68882 NHTSA-98-3588-72

Crash Test Protocol Development for Fuel System Integrity Assessment

Paul T. Eichbrecht
General Motors Corporation

Abstract

This report presents the basis, test description, and test results of a research project comprising rear impact crash tests of five passenger cars. The project's purpose was to study a potential upgrade to existing crash test protocols for motor vehicle fuel system integrity assessment. The research augmented previous National Highway Traffic Safety Administration tests by focusing on small U.S. passenger cars. The test configuration was a 80.5 km/h offset rear impact crash test using a moving deformable barrier. These tests were conducted by GM pursuant to an agreement between GM and U.S. Department of Transportation. The tests constituted Project B.5 under the Fire Safety Research section of that agreement.

Table of Contents

List of Figures

Note: additional figures in Appendices

List of Tables

<u>List of Appendices</u>

1. Background and Introduction

Motor vehicle post-collision fuel-fed fires are rare events, and those that result in a fatality are even less common. Current U.S. federal requirements for passenger motor vehicle fuel system integrity limit the allowable fuel spillage in specified frontal, side and rear impact crash tests. The U.S. Department of Transportation's (USDOT) National Highway Traffic Safety Administration (NHTSA) is evaluating a potential upgrade to these tests. The potential upgrade is a rear impact test different from the one presently incorporated in Federal Motor Vehicle Safety Standard 301, "Fuel System Integrity."

The current FMVSS 301 rear impact crash test is a 48.3 km/h, full overlap, collinear impact using an 1814 kg, flat-faced, rigid moving barrier. The rear impact test under development is a substantially higher energy crash test. It is an 80.5 km/hr, collinear impact engaging 70% of the vehicle's rear width. The impact barrier used in the test under development is an uncrabbed version of the 1368 kg crabbed moving deformable barrier specified for FMVSS 214, "Side Impact Protection," crash testing. Crabbed in this case designates a condition where the barrier wheels are aligned at an acute angle relative to the barrier's longitudinal axis (producing a type of sliding, angled impact motion). Uncrabbed designates the condition in which the barrier wheels are aligned parallel to the barrier's longitudinal axis.

Following an earlier testing phase examining rear impact test configuration differences, the NHTSA evaluated six different U.S. passenger vehicles using the new rear impact test [1]. Of those vehicles, the three larger ones met the fuel spillage limits of FMVSS 301 (the basic spillage rate limit by weight is 28 grams / minute), and the three smaller ones did not. Accordingly, the NHTSA decided that additional testing of small cars was warranted to help determine if the new test would be feasible and achievable as a federally mandated fuel system integrity test.

Consistent with the March 7, 1995 GM / USDOT Settlement Agreement, GM and the NHTSA agreed that the additional rear impact crash tests on small cars would be conducted by GM. Established under the Agreement were a number of Fire Safety Research projects. The project under which the work in this report was conducted was identified as Project B.5 - Development of Crash Test Protocols.

This report summarizes the test configuration basis and presents the test vehicle selection, test conditions, test setup, and test results of the five rear impact research crash tests which constitute Project B.5. A brief discussion and conclusions section also is included. Individual test reports for each test are listed as References [2] - [6]. Each report has been provided to the NHTSA, along with all of the test data, films and photographs [7]. The GM tests were conducted on 1998 Model Year (M.Y.) small U.S. passenger cars during December 1997 and January 1998 at GM's Proving Ground in Milford, Michigan.

2. Test Configuration Basis

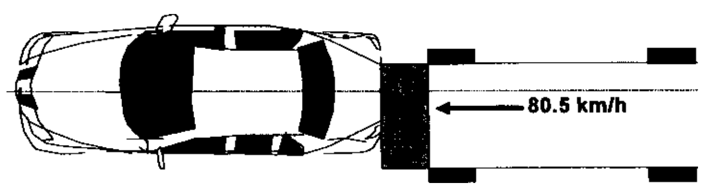
The NHTSA selected the test configuration for the Project B.5 tests. The configuration developed from a NHTSA case study of fatal motor vehicle crashes involving fire [8]. A case study approach was used because none of the existing fatal crash databases provided sufficient information to establish the impact configuration or the cause of the fatality (e.g., impact trauma vs. burn trauma). Sixteen (16) rear impact field collision cases with 30 fatalities were found out of 45 cases (65 fatalities) in which the fatalities were judged to be due to fire. Impact speed was determined for 8 of the 16 cases.

When NHTSA conducted its six tests [1], it chose a specific, consistent test protocol (impact speed, overlap, barrier, etc.) reflecting the results from its case study and the earlier similar tests it had conducted. The test protocol and conditions used in the GM tests were chosen to match, as close as practicable, the protocol and nominal targeted conditions from the six NHTSA tests. The impact speed was agreed to be 80.5 km/h (50 mph).

3. Test Configuration and Test Conditions

Figure 1 illustrates the test configuration. The stationary target vehicle is struck in its rear by the moving deformable barrier. Nominal impact speed is 80.5 km/h and the impact is collinear. Barrier overlap with 70% of the car's rear is established toward the fuel filler side of the car.

Figure 1 - Test Configuration



The impactor for the GM tests was a modified version of the 1368 kg FMVSS 214 dynamic side impact crabbed moving deformable barrier (Appendix A) [9, 10]. It was adjusted to an uncrabbed configuration for collinear impact. Barrier face construction consisted of the normal FMVSS 214 aluminum honeycomb blocks and aluminum faces. However, barrier face height for the new rear impact test was lowered 51 mm from the FMVSS 214-specified height. This modification was determined by NHTSA to represent rear impacts with pre-impact braking. Specifically, it represented the dip at the front bumper or rise at the rear bumper based on average vehicle pitch due to panic braking.

There were some differences between the moving barrier carriage used in the GM tests and the one used in the NHTSA tests. First, GM used an available carriage similar to the FMVSS 214 carriage but which previously had been adapted to allow barrier face height adjustment. The GM carriage had a taller barrier face mounting plate and taller vertical supports behind the barrier face (see the photos in Appendix A). Second, GM's barrier did not incorporate load cells. The barrier that NHTSA used in its tests incorporated five load cells, which are not part of the FMVSS 214 barrier. Even with these differences, the weight of the GM barrier (1371 kg) was comparable to the barrier used in the NHTSA tests (1337 - 1344 kg).

It is not known what effect resulted from the slightly different barrier carriage GM used compared with the barrier carriage used in the NHTSA tests. Review of the crash test films from the GM tests indicated some interaction of the vehicle deck lid with the taller portions of the GM barrier assembly. The interaction was relatively late in the impact event. For this reason, it is believed that a relatively small percentage of the impact loading was carried through those portions of the test car that were contacted by the taller portions of the GM barrier assembly.

4. Test Vehicle Selection and Description

Approved funding for this research project was provided for five crash tests. Accordingly, five 1998 M.Y. small U.S. passenger cars were selected based on the following criteria agreed between the NHTSA and GM:

1. Projected 1998 M.Y. small car market segment sales leaders with 100,000 or more units sold (including "sister" cars)
2. Curb weight under 3000 pounds
3. Car or its "sister" car had not been tested previously in the NHTSA tests
4. No more than one car in the selected group from a single manufacturer.

These criteria were intended to aid selection of a reasonable assortment of small cars to test.

Complete 1997 M.Y. sales data were not available at the time test vehicle selection was required (July 1997). Therefore, based on criteria numbers 1 and 2, the following group of cars were identified from the 1996 calendar year small car market segment sales reported by Ward's Automotive Reports, January 20, 1997:

1. Chevrolet Cavalier (Pontiac Sunfire)
2. Ford Escort
3. Saturn
4. Honda Civic
5. Toyota Corolla
6. Dodge/Plymouth Neon
7. Nissan Sentra
8. Volkswagen Jetta (Golf)

The Corolla was not selected, based on criterion number 3, because it was considered a "sister" car to the Geo Prizm, which NHTSA already had tested. Similarly, the Neon was not selected because it, too, already has been tested by the NHTSA. The Saturn was not selected, based on criterion number 4, because the Cavalier (also manufactured by GM) was selected. The Cavalier selection was based on higher combined sales of the Cavalier/Sunfire line compared to the Saturn line, and higher Cavalier sales compared to the Sunfire.

Accordingly, the five selected test cars were the 1998 Chevrolet Cavalier, Ford Escort, Honda Civic, Nissan Sentra and Volkswagen Jetta. For consistency, only the 4-door models of these cars were chosen (some only were available as 4-door models). The 4-door models generally had higher sales volumes than their 2-door versions (if available), based on the 1996 calendar year data.

The test cars were new and similarly equipped. Each car was ordered with factory equipment expected to be on a large percentage of these models. All had 4-cylinder engines, air conditioning and an automatic transmission except the Jetta, which had a manual transmission.

These equipment choices reflected the best-selling factory-installed equipment / option for the identified feature in each car based on data in the 1997 Wards Automotive Yearbook (for 1996 M.Y. cars). Representative pre-test photographs of each car, along with the car's Vehicle Identification Number (VIN), are provided in Appendix B.

For reference, Table 1 provides the locations of significant fuel system components for each car.

Table 1 - Fuel Tank, Filler Neck and Fuel Line Locations
(Cars listed in order tested)

	Fuel Tank	Filler Neck	Fuel Line Path to Front
Honda Civic	Between and forward of rear wheels	Left rear quarter	Left center underbody
Ford Escort	Forward of rear wheels	Left rear quarter	Left center underbody
Volkswagen Jetta	Between rear wheels	Right rear quarter	Right center underbody
Nissan Sentra	Forward of rear wheels	Left rear quarter	Left center underbody
Chevrolet Cavalier	Between and forward of rear wheels	Right rear quarter	Left center underbody

5. Vehicle Preparation

Each test car initially was prepared generally as it would be for an FMVSS 301 rear impact test. This included establishing the test mass and the fuel system fill level.

The target test mass (kg) was established using a procedure similar to that described in the reports of the NHTSA tests, and outlined below:

RCLW = Rated Cargo and Luggage Weight = VCW - (68 x DSC)
UDW = Unloaded Delivered Weight
VCW [a] = Vehicle Capacity Weight
DSC = Designated Seating Capacity

Target test mass = UDW + RCLW + (2 test dummies x 90 kg / dummy [b])

[a] From car's tire load label
[b] Hybrid III 50th % adult male (highly instrumented, including cables).

Actual test mass (Table 2) was established as close as practical to the target mass.

Pre-test vehicle attitude measurements are shown in Table 3.

Fuel tank usable capacity was determined from the car's manufacturer or the owners manual. The 93% Stoddard solvent fill level, added to the unusable level in the tank, was consistent with that used in the NHTSA tests. It is the center of the range (90-95%) specified in FMVSS 301.

Fuel tank fill data for each test car are shown in Table 4. As in FMVSS 301 tests, the engine of the test car was cranked for a few seconds (the ignition was moved to the "START" position) pre-test to distribute Stoddard fluid throughout the fuel system.

Table 2 - Vehicle Test Mass

	Test No.	As Received Mass Front / Rear Total (kg)	Target Test Mass Front / Rear Total (kg)*	Actual Test Mass Front / Rear Total (kg)*
Civic	C11817	676 / 404 1080	818 / 488 1306	827 / 527 1354
Escort	C11818	730 / 430 1160	867 / 509 1376	882 / 503 1385
Jetta	C11816	730 / 456 1186	850 / 567 1417	853 / 576 1429
Sentra	C11828	697 / 394 1093	781 / 521 1302	831 / 513 1344
Cavalier	C11829	794 / 418 1212	871 / 581 1452	924 / 544 1468

- including **two** instrumented test dummies (**90** kg each)

Table 3 - Pre-test Vehicle Attitude

	Test Attitude LF (mm)*	RF	LRr	Rrr
Civic	160	160	170	170
Escort	200	200	210	210
Jetta	175	175	190	190
Sentra	205	205	220	220
Cavalier	220	225	225	225

* measured **vertically** from rocker to ground
(**L** = left, R = right, F = front. **Rr** = rear)

Table 4 - Fuel Tank Fill Data

	Fuel Tank Usable Capacity (L)	Stoddard Solvent Added to Fuel Tank (L) *
Civic	45.0	41.8
Escort	48.1	44.7
Jetta	55.0	51.2
Sentra	50.0	46.5
Cavalier	57.5	53.5

* **93%** of usable capacity (added **to** unusable capacity)

Additional vehicle preparation highlights are listed below:

- The standard equipment spare tire was in its normal stowed position for all tests.

- Each test car, and the moving barrier, was instrumented with accelerometers at various locations. See Section 7 of this report for additional information.

- Underbody components, especially fuel system components, were painted with contrasting colors for film coverage purposes.

- Camera mounts were attached to the front doors of each car to record test dummy motions. The camera and mount on the rear door of the Civic (the first test) were deleted for the subsequent test vehicles. Visual inspection of the Civic post-test indicated that the right rear door was a load path during the impact event (as was the left rear door). This was evidenced by the crush damage that door exhibited. The camera mount on the door may have limited the crush in this area. However, the influence of the mount could not be quantified. To avoid this potential non-representative effect on the subsequent tests, the rear door camera and mount were not used.

6. Test Preparation and Test Procedure

The tests were conducted as close as practicable to the procedures outlined in the test reports for the NHTSA tests and specified in FMVSS 301. Overlap was determined by lateral measurement at the widest point of the car's body vertically in line with the center of the rear wheels.

An instrumented Hybrid III 50th percentile adult male anthropomorphic test device (ATD, or alternatively referred to as test dummy) was positioned in the driver and right front passenger seating positions. FMVSS 208 ("Occupant Crash Protection") positioning procedures (mid fore-aft seat track position, etc.) were used. Each dummy was restrained by the standard equipment 3-point lap and shoulder belt at its seating position. Test dummy instrumentation is described in the next section of this report.

The test vehicle's brakes were not engaged initially and its transmission was in neutral. To retard the vehicle's post-impact motion, the test vehicle's brakes were activated using an auxiliary source approximately 250-300 msec after impact time-zero. The moving barrier motion was also retarded approximately 250 msec after impact time-zero.

Impact speed was measured with radar equipment.

The crash event was recorded by high-speed motion picture cameras as described in Section 7 of this report.

A total of 92 data channels were recorded for each test as follows:

- 39 on each test car
- 26 on the driver test dummy
- 21 on the passenger test dummy
- 6 on the moving barrier.

Section 7 of this report provides additional instrumentation information.

A post-test static roll-over test was conducted according to FMVSS 301 practices following the Civic, Escort and Sentra impact tests. The roll-over test was not conducted following the Jetta and Cavalier impact tests. This decision for the Jetta and Cavalier was based on the need to drain the fuel tank quickly post-test at the impact site to reduce the clean-up task associated with the amount of Stoddard which spilled from the tank.

7. Instrumentation and Camera Coverage

Each test car was instrumented to make the following measurements:

- Center front radiator tie bar 3-axis accelerations
- Upper engine 3-axis accelerations
- Left and right front seat outboard mounting rail 3-axis accelerations
- Left and right front seat back 3-axis accelerations
- Left and right front rocker 3-axis accelerations
- Left and right rear rocker 3-axis accelerations
- Center rear seatback close-out panel 3-axis accelerations
- Left and right rear frame rail 3-axis accelerations.

The moving barrier was instrumented to make the following measurements:

- center of gravity 3-axis accelerations
- rear cross member 3-axis accelerations.

Each test dummy was instrumented to make the following measurements for injury assessment purposes:

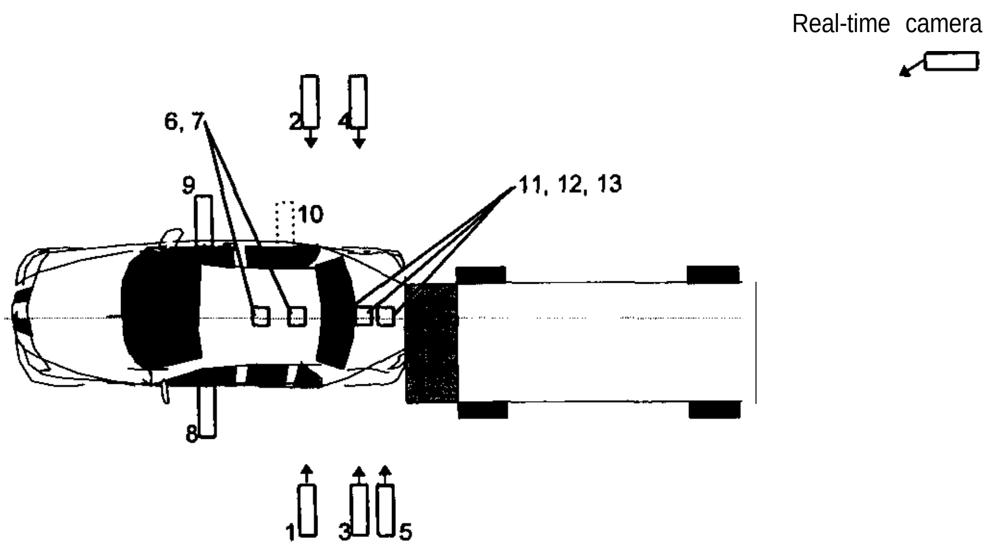
- Head 3-axis accelerations
- Thorax (chest) 3-axis accelerations
- Head/neck interface (upper neck):
    - longitudinal shear force (Fx)
    - lateral shear force (Fy)
    - axial force (Fz)
    - moments about longitudinal, lateral and vertical axes (Mx, My, Mz)
- Neck/torso interface (lower neck) - driver dummy only:
    - longitudinal shear force (Fx)
    - lateral shear force (Fy)
    - axial force (Fz)
    - moments about longitudinal, lateral and vertical axes (Mx, My, Mz)

- Chest (sternum) compressive displacement
- Lower lumbar:
  - longitudinal shear force (Fx)
  - axial force (Fz)
  - moment about lateral axis (My)
- Pelvis 3-axis accelerations
- Femur axial loads, left and right femurs.

Real-time and high-speed motion picture cameras were used to film each test. Cameras were located as illustrated in Figure 2. Post-test conditions and the post-test static roll-over tests were documented by video camera.

Still photographs also were taken to document the pre- and post-test conditions of each test.

Figure 2 - High-speed Motion Picture Camera Locations



1, 2 - Overall side view
3, 4 - Rear half side view
5 - Fuel filler / quarter panel side view
6 - Overall overhead offboard
7 - Rear half overhead offboard
8 - Driver rearward motion onboard
g - Passenger rearward motion onboard
10 - Driver / passenger rearward motion onboard - Civic only
11 - Underbody wide angle in pit
12 - Underbody fuel tank area in pit
13 - Underbody fuel tank area in pit

8. Test Results

Fuel System Integrity

Fuel system integrity test results are summarized in Table 5. Additional details are provided in the paragraphs below. Representative post-test photographs are provided in Appendix C. For reference, the relevant FMVSS 301 Stoddard fluid fuel system spillage limits by weight are: 28 grams / minute and 142 grams / 5 minutes.

Civic - There was no fuel system fluid spillage from the car during or after the impact test or during the two subsequent quasi-static roll-over tests. The car was rolled in both the clockwise and counterclockwise directions about its longitudinal axis.

Escort - A trace amount (0.3 gram) constituting a few drops of Stoddard fluid dripped from the vehicle during the 30 minutes after impact. The source of the spillage could not be confirmed at the impact test site.

During the first 90-degree quadrant of the post-test quasi-static roll-over test (the fuel filler neck side of the car was rolled downward first), an amount of Stoddard fluid noticeably exceeding 142 grams spilled from the fuel filler cap area in the first 5 minutes. Due to this result, the remaining roll-over testing was terminated. Inspection revealed that the fuel filler cap exterior had fractured off, and the top end of the filler neck had deformed. The plastic "plug" or sealing portion of the cap remained in the filler neck. However, a portion of the plug periphery appeared to have deformed and partially fractured during the impact test, allowing the spillage during the roll-over test. This result appeared to have been caused by the local deformation and crash forces in the fuel filler area.

Jetta - During the first 5 minutes after impact, at least 421 grams of Stoddard fluid spilled from the vehicle. The spillage source appeared to be from somewhere on the top of the fuel tank. The fuel tank top was not visible or accessible at the impact site due to the impact deformation of the car.

Due to the amount of fluid spillage at the impact test site, and the need to quickly drain the fuel tank to reduce the site clean-up task, it was decided not to conduct the quasi-static roll-over test. Instead, a post-test inspection and partial disassembly of the test car were conducted to reveal the site of the fluid spillage. Many of the vehicle components in the rear of the vehicle (suspension, wheels, etc.) had to be removed (some cut away) to extricate the plastic fuel tank in order to inspect its top. Additionally, the tank had to be cut away from its integral filler neck to remove the tank from the vehicle.

Inspection revealed a fracture (hairline type crack) in the fuel sender unit plastic sealing plate on the tank top side. The fracture was at the base of the attachment of the sender unit electrical connector to the sealing plate. This fracture site was confirmed by partially refilling the tank, inverting it, and observing the Stoddard fluid leakage through the crack. It appeared that crash forces exerted by contact of the connector/attachment with the floor pan may have caused the fracture.

Sentra - There was no fuel system fluid spillage during the 30 minutes after the impact test. There also was no spillage during the first quasi-static roll-over test which placed the fuel filler side (left side) of the car downward during the first quadrant of the roll.

Similarly, no spillage occurred during the first two quadrants of the second quasi-static roll-over test. However, during the 3rd quadrant of this roll-over (the fuel filler side of the car was downward during this quadrant), a trace amount (a few drops, substantially less than 28 grams) of Stoddard fluid spillage was observed. The spillage came from the vent tubing which had become disconnected from the vapor canister due to the crash forces. The vapor canister was located on the car's left side outboard of the spare tire tub.

Cavalier - During the first 5 minutes after impact, at least 450 grams of Stoddard fluid spilled from the vehicle. The spillage came from a cut in the fuel tank. The deformed right rear underside of the tank had been penetrated by a protruding edge (from crash deformation) of the intruding right side rear suspension trailing arm bracket.

Due to the amount of fluid spillage at the impact test site, and the need to quickly drain the fuel tank to reduce the site clean-up task, the quasi-static rollover tests were not conducted for the Cavalier. A post-test inspection confirmed the tank fuel spillage location and cause.

Table 5 - Fuel System and Injury Measurements Performance Results Summary

	Impact Speed (km/h)	Impact Test Stoddard Spillage	Roll-over Test Stoddard Spillage	Test Dummy Data
Civic	80.7	None	None	All < IARVs*
Escort	80.9	Trace**	> FMVSS 301 limits Fractured fuel filler cap seal	RF HIC > IARV All others < IARVs
Jetta	81.2	> FMVSS 301 limits Fractured fuel sender seal plate	No roll-over conducted	All < IARVs
Sentra	81.0	None	Trace**	All < IARVs
Cavalier	81.0	> FMVSS 301 limits Cut in fuel tank	No roll-over conducted	RF HIC > IARV RF Nk. Ext. > IARV All others < IARVs

* IARV = Injury Assessment Reference Value
** Trace = a few drops (<< 28 grams)

Front Seat Test Dummy Injury Measurements

Table 5 also summarizes the front seat test dummy injury measurement results. Data plots for the head and neck injury measurements are provided in Appendix D -- no other injury criteria limits except for the head and neck were exceeded in any of the Project B.5 tests conducted by GM. Additional details are provided in the following paragraphs.

Civic - None of the Injury Assessment Reference Values (IARVs) described in Appendix E were exceeded for either front seat test dummy.

Escort - The right front passenger test dummy head injury criteria, or HIC (1370), exceeded the IARV (1000). The rear of the dummy's head contacted the intruding right side rear seat back during the time interval of this maximum HIC measurement. No other IARVs were exceeded for the driver and passenger test dummies.

Jetta - None of the IARVs were exceeded for either front seat test dummy.

Sentra - None of the IARVs were exceeded for either front seat test dummy

Cavalier - The right front passenger HIC exceeded the IARV (1000) by an unknown amount. The dummy head longitudinal acceleration data channel exceeded its full scale value (approximately 150 g) during the time interval in which the rear of the dummy's head contacted the intruding rear seat back and rear package shelf. The right front dummy neck extension moment (103 N•m) also exceeded the IARV (57 N•m). No other IARVs were exceeded for either dummy.

Test Vehicle Velocity Change and Residual Crush

Table 6 summarizes two measurements illustrating the crush performance for each test car. The first is the longitudinal velocity change (delta V) the car experienced. The delta V was obtained by integrating the car's longitudinal acceleration measured at the front rocker on the side opposite to the impact overlap side. Corresponding data plots are provided in Appendix F. The second measurement is the residual crush or difference between the pre-test and post-test static longitudinal reference measurements made on the vehicle.

Table 6 - Delta V and Crush Results

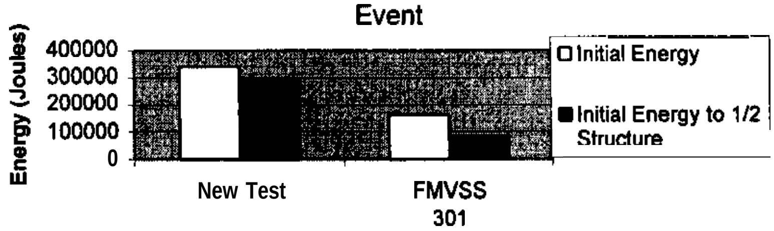
	Car Delta V (km/h)	Car Residual Crush Driver I Passenger Sides (mm)
Civic	41.5	1190 / 465
Escort	40.5	1030 / 495
Jetta	40.4	490 I 990
Sentra	42.8	970 / 465
Cavalier	40.2	640 / 1250

9. Discussion and Conclusions

This new rear impact test constitutes a substantial initial impact energy increase over the existing FMVSS 301 rear impact test (Figure 3). Initial impact energy (the kinetic energy of the moving barrier) is approximately twice that of the FMVSS 301 test[1]. In this new test, the kinetic energy of the moving barrier primarily is dissipated by the crush of the test vehicle and the deformable element barrier. In the existing FMVSS 301 rear impact test, the kinetic energy primarily is dissipated by the crush of the test vehicle.

[1] Initial K.E. = $1/2(m)(v)^2$; m and v are the mass and impact velocity, respectively, of the moving barrier. Accordingly, $K.E._{new} / K.E._{301} = (m_{new} / m_{301})(v_{new} / v_{301})^2 = (1368 / 1814)(80.5 / 48.3)^2 = 2.1$.

Figure 3 - Comparison of Initial Energy by Rear Impact Event



Fuel system integrity performance was mixed among the cars in the GM tests, but two of the cars performed reasonably well in this regard. No measure of performance repeatability was available because only one test of each car was conducted.

The potential for occupant injury induced by crash forces in these tests cannot be established from the results of the Project B.5 tests. However, the tests provided some qualitative insight regarding that potential. For example, the front seat test dummy head or neck injury measurement data in two of the Project B.5 tests were above injury assessment reference levels described in Appendix E. Representativeness (biofidelity) of some of the injury measurements has been debated regarding use of the Hybrid III 50th-percentile adult male test dummy in rear impact tests. However, some researchers [12] have found that this test dummy is suitable for rear impact testing. Also, there was noticeable reduction of the rear seat occupant space in the Project B.5 tests. Qualitatively, this space often is associated with rear occupant injury or survivability potential.

Accordingly, even if all small cars could be developed to meet fuel system performance requirements in a repeatable fashion during this test, taken together, the results and observations from the Project B.5 tests suggest that further study may be appropriate regarding what level of crash-induced injury occupants would experience in this type of crash.

References

1. Ragland, Carl L., NHTSA, "Research Tests to Develop Improved FMVSS 301 Rear Impact Test Procedure," paper no. 98-S4-P-16, 16th International Conference on the Enhanced Safety of Vehicles, Windsor, Ontario, Canada, May 31 - June 4, 1998

2. GM Test Report No. PG-68269, Test No. C11817, 1998 Honda Civic 4-door

3. GM Test Report No. PG-68270, Test No. C11818, 1998 For Escort 4-door

4. GM Test Report No. PG-68351, Test No. C11816, 1998 Volkswagen Jetta 4-door

5. GM Test Report No. PG-68353, Test No. C11828, 1998 Nissan Sentra 4-door

6. GM Test Report No. PG-68354, Test No. C11829, 1998 Chevrolet Cavalier 4-door

7. June 26, 1998 letter from David A. Collins (GM) to Philip R. Recht (NHTSA) transmitting test report, test data, video and photographs from the five tests conducted under Project B.5.

8. Ragland, Carl L., Hsia, Hsi-Sheng, NHTSA, "A Case Study of 214 Fatal Crashes Involving Fire," paper no. 98-S4-O-08, 16th International Conference on the Enhanced Safety of Vehicles, Windsor, Ontario, Canada, May 31 - June 4, 1998

9. Title 49 Code of Federal Regulations, Part 571.214, Side Impact Protection (FMVSS 214)

10. Title 49 Code of Federal Regulations, Part 587, Side Impact Moving Deformable Barrier

11. AGARD Report AR-330, " Anthropomorphic Dummies for Crash and Escape System Testing," Advisory Group for Aerospace Research and Development, Neuilly-Sur Seine, France, July 1996.

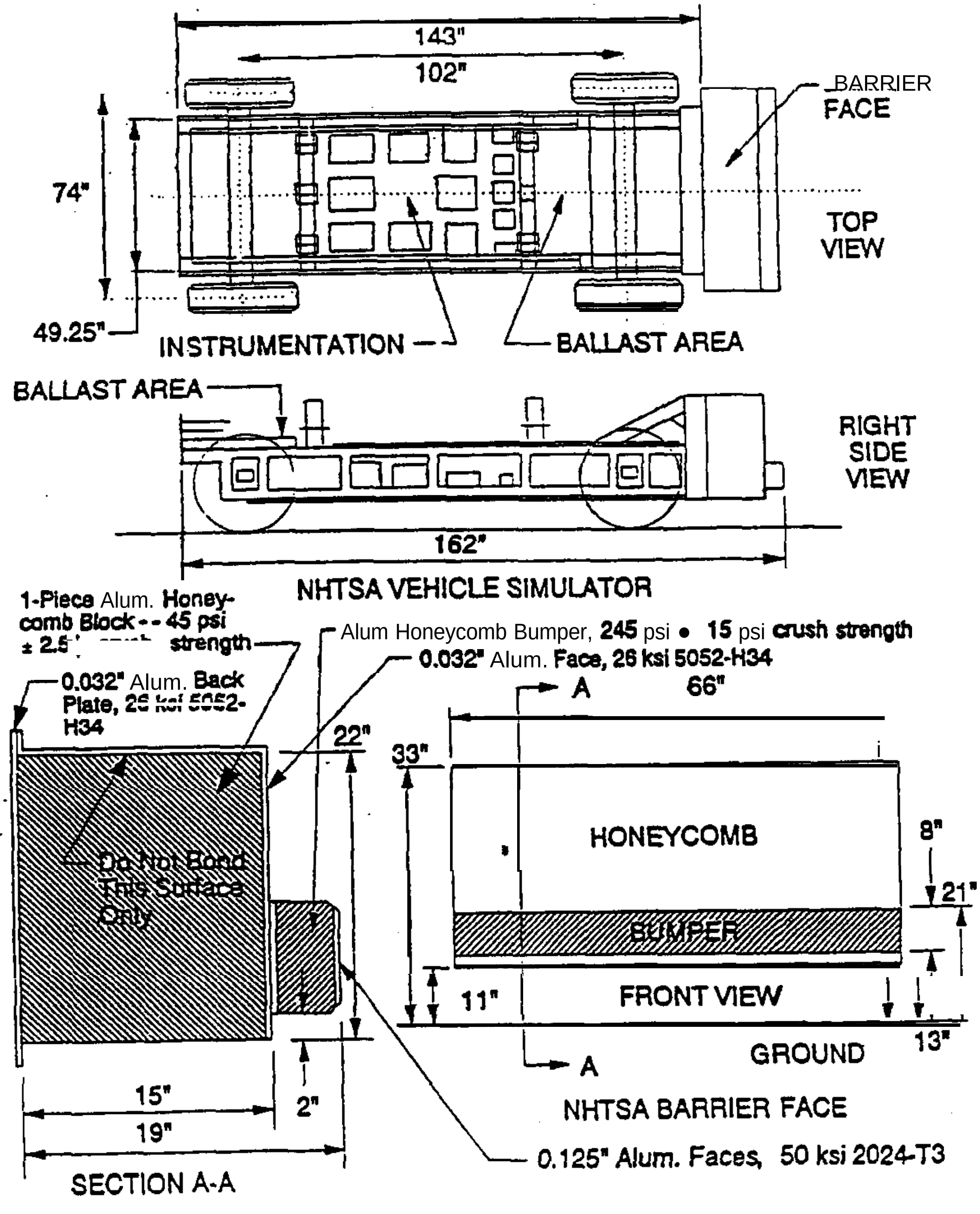
12. Prasad, P., et al, "Biofidelity of Anthropomorphic Test Devices for Rear Impact," SAE Technical Paper No. 973342.

13. Melvin, J.W., "Lumbar Spine Injury Assessment Values for 50th Percentile Male and 5th Percentile Female Dummies," General Motors Corporation research paper, January, 1988.

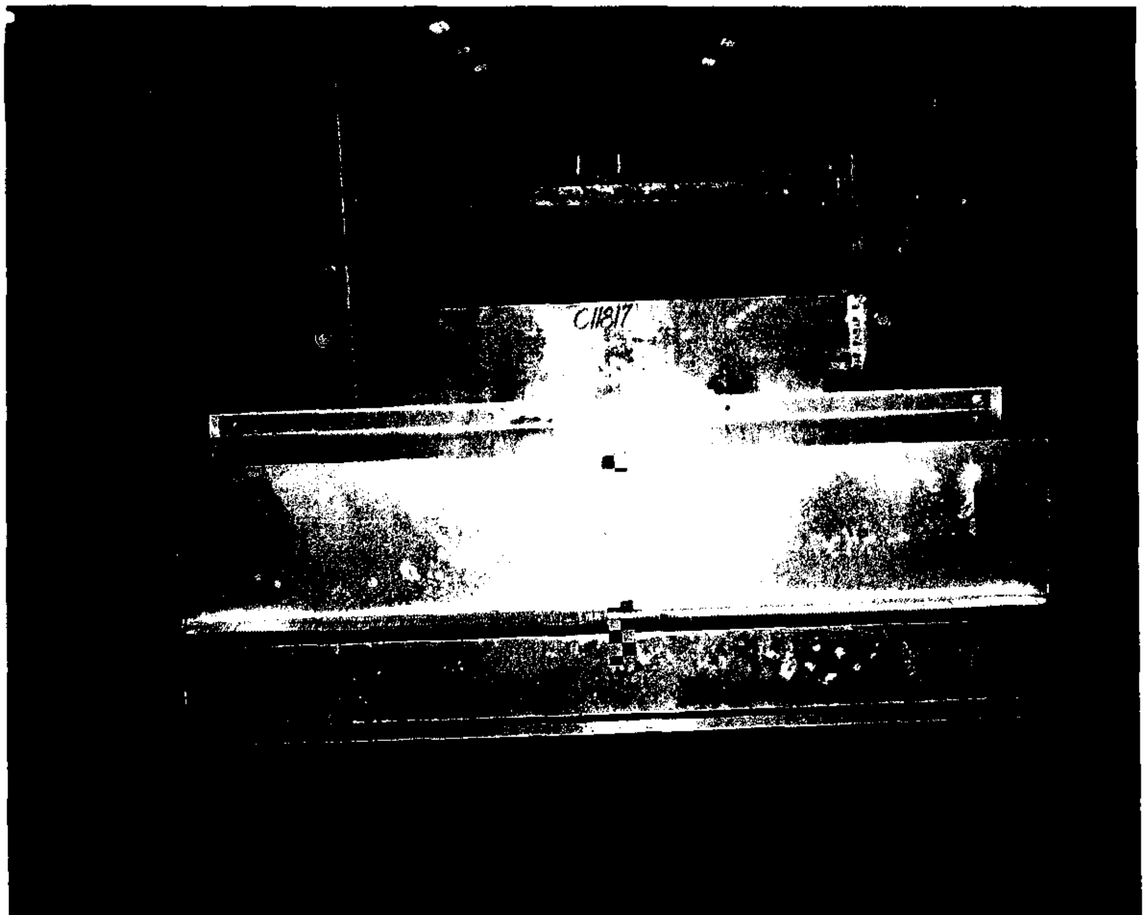
Appendix A

Moving Deformable Barrier

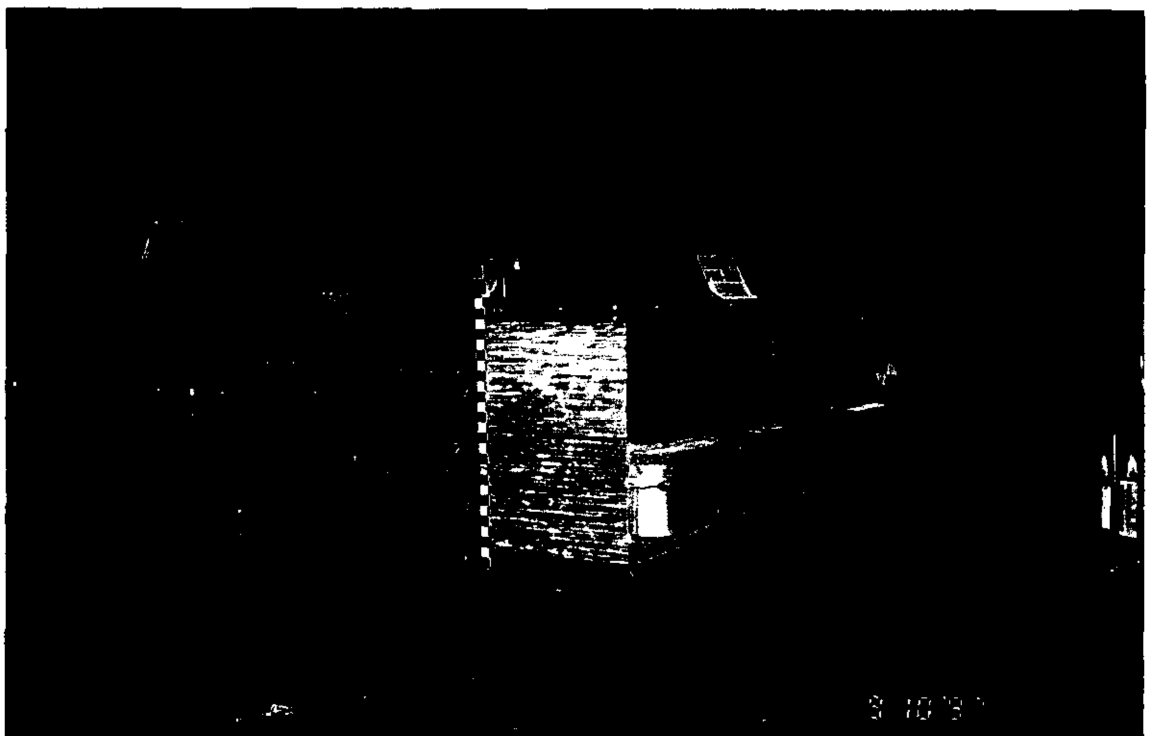
MOTOR VEHICLE SAFETY STANDARD No. **214** SIDE IMPACT PROTECTION -PASSENGER CARS, TRUCKS, BUSES **&** MULTIPURPOSE PASSENGER VEHICLES WITH A **GVWR** OF **10,000** POUNDS OR LESS



