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LOCOMOTIVE TO AUTOMOBILE BASELINE CRASH TESTS

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FINAL REPORT

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16. Abstract

Four Locomotive to Automobile Crash tests were performed by the Dynamic Science Division of Ultrasystems at DOT's High Speed Ground Test Center, under contract to the Transportation Systems Center, which is conducting the work for the Federal Railroad Administration. This report documents these four tests, which will provide baseline data for evaluation of future locomotive front structure modifications designed to attenuate the severity of the grade crossing accident. The automobiles were all 1973 standard size sedans of the same model with similar options. For each test, a 130-ton Alco locomotive impacted a stationary automobile at a nominal 50 mph. The first two tests contained no instrumentation on either the locomotive or automobile except for high-speed cameras. The last two tests were instrumented repeats of the first two tests which also involved a direct side impact and a side impact centered on the automobile front fender. The last two tests had an anthropomorphic dummy in the automobile and over 50 accelerometers installed in it. Each test had extensive high frame rate photographic coverage.

17. Key Words
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PREFACE

This report was prepared under PPA RR-312 "Rail Safety/Equipment," which seeks the improvement of railroad safety and efficiency by providing a technological basis for improvement and possible regulation in rail vehicle crashworthiness, inspection of equipment, surveillance of equipment, and other important areas. The purpose of this work is to improve railroad safety through a study of crashworthiness of rail vehicles and techniques for their delethalization. The work reported on was performed at the DOT/Transportation Test Center, at Pueblo, Colorado. Photographic and transducer data is presented which will serve as a data base for measuring the effectiveness of planned locomotive impact energy-managing devices currently under development for decreasing the loss of life, the rate of injury and the extent of property damage in grade-crossing accidents.

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1.0 INTRODUCTION

The Federal Railroad Administration is concerned with reducing the injury rate and loss of life and property due to grade crossing accidents. There are two avenues of approach for solving this problem. The first is to improve grade crossings with the aid of lights, guard signs, and other warning devices. The second approach is to reduce the accident severity by modifying the structure of the locomotive. This test project was designed to acquire baseline data for use in the latter approach. The objective of this test series was to provide the following data on locomotive-to-automobile interaction:

- Automobile lateral and locomotive frontal deformation behavior
- Force levels on automobile and dummy occupant
- Automobile and locomotive dynamics (trajectories, derailment)
- Automobile and locomotive interaction (intrusion, rolling of automobile)
- Possible injury modes.

This effort consisted of four locomotive-striking-automobile tests. The first two had photographic documentation only. The last two had a dummy and instrumentation, as well as photographic documentation.

2.0 TEST CONDITIONS

The test matrix for this project, showing the automobile orientation and test condition for each test, is shown in Figure 1.

Two side impact orientations were considered. The first orientation (TGB-1, TGB-3) was with the automobile centered on the track. There was little chance of yaw rotation for this orientation. The second automobile orientation (TGB-2, TGB-4) placed only the front portion of the automobile on the tracks. For this orientation there was the possibility of the automobile yawing significantly, even to the extent of being deflected and thrown free of the locomotive. In these offset tests, the front portion of the automobile was judged to be more critical than the rear since the driver seat is located toward the forward end and is the seat most likely to be occupied.

Tests TGB-3 and TGB-4 were repeats of Tests TGB-1 and TGB-2, respectively. There were two basic reasons why the tests were repeated. The first reason was to establish the repeatability of this type of test. The second reason was that a definition of the automobile crush behavior is desirable prior to placing a large quantity of expensive equipment on board the automobile. The first series of tests was designed to provide insight as to where and how to install the instrumentation.

Speeds up to 50 mph account for about 80 percent of the grade crossing accidents. This can be seen from the distribution of train-striking-highway vehicle accidents, as a function of speed for 1969, as shown in Figure 2.*

The nominal test speed chosen for all four tests was 50 mph.

*"Rail-Highway Grade-Crossing Accidents For the Year Ended December 31, 1969", DOT, FRA, Bureau of Railroad Safety.

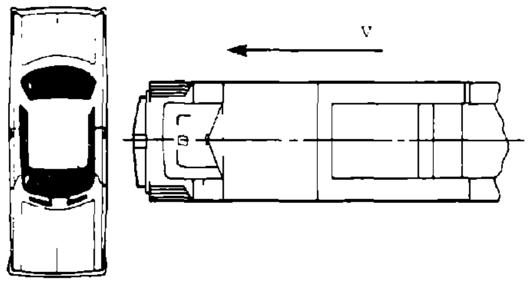
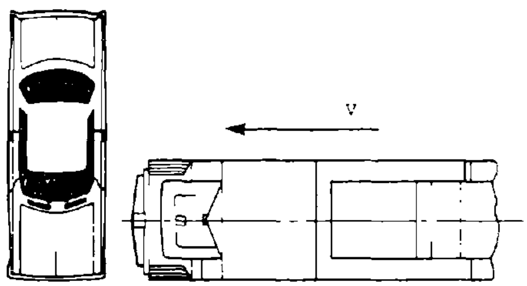
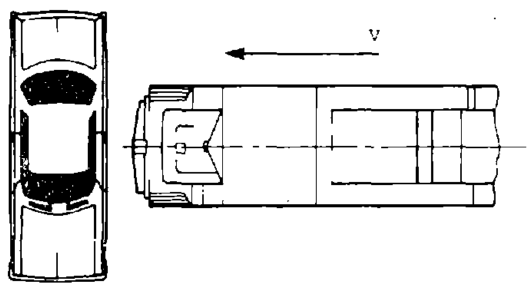
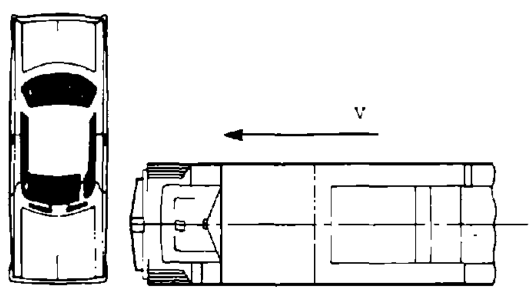
Test Number	Struck Vehicle Stationary 1973 Sedan / Striking Vehicle Locomotive	Instrumentation	Speed (mph)	Orientation
TGB-1		CAMERAS ONLY	50	DIRECT SIDE
TGB-2		CAMERAS ONLY	50	OFFSET SIDE
TGB-3		CAMERAS, DUMMY, ACCELEROMETERS	50	DIRECT SIDE
TGB-4		CAMERA, DUMMY, ACCELEROMETERS	50	OFFSET SIDE

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Figure 1. Grade Crossing Impact Test Matrix.

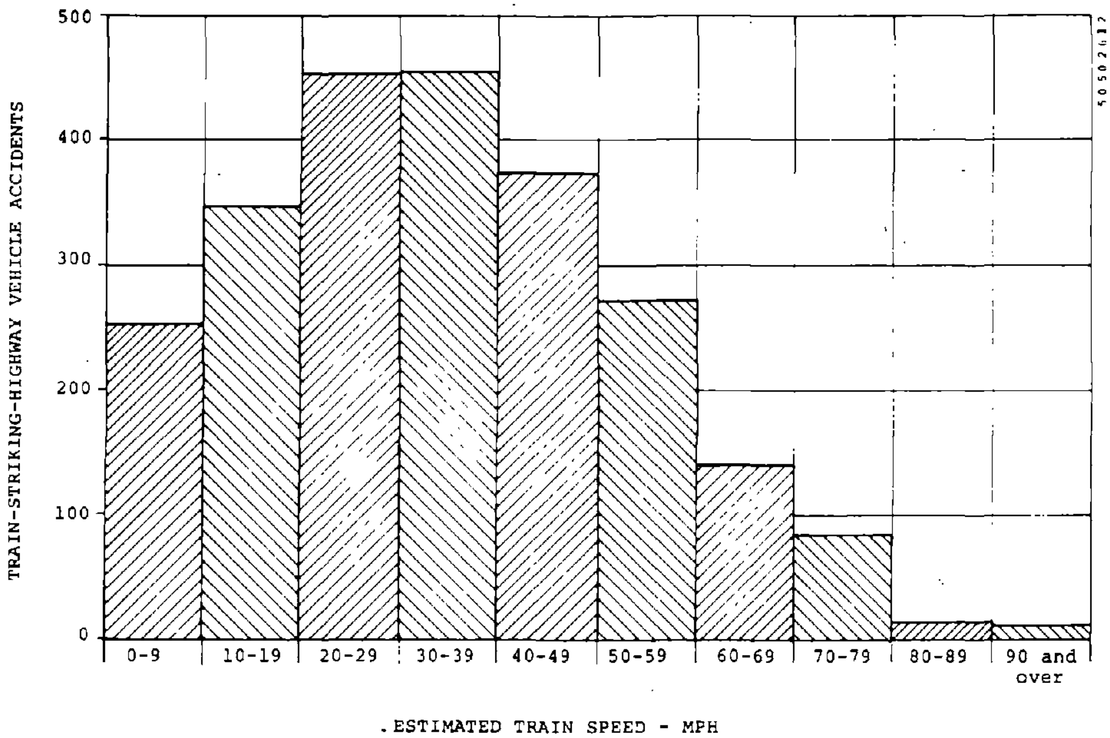

Figure 2. Accident-Versus-Estimated Train Speed for Year 1969.

3.0 FACILITIES, TEST PREPARATION, AND DATA ACQUISITION

3.1 FACILITIES

Two basic facilities were utilized during the program. The Federal Railroad Administration's High Speed Ground Test Center (HSGTC) in Pueblo, Colorado was the actual impact site.

All other work including vehicle preparation, instrumentation, and data reduction was performed in Phoenix, Arizona, at the facilities of Ultrasystems, Inc., the Dynamic Science Division.

Figure 3 is a map showing the HSGTC facility.

The locomotive was accelerated along the train dynamic track and onto the impact track where the actual test took place. The impact site was remote from any buildings or any utilities.

3.2 DATA ACQUISITION SYSTEM

3.2.1 Photography

All tests had an array of high frame rate and real-time cameras covering the impact. The high frame rate photographic coverage was complemented with still photography both before and after the test. Flashbulbs provided impact time correlation between cameras.

A timing generator with an accuracy of better than one percent triggered a lamp inside the high frame rate cameras to provide a reference time base for establishing a precise sequence of events. The high frame rate cameras were turned on by a breakwire trap triggered by a mechanical arm attached to the locomotive. Camera turn-on occurred approxiamtely 1.5 seconds prior to impact in order to allow the cameras to reach their speed. A control unit also turned off the cameras after a predetermined time. Figure 4 is a schematic showing typical fields of view and nominal frame rates for the ground-based cameras.

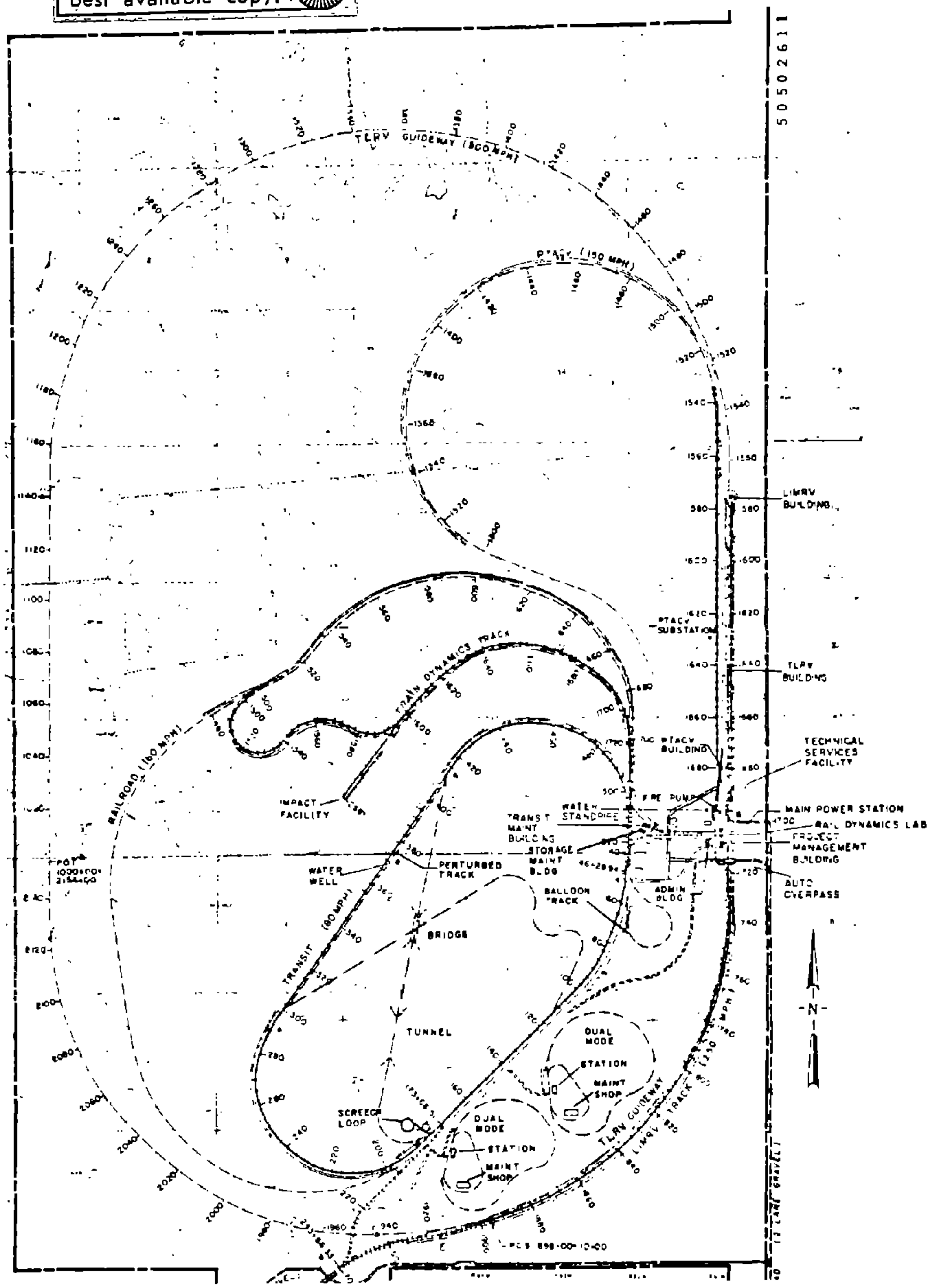

Figure 3. Locomotive-to-Automobile Impact Test Site at High-Speed Ground Test Center.

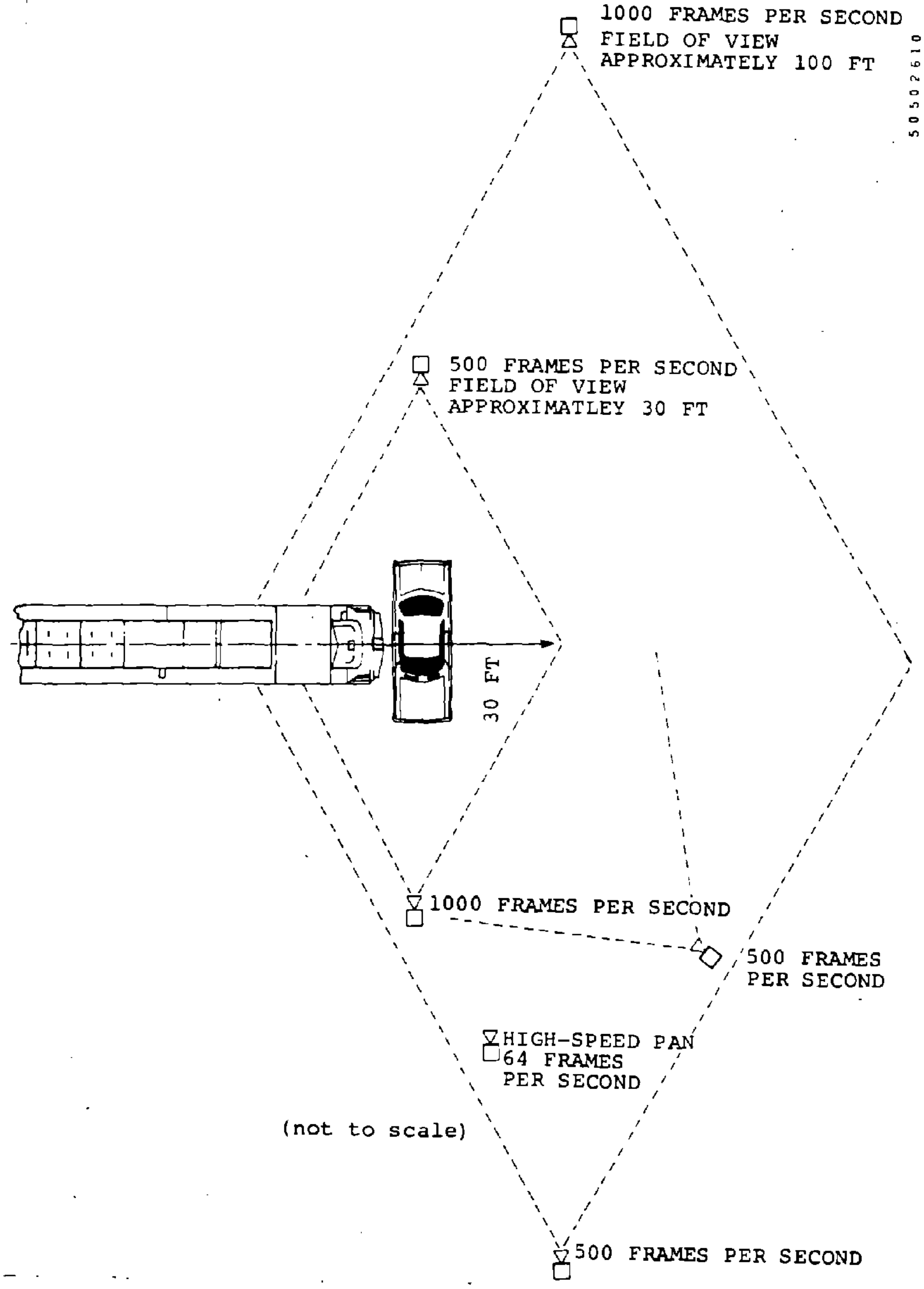

Figure 4. Field of View and Nominal Frame Rates of Ground-based Cameras.

Camera speeds and locations were chosen based upon Ultrasystems' experience with automobile-to-automobile and automobile-to-rigid barrier impacts. Frame rates of 1000 frames per second were chosen to cover areas that were expected to experience rapid buckling and crushing of metal structure. The 1000 frame-per-second cameras are useful in establishing an accurate time at which a structural failure or other rapid event occurs. The 500 frames-per-second cameras typically yield a crisper picture and are more appropriate for observing nonstructural events like dummy dynamics and overall motions of the locomotive and automobile. Time resolutions to within two to three milliseconds are possible with 500 frame-per-second cameras.

The ground cameras were positioned for basically two fields of view. The first field of view covered the initial impact and the second field of view redundantly covered the initial impact, in addition to an expanded downstream field of view. Panning and oblique cameras provided additional documentation and an overview of the entire event.

Two cameras were on board the automobile for each of the tests. One camera (500 frames per second) had a field of view covering the driver area inside the automobile and thus covered the dummy on the instrumented tests. The second camera (1000 frames per second) was focused upon the impact area which was the rear door on the first and third tests and the front fender on the second and fourth tests. Lighting on board the vehicles was supplemented by long-duration flashbulbs that were triggered prior to impact to allow the bulbs to reach their full intensity prior to the actual impact.

Two high frame rate overhead cameras (500 and 1000 frames per second) were mounted on the locomotive for the first two impact tests to provide a top view of the automobile during impact. A third high frame rate camera (500 frames per second) focusing on a close-up at the impact area, and a real-time camera (24 frames per second) mounted outside the cab window looking down the track, were added for the last two impact tests.

3.2.2 Speed

All tests required an accurate measurement of the impact speed. The measurement device was a breakwire speed trap mounted on the cross ties. The trap was triggered by a rigid mechanical arm attached to the locomotive such that the trap was triggered just prior to impact. The signals from each of the breakwires were recorded on an oscillograph along with a 1000-Hz timing signal. Since the distance between the wires was accurately known, the impact speed could be calculated to within 0.3 percent.

3.2.3 Transducer Data

The last two tests contained accelerometers in the dummy and on the automobile and locomotive structures.

The dummy was placed in the driver location with a triaxial accelerometer located in the head and thorax. A schematic of the automobile illustrating the location of the structural accelerometers is presented in Figure A-2 along with the data in the Appendix. The large number of instruments provided a redundancy and reflected what happened at different regions of the structure. Data from these instruments could conceivably be input to a computer simulation model to aid in a crashworthy design program.

A schematic of the locomotive illustrating the location of the structural accelerometers is presented in Figure A-1 along with the data in the Appendix.

Signals from the accelerometers and a signal from a contact closure switch placed at the impact point were fed into a Remote Signal Conditioning Module (RSCM). The RSCM amplified, frequency modulated, and multiplexed the signal for transmission to the tape recorder. The data from the locomotive were transmitted along with the feedback information from the controller via telemetry to the tape deck. The other data were transmitted down a 50-foot-long umbilical cord. The umbilical disconnected at a set of connectors after the automobile had traveled far enough to take out all of the slack (at least 30 feet).

3.3 DATA REDUCTION TECHNIQUES

The data reduction techniques and analysis employed depended upon the type of data recorded. Basically, three types of data (transducer, film, and supplementary) were collected.

3.3.1 Transducer Data

Transducer data were recorded continuously as a function of time on an FM/FM magnetic tape recorder. These data consisted of accelerometer-versus-time records.

These data were reproduced in two forms: quick-look and digitized.

The quick-look data were obtained by demodulating the FM data tape and displaying it on an oscillograph strip chart as a quick check on the completeness and general nature of all data.

In order to do a complete engineering analysis of these data, the data tape was then digitized for further computations on a digital computer. The computer is programmed to write a plot tape to drive an automatic plotter.

3.3.2 Film Data

Film data consisted primarily of high-speed footage which was analyzed with a Vanguard Film Analyzer. This process makes it possible to order events in the crash sequence and establish vehicle kinematics. From this, a chronology of events during the crash sequence was constructed which, when correlated with the transducer data, added significantly to the interpretation of the dynamic response of the automobile.

3.3.3 Supplementary Data

Supplementary data consisted of all data that did not require continuous recording. This included pre- and post-test measurements, still photographs, observations, and various other parameters that were necessary to establish the test conditions and analyze the overall test. Measurements taken include linear dimensions between interior points of the automobile before and after test to give an indication of the extent of the permanent deformation. The initial and final position and orientation of the test vehicle and vehicle components are also recorded. Still photographs recorded the pre-test configuration of the automobile and locomotive as well as the post-test deformation.

3.4 TEST PREPARATION

Prior to test, work was required in the following areas:

- Locomotive preparation
- Controller design, fabrication, and checkout
- Automobile acquisition and preparation
- Equipment preparation
- Facility preparation.

3.4.1 Locomotive Preparation

The test locomotive was a 130-ton Alco locomotive built in May of 1945 for the United States Army. The unit was used during the latter part of World War II in Russia. From then until the implementation of this project, the unit was in storage.

Prior to being used for the impact tests, the unit required an overhaul. This overhaul was performed by the Army Corps of Engineers at the Pueblo Army Depot.

A brief survey was made of switching-type locomotives to compare the proposed test locomotive with those currently in service. All observed locomotives in service had vertical plates at each end that typically extended from 3 to 4 inches above the rail to the deck approximately 6 feet above the rail and covered the width of the locomotive. The plate was fitted around the buffer casting, hoses, lines, and handrail attachments and was supported by the locomotive sill structure.

The proposed test locomotive had no structure, besides steps at either side of the coupler. The probability of derailment was increased without the plate structure since a piece of the automobile such as the engine block could more easily become lodged under the wheels of the locomotive. Since a locomotive without a plate structure was atypical and locomotive derailment was not the test objective, a plate structure was added to each end of the locomotive. The initial plate was 5/8-inch thick and braced at the lower outboard corners with struts bolted to the underside of the locomotive structure. Additional struts and stiffening were added along with an increase in plate thickness to 3/4-inch after the first impact caused significant damage (about 11 inches permanent deformation to the lower corner of the plate).

Prior to test, the controller, camera mounts, antennae, and other instrumentation were secured on board the locomotive.

3.4.2 Controller Preparation

The remote control system is discussed in Section 4.0. The control unit was designed and fabricated by Ultrasystems due to unavailability of a suitable commercially-available unit.

A series of checkout and characterization tests was performed at Pueblo, Colorado to verify the system.

3.4.3 Automobile Preparation

The test automobiles were 1973 standard-sized 4-door sedans. Tests TGB-1 through TGB-4 were prepared in an identical manner except for the instrumentation used on the last two tests. Both automobiles for Tests TGB-3 and TGB-4 contained an instrumented 50th percentile male (VIP 50) anthropomorphic dummy in the driver position and an array of structural accelerometers. See the Appendix for a description of automobile and dummy instrumentation locations. All automobiles had two high frame rate cameras mounted on board. Table 1 summarizes the tasks required to prepare the automobiles for the tests.

TABLE 1. SUMMARY OF AUTOMOBILE PREPARATION TASKS

Item Number	Task Description
1	Weigh automobile as shipped (curb weight).
2	Leave all oil and water as is. Fill gas tank to 90 percent dyed water and antifreeze to -10 degrees Fahrenheit.
3	Steam clean underside and engine as required.
4	Clean inside of automobile as required.
5	Paint inside of automobile white to enhance photography.
6	Install lights inside automobile.
7	Fabricate camera mounts for 2 cameras: (1) front door, (1) rear door.
8	Install camera mounts on passenger door viewing opposite door interior.
9	Install correlation bulb, switch, and battery for same.
10	Mark level lines around perimeter of automobile and install reference markers.
11	Install head and thorax instrumentation in 50 percentile male dummy. Install dummy in driver position (Tests 3 and 4 only).
12	Install accelerometers as per test plan (Tests 3 and 4 only).
13	Drill holes and tape edges for control lines to run out from automobile to ground station equipment.
14	Weigh automobile.
15	Load automobile on trailer and protect with plastic wrap.
16	Remove automobile from trailer and check everything out - set up per Project Engineer instructions.
17	Take pre-test photographs.
18	Crash locomotive into automobile.
19	Take post-crash photographs.
20	Strip out parts and equipment required for next test.
21	Load and secure crashed automobile and all parts on trailer.
22	Unload crashed automobile and loose parts in service storage yard.
23	Return all equipment to shop, lab, and photo storage areas.

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3.4.4 Facility Preparation

The track and grade crossing were provided by the HSGTC.

Camera power, control lines, instrumentation cables, antennae, and speed traps had to be installed at the test site and connected to the instrumentation and controller setup in the control center. All lines and systems had to be thoroughly checked out prior to conducting the tests.

3.5 TEST PROCEDURES

Ninety minutes prior to test after the basic test preparation was complete, the countdown, according to the checklist shown in Figure 5, was initiated. The checklist assured that a track conditioning run had been accomplished, security was in force, the remote controller was functioning properly, the camera systems were in readiness, and the instrumentation systems were in readiness for test.

TEST CONDUCTOR COUNTDOWN

LOCOMOTIVE/AUTOMOBILE CRASH

DATE: ______________ TEST: __________

ITEM NO.		FUNCTION	TIME	BY
1	______	Ensure engine is running	______	______
2	______	Ensure reverser is in neutral	______	______
3	______	Ensure manual throttle is in idle	______	______
4	______	Ensure manual brake is in slow brake	______	______
5	______	Turn on local controller main power	______	______
6	______	Turn on 28V servo power supply	______	______
7	______	Turn on RCVR-XMTR power	______	______
8	______	Turn local-remote switch to local	______	______
9	______	Externally power up train RSCM	______	______
10	______	Check operation of local throttle control switches	______	______
11	______	Check operation of local brake control switches	______	______
12	______	Place local and remote throttle control switches to idle and brake control switches to slow brake	______	______
13	______	Turn local-remote switch to remote	______	______
14	______	Check operation of remote throttle control switches	______	______
15	______	Check operation of remote brake control switches	______	______
16	______	Make fail-safe checks	______	______

Figure 5. Countdown Checklist.

ITEM NO.		FUNCTION	TIME	BY
17	______	Place remote throttle control switch to idle and brake control switch to slow brake	______	______
18	______	Place local-remote switch to local	______	______
19	______	Turn off local controller main power	______	______
20	______	Turn off 28V servo power supply	______	______
21	______	Manually move locomotive to end of run position	______	______
22	______	Ensure reverser is in neutral	______	______
23	______	Ensure manual throttle is in idle	______	______
24	______	Ensure manual brake is in slow brake	______	______
25	______	Turn on local controller main power	______	______
26	______	Turn on 28V servo power supply	______	______
27	______	Turn on local RCVR-XMTR power	______	______
28	______	Place local-remote switch to remote	______	______
29	______	Check operation of remote throttle control switches	______	______
30	______	Check operation of remote brake control switches	______	______
31	______	Make fail-safe checks	______	______
32	______	Place remote throttle control switch to idle and brake control switch to slow brake	______	______
33	______	Place local-remote switch to local	______	______
34	______	Turn off local controller main power	______	______

Figure 5 (Continued). Countdown Checklist.

ITEM NO.		FUNCTION	TIME	BY
35	______	Turn off 28V servo power supply	______	______
36	______	Manually move locomotive to impact position	______	______
37	______	Position automobile at impact point	______	______
38	______	Install and check out impact switches (two on automobile, one on locomotive)	______	______
39	______	Manually move locomotive to ensure proper positioning of all speed traps and breakwires	______	______
40	______	Manually move locomotive to run begin position	______	______
41	______	Ensure reverser is in neutral	______	______
42	______	Ensure manual throttle is in idle	______	______
43	______	Ensure manual brake is in slow brake	______	______
44	______	Turn on local controller main power	______	______
45	______	Turn on 28V servo power supply	______	______
46	______	Place local-remote switch to remote	______	______
47	______	Check operation of remote throttle control switches	______	______
48	______	Check operation of remote brake control switches	______	______
49	______	Make fail-safe checks	______	______
50	______	Place remote throttle control switch to idle and brake control switch to slow brake	______	______
51	______	Load all breakwires and speed traps	______	______

Figure 5 (Continued). Countdown Checklist.

ITEM NO.		FUNCTION	TIME	BY
52	______	Ensure long-duration camera control box power switch is off	______	______
53	______	Make all connections to all camera control boxes	______	______
54	______	Ensure fuse in automobile camera control box is good	______	______
55	______	Install photo flashbulbs	______	______
56	______	Ensure test controller ready for test	______	______
57	______	Ensure crash 1 ready for test	______	______
58	______	Obtain control from chief crash engineer	______	______
59	______	Ensure locomotive engines are running	______	______
60	______	Ensure reverser in neutral	______	______
61	______	Ensure throttle in idle	______	______
62	______	Ensure on-board controller power on	______	______
63	______	Ensure remote controller power on	______	______
64	______	Ensure on-board controller RCVR-XMTR on	______	______
65	______	Ensure remote controller RCVR-XMTR on	______	______
66	______	Ensure on-board controller set to idle throttle and slow brake	______	______
67	______	Ensure on-board 28V servo power supply on	______	______
68	______	Turn on-board controller to remote	______	______
69	______	Make remote control checks	______	______

Figure 5 (Continued). Countdown Checklist.

ITEM NO.		FUNCTION	TIME	BY
70	______	Make fail-safe checks	______	______
71	______	Verify camera timing on all cameras	______	______
72	______	Verify operation of all cameras and lights	______	______
73	______	Verify exposure settings and bore site cameras	______	______
74	______	Power up all RSCM's (internal power)	______	______
75	______	Ensure reception from all RSCM's	______	______
76	______	Turn on tape deck	______	______
77	______	Set record levels	______	______
78	______	Conduct pre-cal	______	______
79	______	Remove all loose gear from locomotive	______	______
80	______	Ensure speed trap power on	______	______
81	______	On-board personnel depart from locomotive	______	______
82	______	Confirm all stations ready for test	______	______
83	______	Brake to run	______	______
84	______	Throttle to 1	______	______
85	______	Receive confirmation of motion	______	______
86	______	Long-duration camera control box power on	______	______
87	______	Throttle to 8	______	______
88	______	Announce test has begun	______	______

Figure 5 (Continued). Countdown Checklist.

ITEM NO.		FUNCTION	TIME	BY
89	______	Throttle to 5 (through switch)	______	______
90	______	Throttle to 8	______	______
91	______	Acquire and maintain 50 mph	______	______
92	______	Oscillograph on	______	______
93	______	Throttle to idle	______	______
94	______	Brake to slow brake	______	______
95	______	Impact	______	______
96	______	Oscillograph off	______	______
97	______	Brake to lap	______	______
98	______	Stop locomotive	______	______
99	______	Turn off tape deck	______	______
100	______	Speed trap power off	______	______
101	______	Power down all RSCM's	______	______
102	______	On-board 28V servo power supply off	______	______
103	______	On-board controller RCVR-XMTR off	______	______
104	______	On-board controller to local	______	______
105	______	On-board controller main power off	______	______
106	______	Remote controller RCVR-XMTR off	______	______
107	______	Remote controller main power off	______	______

Figure 5 (Continued). Countdown Checklist.

4.0 LOCOMOTIVE CONTROLLER

The locomotive was remotely controlled during the impact. The controller consisted of a control box, throttle relays, and brake lever servomotor on the locomotive and a control console which was placed inside the test control center near the impact site. The locomotive was started and positioned at the initial position manually by a locomotive operating crew.

The controller was required to control the braking and throttle functions. The throttle has eight discrete positions in addition to idle. The controller utilizes a series of relays that parallel the switches inside the control panel of the locomotive itself.

The brake lever has five positions as follows:

- Fast brake - applies brake pressure at a rapid rate
- Slow brake - applies brake pressure at a slow rate
- Lap - holds the brake pressure at the level in existence when lever is placed into this position
- Run - slowly releases brake pressure
- Release - rapidly releases brake pressure.

A servomotor physically positions the brake lever on the locomotive brake valve in one of the brake positions.

The operator at the remote console has the required confirmation of throttle position, locomotive speed, and brake line pressure.

The locomotive speed was determined by attaching an optical target of alternating black and white strips on the inside of a drive wheel and observing the frequency of pulses generated by a photo cell sensor attached to the locomotive frame. The pulse frequency was converted to an analog signal that was scaled as velocity.

The brake line pressure was obtained by installing a pressure transducer in the brakeline.

Two radio frequencies were required for the controller system:

- 416.6 MHz for the command link
- 219.0 MHz for the feedback link.

The on-board control box is shown in Figure 6. The on-board unit contains the control electronics and also has the capability to control the locomotive in a local mode directly from the unit. The series of five buttons in the upper left corner are for selecting the brake setting when the brake is to be controlled from on board the locomotive in the local mode via the brake servomotor (eliminating the radio link). The series of nine buttons on the upper right corner of the console are for on-board local control of the throttle using the relays. The series of buttons in the center top of the front panel turn on various subsystems of the unit.

Figure 7 is a block diagram of the on-board control unit. The upper series of blocks follows the signal from the receiver to the discriminators. The locomotive can be controlled in a local mode on board via the control switches or using the discriminated telemetry signal from the remote console. The lower series of blocks traces the feedback from the sensors through the signal conditioning and into the transmitter for input to the remote unit.

Figure 8 is a photo of the remote control console. The buttons duplicate the buttons required for local control of the on-board unit. The left and right meters display the brake line pressure and locomotive velocity, respectively. Lights internal to the throttle switches and brake position switches indicate the position of the controls.

Buttons under the meters turn on various subsystems of the control units, and the termination above the switches provides checkpoints for checkout of the system.

Figure 9 is a block diagram of the remote control console.

