246908

Memorandum

U.S. Department of Transportation

National Highway Traffic Safety Administration

Subject: Docket Submittal: Docket NHTSA-03-15351 – 4
Child Restraint Systems

Date: JUN 25 2003

From: Mike Huntley, Safety Standards Engineer
Structures and Special Systems Division

Reply to Attn. of:

To: Docket Section

THRU: Roger A. Saul, Director
Office of Crashworthiness Research

Jacqueline S. Glassman
Chief Counsel

On November 1, 2000, the Transportation Recall Enhancement, Accountability, and Documentation (TREAD) Act was enacted, which directs the National Highway Traffic Safety Administration (NHTSA) to initiate a rulemaking proceeding for the purpose of improving the safety of child restraints.

In support of this mandate, NHTSA contracted with the Naval Air Warfare Center (NAVAIR), Aircraft Division located in Patuxent River, MD to perform an evaluation comparing (1) the geometry of the existing test seat assembly used in Federal motor vehicle safety standard (FMVSS) No. 213 compliance testing to the geometry of vehicle seats in the existing vehicle fleet, and (2) the crash pulse used in FMVSS No. 213 compliance testing to the crash pulse of existing vehicles during New Car Assessment Program (NCAP) and FMVSS No. 208 tests.

NHTSA published a Notice of Proposed Rulemaking (NPRM) on May 1, 2002 (67 FR 21806), that, based in part on the evaluation of vehicle seat geometry noted above, proposed a number of changes to the existing test seat assembly used in FMVSS No. 213 compliance testing. Subsequently, NAVAIR constructed a test seat assembly incorporating the proposed changes, and conducted a comprehensive series of dynamic sled tests to evaluate the effect of these changes to the test seat assembly on child restraint performance.

Please transmit the attached report to the subject docket.

Attachment
"Dynamic Crash Test Series Conducted Using Modified FMVSS No. 213 Test Bench Assembly"

Get it together!
SAFETY BELTS SAVE LIVES

NAVAL AIR WARFARE CENTER AIRCRAFT DIVISION
PATUXENT RIVER, MARYLAND

TECHNICAL REPORT

REPORT NO: NAWCADPAX/TR2003/124

TECHNICAL REPORT ON

DYNAMIC CRASH TEST SERIES CONDUCTED USING MODIFIED FMVSS 213 TEST BENCH ASSEMBLY.

by

William Glass

March 2003

Approved for Public Release; distribution is unlimited

DEPARTMENT OF THE NAVY
NAVAL AIR WARFARE CENTER AIRCRAFT DIVISION
PATUXENT RIVER, MARYLAND

NAWCADPAX/TR2003/124

TECHNICAL REPORT ON DYNAMIC CRASH TEST SERIES CONDUCTED USING MODIFIED FMVSS 213 TEST BENCH ASSEMBLY

by

William Glass

RELEASED BY:

____
JOHN QUARTUCCIO / AIR 4.6.2 / 7 March 2003
Head, In-flight & Crashworthy Escape Systems Division
Naval Air Warfare Center Aircraft Division

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. **PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.**

1. REPORT DATE March 2003	2. REPORT TYPE Technical Report	3. DATES COVERED November 2001 – January 2002
4. TITLE AND SUBTITLE Technical Report on Dynamic Crash Test Series Conducted using Modified 213 Test Bench Assembly.		5a. CONTRACT NUMBER 5b. GRANT NUMBER DTNH22-01-X02064/Mod 0001 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) William Glass		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Air Warfare Center Aircraft Division 22347 Cedar Point Road, Unit #6 Patuxent River, Maryland 20670-1161		8. PERFORMING ORGANIZATION REPORT NUMBER NAWCADPAX/TR2003/124
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Highway Traffic Safety Administration Office of Crashworthiness Standards ATTN: Dr. George E. Mouchahoir, Chief, SV&SD 400 Seventh Street, S.W. Washington, D.C. 20590		10. SPONSOR/MONITOR'S ACRONYM(S) NHTSA 11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAI LIABILITY STATEMENT Approved for public release; distribution is unlimited		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS Pulse validation dynamic validation tests child restraint systems		

16. SECURITY CLASSIFICATION OF: Unclassified			17. LIMITATION OF ABSTRACT None	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON William Glass
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER (include area code)(301) 342-8450

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18

Contents

References:

1. Department of Transportation Docket # NHTSA-2002-11707-9.

2. Department of Transportation Laboratory Test Procedure # TP-213-04, September 1, 1997.

Abstract

Under the Transportation Recall Enhancement, Accountability, and Documentation (TREAD) Act, National Highway Traffic Safety Administration (NHTSA) was required to initiate several rulemaking actions. One of the rulemaking actions is intended to improve the safety of child restraint systems. As part of that rulemaking, the agency initiated an effort to consider modifying the current Federal Motor Vehicle Safety Standard 213 (FMVSS 213) test bench assembly to more closely reflect the seating and restraint geometry of the current vehicle fleet. As a result, NHTSA funded Naval Air Systems Command (NAVAIR)-Pax River to develop a test procedure for measuring and collecting vehicle interior geometry data and analyzing the resulting data. NAVAIR was also funded to conduct dynamic tests using a modified FMVSS 213 test bench assembly.

This report documents the findings of the vehicle interior geometry survey and details the results of dynamic tests that were performed on the modified FMVSS 213 test bench.

List of Figures

List of Tables

Acknowledgements

The author would like to acknowledge the following people for their contributions to this document:

Mr. Jules Lewyckyj, Competency Manager, Naval Air Systems Command, Crew Systems, Code 4.6.2.2, Naval Air Station, Patuxent River, Maryland.

Technical Summary

A crash test simulation program was conducted using the Horizontal Accelerator located at the test facility in Patuxent River, MD. The purpose of the crash test program was to determine if proposed changes to the current FMVSS 213 test bench would affect the child restraint performance. Crash dummies (used as human surrogates) representing the anthropometric measurements of children ranging in size and age from newborns to 6 year olds were used to collect responses to simulated crash impacts. The test series was conducted using Hybrid II, Hybrid III, and CRABI dummies.

In order to generate the data necessary to calculate the neck injury criterion, Nij, the forces and moments generated at the upper neck of the CRABI and HIII 6-year olds were measured. These measurements are not taken during current standard 213 testing. However, the agency was interested in evaluating the Nij response of these dummies to the modifications that were implemented on the test bench used to conduct this test series.

The following FMVSS 213 test bench parameters were modified before conducting the dynamic test series reported in this document:

- Seat back reclination angle increased from 15° to 22°.
- Seat bottom inclination angle increased from 8° to 15°.
- Lap belt anchor spacing was increased for both the center and outboard seating positions.
- The lap belt anchor spacing in the center position was increased from 222mm to 392mm. The spacing in the outboard position was decreased from 500mm to 472mm.
- The bench seat back was made rigid by replacing the current aluminum rod with a steel rod.
- Anchor points necessary for conducting LATCH testing were added to the bench.

A total of 48 dynamic tests were conducted using this modified bench. Dummy responses during these tests are noted in this report. The test series did not produce any discernable change in calculated injury criteria, head excursions, knee excursions, or child seat back rotations. Details of the dummy responses are presented later in the text.

This report documents the changes that were incorporated into the FMVSS 213 test bench assembly as a result of the findings of the vehicle interior geometry survey. The report also discusses the results of dynamic tests that were conducted with the modified FMVSS 213 test bench assembly.

1.0 Vehicle Interior Geometry Survey

1.1 Evaluation of Interior Parameters

The physical characteristics of the test bench used in FMVSS 213 to evaluate the performance of child restraints were based on the front seat of a 1974 Chevrolet Impala. "Moreover, NHTSA no longer recommends that children be allowed to ride in the front passenger seat." (Reference 1). In fact, the agency explicitly recommends that children 12 years and under ride exclusively in the rear seat.

Therefore, as part of this FMVSS 213 evaluation process, NHTSA contracted Veridian Engineering (Veridian in Buffalo, NY) to conduct a comprehensive survey of seating and restraint geometry characteristics for 2001 model year (MY) vehicles. Veridian conducted a survey of 41 vehicle interiors. A complete list of these vehicles is shown in Table 1. Before changes to the FMVSS 213 test bench were considered, this data was used to provide a concise description of the salient features of the current vehicle fleet interiors. The following parameters associated with the ***rear seat*** were measured, evaluated, and are reported on in this document:

- Seat Back Cushion Angle
- Seat Bottom Cushion Angle
- Seat Bottom Cushion Length
- Lap Belt Anchor Spacing
- Tether Anchor Location
- Shoulder Belt Anchor Location
- Clearance between rear and front seats
- Seat Cushion Stiffness

Table 1. List of Vehicles Surveyed for Vehicle Interior Geometry.

1	2000 Ford Explorer
2	2000 Ford Windstar
3	2000 Mercury Grand Marquis
4	2000 Toyota Camry
5	2001 Buick Le Sabre
6	2001 Chevrolet Impala
7	2001 Chevrolet Suburban - Rows 2 & 3
8	2001 Chevrolet Tracker
9	2001 Chevrolet Venture - Rows 2 & 3
10	2001 Chevy Malibu
11	2001 Chrysler Sebring Convertible
12	2001 Daewoo Leganza
13	2001 Dodge Durango - Rows 2 & 3
14	2001 Dodge Grand Caravan - Rows 2 & 3
15	2001 Dodge Stratus
16	2001 Ford Escape-interior measurements
17	2001 Ford Expedition - Rows 2 & 3
18	2001 Ford Mustang
19	2001 Honda Accord
20	2001 Jeep Grand Cherokee
21	2001 Lincoln L
22	2001 Mazda Protege
23	2001 Mercury Sable
24	2001 Mitsubishi Montero Sport
25	2001 Nissan Frontier
26	2001 Nissan Sentra
27	2001 Pontiac Aztek
28	2001 Pontiac Grand Am 2 Door
29	2001 Toyota 4Runner
30	2001 Toyota Avalon
31	2001 Toyota Celica
32	2001 Toyota Rav4
33	2001 Chrysler Voyager - Rows 2 & 3
34	2001 Chrysler Sebring
35	2001 Chrysler LHS
36	2001 Chevrolet Monte Carlo
37	2001 Honda Civic
38	2001 Chevrolet Tahoe
39	2001 Honda Accord
40	2001 Ford F150 Super Crew
41	2001 Lexus IS300

2.0 Summary of Vehicle Interior Geometry Survey Results

The interior geometry of 41 2001 NCAP vehicles were measured as part of the survey. The sample population was comprised of 23 cars, 12 Sports Utility Vehicles (SUVs), 2 Trucks, and 4 minivans.

Each seating position where a child safety seat could be placed was measured. However, in cases where outboard seating positions yielded identical measurements, only one datum was included in the analysis. Using this methodology, up to 90 datum were collected and analyzed for some of the parameters measured in this survey. A brief summary of the results of each vehicle interior parameter studied as part of this survey is described below. A more comprehensive description of how these data were collected and analyzed is given in NHTSA Docket # NHTSA-2002-11707-9. Please refer to that document if further details are needed.

