June 1981
Test Report

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NRD-12, G. Bell

U.S. Department of Transportation
National Highway Traffic Safety Administration

Heavy Truck Pilot Crash Test

Frontal Impact

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16. Abstract

A frontal impact test of a tractor-trailer into a crushable barrier at a nominal initial speed of 30 mph was performed. The test vehicle, which was operated at a total combination weight of 34,690 lbs., carried two 50th percentile Part 572 anthropomorphic test devices - one unrestrained at the driver position and the other restrained by a lap belt at the co-driver position. Test instrumentation consisted of 38 data channels providing acceleration information on both vehicle and dummy motions and force information on barrier performance as well as photographic coverage by eight real time and high speed motion picture cameras. This test report describes all aspects of the experiment - physical and operational characteristics of the vehicle, occupants, and barrier; instrumentation and photographic coverage; data acquisition and reduction; and time histories for all measured vehicle and dummy responses.

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Heavy Truck Crash Test Crushable Barrier Crash Test Articulated Truck Crash Test	Document availability is unlimited to the public through the National Technical Information Service, Springfield, Va. 22161

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I. INTRODUCTION

This report describes a frontal impact test of a tractor-trailer into a crushable barrier performed at the Advanced Technology Center of Calspan Corporation on November 5, 1980. This test was part of the Heavy Truck Pilot Crash Test Program sponsored by the National Highway Traffic Safety Administration (NHTSA) under Contract No. DTNH22-80-C-07537.

The objectives of this test were to obtain baseline information relative to test procedures, instrumentation, and variables of interest that are appropriate for crashes of vehicles of this size. The test was intentionally designed not to be catastrophic, as many types of truck crashes are, so that data on vehicle damage and occupant motions could be obtained. An analytical review of in-depth accident investigations indicates that the test approximates the type of low deceleration crash conditions that heavy trucks of this type encounter when they contact other structurally yielding objects such as roadside guardrails and/or automobiles.

In addition to this test report, full photographic documentation of the crash event, as well as pre-test and post-test scenes, has been provided in a film containing all coverage from the several cameras used in the program. Background information for the test is contained in References 1

II. SUMMARY OF TEST

A 1975 tandem axle General Motors Astro "95" towing a 1974 35 ft. trailco flat bed semi-trailer was subjected to a 29.2 mph frontal impact into a Crushable Drum Barrier at the Calspan Corporation, Advanced Technology Center on November 5, 1980. A summary of the test condition can be found in Table 1 and pre- and post-test photographs can be found in Appendix A.

Two 50th percentile Part 572 anthropomorphic test devices (ATDs) each weighing 162 lbs. were placed in the driver and right front passenger positions. The driver was unrestrained and the right front passenger was secured with a lap belt. Both ATDs were fully instrumented with femur load cells and triaxial accelerometers in the head and chest areas.

Dummy and barrier data are presented in Table 1. Appendix B contains dummy response data traces along with vehicle acceleration data traces.

The vehicle was loaded with 7,600 lbs. of concrete ballast to a total combination weight of 34,690 lbs. Special precautions were taken to restrain the load longitudinally on the deck of the trailer. A failsafe cable system was attached between the frames of the tractor and the semi-trailer to prevent catastrophic consequences in the event the vehicle's fifth wheel plate/kingpin assembly failed.

TABLE 1

CRASH TEST SUMMARY

TEST NO.	1	PROJECT:	Heavy Truck Pilot Crash Test
DATE:	11/5/80	TIME:	1435 TEMP: 41°F

VEHICLE	GMC Astro '95'/Trailco Flat Bed Semi-Trailer
TEST WEIGHT (lbs)	34,690
IMPACT ANGLE (deg)*	0
IMPACT VELOCITY (mph)**	29.2
MAX. VEHICLE CRUSH (in) STATIC	7.3 (right side of vehicle)
MAX. VEHICLE INTRUSION (in)	0.2

DUMMIES

TYPE	Part 572, 50th Percentile	Part 572, 50th Percentile
LOCATION	LF (1)	RF (2)
RESTRAINT	Unrestrained	Lap Belt
I.D. NUMBER	110	97
DUMMY WEIGHT	162	162

BARRIER

TYPE	Steel drum array backed by a fixed concrete SAE barrier
DRUM ARRAY DIMENSIONS	20 ft. long x 12 ft. wide (60 barrels in 10 x 6 array)
DRUM PHYSICAL CHARACTERISTICS	55 gal; 24 in. diameter; 35 in. high; 18 gauge (shell & cover)
NOTE:	The design of this special-purpose crash barrier is discussed in detail in Appendix A.

NUMBER OF DATA CHANNELS	39
NUMBER OF HIGH SPEED CAMERAS	10 + 1 real time

*With respect to two track Centerline

**Speed trap measurement (± .05% accuracy)

III. DESCRIPTIONS OF TEST CONDITIONS AND EQUIPMENT

This section contains detailed numerical data defining the physical conditions and equipment locations for the test. Included are:

- general characteristics of the tractor and trailer (Tables 2-3 and Figures 1-2)
- occupant locations relative to cab interior (Figure 8)
- accelerometer location on the vehicle (Figure 3 and Table 4)
- camera positions and locations (Figure 6 and Table 5)
- description of the crushable drum barrier (Figures 4 and 5)
- occupant injury criteria values (Table 6)

TABLE 2

TEST VEHICLE INFORMATION

TEST VEHICLE INFORMATION - TRACTOR

Vehicle Manufacturer General Motors Corporation

Make/Model GMC COE Astro "95"

Body Style COE Model Year 1975

VIN TDC925V580675

NHTSA No. E28-1-507 Color Yellow

Engine Data 6 cylinders 764 in^3/displacement

Transmission Data 10 speed (xx) Manual ( ) Automatic

GVRW 44860 lbs GAWR: front 10860 lbs rear 34000 lbs

Tire Pressure (up to capacity) - Front 85 psi rear 85 psi

Recommended Tire Size 10.00-20 Load Range: __B __C __D xx F

Vehicle Capacity: Types of Seats __ Bench xx Bucket __ Split Bench

Number of Occupants (Designated Seating Capacity): 2 Front
1 Rear (Sleeper)
TOTAL

TEST VEHICLE INFORMATION - TRAILER

Vehicle Manuafacturer Trailco 35 FS T 7

Make/Model flat-bed semi-trailer, Model Year 1974

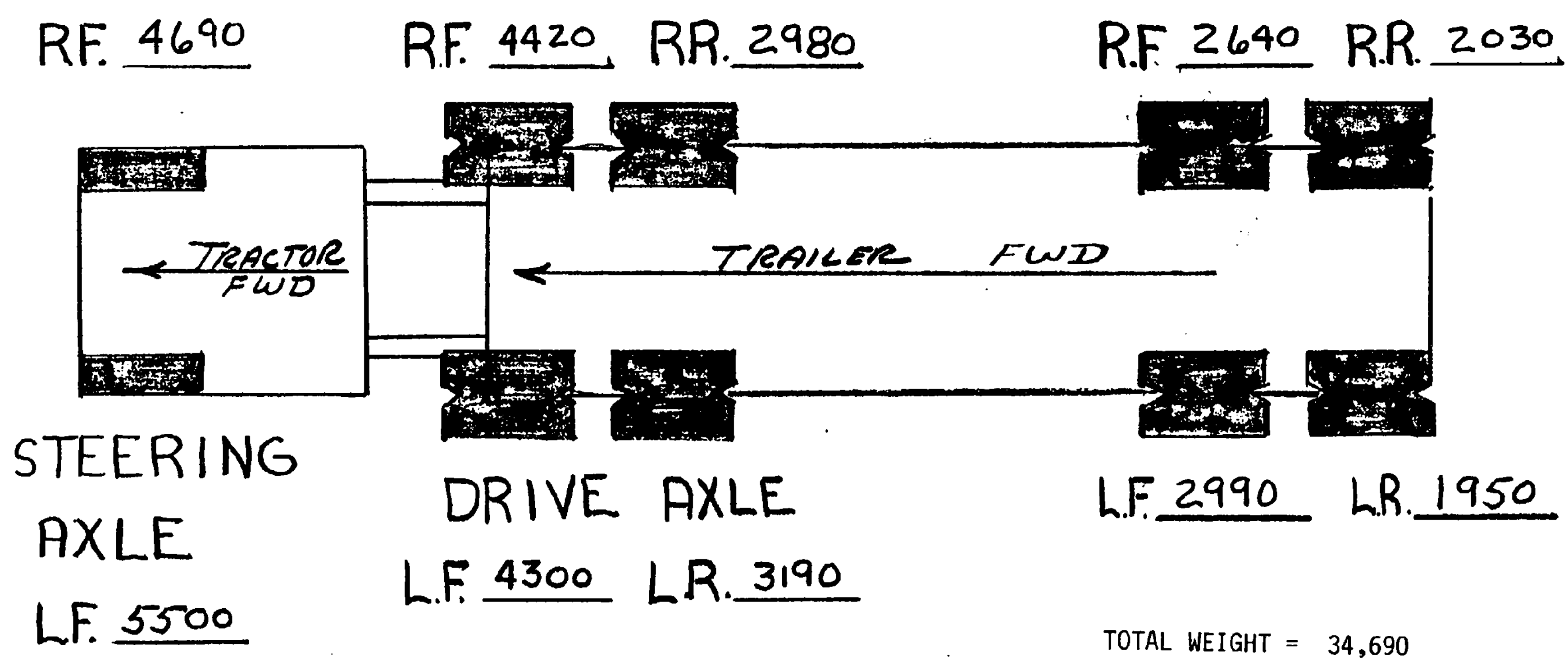
Axle tandem-dual

LOADING CONDITIONS FOR TEST

See Figure 1

TRACTOR MAKE GMC. ASTRO C.O.E.

TRAILER MAKE TRAILCO



TOTAL WEIGHT = 34,690

FIGURE 1 WEIGHT DISTRIBUTION

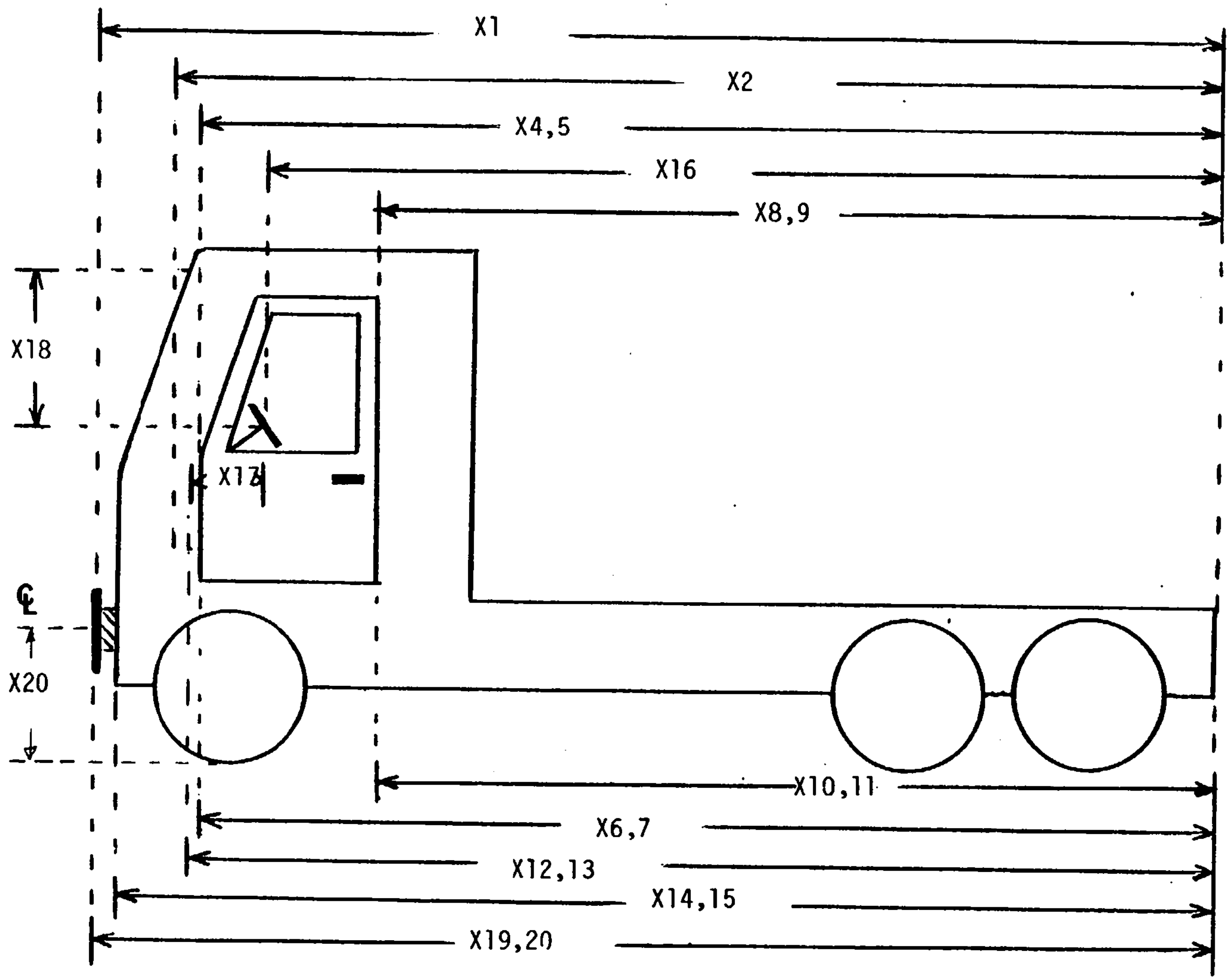


FIGURE 2 PRE- AND POST-TEST MEASUREMENT POINTS

TABLE 3

VEHICLE MEASUREMENTS

All Dimensions in inches

NO.		Pre-Test	Post-Test	Δ
X1	Total Length of Vehicle at Centerline	228.6	228.0	.6
X2	Rear Surface of Vehicle to Front of Engine	208.2	208.2	0
X3	Rear Surface of Vehicle to Upper Leading Edge of Right Door	217.0	217.0	0
X4	Rear Surface of Vehicle to Upper Leading Edge of Left Door	217.1	217.0	.1
X5	Rear Surface of Vehicle to Lower Leading Edge of Right Door	217.1	217.0	.1
X6	Rear Surface of Vehicle to Lower Leading Edge of Left Door	217.0	217.0	0
X7	Rear Surface of Vehicle to Upper Trailing Edge of Right Door	182.8	182.8	0
X8	Rear Surface of Vehicle to Upper Trailing Edge of Left Door	182.8	182.8	0
X9	Rear Surface of Vehicle to Lower Trailing Edge of Right Door	182.8	182.8	0
X10	Rear Surface of Vehicle to Lower Trailing Edge of Left Door	183.0	183.0	0
X11	Rear Surface of Vehicle to Bottom of "A" Post of Right Side	212.4	212.3	.1
X12	Rear Surface of Vehicle to Bottom of "A" Post of Left Side	212.5	212.4	.1
X13	Rear Surface of Vehicle to Front Wall - Right Side	226.6	226.4	.2
X14	Rear Surface of Vehicle to Front Wall - Left Side	226.5	226.3	.2
X15	Rear Surface of Vehicle to Steering Column	209.0	209.0	0
X16	Center of Steering Column to "A" Post	15.2	15.2	0
X17	Center of Steering Column to Headliner	20.5	20.4	.1
X18	Rear Surface of Vehicle to Right Side of Front Bumper	226.5	219.2	7.3
X19	Rear Surface of Vehicle to Left Side of Front Bumper	226.4	222.0	4.4
X20	℄ of Frame Rail Height/Front Bumper	31	31	0

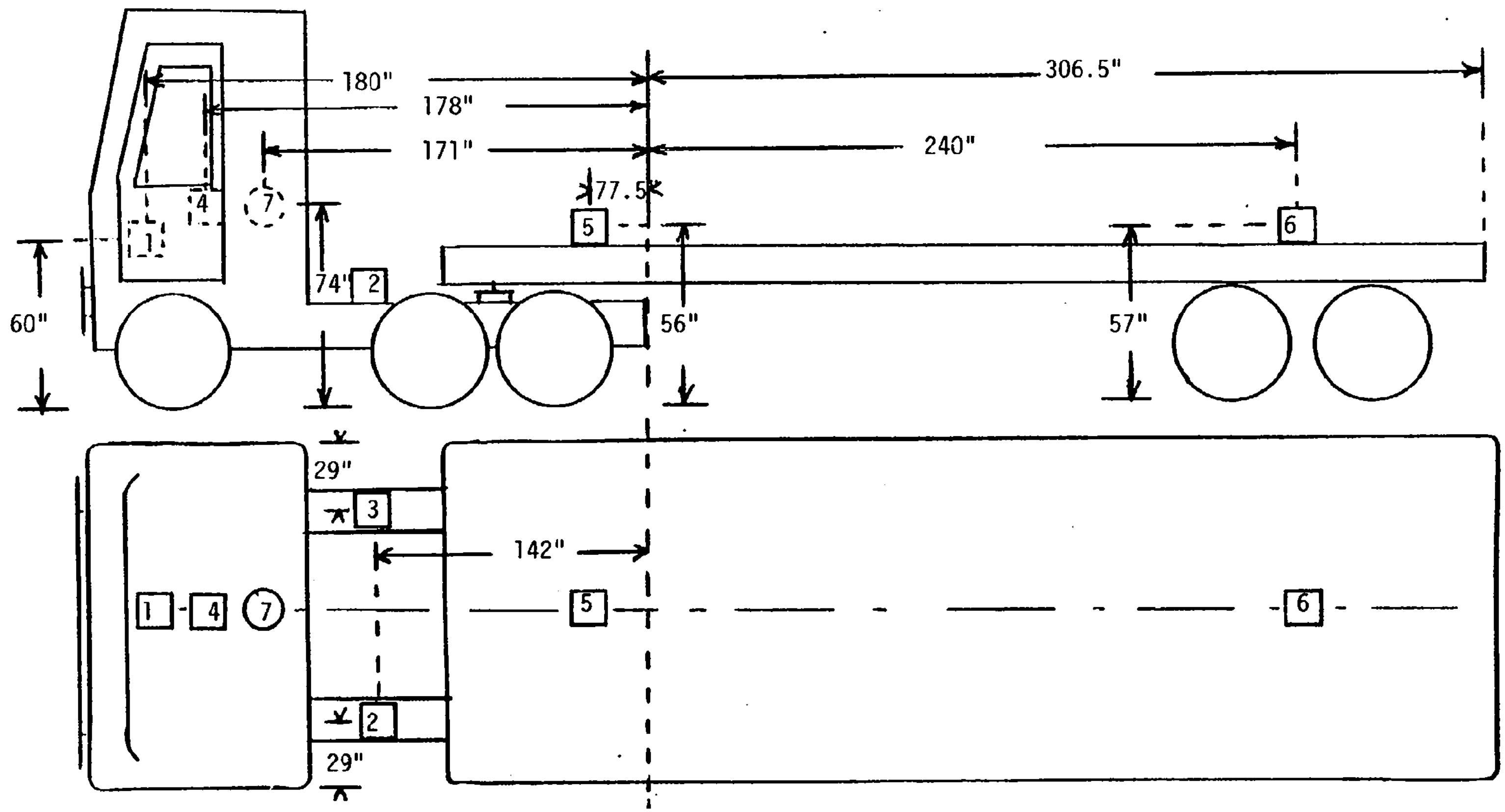
TABLE 4

ELECTRONIC INSTRUMENTATION TEST No. 1

CAR 1 - STRIKING VEHICLE

TRANSDUCER DESCRIPTION OR ACCELEROMETER LOCATION*	DIRECTION OF PARAMETER BEING MEASURED	LOCATION ON VEHICLE	DESCRIPTION LISTED ON DATA PLOTS
Vehicle Accelerometers			
Engine	X, Y, Z	Top of Engine	Engine
Left Frame Rail	X, Z	Left Tractor Frame	Left Frame Rail
Right Frame Rail	X, Z	Right Tractor Frame	Right Frame Rail
Cab Center Line	X, Y, Z	Inside Cab Compartment	Cab Centerline
Trailer Front	X, Y, Z	Front of Trailer Bed	Trailer Front
Trailer Rear	X, Z	Rear of Trailer Bed	Trailer Rear
Pitch Rate Gyro	X	Inside Cab Compartment	Pitch Rate
Barrier			
Barrier Load Cells (4)	X	Fixed Barrier Face	Barrier Loads
Barrier Accelerometers (2)	X	Front of Drum Barrier Face	Lost Data (cut wires)
Dummy			
Driver Head	X, Y, Z	Driver Position No. 1	Position No. 1 Head
Driver Chest	X, Y, Z	Driver Position No. 1	Position No. 1 Chest
Driver Femur	Left & Right Femur	Driver Position No. 1	Position No. 1 Femur
Right Front Passenger Head	X, Y, Z	RFP Position No. 2	Position No. 2 Head
Right Front Passenger Chest	X, Y, Z	RFP Position No. 2	Position No. 2 Chest
Right Front Passenger Femur	Left & Right Femur	RFP Position No. 2	Position No. 2 Femur

*SEE ACCELEROMETER LAYOUT DIAGRAM FIGURE 3



ACCELEROMETER NUMBER *	ACCELEROMETER LOCATION	DIRECTION X	DIRECTION Y	DIRECTION Z
1	Engine	x	x	x
2	Left Frame Rail	x		x
3	Right Frame Rail	x		x
4	Cab C/L	x	x	x
5	Trailer Front	x	x	x
6	Trailer Rear	x		x
7	Pitch Rate Gyro	x		

FIGURE 3 VEHICLE ACCELEROMETER LOCATIONS

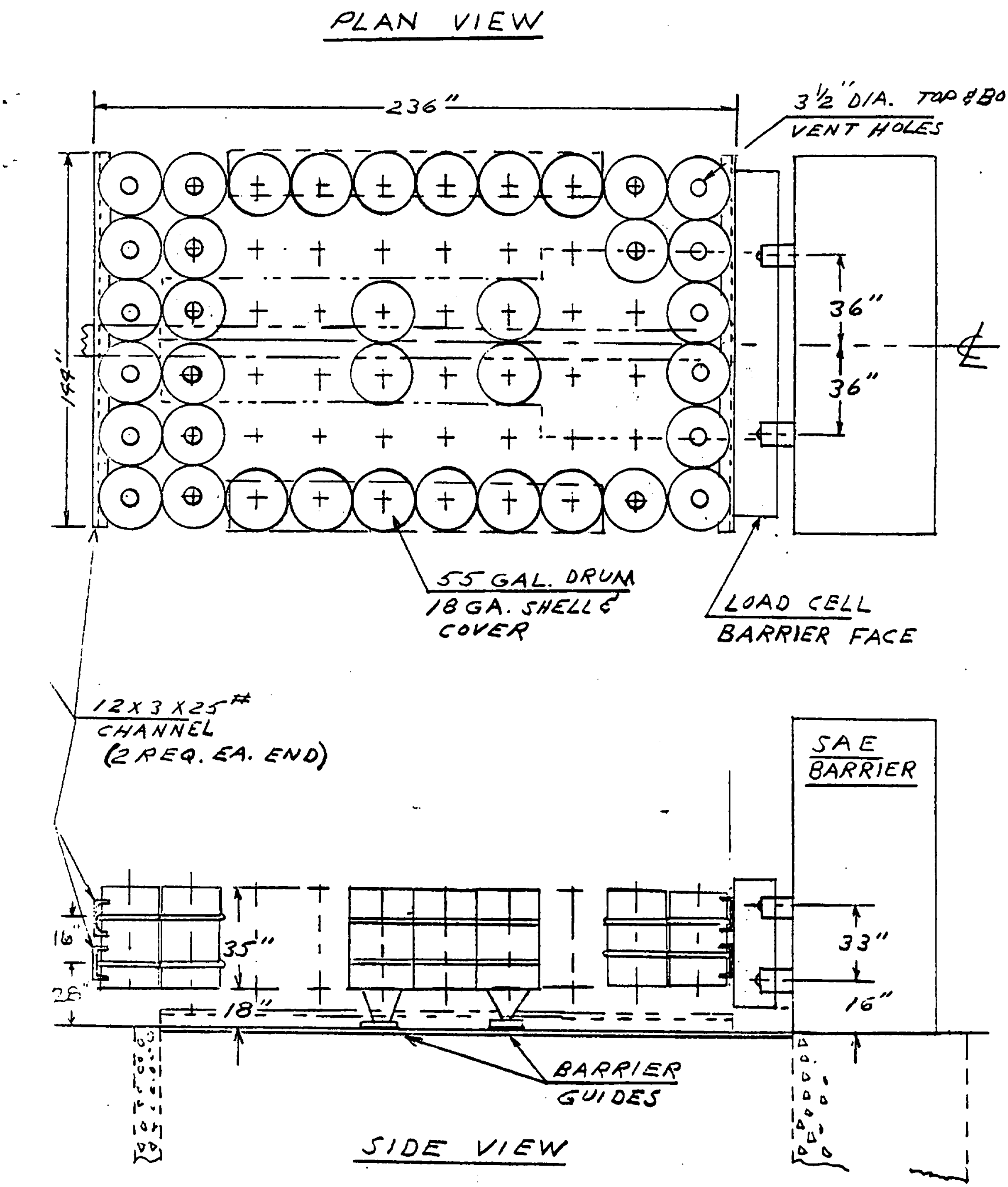

PLAN VIEW
236"
3 1/2" DIA. TOP & BOTT. VENT HOLES
144"
36"
36"
55 GAL. DRUM 18 GA. SHELL & COVER
LOAD CELL BARRIER FACE
12 X 3 X 25# CHANNEL (2 REQ. EA. END)
SAE BARRIER
16"
28"
35"
18"
33"
16"
BARRIER GUIDES
SIDE VIEW

FIGURE 4

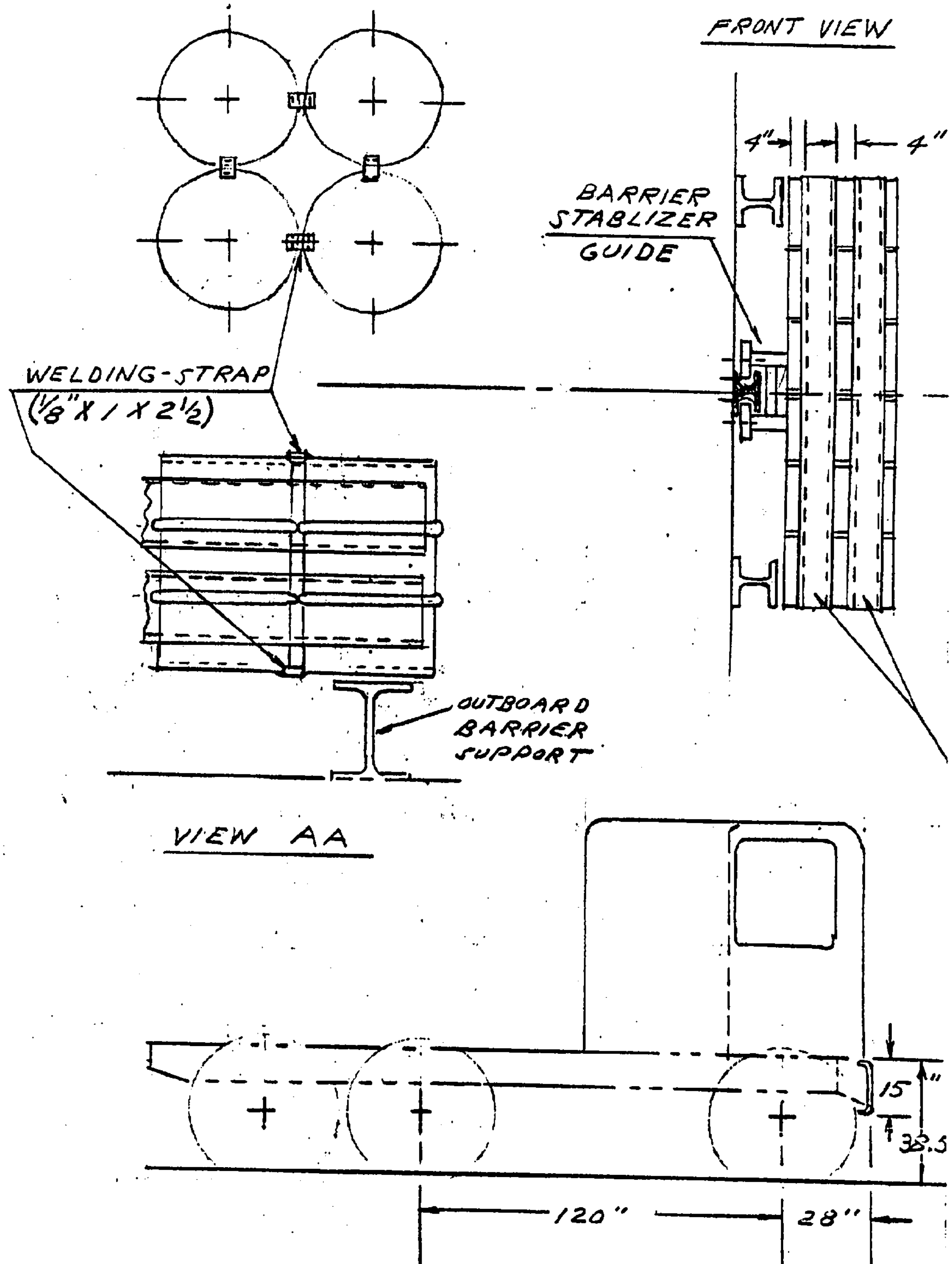

FRONT VIEW
4"
4"
BARRIER
STABLIZER
GUIDE
WELDING-STRAP
(1/8"X 1 X 2 1/2)
OUTBOARD
BARRIER
SUPPORT
VIEW AA
15"
120"
28"

FIGURE 5

NOTE: Camera Information Shown on Table

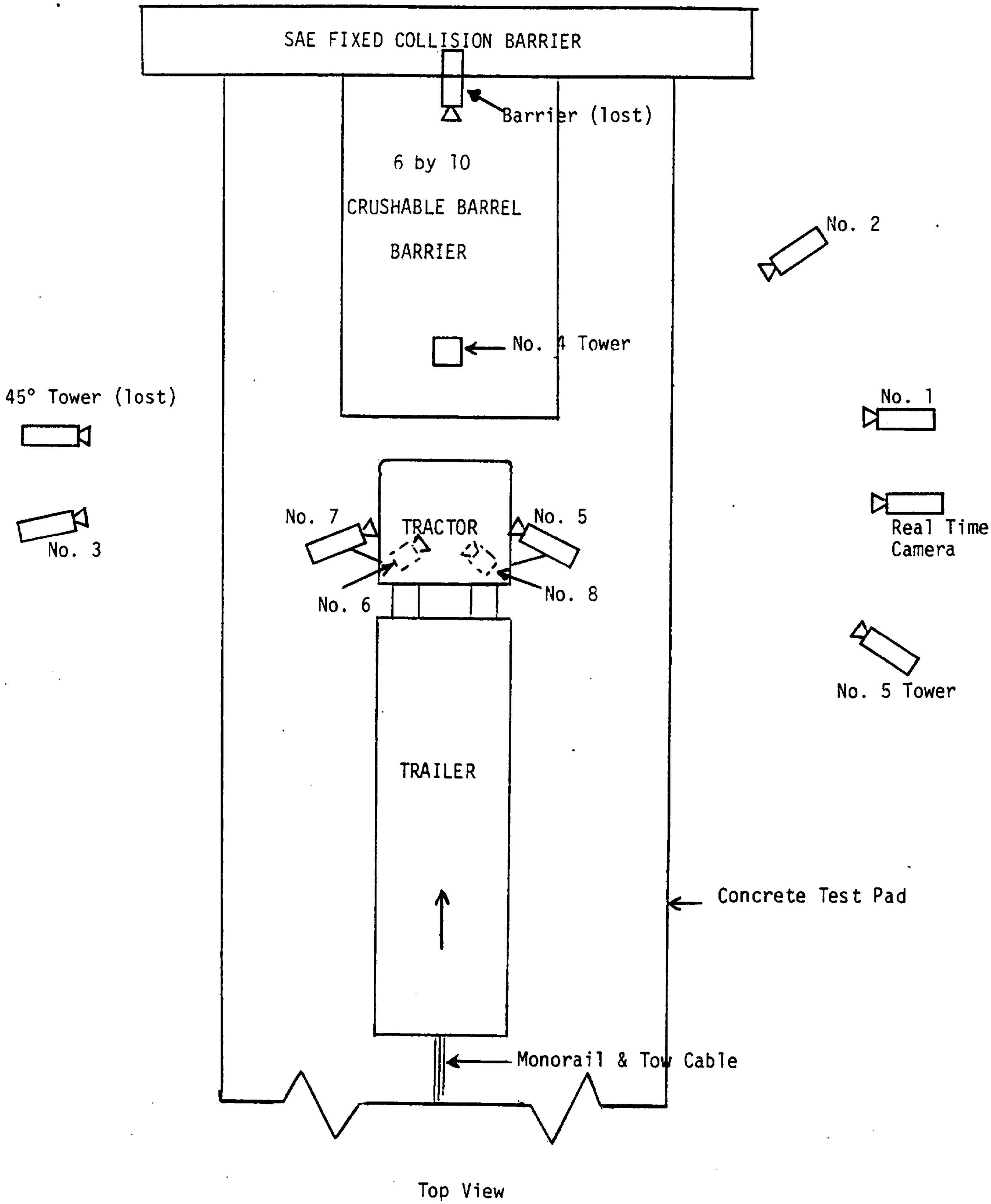


FIGURE 6 CAMERA POSITION FOR FRONTAL IMPACTS

Table 5

HIGH SPEED CAMERA LOCATIONS

Test No.: 1 Vehicle No. E28-1-507

CAMERA NUMBER	VIEW	CAMERA POSITIONS (IN)* X	Y	Z	CAMERA ANGLE (DEG)**	FILM PLANE TO HEAD TARGET (IN) X
1	Impact Event	315	96	56	-2	--
2	Frontal Angle	360	150	56	-4.5	--
3	Impact Event	540	132	150	-10	--
4	Overhead (Tower)	0	60	120	-90	--
5	Right Front Passenger	--	--	--	--	--
6	Right Front Passenger	--	--	--	--	--
7	Driver	--	--	--	--	--
8	Driver	--	--	--	--	--

*X = film plane to monorail centerline
Y = film plane to impact location
Z = film plane to ground

**Referenced to Horizontal Plane

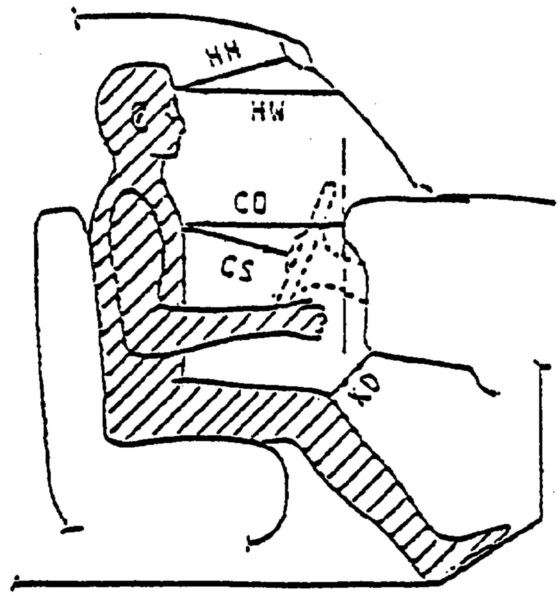
CAMERA NO.	LOCATION	TYPE	LENS (mm)	SPEED (fps)
1	Impact Event	Photosonic	13 mm	900
2	Frontal Angle	Photosonic	25 mm	900
3	Impact Event	Photosonic	13 mm	750
4	Overhead (Tower)	Photosonic	8 mm	850
5	Right Front Passenger	Stalex	8 mm	1550
6	Right Front Passenger	Stalex	8 mm	1400
7	Driver	Stalex	8 mm	1300
8	Drive	Stalex	8 mm	1450
-	Barrier Face	Lost in Film	Processor	--
-	45° Tower	Lost in Film	Processor	--

NOTE: Cameras are numbered according to splicing sequence of film.

(24 fps) real time movie film coverage or pre-crash, post-crash and crash event spliced at start of film.

FIGURE 7 HIGH SPEED CAMERA INFORMATION

	DRIVER	PASS
HH	27	25
HW	31	29.5
CD	31.5	29.5
CS	18.5	
KDL	7.2	8.5
KDR	5.7	8.7



HR	9.5	9.5
HS	9.5	9.5
AD	2.5	3.2
HD	3.0	3.0

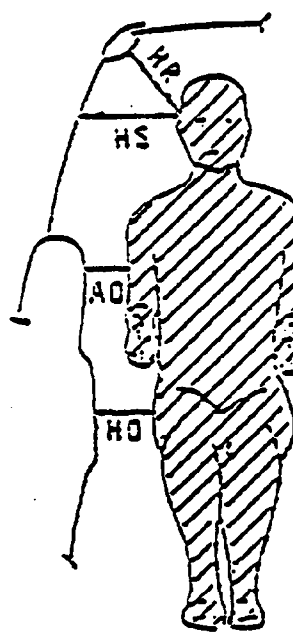


FIGURE 8 OCCUPANT CLEARANCE DIMENSIONS

TABLE 6

DUMMY INJURY CRITERIA VALUES

	MAXIMUM ACCELERATION ("G") *											
	HEAD				CHEST				PELVIS			
	X	Y	Z	R	X	Y	Z	R	X	Y	Z	R
DUMMY (1)	-17	-4	10	18	-11	-2	8	13				
DUMMY (2)	-3	3	6	7	-3	2	5	7				

	MAXIMUM FORCE-FEMUR LOAD (LBS)	
	RIGHT FEMUR	LEFT FEMUR
DUMMY (1)	210	200
DUMMY (2)	30	40

	HEAD INJURY CRITERIA**				SEVERITY INDEX	
	HIC	t_1 (SEC)	t_2 (SEC)	AVE. ACC. (g) t_1 TO t_2	HEAD	CHEST
DUMMY (1)	33.4	.3066	.3399	15.9	47.5	
DUMMY (2)	22.5	.1923	.6993	4.6	28.0	

*DEFINED AS EXCEEDING 0.003 SEC. DURATION
**AS DEFINED IN FMVSS NO. 208

NOTE: Resultant (R) accelerations are computed as functions of time. See Figures B-4, B-8, B-14, and B-18.

IV. DISCUSSION OF RESULTS

The test was a planned low deceleration, controlled event. The barrel array forming the crushable barrier had been designed to produce an impact pulse of approximately 2.5 g at about 1/2 second duration after the initial transient. Test values were very close to these calculations even though individual elements of the barrier crushed in a variety of patterns. A four-unit load cell array measuring impact forces at the rear of the barrier indicated excellent lateral symmetry in the crush but somewhat higher loading of the top pair (i.e., vertical load asymmetry).

Vehicle damage was limited to minor sheet metal distortion at the front end of the tractor. This was because the deceleration loads were taken out through the vehicle's two longitudinal frame rails, the ends of which are located at the front-most position of the vehicle. These frame rails are the main load-bearing members of the vehicle's structure. The vehicle's front bumper attaches directly to the ends of the frame rails. There was no deformation or buckling of these frame rails. The unbelted driver seat occupant contacted the steering wheel at both head and chest areas but contact forces were low due to the low deceleration loads experienced during the test. The restrained co-driver seat occupant did not make contact with any internal surface. After the crash, the vehicle was driveable under its own power following removal of a minor interference between the clutch pedal arm and the distorted sheet metal.

Relative to fixed barrier impacts, which commonly have durations of less than 200 milliseconds, this crash event continued through about two-thirds of a second. The substantive driver seat occupant responses - contacts of head and chest with the steering wheel - occurred in the neighborhood of 300 milliseconds. In the mild crash environment of only about 2-1/2 g's as measured in the cab, the chest deceleration and HIC number were small (see Appendix B).

This test represents one point on a continuum of values for non-catastrophic deceleration of a heavy truck frontal impact. It is evident that the mild crash conditions investigated in this test, which are considered to be representative of many real-life heavy rig accidents where the vehicle stays upright, the occupants remain in the cab, and the vehicle comes to rest over a very long stroke, do not produce serious injury to the occupants. Continued analysis of heavy truck accident data files by Calspan under a separate contract (DTNH22-80-C-07457) is designed to identify the number and type of crashes, similar to this but in which truck occupants are more seriously injured. The conditions producing these higher levels of trauma, assuming they are not totally catastrophic in nature, could serve as the basis for further testing of this type.

Of particular note is the structural response of the combination unit to this type of crash loading. Under these conditions the entire vehicle acted as a rigid, unyielding column. The load was essentially transferred equally and almost instantaneously throughout the length of the combination unit vehicle. Such a response points to the need to study tractor-trailer attachment mechanisms, cargo retention techniques/mechanisms, as well as trailer cargo retaining structure relative to their respective abilities to withstand crash loading conditions which would otherwise be survivable.

It would be inappropriate to extrapolate the findings of this test to conditions of higher deceleration. Therefore, additional tests involving impacts at higher deceleration values (perhaps at a 10 g level) are recommended.

Reference:

1. Test Plan for Heavy Truck Pilot Crash Tests. Calspan Report No. 6748-V-1. October 1980.

APPENDIX A

PHOTOGRAPHS

This appendix contains still photographs of various facets of the test. Both pre-test and post-test photographs are included and groupings have been made in an effort to illustrate test operations in the most effective way. Particular attention is called to:

- Figure A-4, which shows the minor damage sustained by the vehicle in this impact.
- Figure A-11, which illustrates the deformation of the drum array and the bending of the front face that produced the vehicle damage.
- Figure A-15, which shows the cabling employed to inhibit articulation and catastrophic separation of the tractor and trailer in the crash event.
- Figure A-18, which provides a view of the means used to tie down the load so as to prevent shifting.