NHTSA SIDE IMPACTOR - MOVING DEFORMABLE BARRIER
FIGURE 2



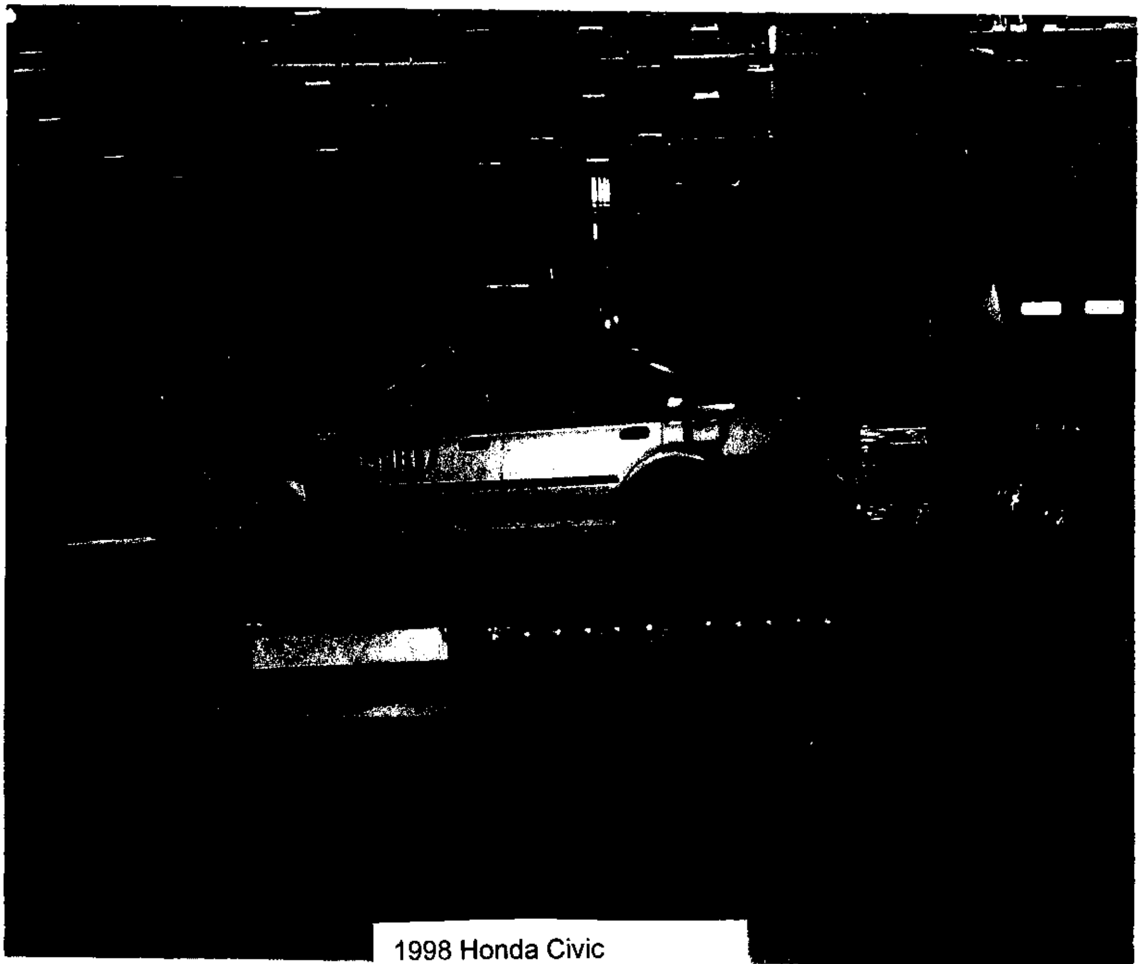
Project B.5 Moving Deformable Barrier



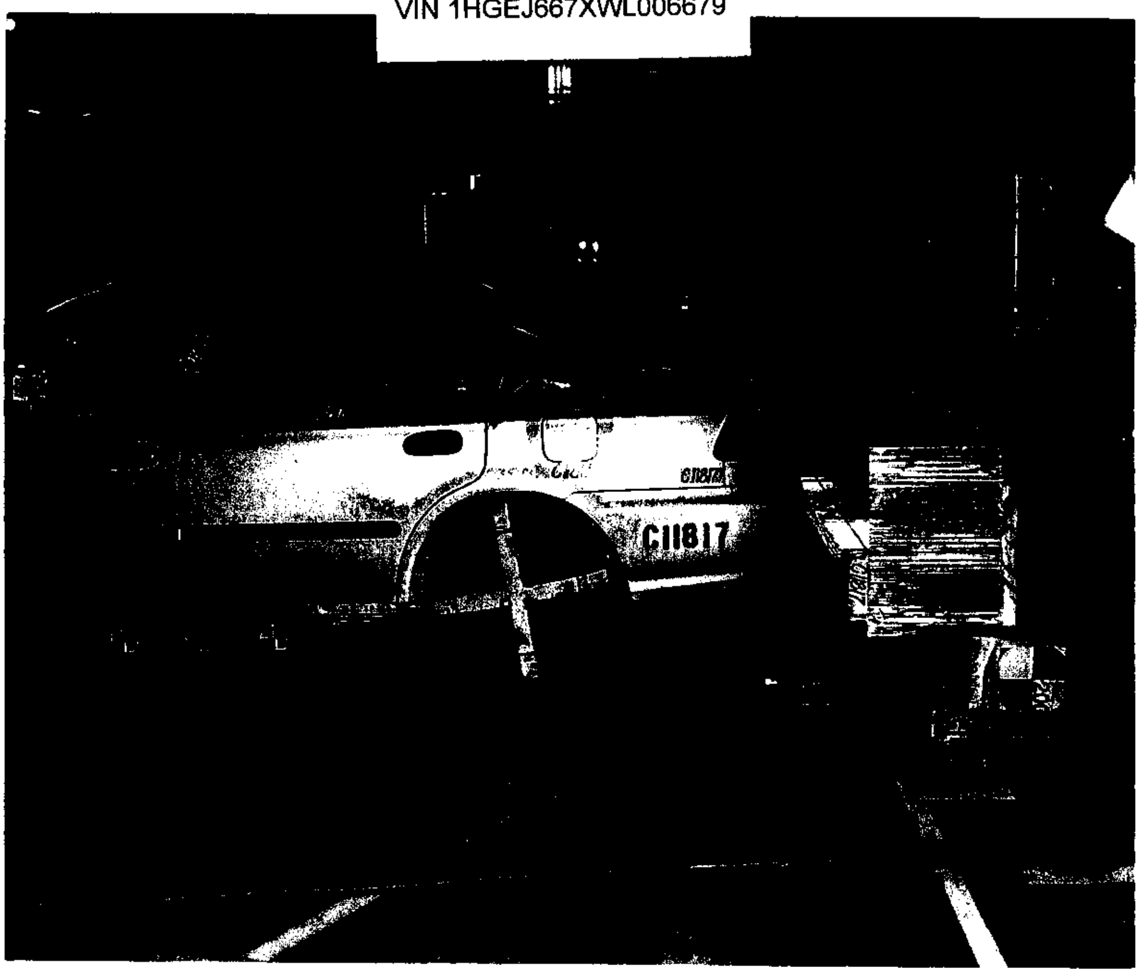
FMVSS 214 Moving Deformable Barrier

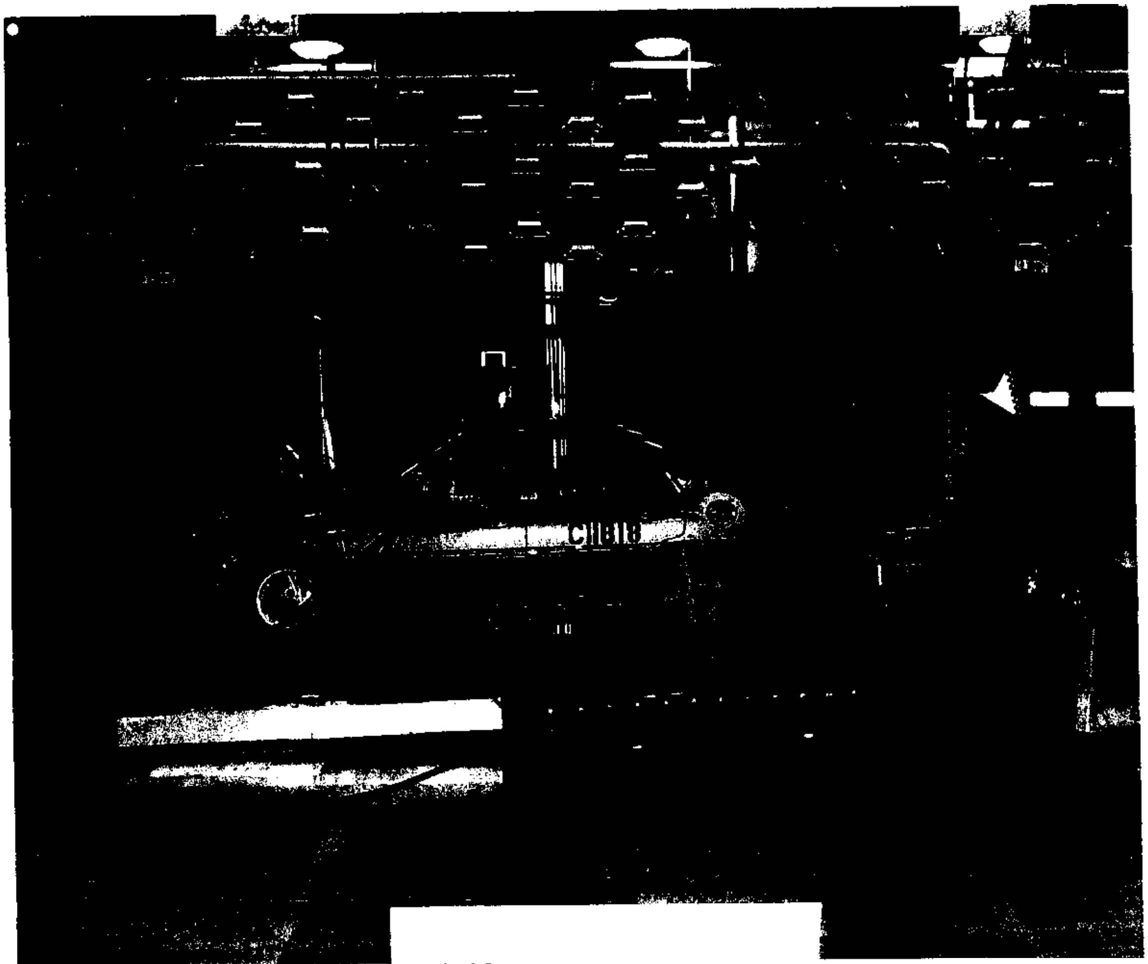
Appendix B

Representative Pre-test Photographs

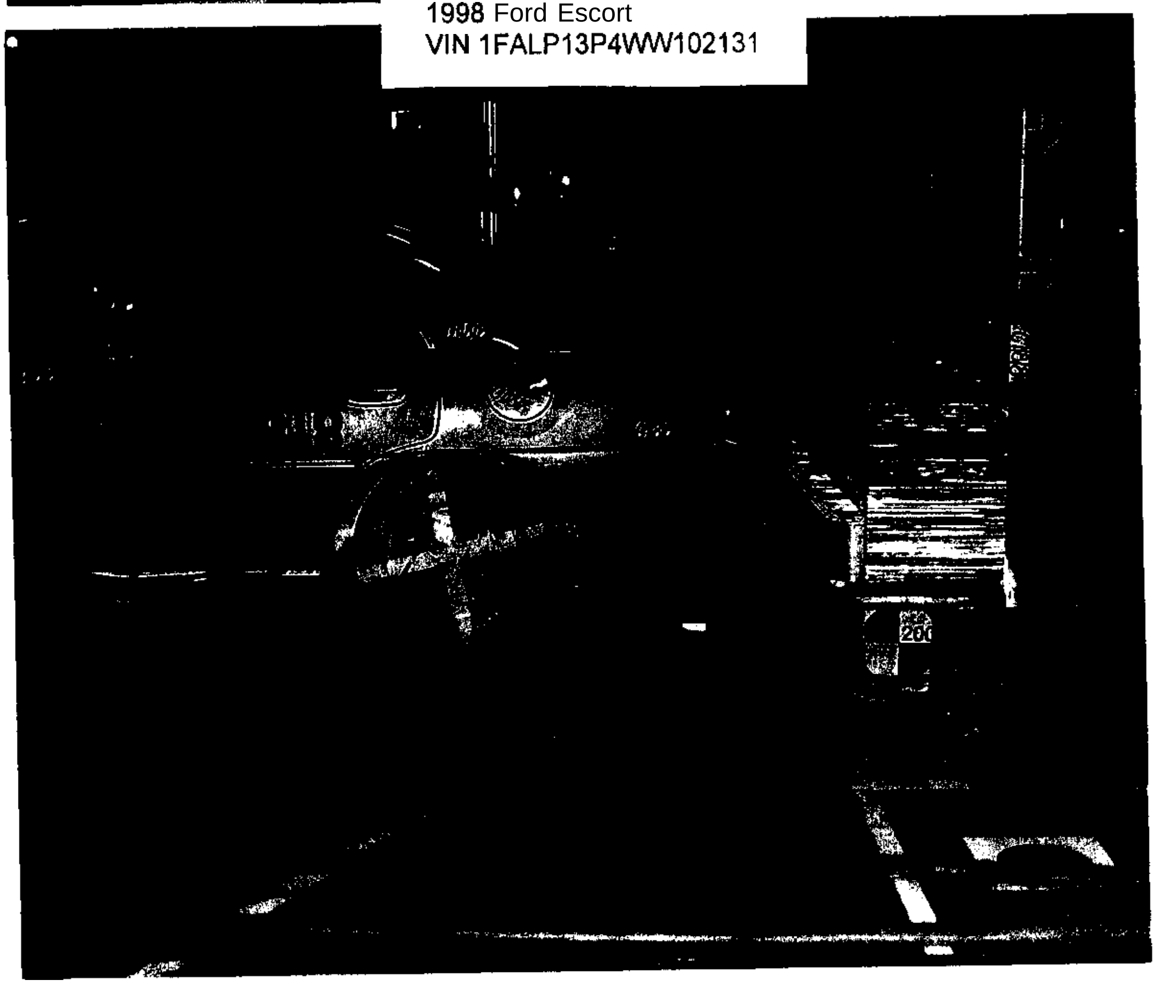


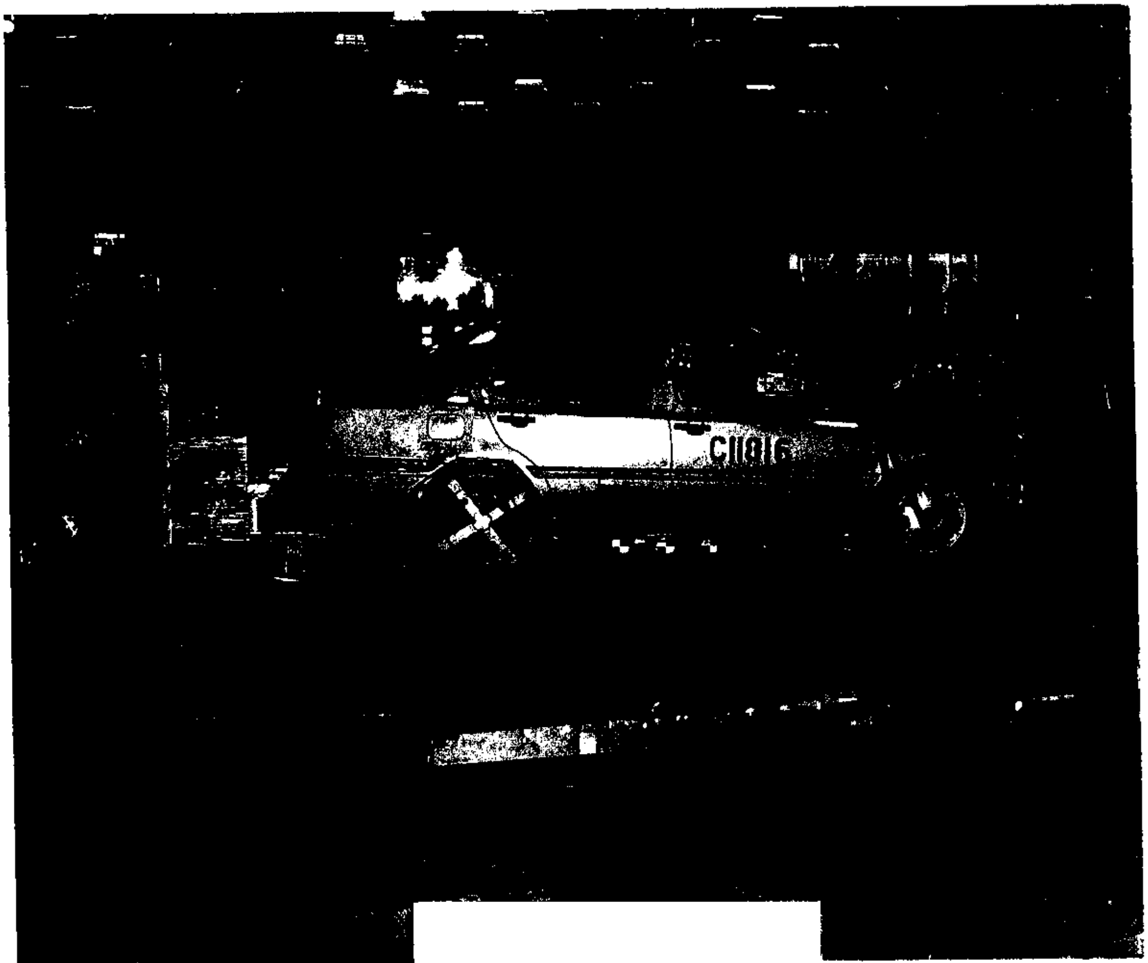
1998 Honda Civic
VIN 1HGEJ667XWL006679



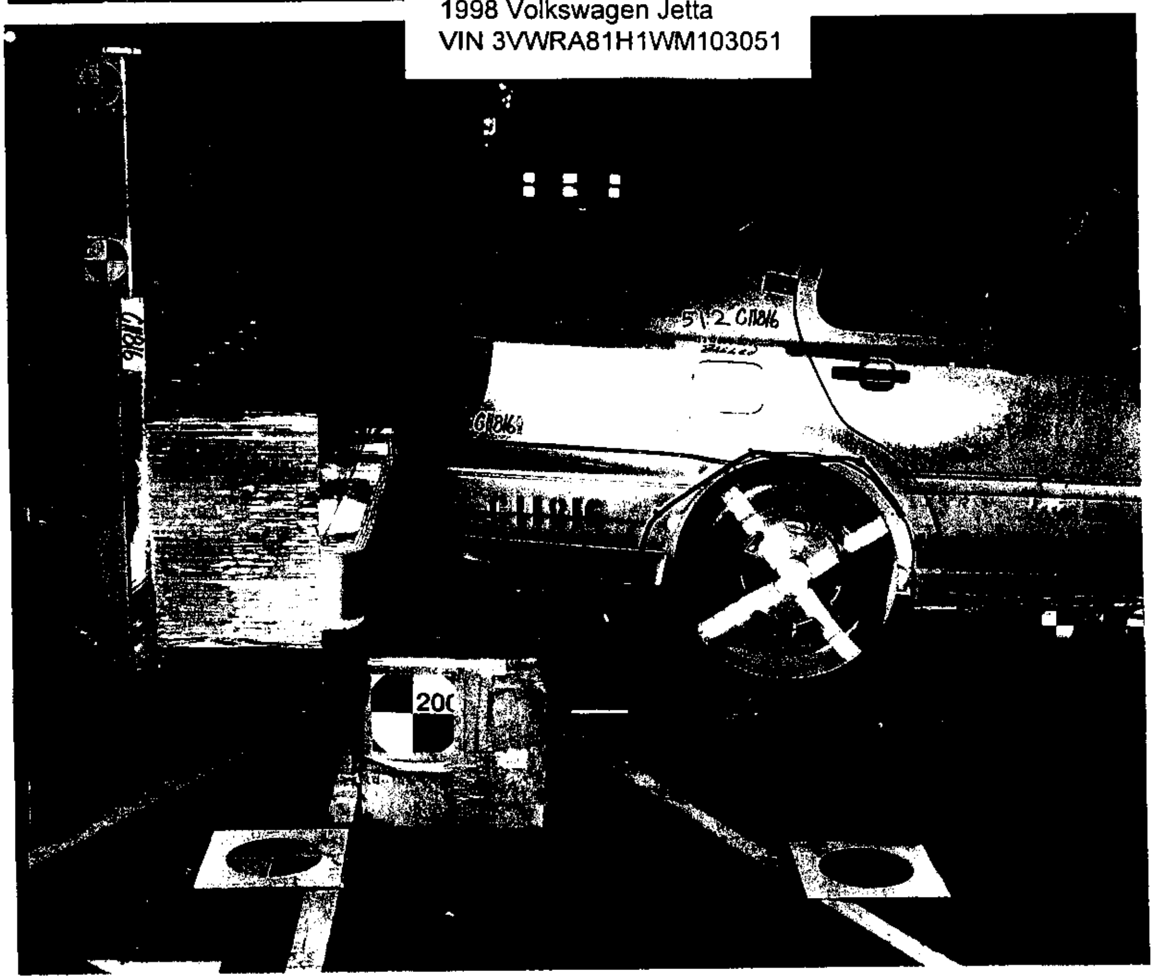


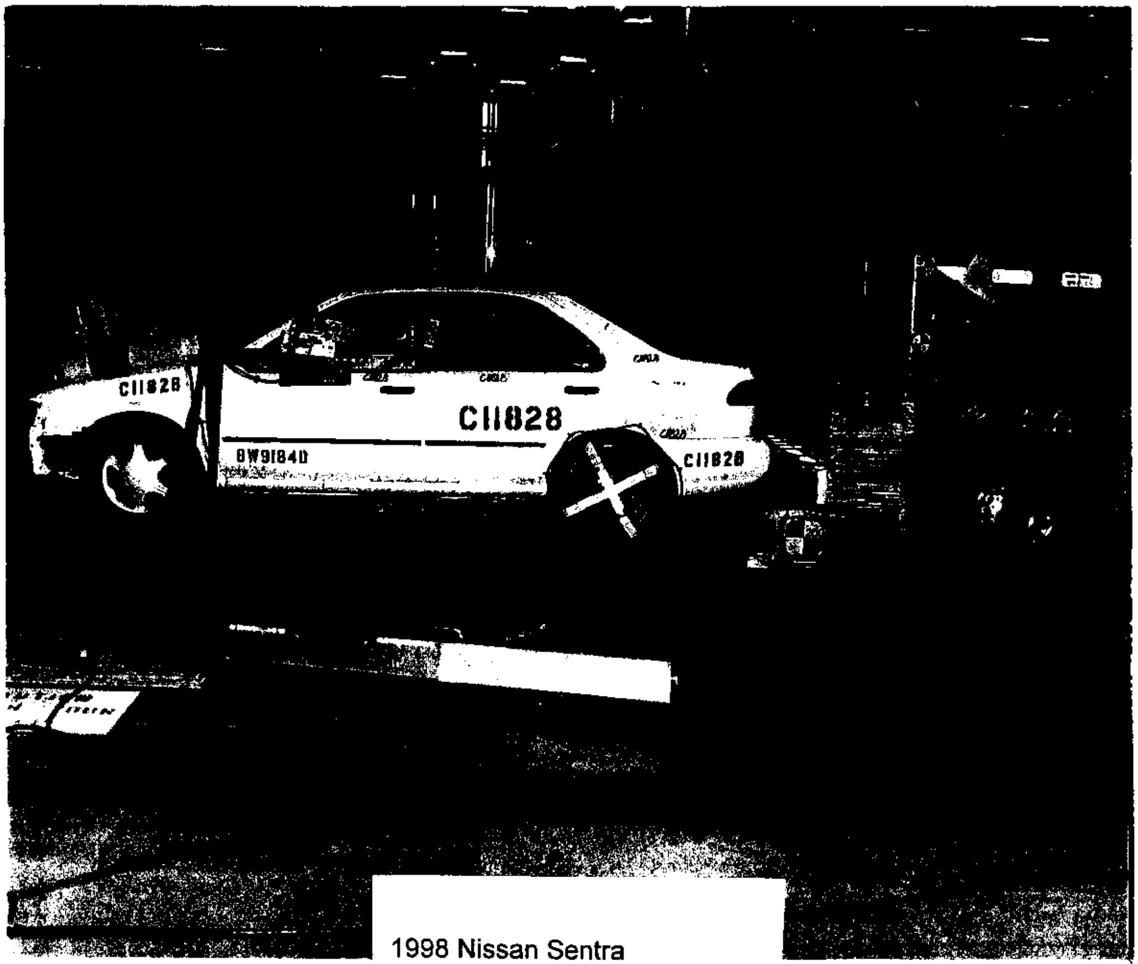
1998 Ford Escort
VIN 1FALP13P4WW102131



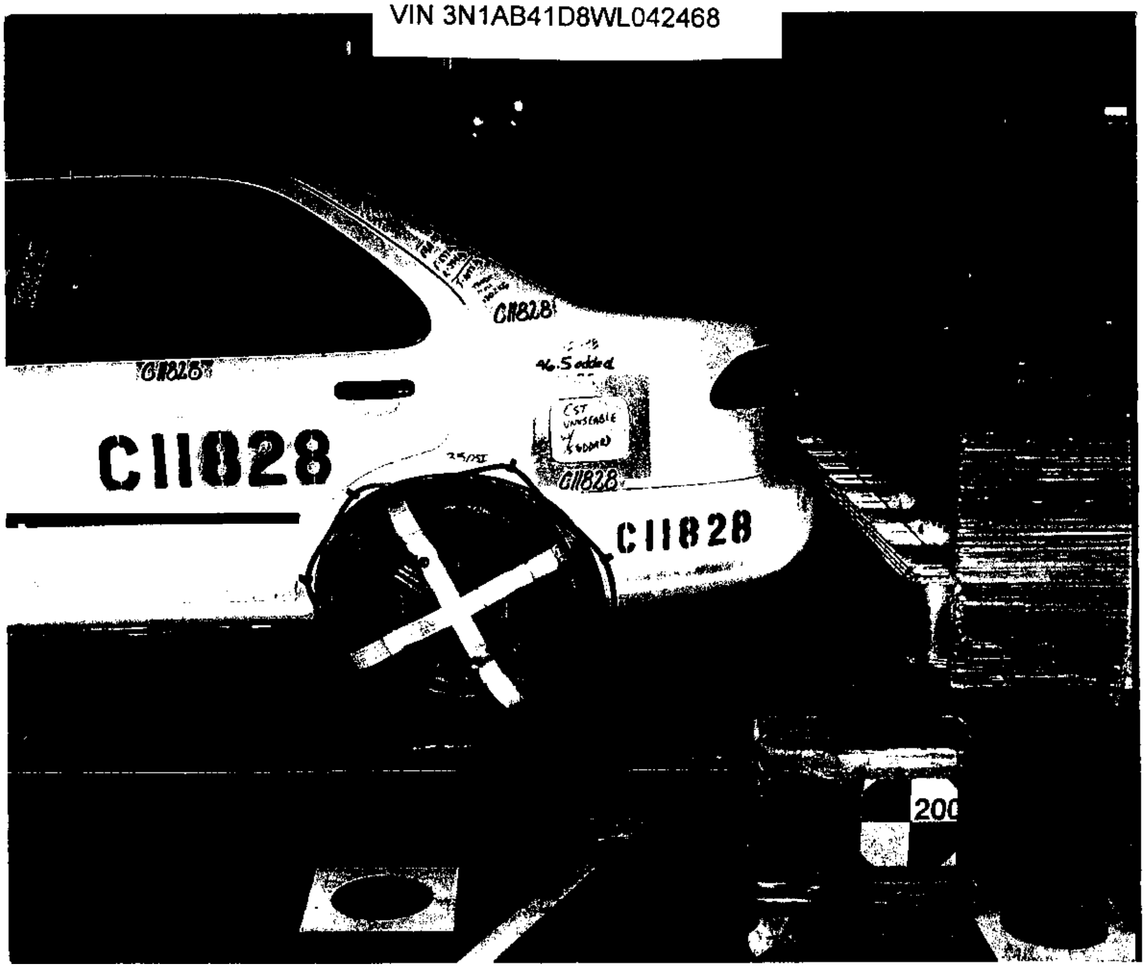


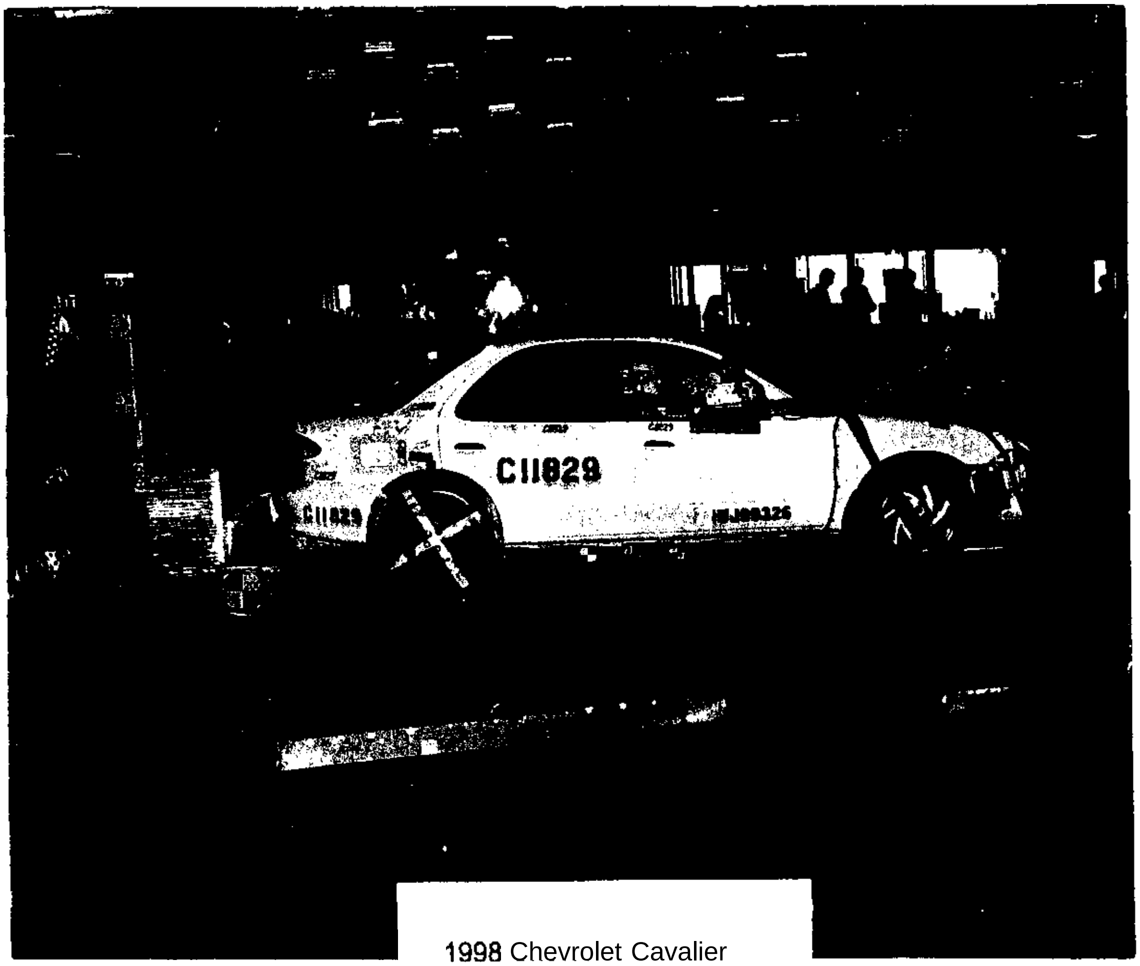
1998 Volkswagen Jetta
VIN 3VWRA81H1WM103051



