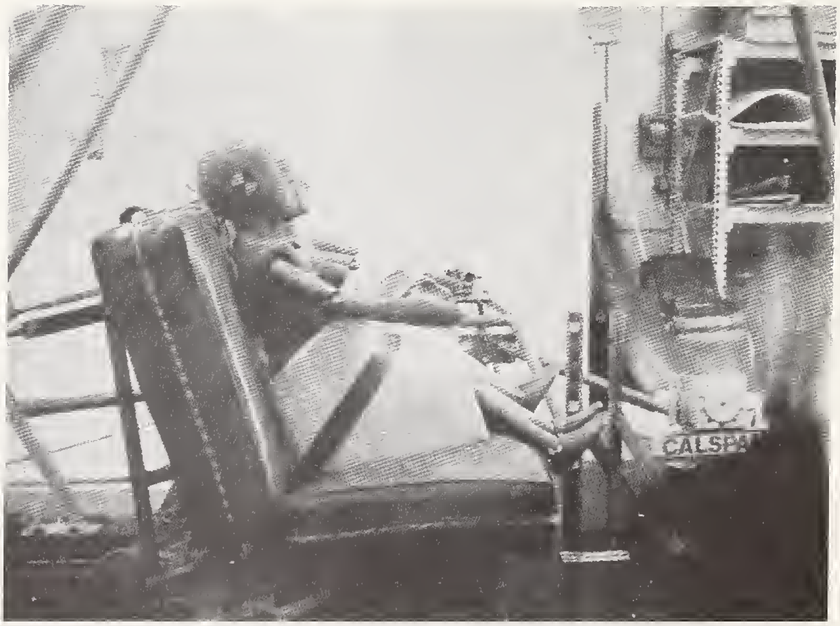
9 MONTH AND 6 YEAR OLD DUMMIES

**Figure 5 DUMMIES IN LAP BELT RESTRAINT CONFIGURATION**



7516-1

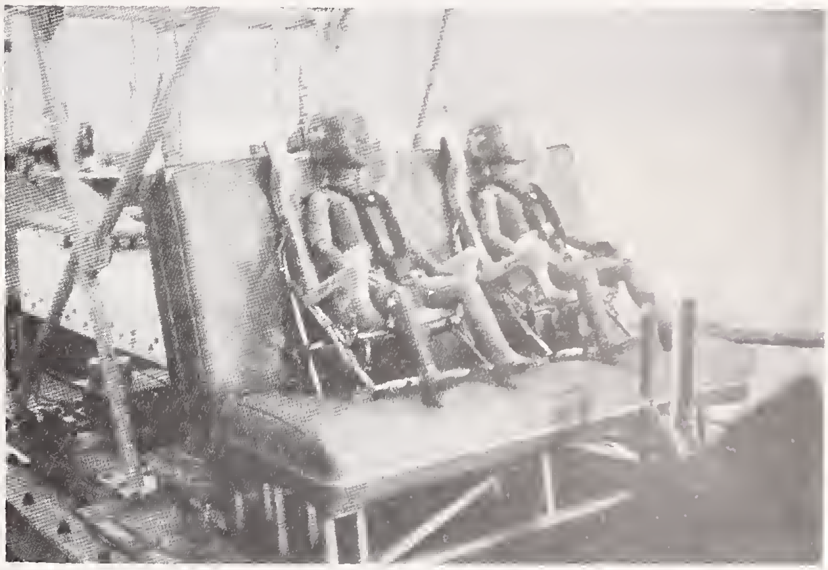
3 YEAR OLD DUMMIES



6 YEAR OLD DUMMIES

Figure 6 DUMMIES IN BOOSTER/SHIELD CONFIGURATION

9 MONTH OLD DUMMY

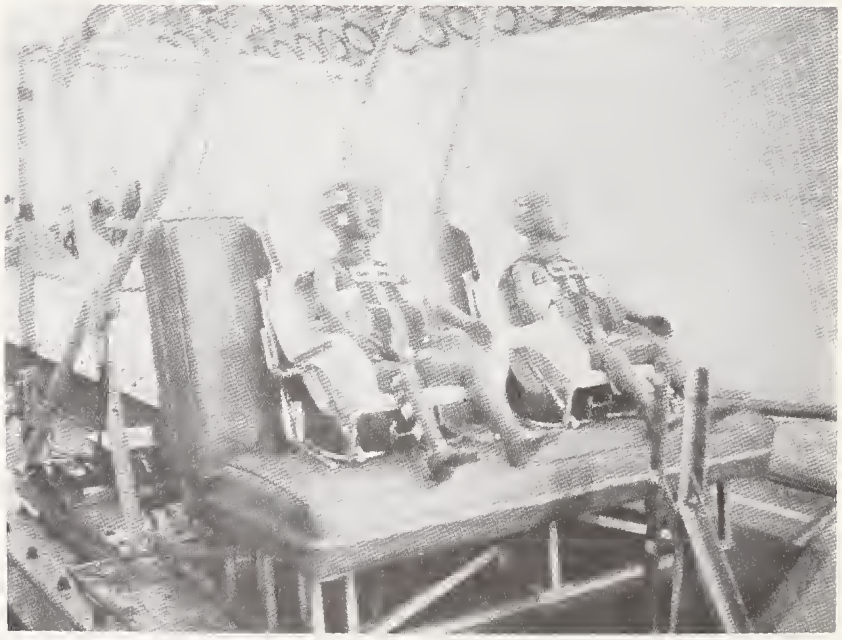


3 YEAR OLD DUMMIES

6 YEAR OLD DUMMIES

**Figure 7** DUMMIES IN 5-POINT HARNESS CONFIGURATION

9 MONTH OLD DUMMY



3 YEAR OLD DUMMIES

Figure 8 DUMMIES IN HARNESS/SHIELD CONFIGURATION

Table 12

**MEASURED VARIABLES AND INSTRUMENTATION**

| Variable | Equipment and Model Number |
| --- | --- |
| Head X,Y,Z Acceleration (9-mo, 3-yr old dummy) | Accelerometer, Endevco 7267A |
| Chest X,Y,Z Acceleration (3-yr old dummy) | Accelerometer, Endevco 7267A |
| Head X,Y,Z Acceleration (6-yr old dummy) | Accelerometer, Endevco 2264 |
| Chest X,Y,Z Acceleration (9-mo, 6-yr old dummy) | Accelerometer, Endevco 2264 |
| Femur Loads (6-yr old dummy) | Load Cell, GSE Model T11654 |
| Abdominal Pressures (3-yr, 6-yr old dummy) | Pressure Transducer, Endevco 8510-B-100 |
| Restraint Belt Loads | Lebow Load Cell, Model 3419 |
| Head Displacement | Camera, Stalex Model WSI-C |
| Knee Displacement | Camera, Stalex Model WSI-C |
| Sled Acceleration | Accelerometer, Kistler Model 305/515T |

In order to set the initial 12 pounds of tension in the restraint straps which secure the child seat to the standard seat assembly, a hand-held gauge was used. This unit was modified at Calspan from a basic belt tensioning gauge and is capable of measuring belt tensions from approximately 5 to 25 pounds.

Calspan's Digital Data Acquisition System (DDAS) was used to record all the time varying data from the sled tests. These data were recorded on Sangamo Model 3500 one-inch 14 track FM recorders, using a recording speed of 60 inches/second. One channel of the tape contained the time reference trace. All instrumentation, signal conditioning, data recording, data playback and filtering conform to the SAE Recommended Practice No. J211b. These SAE data filtering classes are as follows: Head acceleration - Class 1000, Thorax acceleration - Class 180, Femur loads - Class 600, and sled acceleration - Class 60. For event timing, all electronic recording equipment and high-speed movie timing lights were fed a signal from a common time zero pulse and a common timing mark generator.

## 4.5 SLED TEST RESULTS

The sled test results for the 15 runs at a nominal velocity of 30 mph, using two test dummies in each run, are presented in Table 13. Typical time - history graphs of all recorded parameters for three lap belted dummy runs are presented in Appendix A. The first series of five tests employed the three-year-old child dummies in lap belts, shield-type seats, and 5-point harness restraints. Various methods were tried in an attempt to obtain good, readable contact areas between the dummies and the restraints. The Acutred contact paper worked well under lap belt conditions, but had a disadvantage of tearing somewhat because of its inability to wrap smoothly around 3-dimensional objects. However, it did indicate the actual outside edges of the restraint belts and, in some cases, showed the "roping" effect of the webbing as it penetrated into the soft abdomen area. The roped area of the belt was darker than the surrounding print on the paper. Several typical photographs of actual contact areas are presented in Figure 9 obtained with Acutred contact paper. The outline around the peripheries of the shaded zones are those used to determine the contact areas. The difference in shading between the belt produced print and the Tot-Guard shield is apparent.

For the first test in this series, Test No. 4511, the recorded lap belt loads and the measured contact areas produced abdominal pressures of 43.8 psi and 57.5 psi for dummies S/N 39 and 38, respectively. These data can be compared to the peak abdominal pressures measured directly by the abdominal pressure measuring device of 43.5 psi and 26.5 psi. It is presently not known why the pressure reading of the second dummy (S/N 38) was 39% lower than the first dummy, but it must be recognized that these direct pressure readings are very sensitive to where the pressure is applied and how it is applied. For this test, the belts were placed approximately in the mid-sensitive area of the abdomen, but one belt could have roped more than the other, producing different peak pressures.

The second test (No. 4512) with the three-year-old dummies and lap belt restraints, employed Bubble Pac material under the straps to indicate contact areas. The size of these plastic bubbles were approximately 3/8 inch in diameter by 3/16 inch high. This material did not show clearly the belt contact areas, because all the bubbles under the webbing did not rupture. Some of the bubbles were broken and some were not - showing inconsistencies. The calculated abdominal pressures were similar to the

## Table 13

## SUMMARY OF SLED BASELINE TEST DATA

## TASK II

| Test No. | Child Restraint Configuration | Dummy | Head Peak Res. Accel. (g) | HIC | Chest Peak Res. Accel. (g) | Peak Child Lap Belt Load (LBS) | Contact Area ($IN^2$) | Abdom. Press. Calculated (PSI) | Abdom. Press. Measured (PSI) | Peak Auto Lap Belt Load (LBS) | Dummy Excurs. Hd./Knee (IN) | Sled Accel./Vel. (g/MPH) | Method Used to Obtain Dummy Contact Area (See Key) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4511 | Auto Lap Belt | 3 yr. old 39 | 55 | 610 | 29.2 | 874 | 19.9 | 43.8 | 43.5 | 874 | 33.2/31.0 | 22.9/28.7 | 1 |
| | ↓ | 3 yr. old 38 | 62 | 824 | 30.0 | 813 | 14.2 | 57.5 | 26.5 | 813 | 33.0/30.0 | ↓ | 1 |
| 4512 | Auto Lap Belt | 3 yr. old 39 | 47 | 386 | 29.7 | 1008 | 18.6 | 54.2 | 28.1 | 1008 | 32.0/31.3 | 22.3/27.8 | 2 |
| | ↓ | 3 yr. old 38 | 43 | 404 | 33.1 | 993 | 17.4 | 57.1 | 23.0 | 993 | 31.7/31.2 | ↓ | 2 |
| 4514 | Stiff Shield (Ford Tot-Guard) | 3 yr. old 39 | 52 | 648 | 34.2 | 1946 | 52.0 | 37.4 | 1.9 | 2040 | 34.2/26.6 | 23.0/28.6 | 5 |
| | ↓ | 3 yr. old 38 | 65 | 754 | 36.9 | 1766 | 48.5 | 36.4 | 0.2 | 1860 | 33.7/25.6 | ↓ | 1 |
| 4518 | 5-Pt. Harness (Strolee 610) | 3 yr. old 39 | 44 | 613 | 34.8 | 420 | 8.9 | 47.5 | 0 | 2100 | 28.0/33.9 | 23.2/28.5 | 1 |
| | ↓ | 3 yr. old 38 | 45 | 582 | 36.8 | 415 | 10.2 | 40.5 | 0 | 2160 | 27.7/33.5 | ↓ | 3 |
| 4519 | 5-Pt. Harness (Strolee 610) | 3 yr. old 39 | 45 | 561 | 31.0 | 550 | 9.9 | 55.3 | 0 | 2000 | 28.4/34.0 | 23.5/28.9 | 1 |
| | ↓ | 3 yr. old 38 | 44 | 610 | 34.6 | 450 | 10.1 | 44.4 | 0 | 2000 | 27.7/33.5 | ↓ | 4 |
| 4520 | Auto Lap Belt | 6 yr old 133 | 65[1] | 715[1] | 32.7 | 1250 | 17.7 | 70.7 | 54.0 | 1250 | 32.0/33.0 | 23.1/28.9 | 1 |
| | 5-Pt. Harness (Strolee 610) | 9 mo. old | 65 | 567 | 45.1[2] | 340 | 10.5 | 32.3 | -- | 1360 | 25.5/23.4 | ↓ | 6 |
| 4521 | Auto Lap Belt | 6 yr. old 133 | 70[1] | 707[1] | 33.2 | 1320 | 21.7 | 60.9 | 50.5 | 1320 | 32.3/34.0 | 24.0/28.8 | 7 |
| | ↓ | 9 mo. old | 92 | 1341 | 70.3 | 1400 | 15.7 | 89.2 | -- | 1400 | 27.2/22.1 | ↓ | 10 |
| 4522 | Auto Lap Belt | 6 yr. old 133 | 70 | 808 | 33.1 | 1350 | 23.9 | 56.6 | 39.0 | 1350 | 32.3/33.2 | 22.9/28.5 | 1 |
| | ↓ | 9 mo. old | 106 | 1369 | 79.9 | 1400 | 15.5 | 90.3 | -- | 1400 | 26.5/20.0 | ↓ | 2 |

## Table 13 (Cont'd.)

## SUMMARY OF SLED BASELINE TEST DATA

## TASK II

| Test No. | Child Restraint Configuration | Dummy | Head Peak Res. Accel. (g) | HIC | Chest Peak Res. Accel. (g) | Peak Child Lap Belt Load (LBS) | Contact Area (IN²) | Abdom. Press. Calculated (PSI) | Abdom. Press. Measured (PSI) | Peak Auto Lap Belt Load (LBS) | Dummy Excurs. Hd./Knee (IN) | Sled Accel./Vel. (g/MPH) | Method Used to Obtain Dummy Contact Area (See Key) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4523 | Auto Lap Belt | 6 yr. old 133 | 65 | 610 | 31.6[3] | 1270 | 19.7 | 64.7 | 36.1 | 1270 | 31.8/33.8 | 23.1/29.0 | 6 |
| | Flex. Shield (Century 200) | 9 mo. old | 58 | 566 | 42.1 | 538 | 14.1 | 38.3 | -- | 1100 | 30.9/26.9 | ↓ | 1 |
| 4524 | Stiff Shield[5] (Ford Tot-Guard) | 6 yr. old 133 | 53 | 545 | 34.9 | 2330 | 50.6 | 46.1 | 2.6 | 2420 | 33.1/30.4 | 24.1/29.1 | 5 |
| | ↓ | 6 yr. old 121 | 56 | 583 | 39.2 | 1970 | 52.5 | 37.5 | Data Lost | 2060 | 33.6/29.0 | ↓ | 5 |
| 4525 | 5-Pt. Harness (Century 100) | 6 yr. old 133 | 51 | 538 | 35.0 | 380 | 11.7 | 32.4 | 0.4 | 1960 | 32.2/36.2 | 23.6/29.3 | 1 |
| | ↓ | 6 yr. old 121 | 65 | 677 | 40.0 | 340 | 12.6 | 27.0 | 6.0 | 1760 | 32.6/35.3 | ↓ | 1 |
| 4526 | 5-Pt. Harness (Century 100) | 6 yr. old 133 | 42 | 364 | 36.3 | 370 | 10.8 | 34.2 | 0.2 | 2120 | 30.0/36.4 | 23.0/28.4 | 8 |
| | ↓ | 6 yr. old 121 | 44 | 347 | 27.5 | 360 | 10.4 | 34.7 | 0.0 | 2160 | 30.5/36.4 | ↓ | 8 |
| 4527 | Auto Lap Belt | 6 yr. old 133 | 55 | 496 | 38.1 | 1186 | 21.6 | 54.9 | 29.0 | 1186 | 31.4/33.5 | 23.0/28.4 | 9 |
| | ↓ | 6 yr. old 121 | 62 | 606 | 36.0 | 1000[4] | 22.5 | 44.5 | 87.5 | 1000[4] | 32.5/32.1 | ↓ | 1 |
| 4528 | Flex. Shield (Century 200) | 3 yr. old 39 | 45 | 372 | 37.5 | 630 | 21.7 | 29.0 | 0.0 | 1750 | 31.1/34.0 | 23.2/29.1 | 1 |
| | ↓ | 3 yr. old 38 | 42 | 279 | 36.0 | 835 | 21.3 | 39.1 | 0.0 | 1650 | 30.7/34.0 | ↓ | 1 |
| 4529 | Flex. Shield (Century 200, No Pad) | 3 yr. old 39 | 45 | 357 | 38.1 | 625 | 18.3 | 34.2 | 0.0 | 1820 | 30.4/33.8 | 23.1/28.6 | 1 |
| | ↓ | 3 yr. old 38 | 41 | 322 | 36.3 | 692 | 18.4 | 37.5 | 0.0 | 1630 | 29.1/34.0 | ↓ | 1 |

Notes:
(1) Head X-Component Accel. Lost
(2) Chest Y-Component Accel. Lost
(3) Chest Z-Component Accel. Lost
(4) Left Belt Load Not Correct, Assumed left side was equal to right side
(5) North Side Dummy (S/N 133) was ejected out of seat

## Table 13 (Cont'd.)

## KEY TO DUMMY CONTACT AREA METHODS

| | Method | Post-Test Comments |
|---|---|---|
| 1 | Acutred Contact Paper | Gave good trace but paper difficult to place around 3-D objects. |
| 2 | Plastic Bubble PAC, 3/8 x 3/16" Cell Size | Easy to handle, not accurate because all bubbles did not break under load, difficult to read. |
| 3 | Plastic Bubble PAC, 3/8 x 1/8" Cell Size | Same as above material. |
| 4 | Plastic Bubble PAC, 1" x 1/2" Cell Size | Same as above material with less accuracy. |
| 5 | Blue Chalk on Dummy Torso | Gave good trace, messy to work with, cannot differentiate between low and high pressures. |
| 6 | White Cloth and Paper Carbon Sheet | Less sensitive than No. 1, works best with concentrated loads as lap belts. |
| 7 | White Cloth and Plastic Carbon Sheet | Same as No. 6, slightly less sensitive. |
| 8 | Stiff White Cloth and Plastic Carbon Sheet | Same as No. 6 with approximately same sensitivity |
| 9 | Stiff White Cloth and Paper Carbon Sheet | Same as No. 8 |
| 10 | Denim Cloth and Plastic Carbon Sheet | Not sufficiently sensitive to produce good readable trace. |

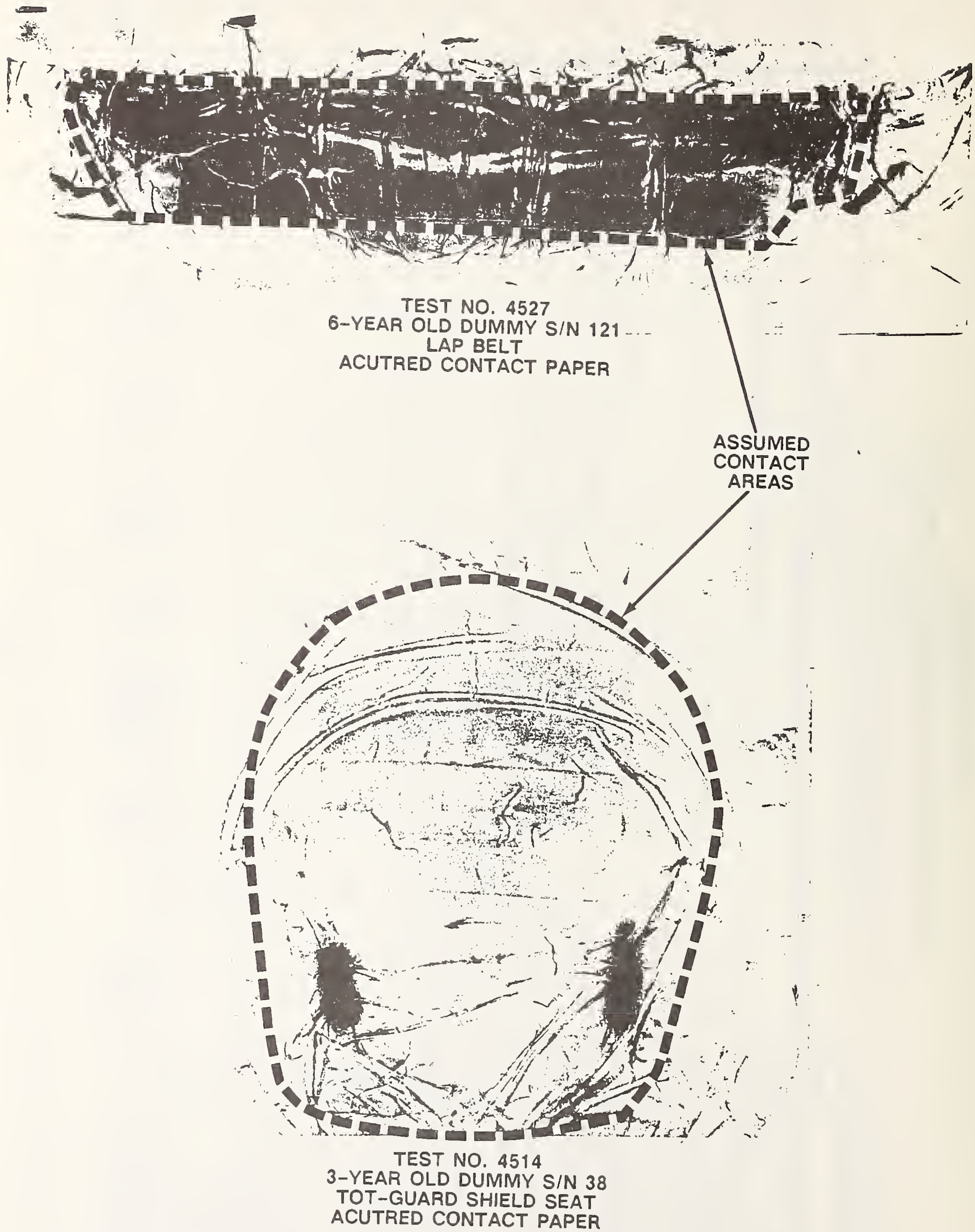



Figure 9 TYPICAL DUMMY CONTACT AREA PATTERNS

previous test data of about 56 psi, but the directly measured pressure data were both reduced - 28.1 psi and 23.0 psi.