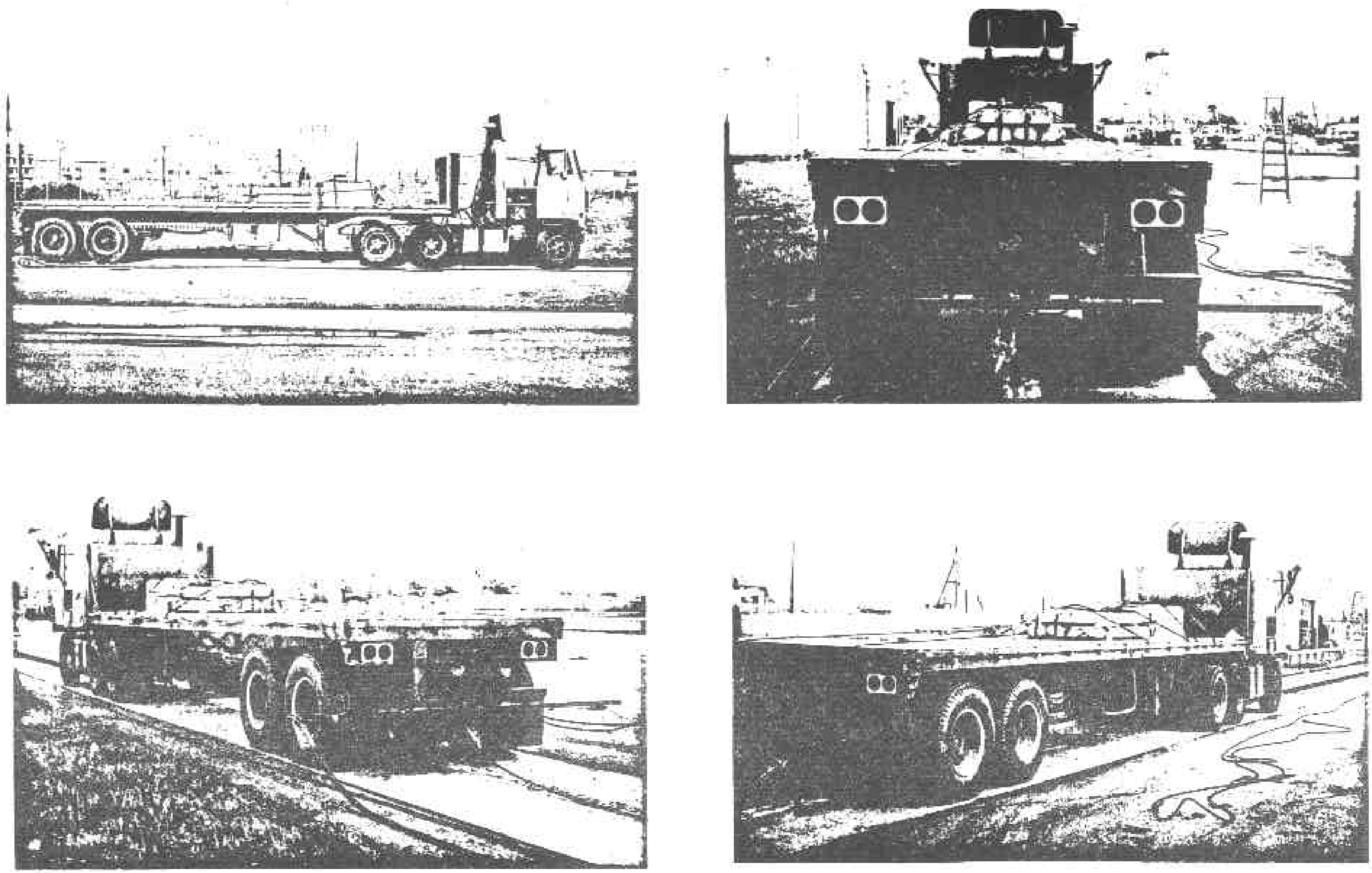


FIGURE A-1 PRE-TEST VIEW OF TRACTOR AND TRAILER

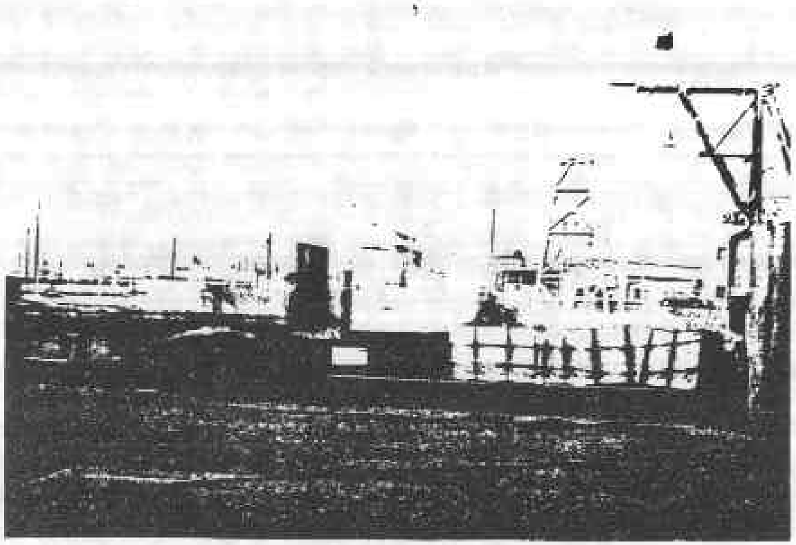


FIGURE A-2 VIEW OF IMPACT

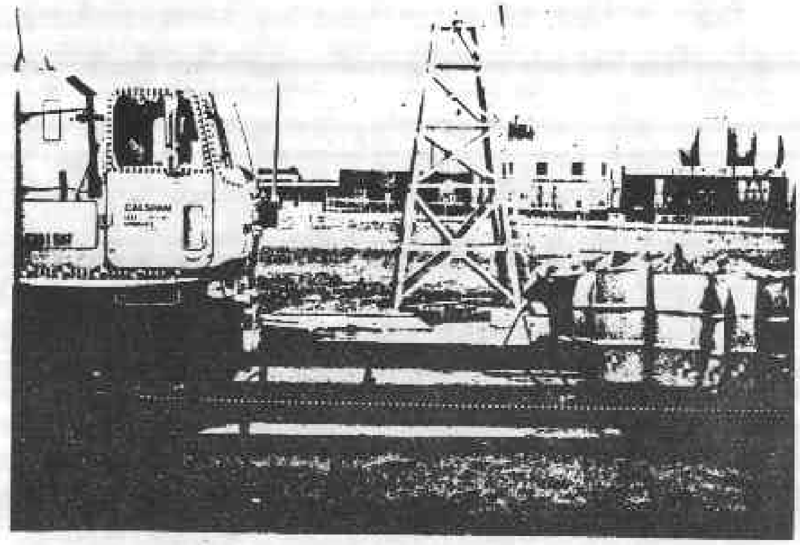


FIGURE A-3 POST-TEST VIEW OF IMPACT

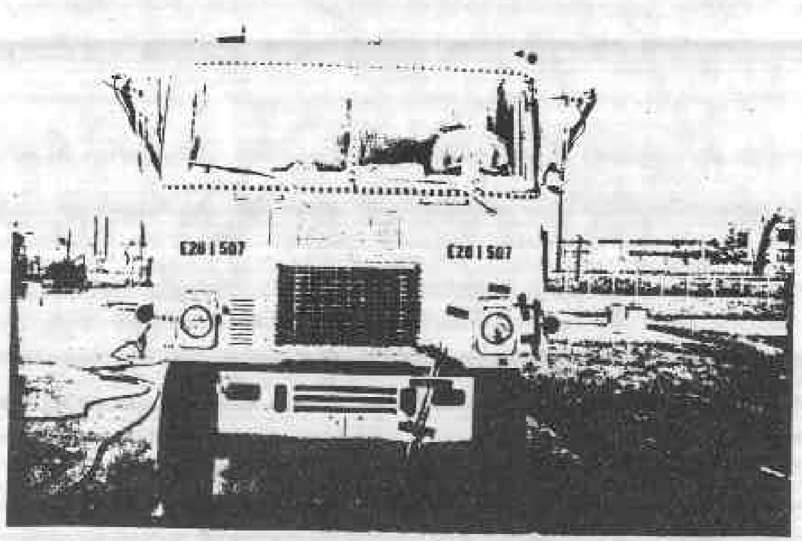


FIGURE A-4 PRE- AND POST-TEST VIEW OF VEHICLE FRONT

FIGURE A-5 PRE- AND POST-TEST VIEW OF FRONT THREE QUARTER

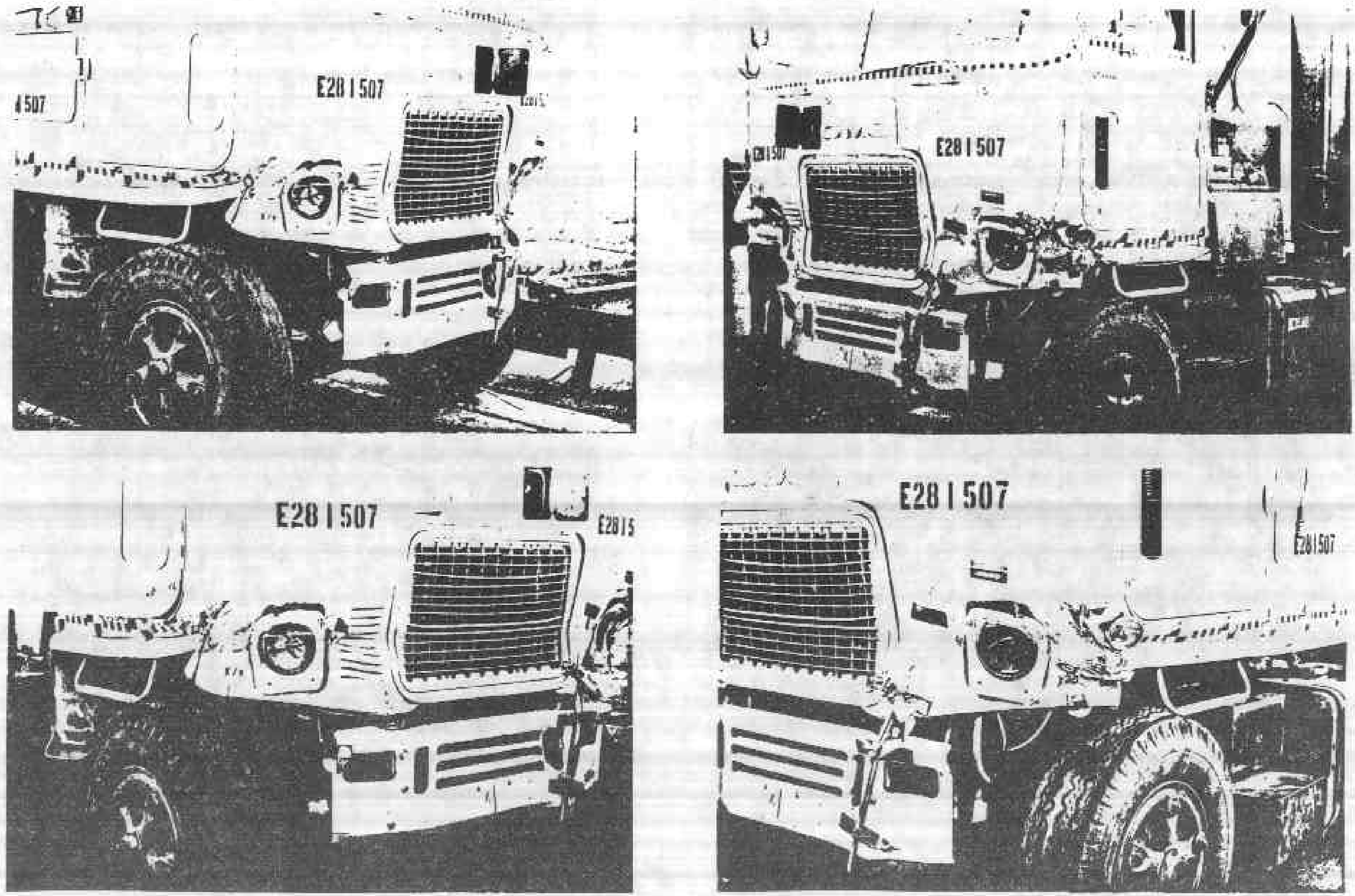


FIGURE A-6 POST-TEST VIEWS OF VEHICLE FRONT DAMAGE

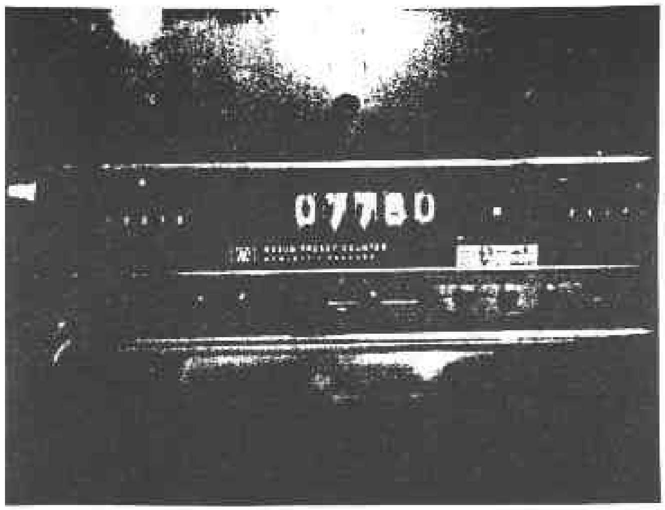


FIGURE A-7 VELOCITY TRAP COUNTER DISPLAY TIME IN SECONDS OVER 40 INCHES

FIGURE A-8 PRE-TEST VIEW OF CRACK IN STEERING WHEEL

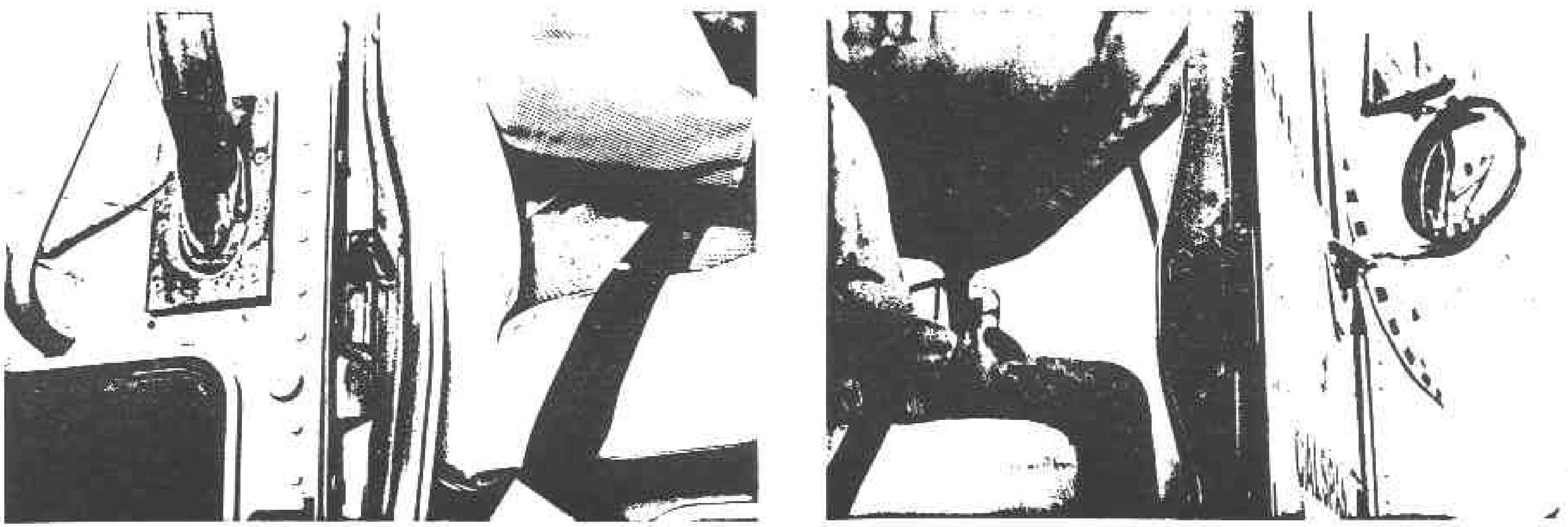


FIGURE A-9 VIEW OF DOOR LOCKING MECHANISM

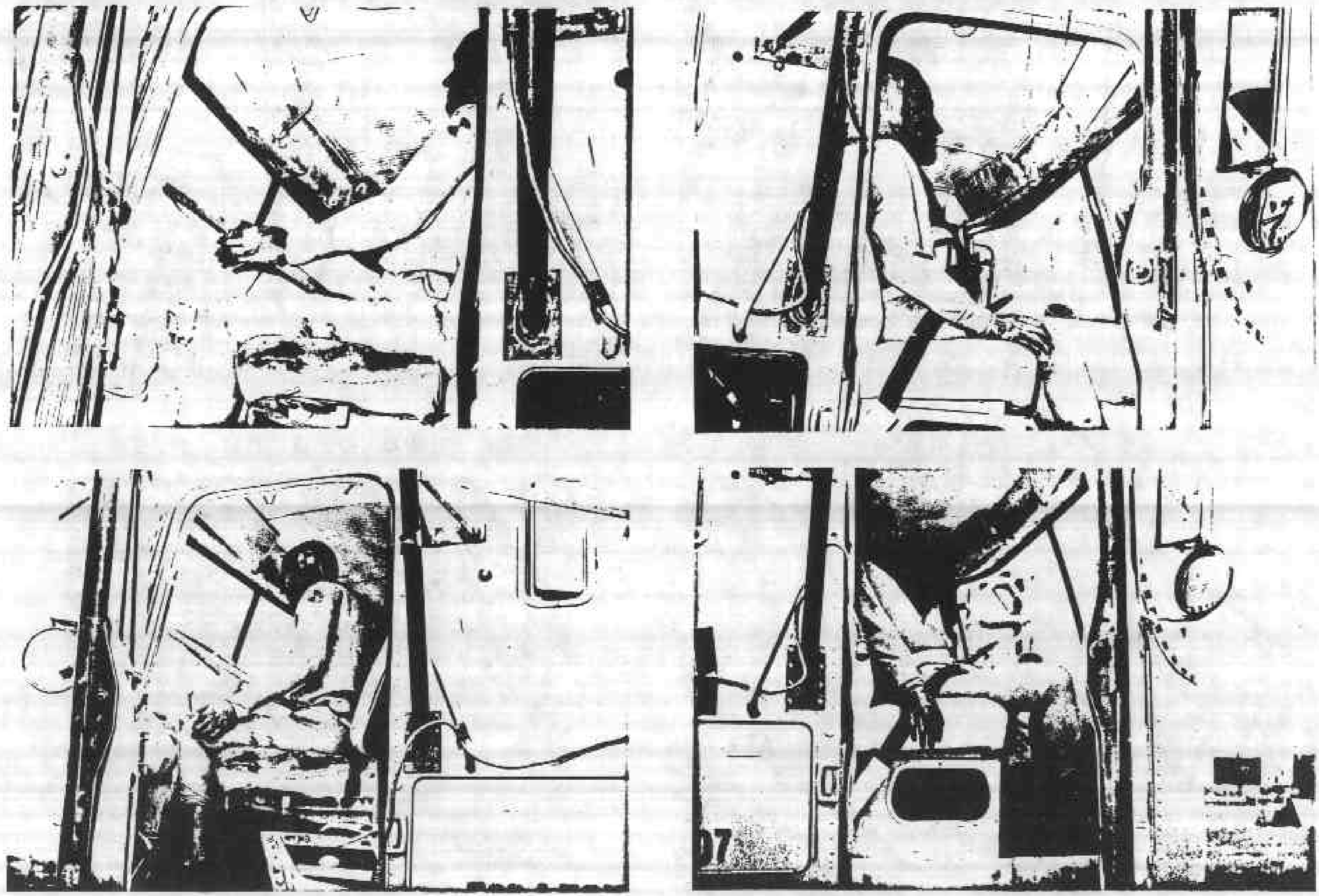


FIGURE A-10 PRE- AND POST-TEST VIEWS OF DRIVER AND RIGHT FRONT PASSENGER POSITION

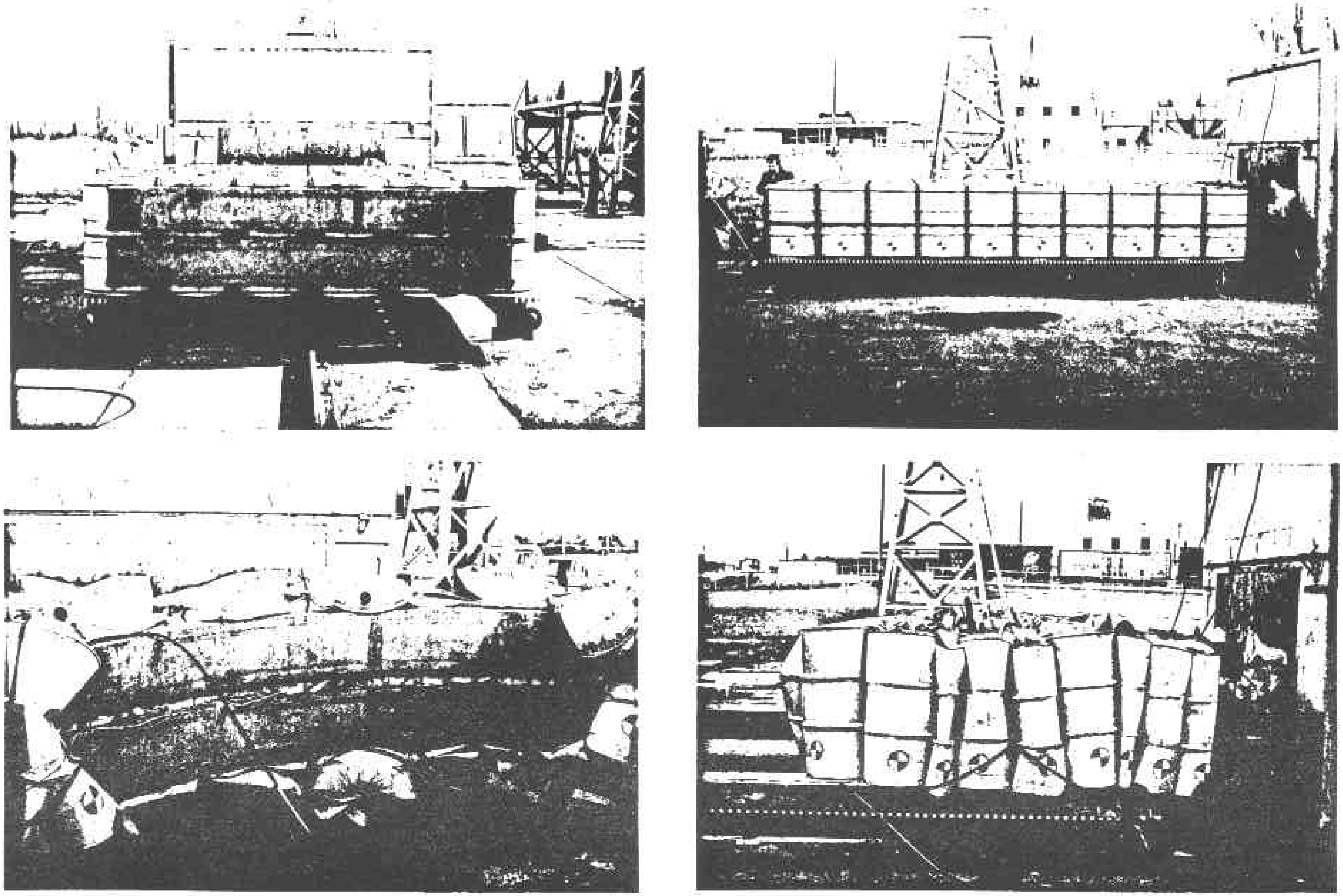


FIGURE A-11   PRE- AND POST-TEST VIEW OF CRUSHABLE BARREL BARRIER

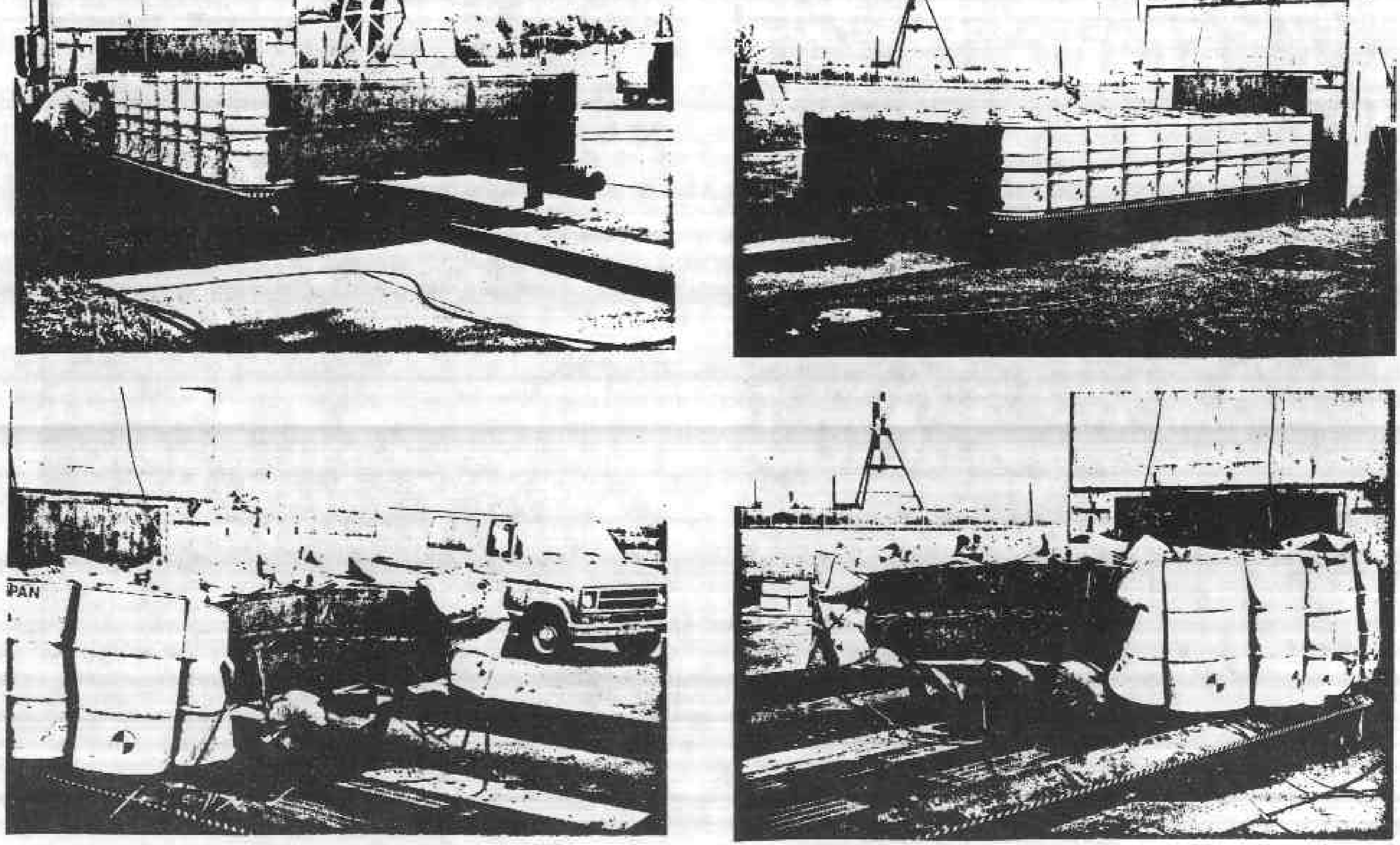


FIGURE A-12 PRE- AND POST-TEST THREE QUARTER VIEW OF CRUSHABLE BARREL BARRIER

FIGURE A-13 PRE- AND POST-TEST OVERHEAD VIEW OF CRUSHABLE BARREL BARRIER

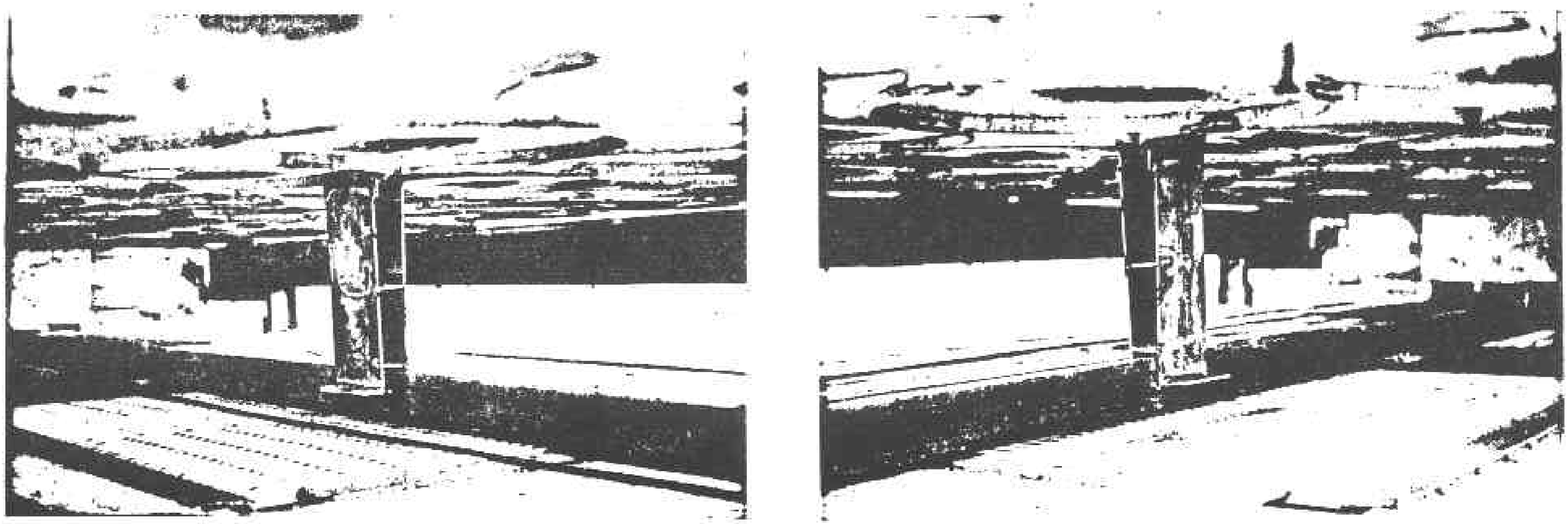


FIGURE A-14 VIEW OF METAL LEG TO ELEVATE AND GUIDE BARREL ARRAY

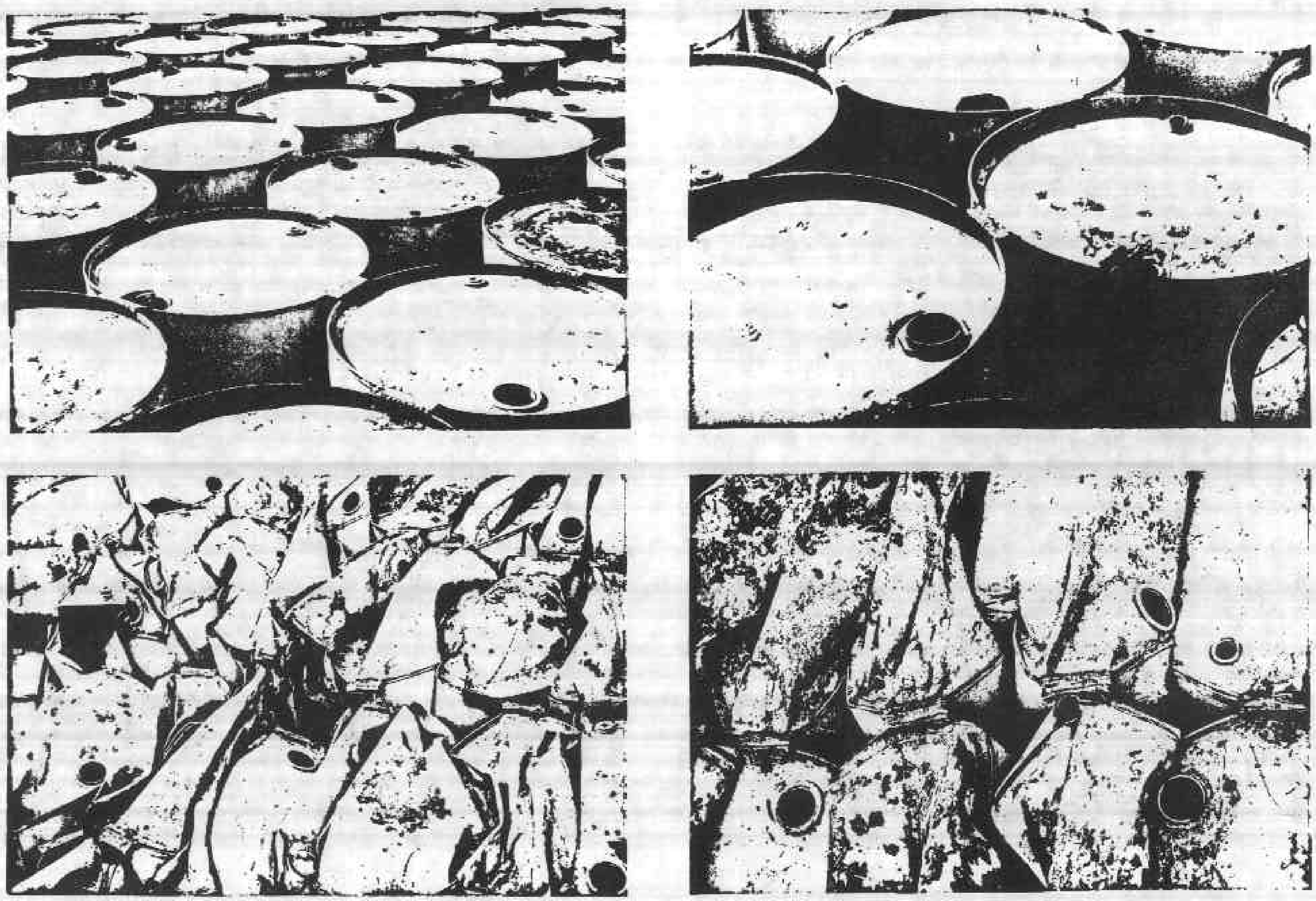


FIGURE A-15 VIEW OF BARREL INTERCONNECTED WELDMENTS

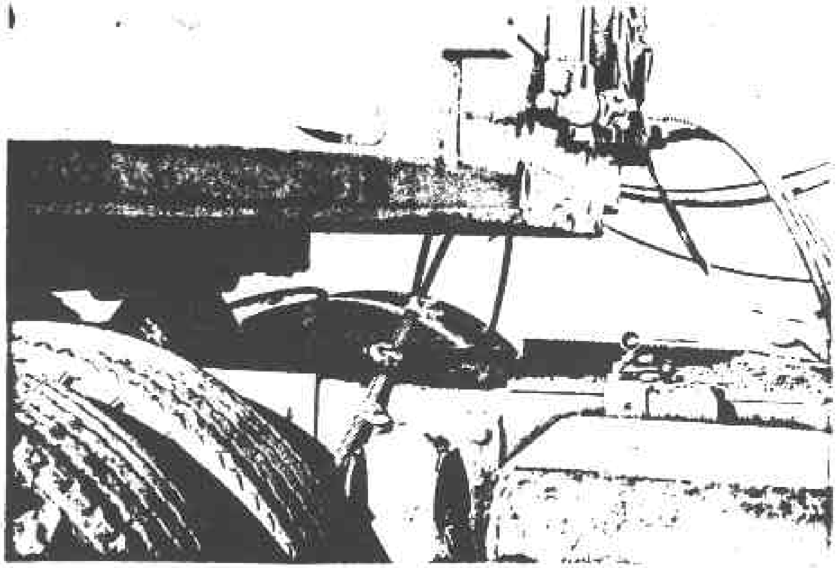


FIGURE A-16 VIEW OF CABLE BETWEEN TRACTOR AND TRAILER

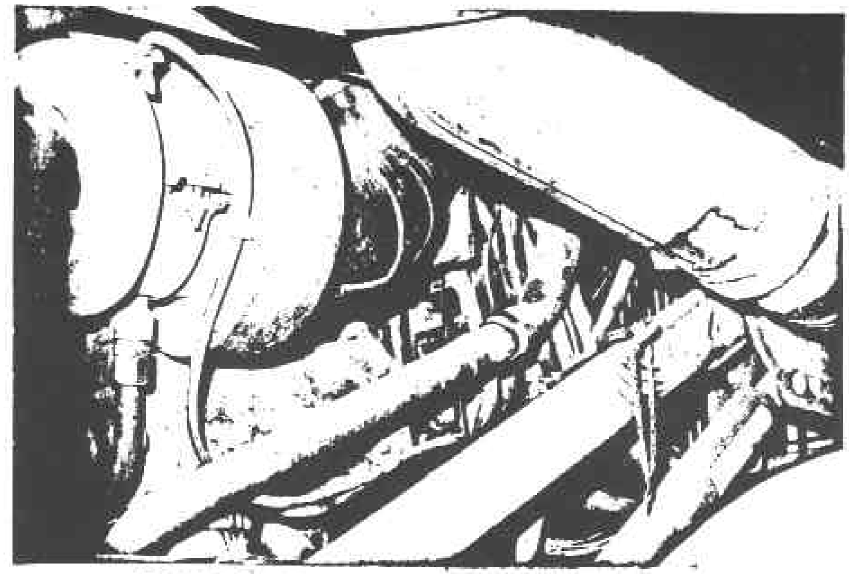


FIGURE A-17 VIEW OF ENGINE

FIGURE A-18 VIEW OF RIGHT AND LEFT TRACTOR WHEEL WELLS

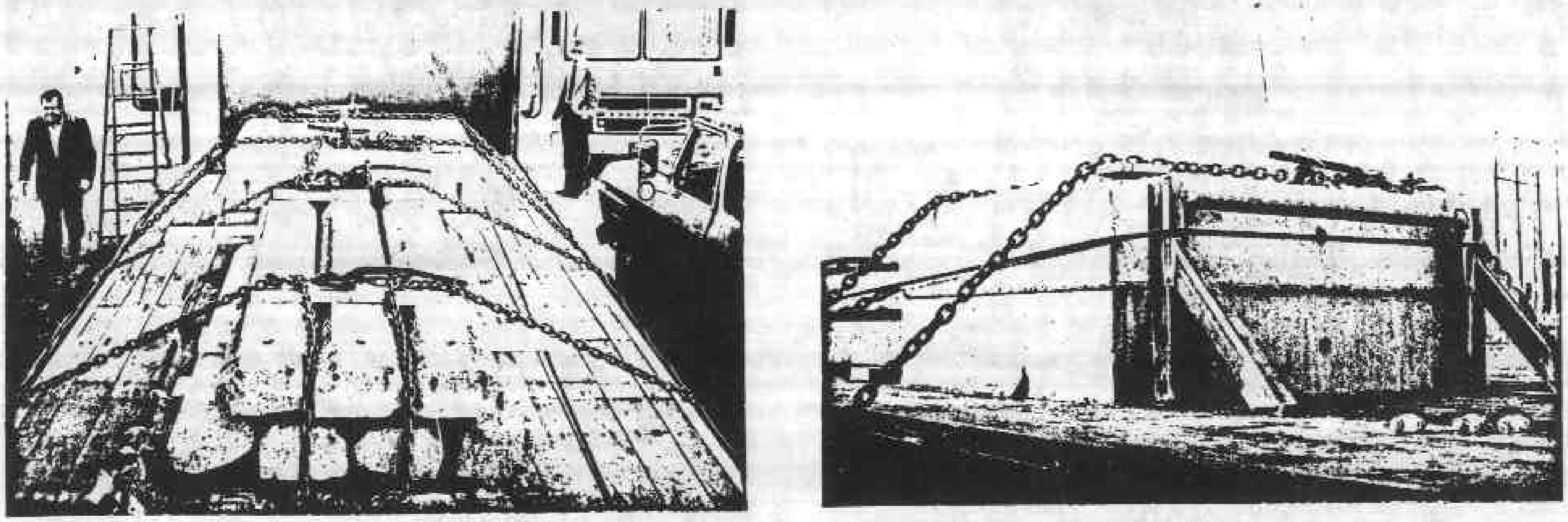


FIGURE A-19 VIEW OF CHAINS AND CABLES USED TO TIE DOWN TRAILER LOAD

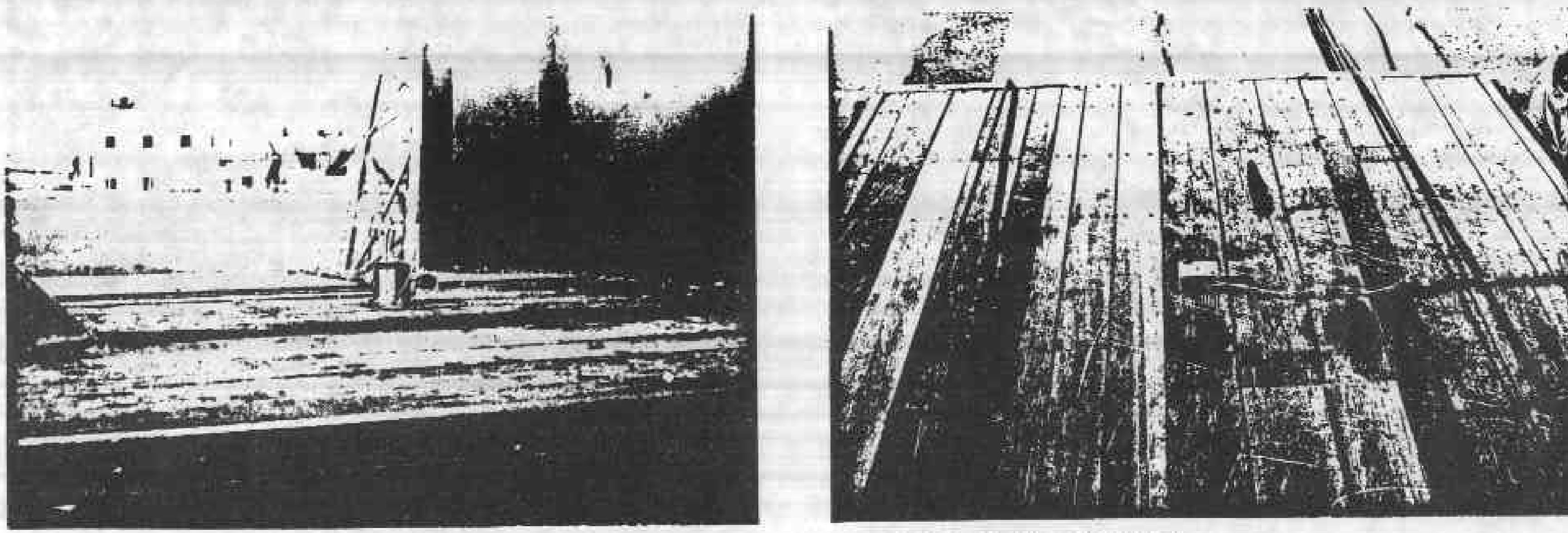


FIGURE A-20 VIEW OF FRONT AND REAR TRAILER ACCELEROMETERS

FIGURE A-21 ENGINE MOUNTED ACCELEROMETER

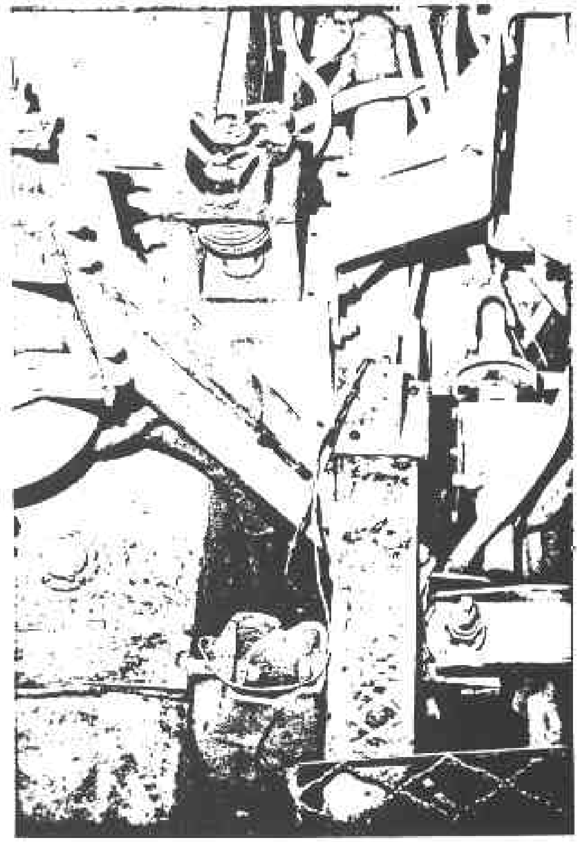


FIGURE A-22 TRACTOR LEFT FRAME RAIL ACCELEROMETER

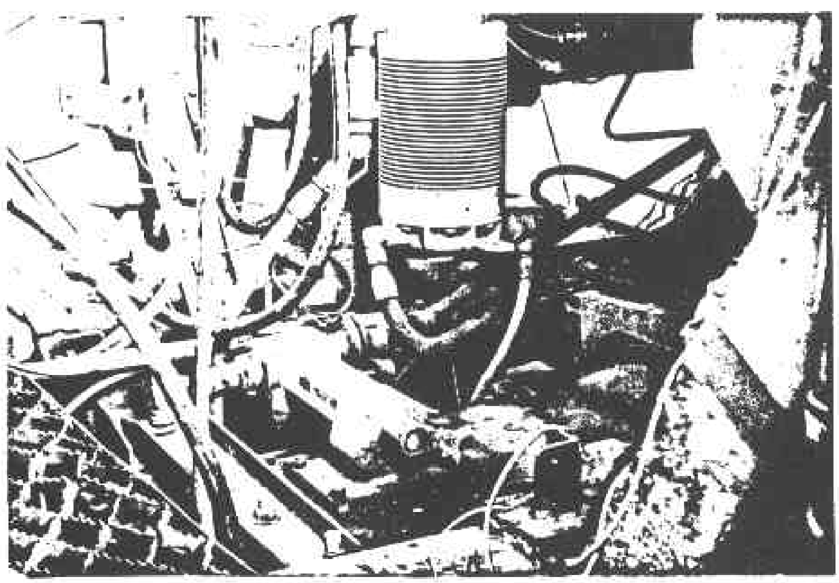


FIGURE A-23 TRACTOR RIGHT FRAME RAIL ACCELEROMETER

APPENDIX B

VEHICLE AND DUMMY RESPONSE DATA

This appendix contains processed time histories for each of the data channels that were utilized in the test. In addition to the directly measured variables, plots of selected accelerometer outputs (to provide velocity and distance information) are presented. All data have been filtered through specified filters defined in the following list -

Occupant head accelerometer data:	1000 Hz
Occupant chest accelerometer data:	180 Hz
Occupant femur load data	600 Hz
Vehicle acceleration data	60 Hz
Barrier load cells	60 Hz

Response data were reduced for a period of about 800 milliseconds beyond initial impact. The Calspan DDAS (for Digital Data Analysis System) was reprogrammed to accommodate this elongated event duration.