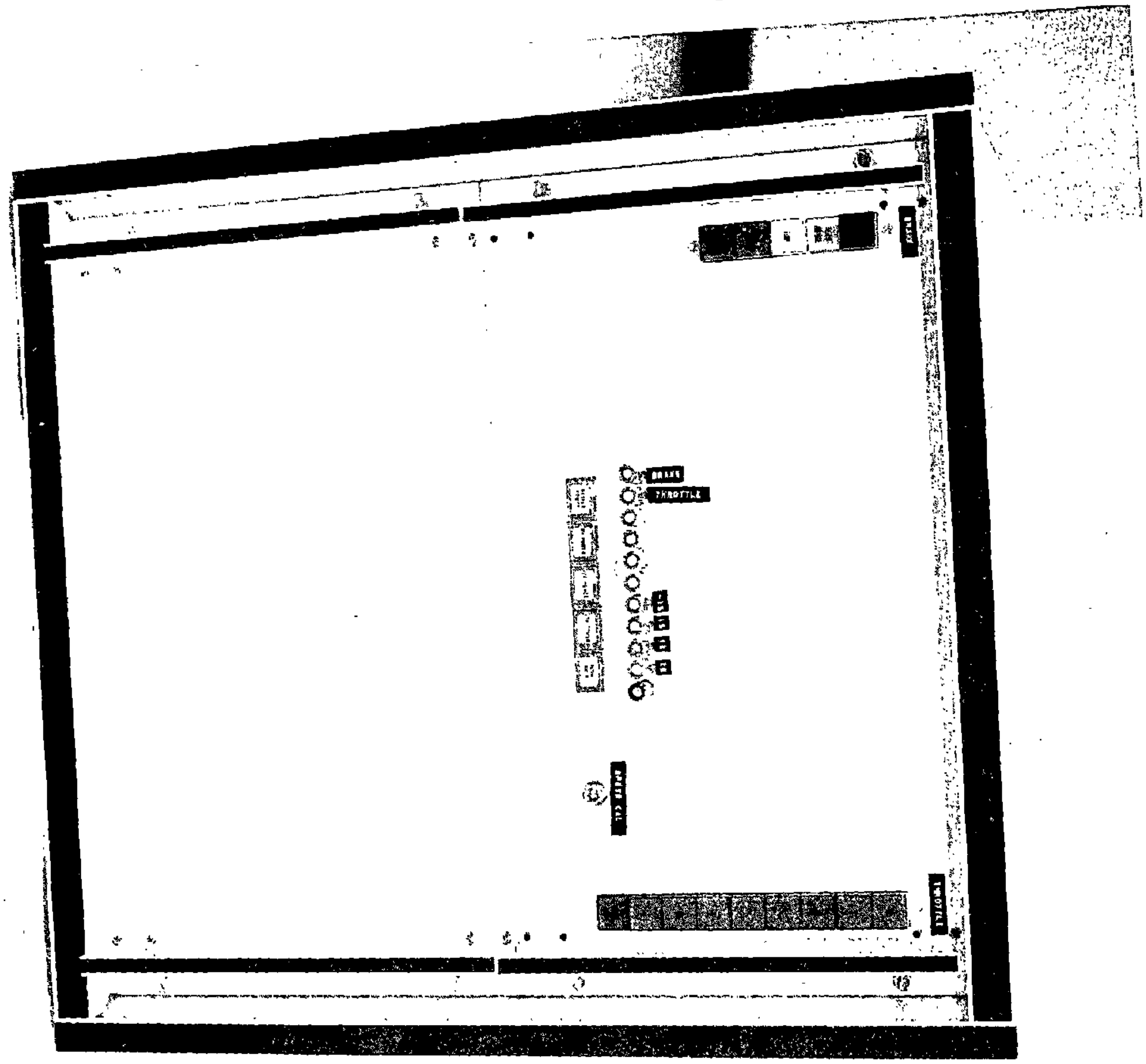
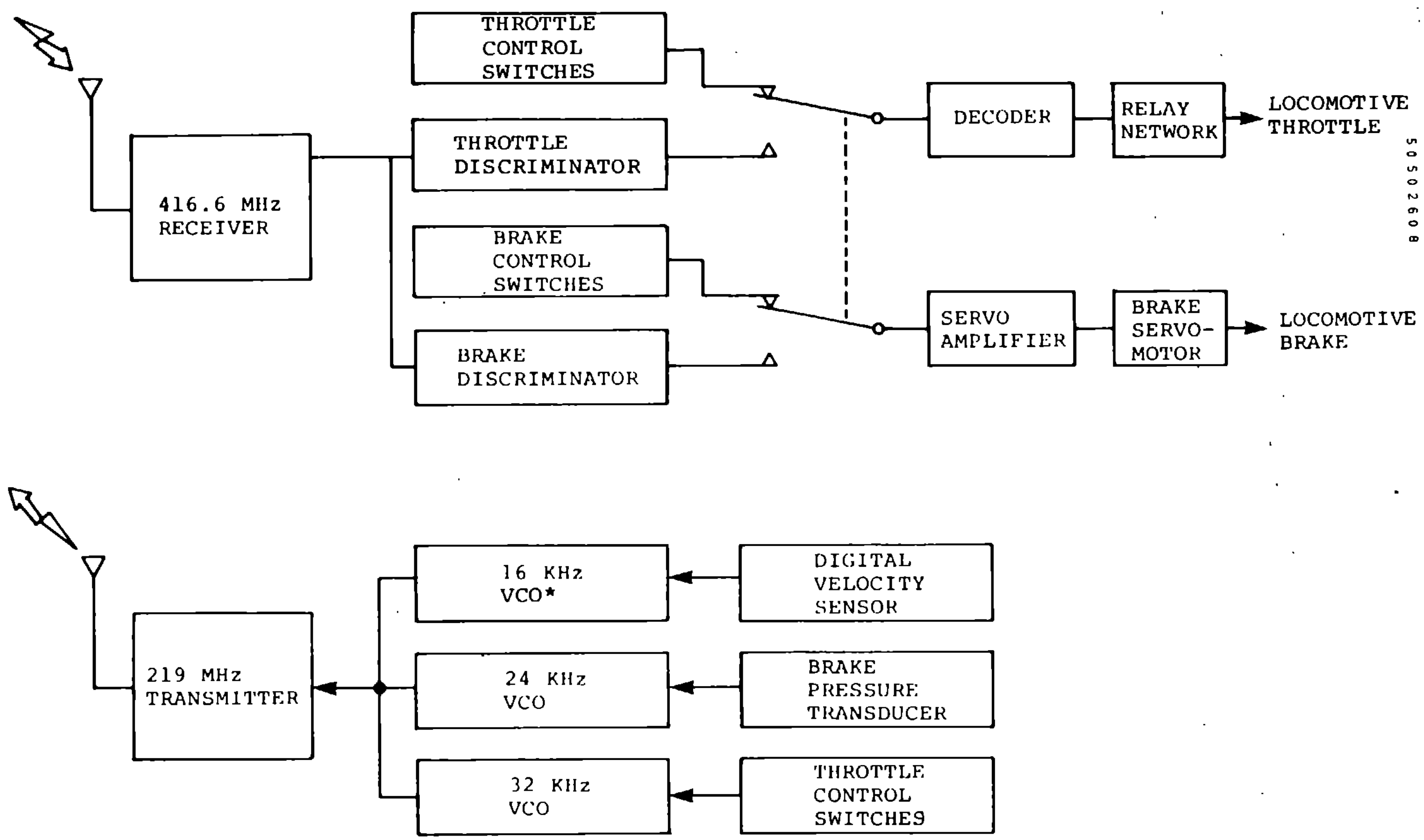


Figure 6. On-Board Control Unit.



*Voltage Controlled Oscillator.

Figure 7. Diagram of On-Board Control Unit.

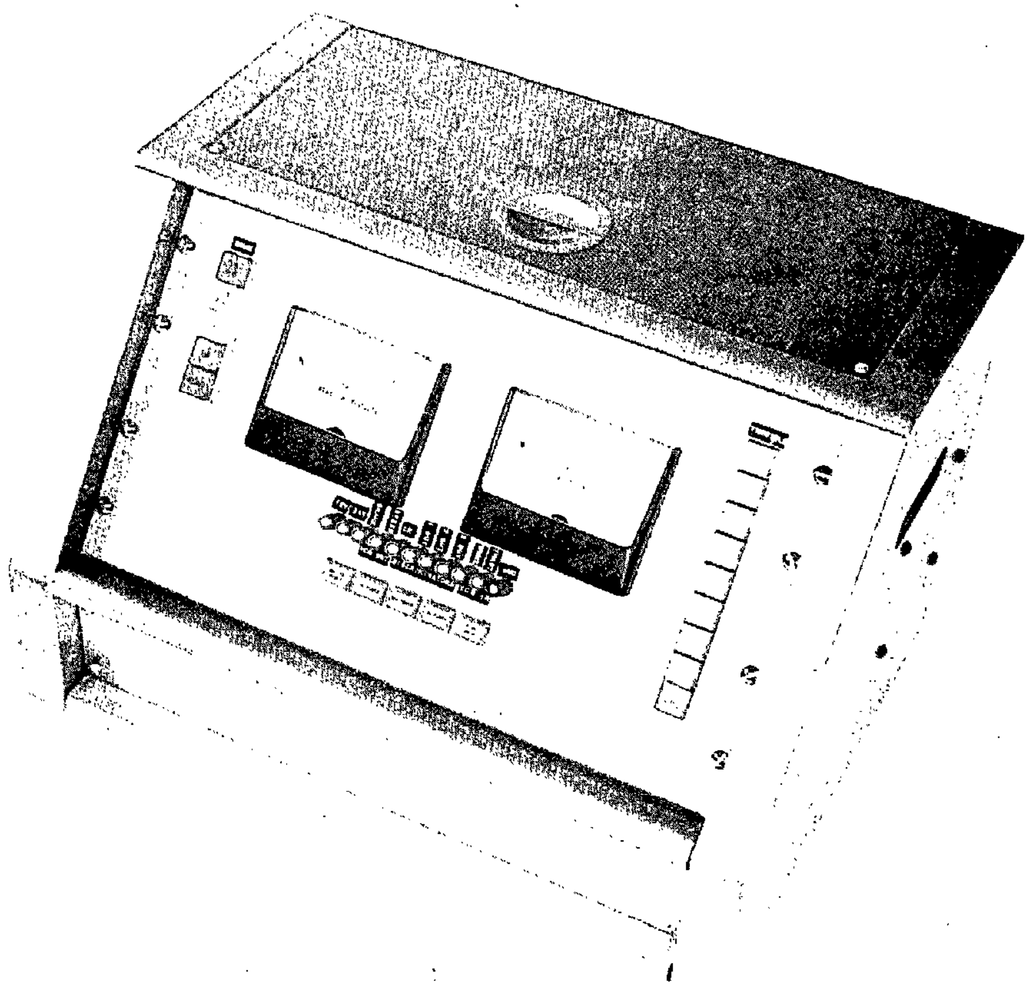


Figure 8. Remote Control Console.

The upper set of blocks traces the command link from the switches through the signal conditioning and to the transmitter for transmission to the on-board contoller. The lower set of blocks illustrates the feedback information from the on-board unit through the discriminators and into the displays.

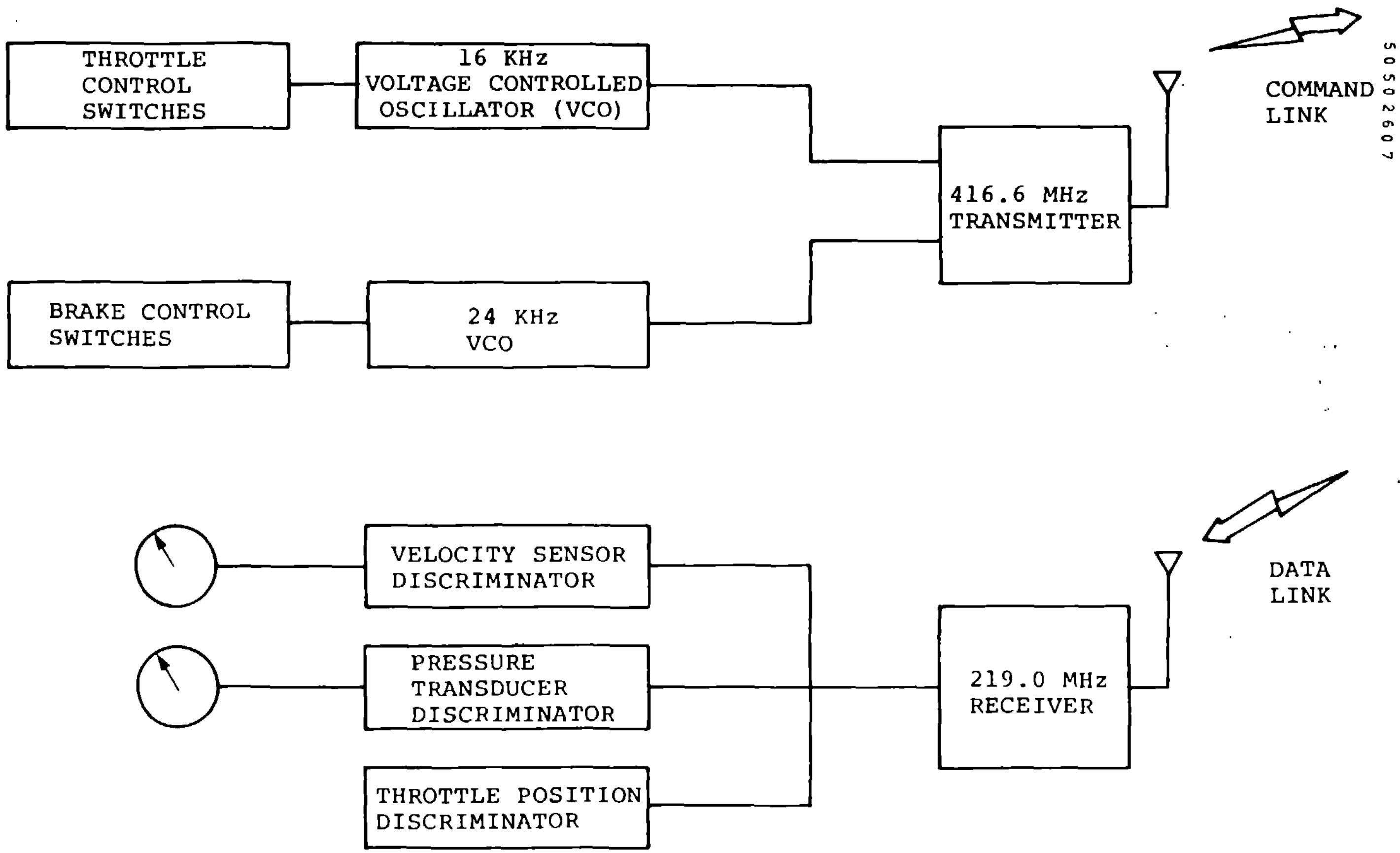


Figure 9. Block Diagram of Remote Control Console.

5.0 TEST SUMMARIES

5.1 FIRST LOCOMOTIVE-TO-AUTOMOBILE IMPACT TEST (TGB-1)

The first locomotive grade crossing baseline test (TGB-1) was conducted as follows:

Test Date:	February 12, 1974
Test Automobile:	1973 standard-size 4-door sedan
Automobile Test Weight:	4,074 Pounds
Test Locomotive:	130-ton Alco
Locomotive Impact Speed:	51.9 mph
Automobile Impact Area:	Center driver's side
Weather:	Clear
Track Condition:	Clear and dry

Upon impact, the coupler penetrated the automobile just behind the front door. Penetration was almost complete before any significant movement of the rest of the automobile occurred. After 84 msec the coupler was at maximum penetration and the occupant compartment was moving at the approximate velocity of the locomotive. The post-test speed of the locomotive and automobile combination, assuming conservation of linear momentum, is 51.1 mph for a locomotive speed reduction of about 0.8 mph. The front section of the automobile from the firewall forward broke loose and rotated into the side of the locomotive, held only by the sheet metal of the left front fender.

The automobile remained in contact with the front of the locomotive from impact until the locomotive came to rest. During impact a brake line on the locomotive broke causing the locomotive to go into emergency brake. The high brake pressure, resulting from having the locomotive in emergency, could have caused wheel slide if it had not been successfully bled off remotely via the remote controller.

Table 2 shows the sequence of events during the impact obtained from an analysis of the high-speed film. Table 3 contains a list of the significant damage observed after the impact test. Measurements were taken between selected points both before and after the impact to help quantify the structural deformation. Some convenient automobile structural terminology is defined in Figure 10. Table 4 summarizes the deformations experienced during the first test. Table 5 lists the significant debris found along the track along with the distance from impact and the distance from the southernmost rail.

Figures 11 and 12 are overall and close-up views of the pretest impact orientation for Test TGB-1. Figures 13 and 14 are post-test views of the locomotive and automobile. The coupler penetration is illustrated in Figures 15 and 16. During the impact, the fuel tank was damaged, causing a steady flow of the dyed water from near the top of the tank. The deformed tank is shown in Figure 17. During impact, the rear axle contacted the front plate on the train and was driven against the fender on the opposite side of the car. Figure 18 shows the deformation on the passenger side of the automobile due to the rear axle. The front section of the automobile from the firewall forward was broken loose, as mentioned earlier, but remained connected by the left front fender. Figure 19 shows how the engine compartment was opened up and how the transmission penetrated into the ballast at the side of the track during the stop. The front of the locomotive suffered significant deformation. The front plate was bent back as much as 11 inches at the lower right corner. The locomotive steps, which were part of the support of the front plate, sheared with permanent set are seen in Figure 20. Figure 21 shows a close-up of the broken pipe on the front of the locomotive. The post-test condition of the front of the locomotive is illustrated in Figure 22. The imprint of the left rear wheel can be seen on the lower left-hand side of the plate.

TABLE 2. SEQUENCE OF EVENTS DURING TEST TGB-1	
Time (msec)	**Event**
0	Impact
5	Driver's side rear door window breaks
5	Headliner, (inside roof covering) begins wrinkling
8	B post at sill level on driver's side begins moving inward
10	Front door window breaks on driver's side
13	Front seat begins buckling
16	Headrest begins sideways travel
18	Driver's side headrest rotates out of socket
20	Pipes on right side of locomotive contact automobile
21	Coupler visible from inside camera below sill level through front door
22	Roof begins rippling
22	Roof buckles up near B post
24	Front plate on locomotive contacts automobile
28	Rear wheels begin to slide
32	Far side of automobile (camera boxes) begins to move
32	Angle cock on left side of coupler contacts side of automobile
34	Front windshield breaks
37	Driver's door impacts steering wheel
39	Left front door armrest contacts seat
39	Right rear fender begins to rotate towards side of locomotive (trunk shearing)
41	Rear window breaks
41	Entire coupler is inside automobile
42	Right side of automobile begins to bow outward
45	Trunk lid begins to buckle open near right lower corner of rear window
50	Front seat bench begins upward buckling in center
56	Hood on right side near window buckles open
60	Right front fender begins to separate from body
84	Maximum intrusion into automobile
98	Rear of automobile begins forward motion (rotation) with respect to locomotive
98	Right front edge of right fender begins down-track motion
134	Body of automobile begins to yaw (oscillates)
139	Right front fender separates from body

TABLE 3. SIGNIFICANT DAMAGE OBSERVED AFTER TEST TGB-1
Spot weld was broken on right front stub frame, allowing rotation of front section of automobile
Both front frame rails were loose
Coupler was rotated to left (facing forward)
Transmission pulled out drive shaft, and rear housing was broken
Heater motor was torn loose (on right side of automobile)
Only right front window survived (right side windows were wound down, all other windows up). Doors were locked
Fuel tank was ruptured
Imprint of rear wheel was observed on locomotive front plate
Axle was shoved so that left side stub frame buckled (cave in), opposite side fenders were torn outward
Right rear wheel well was torn loose from trunk floor - jack had fallen out (jack was bent)
Both head restraints were pulled out and were on right rear seat
Left side of dash had been completely crushed
Top left side B post was partially separated from roof - rear header member had broken
Right rear stub frame had split as frame began to curve up over axle
Left side of automobile was sheared upward with respect to right side
Right fender was bent inward beginning at rear deck
Steps on locomotive front were parallelogramed backwards on both sides of locomotive
Angle cock was broken on locomotive
Skid marks showed rear wheels had slid straight sideways but front wheels had rotated immediately with engine dragging before it left the grade crossing

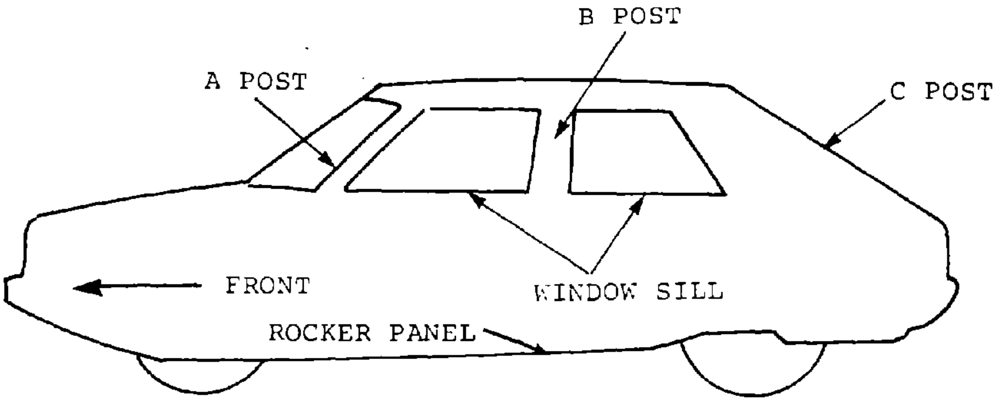


Figure 10. Definition of Selected Automobile Structural Terminology.

TABLE 4. TEST TGB-1 PERMANENT DEFORMATIONS

Measurement	Deformation* (in.)
Between top of B** posts	28.3
Between center of B** posts	37.3
Between bottom of C** posts	19***
Between front window sills	27.6
Between rear window sills	39.4
Between C** posts	14.4
Between top of A** posts	22.5
Steering wheel to left door	7.5
Steering wheel to right door	16.9
Engine to right fender	-8.0
Engine to left fender	5.8

*Negative number indicates an increase.
**See Figure 10 for definition of A post, B post, and C post.
***Estimated.

TABLE 5. LOCATION OF DEBRIS FOLLOWING TEST TGB-1			
Part	Station Distance from Impact	Distance from South Rail	Direction
Linkage (throttle)	75 ft 4 in.	1 ft	South
Squirrel cage for blower	60 ft 1 in.	18 ft 1 in.	South
3/4" bolt from front locomotive plate	62 ft	16 in.	South
Windshield wiper	82 ft 8 in.	16 ft 10 in.	South
Plug wire	84 ft 2 in.	11 in.	South
Chrome strip	70 ft 4 in.	14 ft 2 in.	South
Heater housing parts	86 ft 5 in.	11 ft	South
	94 ft	17 ft 9 in.	South
Hub cap	112 ft 1 in.	22 ft 3 in.	South
Hood spring	119 ft 8 in.	14 ft	South
Heater motor	139 ft 6 in.	10 ft 4 in.	South
Emergency brake cable	135 ft	2 ft 9 in.	North
Chrome piece	113 ft 8 in.	4 ft	South
Hub cap (with hole in it)	155 ft 8 in.	15 ft 10 in.	South
Windshield	182 ft 10 in.	29 ft 4 in.	South
Automobile	1420 ft		

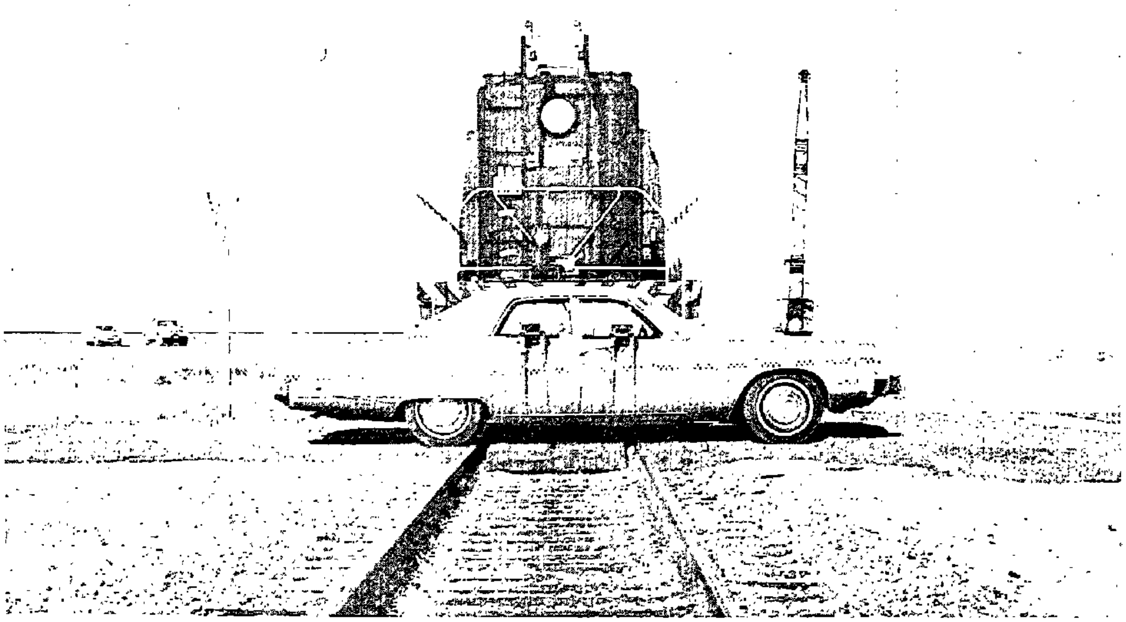


Figure 11. Pre-test View of Locomotive and Automobile (Test TGB-1).

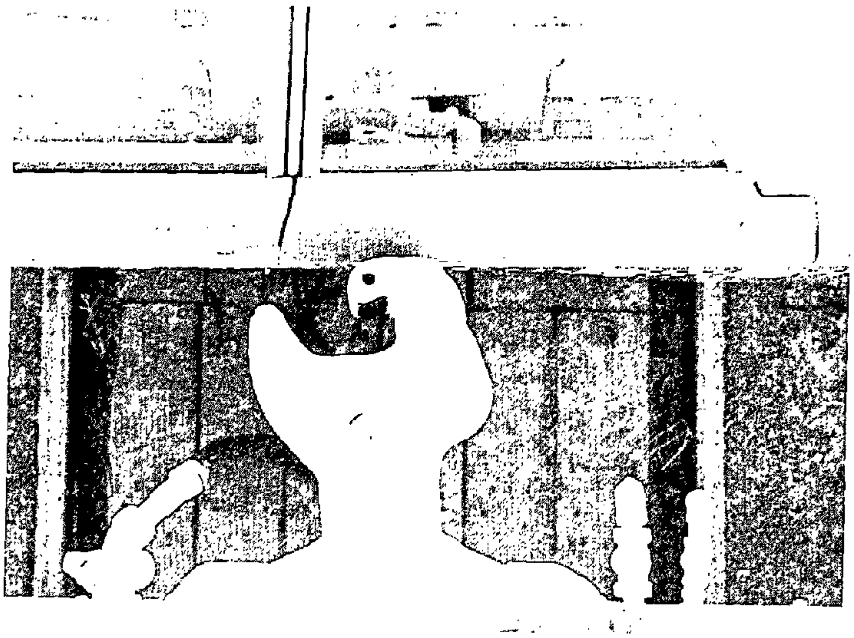


Figure 12. Pre-test Overhead View of Impact Area (Test TGB-1).

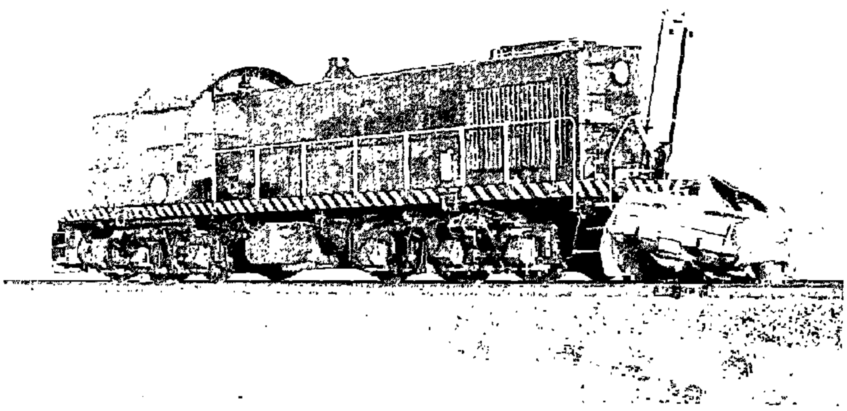


Figure 13. Post-test Orientation of Automobile (Test TGB-1).

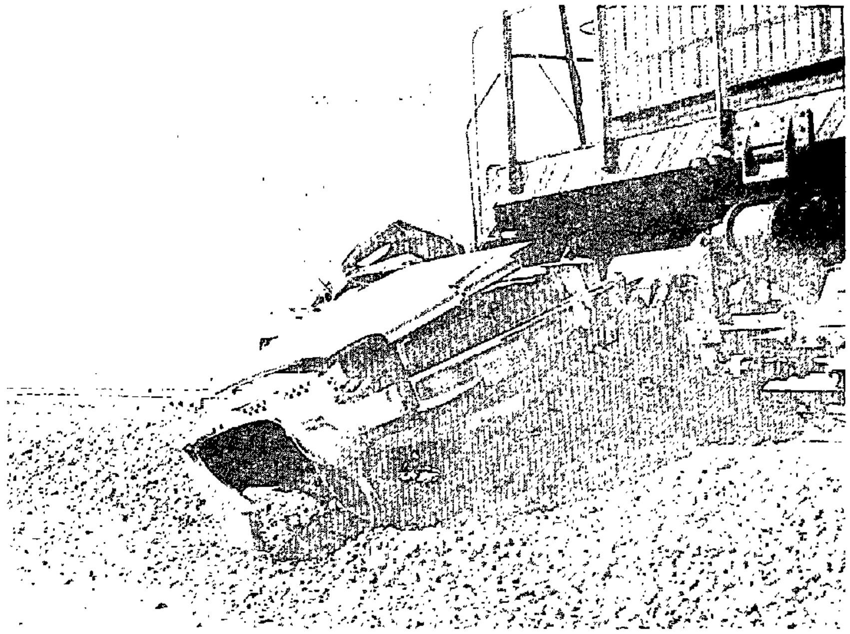


Figure 14. Post-test View of Automobile Front Section (Test TGB-1).

Figure 15. Overhead Post-test View of Automobile Showing Coupler Penetration (Test TGB-1).

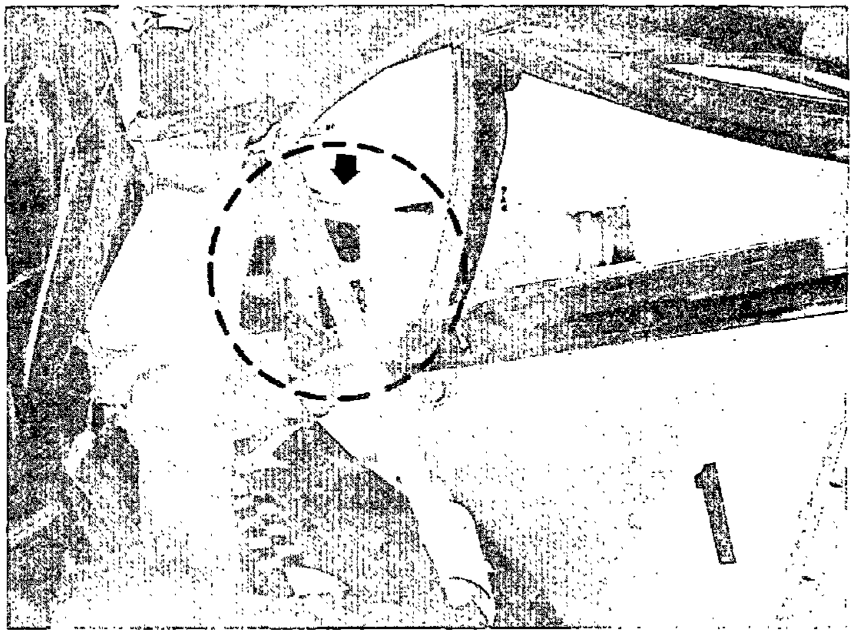


Figure 16. Post-test View of Coupler Penetration (Test TGB-1).

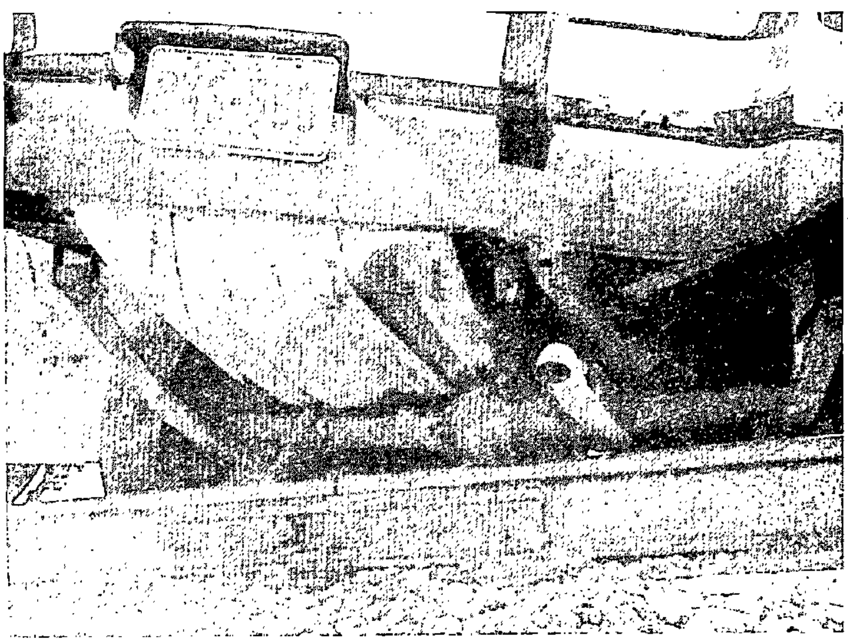


Figure 17. Post-test View of Fuel Tank (Test TGB-1).

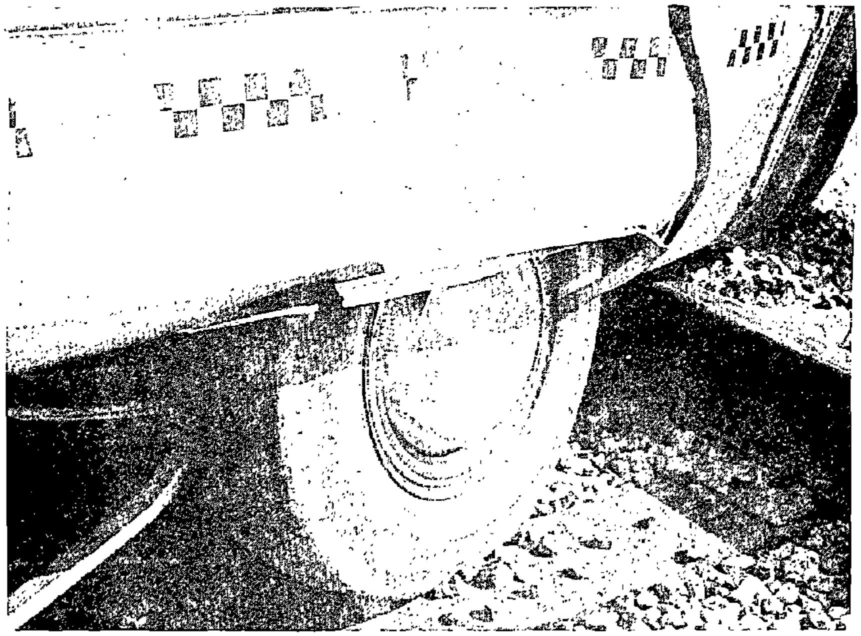


Figure 18. Deformation on Right Side of Automobile Due to Rear Axle Striking Locomotive Front Plate (Test TGB-1).

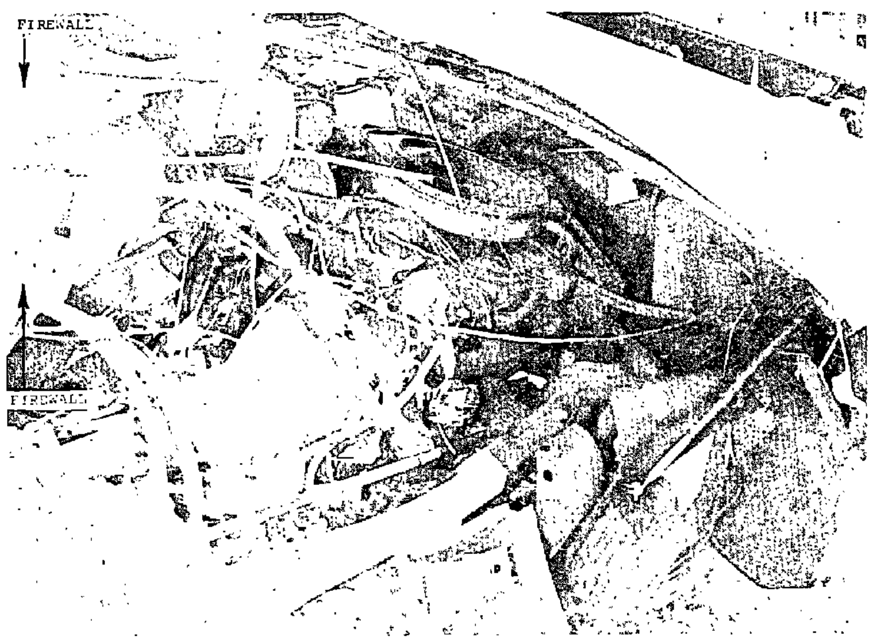


Figure 19. Post-test View of Engine Compartment (Test TGB-1).

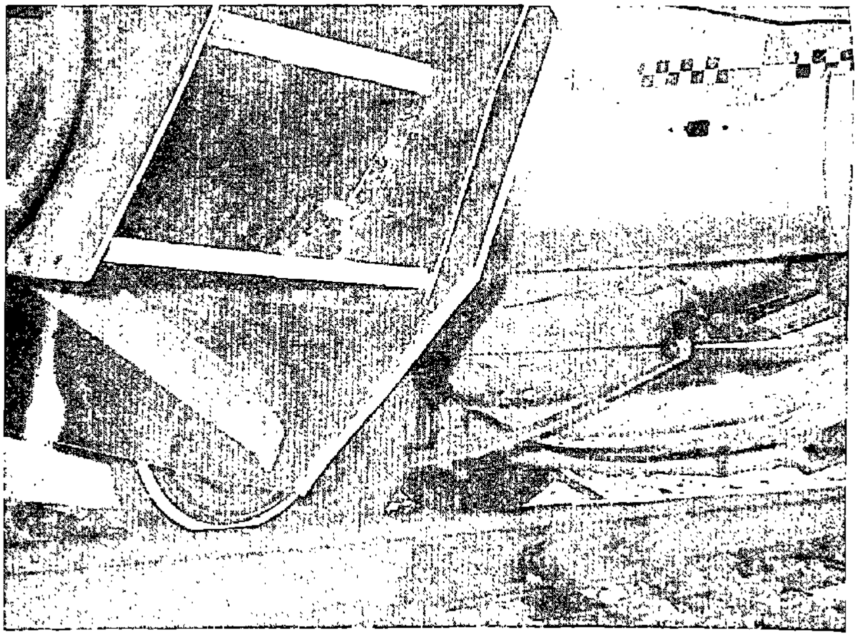


Figure 20. Permanent Set in Locomotive Steps After Test TGB-1.

Figure 21. Broken Pipe on Locomotive After Locomotive-to-Automobile Impact (Test TGB-1).