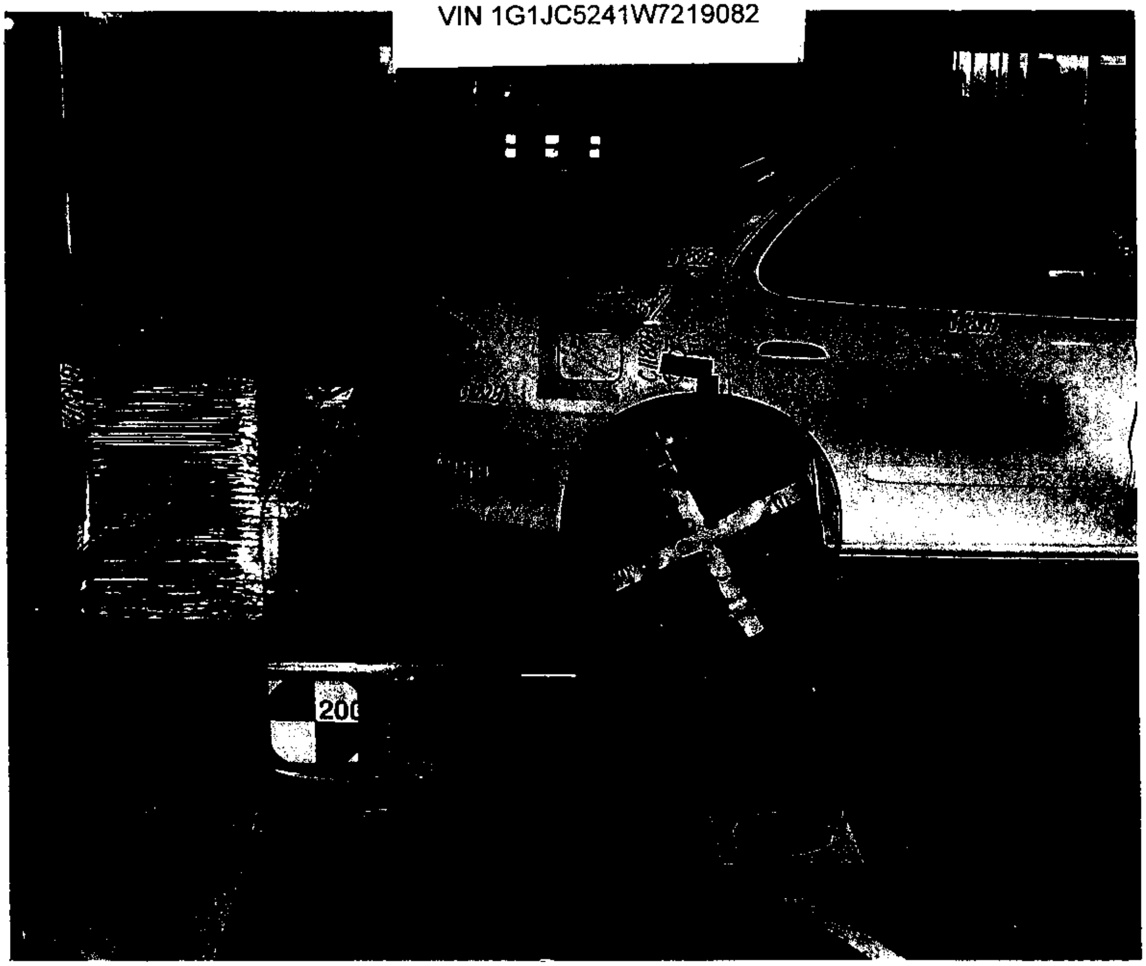


1998 Nissan Sentra
VIN 3N1AB41D8WL042468



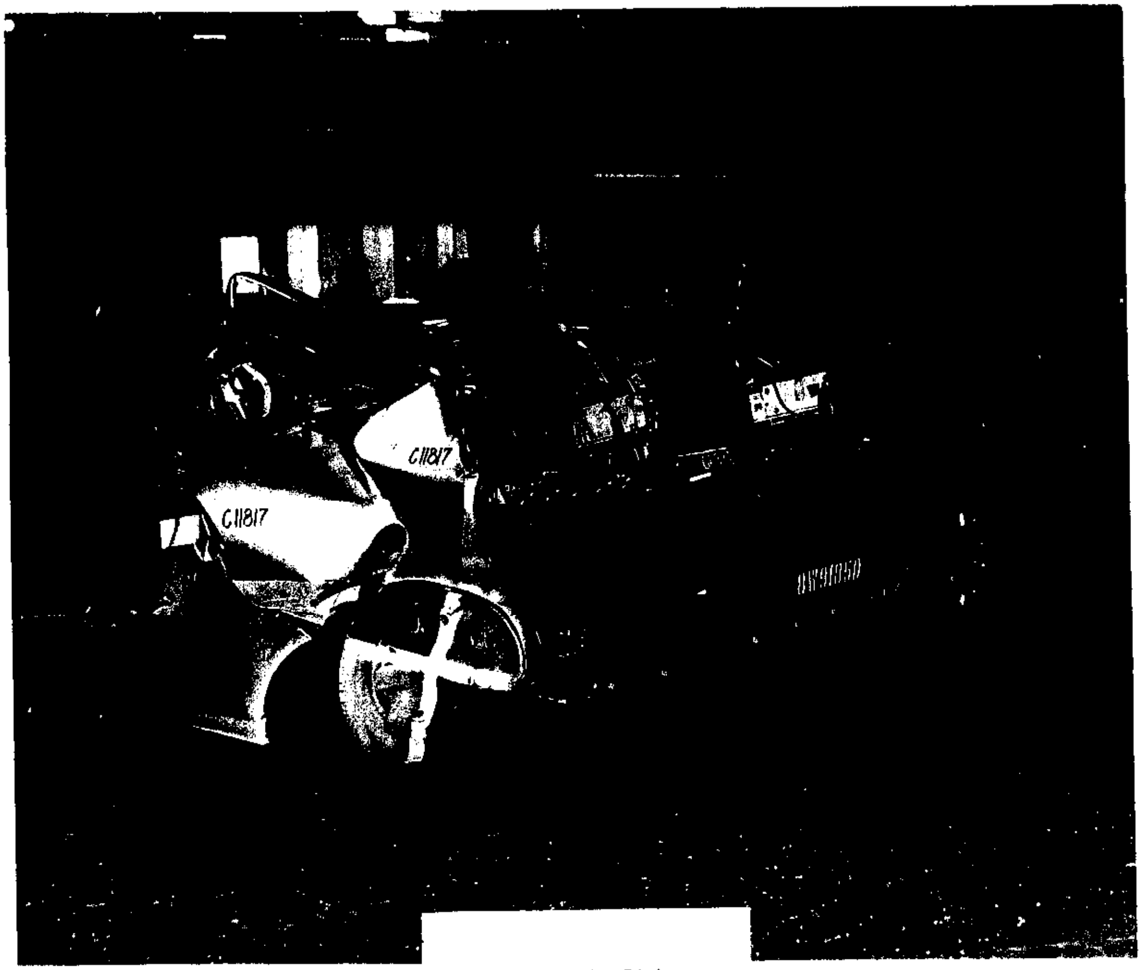


1998 Chevrolet Cavalier
VIN 1G1JC5241W7219082

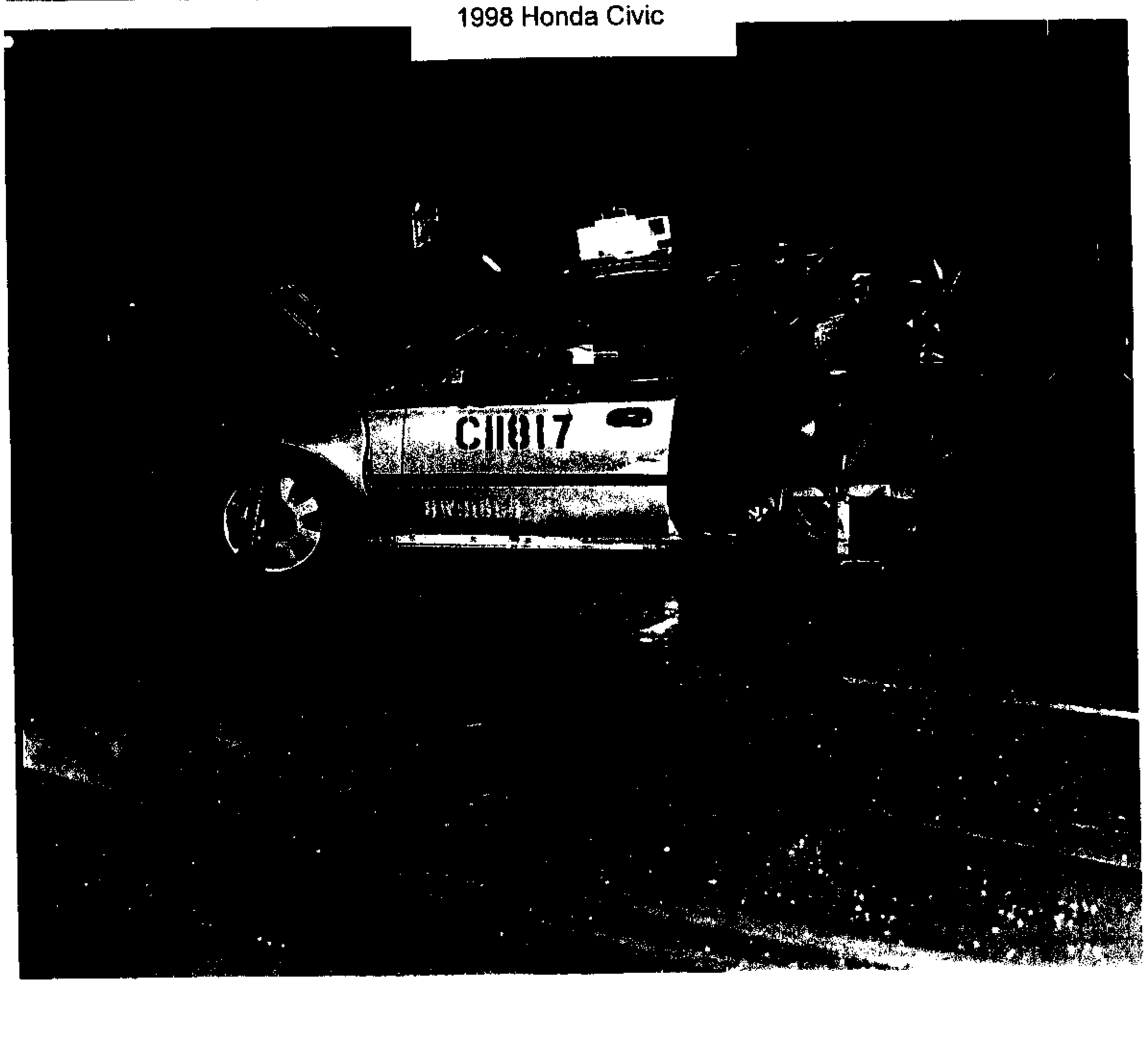


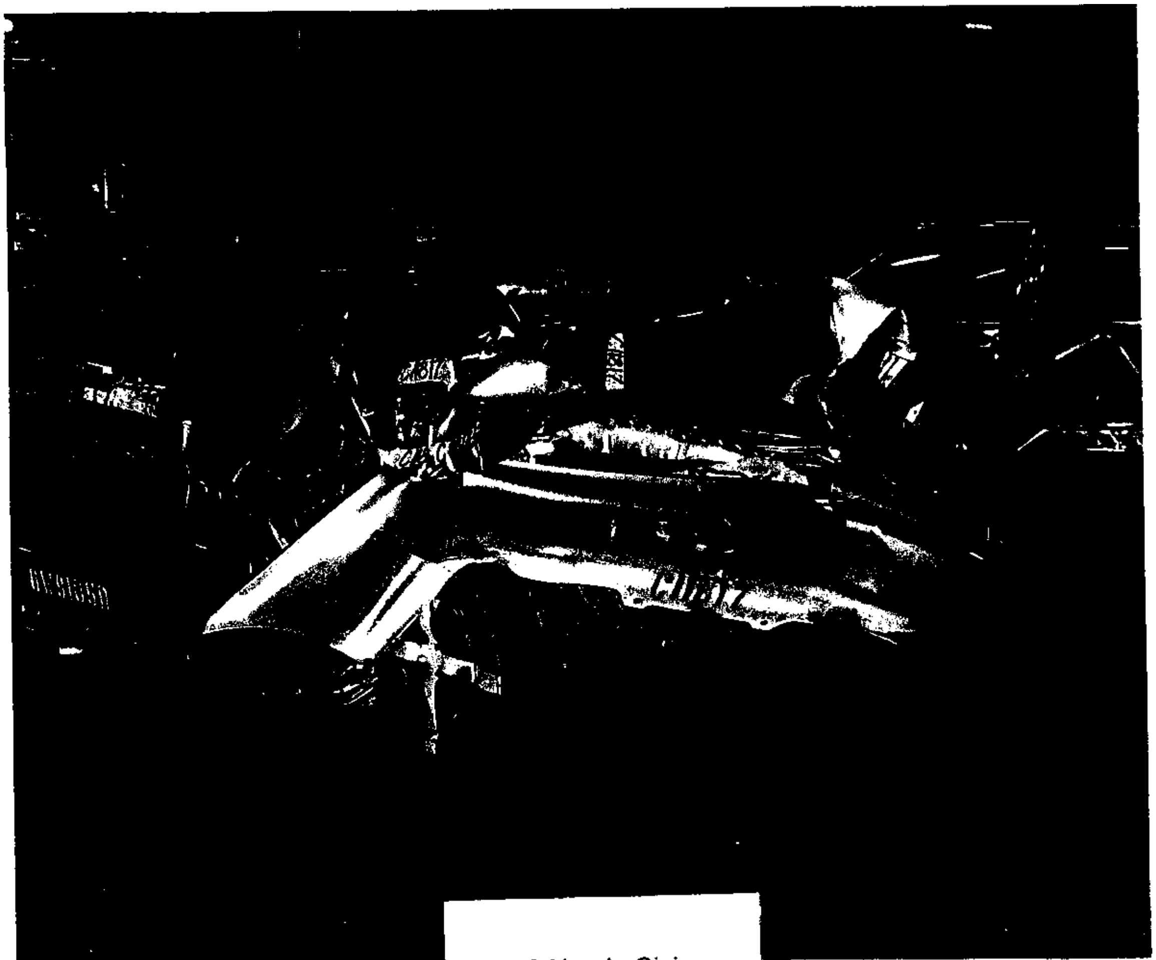
Appendix C

Representative Post-test Photographs

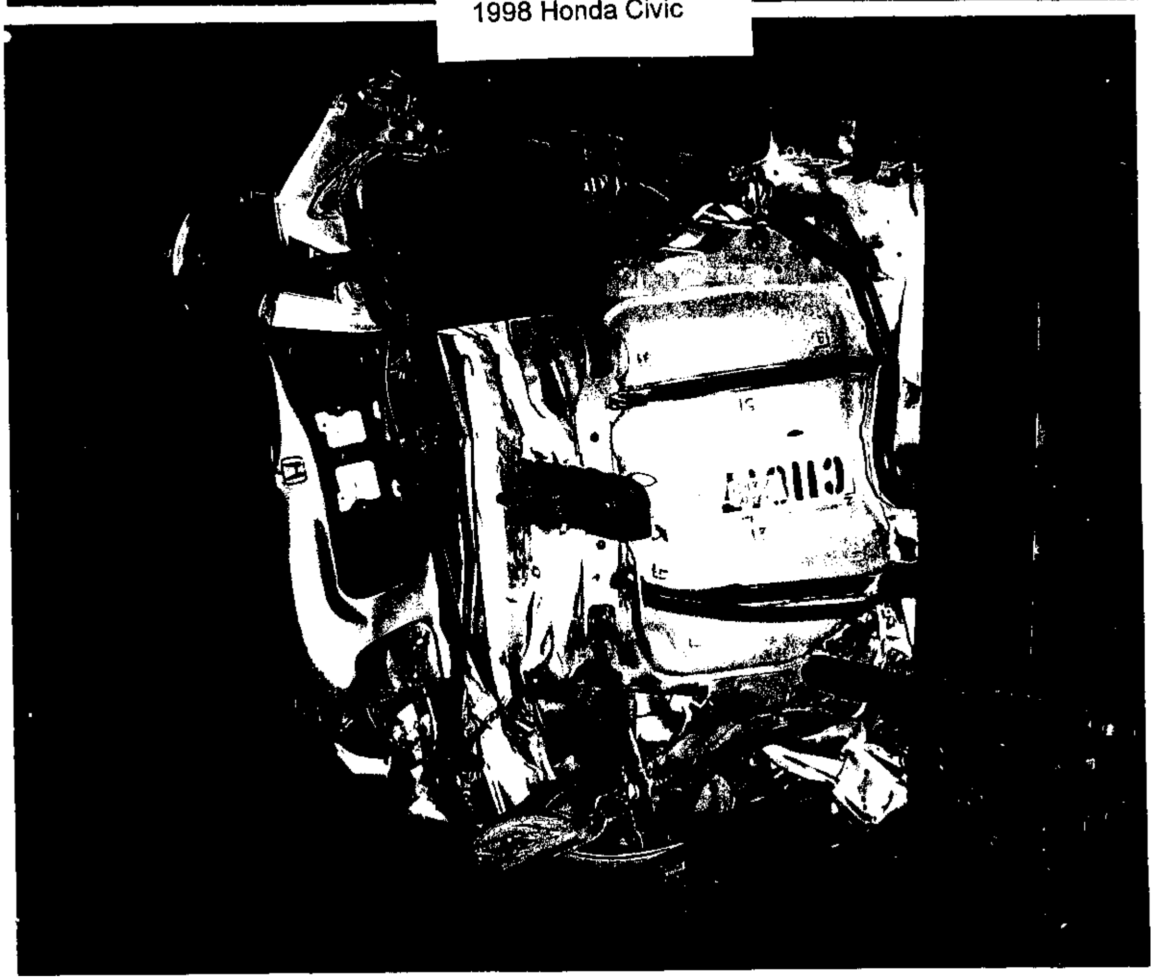


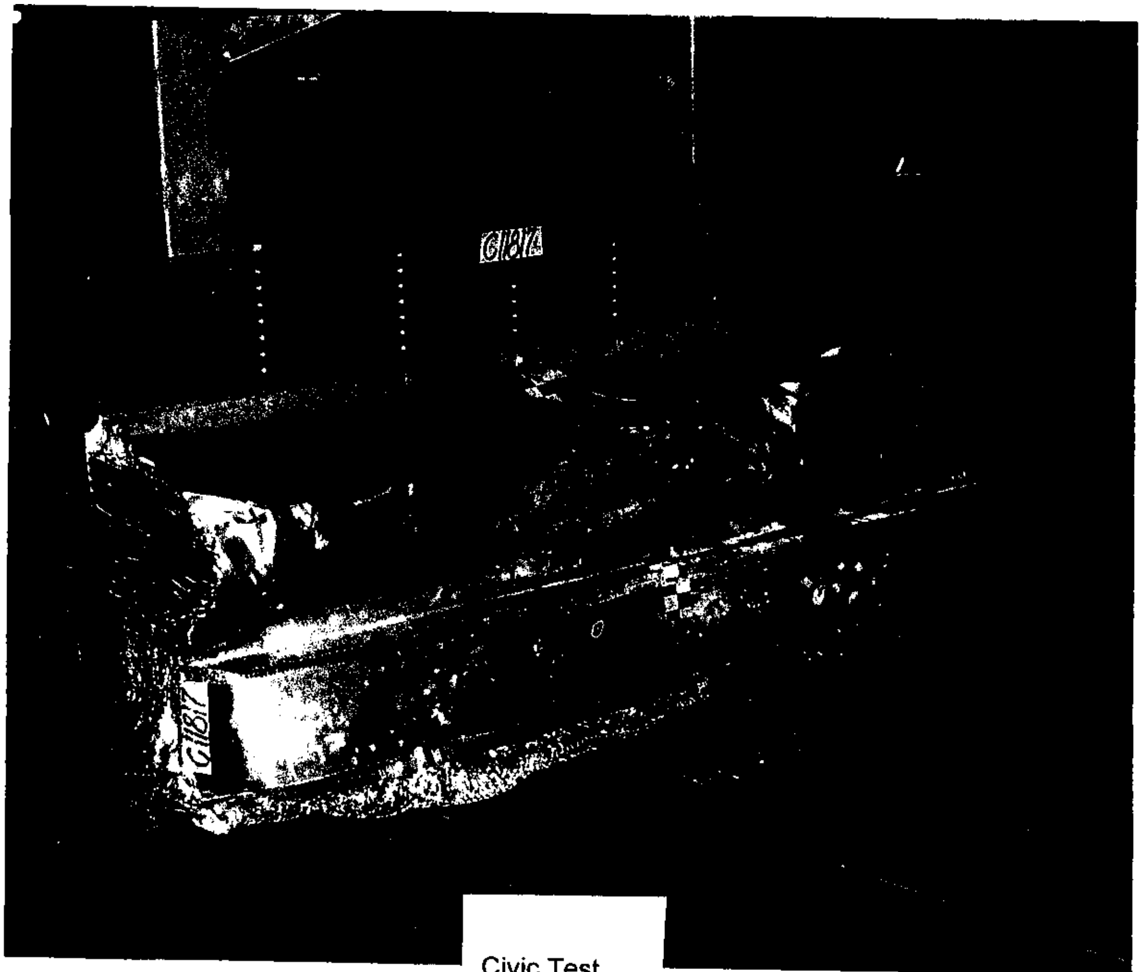
1998 Honda Civic



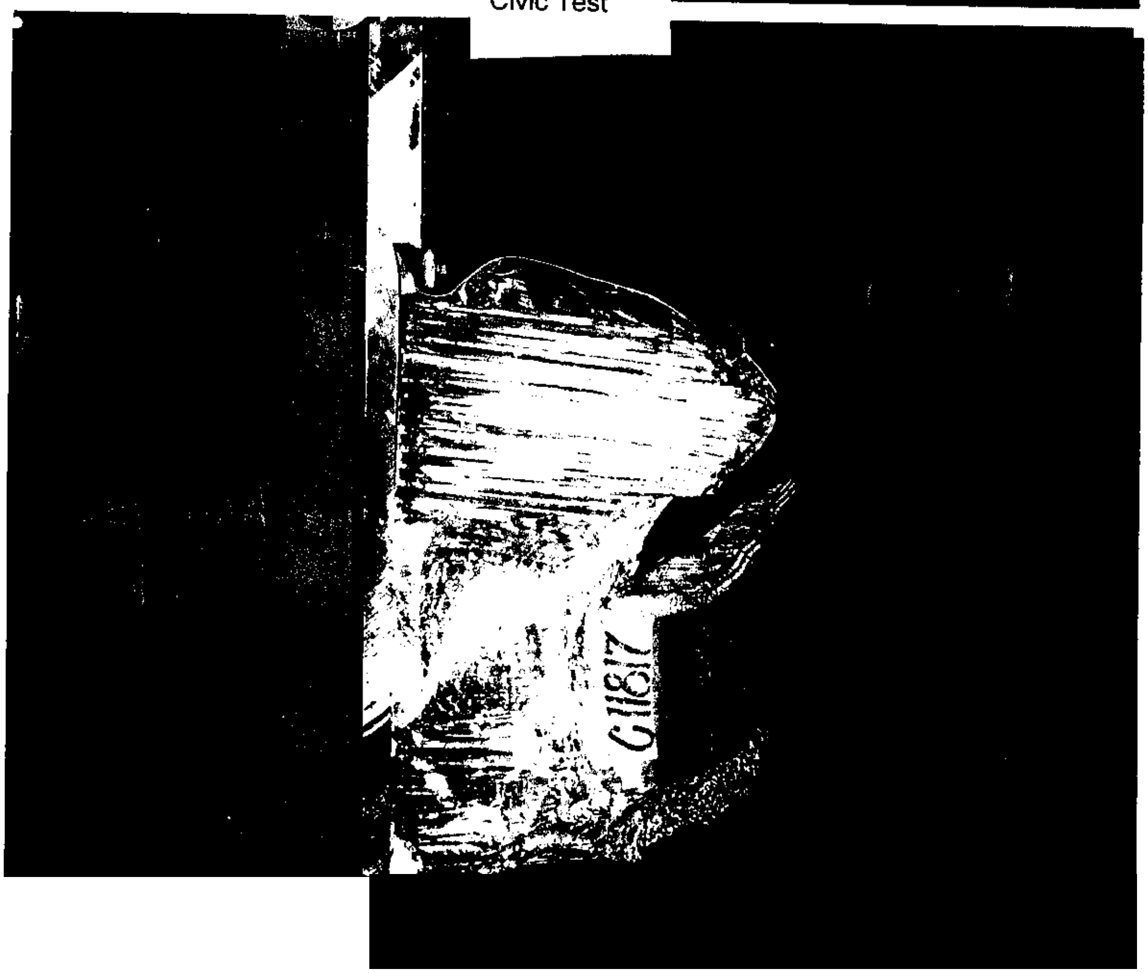


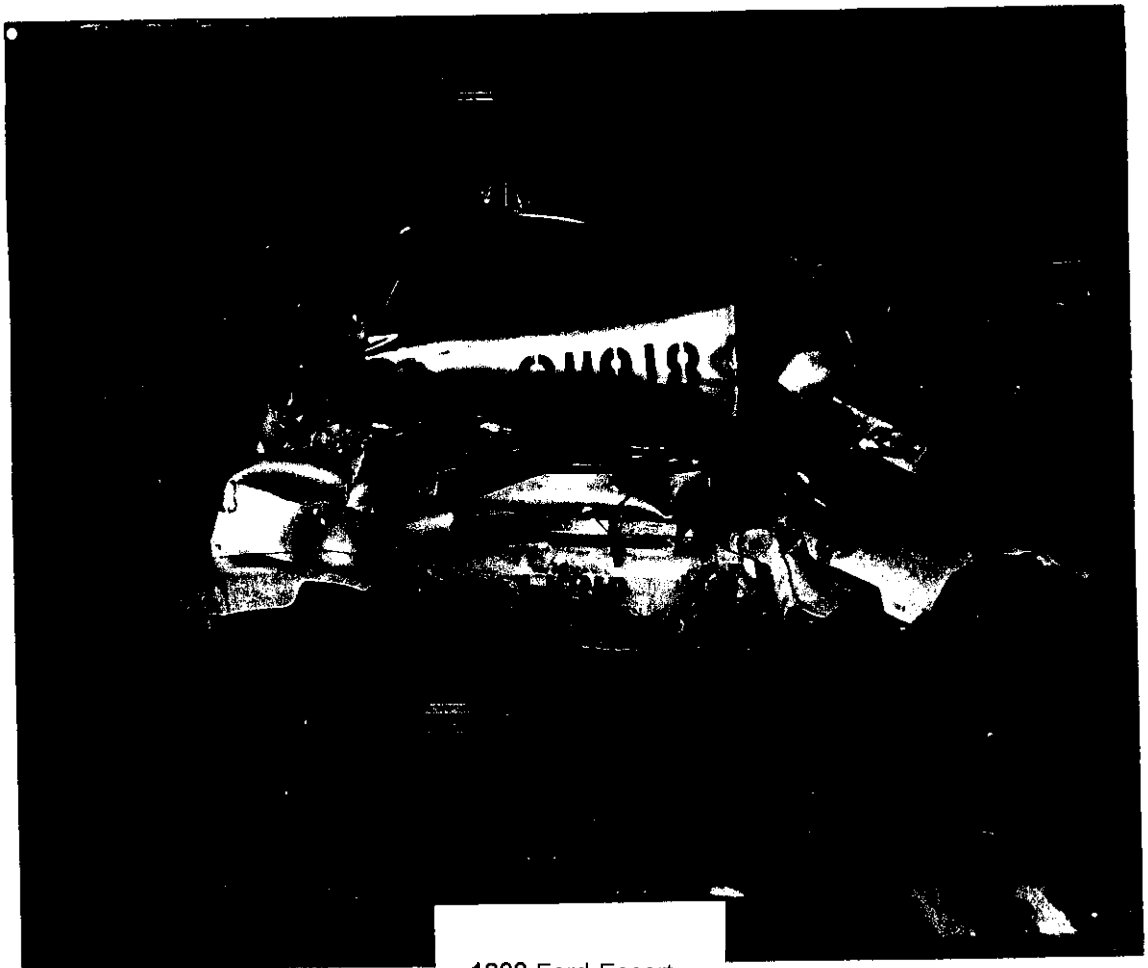
1998 Honda Civic



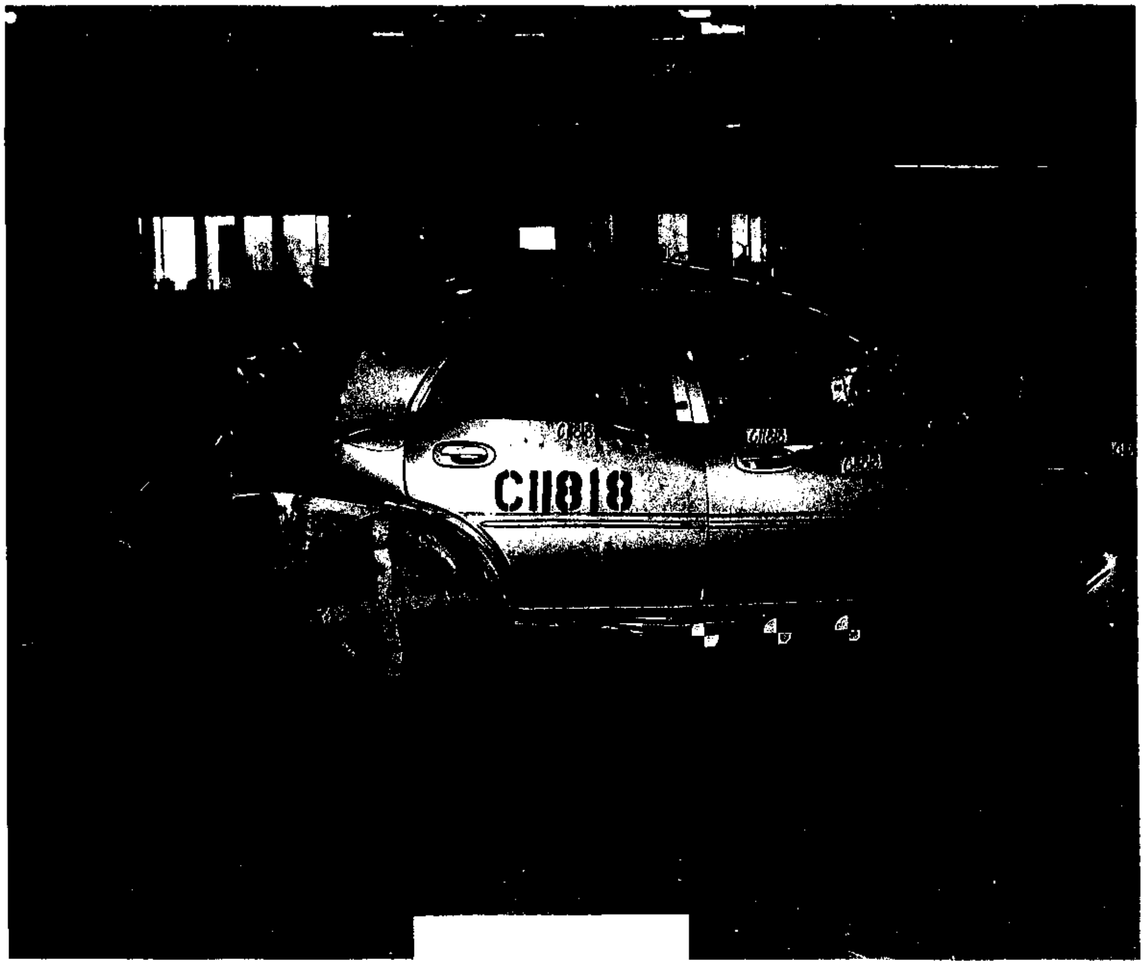


Civic Test

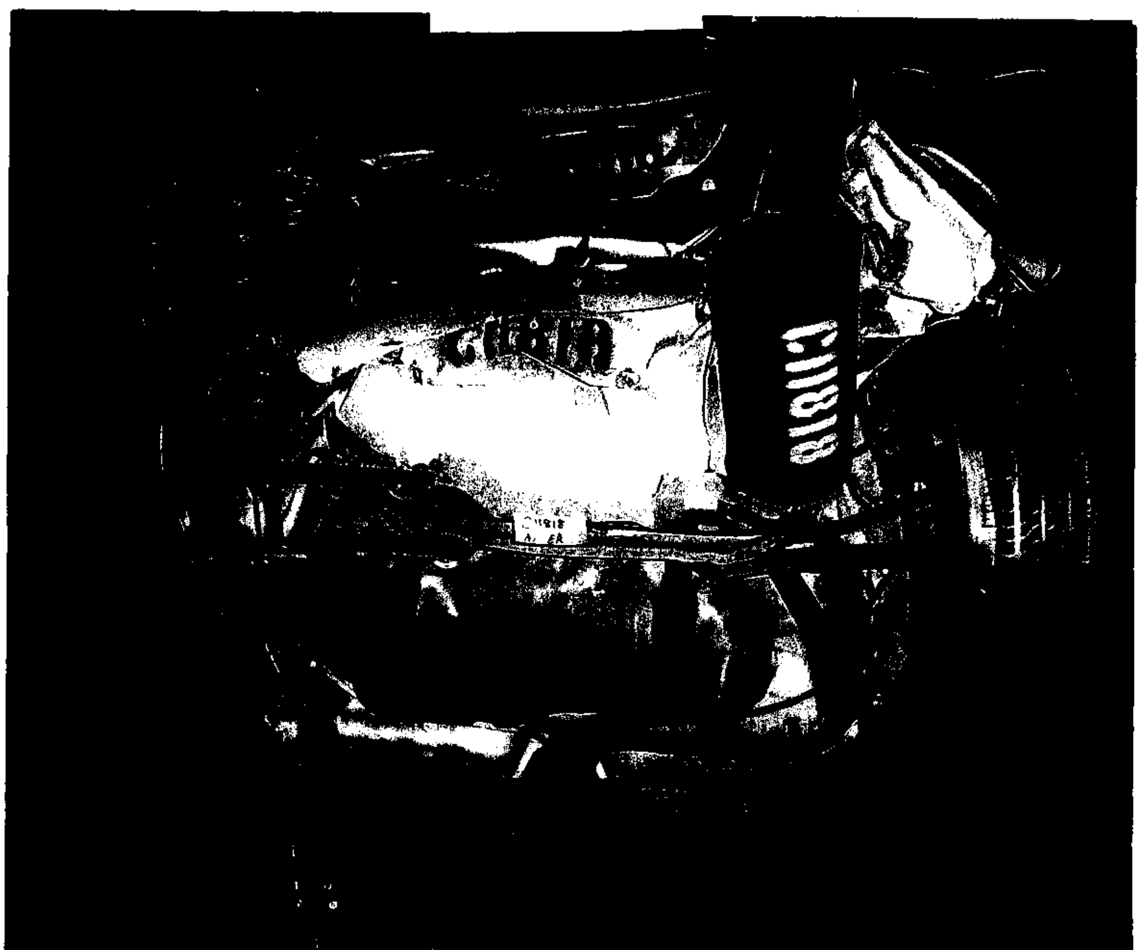


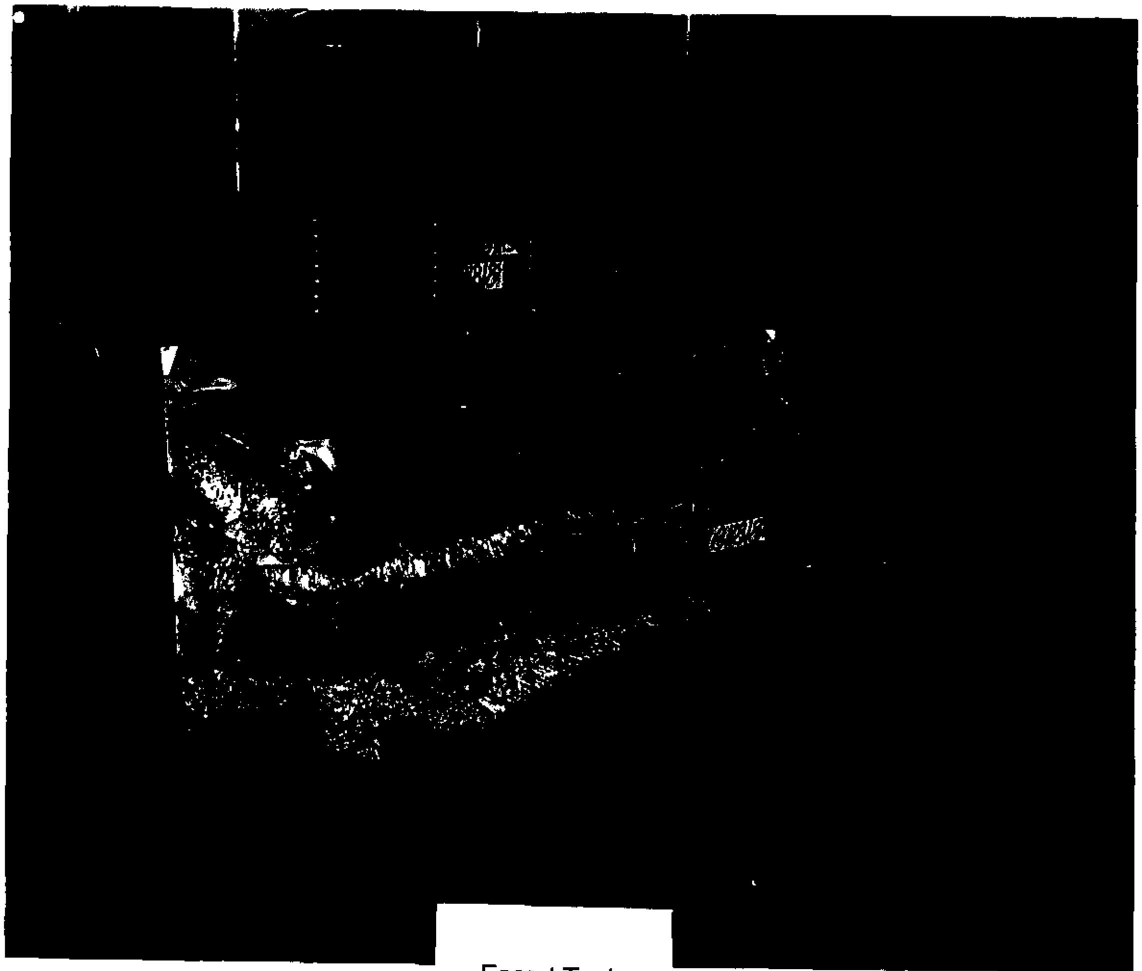


1998 Ford Escort

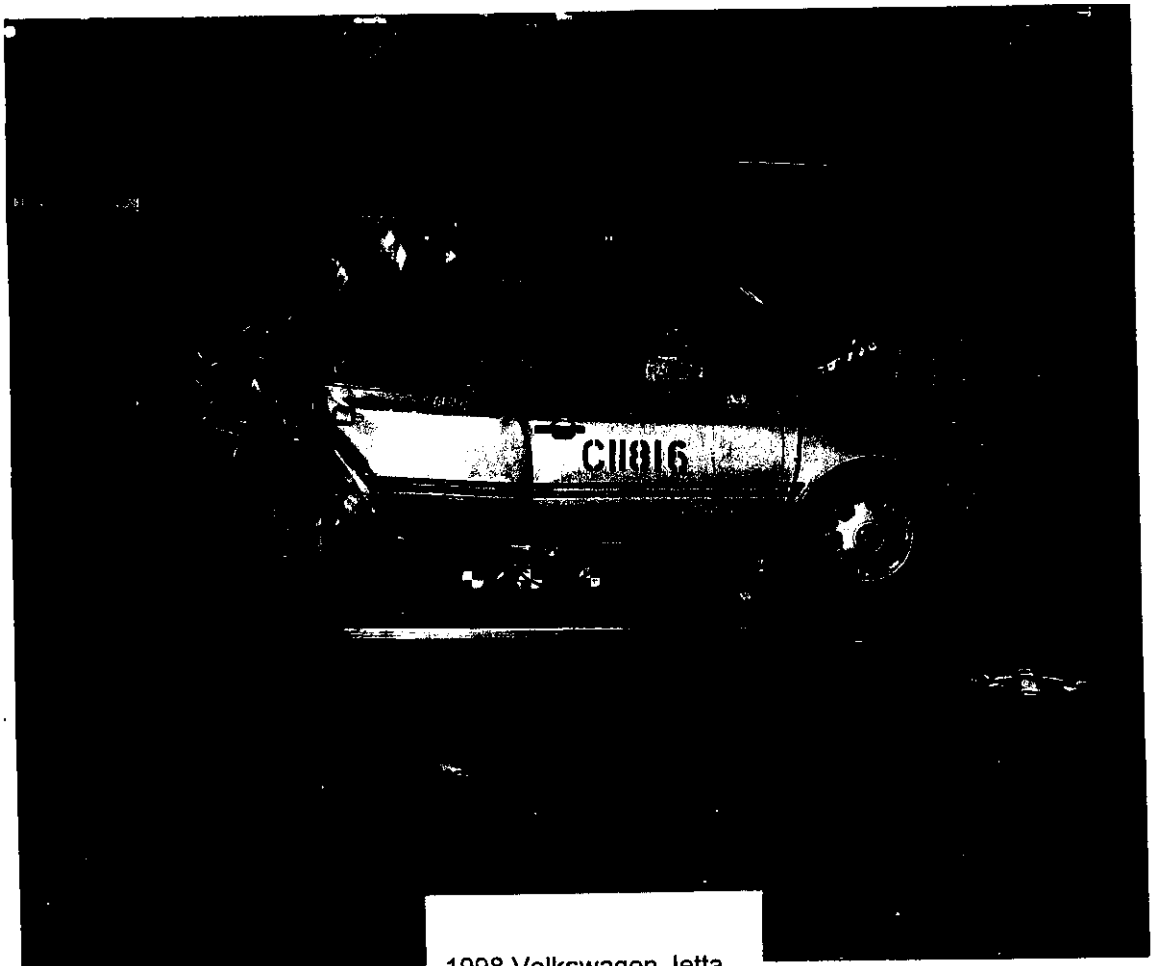


1998 Ford Escort

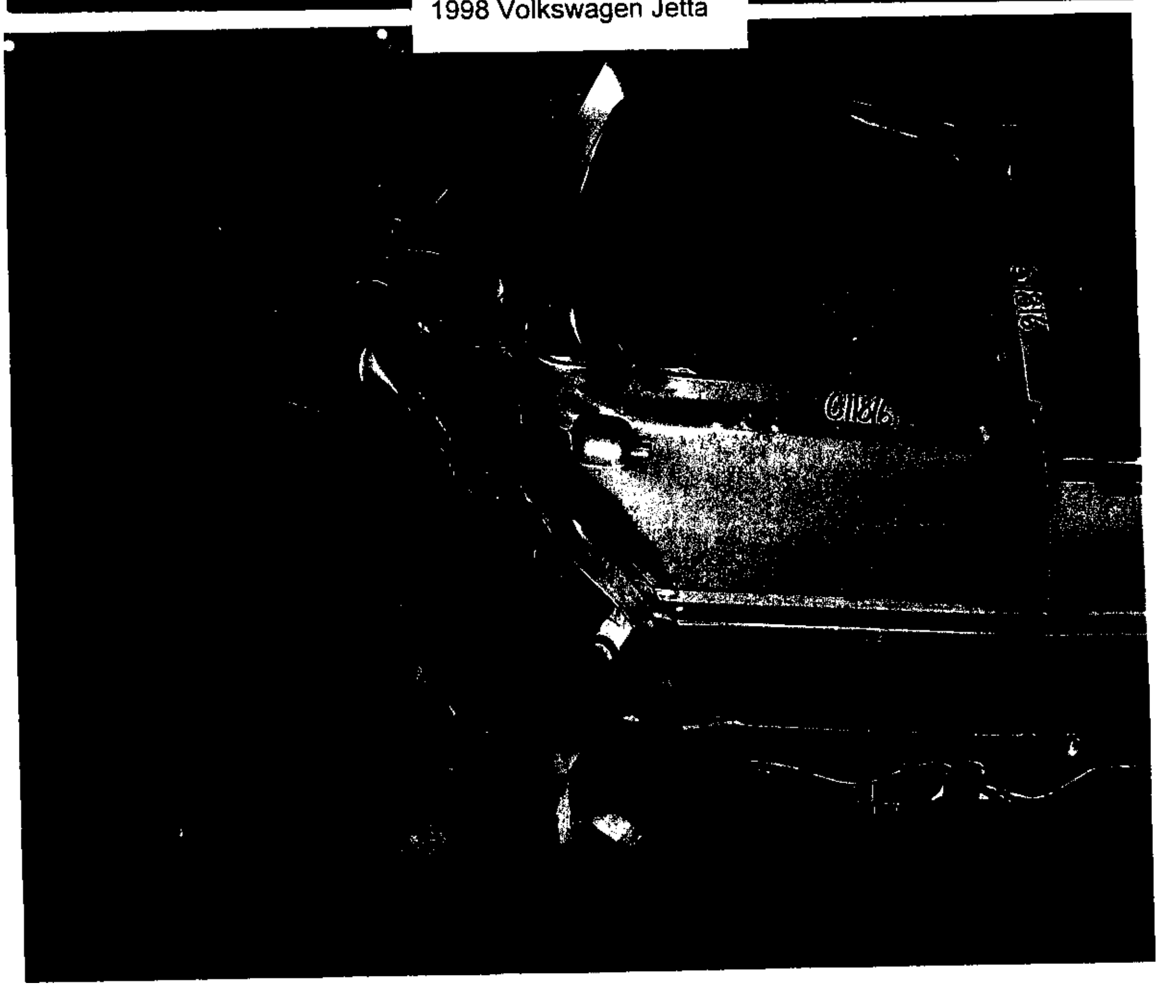


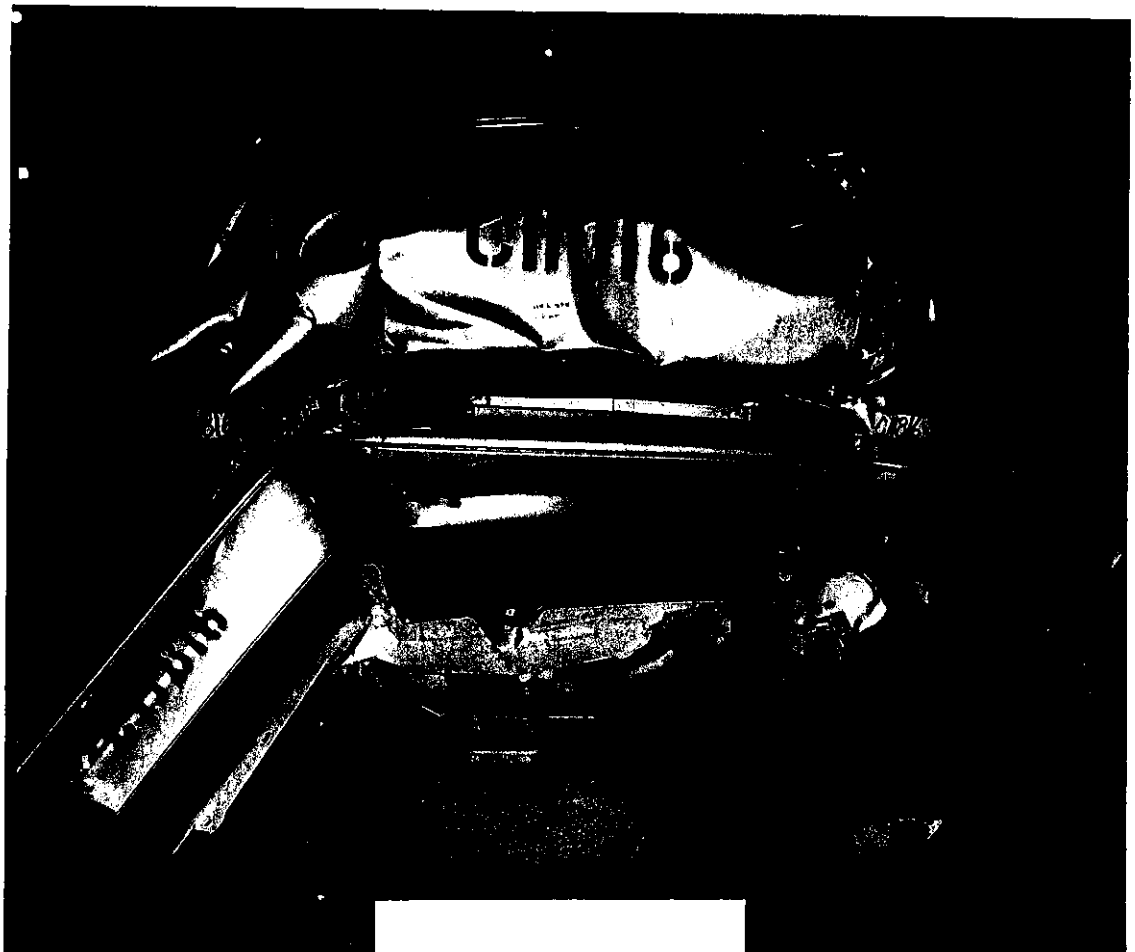


Escort Test

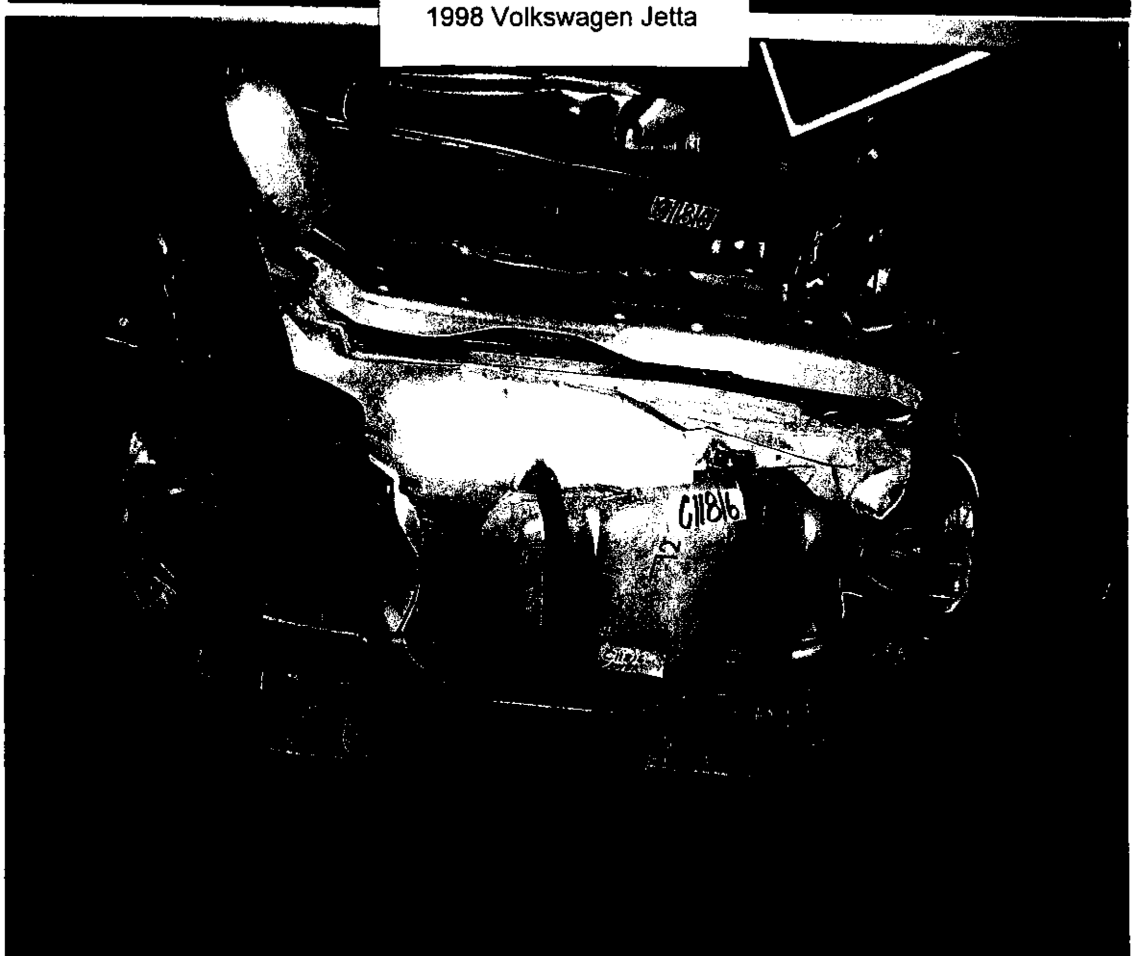


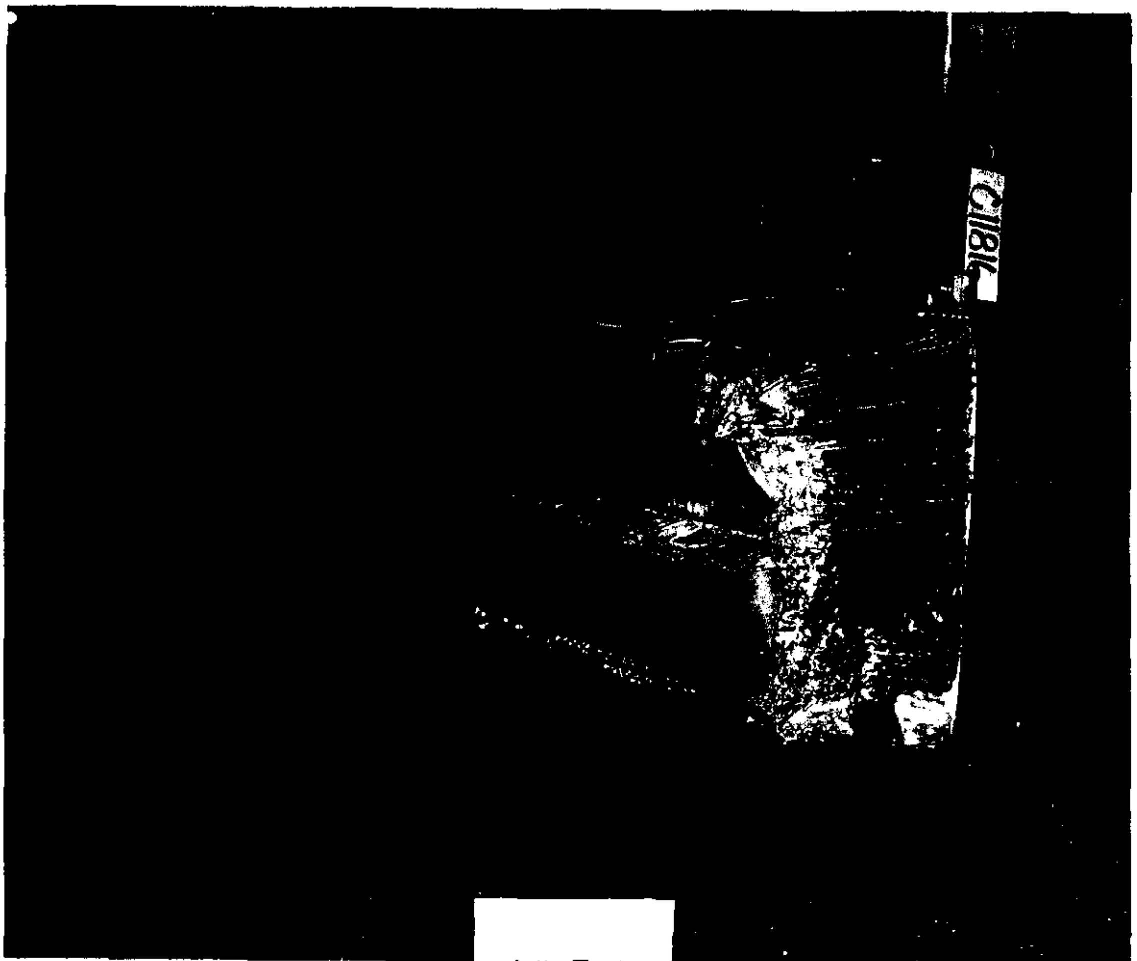
1998 Volkswagen Jetta



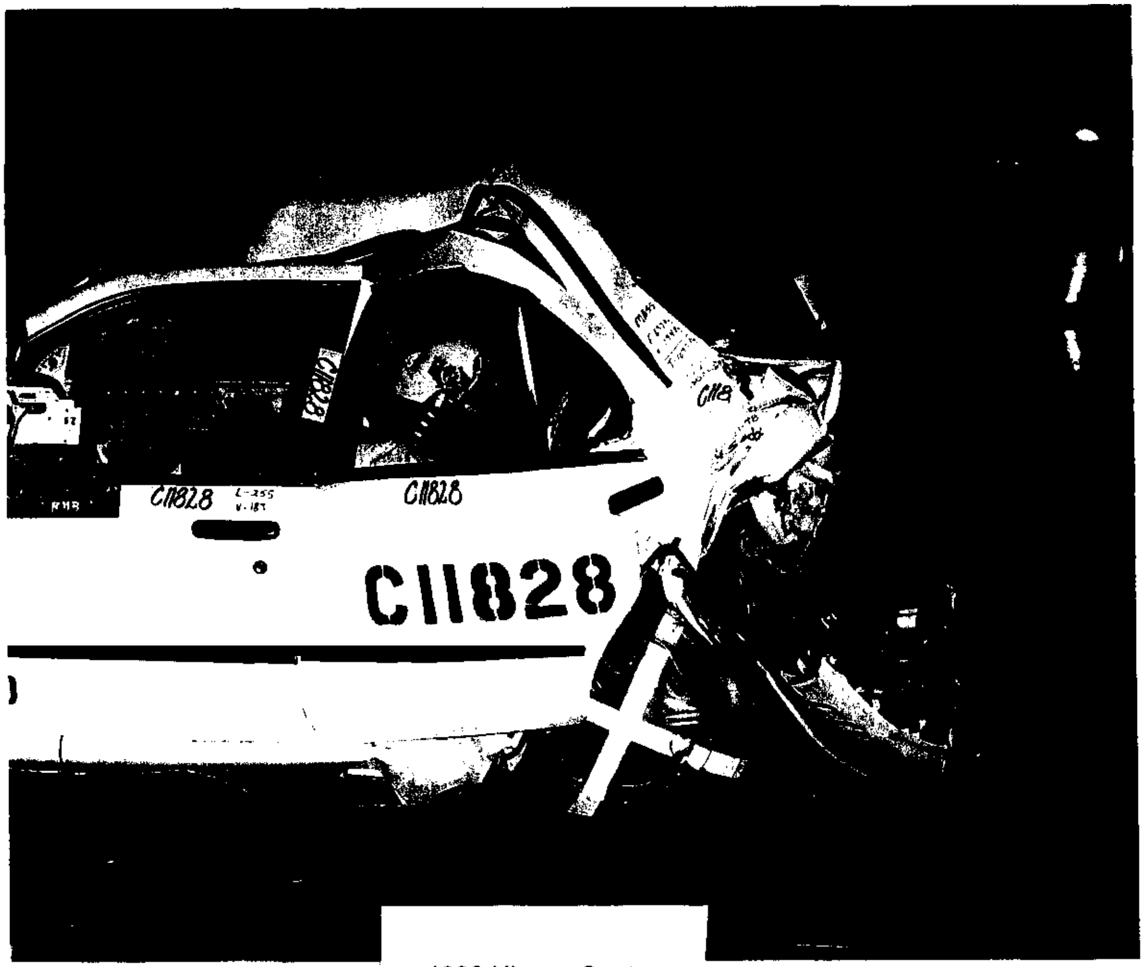


1998 Volkswagen Jetta

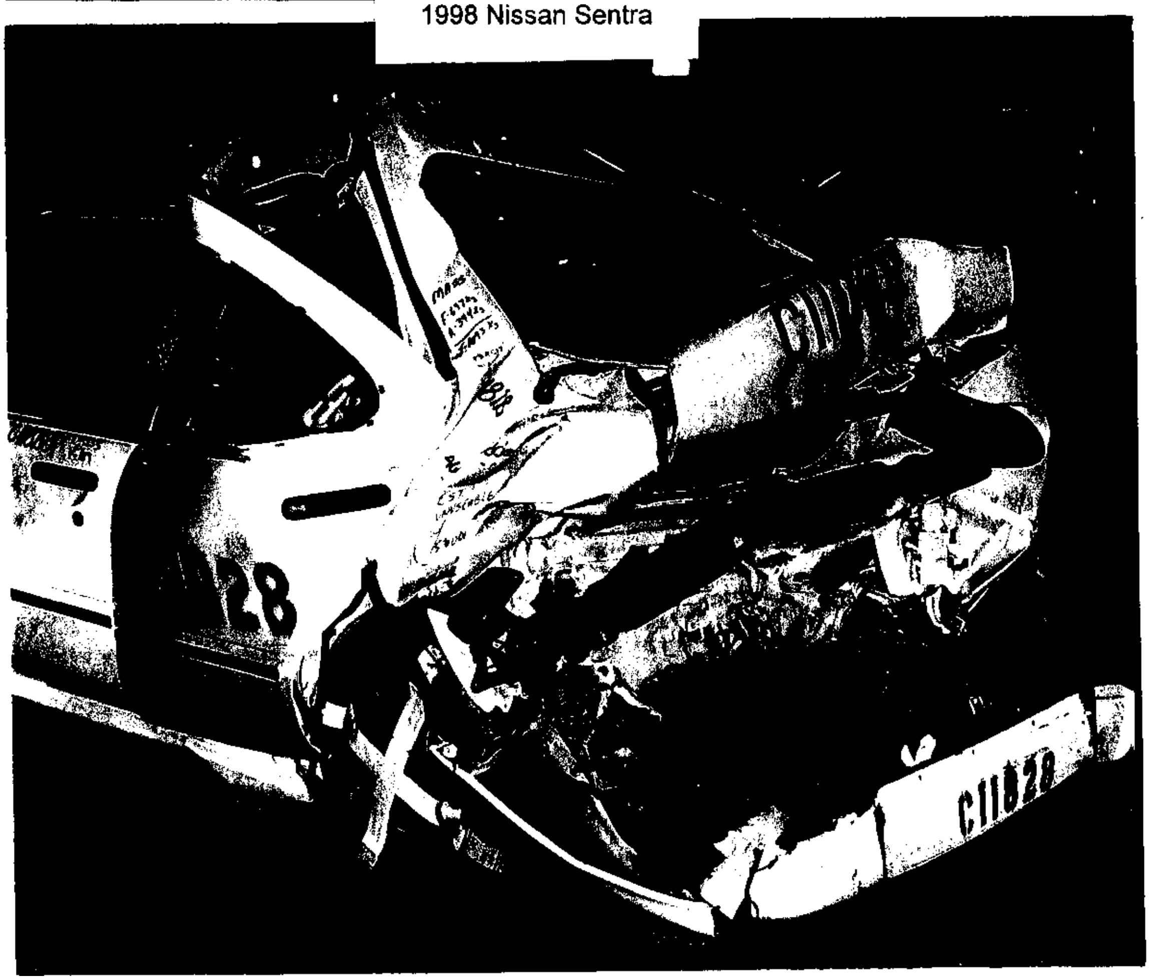


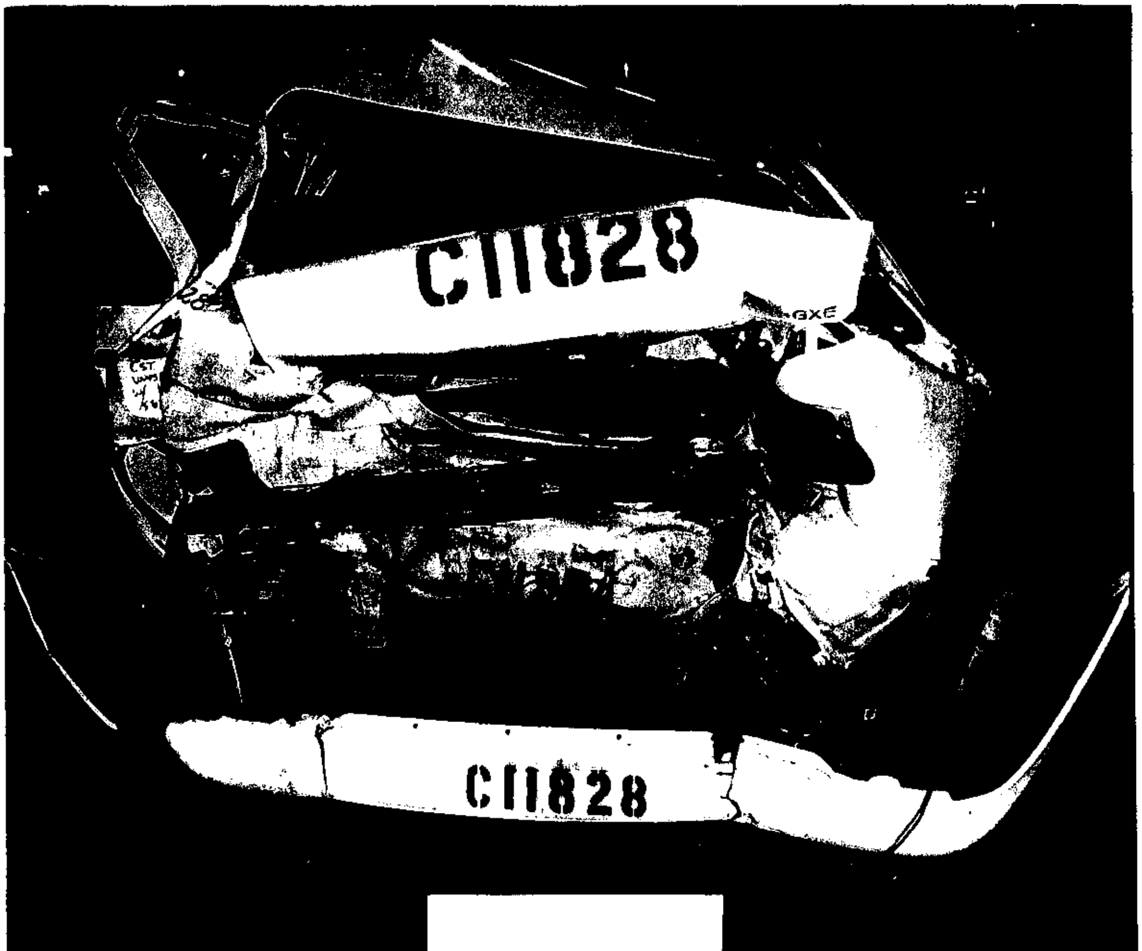


Jetta Test

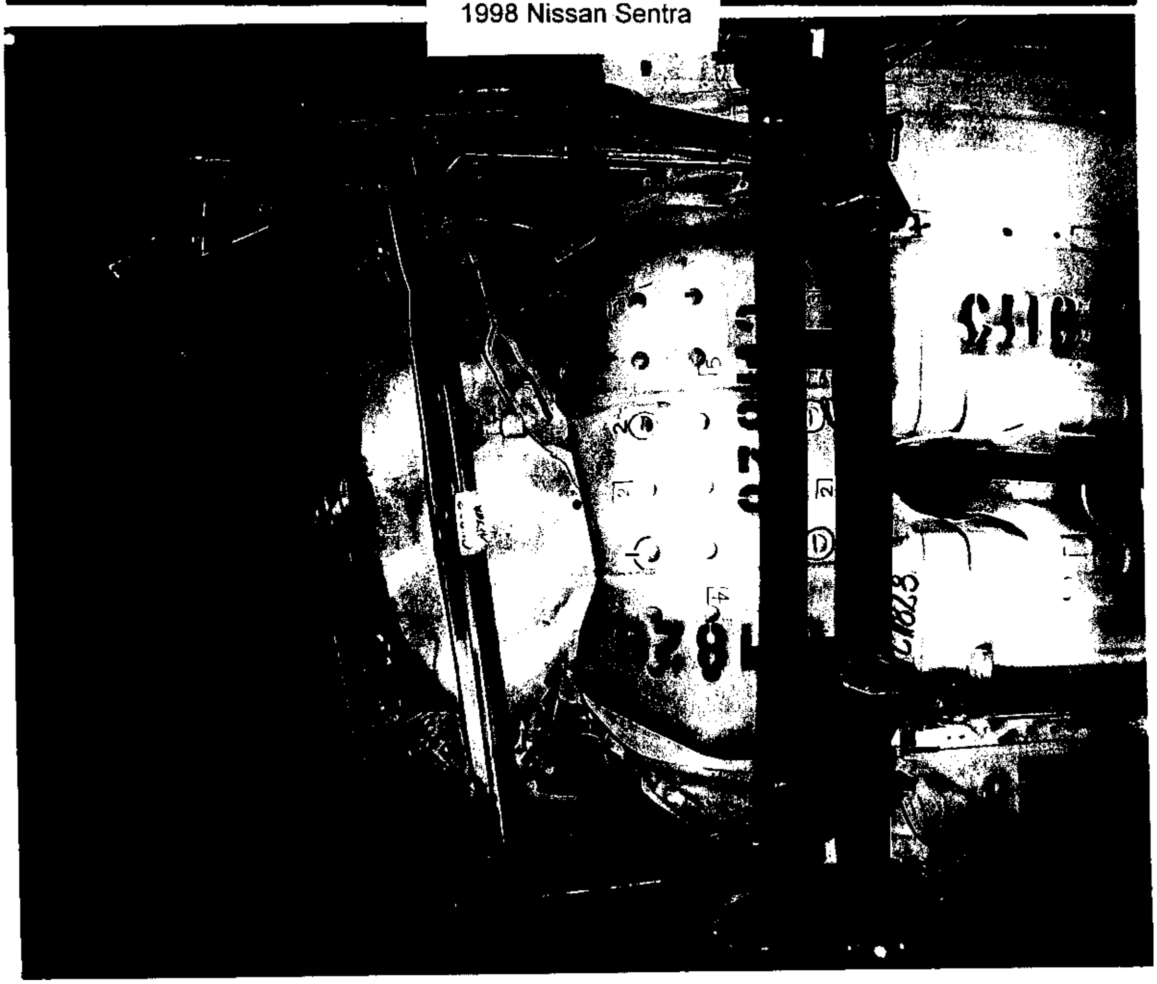


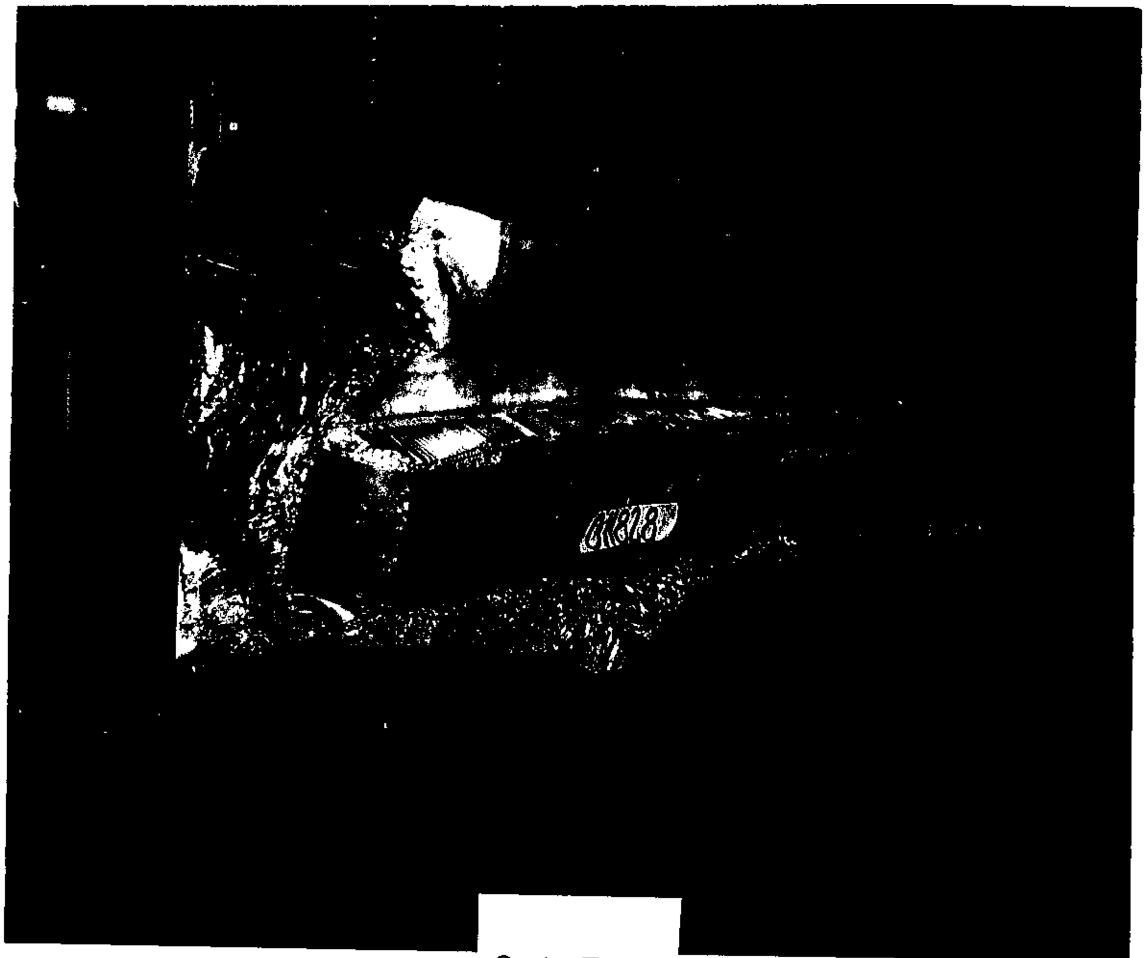
1998 Nissan Sentra



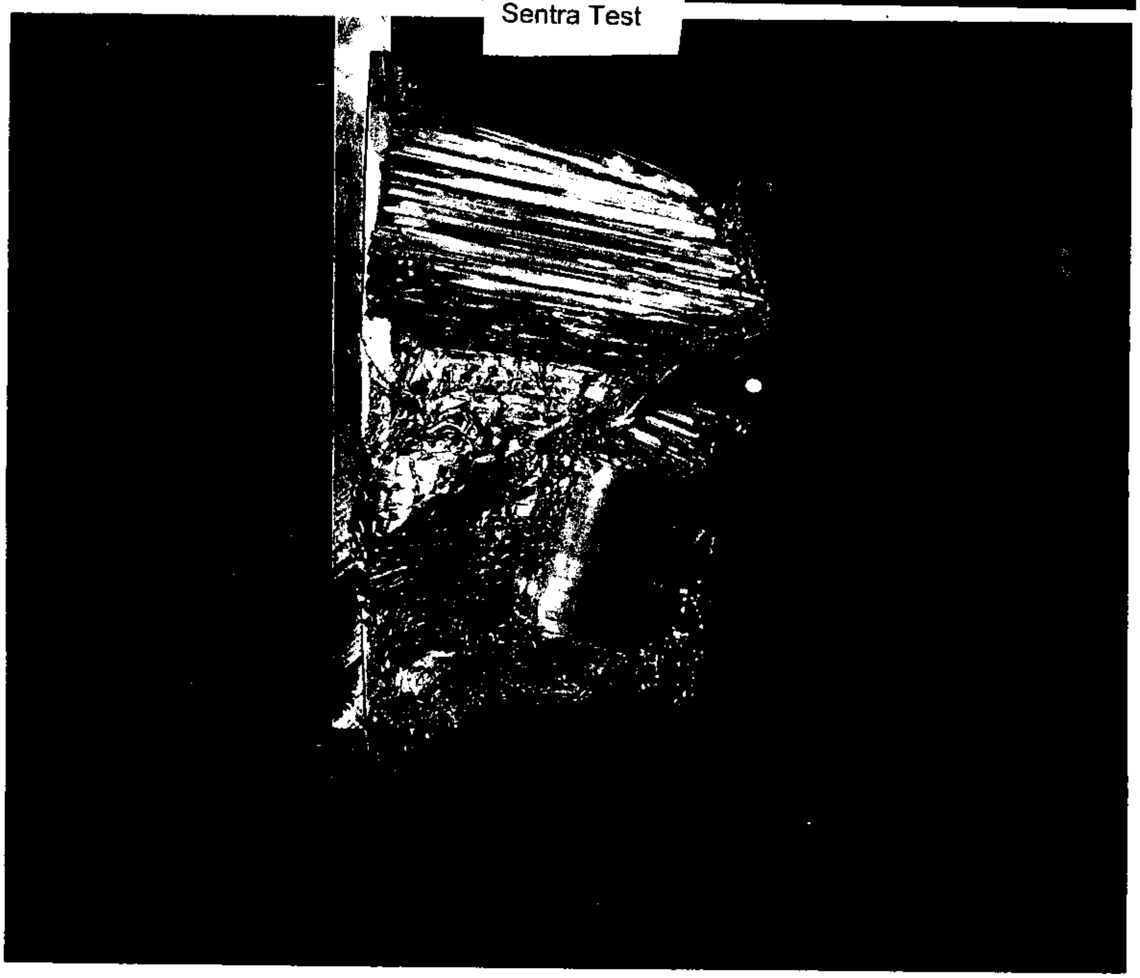


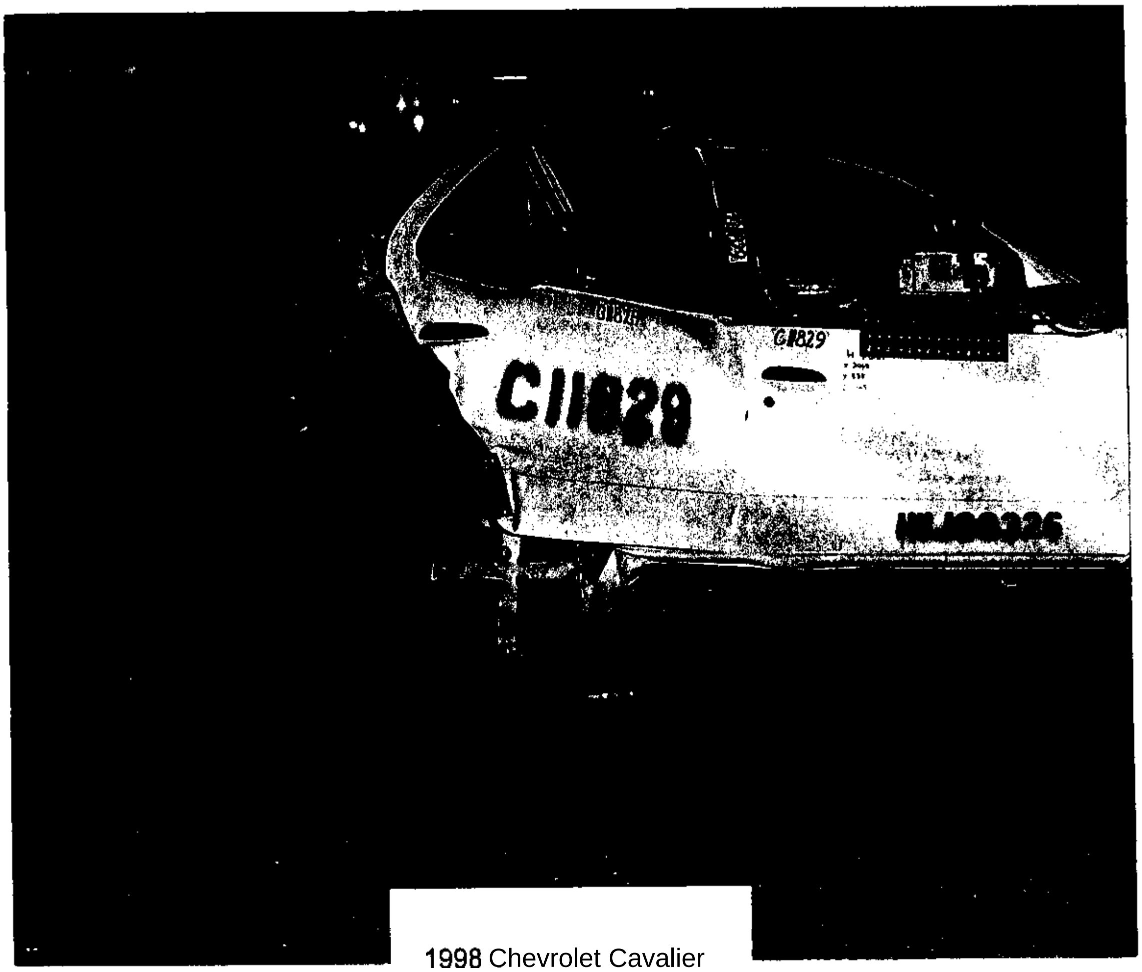
1998 Nissan Sentra



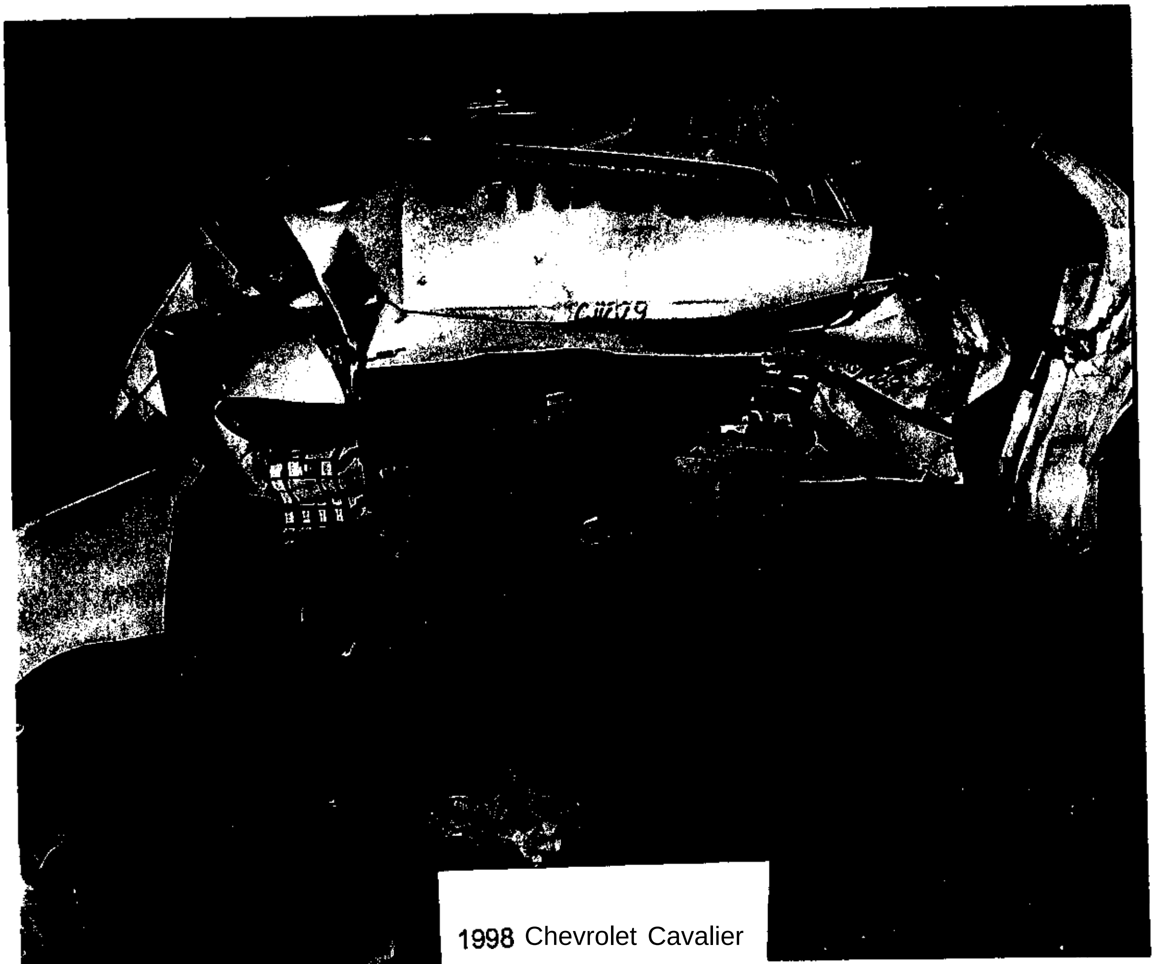


Sentra Test

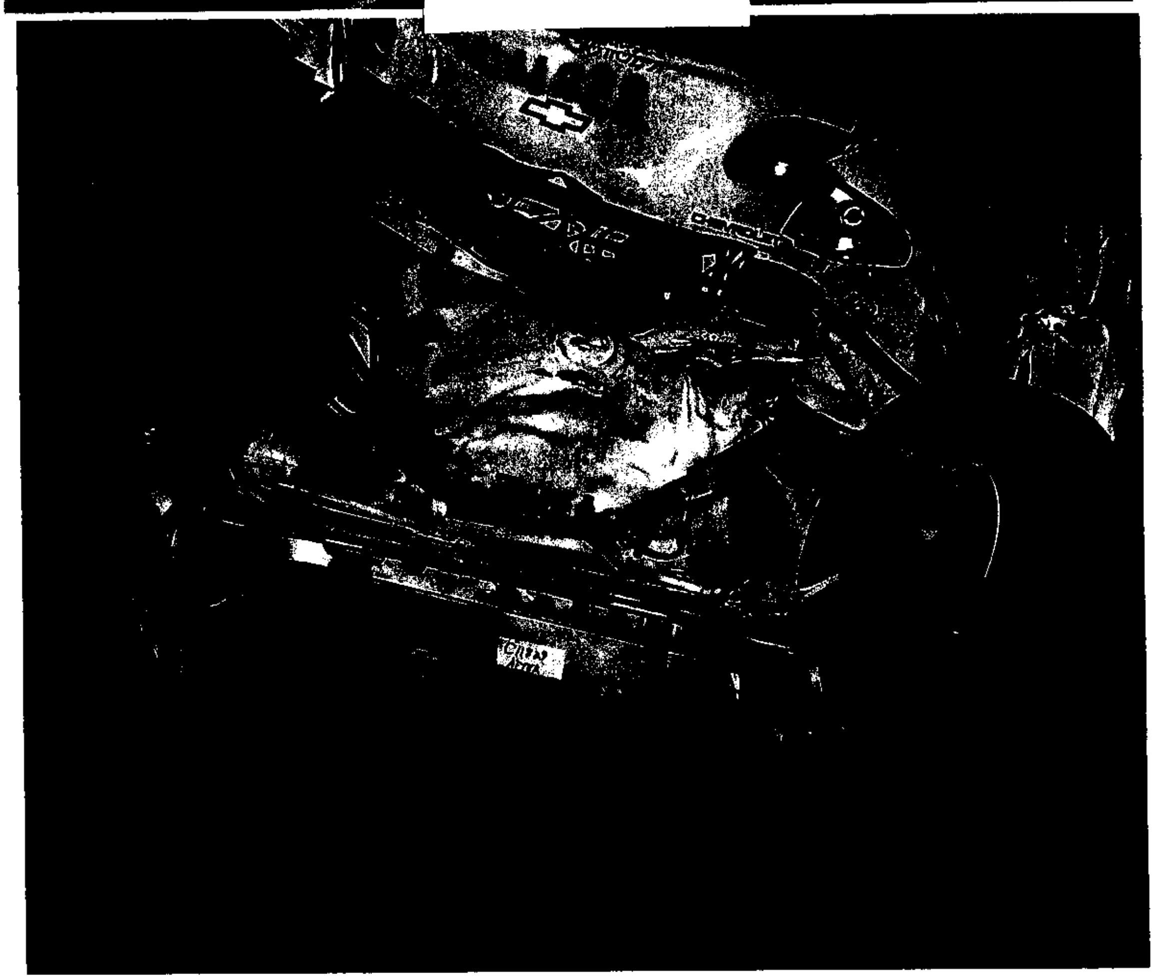




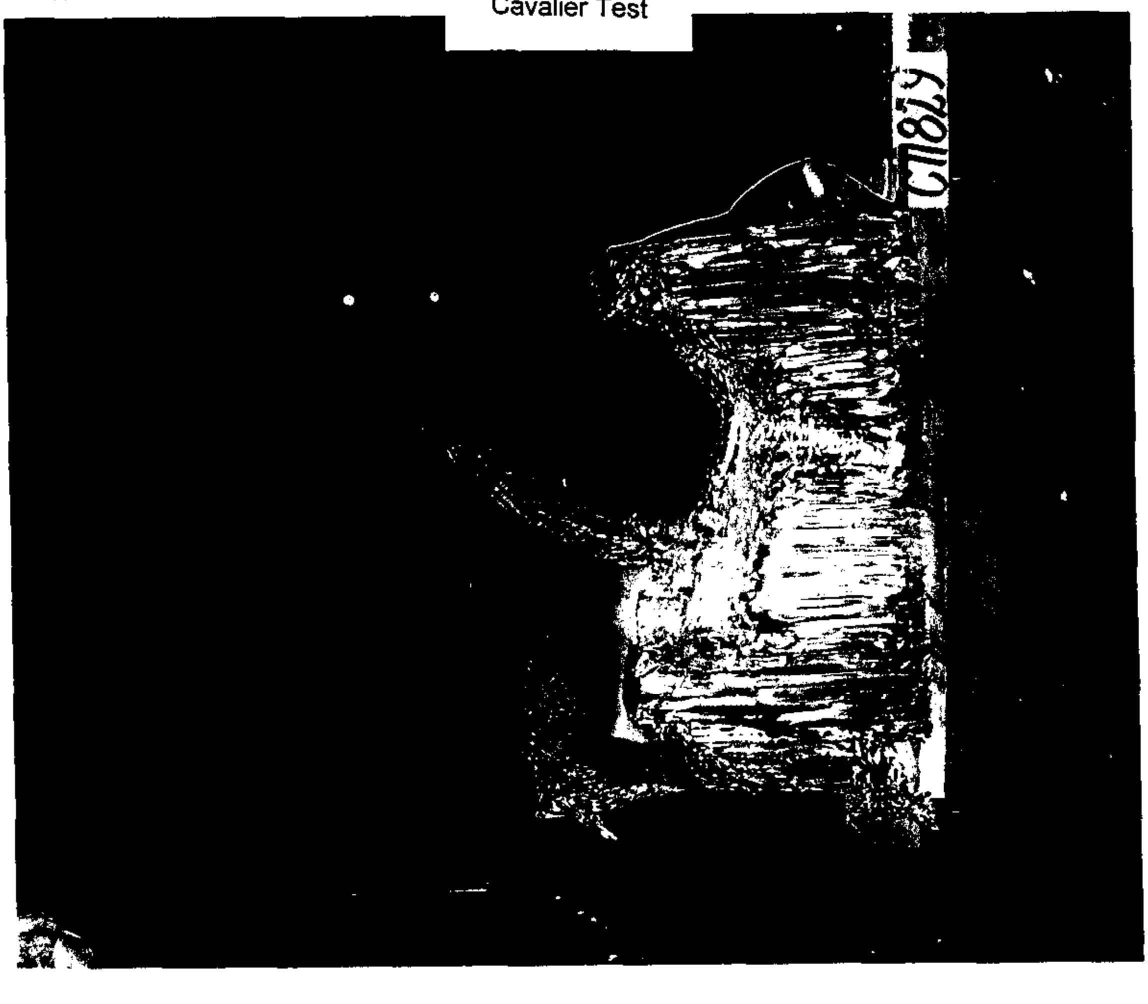
1998 Chevrolet Cavalier



1998 Chevrolet Cavalier



Cavalier Test



Appendix D

Head and Neck Injury Measurement Data Plots

C11817 L.REAR IMP 70% OVERLAP LTV MOE TO STATIONARY VEHICLE 80.7KM/H

ATD TYPE: GM50H

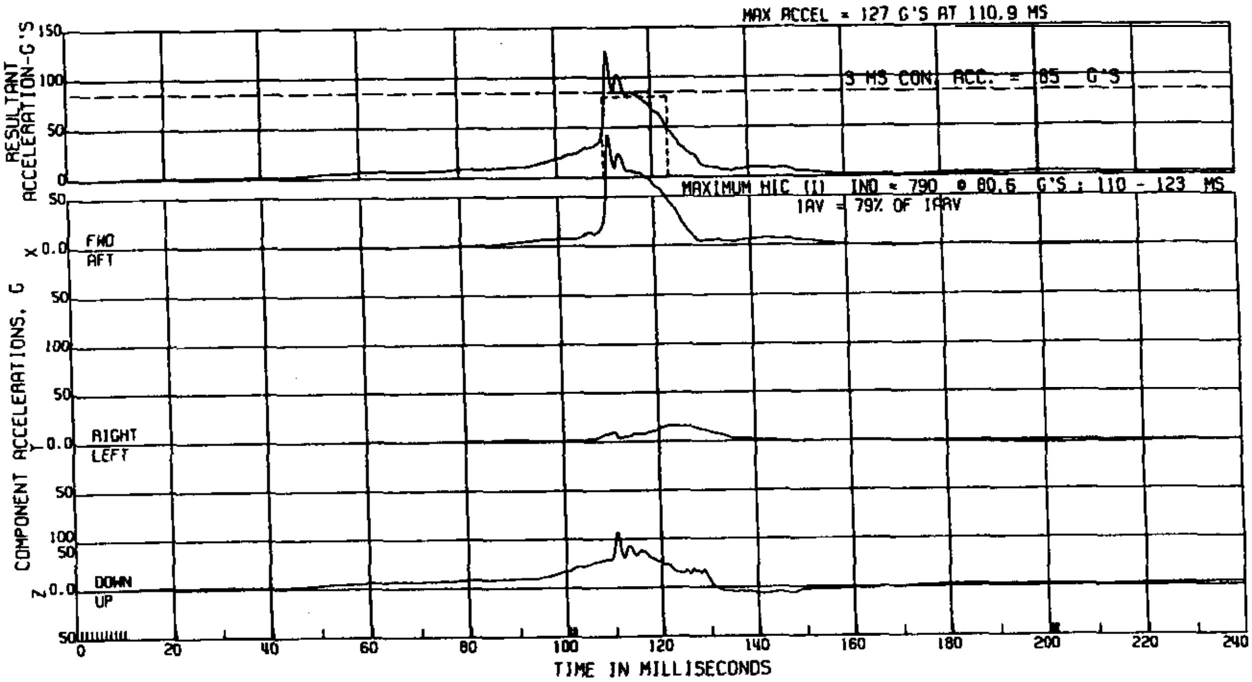
SC 8W91850 4-DOOR

L. FRT HEAD ACCEL.

TEST DATE:12/18/1997

ELEC DATA, SAE CLASS 1000

(HIC I LIMITED TO 15MS)



1 PROCESSED 12/18/1997 14:16 V2.07

C11817 L.REAR IMP 70% OVERLAP LTV MDB TO STATIONARY VEHICLE 80.7KM/H

ATD TYPE: GM50H

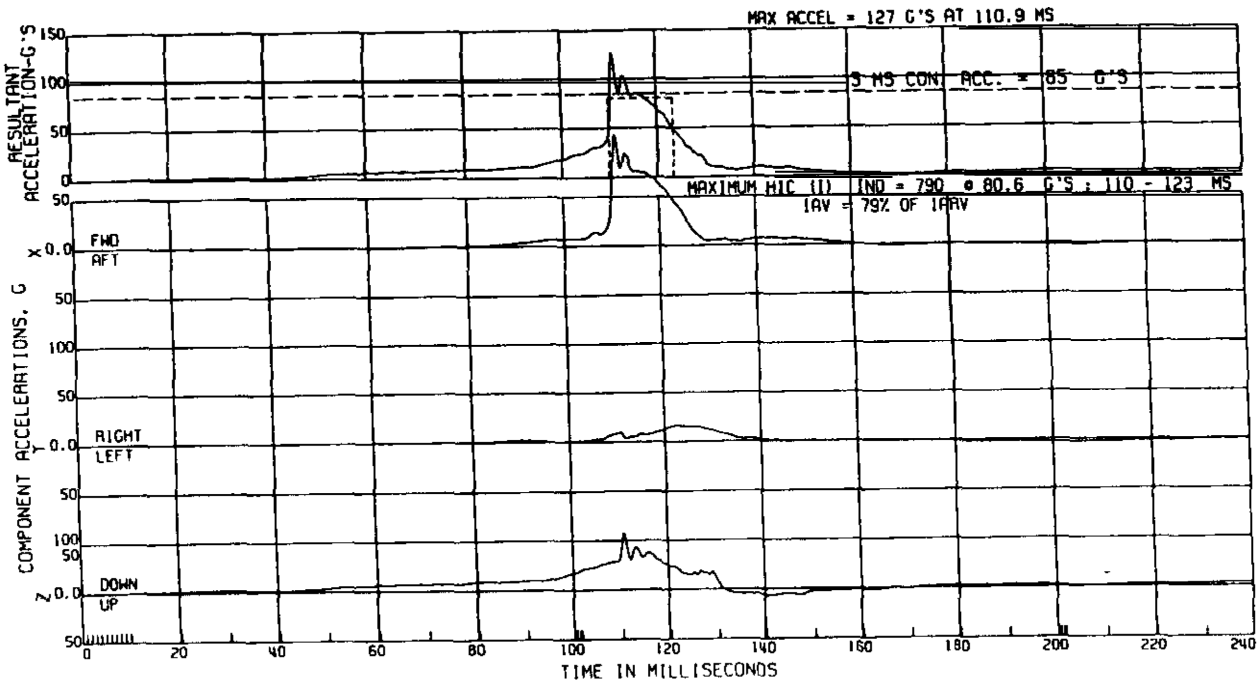
SC 8W91850 4-DOOR

L. FRT HEAD ACCEL.

TEST DATE:12/18/1997

ELEC DATA, SAE CLASS 1000

(HIC I LIMITED TO 36MS)



C11817 L.REAR I M P 70% OVERLAP LTV MOE TO STATIONARY VEHICLE 80.7KM/H

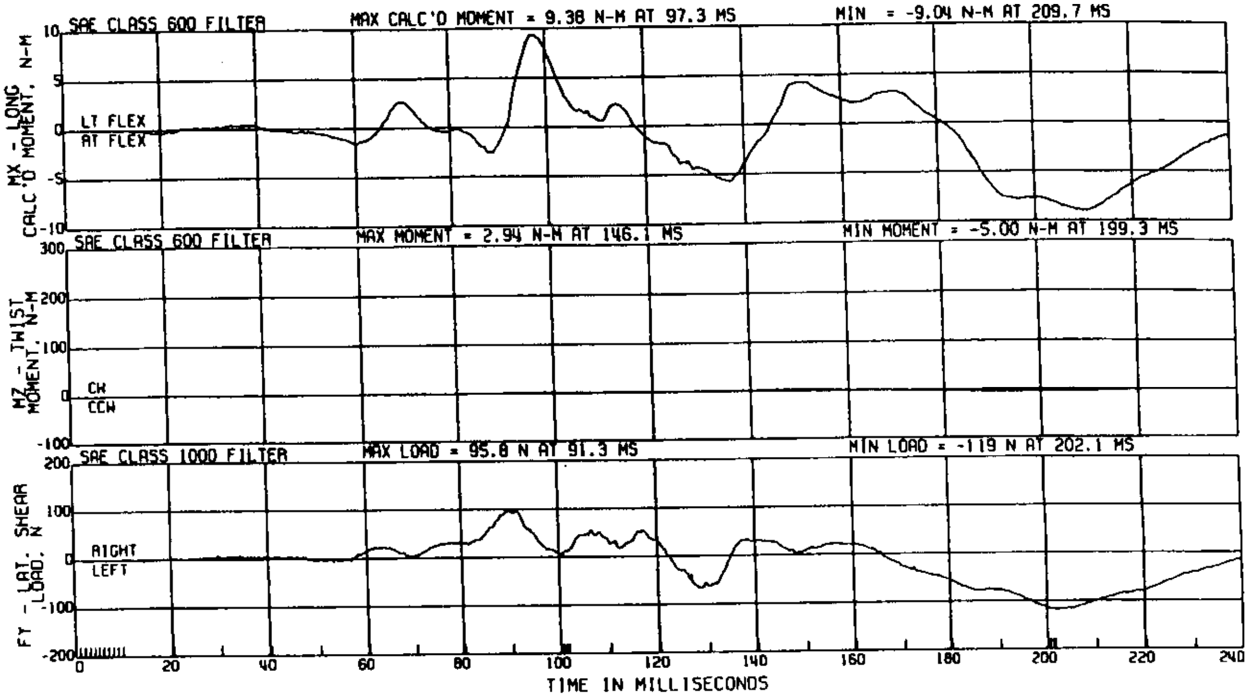
SC 8W9185D 4-DOOR L. FRT NECK LOADING ON HEAD, UPPER LOAD

ATD TYPE: GM50H

TEST DATE:12/18/1997

ELEC DATA

L.FRT NECK LOADING ON HEAD



10 PROCESSED 12/18/1997 14:17 V2.07

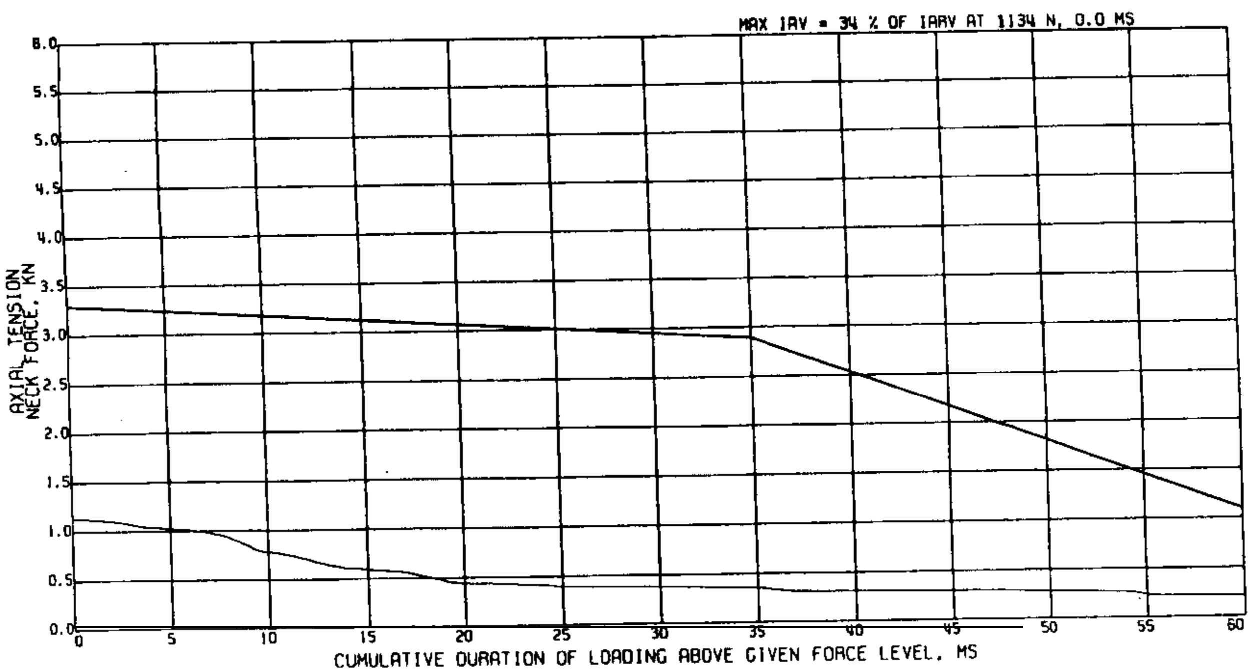
C11817 L.REAR IMP 70% OVERLAP LTV MOE TO STATIONARY VEHICLE 80.7KM/H

ATD TYPE: GM50H

SC 8W9185D 4-DOOR AXIAL TENSION ON HEAD,

TEST DATE:12/18/1997

ELEC DATA, SAE CLASS 1000 L.FRT INJURY REFERENCE



15 PROCESSED 12/18/1997 14:17 V2.07

C11817 L.REAR IMP 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 80.7KM/H

ATD TYPE: GM50H

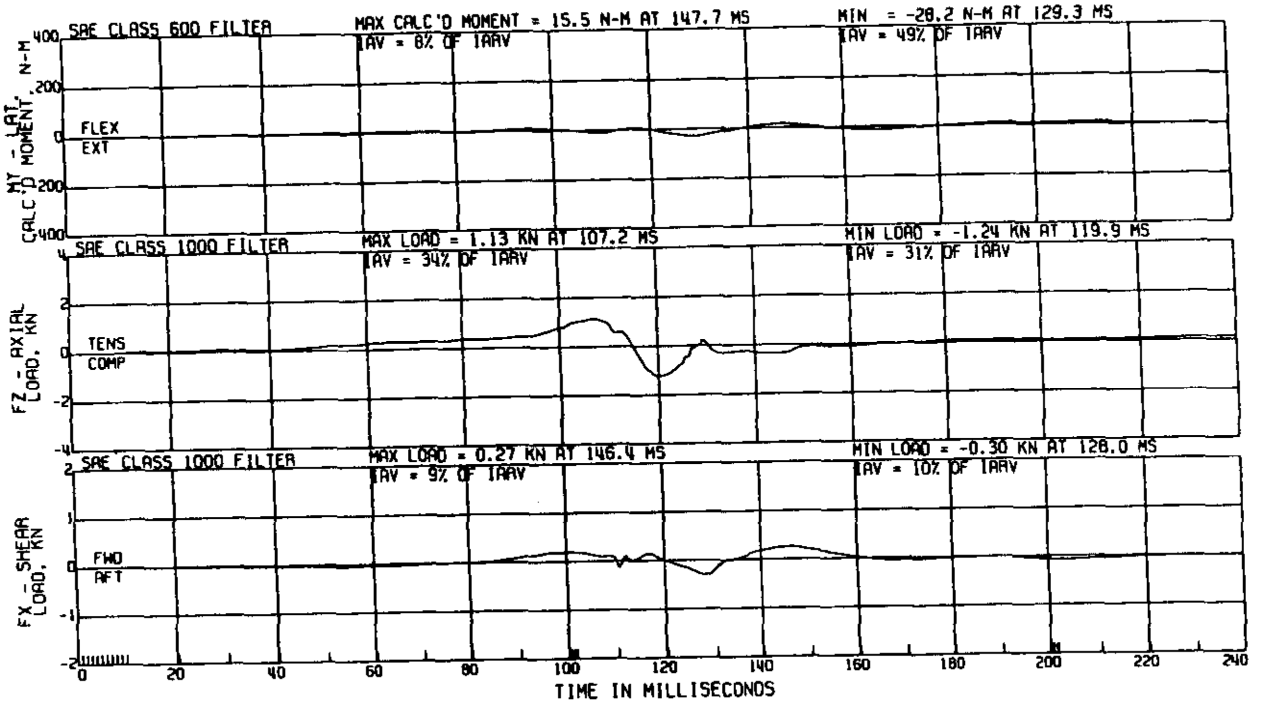
SC 8W9185D 4-DOOR

TEST DATE:12/18/1997

ELEC DATA

NECK LOADING ON HEAD

L. FRT NECK LOADING ON HEAD



PROCESSED 12/18/1997 14:17 V2.07

C11817 L.REAR IMP 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 80.7KM/H

ATD TYPE: GM50H

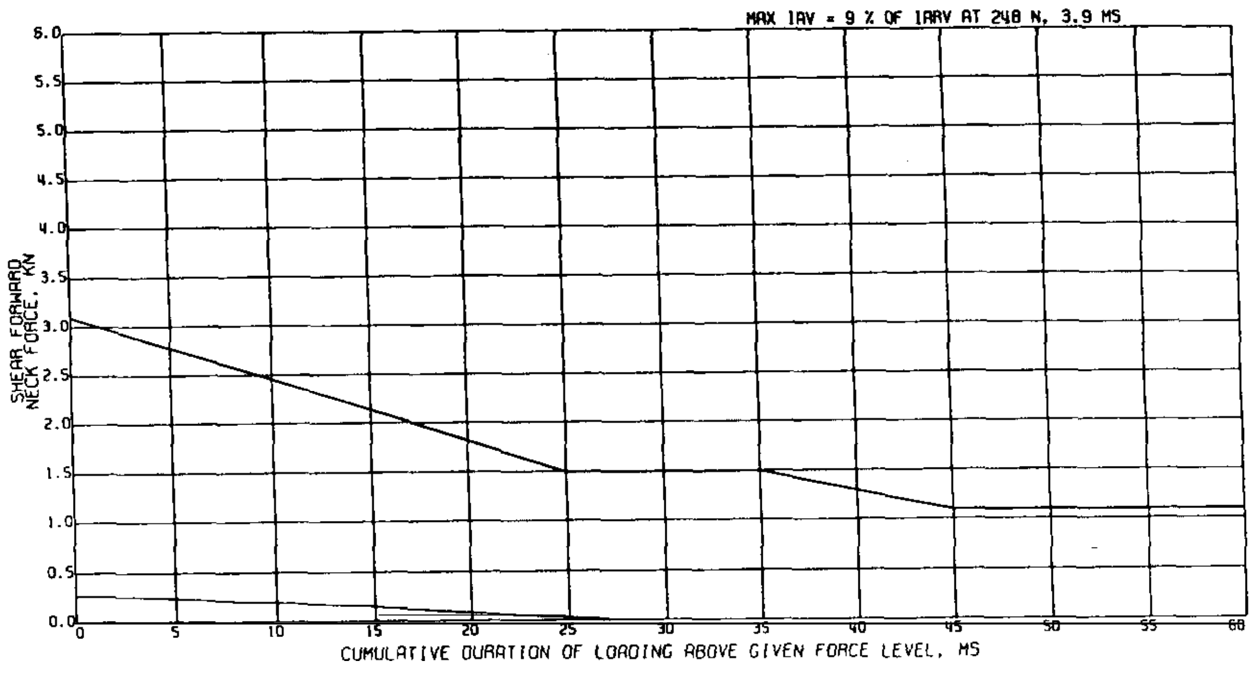
SC 8W9185D 4-DOOR

TEST DATE:12/18/1997

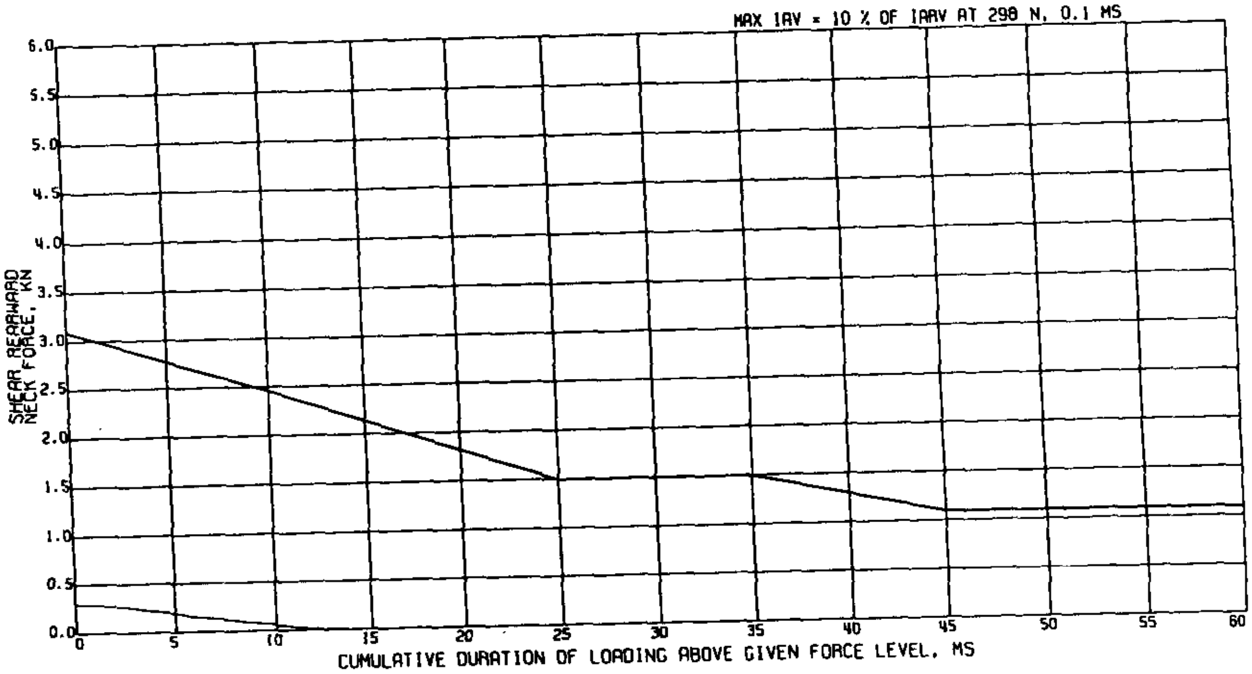
ELEC DATA, SAE CLASS 1000

FORWARD NECK SHEAR ON HEAD.