In the format of this section, the individual data channels are identified in Table B-1; then, the driver seat occupant data (Pos #1) are given in Table B-2 and Figures B-1 through B-10. These are followed by similar information for the co-driver occupant (Pos #2) in Table B-3 and Figures B-11 through B-20. A series of vehicle acceleration traces are presented next; velocity and displacement information in the longitudinal (X) axis for the sensors at the engine (Figures B-21, B-22, and B-23), the left frame rail (Figures B-26, B-27, and B-28), the cab centerline (Figures B-32, B-33, and B-34), the trailer front (Figures B-37, B-38, and B-39), and the trailer rear (Figures B-42, B-43, and B-44) is also given. Data from the load cells, which were mounted between the drum array and the fixed barrier, are shown in Figures B-46 through B-47. Finally, tractor pitching motion, as measured by a rate gyro mounted in the cab, is illustrated by Figure B-50. The associated pitch angle (obtained by integration over the 800 milliseconds for data were reduced) is shown in Figure B-51.

TABLE B-1

*** ACTIVE CHANNELS ***

CHANNEL	DESCRIPTION
1	POS#1 HEAD X
2	POS#1 HEAD Y
3	POS#1 HEAD Z
4	POS#1 CHEST X
5	POS#1 CHEST Y
6	POS#1 CHEST Z
7	POS#1 RIGHT FEMUR
8	POS#1 LEFT FEMUR
9	POS#2 RIGHT FEMUR
10	POS#2 LEFT FEMUR
11	PITCH RATE
12	TOP RIGHT BARRIER
13	LOWER BARRIER FACE
14	POS#2 HEAD X

TABLE B-1 (Cont'd)

*** ACTIVE CHANNELS ***

CHANNEL	DESCRIPTION
15	POS#2 HEAD Y
16	POS#2 HEAD Z
17	POS#2 CHEST X
18	POS#2 CHEST Y
19	POS#2 CHEST Z
20	ENGINE X
21	ENGINE Y
22	ENGINE Z
23	LEFT FRAME RAIL X
24	LEFT FRAME RAIL Z
25	RIGHT FRAME RAIL X
26	RIGHT FRAME RAIL Z
27	CAB CENTERLINE X
28	CAB CENTERLINE Y

TABLE B-1 (Cont'd)

*** ACTIVE CHANNELS ***

CHANNEL	DESCRIPTION
29	CAB CENTERLINE Z
30	TRAILER FRONT X
31	TRAILER FRONT Y
32	TRAILER FRONT Z
33	TRAILER REAR X
34	UPPER BARRIER FACE
35	TRAILER REAR Z
36	BOTTOM LT. BARRIER
37	TOP LEFT BARRIER L
38	BOTTOM RT. BARRIER
39	TOTAL BARRIER LOAD
40	TIMING

TABLE B-2

HEAD INJURY CRITERION
HEAD SEVERITY INDEX

GMC HEAVY TRUCK BARRIER TEST #1

RUN= 507

POS#1 HEAD RESULTANT

HIC= 33.4 FROM T1= .30660 TO T2= .33990

AVERAGE ACCELERATION BETWEEN T1 AND T2= 15.9G'S

EVENT TIME= 800.0 MSEC

SEVERITY INDEX= 47.5

FIGURE B-1

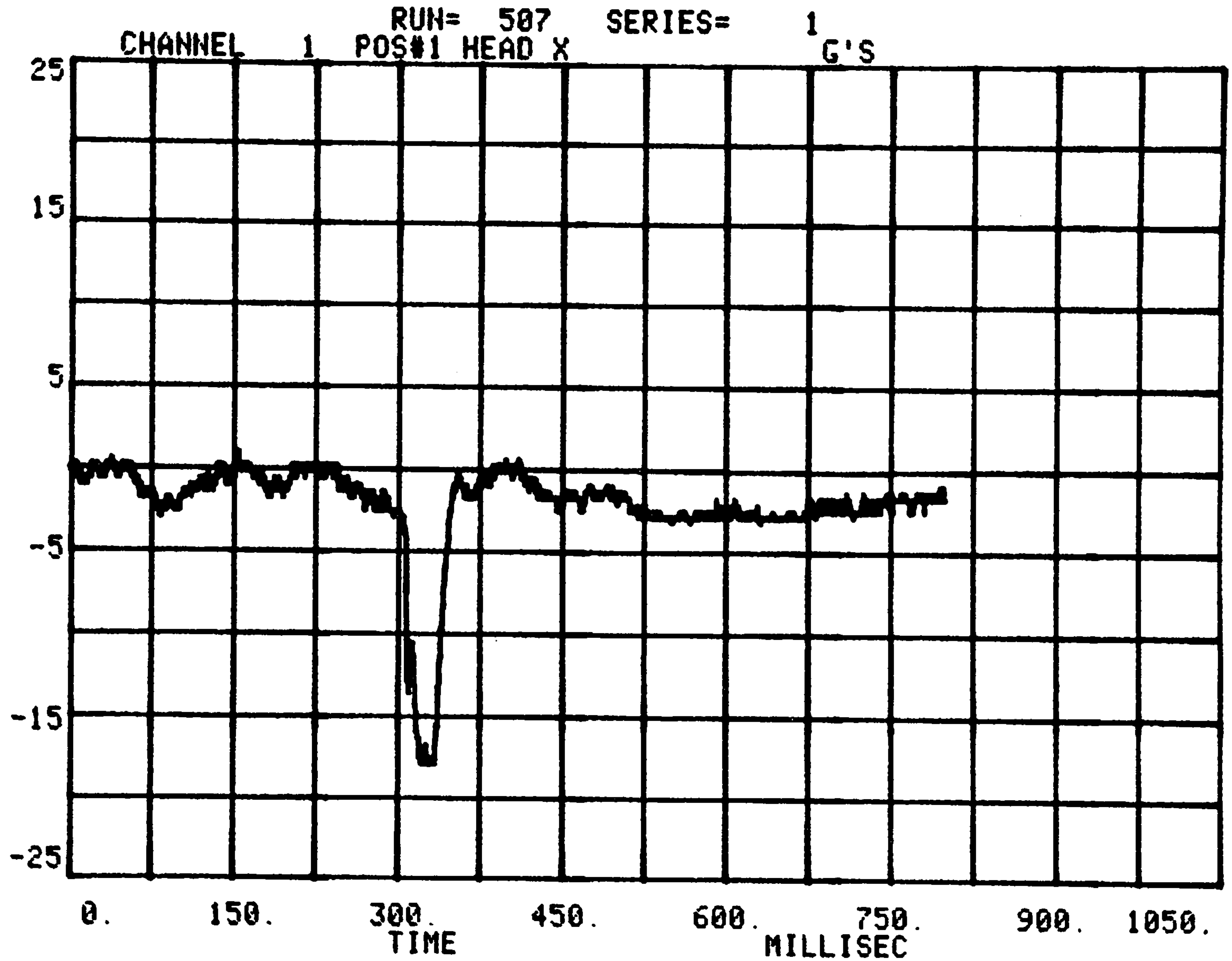

RUN= 507 SERIES= 1
CHANNEL 1 POS#1 HEAD X
G'S
25
15
5
-5
-15
-25
0.
150.
300.
450.
600.
750.
900.
1050.
TIME
MILLISEC

FIGURE B-2

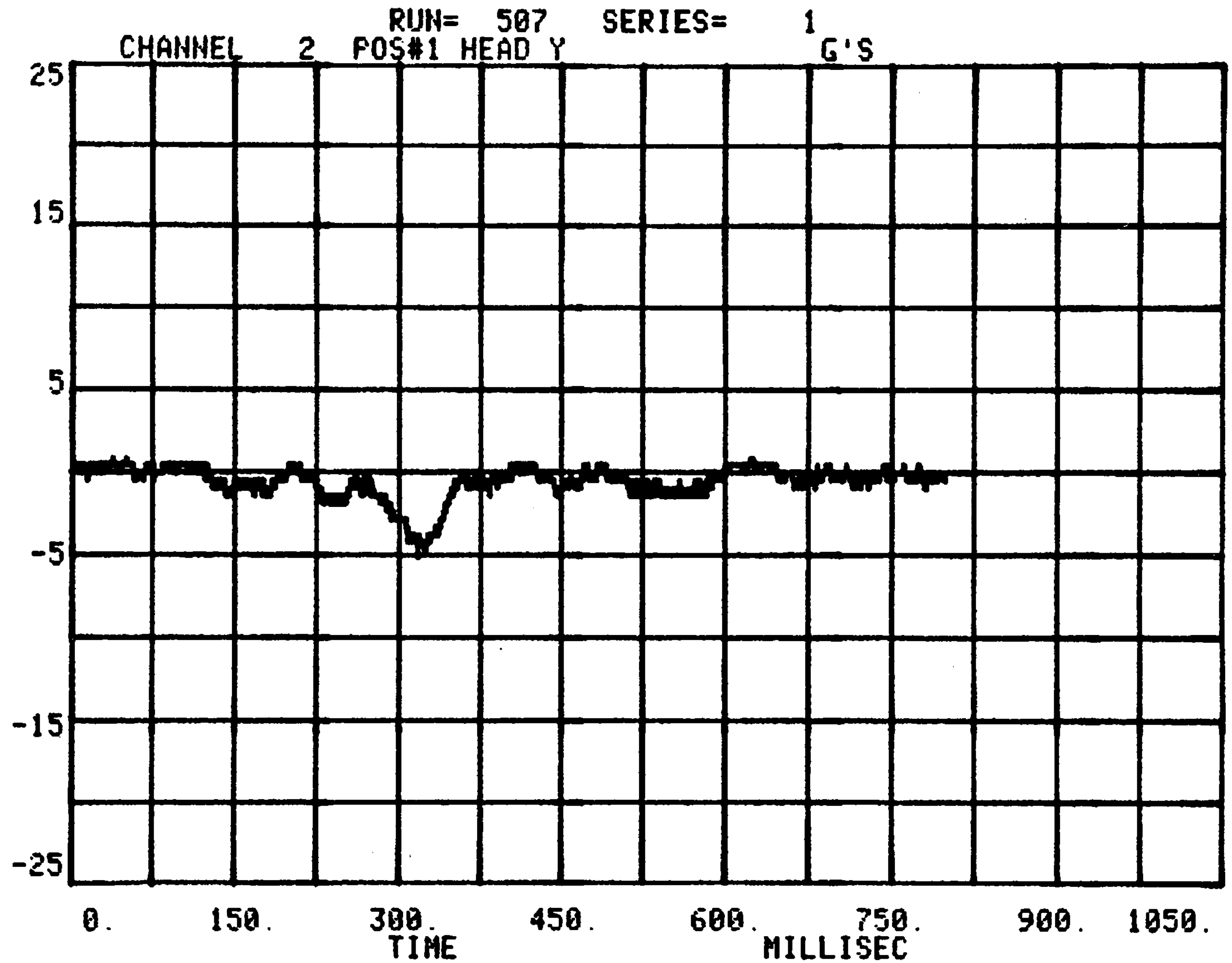

RUN= 507 SERIES= 1
CHANNEL 2 POS#1 HEAD Y
G'S
25
15
5
-5
-15
-25
0.
150.
300.
450.
600.
750.
900.
1050.
TIME
MILLISEC

FIGURE B-3

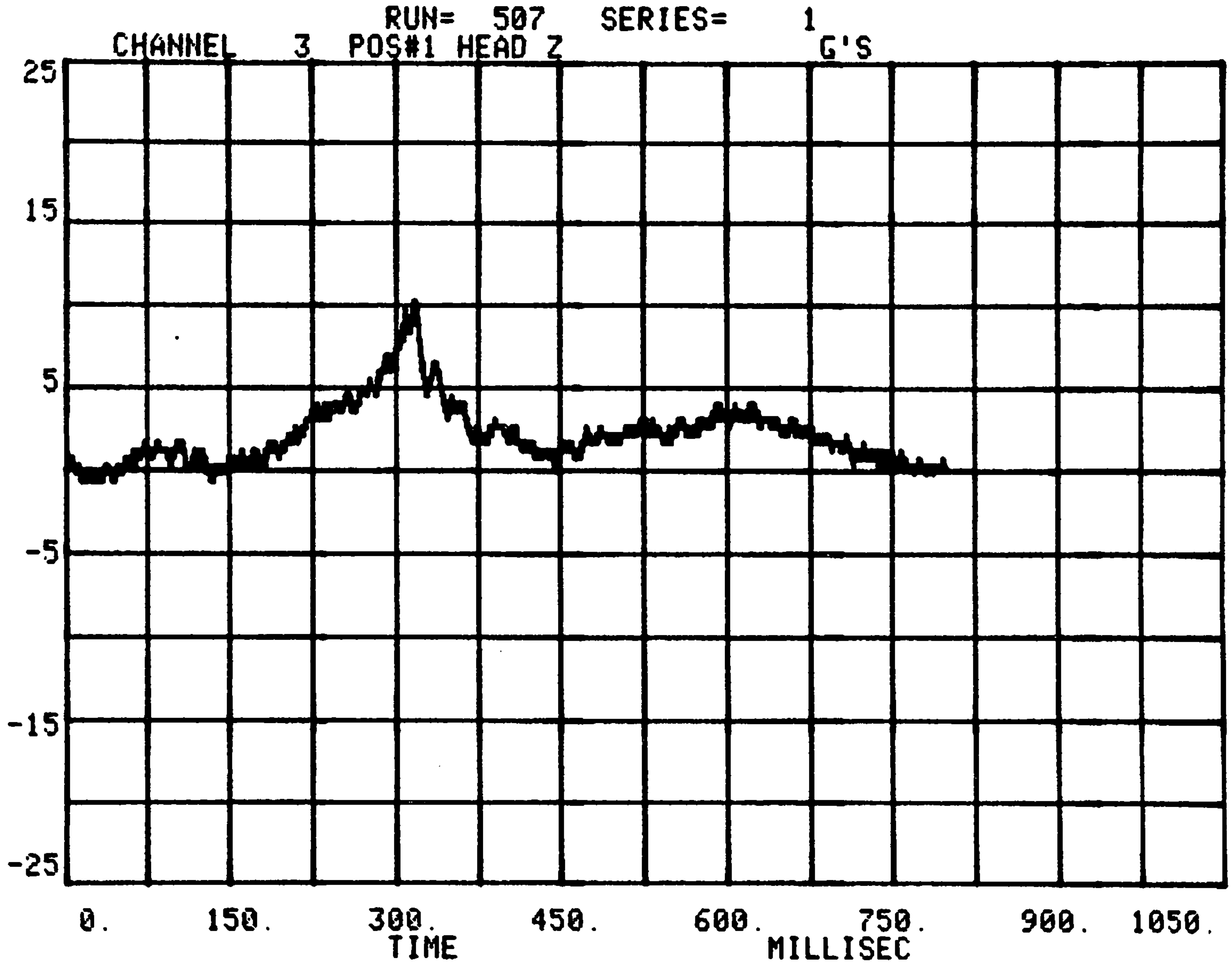
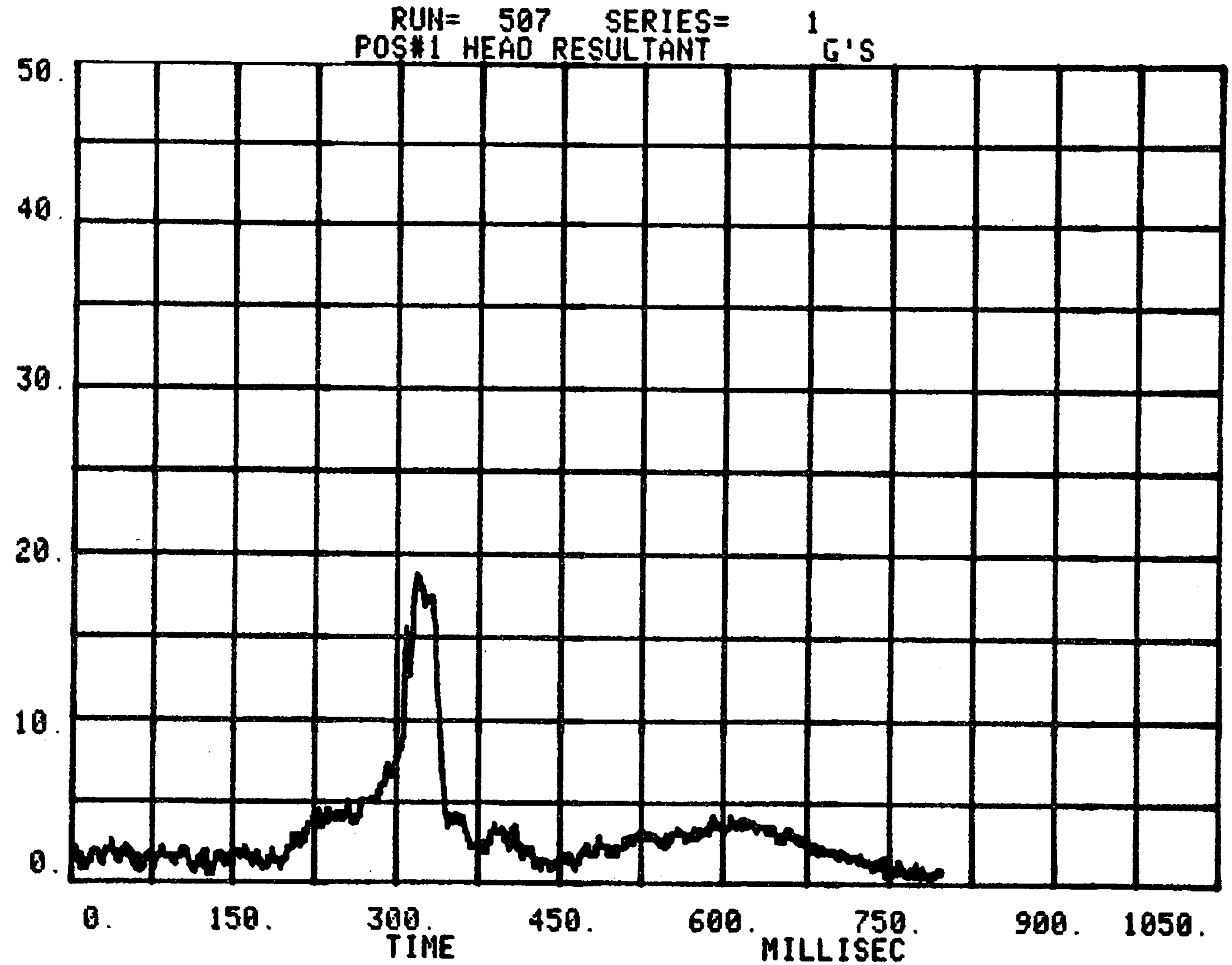
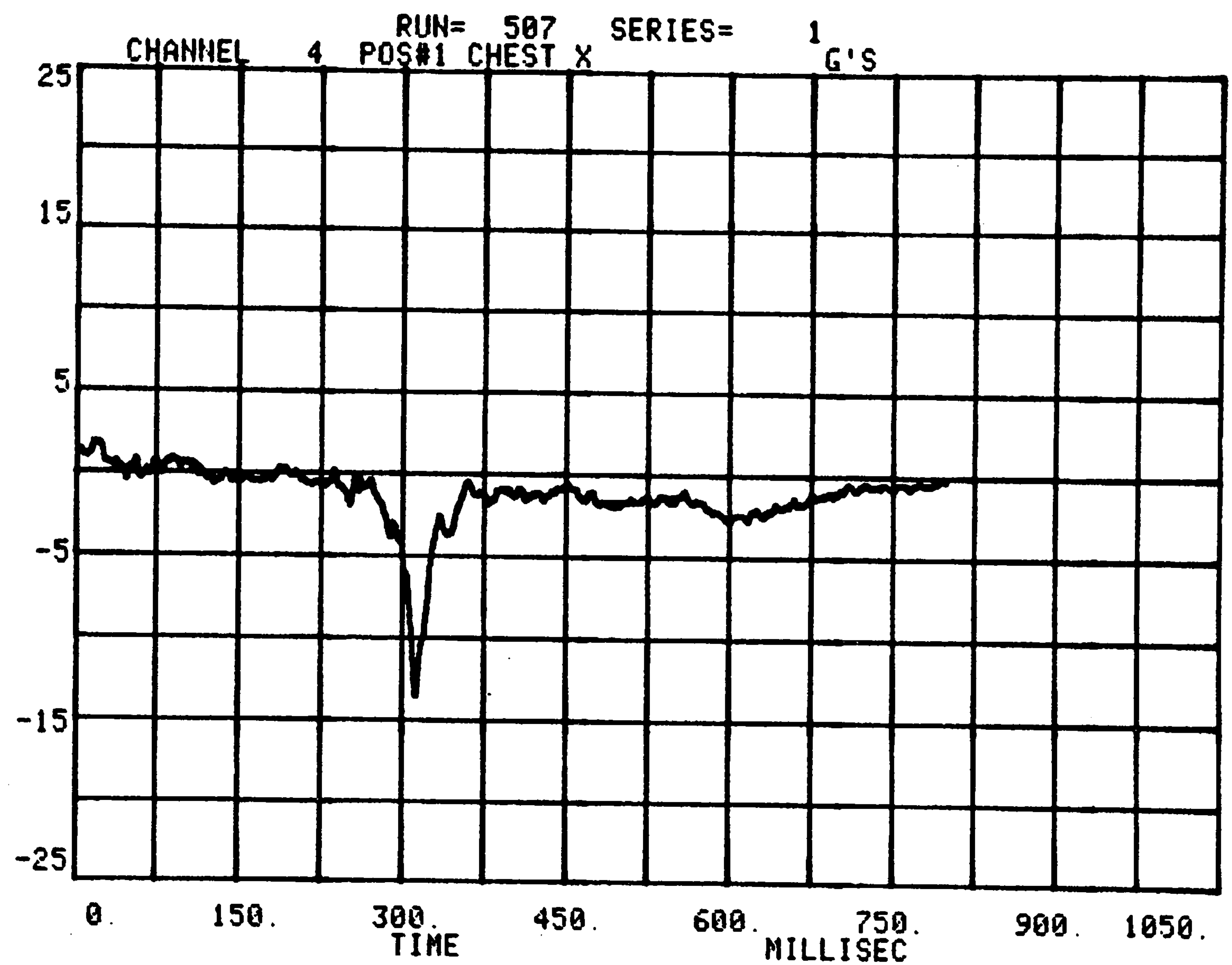

RUN= 507 SERIES= 1
CHANNEL 3 POS#1 HEAD Z
G'S
25
15
5
-5
-15
-25
0.
150.
300.
450.
600.
750.
900.
1050.
TIME
MILLISEC

FIGURE B-4



RUN= 507 SERIES= 1
POS#1 HEAD RESULTANT G'S
50.
40.
30.
20.
10.
0.
0.
150.
300.
450.
600.
750.
900.
1050.
TIME
MILLISEC

FIGURE B-5



RUN= 507 SERIES= 1
CHANNEL 4 POS#1 CHEST X
G'S
25
15
5
-5
-15
-25
0.
150.
300.
450.
600.
750.
900.
1050.
TIME
MILLISEC

FIGURE B-6

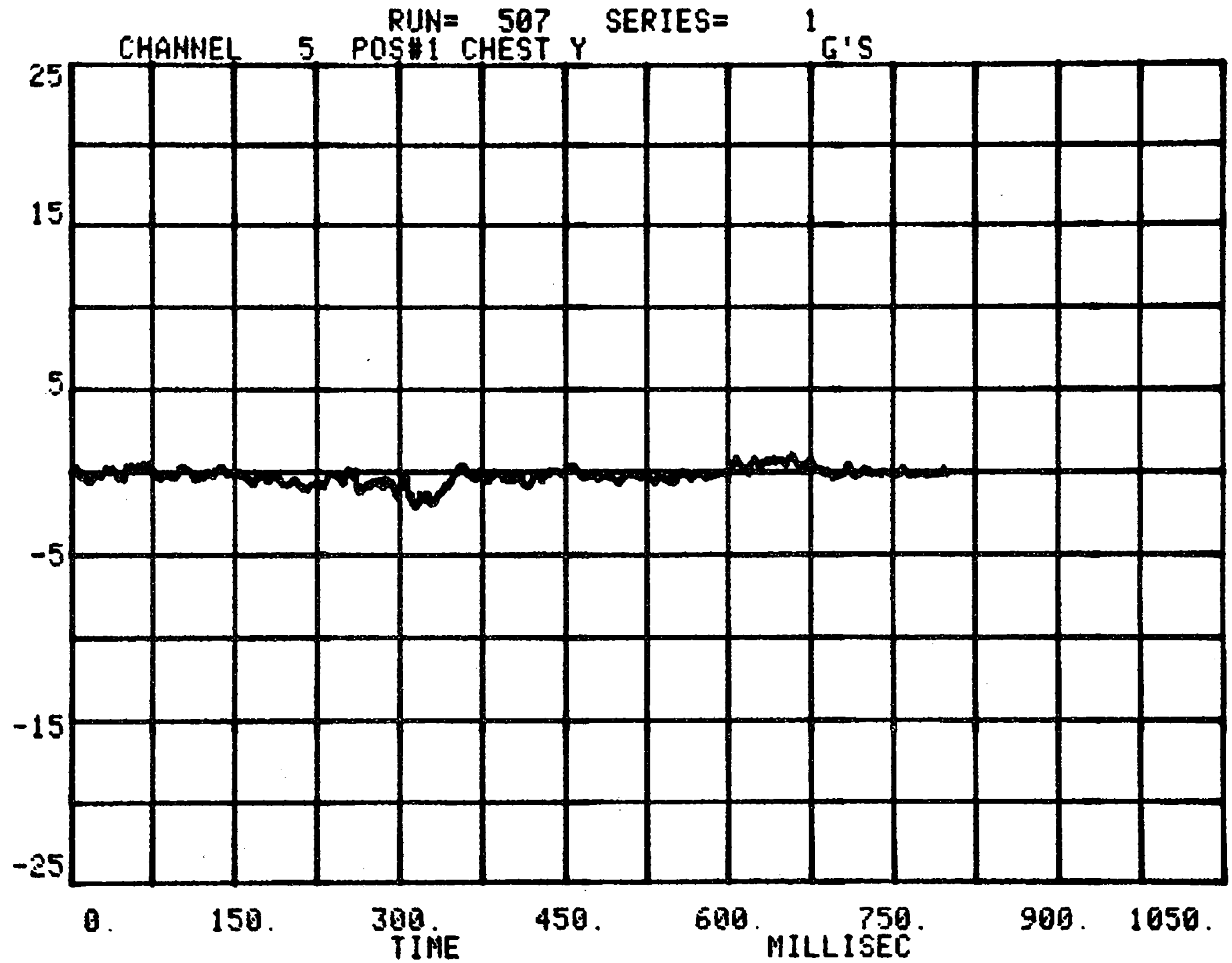

RUN= 507 SERIES= 1
CHANNEL 5 POS#1 CHEST Y G'S
25
15
5
-5
-15
-25
0.
150.
300.
450.
600.
750.
900.
1050.
TIME
MILLISEC

FIGURE B-7

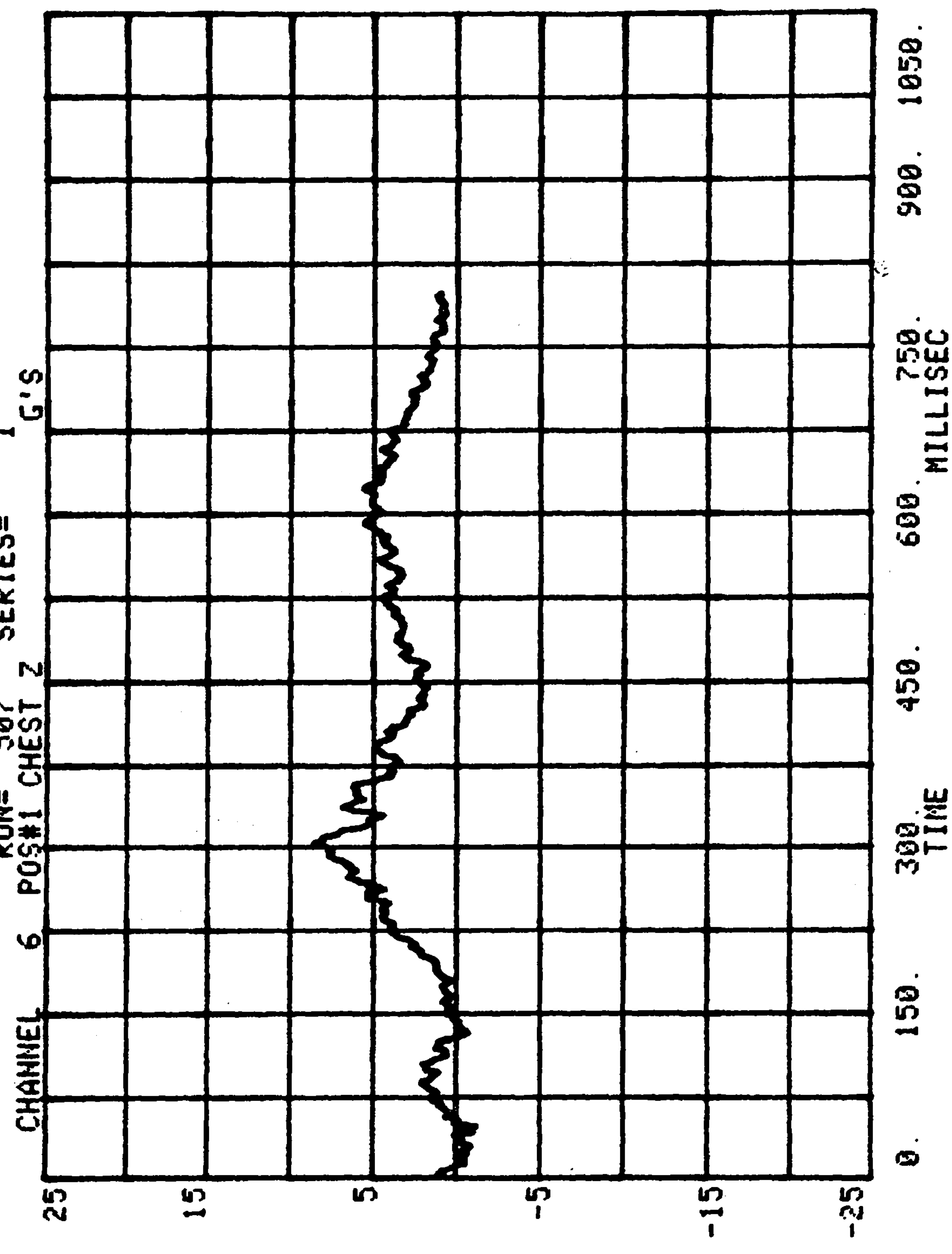

CHANNEL 6 RUN= 507 SERIES= 1
POS#1 CHEST Z G'S
25
15
5
-5
-15
-25
0.
150.
300.
450.
600.
750.
900.
1050.
TIME
MILLISEC

FIGURE B-8

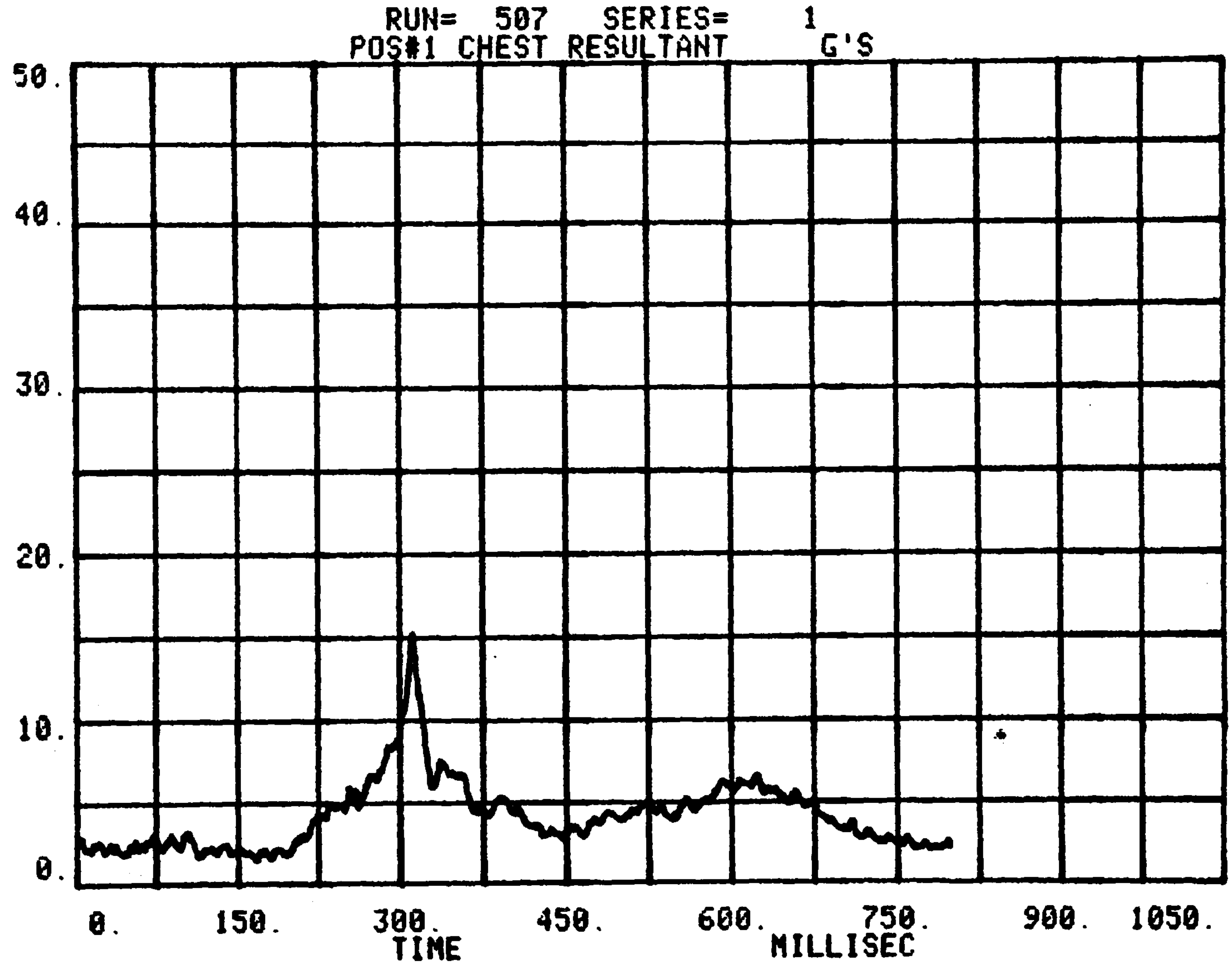

RUN= 507 SERIES= 1
POS#1 CHEST RESULTANT G'S
50.
40.
30.
20.
10.
0.
0.
150.
300.
450.
600.
750.
900.
1050.
TIME
MILLISEC

FIGURE B-9

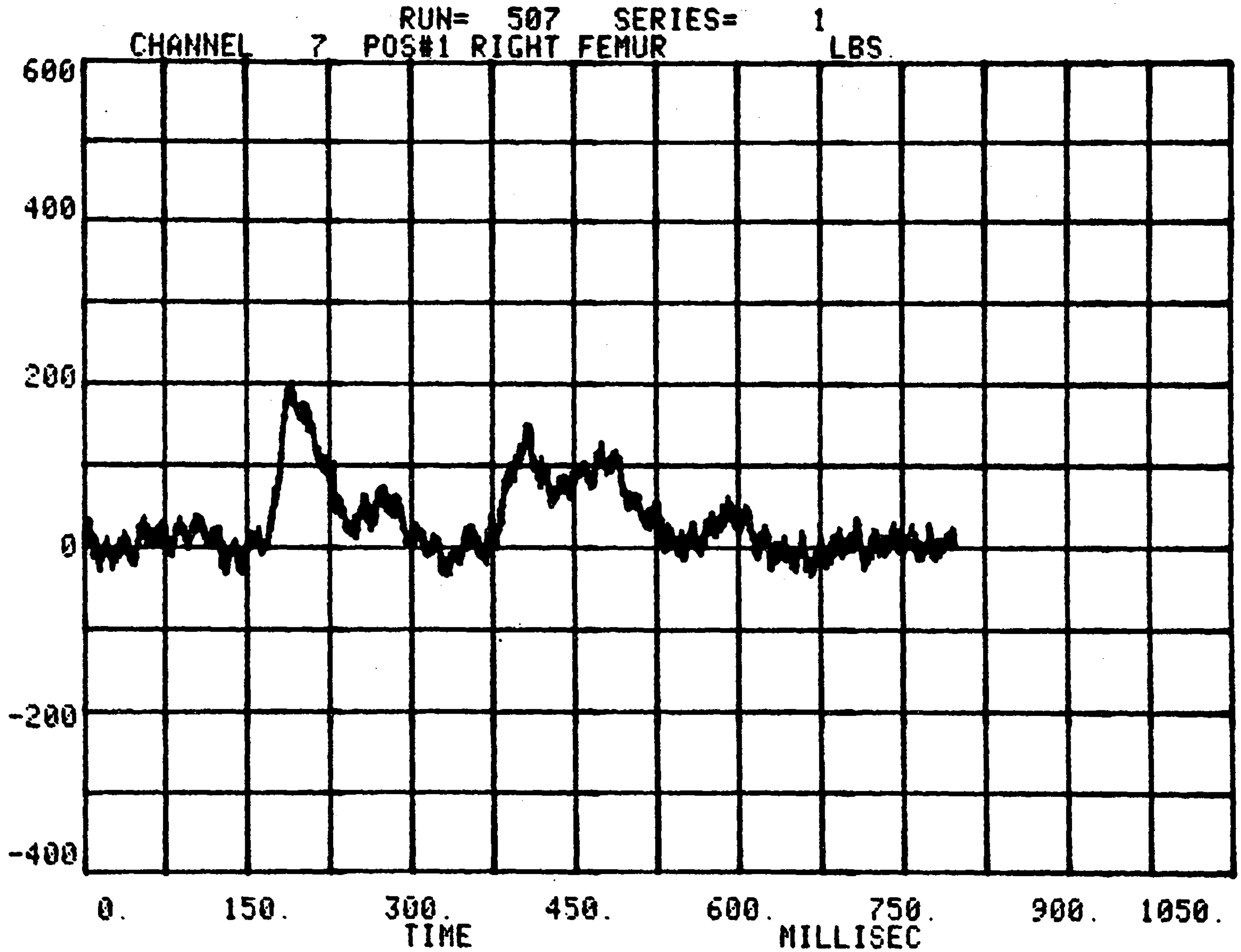

RUN= 507 SERIES= 1
CHANNEL 7 POS#1 RIGHT FEMUR LBS
600
400
200
0
-200
-400
0.
150.
300.
450.
600.
750.
900.
1050.
TIME
MILLISEC

FIGURE B-10

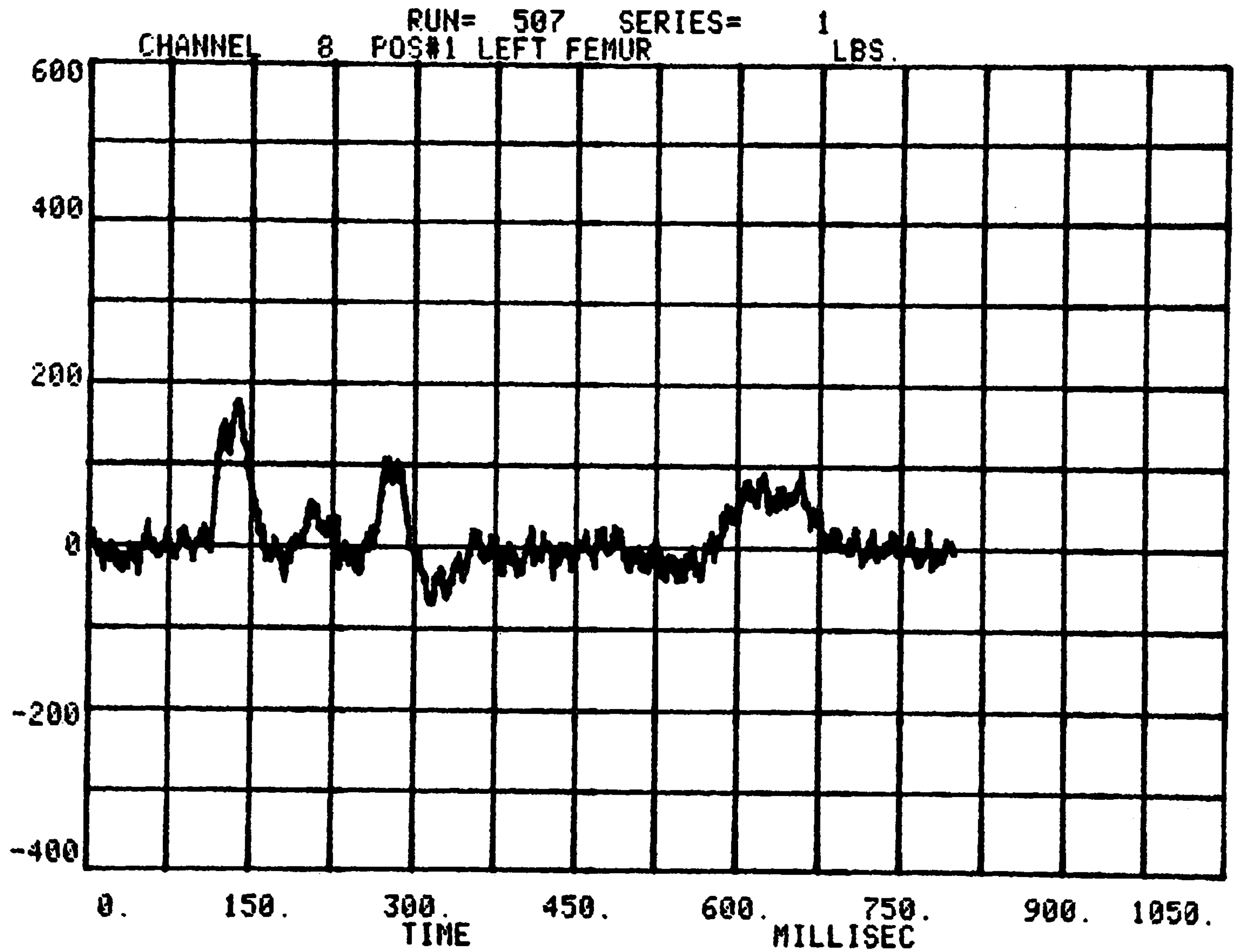

RUN= 507 SERIES= 1
CHANNEL 8 POS#1 LEFT FEMUR LBS.
600
400
200
0
-200
-400
0.
150.
300.
450.
600.
750.
900.
1050.
TIME
MILLISEC