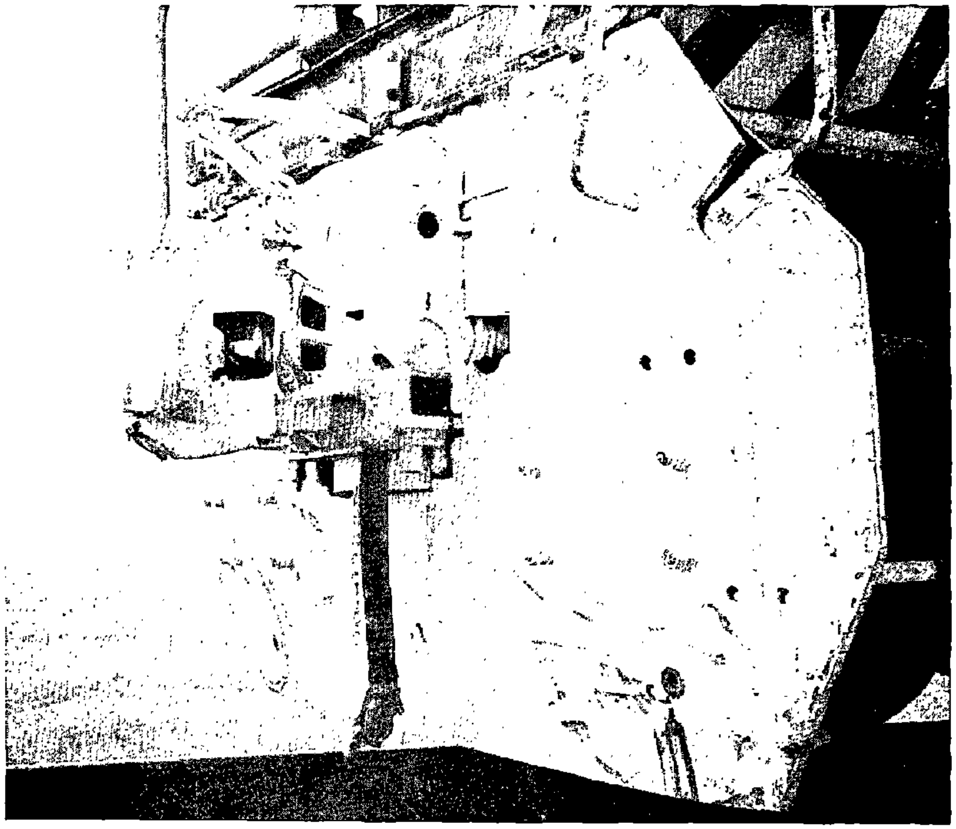


Figure 22. Post-test Condition of Locomotive Front (Test TGB-1).

While the automobile and locomotive remained in contact during the post-impact travel, the locomotive was easily separated from the automobile by simply backing away.

5.2 SECOND LOCOMOTIVE-TO-AUTOMOBILE IMPACT TEST (TGB-2)

The second remote controlled locomotive-to-automobile impact test (TGB-2) was conducted as follows:

Test Date:	February 15, 1974
Test Automobile:	1973 standard-size 4-door sedan
Automobile Test Weight:	4,065 Pounds
Test Locomotive:	130-ton Alco

Locomotive Impact Speed:	51.0 mph
Automobile Impact Area:	Left front fender
Weather:	Clear
Track Condition:	Clear and dry

The locomotive coupler contacted the left front fender of the automobile above the front wheel. The fender was crushed and the coupler contacted the top part of the engine, crushing the valve cover, cracking the head, and breaking off the carburetor.

Since the impact force was ahead of the center of mass of the automobile, the automobile rotated into the locomotive. The rear portion of the automobile actually briefly moved in an up-track direction. The left rear fender impacted the side of the locomotive leaving paint on the brake cylinder and causing minor damage to the bearing box cover.

The automobile was thrown free of the locomotive - turned right, rolled, and yawed until it ended up on its right side about 95 feet from the impact point and 32 feet north of the northernmost rail. The automobile final orientation was pointing up the track. A brake line on the locomotive was broken during impact, causing the locomotive brakes to go into emergency. The brake pressure was then remotely bled off, thereby preventing wheel slide.

Table 6 shows the sequence of events during the impact, obtained from an analysis of the high-speed film. Table 7 contains a list of the significant damage observed after the impact.

Table 8 summarizes deformation which was determined by making pre- and post-test measurements between selected points on the automobile structure. Table 9 lists the significant debris found in the impact zone near the path of the automobile along with the distance from impact point to the part and the distance from the northernmost rail.

TABLE 6. SEQUENCE OF EVENTS DURING TEST TGB-2

Time (msec)	Event
0	Impact
5	Left front fender buckles on top
15	Hood begins to wrinkle
17	Front door begins to open
24	Right rear corner of hood begins to buckle up
29	Locomotive front plate contacts driver's side door
32	Front bumper contacts locomotive front plate
34	Front windshield begins to break starting at lower left corner
37	Driver's window breaks
37	Rear of automobile begins to rotate to left (toward locomotive)
73	Front bumper leaves locomotive front plate
137	Automobile rotates clear of coupler
250	Automobile is approximately parallel to locomotive
252	Left front fender and left side hood begin to separate from firewall
264	Front door opens wide
824	Automobile has rotated approximately 180 degrees and is facing away from and perpendicular to track
824	Wheels begin to dig in, and automobile begins to roll to the left while yawing

Figures 23 and 24 are overall and overhead views of the pre-test impact orientation. Figures 25 through 29 show the post-test deformation of various sections of the automobile.

TABLE 7. SIGNIFICANT DAMAGE OBSERVED AFTER TEST TGB-2
Front cross frame under engine front was buckled
Battery was on ground
Radiator hose was on ground
Carburetor was broken in two
Left front fender was separated
Front windshield was crushed - retained on bottom and lower right side
Rear window was partially separated near roof dent on right side
Right rear fender was bent inward
Front seat was buckled up on left side
Glove box door had opened
Left valve cover was off of engine
Fuel tank was dented but only leakage was from around cap
Entire left rear fender was bent up
Transmission housing was cracked
Rear cross frame for transmission support had buckled
Right front torsion bar had pulled out
Both stub frames were bent but still attached
Drive shaft was out
Tunnel had collapsed back to rear seat area - left floor under rear seat had buckled
Rear spring clip was gone - front right - rear left
All engine mounts were broken

TABLE 8. TEST TGB-2 PERMANENT DEFORMATIONS	
Measurement	Deformation (in.)
Between bottom of A* posts	19.0
Between top of A posts	7.5
Between top of B posts	5.0
Between center of B posts	5.9
Between lower front rocker panels	21.0
Between C posts	1.0

*See Figure 10 for definitions of A, B, and C posts.

TABLE 9. LOCATION OF DEBRIS FOLLOWING TEST TGB-2

Part	Station Distance from Impact	Distance from North Rail	Direction
Drive shaft	54 ft 6 in.	14 ft	North
Grill piece	56 ft 9 in.	9 ft 7 in.	North
Fender liner	60 ft 2 in.	22 ft 9 in.	North
Grill piece	71 ft 4 in.	16 ft 7 in.	North
Chrome strip	74 ft 7 in.	16 ft 1 in.	North
Side rear-view mirror glass	83 ft 2 in.	21 ft 9 in.	North
Hub cap	93 ft 4 in.	20 ft 3 in.	North
Automobile	93 ft	31 ft 7 in.	North
Front fender piece	109 ft 10 in.	7 ft 4 in.	North
Hub cap	117 ft 4 in.	22 ft 9 in.	North
Fender piece	178 ft 11 in.	18 ft 7 in.	North
Grill piece	148 ft 11 in.	12 ft 6 in.	North
Hub cap	23 ft 9 in.	18 in.	South

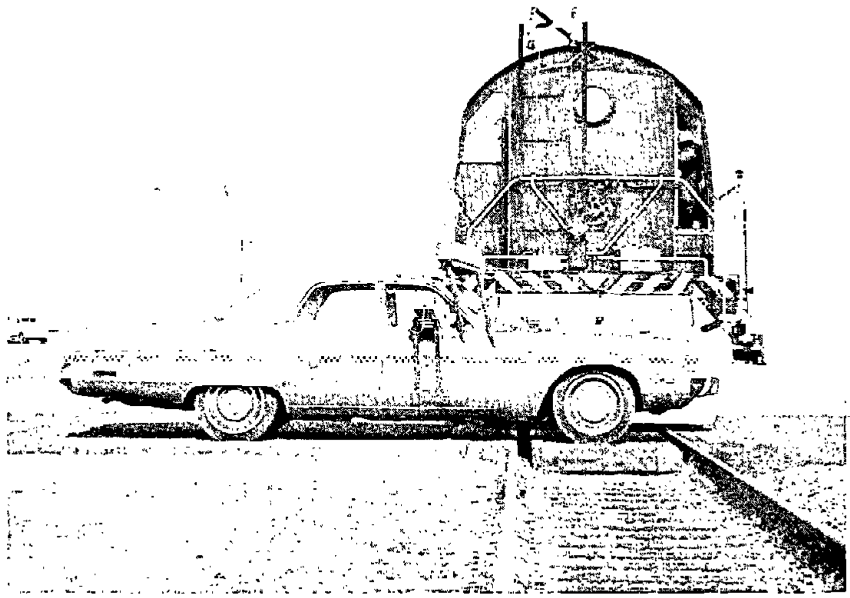


Figure 23. Pre-test View of Locomotive and Automobile (Test TGB-2).

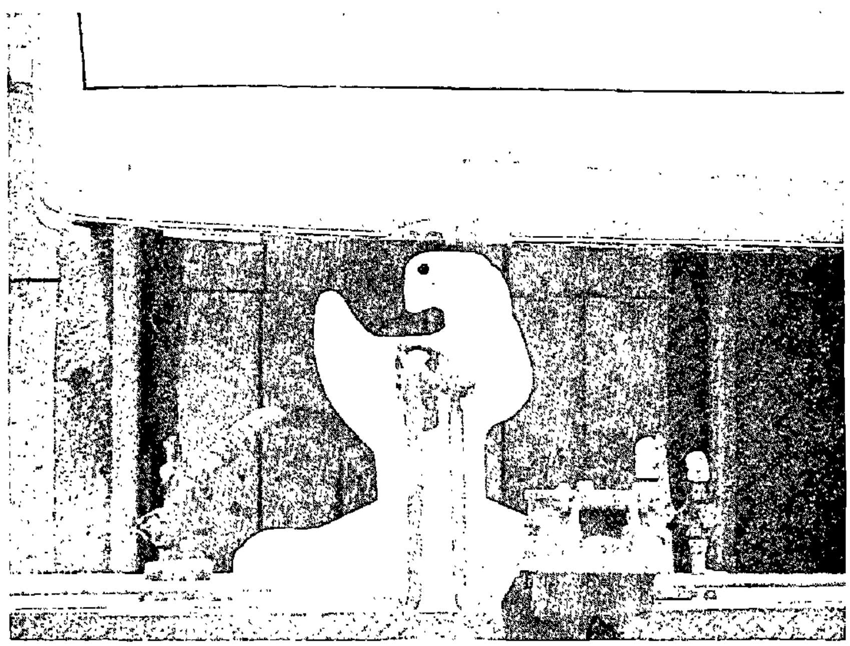


Figure 24. Pre-test Overhead View of Impact Area (Test TGB-2).

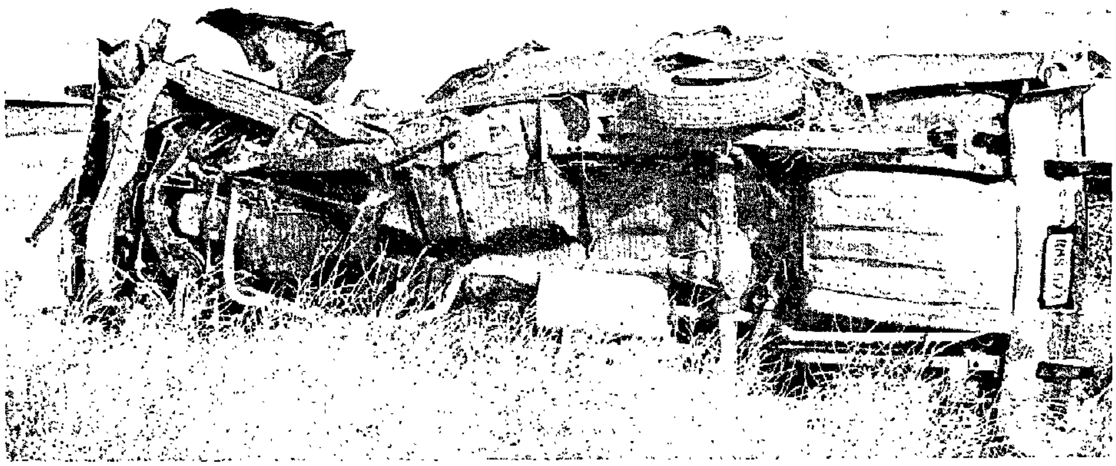


Figure 25. Post-test Orientation of Automobile (Test TGB-2).

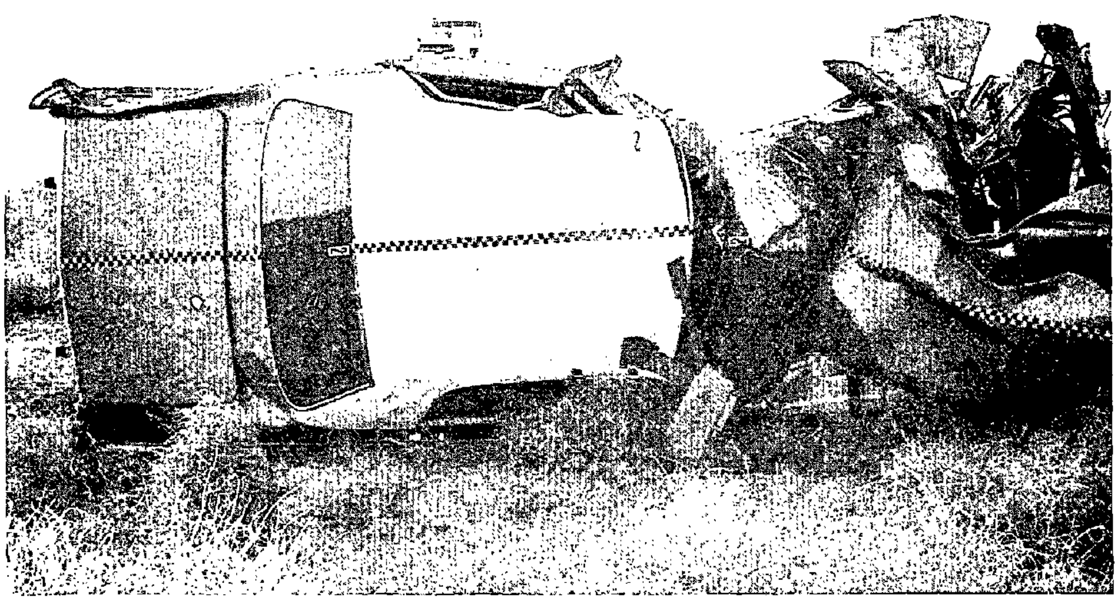


Figure 26. Post-test View of Top of Automobile (Test TGB-2).

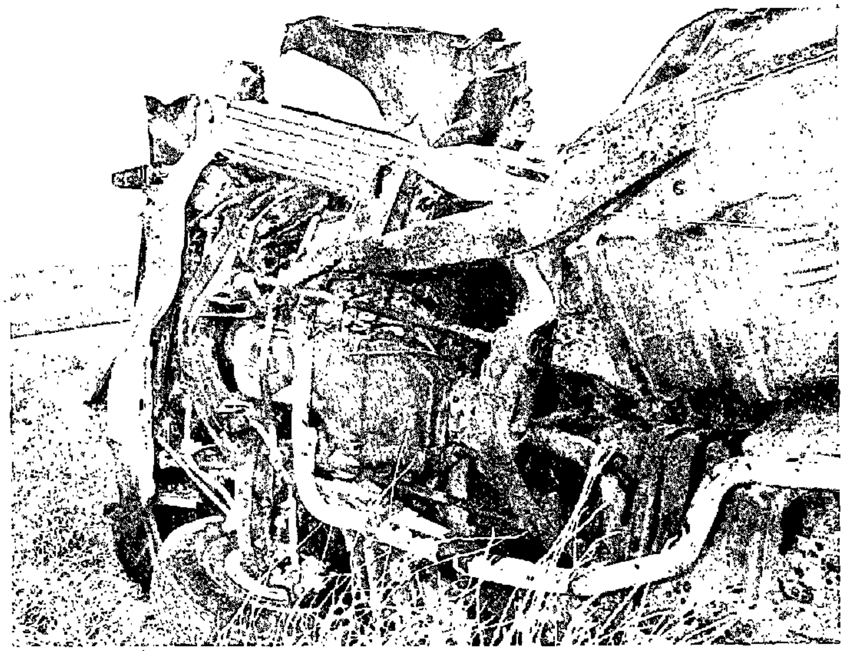


Figure 27. Post-test Underside View of Front Section of Automobile (Test TGB-2).

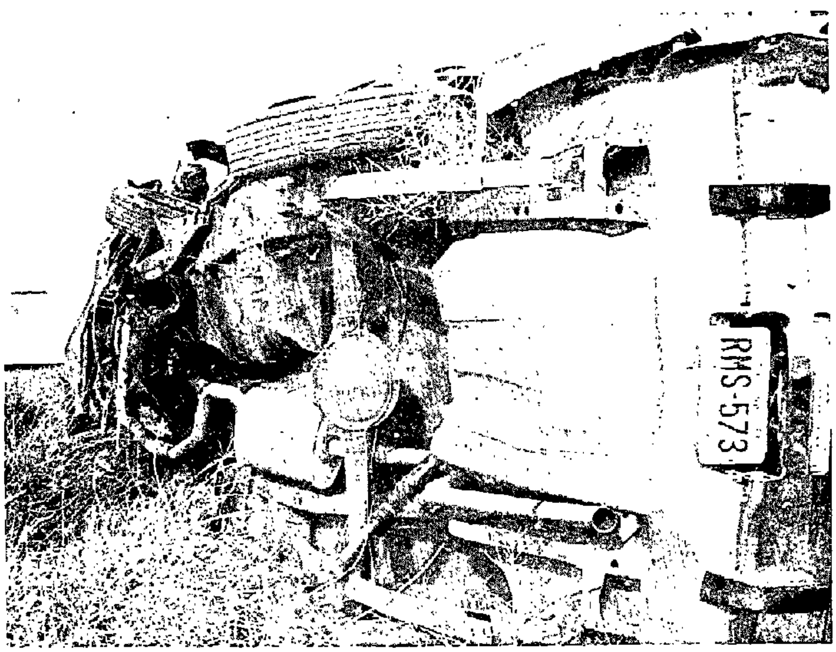


Figure 28. Post-test Underside View of Automobile (Test TGB-2).

Figure 29. Post-test View of Driver Area (Test TGB-2).

The imprint of the automobile on the locomotive front plate is shown in Figure 30. The automobile caused minor damage to the side of the locomotive when the left rear fender rotated into its side, as shown in Figures 31 and 32.

5.3 THIRD LOCOMOTIVE-TO-AUTOMOBILE IMPACT TEST (TGB-3)

The third remote controlled locomotive-to-automobile impact test (TGB-3) was conducted as follows:

Test Date:	March 5, 1974
Test Automobile:	1973 standard-size 4-door sedan
Automobile Test Weight:	4,693 Pounds

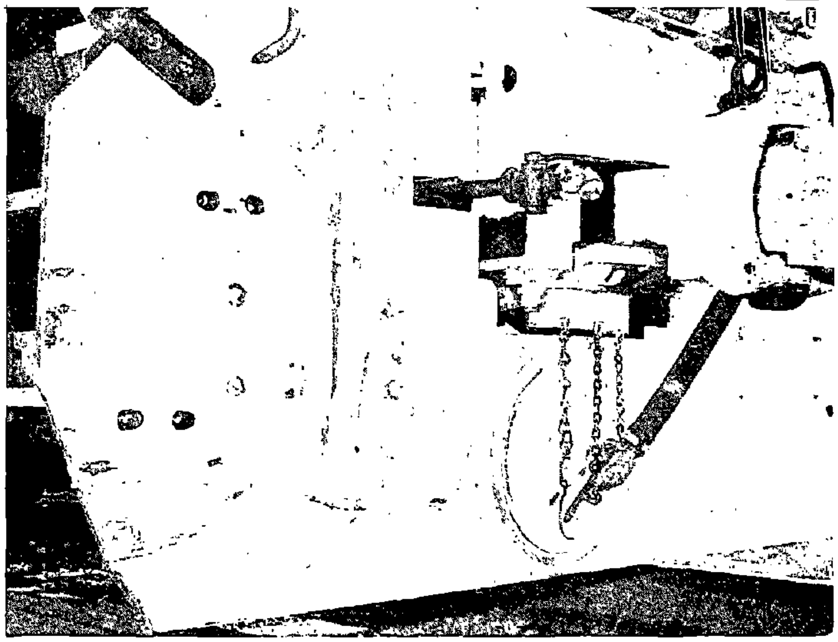


Figure 30. Post-test View of Locomotive Front Plate Showing Automobile Imprint (Test TGB-2).

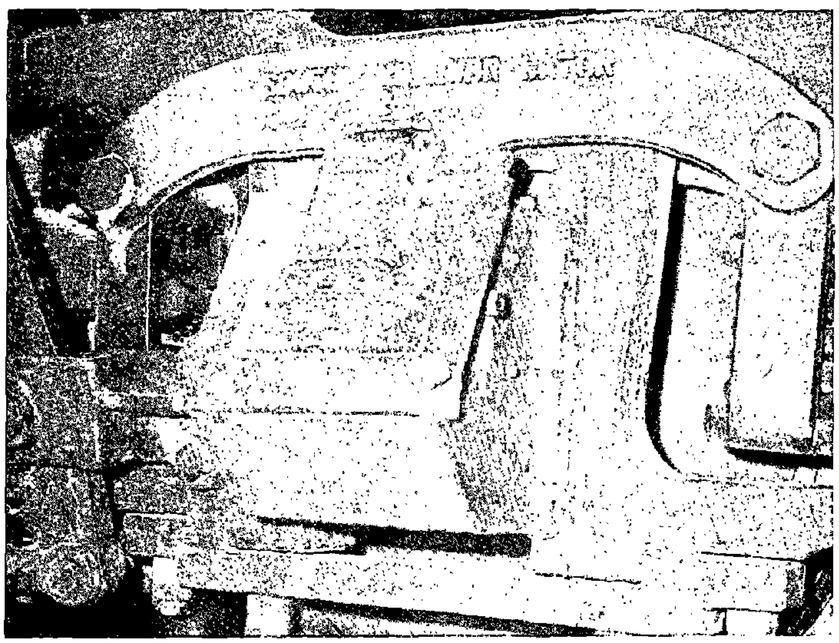


Figure 31. Post-test View of Axle Box Showing Minor Damage (Test TGB-2).

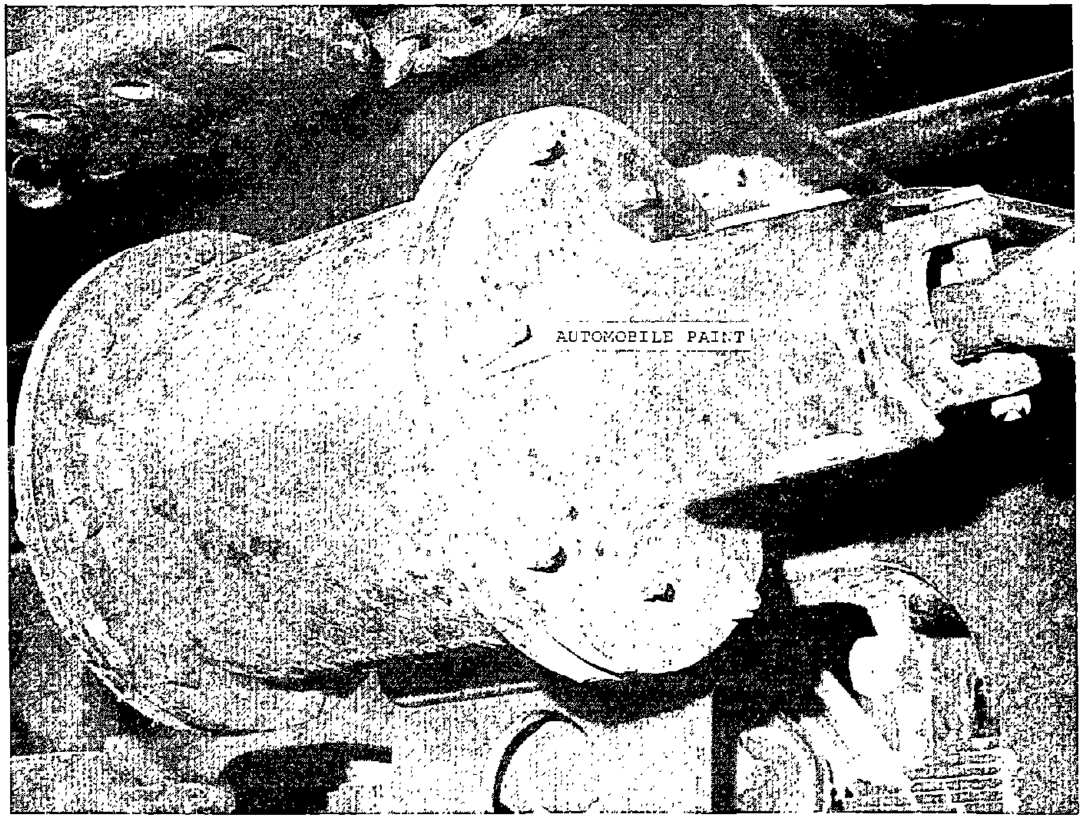


Figure 32. Post-test View of Locomotive Brake Cylinder With Automobile Paint Visible Around Front Collar.

Test Locomotive:	130-ton Alco
Locomotive Impact Speed:	49.1 mph
Automobile Impact Area:	Center driver's side
Weather:	Clear
Track Condition:	Clear and dry

The impact configuration for Test TGB-3 was identical with Test TGB-1 (conducted February 12, 1974) with the addition of an array of accelerometers and an instrumented anthropomorphic dummy. The post-impact speed of the locomotive and automobile based upon conservation of linear momentum is 48.2 for a 0.9 mph reduction in locomotive speed. The performance of the automobiles in Tests TGB-1 and TGB-3 was basically the same except for minor differences, such as:

- The windshield came completely out during Test TGB-1 but not during Test TGB-3
- The B post was inside the jaws of the coupler after Test TGB-3 but was in front of the coupler after Test TGB-1
- The front plate on the locomotive which deformed during Test TGB-1, due to stiffening, remained undeformed during Test TGB-3
- The right rear fender tore adjacent to the door opening during Test TGB-3 but not during Test TGB-1
- One stub frame mount remained attached during Test TGB-3 but the frame was completely detached during Test TGB-1.

The two tests were similar in that the automobile remained in contact with the front of the locomotive and the front section of the automobile rotated approximately 90 degrees with respect to the rest of the automobile.

Table 10 presents the sequence of events as obtained from an analysis of the high-speed film. Table 11 lists the significant damage observed after the impact test.

Table 12 summarizes deformation which was determined by making pre- and post-test measurements between selected points on the automobile structure. Table 13 lists all of the significant debris found along the track together with the distance from impact and distance from the southernmost rail.

Figures 33 and 34 are overall and close-up views of the pretest impact orientation of Test TGB-3. Figure 35 is an overall post-test view of the automobile and locomotive which shows the broken front section of the automobile as well as the torn right rear fender and overall condition of the automobile. Figures 36,

TABLE 10. SEQUENCE OF EVENTS DURING TEST TGB-3	
Time (msec)	Event
2	Rear door dented (width of dent approximately 2 feet)
5	Driver's side rear door window breaks
5	B post begins inward deflection
7	Coupler contacts front door handle
8	Rear window sill on inside begins to cave in
9	Front door window on driver's side breaks
13	Front seat back begins to rotate rearward
20	Buckle forms in roof above B post on driver's side
28	Locomotive front plate contacts automobile side
28	Dummy head begins to rotate toward door (indicating shoulder impacted by side of automobile)
32	Front section of automobile begins to rotate
34	Left side of windshield begins to break
38	Rear window breaks
38	Panel under dash begins to come loose
45	Trunk area begins to shear sideways
46	Dummy head in contact with front window header
48	Right rear fender is pushed outward by rear axle
49	Trunk lid begins to open at right front corner
51	Coupler face is inside automobile
53	A post contacts steering wheel
54	Right front fender begins to separate from automobile
214	Front section of automobile is approximately parallel with the train track

TABLE 11. SIGNIFICANT DAMAGE OBSERVED AFTER TEST TGB-3
Left rear fender was torn near front up to window sill
Right rear leaf spring had come apart
Dyed water was lost from fuel tank - spring had cut hole in tank
Rear end was bent to left
Left rear fender was completely wrapped around front plate of locomotive, extending past plate about four inches
Trunk lid had buckled
Rear bumper was bent
Tail pipe had pulled free
Rear window was broken out
B post was inside coupler
Right front section of automobile had pulled loose
Dummy head had contacted door header
Front and rear seat pan had buckled up in center
Windshield was barely retained at lower right corner
Left side of dash was crushed
Dummy pelvis was wedged in between buckled up seat and front door
Transmission housing had broken
Right front stub frame had pulled loose
Left front stub frame rear mount was still attached
Heater motor was missing
Right front wheel and stub frame had dragged ballast
Drive shaft had pulled out of transmission
Left front wheel was behind steps on left side of locomotive
Front side railing on locomotive had dented left rear corner of hood
Rear axle was driven through right rear fender
Left lower step had bent slightly
Left rear fender was torn near lower left corner of window
Trunk lid was loose
Both passenger side doors could be opened with moderate difficulty (held by latch) (latch worked)

TABLE 12. TEST TGB-3 PERMANENT DEFORMATIONS	
Measurement	Deformation* (in.)
Between top of B** posts	21.5
Between center of B posts	29.8
Between front window sills	23.3
Between rear window sills	31.3
Between C posts**	13.9
Between top A posts**	17.4
Steering wheel to left door	5.6
Steering wheel to right door	20.9
Engine to right fender	-16.4
Engine to left fender	5.9

*Negative number indicates an increase.
**See Figure 10 for definitions of A, B, and C posts.

TABLE 13. LOCATION OF DEBRIS FOLLOWING TEST TGB-3			
Part	Station Distance From Impact	Distance From South Rail	Direction
Heater housing	70 ft 4.5 in.	8 ft 4 in.	South
Locomotive brake pipe	72 ft 6 in.	3 ft 8 in.	North
Hood spring	117 ft 6 in.	13 ft 11 in.	South
Heater motor	133 ft 1 in.	20 ft 10 in.	South
Locomotive brake pipe	154 ft 7 in.	3 ft	North
Steering column shaft	265 ft 8 in.	13 ft 1 in.	South
Hub cap	269 ft 11 in.	29 ft 6 in.	South
Automobile	1,000 ft	0	

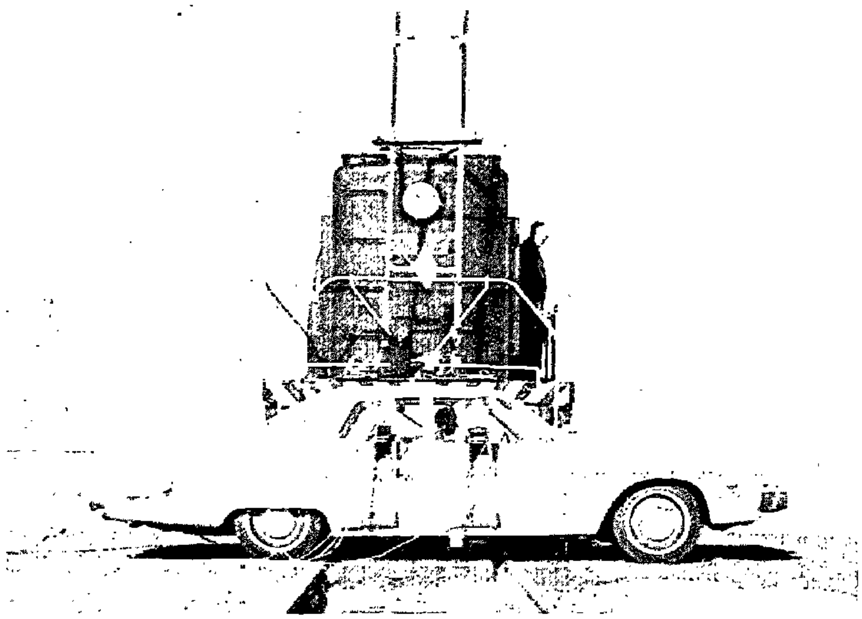


Figure 33. Pre-test View of Locomotive and Automobile (Test TGB-3).

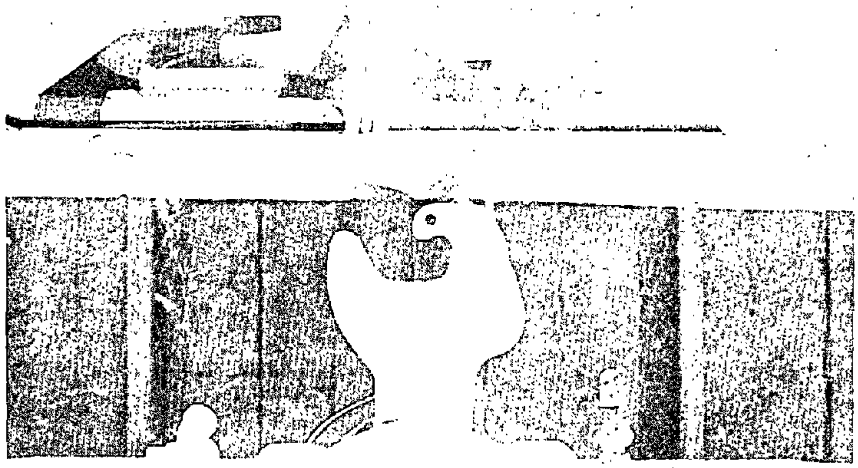


Figure 34. Pre-test Overhead View of Impact Area (Test TGB-3).

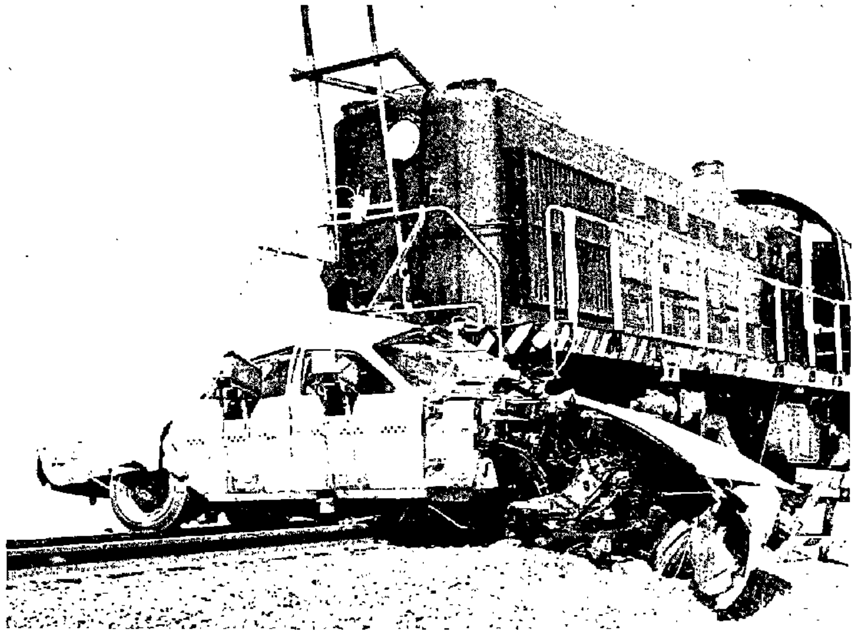


Figure 35. Post-test View of Locomotive and Automobile (Test TGB-3).

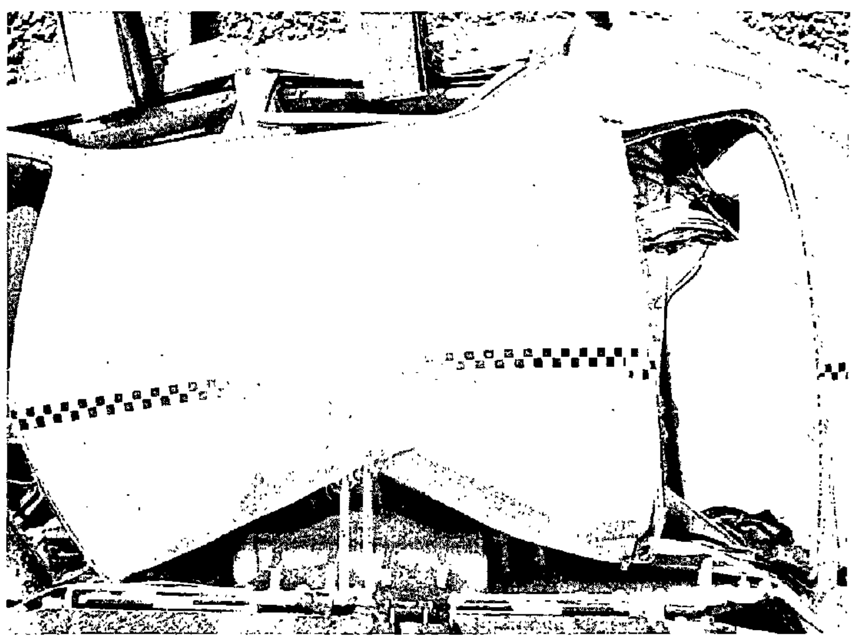


Figure 36. Post-test Overhead View of Center Section of Automobile (Test TGB-3).

37, and 38 are post-test overhead views of the center, front, and rear sections of the automobile showing how the automobile is wrapped around the locomotive front plate and coupler.