The third sled test used Tot-Guard shield-type restraints in combination with blue chalk on the torso of one dummy and the Acutred paper on the second seat. The chalk transfer to the shield, during the run, was sufficient to determine dummy contact area. The contact paper on the second restraint also produced readable results. This test setup is depicted in Figure 6, showing the three-year old dummies in the high (adjustable) seat position. The calculated abdominal impact pressures were somewhat lower for this type of restraint - approximately 37 psi. Even though the shield was aligned with the abdomen of the dummies for this test, the shield consists of such a large area that the measured pressures were almost zero. Dummy 39 indicated a peak abdominal pressure of 1.9 psi and dummy 38 showed 0.2 psi. The shield contains a vertical flat area, facing the dummies, of about 4 inches deep, which in itself is deeper than the sensitive area of the abdomen. The contact area of this shield was too large for the modified abdominal areas to sense any significant pressure change.

For the 5-point harness restraint of the Strolee 610 tested with the three-year old dummies the abdominal pressures measured with the special devices were approximately zero in two sled tests numbered 4518 and 4519. This was due to the fact that the buckle and lap belt portions of the restraint fit low on the pelvic area of the dummy. The buckle was even placed intentionally higher up on the abdomen, before the runs, and this action still did not activate the pressure measuring system. The calculated pressures were on the order of 45 psi for these 5-point runs. Several sizes of plastic bubble pacs were used to determine contact areas, but these materials were not sufficiently reliable.

The six-year-old dummy was tested with lap belts only in Test Nos. 4520 to 4523, and 4527. The calculated abdominal pressure varied from 54.9 psi to 70.7 psi. In comparison, the pressures measured with abdominal sensing devices ranged from 29.0 psi to 87.5 psi. Since the lap belts for these runs were placed slightly higher on the abdomens, the water-filled tubes in the dummies were able to record distinct pressure levels.

Various contact area methods were tried in tests with the six-year-old dummies, such as the white cloth and paper carbon or plastic carbon sheets. These methods produced readable traces and worked best with concentrated loads, as with lap belt restraints. They were not as sensitive as the Acutred contact paper so when they were tested under restraints such as the 5-point harness, the traces were somewhat light and difficult to read.

The nine-month-old infant dummy was tested alongside of the six-year-old dummy in four sled tests. The restraints tested were the 5-point harness, the lap belt, and the flexible shield. The calculated abdominal pressures for the infant dummy indicated a relatively large range, from a low of 32.3 psi to a maximum of 90.3 psi. The method employed to obtain the contact area of the lap belt run in Test No. 4522 (calculated pressure of 90.3 psi) was a plastic Bubble Pac with 3/8 by 3/16 inch bubble sizes. As stated above, the accuracy of the bubble material is less than contact paper and less than cloth plus carbon sheets. In this same test, the peak total belt load of 1400 lbs appeared excessive because the infant dummy is lighter than the other units. However, a check was made of the impulse of the force-time curve presented in Figure 10 and it was observed that:

$$J = \int_{t_1}^{t_2} F\,(dt) = 24.9 \text{ lb-sec.}$$

This impulse must be equal to the change in linear momentum, $m\Delta V$, which calculates to:

$$m(\Delta V) = \frac{20.19}{32.2}(41.81) = 26.2 \text{ lb-sec}$$

The change in momentum agrees with the impulse to within 5%. Moreover, the lower curve in Figure 10 is from the lap belted three-year-old child dummy (Test No. 4512) and its impulse, J, calculates to 45.7 lb-sec. even though the peak force is lower than the infant dummy curve - 1008 lbs. The momentum change of the three-year-old dummy is:

$$m(\Delta V) = \frac{33.69}{32.2}(40.78) = 42.7 \text{lb-sec.}$$

This momentum change is within 6.6% of the impulse. These checks appear to verify that the belt load cell data of the infant dummy are correct. The construction of the small infant dummy must be relatively stiff in the abdomen-pelvic area which leads to the "spikey" curve and the 1400 lb peak.

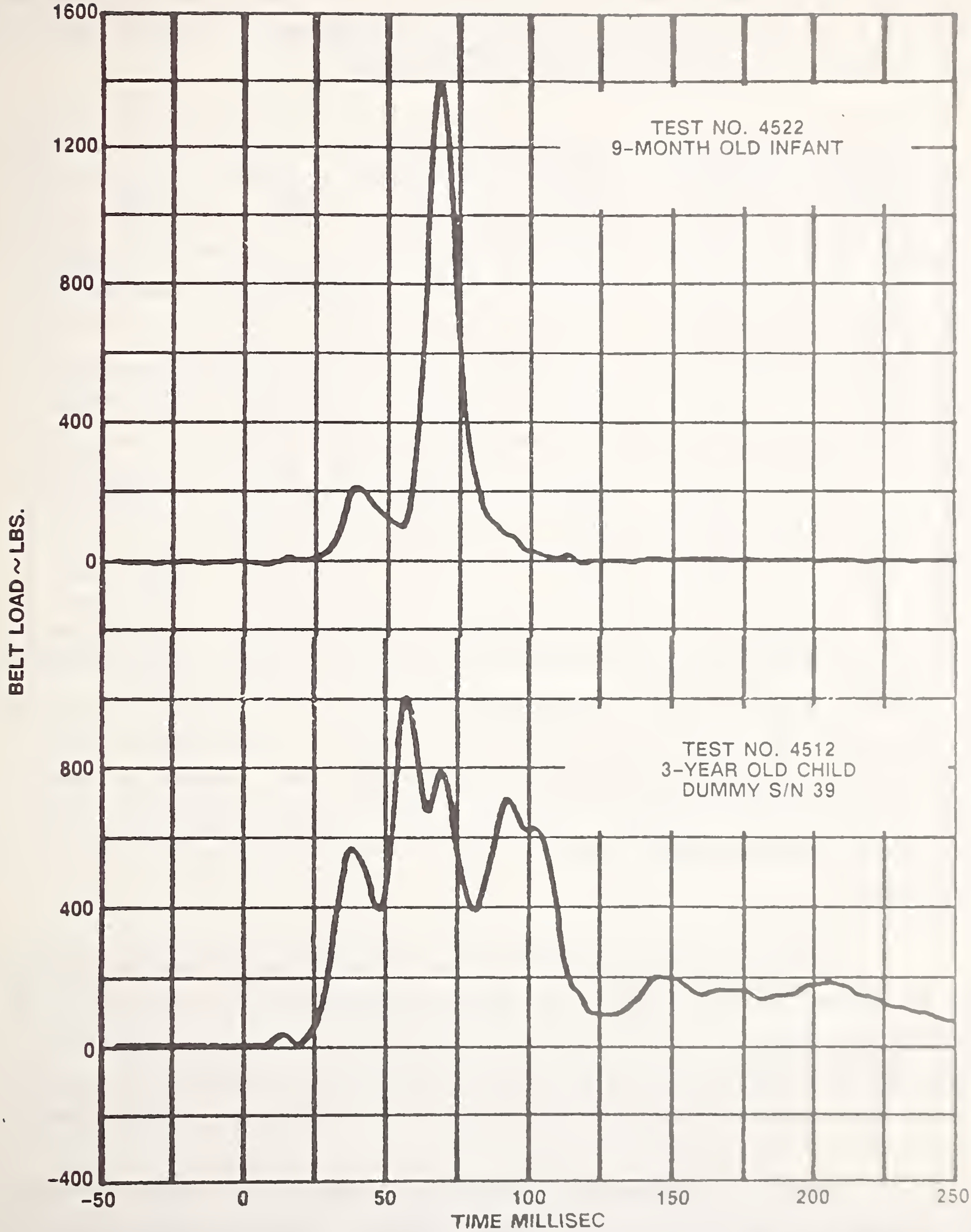



Figure 10 TOTAL LAP BELT LOADS FOR 9-MONTH OLD INFANT AND 3-YEAR OLD CHILD DUMMIES

In sled Test No. 4521 with the nine-month-old infant dummy restrained by a lap belt, a stiff denim material, in combination with a plastic carbon sheet, was employed to determine the contact area. This combination of materials was not sensitive enough to produce well-defined contact traces.

The six-year-old test dummies were tested again in side-by-side tests using 5-point harness child seats. In these 5-point harness runs, Test No.s 4525 and 4526, very little abdominal pressures were measured directly by the University of Michigan pressure sensing mechanism. This was probably caused by the fact that the buckle and the 5 harnesses of the Century 100 restraint cannot be aligned over the pressure sensing areas of the dummy's abdomen. In Test No. 4525, the buckle was placed approximately 1.5 inches higher than a normal installation for the right side dummy and about 2.5 inches higher on the left dummy. Even with these slightly raised buckle positions, minimal pressures were recorded. The calculated pressures, however, from the lap belt contact areas, were 32.4 psi for the left side dummy and 27.0 psi for the right side. The six-year old dummies were also tested in Tot-Guard restraints in Test No. 4524 using the low seat positions (Figure 6).

The final two tests in the Task II series included the abdominal pressure measurements using three-year-old dummies restrained by Century 200 seats which contained the moveable shields. The padded shields were kept in place in front of the occupants by direct connections to two shoulder straps and a crotch strap. Test No. 4528 contained standard padded shields, which gave close to zero pressures as measured with the instrumented abdomens. The abdominal pressures calculated from belt load/contact area measurements were 29.0 psi and 39.1 psi for dummy S/N 39 and 38, repsectively.

In an attempt to obtain better contact area definition between the dummies and the shields, Test No. 4529 was run with the padding material removed from the Century 200 shields. The Acutred contact paper was used for both dummies. The results showed a slightly darker contact print, in certain areas, compared to the previous run with a small increase in definition of the outline of the shield, but no major changes.

In order to condense all the test data in Table 13 and to show it in more understandable terms, the data were averaged for the four types of restraints with the various dummies and is presented in Table 14. All the averaged data points do not contain the same number of tests. These data indicate (from calculated values) that

Table 14

AVERAGE ABDOMINAL PRESSURE DATA

| Restraint Type | Dummy Size | Average Contact Area ($IN^2$) | Average Child Lap Belt Load (LBS.) | Average Calculated Abdominal Pressure (PSI) | Average Measured Abdominal Pressure (PSI) |
|---|---|---|---|---|---|
| Lap Belt | 9-mo. old | 15.6 | 1400 | 89.7 | -- |
| ↓ | 3-yr. old | 17.5 | 922 | 52.6 | 30.3 |
| | 6-yr. old | 21.2 | 1229 | 58.0 | 49.4 |
| 5-point Harness | 9-mo. old | 10.5 | 340 | 32.3 | -- |
| (Strolee 610) | 3-yr. old | 9.8 | 459 | 46.8 | 0 |
| ↓ | 6-yr. old | 11.4 | 363 | 31.8 | 1.7 |
| Stiff Shield | 9-mo. old | -- | -- | -- | -- |
| (Tot-Guard) | 3-yr. old | 50.3 | 1856 | 36.9 | 1.1 |
| ↓ | 6-yr. old | 51.6 | 2150 | 41.7 | 2.6 |
| Flexible Shield | 9-mo. old | 14.1 | 538 | 38.2 | -- |
| (Century 200) | 3-yr. old | 19.9 | 696 | 35.0 | 0 |
| ↓ | 6-yr. old | -- | -- | -- | -- |

lap belt abdominal pressures are in the range of 50 psi except for the nine-month-old infant, which indicated a high pressure of 89.7 psi. Abdominal pressures for 5-point harness restraints drop down to approximately 30 to 40 psi which seems reasonable because upper straps aid in carrying the torso loads plus a crotch strap restrains the lower body. The Tot-Guard type of restraint, with its large, stiff shield, produces abdominal pressures in the 35 to 40 psi range. This pressure is probably not totally imposed over the abdominal area but a portion of it is supported by the stiffer rib cage area. This is an inherent advantage in these type seats when viewing the contact pressures from the child injury standpoint. The flexible shield type restraint indicated abdominal pressures from 35 to 38 psi. In this case, which is very similar to the 5-point harness, the upper torso is supported by the two shoulder straps which relieves the forces acting directly on the abdominal area.

In reviewing the ten different methods of obtaining dynamic contact areas between the dummies and the restraints, the Acutred contact paper produced the most readable and definable results. This system therefore, was employed in the next series of sled tests in which all child booster seats currently on the market were tested.

## 5.0 EVALUATION OF HARNESS AND SHIELD-TYPE BOOSTER SEATS, TASKS III, IV

In this section, all child booster seats, that were currently available on the market, were tested on the accelerator sled. The tests required under Task III, using three-year old child dummies and the Task IV tests with nine-month old infant and six-year old child dummies, were combined into one test group. All three sizes of dummies were tested with the booster seats and the results are presented in this section.

## 5.1 CHILD BOOSTER SEATS

A list of the ten currently available booster seats, that were tested, is presented in Table 15 along with additional pertinent information about each seat. An additional booster type seat, Tot-Guard, was tested with the three-year old and six-year old dummies and results of that testing are presented in Table 13. As listed in the second column of Table 15, all restraints have a shield mounted in front of the seat occupants to perform the restraining function. Four of these restraints indicated in their instructions that an automobile 3-point harness could also be employed for larger occupants when riding in vehicle front seats. Consequently, these four restraints were tested, not only in their standard configuration, but also with a 3-point belt system. The Evenflo 7-Year seat was the only restraint which contained two upper torso harness straps in addition to the impact shield.

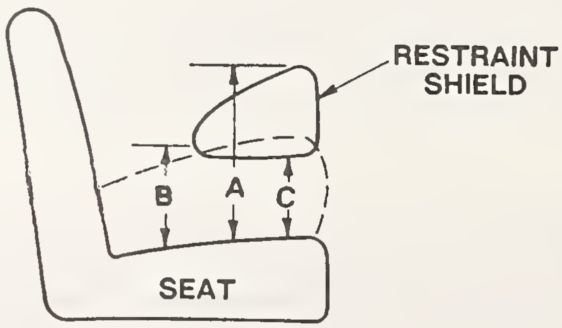
Table 15 shows the general allowable occupant sizes in the form of weight ranges. These data were taken from the instructions posted on the sides of the seats. According to these weight ranges, the actual dummy sizes that were tested are listed in the table. The seats which allowed 20 to 25 lb. occupants and heavier were tested with all three dummies. The restraints designed for heavier children, in the 30-60 lb. range, used only the two larger dummies. Also listed in the table are the weights of each restraint.

The third column in Table 15 presents several important dimensions of the impact shields. Note that all the shields do not have the same height A above the seating surface. This dimension is important in preventing excessive forward stroke distances of the occupant's head. The B dimension is an average height of the part of

## Table 15

## BOOSTER SEATS TESTED IN TASKS III AND IV

| Child Restraint | Type of Restraint | Booster Seat Shield Geometry (in.) | | | Child Size Restrictions (from Instructions) | Seat Wgt. (lbs) | Dummies Tested |
|---|---|---|---|---|---|---|---|
| | | A | B | C | | | |
| Century Commander Booster, 4810 | Shield | 9.5 | 6.5 | 4.5 | 20–65 lbs. 1–10 yrs. | 4.75 | 9 mo., 3 yr., 6 yr. old |
| Cosco Explorer 1, 299A | Shield | 9.5 | 6.7 | 4.0 | 30–60 lbs. | 4.69 | 3 yr. and 6 yr. old |
| Evenflo Wings | Shield (also use with 3-pt. harness) | 10.6 | 7.0 | 4.0 | 30–60 lbs. | 7.00 | 3 yr. and 6 yr. old |
| Evenflo 7-Year | Harness/Shield (also use with 3-pt. harness) | 9.8 | 6.5 | 4.4 | 17–60 lbs. | 18.63 | 9 mo., 3 yr., 6 yr. old |
| Gerry Voyager Booster | Shield | 8.8 | 6.5 | 4.5 | 30–60 lbs. | 9.06 | 3 yr. and 6 yr. old |
| Kolcraft Flip'n Go | Shield | 9.0 | 5.6 | 3.3 | 25–55 lbs. | 3.88 | 9 mo., 3 yr., 6 yr. old |
| Kolcraft Flip'n Go II | Shield | 9.0 | 5.6 | 3.3 | 25–55 lbs. | 3.88 | 9 mo., 3 yr., 6 yr.old |
| Kolcraft Quick-Step Tot-Rider | Shield | 9.4 | 6.8 | 3.5 | 20–60 lbs. | 4.88 | 9 mo., 3 yr., 6 yr. old |
| Pride-Trimble Click'n Go, 891 | Shield (also use with 3-pt. harness) | 8.0 | 5.8 | 3.3 | 25–65 lbs. | 6.38 | 9 mo., 3 yr., 6 yr. old |
| Strolee Quick-Click, 605 | Shield (also use with 3-pt. harness) | 9.5 | 6.8 | 4.3 | 30–70 lbs. | 5.00 | 3 yr. and 6 yr. old |



the shield which is closest to the dummy; this area will contact the dummy first. For some of the shields, this distance is not necessarily half way between the A and C dimensions. If the B distance is compared to the mid-position of the pressure measuring systems in the dummies, (see Figures 2 and 3) the impact point of the shields on the abdomens can be approximated. The three-year old dummy had an abdominal mid-point approximately 6.6 inches up from the seat and the six-year old dummy contained a mid-point of 7.8 inches. Comparing these distances of the three-year old dummy, for example, with the Kolcraft Flip'n Go shows the shield will contact the dummy low in the abdomen while the Evenflo Wings should contact higher than the abdomen center. The C dimension is the minimum distance between the shield and the seating surface.

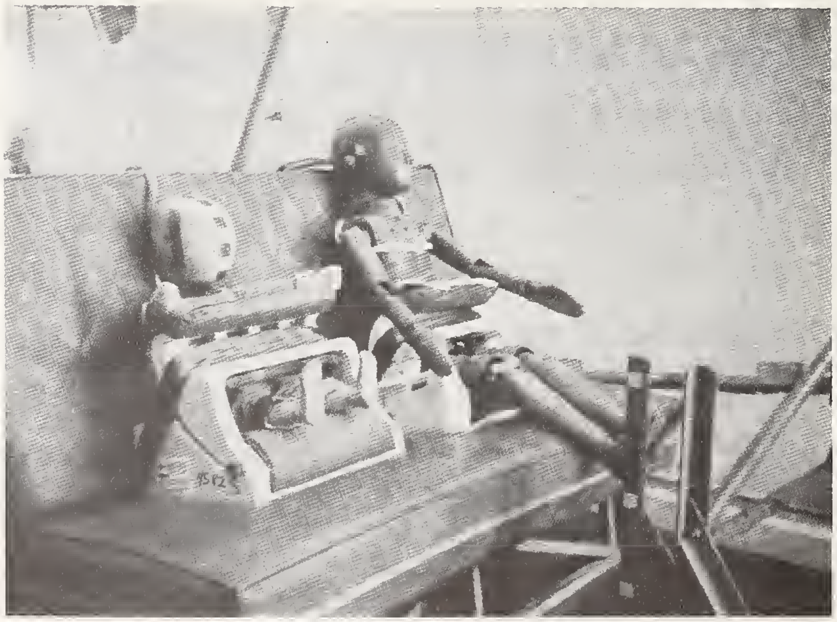
The nine-month old infant dummy sat very low with a distance of 11 inches to the shoulders and 2.8 inches to the top of the thighs, above the seat. If the three-year old dummy abdomen area (area modified with the pressure sensing device) is ratioed down to the infant dummy size, using sitting shoulder height distances, the infant's abdomen would be at 4.4 inches to 6.5 inches up from the seat with a mid-point at 5.4 inches. From Table 15, it is seen that all the booster shield B distances are above the 5.4 inch middle abdomen distance. This means that booster shield contacts will occur to the infant dummy in the area approximately from mid-abdomen to the lower chest.