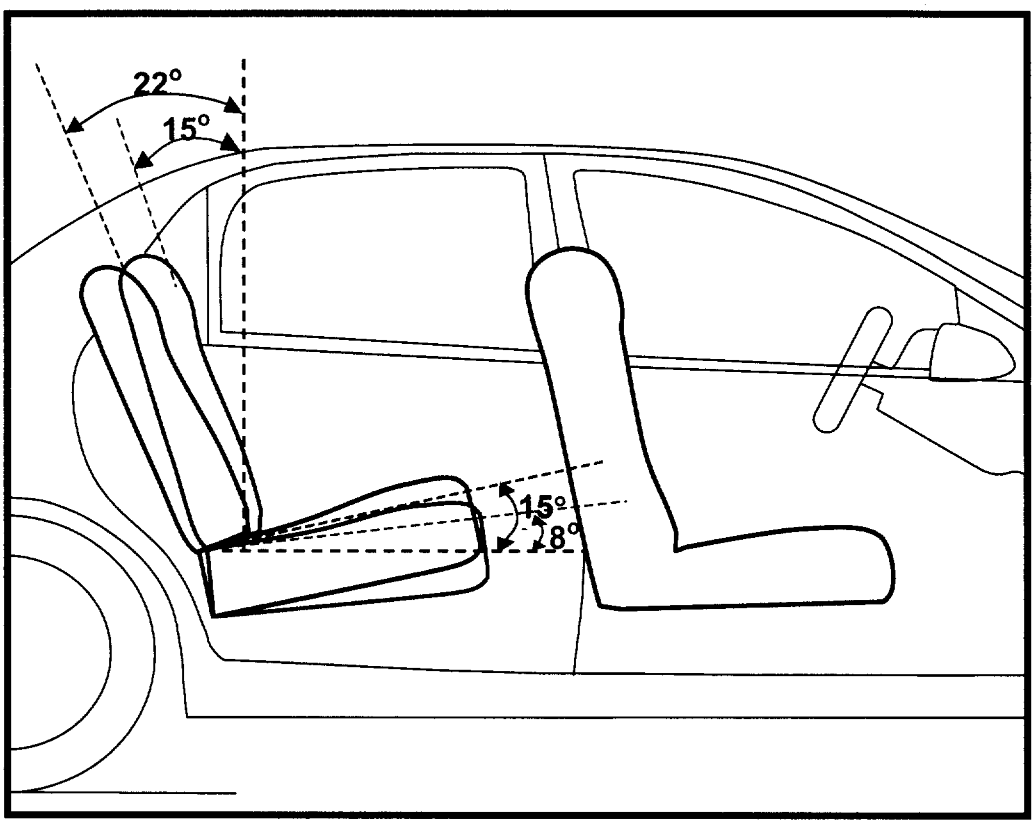
2.1 Seat Back Cushion Angle.

The data reported represent the composite average of all the seating position reclination angles. Some vehicles are configured such that there is potential to place a child safety seat in either of two aft rows of 'rear seats'. This multiple-row situation existed only for minivans and SUVs. Every rear seat location where it was possible to place a child seat was measured except in cases where two locations were identical. A total number of the 90 measurements were taken from the center and outboard seating positions. The average seat back recline angle was 22° with a standard deviation of 5° (Figure 1). The current 213 test bench has a seat back reclination angle of 15°, 7° more vertical than the average seating position in which a child seat could be placed.

2.2 Seat Bottom Cushion Angle.

The same procedure outlined in the previous section was used in surveying vehicles in order to quantify the seat bottom cushion angle. Some SUVs and minivans were configured with multiple rows of seats capable of securing a child restraint. For these vehicles, at least two data points were collected. However in some vehicles, there were 5 seating positions where seat bottom angles were measured. Therefore, the total number of seat bottom angle measurements recorded was much greater than the number of vehicles surveyed. Ninety (90) measurements were collected from center and outboard seating positions. Because the center seating position is not always available and sometimes not compatible with are child seat, the seat bottom angle data is reported as an average of ***all the seating positions measured***. The average seat bottom angle was 15° from horizontal with a standard deviation of 5° (Figure 1). With a seat bottom angle of 8°, the current 213 test bench is more horizontal than the average seating position in which a child seat may be placed.

Figure 1. Seat Back and Seat Bottom Reclination Angles.



— FMVSS-213 CURRENT TEST BENCH

— VEHICLE SURVEY RESULTS (AVERAGE)

2.3 Seat Bottom Cushion Length.

The procedure used in gathering data on the seat back and seat bottom angle measurements was also followed in measuring the seat bottom lengths. For multi-row vehicles such as minivans and SUVs, each seating position where a child seat could be placed was measured and recorded. Hence, the total number of seat bottom lengths recorded was much greater than the number of vehicles (41) surveyed. A total of 89 seat pan length measurements were taken. The seat bottom length data are an average of ***all the seat lengths measured.*** The average seat bottom length was 461mm with a standard deviation of 46mm. With a seat bottom length of 508mm, the current 213 test bench is 47mm greater in length than the average seating position in which a child seat may be placed.

2.4 Shoulder Belt Anchor Location.

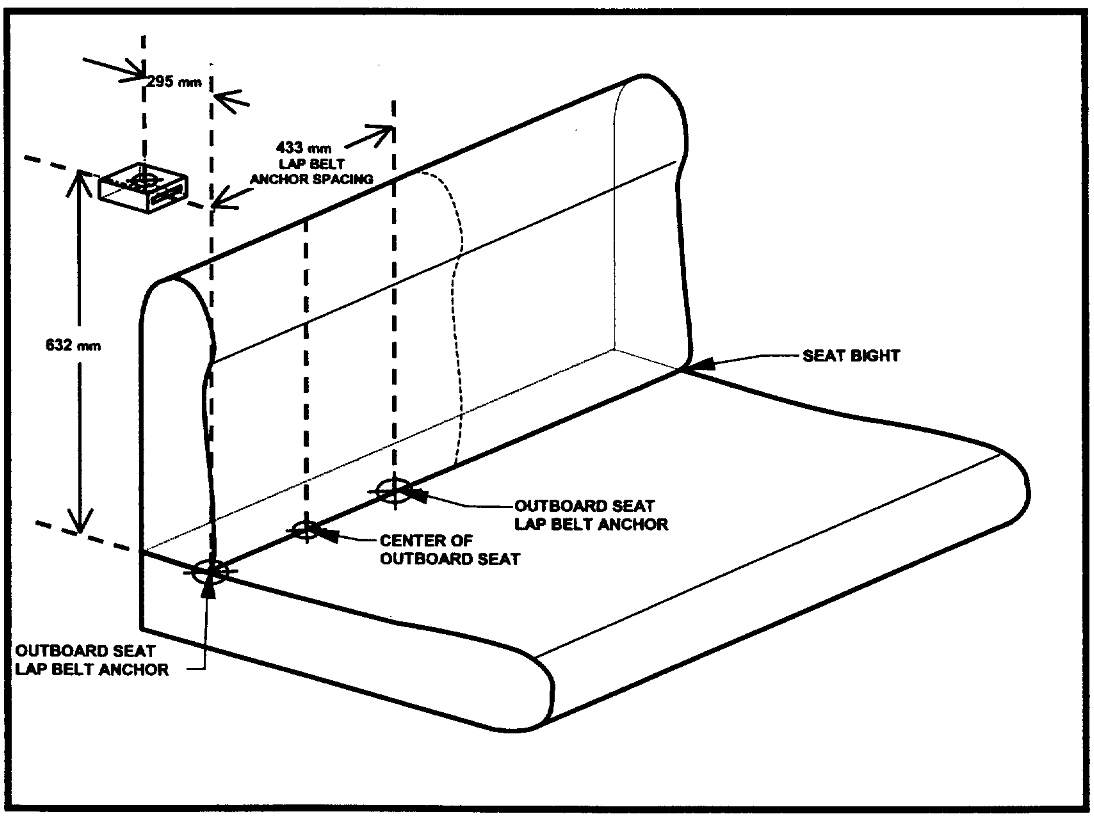
A total of 69 seating position measurements were gathered on shoulder belt anchor locations. Because the shoulder belt location is a point in space, it takes three coordinates to define its location. Accordingly, the data reported in this section are given with respect to the centerline of the seat bight of the seating position being measured. The x-coordinate is defined as the distance forward/aft from the seat bight to the shoulder belt anchor location. The y-coordinate is defined as the lateral distance from the centerline of the seating position, at the seat bight, to the shoulder belt anchor location. The z-coordinate is defined as the vertical distance from the seat bight to the shoulder belt anchor location. The sign convention is: rearward of the bight is considered positive, right of the bight is considered positive, and up from the bight is considered positive.

On average, the shoulder belt anchor was located 295mm rearward (x-coordinate) of the centerline of the seat bight, 247mm to the side (y-coordinate), and 632mm above (z-coordinate) the seat bight (Figure 2). According to Laboratory Test Procedure #TP-213-04 dated September 1, 1997, the FMVSS 213 test bench shoulder belt anchors are located 299mm aft, 261mm to the side, and 688mm above the seat bight centerline. Only the vertical location is significantly different from the average anchor location for the current model-year vehicles (632mm measured vs. 688mm for 213 bench).

2.5 Lap Belt Anchor Spacing.

A total of 90 lap belt anchor spacing measurements were gathered. The average lap belt anchor spacing at all positions was 433 mm with a standard deviation of 100 mm (Figure 2). The average lap belt anchor spacing at center seating positions only was 392mm with a standard deviation of 123 mm. The current FMVSS 213 test bench requires a spacing of 222 mm for the center lap belt anchors. FMVSS 213 requires that the lap belt anchors for the outboard positions, the position used to test belt positioning booster seats, be spaced 500mm apart. Current test procedures also require that all seats other than belt positioning boosters be tested in the center position of the FMVSS 213 test bench.

Figure 2. Shoulder and Lap Belt Anchor Spacing.



2.6 Tether Anchor Location.

A total of 67 measurements were gathered on tether anchor location. The same protocol and sign conventions were followed for this parameter as for the shoulder belt anchor locations.

On average, the tether anchor was located 386mm rearward (x-coordinate) of the centerline of the seat bight, 51 mm laterally off center (y-coordinate), and 409mm above (z-coordinate) the seat bight. The longitudinal location (x-coordinate) of the tether anchor locations ranged from 19mm forward of the seat bight to 763mm rearward of the seat bight. The lateral location (y-coordinate) of the tether anchor locations ranged from 0mm to 279mm off center of the seat bight. The vertical location (z-coordinate) of the tether anchor locations ranged from 133mm below of the seat bight to 874mm above of the seat bight. The corresponding standard deviations of the x, y and z coordinates were 195mm, 60mm, and 306mm, respectively.