TABLE B-3

HEAD INJURY CRITERION
HEAD SEVERITY INDEX

GMC HEAVY TRUCK BARRIER TEST #1

RUN= 507

POS#2 HEAD RESULTANT

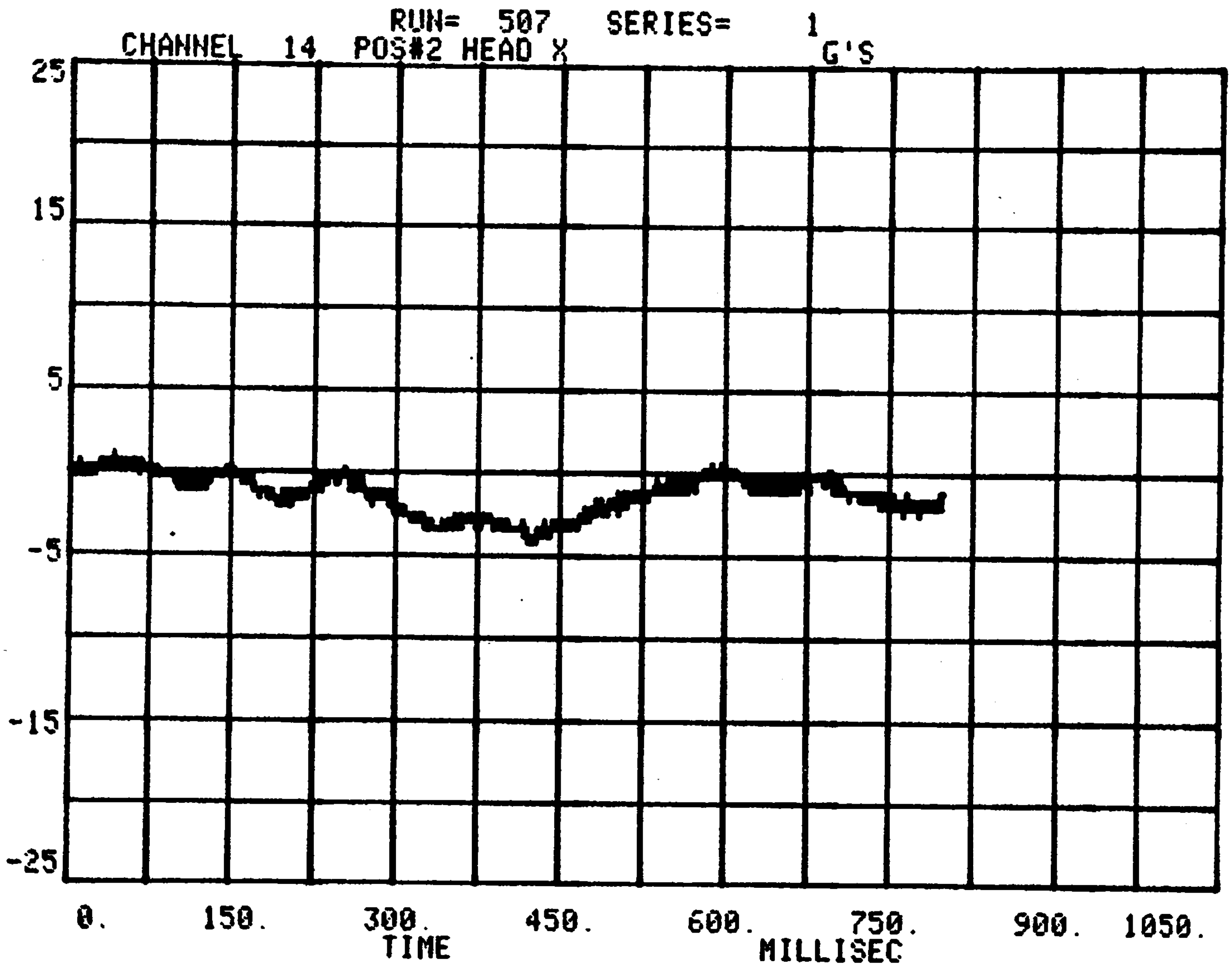
HIC= 22.5 .FROM T1= .19230 TO T2= .69930

AVERAGE ACCELERATION BETWEEN T1 AND T2= 4.6G'S

EVENT TIME= 800.0 MSEC

SEVERITY INDEX= 28.0

FIGURE B-11



RUN= 507 SERIES= 1
CHANNEL 14 POS#2 HEAD X
G'S
25
15
5
-5
-15
-25
0.
150.
300.
450.
600.
750.
900.
1050.
TIME
MILLISEC

FIGURE B-12

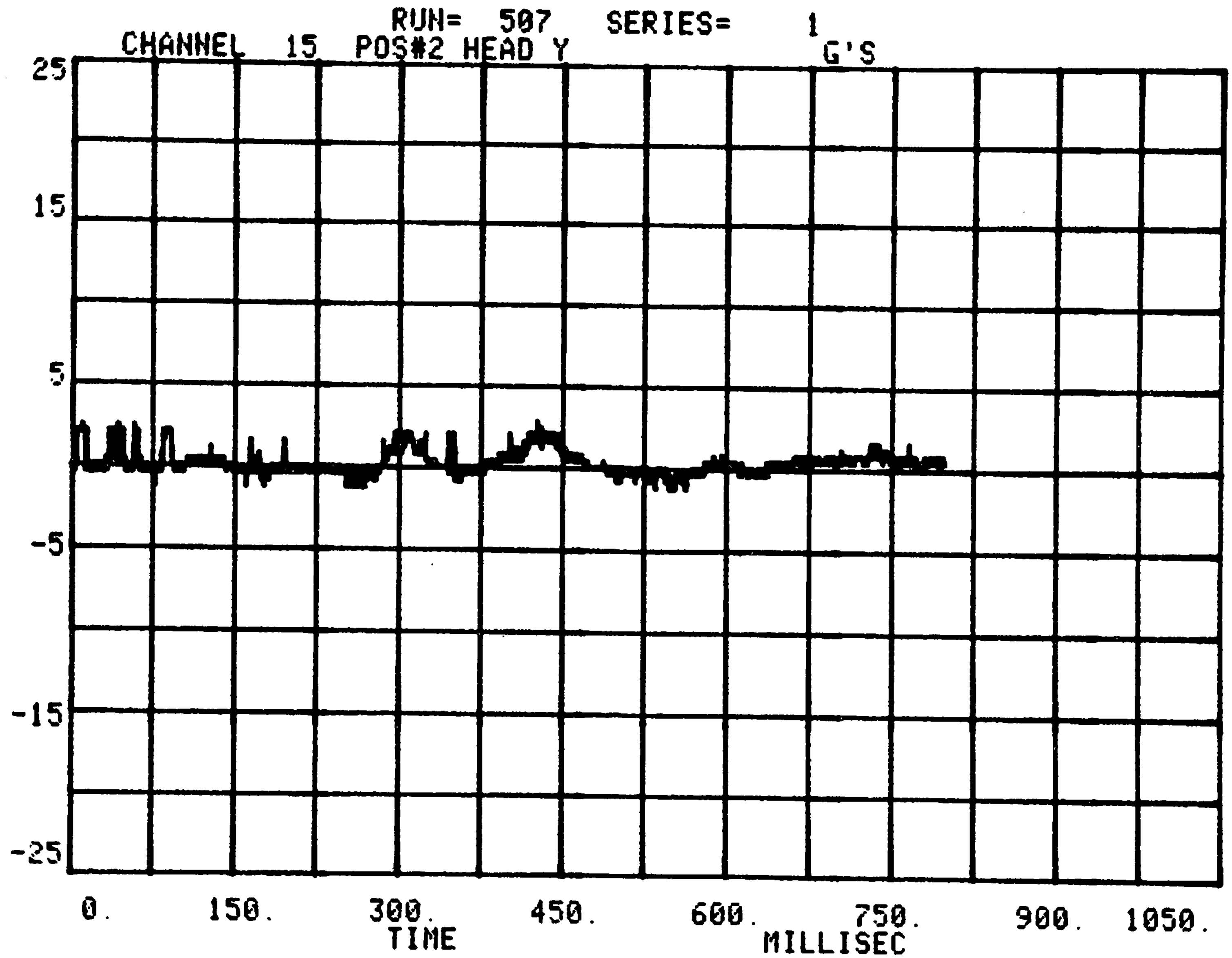

RUN= 507 SERIES= 1
CHANNEL 15 POS#2 HEAD Y
G'S
25
15
5
-5
-15
-25
0.
150.
300.
450.
600.
750.
900.
1050.
TIME
MILLISEC

FIGURE B-13

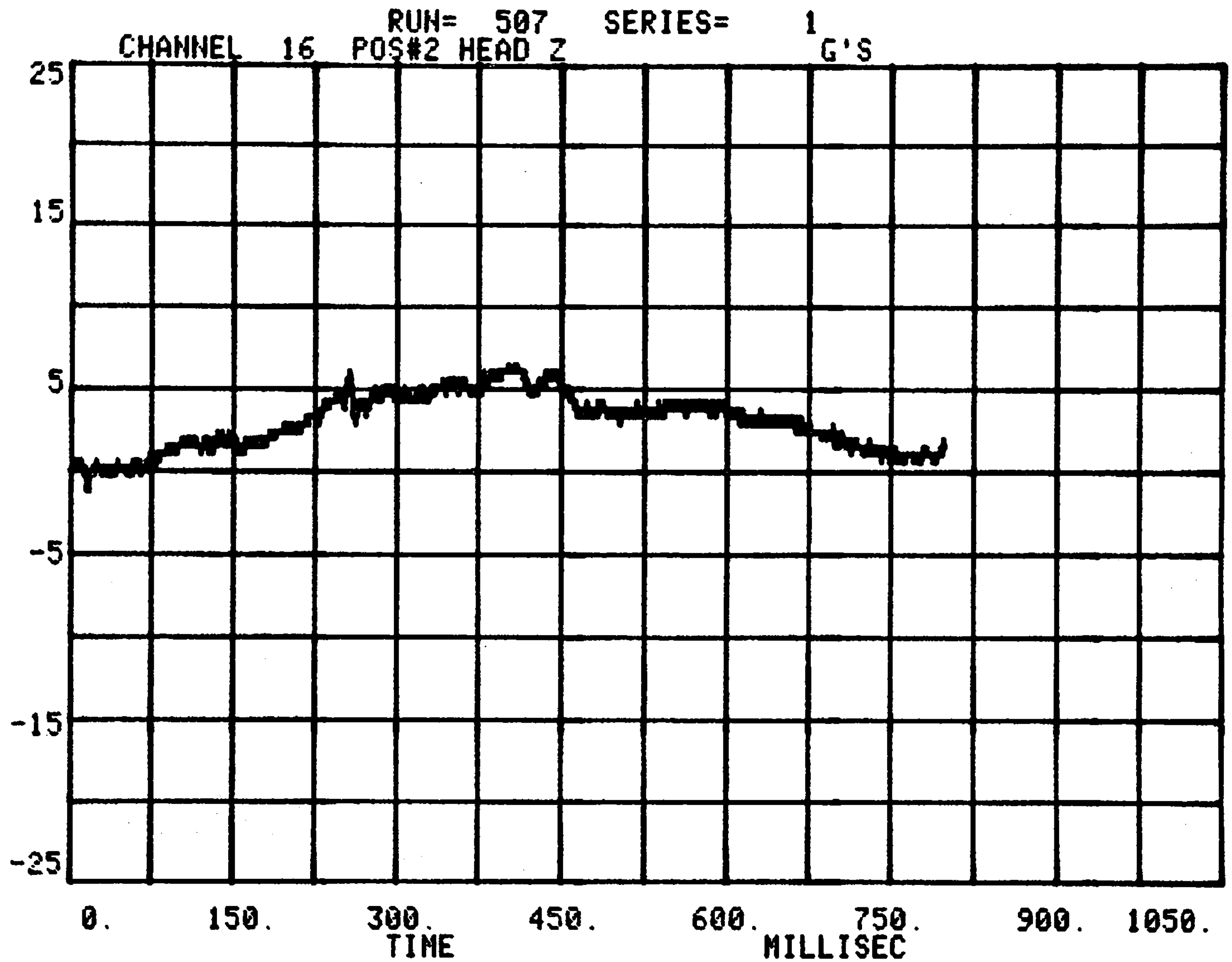

RUN= 507 SERIES= 1
CHANNEL 16 POS#2 HEAD Z
G'S
25
15
5
-5
-15
-25
0.
150.
300.
450.
600.
750.
900.
1050.
TIME
MILLISEC

FIGURE B-14

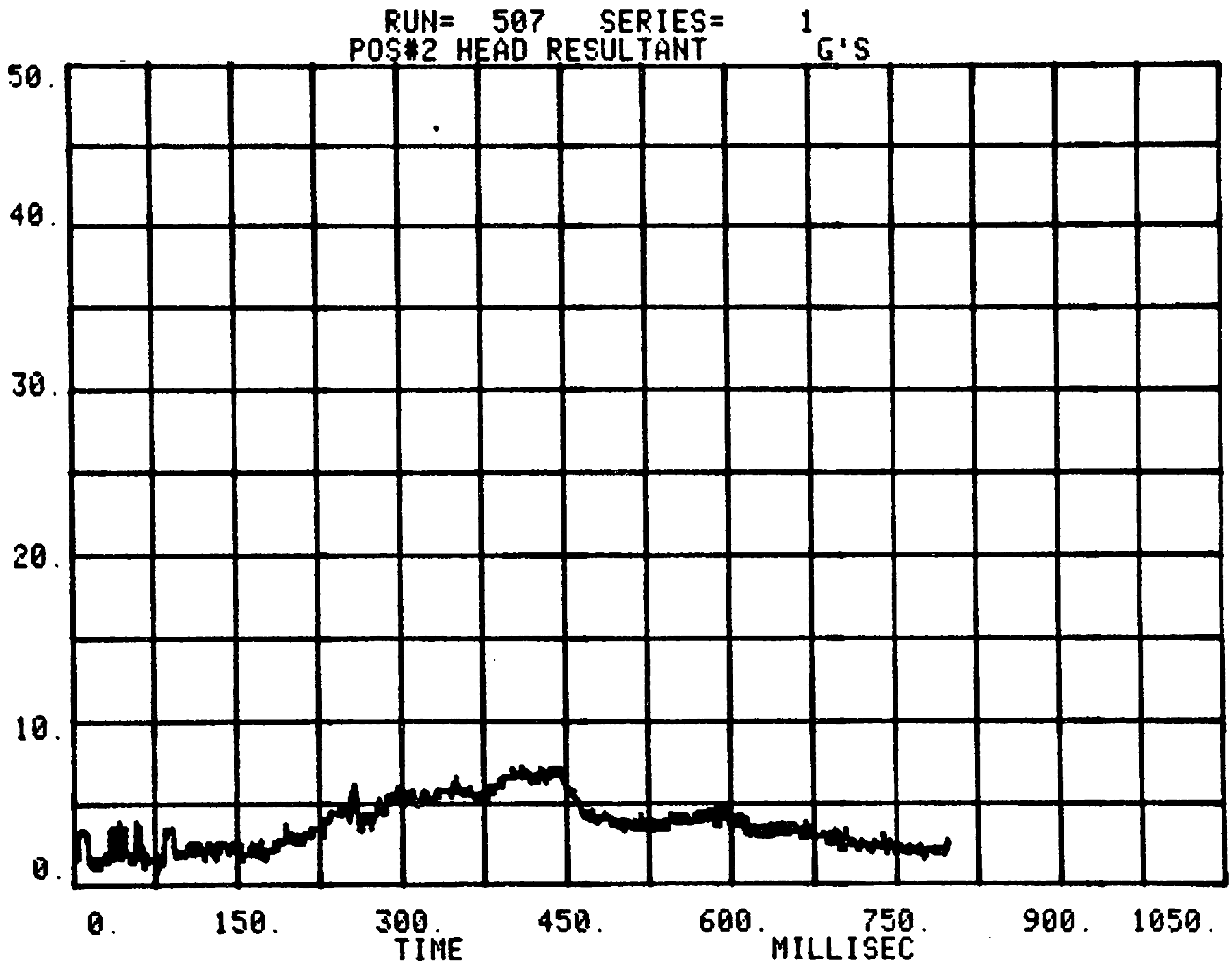
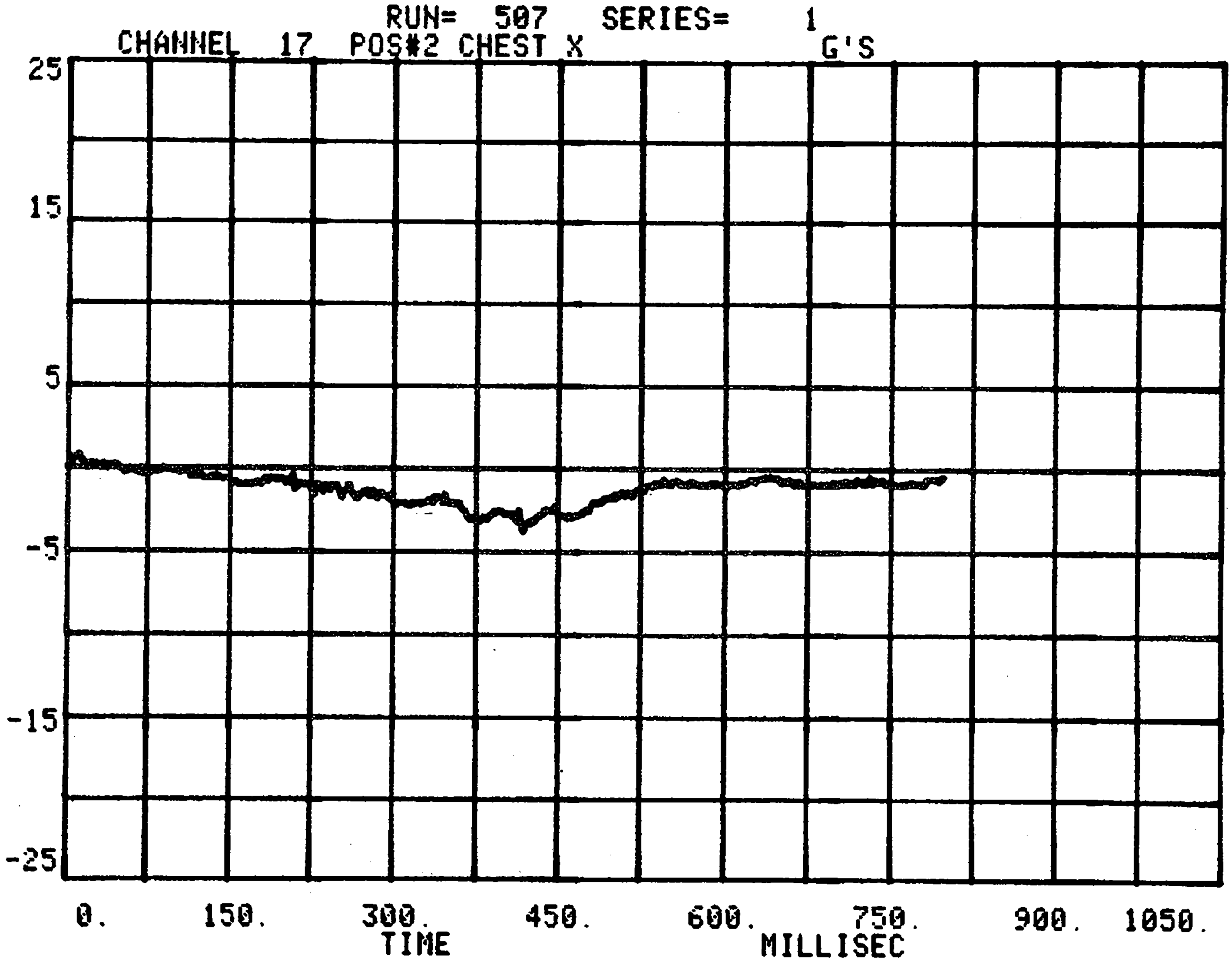
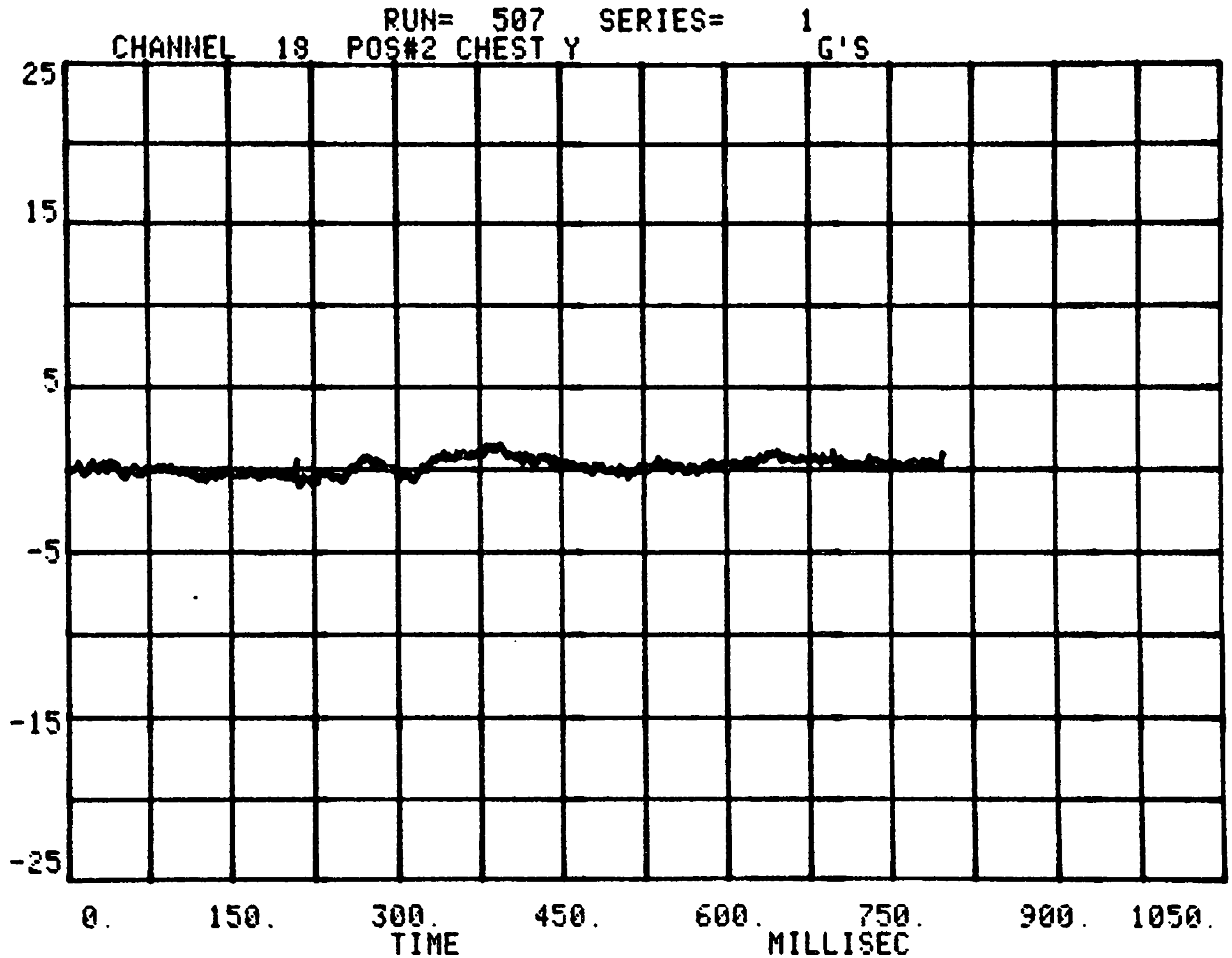

RUN= 507 SERIES= 1
POS#2 HEAD RESULTANT G'S
50.
40.
30.
20.
10.
0.
0.
150.
300.
450.
600.
750.
900.
1050.
TIME
MILLISEC

FIGURE B-15



RUN= 507 SERIES= 1
CHANNEL 17 POS#2 CHEST X
G'S
25
15
5
-5
-15
-25
0.
150.
300.
450.
600.
750.
900.
1050.
TIME
MILLISEC

FIGURE B-16



RUN= 507 SERIES= 1
CHANNEL 18 POS#2 CHEST Y G'S
25
15
5
-5
-15
-25
0.
150.
300.
450.
600.
750.
900.
1050.
TIME MILLISEC

FIGURE B-17

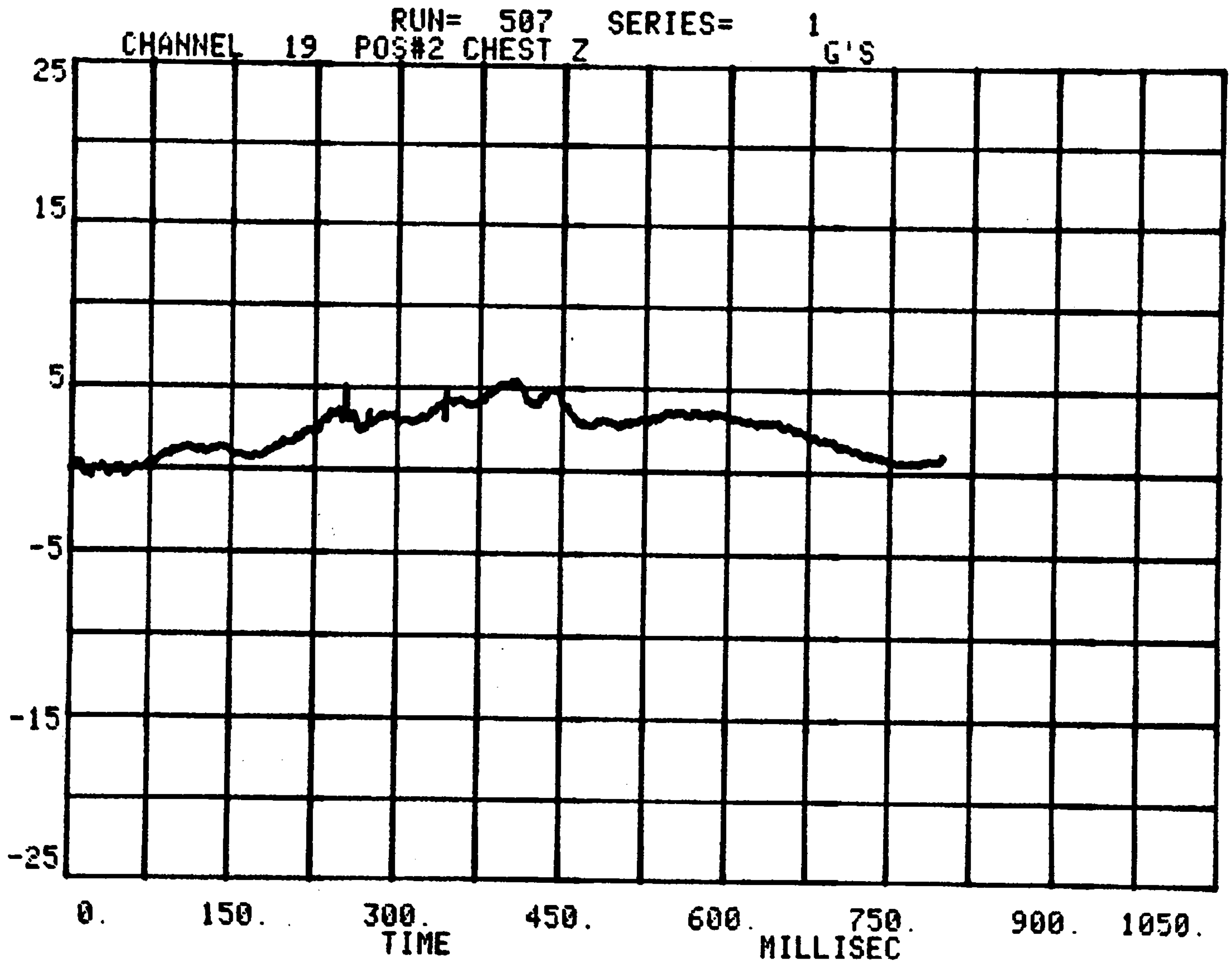

RUN= 507 SERIES= 1
CHANNEL 19 POS#2 CHEST Z
G'S
25
15
5
-5
-15
-25
0.
150.
300.
450.
600.
750.
900.
1050.
TIME
MILLISEC

FIGURE B-18

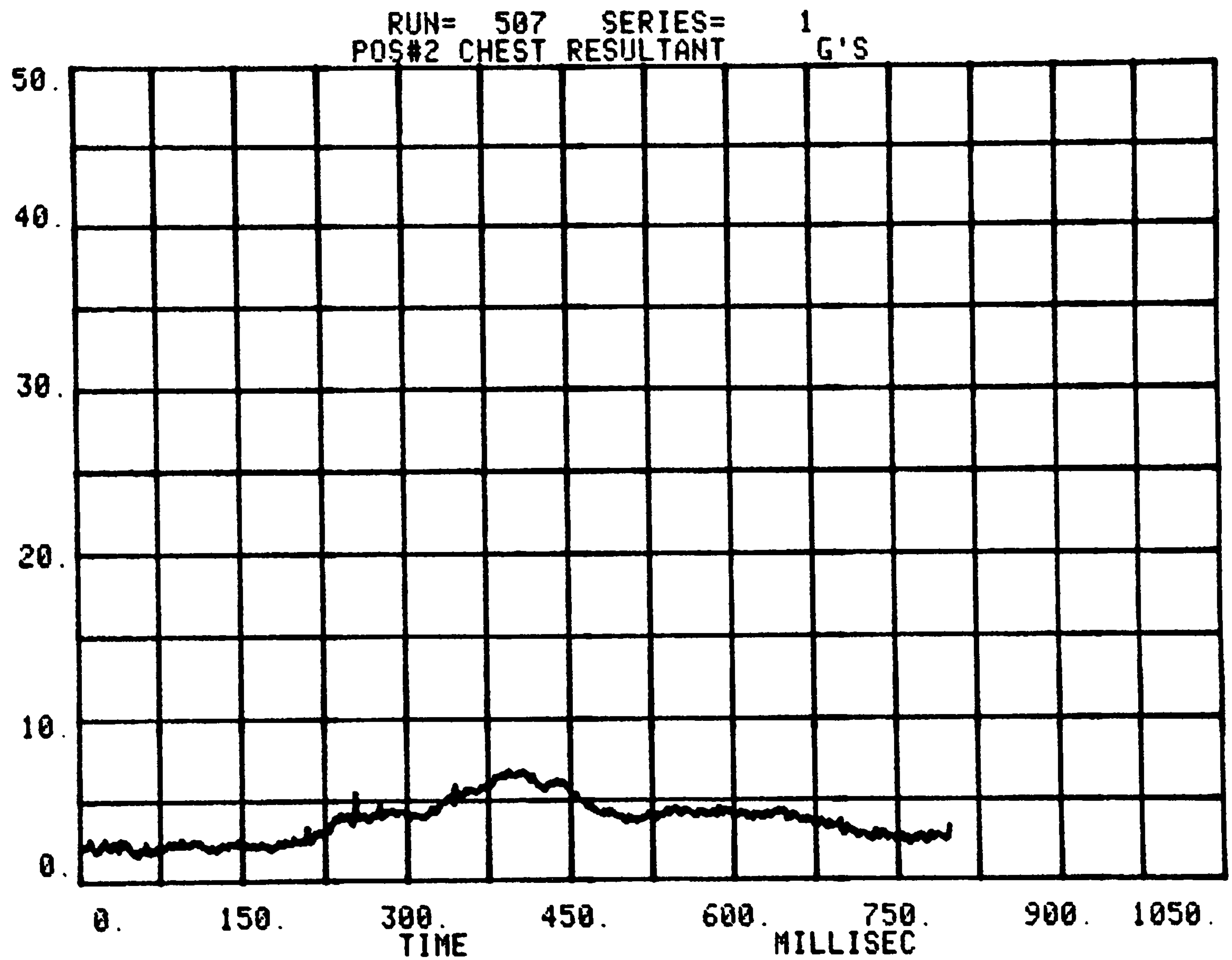
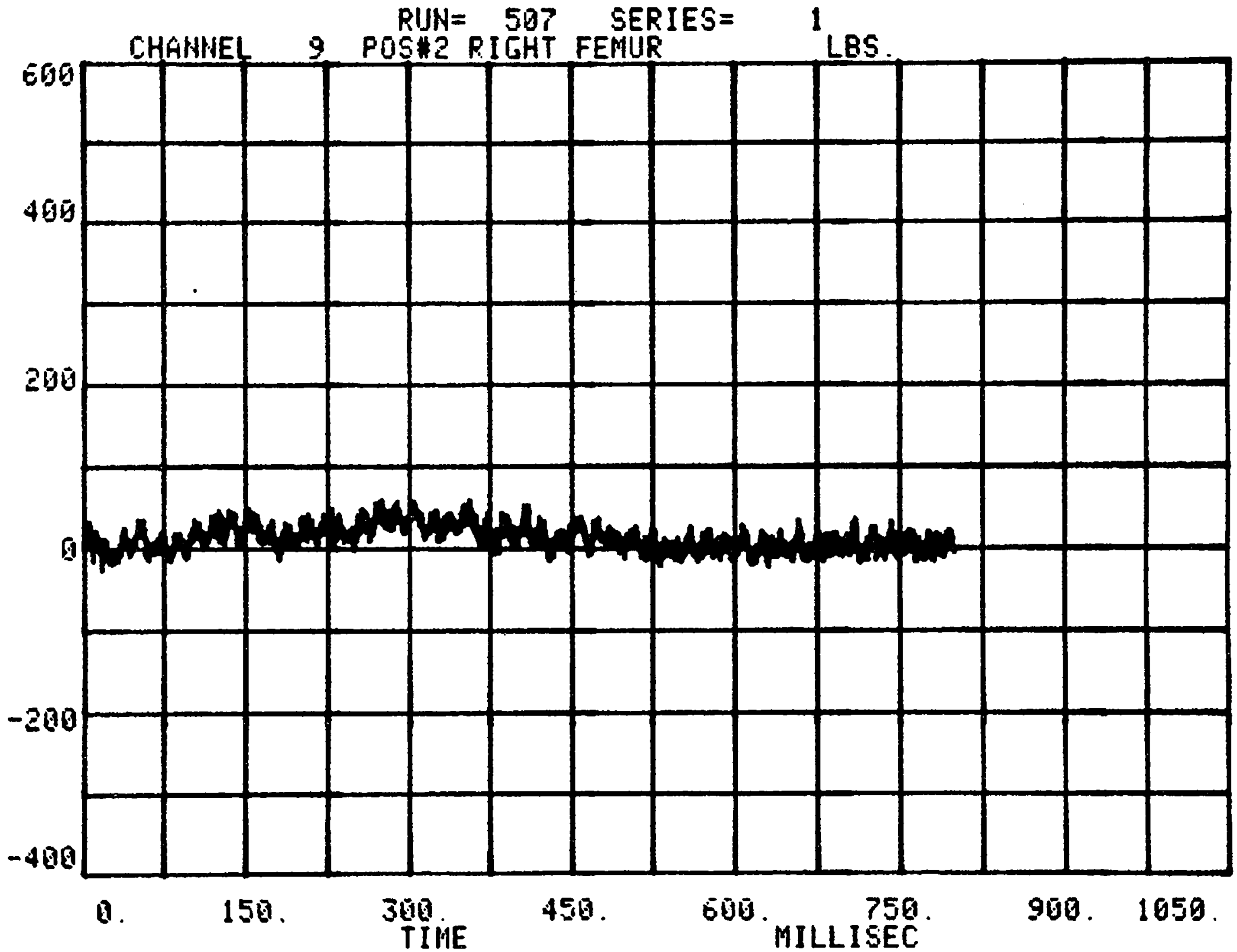

RUN= 507 SERIES= 1
POS#2 CHEST RESULTANT G'S
50.
40.
30.
20.
10.
0.
0.
150.
300.
450.
600.
750.
900.
1050.
TIME
MILLISEC

FIGURE B-19



RUN= 507 SERIES= 1
CHANNEL 9 POS#2 RIGHT FEMUR LBS.
600
400
200
0
-200
-400
0.
150.
300.
450.
600.
750.
900.
1050.
TIME
MILLISEC

FIGURE B-20

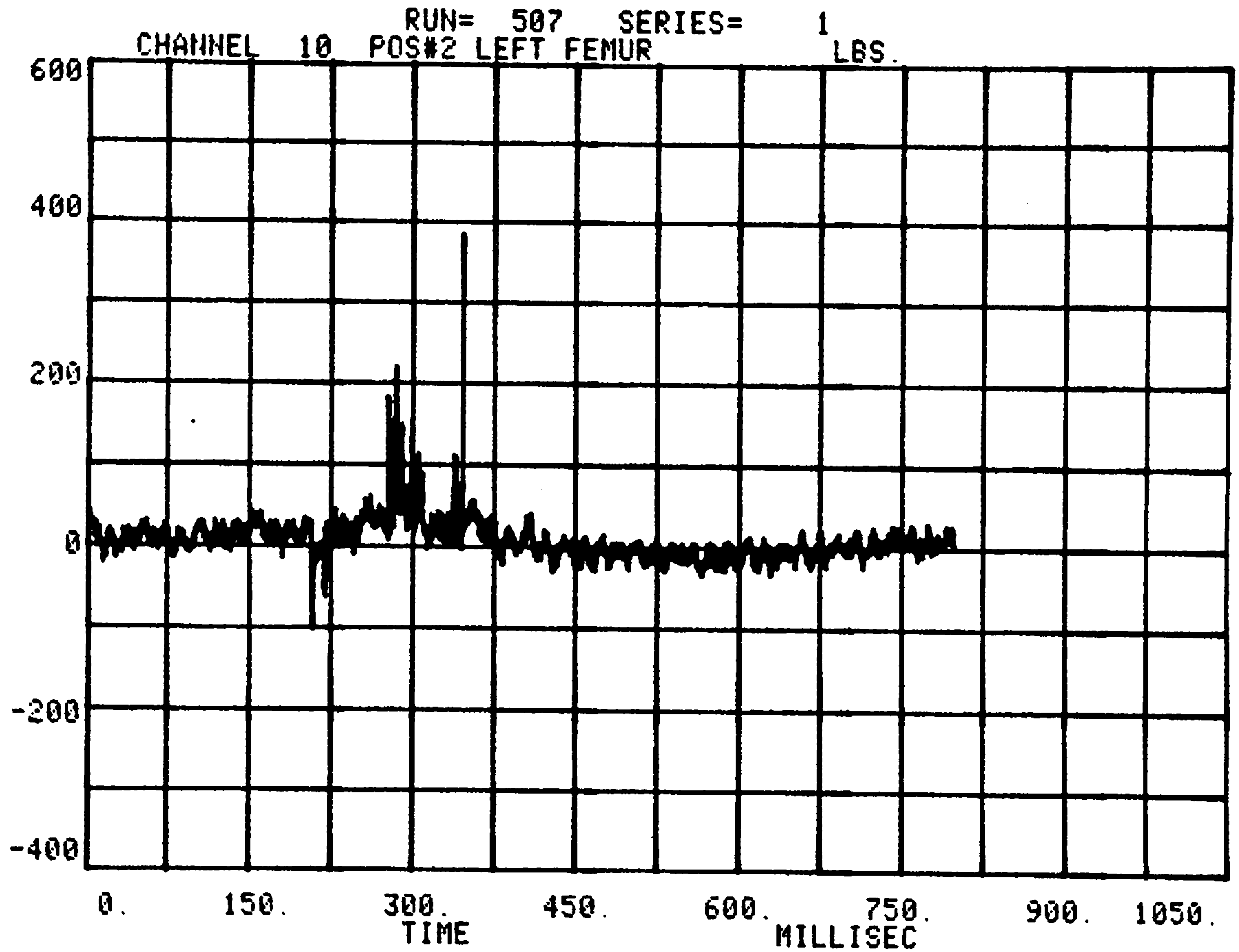
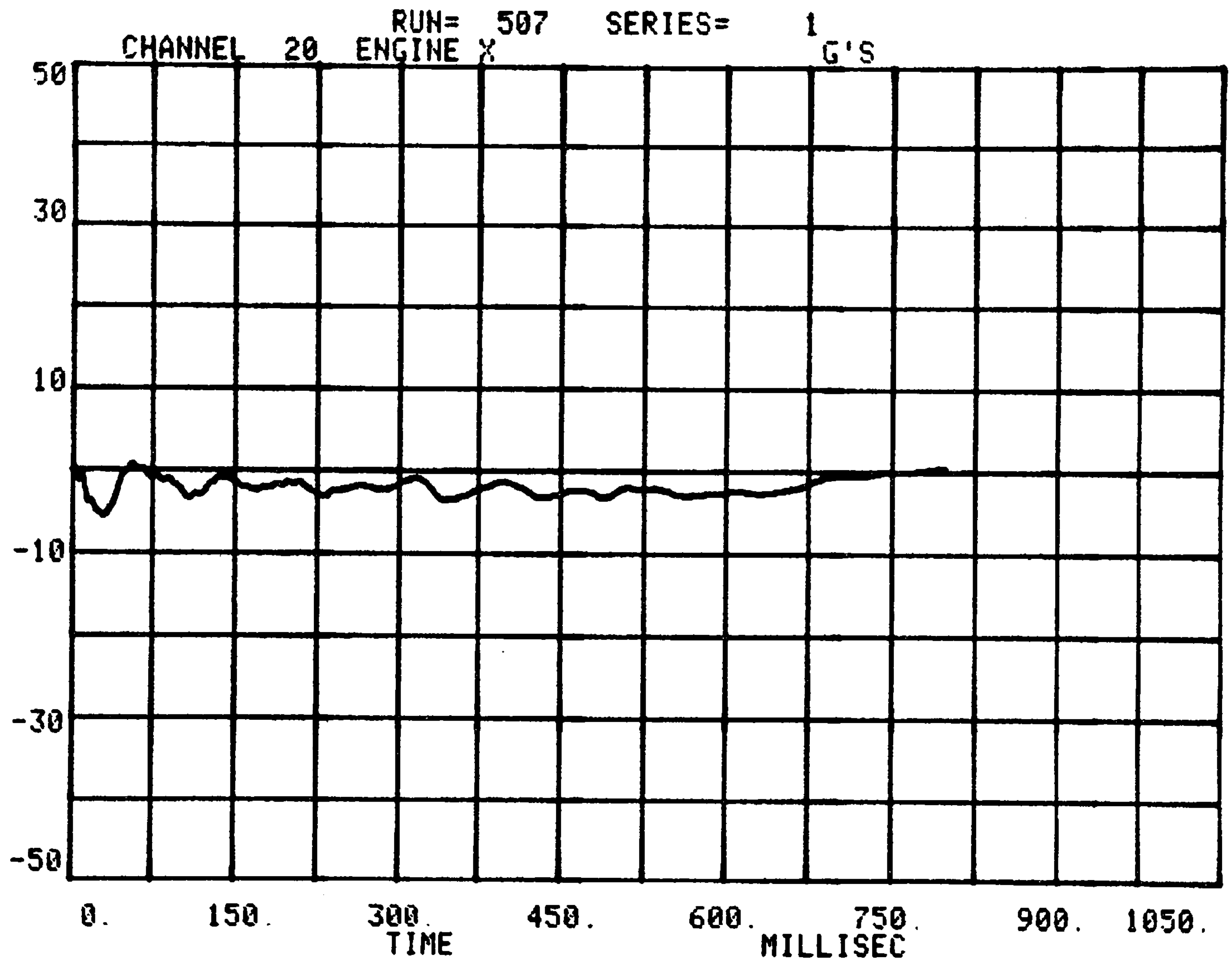

RUN= 507 SERIES= 1
CHANNEL 10 POS#2 LEFT FEMUR LBS.
600
400
200
0
-200
-400
0.
150.
300.
450.
600.
750.
900.
1050.
TIME
MILLISEC