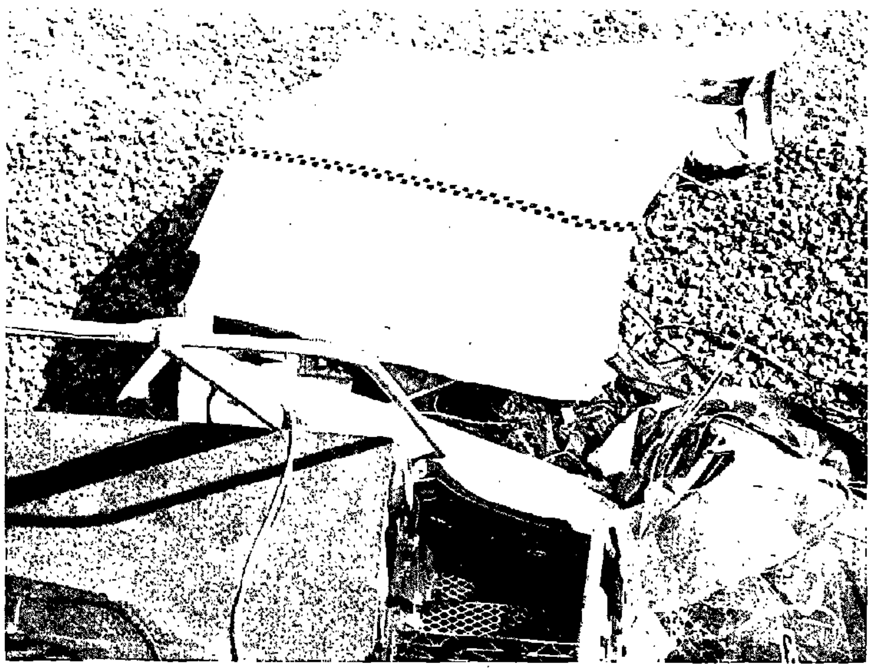


Figure 37. Post-test View of Front Section of Automobile (Test TGB-3).

Figure 39 is a view of the coupler through the right rear door, showing the intrusion into the occupant space of the automobile. Figure 40 is a post-test view of the dummy in the driver area. The dummy retained its structural integrity with no apparent permanent damage, even though the loads experienced during the impact would have been fatal for a human, as will be discussed later. After the front section of the automobile was pulled back, the locomotive was simply backed away from the automobile leaving an imprint as shown in Figure 41.

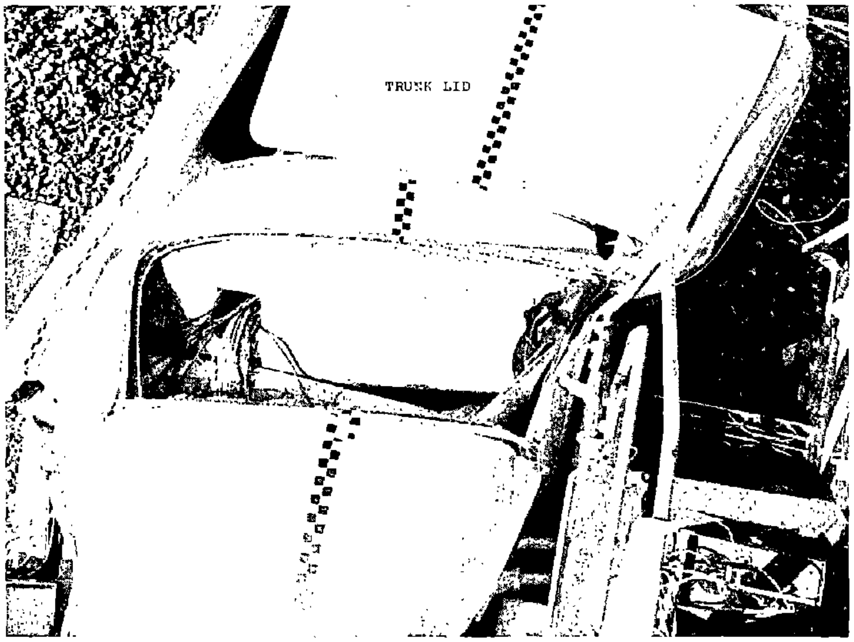


Figure 38. Post-test View of Rear Section of Automobile (Test TGB-3).

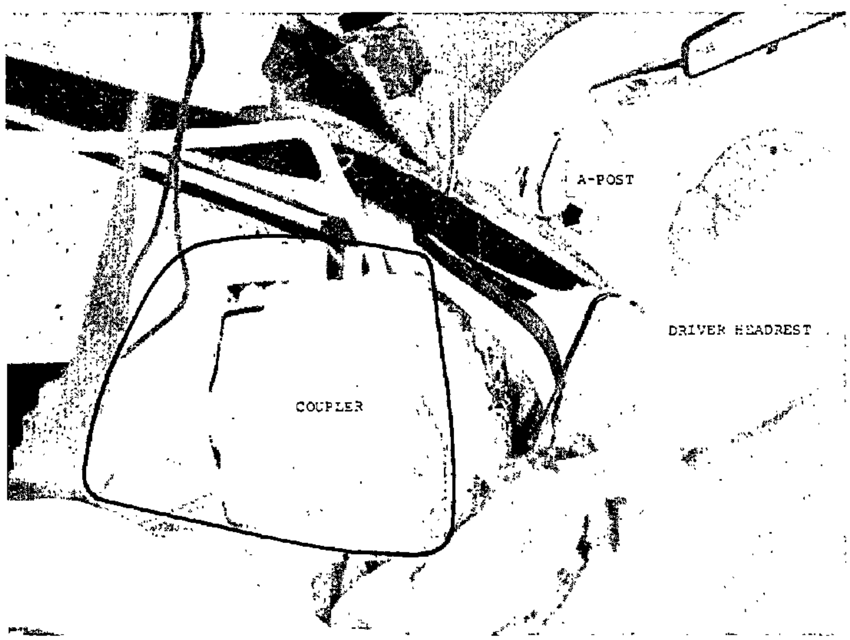


Figure 39. Intrusion of Coupler Into Occupant Compartment (Test TGB-3).

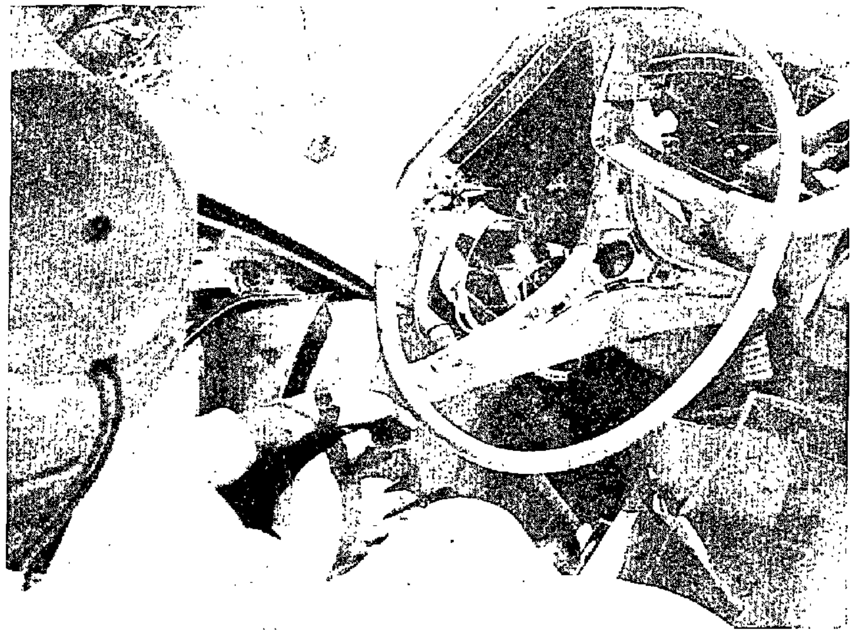


Figure 40. Post-test View of Dummy and Driver Area (Test TGB-3).

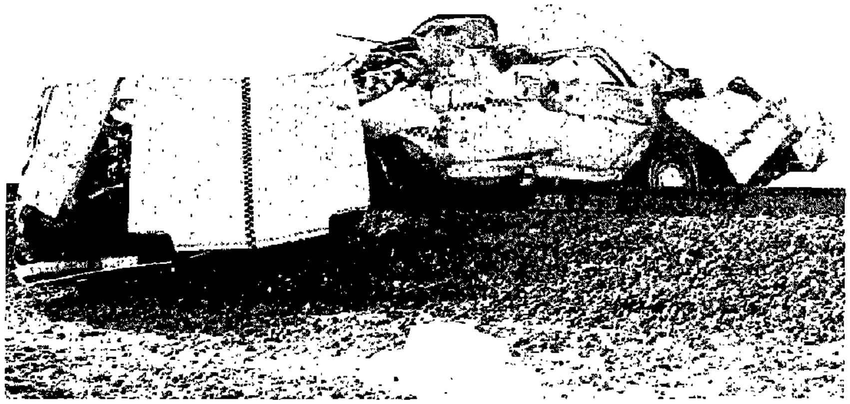


Figure 41. Post-test View of Automobile Showing Imprint of Locomotive Front (Test TGB-3).

Both the automobile and the locomotive contained an array of acceleromters for test TGB-3. Section A.2 in the Appendix contains a description of the instrument locations. Sections A.3 and A.4 in the Appendix contain a complete set of acceleration time records.

During Test TGB-3, the portion of the event with high accelerations was typically over by 110 msec after initial impact, depending upon the location of the instrument within the structure. Figures 42 and 43 compare the two front and two rear lateral accelerations of the locations on the occupant compartment floor. In both cases, the locations nearest to the impact area (Locations 3 and 5) experienced a higher acceleration which also occurred earlier in time. The peak accelerations of corresponding front and rear accelerometers coincided closely in time. The rear accelerations were significantly higher as can be seen in Figure 44 which compares the front and rear right side lateral accelerations.

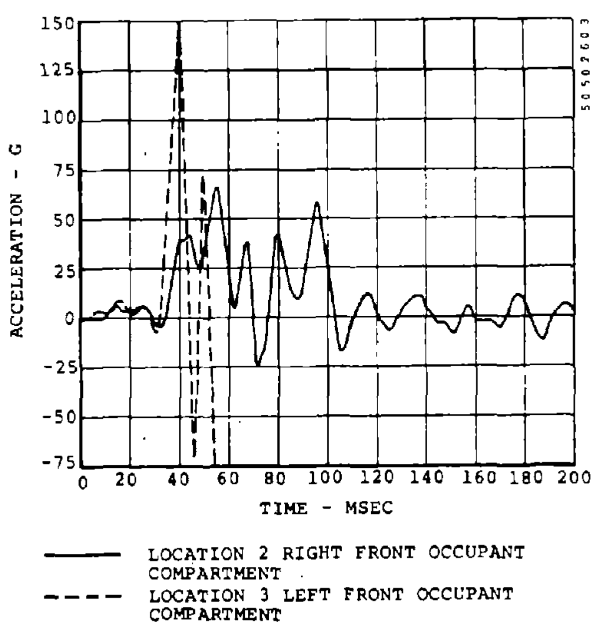


Figure 42. Comparison of Front Occupant Compartment Accelerations (Test TGB-3).

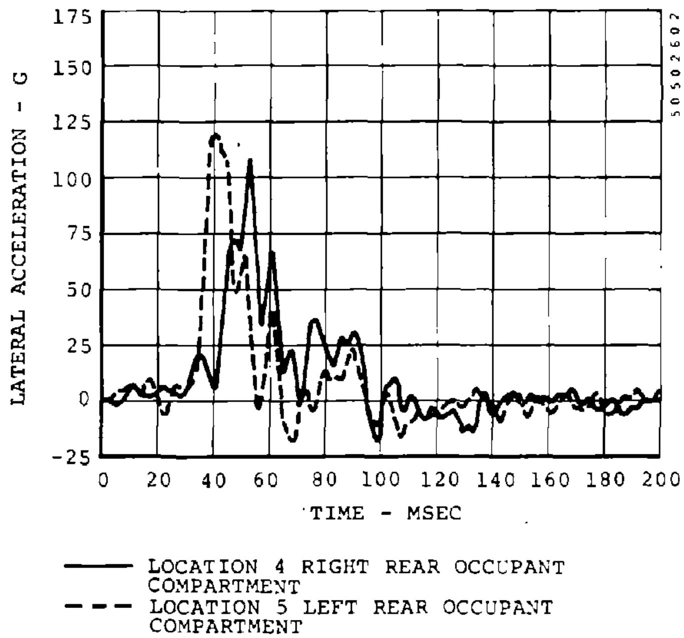


Figure 43. Comparison of Rear Occupant Compartment Accelerations (Test TGB-3).

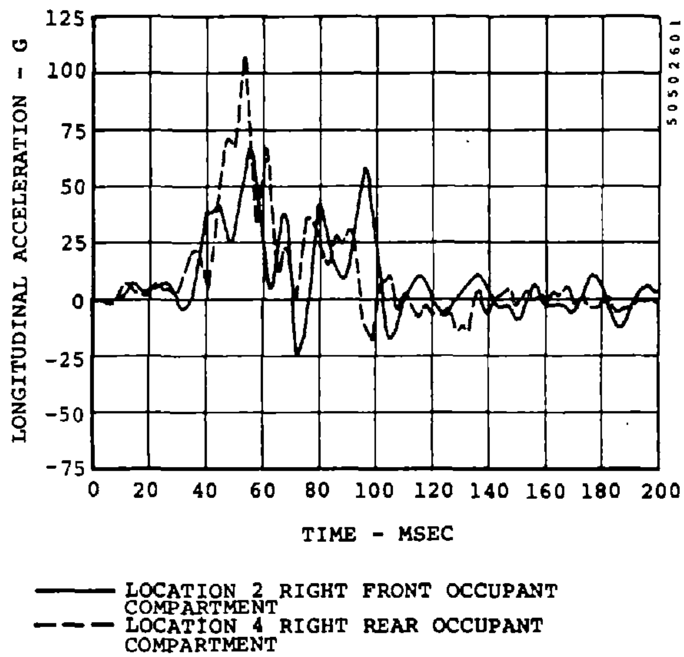


Figure 44. Comparison of Occupant Compartment Right Side Lateral Accelerations (Test TGB-3).

Due to the large deformation of the automobile, as expected, the acceleration at any instant in time for various locations can vary significantly. For this reason, it is not meaningful to specify a typical acceleration for the automobile. Table 14 lists the peak lateral acceleration at each location with the time at which it occurs. The table also estimates the duration of the significant acceleration and the time after impact when significant accelerations ended. Figure 45 is a schematic of the automobile with the peak accelerations at the instrument locations listed along with the times of peak acceleration superimposed on a diagram of the automobile.

TABLE 14. SUMMARY OF PEAK LATERAL AUTOMOBILE ACCELERATIONS (TEST TGB-3).

Number	Location Description	Peak Acceleration (G)	Time Peak Occurred (msec)	Duration of Pulse (msec)	Approximate End of Event (msec)
1	Engine	32	62	70	110
2	R.F. O.C.*	67.7	55	30	105
3	L.F. O.C.	150.2	40	15	100
4	R.R. O.C.	108.6	53	35	95
5	L.R. O.C.	119.9	40	30	95
6	Axle	132.1	41	10	60
7	F. Bumper	26.1	123	70	160
8	R. Bumper	41.1	82	140	170
9	Firewall	73.1	53	30	95
10	Left Rocker Panel	23.8	35	10	-
11	R. B Post	104.2	29	10	110
12	L. B Post	138.4	11	15	70
13	F. Fender	41.3	41	10	-
14	F. Frame	23	74	25	150
15	Right Rocker Panel	126	52	40	95
16	Rear Fender	56	67	60	180
17	Rear Frame	46.9	52	160	180

*O.C. is abbreviation of occupant compartment

Peak Acceleration (G)
Time at Peak (msec)

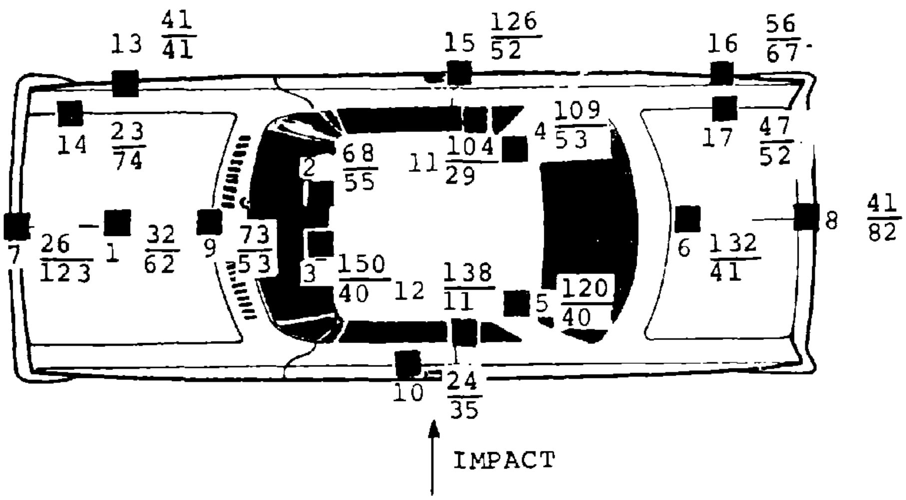


Figure 45. Schematic Presentation of Peak Lateral Accelerations Along With the Time at Which the Peak Occurred for Test TGB-3.

Accelerations on the locomotive itself were significantly lower than on the automobile. Table 15 summarizes the peak accelerations for the locomotive-mounted accelerometers. The accelerations of the locomotive cab were low level (on the order of 2G). The acceleration on the front platform had a 8.5G peak at about 49 msec. Data from the three accelerometers on the locomotive front plate are shown superimposed in Figure 46. Location 104A was protected from direct impact by the automobile since it was at the base of the coupler. The instrument at Location 103A suffered a zero shift, probably at about 60 msec. Figure 47 compares the acceleration from Location 105A on the locomotive with Locations 4 and 5 of the automobile. The major peaks of the locomotive plate instrument correspond in time closely to the major peaks of the occupant compartment.

TABLE 15. SUMMARY OF PEAK LOCOMOTIVE LONGITUDINAL ACCELERATION (TEST TGB-3)					
Location Number	Location Description	Peak Acceleration (G)	Time of Peak (msec)	Duration of Pulse (msec)	End of Event (msec)
101	Cab Floor	-2.2*	59	10	80
102	Front Platform	-8.5	49	10	90
103A	Right Front Plate	-57.8	53	40	90
104A	Center Front Plate	-8.3	59	10	90
105A	Left Front Plate	-35.6	56	10	95

*Negative sign for acceleration denotes a retarding force on the locomotive.

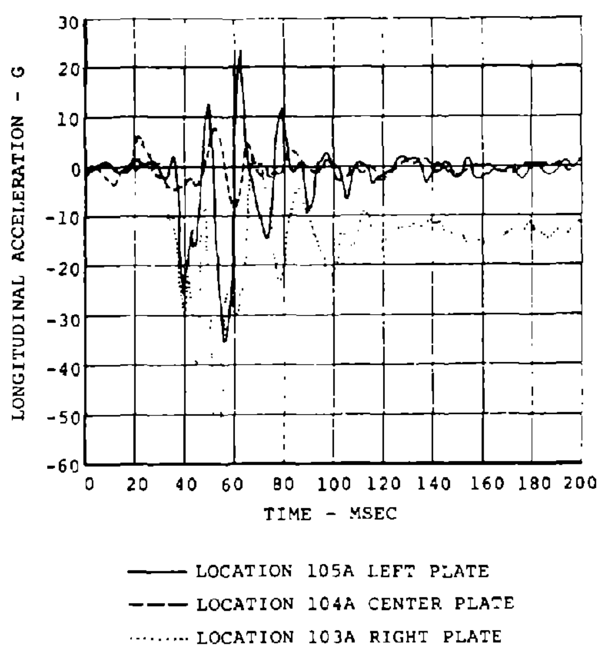


Figure 46. Comparison of Locomotive Front Plate Accelerations (Test TGB-3).

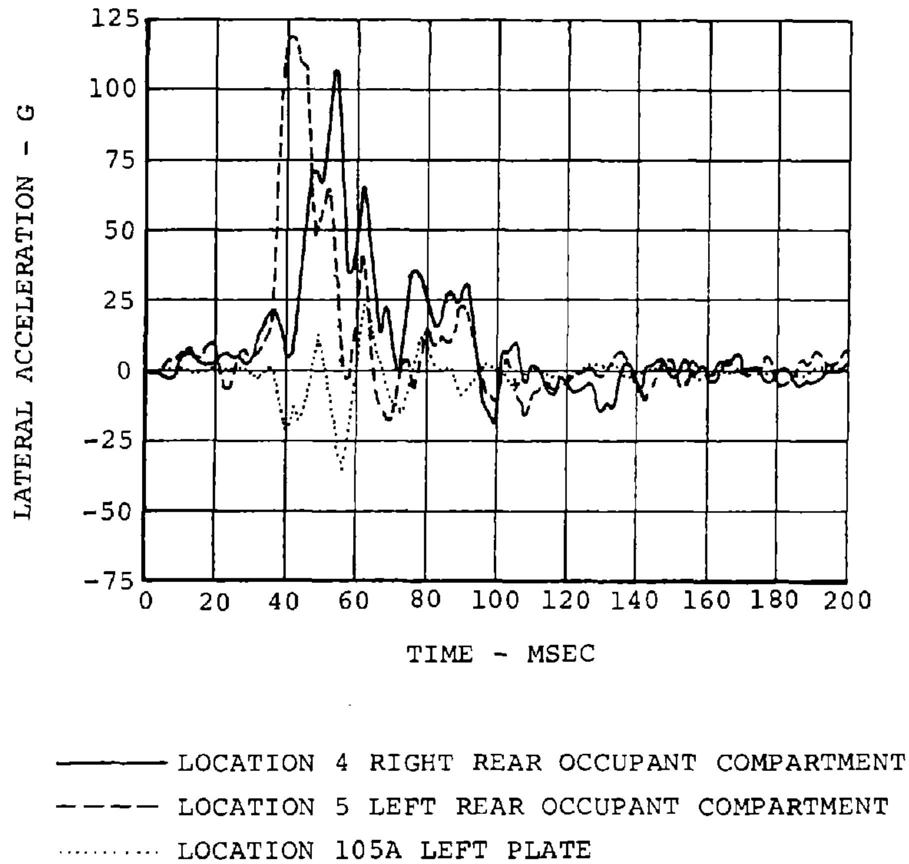


Figure 47. Comparison of Occupant Compartment Acceleration With Locomotive Front Plate Acceleration (Test TGB-3).

The lateral accelerometer data on the automobile and the longitudinal accelerometer data on the locomotive can be integrated to yield a calculated velocity. The ability to obtain an accurate velocity in some instances is limited by a rotation of the instrument. In integrating the acceleration to yield velocity, either the instrument must maintain its original orientation or the angle versus time must also be known. In the absence of the angular data, it must be assumed that the instrument maintains its initial orientation. Table 16 lists the calculated velocity in feet-per-second for each instrument in

TABLE 16. TEST TGB-3 CALCULATED VELOCITY (FPS) FROM AUTOMOBILE LATERAL ACCELEROMETERS AND LOCOMOTIVE LONGITUDINAL ACCELEROMETERS (INITIAL VELOCITY OF 72.01 FPS)

Location	Time (msec)							
	20	40	60	80	100	120	140	160
1	0	.1	10.2	28.7	40.5	41.3	43.8	44.6
2	1.7	7.0	34.6	41.8	57.8	56.8	58.4	57.5
3	2.3	23.6	*	*	*	*	*	*
4	1.4	7.8	46.3	63.6	71.4	71.7	67.4	68.0
5	2.9	18.3	59.1	56.8	61.4	56.9	56.6	55.0
6	.6	9.4	13.0	14.6	16.1	16.8	15.7	17.4
7	.4	12.7	14.2	13.1	31.8	47.1	48.9	44.1
8	.3	2.9	17.8	38.0	56.4	90.1	80.8	83.2
9	2.1	11.6	31.1	27.3	*	*	*	*
10	2.8	*	*	*	*	*	*	*
11	1.9	15.8	47.3	66.2	75.3	77.4	73.8	74.8
12	26.9	28.4	46.5	41.0	40.6	40.9	40.0	39.8
13	7.1	8.3	6.6	*	*	*	*	*
14	-.2	1.6	6.1	13.8	19.6	27.1	29.9	30.3
15	1.7	8.1	45.7	60.1	71.0	71.5	67.3	67.8
16	-.3	3.4	10.7	37.7	46.6	54.0	66.7	69.1
17	.5	5.0	20.5	32.7	49.1	61.9	70.2	74.1
TRAIN TGB-3								
101	72.2	72.0	71.4	71.1	71.3	71.2	70.1	70.1
102	72.2	71.9	71.5	71.2	71.3	70.9	70.7	70.7
103A	71.9	67.5	*	*	*	*	*	*
104A	71.7	71.2	71.2	70.9	71.5	70.7	70.8	70.4
105A	72.0	69.9	61.6	62.4	62.1	60.9	60.9	60.4

*Questionable data at these points due to either cut cables or instrument damage.

20-msec increments (the initial velocity of the locomotive was 72.01 feet-per-second).

The instrument locations near the impact, such as Locations 2, 3, 4, 5, 6, 10, and 12, probably rotated early in the impact due to local structural deformation, thus accounting for the low calculated change in velocity. The front part of the automobile rotated away from the automobile occupant compartment which also caused errors in the accelerometer integration, as in Locations 1, 7, 9, 13, and 14.

The remaining locations sustained lesser amounts of rotation and provide a reasonable estimate of the velocities at those locations for the times indicated.

The instrument locations on the locomotive were not subjected to significant rotation.

The final calculated velocities of Locations 101 and 102, which were not located near the impact point, can be compared with a calculated change in velocity from linear momentum considerations of 0.9 mph or 1.3 feet per second, which yields a post-impact speed of the vehicle of 70.9 feet per second for a perfectly plastic collision with negligible ground and drag forces.

The occupant of the automobile is of utmost concern in a grade crossing accident. The dummy in the driver location simulates a human occupant. Figure 48 is the time history of the resultant dummy head acceleration. The maximum resultant acceleration was 277G at 36 msec. The two most common measures of impact severity based upon head acceleration are the Gadd Severity Index (SI) and the Head Injury Criterion (HIC). These criteria are based upon studies that attempt to correlate human trauma and injury to accelerations of the head. The severity index is defined as follows:

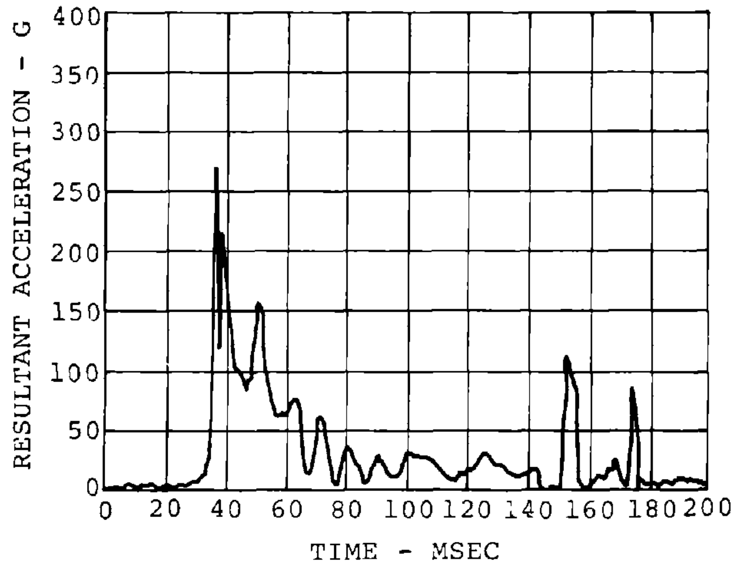


Figure 48. Resultant Dummy Head Acceleration (Test TGB-3).

$$SI(t) = \int_{t_o}^{t} a_R^{2.5}\, dt$$

where t_o = start of event (sec)

a_R = Resultant dummy head acceleration (G)

A plot of the severity index is shown in Figure 49. When SI exceeds a value of 1000 the excessive acceleration is considered to have been fatal if a human had been in place of the dummy. For Test TGB-3 the SI exceeded 1000 at 36 msec. At the end of the computation interval of 200 msec the value of SI had risen to 6062.

The HIC is defined as follows:

$$HIC = \left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a_R\, dt\right]^{2.5} (t_2 - t_1)$$

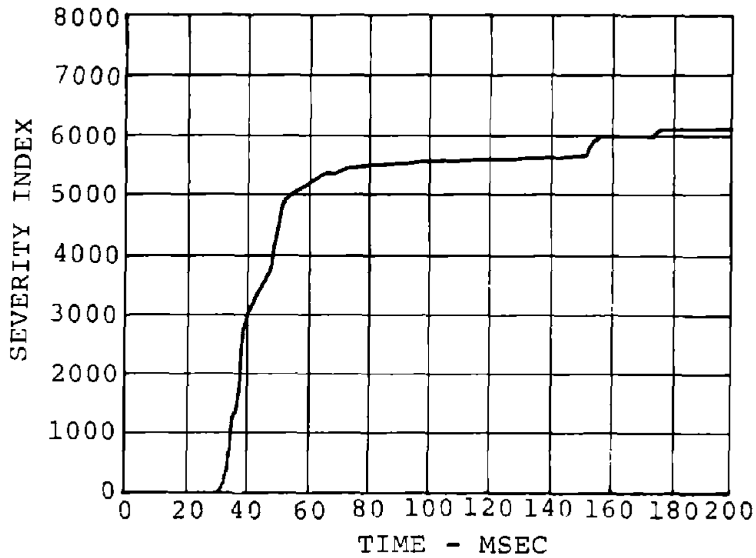


Figure 49. Severity Index for Dummy Head During Test TGB-3.

If the value of HIC exceeds 1000 for any interval $t_2 - t_1$ the impact is considered fatal. The HIC for TGB-3 was 3821.

The dummy thorax resultant acceleration is shown in Figure 50. The maximum thorax resultant acceleration was 136G at 44 msec. The two injury criteria for the thorax acceleration involve the SI and the length of time the acceleration exceeds 60G. Figure 51 shows the thorax SI versus time. When the SI exceeds 1000, the impact is considered fatal. This condition occurred at 45 msec for the dummy thorax during test TGB-3 which is just prior to the dummy head striking the window header.

If the resultant acceleration exceeds 60G for more than 3 msec, the impact is fatal. For Test TGB-3, the resultant dummy thorax acceleration exceeded 60G for 22 msec.

These measures, along with the overall observation of the extent of damage to the automobile, confirm that the impact was not survivable.

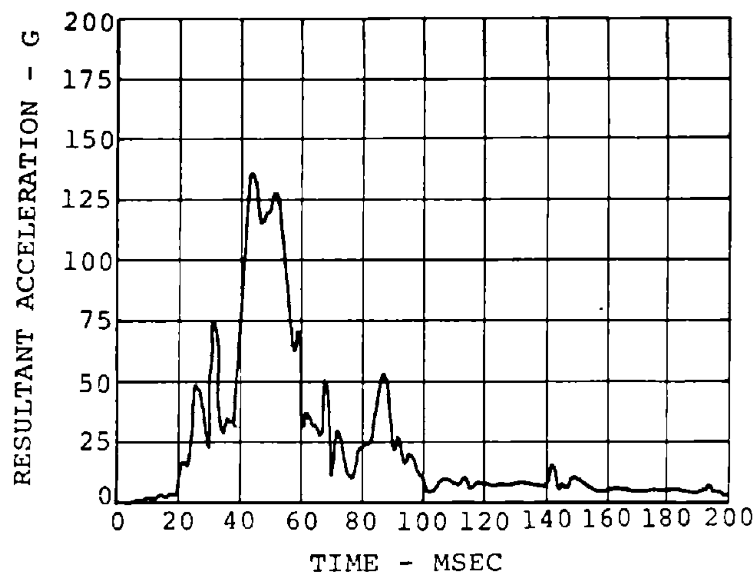


Figure 50. Thorax Acceleration During Test TGB-3.

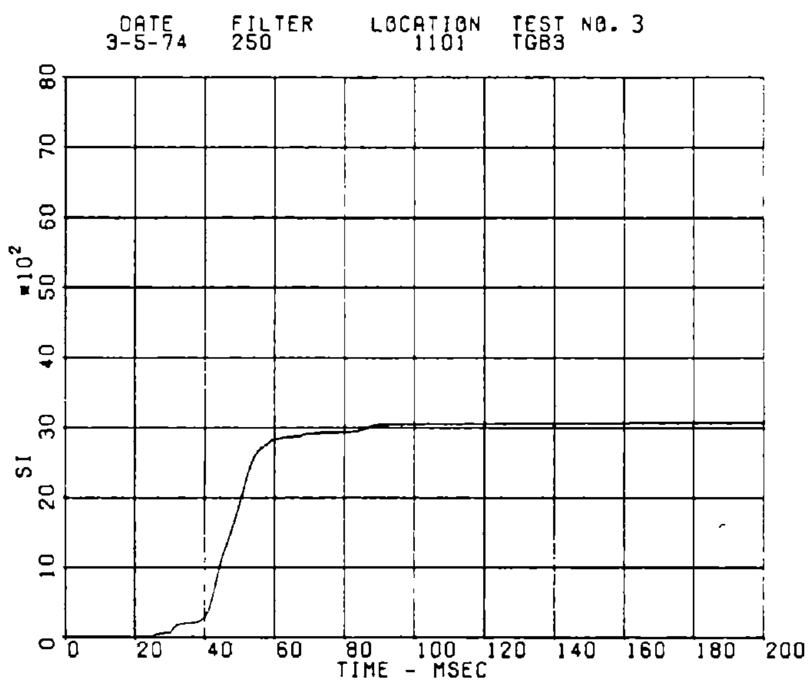


Figure 51. Severity Index for Dummy Thorax During Test TGB-3.

5.4 FOURTH LOCOMOTIVE-TO-AUTOMOBILE IMPACT TEST (TGB-4)

The fourth and final remote controlled impact test was conducted as follows:

Test Date:	March 6, 1974
Test Automobile:	1973 standard-size 4-door sedan
Automobile Test Weight:	4,666 Pounds
Test Locomotive:	130-ton Alco
Locomotive Impact Speed:	49.2 mph
Automobile Impact Area:	Left front fender
Weather:	Clear
Track Condition:	Clear and dry

The configuration for Test TGB-4 was identical to that for Test TGB-2 and the damage and post-test dynamics were basically the same. After impact, the automobile rotated into the locomotive. The left rear fender of the automobile struck the locomotive bearing box. The automobile was thrown free of the locomotive, turned right, rolled, and yawed until it ended up on its wheels about 90 feet down the track and approximately 35 feet north of the northernmost rail. The automobile's final orientation was pointed up the track. It rolled an additional 90 degrees (as compared to Test TGB-2 where it remained on its right side), but the post-test locations and orientations were otherwise very nearly the same.

Table 17 is the sequence of events from Test TGB-4 as obtained from an analysis of the high-speed film. Table 18 lists the significant damage noted after the test. Table 19 summarizes the deformation obtained by making pre- and post-test measurements between selected points on the automobile structure. Table 20 lists the significant debris along with the distance from the impact point and the distance from the northernmost rail.

TABLE 17. SEQUENCE OF EVENTS DURING TEST TGB-4

Time (msec)	Event
14	Coupler contacts hood
27	Driver's window breaks
28	Dummy right arm begins to rotate upward and rearward
30	Locomotive front plate contacts left front door
31	Locomotive front plate contacts front bumper
31	Panel under dash comes loose
35	Left lower corner of front windshield breaks
38	Left front door begins to open
40	Left rear door buckles open at top
44	Dash begins to crush
54	A post contacts steering wheel
57	Front seat begins rearward rotation as dummy torso moves back toward rear window
82	Dummy head passes through rear door window
148	Right front wheel dips between rails
162	Automobile is free of coupler
162	Left front fender and left side of hood begin to rotate away from firewall
189	Right front wheel is on top of north rail
234	Automobile is free of front plate of locomotive
269	Rear of automobile impacts side of locomotive
285	Automobile is approximately parallel to track
775	Automobile is approximately perpendicular to track and facing away from track
1558	Automobile is facing up the track on left (driver's side)
1900	Automobile is on roof, facing up track
2600	Automobile on right (passenger) side, facing up track
3875	Automobile is on wheels, facing up track

TABLE 18. SIGNIFICANT DAMAGE OBSERVED AFTER TEST TGB-4
Windshield was ripped out except on right side
Right rear fender was deformed to left, dented in rear
Dummy head had hit top rear side of B post, probably broke rear window
Rear seat pan had buckled up in center
Front seat pan had buckled up - tunnel collapsed
A post on driver's side had caved in
Rear window was broken
Right rear window was okay
Left rear fender had bent extensively
Trunk lid had opened
Left rear fender was crushed into left rear tire (flat)
Driver's door latch was broken
Left front fender was detached
Left side of hood was detached
Left side door was crushed
Trunk floor had buckled
Left rocker cover was crushed and head cracked on automobile engine
Brake master cylinder was bent, cap missing
Right rear door could be opened
Brake valve was broken off front of locomotive
Wheel had impacted below coupler
Bumper had impacted 33 inches to left of coupler
Locomotive first axle box was dented, minor
Locomotive second axle box was heavily dented
Locomotive brake cylinder had automobile paint on it

Figures 52 and 53 are pre-test overall and overhead views of the test configuration for Test TGB-4.

Figures 54 and 55 are the post-test views of the left and right side of the automobiles, respectively.

TABLE 19. TEST TGB-4 PERMANENT DEFORMATIONS	
Measurement	Deformation (in.)
Between bottom of A* posts	17.0
Between top of A posts	18.1
Between top of B posts	5.0
Between center of B posts	1.5
Between lower front rocker panels	9.5
Between C Posts	12.5
*See Figure 10 for definitions of A, B, and C posts.	

TABLE 20. LOCATION OF DEBRIS (TEST TGB-4)			
Part	Station Distance From Impact	Distance from North Rail	Direction
Hubcap	37 ft 5 in.	28 ft 9 in.	North
Windshield wiper	51 ft 2 in.	18 ft 8 in.	North
Drive shaft	55 ft 4 in.	17 ft 8 in.	North
Grill piece	74 ft 4 in.	34 ft 9 in.	North
Battery	79 ft 2 in.	31 ft 9 in.	North
Automobile	90 ft 2 in.	34 ft 6 in.	North
Hubcap	91 ft 10 in.	17 ft 6 in.	North
Hubcap	112 ft 6 in.	4 ft 3 in.	South

Figure 56 shows the post-test impact point. The coupler contacted the engine head, resulting in a crack in the head.

Figure 57 is a post-test view of the dummy after Test TGB-4. The dummy head touched the window header above the rear door window.