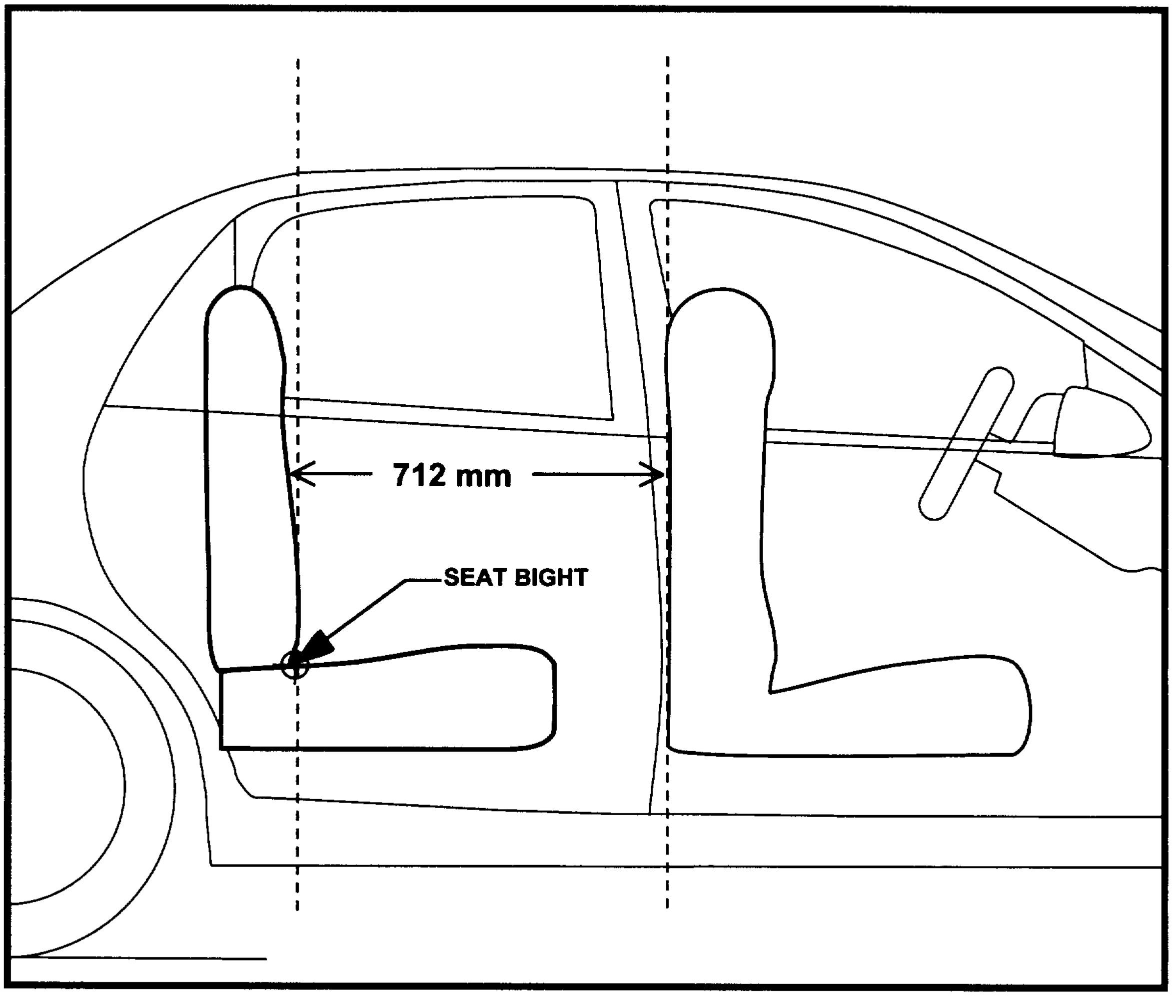
2.7 Seat Back Clearance.

Although seat clearance is not a primary measurement on which the actual test bench geometry will be predicated, it is a very important parameter in determining the overall crash envelope available for the child seat occupant. During a frontal impact, even well-restrained occupants are subject to having their inertial loading displace them forward within the occupant compartment of the vehicle. This is the primary reason for the head and knee excursion limits imposed by the current version of FMVSS 213. In light of these facts, this study attempted to gather data to define the average head clearance as it exists in current model vehicles. The data presented here are intended as a metric for comparing the current FMVSS 213 excursion requirements to the dimensions likely to be encountered in current vehicles.

For the purposes of this report, seat clearance is defined as horizontal distance from the centerline of the rear seat bight to the nearest point on the back of the seat forward of the subject occupant position. This distance is represented in Figure 3. The data reported in this section are for the forward (driver or front passenger) seats set in the mid fore-aft adjustment position. The seat back of the forward seat is adjusted to the nominal upright position; which is defined as the vehicle geometry measurement procedures as suggested by the manufacturer, or set to approx. $25^{\circ}\pm$. As specified in the protocols outlined in previous sections, vehicles were measured at each seating position where an obstruction to head trajectory was presented. However, many center-seating positions in cars had no such obstruction and were not measured. The total number of seat clearance measurements used to determine the average seat clearance with the forward seat in the mid position was 48.

The average seat clearance was 712mm with a standard deviation of 87mm (Figure 3). The 213 excursion limits are based on the horizontal distance from the Z-point of the test bench. The Z-point is approximately 114mm aft of the seat bight of the 213 test bench. Clearance data is based on the horizontal distance from the seat bight of the vehicles measured. Therefore, in order to compare the data collected in this report to the excursion limits of the current 213, the excursion limits will have to be reduced by 114mm. The excursion limits from the seat bight, as opposed to the Z-point of the 213 bench are 597mm for tethered seats and 699m for untethered seats. Thus, all clearance data in this report has been based on the clearance from the seat bight of the vehicles rear seat to the back of the seat in front of it.

Figure 3. Seat Clearance Measurement.



2.8 Seat Cushion Stiffness.

Measurements from 37 2001 model-year vehicles were taken as a part of this survey. The vehicles measured included 24 cars, 9 SUVs, and 4 trucks. The vehicles are listed in Table 2. A 6-inch diameter disk was used to compress the seat cushions at a rate of 0.5 inches per minute. Both seat bottom and seat back cushion stiffness were measured for the outboard and center seat positions. For the seat bottom, data were collected in the center of the seat and at the front edge of the seat.

The cushion stiffness data indicate that the force-deflection properties of the current FMVSS 213 cushion are relatively close to those of the vehicles for about the first 500 Newtons or about 80mm of compression. However, beyond this point, most of the vehicle cushions become much stiffer than the current FMVSS 213 cushion. Figure 4 illustrates the divergence between the FMVSS 213 cushion stiffness and that of 2001 model-year vehicles.

Figure 4. Seat Cushion Force Deflection

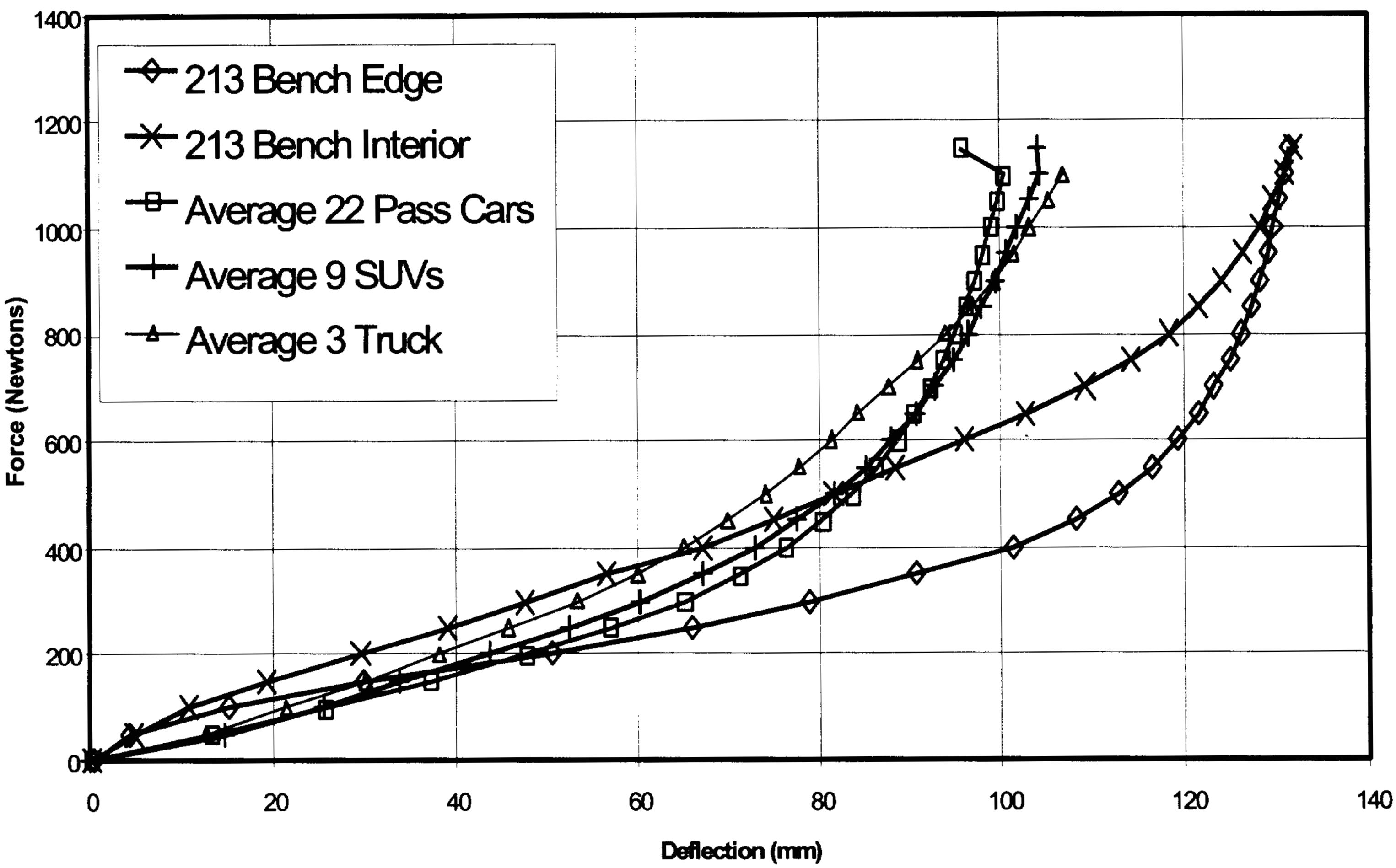


Table 2. List of Vehicles Surveyed for Seat Cushion Stiffness Assessment.

	Vehicle
1	Buick LeSabre
2	Buick Park Ave
3	Chevrolet Impala
4	Chevrolet Malibu
5	Chevrolet Monte Carlo
6	Chevrolet Suburban
7	Chevrolet Tracker
8	Oldsmobile Aurora
9	Pontiac Aztek
10	Pontiac Grand Am
11	Ford Escape
12	Ford Expedition
13	Ford F-150 Ext Cab
14	Ford Mustang
15	Linclon LS
16	Chrysler LHS
17	Dodge Durango
18	Dodge Stratus
19	Chrysler Sebring
20	Hyundai Elantra
21	Toyota Avalon
22	Toyota Celica
23	Toyota RAV4
24	Toyota Tacoma
25	Toyota Tundra
26	Nissan Sentra
27	Acura 3.2TL
28	Mazda Miata
29	Mitsubishi Montero
30	Volvo S60
31	Mazda Protege
32	Honda Accord Sedan
33	Ford Crown Victoria
34	Toyota 4Runner
35	Lexus IS300
36	Nissan Frontier
37	Honda Accord Coupe

3.0 Crash Simulation Testing

3.1 Test Purpose Section

A great deal of research has been conducted in the field of biodynamics, and general guidelines and approximated end points have been determined for impacts involving rapid longitudinal decelerations.

The objective of subjecting child restraints to crash impact simulations was to provide engineers at NHTSA with a cache of performance data that could then be compared to known human tolerance levels for certain regions of the body. Among the metrics used to predict the potential for injury were: resultant head accelerations, resultant chest accelerations, neck loads and moments, head excursion, and knee excursion. Based on this data, injury indexes such as Head Injury Criteria (HIC), and Neck Injury Criteria (Nij) were calculated. The injury levels measured in tests using the proposed seat assembly geometry were then compared to the injury levels measured in compliance tests of identical child restraints using the existing test seat geometry.

The dynamic test series documented in this report was designed to apply crash forces indicated by FMVSS 213. The primary focus of the testing conducted here was to measure the seating system's performance, i.e., its ability to limit the occupant's exposure to accelerations and forces that exceed known human tolerance limits. Because the predominance of motor vehicle accidents involve frontal impacts, the crash tests, specified by FMVSS No. 213 is designed to reproduce the inertial loading that a forward- or rear-facing occupant would experience under high rates of longitudinal deceleration.

The proceeding sections describe in greater detail the test methods, procedures, and evaluation techniques that were used to analyze if any of the modifications to the FMVSS 213 test bench would affect the outcome of injury criteria. For this reason, many of the tests conducted in this test series had been previously conducted using the current, unmodified test bench.