L. FRT INJURY REFERENCE

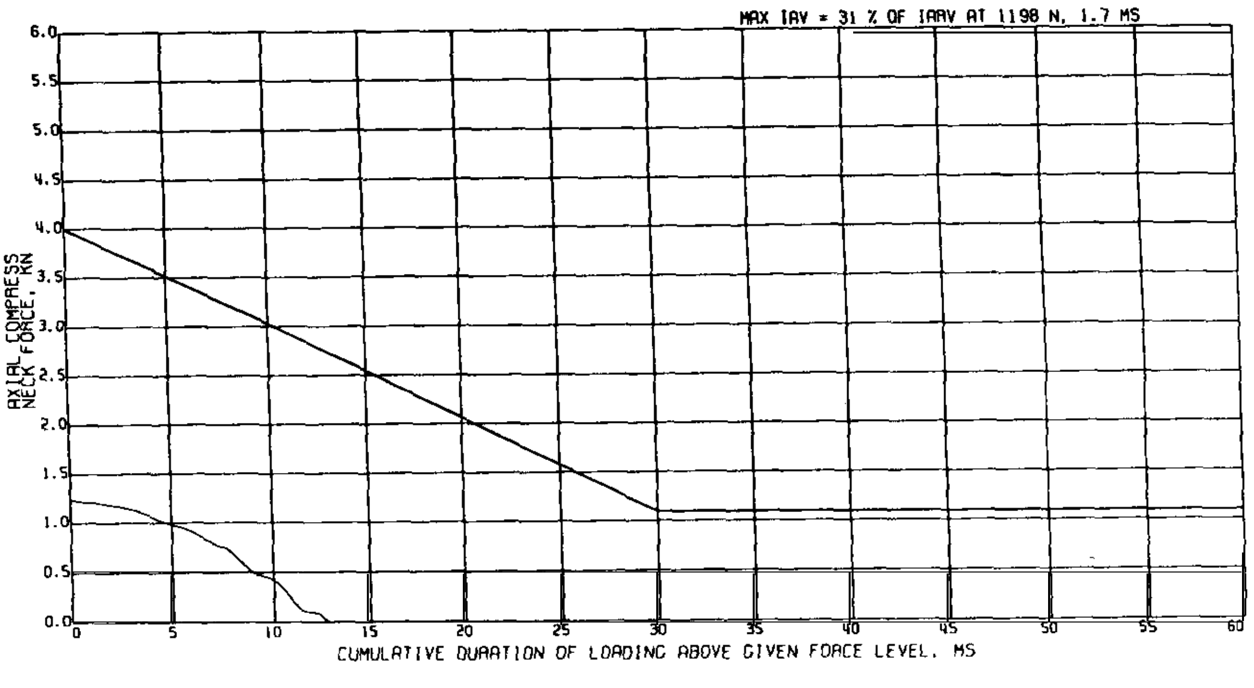


C11817 L.REAR IMP 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 80.7 KM/H
ATD TYPE: GM50H
SC 8W9185D 4-DOOR REARWARD NECK SHEAR ON HEAD, TEST DATE:12/18/1997
ELEC DATA, SAE CLASS 1000 L. FRT INJURY REFERENCE



13 PROCESSED 12/18/1997 14:17 V2.07

C11817 L.REAR IMP 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 80.7KM/H
ATD TYPE: GM50H
SC 8W9185D 4-DOOR AXIAL COMPRESSION ON HEAD, TEST DATE:12/18/1997
ELEC DATA, SAE CLASS 1000 L. FRT INJURY REFERENCE



C11817 L.REAR IMP 70% OVERLAP LTV HOE TO STATIONARY VEHICLE 80.7KM/H

ATD TYPE: GM50H

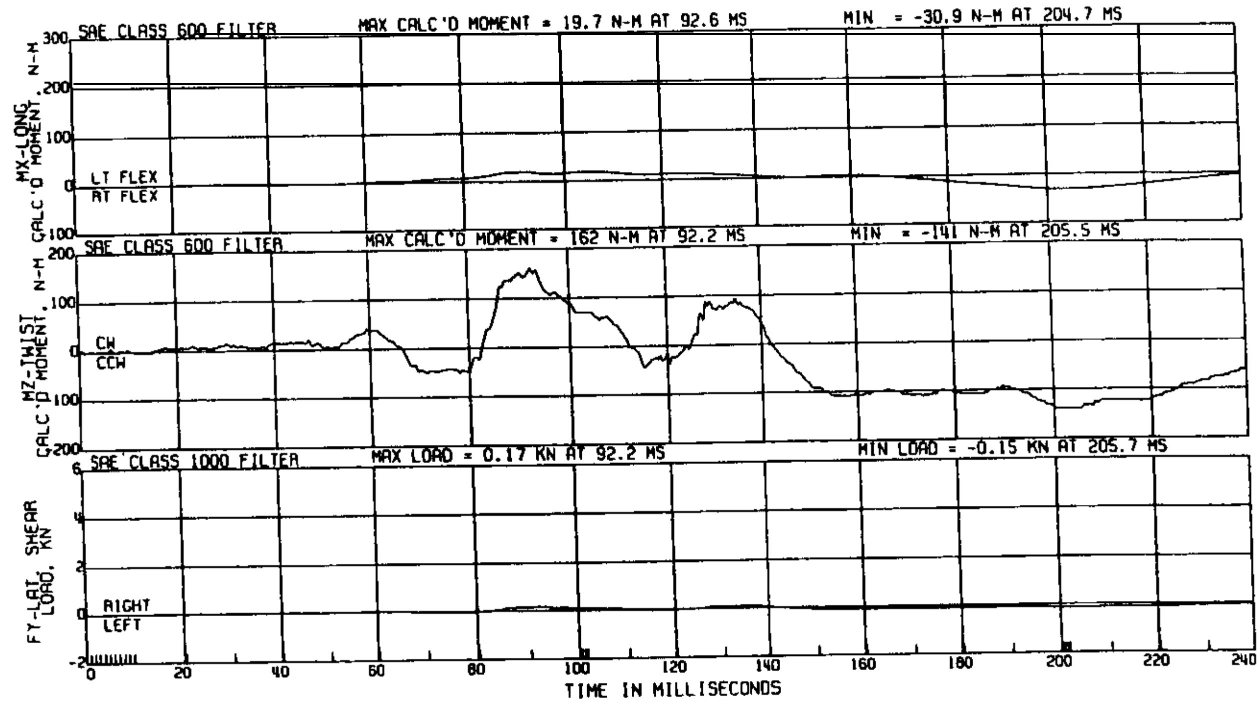
TEST DATE:12/18/1997

SC 8W91850 4-DOOR

ELEC DATA

L.FRT NECK LOADING LOAD

(TORSO ON BASE OF NECK)



PROCESSED 12/19/1997 07:23 V2.07

31

C1 1817 L. REAR IMP 70% OVERLAP LTV MDB TO STATIONARY VEHICLE 80.7KM/H

ATD TYPE: GM50H

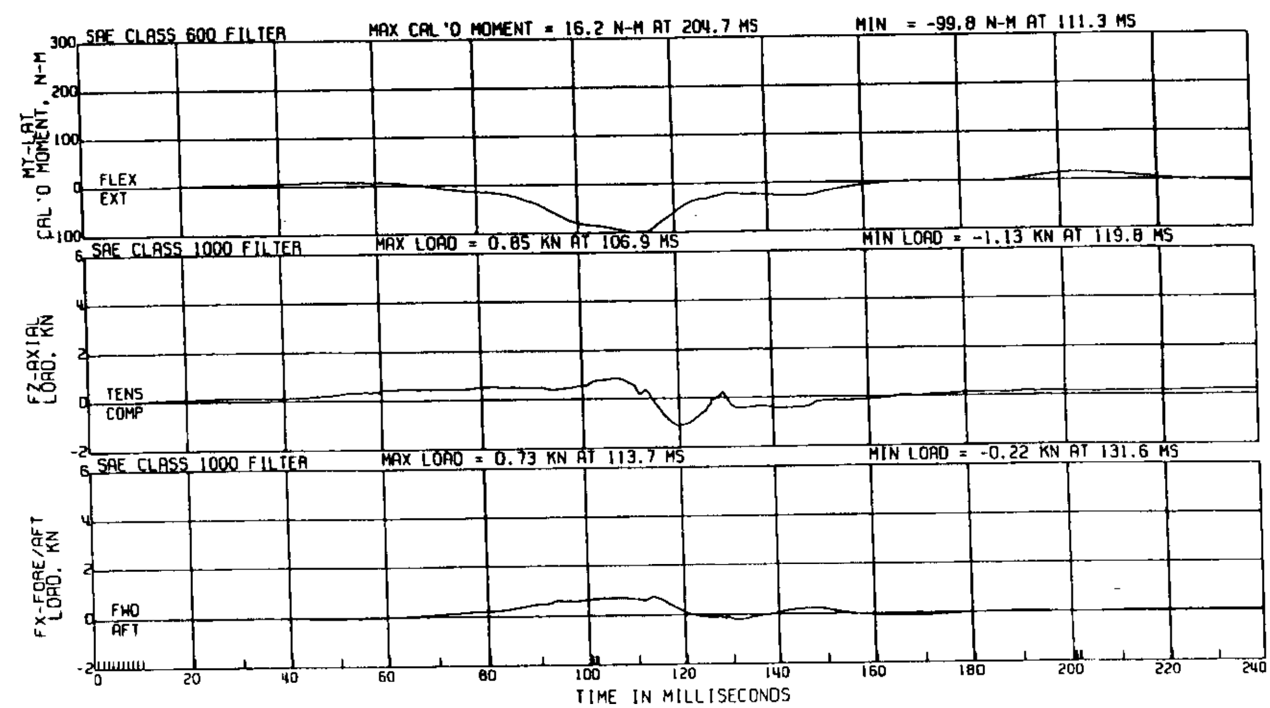
TEST DATE:12/18/1997

SC 8W91850 4-DOOR

ELEC DATA

L.FRT NECK LOADING LOAD

(TORSO ON BASE OF NECK)



C11817 L.REAR I M P 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 80.7KM/H

ATD TYPE: GM50H

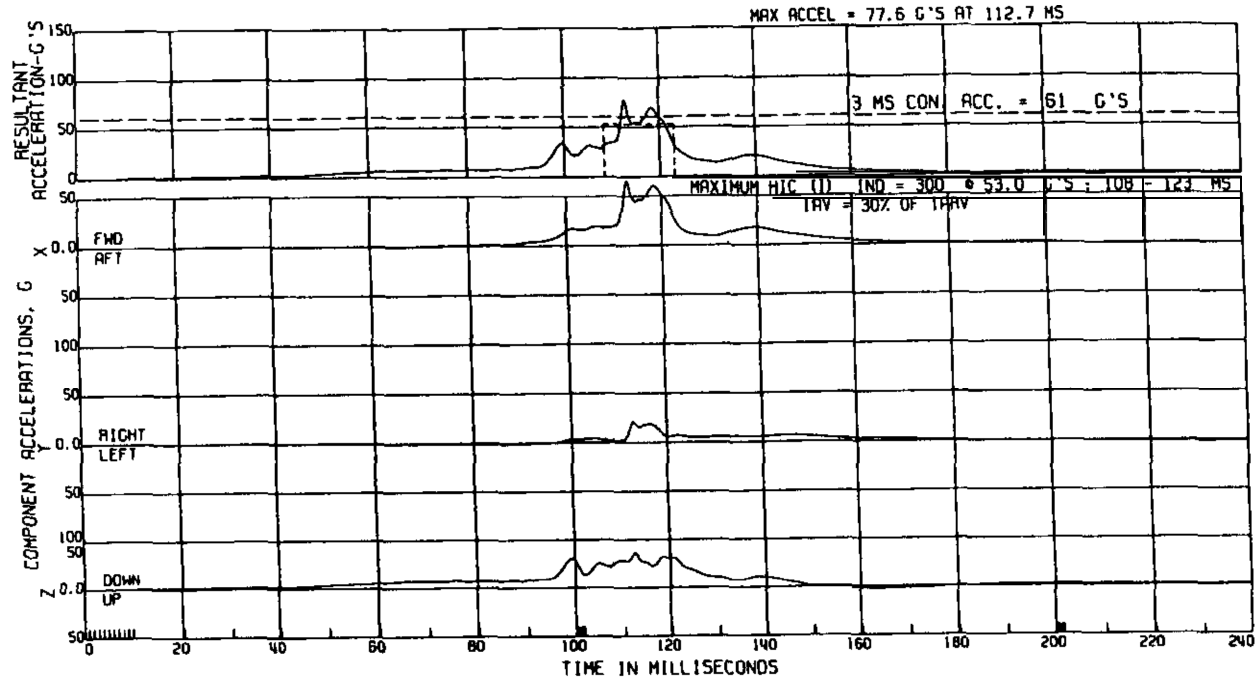
SC 8W9185D 4-DOOR

R. FRT H E R O ACCEL.

TEST DATE: 12/18/1997

ELEC DATA, SAE CLASS 1000

(HIC I LIMITED TO 15MS)



16 PROCESSED 12/18/1997 14:17 V2.07

C11817 L.REAR I M P 70% OVERLAP LTV MOE TO STATIONARY VEHICLE 80.7KM/H

ATD TYPE: GM50H

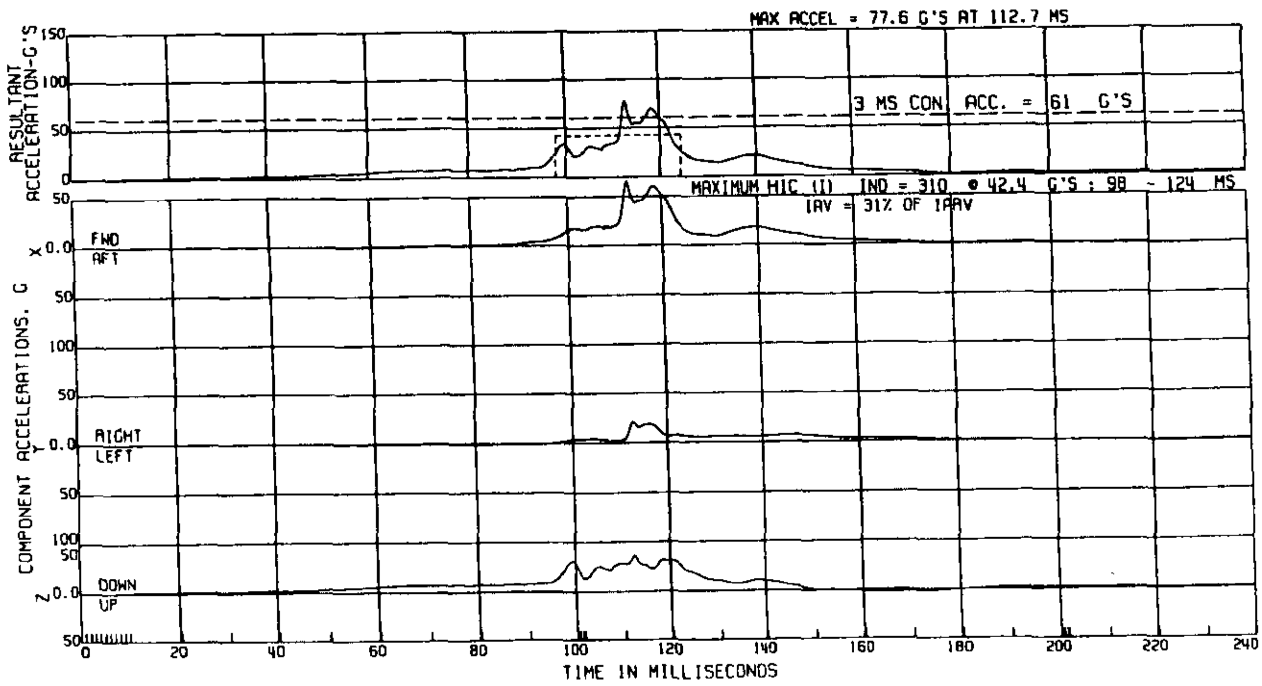
SC 8W9185D 4-DOOR

R. FRT H E R D ACCEL.

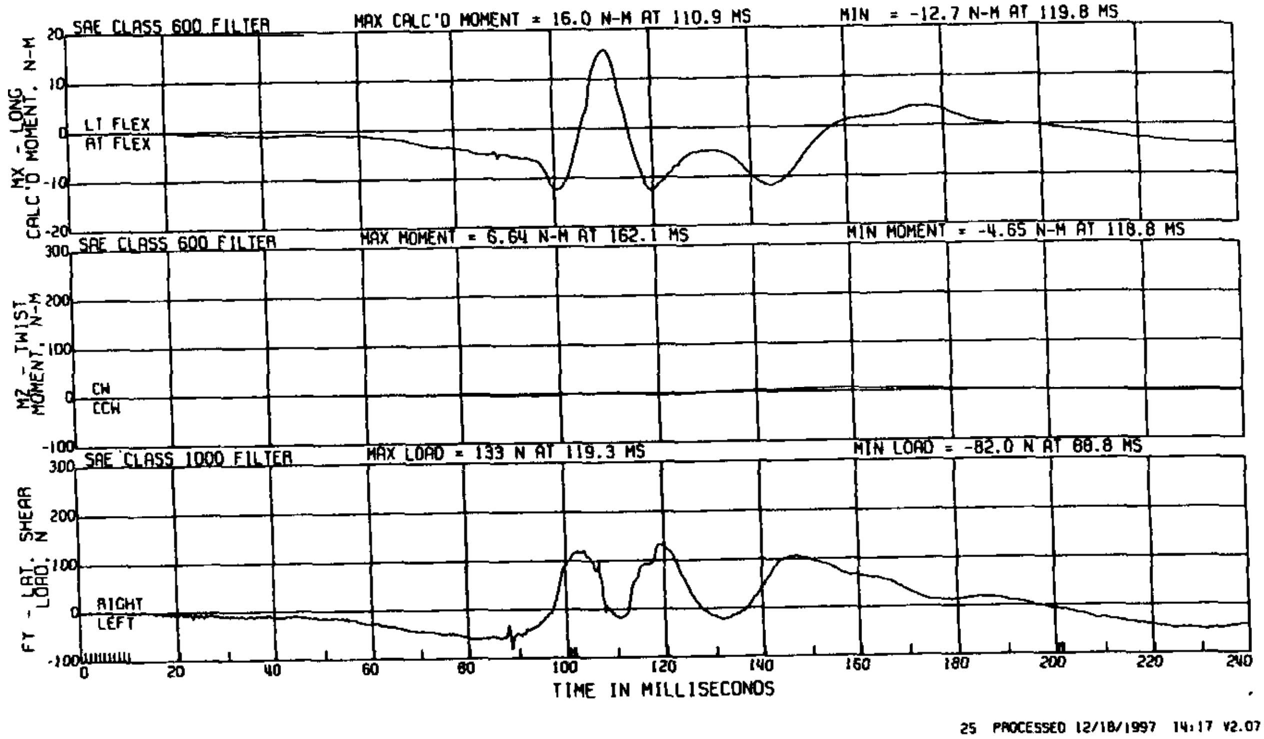
TEST DATE: 12/18/1997

ELEC DATA, SAE CLASS 1000

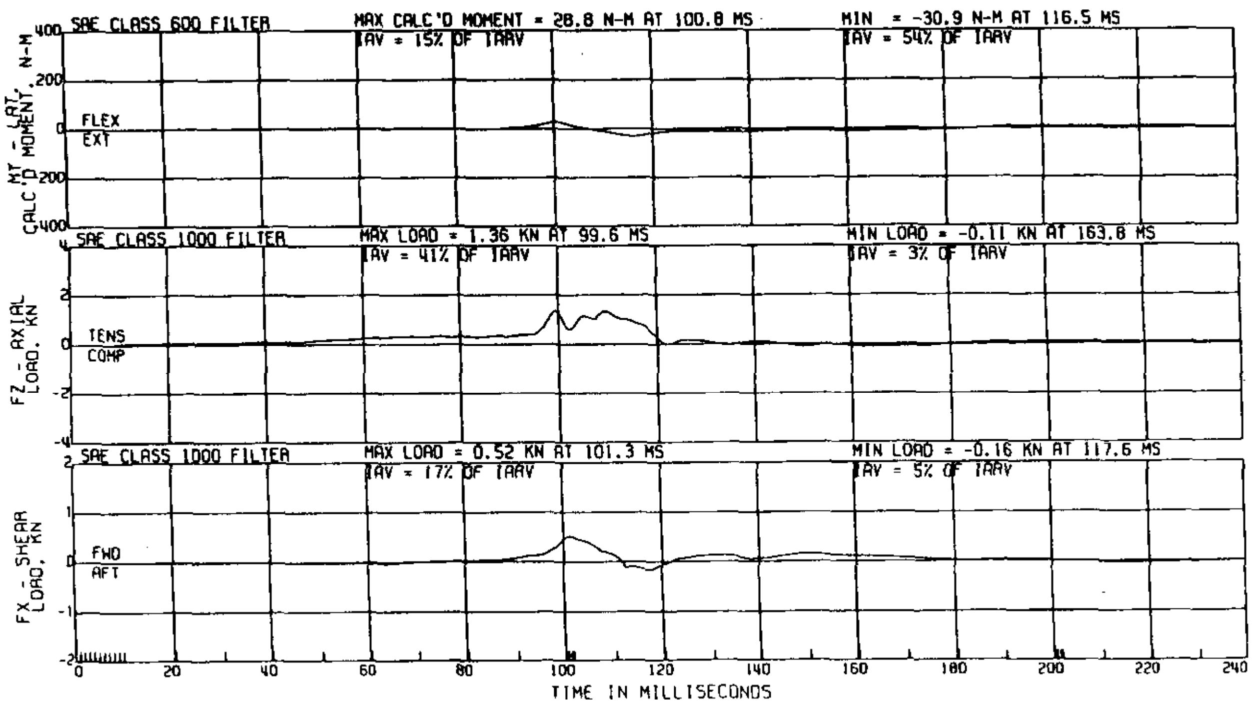
(HIC I LIMITED TO 36MS)



C11817 L.REAR IMP 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 80.7KM/H
ATD TYPE: GM50H
SC 8W91850 4-DOOR R.FRT NECK LOADING ON HEAD, UPPER LOAD TEST DATE:12/18/1997
ELEC DATA
R.FRT NECK LOADING ON HEAD



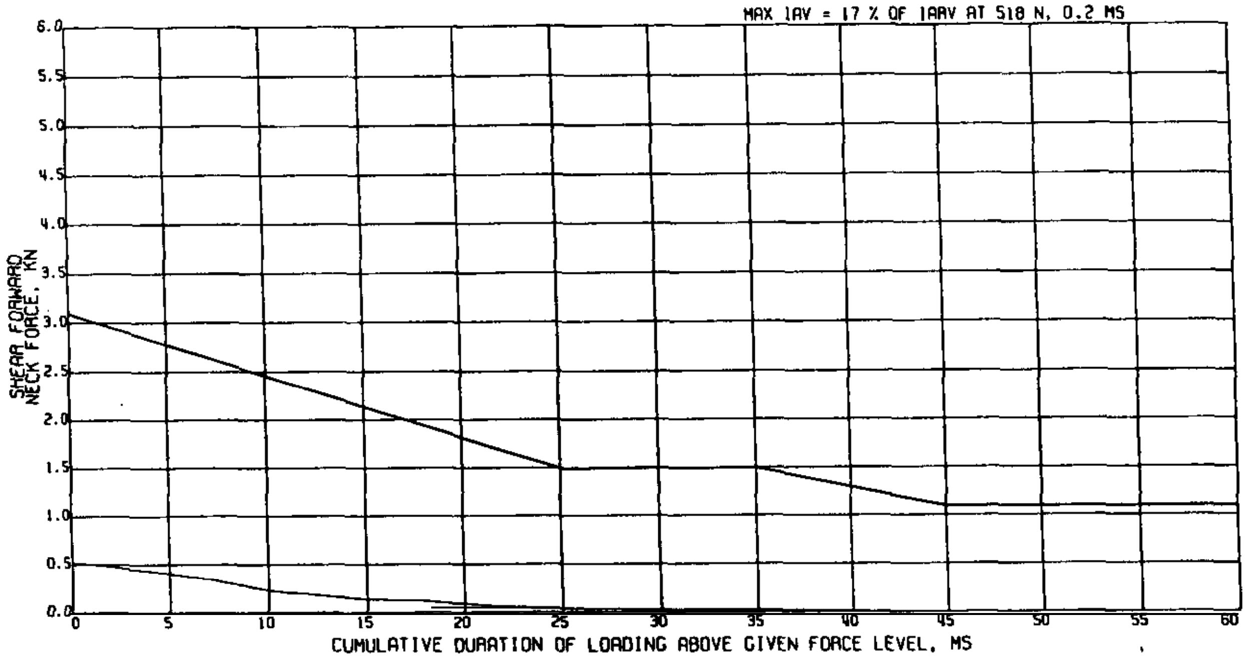
C11817 L.REAR IMP 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 80.7KM/H
ATD TYPE: GM50H
SC 8W91850 4-DOOR NECK LOADING ON HEAD TEST DATE:12/18/1997
ELEC DATA
R.FRT NECK LOADING ON HEAD



C11817 L.REAR IMP 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 80.7KM/H

SC 8W9185D 4-DOOR FORWARD NECK SHEAR ON HEAD. ATD TYPE: GM50H

ELEC DATA, SAE CLASS 1000 R. FRT INJURY REFERENCE TEST DATE:12/18/1997

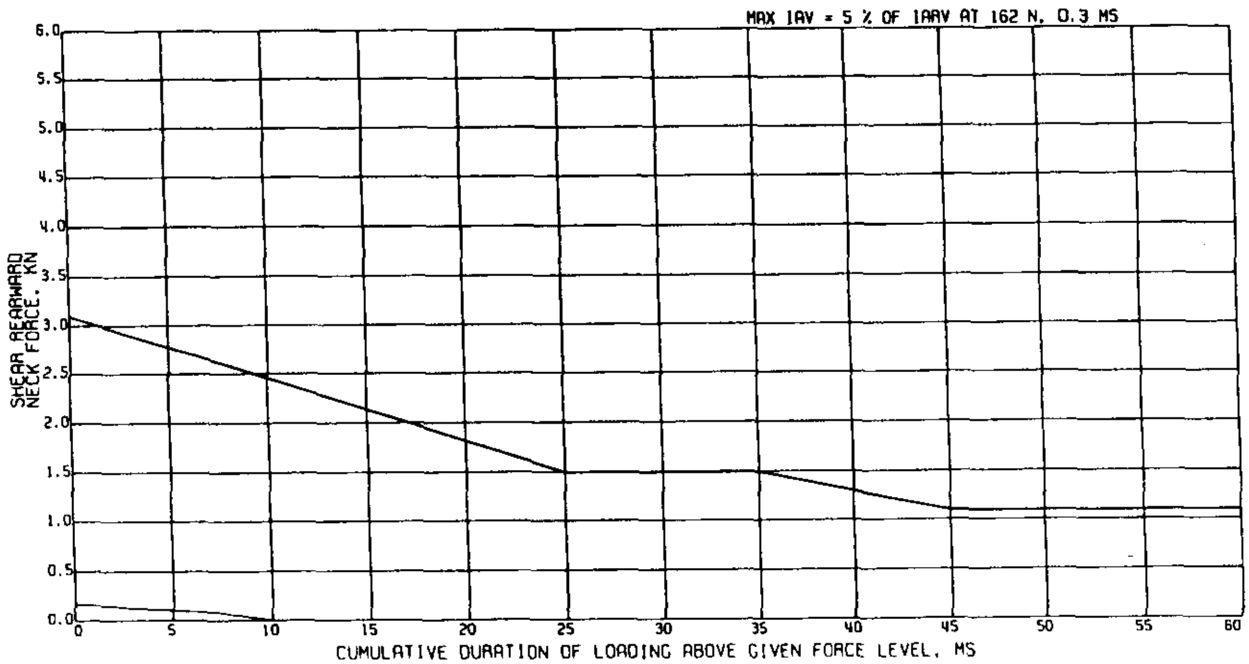


27 PROCESSED 12/18/1997 14:17 V2.07

C11817 L.REAR I M P 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 80.7KM/H

SC 8W9185D 4-DOOR REARWARD NECK SHEAR ON HERO. ATD TYPE: GM50H

ELEC DATA, SAE CLASS 1000 R. FRT INJURY REFERENCE TEST DATE:12/18/1997



C11817 L.REAR I M P 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 80.7KM/H

SC 8W91850 U-DOOR

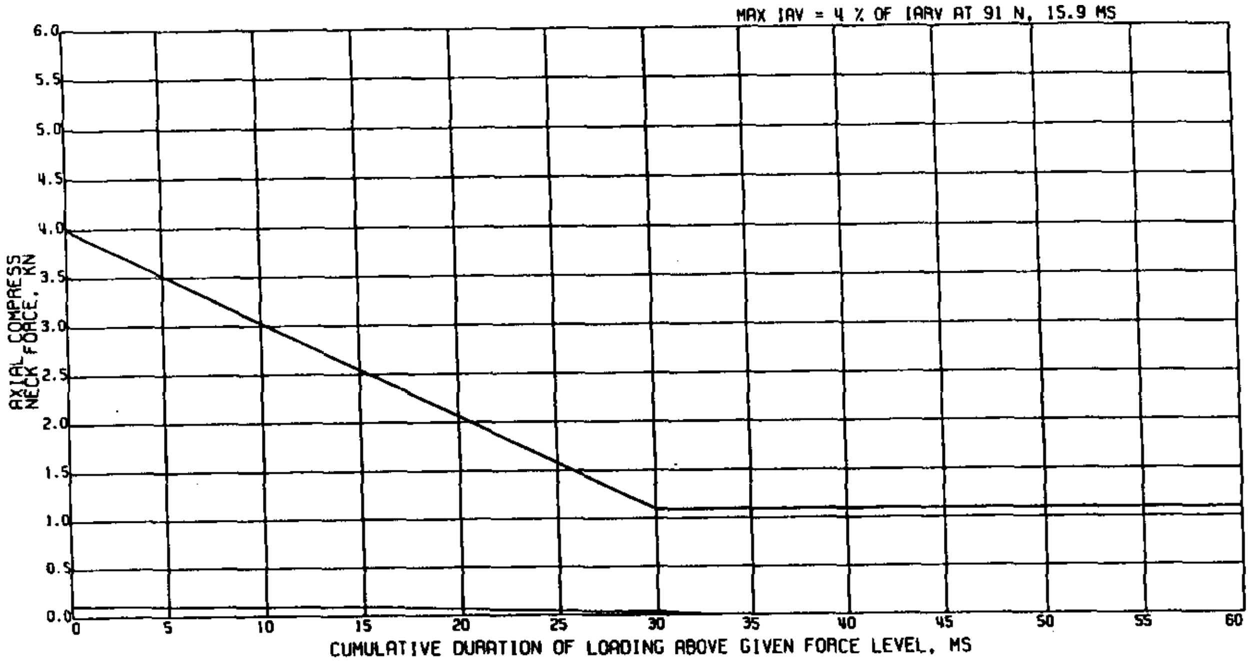
ELEC DATA, SAE CLASS 1000

AXIAL COMPRESSION ON HEAD,

R. FRT INJURY REFERENCE

ATD TYPE: GM50H

TEST DATE:12/18/1997



29 PROCESSED 12/18/1997 14:17 V2.07

C11817 L.REAR I M P 70% OVERLAP L T V MOB TO STATIONARY VEHICLE 80.7KM/H

SC 8W91850 4-DOOR

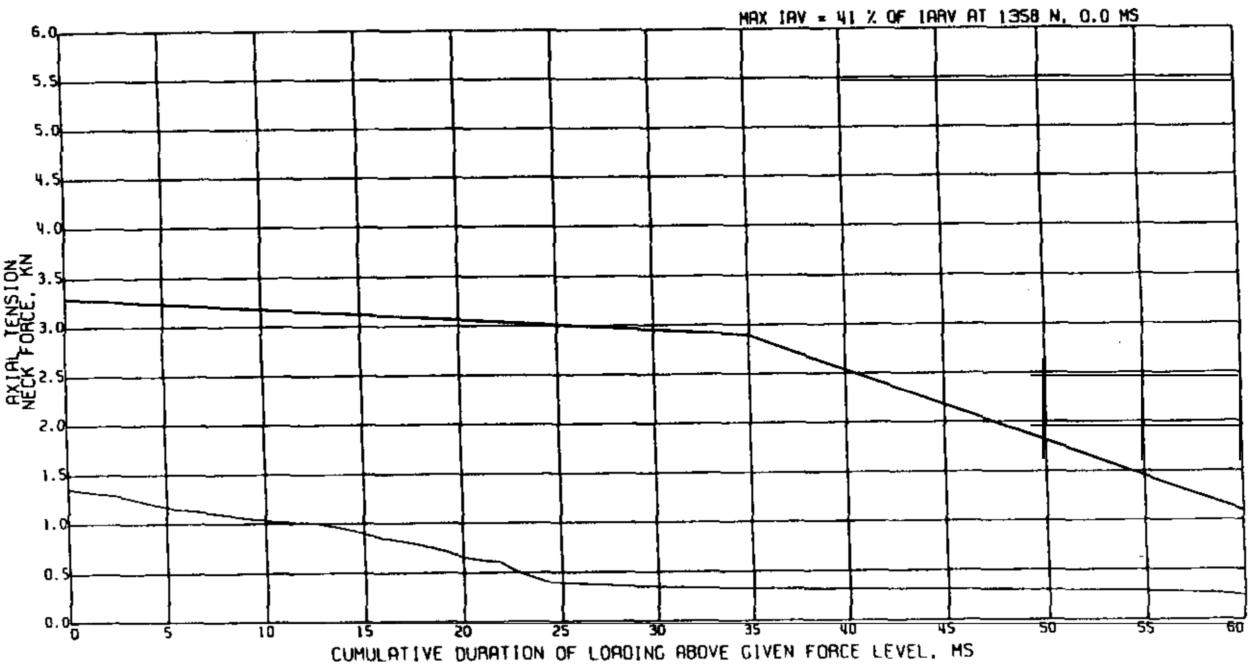
ELEC DATA, SAE CLASS 1000

AXIAL TENSION ON HEAD,

R. FRT INJURY REFERENCE

ATD TYPE: GM50H

TEST DATE:12/18/1997



C11818 L.REAR I M P 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 80.9KM/H

ATD TYPE: GM50H

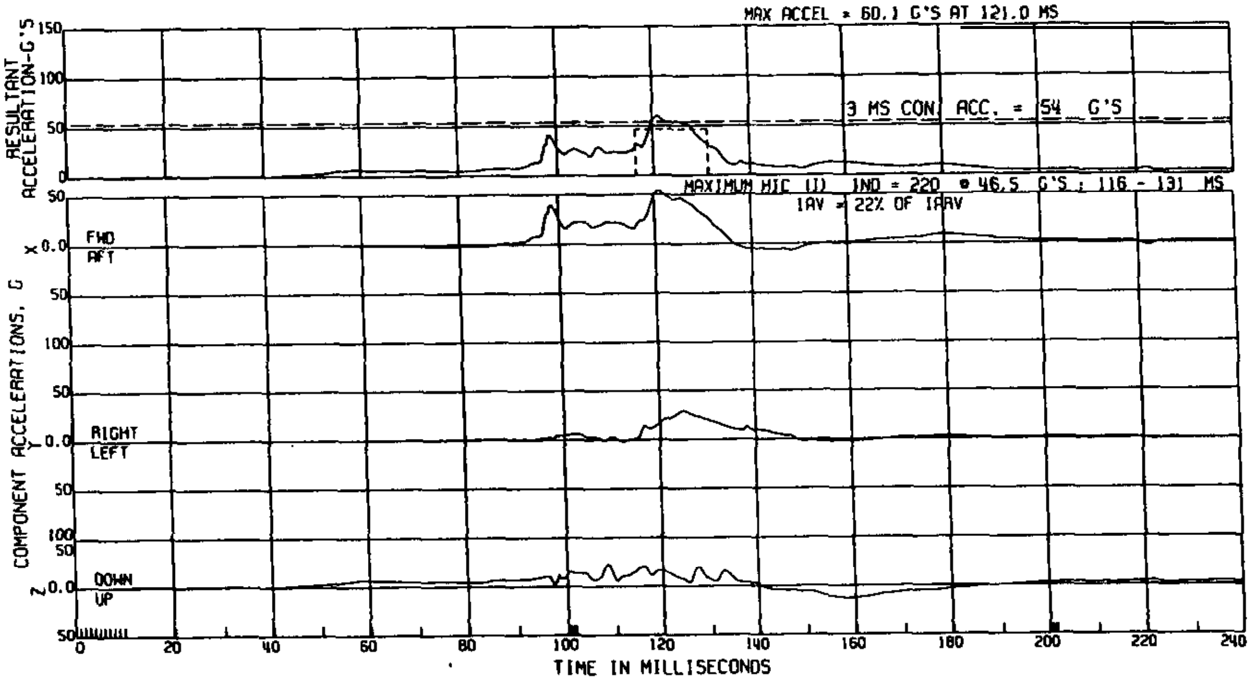
SC 8W91820 4-DOOR

L. FAT HERO ACCEL.

TEST DATE: 12/18/1997

ELEC DATA, SAE CLASS 1000

(HIC I LIMITED TO 15MS)



I PROCESSED 12/18/1997 14:21 V2.07

C11818 L.REAR IMP 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 80.9KM/H

ATD TYPE: GM50H

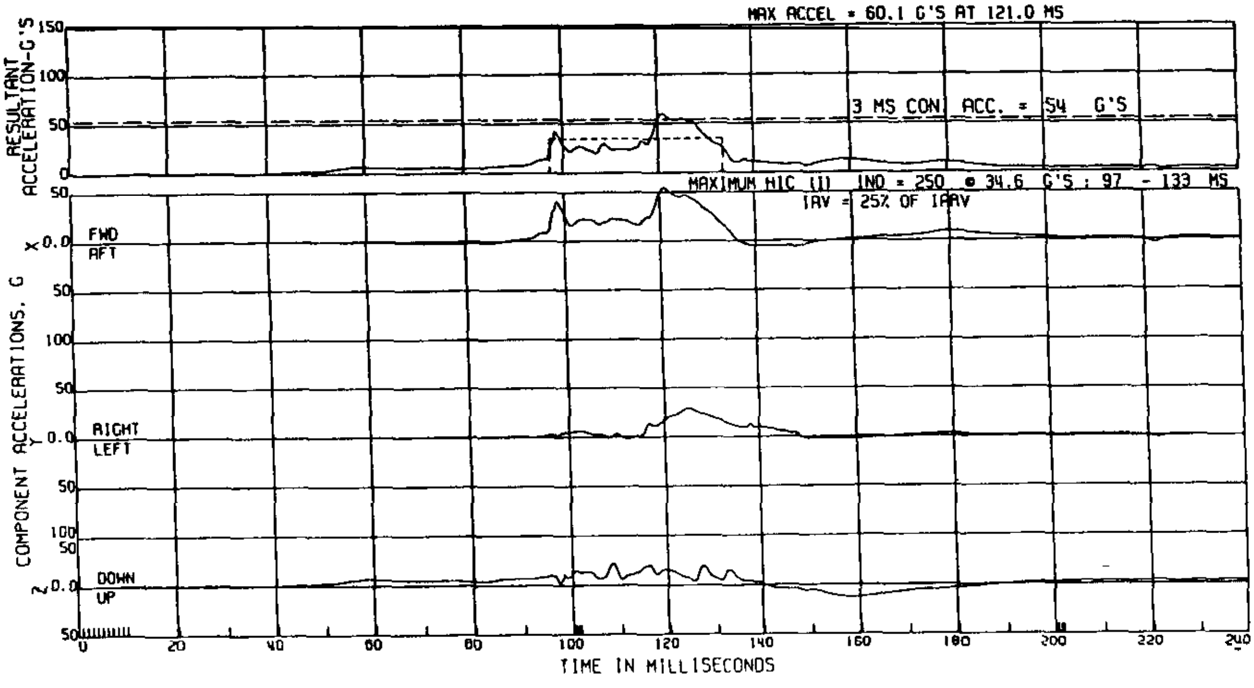
SC 8W91820 4-DOOR

L. FRT HEAD ACCEL.

TEST DATE: 12/18/1997

ELEC DATA, SAE CLASS 1000

(HIC I LIMITED TO 36MS)

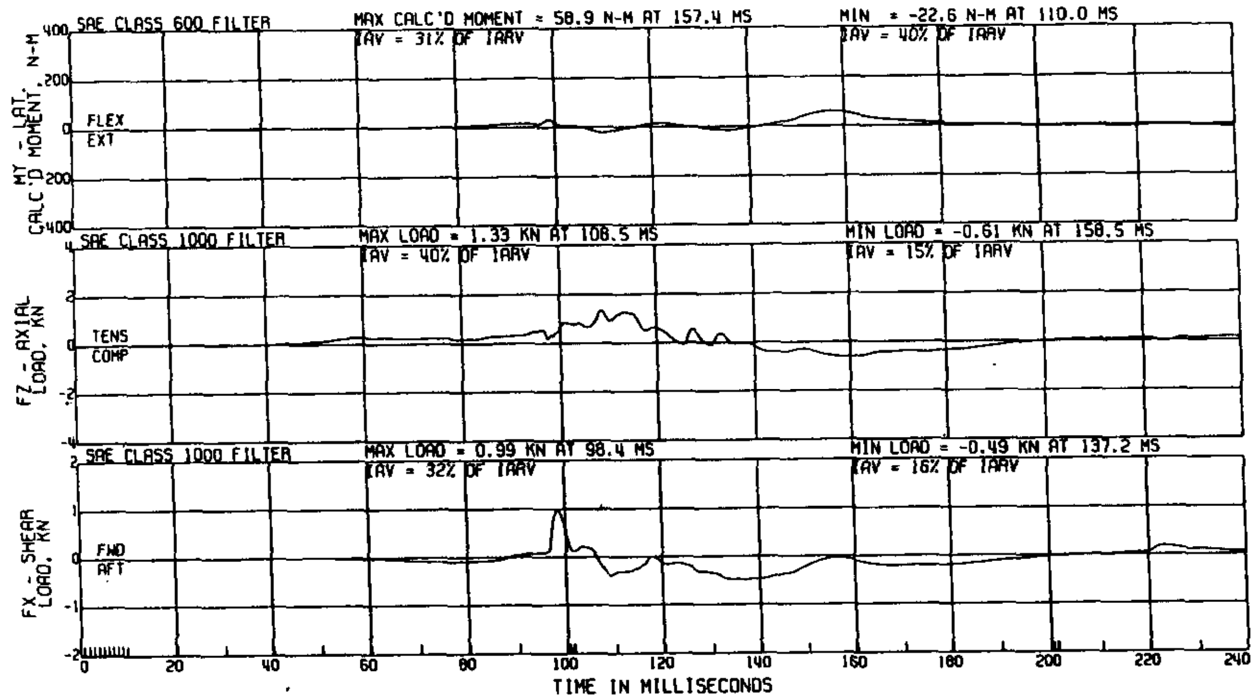


C11818 L.REAR IMP 70% OVERLAP LTV MDB TO STATIONARY VEHICLE 80.9KM/H

ATD TYPE: GM50H

SC 8W91820 4-DOOR NECK LOADING ON HERO TEST DATE:12/18/1997

ELEC DATA L. FRT NECK LOADING ON HEAD



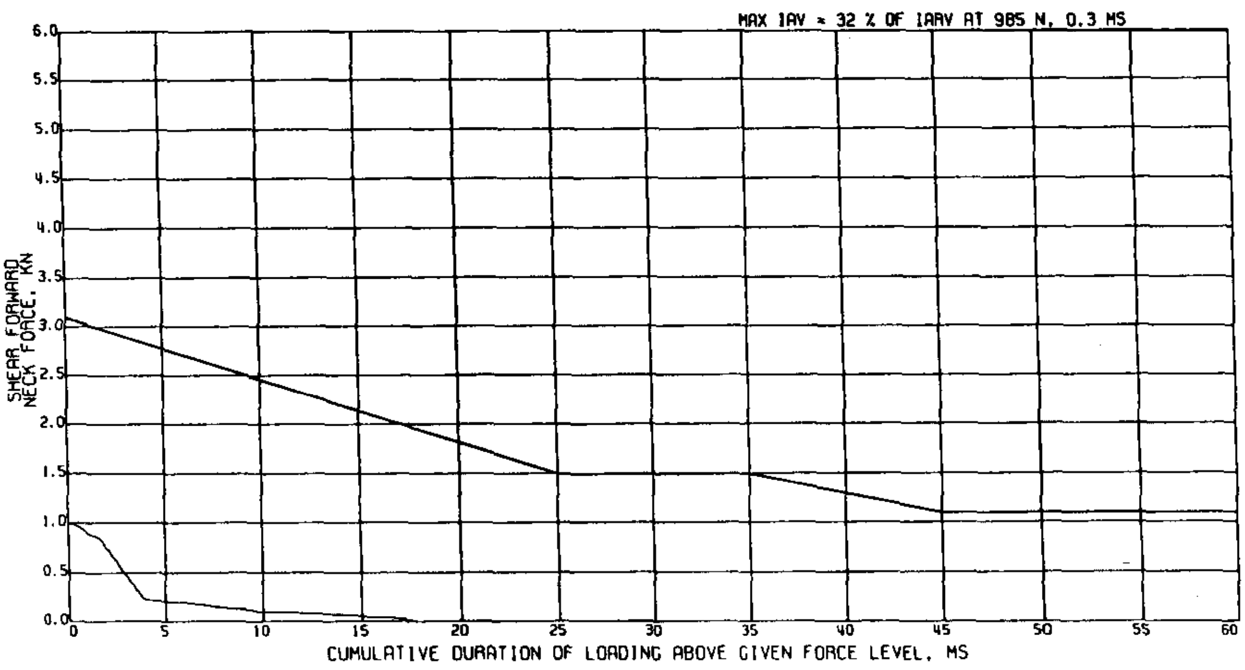
PROCESSED 12/18/1997 14:21 V2.07

C11818 L.REAR IMP 70% OVERLAP LTV MDB TO STATIONARY VEHICLE 80.9KM/H

ATD TYPE: GM50H

SC 8W91820 4-DOOR FORWARD NECK SHEAR ON HERO. TEST DATE:12/18/1997

ELEC DATA, SAE CLASS 1000 L.FRT INJURY REFERENCE



C11818 L.REAR I M P 70% OVERLAP LTV MDB TO STATIONARY VEHICLE 80.9KM/H

ATD TYPE: GM50H

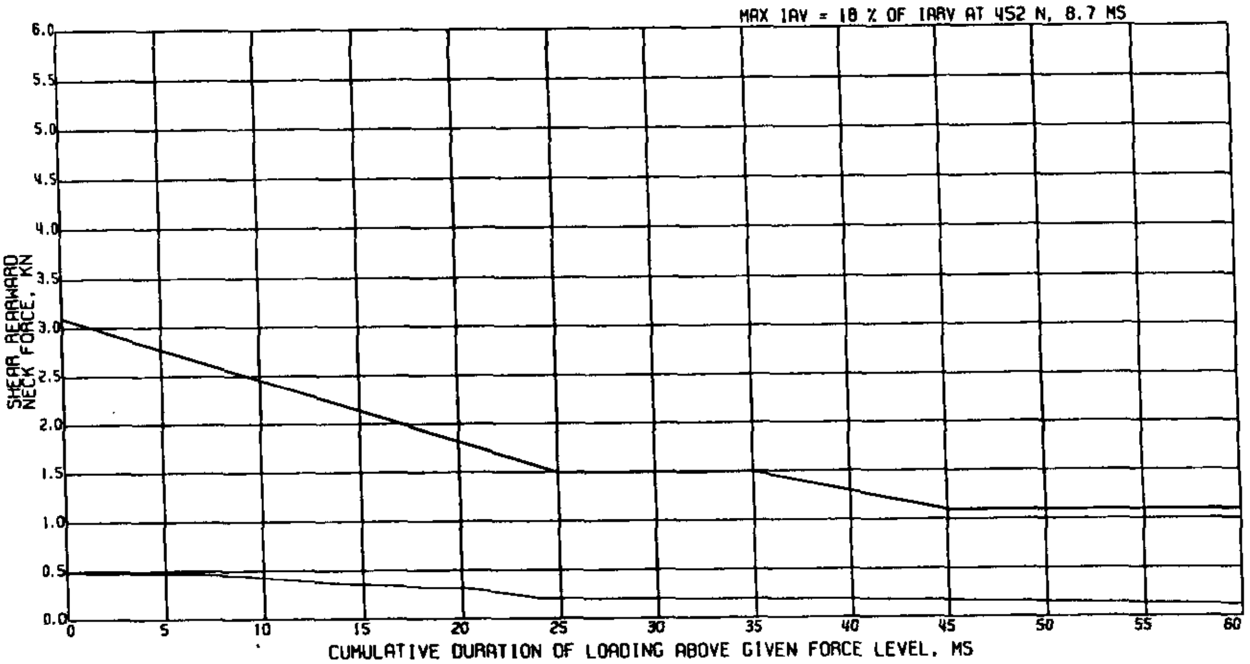
SC 8W91820 4-DOOR

TEST DATE:12/18/1997

ELEC DATA, SAE CLASS 1000

REARWARD NECK SHEAR ON HEAD.

L. FRT INJURY REFERENCE



13 PROCESSED 12/18/1997 14:21 V2.07

C11818 L.REAR I M P 70% OVERLAP LTV MDB TO STATIONARY VEHICLE 80.9KM/H

ATD TYPE: GM50H

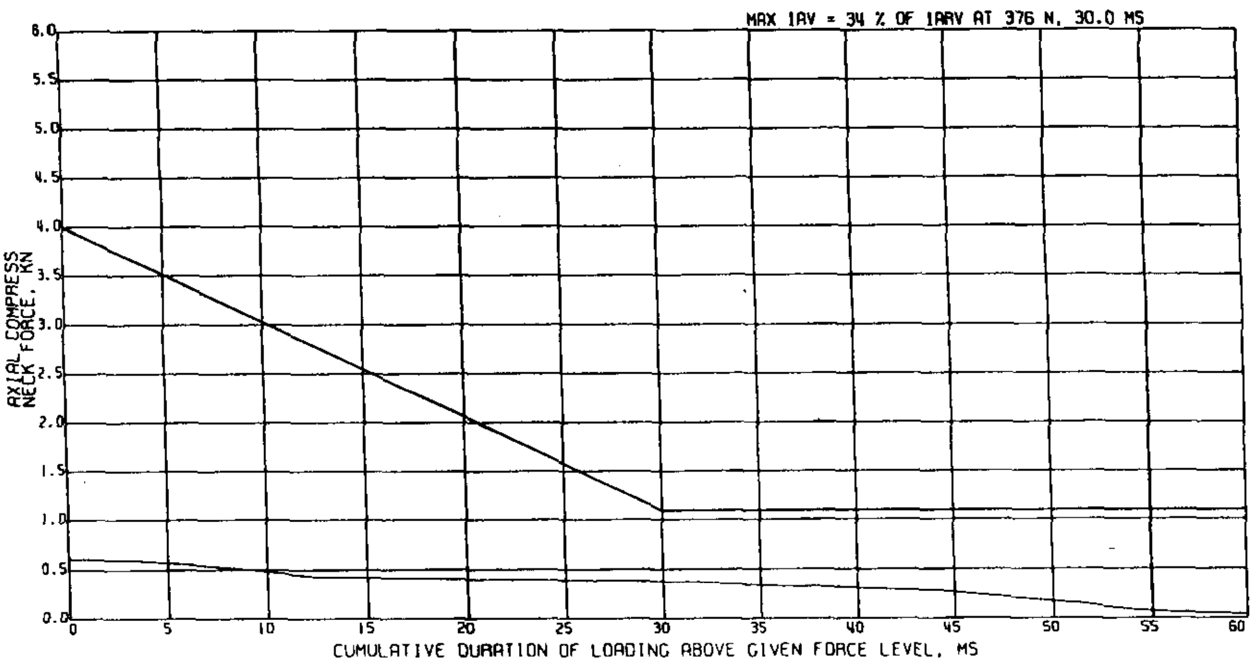
SC 8W91820 4-DOOR

TEST DATE:12/18/1997

ELEC DATA, SAE CLASS 1000

AXIAL COMPRESSION ON HEAD.