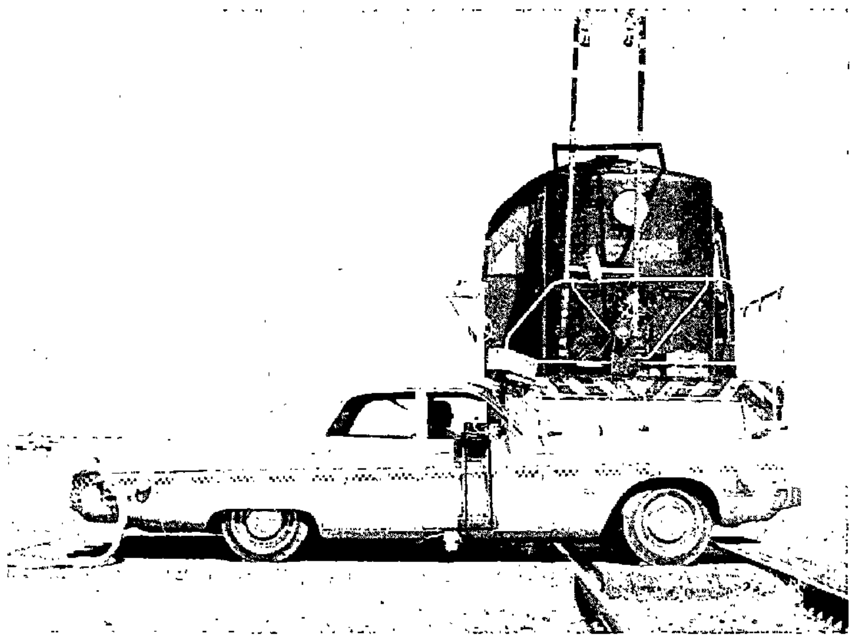


Figure 52. Pre-test View of Locomotive and Automobile (Test TGB-4).

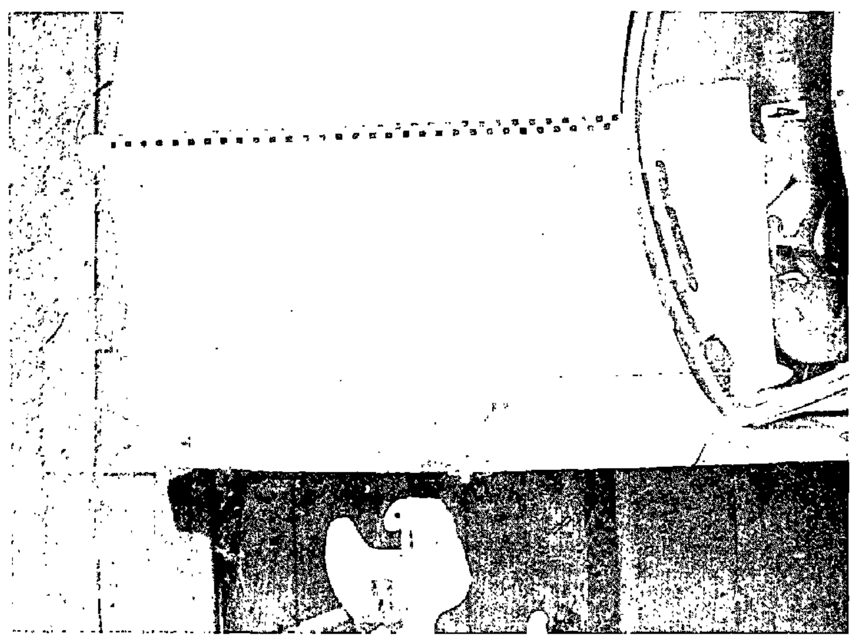


Figure 53. Pre-test Overhead View of Impact Area (Test TGB-4).

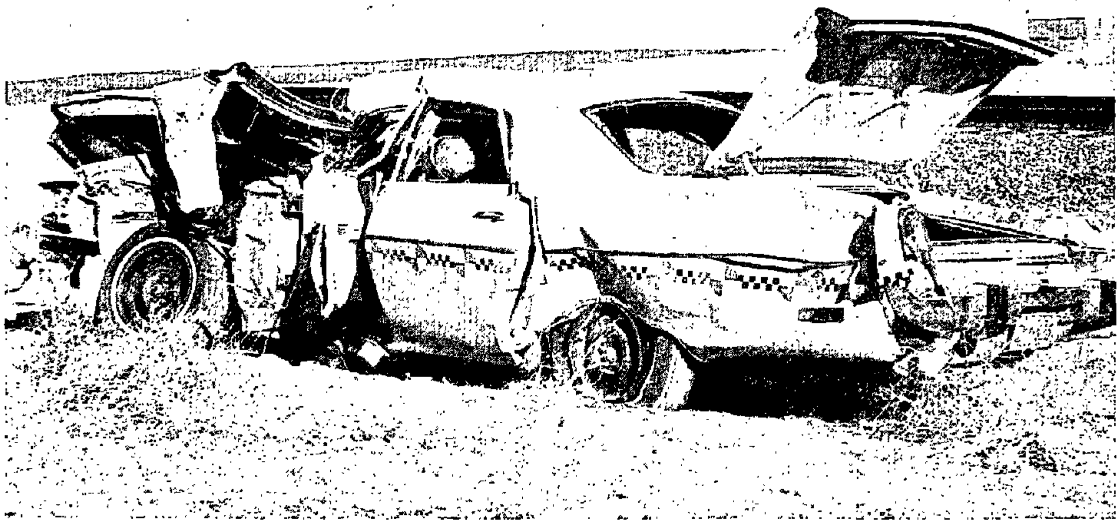


Figure 54. Post-test View of the Left Side of the Automobile (Test TGB-4).

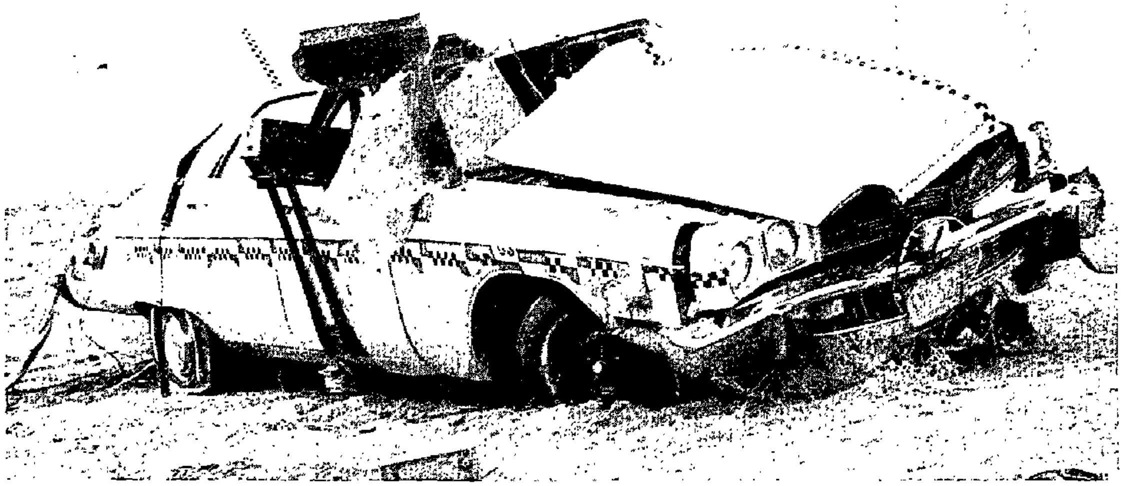


Figure 55. Post-test View of the Right Side of the Automobile (Test TGB-4).

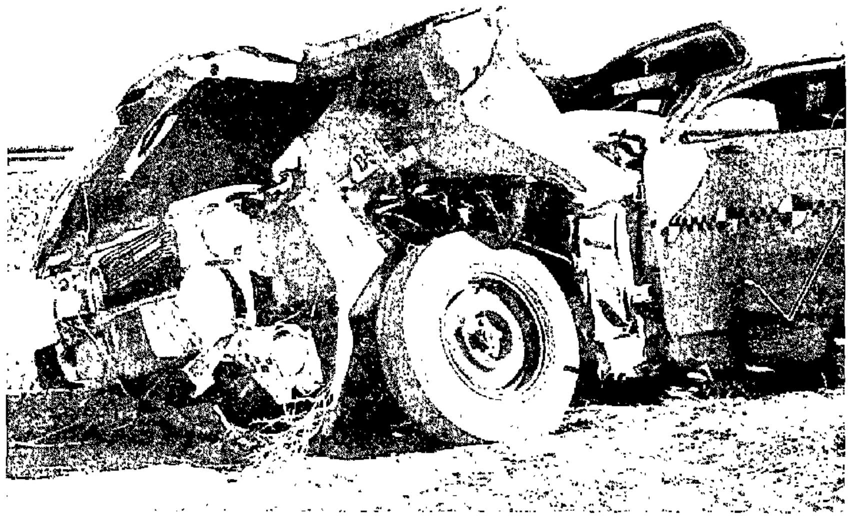


Figure 56. Post-test View of Impact Area (Test TGB-4).

Figure 57. Post-test View of the Dummy (Test TGB-4).

The front of the locomotive was undamaged except for broken brake pipes, as can be seen in Figure 58, which also shows the imprint of the left front wheel on the front face.

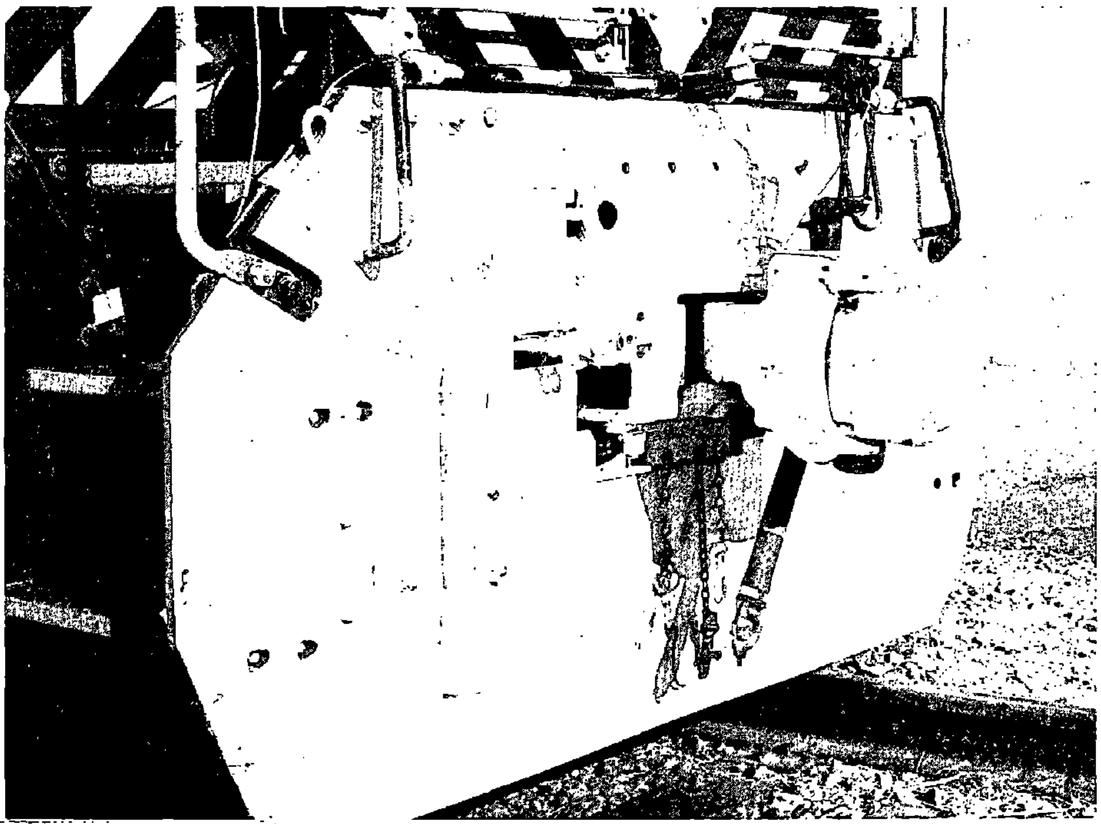


Figure 58. Post-test View of Locomotive Front Plate (Test TGB-4).

The left rear fender impacted the axle box on the locomotive, causing damage shown in Figure 59. The cut cable seen in the upper right corner of Figure 59 caused the loss of speed indication after impact. One of the locomotive steps was also damaged slightly during the impact.

Both the automobile and the locomotive contained an array of accelerometers for Tests TGB-3 and TGB-4. The accelerometers

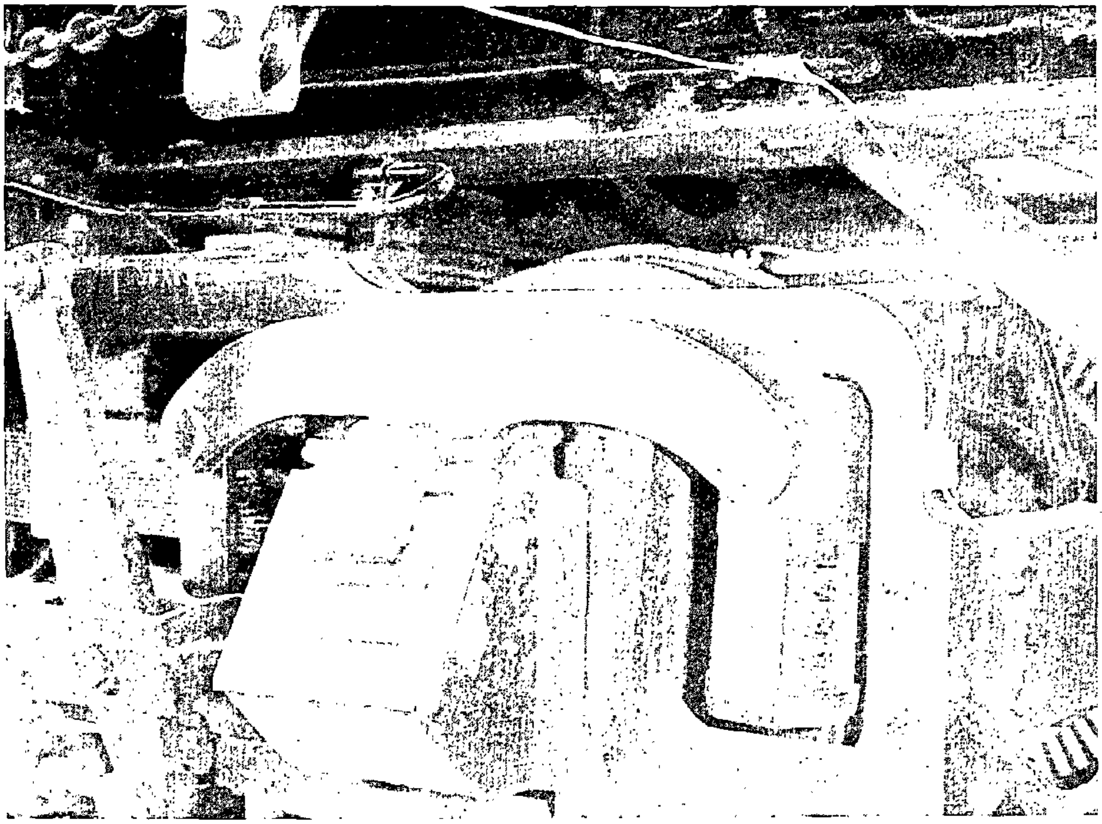


Figure 59. Post-test View of Damage to Locomotive (Test TGB-4).

on the locomotive front plate were changed from one end of the locomotive to the other since the impact direction was reversed between Tests TGB-3 and TGB-4. A description of the instrument locations on both the automobile and locomotive are presented in Sections A.2 and A.3 of the Appendix. A complete set of acceleration time records, is presented in Sections A.4 and A.5 of the Appendix.

During Test TGB-4, the event (or the time during which high accelerations were experienced) was typically over by 100 msec after impact for the structural data--depending upon where the instruments were located within the structure. The location of the impact point on the automobile (forward of the center of mass) caused the automobile to have a large rotational acceleration as well as a translational acceleration. This large rotational acceleration caused locations near the rear of the automobile to have a net acceleration in a direction opposite to the motion of the locomotive. Figure 60 shows the rear bumper lateral acceleration, which emphasizes this change in direction of the acceleration of the rear portion of the automobile. Table 21 summarizes the peak lateral accelerations at each location within the automobile with the time at which they occurred. Table 21 also presents estimates of the duration of the significant accelerations and the time after impact when the significant accelerations ended. Figure 61 is a schematic of the automobile with the peak accelerations and the time at which they occurred superimposed on the diagram of the automobile.

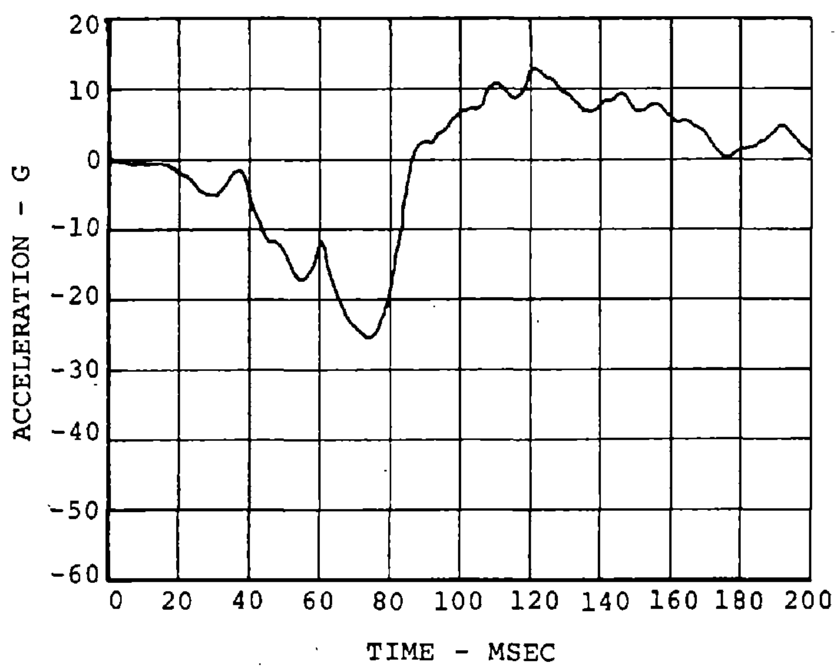


Figure 60. Lateral Acceleration of Rear Bumper (Test TGB-4).

TABLE 21. SUMMARY OF PEAK LATERAL AUTOMOBILE ACCELERATIONS FROM TEST TGB-4

Number	Location Description	Peak Acceleration (G)	Time Peak Occurred (G)	Duration Of Pulse (msec)	Approximate End of Event (msec)
1	Engine	117.1	47	-	-
2	Right Front Occupant Compartment	77.1	51	50	83
3	Left Front Occupant Compartment	89.7	51	30	80
4	Right Rear Occupant Compartment	43.1	53	70	100
5	Left Rear Occupant Compartment	70.6	45	50	80
6	Axle	20.2	66	70	110
7	Front Bumper	74.7	37	30	135
8	Rear Bumper	-26.0	74	60	90
9	Firewall	100.6	48	53	-
10	Left Rocker Panel	56.4	50	38	80
11	Right B Post	78.5	56	65	100
12	Left B Post	91.1	39	50	80
13	Right Front Fender	98.6	47	40	83
14	Right Front Frame	149.7	41	30	83
15	Right Rocker Panel	71.1	51	70	100
16	Right Rear Fender	-14.2	77	60	120
17	Right Rear Frame	-8.2	62	60	100

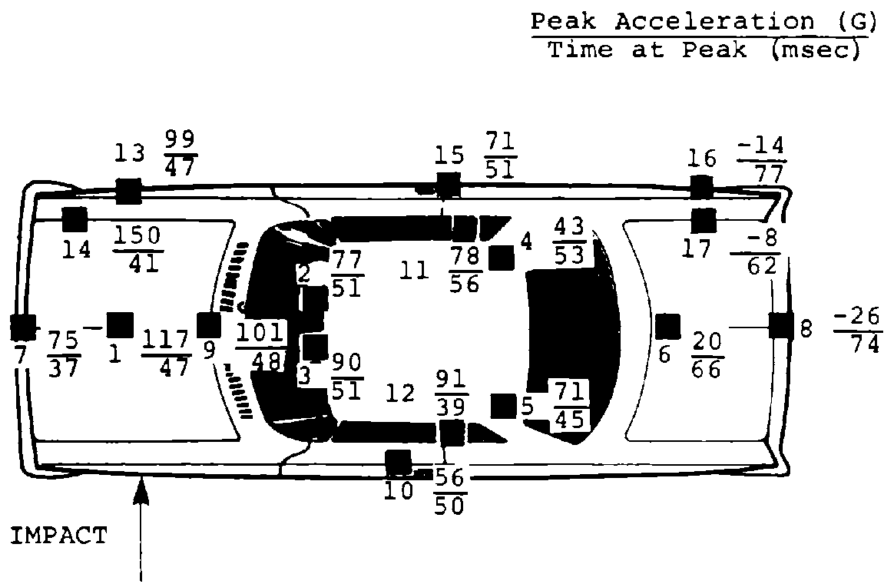


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Figure 61. Schematic Presentation of Peak Lateral Accelerations Along With the Time at Which the Peak Occurred for Test TGB-4.

Due to the nonrigid-body behavior of the structure and the large angular rotations, there is no one representative acceleration characteristic of the automobile or occupant compartment.

Figures 62 and 63 superimpose the front occupant compartment and rear occupant floor acceleration during Test TGB-4. The locations nearest the impact point (3 and 5) experienced a higher peak acceleration which also occurred sooner in time than at the locations more remote from the impact point. The locomotive accelerations were considerably lower than the automobile acceleration (on the order of 3G). Table 22 summarizes the peak accelerations for the instruments located on the locomotive.

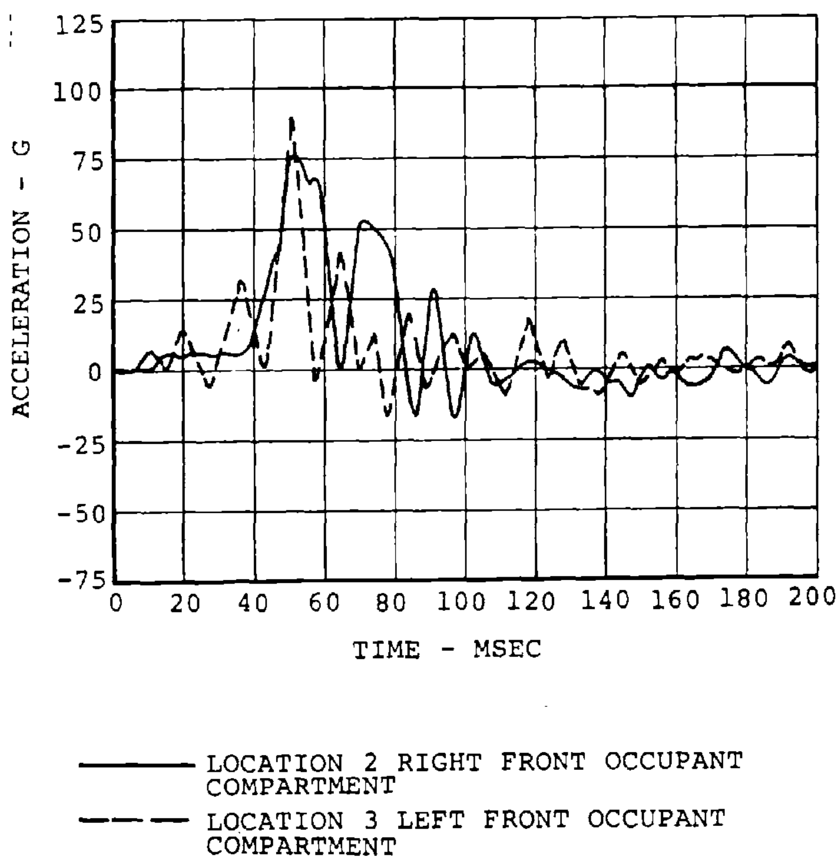


Figure 62. Comparison of Front Occupant Compartment Accelerations (Test TGB-4).

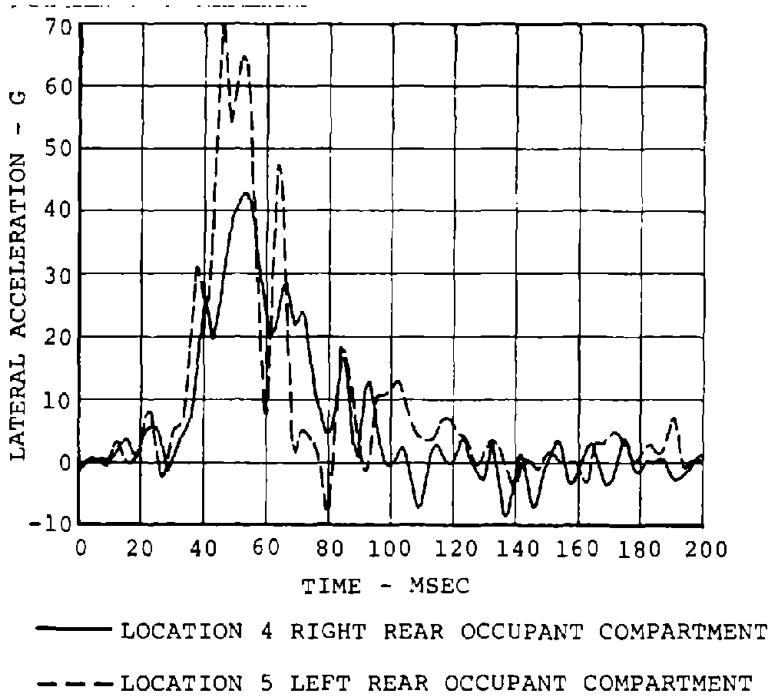


Figure 63. Comparison of Rear Occupant Compartment Accelerations (Test TGB-4).

TABLE 22. SUMMARY OF PEAK LOCOMOTIVE LONGITUDINAL ACCELERATIONS DURING TEST TGB-4

Location		Peak Acceleration (G)	Time of Peak (msec)	Duration of Pulse (msec)
Number	Description			
101	Cab Floor	3.4	54	6
102	Front Platform	1.5	42	10
103B	Right Front Plate	-38.5*	44	10
104B	Center Front Plate	-11.4	46	6
105B	Left Front Plate	-31.1	57	7

*Negative acceleration indicates an acceleration of the location on the locomotive toward the automobile.

Figure 64 shows the longitudinal accelerations of the accelerometers superimposed on the front plate of the locomotive during Test TGB-4. The acceleration at Location 104B had a lower peak than the accelerations at Locations 103B and 105B since the accelerometer was attached to the massive support structure of the coupler.

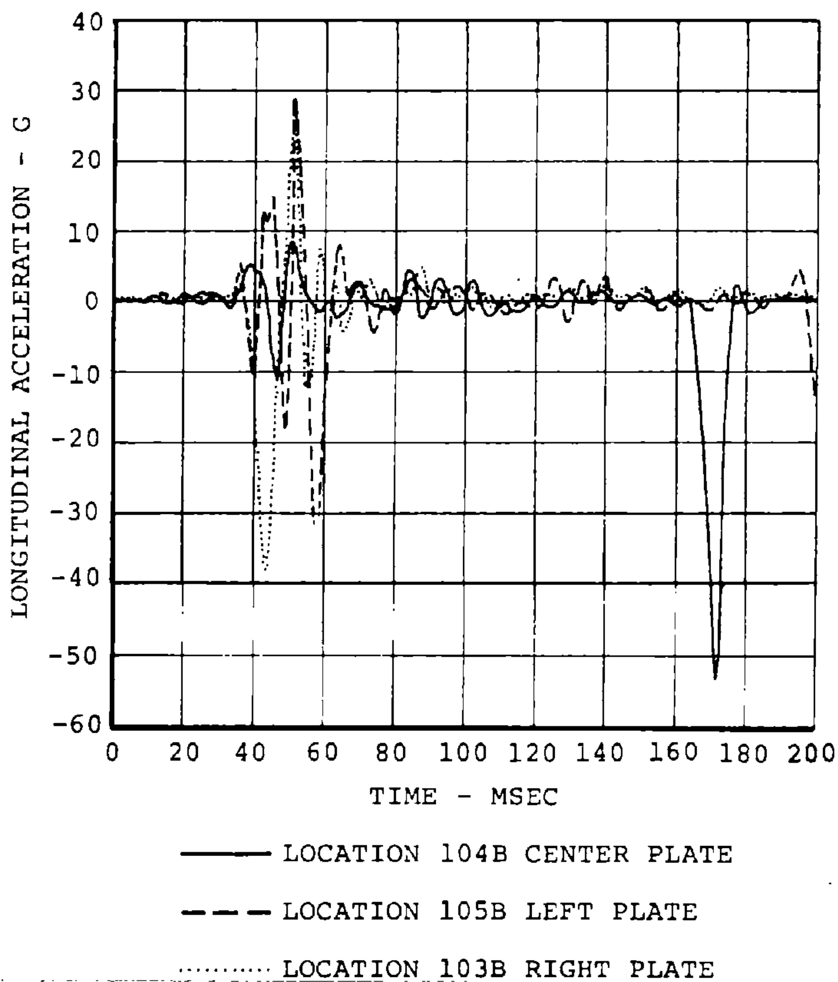


Figure 64. Comparison of Longitudinal Accelerations on Front Plate of Locomotive (Test TGB-4).

The high amplitude vibration (between 40 and 60 msec) of the front plate occurs when the automobile structure is in contact with the locomotive. The automobile also experiences a high acceleration during this time. Since the locomotive did not sustain any significant deformation and did not experience any significant change in velocity, the majority of the acceleration seen on the front plate is simply a vibration, which explains both a positive and negative acceleration. The large negative spike in Location 104 near 170 msec coincides in time with the automobile pulling free of the locomotive coupler and probably represents the force required to detach the automobile from the locomotive.

Figure 65 compares the acceleration at Location 104 (on the center of the locomotive front plate) with the accelerations of the occupant compartment. As anticipated, maximum peaks in both the locomotive and automobile curves occur close to the same time.

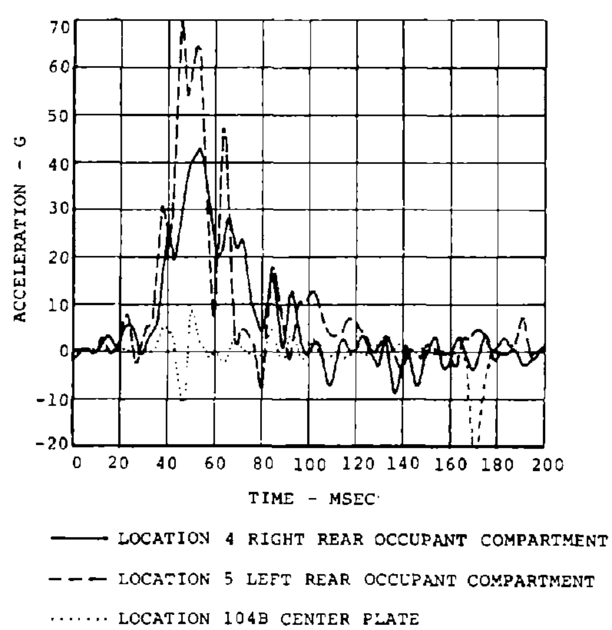


Figure 65. Comparison of Occupant Compartment Accelerations With Locomotive Center Front Plate Acceleration (Test TGB-4).

The lateral accelerometer data on the automobile and the longitudinal accelerometer data on the locomotive has been integrated to yield a calculated velocity. As discussed in Section 5.3, angular displacements of the accelerometer introduce errors in the calculation of velocity from the accelerometers. Since the entire automobile eventually rotated during Test TGB-4, errors in the integrated velocity can be expected in varying degrees as the vehicle is accelerated. Table 23 is a summary of the calculated lateral automobile and longitudinal locomotive velocity in increments of 20 msec. Some instrument locations near the rear of the automobile actually accelerated up the track and had a negative velocity during the initial portion of the impact, as can be seen by Locations 8, 12, 16, and 17. Some parts of the automobile actually bounced away from the locomotive at 160 msec when the automobile was rotating away from the coupler, and had a velocity greater than the locomotive, as can be seen from Instrument Locations 13 and 14.

The initial locomotive speed was 72.2 feet per second and from the two Locomotive Accelerometer Locations 101 and 102, the change in locomotive speed at 160 msec was 1.8 feet-per-second or 1.2 mph.

The occupant accelerations are of utmost concern since they are the most direct indication of impact severity. The anthropomorphic dummy in the driver location represents a human occupant. Figure 66 is the time history of the dummy head resultant acceleration. The maximum acceleration of 141.2G occurred 96 msec after initial impact. The SI and HIC injury criteria were defined in Section 5.3. For Test TGB-4, the head SI exceeded 1000 at 90 msec and reached 3121 by the end of the event (200 msec). A plot of the head SI versus time for this test is shown in Figure 67.

The HIC was computed to be 2142 for this test.

The resultant thorax acceleration is presented in Figure 68. The injury criterion for the thorax is also summarized in Section

Location	Time (msec)							
	20	40	60	80	100	120	140	160
1	-0.1	3.0	62.7	*	*	*	*	*
2	1.6	5.9	42.5	63.9	65.6	66.7	65.0	62.4
3	1.4	9.4	30.8	37.35	41.8	42.8	42.2	41.4
4	0.6	4.8	25.8	37.9	42.5	41.8	40.9	39.7
5	0.4	7.2	37.1	45.0	50.1	54.5	55.4	-
6	0.2	0.4	4.4	15.9	23.0	23.4	24.3	26.6
7	0.4	12.7	14.3	13.1	31.8	47.1	48.9	44.0
8	-0.6	-3.1	-11.9	-25.9	-26.4	-20.4	-14.6	-9.6
9	2.0	6.3	32.9	*	*	*	*	*
10	1.5	11.8	48.1	60.5	65.3	66.9	67.4	66.9
11	0.5	3.8	25.4	35.5	43.0	42.1	38.9	35.0
12	-0.1	-13.0	-36.6	-53.6	-58.8	-66.4	-68.4	-65.6
13	2.5	11.6	51.0	82.2	77.7	77.8	79.5	75.6
14	1.0	13.5	56.7	67.2	73.2	78.8	77.8	81.6
15	0.8	5.2	32.1	44.7	49.4	47.6	44.7	41.4
16	-0.1	-1.1	-2.9	-9.1	-13.3	-14.7	-14.6	-15.1
17	-0.2	-1.6	-2.4	-5.5	-6.7	-6.1	-5.0	-4.2
Train TGB-4								
101	71.9	71.6	71.2	71.1	70.8	70.7	70.4	70.3
102	71.9	71.7	71.3	71.1	71.0	71.1	70.7	70.5
103B	72.4	72.5	69.3	69.4	70.3	70.6	71.3	71.9
104B	71.9	71.0	70.9	70.9	70.3	70.5	70.2	70.1
105B	72.0	72.3	72.5	71.9	71.3	71.6	71.1	71.0

*Questionable data at these points due to either cut cables or instrument damage.

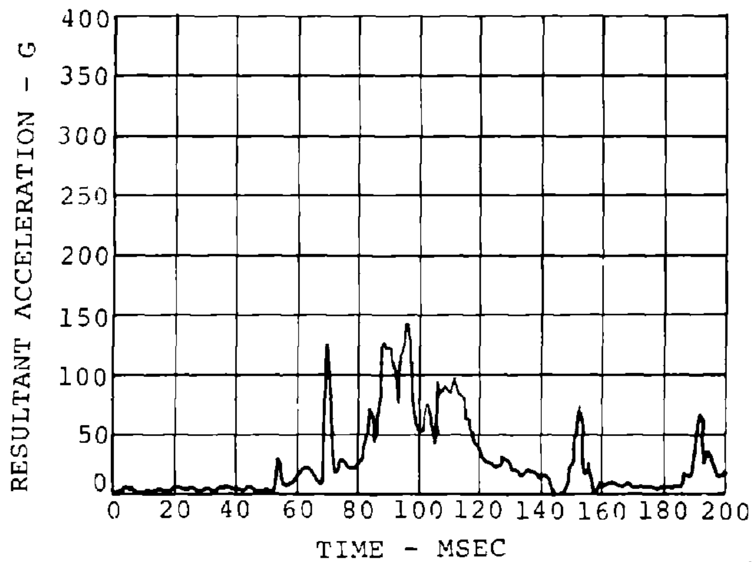


Figure 66. Resultant Head Acceleration (Test TGB-4).

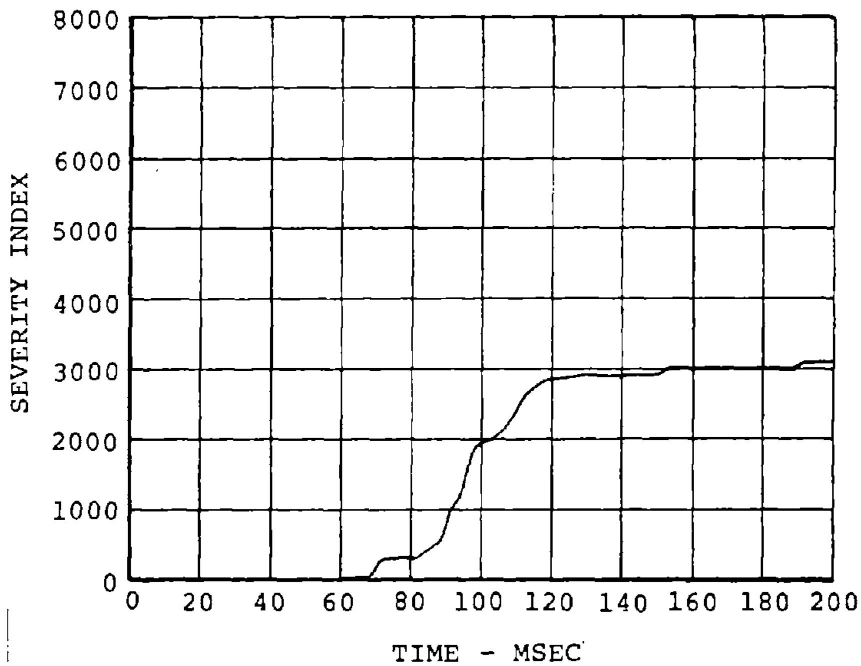


Figure 67. Severity Index for Dummy Head (Test TGB-4).