3.2 Test Devices

3.2.1 Test Bench Assembly Description

The test device used to evaluate the dynamic performance of the add-on child restraints is the standard seat assembly securely attached to a dynamic test platform or impact sled. The standard seat assembly is described in drawing package SAS-100-1000. The test device consists of a simulated vehicle bench seat with three seating positions. Child seats tested in the center seating position can be anchored using a lap belt only or a combination of a lap belt and tether strap. Child seats tested in the outboard positions utilize a three-point belt restraint.

As part of the test procedure protocol for conducting dynamic tests, the bench assembly is mounted on a platform such that the Seat Orientation Reference Line (SORL) of the seat is parallel to the direction of the test platform travel and movement between the base of the assembly and the platform is prevented.

For this test series, add-on child restraints were installed in each of the three seating positions (one center and two outboard) as called for by the type of restraint anchor configuration. However, additional restraint anchor configurations were added to this modified test bench. Table 3 lists all restraint anchor configurations utilized in the test series. Each seating system was installed according to the instructions provided by the manufacturer and in accordance with the procedures outlined in the FMVSS 213 compliance test procedure.

The test bench used to conduct the dynamic tests series was fabricated to be identical to the standard test bench except in the following regards:

- Seat back reclination angle increased from 15° to 22°.
- Seat bottom inclination angle increased from 8° to 15°.
- Lap belt anchor spacing was increased for both the center and outboard seating positions.

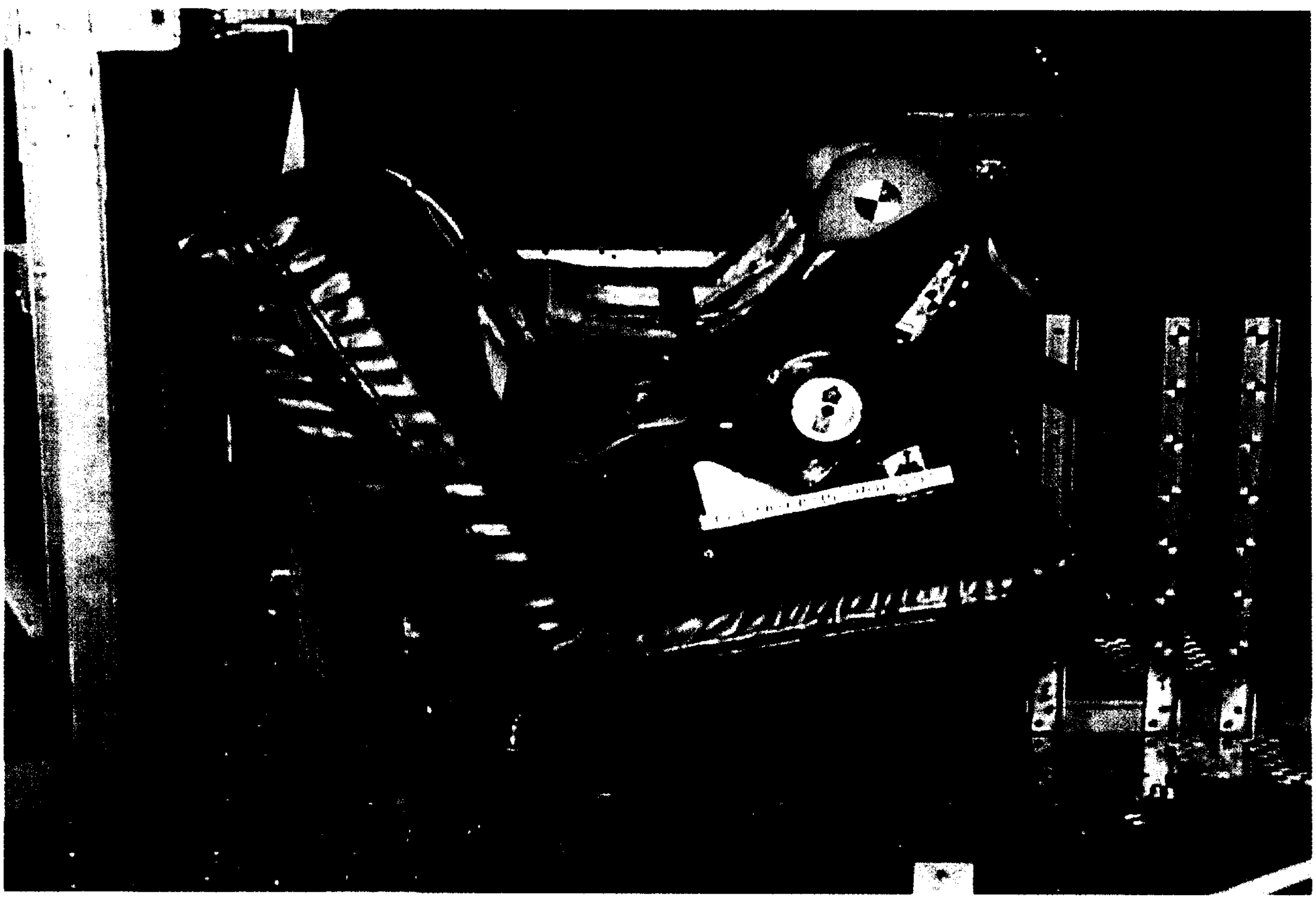
- The lap belt anchor spacing in the center position was increased from 222mm to 392mm. The spacing in the outboard position was decreased from 500mm to 472mm.

- The bench seat back was made rigid by replacing the current aluminum rod with a steel rod.

- Anchor points necessary for conducting LATCH testing were added to the bench.

Figure 6 pictures the modified test bench assembly setup for conducting rear-facing CRS tests.

Figure 5. Dynamic Testing with Modified Test Assembly.



3.2.2 Child Seat Selection

NHTSA determined which child seats and child dummies were to be used during dynamic testing. The following child restraints, child dummies, and anchor configurations were used during this test series.

- Child dummies:
  - ➔ TNO 9 month
  - ➔ CRABI 12 month
  - ➔ Hybrid II 3 year old
  - ➔ Hybrid II 6 year old
  - ➔ Hybrid III 3 year old
  - ➔ Hybrid III 6 year old

- The types of child seats used in dynamic testing were:
  - ➔ Rear-facing infant only
  - ➔ Rear-facing convertible
  - ➔ No-back, belt positioning booster
  - ➔ High back, belt positioning booster
  - ➔ Forward-facing hybrid

- Injury data collected/calculated were:
  - ➔ Knee and head excursion
  - ➔ Seat back rotation
  - ➔ Neck Injury Criterion (Nij)
  - ➔ Chest Acceleration
  - ➔ Head Injury Criterion (HIC)

Table 3. Matrix of dynamic tests conducted.

Test No.	Sled Run No.	Child Restraint Orientation	Vehicle Restraint Type	Dummy	CRS Type
1	02217	Rear-Facing	Lap Belt Only Lap Belt Only	12 month CRABI TNO 9 month	Infant Only Infant Only
2	02218	Rear-Facing	Lap Belt Only Lap Belt Only	12 month CRABI TNO 9 month	Infant Only Infant Only
3	02223	Rear-Facing	Lap / Shoulder Belt Lap Belt Only	12 month CRABI TNO 9 month	Rear-Facing Only Rear-Facing Convertible
4	0224	Rear-Facing	Lap / Shoulder Belt Lap Belt Only	12 month CRABI TNO 9 month	Rear-Facing Convertible Rear-Facing Convertible
5	02225	Rear-Facing Forward-Facing	Lap Belt Only Lap Belt Only	12 month CRABI TNO 9 month	Rear-Facing Convertible Fwd-Facing Convertible
6	02226	Rear-Facing Forward-Facing	Lap Belt Only Lap Belt Only	12 month CRABI TNO 9 month	Rear-Facing Convertible Fwd-Facing Convertible
7	02257	Forward-Facing	Lap / Shoulder Belt LATCH + Tether	Hybrid II 6yr. Old 12 month CRABI	No–Back Belt Pos. Booster Fwd-Facing Convertible
8	02258	Forward-Facing Forward-Facing	Lap / Shoulder Belt Lap Belt Only	Hybrid II 6yr. Old 12 month CRABI	H–Back Belt Pos. Booster Fwd-Facing Convertible)
9	02259	Forward-Facing Forward-Facing	Lap / Shoulder Belt Lap / Shoulder Belt	12 month CRABI Hybrid II 6yr. Old	Fwd-Facing Convertible No–Back Belt Pos. Booster
10	02260	Rear-Facing Forward-Facing	LATCH Lap Belt Only	Newborn 12 month CRABI	Rear-Facing Convertible Fwd-Facing Convertible
11	02262 02264	Rear-Facing Forward-Facing	Lap / Shoulder Belt Lap / Shoulder Belt	12 month CRABI Hybrid III 3yr. Old	Rear-Facing Convertible Fwd-Facing Convertible
12	02270 02263	Fwd-Facing Forward-Facing	LATCH LATCH + Tether	12 month CRABI Hybrid III 3yr. Old	Rear-Facing Convertible Fwd-Facing Convertible
13	02276 02271	Forward-Facing	Lap / Shoulder Belt LATCH + Tether	Hybrid III 6yr. Old 12 month CRABI	No–Back Belt Pos. Booster Fwd-Facing Convertible
14	02273 02277	Rear-Facing Forward-Facing	Lap / Shoulder Belt Lap / Shoulder Belt	12 month CRABI Hybrid III 6yr. Old	Rear-Facing Only H-Back Belt Pos. Booster
15	02274 02278	Forward-Facing Forward-Facing	Lap / Shoulder Belt Lap / Shoulder Belt	12 month CRABI Hybrid III 6yr. Old	Fwd-Facing Convertible No–Back Belt Pos. Booster
16	02275 02279	Forward-Facing	Lap / Shoulder Belt Lap / Shoulder Belt	Hybrid II 6yr. Old Hybrid III 6yr. Old	H–Back Belt Pos. Booster H–Back Belt Pos. Booster
17	02251 02251	Forward-Facing	Lap Belt Only Lap Belt Only	Hybrid II 3yr. Old Hybrid III 3yr. Old	Fwd-Facing Convertible Fwd-Facing Convertible
18	02247 02247	Forward-Facing	Lap Belt Only Lap Belt Only	Hybrid II 3yr. Old Hybrid III 3yr. Old	Fwd-Facing Convertible Fwd-Facing Convertible
19	02248 02248	Forward-Facing	Lap Belt Only Lap Belt Only	Hybrid II 3yr. Old Hybrid III 3yr. Old	Fwd-Facing Hybrid Fwd-Facing Hybrid
20	02250 02250	Forward-Facing	Lap Belt Only Lap Belt Only	Hybrid II 3yr. Old Hybrid III 3yr. Old	Fwd-Facing Hybrid Fwd-Facing Hybrid
21	02275 02265	Rear-Facing Forward-Facing	Lap Belt Only Lap / Shoulder Belt	Hybrid II Newborn Hybrid III 3yr. Old	Infant Only Fwd-Facing Hybrid
22	02266 02266	Rear-Facing Forward-Facing	Lap Belt Only Lap / Shoulder Belt	Hybrid II Newborn Hybrid III 3yr. Old	Infant Only Fwd-Facing Hybrid
23	02269 02269	Rear-Facing Forward-Facing	Lap Belt Only LATCH+Tether	Hybrid II Newborn Hybrid III 3yr. Old	Rear-Facing Convertible Fwd-Facing Convertible
24	02267 02267	Rear-Facing Forward-Facing	Lap Belt Only Lap / Shoulder Belt	Hybrid II Newborn Hybrid III 3yr. Old	Rear-Facing Convertible Fwd-Facing Convertible

3.2.3 Transducers used in the dummies

The following transducers were used in the conduct of this test series:

1) Two accelerometers for monitoring test fixture acceleration.