The seating position of the dummies in several representative booster seats are depicted in the photographs of Figure 11. The six-year old dummy and booster seat configurations with the additional 3-point restraint straps are shown in Figure 12. For these runs the lap portion of the belt was placed around the booster shield and the single upper strap was positioned over the upper torso of the dummies. The position of the torso strap anchor point was similar to that of a late model, American 4-door sedan.

## 5.2 SLED TEST RESULTS

Sixteen sled tests were performed in Tasks III and IV employing all of the child shield/booster restraints currently available on the market. A side-by-side dummy/seat configuration was used for the nominal 30 mph velocity tests. A typical test setup is shown in Figure 13 with the six-year old child dummies in pre-test and

3 YEAR OLD DUMMIIES



9 MONTH AND 6 YEAR OLD DUMMIES

Figure 11 DUMMIES IN STANDARD BOOSTER SEAT CONFIGURATION

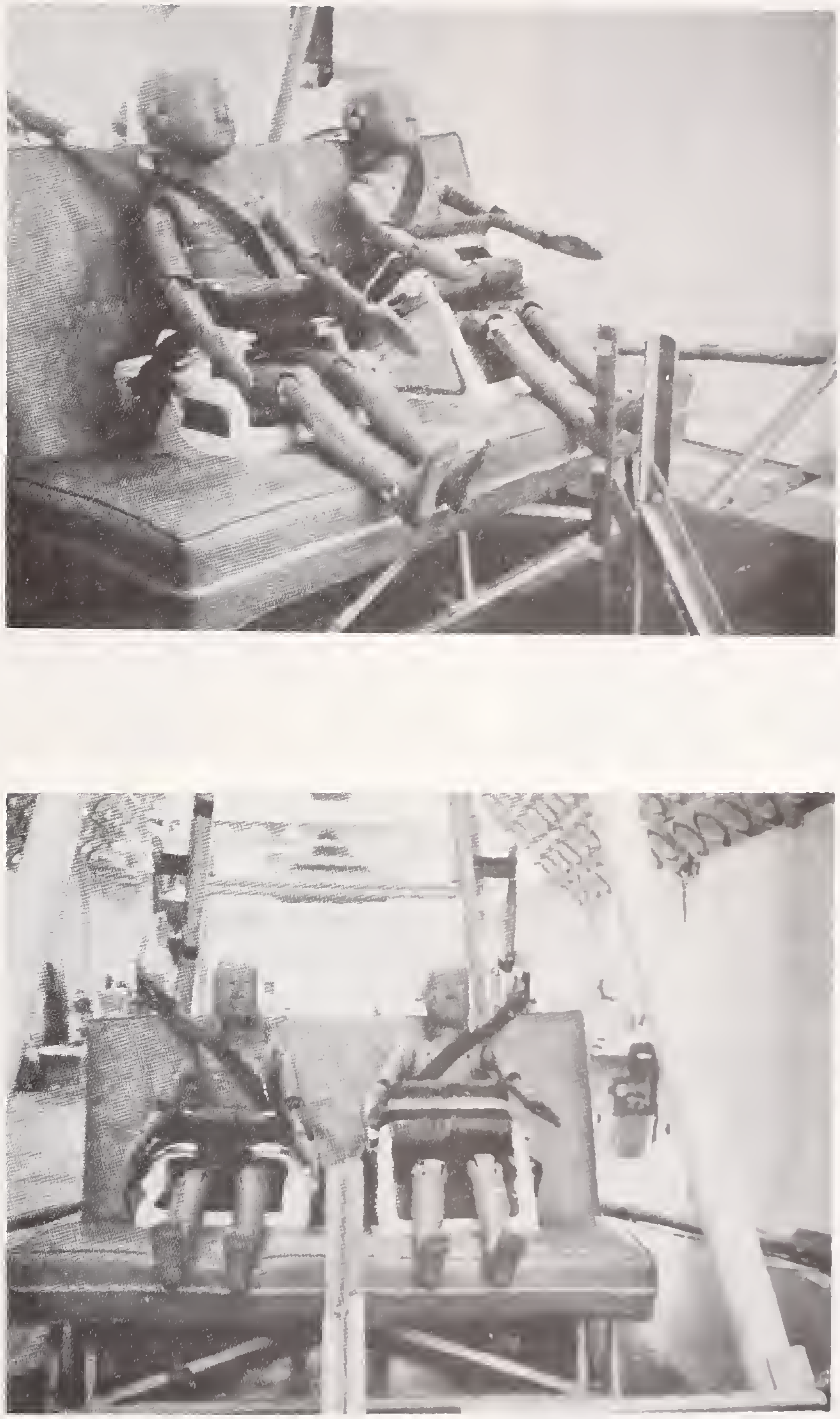
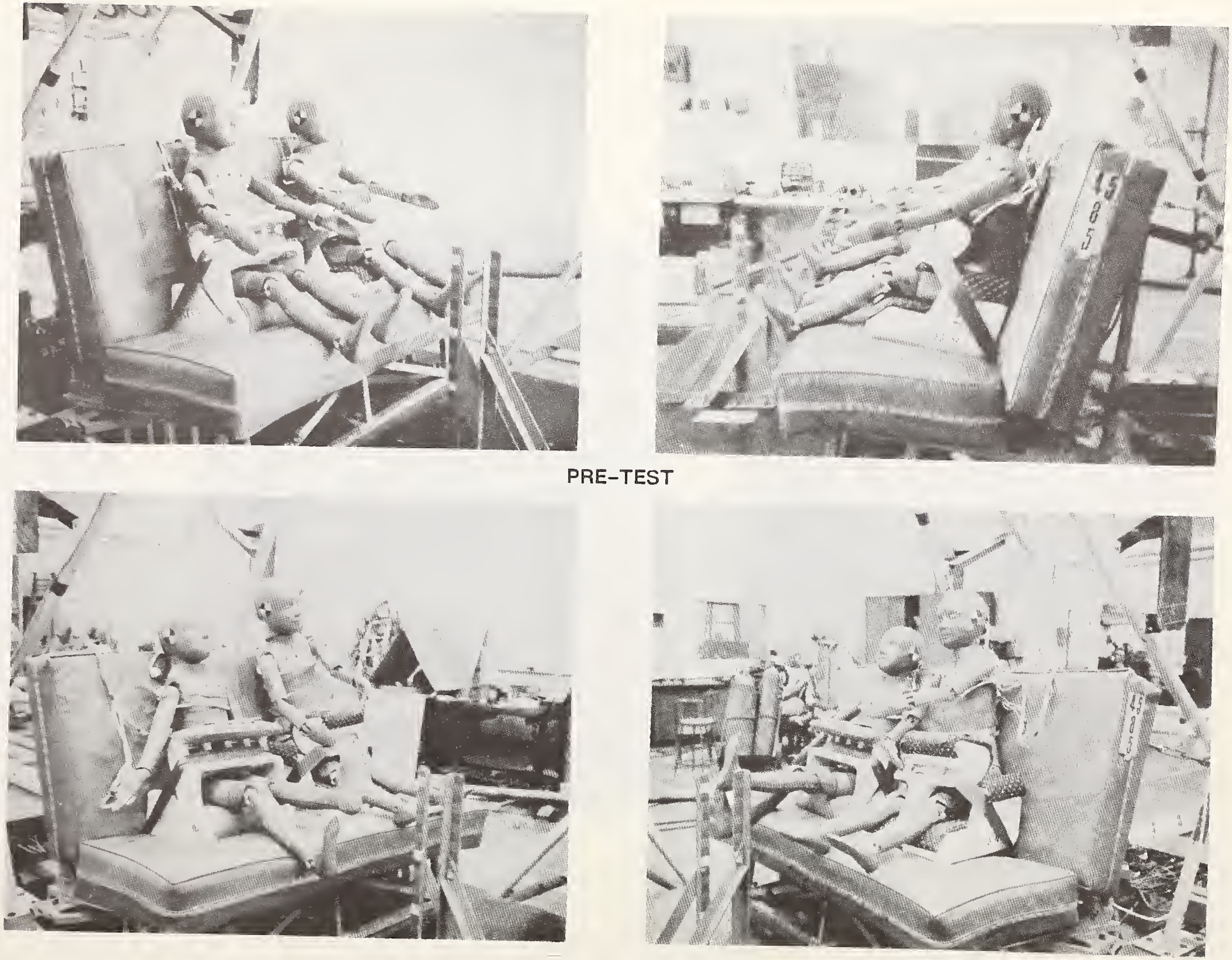


Figure 12 6-YEAR OLD DUMMIES IN STANDARD BOOSTER SEATS WITH 3-POINT AUTO BELT INSTALLATION



PRE-TEST

POST-TEST

Figure 13 6-YEAR OLD DUMMIES IN BOOSTER SEATS SHOWING PRE AND POST-TEST CONDITIONS post-test positions. The child restraint on the left side of the bench seat was a Kolcraft Quick-Step and on the right side, a Kolcraft Flip'n Go II. Lap belt tensions were set to approximately 12 lbs. in all of the runs. Two Lebow load cells monitored the forces in each of the lap belt straps. To record impact contact areas between the dummies and the shields, Acutred contact paper was lightly taped to the shield surface facing the dummies. In addition, a tether rope was placed loosely around the torso of several of the dummies to prevent them from leaving the restraints, either during or following the impact phase.

A summary of the sled test data is presented in Table 16. The corrected peak lap belt loads were derived from the load cell readings on each of the restraint straps and corrected for belt angle with the horizontal. No belt load corrections were required in the top view because belt angles were small relative to seat fore-aft centerlines. The forces in the straps were reduced also by the inertial forces of the child restraints during sled acceleration. An example of these calculations is presented in Appendix B. The corrected lap belt loads are estimates of the forces acting on the abdominal area of the dummies. These loads are used in conjunction with the recorded contact areas, between the dummy and shields, to calculate the abdominal pressures.

The three-year old dummies were employed in the first six sled tests, Test Nos. 4573 to 4578, using those seats that were designed to carry 34 lb. occupants. The calculated abdominal pressures ranged from 22.9 psi to 49.8 psi. The abdominal pressures measured with the University of Michigan devices were much lower, recording a minimum of approximately zero to a maximum of 11.8 psi for the Kolcraft Flip'n Go seat. It appears that a number of restraints with the lower designed shields produced the larger readings with the abdominal pressure measuring devices.

In this first group of runs in Table 16, the dummies riding in the Pride-Trimble Click'n Go (Test 4573) and the Kolcraft Quick-Step (Test 4576) left their restraints during the rebound phase. Both dummies ended up at the end of the run, upside down with their heads touching the sled floor. From inspection of the high-speed camera data, the restraints were seen to pitch forward to high angles and then, on rebound, the dummies moved rearward and upward, pulling away from the seats. Near the end of the run, with the legs almost clear of the seat, they simply pitched forward and fell to the sled floor in front of the bench seat.

The nine-month old infant dummy was tested in the next six runs Test Nos. 4579 to 4584, beside a six-year old dummy. In test 4582, the infant dummy was

## Table 16
## SUMMARY OF CHILD RESTRAINT SLED TEST DATA
## TASKS III & IV

| Test No. | Child Restraint Configuration | Dummy | Head Peak Res. Accel. (g) | HIC | Chest Peak Res. Accel. (g) | Total Peak Lap Belt Load (LBS) | Corrected Lap Belt Load (LBS) | Contact Area ($IN^2$) | Abdom. Press. Calculated (PSI) | Abdom. Press. Measured (PSI) | Dummy Excurs. Hd./Knee (IN) | Sled Accel./Vel. (g/MPH) | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4573 | P-T Click'n Go | 3 yr. old 39 | 72 | 824 | 29.8 | 1480 | 1052 | 26.0 | 40.5 | 8.0 | 33.2/25.3 | 23.7/29.3 | Dummy ejected out of seat on rebound |
| | Cent. Commander, 4810 | 3 yr. old 38 | 63 | 666 | 29.4 | 1150 | 839 | 28.7 | 29.2 | 0.0 | 31.0/24.6 | ↓ | |
| 4574 | Evenflo Wings | 3 yr. old 39 | 52 | 516 | 29.4 | 1600 | 975 | 29.4 | 33.2 | 7.9 | 28.7/28.1 | 23.5/29.2 | |
| | Cosco Explorer 1[1] | 3 yr. old 38 | 55 | 796 | 30.3 | 1090 | 822 | 27.4 | 30.0 | 1.7 | Lost Data | ↓ | |
| 4575 | Kolcraft Flip'n Go | 3 yr. old 39 | 60 | 596 | 31.0 | 1590 | 1181 | 23.7 | 49.8 | 11.8 | 29.6/24.9 | 23.7/29.4 | |
| | Evenflo 7-yr. | 3 yr. old 38 | 59 | 459 | 37.7 | 1890 | 876 | 38.2[6] | 22.9 | 0 | 30.0/33.0 | ↓ | |
| 4576 | Kolcraft Quick-Step | 3 yr. old 39 | 45 | 318 | 26.3 | 1520 | 1184 | 31.0 | 38.2 | 0 | 33.1/26.0 | 23.6/29.4 | Dummy ejected out of seat on rebound |
| | Kolcraft Flip'n Go II | 3 yr. old 38 | 64 | 621 | 32.7 | 1370 | 1018 | 25.3 | 40.2 | 5.8 | 29.7/24.1 | ↓ | |
| 4577 | Strolee 605 | 3 yr. old 39 | 50 | 469 | 24.6 | 1500 | 1129 | 28.8 | 39.2 | 7.1 | 32.4/26.5 | 23.5/29.3 | |
| | Gerry Voyager | 3 yr. old 38 | 70 | 774 | 35.0 | 1830 | 1345 | 32.2 | 41.8 | 4.5 | 31.8/30.4 | ↓ | . |
| 4578 | Gerry Voyager | 3 yr. old 39 | 60 | 530 | 32.1[2] | 2020 | 1434 | 30.0 | 47.8 | 5.6 | 32.6/30.6 | 23.4/29.2 | No pad on shield |
| | Cosco Explore 1 | 3 yr. old 38 | 61 | 785 | 30.8 | 1150 | 917 | 28.5 | 32.2 | 6.0 | 29.2/26.8 | ↓ | Rerun of 4574 S |
| 4579 | P-T Click'n Go | 6 yr. old 133 | 62 | 846 | 29.0 | 1850 | 1330 | 30.8 | 43.2 | 7.5 | 35.3/27.5 | 23.1/29.0 | |
| | Cent. Commander, 4810 | 9 mo. old | 45 | 276 | 35.0 | 750 | 489 | 26.1 | 18.7 | -- | 23.0/18.0 | ↓ | |
| 4580 | Cosco Explorer 1 | 6 yr. old 133 | 55 | 501 | 30.3 | 1650 | 1210 | 32.6 | 37.1 | 5.5 | 32.3/28.5 | 23.3/29.0 | |
| | P-T Click'n Go | 9 mo. old | 52 | 456 | 40.4 | 1150 | 771 | 23.5 | 32.8 | -- | 25.8/19.5 | ↓ | |
| 4581 | Evenflo Wings | 6 yr. old 133 | 45 | 291 | 29.8 | 1800 | 1280 | 32.2 | 39.8 | 4.7 | 30.5/29.6 | 23.3/29.1 | |
| | Evenflo 7-yr. | 9 mo. old | 82 | 583 | 35.0 | 1370 | 812 | 29.6[6] | 27.4 | -- | 25.5/26.6 | ↓ | |

## Table 16 (cont.)

## SUMMARY OF CHILD RESTRAINT SLED TEST DATA

## TASKS III & IV

| Test No. | Child Restraint Configuration | Dummy | Head Peak Res. Accel. (g) | HIC | Chest Peak Res. Accel. (g) | Total Peak Lap Belt Load (LBS) | Corrected Lap Belt Load (LBS) | Contact Area ($IN^2$) | Abdom. Press. Calculated (PSI) | Abdom. Press. Measured (PSI) | Dummy Excurs. Hd./Knee (IN) | Sled Accel./Vel. (g/MPH) | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4582 | Cent. Commander, 4810 | 6 yr. old 133 | 53 | 428 | 27.1 | 1600 | 1164 | 31.3 | 37.2 | 6.0 | 32.8/27.5 | 23.0/28.9 | |
| | Kolcraft Flip'n Go | 9 mo. old | 49 | 400 | 31.9 | 920 | 638 | 21.8 | 29.3 | -- | 22.7/18.0 | ↓ | TNO dummy ejected out of seat on rebound |
| 4583 | Evenflo 7-yr. | 6 yr. old 133 | 29[3] | -- | 32.1 | 2250 | 1612 | 51.4[6] | 31.4 | 0 | 32.0/36.0 | 23.2/29.1 | |
| | Kolcraft Flip'n Go II | 9 mo. old | 52 | 494 | 41.1 | 750 | 509 | 22.5 | 22.6 | -- | 23.7/18.8 | ↓ | TNO dummy ejected on rebound |
| 4584 | Kolcraft Flip'n Go | 6 yr. old 133 | 44 | 213 | 34.6 | 1670 | 1227 | 26.1 | 47.0 | 6.7 | 34.3/27.5 | 23.3/29.1 | Shield cracked under belt |
| | Kolcraft Quick-Step | 9 mo. old | 45 | 362 | 31.6 | 1080 | 739 | 25.9 | 28.5 | -- | 22.7/18.4 | ↓ | TNO dummy ejected on rebound |
| 4585 | Kolcraft Quick-Step | 6 yr. old 133 | 38 | 263 | 21.5 | 2040 | 1547 | 34.6 | 44.7 | 10.8 | 34.5/29.2 | 23.5/29.0[7] | |
| | Kolcraft Flip'n Go II | 6 yr. old 121 | 46 | 241 | 22.5 | 1450 | 1060 | 27.1 | 39.1 | 14.4 | 35.4/26.4 | ↓ | |
| 4586 | Strolee 605 | 6 yr. old 133 | 51 | 516 | 24.6 | 1570 | 1128 | 33.4 | 33.8 | 14.0 | 35.2/28.6 | 23.2/29.0 | |
| | Gerry Voyager | 6 yr. old 121 | 56 | 417 | 33.9 | 1900[4] | 1401 | 34.9 | 40.1 | 8.8 | 34.3/32.0 | ↓ | |
| 4587 | Evenflo Wings + 3-pt. Belt | 6 yr. old 133 | 71 | 903 | 51.2 | 1390/ 740[5] | 403 | 24.3 | 16.6 | 0 | 20.1/32.2 | 23.0/28.8 | |
| | P-T Click'n Go + 3-pt. Belt | 6 yr. old 121 | 69 | 907 | 52.6 | 1790/ 1000[5] | 550 | 27.6 | 19.9 | 4.0 | 20.7/27.3 | ↓ | |
| 4588 | Strolee 605 + 3-pt. Belt | 6 yr. old 133 | 88 | 1238 | 51.8 | 1710/ 1025[5] | 552 | 27.0 | 20.4 | 0 | 19.4/30.5 | 23.1/28.7 | |
| | Evenflo 7-yr. + 3-pt. Belt | 6 yr. old 121 | 67 | 905 | 48.7 | 2130/ 1060[5] | 593 | 27.3 | 21.7 | 0.4 | 20.8/28.2 | ↓ | |

Notes:
1 South Side H-S camera did not run
2 Chest Y-component accel. was lost
3 Head Z-component accel. was lost
4 Right side seat belt load was lost, assumed right side was equal to left side.
5 Torso strap peak load
6 Contact area inlcudes torso strap areas
7 Sled accel. not correct in data reduction, values obtained from console instruments

ejected backwards out of its Kolcraft Flip'n Go seat on rebound, and ended up on the facility floor. For the following runs a rope tether was attached to one of its legs which prevented the same type of ejection from occurring in Tests 4583 and 4584. The calculated abdominal pressures for the infant dummy indicated a minimum of 18.7 psi and a maximum of 32.8 psi.

The six-year old dummies were tested in the same six runs as the infant dummy and also in two additional tests using a side-by-side configuration. The abdominal pressures measured internally in the six-year old dummies were never very high; Test No. 4585, showed a maximum of 14.4 psi in a Kolcraft Flip'n Go II restraint. The maximum calculated abdominal pressure employing the belt load/contact area method was 47.0 psi with the Kolcraft Flip'n Go restraint. The minimum pressure was 31.4 psi recorded with the Evenflo 7-Year restraint in Test No. 4583.

In Test No. 4584 with the six-year old dummy, the shield of the Kolcraft Flip'n Go booster seat sustained two long cracks in the area of lap belt contact. The damaged shield did not seem to have a detrimental effect on the results of this test.

During all of the tests with the larger (six-year old) dummy, loose rope tethers were placed around the torsos to prevent ejection. In Test No. 4581 with an Evenflo Wings restraint, the dummy ended up approximately half way out of the seat, even with the rope safety line.