FIGURE B-21



RUN= 507 SERIES= 1
CHANNEL 20 ENGINE X
G'S
50
30
10
-10
-30
-50
0.
150.
300.
450.
600.
750.
900.
1050.
TIME
MILLISEC

FIGURE B-22

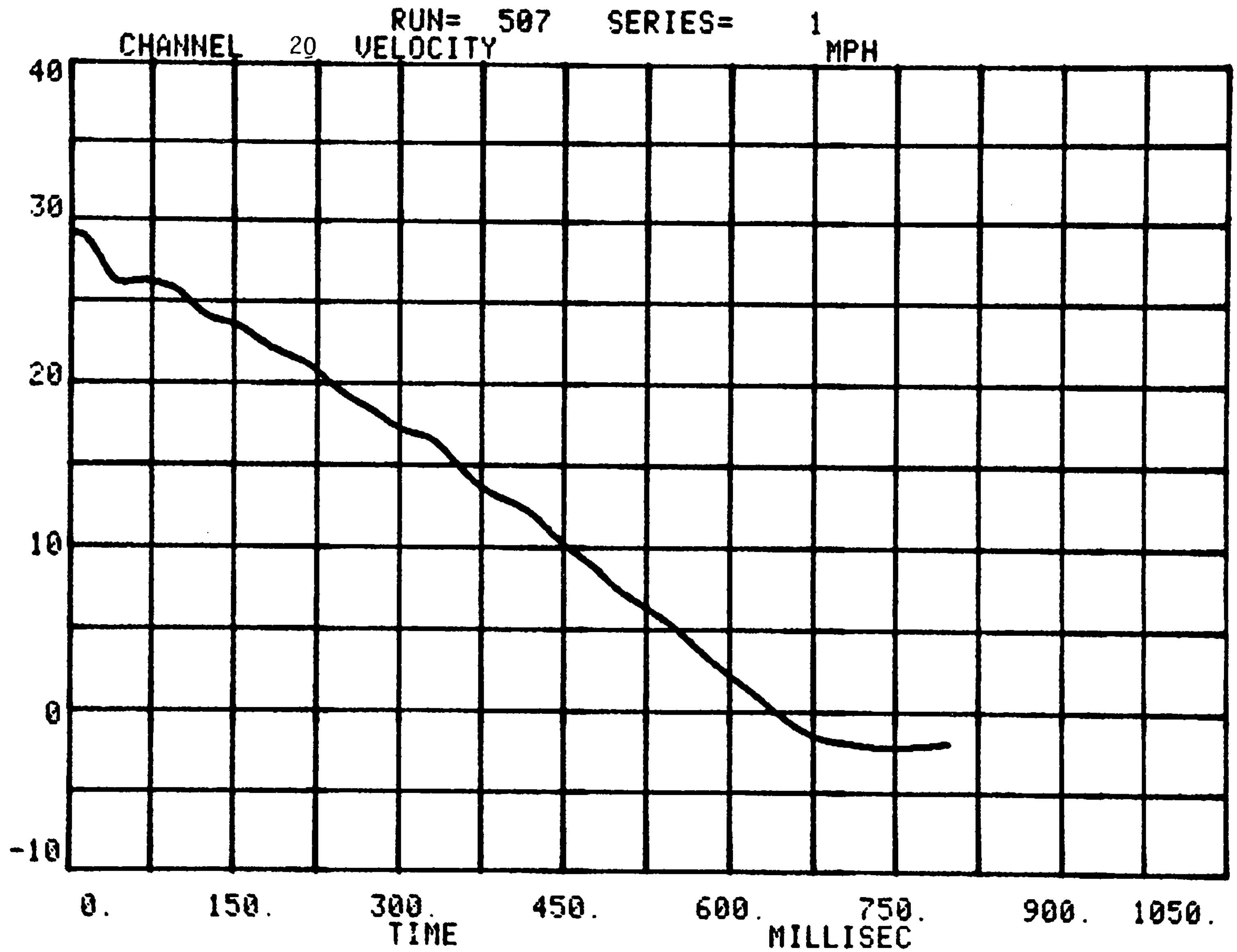

RUN= 507 SERIES= 1
CHANNEL 20 VELOCITY
MPH
40
30
20
10
0
-10
0.
150.
300.
450.
600.
750.
900.
1050.
TIME
MILLISEC

FIGURE B-23

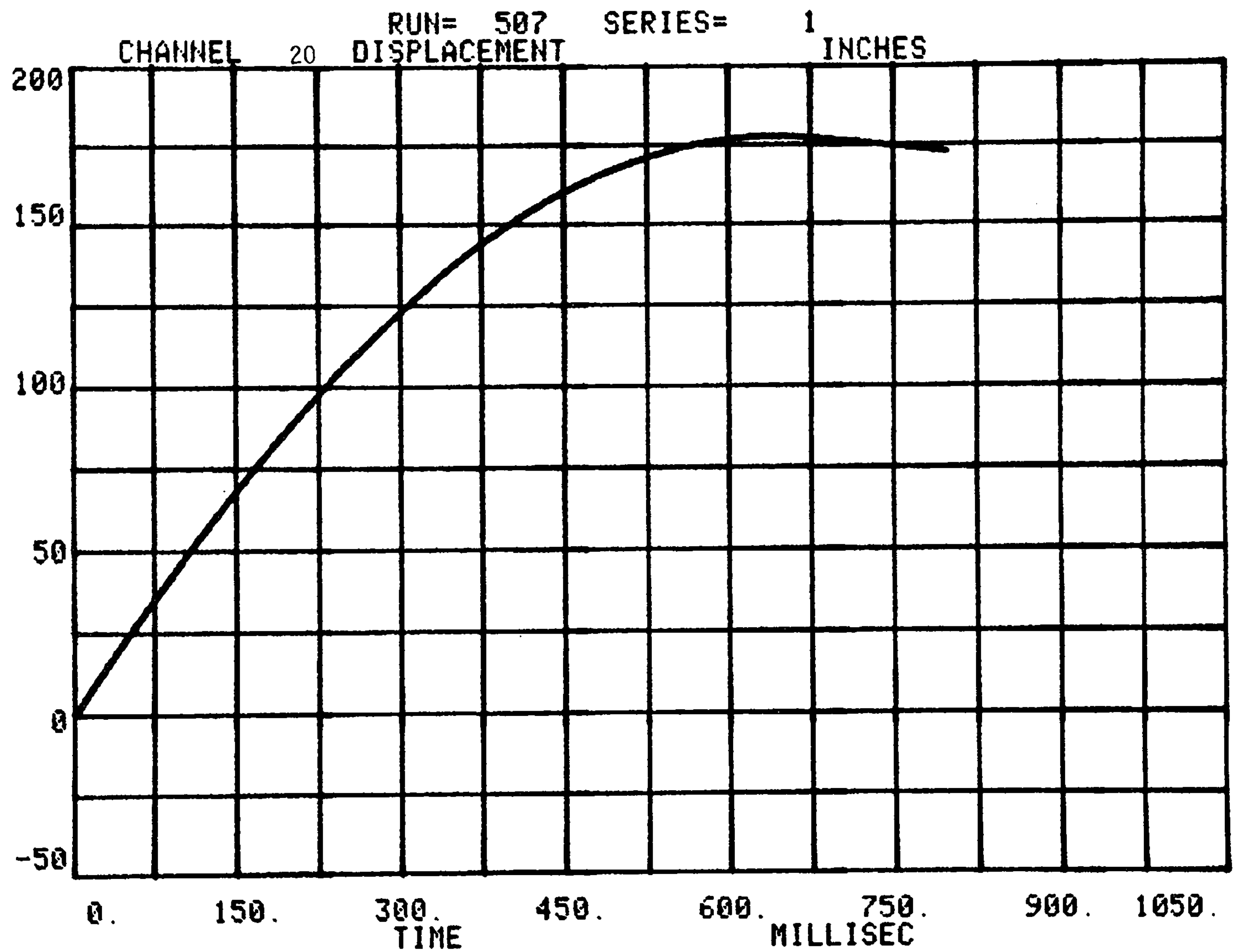

RUN= 507 SERIES= 1
CHANNEL 20 DISPLACEMENT INCHES
200
150
100
50
0
-50
0.
150.
300.
450.
600.
750.
900.
1050.
TIME
MILLISEC

FIGURE B-24

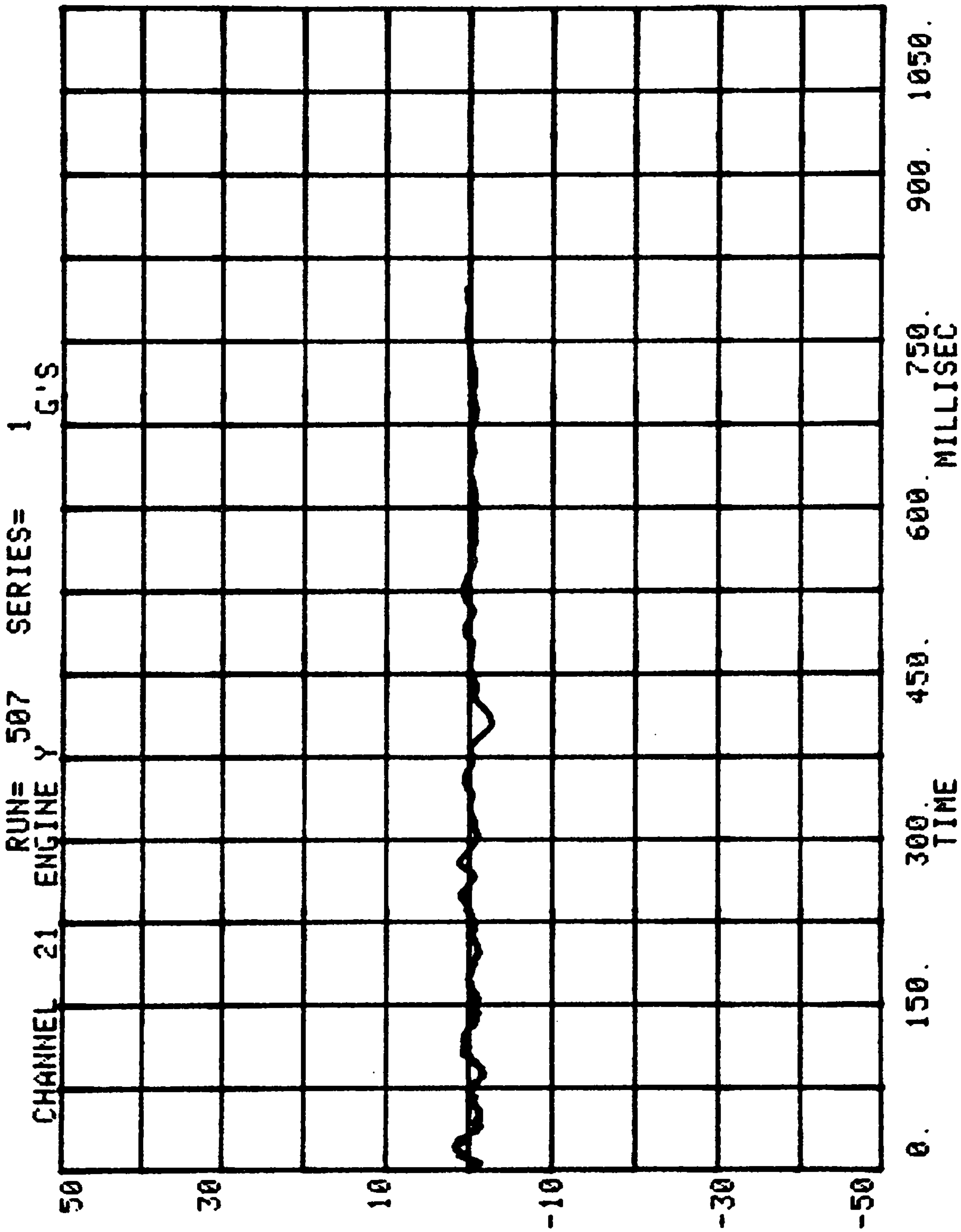

CHANNEL 21 RUN= 507 SERIES= 1
ENGINE Y G'S
50
30
10
-10
-30
-50
0.
150.
300.
450.
600.
750.
900.
1050.
TIME MILLISEC

FIGURE B-25

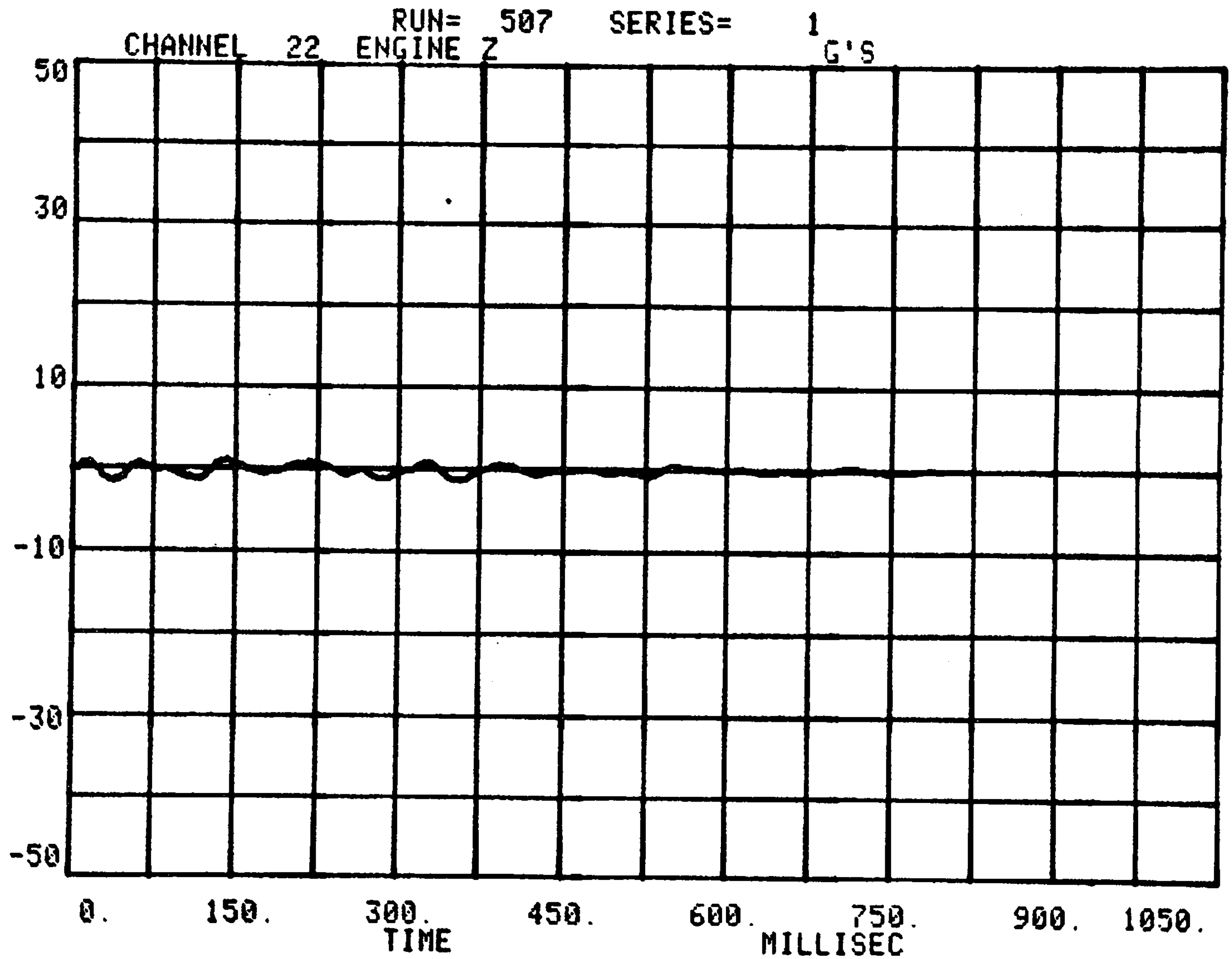

RUN= 507 SERIES= 1
CHANNEL 22 ENGINE Z
G'S
50
30
10
-10
-30
-50
0.
150.
300.
450.
600.
750.
900.
1050.
TIME
MILLISEC

FIGURE B-26

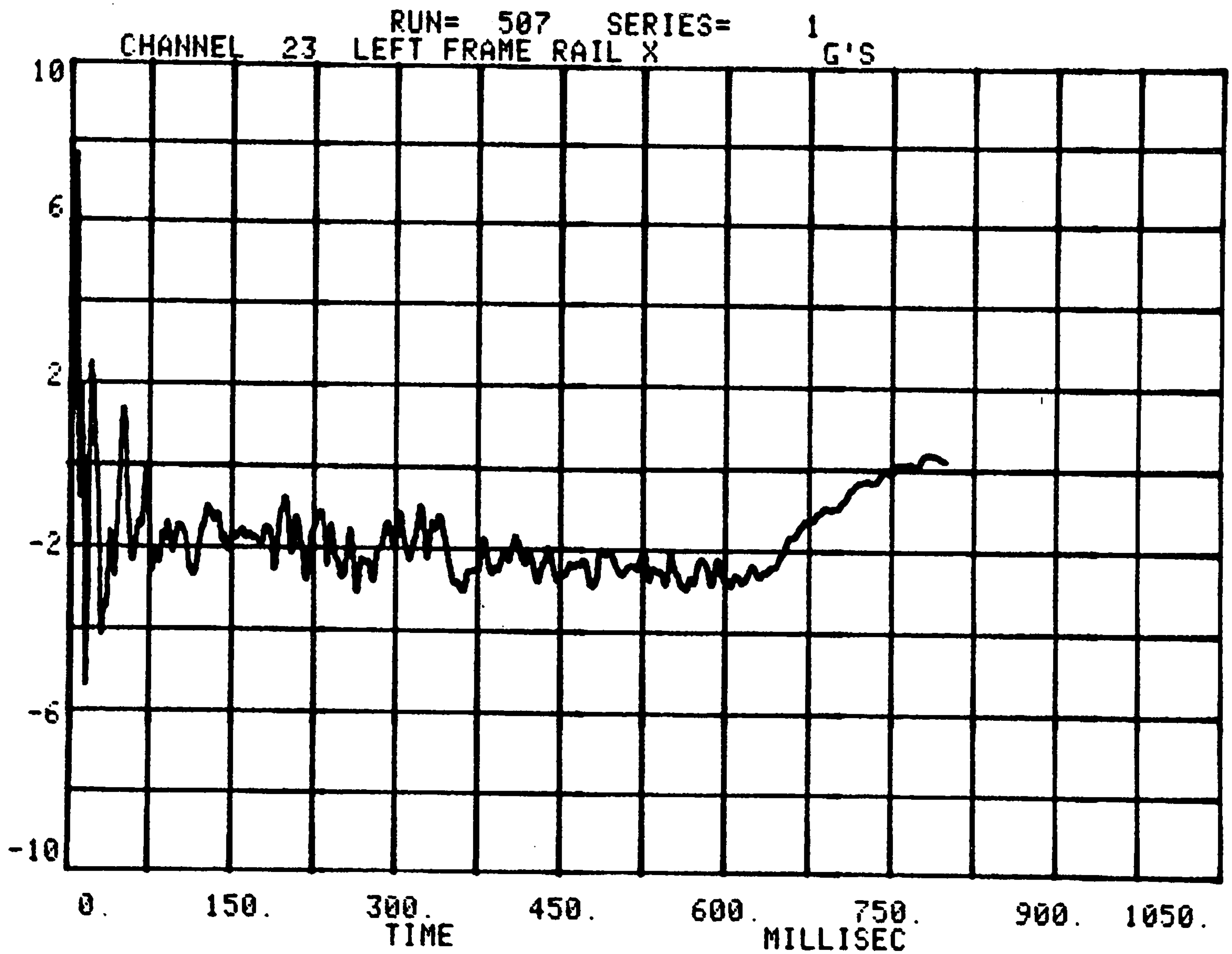

RUN= 507 SERIES= 1
CHANNEL 23 LEFT FRAME RAIL X G'S
10
6
2
-2
-6
-10
0. 150. 300. 450. 600. 750. 900. 1050.
TIME MILLISEC

FIGURE B-27

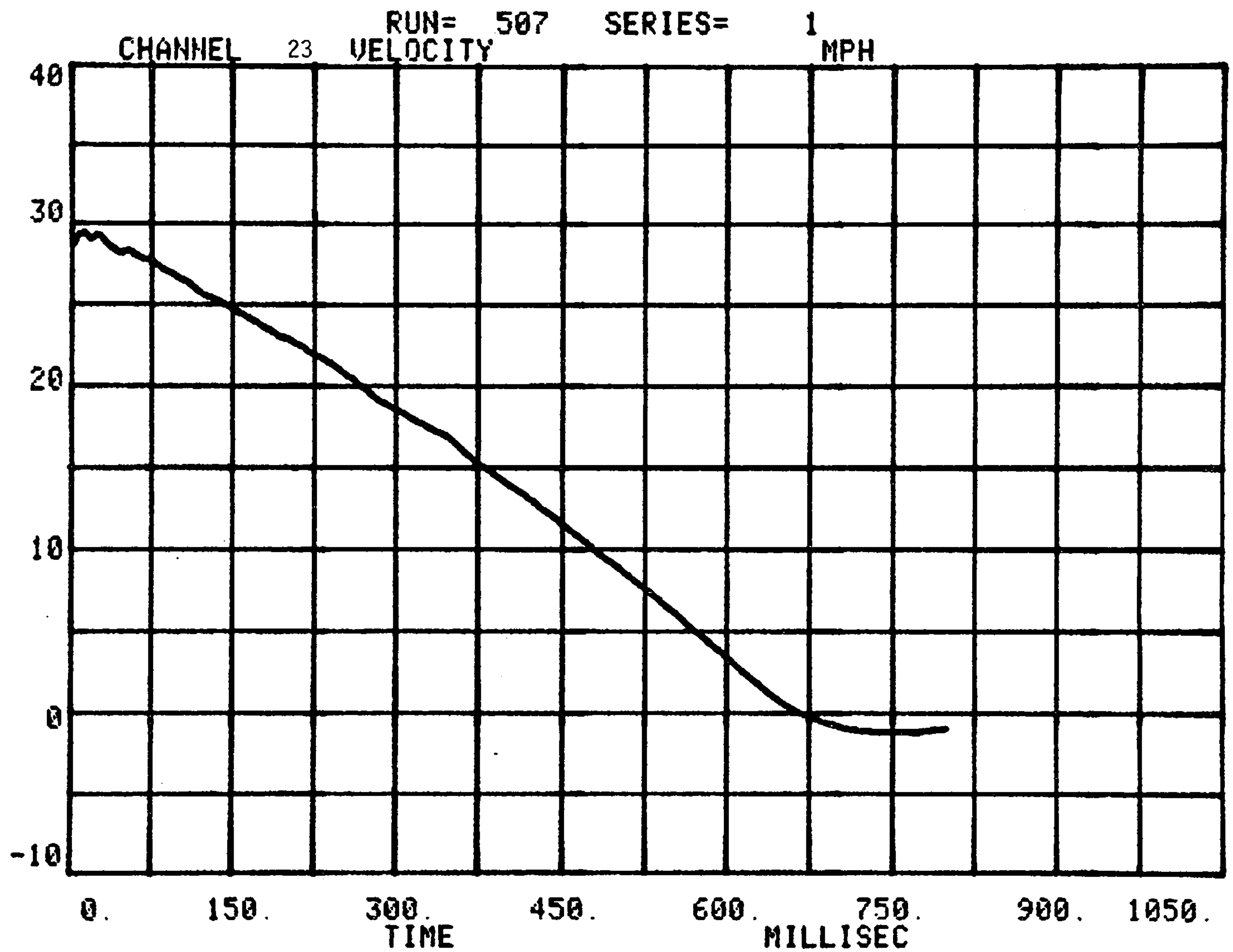
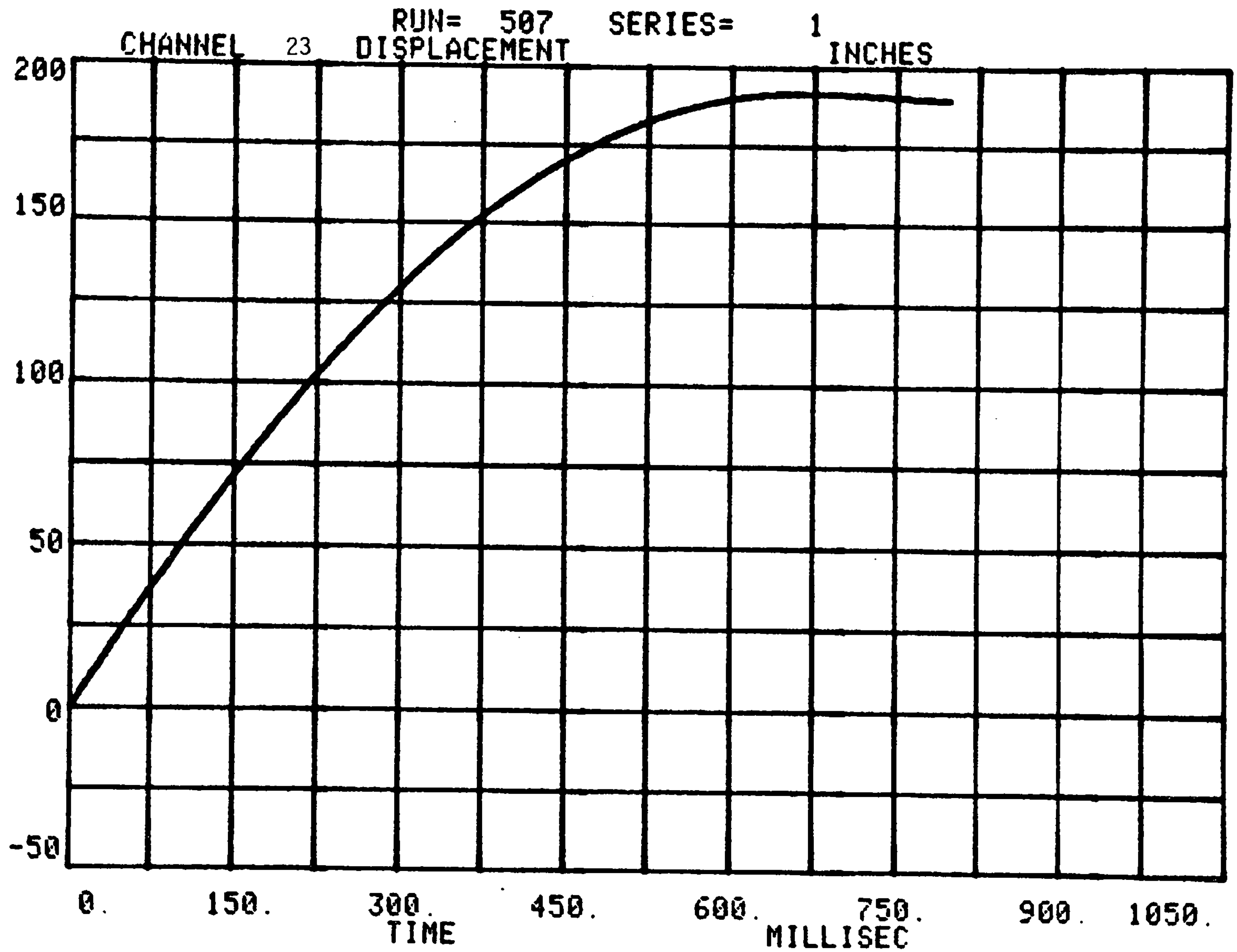
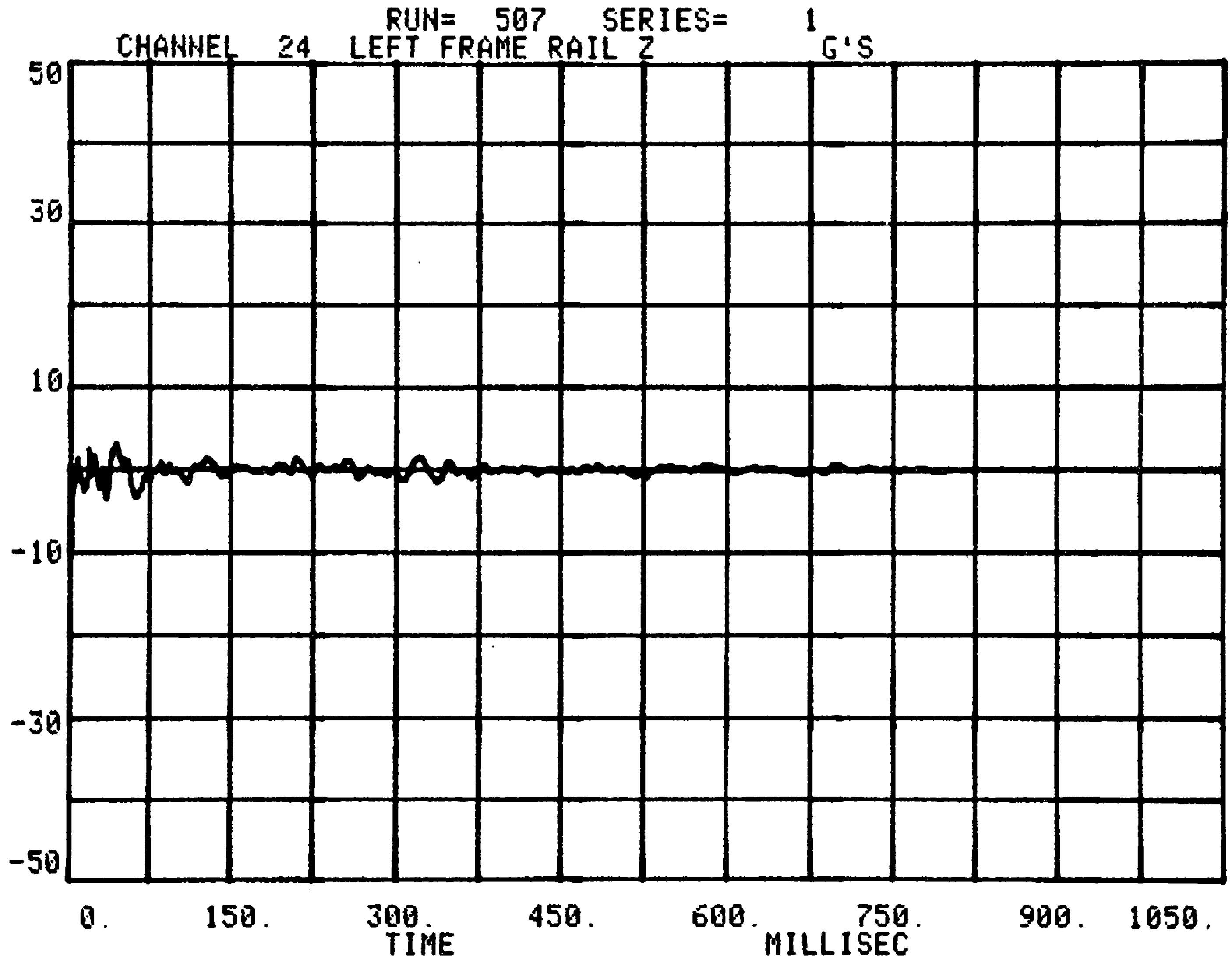

RUN= 507 SERIES= 1
CHANNEL 23 VELOCITY MPH
40
30
20
10
0
-10
0.
150.
300.
450.
600.
750.
900.
1050.
TIME MILLISEC

FIGURE B-28



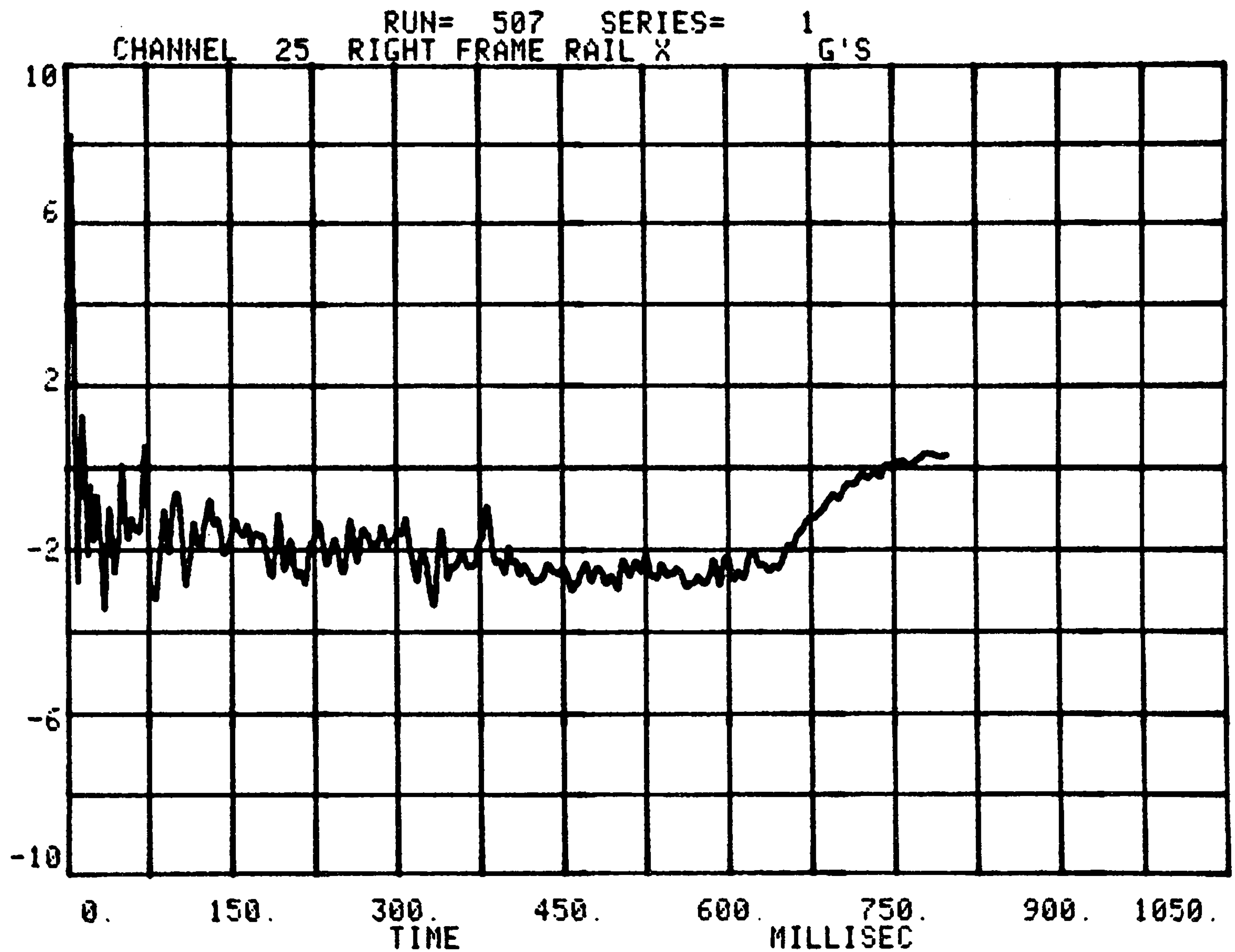
RUN= 507 SERIES= 1
CHANNEL 23 DISPLACEMENT
INCHES
200
150
100
50
0
-50
0.
150.
300.
450.
600.
750.
900.
1050.
TIME
MILLISEC

FIGURE B-29



RUN= 507 SERIES= 1
CHANNEL 24 LEFT FRAME RAIL Z G'S
50
30
10
-10
-30
-50
0.
150.
300.
450.
600.
750.
900.
1050.
TIME
MILLISEC

FIGURE B-30



RUN= 507 SERIES= 1
CHANNEL 25 RIGHT FRAME RAIL X G'S
10
6
2
-2
-6
-10
0.
150.
300.
450.
600.
750.
900.
1050.
TIME
MILLISEC

FIGURE B-31

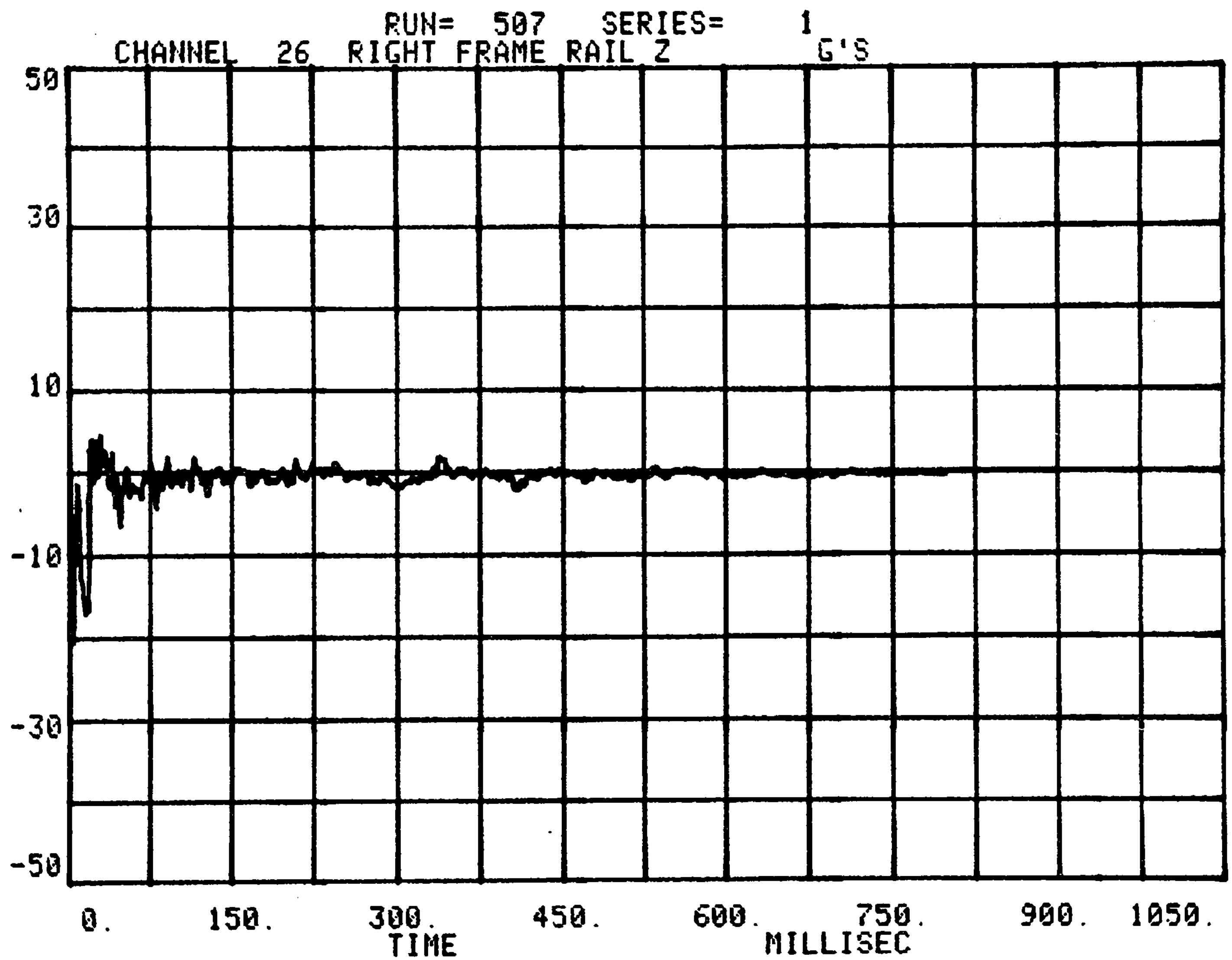

RUN= 507 SERIES= 1
CHANNEL 26 RIGHT FRAME RAIL Z G'S
50
30
10
-10
-30
-50
0.
150.
300.
450.
600.
750.
900.
1050.
TIME
MILLISEC