2) Two tri-axial accelerometer packages were mounted in the head and the thorax of the 12 month old CRABI, 3 year old Hybrid II & III, and 6 year old Hybrid II & III (the TNO 9-month-old dummy is not instrumented). Each axis of the accelerometers met the following minimum performance requirements:

Mounting frequency response:	± 5%, 0 to 2000 Hz
Maximum damping:	0.005 of critical, nominal
Transverse Sensitivity:	5% maximum
Linearity and hysteresis:	± 3% of reading, maximum
Dynamic range:	± 500 g, minimum

3) Seat belt webbing load cells were used to monitor belt pre-load during installation.

4) Integration of the sled accelerometer outputs was used to determine the dynamic impact test velocity.

5) Force transducers mounted in the upper neck of the CRABI, and Hybrid III 6 year old to measure axial forces generated during testing.

6) Force transducers mounted in the upper neck of the CRABI, and Hybrid III 6 year old to measure bending moments generated during testing.

3.2.4 High Speed Cameras

In order to record the performance of the child restraint system during the test event, four onboard high-speed video cameras were placed perpendicular to the test bench SORL. These cameras were focused on the head and legs of the child test dummy. These cameras were used to record the head and knee excursions of the test dummies during the application of crash loads. The cameras collected images at a rate of 1000 frames per second. The data were later analyzed to determine the head and knee excursion of forward-facing tests. For child restraints that were tested in a rear-facing configuration, the cameras were used to capture seat back rotation data. These data were analyzed to determine the maximum seat back rotation.

3.3 Test Conditions

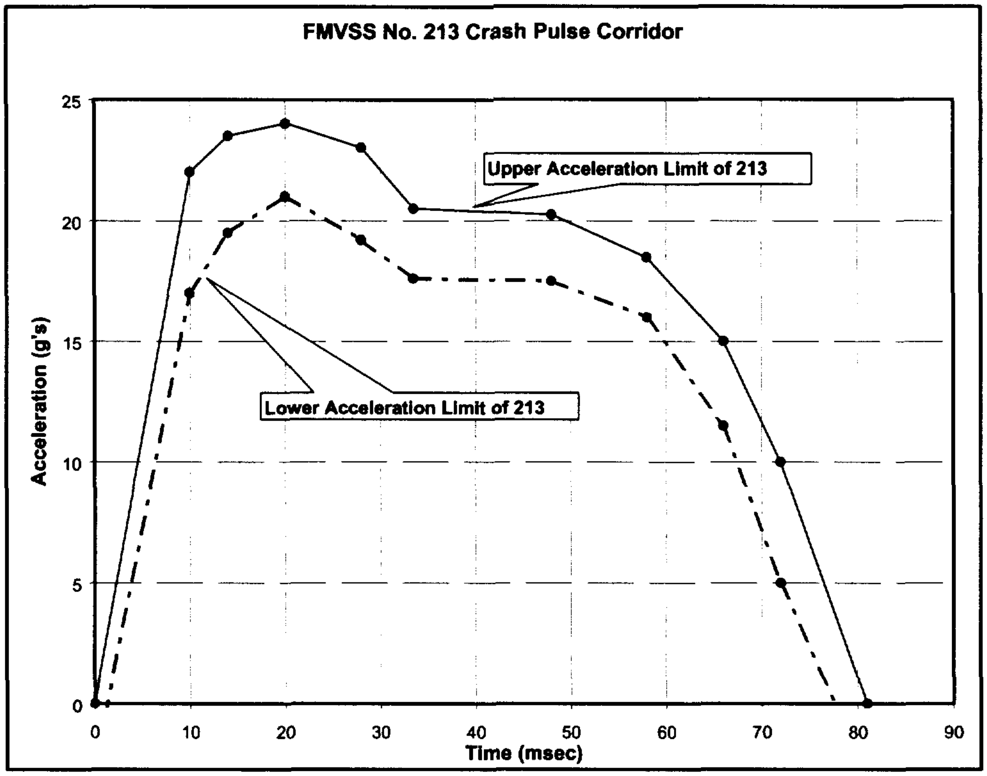
3.3.1 Simulated Crash Impact Conditions

The crash test pulse implemented for this dynamic test series was calibrated to adhere to the configuration I, crash pulse defined in FMVSS No. 213. The standard calls for an impact speed of 30mph, +0, -2 mph. The crash test facility is required to generate a pulse that lies within the corridor defined in Table 4 and Figure 6 below. The impact acceleration may not exceed the upper limit of the corridor at any time.

Table 4. Configuration I Acceleration Function Envelope.

Time (msec)	Upper Limit Accel. (G's)	Lower Limit Accel (G's)
0	0.0	-2.5
10	22.0	17.0
14	23.5	19.5
20	24.0	21.0
28	23.0	19.2
33.5	20.5	17.6
48	20.25	17.5
58	18.5	16.0
66	15.0	11.5
72	10.0	5.0
81	0.0	-3.0

Figure 6. Configuration I Acceleration Function Curve.



3.3.2 Test Facility Description

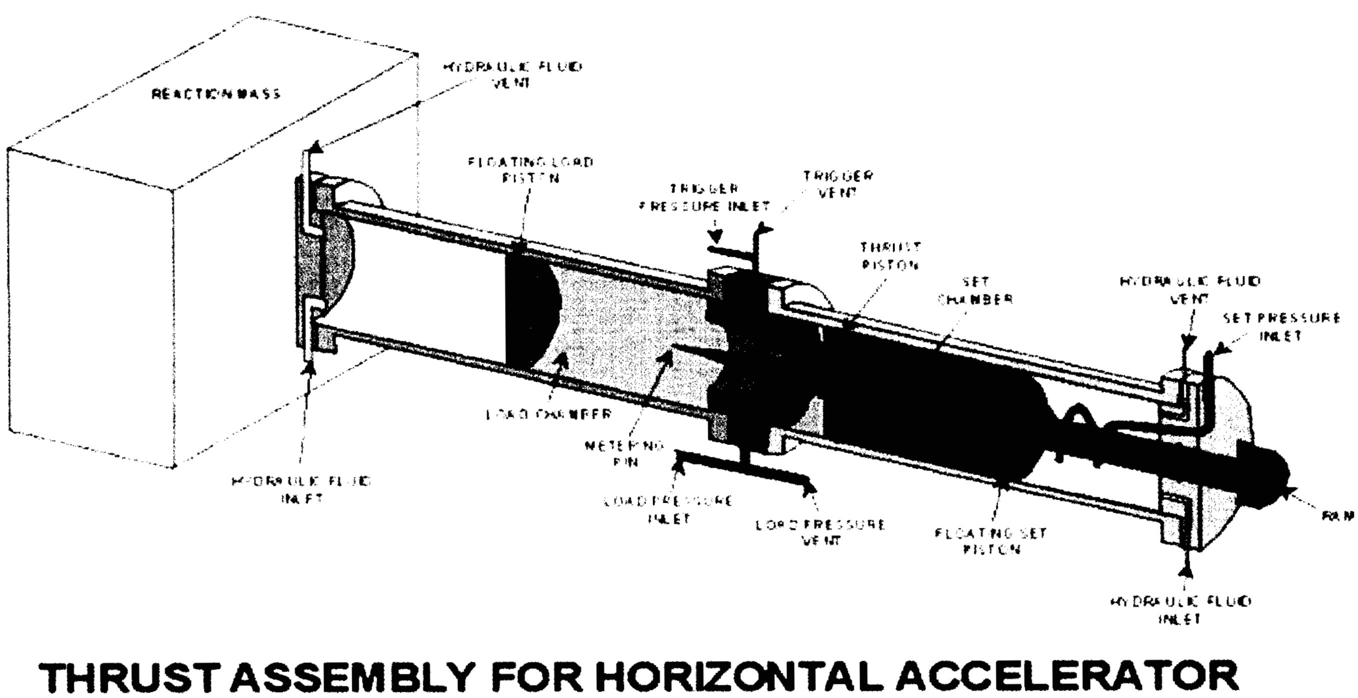
The dynamic test series was performed by Crew Systems Department, Crashworthy Escape Systems Branch (NAVAIR Code 4.6.2.2) using a horizontal accelerator.

The Horizontal Accelerator consists of three main assemblies:

1. Accelerating mechanism
2. Test Sled
3. Guide rails

The accelerating mechanism is a 12-inch HYGE actuator which consists of a stainless steel cylinder divided into two 12 ft. long chambers. The energy required to produce the impact acceleration is generated within the actuator cylinder by means of differential gas pressures acting upon a thrust piston. The rear chamber contains compressed air used as the firing pressure. The front chamber is filled with hydraulic fluid, used to apply thrust to the ram. Upon actuation, air is introduced into the front chamber, forcing the thrust assembly forward. A metering pin located between the two chambers, controls the acceleration-time profile applied to the sled. A maximum force of 225,000 lbs. of gross thrust can be generated. This force is reacted by a reinforced concrete block weighing 75 tons. The result is a smooth transition of energy from the cylinder to the test sled. The standard pulse shape is a "half-sine" waveform. Figure 8 provides a cut-away view of the horizontal accelerator thrust assembly.

Figure 7. Horizontal Accelerator Pneumatically Actuated Thrust Assembly Mechanism.



3.4 Pre and Post Impact Test Procedures

In accordance with NHTSA Laboratory Test Procedure TP-213-04 (Reference 2), the following pre-test checks were conducted for each test:

3.4.1 Pre-Test Checks

1) The restraint system and dummy are properly installed on the standard seat, and all belts are adjusted and tensioned as required.
2) Restraint and dummy targeting required to measure performance are properly installed.
3) All required calibrations of instrumentation, transducers, and high speed movie/video camera field are completed and recorded.
4) All parameters relating to the required impact severity and velocity have been correctly set.
5) The environmental requirements are met.

3.4.2 Post-Test Checks

NHTSA Laboratory Test Procedure TP-213-04 (Reference 2), requires that the following post-test steps be followed:

1) Immediately after the dynamic impact test, photograph the restraint and dummy in their final posttest positions and configurations on the standard seat or vehicle.
2) Plot the sled/vehicle acceleration-time history showing its relationship to the acceleration-function envelope.
3) Record the actual sled/vehicle velocity change for the test and the cumulative velocity change associated with acceleration deviations below the acceleration-function envelope.

4.0 Results

The dynamic tests conducted as part of this program were designed to assess the differences , if any, that the changes to the seat assembly had on CRS performance. A total of 48 dynamic tests were conducted using a FMVSS 213 test bench assembly with minor modifications to the seat back and seat bottom reclination angles, restraint anchor spacing, and seat back flexibility. The specifics of these modifications are discussed in previous sections of this report. Among the injury tolerance parameters that were used to evaluate CRS performance were: head acceleration, chest acceleration, head excursion, knee excursion, and seat back rotation.

Based on the performance metrics listed above, each CRS demonstrated the capacity to maintain to predictive injury indexes at levels that were below tolerance thresholds. Table 4 provides a complete record of the injury index parameters that were evaluated for each test. Additional information such as post-test damage assessment of major structural seat components, adjuster slippage, and buckle release actuation were noted and provided to NHTSA outside of this report.