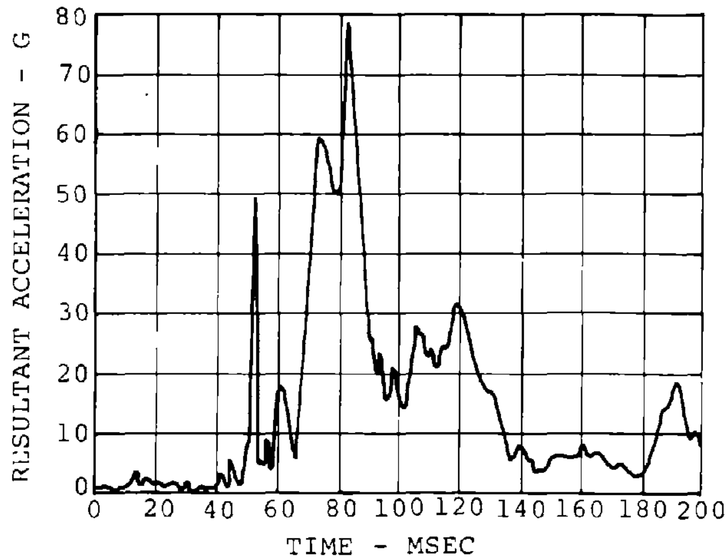


Figure 68. Resultant Thorax Acceleration (Test TGB-4).

5.3. The thorax had a maximum resultant acceleration of 79.4G 80 msec after impact. The thorax acceleration exceeded 60G for a total of 6 msec. Figure 69 is a plot of thorax severity index versus time. For this test, the thorax severity index was only 640.

Observation of the damage to the automobile along with the high values of the injury criteria substantiate that the impact of Test TGB-4 would have been lethal for a human occupant.

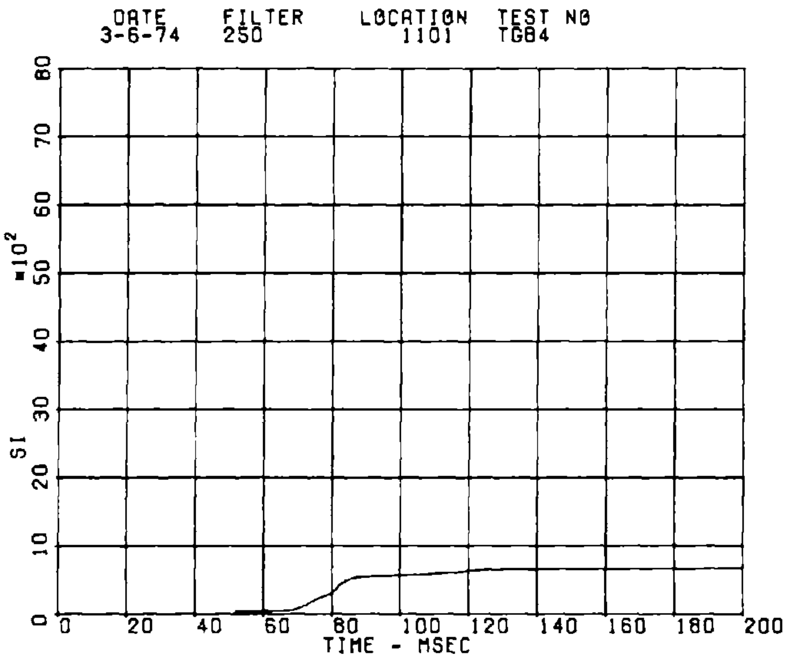


Figure 69. Thorax Severity Index Versus Time.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The basic objective of this effort is to provide baseline locomotive-to-automobile impact data. These data will be utilized in the planning of future crashworthiness efforts such as the determination of the effectiveness of locomotive attenuator devices.

This section will address the question of test repeatability by comparing tests with the same configuration.

A summary of the severity of the test will also be presented along with some general requirements for reducing the severity of the locomotive-to-automobile impact.

6.1 CONCLUSIONS

6.1.1 Repeatability of Locomotive-to-Automobile Impacts

Since Tests TGB-3 and TGB-4 were essentially repeats of tests TGB-1 and TGB-2, respectively, a comparison can be made between the similar tests to quantify the variation in test results when test items and test conditions are as similar as possible.

Tables 24 and 25, respectively, compare test conditions for the direct side (Tests TGB-1 and TGB-3) and the offset side (Tests TGB-2 and TGB-4) impacts.

All four automobiles were of the same year, make, model, engine, and transmission.

In both cases, the second automobile weighed approximately 600 pounds more than the first as a result of the addition of the simulated occupant and other instrumentation. The test velocities for all four tests were within the target tolerance of 50 ±2 mph.

6.1.1.1 Comparison of Tests TGB-1 and TGB-3

In the first test (TGB-1), the locomotive front plate suffered permanent deformation (see Section 5.1). Subsequently, a

TABLE 24. COMPARISON BETWEEN TEST CONDITIONS FOR DIRECT SIDE LOCOMOTIVE-TO-AUTOMOBILE

	Test TGB-1	Test TGB-3
Test Automobile	1973 standard-size 4-door sedan	1973 standard-size 4-door sedan
Test Weight	4,074 lb	4,693 lb
Locomotive Impact Speed	51.9 mph	49.1 mph
Dummy Occupant	No dummy	Driver anthropomorphic dummy
Structural Instrumentation	No instrumentation	17 automobile and 4 locomotive instrument locations (accelerometers)
Rigid Locomotive Front Plates	Front plate installed	Plate stiffened since Test TGB-1
Test Locomotive	130-ton Alco Number 8670	130-ton Alco Number 8670
Locomotive Orientation	Long end leading	Long end leading
Coupler Configuration	Centered straight ahead	Centered straight ahead
Automobile Impact Area	Left front door	Left front door
Track Condition	Clear and dry	Clear and dry
Weather	Clear	Clear
Test Date	February 12, 1973	March 5, 1973

heavier front plate with better support was designed and installed. No significant permanent deformation of the locomotive front plate was experienced after the first test.

The structural damage to the automobile was very similar between Tests TGB-1 and TGB-3, with minor variations as follows:

TABLE 25. COMPARISON BETWEEN TEST CONDITIONS FOR OFFSET LOCOMOTIVE-TO-AUTOMOBILE

	Test TGB-2	Test TGB-4
Test Automobile	1973 standard-size 4-door sedan	1973 standard-size 4-door sedan
Test Weight	4,065 lb	4,666 lb
Locomotive Impact Speed	51.0 mph	49.2 mph
Dummy Occupant	No dummy	Driver anthropomorphic dummy
Structural Instrumentation	No instrumentation	17 automobile and 4 locomotive instrument locations
Rigid Locomotive Front Plate	Rigid front plate	Rigid front plate
Test Locomotive	130-ton Alco Number 8670	130-ton Alco Number 8670
Locomotive Orientation	Cab end leading	Cab end leading
Coupler Configuration	Centered straight ahead	Centered straight ahead
Automobile Impact Area	Left front fender	Left front fender
Track Condition	Clear and dry	Clear and dry
Weather	Clear	Clear
Test Date	February 15, 1973	March 6, 1973

- The windshield came completely out during Test TGB-1 but not during Test TGB-3
- The B post was inside the jaws of the coupler after Test TGB-3 but was in front of coupler after Test TGB-1
- The right rear fender tore adjacent to the door opening during Test TGB-3 but not during Test TGB-1

- One stub frame mount remained attached after Test TGB-3, but the frame was completely detached after Test TGB-1

- The front plate on the locomotive deformed during Test TGB-1, but, due to stiffening, remained undeformed after Test TGB-3.

Permanent deformations were quantified by measuring between two points on the automobile both before and after impact. Table 26 is a comparison of comparable measurements between Tests TGB-1 and TGB-3. Deformations for Test TGB-1 are seen to be consistently higher than for TGB-3. This is due in part to the higher speed and therefore the higher exchange of energy for Test TGB-1. During Test TGB-1, the front plate of the locomotive yielded on the edges, which possibly allowed further penetration of the coupler at the center of the automobile.

TABLE 26. COMPARISON OF PERMANENT DEFORMATIONS BETWEEN TEST TGB-1 AND TEST TGB-3

Measurement	Deformation* - in.		
	Test TGB-1	Test TBG-3	Difference
Between top of B posts	28.3	21.5	6.8
Between center of B posts	37.3	29.8	7.5
Between bottom of C posts	19.0**	-	-
Between front window sills	27.6	23.3	4.4
Between rear window sills	39.4	31.3	8.1
Between C posts	14.4	13.9	0.5
Between top A posts	22.5	17.4	5.1
Steering wheel to left door	7.5	5.6	1.9
Steering wheel to right door	16.9	20.9	4.0
Engine to right fender	-8.0*	-16.4	8.4
Engine to left fender	5.8	5.9	0.1

*Negative number indicates an increase.
**Estimated.

The sequence of events obtained from the film analysis points out various events for each impact. The following common events were observed for both Tests TGB-1 and TGB-3 at times that differed as noted.

- Rear door window on driver's side broke at same time
- Front door window on driver's side broke within 1 msec
- Rear window broke within 3 msec
- Front plate of locomotive contacted car within 4 msec
- Recognition of shearing of trunk was noted within 6 msec
- Front seat buckled at same time
- Rear window sill and sill level of B post deflected at same time
- Buckle formed in roof above B post within 2 msec
- Windshields broke at same time
- Trunk lid buckled open within 4 msec
- Right front fender separation recognized within 6 msec.

Some of the events described in the sequence of events (see Tables 2 and 10) are defined in a subjective manner since many of the events do not happen abruptly and precise definition of the start of the event is difficult.

The two tests were similar in that the automobiles remained in contact with the front of the locomotive and the front section of the automobile rotated approximately 90 degrees with respect to the rear of the automobile.

6.1.1.2 Comparison of Tests TGB-2 and TGB-4

The trajectories of the automobiles after impact were very similar with the exception of an additional 90-degree roll at the end of the travel for Test TGB-4. The overall appearance of the two test automobiles was very similar.

Permanent deformation between comparable points on automobiles involved in Tests TGB-2 and TGB-4 is compared in Table 27.

TABLE 27. COMPARISON OF PERMANENT DEFORMATIONS BETWEEN TESTS TGB-2 AND TGB-4

Measurement	Deformation (in.)		
	Test TGB-2	Test TGB-4	Difference
Between bottom A posts*	19.0	17.0	2.0
Between top A posts	7.5	18.1	10.6
Between top of B posts*	5.0	5.0	0.0
Between center B posts	5.9	1.5	4.4
Between lower front rocker panels	21.0	9.5	11.5
Between C posts*	1.0	12.5	11.5

*See Figure 10 for definition of A, B, and C posts.

The deflections as tabulated are not consistently greater for one automobile or the other. For some of the points chosen, as, for example, between the upper B post and lower A post, the changes were small. For the other locations the differences of displacement are significant. The additional 90-degree roll of the automobile, as well as the addition of the reaction of the occupant and instrumentation, could help explain some of the variation experienced.

The following common events between Tests TGB-2 and TGB-4 were observed from the sequence analysis of the high-speed film:

- Locomotive front plate contacts left front door within 1 msec
- Locomotive front plate contacts front bumper within 1 msec
- Front windshield breaks within 1 msec
- Driver window breaks within 10 msec

- Automobile is observed parallel to track within 35 msec
- Left front fender and hood separated from firewall within 110 msec.

The comparison between similar tests showed that the overall performance of both automobiles was similar. Some variation did occur and the repetition of these tests gives an idea of the variance to be expected between similar test items. Contributions to the reasons for variance between similar tests include:

- Small variations in initial test conditions
- Variations in loading of automobile
- Variations in automobile structure even though they were manufactured by the same company and the automobiles are of the same model.

These comparisons should prove valuable later when comparing test results with the baseline test results. These two data points can give an idea of the confidence level to be expected from one automobile to another.

6.1.2 Severity of Tests

As discussed in Sections 5.3 and 5.4, each of the impacts was severe enough to be almost certainly fatal. The severity index, as defined in Section 5.3, must remain below 1000 for both the head and thorax of the dummy in order for the impact to be considered survivable. In addition, the HIC must remain below 1000 for the dummy head, and the thorax accelerations must not exceed 60G for more than a total of 3 msec.

Figure 70 compares the Severity Index for the dummy head between Tests TGB-3 and TGB-4. Figure 71 provides a comparison of the severity index for the thorax between Tests TGB-3 and TGB-4.

Table 28 summaries the Injury Criteria for Tests TGB-3 and TGB-4.

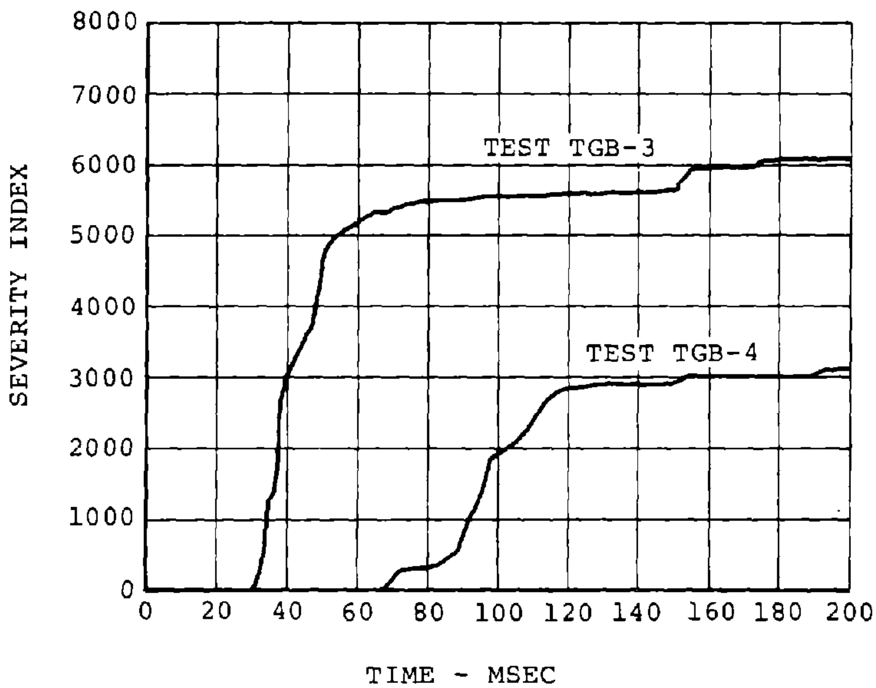


Figure 70. Comparison of Severity Index for Dummy Head Between Tests TGB-3 and TGB-4.

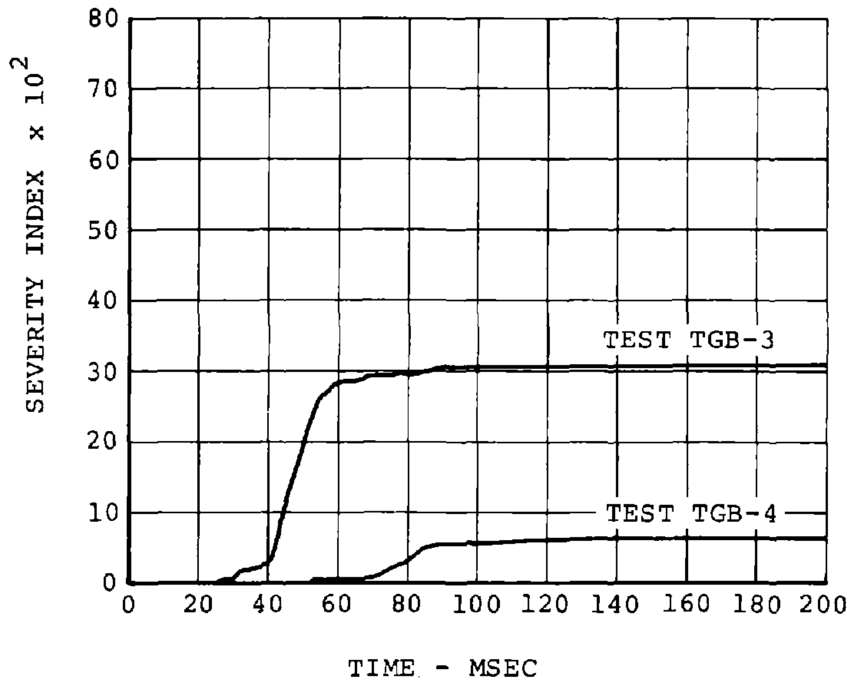


Figure 71. Comparison of Thorax Severity Index Between Tests TGB-3 and TGB-4.

TABLE 28. SUMMARY OF IMPACT SEVERITY FOR ANTHROPOMORPHIC DUMMIES DURING TESTS TGB-3 AND TGB-4		
	Test TGB-3	Test TGB-4
Head SI after 200 msec	6062	3121
Time at which head SI >1000	36 msec	90 msec
HIC	3821	2142
Thorax SI after 230 msec	3005	640
Time at which thorax SI >1000	45 msec	-
Time resultant thorax acceleration > 60G	22 msec	6 msec

This comparison points out that Test TGB-3 was more severe in all categories than Test TGB-4.

The obvious conclusion, based upon these data and reinforced by observation of the automobiles, is that each of these impacts probably would have been fatal.

6.2 RECOMMENDATIONS

The current effort summarized in this report serves to document the severity of the locomotive-to-automobile impact involving the full-size American-made automobile. Consideration must be given to reducing the severity of the impact. A generalized analytical computer simulation model should be developed to expand the results of this program to include consideration of various kinds of highway vehicles and locomotive structures.

Scale model testing can also provide valuable insight into collision dynamics and performance evaluation of modified locomotive structures. Care must be taken to ensure that the scale models retain the essential features of the full-scale model.

6.2.1 Impact Severity Reduction

Structural modification to either the locomotive or the automobile can reduce the severity of the impact. Improvements of restraint systems and structural strengths of the automobile have been investigated in recent years by the various automobile manufacturers and NHTSA. However, even with the proposed automobile improvements, significant changes must be implemented on the larger, stiffer locomotive in order to make the two structures more compatible during an impact.

The severity of the impact is a result of one or more of the following:

- Intrusion
- High forces
- Override or underride

The small cross section of the coupler and the relatively soft nature of the automobile caused a stress concentration high enough to cause significant intrusion of the coupler into the automobile. The modified front structure of the locomotive should present a large cross sectional area to the automobile in order to reduce the stress concentration caused by the coupler.

On impact, the automobile is accelerated from rest to the locomotive speed. In order to do this without generating high accelerations and high forces, adequate accelerating distance must be provided. The forces on the automobile during this acceleration must be limited so that the automobile structure is not significantly damaged, causing collapse of the structure and intrusion into the occupant space. The loads must also be kept below those levels causing lethal accelerations to occupants of the automobile.

This load limiting can be provided by a crushable or deformable structure or "shock absorber" on the front of the locomotive that will yield at a low force over a large enough distance to allow the automobile to achieve the locomotive velocity. Hydraulic cylinders, crushable plastic foams, paper or aluminum honeycomb, and elastomeric materials can all be adapted into a device which will attenuate the impact loads.

Once this device has been designed, care must be taken to ensure that the device will not buckle, override, or underride the automobile or that it will not present an inadequate cross-sectional area to the automobile.

6.2.2 Consideration of Other Highway Vehicles

In the design of a device to reduce the severity of an impact, care must be taken to consider the entire spectrum of highway vehicles. The design should accommodate as many different types of highway vehicles as possible. The vehicles of importance range from trucks and buses down to compact and subcompact automobiles.

The investigation of other types of vehicles can be accomplished in several ways, including additional baseline testing, scale model testing, analytical mathematical modeling, or a combination of these techniques.

APPENDIX A

TEST DATA SUMMARY

A.1 INTRODUCTION

The last two locomotive-to-automobile impact tests (TGB-3 and TGB-4) were a repeat of the first two (TGB-1 and TGB-2) with the addition of a dummy in the automobile and accelerometers mounted in the dummy and on the locomotive and automobile structures in Tests TGB-3 and TGB-4. This appendix describes the locations of the accelerometers and presents a complete set of time histories of the data.

All data processing was performed in accordance with SAE Recommended Practice J211a, entitled "Instrumentation for Impact Tests." The data are presented in the form of Calcomp plots. Two filtering frequencies were used to generate each plot. They are listed in each plot in the following manner:

- The first number denotes the cutoff frequency of the presampling analog filter (the 3-dB point).

If the analog data are not low-pass filtered to eliminate the frequencies down to about one-half of the sample rate or lower, the higher frequencies may appear as an aliasing* error. For instance, if a high frequency component occurs in the data which is exactly five times the sample rate, the sample will be taken at the same amplitude, but on every fifth cycle. The digitized data will show this frequency as a constant DC level instead of varying at a high frequency. High frequency components must be removed to ensure an accurate representation of the data in digital form. A data sample must be taken at least every half cycle to detect a component of that frequency. Further filtering to make the data more readable is accomplished by applying a digital filter to the digitized data.

*Bendat, J. S. and Piersol, A. G., "Measurement" and Analysis of Random Data, John Wiley and Sons, 1967.

- The second number is the frequency at the break point in the ideal digital filter applied to the data prior to plotting. After the break point, the data were attenuated at 12 dB/octave. The digital filter utilizes a fast Fourier transformation of the data into the frequency domain, followed by an attenuation of the higher frequencies and an inverse transformation back into the time domain.

A.2 INSTRUMENTATION LOCATIONS

The instrumentation placement falls into three categories as follows:

- Dummy instrumentation
- Locomotive instrumentation
- Automobile instrumentation

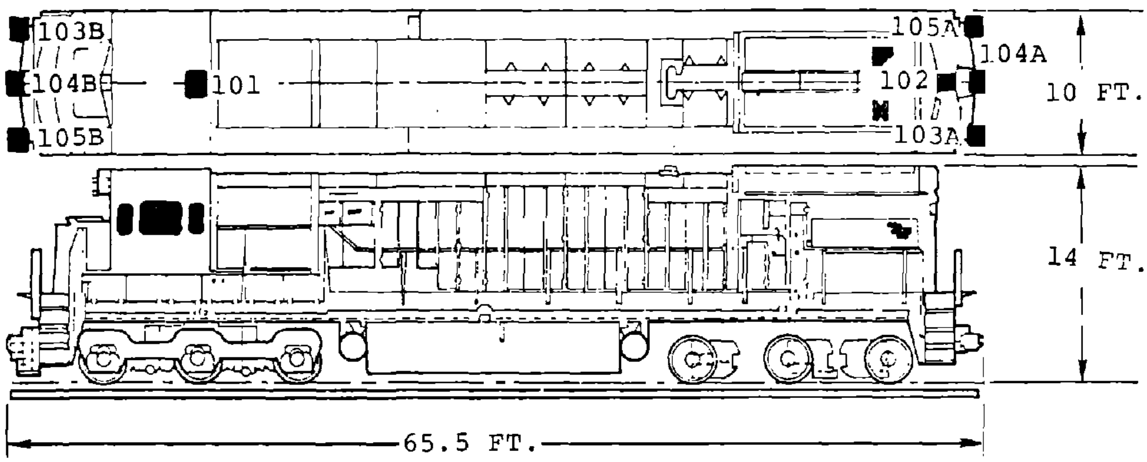
A.2.1 Dummy Instrumentation

Each of the instrumented automobiles contained one 50th percentile male dummy (VIP50). A 50th percentile male dummy represents a male that is larger and heavier than 50 percent of the male population. A triaxial set of accelerometers was mounted in each dummy head and thorax. The data from these instruments provide a basis for calculation injury criteria. The resultant acceleration time histories for the head and thorax of the dummies are presented with the structural data from each test.

A.2.2 Locomotive Instrumentation

The locomotive had an array of five accelerometer locations as shown schematically in Figure A-1. The triaxial accelerometer locations on the centerline of the cab floor and the front platform were the same for both impacts.

The remaining locations on the locomotive were on the right, center, and left sides of the front plate. The front plate is a 5/8-inch steel plate added to each end of the locomotive, as described in Section 3.4.1. Since the leading end of the locomotive was reversed from Test TGB-3 to Test TGB-4, the accelerometers were moved from one end of the locomotive to the other.



Instrument	Location	Direction
101	Cab Floor	Triaxial
102	Front Platform	Triaxial
103A and 103B	Right Side of Front Plate	Longitudinal
104A and 104B	Center of Front Plate	Longitudinal
105A and 105B	Left Side of Front Plate	Longitudinal
■ - Indicates location of accelerometers		

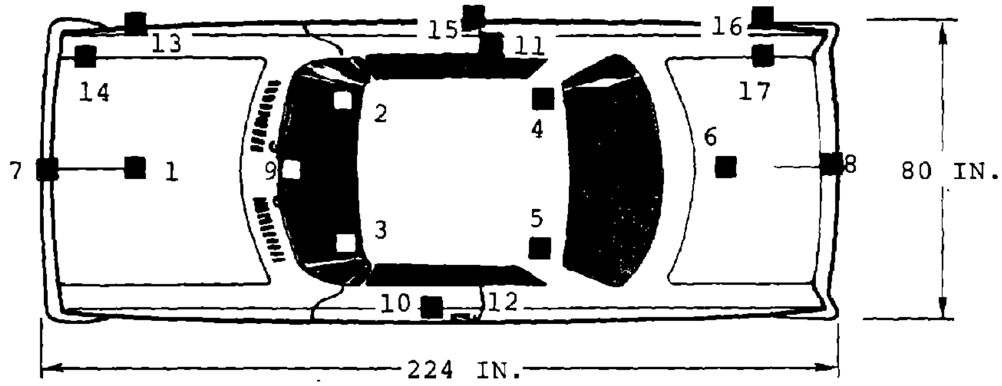
Figure A-1. Accelerometer Locations in Locomotive.

The acceleration time history for each accelerometer is presented in this appendix.

A.2.3 Automobile Instrumentation

Each of the instrumented automobiles had an array of 17 accelerometer locations as shown schematically in Figure A-2. Both automobiles used for Tests TGB-3 and TGB-4 were instrumented in the same manner.

■ - INDICATES LOCATION OF INSTRUMENTS



Instrument Location	Direction
1 - Engine	Triaxial
2 - Right Front Occupant Compartment	Triaxial
3 - Left Front Occupant Compartment	Triaxial
4 - Right Rear Occupant Compartment	Lateral
5 - Left Rear Occupant Compartment	Lateral
6 - Axle	Triaxial
7 - Front Bumper	Triaxial
8 - Rear Bumper	Triaxial
9 - Firewall	Triaxial
10 - Left Rocker Panel	Triaxial
11 - Right B Post	Triaxial
12 - Left B Post	Lateral
13 - Right Front Fender	Lateral
14 - Right Front Frame	Lateral
15 - Right Rocker Panel	Lateral
16 - Right Rear Fender	Lateral
17 - Right Rear Frame	Lateral

Figure A-2. Accelerometer Locations in Automobile.

A.3 INSTRUMENT SIGN CONVENTION

The positive sense for the data is defined by a coordinate system fixed to the automobile as shown in Figure A-3. A corresponding coordinate system is applied to the locomotive. The positive direction, with respect to the vehicle, is taken as forward, to the right, and down for the X, Y, and Z axes, respectively.

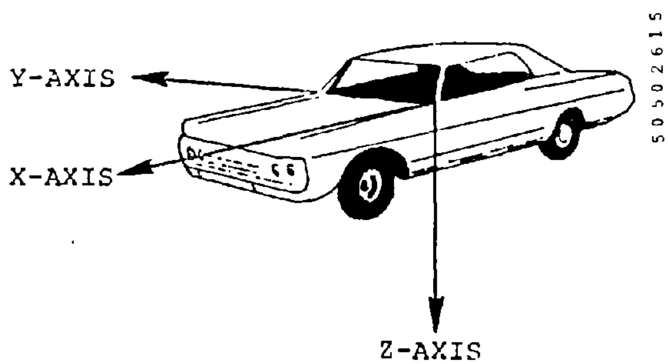


Figure A-3. Vehicle Coordinate System (Per SAE J670a).

It should be kept in mind that an accelerometer is defined by its original orientation. If, during the crash, the instrument is oriented in a new direction, the acceleration shown on the time history will be in the direction in which the instrument is oriented at that instant of time, but will still be labeled according to the original direction.

A.4 DATA FROM TEST TGB-3

A description of Test TGB-3 appears in Section 5.3 in the text. This section contains a complete set of time histories for Test TGB-3.

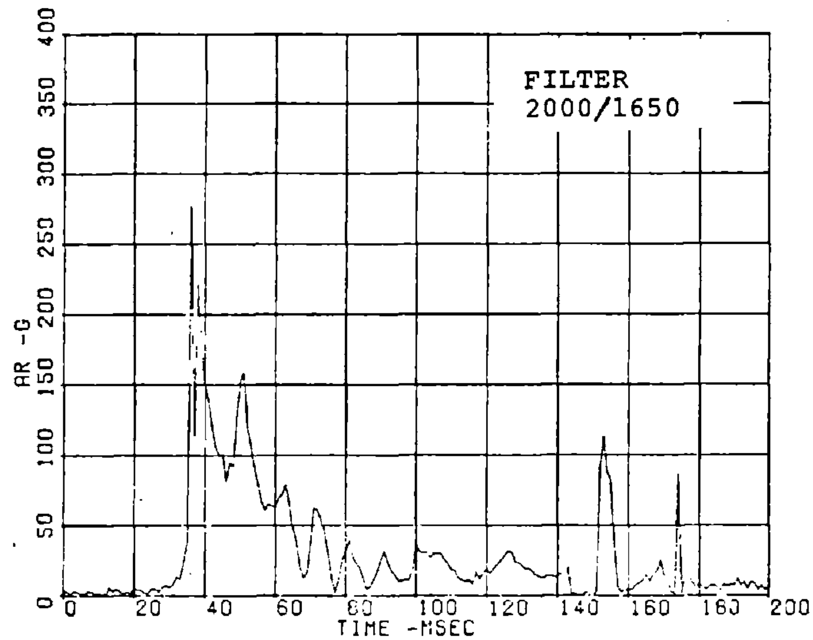


Figure A-4. Resultant Dummy Head Acceleration for Driver During Test TGB-3.

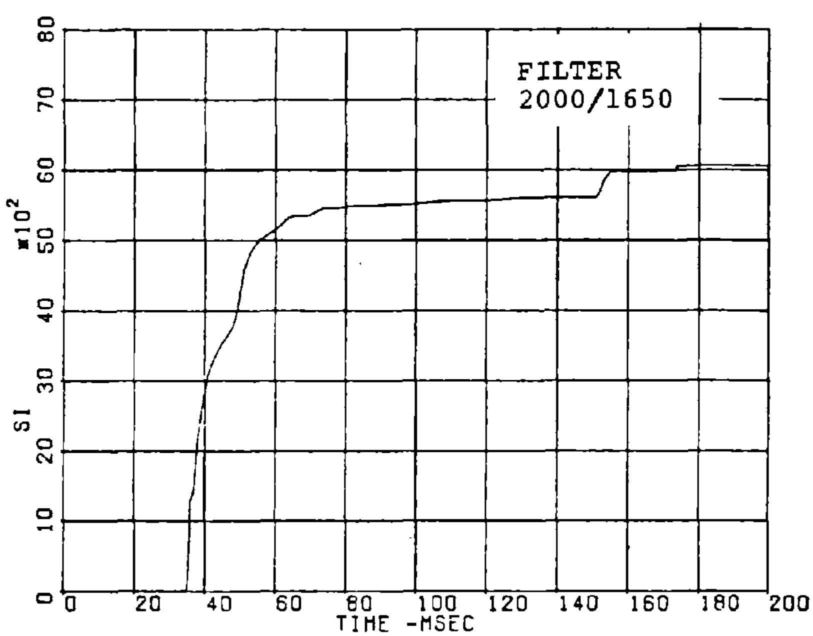


Figure A-5. Cumulative Severity Index for Dummy Head of Driver During Test TGB-3.

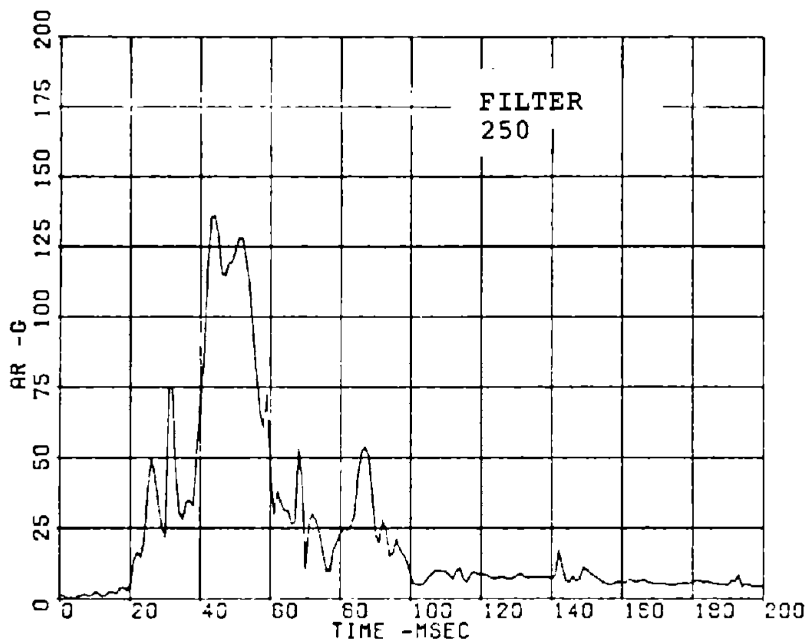


Figure A-6. Dummy Thorax Resultant Acceleration for Driver During Test TGB-3.

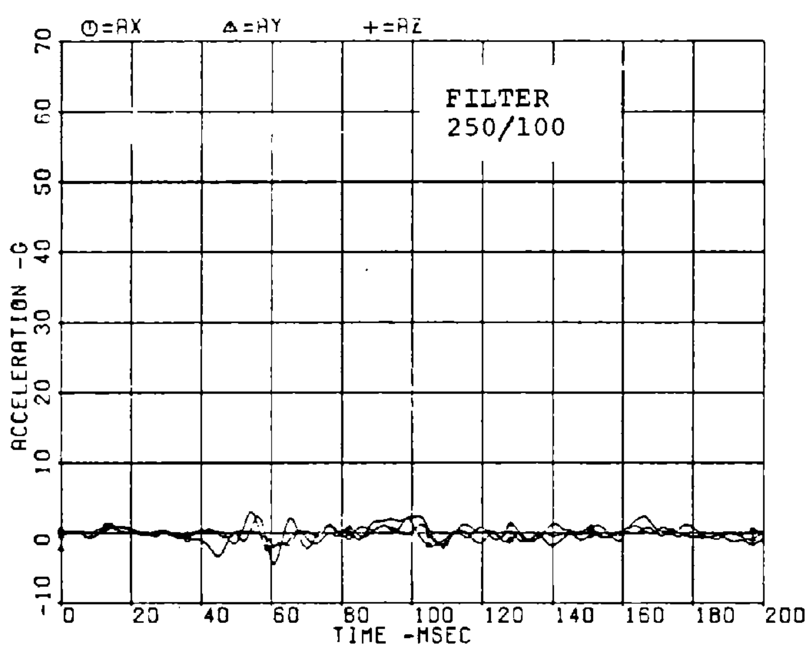


Figure A-7. Locomotive Cab Acceleration During Test TGB-3 (Location 101).

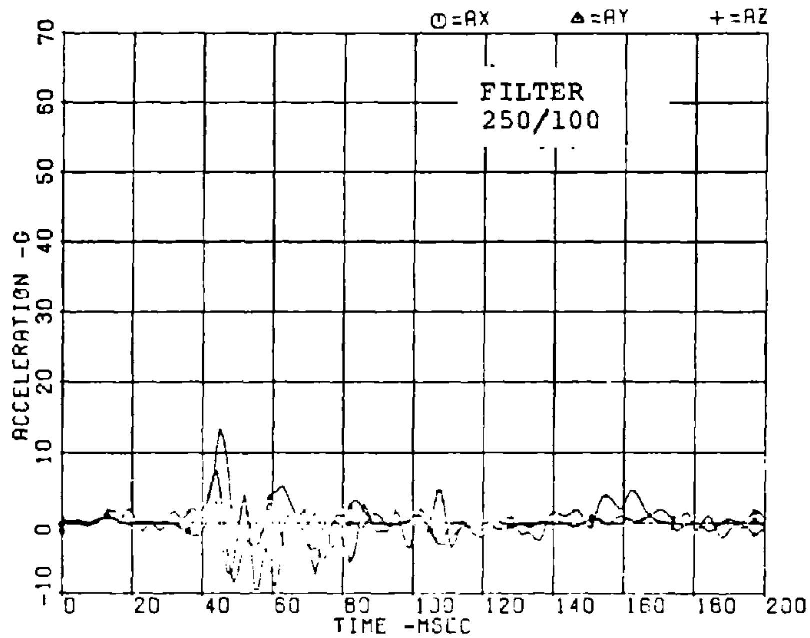


Figure A-8. Locomotive Front Platform Acceleration During Test TGB-3 (Location 102).

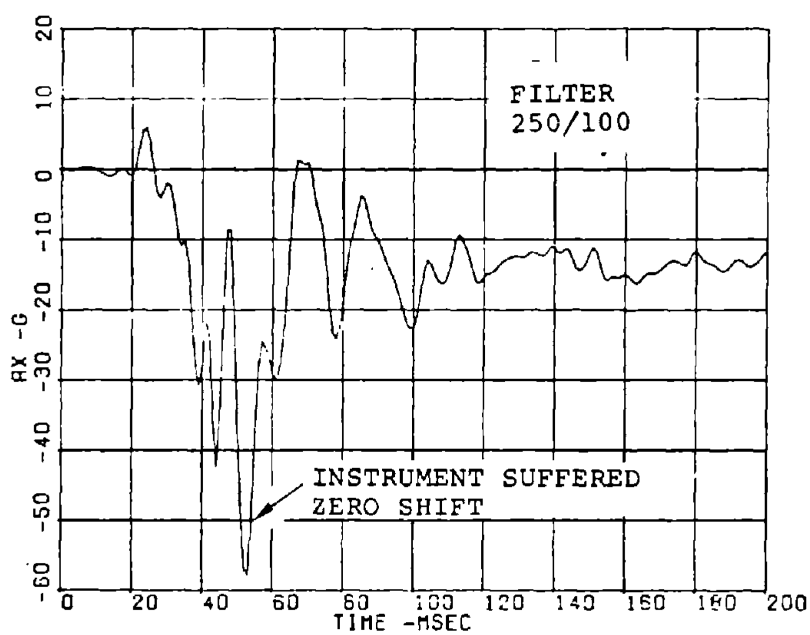


Figure A-9. Acceleration of Right Side of Front Plate of Locomotive During Test TGB-3 (Location 103A).