FIGURE B-32

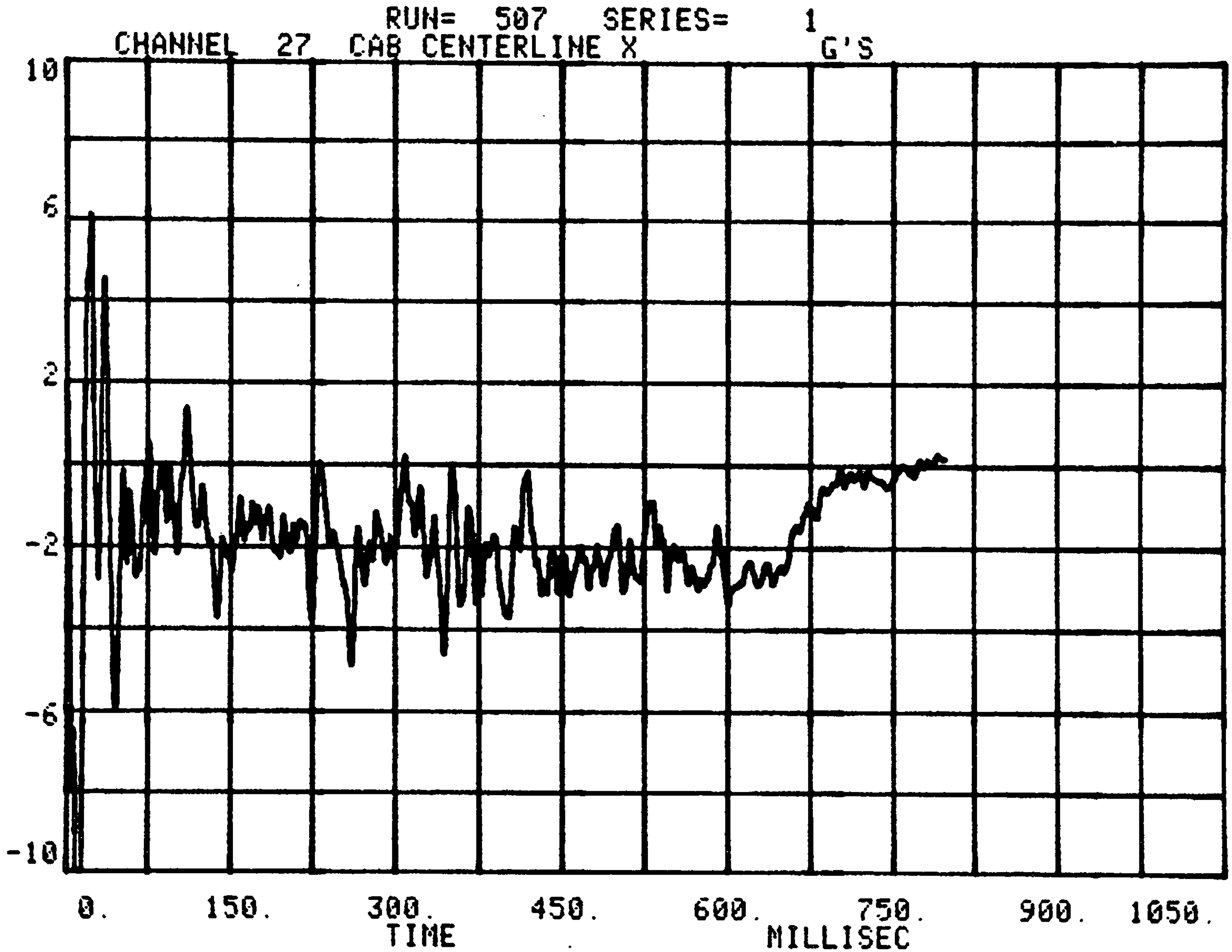
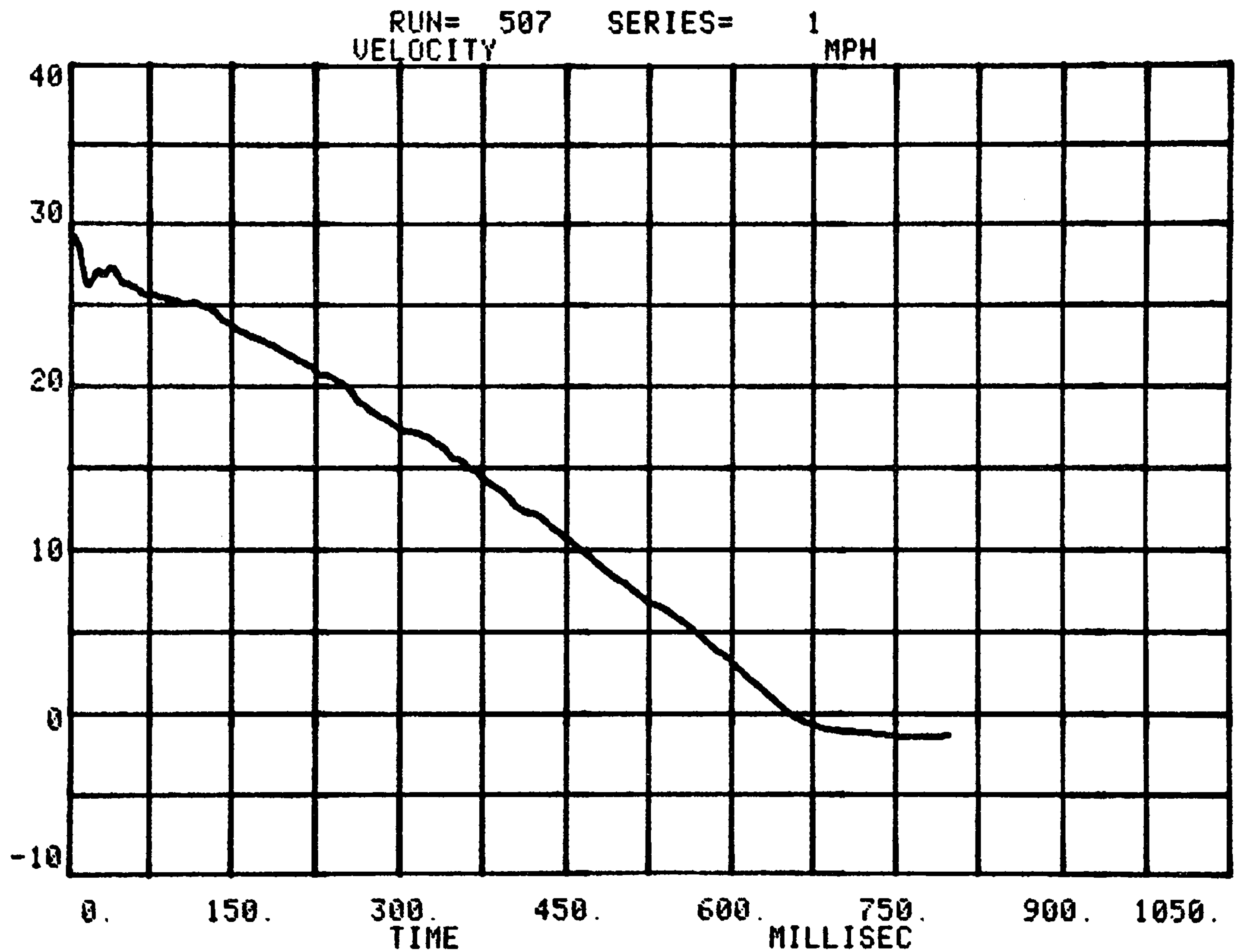
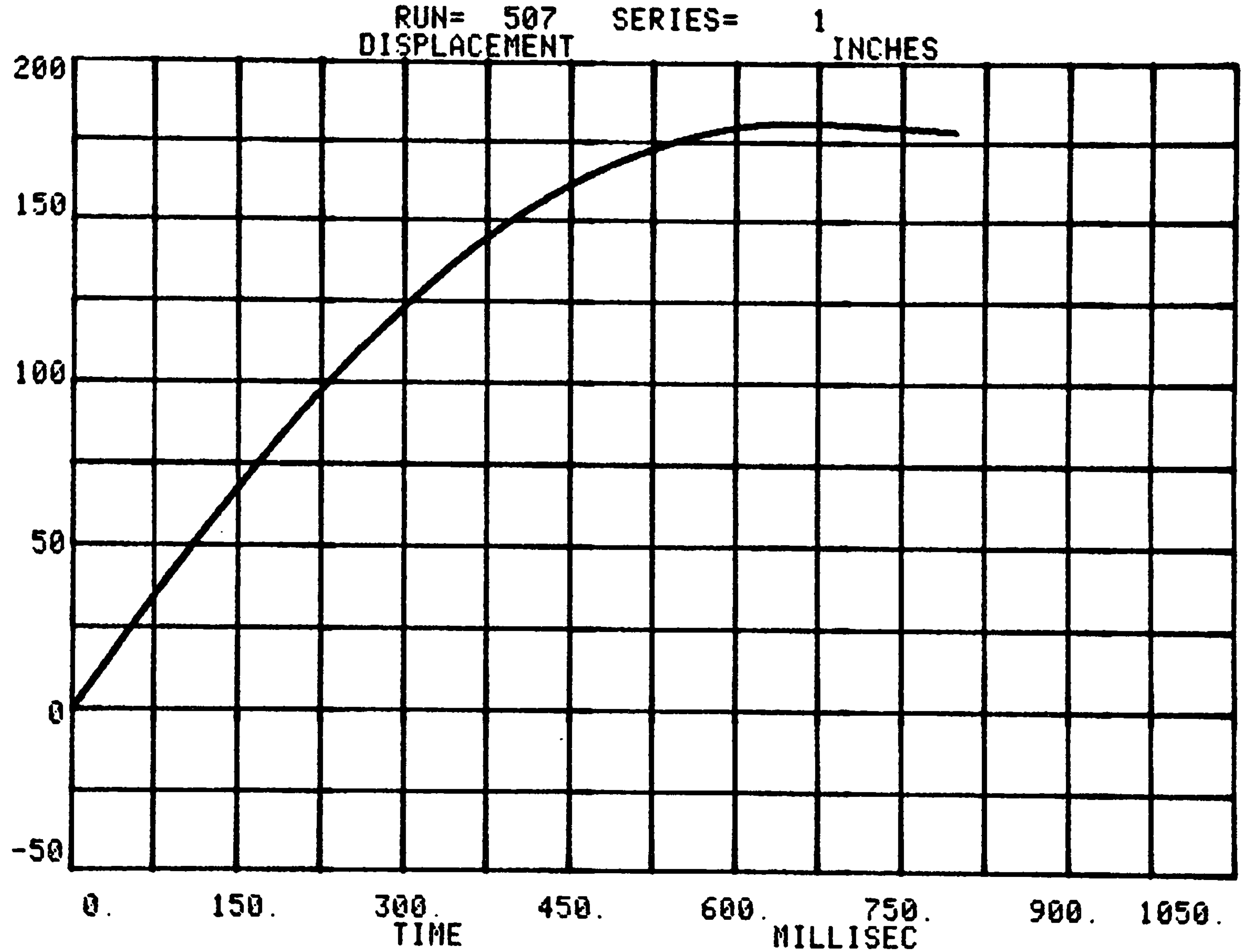

RUN= 507 SERIES= 1
CHANNEL 27 CAB CENTERLINE X G'S
10
6
2
-2
-6
-10
0.
150.
300.
450.
600.
750.
900.
1050.
TIME
MILLISEC

FIGURE B-33



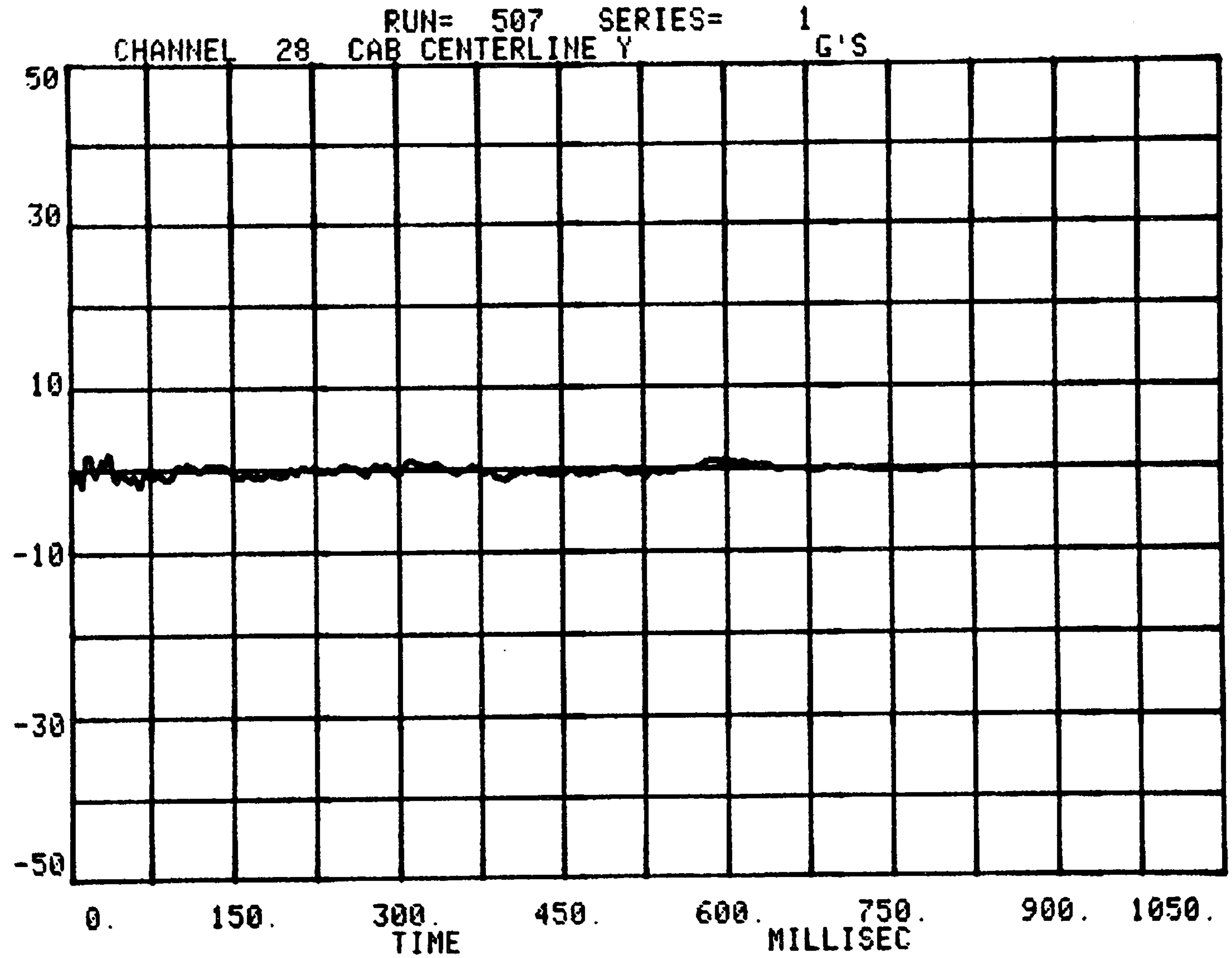
RUN= 507 SERIES= 1
VELOCITY
MPH
40
30
20
10
0
-10
0.
150.
300.
450.
600.
750.
900.
1050.
TIME
MILLISEC

FIGURE B-34



RUN= 507 SERIES= 1
DISPLACEMENT
INCHES
200
150
100
50
0
-50
0.
150.
300.
450.
600.
750.
900.
1050.
TIME
MILLISEC

FIGURE B-35



RUN= 507 SERIES= 1
CHANNEL 28 CAB CENTERLINE Y G'S
50
30
10
-10
-30
-50
0.
150.
300.
450.
600.
750.
900.
1050.
TIME
MILLISEC

FIGURE B-35

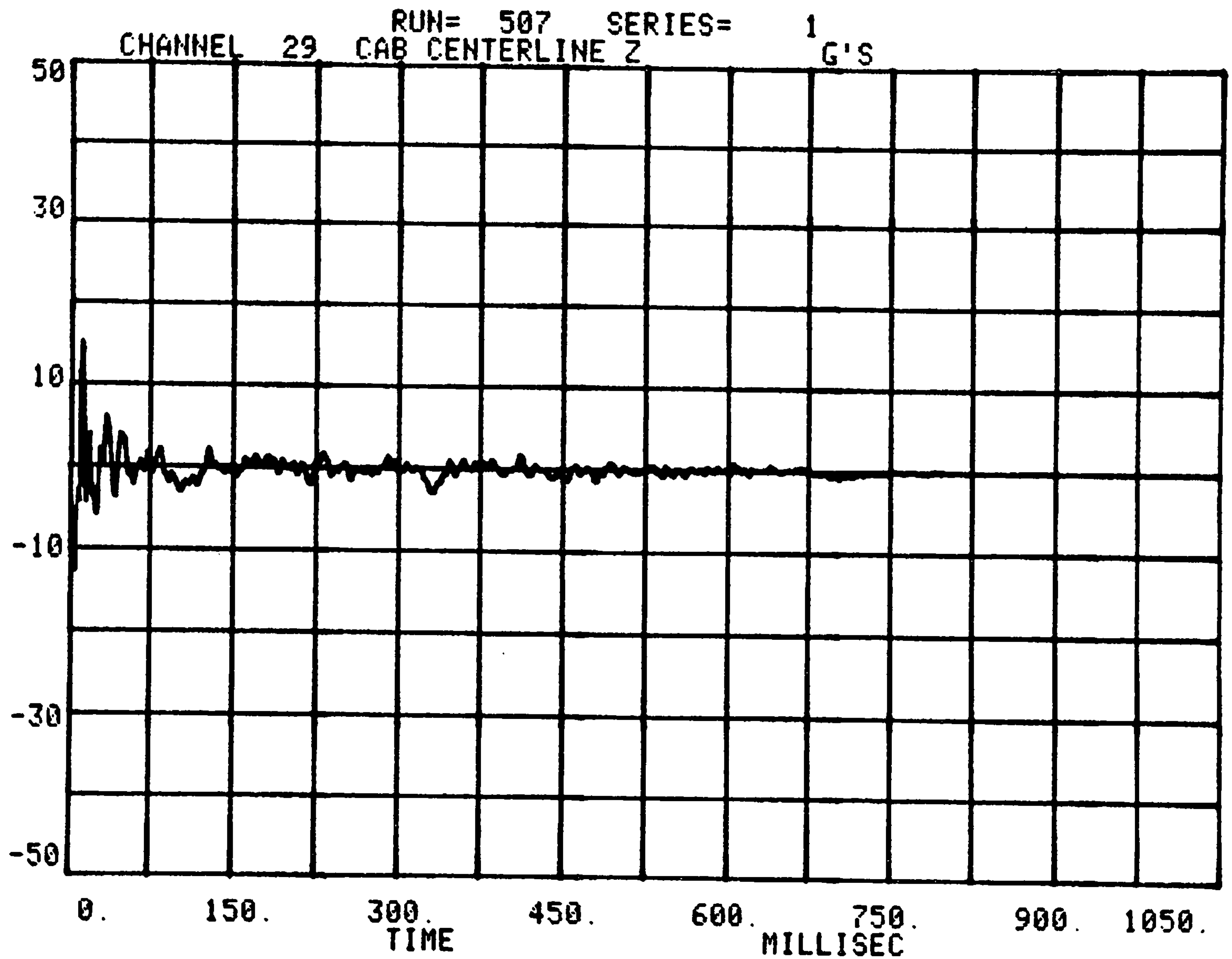
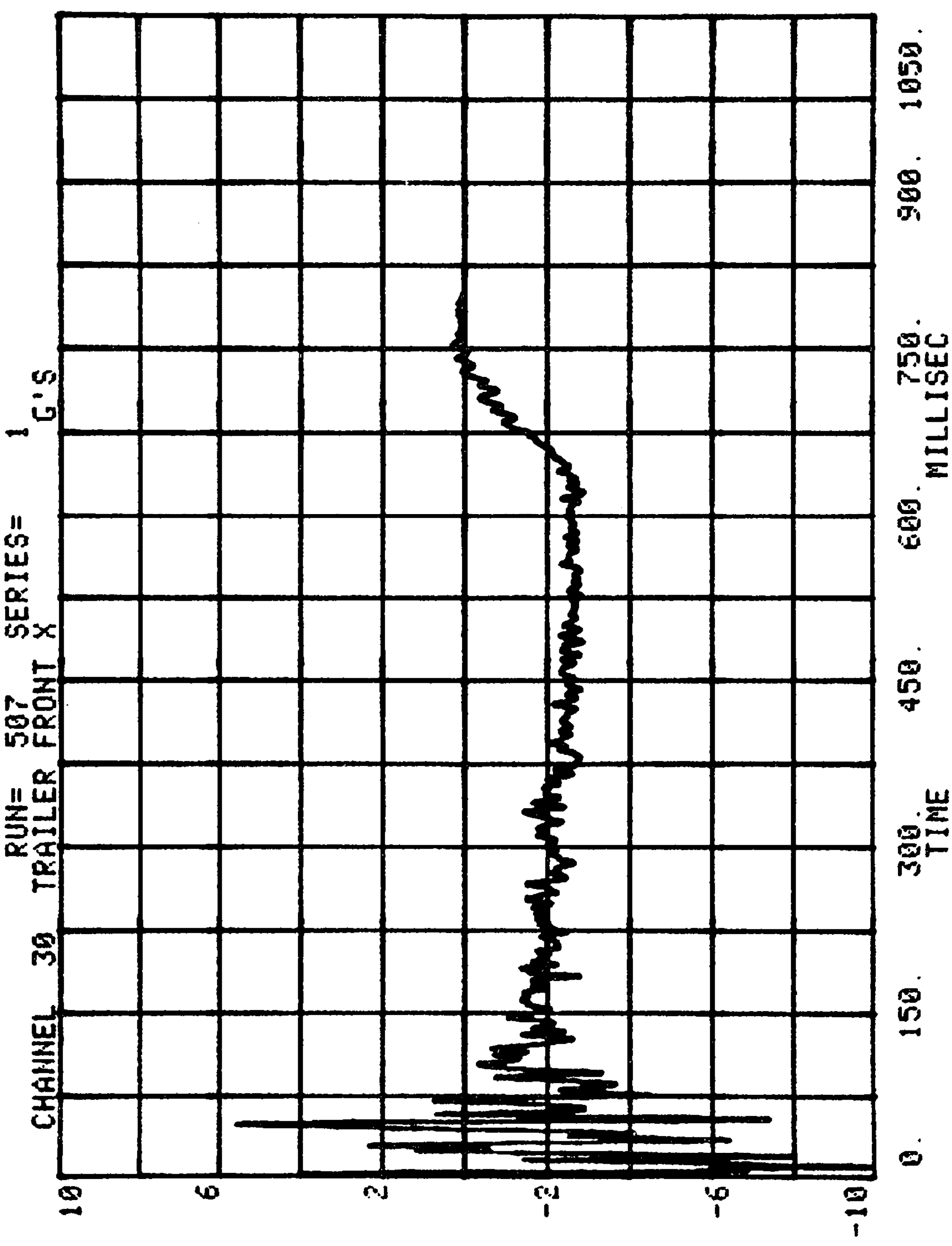
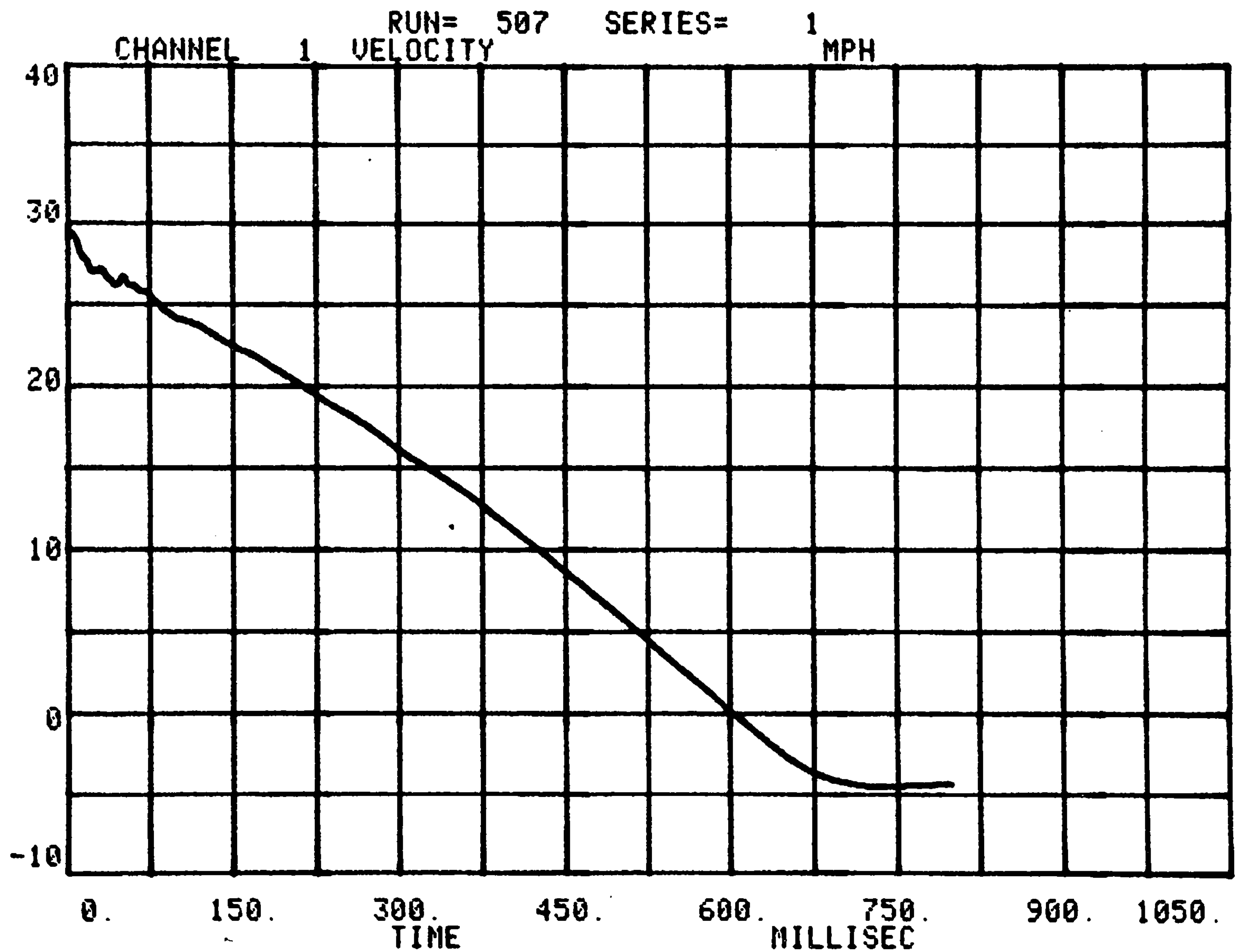

RUN= 507 SERIES= 1
CHANNEL 29 CAB CENTERLINE Z
G'S
50
30
10
-10
-30
-50
0.
150.
300.
450.
600.
750.
900.
1050.
TIME
MILLISEC

FIGURE B-37



CHANNEL 30 RUN= 507 SERIES= 1
TRAILER FRONT X G'S
10
6
2
-2
-6
-10
0.
150.
300.
450.
600.
750.
900.
1050.
TIME MILLISEC

FIGURE B-38



RUN= 507 SERIES= 1
CHANNEL 1 VELOCITY MPH
40
30
20
10
0
-10
0.
150.
300.
450.
600.
750.
900.
1050.
TIME MILLISEC

FIGURE B-39

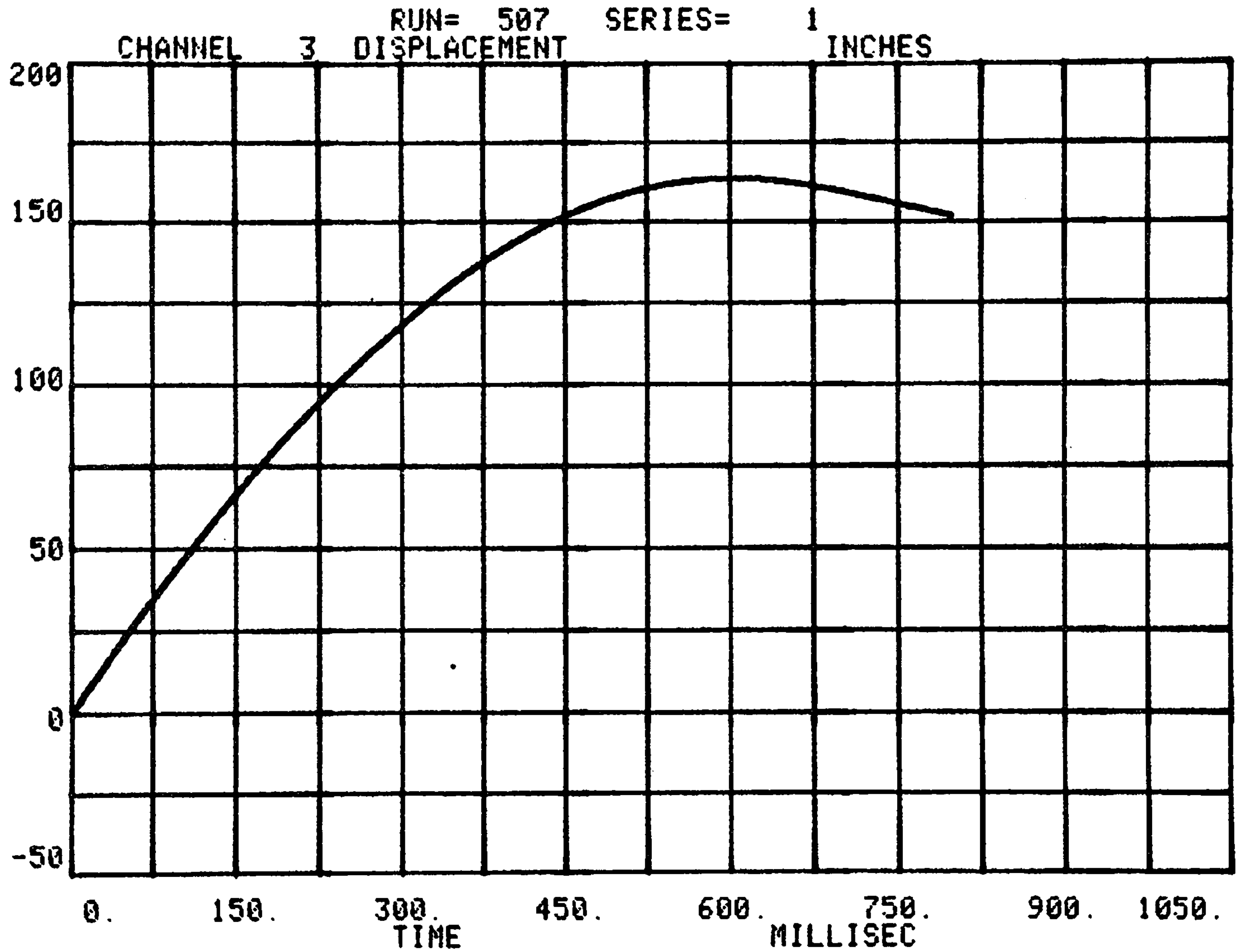

RUN= 507 SERIES= 1
CHANNEL 3 DISPLACEMENT INCHES
200
150
100
50
0
-50
0.
150.
300.
450.
600.
750.
900.
1050.
TIME MILLISEC

FIGURE B-40

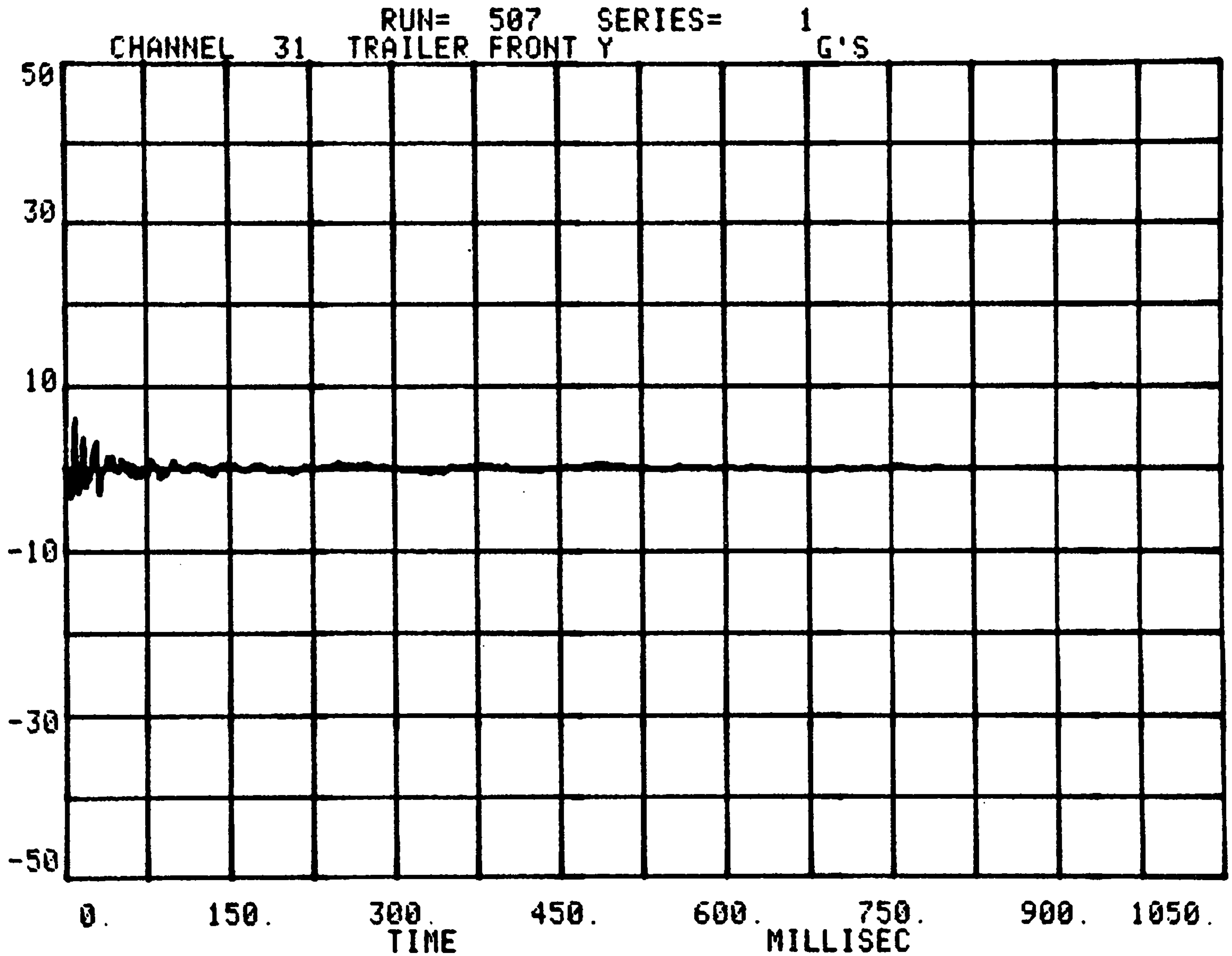

RUN= 507 SERIES= 1
CHANNEL 31 TRAILER FRONT Y G'S
50
30
10
-10
-30
-50
0.
150.
300.
450.
600.
750.
900.
1050.
TIME
MILLISEC

FIGURE B-41

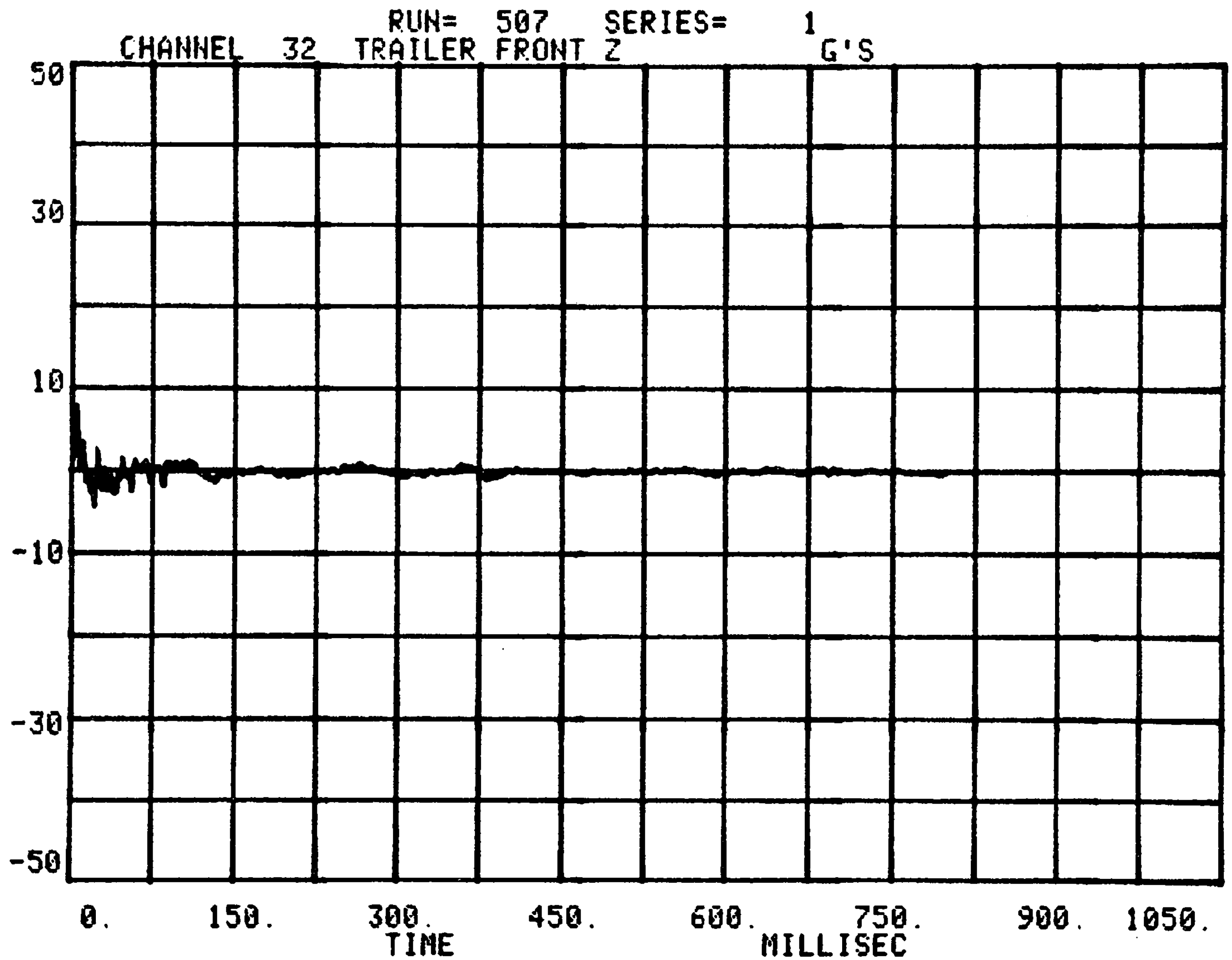

RUN= 507 SERIES= 1
CHANNEL 32 TRAILER FRONT Z G'S
50
30
10
-10
-30
-50
0.
150.
300.
450.
600.
750.
900.
1050.
TIME
MILLISEC

FIGURE B-42

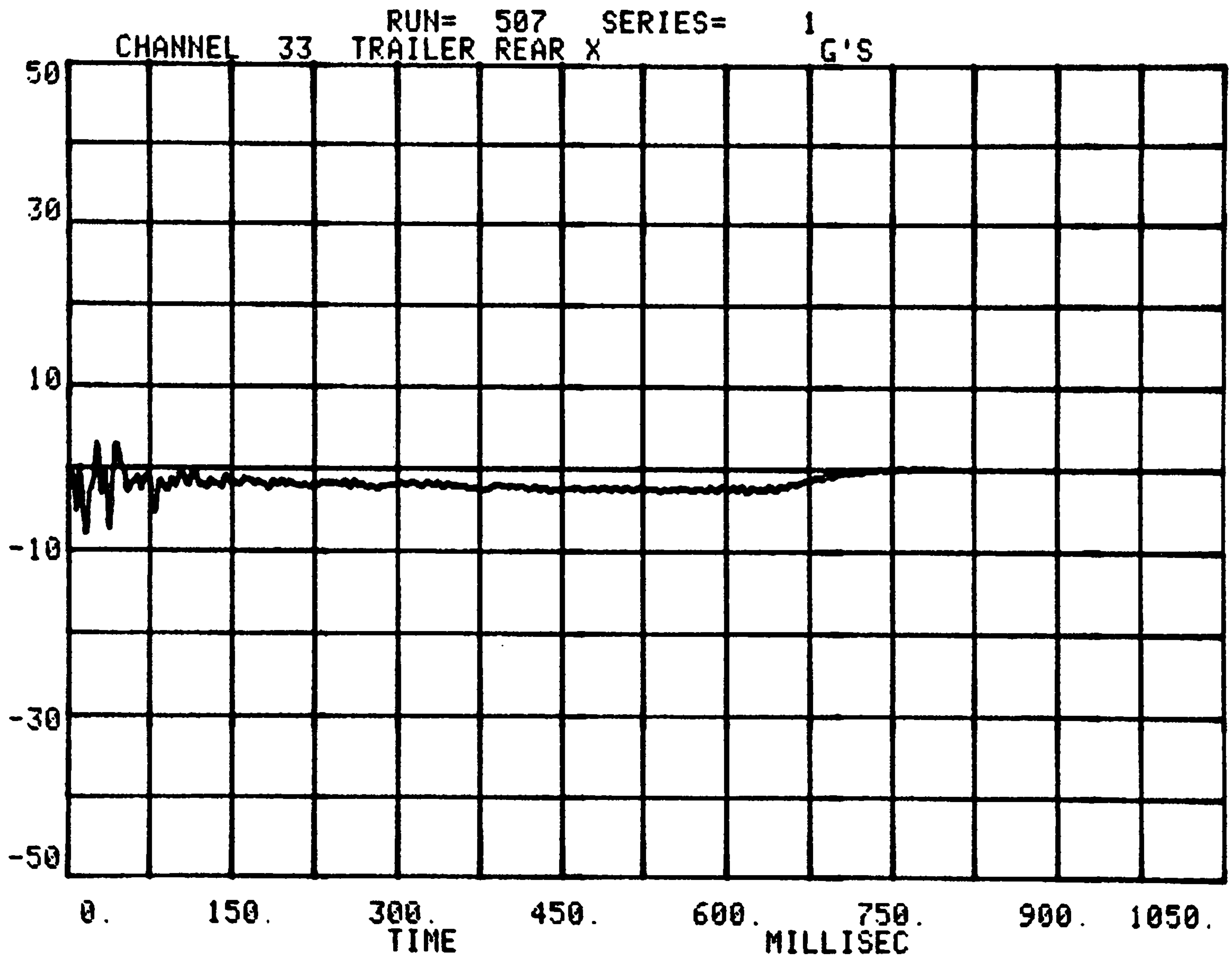
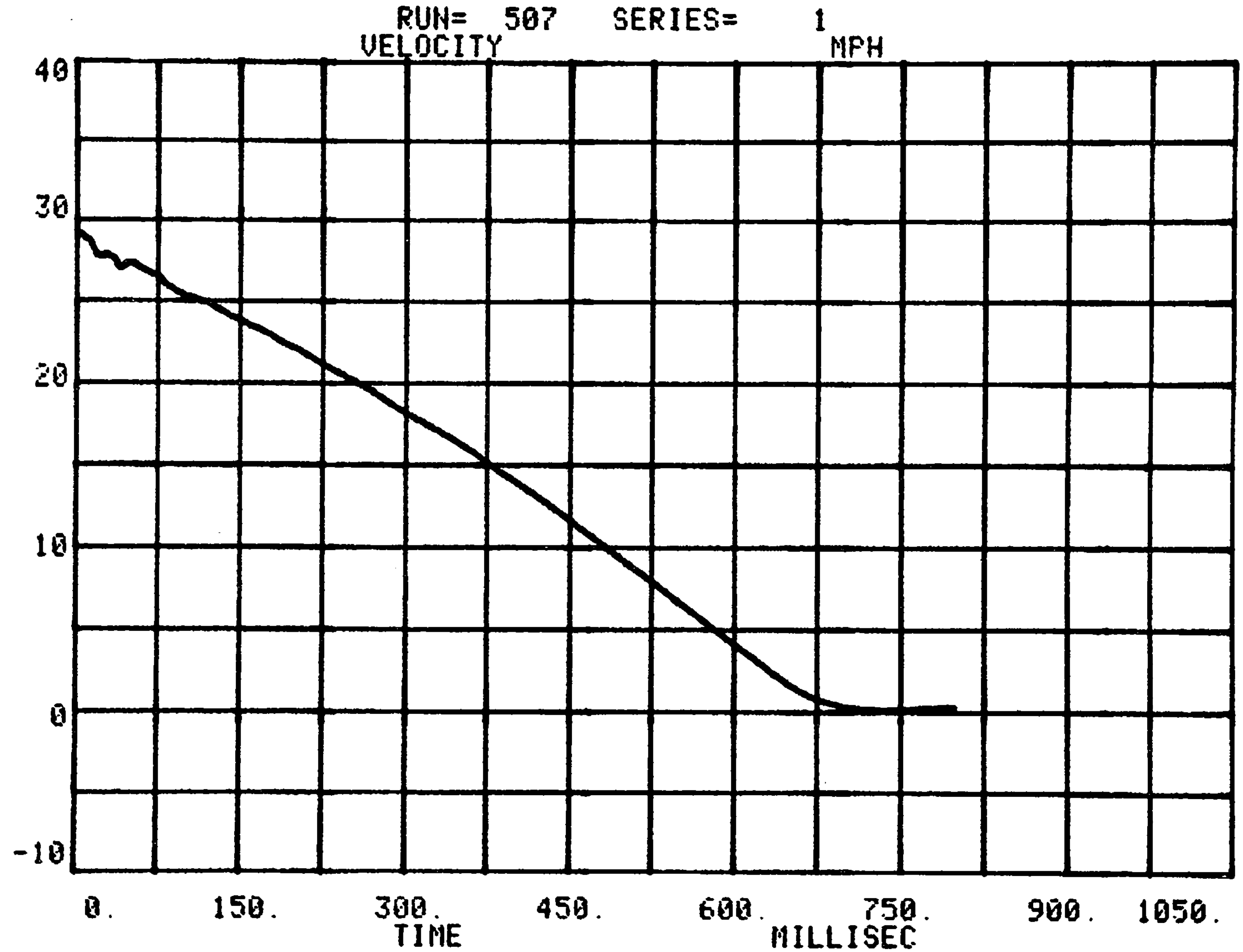

RUN= 507 SERIES= 1
CHANNEL 33 TRAILER REAR X
G'S
50
30
10
-10
-30
-50
0.
150.
300.
450.
600.
750.
900.
1050.
TIME
MILLISEC