4.1 Test Summary

- All crash tests were conducted in compliance with the FMVSS 213 Configuration I acceleration function curve. Figure 7 (¶ 2.3.1) graphically illustrates the bounds of this corridor.
- All CRS complied with current FMVSS No. 213 pass/fail regarding injury criteria.
- This test series did not include any tests with the current FMVSS 213 test bench assembly.
- Both Hybrid II and Hybrid III dummies were used to conduct this test series.
- There was no discernable difference in injury tolerance measurements between the two dummy types.
- NHTSA will use the data generated here to conduct a comparative analysis of injury criteria from tests conducted on the standard bench assembly and the modified test bench assembly.
- A total of 48 dynamic tests were conducted with:
    - ♦ Child dummies sized to represent children ranging in age from 9 months to 6 years old.
    - ♦ All restraint configurations possible in motor vehicles were used.

- Criteria included head and knee excursions, head and chest accelerations, and seat back rotation angles. Though they were not used in the determination of success or failure, loads applied to a load cell located at the upper neck of the CRABI and Hybrid III 6 year old were also measured.

- The following limitations were imposed for a Child Restraint Systems (CRS) to be considered successful at limiting the potential for occupant injury:

  - **Head Acceleration** – Resultant head acceleration calculated from a tri-axial accelerometer located at the center of gravity of the dummy was used to compute Head Injury Criterion (HIC). HIC was calculated using an unwindowed time period as currently specified in the standard, and using a 15 ms window as proposed in a Notice of Proposed Rulemaking (NPRM) published by NHSTA on May 1, 2002 in response to the TREAD Act. The HIC (unwindowed) threshold is 1000 for the Hybrid II dummies, and 390, 570, and 700 for the CRABI and Hybrid III 3- and 6-year-old dummies, respectively.

  - **Chest Acceleration** – Resultant chest acceleration was not allowed to exceed 60 g's for more than 3 milliseconds.
  - **Head Excursions**
    - **Untethered CRS** – Excursion was limited to 32 inches (813 mm) for forward-facing CRS not using an upper tether anchor to aid in the restraint.
    - **Tethered CRS** – Excursion was limited to 28 inches (720 mm) for forward-facing CRS using an upper tether anchor to aid in the restraint.

  - **Knee Excursion** – Excursion was limited to 36 inches (915 mm) for all forward-facing CRS regardless of the vehicle restraint configuration utilized.

  - **Neck Injury Criterion** – Axial forces (±Fz) applied along the longitudinal axes of the upper neck were measured. Bending moments (± My) that were applied at the upper neck were collected. These data were used to calculate the Nij Index.

Currently, Nij is not an injury criterion evaluated as part of the CRS compliance with FMVSS No. 213. These data will be used by NHTSA engineers to make a determination as to the feasibility of using the Neck Injury Criterion (Nij) as part of the pass/fail criteria for FMVSS 213 compliance testing.

Table 5. Matrix of Injury Tolerance Results

Test No.	Sled Run No.	Head Excur-sion	Knee Excur-sion	Seat Back Rotation	Nij Index	Peak Chest Accel	Head Injury Criteria (Unlimited Window)	Head Injury Criteria (15 msec Window)	Child Restraint Orientation	Vehicle Restraint Type	Dummy	CRS Type
1	02217	———	———	56.1	1.46 Ten-Ext	35.8	424.0	165.4	Rear-Facing	Lap Belt Only	12 month CRABI	Infant Only
				53.9	N/A	N/A	N/A	N/A		Lap Belt Only	TNO 9 month	Infant Only
2	02218	———	———		0.56 Ten-Ext	39.6	234.0	138.1	Rear-Facing	Lap Belt Only	12 month CRABI	Infant Only
				52.9	N/A	N/A	N/A	N/A		Lap Belt Only	TNO 9 month	Infant Only
3	02223	———	———	52.3	1.20 Ten-Ext	37.65	265.4	94.7	Rear-Facing	Lap / Shoulder Belt	12 month CRABI	Rear-Facing Only
				50.6	N/A	N/A	N/A	N/A		Lap Belt Only	TNO 9 month	Rear-Facing Convertible
4	0224	———	———	59.7	1.17 Ten-Ext	37.7	265.4	97.4	Rear-Facing	Lap / Shoulder Belt	12 month CRABI	Rear-Facing Convertible
				63.0	N/A	N/A	N/A	N/A		Lap Belt Only	TNO 9 month	Rear-Facing Convertible
5	02225			45.0	0.92 Ten-Ext	33.6	264.1	100.4	Rear-Facing	Lap Belt Only	12 month CRABI	Rear-Facing Convertible
		17.1	21.5	----	N/A	N/A	N/A	N/A	Forward-Facing	Lap Belt Only	TNO 9 month	Fwd-Facing Convertible
6	02226			66.0	1.56 Ten-Ext	36.6	365.6	174.9	Rear-Facing	Lap Belt Only	12 month CRABI	Rear-Facing Convertible
		15.6	19.1		N/A	N/A	N/A	N/A	Forward-Facing	Lap Belt Only	TNO 9 month	Fwd-Facing Convertible
7	02257	14.3	24.0	———	N/A	49.2	267.1	267.1	Forward-Facing	Lap / Shoulder Belt	Hybrid II 6yr. Old	No–Back Belt Pos. Booster
		9.9	13.1		1.16 Ten-Flex	44.9	333.9	163.0		LATCH + Tether	12 month CRABI	Fwd-Facing Convertible
8	02258	19.7	19.7	———	N/A	35.1	209.4	209.4	Forward-Facing	Lap / Shoulder Belt	Hybrid II 6yr. Old	H–Back Belt Pos. Booster
		18.5	20.0		1.04 Ten- Flex	36.5	289.6	207.7	Forward-Facing	Lap Belt Only	12 month CRABI	Fwd-Facing Convertible)
9	02259	16.5	25.3	———	1.11 Ten- Flex	38.3	314.2	231.7	Forward-Facing	Lap / Shoulder Belt	12 month CRABI	Fwd-Facing Convertible
		18.0	25.7		N/A	38.6	328.2	328.2	Forward-Facing	Lap / Shoulder Belt	Hybrid II 6yr. Old	No–Back Belt Pos. Booster
10	02260			43.1	N/A	N/A	N/A	N/A	Rear-Facing	LATCH	Newborn	Rear-Facing Convertible
		16.7	21.3		0.86 Ten- Flex	35.6	351.3	185.6	Forward-Facing	Lap Belt Only	12 month CRABI	Fwd-Facing Convertible
11	02262			64.0	1.24 Ten- Flex	45.6	494.5	233.6	Rear-Facing	Lap / Shoulder Belt	12 month CRABI	Rear-Facing Convertible
	02264	15.4	19.7			31.4	286.0	148.5	Forward-Facing	Lap / Shoulder Belt	Hybrid III 3yr. Old	Fwd-Facing Convertible
12	02270	19.7	21.6	———	1.47 Ten- Flex	42.8	369.8	327.8	Fwd-Facing	LATCH	12 month CRABI	Rear-Facing Convertible
	02263	17.5	18.8			46.5	294.1	176.1	Forward-Facing	LATCH + Tether	Hybrid III 3yr. Old	Fwd-Facing Convertible
13	02276	11.7	19.6	———	0.82 Ten-Ext	37.8	357.6	139.6	Forward-Facing	Lap / Shoulder Belt	Hybrid III 6yr. Old	No–Back Belt Pos. Booster
	02271	14.6	14.5		0.81 Ten- Flex	46.6	428.3	184.2		LATCH + Tether	12 month CRABI	Fwd-Facing Convertible
14	02273			55.4	1.20 Ten-Ext	44.7	255.6	225.8	Rear-Facing	Lap / Shoulder Belt	12 month CRABI	Rear-Facing Only
	02277	20.0	11.7		0.77 Ten-Ext	41.4	415.7	158.2	Forward-Facing	Lap / Shoulder Belt	Hybrid III 6yr. Old	H-Back Belt Pos. Booster
15	02274	16.7	19.4	———	0.89 Ten-Ext	30.5	317.4	113.3	Forward-Facing	Lap / Shoulder Belt	12 month CRABI	Fwd-Facing Convertible
	02278	19.1	21.0		0.59 Ten-Flex	36.0	276.2	108.0	Forward-Facing	Lap / Shoulder Belt	Hybrid III 6yr. Old	No–Back Belt Pos. Booster
16	02275	17.6	27.6	———	N/A	42.4	380.7	380.7	Forward-Facing	Lap / Shoulder Belt	Hybrid II 6yr. Old	H–Back Belt Pos. Booster
	02279	18.4	24.0		1.59 Ten-Ext	38.3	756.1	343.5		Lap / Shoulder Belt	Hybrid III 6yr. Old	H–Back Belt Pos. Booster
17	02251	19.6	26.4	———	N/A	40.4	702.8	702.8	Forward-Facing	Lap Belt Only	Hybrid II 3yr. Old	Fwd-Facing Convertible
	02251	15.5	26.4			37.6	446.8	216.2		Lap Belt Only	Hybrid III 3yr. Old	Fwd-Facing Convertible
18	02247	19.5	26.8	———	N/A	26.8	626.5	626.5	Forward-Facing	Lap Belt Only	Hybrid II 3yr. Old	Fwd-Facing Convertible
	02247	19.9	25.2			36.1	355.3	182.6		Lap Belt Only	Hybrid III 3yr. Old	Fwd-Facing Convertible

Test No.	Sled Run No.	Head Excur-sion	Knee Excur-sion	Seat Back Rotation	Nij Index	Peak Chest Accel	Head Injury Criteria (Unlimited Window)	Head Injury Criteria (15 msec Window)	Child Restraint Orientation	Vehicle Restraint Type	Dummy	Seat Type
19	02248 02248	22.5 21.3	27.4 29.1	———	N/A	29.2 50.1	669.7 536.8	669.7 299.4	Forward-Facing	Lap Belt Only Lap Belt Only	Hybrid II 3yr. Old Hybrid **III** 3yr. Old	Fwd-Facing Hybrid Fwd-Facing Hybrid
20	02250 02250	22.5 13.4	26.0 22.4	———	N/A	41.6 41.6	446.4 704.9	446.4 213.0	Forward-Facing	Lap Belt Only Lap Belt Only	Hybrid II 3yr. Old Hybrid **III** 3yr. Old	Fwd-Facing Hybrid Fwd-Facing Hybrid
21	02275 02265	 14.7	 19.6	51.5	N/A	N/A 40.4	N/A 691	N/A 474.0	Rear-Facing Forward-Facing	Lap Belt Only Lap / Shoulder Belt	Hybrid II Newborn Hybrid **III** 3yr. Old	Infant Only Fwd-Facing Hybrid
22	02266 02266	 10.2	 19.2	42.5	N/A	N/A 30.7	N/A 479.1	N/A 296.2	Rear-Facing Forward-Facing	Lap Belt Only Lap / Shoulder Belt	Hybrid II Newborn Hybrid **III** 3yr. Old	Infant Only Fwd-Facing Hybrid
23	02269 02269	 15.6	 18.4	50.7	N/A	N/A 40.0	N/A 383.0	N/A 245.7	Rear-Facing Forward-Facing	Lap Belt Only LATCH+Tether	Hybrid II Newborn Hybrid **III** 3yr. Old	Rear-Facing Convertible Fwd-Facing Convertible
24	02267 02267	 18.7	 20.6	40.0	N/A	N/A 36.5	N/A 392.8	N/A 223.4	Rear-Facing Forward-Facing	Lap Belt Only Lap / Shoulder Belt	Hybrid II Newborn Hybrid **III** 3yr. Old	Rear-Facing Convertible Fwd-Facing Convertible