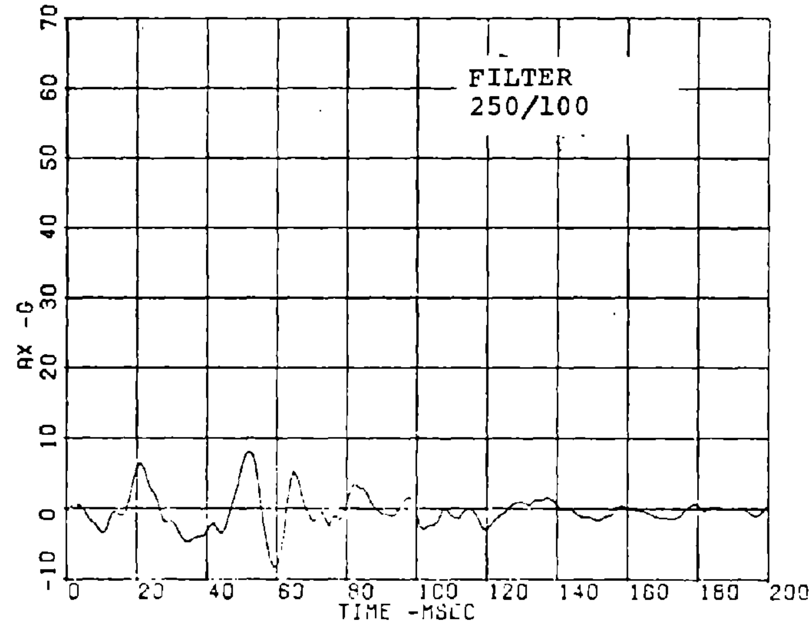


Figure A-10. Acceleration of Center of Front Plate of Locomotive During Test TGB-3 (Location 104A).

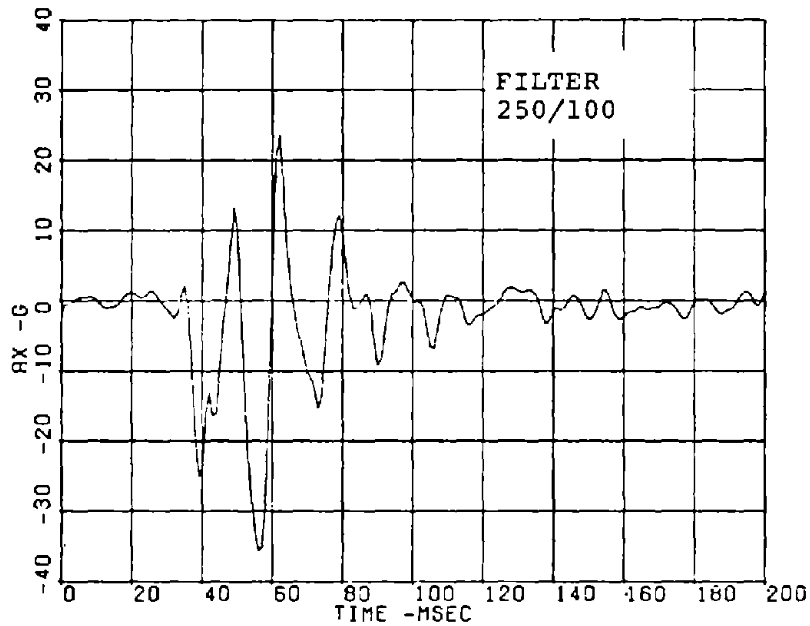


Figure A-11. Acceleration of Left Side of Front Plate of Locomotive During Test TGB-3 (Location 105A).

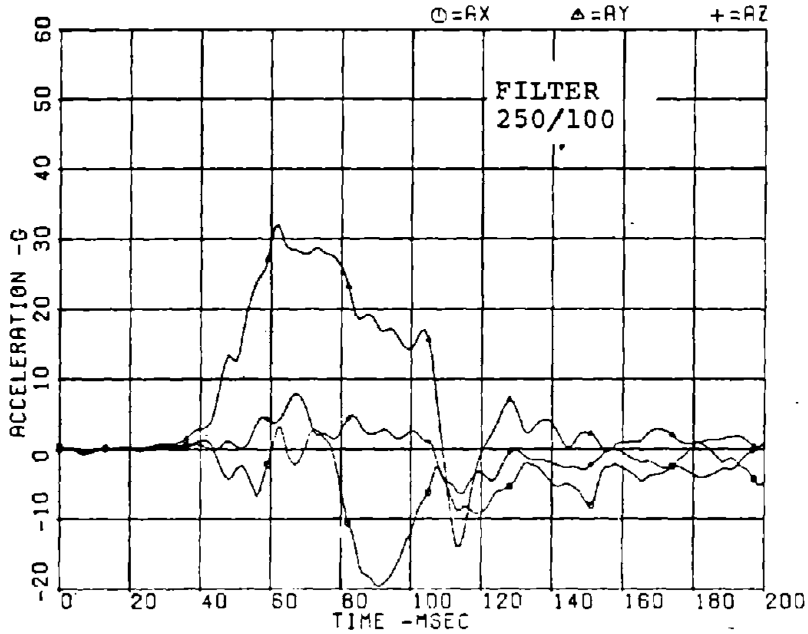


Figure A-12. Acceleration at Automobile Engine During Test TGB-3 (Location 1).

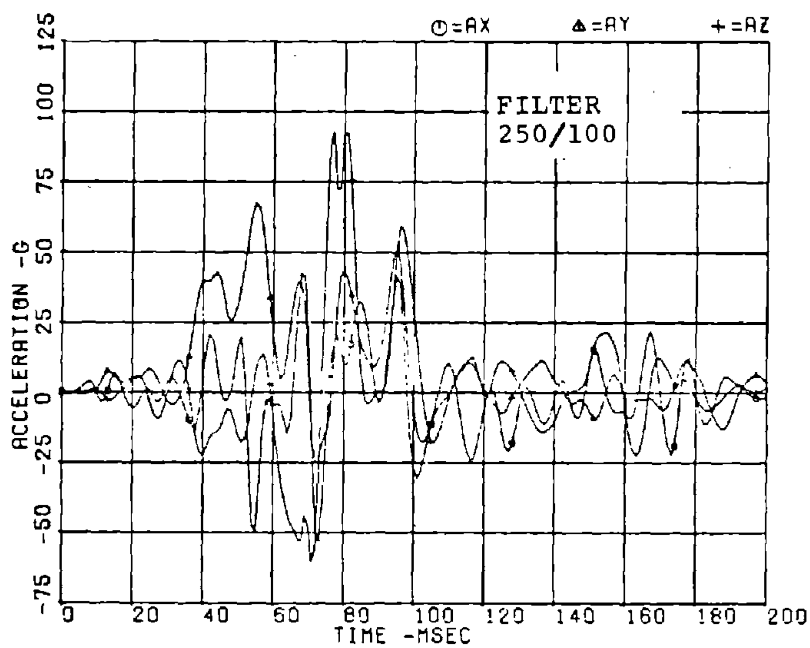


Figure A-13. Right Front Occupant Compartment Acceleration During Test TGB-3 (Location 2).

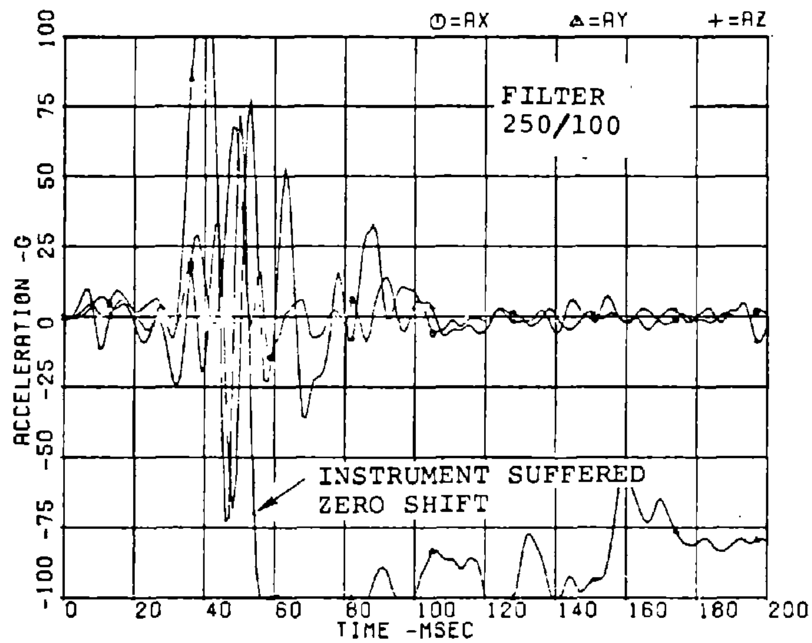


Figure A-14. Left Front Occupant Compartment Acceleration During Test TGB-3 (Location 3).

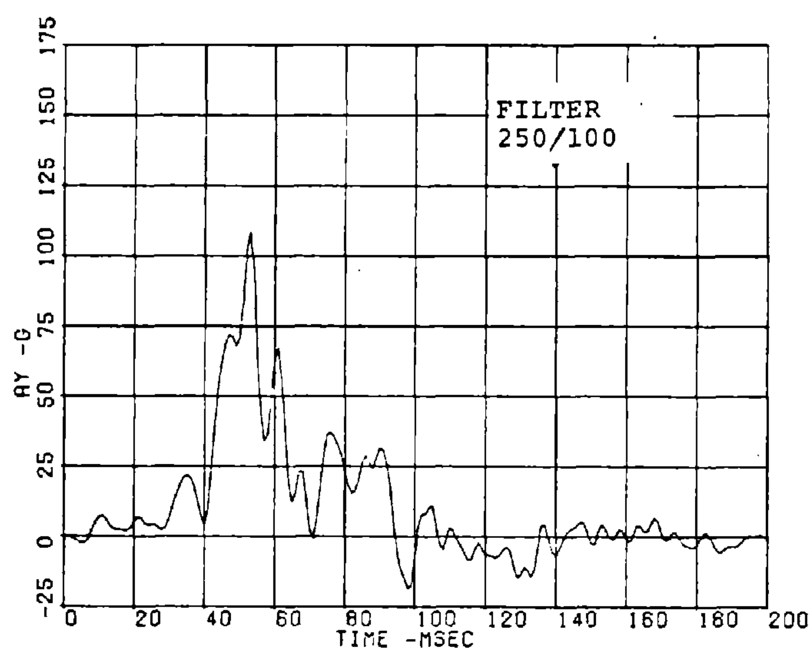


Figure A-15. Right Rear Occupant Compartment Acceleration During Test TGB-3 (Location 4).

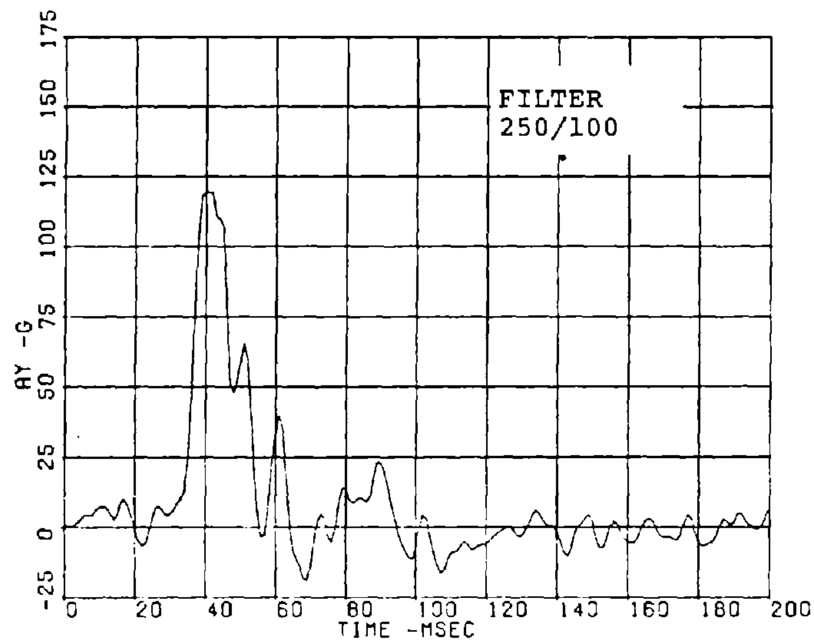


Figure A-16. Left Rear Occupant Compartment Acceleration During Test TGB-3 (Location 5).

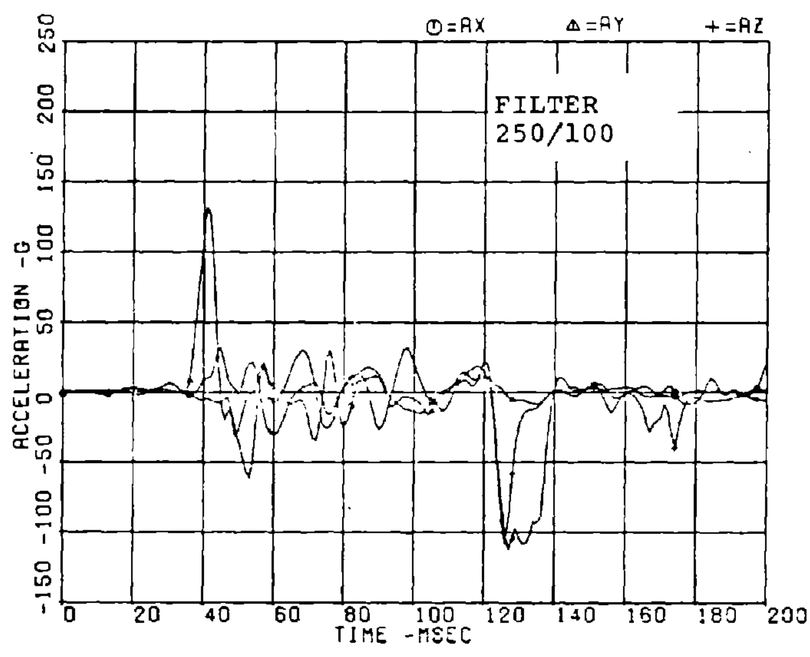


Figure A-17. Axle Acceleration During Test TGB-3 (Location 6).

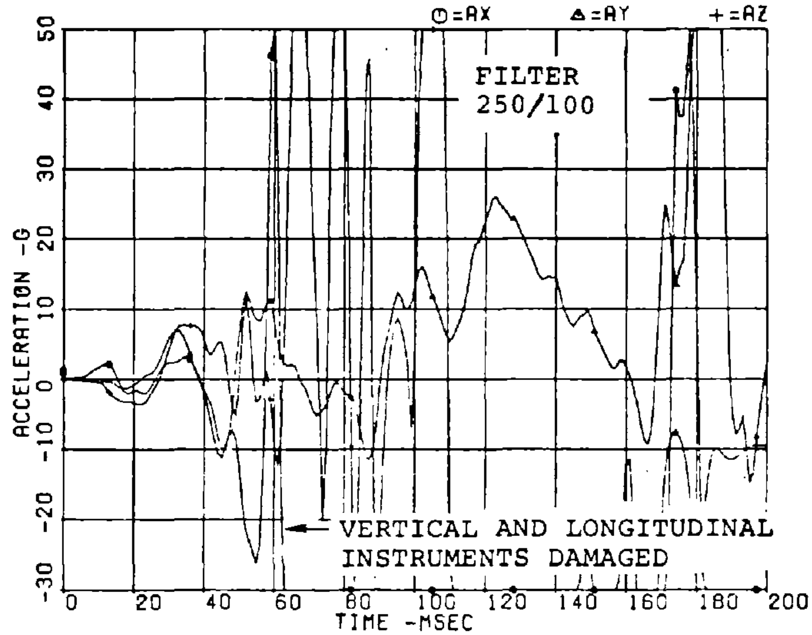


Figure A-18. Front Bumper Acceleration During Test TGB-3 (Location 7).

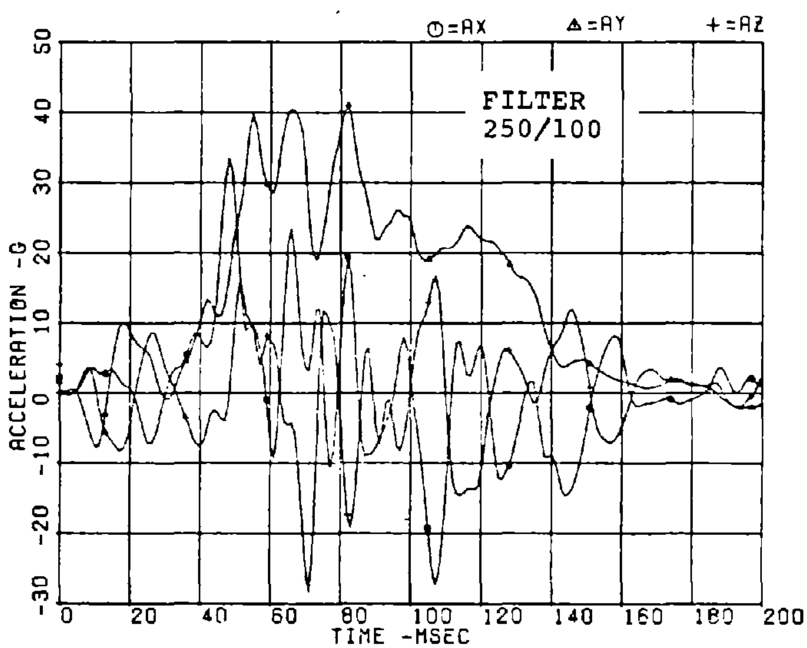


Figure A-19. Rear Bumper Acceleration During Test TGB-3 (Location 8).

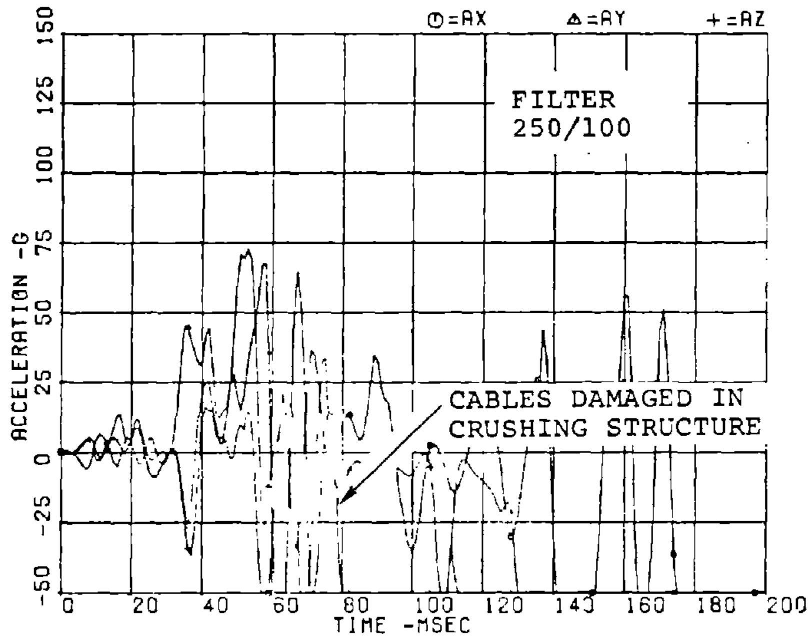


Figure A-20. Firewall Acceleration During Test TGB-3 (Location 9).

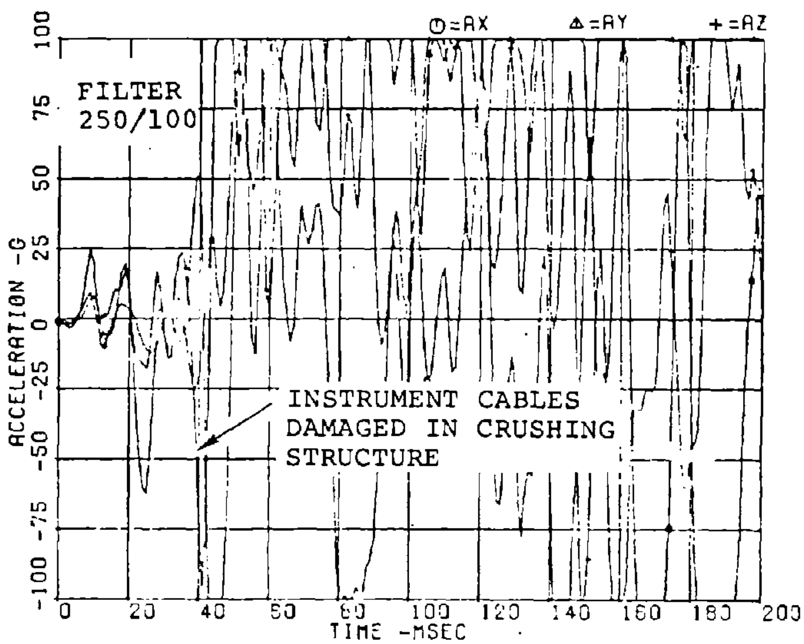


Figure A-21. Left Rocker Panel Acceleration During Test TGB-3 (Location 10).

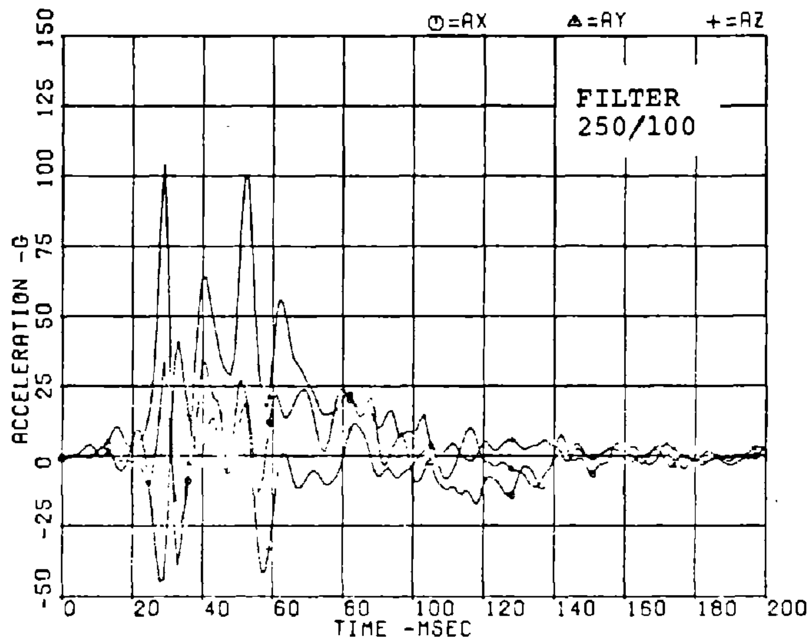


Figure A-22. Right B Post Acceleration During Test TGB-3 (Location 11).

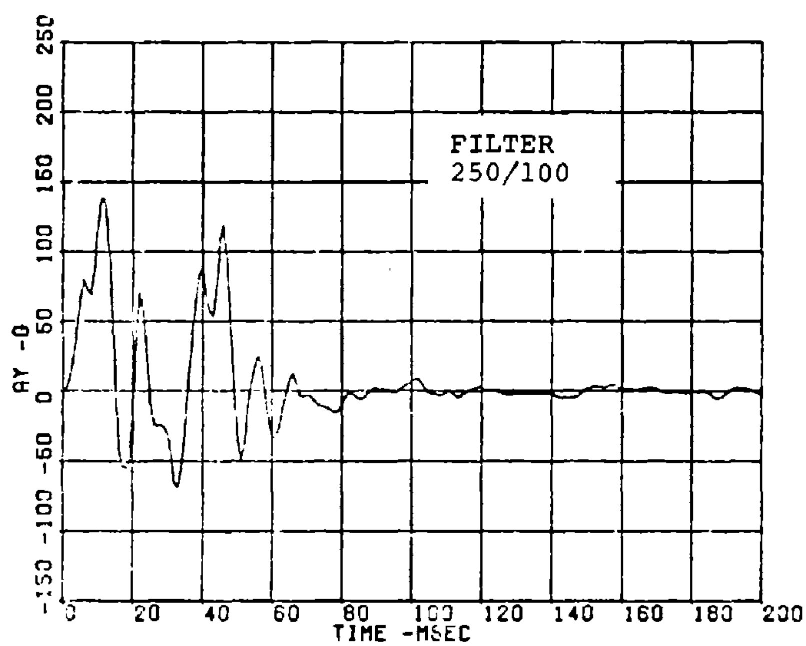


Figure A-23. Left B Post Acceleration During Test TGB-3 (Location 12).

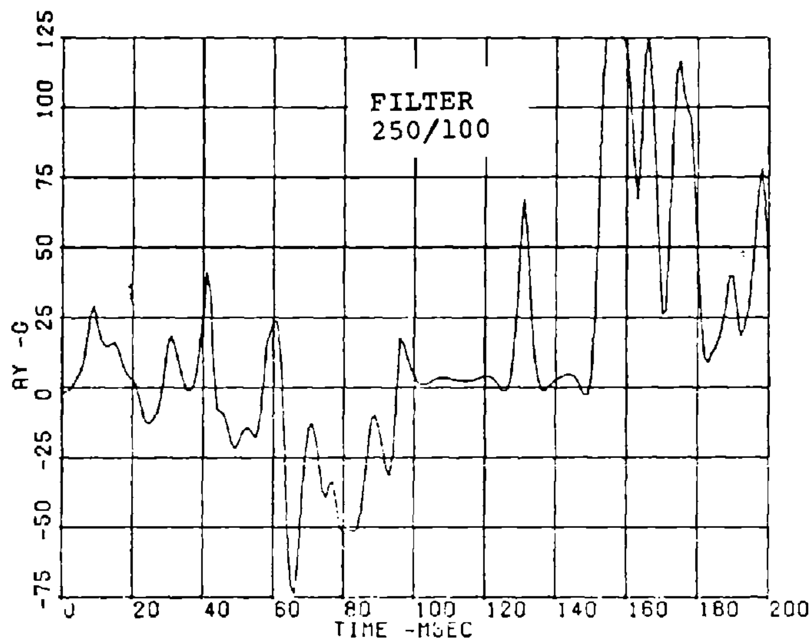


Figure A-24. Right Front Fender Acceleration During Test TGB-3 (Location 13).

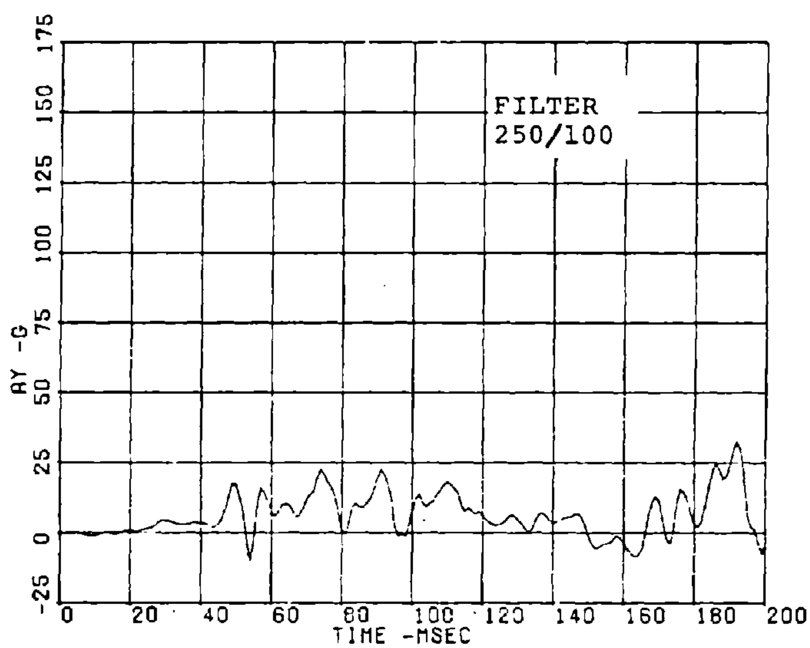


Figure A-25. Right Front Frame Acceleration During Test TGB-3 (Location 14).

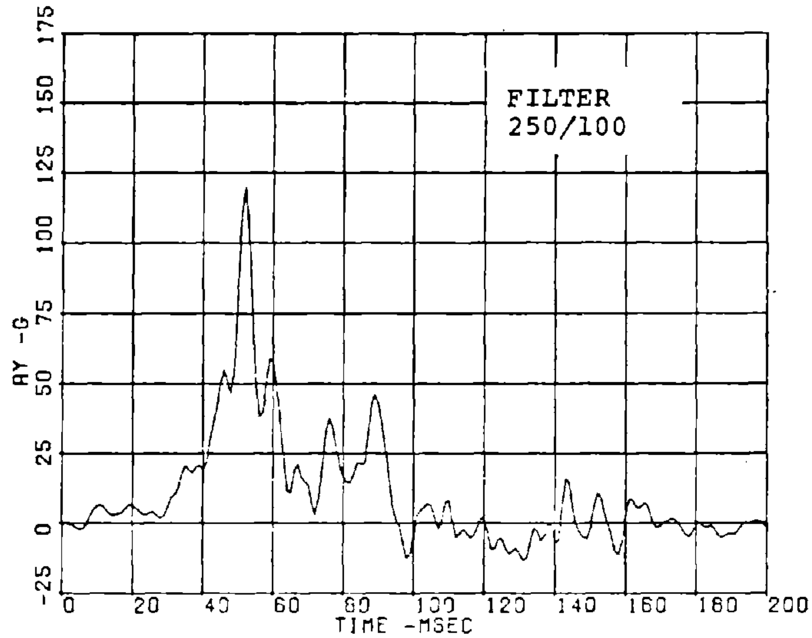


Figure A-26. Right Rocker Panel Acceleration During Test TGB-3 (Location 15).

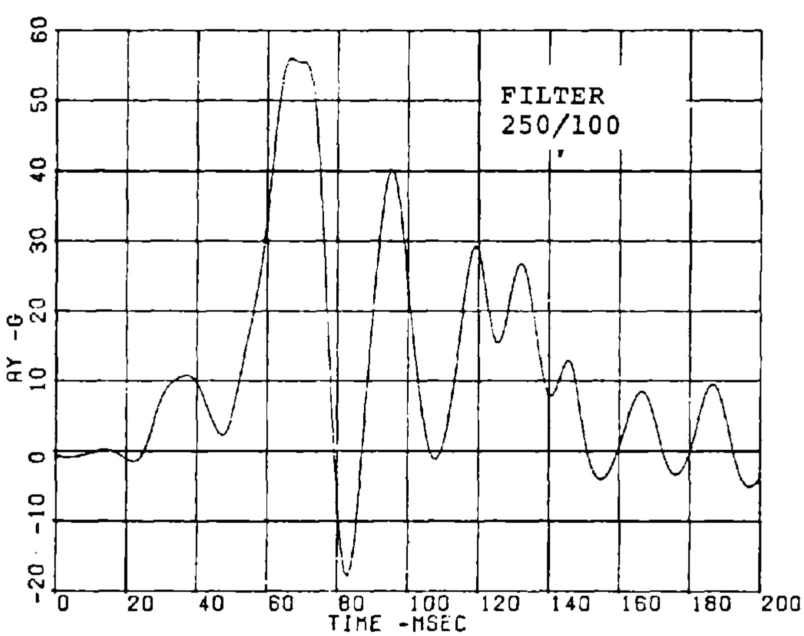


Figure A-27. Right Rear Fender Acceleration During Test TGB-3 (Location 16).

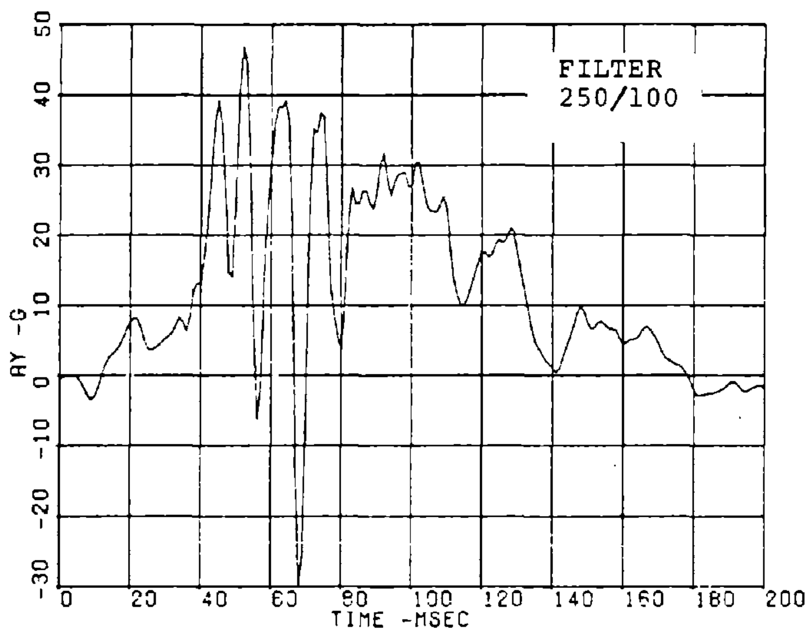


Figure A-28. Right Rear Frame Acceleration During Test TGB-3 (Location 17).

A.5 DATA FROM TEST TGB-4

A description of Test TGB-4 appears in Section 5.4 in the text. This section contains a complete set of time histories for Test TGB-4.

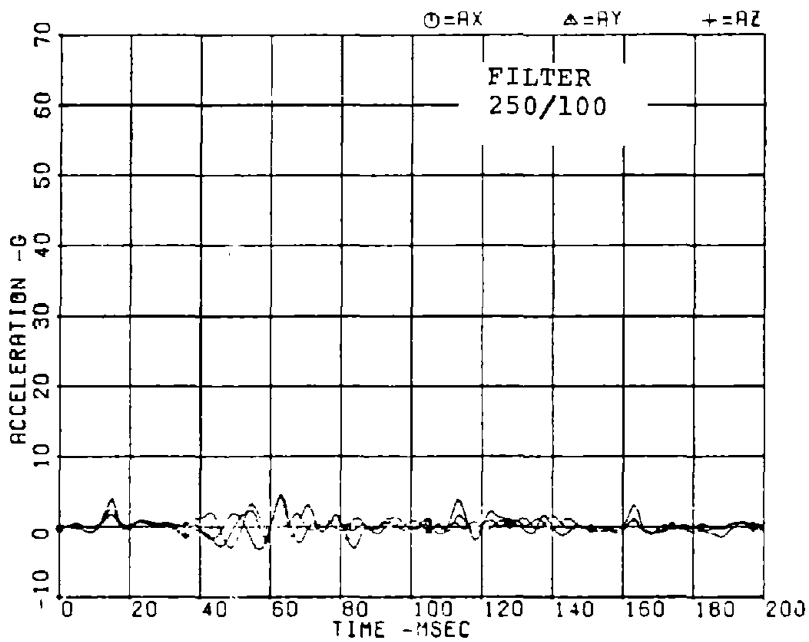


Figure A-29. Locomotive Cab Acceleration During Test TGB-4 (Location 101).

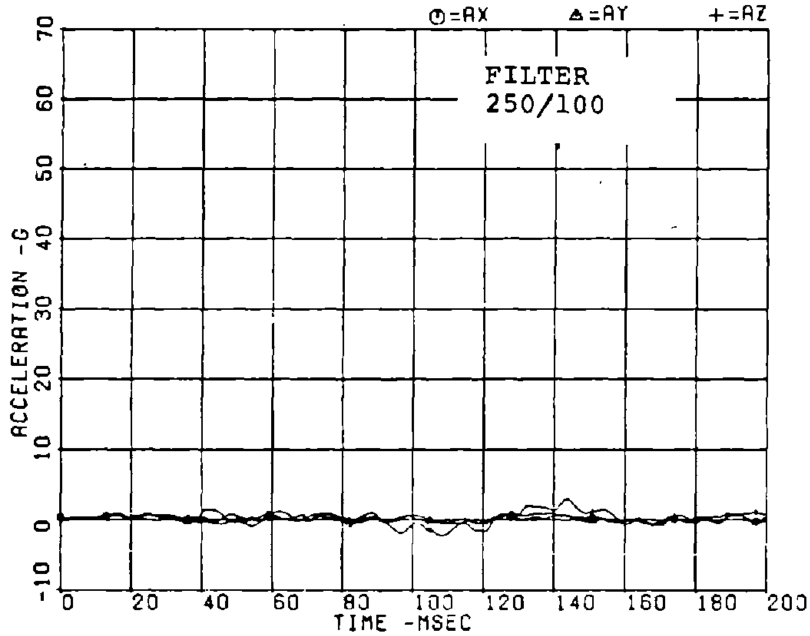


Figure A-30. Locomotive Front Platform Acceleration During Test TGB-4 (Location 102).

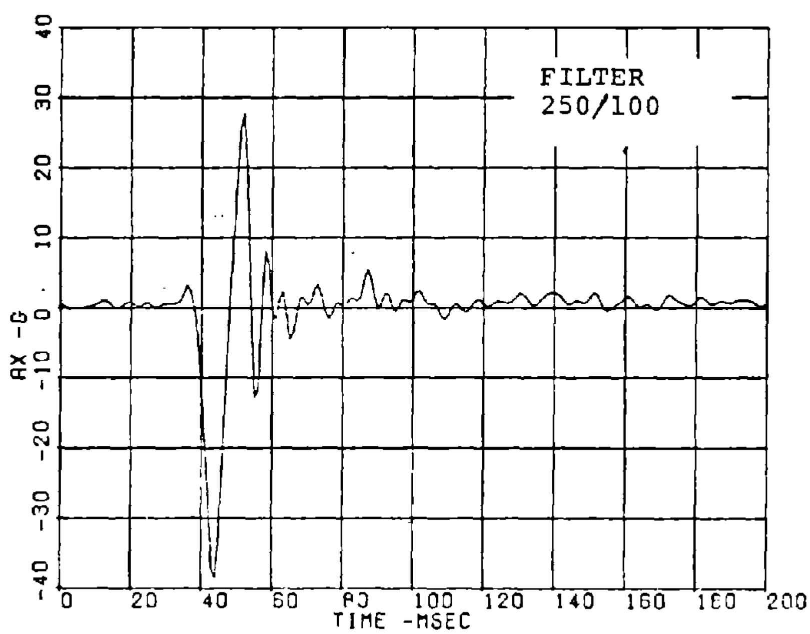


Figure A-31. Acceleration of Right Side of Front Plate on Locomotive During Test TGB-4 (Location 103B).