In the final two tests, Test Nos. 4587 and 4588, the six-year old dummies were restrained by standard booster seats plus 3-point automobile harnesses. The operating instructions for these seats state that the restraints could be used in vehicle front seat positions with the heavier children if the 3-point harnesses were also employed. In setting the upper torso straps around the dummies, approximately two inches of slack was set into the straps at the mid-chest position. One Lebow load cell was placed on the upper strap near the top anchor point and two load cells were on the lap straps, one on each side of the seat, near the lower anchor points. In Table 16 both the torso strap peak loads and the lap belt loads are presented. The upper strap loads were resolved into components at the buckle and the lap belt forces corrected for angles and seat inertial forces. The corrected lap belt loads are presented in the table and these forces were used to calculate abdominal pressures. The range of the calculated pressures was from 16.6 psi to 21.7 psi for the four dummy runs. In comparison, the pressures measured with the abdominal devices were very low, from 0 to approximately 4.0 psi. The reduced abdominal contact pressures, during these runs, verifies the fact that upper torso straps will generally reduce the impact loads and pressures on occupant abdomens.

The dummy head and knee forward excursion data were determined by analyzing the high-speed movie films. The data in Table 16 indicate a number of cases where the heads moved beyond the maximum limit of 32.0 inches (FMVSS No. 213 limit). For the three-year old dummies, the lighter initial tension set into the restraint lap straps of about 12 lbs. may have allowed the heads to slip over the limit. A tension of 12 to 15 lbs. is allowed to be preset in the seat restraint belts. In the case of the six-year old dummies, eight heads showed excursions over the 32.0 inch limit, but this is explainable in the sense that the larger dummy sits up higher in the seat with a higher torso/head C.G. position. In addition, there is more upper-body mass to propel the head out further during sled acceleration. Some of the lower shield seats had head excursions well past the limit, such as, the Pride-Trimble Click'n Go (35.3 inches) and the Kolcraft Flip'n Go (34.3 inches). If judged under the FMVSS No. 213 regulations, these restraints would have failed the head excursion criterion.

In one other test (Test No. 4588) involving a Strolee Booster Seat with a six-year old dummy restrained with a shoulder strap of a 3-point belt, the restraint would have failed the FMVSS No. 213 requirement of HIC Number 1000. The head resultant acceleration data showed a very large spike at a time of approximately .068 seconds which produced a 1238 HIC value. In these particular runs, with an upper torso restraint, the head is often-times decelerated very rapidly when the torso is suddenly restrained by the upper strap. This snapping action of the head caused the large spike in the head acceleration data even though there was no direct head contact.

An inspection of the child restraint data in Table 16, to determine which seats indicated the lowest abdominal pressures, produced the seat rankings shown in Table 17. The rankings were separated according to dummy size and were based solely on calculated abdominal pressures. Only the first six seats are listed to indicate which restraints were performing the best. The Century Commander had the lowest abdominal pressure (18.7 psi) when tested with the nine-month old infant. It was ranked second with the three-year old child and fourth with the six-year old dummy. Another "good"

## Table 17

## SEAT RANKING ACCORDING TO ABDOMINAL PRESSURE [(1)]

| Seat Ranking (No. 1 = Best) | Test Dummies | | |
|---|---|---|---|
| | 9-Mo. Old Infant | 3-Yr. Old Child | 6-Yr. Old Child |
| 1 | Century Commander 18.7 PSI | Evenflo 7-Year 22.9 PSI | Evenflo 7-Year 31.4 PSI |
| 2 | Kolcraft Flip'n Go II 22.6 PSI | Century Commander 29.2 PSI | Strolee 605 33.8 PSI |
| 3 | Evenflo 7-Year 27.4 PSI | Cosco Explorer 1 30.0, 32.2 PSI | Cosco Explorer 1 37.1 PSI |
| 4 | Kolcraft Quick-Step 28.5 PSI | Evenflo Wings 33.2 PSI | Century Commander 37.2 PSI |
| 5 | Kolcraft Flip'n Go 29.3 PSI | Kolcraft Quick-Step 38.2 PSI | Kolcraft Flip'n Go II 39.1 PSI |
| 6 | P-T. Click'n Go 32.8 PSI | Strolee 605 39.2 PSI | Evenflo Wings 39.8 PSI |

Note: (1) Calculated abdominal impact pressures are given below each restraint.

seat was the Evenflo 7-Year which was first in ranking with both the three-year and six-year old dummies and third with the infant dummy. Several other restraints appear in at least two columns, indicating that they also performed well in limiting abdominal pressure for several size dummies.

## 6.0 CONCLUSIONS

(1) All child booster seats found on the market during summer 1987 were tested in 30 mph sled tests with dummy occupants that represented nine-month old infants, three-year old, and six-year old children. A total of 11 booster seats were tested with appropriate dummy occupants in accordance with the manufacturers' recommended use. Thus, six seats recommended for use by children weighing 25 pounds or less were tested with a nine-month old infant dummy while 11 seats recommended for use by children weighing from 25 to 55 pounds, or over, were tested with three-year old and six-year old child dummies. In addition, four of these models recommended for use by larger children, were tested with a six-year old child dummy plus a 3-point automobile belt.

In the performance of these tests, the procedures and criteria prescribed by the FMVSS No. 213 were employed wherever possible. The only significant changes were that the test dummies (three-year old and six-year old children) were modified dummies and not standard units, that the tests were performed in a side-by-side seating configuration, and the foam cushions in the Standard Bench Seat were not replaced after each test.

(2) The measured performance of ten tested seat models is summarized in Table 16 and 17, while the performance of another model, the Tot-Guard, is found in Table 13. These tables indicate that for 11 models tested with a three-year old dummy, the head excursion limit of 32 inches specified by FMVSS No. 213, was exceeded by four models. In tests with a six-year old dummy, one model had a head excursion of 30.5 inches while for the remaining ten models, this measurement was in a range from 32.0 to 35.4 inches. Also, out of four models tested with a 3-point belt and a six-year old dummy, three models showed fairly high HIC numbers of approximately 900 and one registered 1238. Another performance of concern was dummy ejections from the restraints during the rebound phase, occurring for three out of six seats tested with a

nine-month old infant, for two models with the three-year old dummy and for one model with a six-year old dummy.

(3) Two basic methods for measurement of the test dummy's abdominal loads during impacts were evaluated, one by a University of Michigan special measuring device installed in the dummy's abdomen and the other by measuring the Standard Seat belt loads or the occupants lap belt loads together with the contact area between the dummy and its restraint. In the first method abdominal pressures were obtained by direct measurement while in the second method, average abdominal pressures were calculated from restraint belt forces and contact areas. Four typical restraint systems were used which consisted of the Standard Seat lap belt and the child restraints including a 5-point harness, a shield restraint, and a shield/shoulder harness combination. The obtained results indicate the following:

(a) The University of Michigan pressure device in the abdominal area is location sensitive, i.e., it only measures loads applied directly to it. Thus, its use appears to be limited to systems applying loads to the dummy's mid-abdomen section such as vehicle belts or low, narrow shield restraints.

(b) The belt load/contact area pressure measuring method is dependent on the time-history of the belt loading curve which is a function of the force-deflection characteristics of both the lap belt and the abdomen of the dummy. The amount of contact area between the dummy and the restraint is also a function of the compliance between these two systems (since they are in direct contact) whether the restraint is a lap belt or a shield. Thus, to obtain accurate abdominal pressure measurements, the dummy's abdomen has to have reasonably good biomechanical representation of a childs abdomen.

(4) The abdominal pressures measured with the University of Michigan special device in the three-year old and six-year old dummies seemed

to be erratic during the tests. This may have been due to the vertical location or to the various sizes and shapes of the impacting shields. For example, the peak pressure measured with a three-year old dummy test of a Kolcraft Flip'n Go was 11.8 psi and in the following test of a Kolcraft Quick-Step the pressure was approximately zero. The maximum abdominal pressure recorded with the pressure device in the booster seat series of tests was 14.4 psi compared to a calculated pressure, during the same test, of 39.1 psi.

On the basis of these initial tests, this type of fluid device has promise in that it can sense impact pressures. However, it was an "add-on" device to the standard dummies so it did not perform as well as it could have. For example, the system could have contained several bleed valves so that any trapped air could be periodically and quickly purged from the lines. If a pressure sensing device such as this is adopted for future use, it should be designed and manufactured into the standard dummies so that it is more flexible and useable. Another possibility is to design a pneumatic abdominal pressure system for the child dummies such as that currently being tested in the Hybrid III 50th percentile dummies. This type of system appears to function well and it eliminates the disadvantages of a fluid-filled system.

(5) Contact areas between the test dummies and various types of restraints, including, lap belts only, 5-point harnesses, flexible shields, and stiff booster shields, were measured. Ten different methods were tried in an attempt to obtain sharp, well-defined contact areas. The most accurate and usable material was a contact/carbon paper called Acutred. The Acutred paper worked well on highly loaded restraints such as lap belts, but it produced much lighter prints with systems like the 5-point harnesses.

(6) The loads imposed on the dummy's abdomen during the impact tests were estimated by measuring the seat belt loads or the occupant strap loads with Lebow webbing load cells. The occupant strap

loads were somewhat difficult to measure in the restraint itself because of the tight space restrictions between the dummy and the sides of the child seats. However, those strap loads that were obtained, were corrected for belt angles and child seat inertial forces to obtain the horizontal force components acting on the dummy. These horizontal force components were summed to obtain the total loads used in the calculations of abdominal pressures.

(7) Dummy abdominal pressures were calculated from the measurement of impact areas and restraint belt forces. These results were average pressures distributed across the total contact areas. The abdominal pressures in tests of the booster seats ranged from 18.7 psi to 32.8 psi for the nine-month old infant dummy, from 22.9 psi to 49.8 psi for the three-year old child dummies, and from 31.4 psi to 47.0 psi for the six-year old dummies. Shield impacts occurred mostly to the dummy abdominal areas. Several of the larger shields contacted the three-year old dummies in a range of areas from the lower abdomen to the lower ribs. In tests of the six-year old dummies, shield impacts were slightly lower on the abdomen, but still in the area of the abdomen to the ribs.

(8) The child booster/shield restraints exhibited a wide range of impact pressure levels on the abdomens of the test dummies. Based on calculated data, the restraints indicating the lowest abdominal pressures were the Century Commander in tests of the infant dummies (18.7 psi), and the Evenflo 7-Year seat for both the three-year old (22.9 psi) and the six-year old (31.4 psi) child dummies. A Kolcraft Flip'n Go booster seat showed the highest calculated abdominal pressure of 49.8 psi when tested with a three-year old child dummy.

## 7.0 REFERENCES


1. Naab, Kenneth N., "Performance Evaluation of Child Restraint Systems," Calspan Report No. 7063-V-1, July 1982, Final Report.

2. Naab, Kenneth N., "Establishment of the Repeatability of Performance of the Six-Year Old Child Test Dummies," Calspan Report No. 7215-1, September 1984, Final Report.

3. "Anthropomorphic Test Dummies," National Highway Traffic Safety Administration, Department of Transportation, Docket 78-09, Notice 8, 49 CFR Part 572, Subpart C - Three-Year Old Child, December 15, 1980.

4. The T.N.O. Child Dummies P3/4, P3, P6 and P10, Institut voor Wegtransport middelen, January 1979.

5. Weber, Kathleen, "Abdominal Intrusion Sensor For Child Dummies, Users Manual," University of Michigan Transportation Research Institute, Contract No. DTNH22-86-P-02046, December 1986.

## APPENDIX A

## SLED TEST TIME-HISTORIES OF LAP BELTED DUMMIES

| | |
|---|---|
| Test 4522: | 9-Month Old Infant Dummy |
| Test 4511: | 3-Year Old Child Dummy |
| Test 4522: | 6-Year Old Child Dummy |

HEAD INJURY CRITERION
HEAD SEVERITY INDEX

CHILD ABDOMINAL TEST

RUN=4522

SOUTH HEAD R

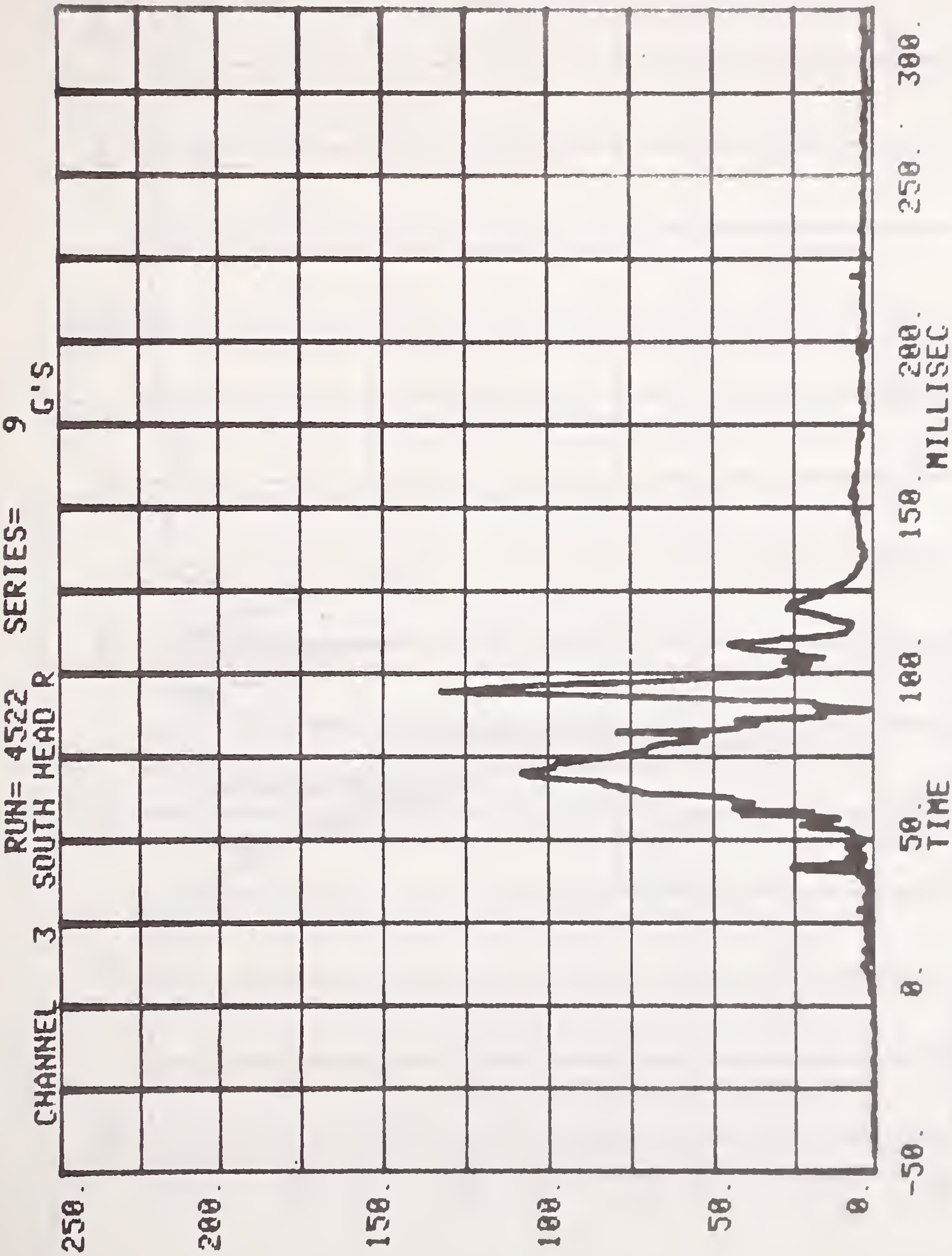
HIC=1369.4 FROM T1= .05940 TO T2= .09930