Figure 8. Head Excursions for Forward-Facing Child Restraints

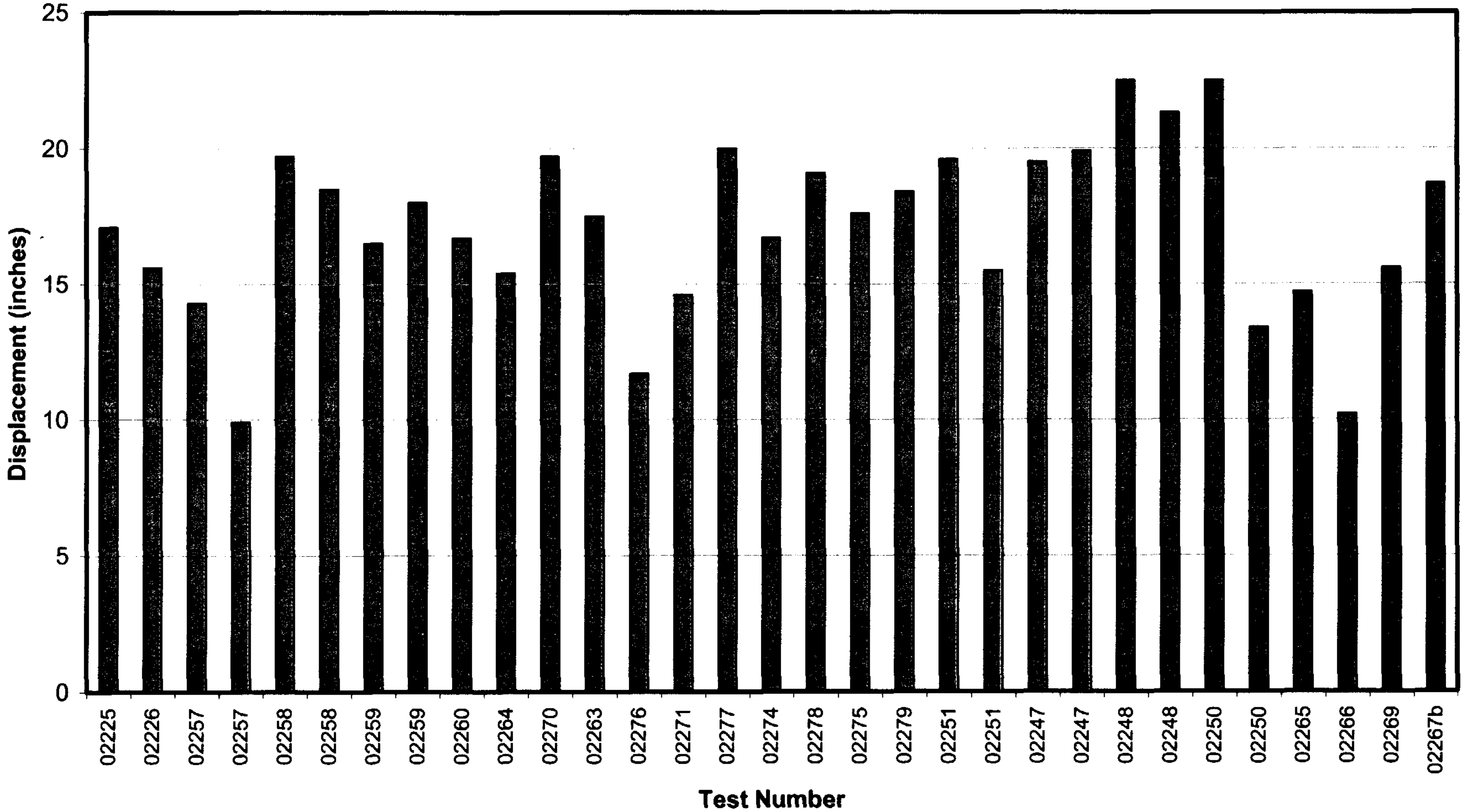


Figure 9. Knee Excursions for Forward-Facing Child Restraints

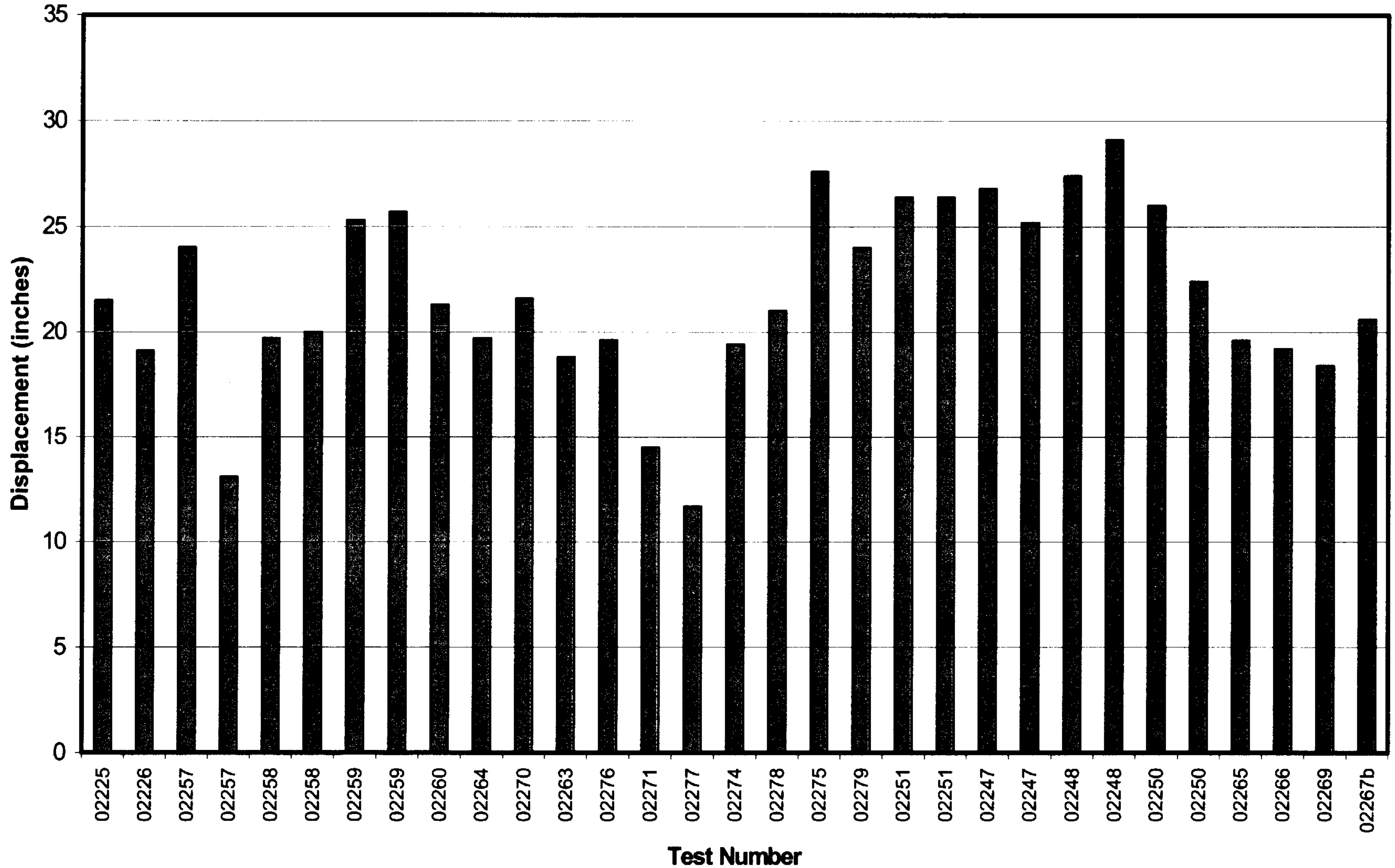


Figure 10. Seat Back Rotation for Rear-Facing Seats

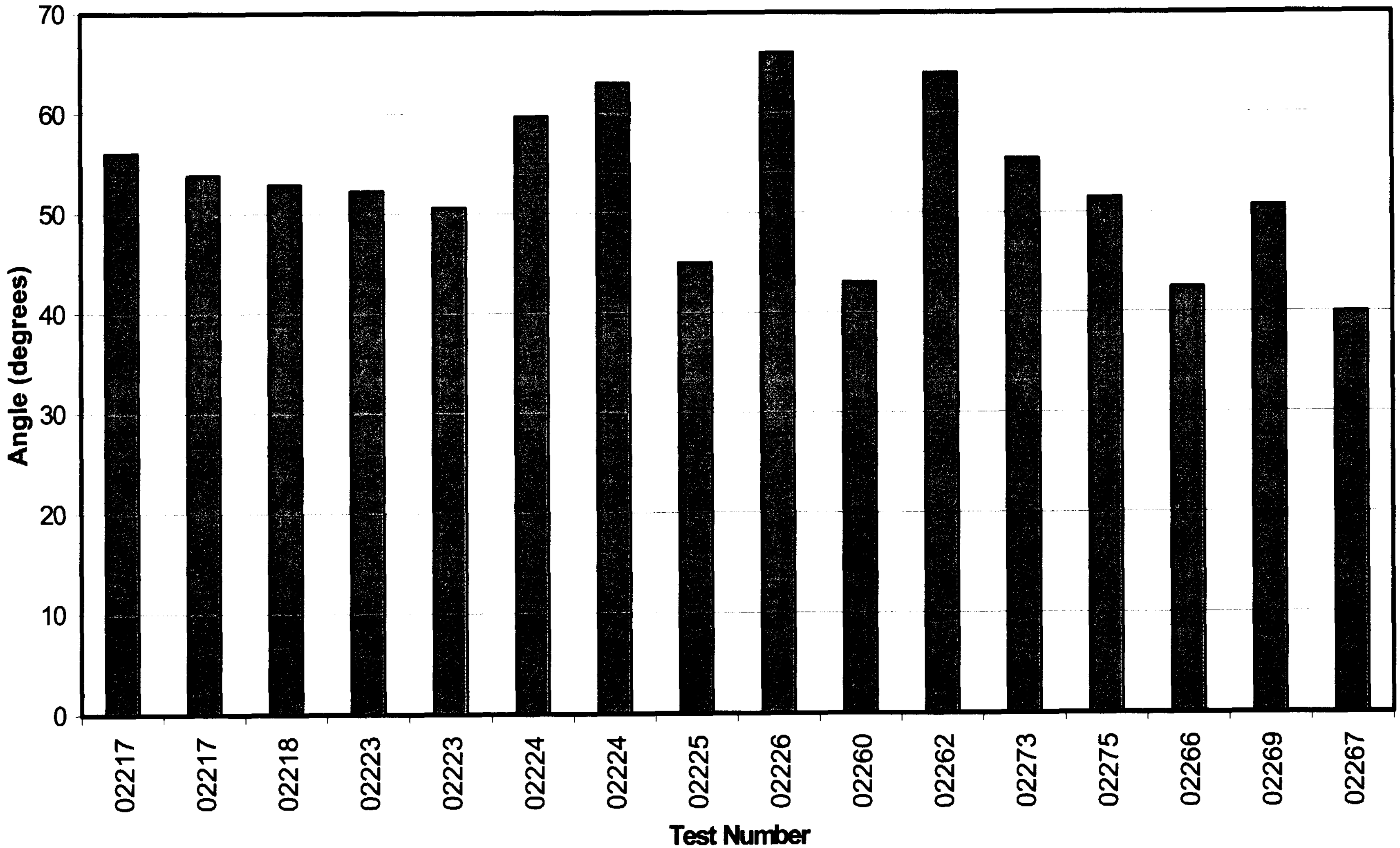


Figure 11. Neck Injury Criterion for Forward-Facing Child Restraints