L. FRT INJURY REFERENCE



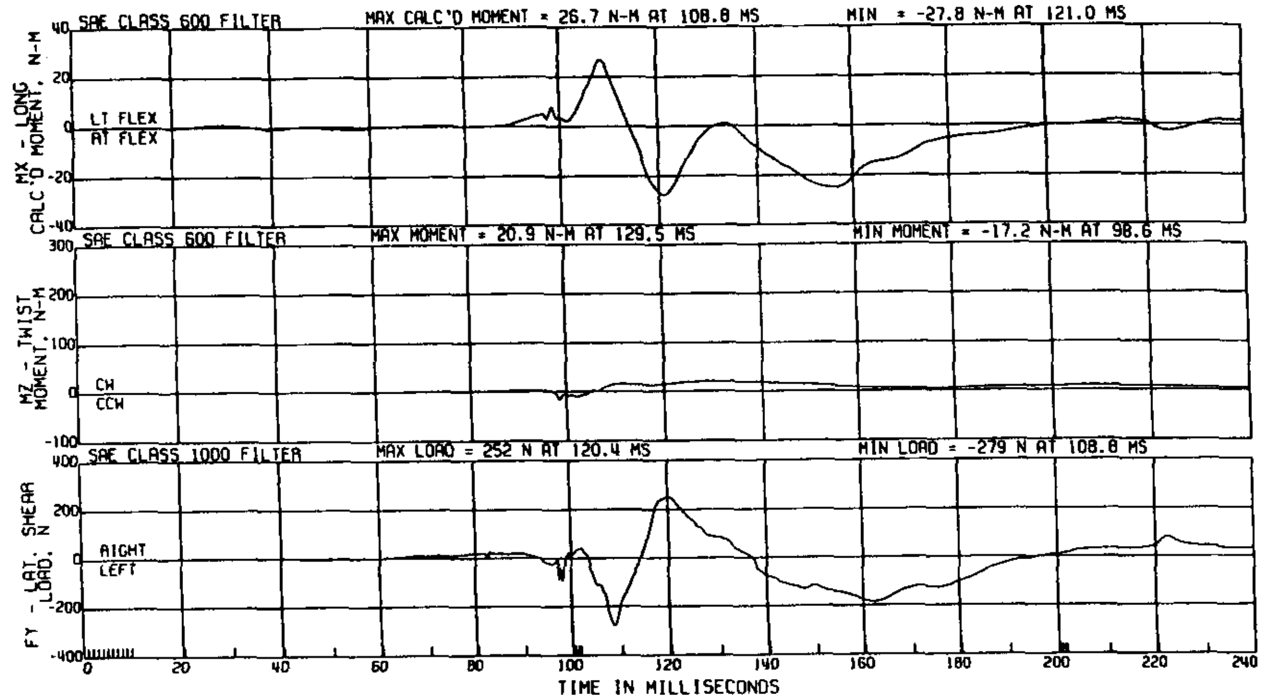
C11818 L.REAR IMP 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 80.9KM/H

ATD TYPE: GM50H

SC 8W9182D 4-DOOR L.FRT NECK LOADING ON HEAD, UPPER LOAD TEST DATE:12/18/1997

ELEC DATA

L.FRT NECK LOADING ON HEAD



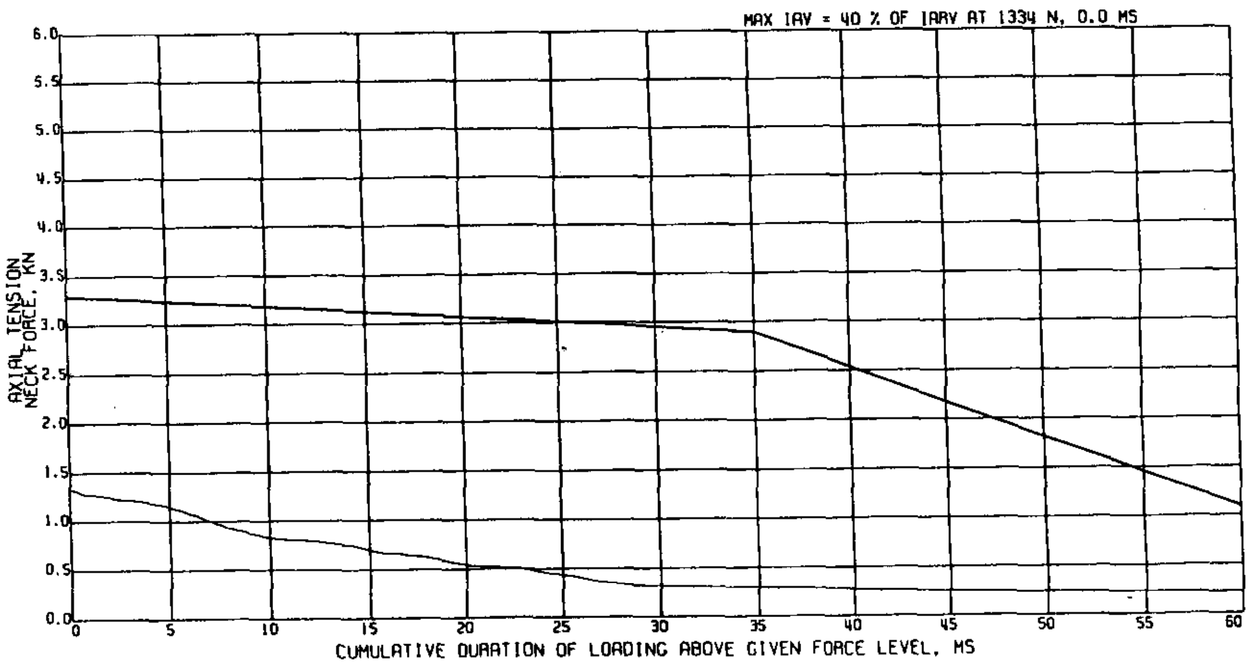
10 PROCESSED 12/18/1997 14:21 V2.07

C11818 L.REAR IMP 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 80.9KM/H

ATD TYPE: GM50H

SC 8W91820 4-DOOR AXIAL TENSION ON HEAD, TEST DATE:12/18/1997

ELEC DATA, SAE CLASS 1000 L.FRT INJURY REFERENCE



15 PROCESSED 12/18/1997 14:21 V2.07

C11818 L.REAR IMP 70% OVERLAP LTV MDB TO STATIONARY VEHICLE 80.9KM/H

SC 8W91820 U-ODOR

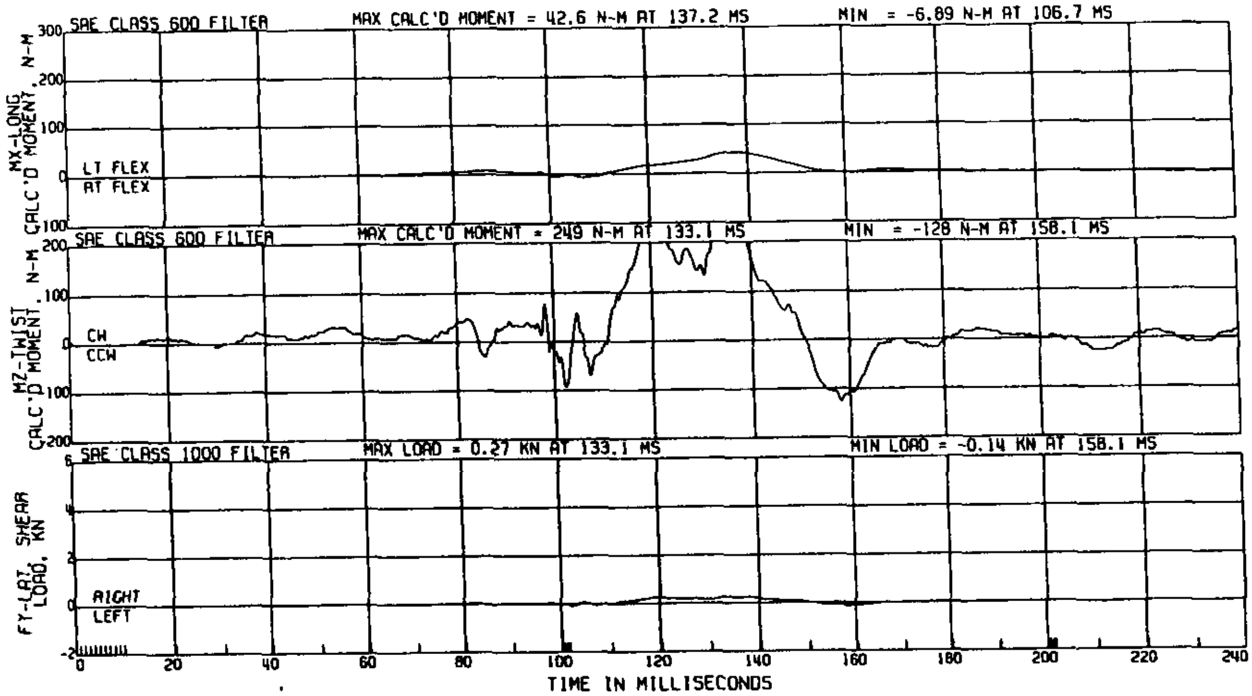
ELEC DATA

L. FRT NECK LOADING LOAD

(TORSO ON BASE OF NECK)

ATD TYPE: GM50H

TEST DATE:12/18/1997



3l PROCESSED 12/19/1997 07:24 V2.07

C11818 L.REAR IMP 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 80.9KM/H

SC 8W91820 U-DOOR

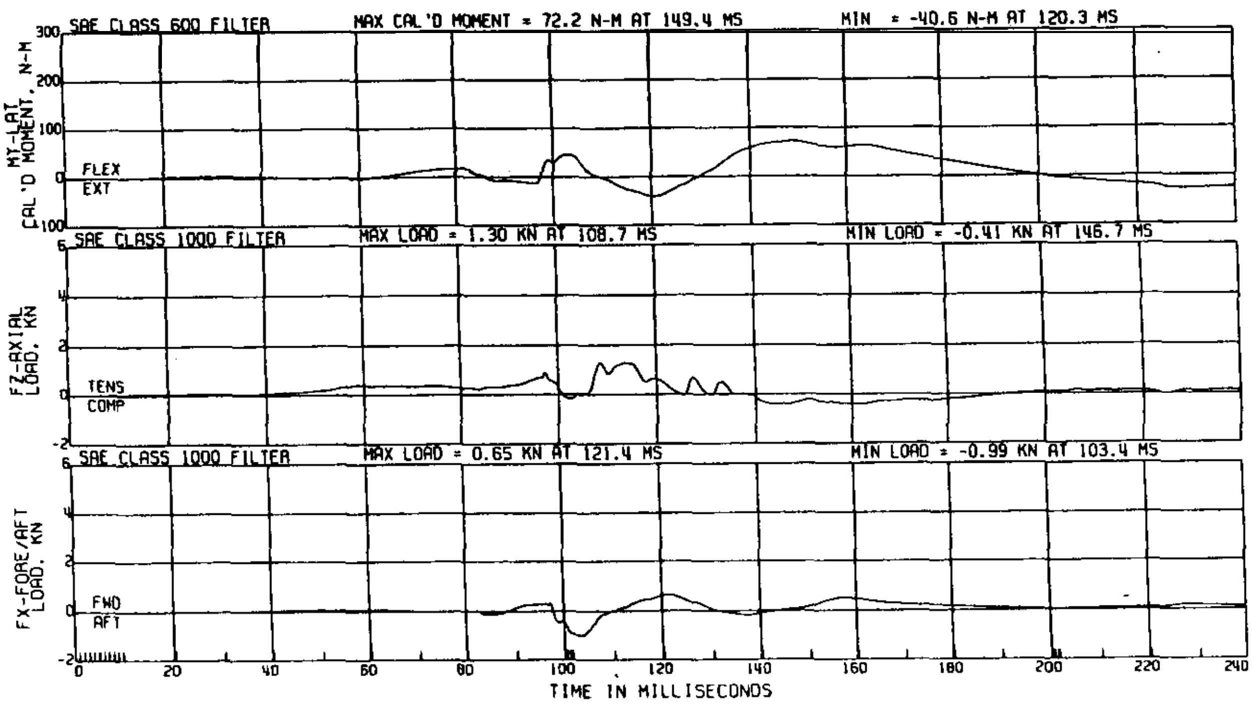
ELEC DATA

L. FRT NECK LOADING LORD

(TORSO ON BASE OF NECK)

ATD TYPE: GM50H

TEST DATE:12/18/1997



C11818 L.REAR IMP 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 80.9KM/H

SC 8W91820 4-DOOR

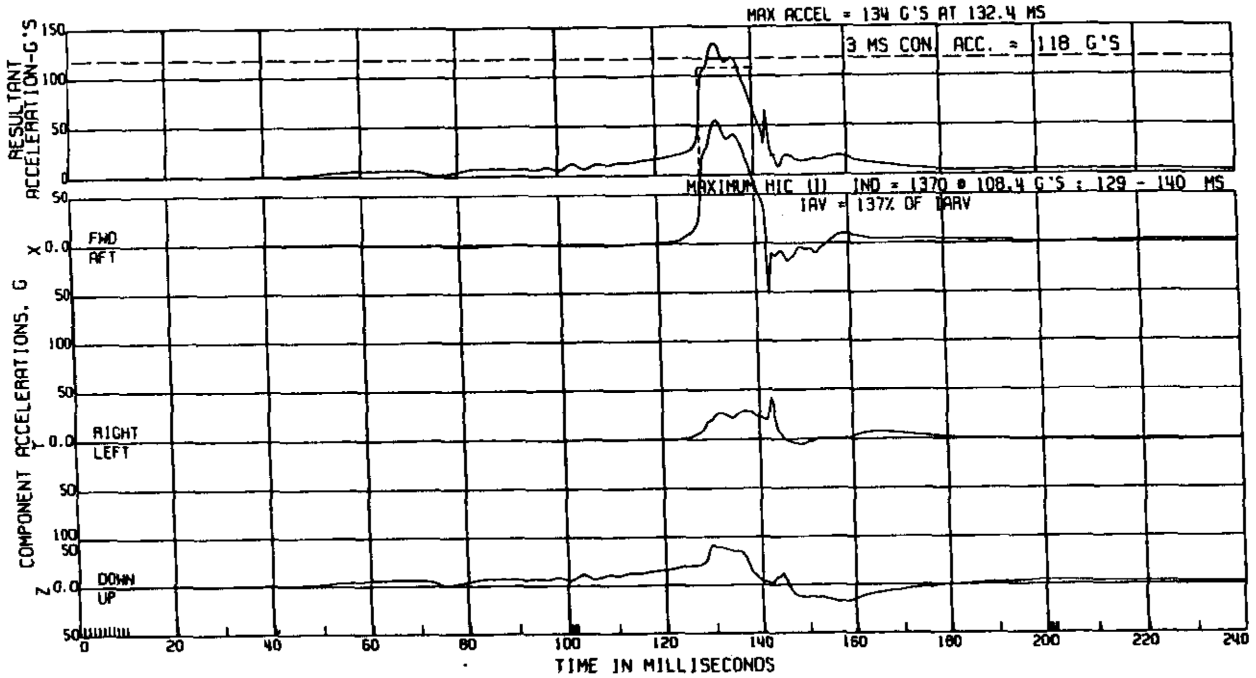
ELEC DATA, SAE CLASS 1000

R. FRT HERO ACCEL.

(HIC I LIMITED TO 15MS)

ATD TYPE: GM50H

TEST DATE: 12/18/1997



16 PROCESSED 12/18/1997 14:21 V2.07

C11818 L.REAR IMP 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 80.9KM/H

SC 8W91820 4-DOOR

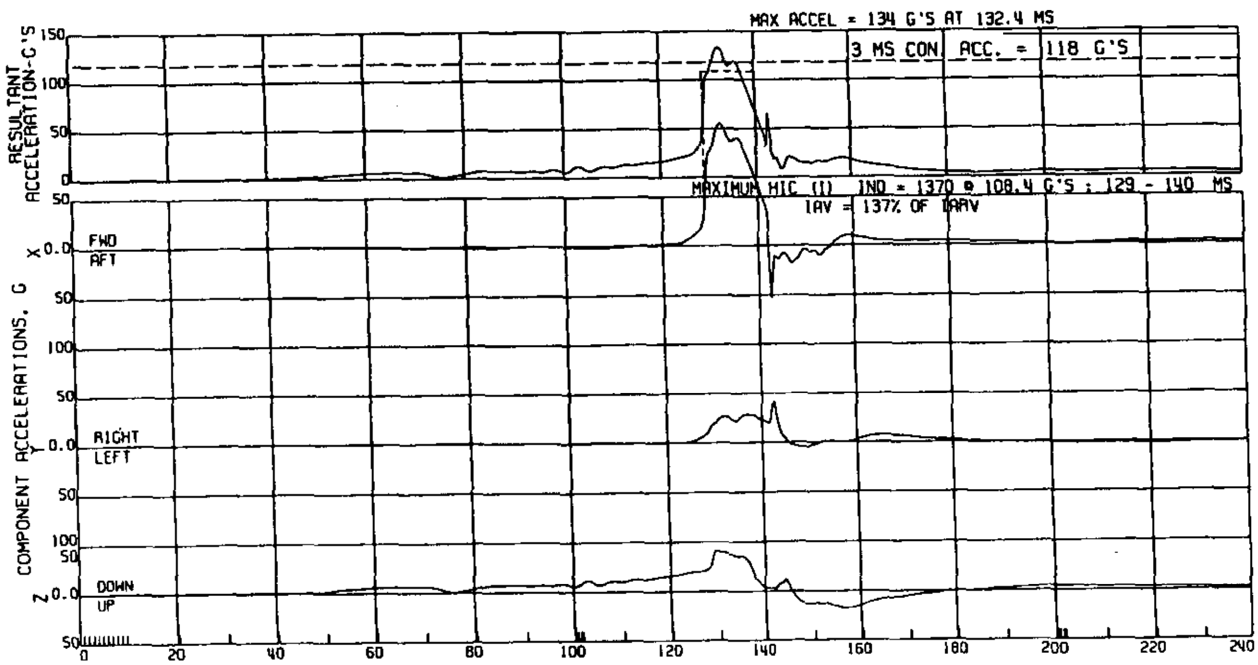
ELEC DATA, SAE CLASS 1000

R. FRT HERO ACCEL.

(HIC I LIMITED TO 36MS)

ATD TYPE: GM50H

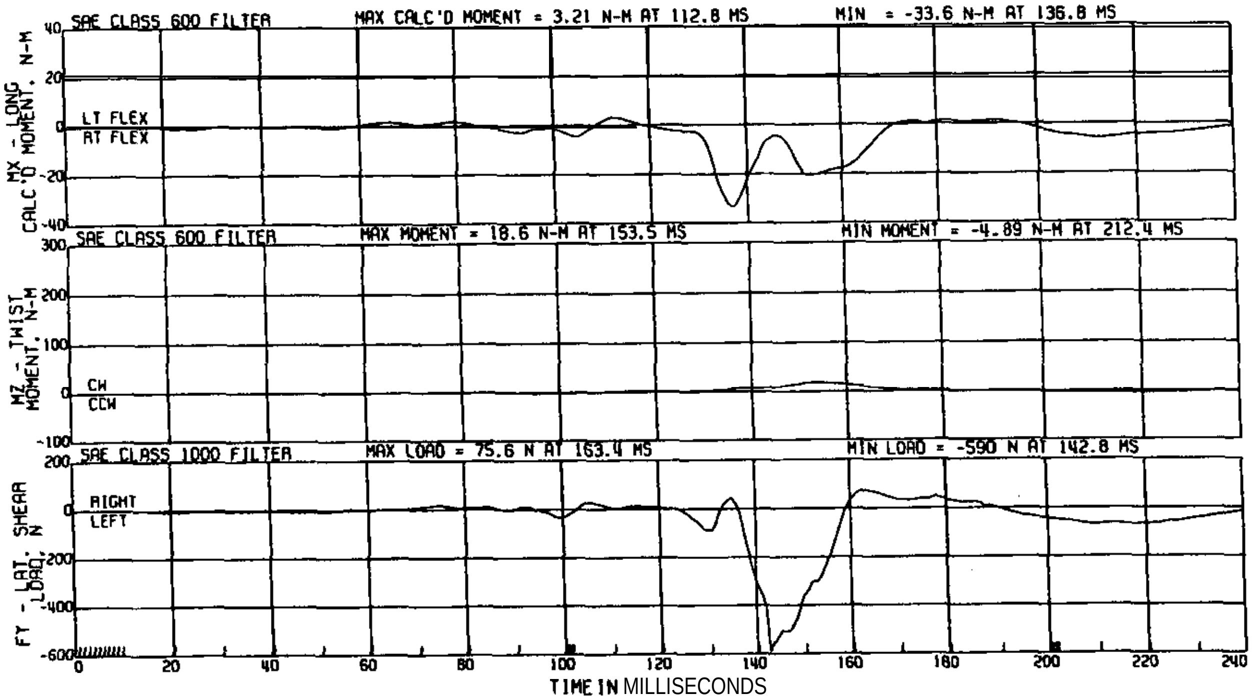
TEST DATE: 12/18/1997



C11818 L.REAR I M P 70% OVERLAP LTV MDB TO STATIONARY VEHICLE 80.9KM/H

SC 8W91820 4-DOOR R. FRT NECK LOADING ON HERO. UPPER LOAD ATD TYPE: GM50H TEST DATE:12/18/1997

ELEC DATA R. FRT NECK LOADING ON HERO



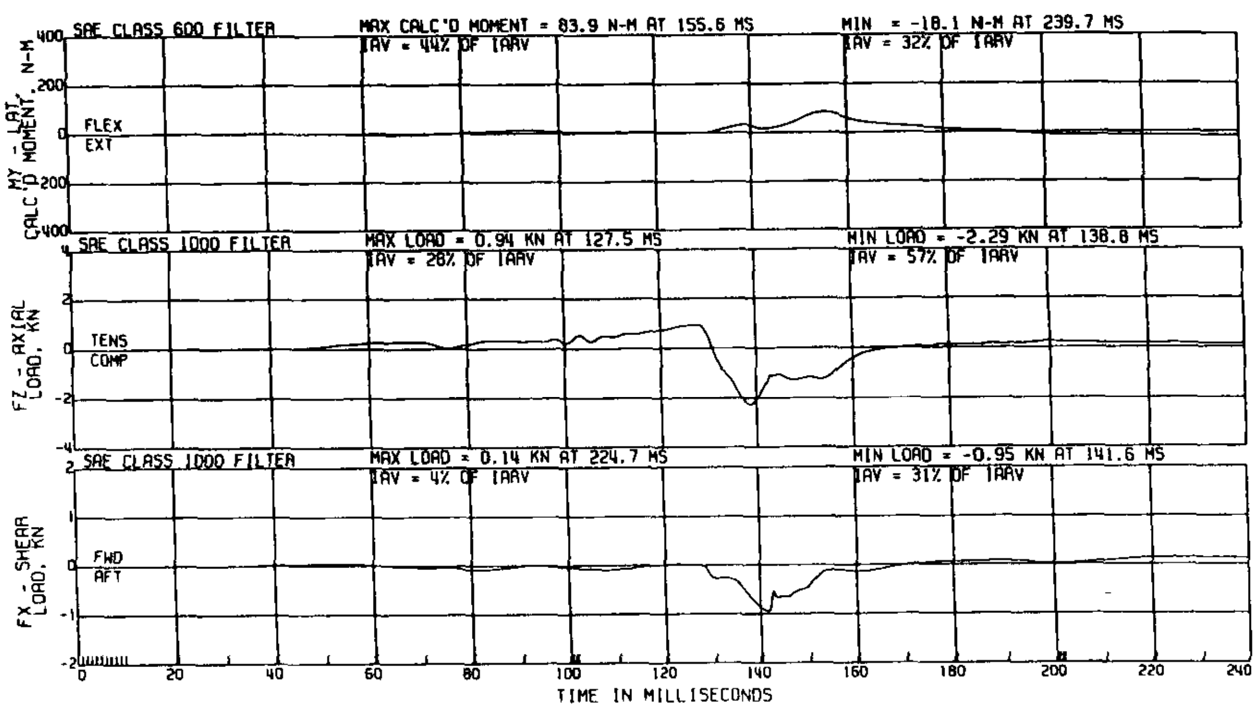
25 PROCESSED 12/18/1997 14:22 V2.07

C11818 L.REAR IMP 70% OVERLAP LTV MDB TO STATIONARY VEHICLE 80.9KM/H

ATD TYPE: GM50H

SC 8W91820 U-ODOR NECK LOADING ON HERO TEST DATE:12/18/1997

ELEC DATA R. FRT NECK LOADING ON HERO



C11818 L.REAR I M P 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 80.9KM/H

SC 8W91820 4-DOOR

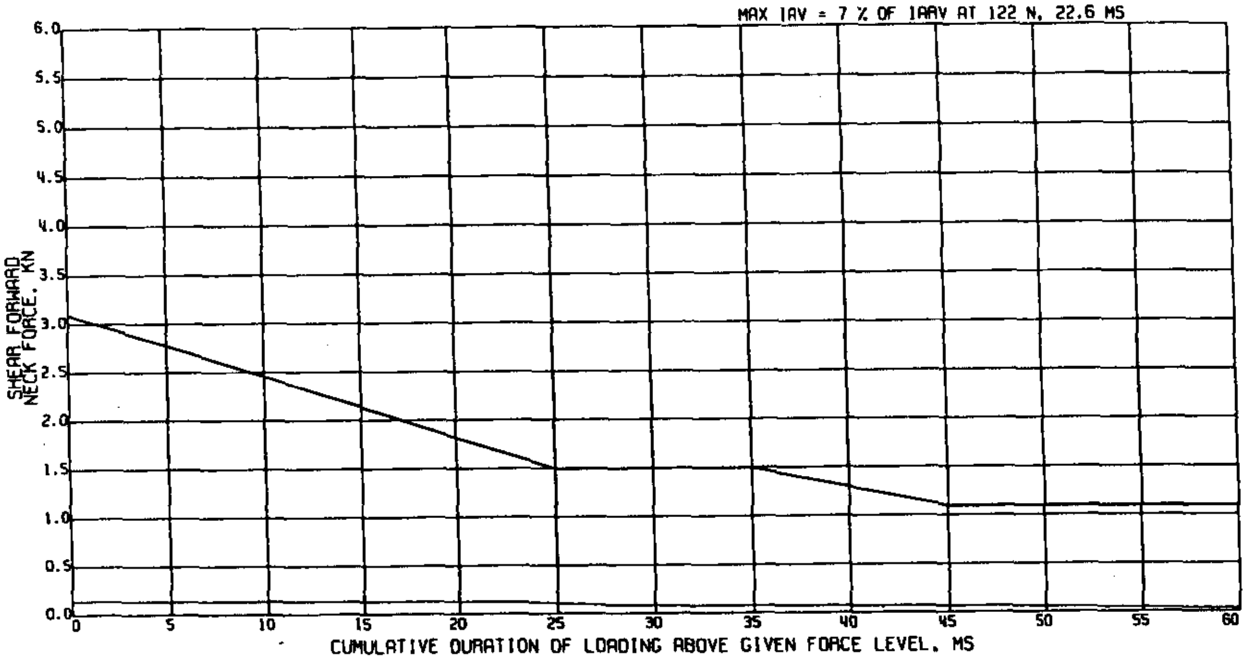
ELEC DATA, SAE CLASS 1000

FORWARD NECK SHEAR ON HERO.

A. FRT INJURY REFERENCE

ATD TYPE: GM50H

TEST DATE:12/18/1997



27 PROCESSED 12/18/1997 14:22 V2.07

C11818 L.REAR I M P 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 80.9KM/H

SC 8W91820 U-DOOR

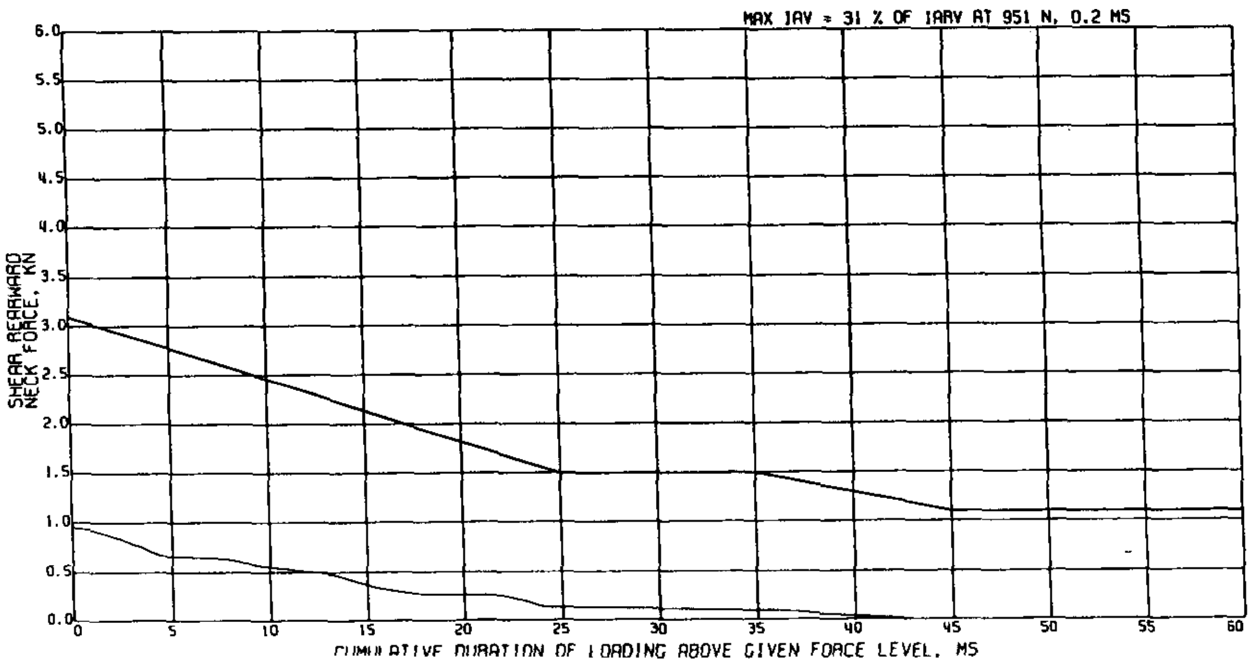
ELEC DATA, SAE CLASS 1000

REARWARD NECK SHEAR ON HERO.

R. FRT INJURY REFERENCE

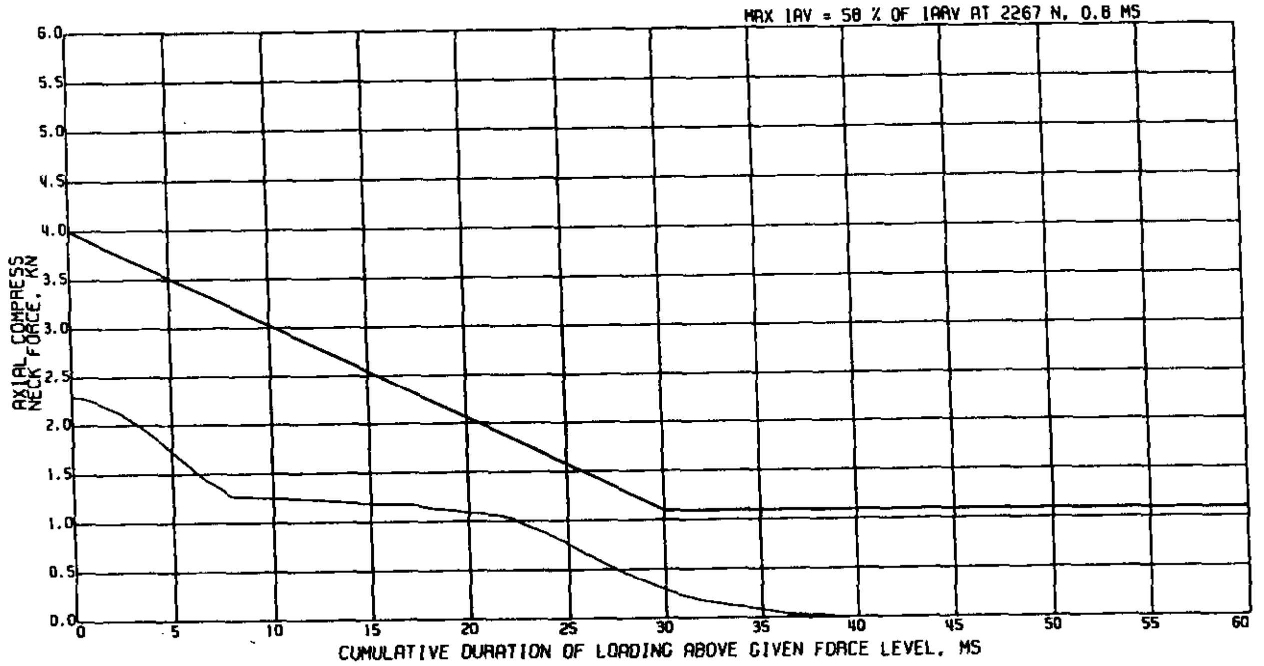
ATD TYPE: GM50H

TEST DATE:12/18/1997



C11818 L.REAR IMP 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 80.9KM/H
ATD TYPE: GM50H
TEST DATE: 12/18/1997
SC 8W91820 4-DOOR
ELEC DATA, SAE CLASS 1000

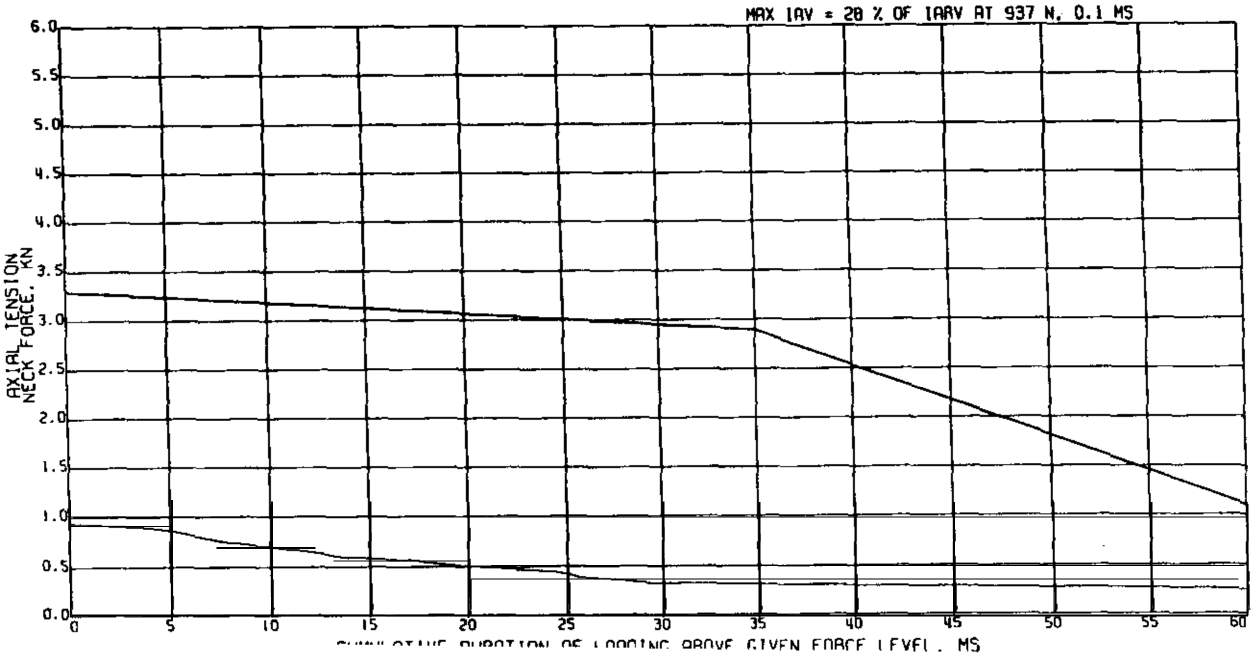
AXIAL COMPRESSION ON HEAD.
R. FRT INJURY REFERENCE



29 PROCESSED 12/18/1997 14:22 V2.07

C11818 L.REAR IMP 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 80.9KM/H
ATD TYPE: GM50H
TEST DATE: 12/18/1997
SC 8W91820 4-DOOR
ELEC DATA, SAE CLASS 1000

AXIAL TENSION ON HEAD.
R. FRT INJURY REFERENCE



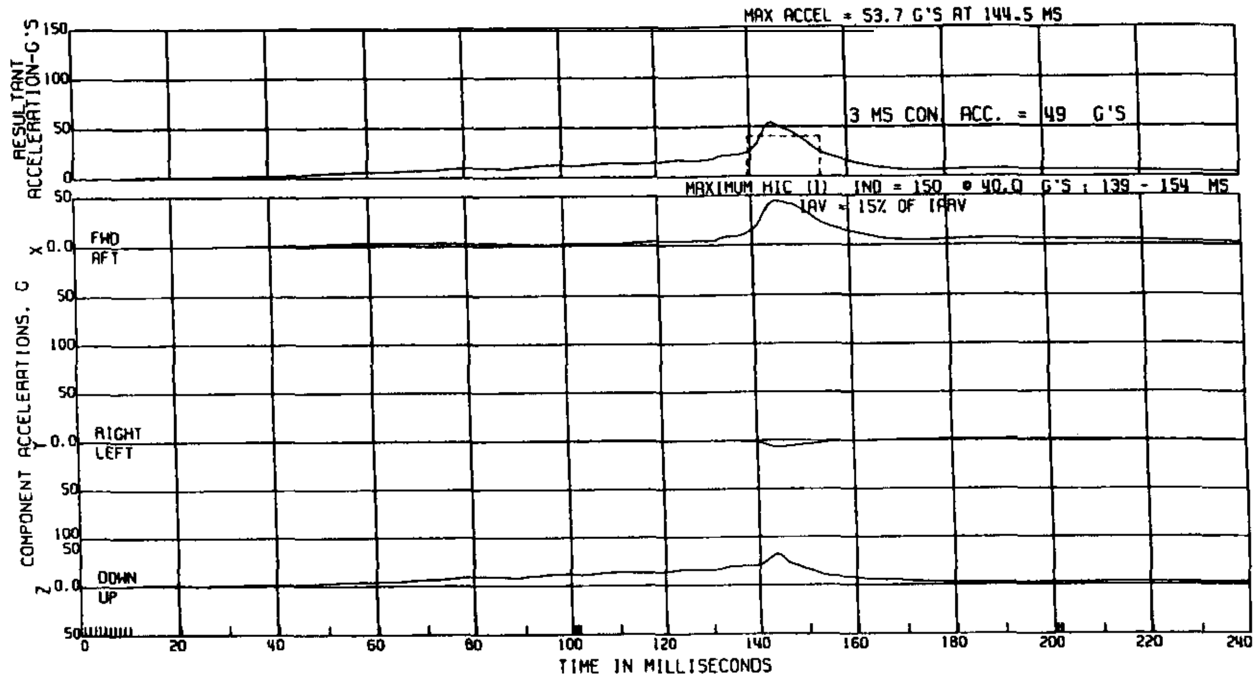
C11816 R.REAR IMP 70% OVERLAP LTV MDB TO STATIONARY VEHICLE 81.2KM/H

ATD TYPE: GM50H

SC 8W9183D 4-DOOR L. FRT HERO ACCEL. TESTDATE:01/28/1998

ELEC DATA, SAE CLASS 1000

(HIC I LIMITED TO 15MS)



1 PROCESSED 1/28/1998 09:07 V2.07

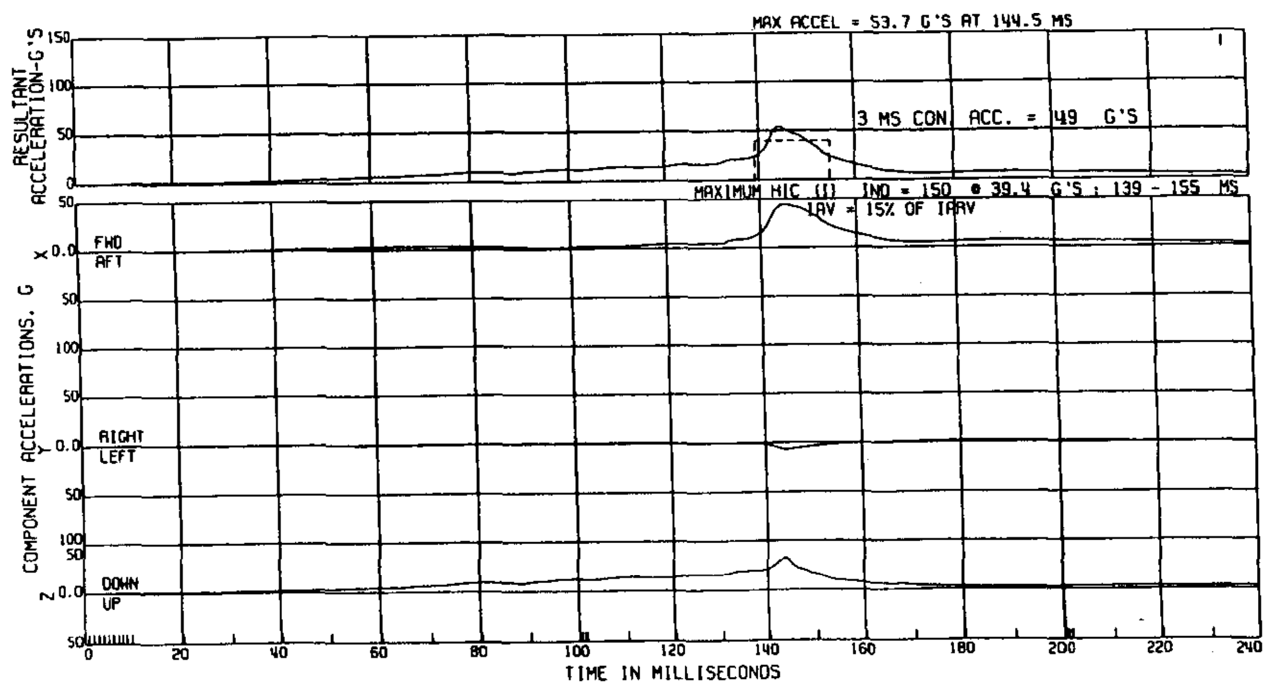
C11816 R.REAR IMP 70% OVERLAP LTV HOE TO STATIONARY VEHICLE 81.2KM/H

ATD TYPE: GM50H

SC 8W9183D 4-DOOR L. FRT HERO ACCEL. TEST DATE:01/28/1998

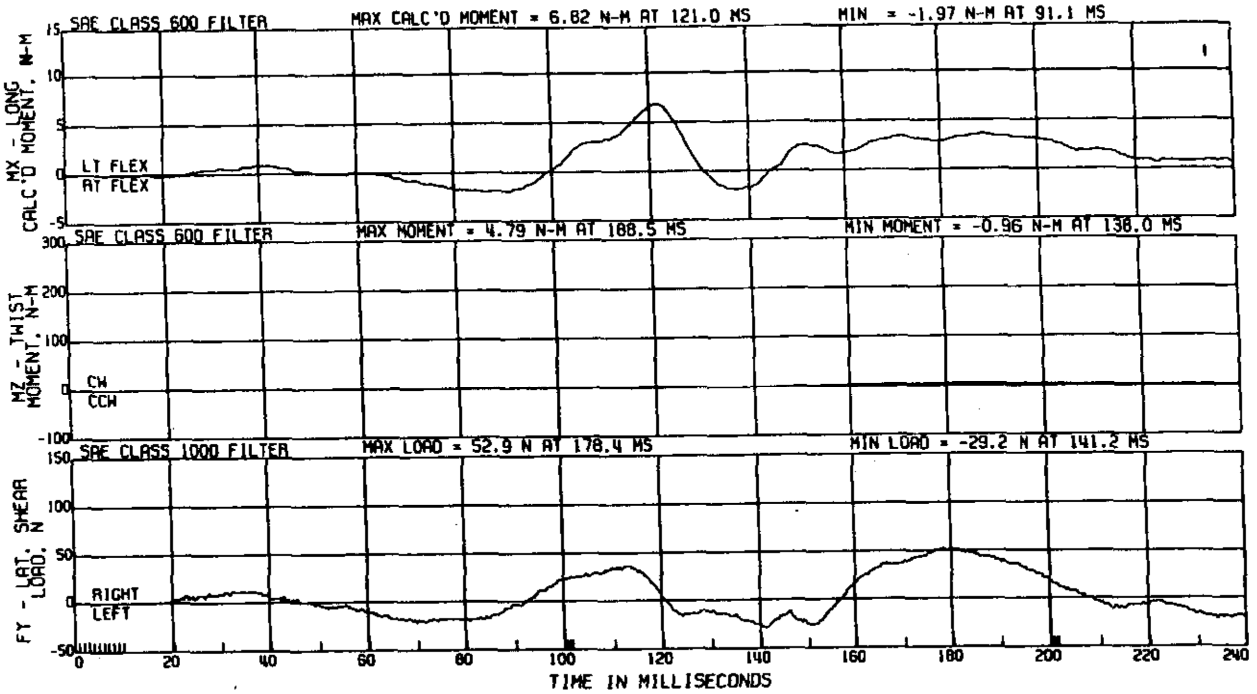
ELEC DATA, SAE CLASS 1000

(HIC I LIMITED TO 36MS)

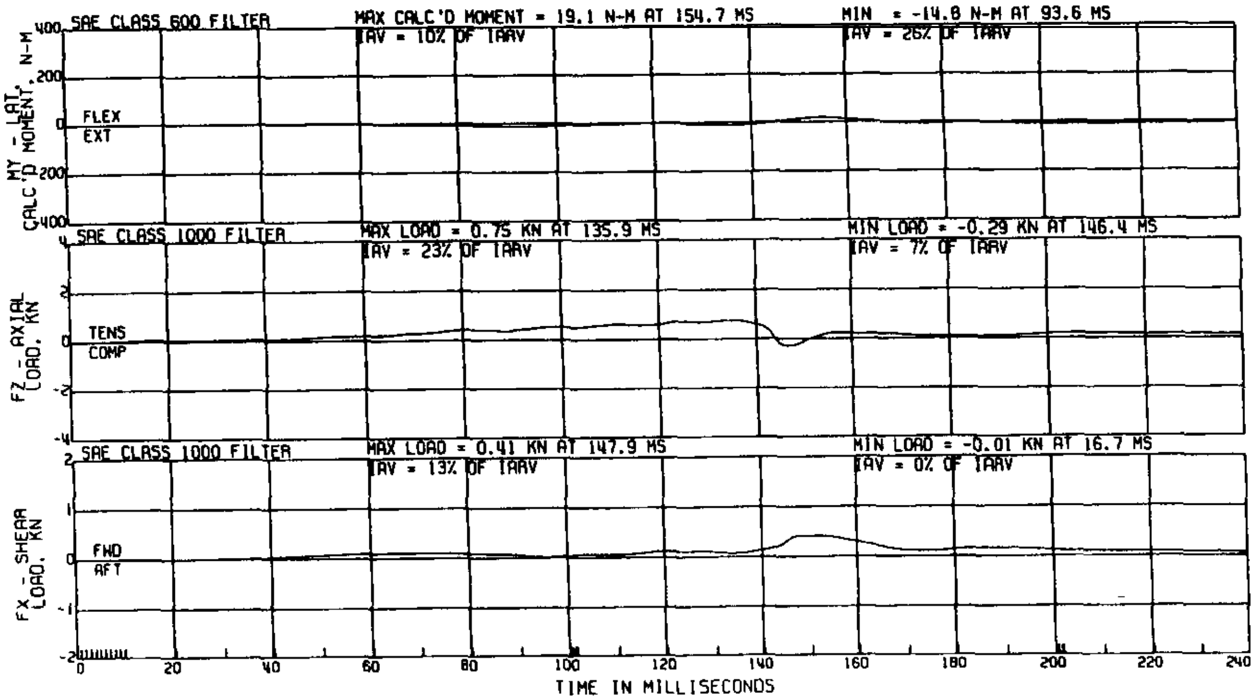


2 PROCESSED 1/28/1998 09:07 V2.07

C11816 R.REAR I M P 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 81.2KM/H
ATD TYPE: GM50H
SC 8W91830 4-DOOR L. FRT NECK LOADING ON HEAD, UPPER LOAD T E S T DATE:01/28/1998
ELEC DATA
L. FRT N E C K LOADING ON HEAD



C11816 R.REAR IMP 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 81.2KM/H
ATD TYPE: GM50H
SC 8W91830 U-DOOR NECK LOADING ON HERO TEST DATE:01/28/1998
ELEC DATA
L. FRT N E C K LOADING O N H E R O



C11816 R.REAR IMP 70% OVERLAP LTV MDB TO STATIONRAY VEHICLE 81.2KM/H

ATD TYPE: GM50H

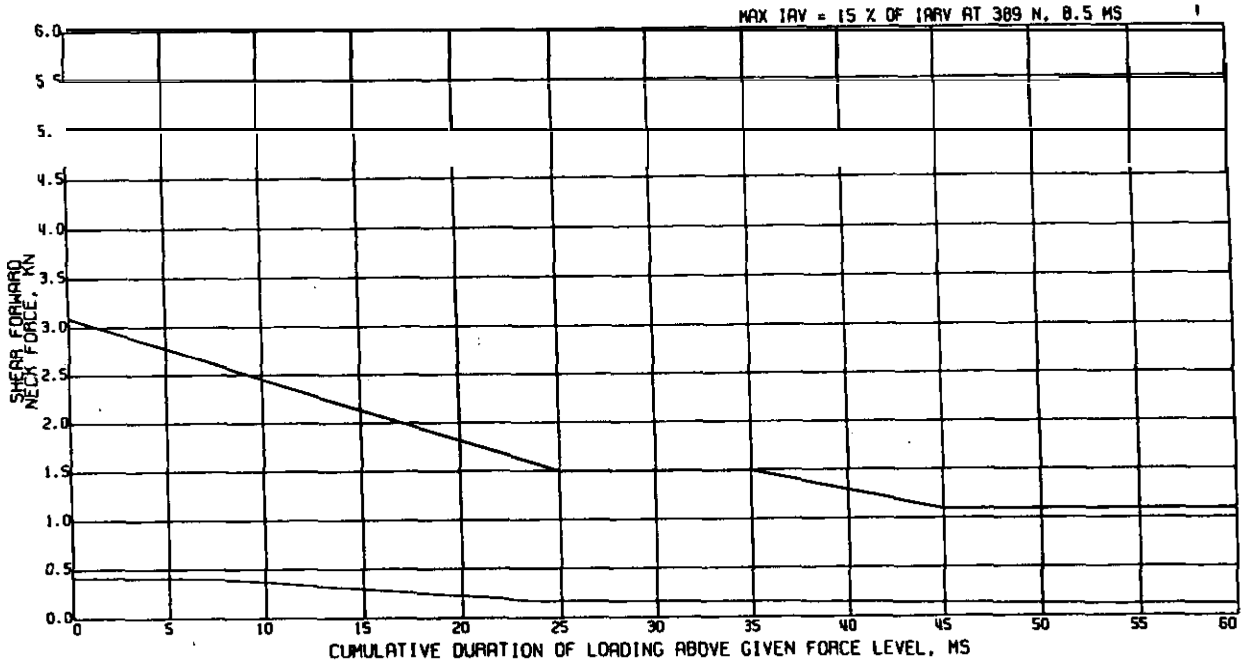
SC 8W9183D Y-DOOR

FORWARD NECK SHEAR ON HEAD,

TEST DATE:01/28/1998

ELEC DATA, SAE CLASS 1000

L . FRT INJURY REFERENCE



12 PROCESSED 1/28/1998 09:07 V2.07

C11816 R.REAR I M P 70% OVERLAP LTV MDB TO STATIONARY VEHICLE 81.2KM/H

ATD TYPE: GM50H

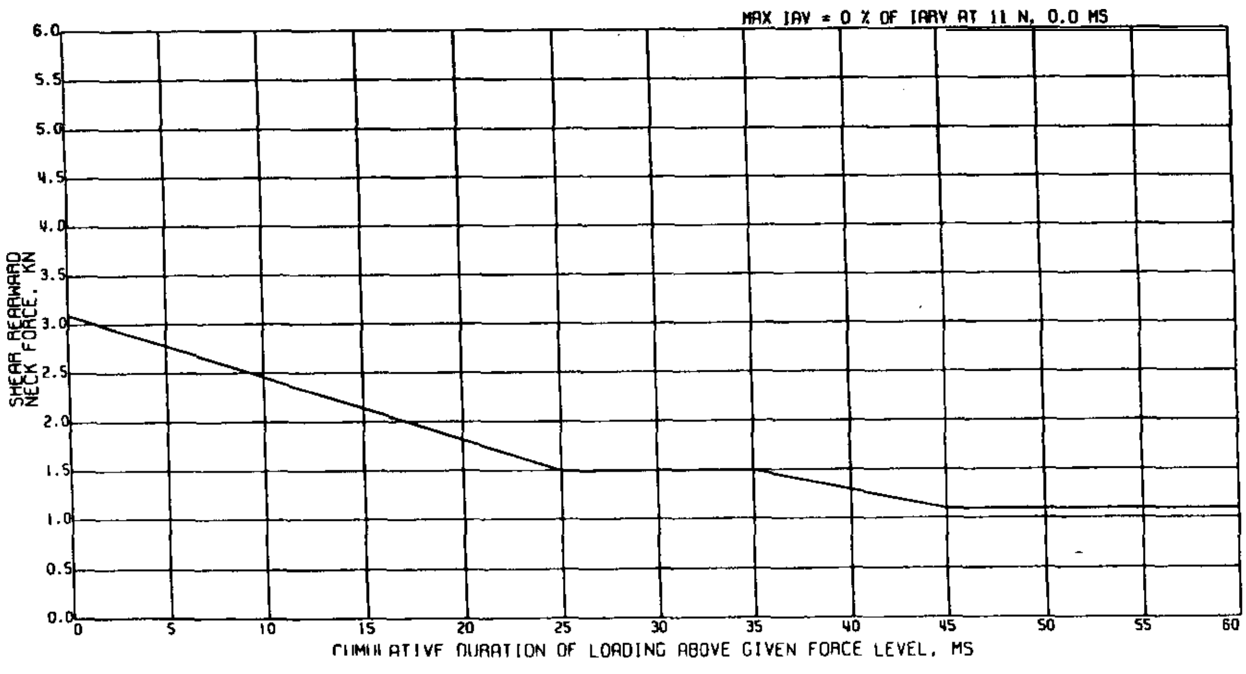
SC 8W9183D 4-DOOR

REARWARD NECK SHEAR ON HEAD,

TEST DATE:01/28/1998

ELEC DATA, SAE CLASS 1000

L. FRT INJURY REFERENCE



C11816 R.REAR IMP 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 81.2KM/H

ATD TYPE: GM50H

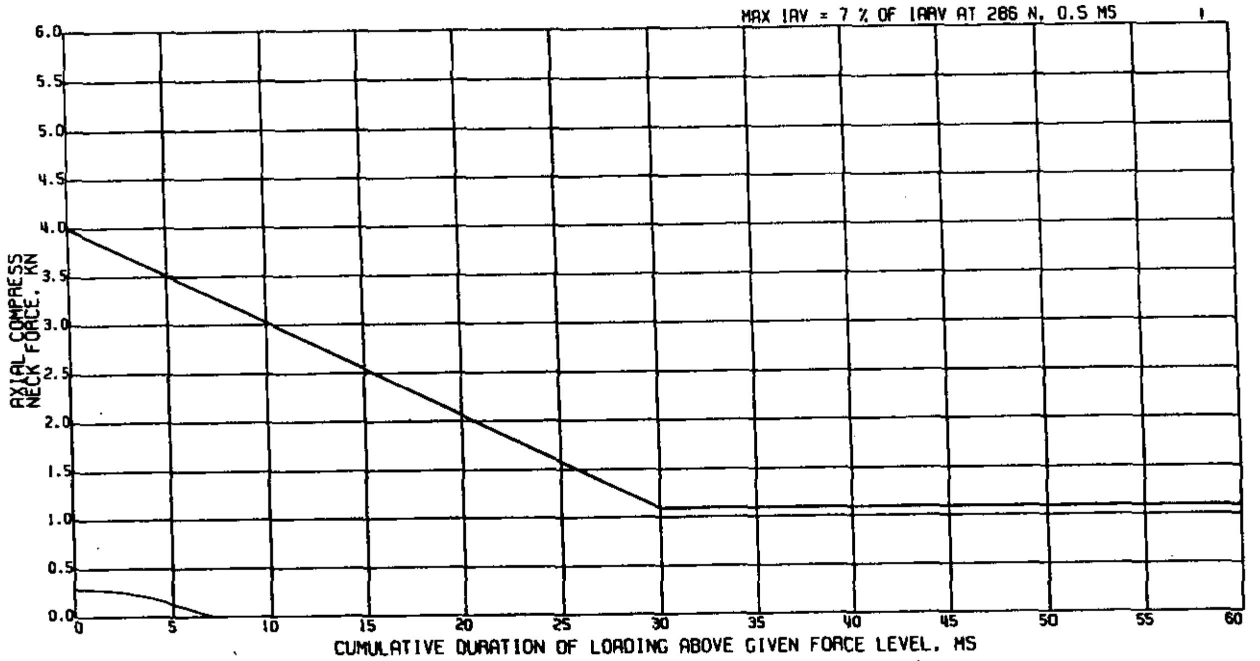
SC 8W91830 U-ODOR

AXIAL COMPRESSION ON HERO.

YES, DATE:01/28/1998

ELEC DATA, SAE CLASS 1000

L. FRT INJURY REFERENCE



14 PROCESSED 1/28/1998 09:07 V2.07

C11816 R.REAR IMP 70% OVERLAP LTV MDB TO STATIONARY VEHICLE 81.2KM/H

ATD TYPE: GM50H

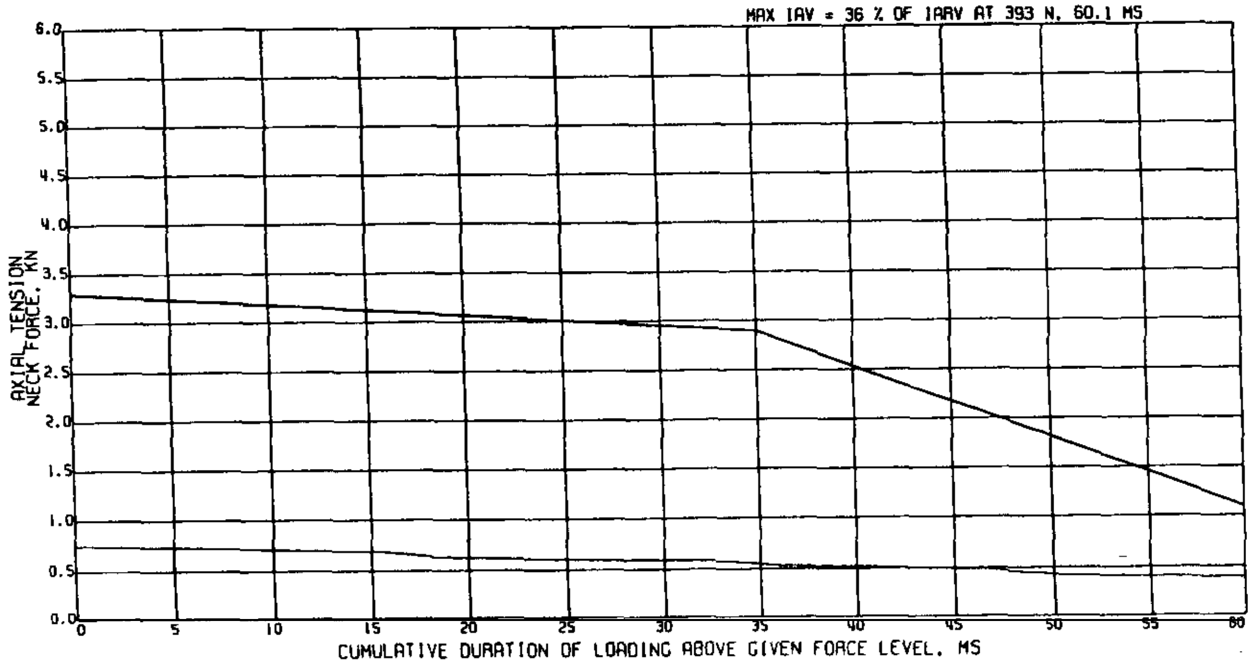
SC 8W91830 4-DOOR

AXIAL TENSION ON HERO.