AVERAGE ACCELERATION BETWEEN T1 AND T2= 65.2G'S

EVENT TIME= 300.0 MSEC

SEVERITY INDEX=2019.0

| CHANNEL | TITLE | 3 MS. CLIPPED PEAK |
|---|---|---|
| 4 | SOUTH CHEST R | 79.912 G'S |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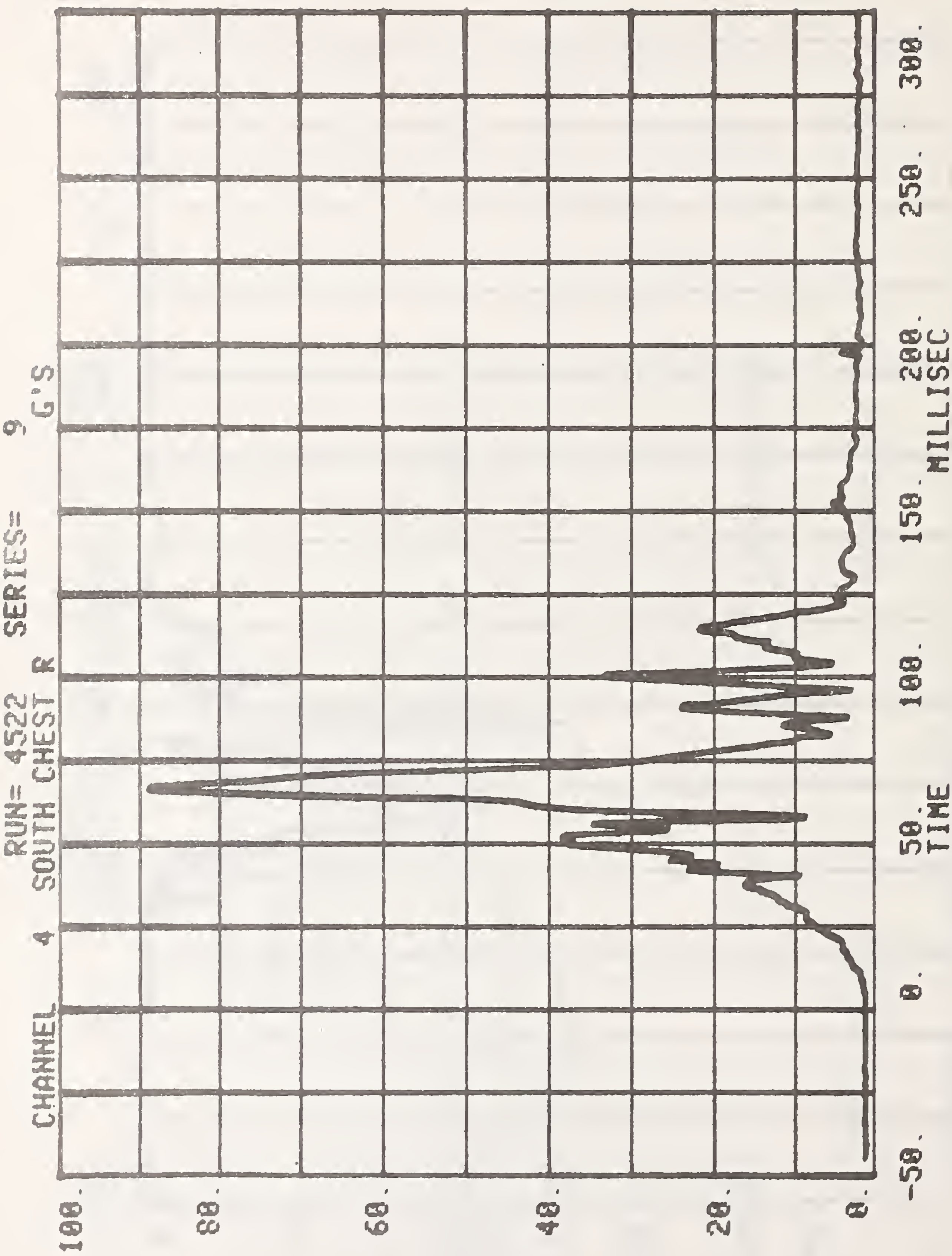
SOUTH HEAD R G'S
250. 200. 150. 100. 50. 0.
-50. 0. 50. 100. 150. 200. 250. 300.
TIME MILLISEC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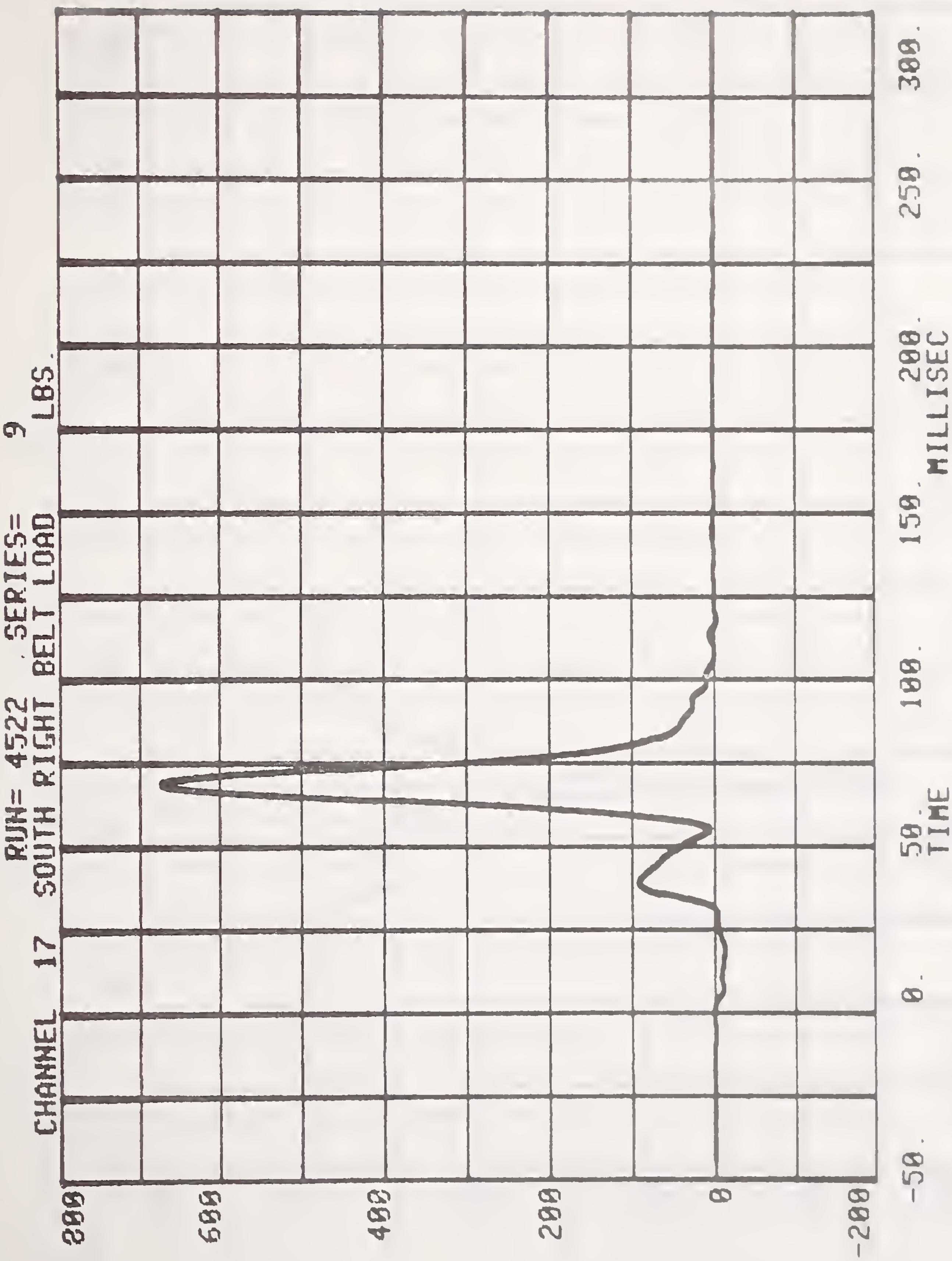
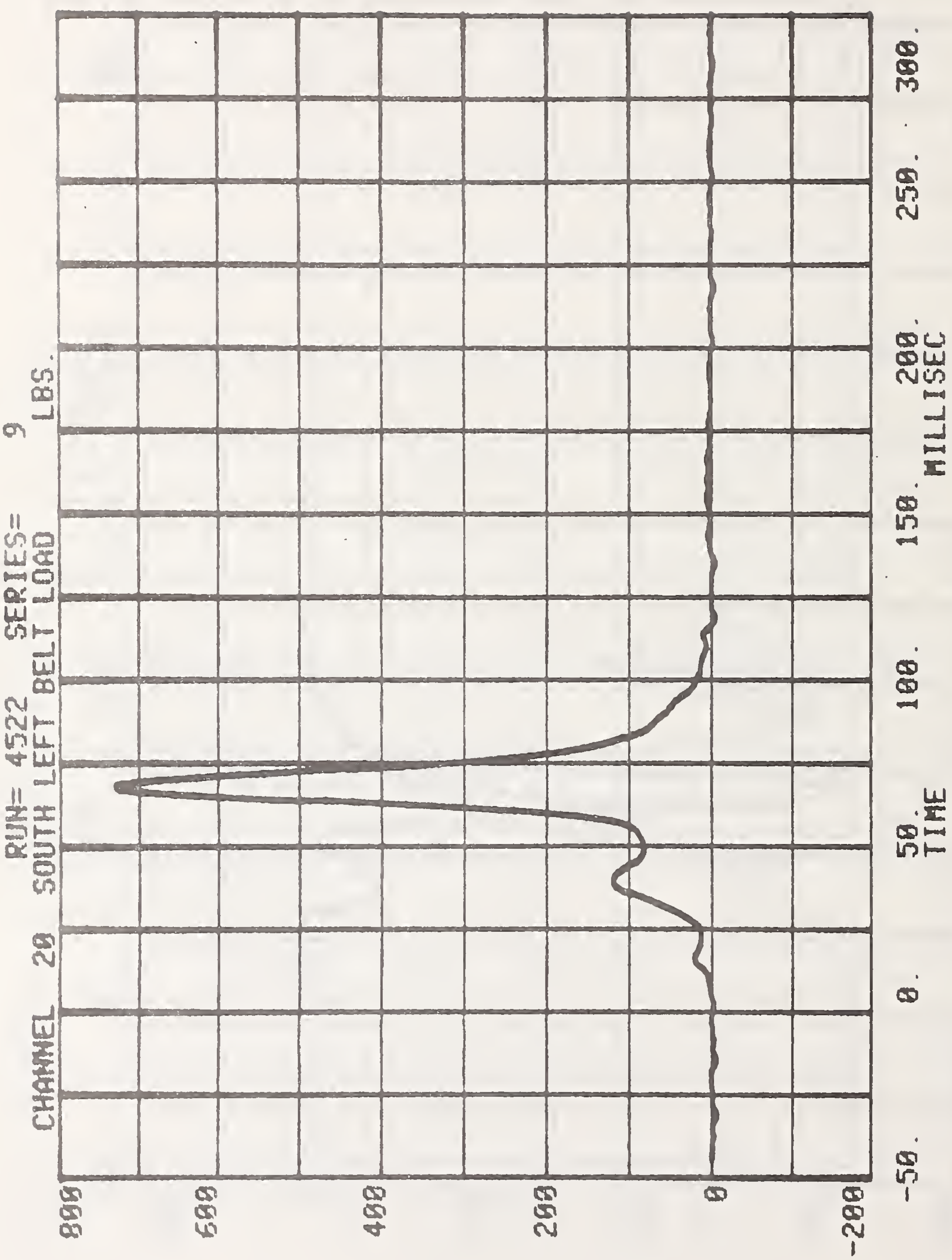
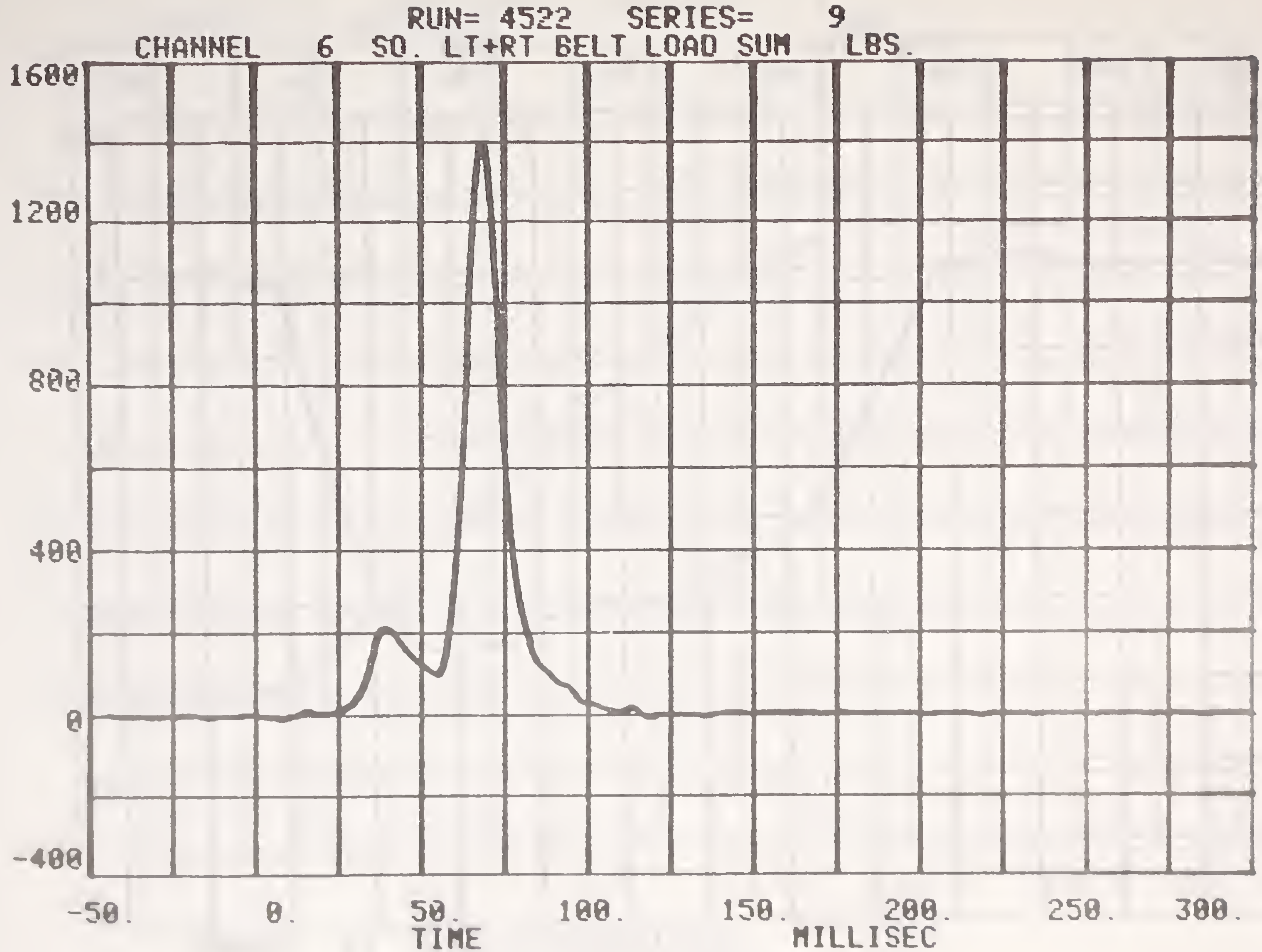
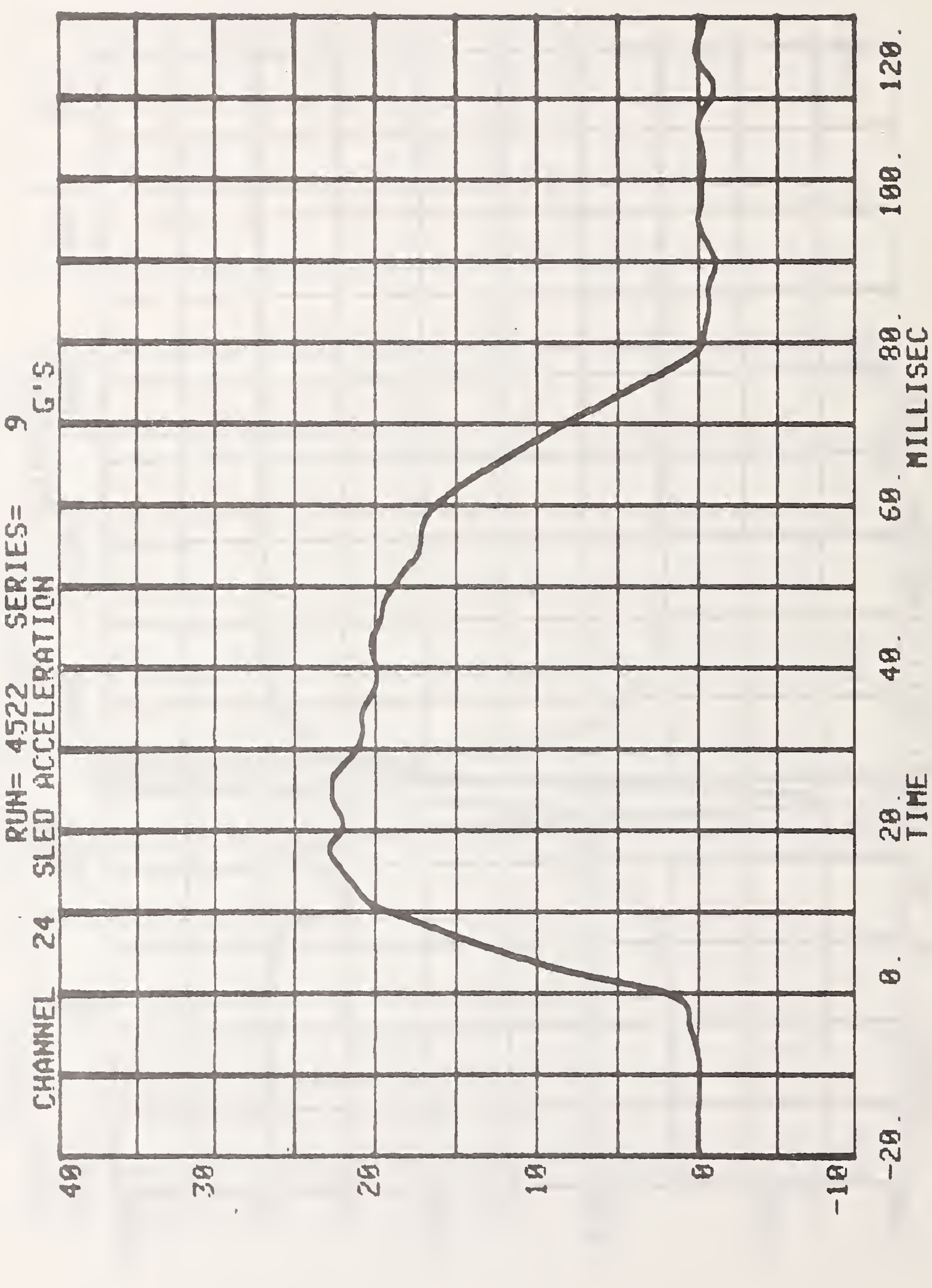
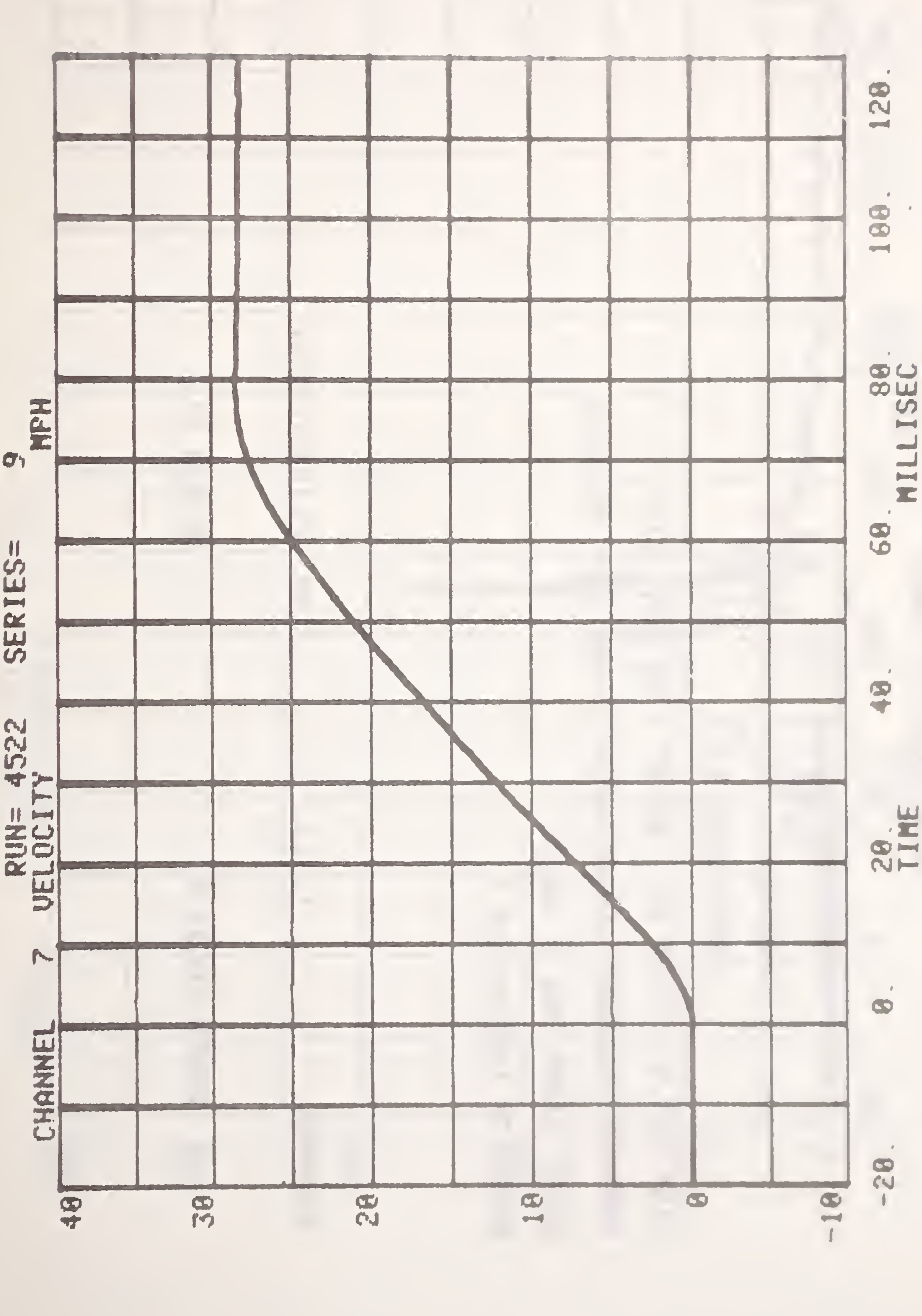
SOUTH CHEST R
G'S
100.
80.
60.
40.
20.
0.
-50.
0.
50.
100.
150.
200.
250.
300.
TIME
MILLISEC


CHANNEL 17 RUN= 4522 SERIES= 9
SOUTH RIGHT BELT LOAD LBS.
800
600
400
200
0
-200
-50.
0.
50.
100.
150.
200.
250.
300.
TIME MILLISEC


CHANNEL 20 RUN= 4522 SERIES= 9
SOUTH LEFT BELT LOAD LBS.
800
600
400
200
0
-200
-50.
0.
50.
100.
150.
200.
250.
300.
TIME MILLISEC


RUN= 4522 SERIES= 9
CHANNEL 6 SO. LT+RT BELT LOAD SUM LBS.
1600
1200
800
400
0
-400
-50.
0.
50.
100.
150.
200.
250.
300.
TIME
MILLISEC