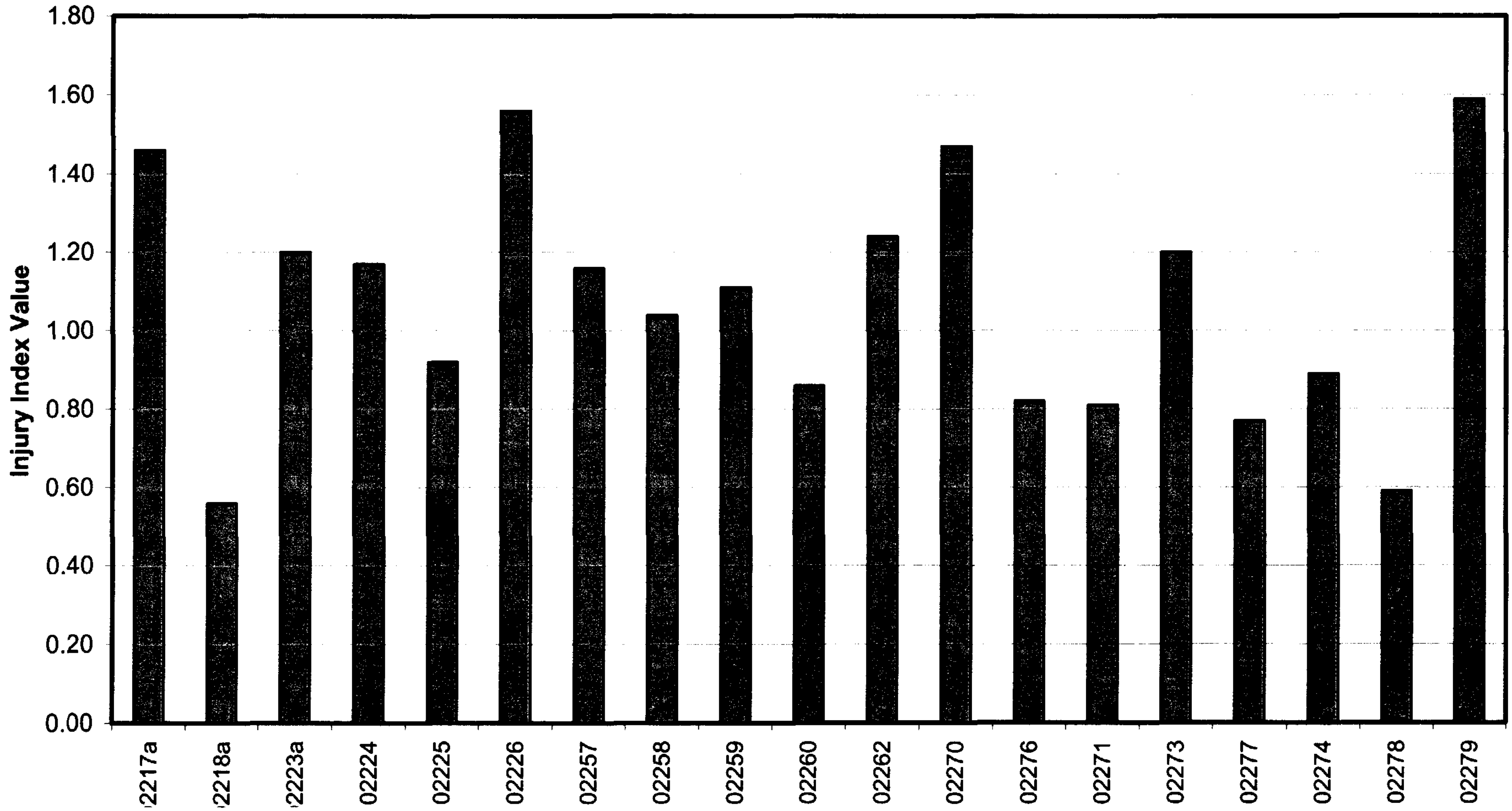


Figure 12. Peak Chest Acceleration for Forward-Facing and Rear-Facing Child Restraints

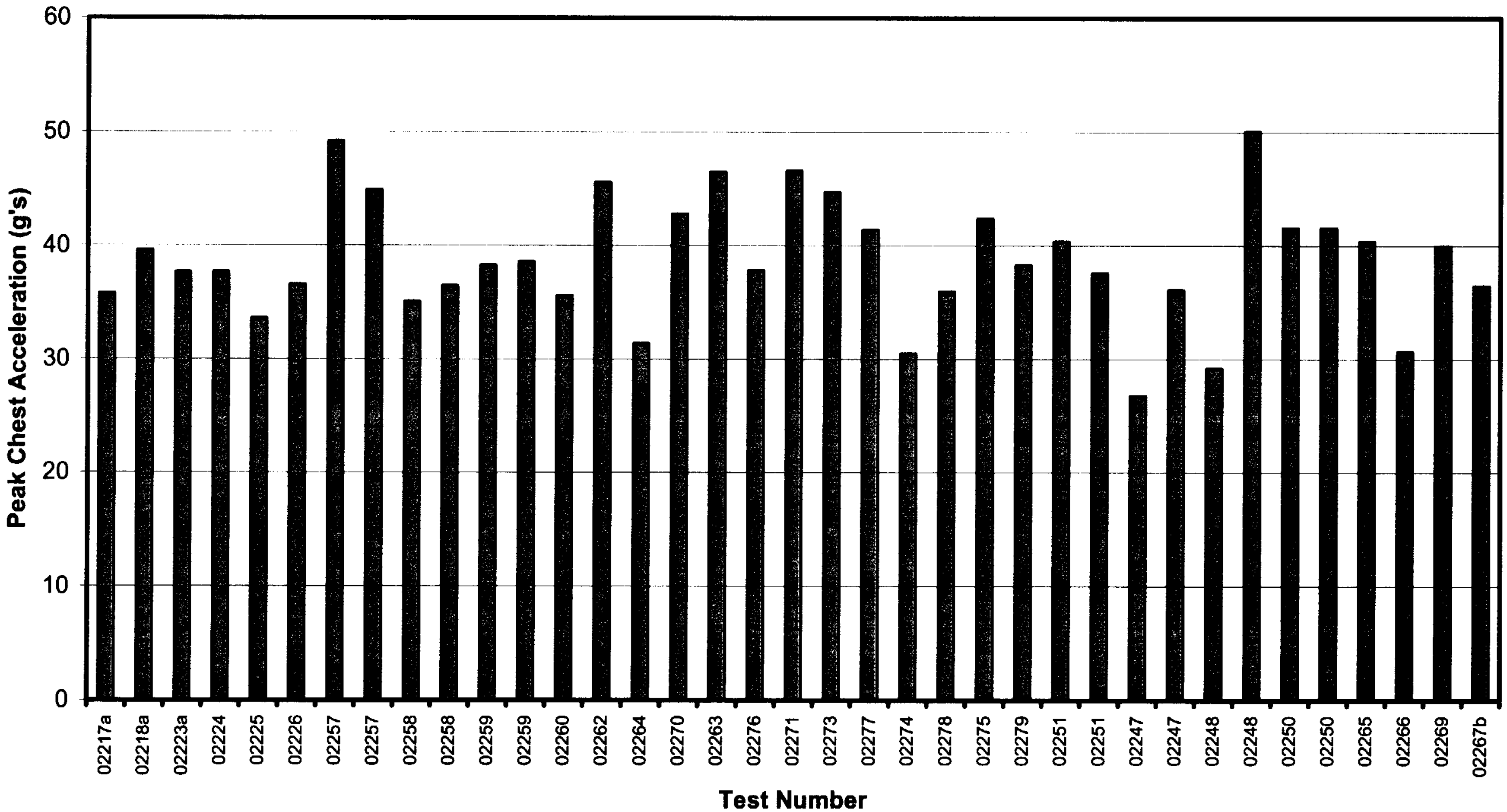


Figure 13. Head Injury Criterion (HIC) for Forward-Facing and Rear-Facing Child Restraints

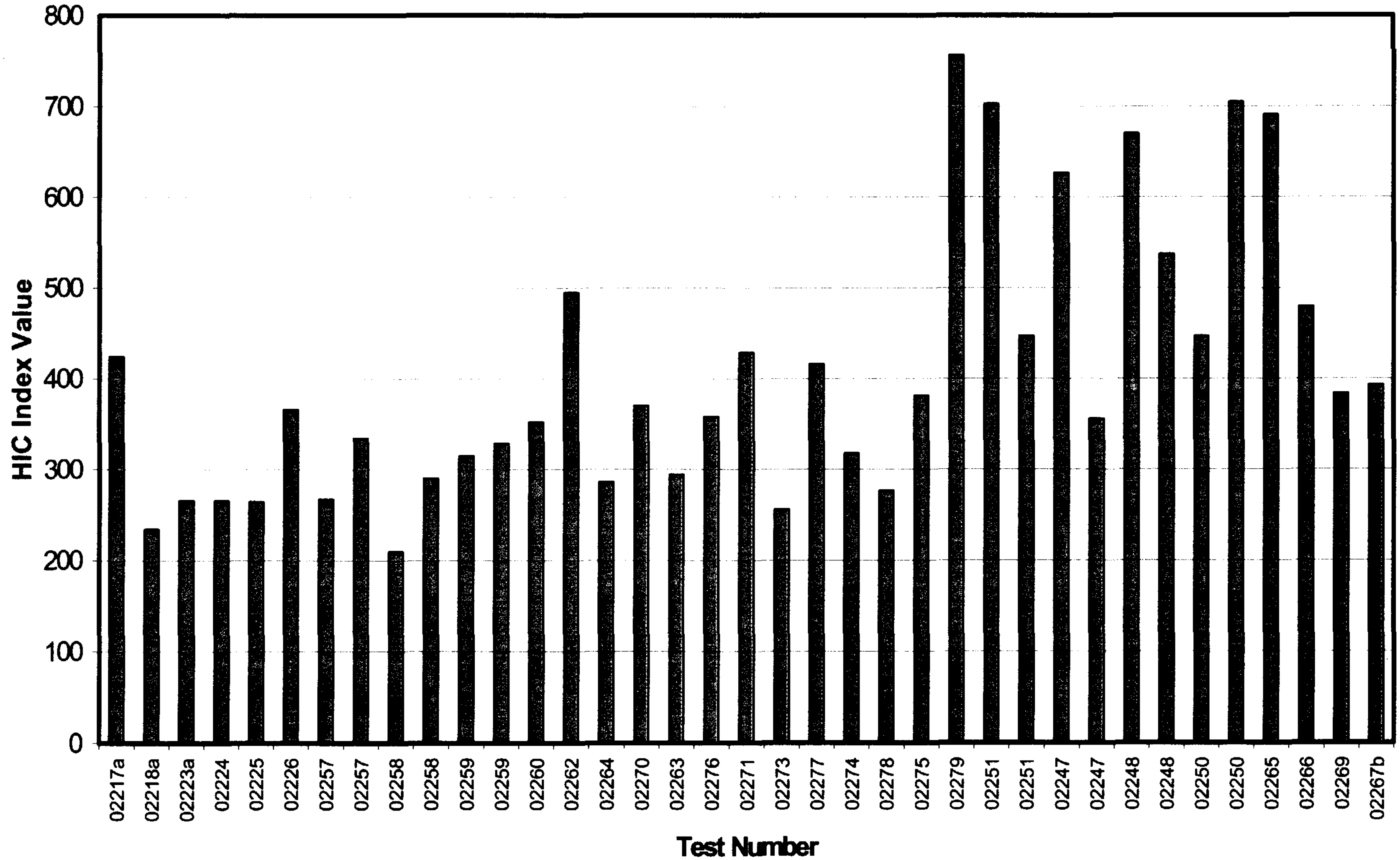


Figure 14. Head Injury Criteria (15msec Clip) for Forward-Facing and Rear-Facing Child Restraints