TEST DATE:01/28/1998

ELEC DATA, SAE CLASS 1000

L. FRT INJURY REFERENCE



C11816 R.REAR IMP 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 81.2KM/H

SC 8W9183D 4-DOOR

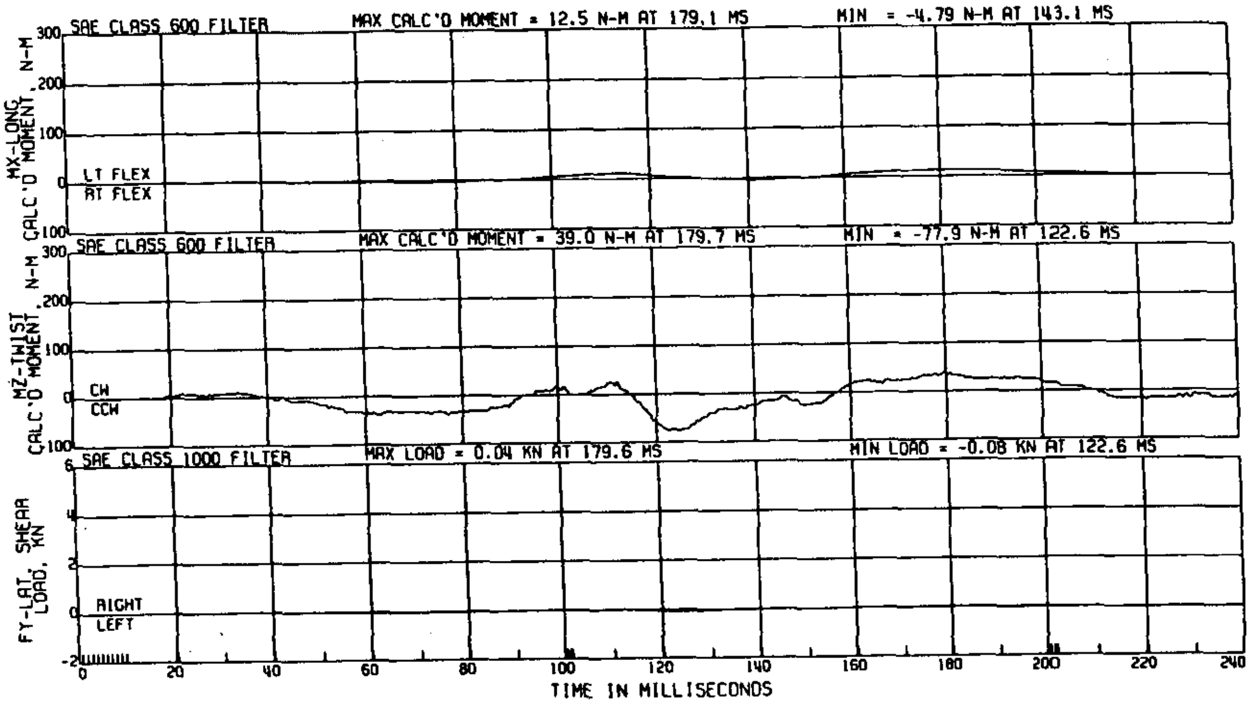
ELEC DATA

L.FRT NECK LOADING LOAD

(TORSO ON BASE OF NECK)

ATD TYPE: GM50H

TEST DATE:01/28/1998



31 PROCESSED 1/28/1998 09:07 V2.07

C11816 R.REAR IMP 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 81.2KM/H

SC 8W9183D U-DOOR

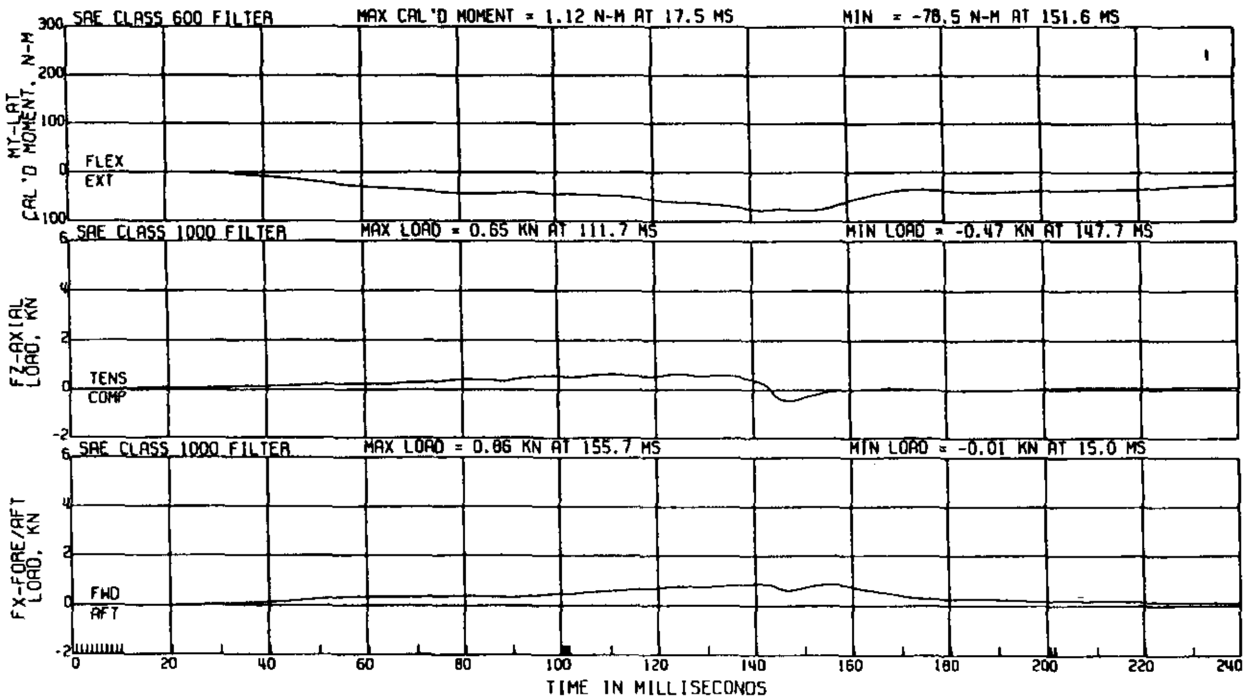
ELEC DATA

L.FRT NECK LOADING LOAD

(TORSO ON BASE OF NECK)

ATD TYPE: GM50H

TEST DATE:01/28/1998

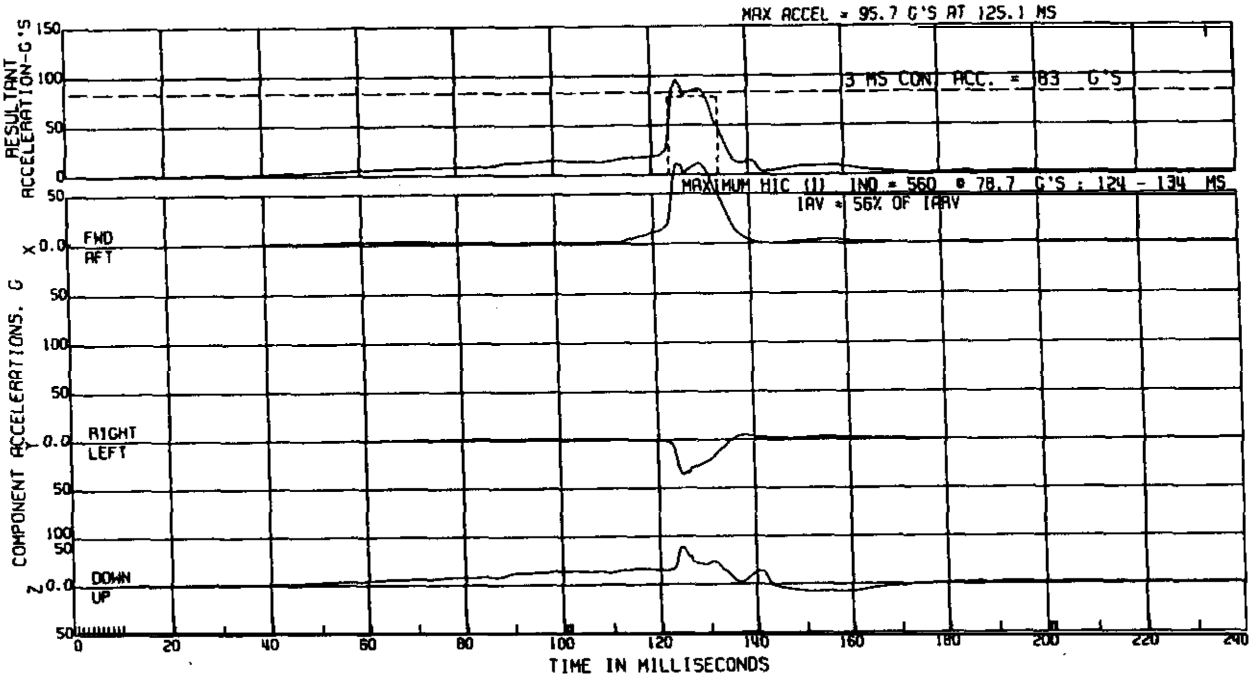


C11816 R.REAR I M P 70% OVERLAP LTV MDB TO STATIONARY VEHICLE 81.2KM/H

ATD TYPE: GM50H

SC 8W9183D 4-DOOR R.FRT HERD ACCEL. TEST DATE:01/28/1998

ELEC DATA, SAE CLASS 1000 (HIC I LIMITED TO 15MS)



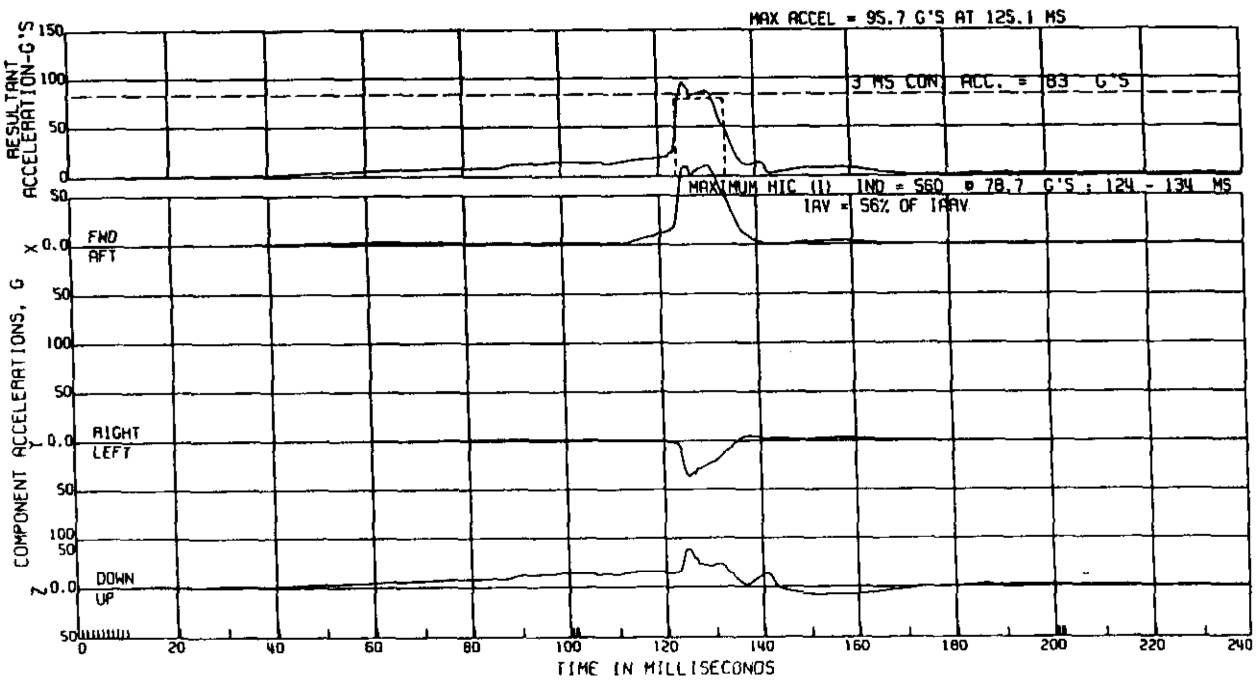
IG PROCESSED 1/28/1998 09:07 V2.07

C11816 R.REAR IMP 70% OVERLAP LTV MDB TO STATIONARY VEHICLE 81.2KM/H

ATD TYPE: GM50H

SC 8W9183D 4-DOOR R. FRT HEAD ACCEL. TEST DATE:01/28/1998

ELEC DATA, SAE CLASS 1000 (HIC I LIMITED TO 36MS)

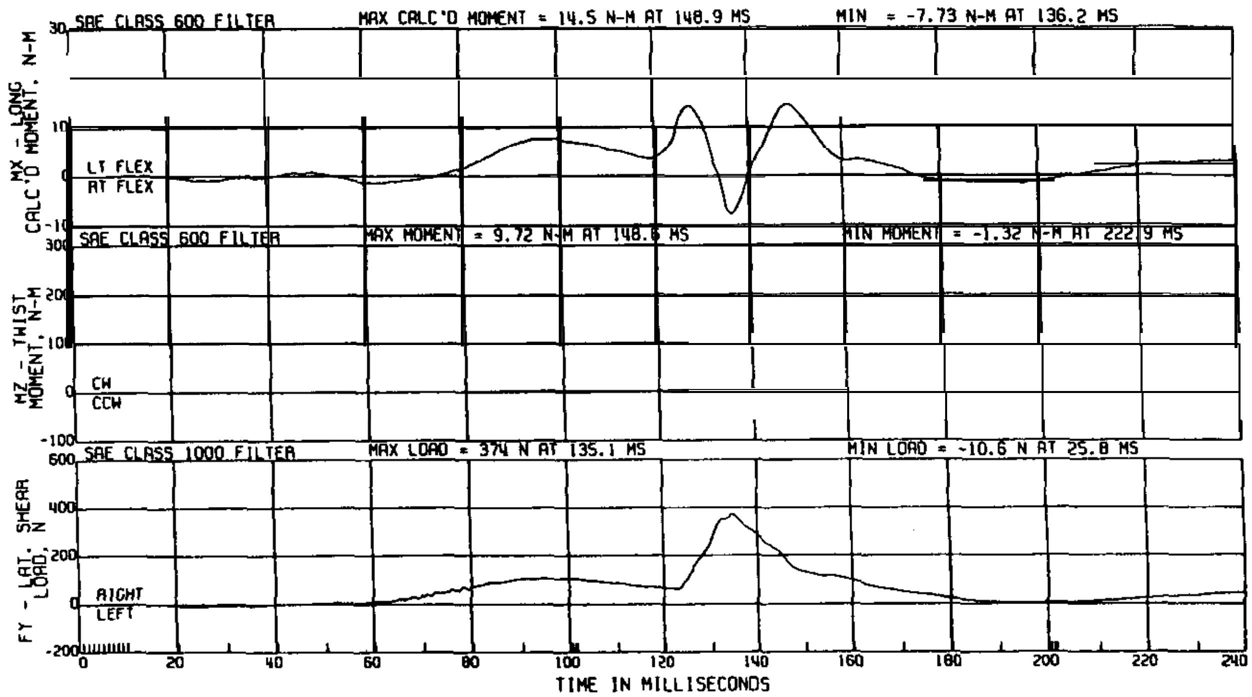


C11816 R.REAR IMP 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 81.2KM/H

ATD TYPE: GM50H

SC 8W91830 4-DOOR R. FRT NECK LOADING ON HEAD, UPPER LOAD TEST DATE:01/28/1998

ELEC DATA R. FRT NECK LOADING ON HEAD



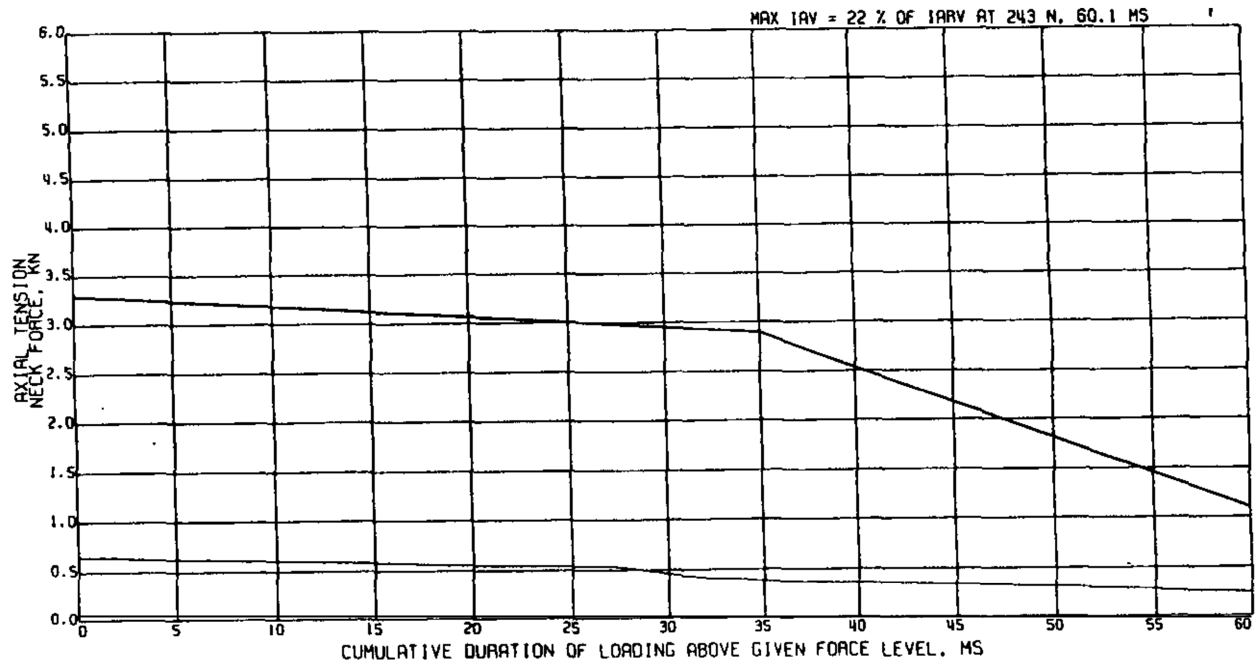
25 PROCESSED 1/28/1998 09:07 V2.07

C11816 R.REAR IMP 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 81.2KM/H

ATD TYPE, GM50H

S C 8W9183D 4-DOOR AXIAL TENSION ON HEAD, TEST DATE:01/28/1998

ELEC DATA, SAE CLASS 1000 R.FRT INJURY REFERENCE



C11816 R.REAR I M P 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 81.2KM/H

SC 8W9183D 4-DOOR

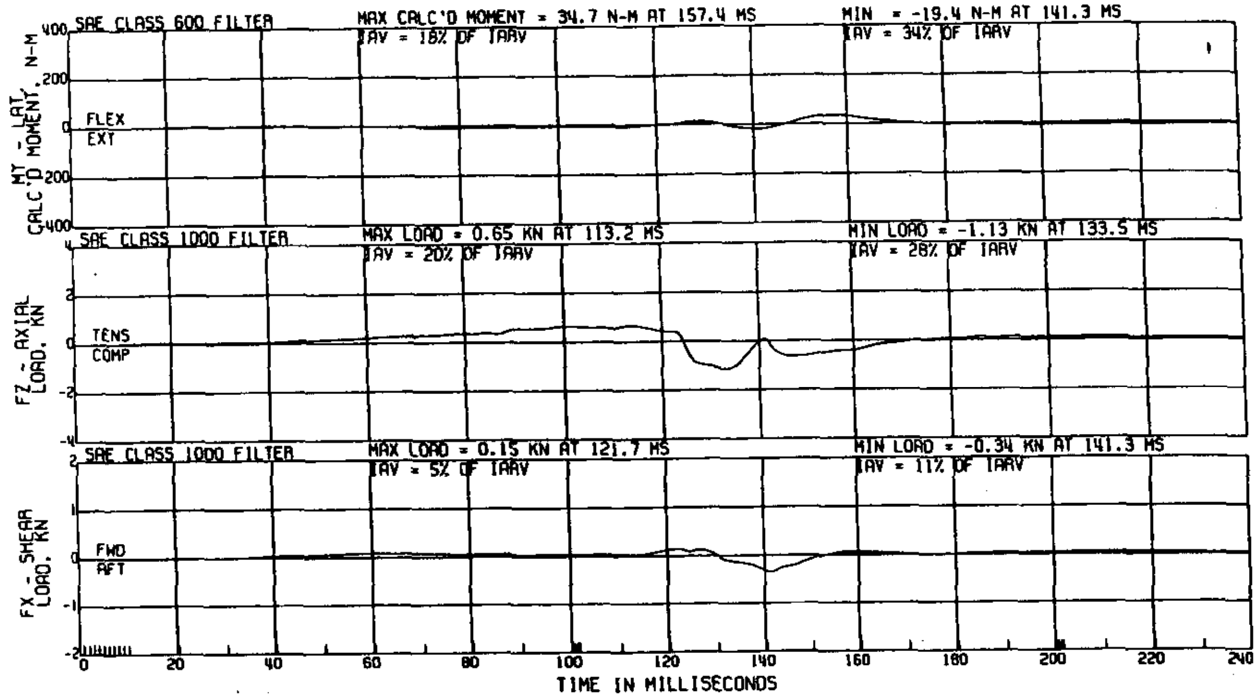
ELEC DATA

ATD TYPE: GM50H

TEST DATE:01/28/1998

NECK LOADING ON HEAD

R. FRT NECK LOADING ON HEAD



26 PROCESSED 1/28/1998 09:07 V2.07

C1 1816 R.REAR IMP 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 81.2KM/H

SC 8W9183D 4-DOOR

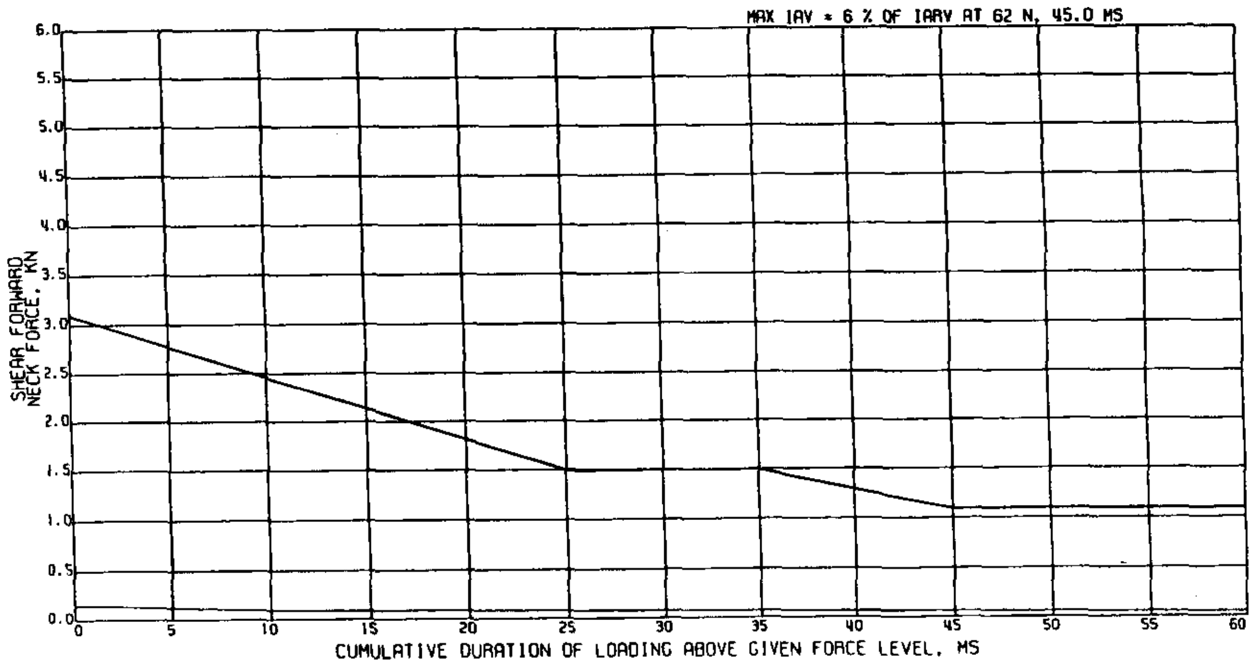
ELEC DATA, SAE CLASS 1000

ATD TYPE: GM50H

TEST DATE:01/28/1998

FORWARD NECK SHEAR ON HEAD,

R. FRT INJURY REFERENCE



C11816 R.REAR I M P 70% OVERLAP LTV MDB TO STATIONARY VEHICLE 81.2KM/H

SC 8W9183D 4-DOOR

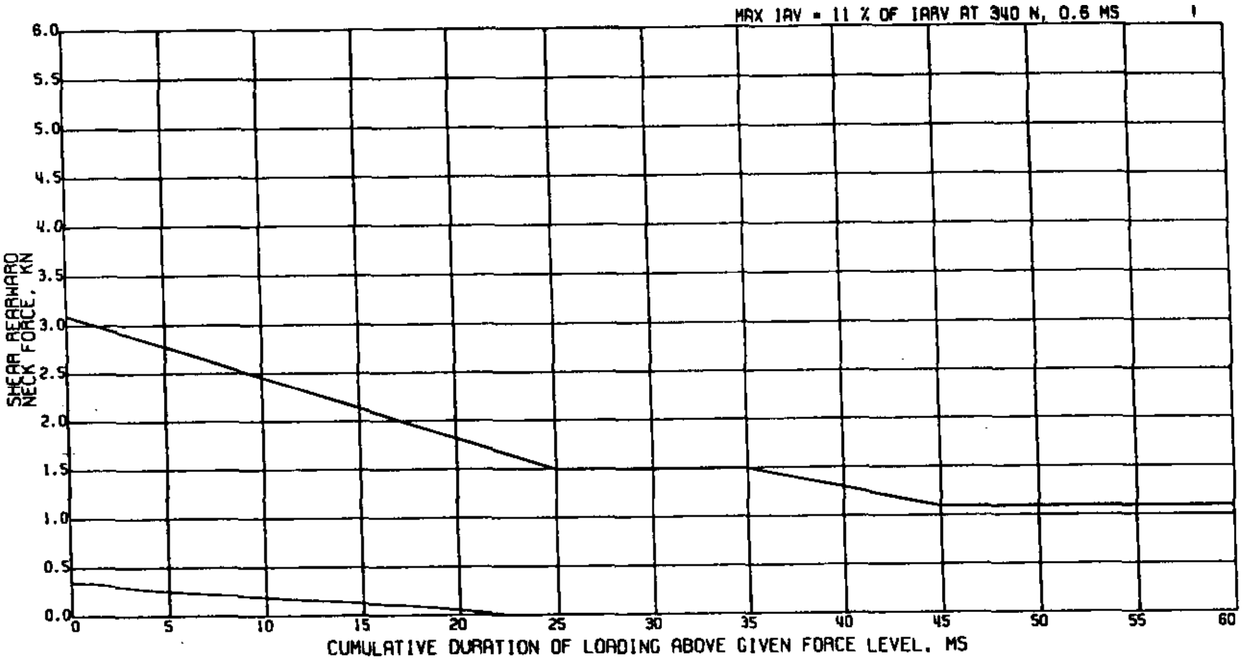
ELEC DATA, SAE CLASS 1000

REARWARD NECK SHEAR ON HEAD,

R.FRT INJURY REFERENCE

ATD TYPE: GM50H

TEST DATE:01/28/1998



28 PROCESSED 1/28/1998 09:07 V2.07

C11816 R.REAR I M P 70% OVERLAP LTV MDB TO STATIONARY VEHICLE 81.2KM/H

SC 8W9183D 4-DOOR

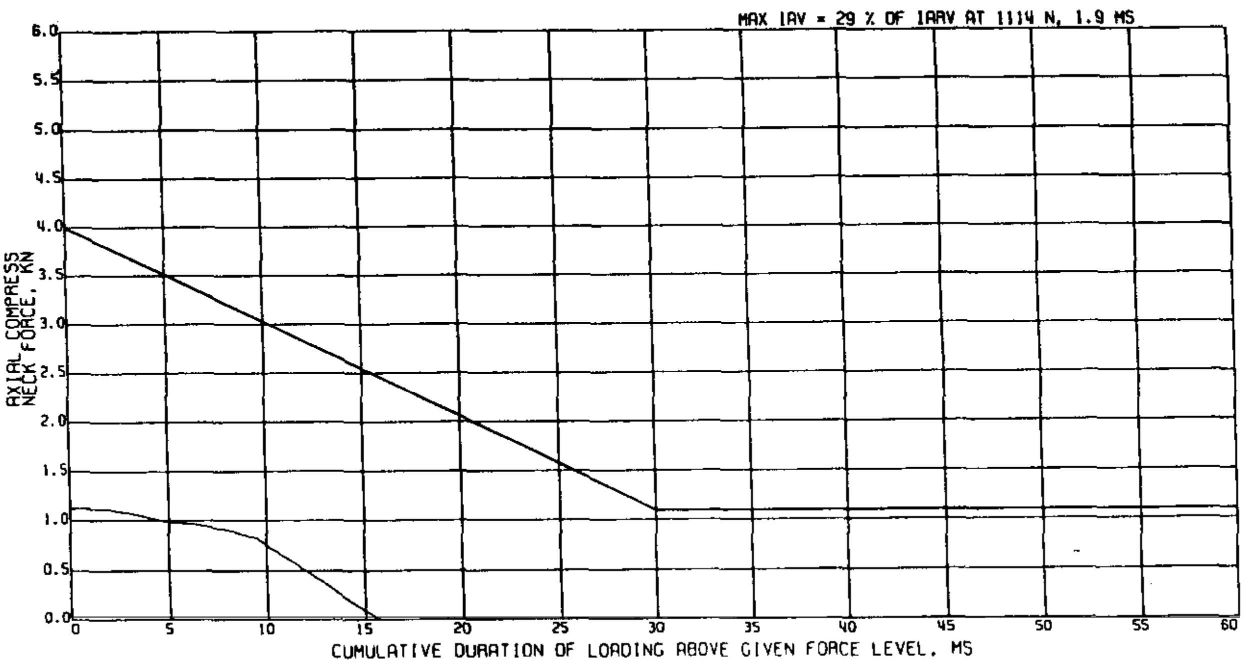
ELEC DATA, SAE CLASS 1000

AXIAL COMPRESSION ON HEAD,

R.FRT INJURY REFERENCE

ATD TYPE: GM50H

TEST DATE:01/28/1998



C11828 L.REAR IMP 70% OVERLAP LTV MDB TO STATIONARY VEHICLE 81.0KM/H

ATD TYPE: GM50H

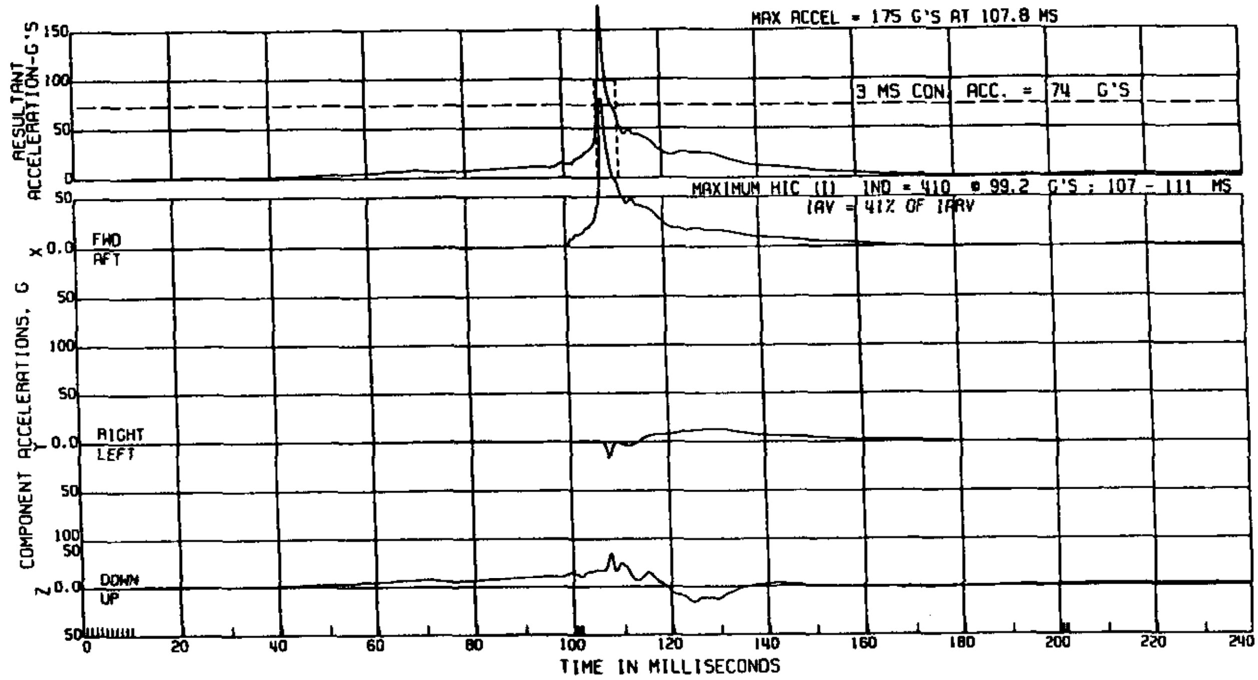
SC 8W91840 4-DOOR

L. FRT HEAD ACCEL.

TEST DATE:01/28/1998

ELEC DATA, SAE CLASS 1000

(HIC I LIMITED TO 15MS)



1 PROCESSED 1/29/1998 07:59 V2.07

C11828 L.REAR IMP 70% OVERLAP LTV MOE TO STATIONARY VEHICLE 81.0KM/H

ATD TYPE: GM50H

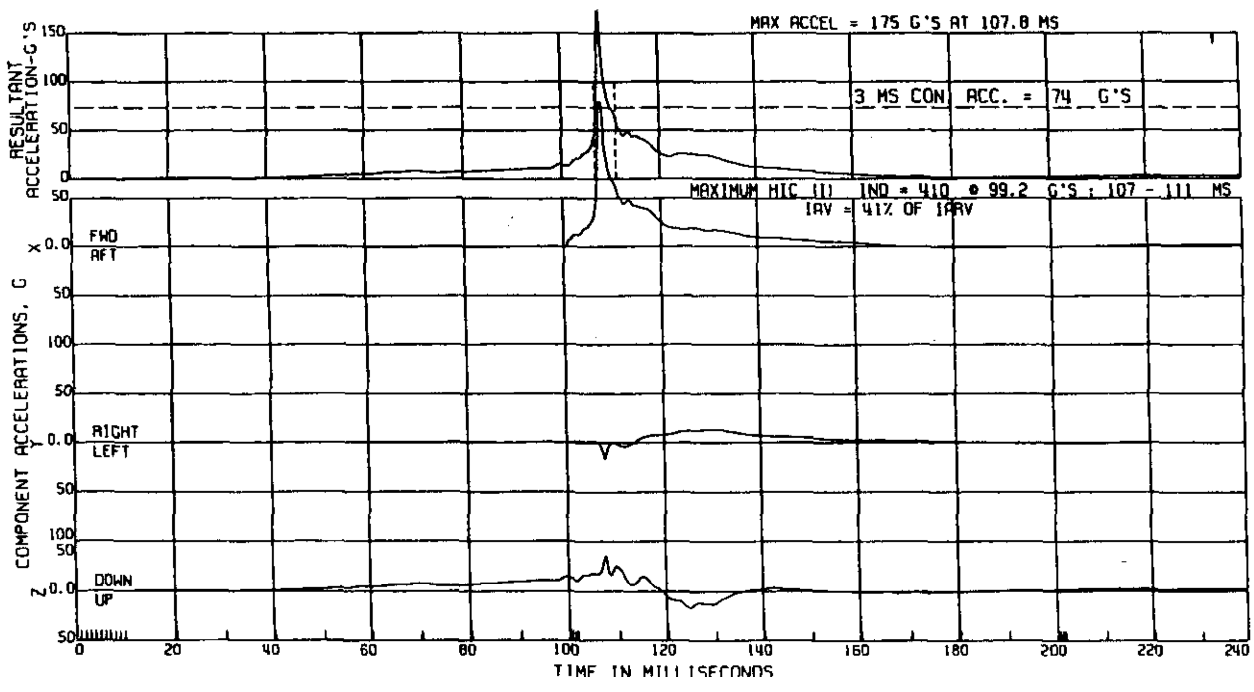
SC 8W91840 4-DOOR

L. FRT HERO ACCEL.

TEST DATE:01/28/1998

ELEC DATA, SAE CLASS 1000

(HIC I LIMITED TO 36MS)



C11828 L.REAR IMP 70% OVERLAP LTV MDB TO STATIONARY VEHICLE 81.0KM/H

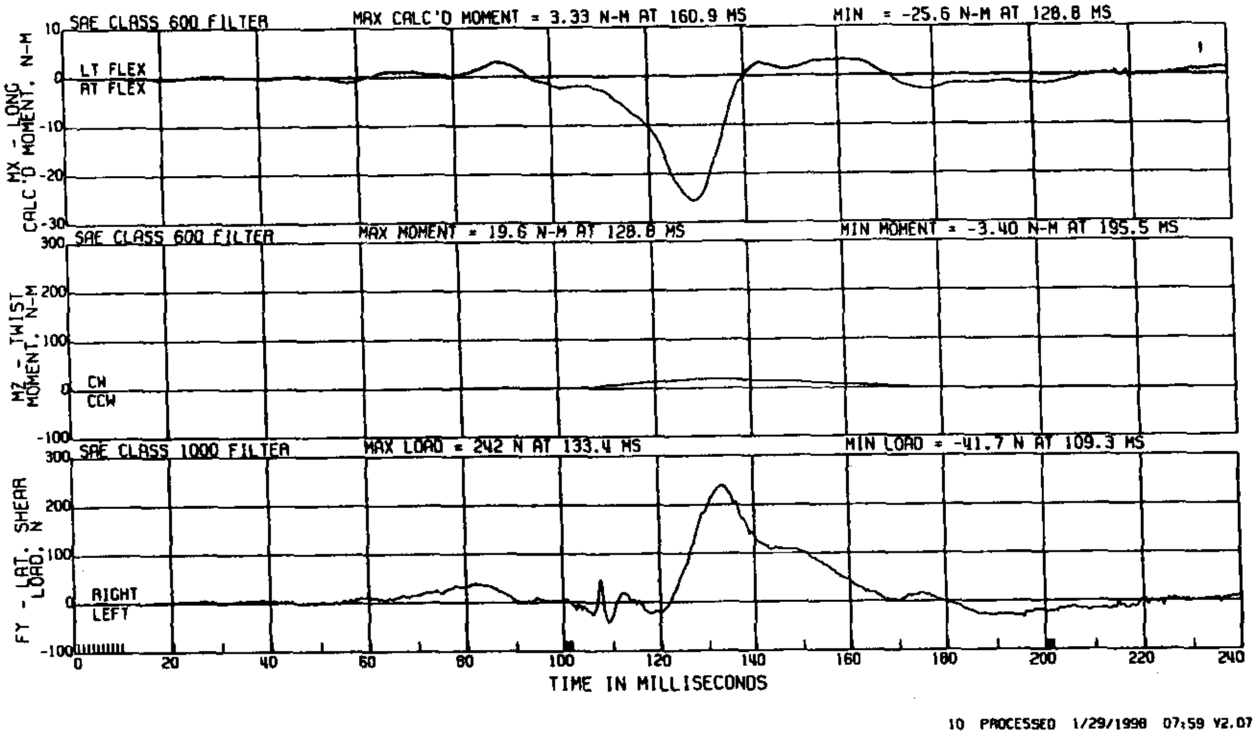
SC 8W9184D 4-DOOR L. FRT NECK LOADING ON HEAD, UPPER LOAD

ATD TYPE: GM50H

TEST DATE:01/28/1998

ELEC DATA

L.FRT NECK LOADING ON HEAD



C11828 L.REAR IMP 70% OVERLAP LTV MOE TO STATIONARY VEHICLE 81.0KM/H

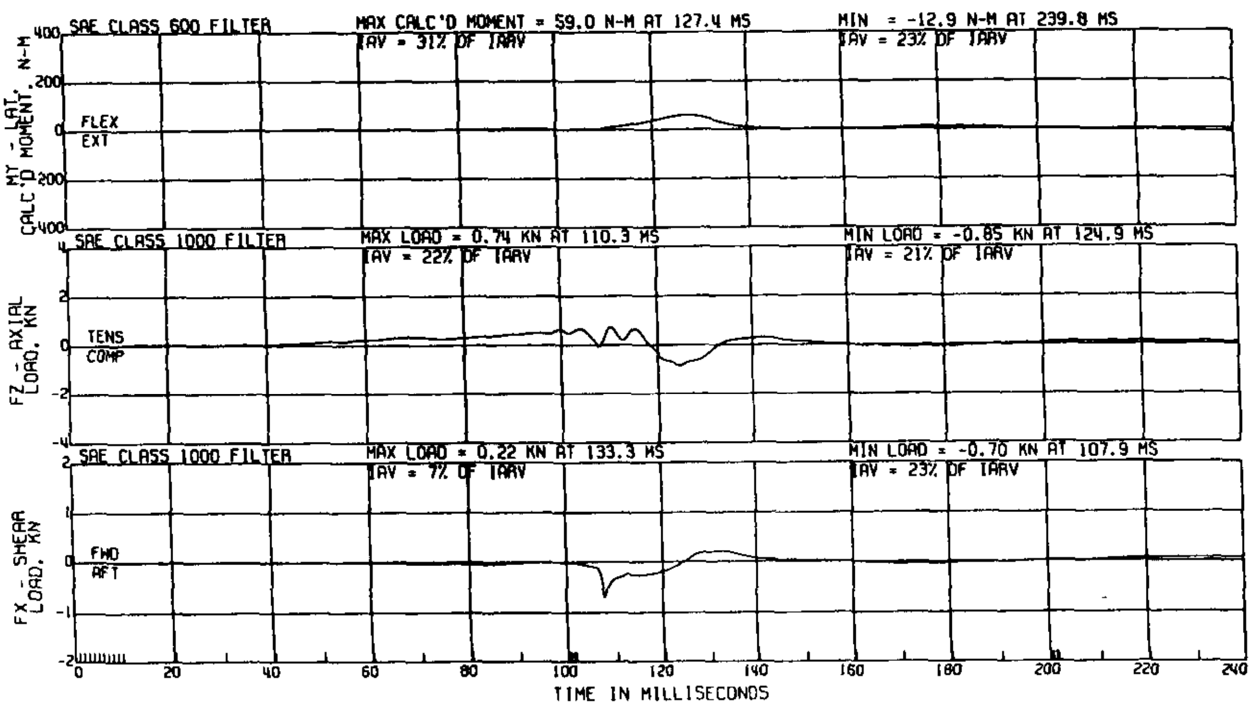
ATD TYPE: GM50H

SC 8W9184D 4-DOOR NECK LOADING ON HEAD

TEST DATE:01/28/1998

ELEC DATA

L.FRT NECK LOADING ON HEAD



C11828 L.REAR IMP 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 81.0KM/H

SC 8W91840 4-DOOR

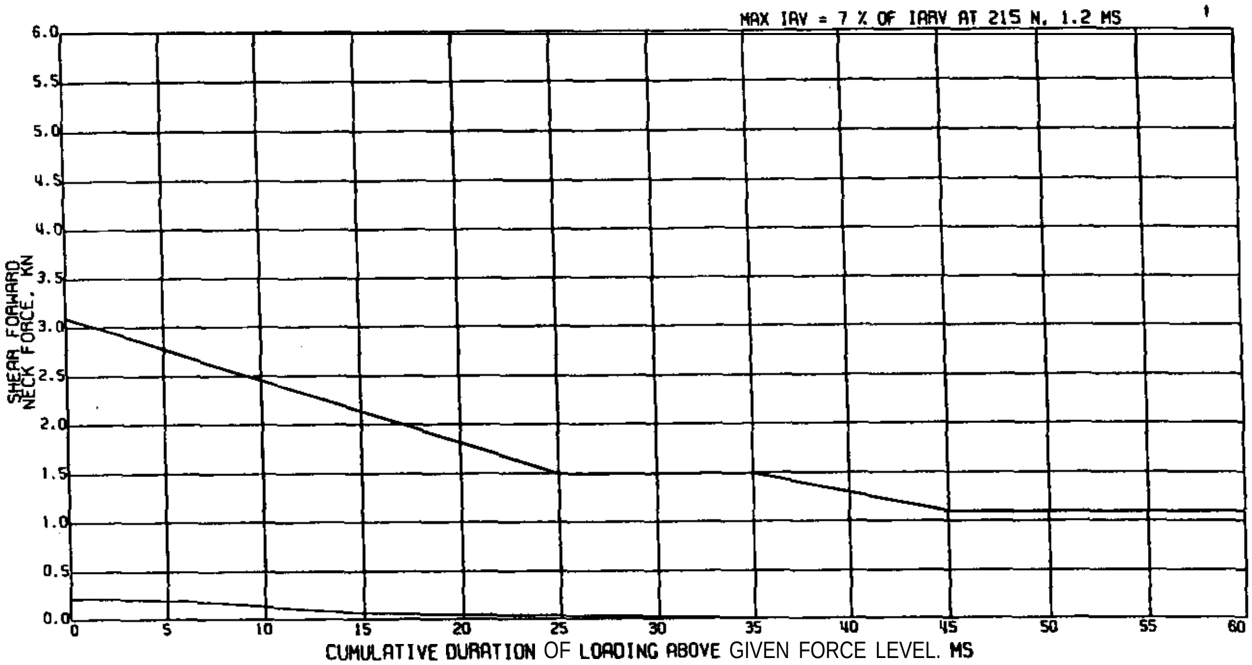
ELEC DATA, SAE CLASS 1000

FORWARD NECK SHEAR ON HERO.

L.FRT INJURY REFERENCE

ATD TYPE: GM50H

TEST DATE:01/28/1998



12 PROCESSED 1/29/1998 07:59 V2.07

C11828 L.REAR IMP 70% OVERLAP LTV NOB TO STATIONARY VEHICLE 81.0KM/H

SC 8W91840 4-DOOR

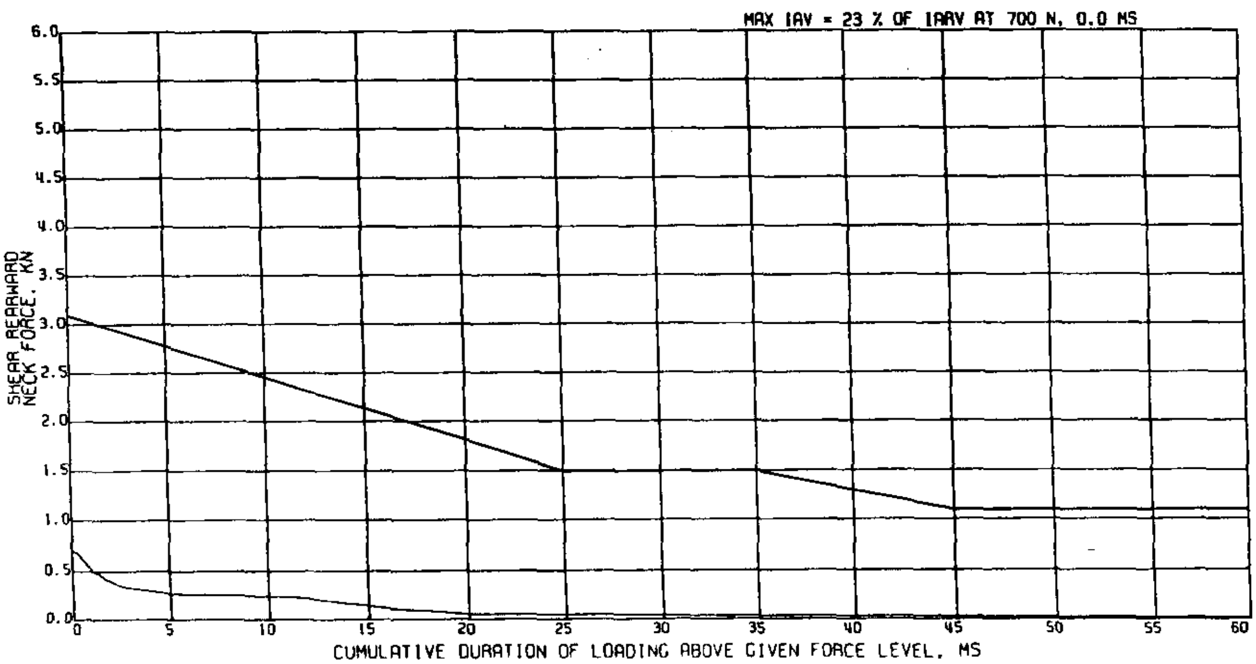
ELEC DATA, SAE CLASS 1000

REARWARD NECK SHEAR ON HERO.

L.FRT INJURY REFERENCE

ATD TYPE: GM50H

TEST DATE:01/28/1998



C11828 L.REAR I M P 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 81.0KM/H

SC 8W9184D 4-DOOR

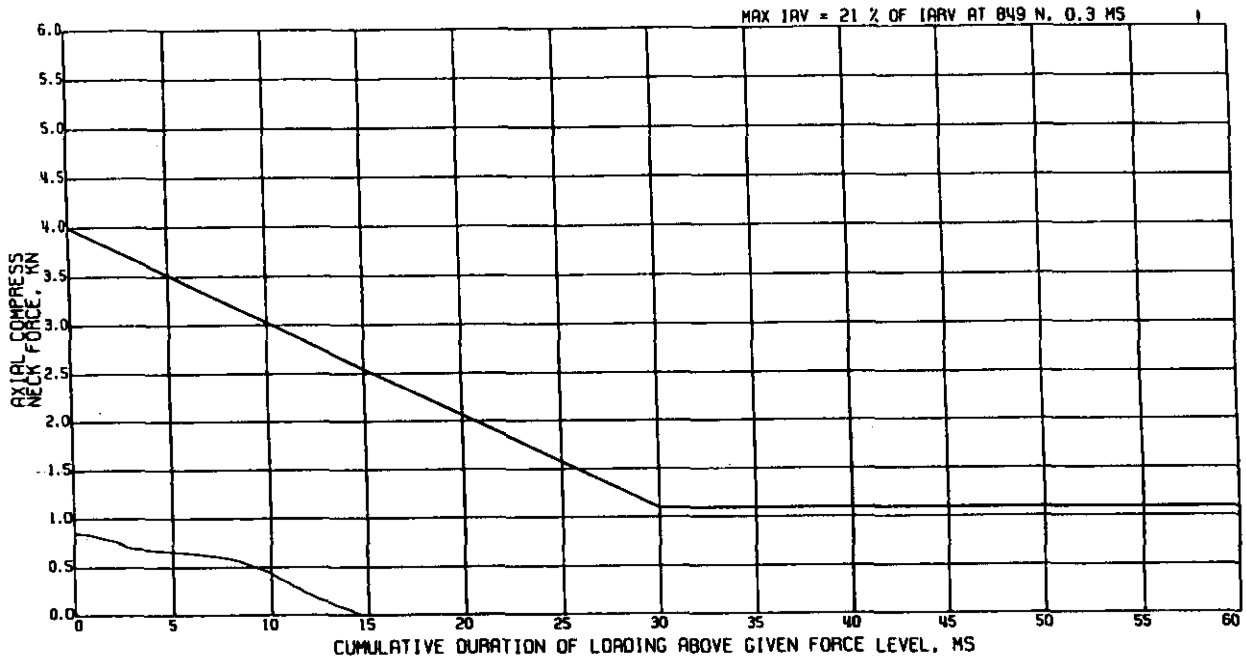
ELEC DATA, SAE CLASS 1000

AXIAL COMPRESSION ON HEAD,

L. FRT INJURY REFERENCE

ATD TYPE: GM50H

TEST DATE:01/28/1998



14 PROCESSED 1/29/1998 07:59 V2.07

C11828 L.REAR IMP 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 81.0KM/H

SC 8W9184D 4-DOOR

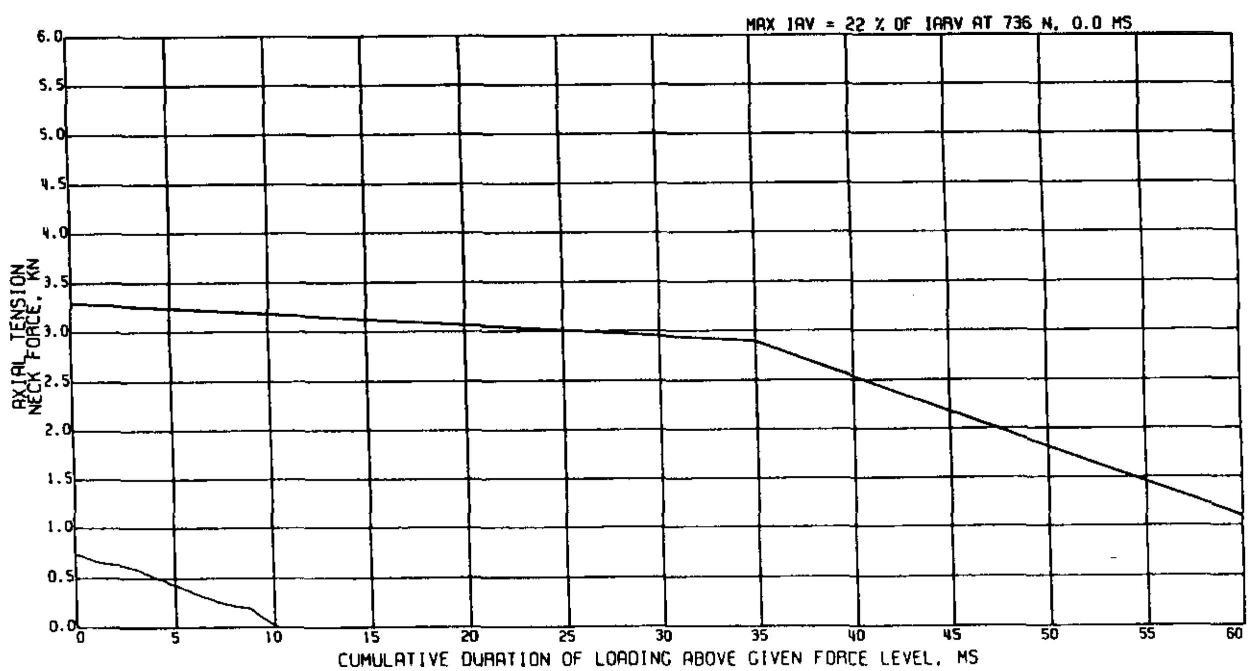
ELEC DATA, SAE CLASS 1000

AXIAL TENSION ON HEAD.

L. FRT INJURY REFERENCE

ATD TYPE: GM50H

TEST DATE:01/28/1998



C11828 L.REAR IMP 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 81.0KM/H

ATD TYPE: GM50H

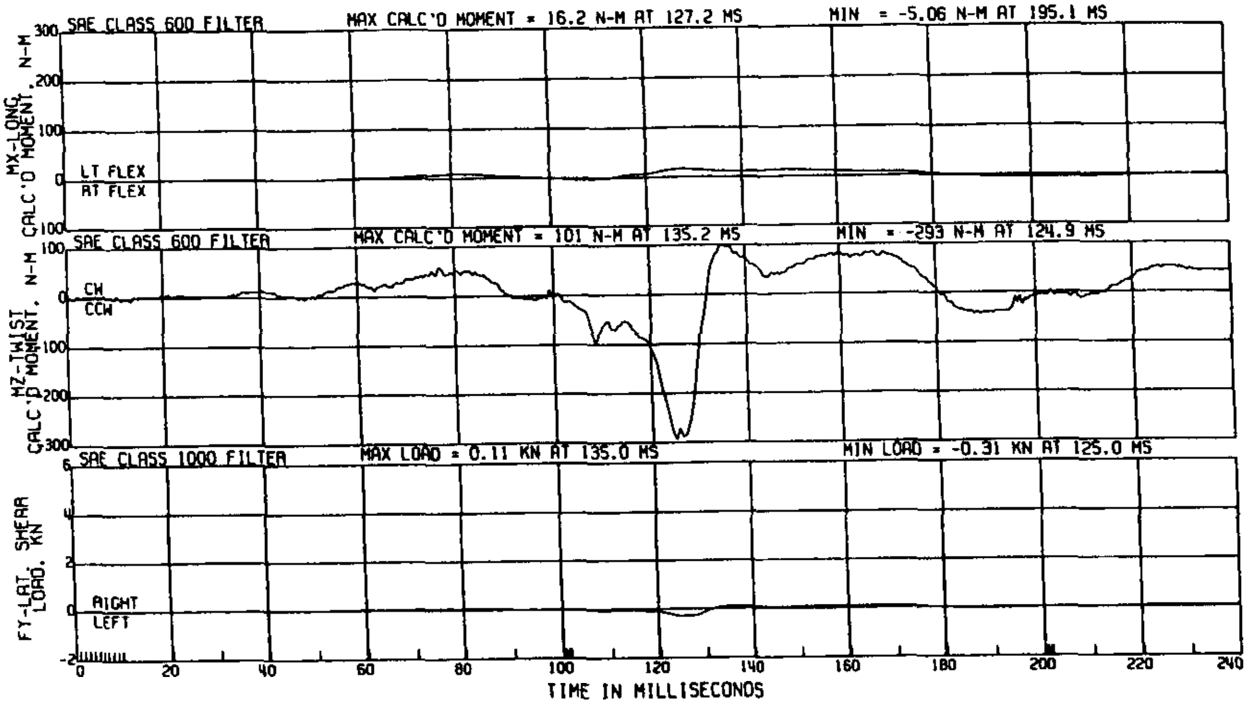
SC 8W91840 4-DOOR

L. FRT NECK LOADING LOAD

TEST DATE:01/28/1998

ELEC DATA

(TORSO ON BASE OF NECK)



31 PROCESSED 1/29/1998 08:00 V2.07

C11828 L.REAR IMP 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 81.0KM/H

ATD TYPE: GM50H

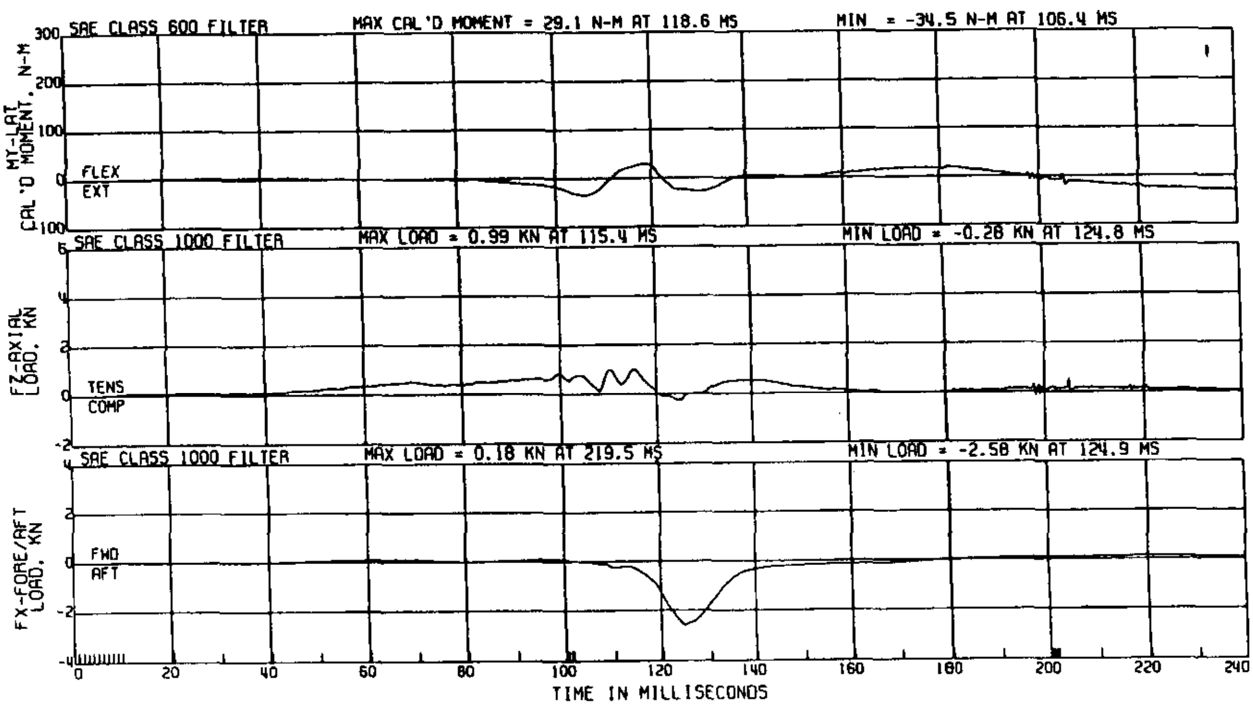
SC 8W91840 4-DOOR

L. FRT NECK LOADING LOAD

TEST DATE:01/28/1998

ELEC DATA

(TORSO ON BASE OF NECK)



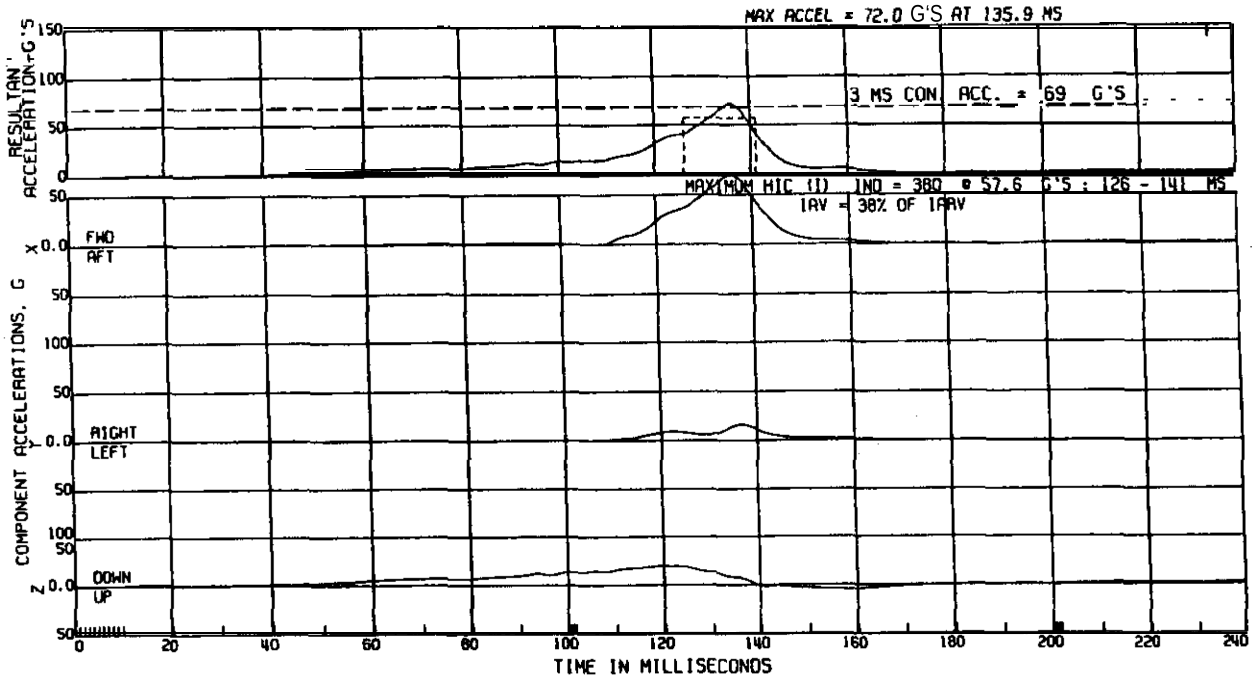
32 PROCESSED 1/29/1998 08:00 V2.07

C11828 L.REAR IMP 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 81.0KM/H

ATD TYPE: GM50H

SC 8W91840 4-DOOR R.FRT HERO ACCEL. TEST DATE:01/28/1998

ELEC DATA, SAE CLASS 1000 (HIC I LIMITED TO 15MS)