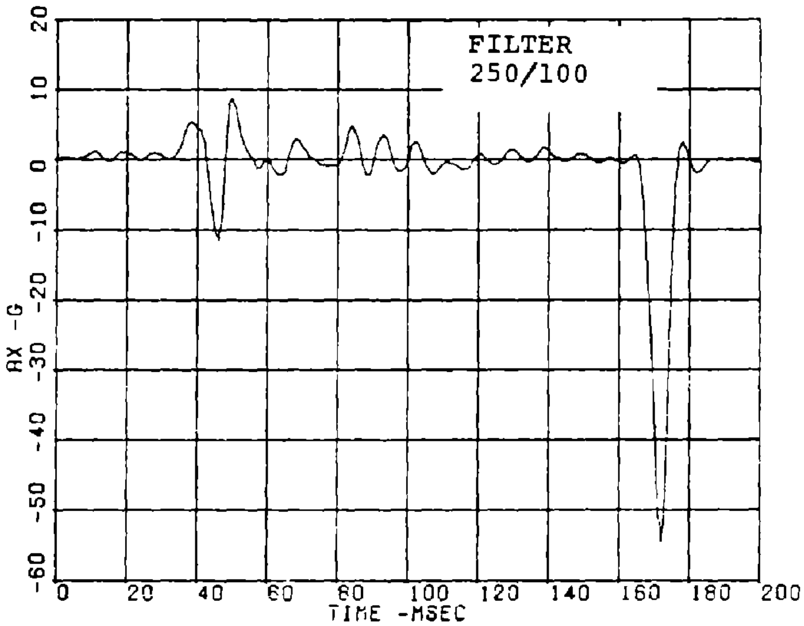


Figure A-32. Acceleration of Center of Front Plate on Locomotive During Test TGB-4 (Location 104B).

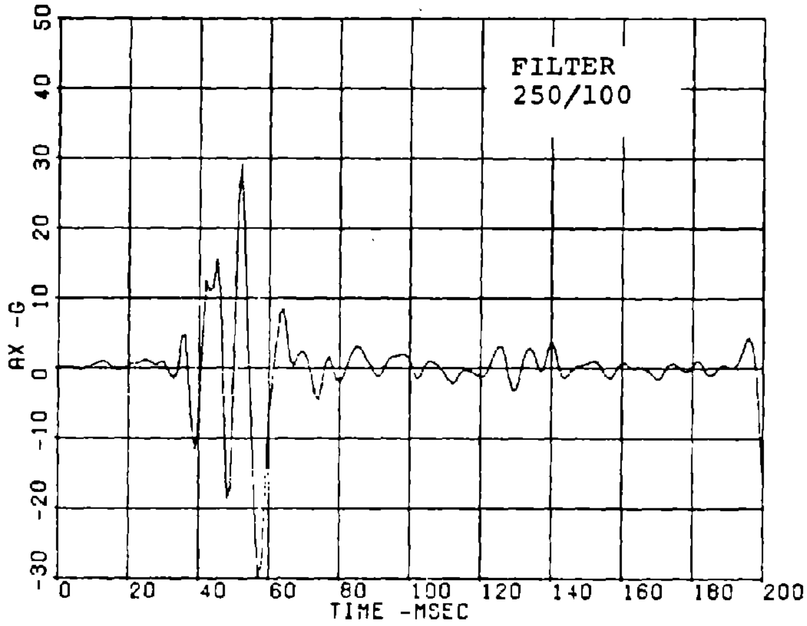


Figure A-33. Acceleration of Left Side of Front Plate on Locomotive During Test TGB-4 (Location 105B).

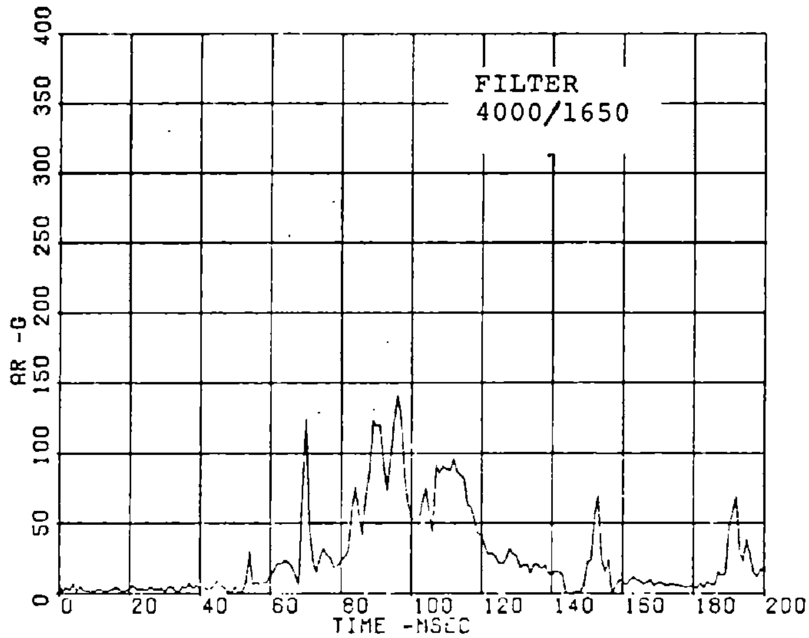


Figure A-34. Dummy Head Resultant Acceleration for Driver During Test TGB-4.

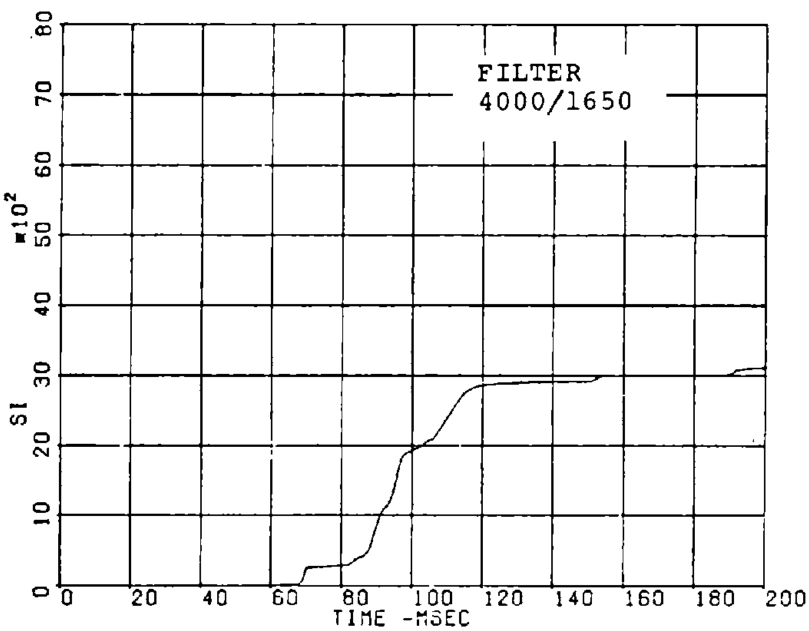


Figure A-35. Cumulative Severity Index for Driver Dummy Head During Test TGB-4.

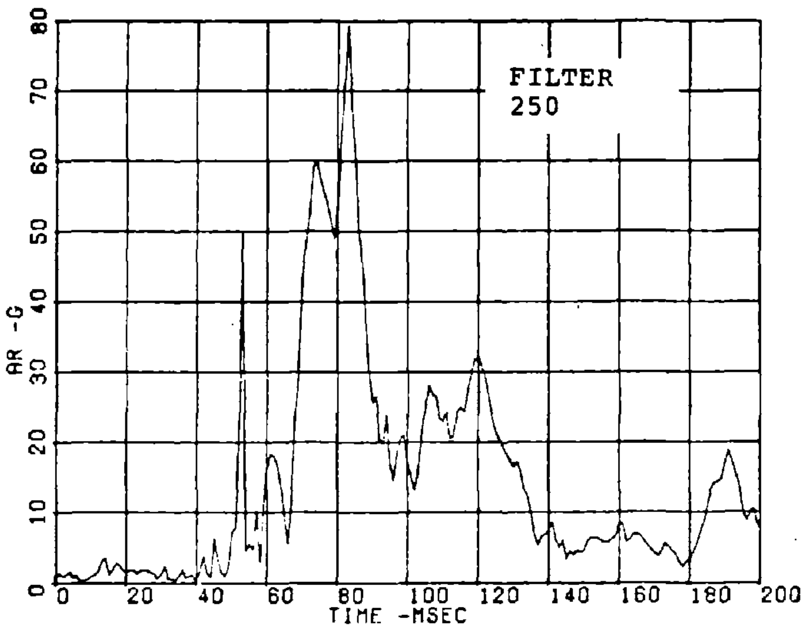


Figure A-36. Driver Dummy Thorax Resultant Acceleration During Test TGB-4.

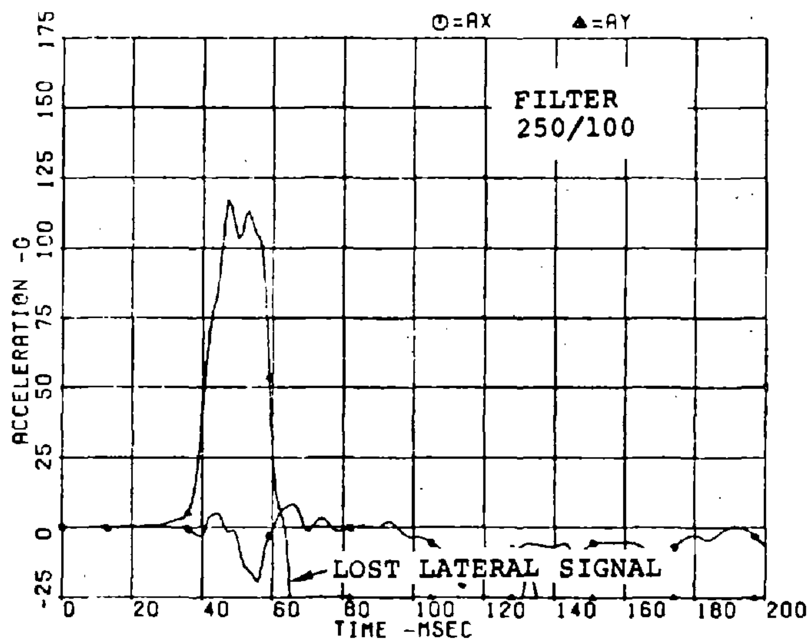


Figure A-37. Acceleration at Automobile Engine During Test TGB-4 (Location 1).

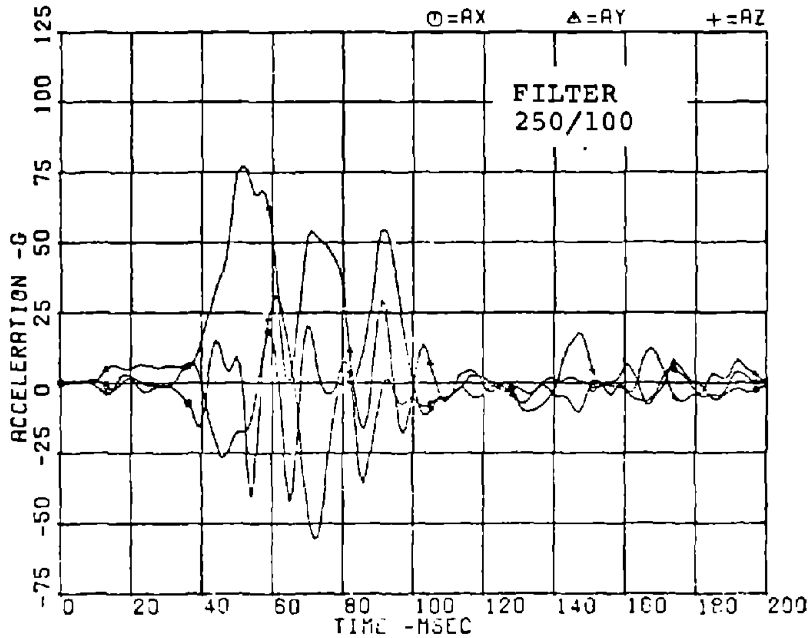


Figure A-38. Right Front Occupant Compartment Acceleration During Test TGB-4 (Location 2).

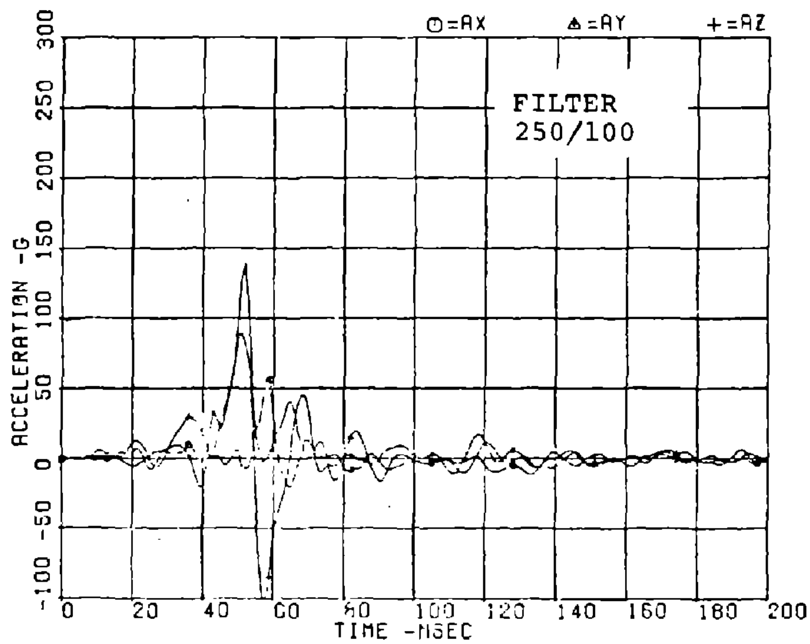


Figure A-39. Left Front Occupant Compartment Acceleration During Test TGB-4 (Location 3).

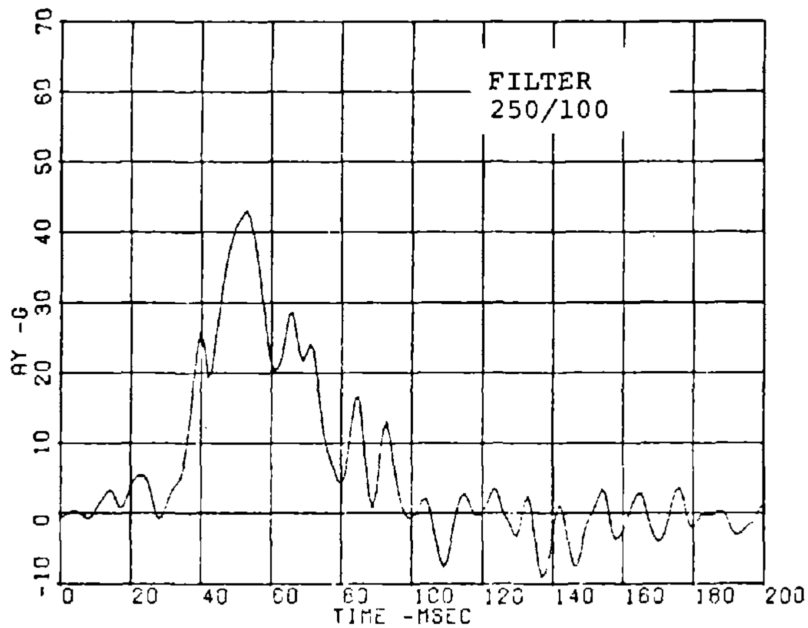


Figure A-40. Right Rear Occupant Compartment
Acceleration During Test TGB-4 (Location 4).

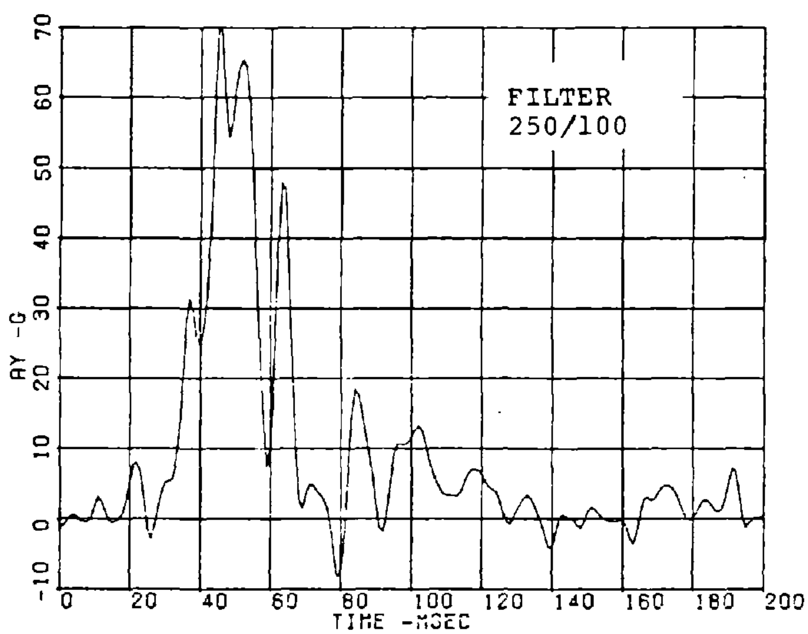


Figure 41. Left Rear Occupant Compartment
Acceleration During Test TGB-4 (Location 5).

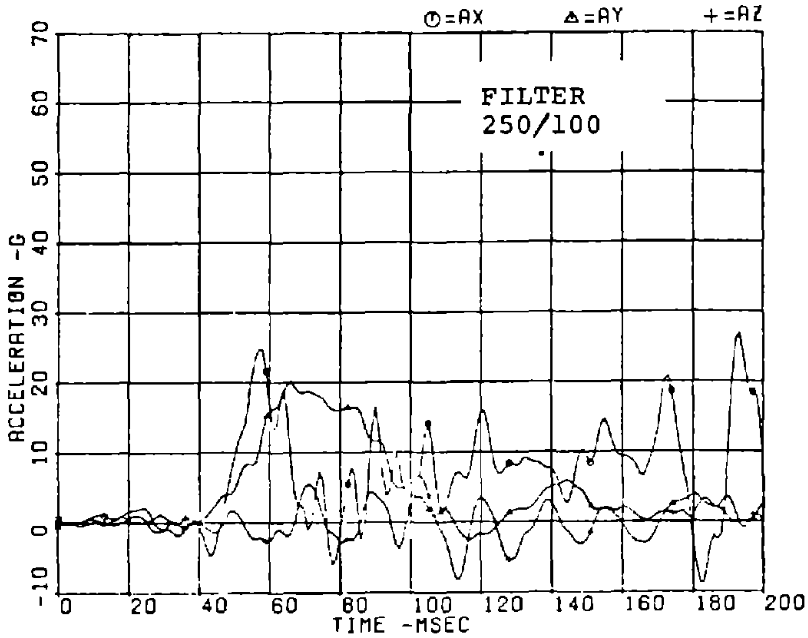


Figure A-42. Axle Acceleration During Test TGB-4 (Location 6).

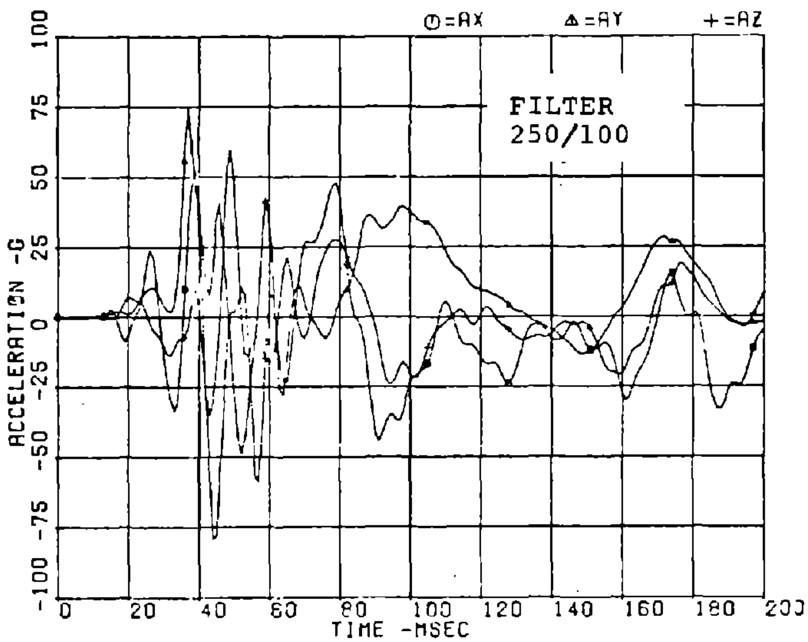


Figure A-43. Front Bumper Acceleration During Test TGB-4 (Location 7).

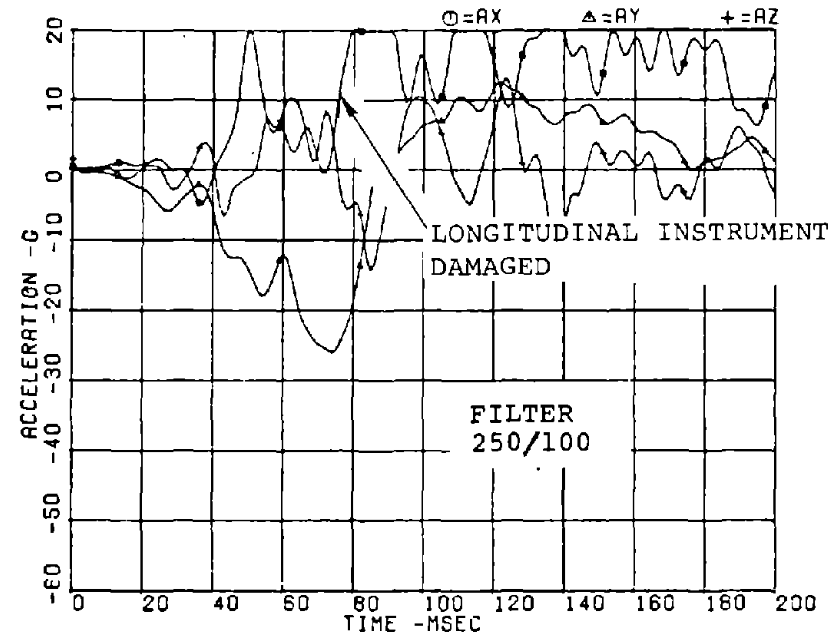


Figure A-44. Rear Bumper Acceleration During Test TGB-4 (Location 8).

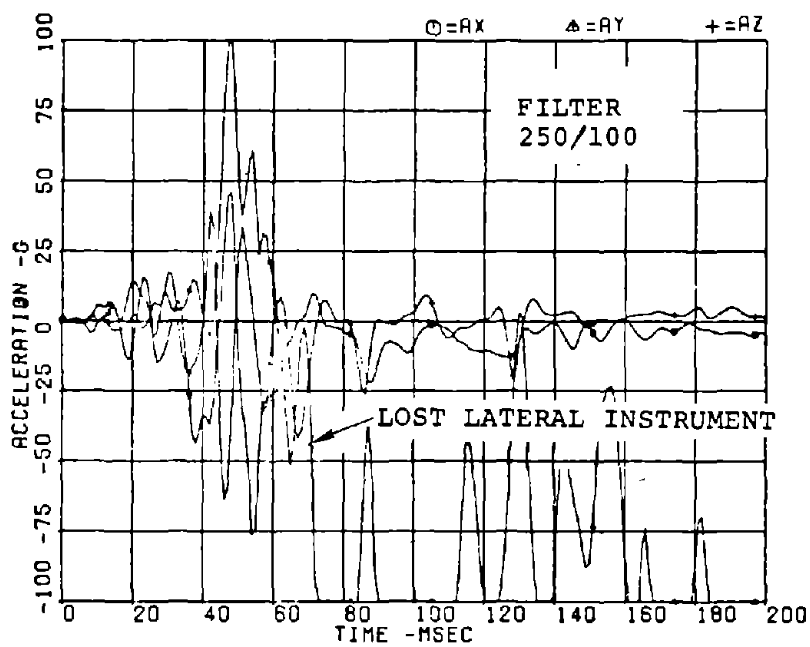


Figure A-45. Firewall Acceleration During Test TGB-4 (Location 9).

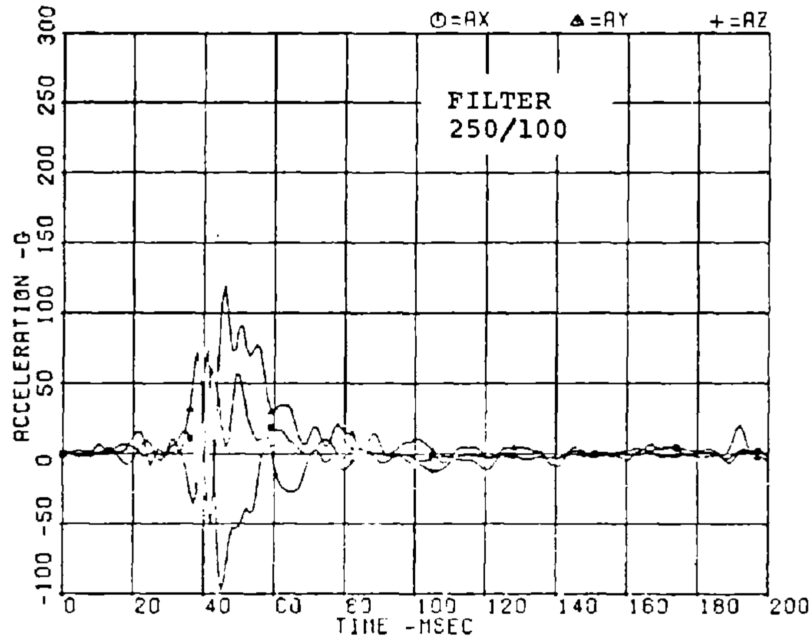


Figure A-46. Left Rocker Panel Acceleration During Test TGB-4 (Location 10).

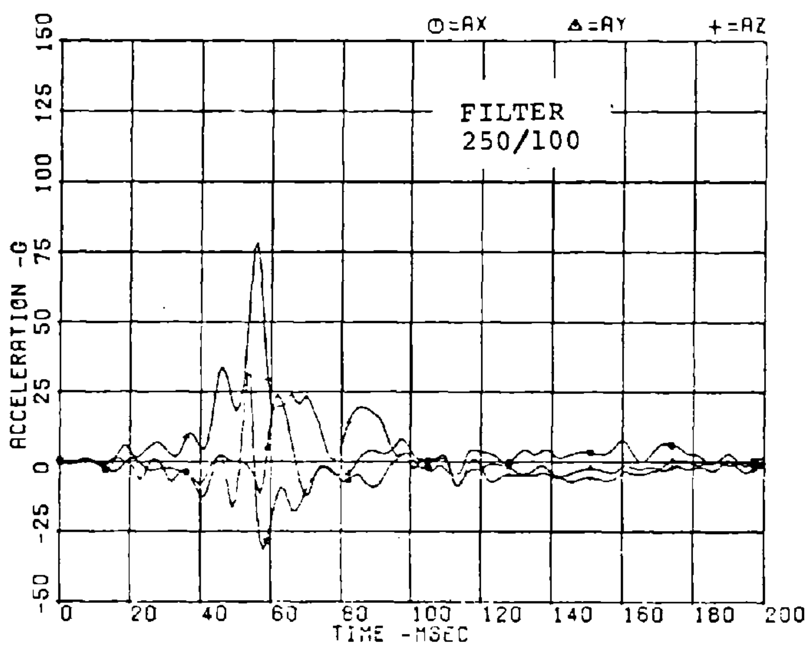


Figure A-47. Right B Post Acceleration During Test TGB-4 (Location 11).

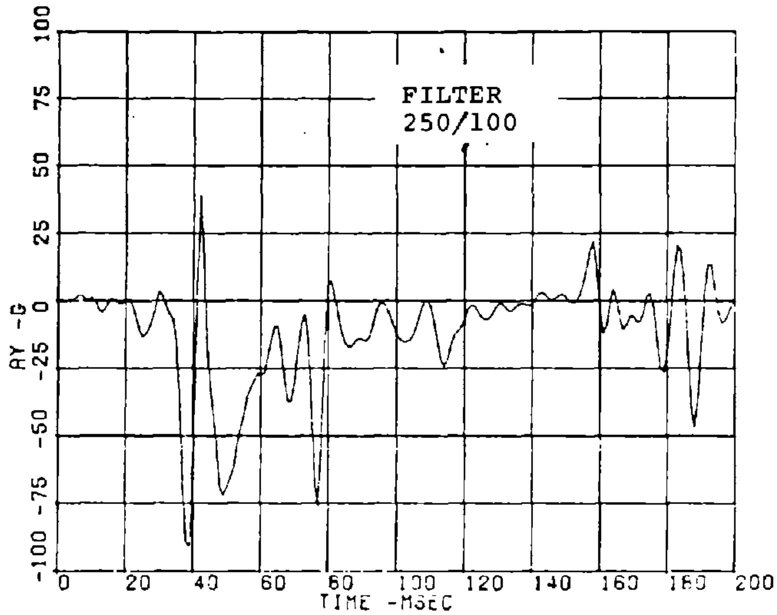


Figure A-48. Left B Post Acceleration During Test TGB-4 (Location 12).

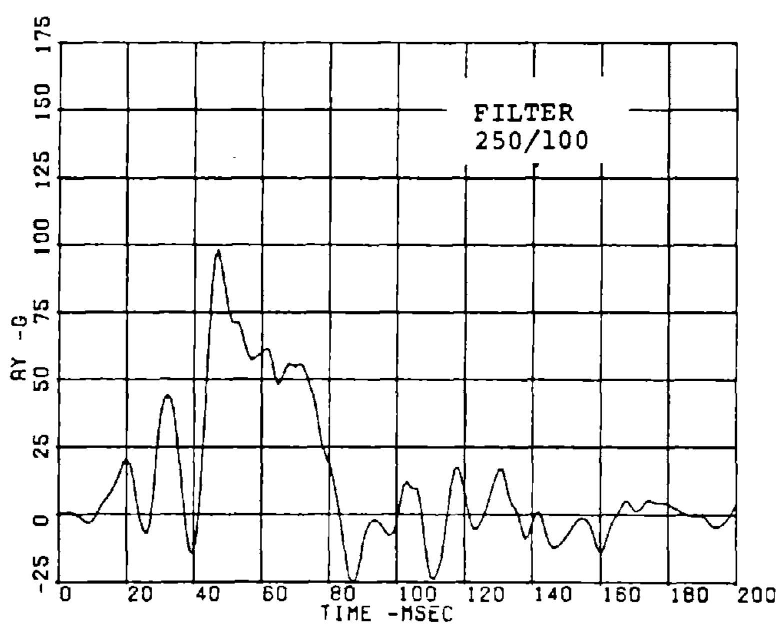


Figure A-49. Right Front Fender Acceleration During Test TGB-4 (Location 13).

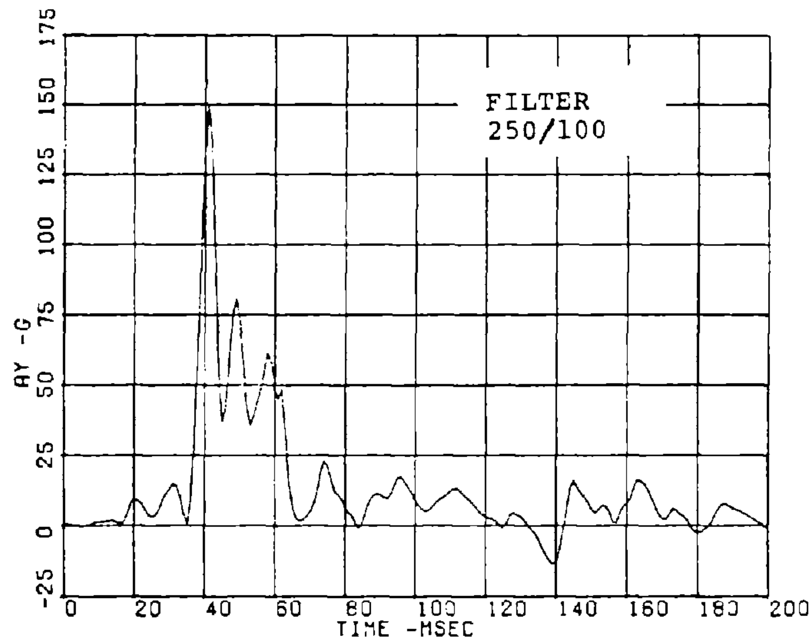


Figure A-50. Right Front Frame Acceleration During Test TGB-4 (Location 14).

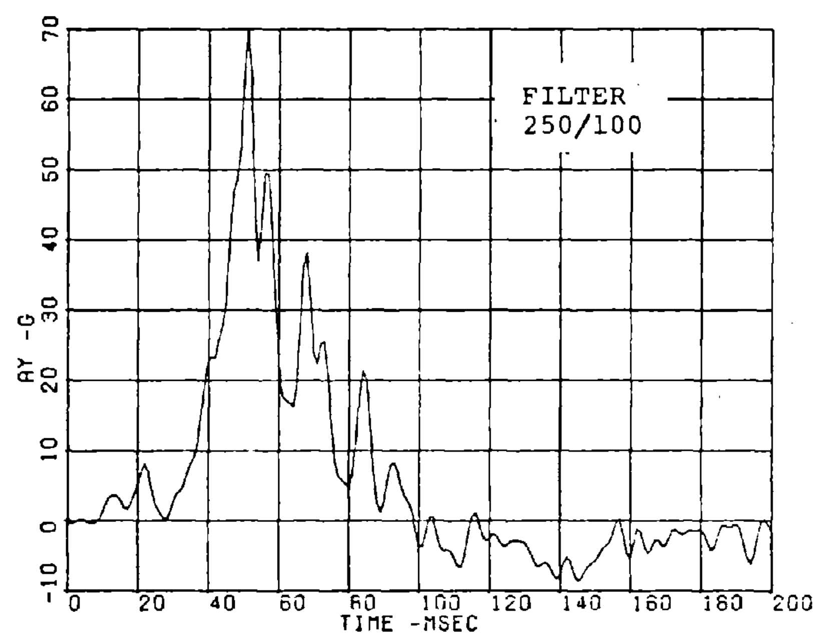


Figure A-51. Right Rocker Panel Acceleration During Test TGB-4 (Location 15).

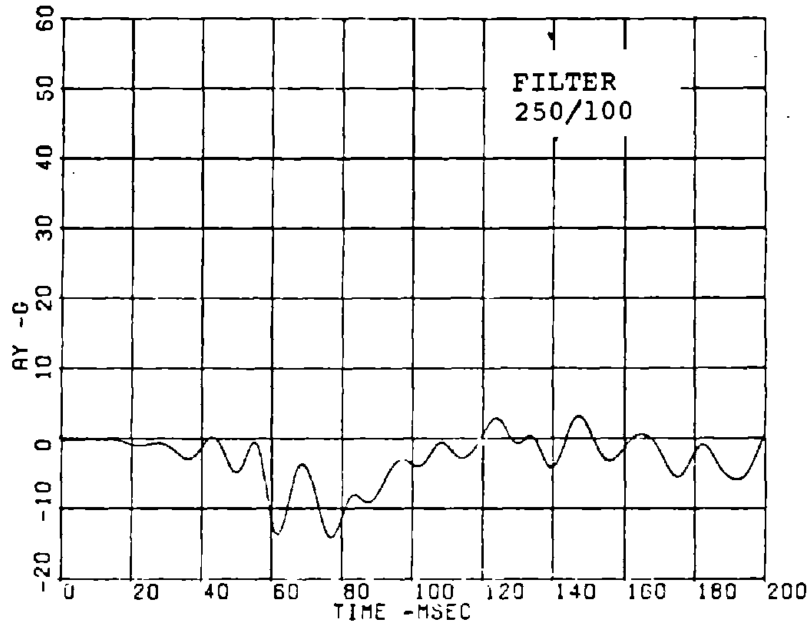


Figure A-52. Right Rear Fender Acceleration During Test TGB-4 (Location 16).

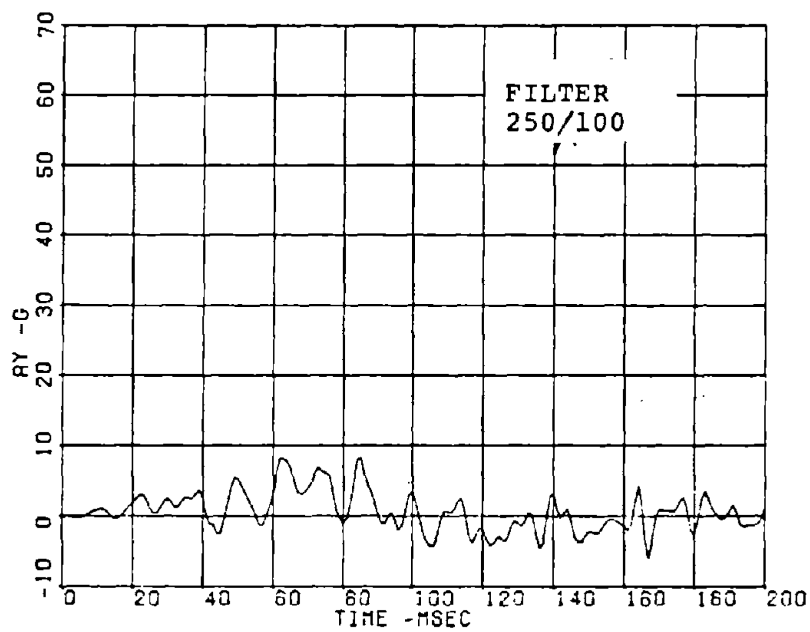


Figure A-53. Right Rear Frame Acceleration During Test TGB-4 (Location 17).

APPENDIX B

REPORT OF INVENTIONS

After a diligent review of the work performed under this contract, no new innovation, discovery, improvement, or invention was made.