FIGURE B-43



RUN= 507 SERIES= 1
VELOCITY
MPH
40
30
20
10
0
-10
0.
150.
300.
450.
600.
750.
900.
1050.
TIME
MILLISEC

FIGURE B-44

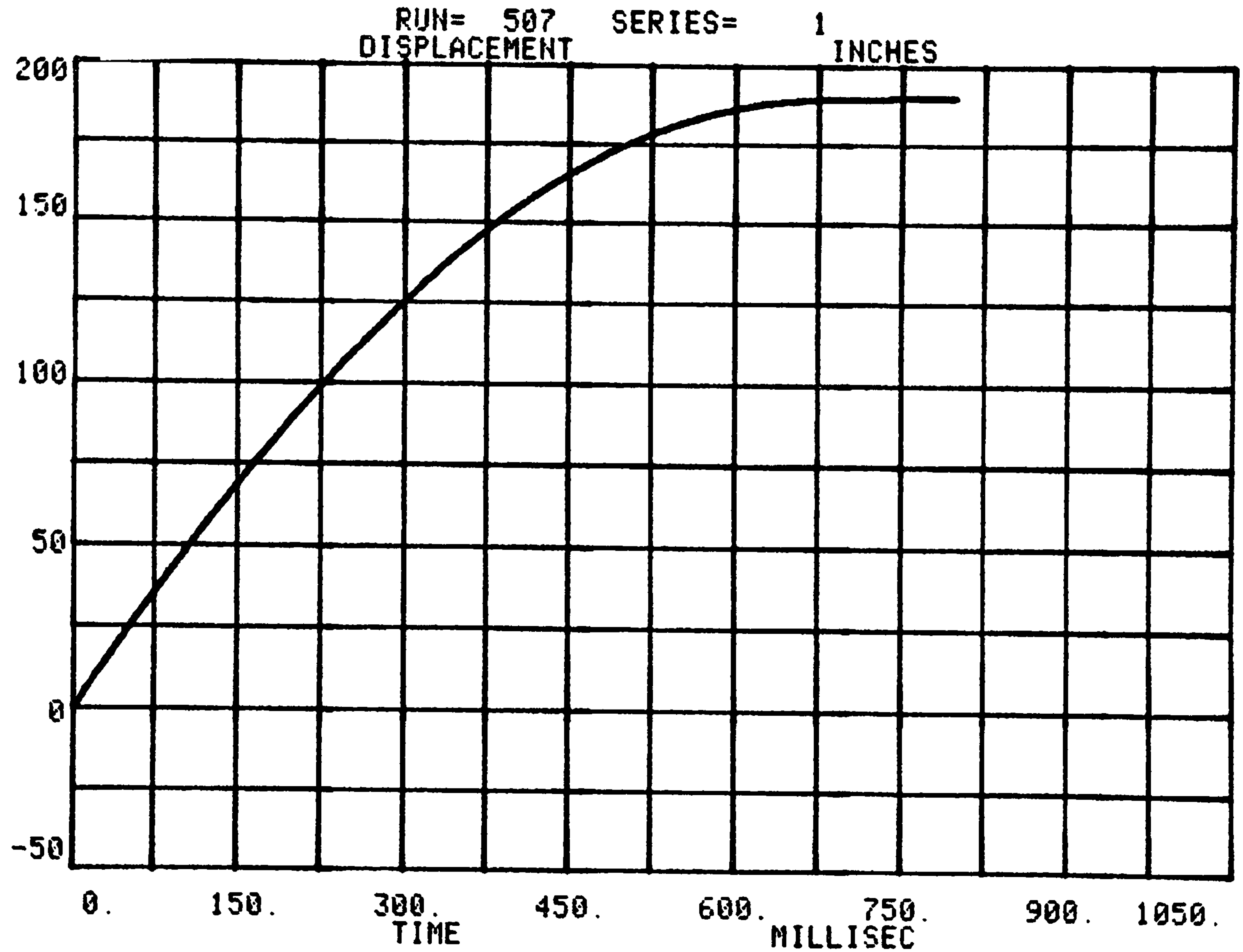

RUN= 507 SERIES= 1
DISPLACEMENT
INCHES
200
150
100
50
0
-50
0.
150.
300.
450.
600.
750.
900.
1050.
TIME
MILLISEC

FIGURE B-45

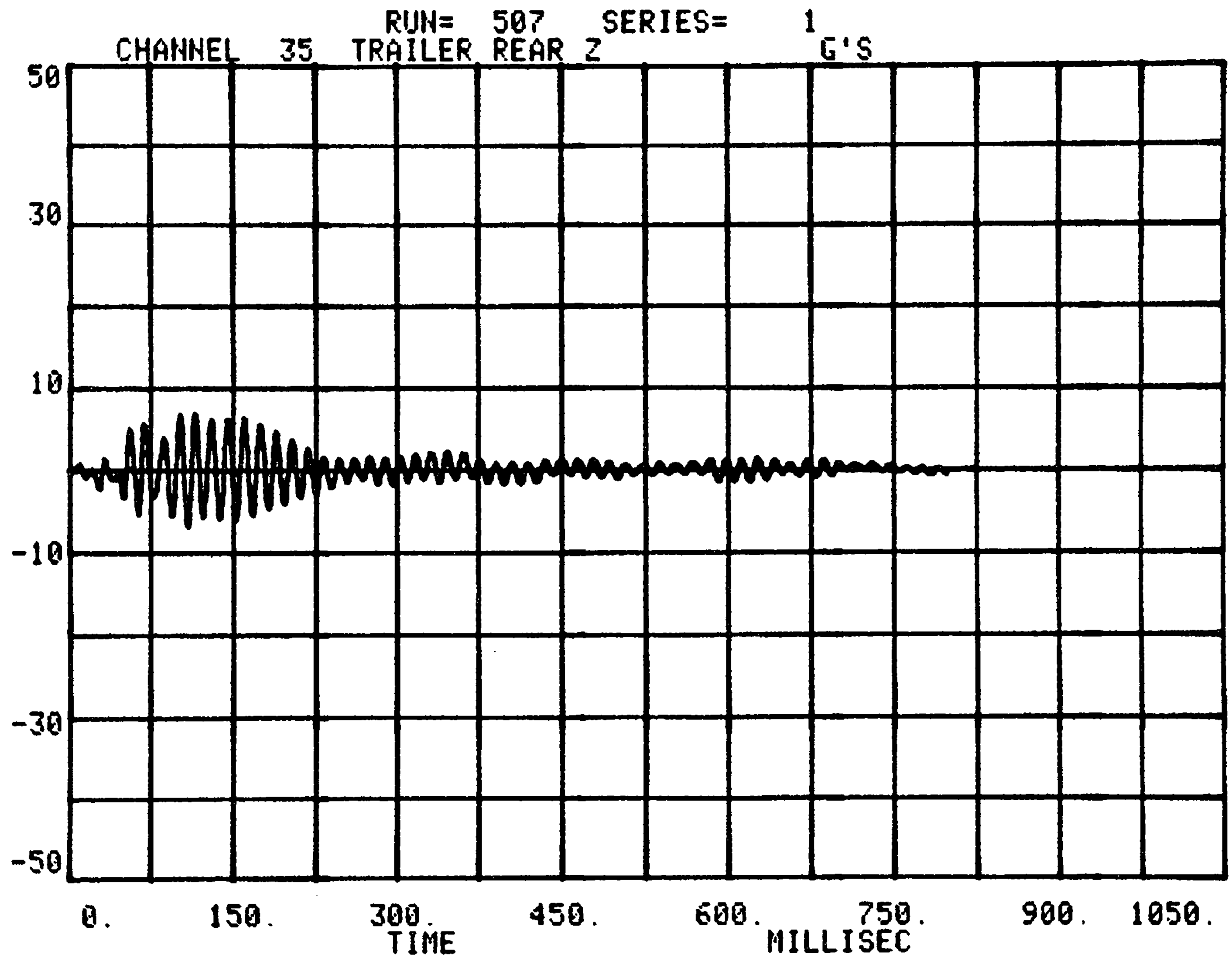

RUN= 507 SERIES= 1
CHANNEL 35 TRAILER REAR Z G'S
50
30
10
-10
-30
-50
0.
150.
300.
450.
600.
750.
900.
1050.
TIME
MILLISEC

FIGURE B-46

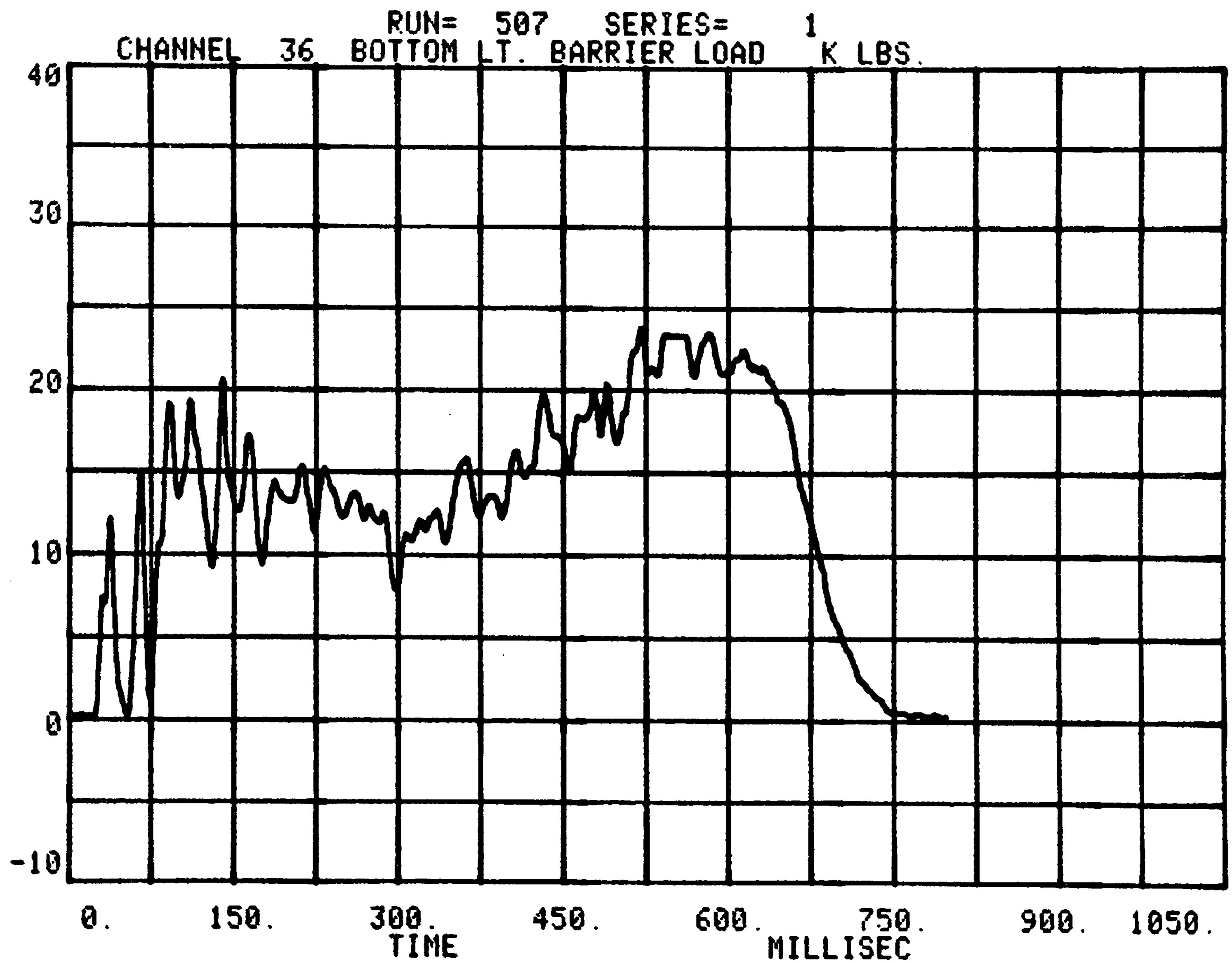

RUN= 507 SERIES= 1
CHANNEL 36 BOTTOM LT. BARRIER LOAD K LBS.
40
30
20
10
0
-10
0.
150.
300.
450.
600.
750.
900.
1050.
TIME
MILLISEC

FIGURE 47

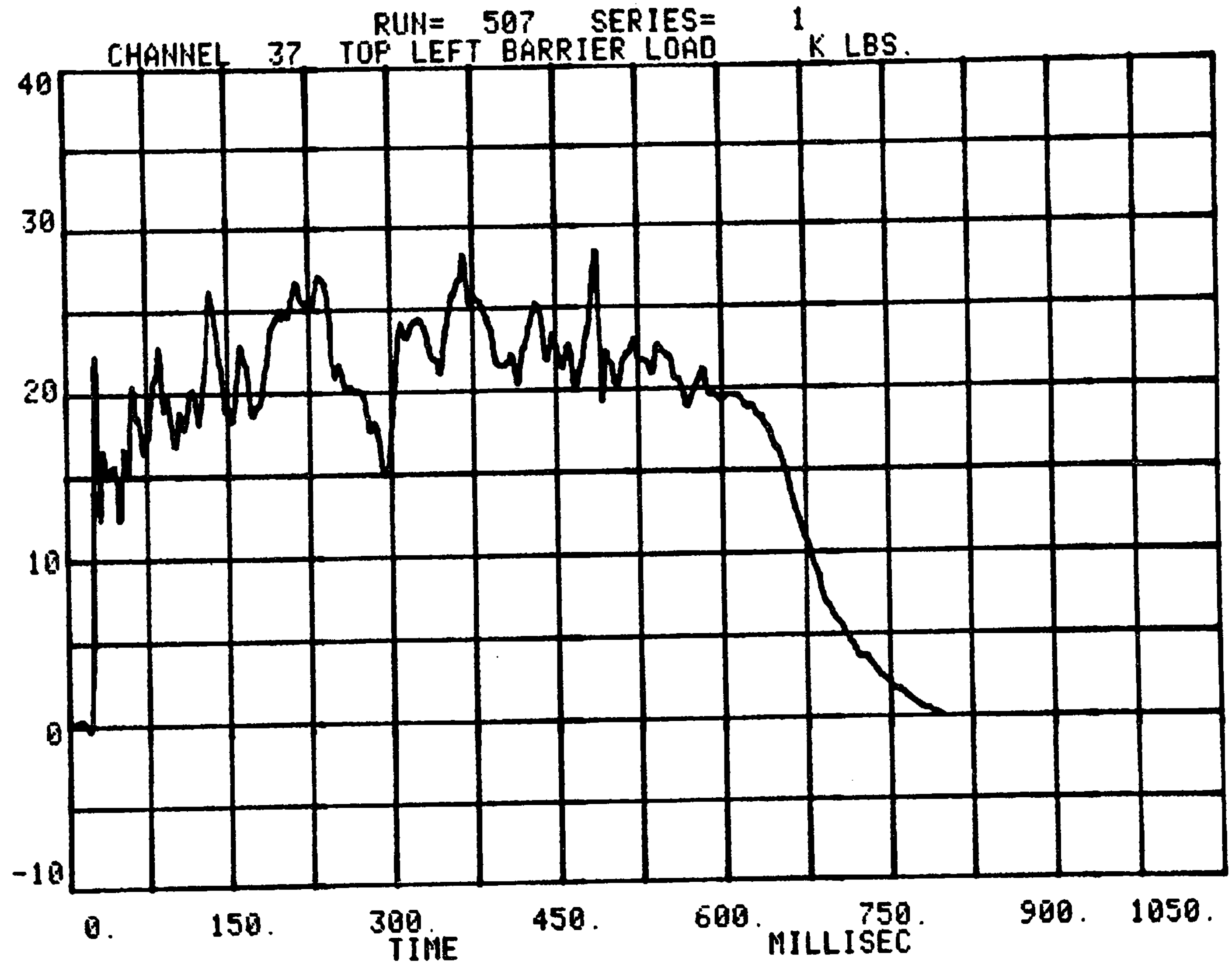

RUN= 507 SERIES= 1
CHANNEL 37 TOP LEFT BARRIER LOAD K LBS.
40
30
20
10
0
-10
0.
150.
300.
450.
600.
750.
900.
1050.
TIME
MILLISEC

FIGURE B-48

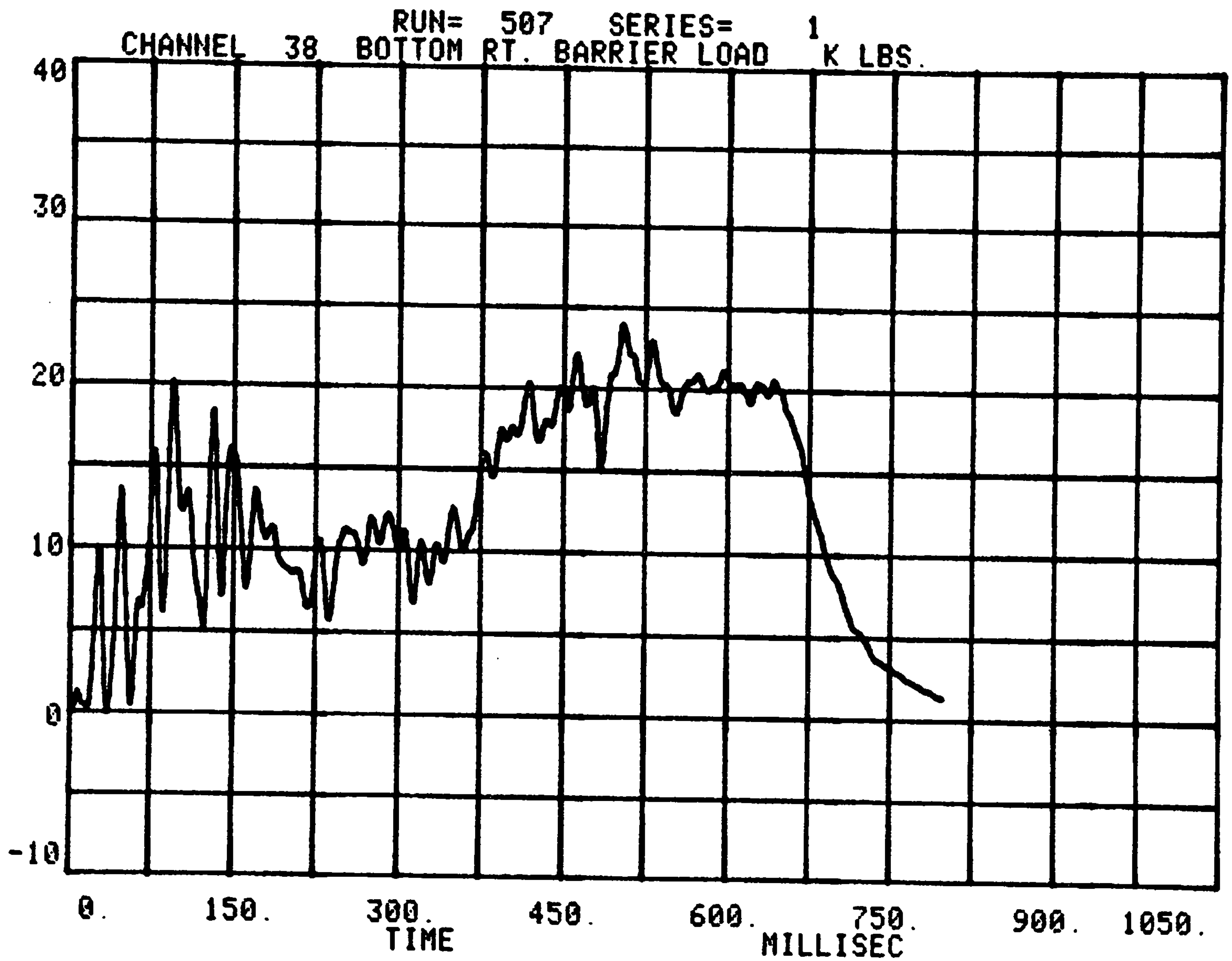

RUN= 507 SERIES= 1
CHANNEL 38 BOTTOM RT. BARRIER LOAD K LBS.
40
30
20
10
0
-10
0.
150.
300.
450.
600.
750.
900.
1050.
TIME
MILLISEC

FIGURE B-49

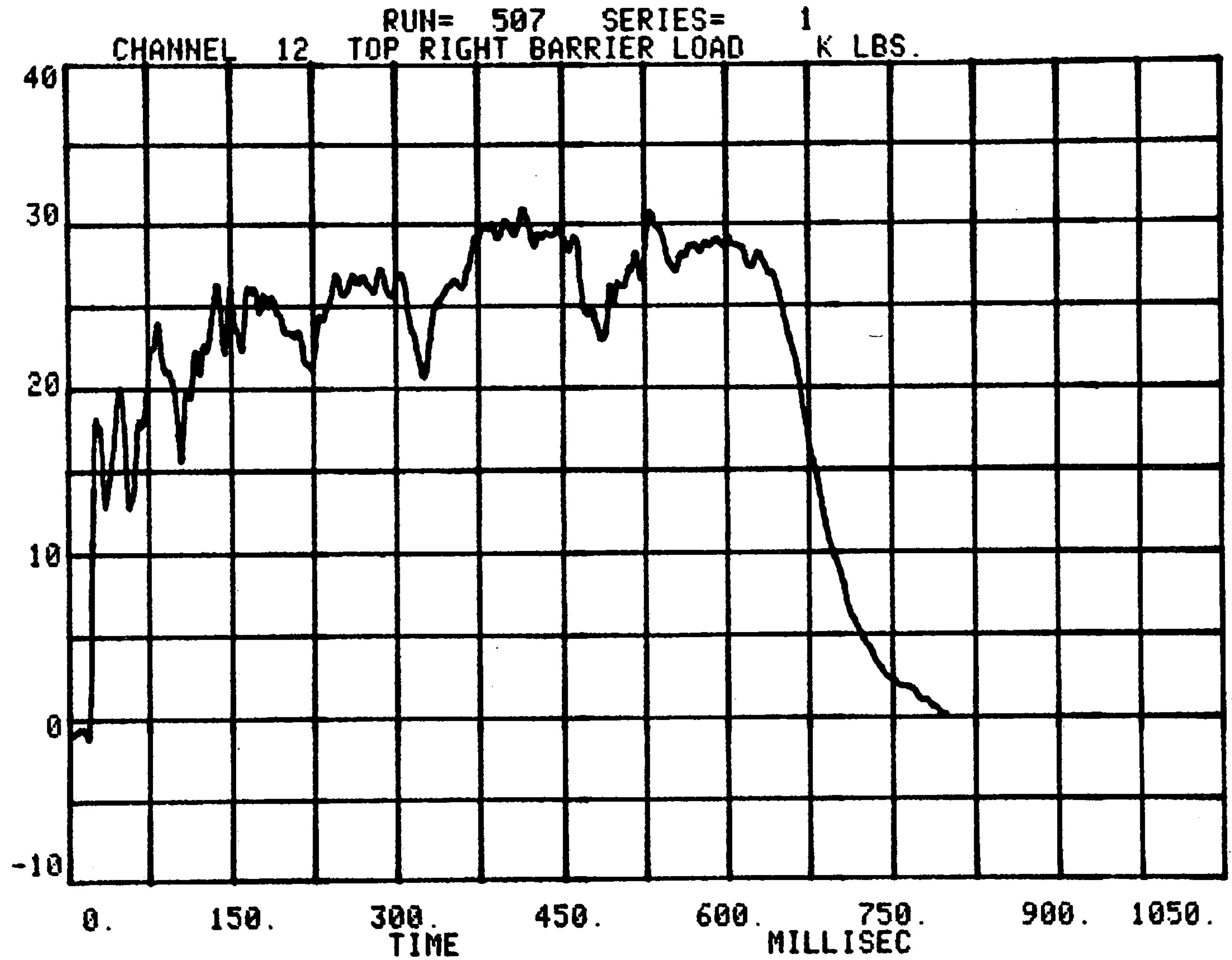
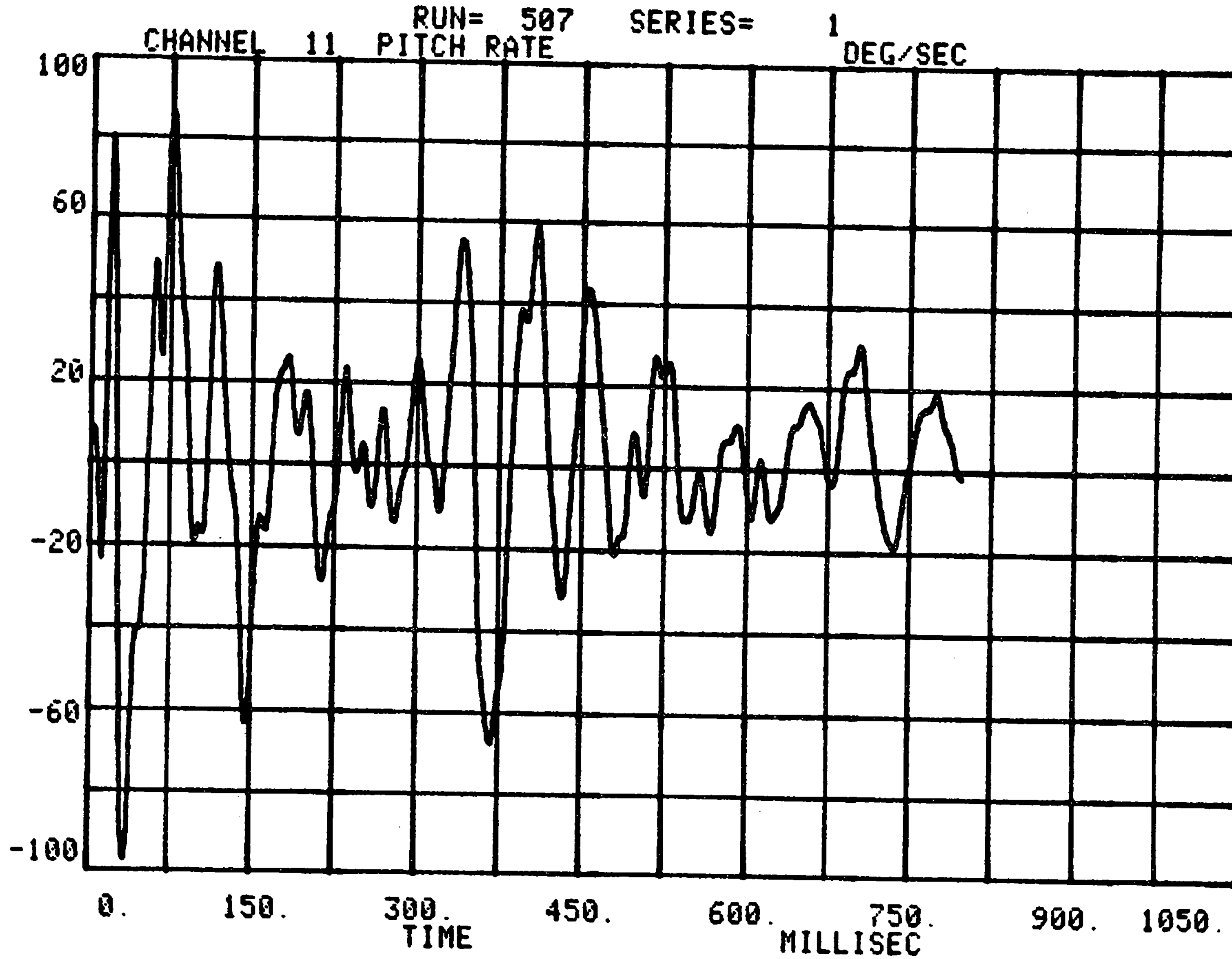
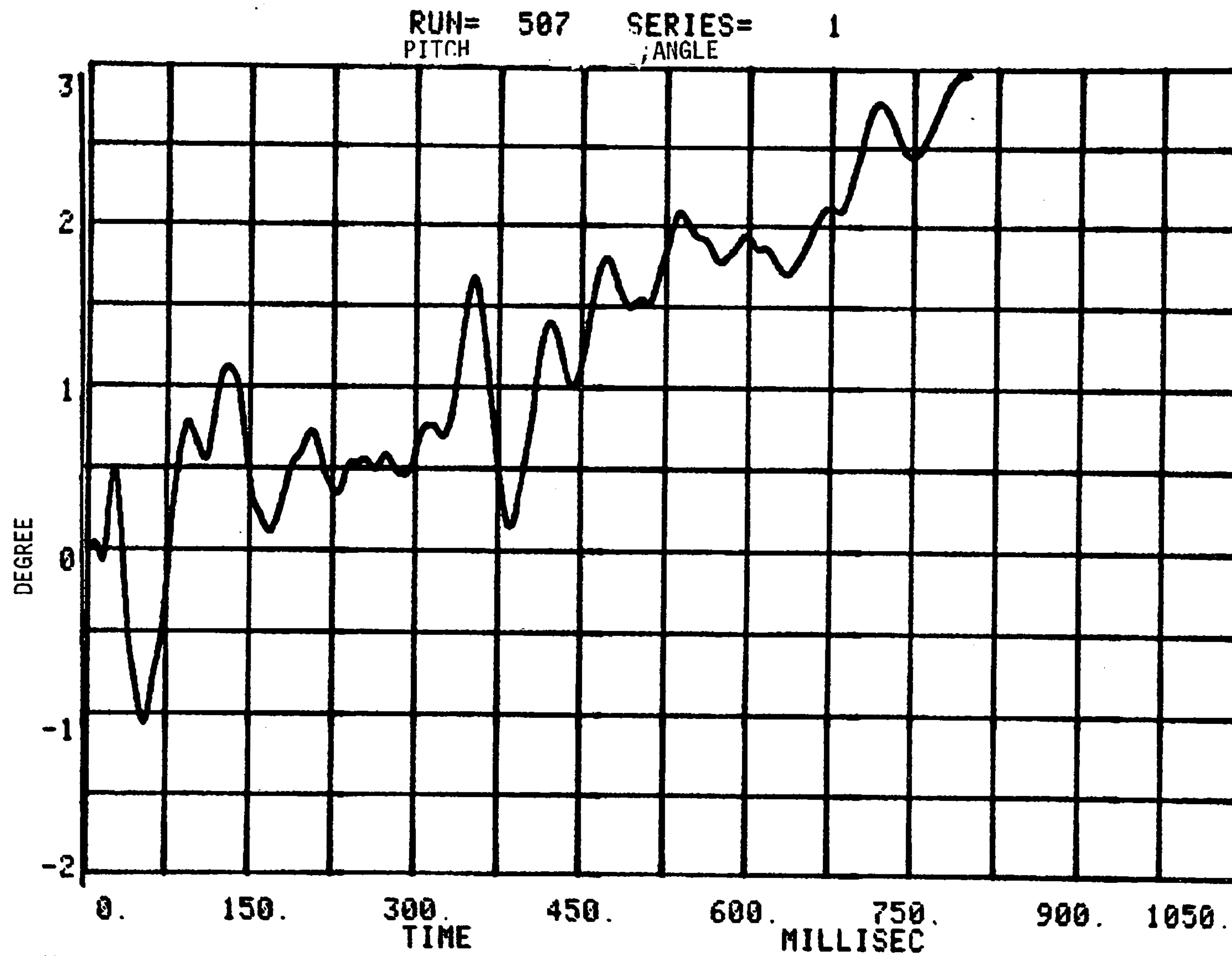

RUN= 507 SERIES= 1
CHANNEL 12 TOP RIGHT BARRIER LOAD K LBS.
40
30
20
10
0
-10
0.
150.
300.
450.
600.
750.
900.
1050.
TIME
MILLISEC

FIGURE B-50



RUN= 507 SERIES= 1
CHANNEL 11 PITCH RATE
DEG/SEC
100
60
20
-20
-60
-100
0.
150.
300.
450.
600.
750.
900.
1050.
TIME
MILLISEC

FIGURE B-51


RUN= 507 SERIES= 1
PITCH ;ANGLE
DEGREE
3
2
1
0
-1
-2
0.
150.
300.
450.
600.
750.
900.
1050.
TIME
MILLISEC

APPENDIX C

DESIGN AND EVALUATION
OF A STEEL DRUM CRASH BARRIER FOR HEAVY TRUCKS

Norris E. Shoemaker

This appendix contains a discussion of the design of the crushable drum barrier. It is also available as a separate report under the same title - (Calspan Report No. 6748-V-3.)

APPENDIX C

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APPENDIX C

1.0 INTRODUCTION

This section describes the design methodology and experimental performance of the steel drum crash cushion used in the truck frontal impact test.

A deformable crash barrier face was selected as being more representative of potentially survivable real-life truck accidents when compared to the fixed rigid barrier tests now required in the Federal Motor Vehicle Safety Standard (FMVSS) No. 208 for passenger cars and light trucks. In the FMVSS 208 impacts the vehicle deceleration pulses are defined by the pattern of energy absorbed in deforming the vehicle's front structure. In heavy truck tractors there is little deformable material forward of the frame rails to absorb energy; therefore, the impact forces are almost immediately transmitted to the vehicle's frame rails. Since these longitudinal rails are highly resistant to buckling, and since the vehicle's kinetic energy is generally high, (if for no other reason due to its mass), generally one of two outcomes results. The first is that the object struck by the truck yields and the heavy truck's velocity and kinetic energy is reduced somewhat. In the second case, the object struck acts as a rigid barrier and the heavy truck sustains catastrophic deformation while dissipating the extremely high kinetic energy levels present. Since these later conditions were not deemed amenable to the development of reasonable energy management countermeasures, even under the best of circumstances, the rigid barrier concept was not considered to be a worthwhile approach.

The steel drum crash cushion which is described in the following sections is based on Calspan's pre-test estimates of impact conditions which could generate representative data for evaluating occupant kinematics in a potentially survivable frontal collision.

2.0 DEFORMABLE BARRIER FACE DESIGN

The "Texas" type steel drum concept was selected for the deformable barrier in this test because previous research and experimental testing had demonstrated the feasibility of adapting this design to contain the crash loads generated by a heavy truck. This was based on the realization that successful impact attenuation of passenger cars at impact velocities ranging up to 60 mph had been accomplished by Calspan and Texas Transportation Institute using the steel drum concept (Ref. 1, 2 and 3).

The design of the steel drum crash attenuation barrier for the pilot heavy truck program was based on the principal of predictable crush at constant force level - the amount of crush and force being a function of the drum material gauge, and top and bottom closure characteristics. In the interest of achieving a constant deceleration level for the truck during the complete event, a rectangular array of 55 gallon drums was designed to produce a 2.5 g stopping pulse for a 35,000 pound tractor-trailer rig, as shown in Figure 1.

The drums needed for this application had the following specifications:

Size:	55 gallon; 24 in. diameter x 35 in. high
Material:	steel - 18 gauge shell and cover (closed top)
Collapse Force Ref. 1:	10 Kips/drum - static 10 x 1.5 = 15 Kips/drum - dynamic
Energy Absorption:	19,500 ft. lbs./drum (measured statically) (based on 16 inch crush)

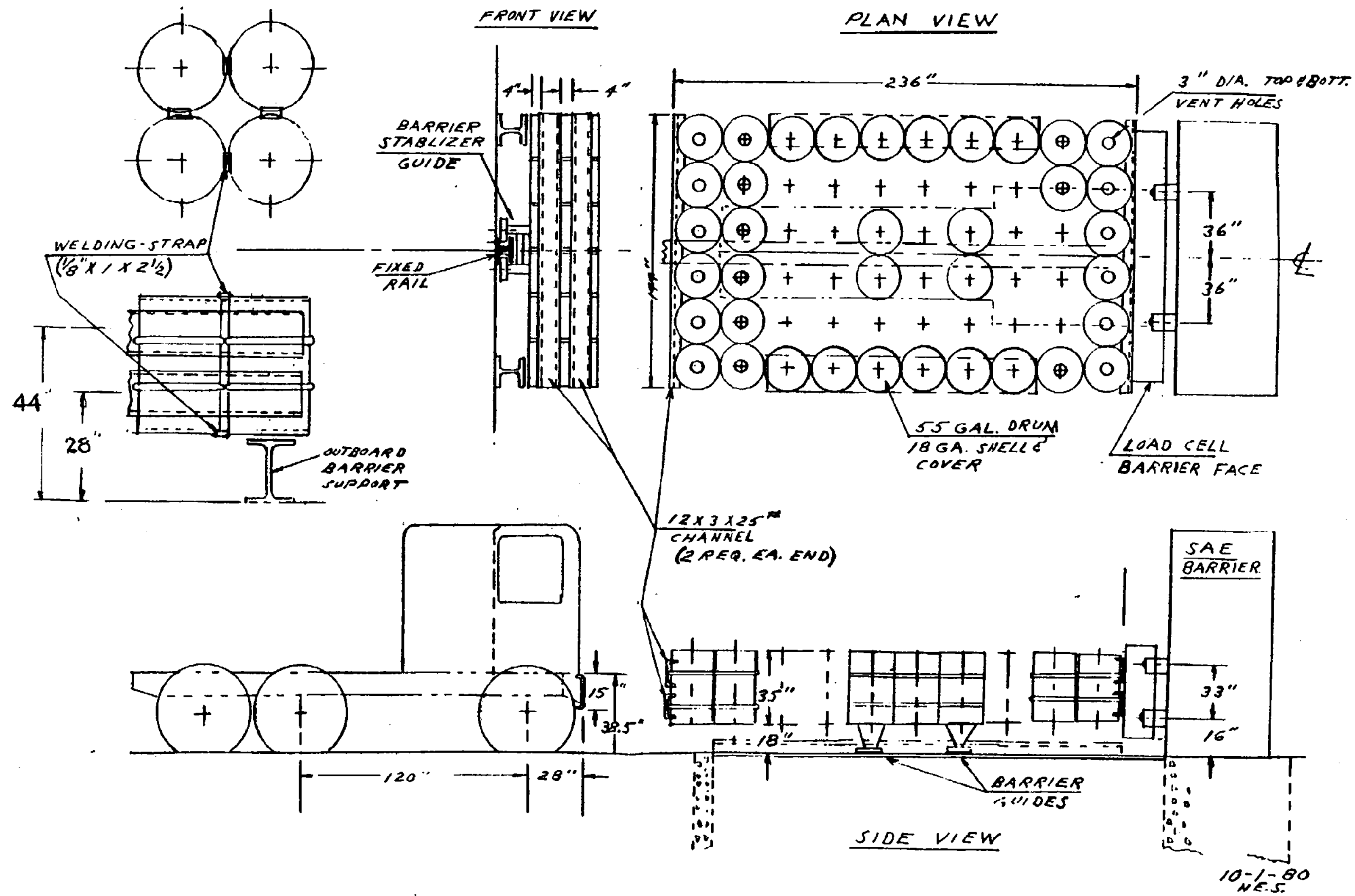


Figure 1 STEEL DRUM BARRIER LAYOUT

Analysis of the test data from previous tests (Ref. 1) has indicated that the individual energy absorption per drum, when summed in a modular barrier array, is approximately 50 percent higher than the static force - deformation data measured on a single drum. Crash tests have also shown that the average deformation of each drum ranges between 2/3 and 3/4 of its original diameter during the constant force phase of each drum collapse.

The crash attenuator for this test was designed to achieve a constant 2.5 g acceleration pulse for a 35,000 pound vehicle traveling at 30 mph (44 ft./sec.), using the following pre-test assumptions and calculations:

$$\text{Total Barrier Deformation Force} = \frac{W}{g} \times a$$

$$F_b = Wg = 35{,}000 \times 2.5 = 87.5 \text{ Kips}$$

$$\text{Vehicle Kinetic Energy} = 1/2\ W/g\ V^2$$

$$KE = 1/2\ \frac{35{,}000}{32.2}\ (44)^2 = 1.05 \times 10^6 \text{ ft. lbs.}$$

$$\text{Minimum Number Drums} = \frac{\text{KE of Vehicle}}{\text{Energy Absorption/drum}}$$

$$N_d = \frac{1.05 \times 10^6 \text{ ft. lbs.}}{19.5 \times 10^3 \text{ ft. lbs./drum}} = 54 \text{ drums}$$

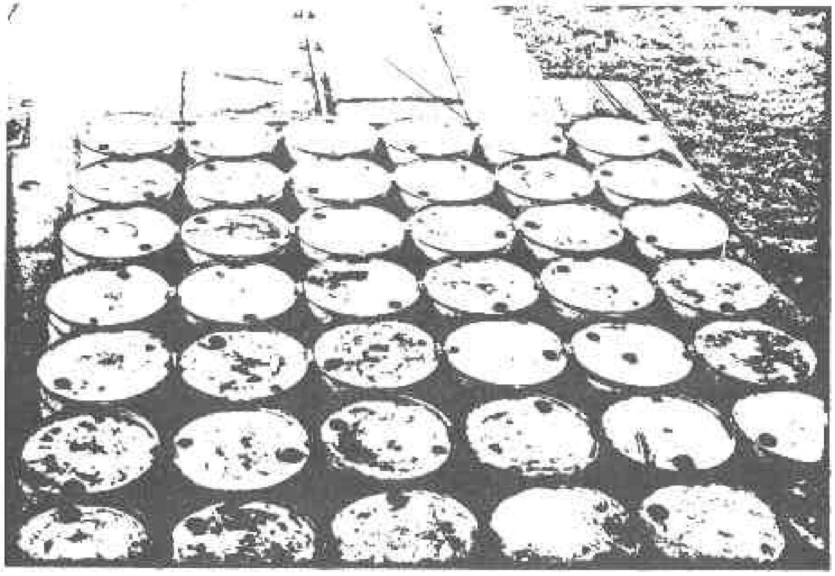
$$\text{Number Drums/row} = \frac{\text{Total Deformation Force}}{\text{Deformation Force/drum}}$$

$$N_w = \frac{87.5 \text{ Kips}}{15 \text{ Kips/drum}} = 6 \text{ drums wide}$$

$$\text{Minimum Number Drum Rows} = \frac{\text{Total Number of Drums}}{\text{Number Drums/row}}$$

$$N_r = \frac{54}{6} = 9 \text{ rows deep}$$

In the interest of providing additional crush distance, ten rows of drums were selected for the six column wide array for a total of 60 drums. This array of drums positioned on the face of Calspan's SAE barrier is shown in Figure 2.



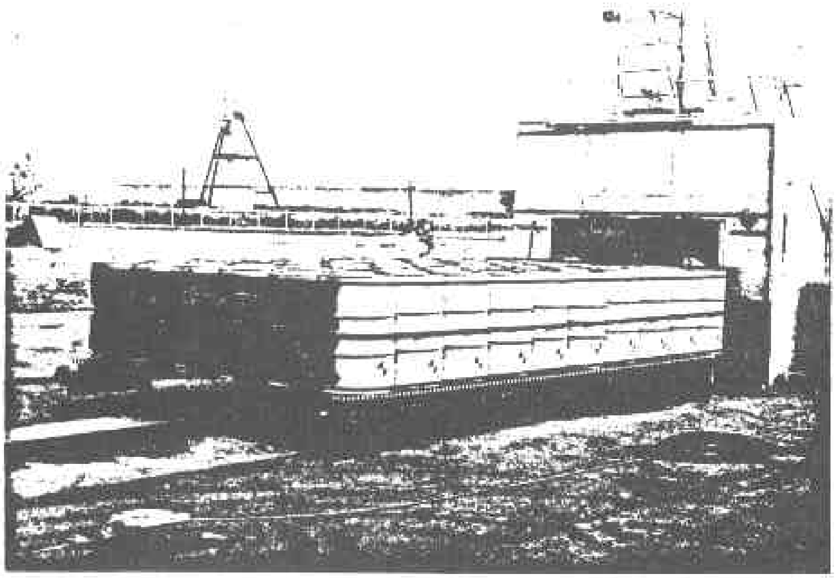


Figure 2 STEEL DRUM BARRIER INSTALLATION

The total weight of the crash cushion, including the two 12-inch channels on the barrier impact face, was 3600 pounds. The two channels weighed a total of 500 pounds. The average weight of each drum was approximately 51 pounds. Because the vehicle-to-barrier effective weight ratio was large, the inertia effect of the steel drums was neglected in the above calculation.

3.0 CRASH BARRIER CONSTRUCTION

The sketch used in the construction of the modular array of drums is shown in Figure 1. The array of 60 drums were welded together at every tangent point (top and bottom) where their rims contacted. To strengthen the weld connection, a metal strap (1/2 x 1 x 2) was welded to the adjacent drums as shown in Figure 3. The array was also contained by three steel banding straps as shown in Figure 2.

To provide a structurally flat interface between the truck and barrier, two 12-inch 25 pound per ft. steel channels were welded to the impact surface of the drums, as shown in Figure 2. Two 12-inch channels were also used to secure the drums to the load cell barrier face. The drums were vented to prevent pressurization by providing a three-inch diameter hole in the top and bottom covers of each drum.

Two barrier stabilizer guides were provided on the center line of the array at ground level as shown in Figures 1 and 3. The guide assembly provided vertical and lateral stability without restricting the longitudinal collapse of the drum array.

The crash cushion assembly was secured to the SAE load cell barrier face as shown in Figure 1. The elevation of the crash cushion was established by placing the center of the drums at the same elevation as the center of the tractor frame rails. The drums were positioned approximately 18 inches above the road surface. To support the barrier assembly at the desired elevation, the two outboard columns of drums were supported on a steel I-beam as shown in Figure 1.