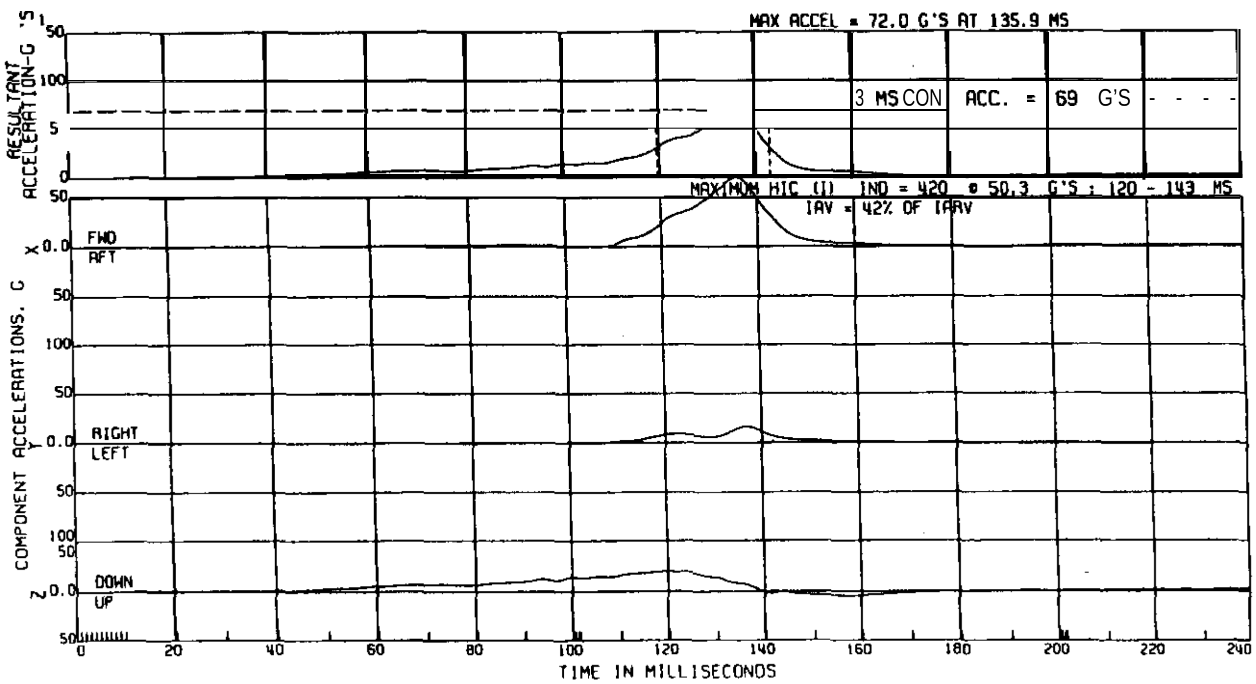
16 PROCESSED 1/29/1998 07:59 V2.07

C11828 L.REAR IMP 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 81.0KM/H

ATD TYPE: GM50H

SC 8W91840 4-DOOR R.FRT HERO ACCEL. TEST DATE:01/28/1998

ELEC DATA, SAE CLASS 1000 (HIC I LIMITED TO 36MS)

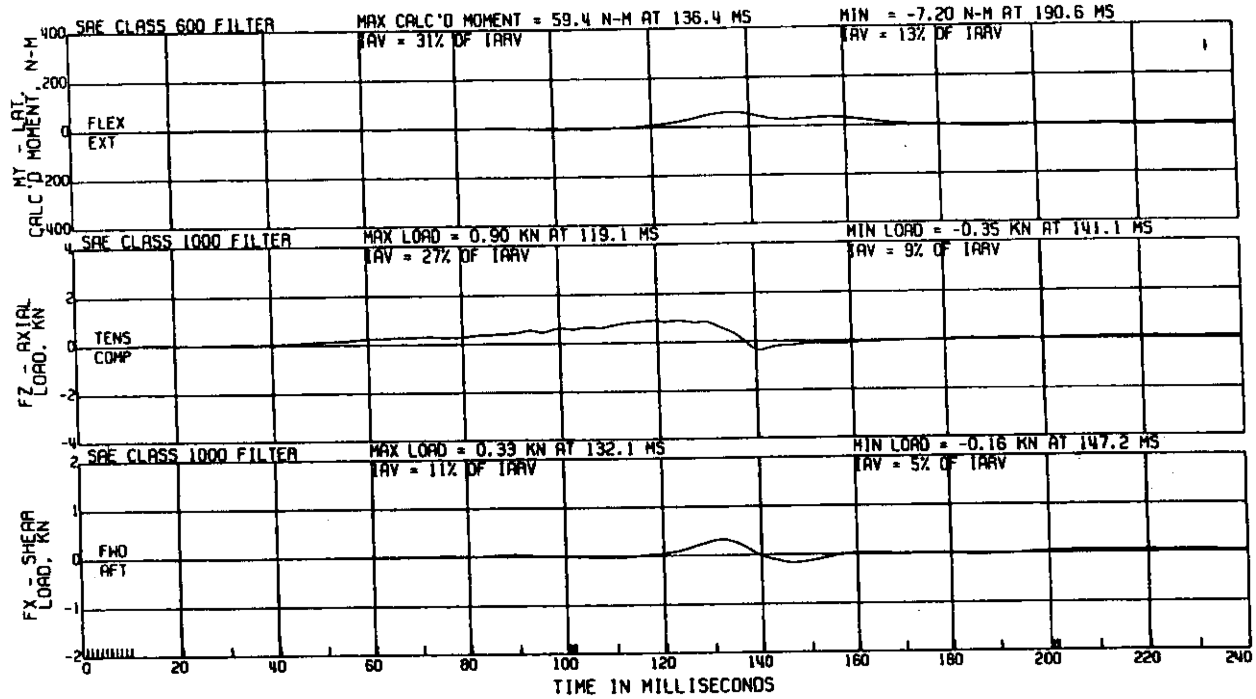


C11828 L.REAR IMP 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 81.0KM/H

ATD TYPE: GM50H

SC 8W9184D 4-DOOR NECK LOADING ON HEAD TEST DATE:01/28/1998

ELEC DATA R.FRT NECK LOADING ON HEAD



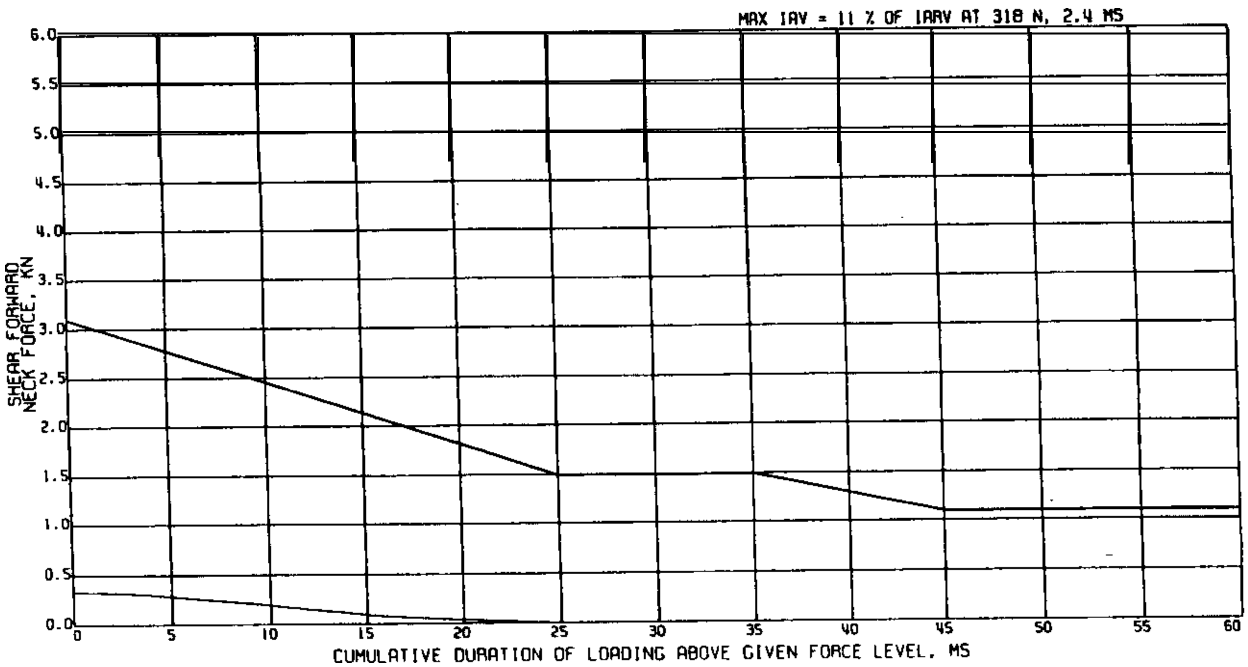
26 PROCESSED 1/29/1998 08:00 V2.07

C11828 L.REAR IMP 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 81.0KM/H

ATD TYPE: GM50H

SC 8W9184D 4-DOOR FORWARD NECK SHEAR ON HEAD, TEST DATE:01/28/1998

ELEC DATA, SAE CLASS 1000 R. FRT INJURY REFERENCE



C11828 L.REAR IMP 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 81.0KM/H

SC 8W9184D U-DOOR

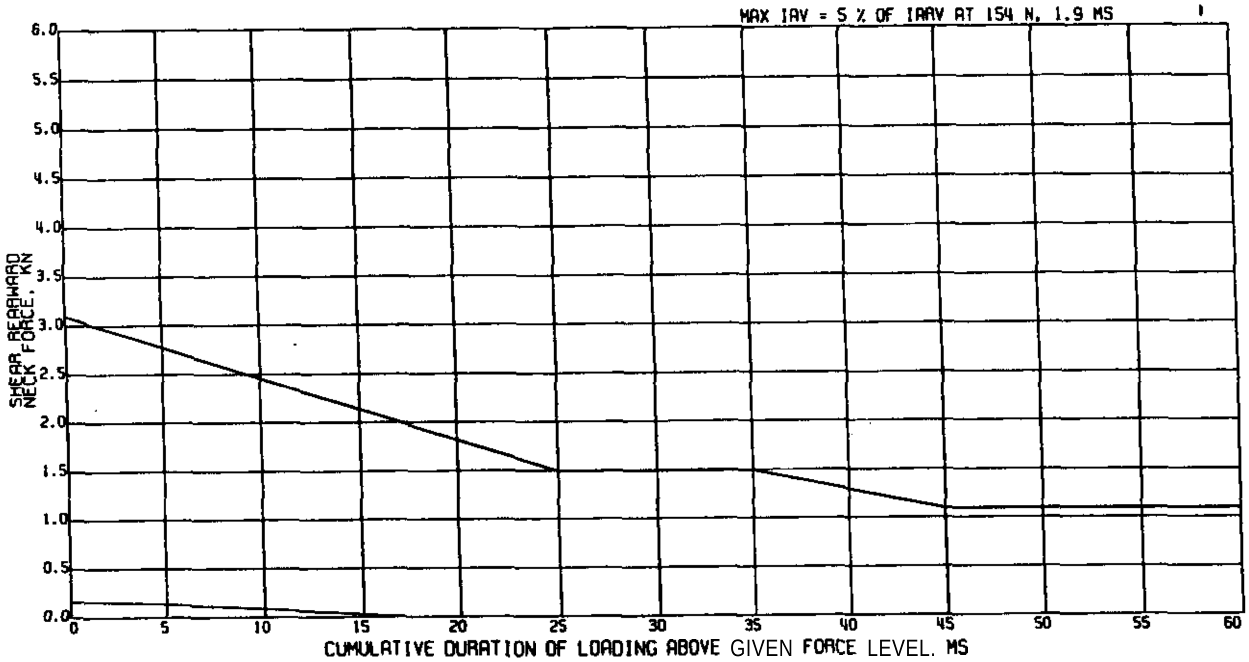
ELEC DATA, SAE CLASS 1000

REARWARD NECK SHEAR ON HEAD,

R. FRT INJURY REFERENCE

ATD TYPE, GM50H

TEST DATE:01/28/1998



28 PROCESSED 1/29/1998 08:00 V2.07

C11828 L.REAR IMP 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 81.0KM/H

SC 8W9184D 4-DOOR

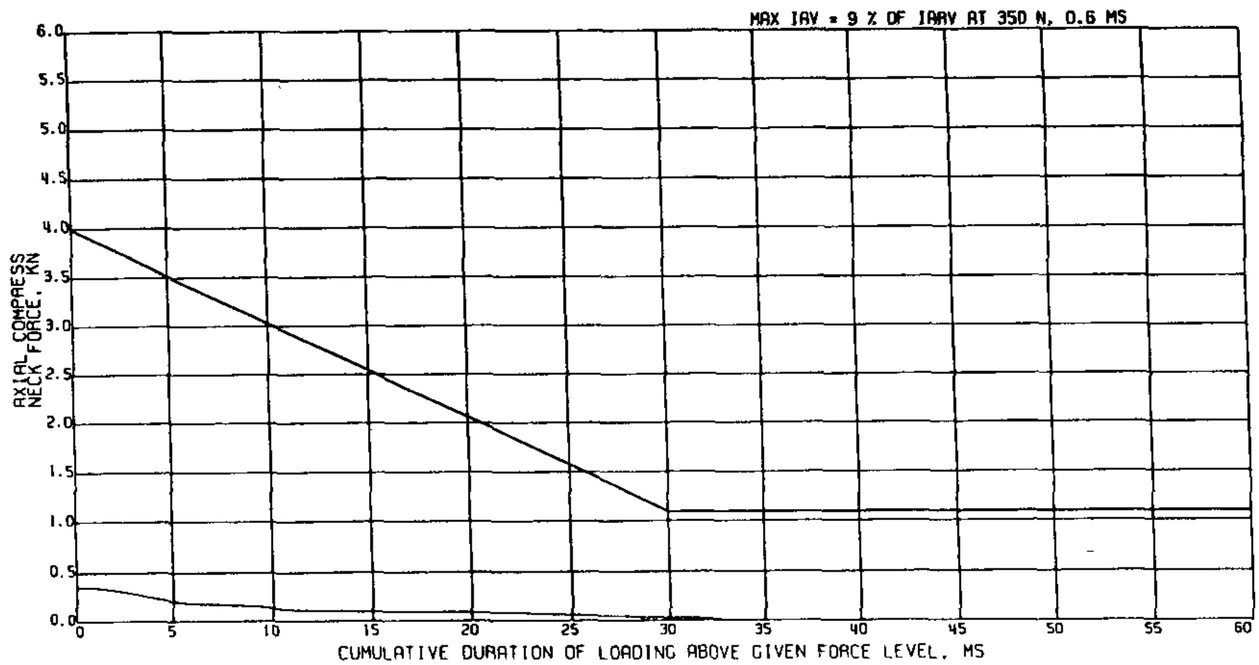
ELEC DATA, SAE CLASS 1000

AXIAL COMPRESSION ON HEAD,

R. FRT INJURY REFERENCE

ATD TYPE: GM50H

TEST DATE:01/28/1998

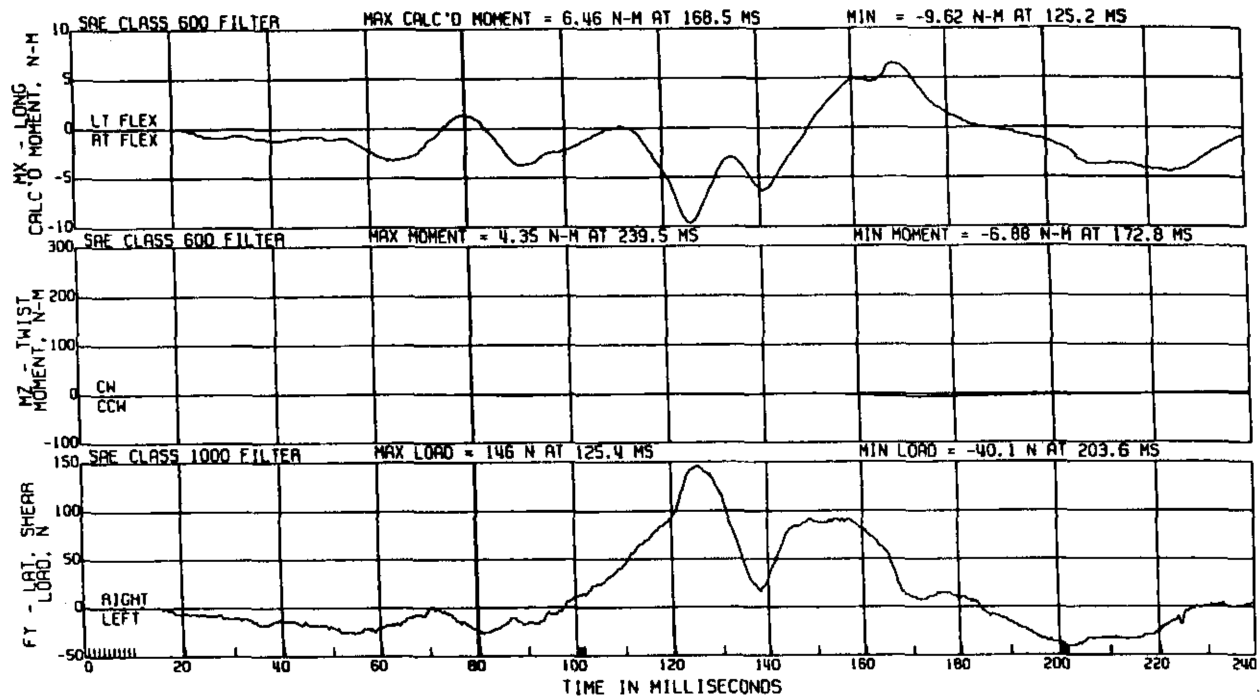


C11828 L.REAR I M P 70% OVERLAP LTV MDB TO STATIONARY VEHICLE 81.0KM/H

ATD TYPE: GM50H

SC 8W91840 4-DOOR R. FRT NECK LOADING ON HEAD. UPPER LOAD TEST DATE: 01/28/1998

ELEC DATA R. FRT NECK LOADING ON HEAD



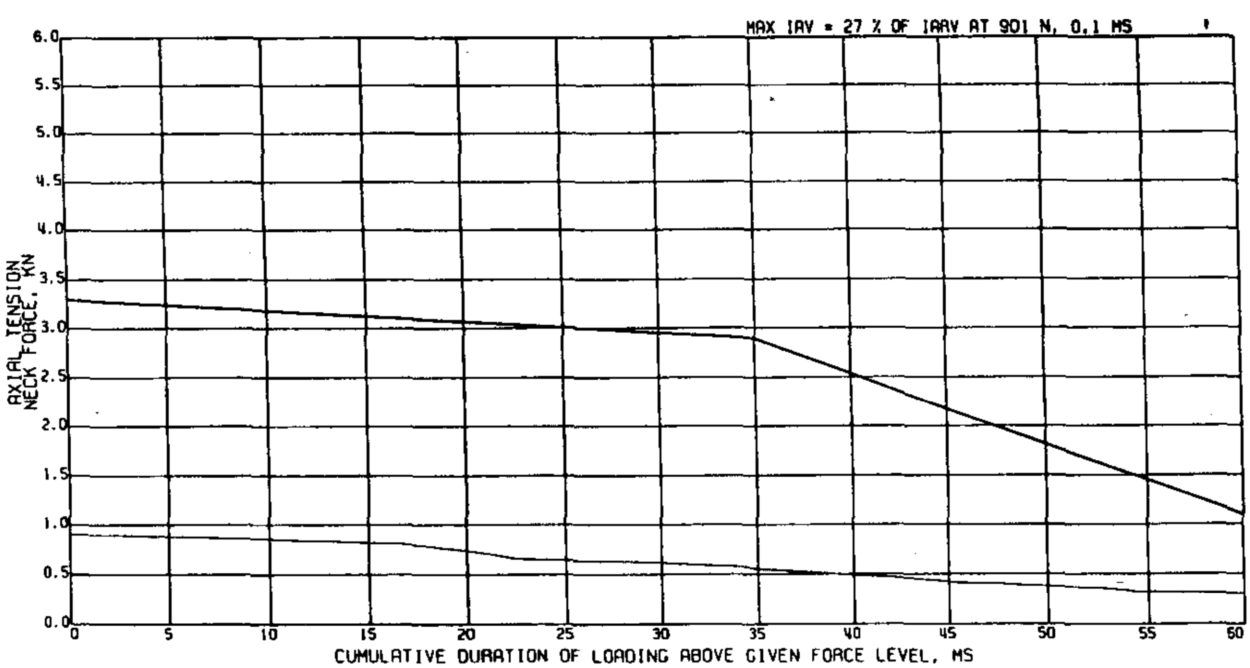
25 PROCESSED 1/29/1998 08:00 V2.07

C11828 L.REAR IMP 70% OVERLAP LTV MDB TO STATIONARY VEHICLE 81.0KM/H

ATD TYPE: GM50H

SC 8W91840 4-DOOR AXIAL TENSION ON HEAD. TEST DATE: 01/28/1998

ELEC DATA, SAE CLASS 1000 R. FRT INJURY REFERENCE



30 PROCESSED 1/29/1998 08:00 V2.07

C11829 R.REAR I M P 70% OVERLAP LTV MOE TO STATIONARY VEHICLE 81.0KM/H

ATD TYPE: GM50H

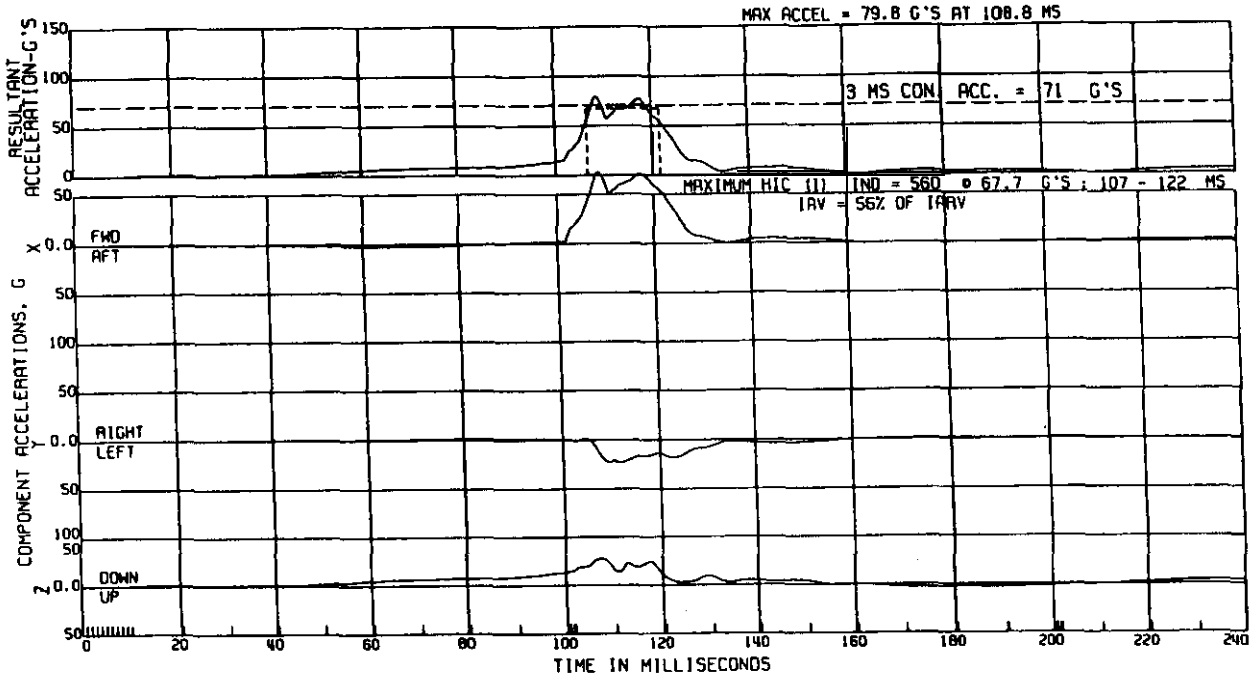
SC 1JW99326 4-DOOR

L.FRT HERD ACCEL.

TEST DATE:01/28/1998

ELEC DATA, SAE CLASS 1000

(HIC I LIMITED TO 15MS)



1 PROCESSED 1/28/1998 15:12 V2.07

C11829 R.REAR I M P 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 81.0KM/H

ATD TYPE: GM50H

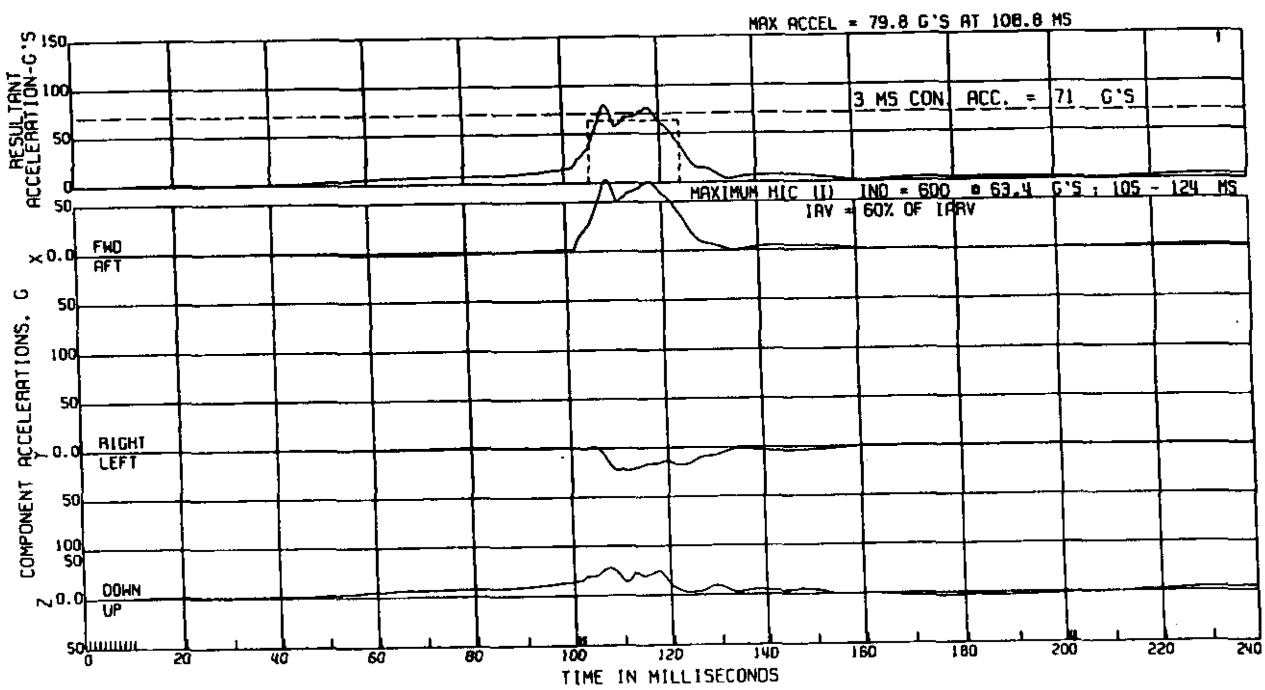
SC 1JW99326 4-DOOR

L.FRT HEAD ACCEL.

TEST DATE:01/28/1998

ELEC DATA, SAE CLASS 1000

(HIC I LIMITED TO 36MS)



2 PROCESSED 1/28/1998 15:12 V2.07

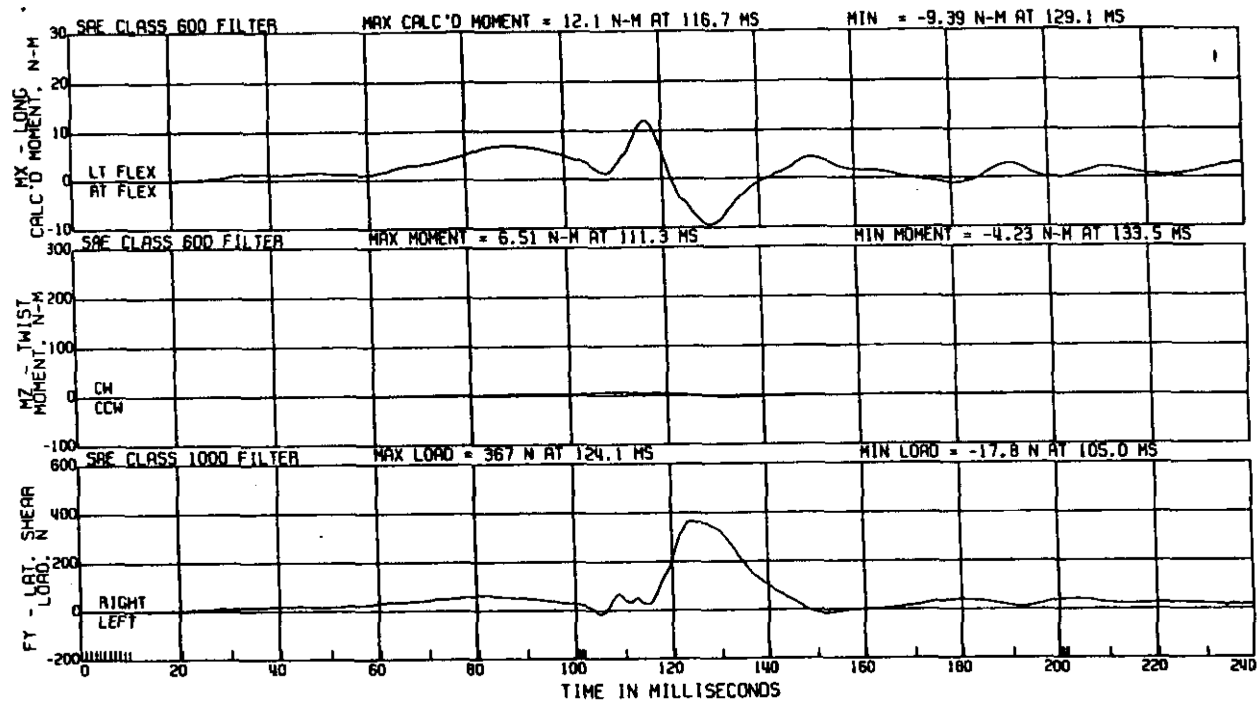
C11829 R.REAR I M P 70% OVERLAP LTV MDB TO STATIONARY VEHICLE 81.0KM/H

ATD TYPE: GM50H

SC 1JW99326 4-DOOR FRT NECK LOADING ON HEAD, UPPER LOAD TEST DATE:01/28/1998

ELEC DATA

L. FRT NECK LOADING ON HEAD



10 PROCESSED 1/28/1998 15:12 V2.07

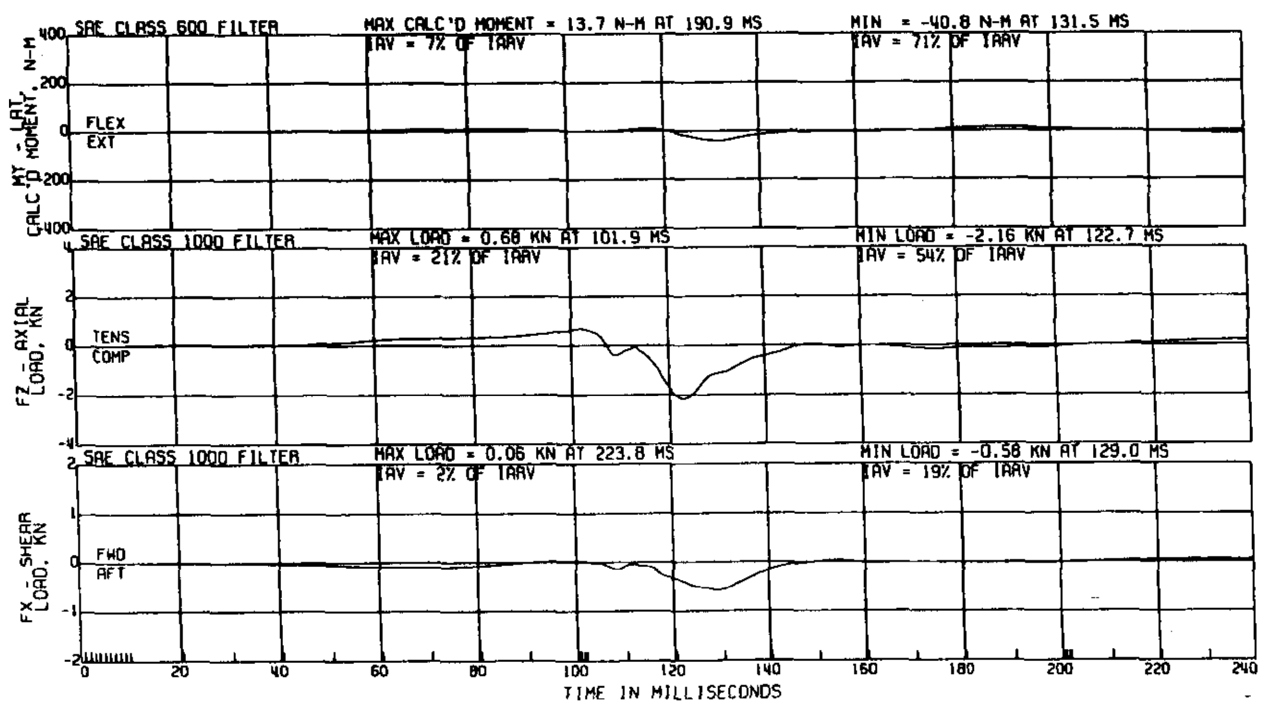
C11829 R.REAR I M P 70% OVERLAP LTV MDB TO STATIONARY VEHICLE 81.0KM/H

ATD TYPE: GM50H

SC 1JW99326 4-DOOR NECK LOADING ON HEAD TEST DATE:01/28/1998

ELEC DATA

L. FRT NECK LOADING ON HEAD



C11829 R.REAR IMP 70% OVERLAP LTv MDB TO STATIONARY VEHICLE 81.0KM/H

ATD TYPE: GM50H

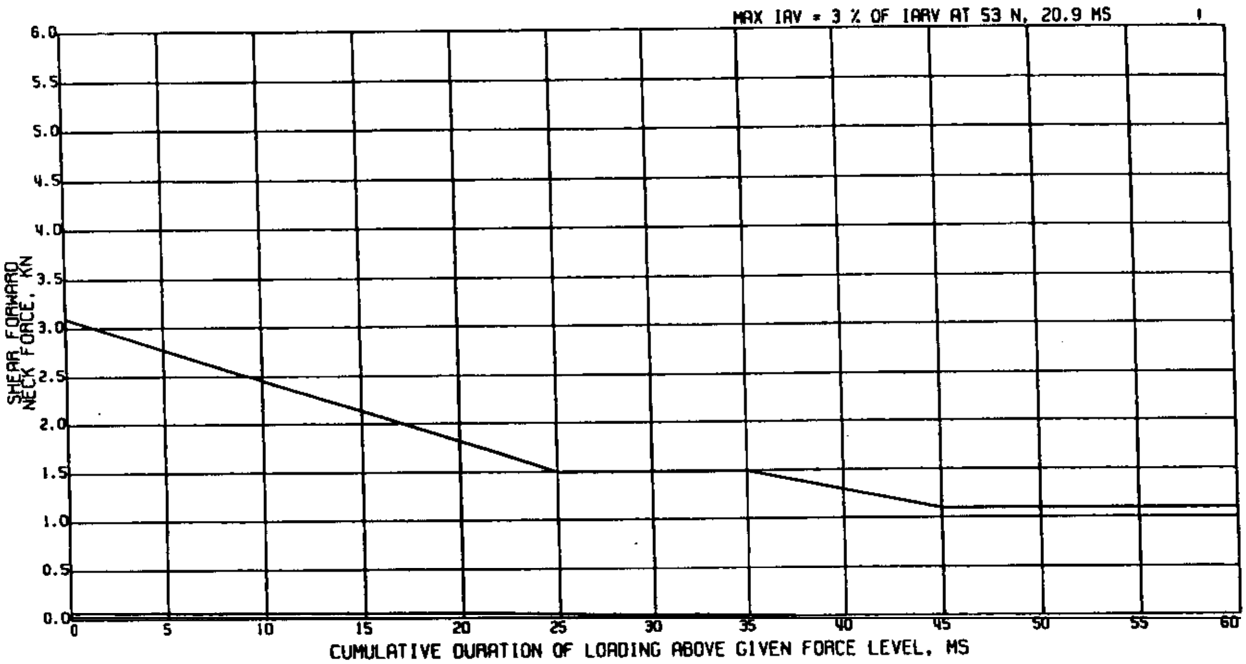
SC 1JW99326 4-DOOR

FORWARD NECK SHEAR ON HERO.

TEST DATE:01/28/1998

ELEC DATA, SAE CLASS 1000

L. FAT INJURY REFERENCE



12 PROCESSED 1/28/1998 15:12 V2.07

C11829 R.REAR IMP 70% OVERLAP LTV MDB TO STATIONARY VEHICLE 81.0KM/H

ATD TYPE: GM50H

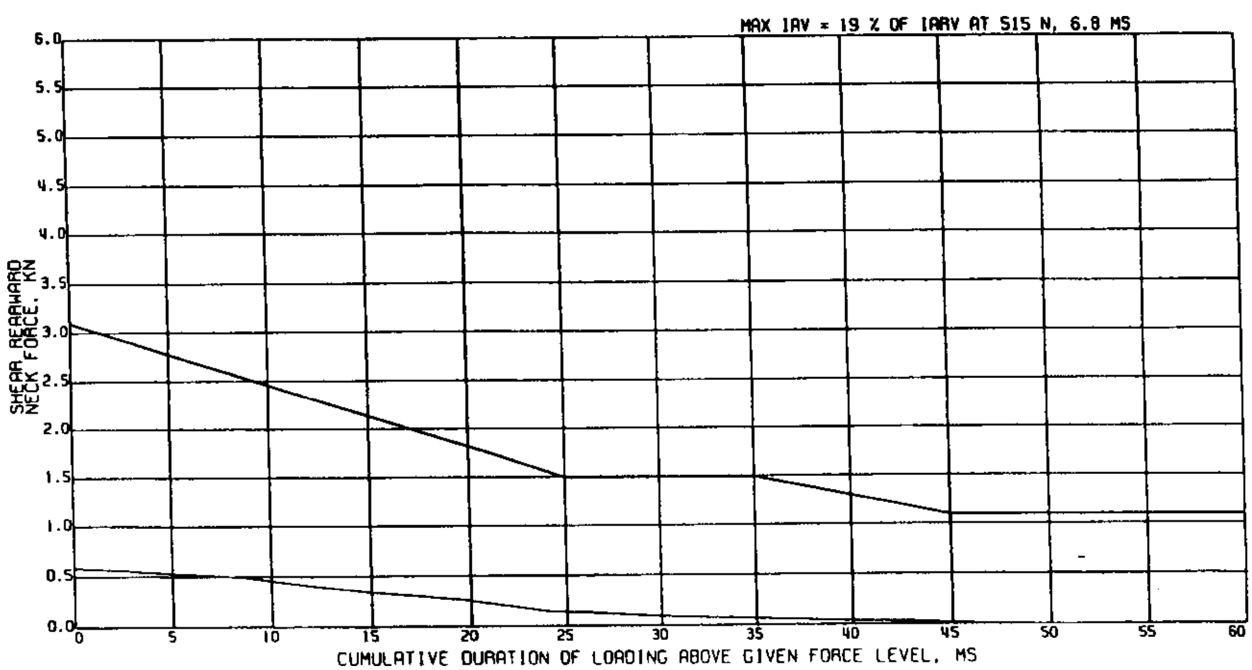
SC 1JW99326 4-DOOR

REARWARD NECK SHEAR ON HEAD.

TEST DATE:01/28/1998

ELEC DATA, SAE CLASS 1000

L. FAT INJURY REFERENCE



C11829 R.REAR I M P 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 81.0KM/H

ATD TYPE: GM50H

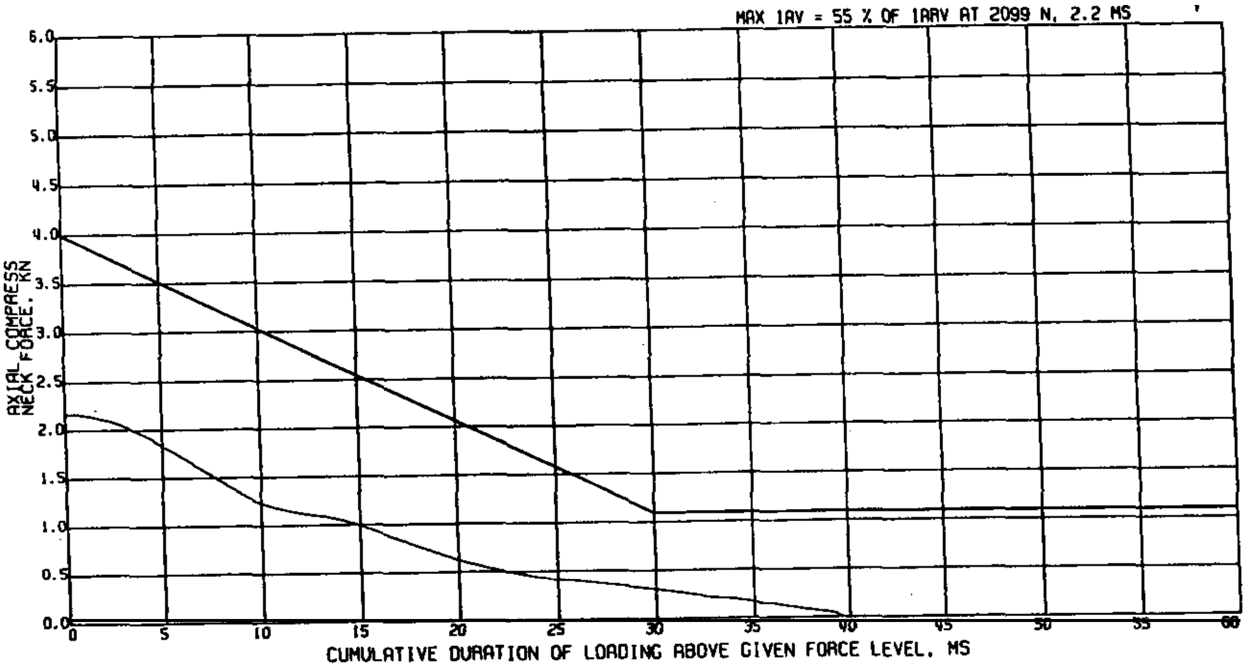
SC 1JW99326 4-DOOR

AXIAL COMPRESSION ON HEAD.

TEST DATE:01/28/1998

ELEC DATA, SAE CLASS 1000

L.FRT INJURY REFERENCE



14 PROCESSED 1/28/1998 15:12 V2.07

C11829 R.REAR IMP 70% OVERLAP LTV MOE TO STATIONARY VEHICLE 81.0KM/H

ATD TYPE: GM50H

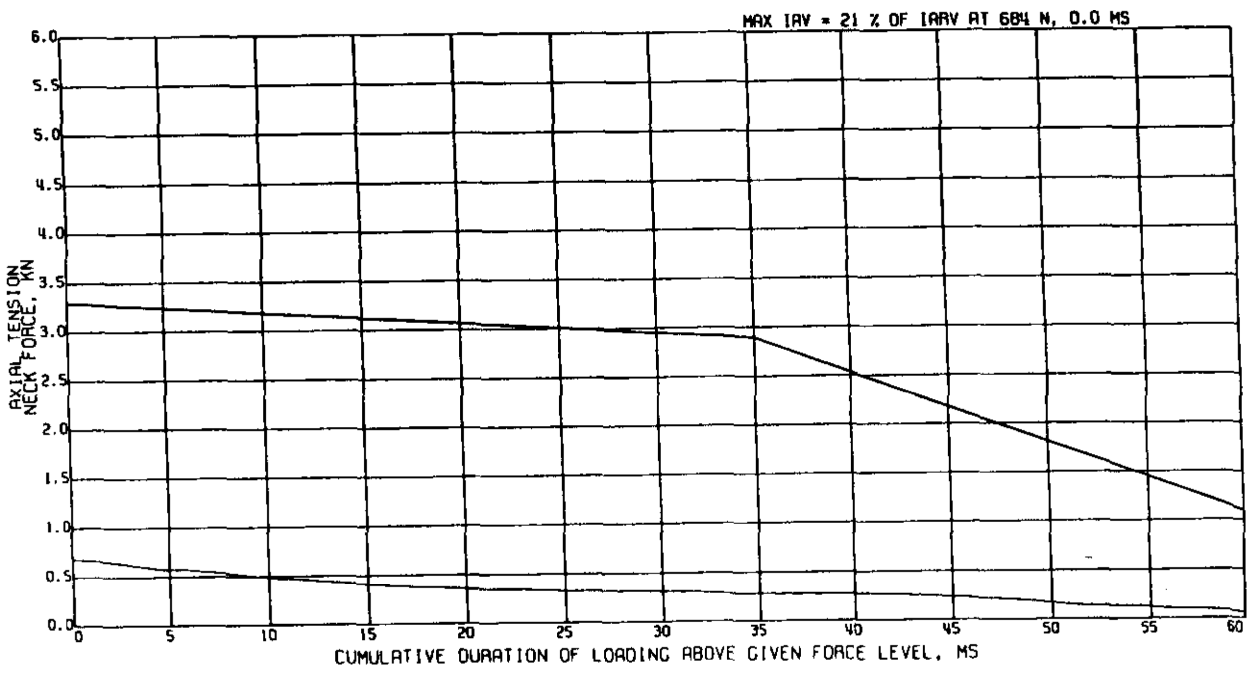
SC 1JW99326 4-DOOR

AXIAL TENSION ON HEAD,

TEST DATE:01/28/1998

ELEC DATA, SAE CLASS 1000

L.FRT INJURY REFERENCE

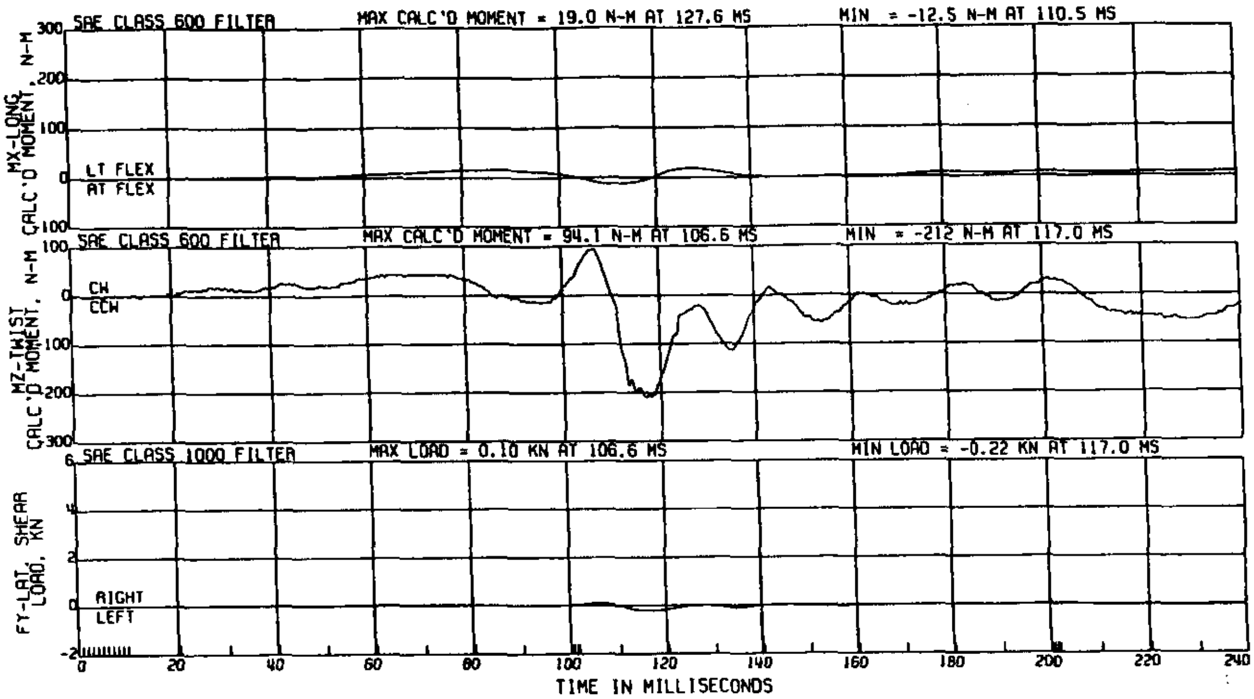


C11829 R.REAR I M P 70% OVERLAP LTV MOE TO STATIONARY VEHICLE 81.0KM/H

ATD TYPE: GM50H

SC 1JW99326 4-DOOR L. FRT NECK LOADING LOAD TEST DATE:01/28/1998

ELEC DATA (TORSO ON BASE OF NECK)



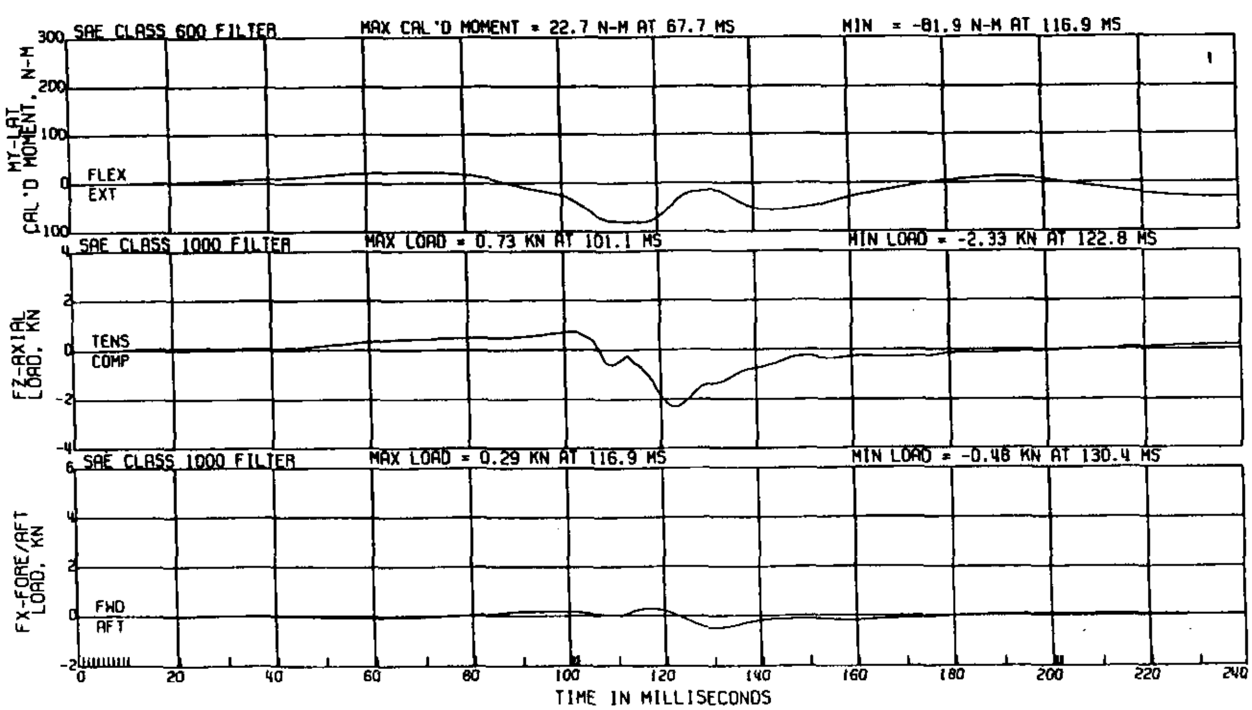
31 PROCESSED 1/28/1998 15:13 V2.07

C11829 R.REAR I M P 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 81.0KM/H

ATD TYPE: GM50H

SC I JW99326 4-DOOR L. FRT NECK LOADING LORD TEST DATE:01/28/1998

ELEC DATA (TORSO ON BASE OF NECK)



32 PROCESSED 1/28/1998 15:13 V2.07

C11829 A.REAR I M P 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 81.0KM/H

ATD TYPE: GM50H

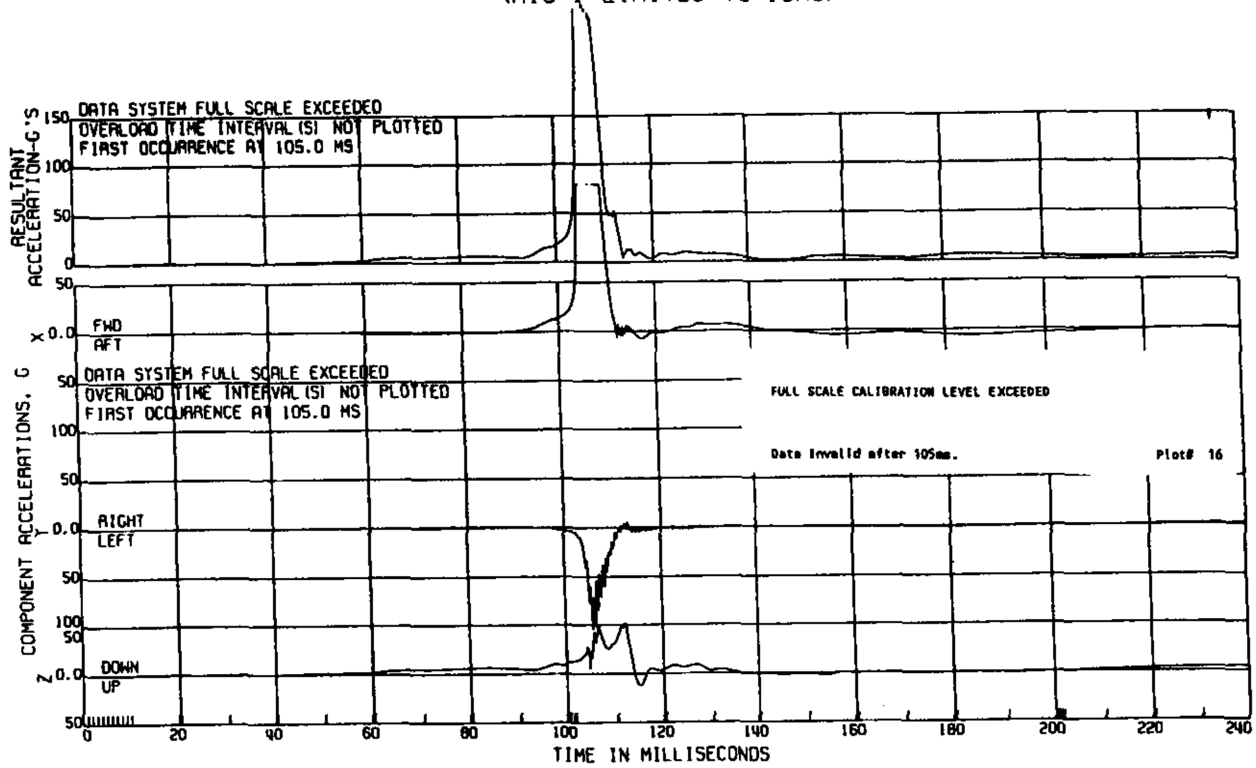
SC 1JW99326 4-DOOR

TEST DATE:01/28/1998

ELEC DATA, SAE CLASS 1000

R. FRT HEAD ACCEL.

(HIC I LIMITED TO 15MS)



16 PROCESSED 1/28/1998 15:12 V2.07

C11829 A.REAR IMP 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 81.0KM/H

ATD TYPE: GM50H

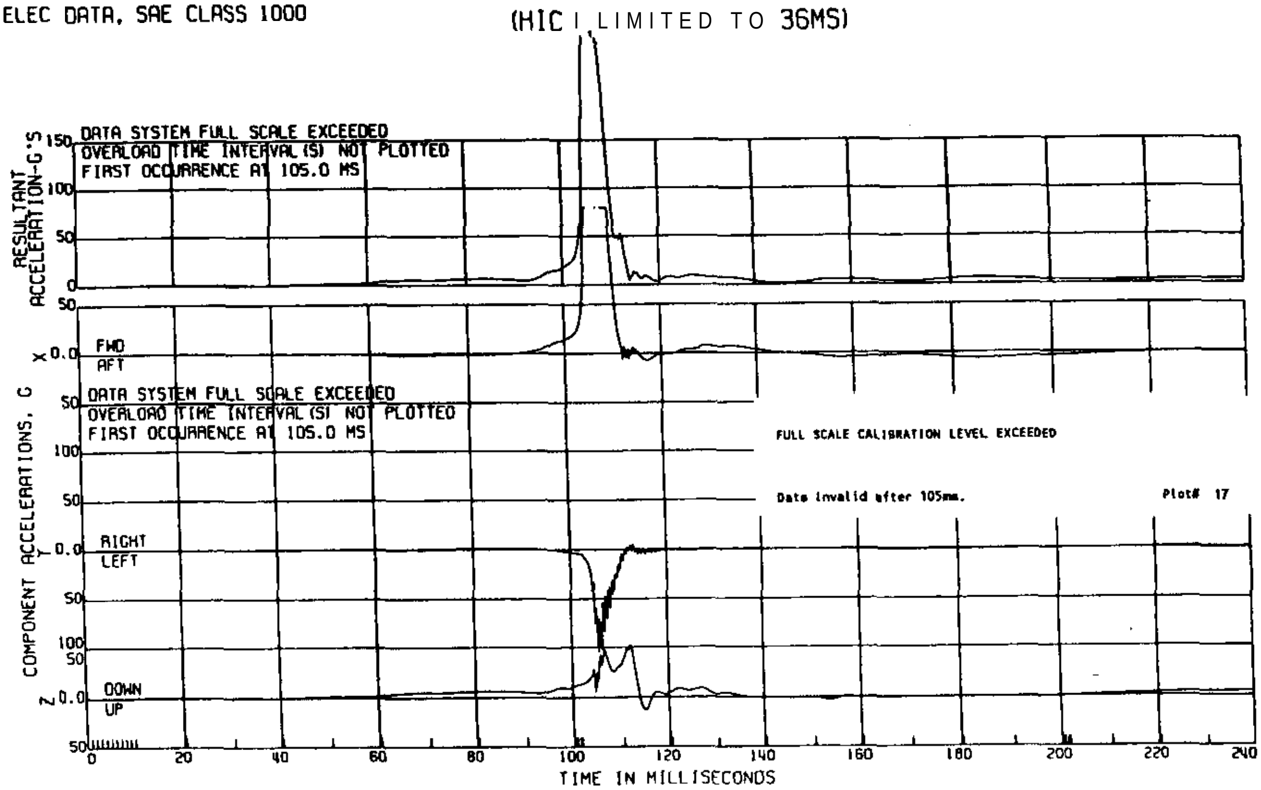
SC 1JW99326 4-DOOR

TEST DATE:01/28/1998

ELEC DATA, SAE CLASS 1000

R. FRT HEAD ACCEL.

(HIC I LIMITED TO 36MS)



C11829 R.REAR IMP 70% OVERLAP LTV MOE TO STATIONARY VEHICLE 81.0KM/H

SC 1JW99326 4-DOOR

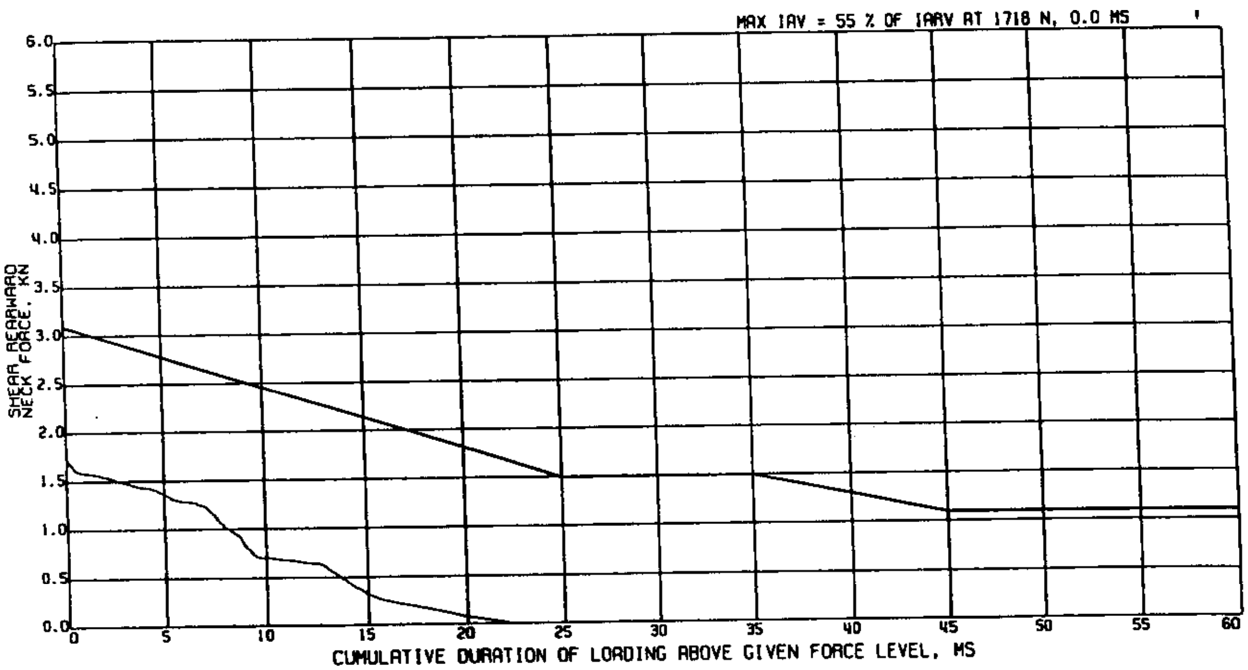
ELEC DATA, SAE CLASS 1000

REARWARD NECK SHEAR ON HEAD.