CHANNEL 24 RUN= 4522 SERIES= 9
SLED ACCELERATION G'S
40
30
20
10
0
-10
-20.
0.
20.
40.
60.
80.
100.
120.
TIME MILLISEC



CHANNEL 7 RUN= 4522 SERIES= 9
VELOCITY MPH
40
30
20
10
0
-10
-20.
0.
20.
40.
60.
80.
100.
120.
TIME MILLISEC

HEAD INJURY CRITERION
HEAD SEVERITY INDEX

CHILD ABDOMINAL TEST

RUN=4511

SOUTH HEAD R

HIC= 824.0   FROM T1= .08197   TO T2= .11797

AVERAGE ACCELERATION BETWEEN T1 AND T2=  55.4G'S

EVENT TIME= 300.0  MSEC

SEVERITY INDEX=1479.6

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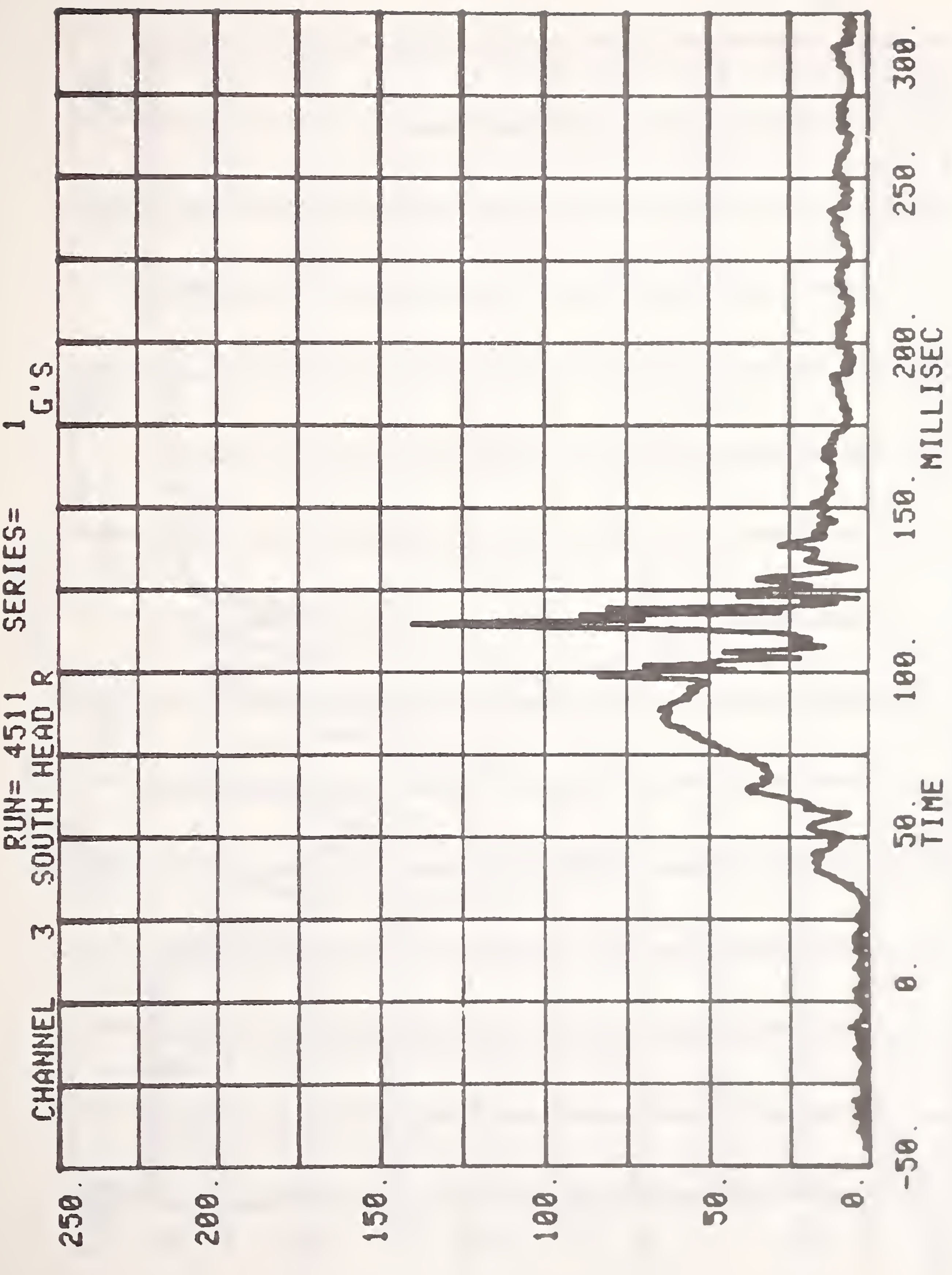
| --- | --- | --- |
| 4 | SOUTH CHEST R | 30.038 G'S |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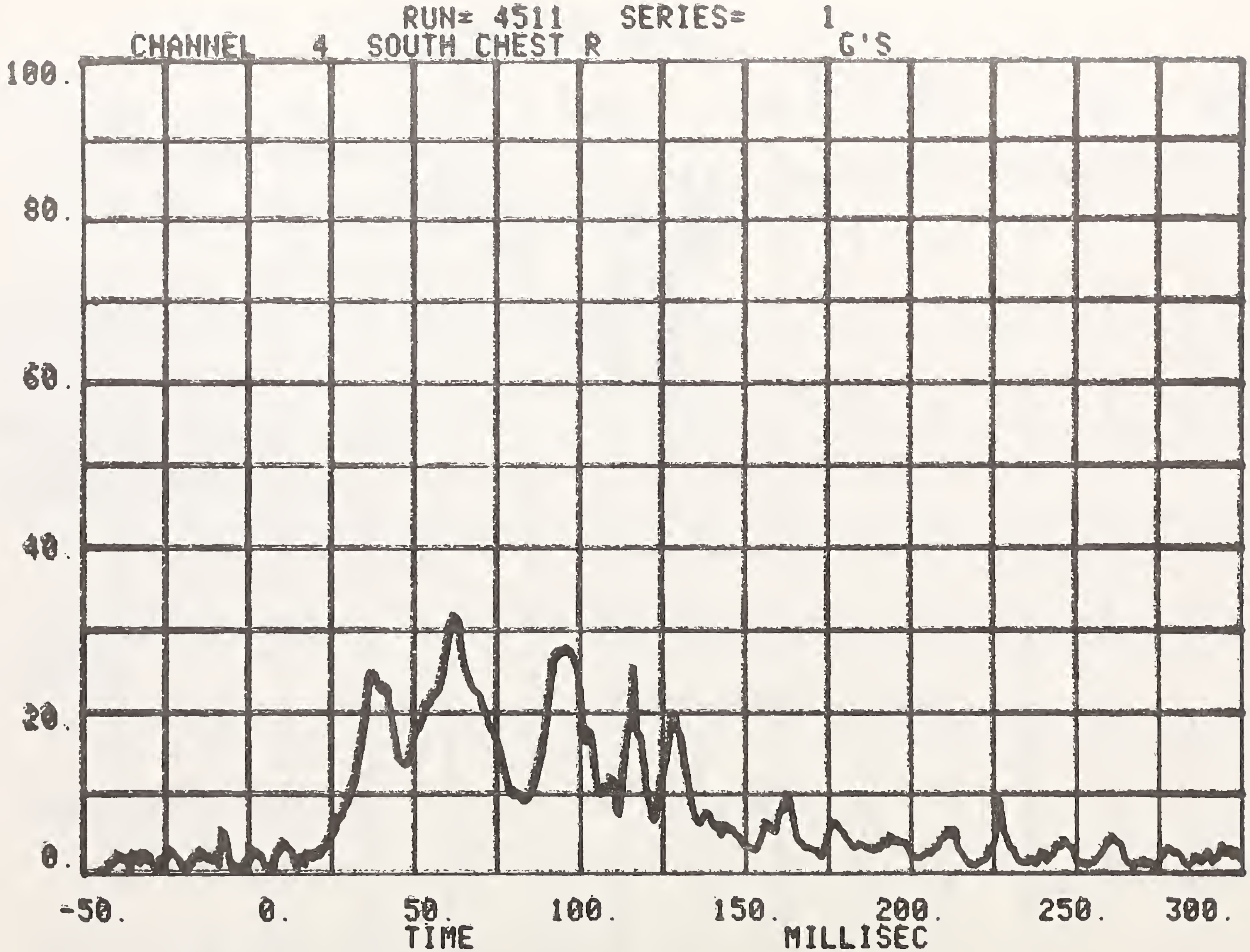
SOUTH HEAD R
G'S
250.
200.
150.
100.
50.
0.
-50.
0.
50.
100.
150.
200.
250.
300.
TIME
MILLISEC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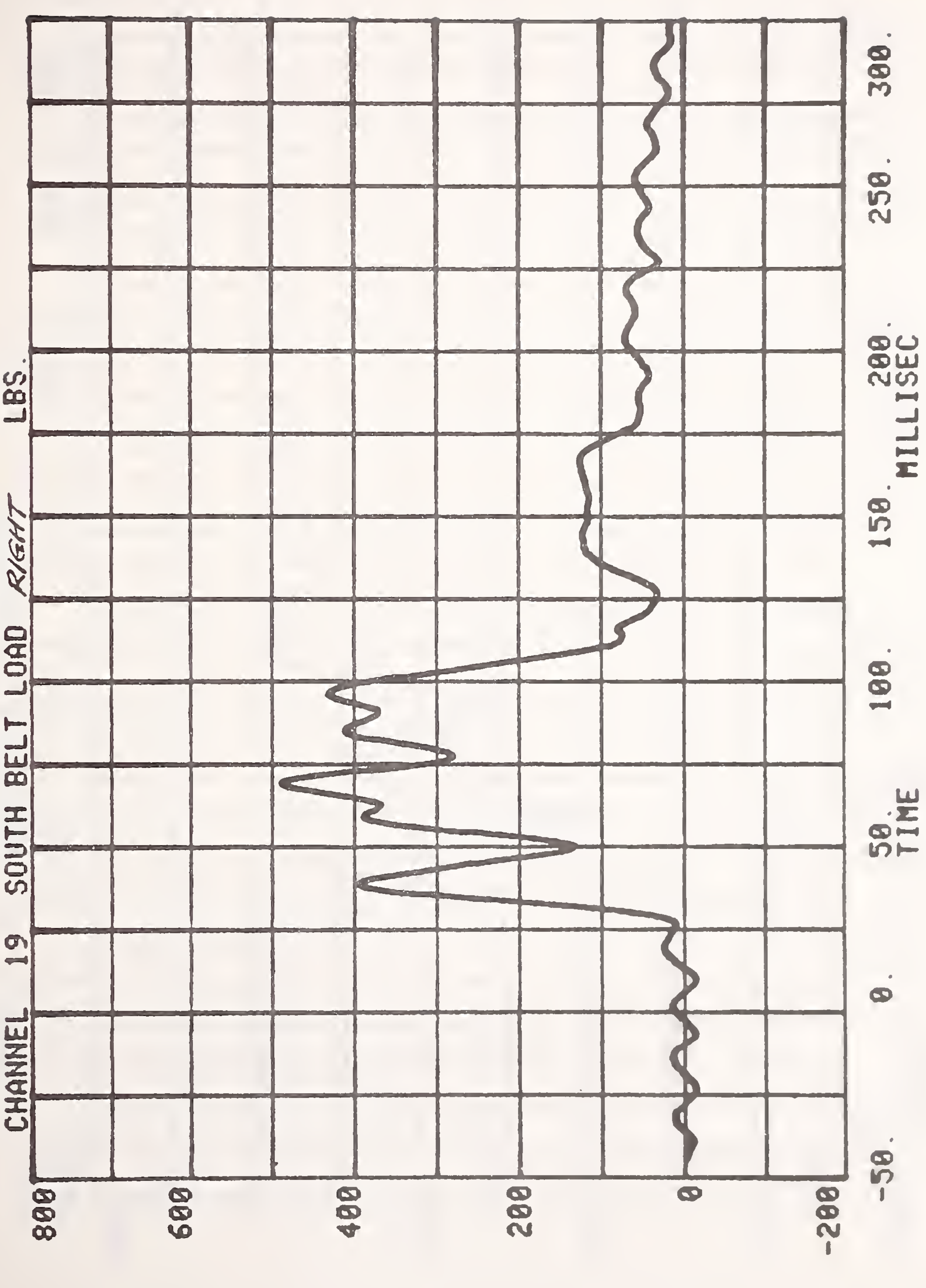
CHANNEL 4 SOUTH CHEST R G'S
100.
80.
60.
40.
20.
0.
-50.
0.
50.
100.
150.
200.
250.
300.
TIME
MILLISEC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SOUTH BELT LOAD RIGHT LBS.
800
600
400
200
0
-200
-50.
0.
50.
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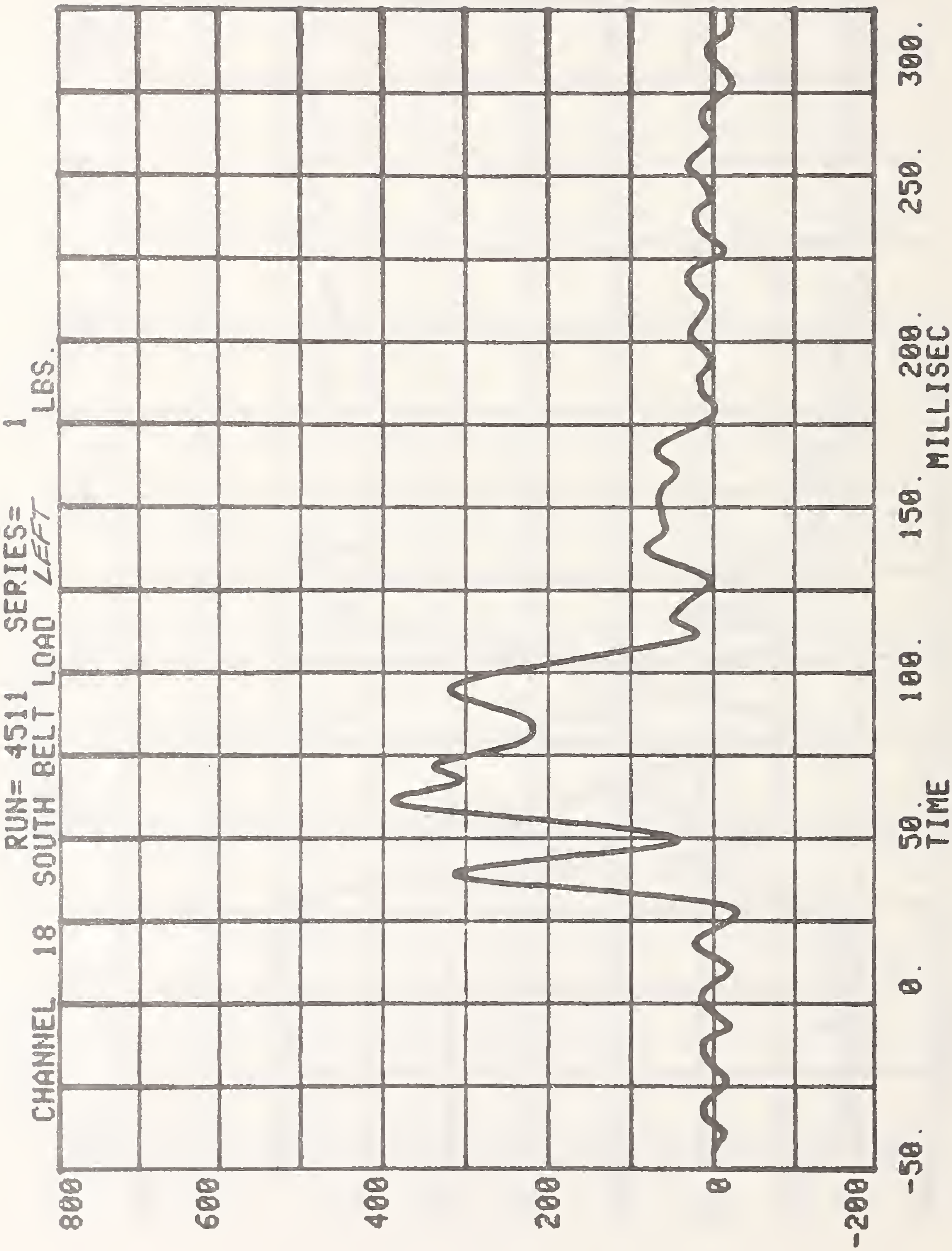
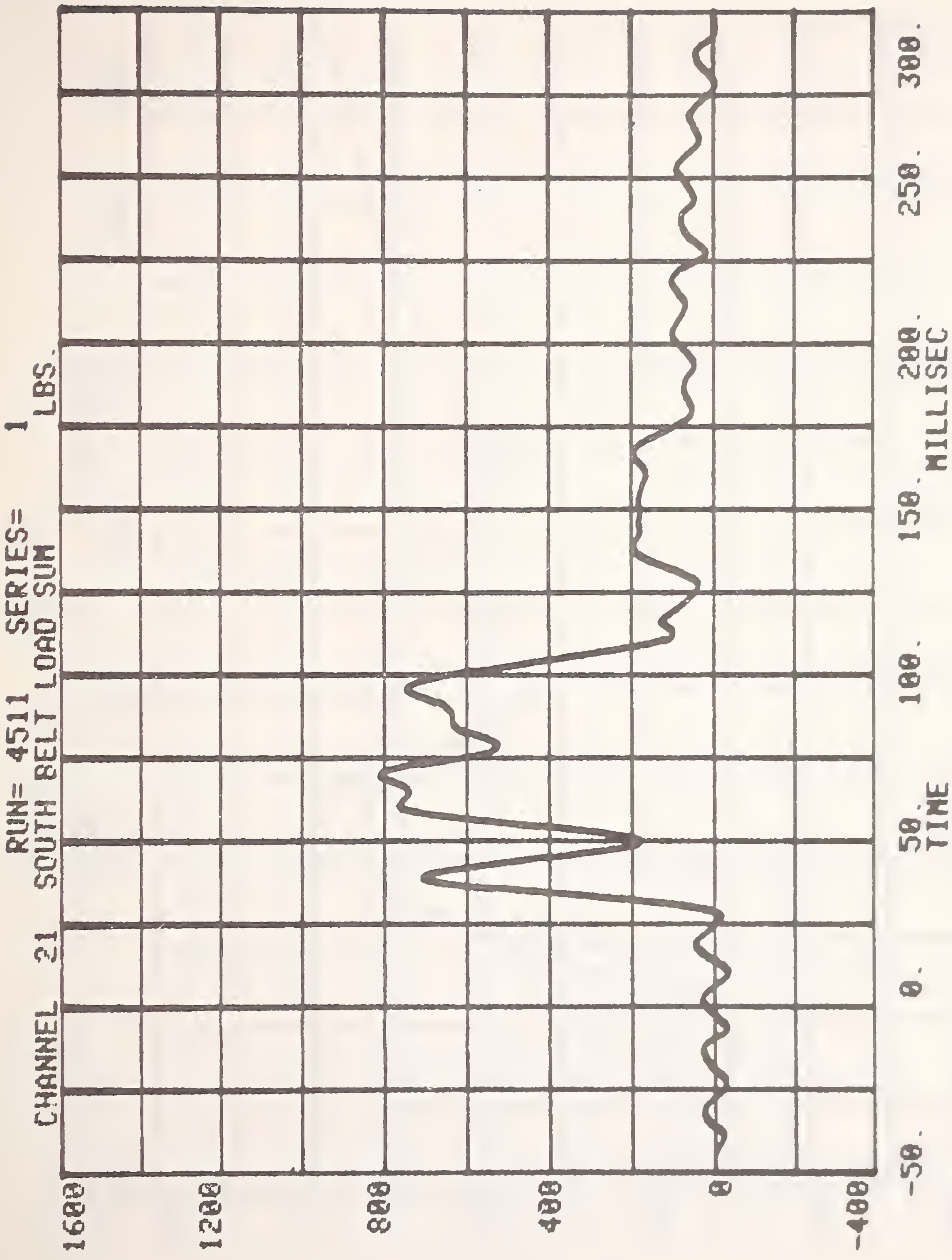
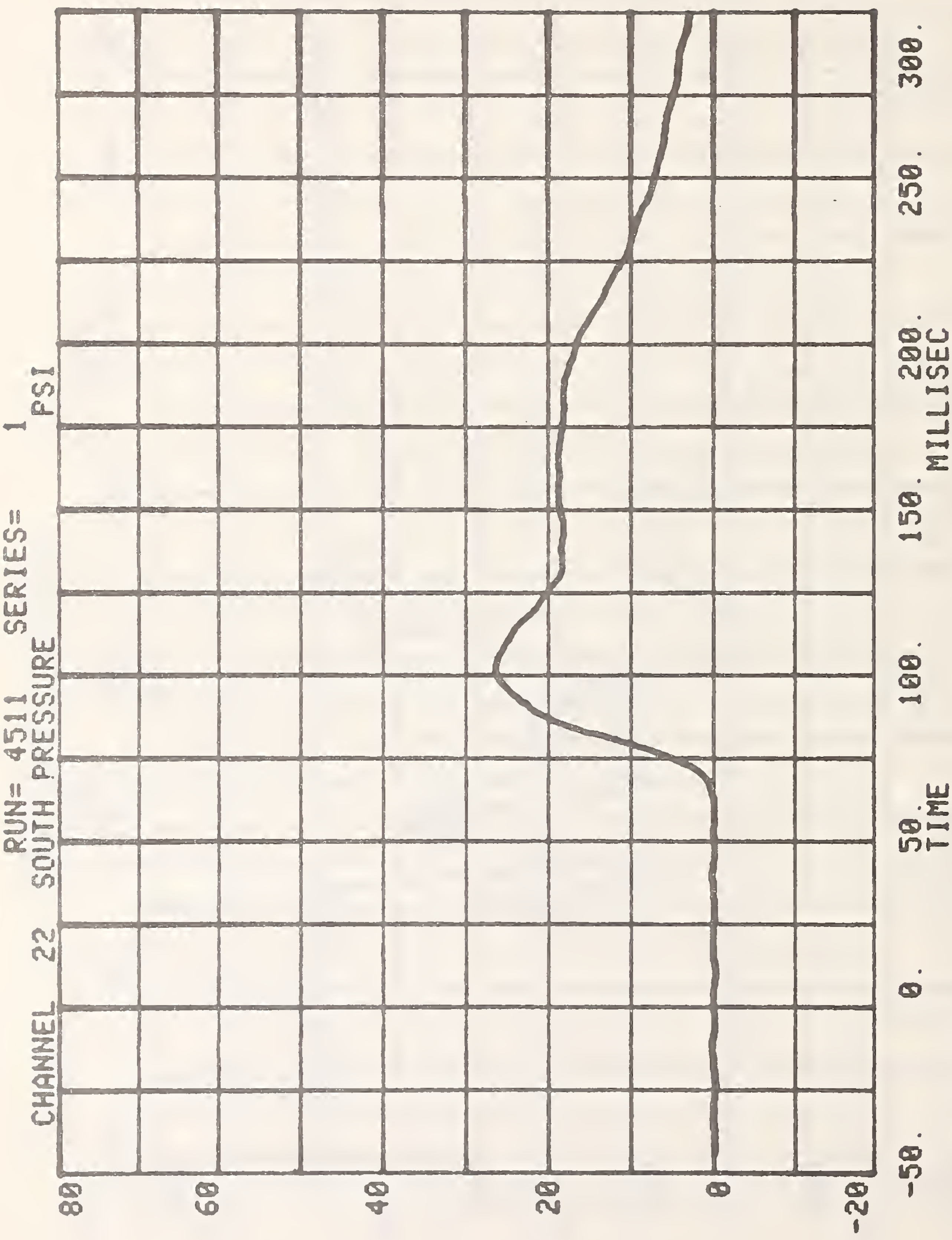
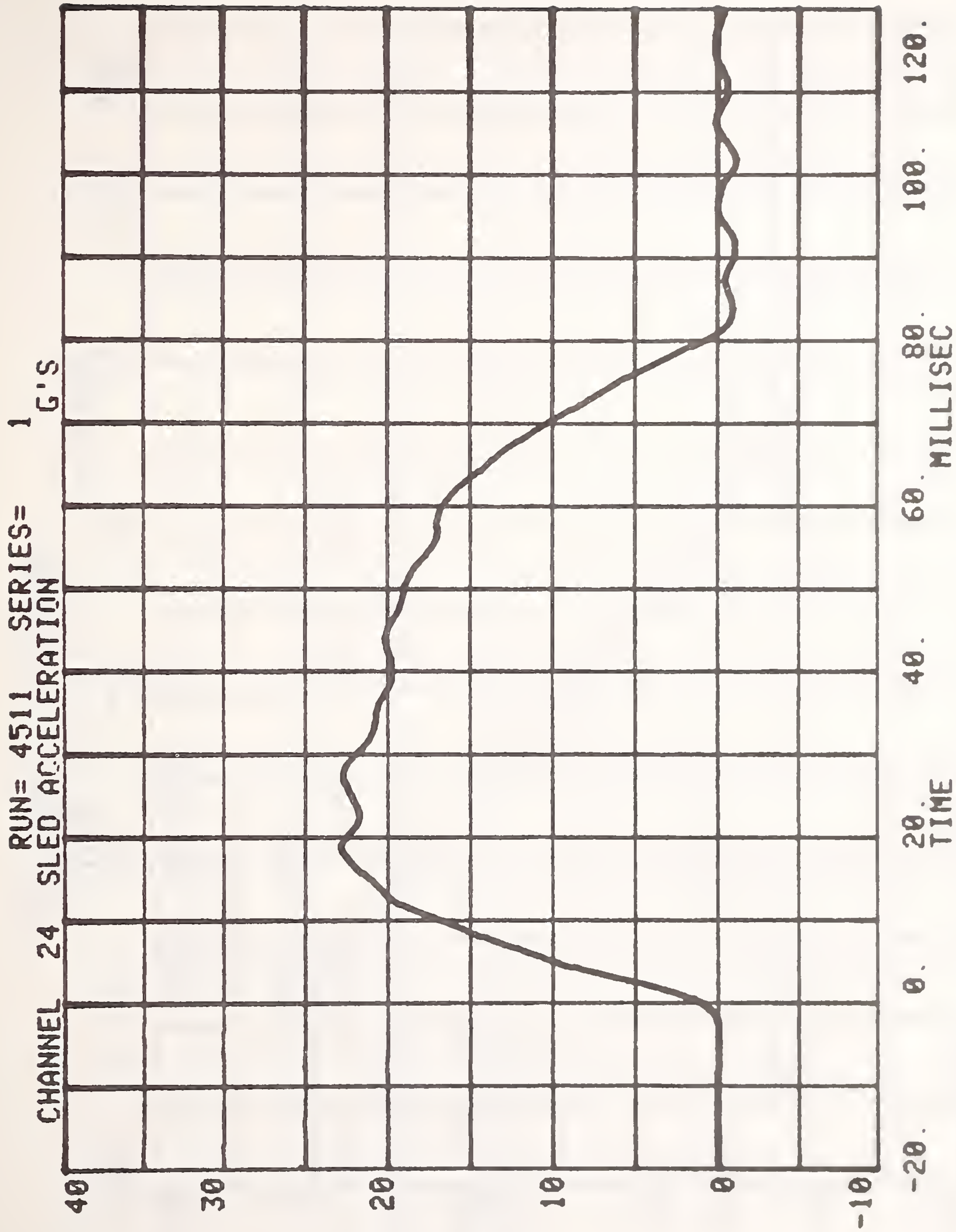
150.
200.
250.
300.
TIME MILLISEC