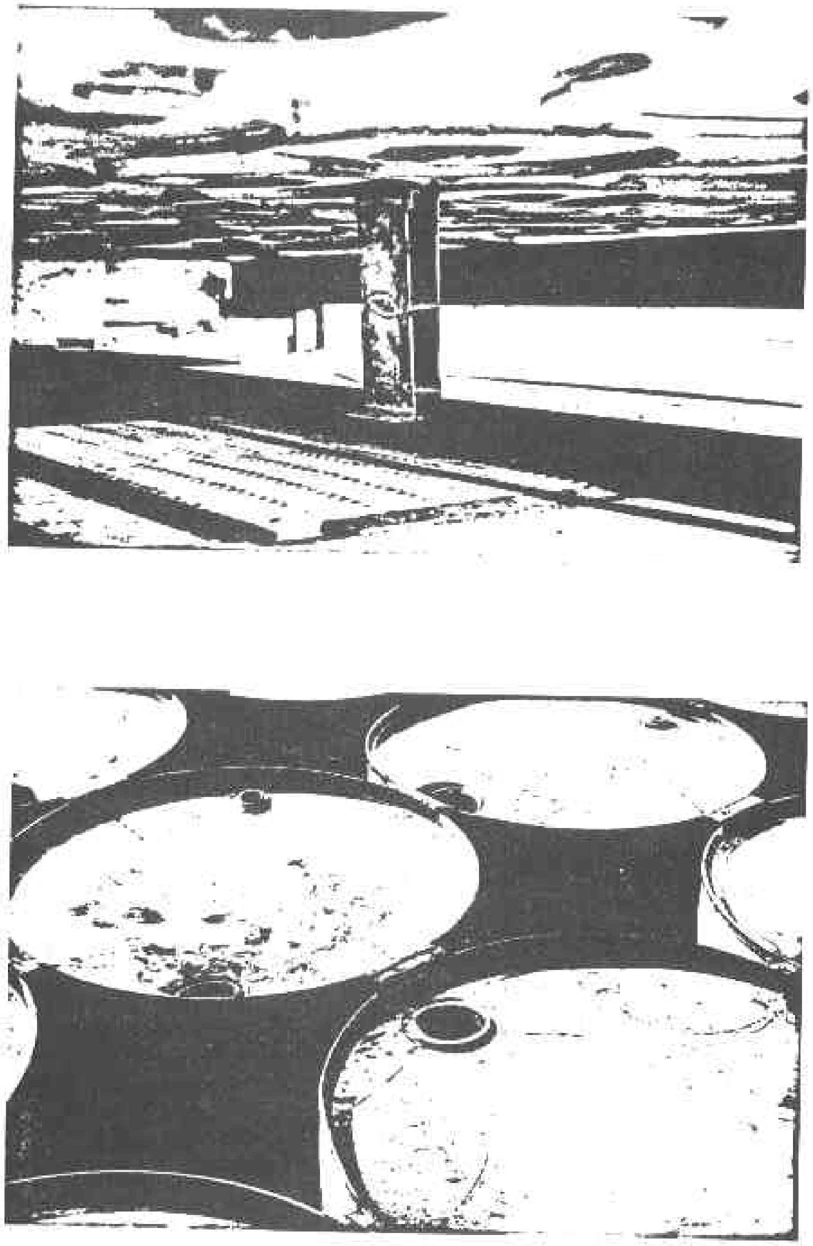


Figure 3 BARRIER STABILIZER GUIDE AND DRUM WELDING STRAP

4.0 EXPERIMENTAL RESULTS - FRONTAL TRUCK IMPACT

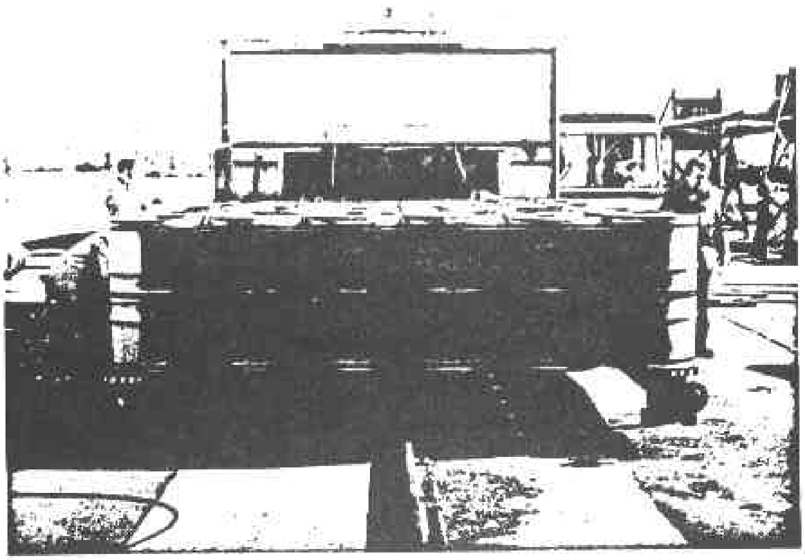
The 34,690 pound loaded tractor-trailer rig struck the steel drum crash barrier head-on at the center line at 29.2 mph (42.6 ft./sec.). The vehicle tow cable was released prior to barrier impact. The vehicle guidance system remained in effect during the complete impact event.

4.1 Barrier Performance

The impact produced 14.2 feet of permanent deformation at the center of the barrier, as shown in Figure 4. Based on film analysis, the dynamic deformation was 15.5 feet. The barrier deformation profile is shown in Figure 5 with the vehicle rebounding 11.6 feet. The pre- and post-impact configuration for the left and right sides of the barrier module are shown in Figures 6 and 7. The pre- and post-test dimensions for the drum array photo-targets are presented in Figure 8. The collapse characteristics of the drums are presented in Figures 9 and 10.

The deformable barrier collapsed in a predictable and stable manner with no lateral or vertical barrier buckling or ramping of the truck. The overall barrier stability during the dynamic event was attributed to the guide rail feature provided at the center of the barrier. There was negligible elastic rebound of the barrier system.

The barrier force time history data is presented in Figure 11. Based on the flat response characteristics of the barrier forces, the drum array dissipated the truck kinetic energy in a controlled manner at near a constant rate. The vehicle deceleration ranged between 2 and 2.5 g's during most of the event.



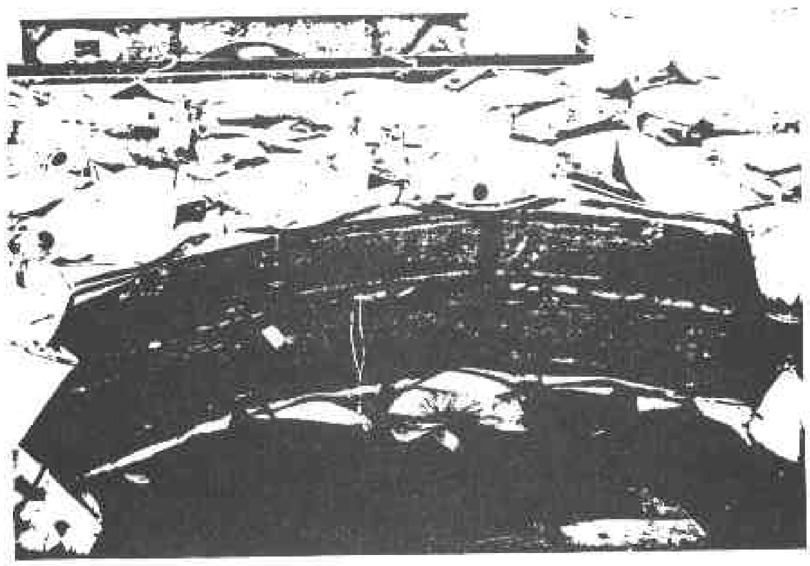


Figure 4 PRE & POST BARRIER TEST CONFIGURATION FRONTAL VIEW

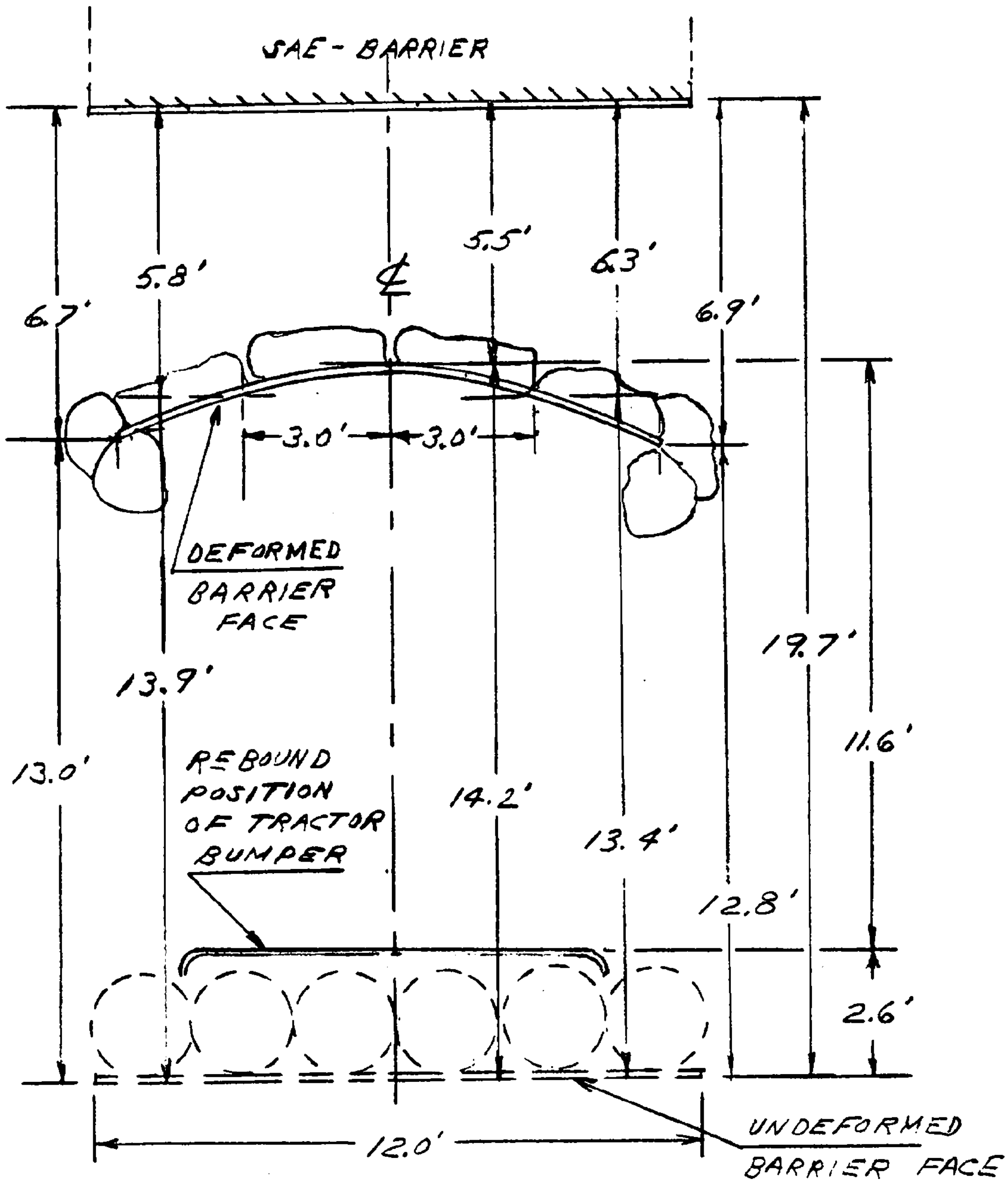


Figure 5 BARRIER DEFORMATION PROFILE

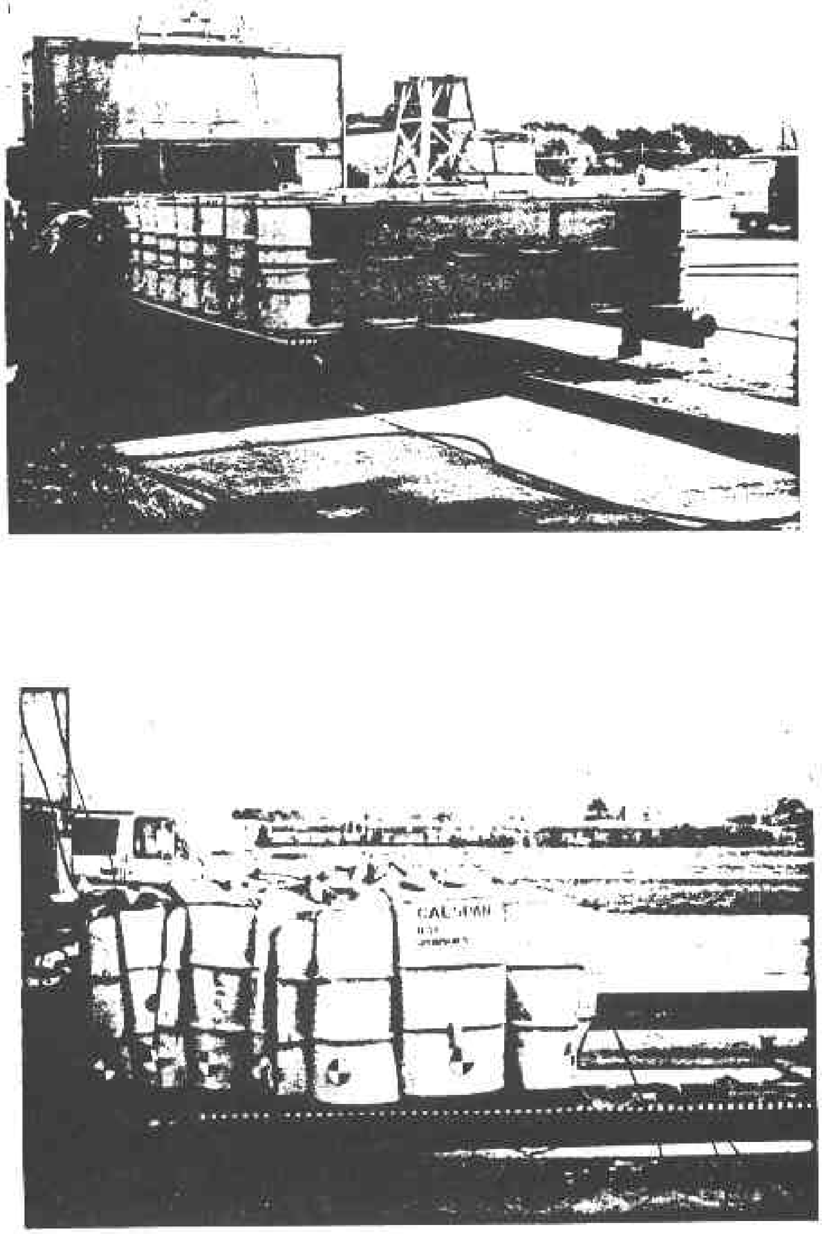
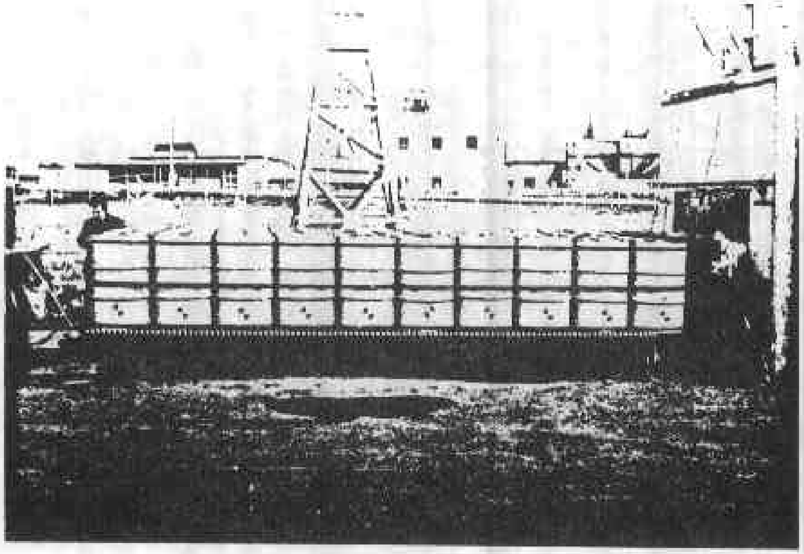


Figure 6 PRE & POST BARRIER TEST CONFIGURATION – LEFT SIDE



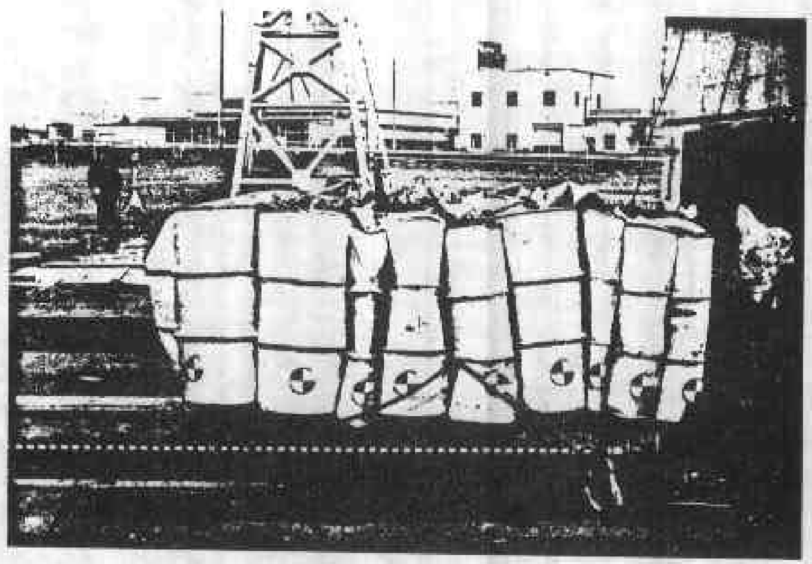
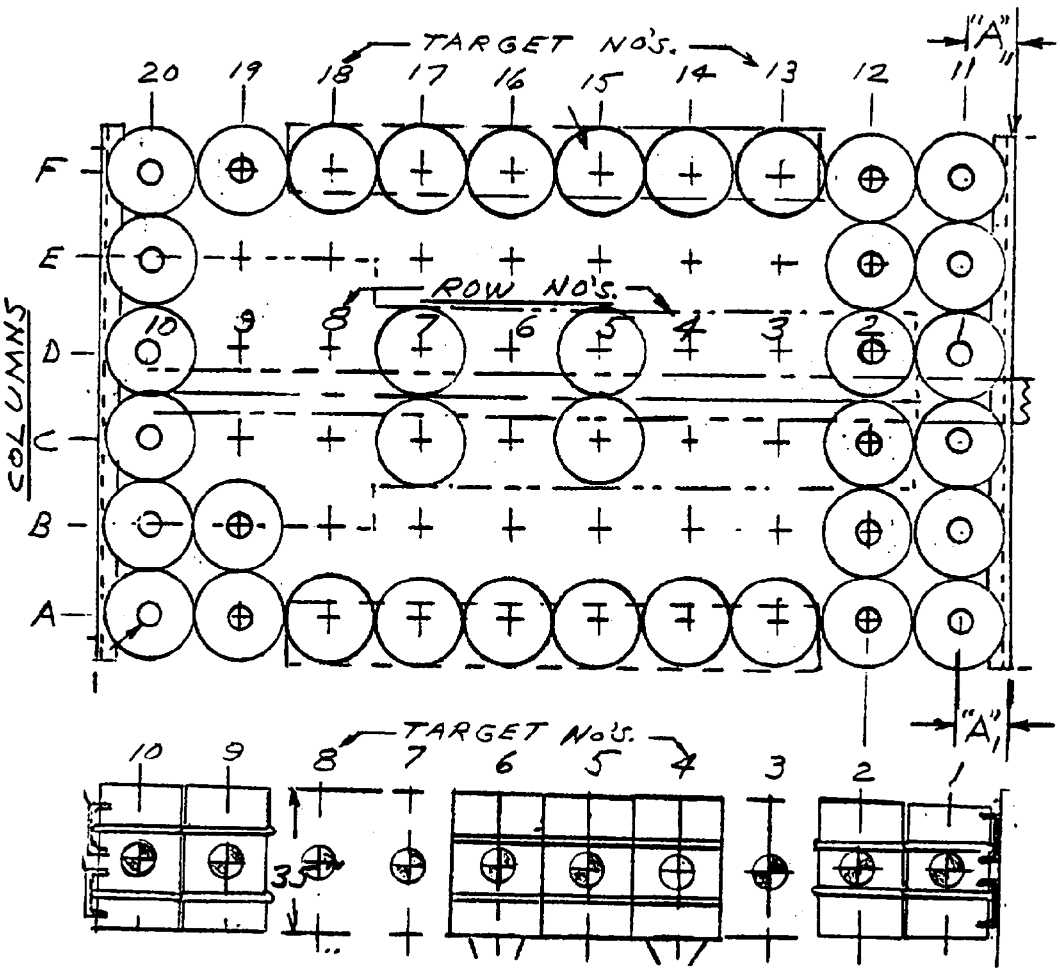


Figure 7 PRE & POST BARRIER TEST CONFIGURATION – RIGHT SIDE



TARGET No.	"A" DIMENSION PRE-TEST	POST	TARGET No.	"A" DIMENSION PRE-TEST	POST
1	13	-2	11	13	2
2	35	9.7	12	36.7	12.5
3	59.5	18.5	13	60	13.5
4	82.5	24.5	14	82.7	23.5
5	105.7	37.5	15	105.5	33
6	129	52.5	16	130.2	35.5
7	153.7	60.5	17	153	47.5
8	176	71	18	176.5	70
9	199	87.5	19	197.5	35
10	220.7	—	20	223.5	—

Figure 8 DRUM PHOTO TARGETS PRE & POST TEST

Figure 9 DRUM COLLAPSE PATTERN

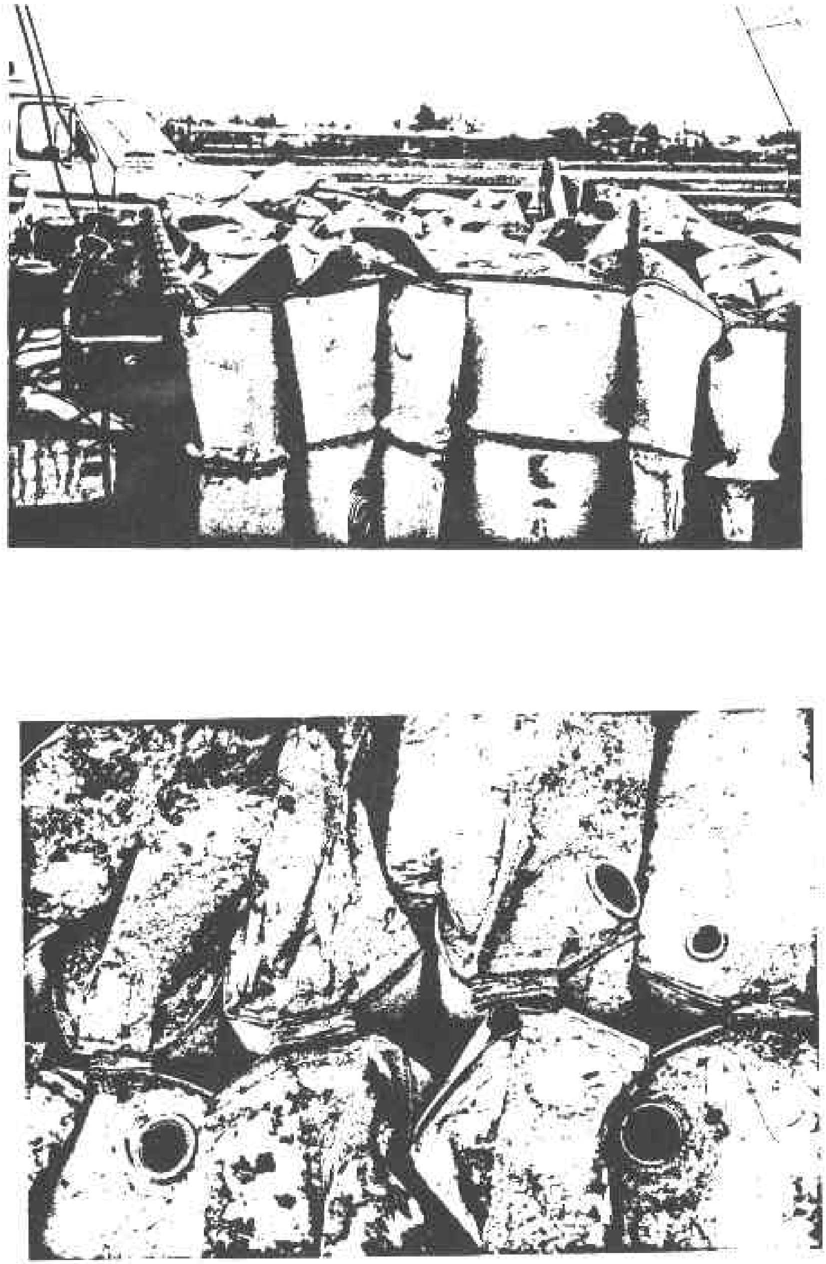


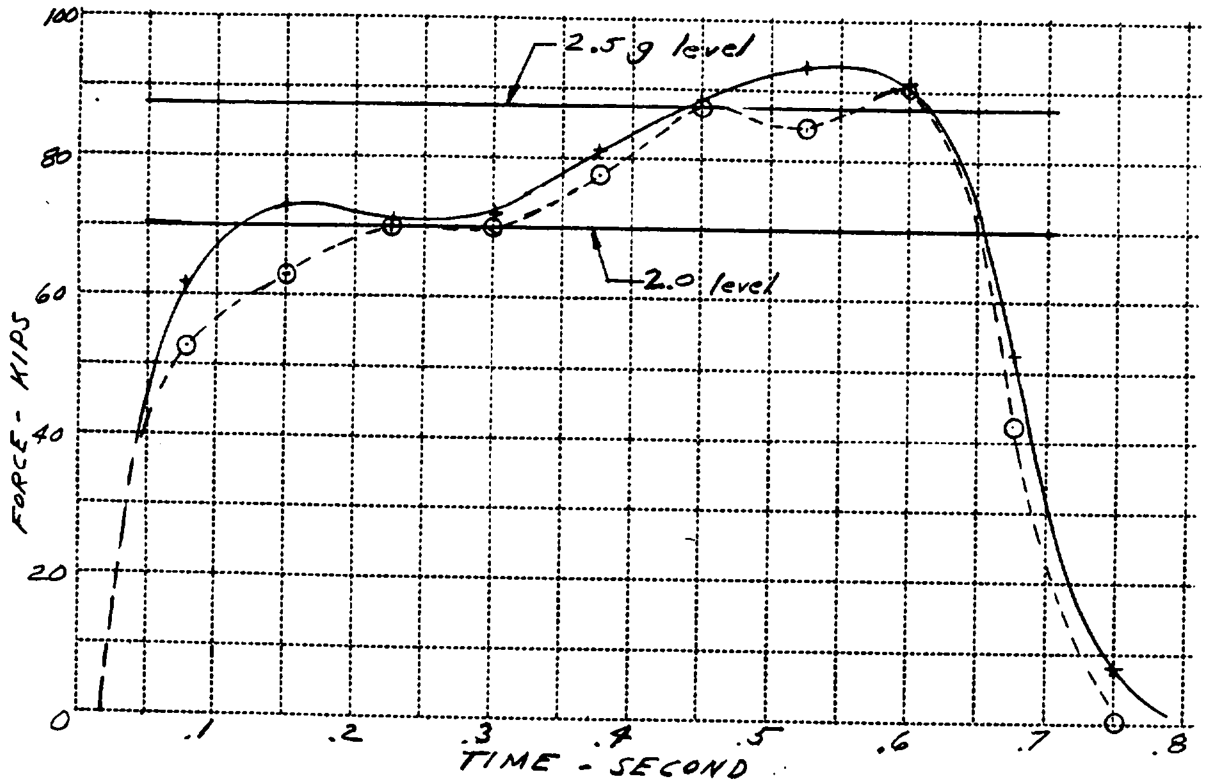
Figure 10 DRUM ATTACHMENTS POST TEST

The barrier reaction force and the truck impact force are presented in Figure 11. The reaction force time history was measured at the SAE barrier face by four load cells. The total reaction force was obtained by the summation of the four load cells. The truck impact force was calculated by multiplying the truck weight (34,690 lbs.) by the truck acceleration value measured at the right frame rail (see Figure 12). The 2.5 g design prediction value is also presented in Figure 11.

The correlation in Figure 11, between the measured barrier reaction force and the calculated truck impact force, is considered good. This good correlation is attributed to the truck-barrier mass ratio being greater than 10 to 1. In fact, the effective mass of the barrier is less than the total barrier mass because the displacement of the drum array occurs in sequence (in rows), thereby minimizing the mass effect of the barrier under dynamic conditions. The relatively long time duration and low g value of the complete events also minimizes the dynamic effect of the drum mass.

4.2 Vehicle Response

The truck was decelerated in a controlled manner with no significant pitch, roll or yaw. Based on the vehicle right frame accelerometer data, as shown in Figure 12, the impulse duration was .75 seconds with the g level ranging between 2 and 2.5 g's during most of the complete event. The 2.5 g level occurred during the last half of the event. The vehicle velocity time history presented in Figure 13 shows a 1 mph rebound velocity. The low rebound velocity supports the fact the deformable barrier has negligible elastic properties. The vehicle displacement time history presented in Figure 14 shows a maximum truck displacement of 193 inches (16 ft.) occurring at .67 seconds after barrier contact. The above truck velocity and displacement data were generated by integration of the acceleration data.



BARRIER REACTION FORCE

TRUCK IMPACT FORCE

2.5g LEVEL DESIGN PREDICTION

Figure 11 TOTAL BARRIER FORCE TIME HISTORY

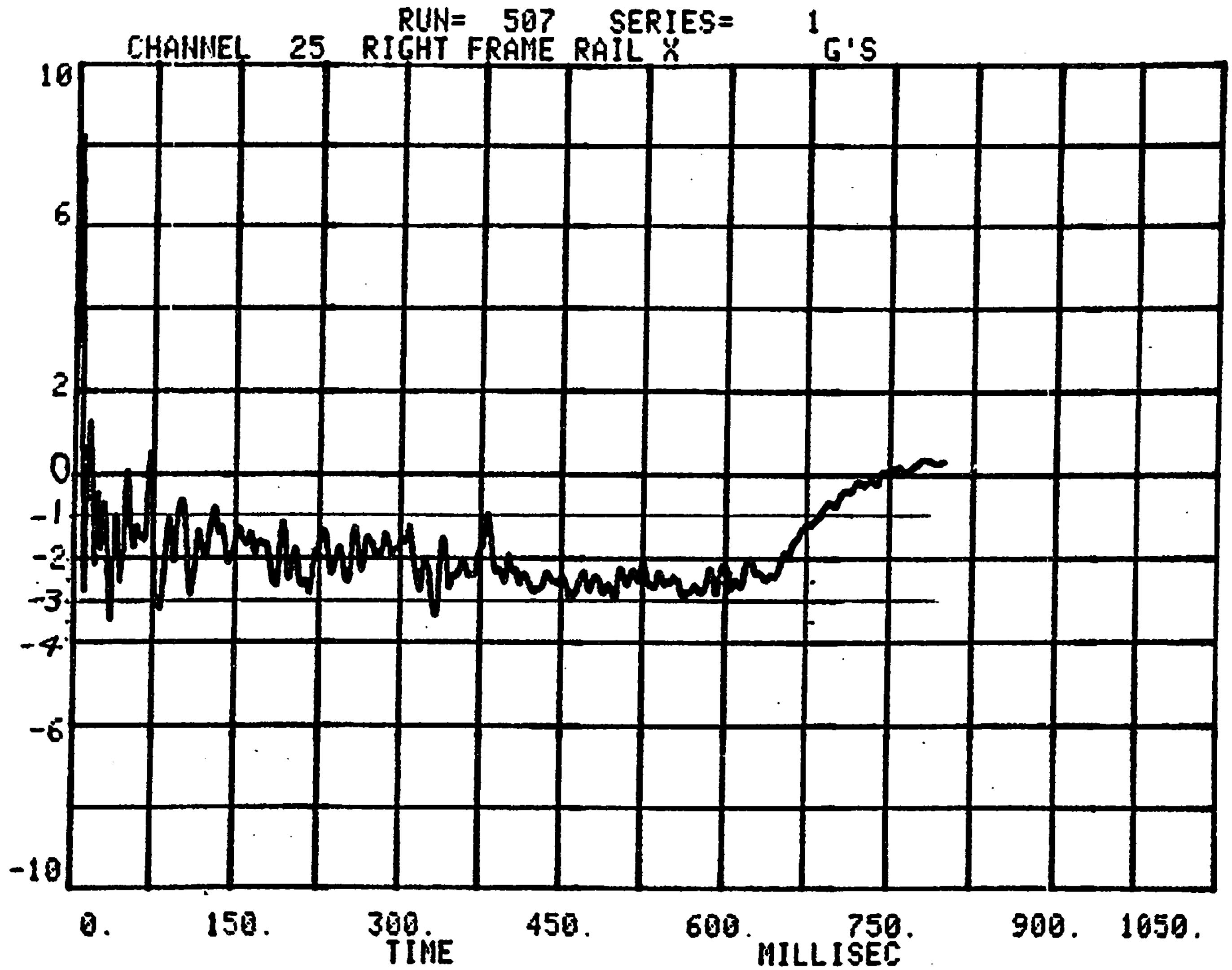


Figure 12 TRACTOR ACCELERATION TIME HISTORY RIGHT FRAME RAIL

The vehicle damage was restricted to the front of the tractor, which included sheet metal, bumper face bar and head-light assemblies as shown in Figure 15. No tractor or trailer frame structural damage was noted. The trailer remained properly secured to the tractor with no observed shift in load. The truck was driven from the test site.

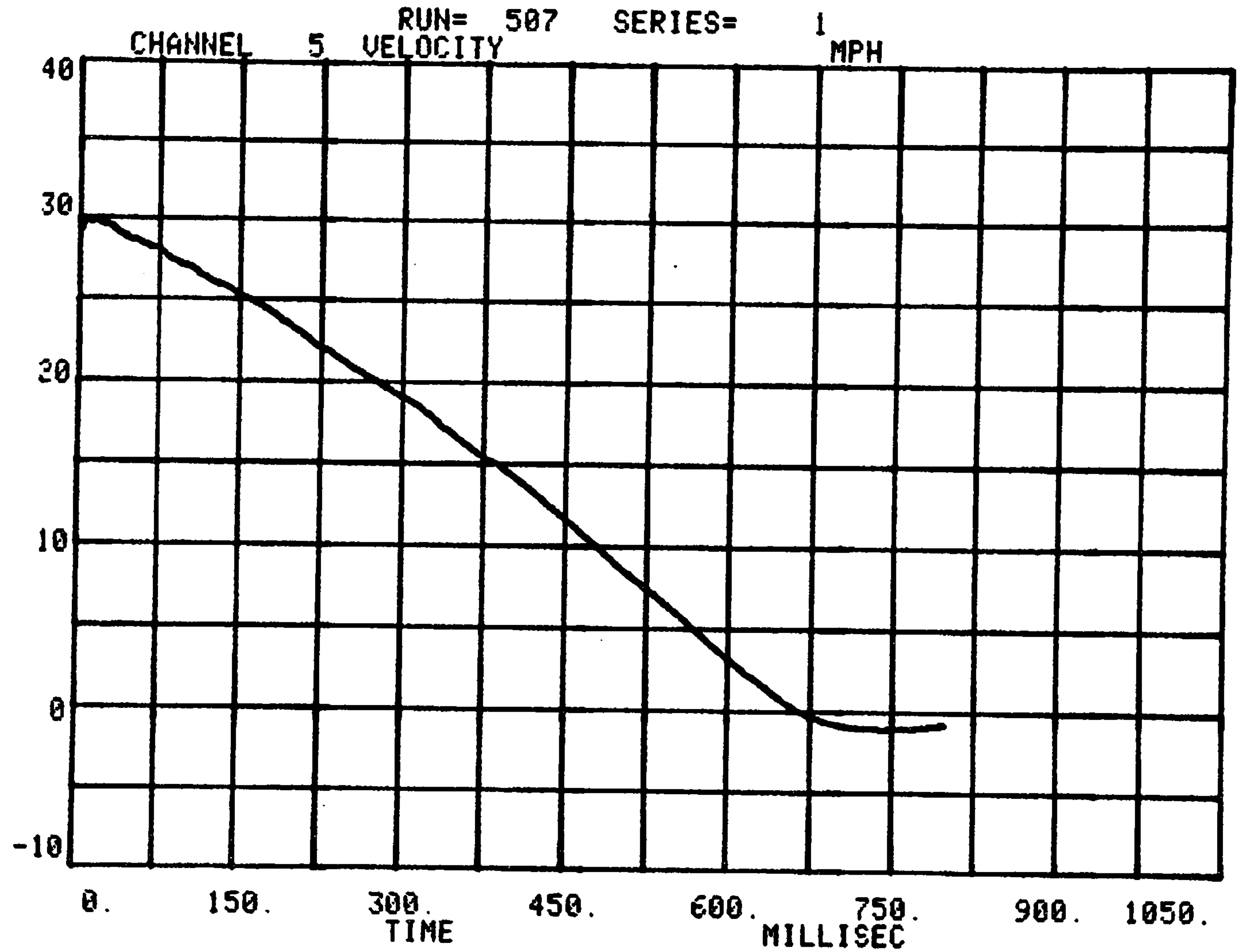
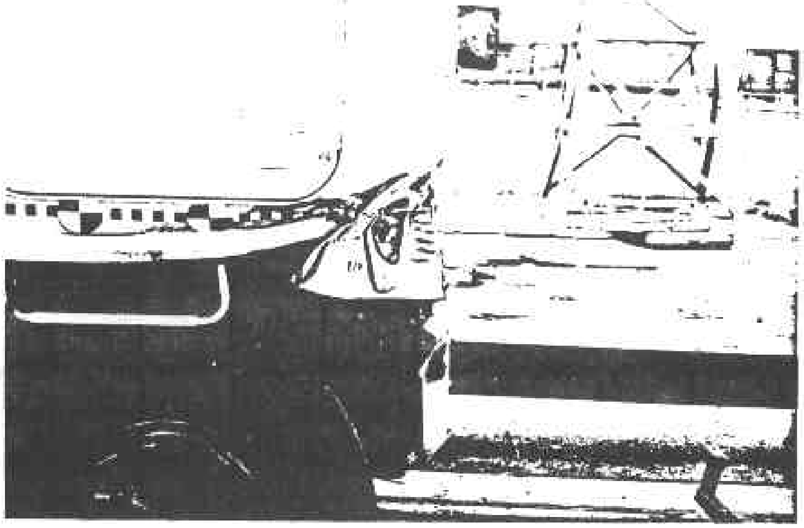


Figure 13 TRACTOR VELOCITY TIME HISTORY



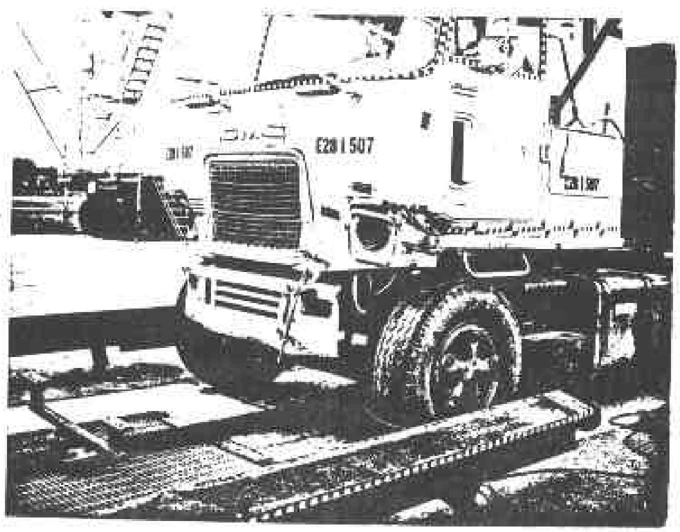


Figure 15 VEHICLE DAMAGE

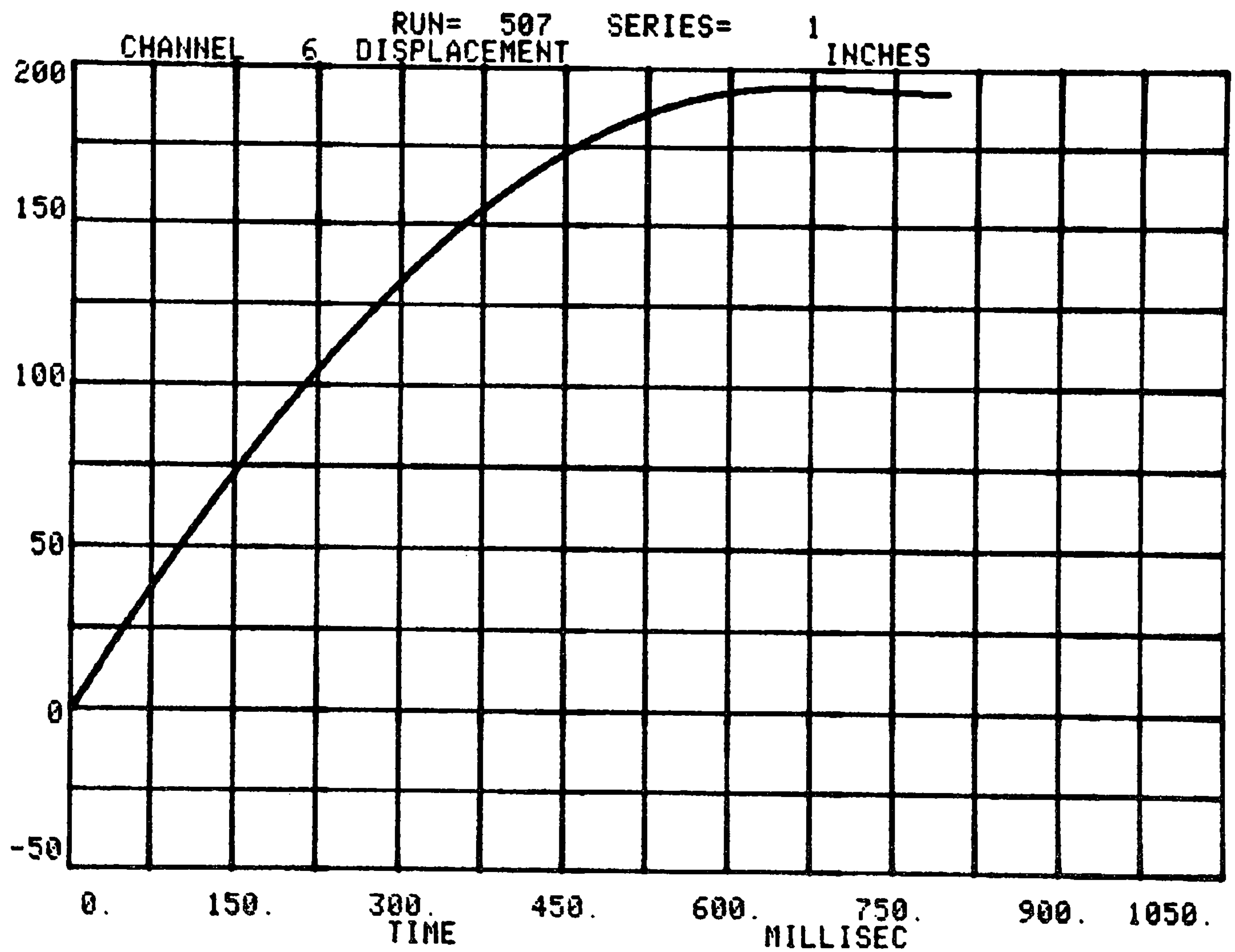


Figure 14 TRACTOR DISPLACEMENT TIME HISTORY

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