R. FRT INJURY REFERENCE

ATD TYPE: GM50H

TEST DATE:01/28/1998



28 PROCESSED 1/28/1998 15:13 V2.07

C11829 R.REAR IMP 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 81.0KM/H

SC 1JW99326 4-DOOR

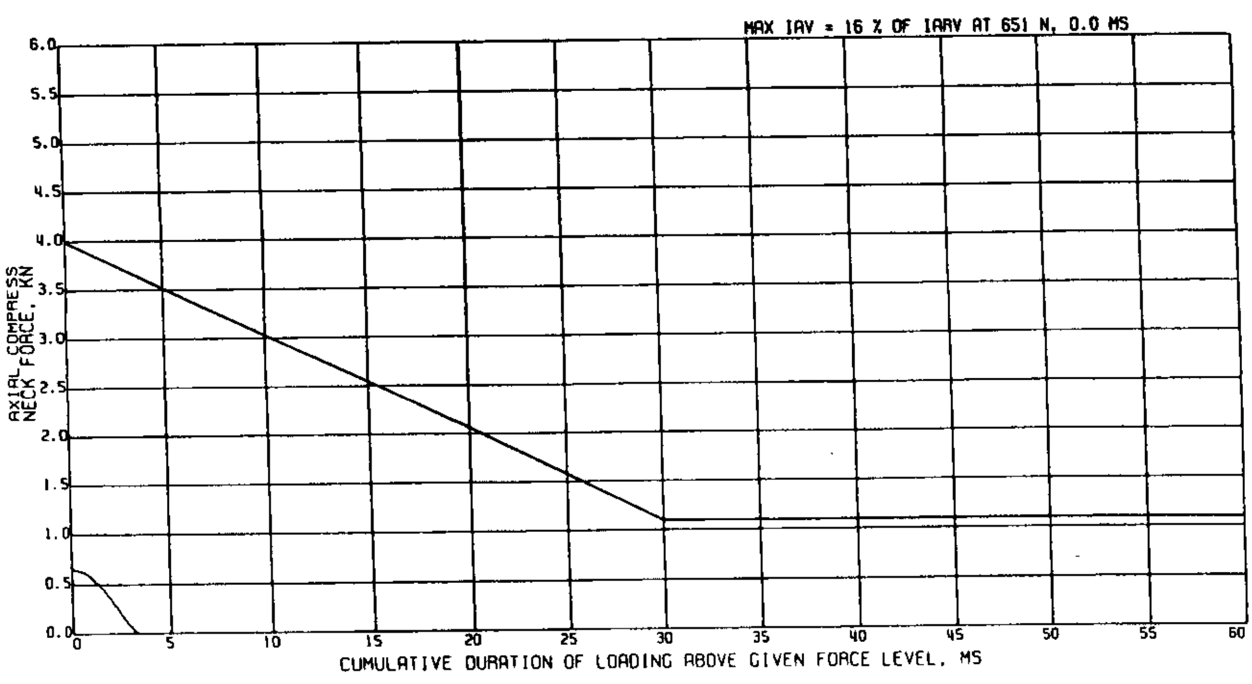
ELEC DATA, SAE CLASS 1000

AXIAL COMPRESSION ON HEAD.

R. FRT INJURY REFERENCE

ATD TYPE: GM50H

TEST DATE:01/28/1998



C11829 R.REAR I M P 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 81.0KM/H

ATD TYPE: GM50H

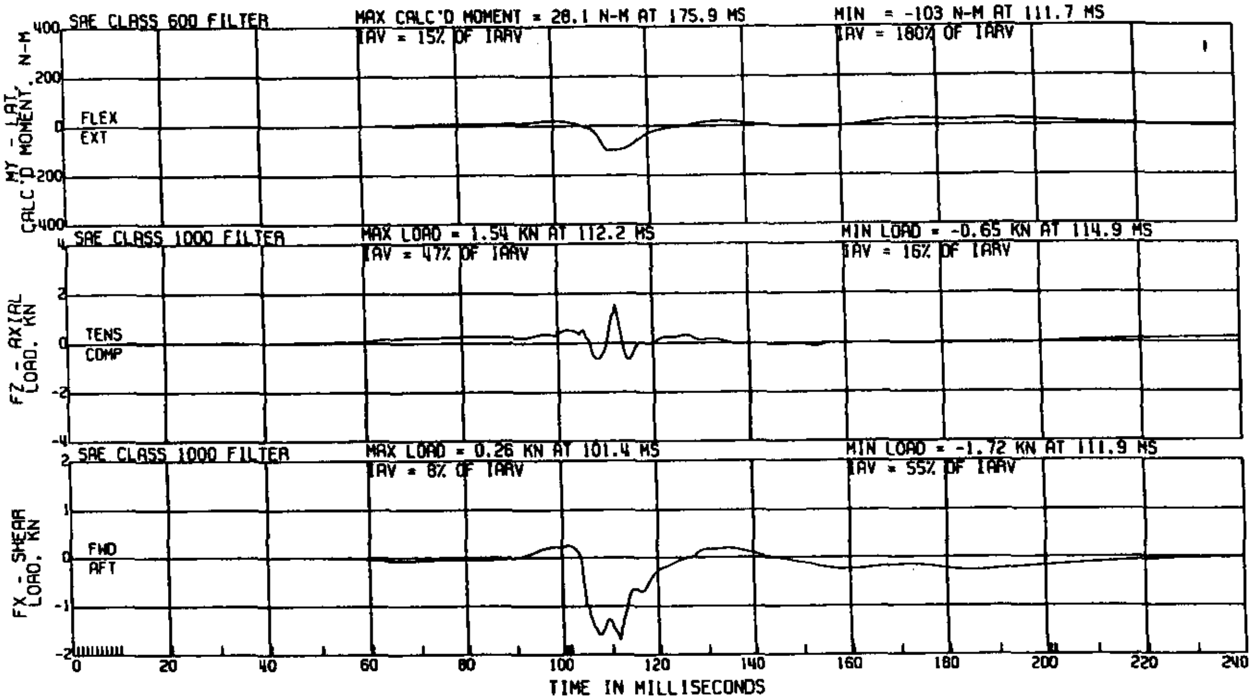
SC 1 JW99326 4-DOOR

NECK LOADING ON HEAD

TEST DATE:01/28/1998

ELEC DATA

R. FRT NECK LOADING ON HEAD



26 PROCESSED 1/28/1998 15:13 V2.07

C11829 R.REAR I M P 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 81.0KM/H

ATD TYPE: GM50H

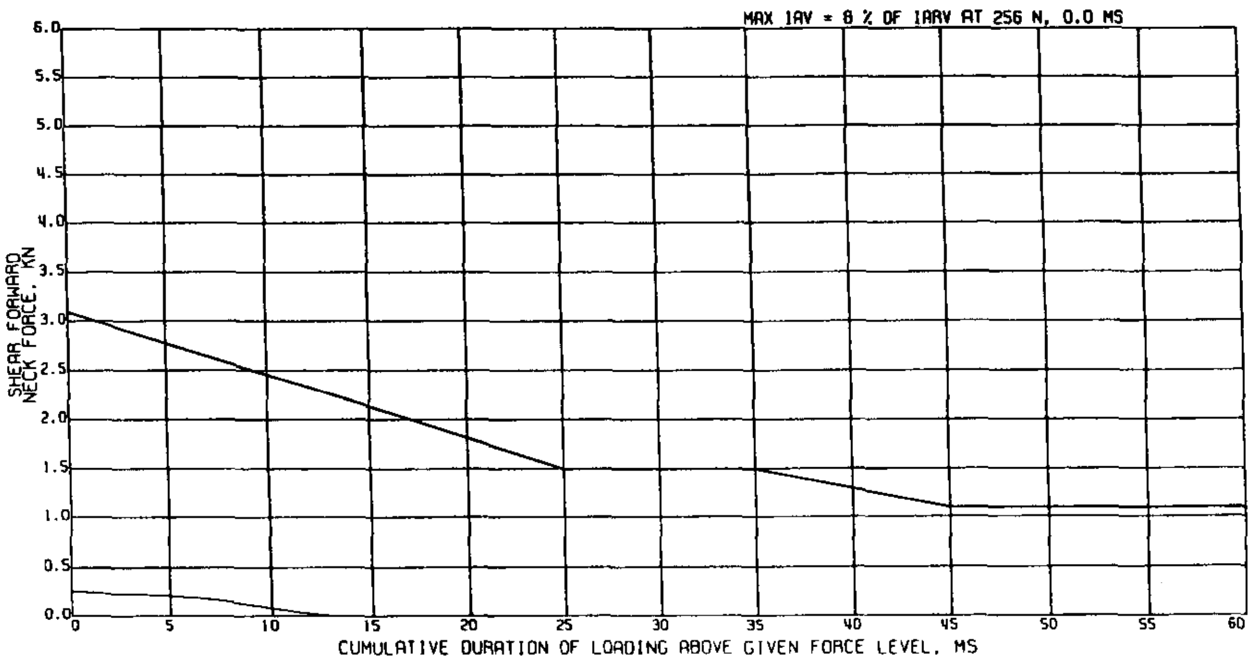
SC 1JW99326 4-DOOR

FORWARD NECK SHEAR ON HEAD,

TEST DATE:01/28/1998

ELEC DATA, SAE CLASS 1000

R. FRT INJURY REFERENCE



C11829 R.REAR I M P 70% OVERLAP LTV MDB TO STATIONARY VEHICLE 81.0KM/H

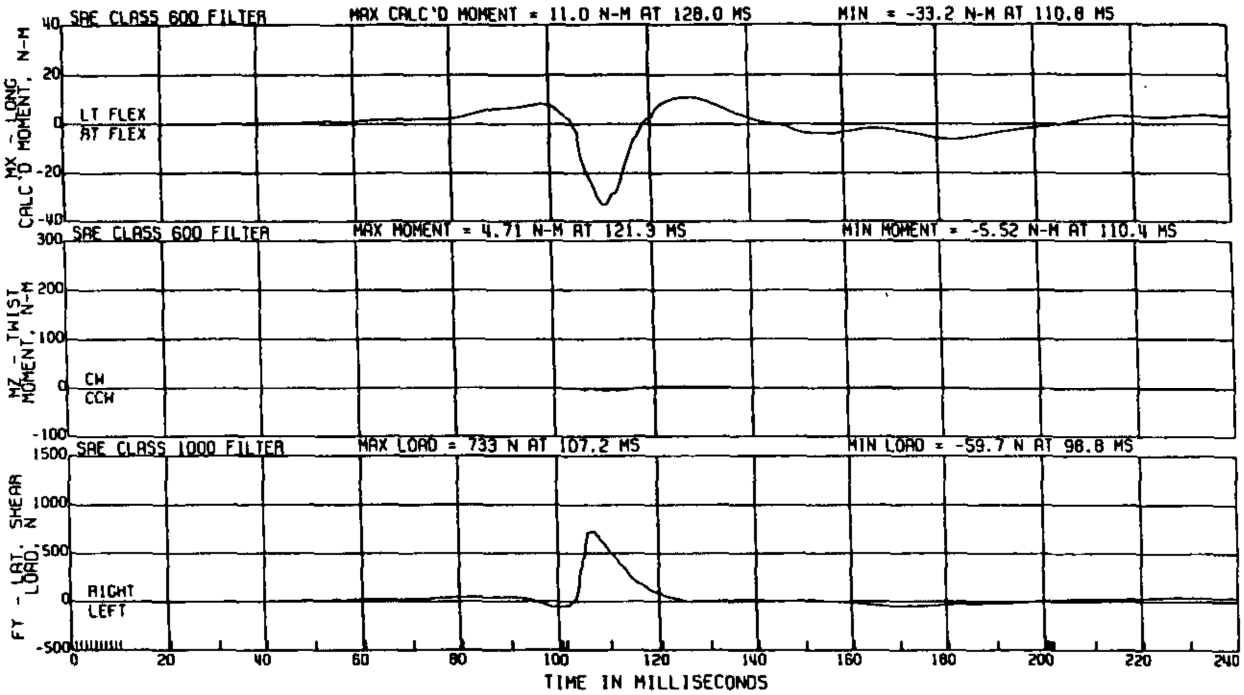
SC 1JW99326 4-000R R. FRT NECK LOADING ON HEAD, UPPER LOAD

ATD TYPE: GM50H

TEST DATE:01/28/1998

ELEC DATA

R. FRT NECK LOADING ON HEAD



2S PROCESSED 1/28/1998 15:13 V2.07

C11829 R.REAR IMP 70% OVERLAP LTV MDB TO STATIONARY VEHICLE 81.0KM/H

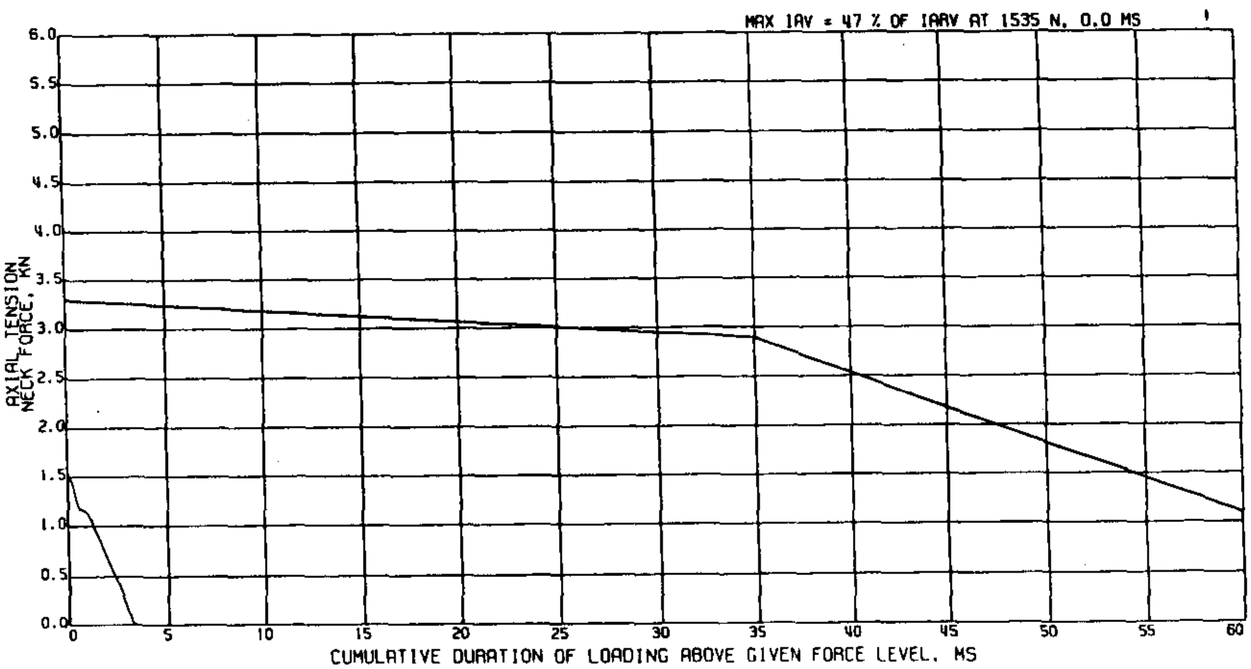
ATD TYPE: GM50H

SC 1 JW99326 4-000R AXIAL TENSION ON HEAD.

TEST DATE:01/28/1998

ELEC DATA, SAE CLASS 1000

R. FRT INJURY REFERENCE



Appendix E

Anthropomorphic Test Device (ATD) Injury Assessment Reference Values (IARVs)

The IARVs used for the mid-sized adult male Hybrid III ATD in the Project B.5 tests are recreated here from the Advisory Group for Aerospace Research & Development, Report 330, "Anthropomorphic Dummies for Crash and Escape System Testing" [11], except for the lower neck extension moment IARV which came from SAE Technical Paper No. 973342 [12] and the lumbar spine IARVs which came from a General Motors Corporation research paper [13].

Body Region Injury Assessment Criteria	Injury Assessment Reference Value for the mid sized male Hybrid III
Head HIC; $(t_2 - t_1) \leq 15$ msec*	1000
Head/Neck Interface Upper neck longitudinal shear force, +Fx and –Fx Upper neck axial force, compression, -Fz Upper neck axial force, tension, +Fz Upper neck longitudinal moment, flexion, +My Upper neck longitudinal moment, extension, -My Neck/Thorax Interface Lower neck longitudinal shear force, +Fx and –Fx Lower neck axial force, compression, -Fz Lower neck axial force, tension, +Fz Lower neck longitudinal moment, extension, -My	 Figure E1 Figure E2 Figure E3 190 N•m 57 N•m Figure E1 Figure E2 Figure E3 154 N-m
Thorax/Chest Resultant spinal acceleration Sternal deflection due to shoulder belt	 60 g 50 mm
Femurs Axial compression	 Figure E4
Lumbar spine Bending, flexion Bending, extension Axial force, tension Axial force, compression Fore - aft shear force	 1125 N•m 338 N•m Figure E5 Figure E6 Figure E7

- The Head Injury Criterion (HIC) is defined as: HIC = $(Aavg)^{2.5}(t_2 - t_1)$, where Aavg is the average resultant acceleration of the center of mass of the head (expressed in gs) for the time interval $t_2 - t_1$ (expressed in seconds).

Figure E1 - Injury Assessment Criteria for Fore/Aft Neck Shear Force Measured with Hybrid III Mid-sized Adult Male ATD

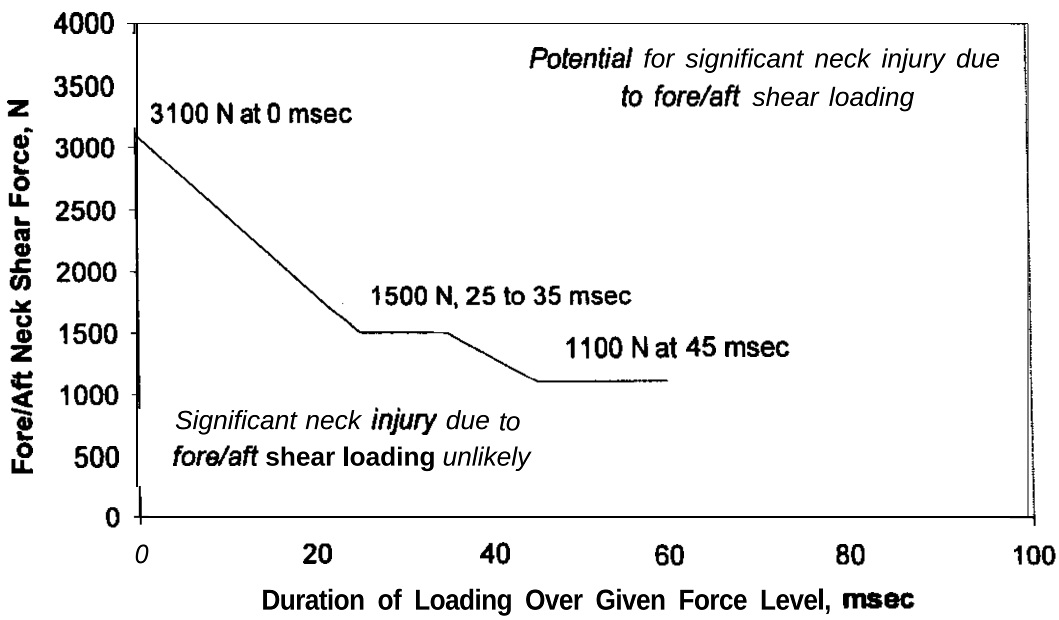


Figure E2 - Injury Assessment Criteria for Axial Neck Compression Measured with Hybrid III Mid-sized Adult Male ATD

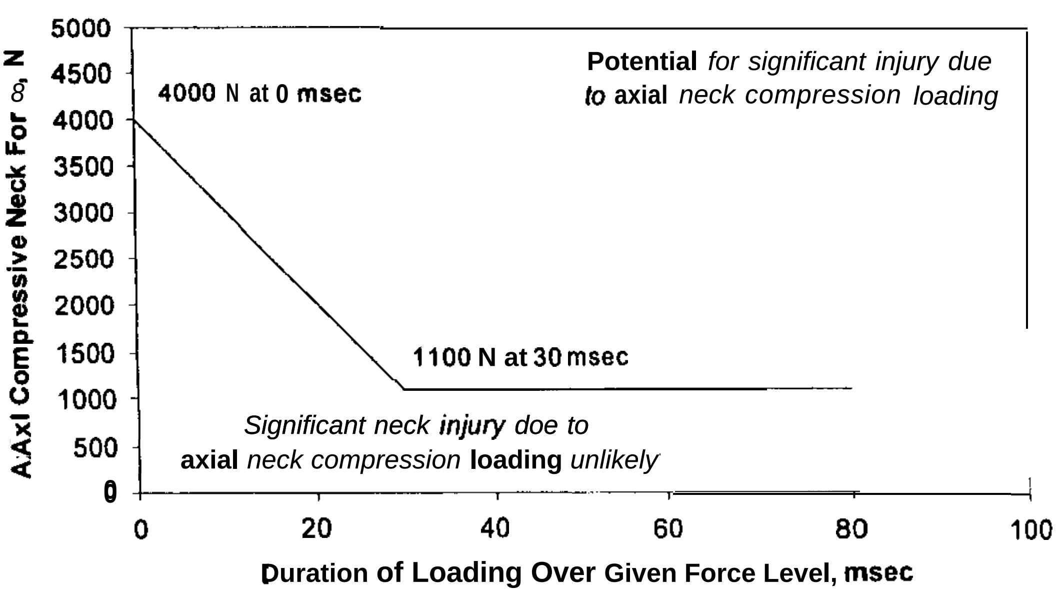


Figure E3 - Injury Assessment Criteria for Axial Neck Tension Measured with Hybrid III Mid-sized Adult Male ATD

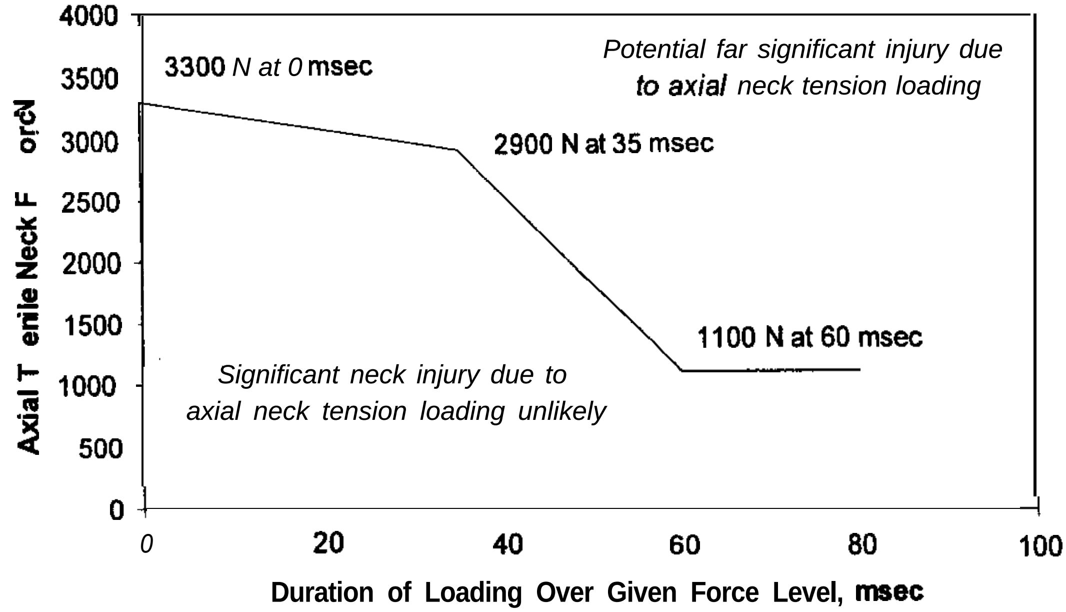


Figure E4 - Injury Assessment Criteria for Axial Compressive Femur Force Measured with Hybrid III Mid-sized Adult Male ATD

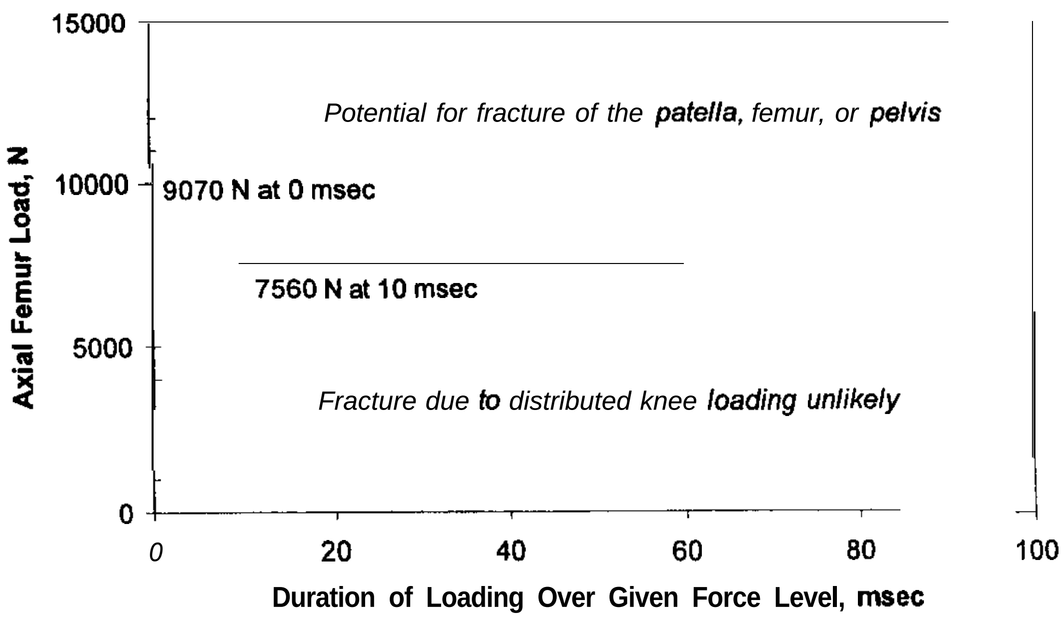


Figure E5 - Injury Assessment Criteria for Lumbar Spine Tension Loading Measured with Hybrid III Mid-sired Adult Male ATD

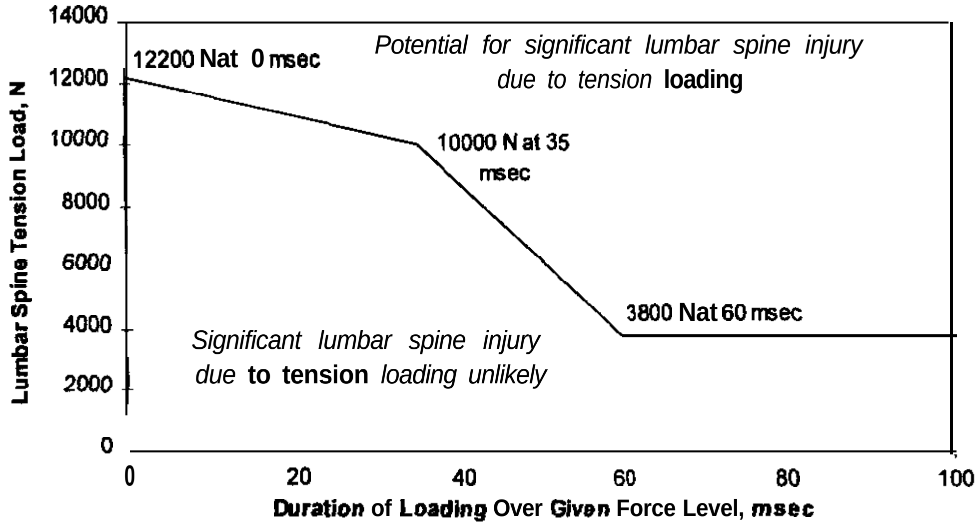


Figure E6 - Injury Assessment Criteria for Lumbar Spine Compression Loading Measured with Hybrid III Mid-sized Adult Male ATD

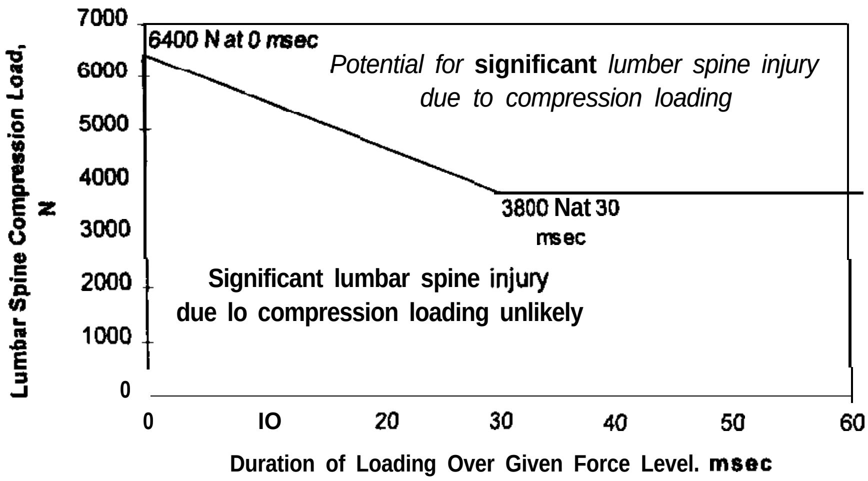
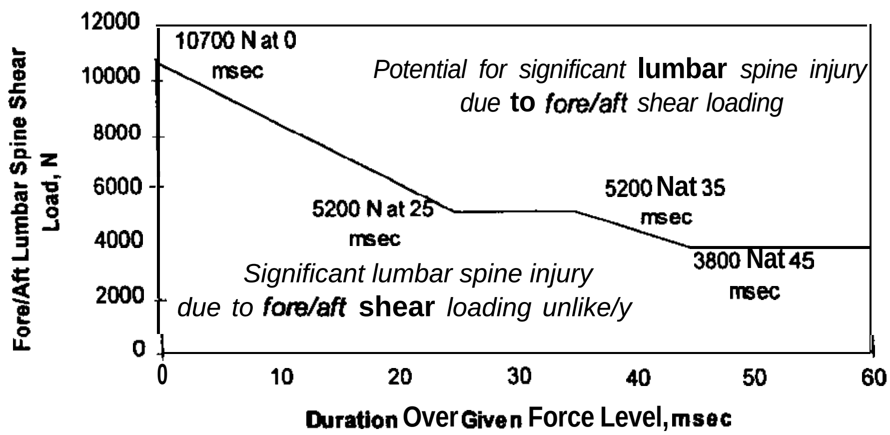


Figure E7 - Injury Assessment Criteria for Lumbar Spine Fore/Aft Shear Force Measured with Hybrid III Mid-sized Adult Male ATD



Appendix F

Test Vehicle Acceleration, Velocity and Displacement Data Plots

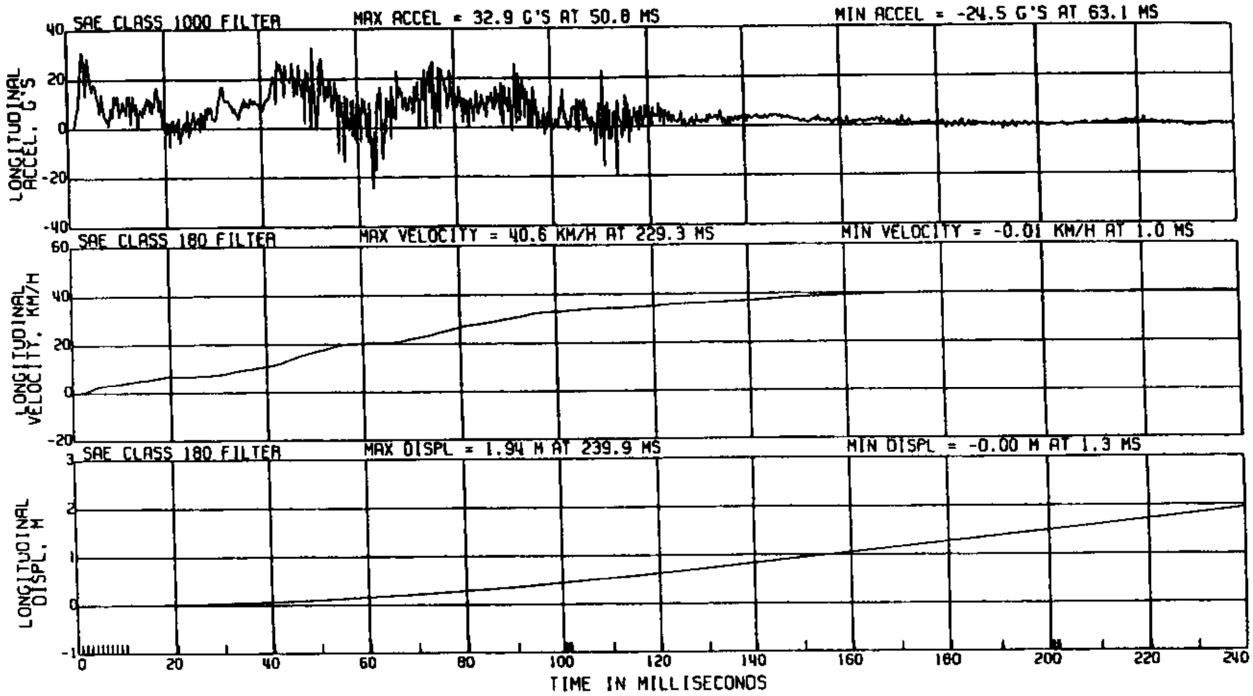
C11817 L.REAR I M P 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 80.7KM/H

SC 8W9185D 4-DOOR

L. FRT ROCKER

TEST DATE:12/18/1997

ELEC DATA



57 PROCESSED 12/18/1997 14:17 V2.07

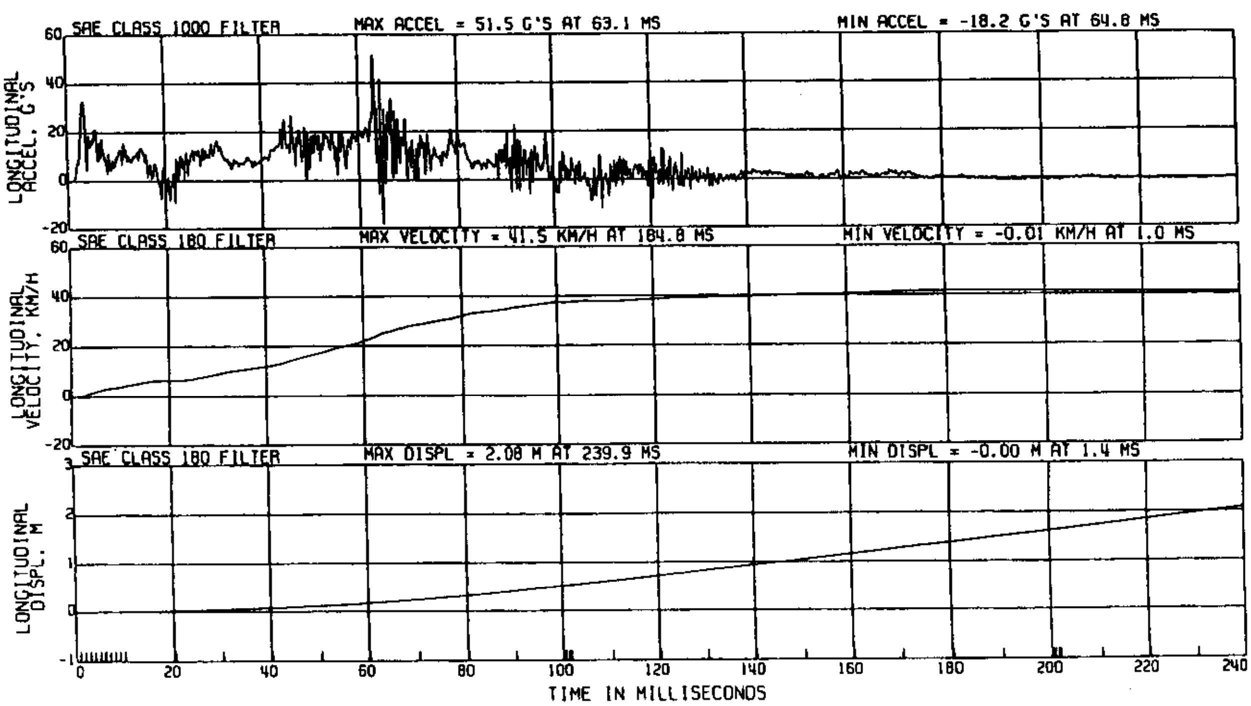
C1 1817 L.REAR IMP 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 80.7KM/H

SC 8W9185D 4-DOOR

R. FRT ROCKER

TEST DATE:12/18/1997

ELEC DATA

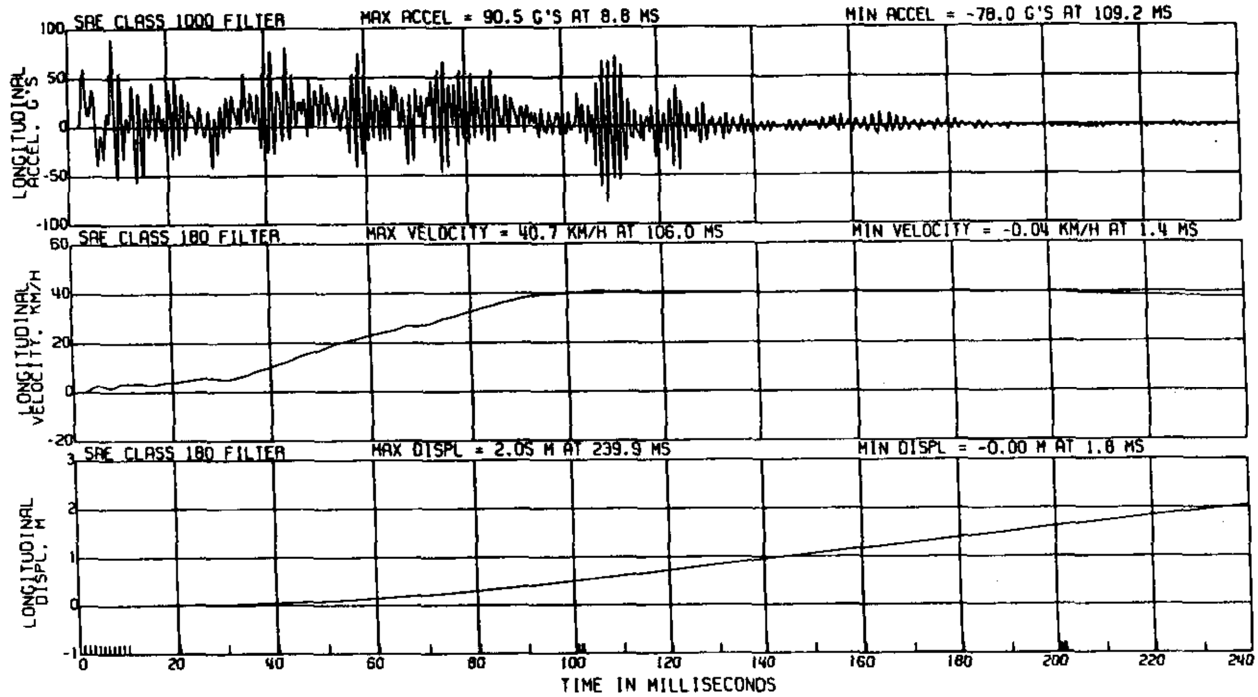


60 PROCESSED 12/18/1997 14:17 V2.07

C11818 L.REAR I M P 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 80.9KM/H

SC 8W9182D 4-DOOR L. FRT ROCKER TEST DATE:12/18/1997

ELEC DATA

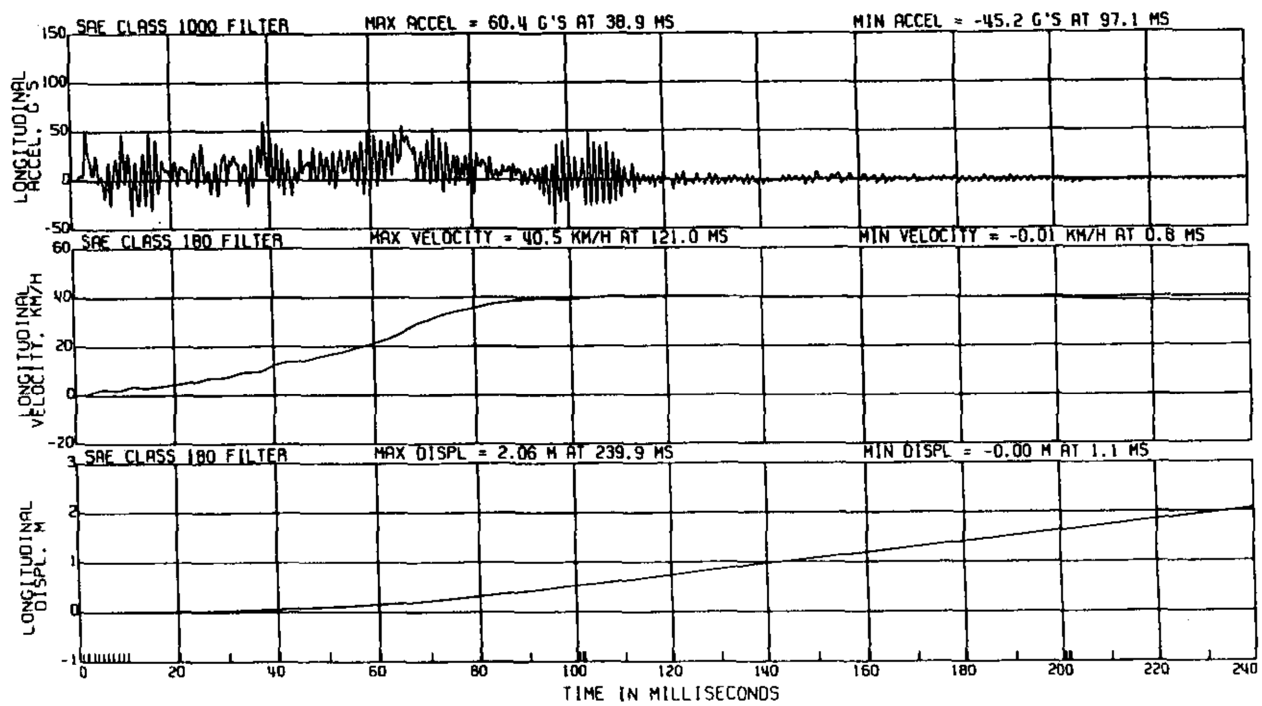


S7 PROCESSED 12/18/1997 14:22 V2.07

C11818 L.REAR I M P 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 80.9KM/H

SC 8W9182D 4-DOOR R. FRT ROCKER TEST DATE:12/18/1997

ELEC DATA



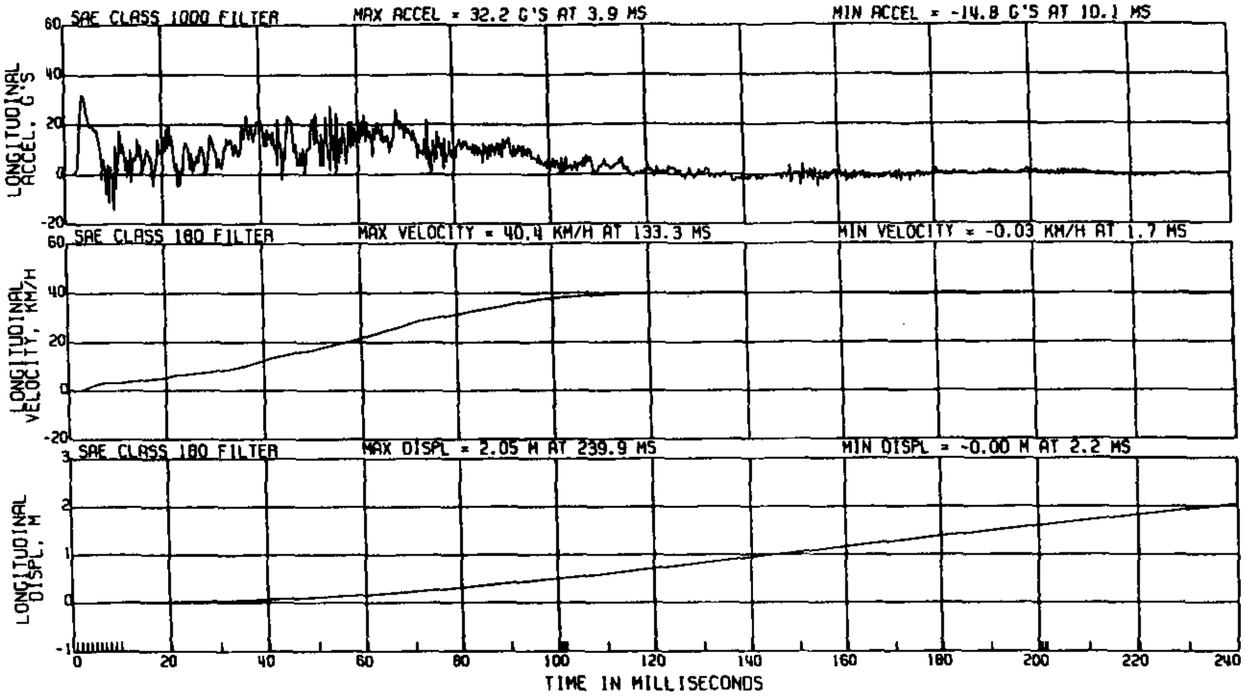
C11816 R.REAR I M P 70% OVERLAP LTV MOE TO STATIONARY VEHICLE 81.2KM/H

SC 8W91830 4-DOOR

L. FRT ROCKER

TEST DATE:01/28/1998

ELEC DATA



57 PROCESSED 1/28/1998 09:08 V2.07

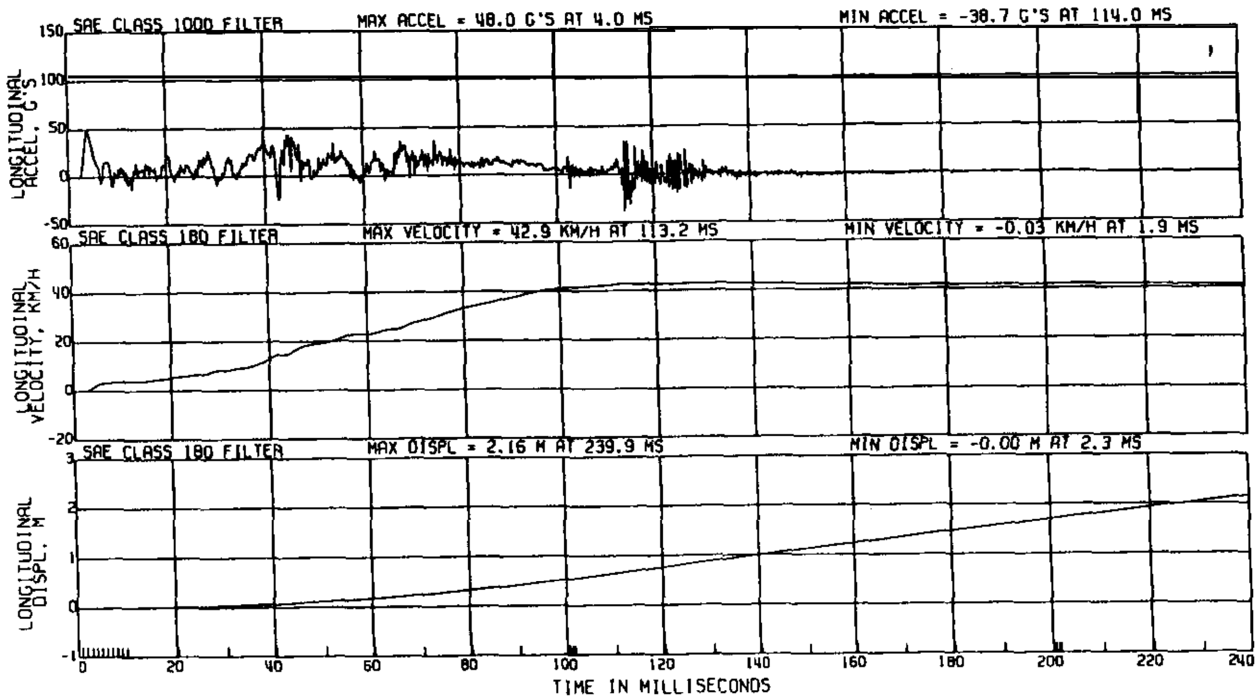
C11816 R.REAR I M P 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 81.2KM/H

SC 8W91830 4-DOOR

R. FRT ROCKER

TEST DATE:01/28/1998

ELEC DATA



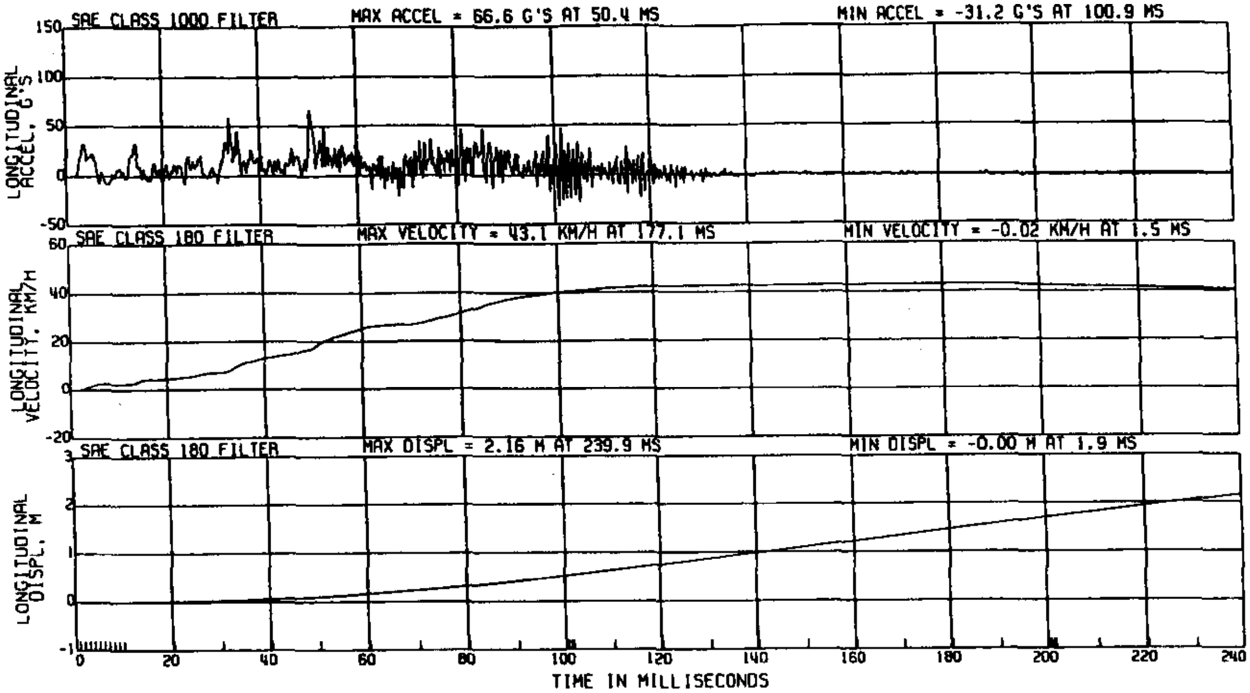
C11828 L.REAR IMP 70% OVERLAP LTV MOE TO STATIONARY VEHICLE 81.0KM/H

SC 8W91840 4-DOOR

L. FRT ROCKER

TEST DATE:01/28/1998

ELEC DATA



S7 PROCESSED 1/29/1998 08:00 V2.07

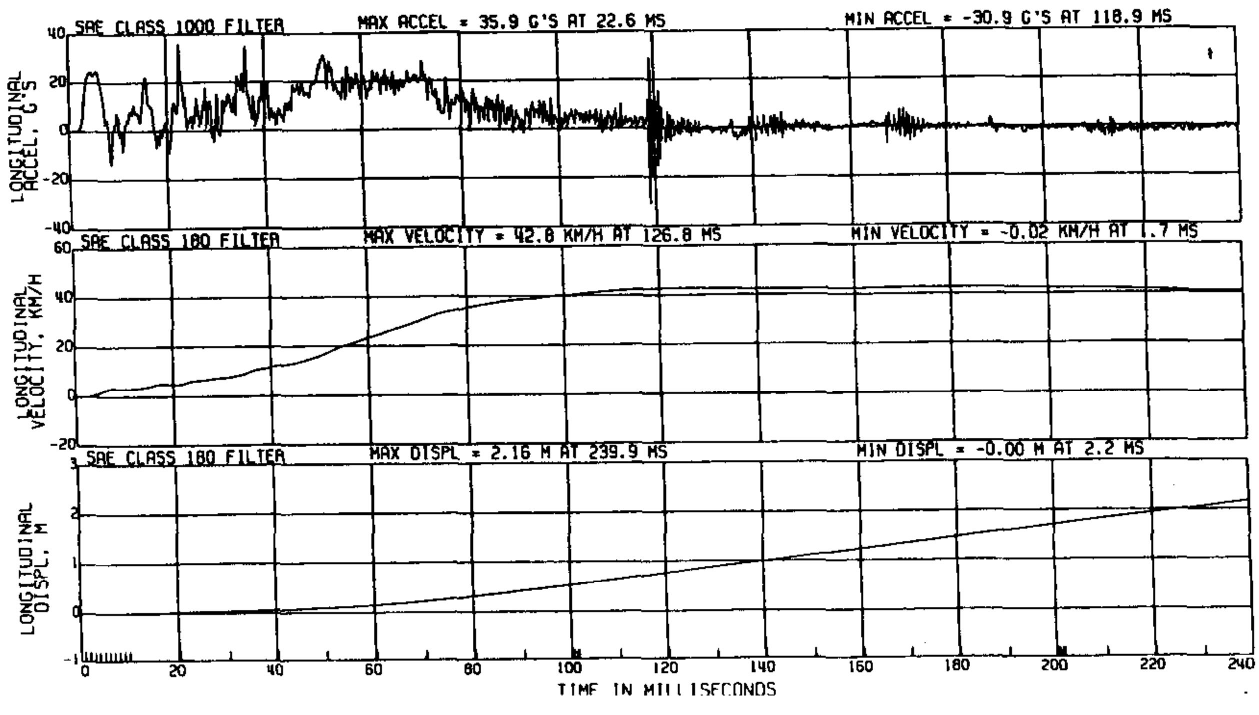
C11828 L.REAR IMP 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 81.0KM/H

SC 8W91840 4-DOOR

R. FRT ROCKER

TEST DATE:01/28/1998

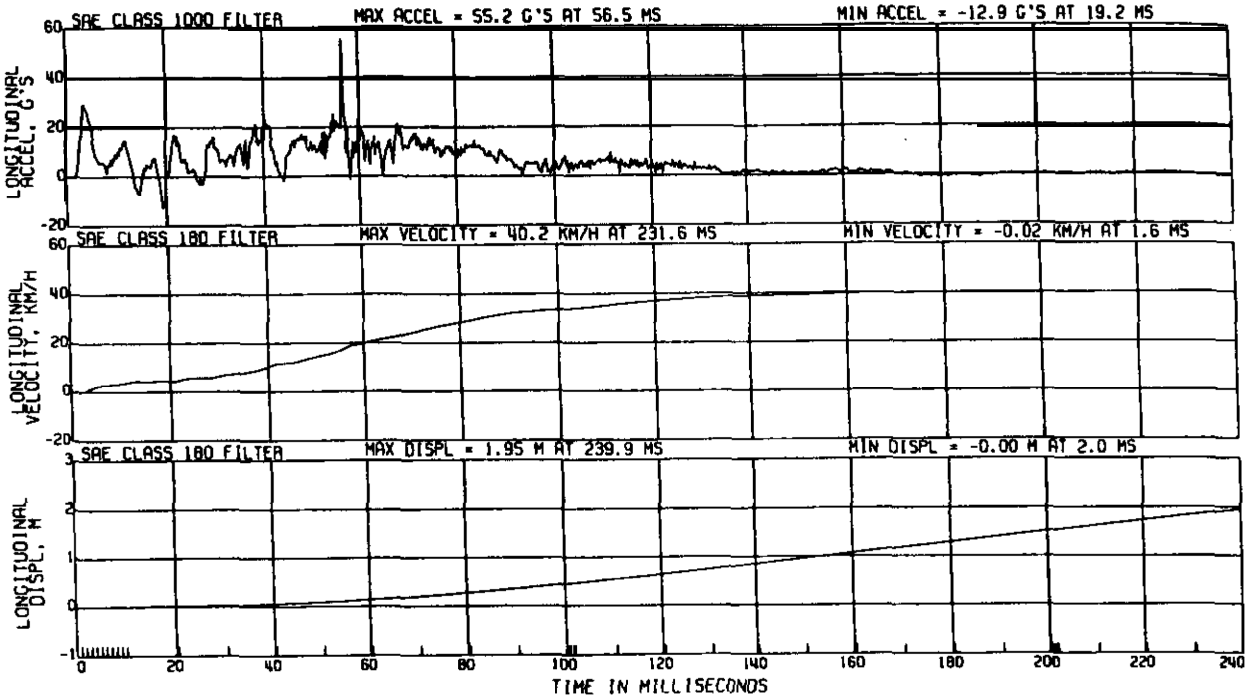
ELEC DATA



C11829 R.REAR I M P 70% OVERLAP LTV MOB TO STATIONARY VEHICLE 81.0KM/H

SC 1JW99326 4-DOOR L.FRT ROCKER TEST DATE:01/28/1998

ELEC DATA

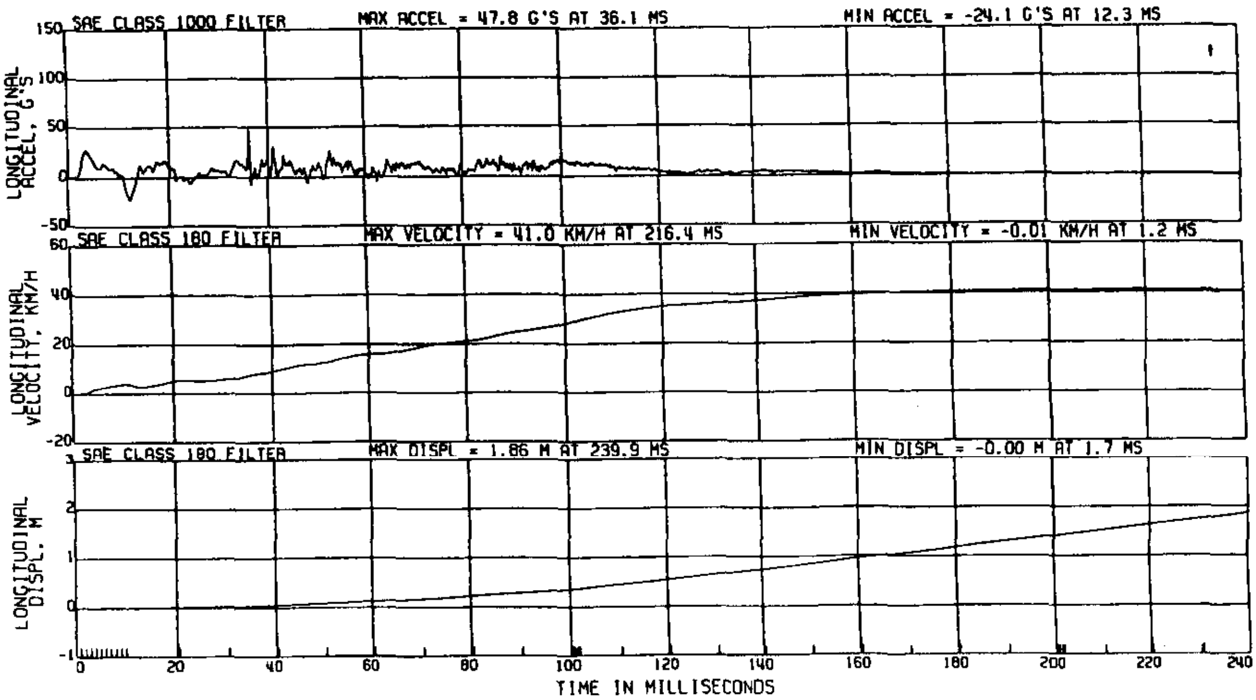


57 PROCESSED 1/28/1998 15:14 V2.07

C11829 R.REAR I M P 70% OVERLAP LTV MOE TO STATIONARY VEHICLE 81.0KM/H

SC 1JW99326 4-DOOR R.FRT ROCKER TEST DATE:01/28/1998

ELEC DATA



60 PROCESSED 1/28/1998 15:14 V2.07