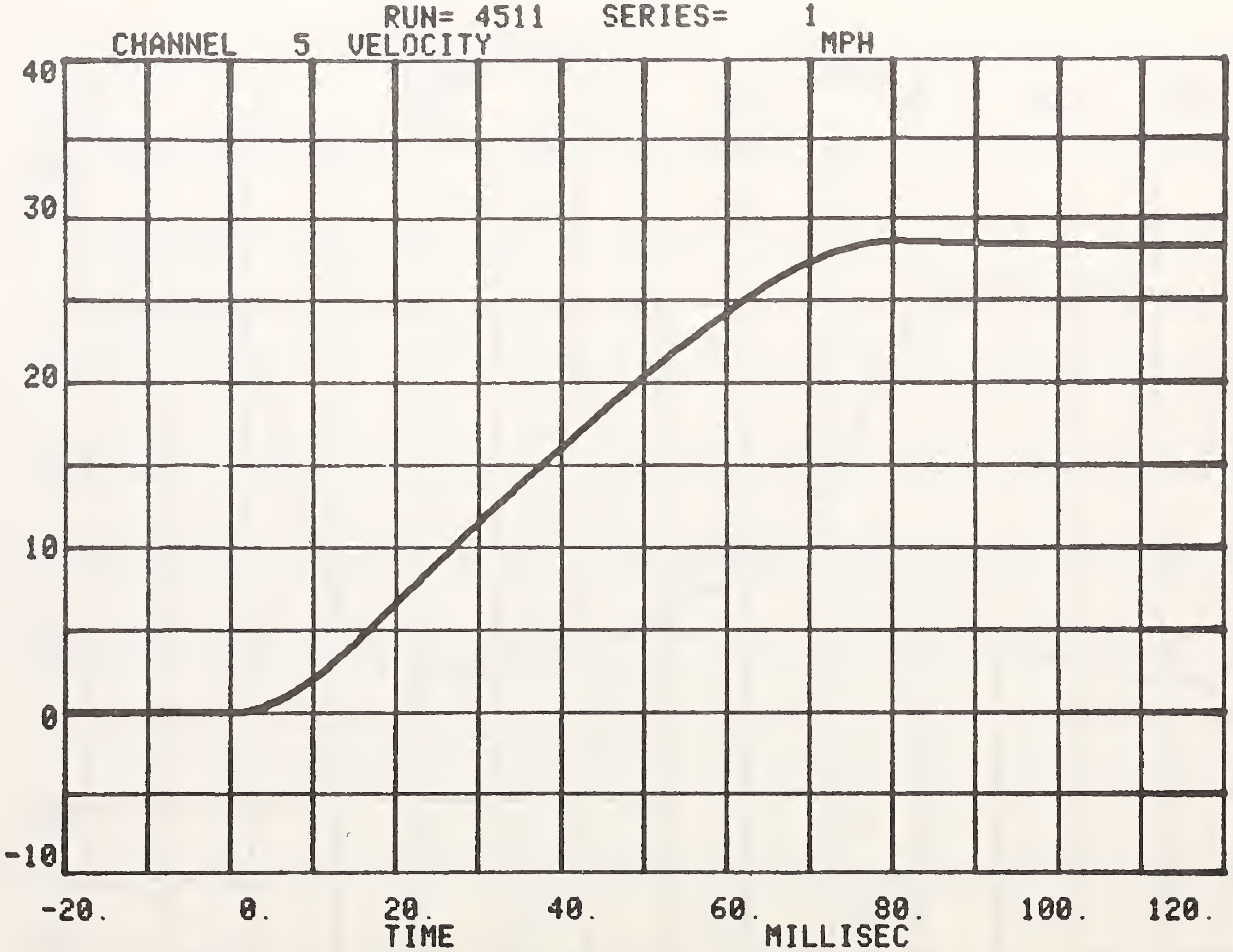

RUN= 4511 SERIES= 1 LBS.
CHANNEL 18 SOUTH BELT LOAD LEFT
800
600
400
200
0
-200
-50.
0.
50.
100.
150.
200.
250.
300.
TIME MILLISEC


CHANNEL 21 RUN= 4511 SERIES= 1 LBS.
SOUTH BELT LOAD SUM
1600
1200
800
400
0
-400
-50.
0.
50.
100.
150.
200.
250.
300.
TIME MILLISEC


CHANNEL 22 RUN= 4511 SERIES= 1
SOUTH PRESSURE PSI
80
60
40
20
0
-20
-50.
0.
50.
100.
150.
200.
250.
300.
TIME MILLISEC



CHANNEL 24 RUN= 4511 SERIES= 1
SLED ACCELERATION G'S
40
30
20
10
0
-10
-20.
0.
20.
40.
60.
80.
100.
120.
TIME MILLISEC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CHANNEL 5 VELOCITY
MPH
40
30
20
10
0
-10
-20.
0.
20.
40.
60.
80.
100.
120.
TIME
MILLISEC

HEAD INJURY CRITERION
HEAD SEVERITY INDEX

CHILD ABDOMINAL TEST

RUN=4522

NORTH HEAD R

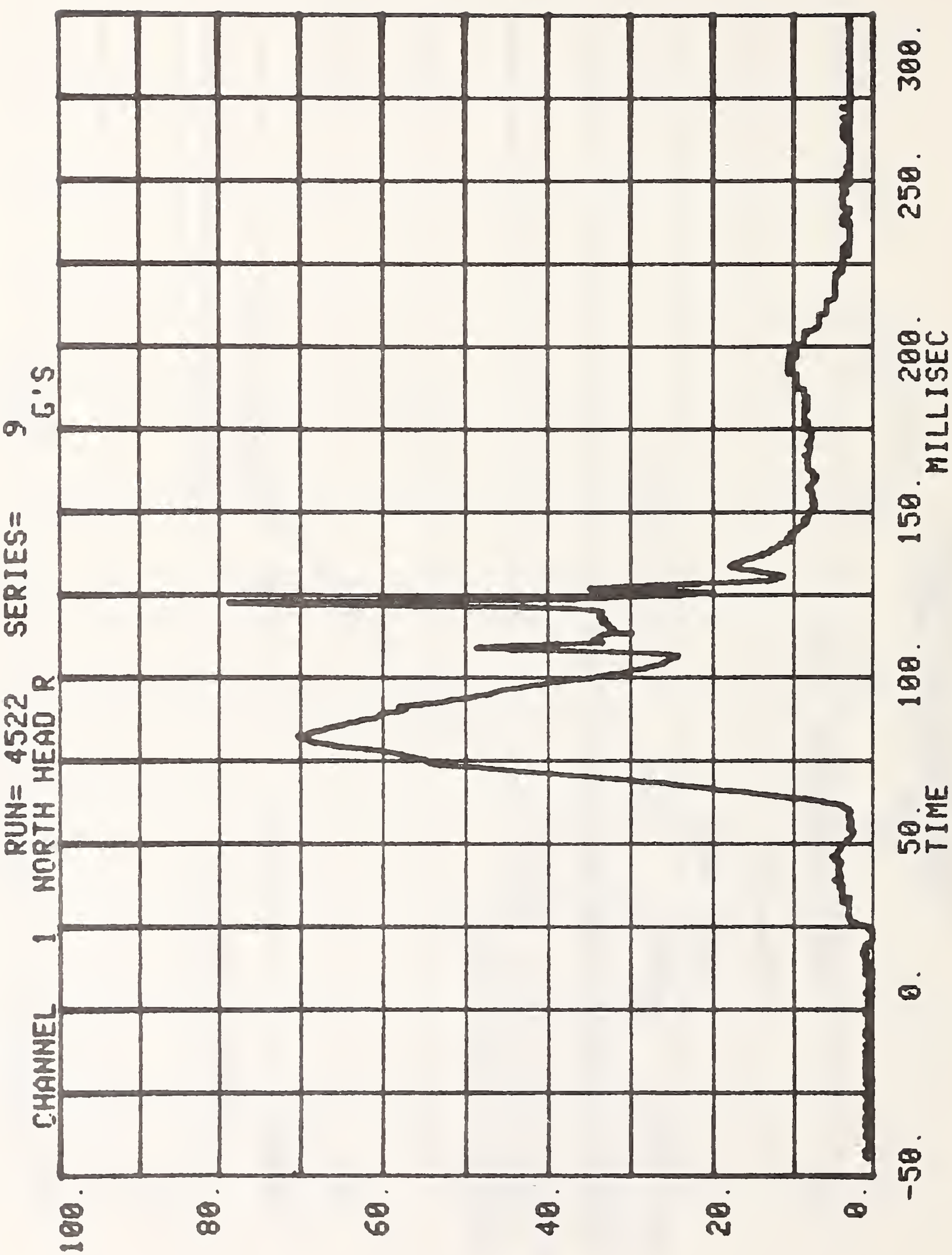
HIC= 808.2   FROM T1= .06900   TO T2= .12510

AVERAGE ACCELERATION BETWEEN T1 AND T2=  46.1G'S

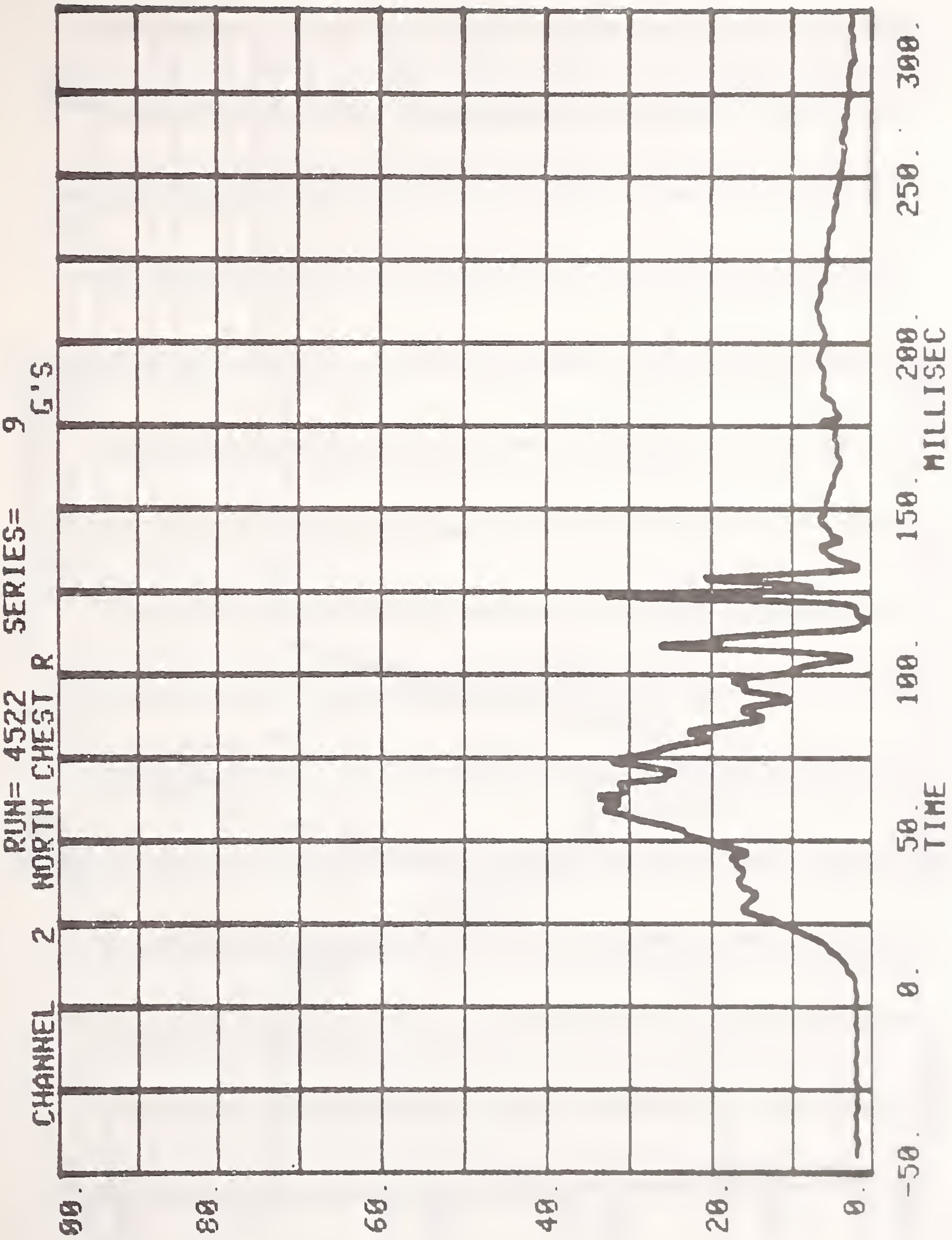
EVENT TIME= 300.0  MSEC

SEVERITY INDEX=1009.3

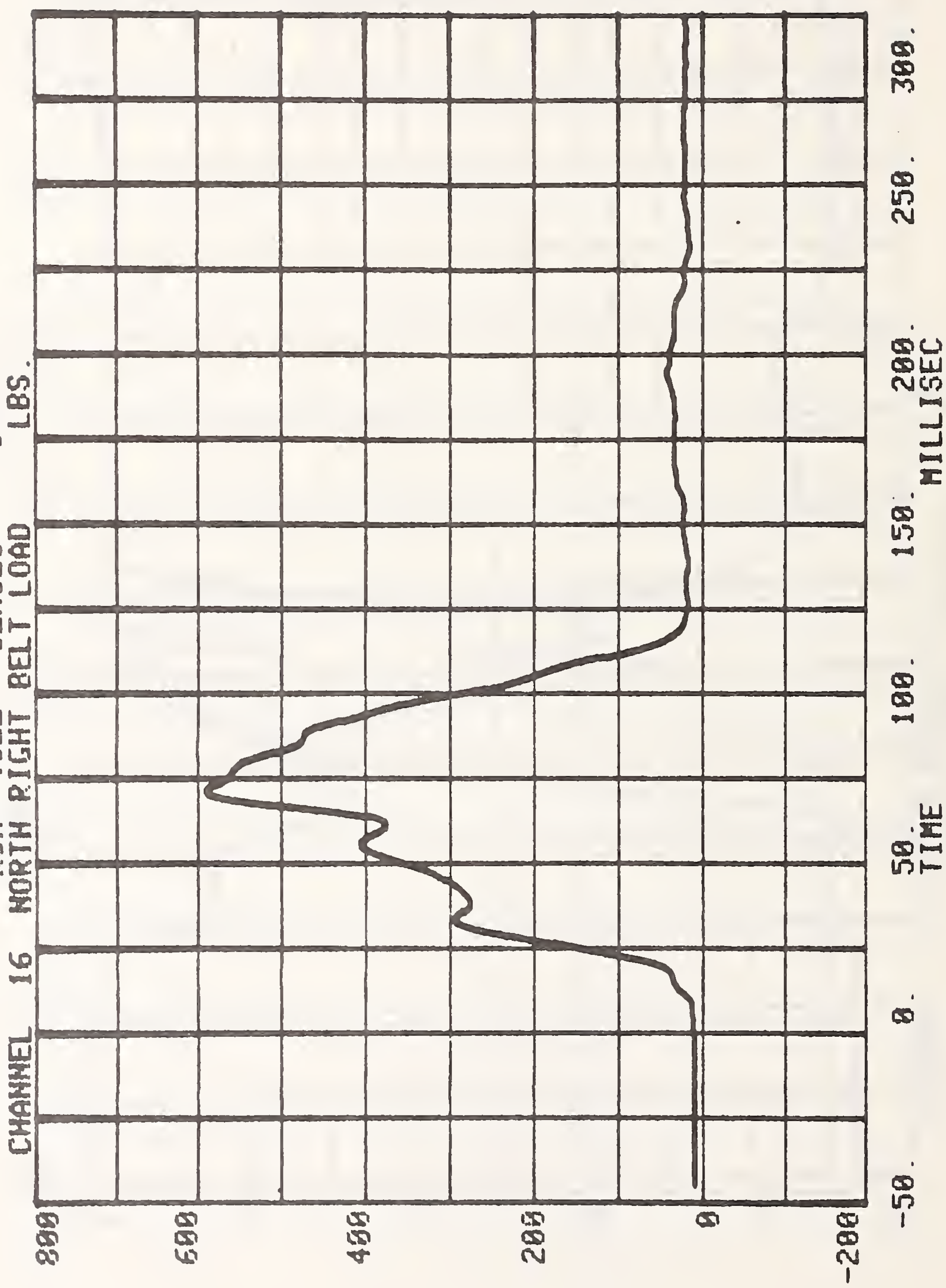
| CHANNEL | TITLE | 3 MS. CLIPPED PEAK |
|---|---|---|
| 2 | NORTH CHEST R | 33.087 G'S |



CHANNEL 1 RUN= 4522 SERIES= 9
NORTH HEAD R G'S
100.
80.
60.
40.
20.
0.
-50.
0.
50.
100.
150.
200.
250.
300.
TIME MILLISEC



CHANNEL 2 RUN= 4522 SERIES= 9
NORTH CHEST R
G'S
100.
80.
60.
40.
20.
0.
-50.
0.
50.
100.
150.
200.
250.
300.
TIME MILLISEC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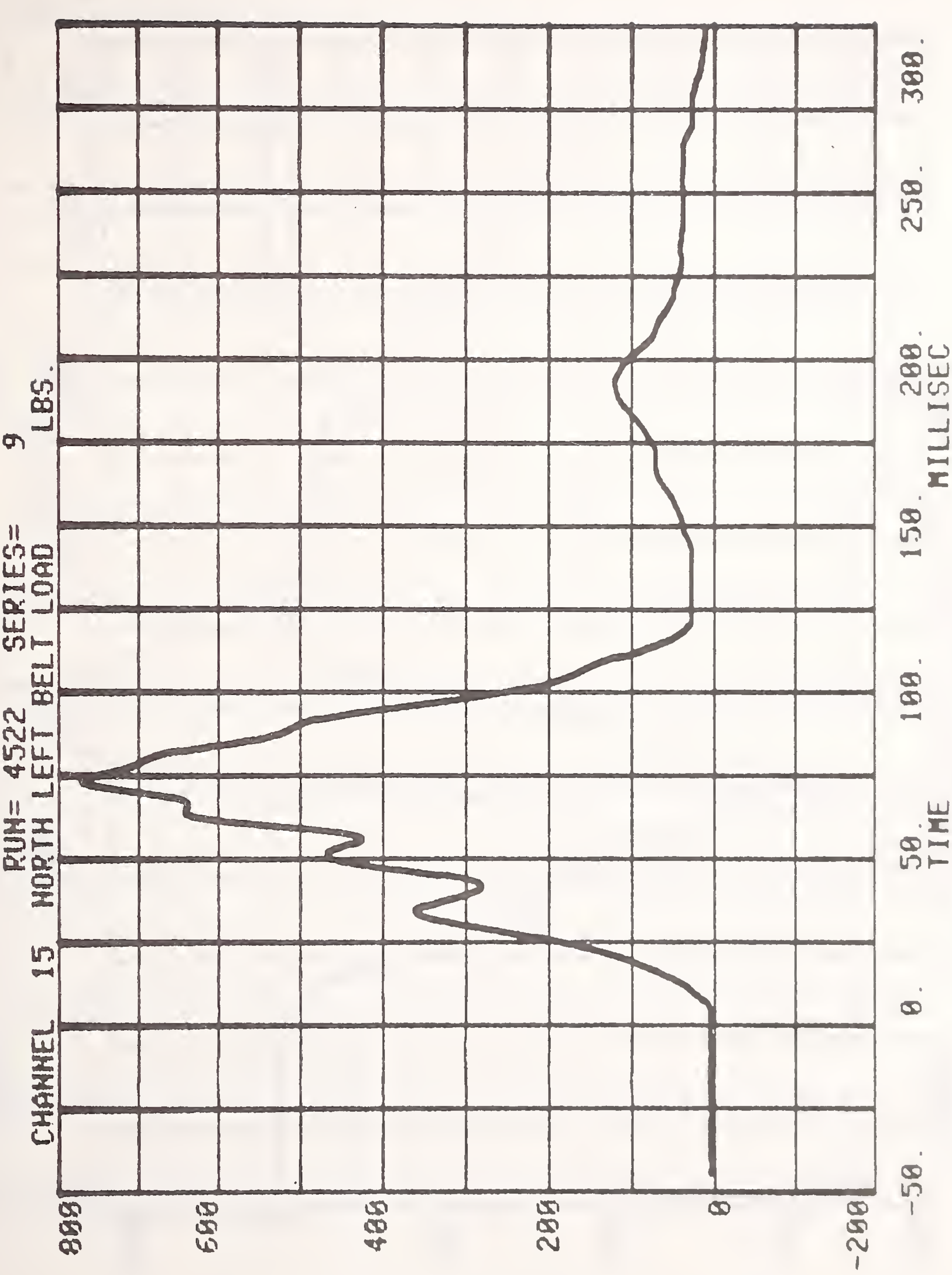
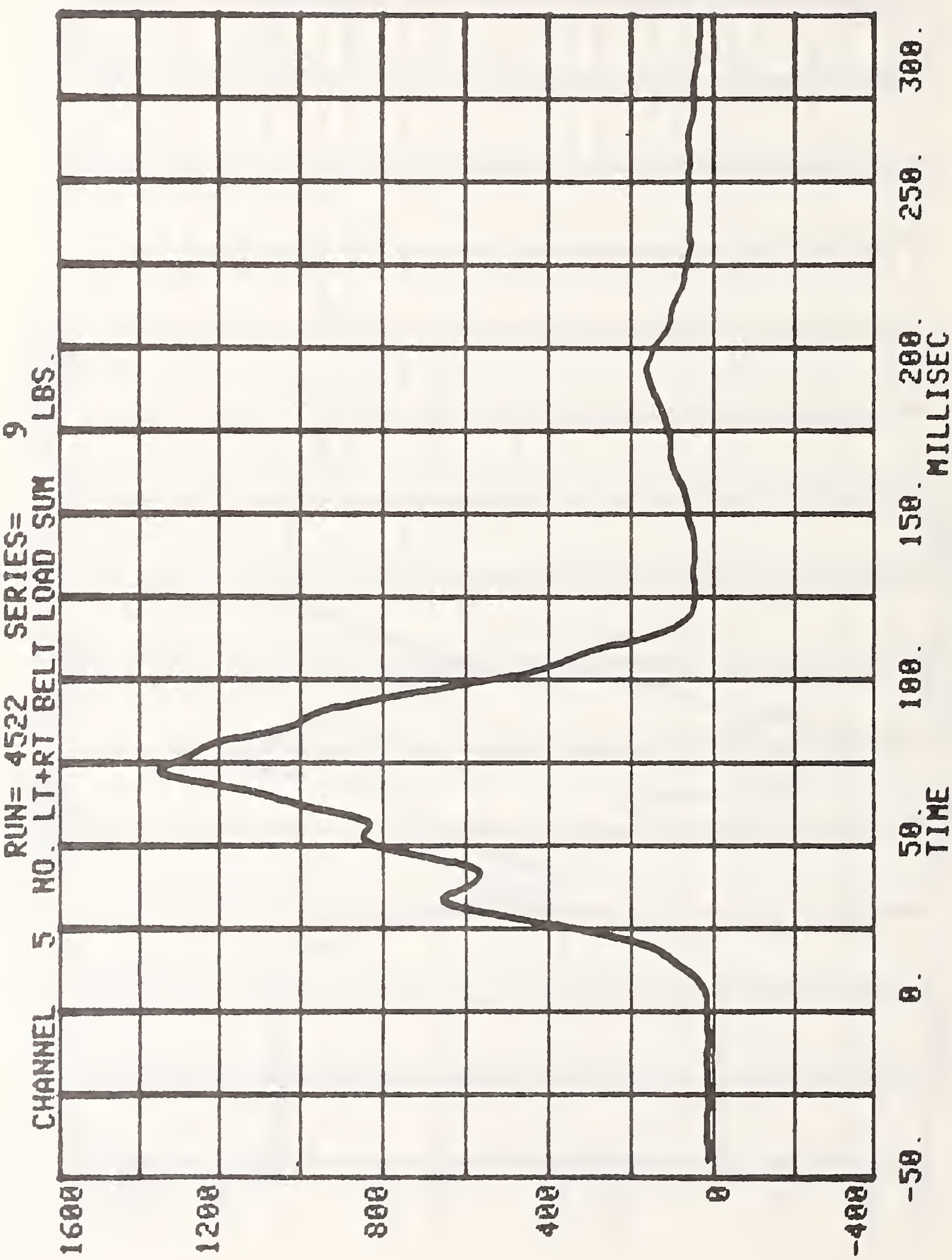
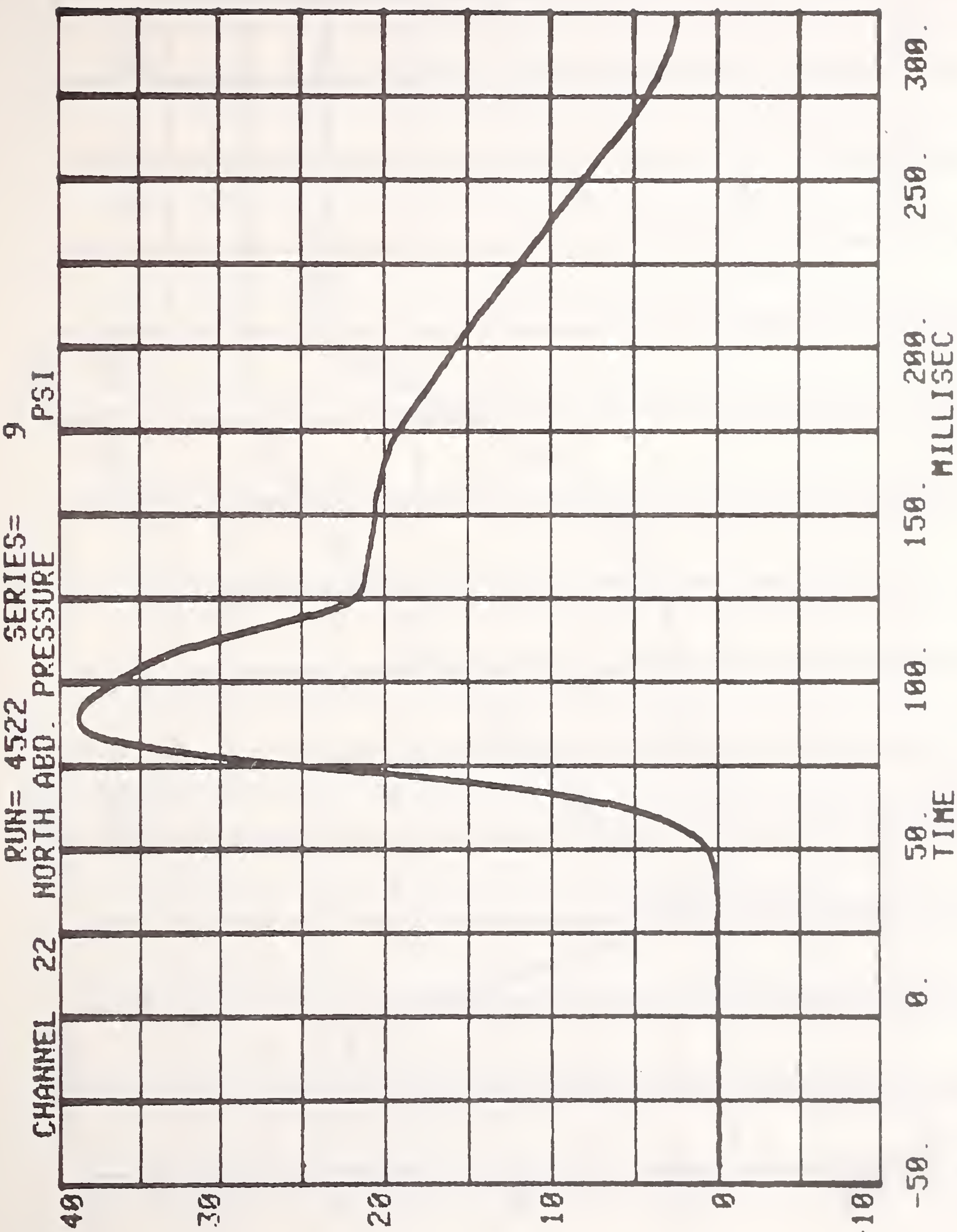
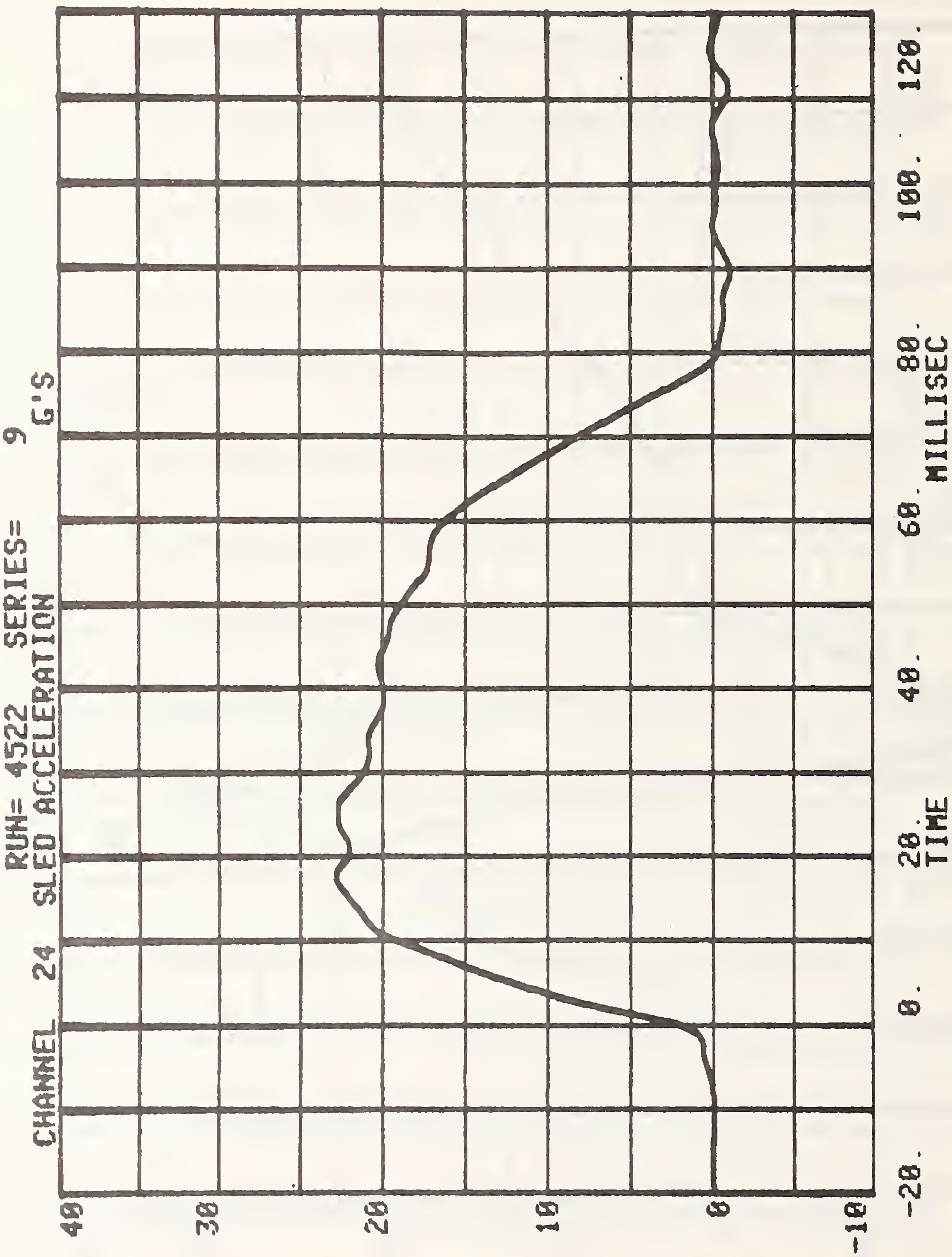
NORTH RIGHT BELT LOAD LBS.
800
600
400
200
0
-200
-50.
0.
50.
100.
150.
200.
250.
300.
TIME MILLISEC

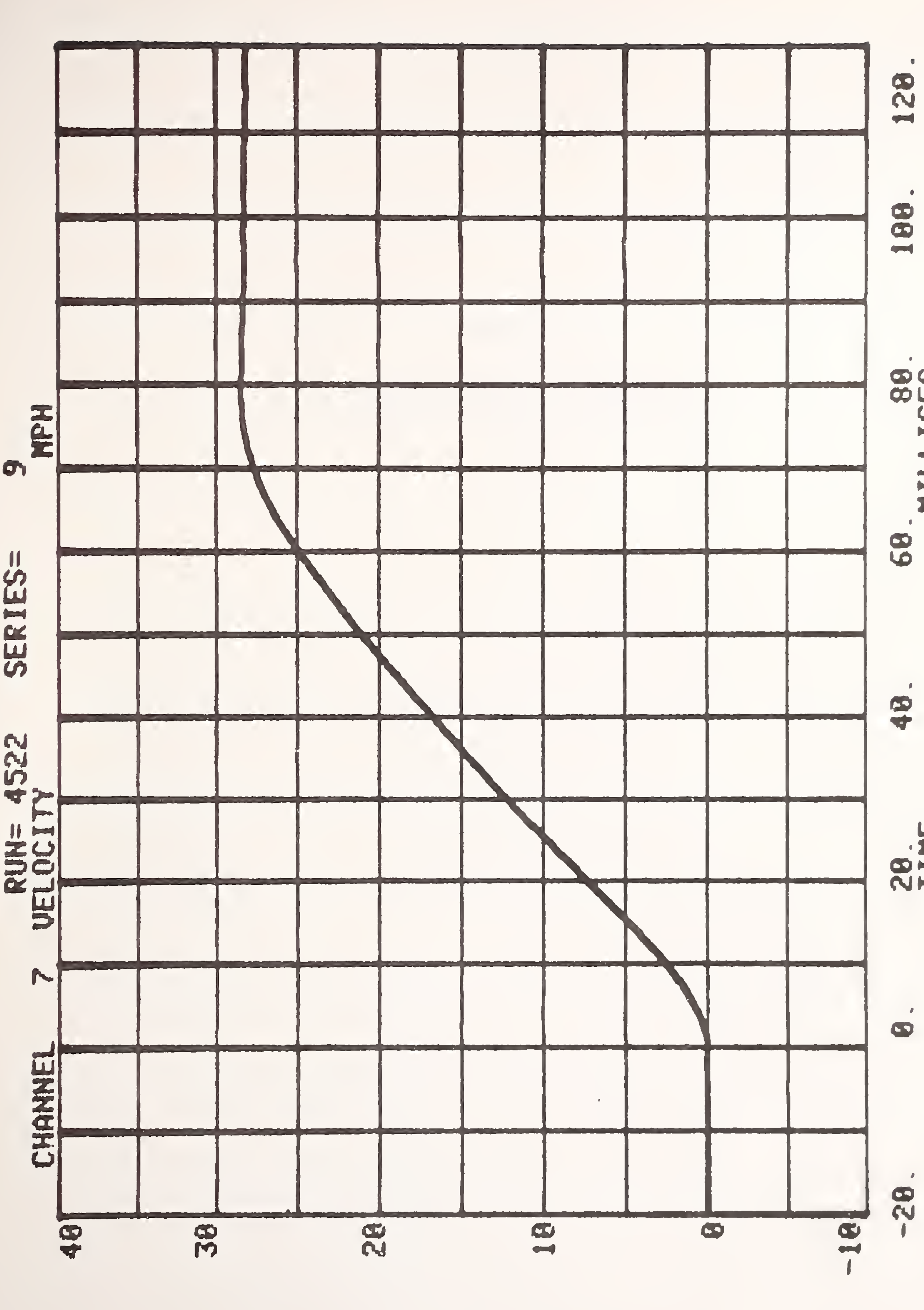

CHANNEL 15 RUN= 4522 SERIES= 9
NORTH LEFT BELT LOAD LBS.
800
600
400
200
0
-200
-50.
0.
50.
100.
150.
200.
250.
300.
TIME MILLISEC



CHANNEL 5 NO. LT+RT BELT LOAD SUM
RUN= 4522 SERIES= 9 LBS.
1600
1200
800
400
0
-400
-50.
0.
50.
100.
150.
200.
250.
300.
TIME MILLISEC


CHANNEL 22
RUN= 4522 SERIES= 9
NORTH ABD. PRESSURE PSI
40
30
20
10
0
-10
-50.
0.
50.
100.
150.
200.
250.
300.
TIME MILLISEC


CHANNEL 24
RUN= 4522 SERIES= 9
SLED ACCELERATION G'S
TIME MILLISEC
-20.
0.
20.
40.
60.
80.
100.
120.
40
30
20
10
0
-10


CHANNEL 7 RUN= 4522 SERIES= 9
VELOCITY MPH
40
30
20
10
0
-10
-20.
0.
20.
40.
60.
80.
100.
120.
TIME MILLISEC

## APPENDIX B

## SAMPLE CALCULATION OF CORRECTED BELT FORCES

CORRECTED BELT FORCES FOR TEST NO. 4577

Three-year old dummy S/N 39

Restraint: Strolee 605 Booster Seat
Weight of seat = 5.0 lbs. (Table 15)

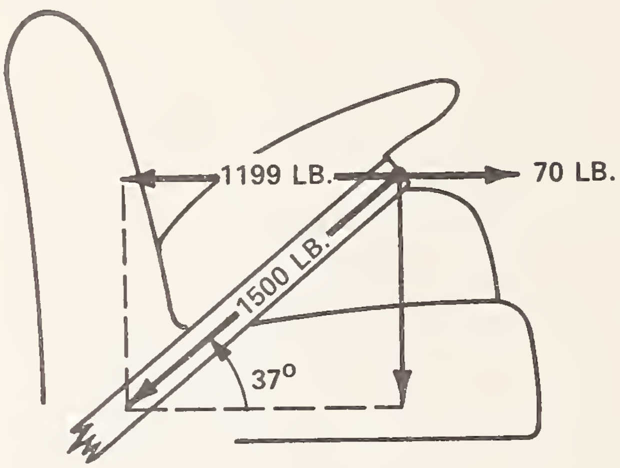
1. The total peak lap belt load = 1500 lbs. at a time of .065 sec.

2. Lap belt angle = 37 deg. relative to horizontal at t = .065 sec. (from high-speed movie films)

3. The horizontal component of 1500 lbs. is:

$F_{HORIZ.}$ = 1500 (cos 37)

$F_{HORIZ.}$ = 1500 (.799) = 1199 lbs.




4. Sled acceleration at t = .065 sec. is 14 g's.

5. Inertia force of seat against lap belt:

$F_{SEAT}$ = 14 g (5.0 lbs.) = 70 lbs.

6. The net horizontal force on dummy abdomen is:

$F_{DUM.}$ = 1199 - 70 = 1129 lbs.

7. The 1129 lbs. is the corrected lap belt load (Table 16).

*U.S. GOVERNMENT PRINTING OFFICE: 1988--523-536/D6588