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**National Highway
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Administration**

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Final Report

Child Seating Test Procedure Development

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16. Abstract

A sled test program was conducted to re-examine the test procedure for evaluating child safety seats relative to FMVSS 213. A sled buck representing the rear seat of a typical late model automobile was developed and several parameters were investigated, primarily to determine whether or not the FMVSS 213 procedures should be updated to better represent today's seating and/or crash environment.

Dummies representing 6 month, 3 year, and 6 year old children were tested in infant, toddler/convertible, and booster child safety seats.

The effects of several vehicle seating, restraint, and crash parameters were measured. Significance of these parameter effects was estimated by comparing response variations from parameter changes with corresponding variation attributable to experimental repeatability.

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Edward C. Hiltner and Thomas F. MacLaughlin	

A sled test program was conducted to re-examine the test procedure for evaluating child safety seats relative to FMVSS 213. A sled buck representing the rear seat of a typical late model automobile was developed and several parameters were investigated, primarily to determine whether or not the FMVSS 213 procedures should be updated to better represent today's seating and/or crash environment.

Dummies representing 6 month, 3 year, and 6 year old children were tested in infant, toddler/convertible, and booster child safety seats.

Repeatability was examined for responses of 3-yr old child dummies in Fisher Price and Ford Tot Guard child seats. Half-range/mean values, averaged over several rear seat test configurations, ranged from 2.5% to 11.7%; the highest were for peak head accelerations and HIC values, and the lowest were for peak chest accelerations.

The significance and magnitude of the effects of several parameters (and parameter combinations) were determined. Parameter levels were selected on the basis of representing the rear seat environment of today's passenger cars more closely than is done in the FMVSS 213 test procedures. Significance was estimated by comparing response variations from parameter changes with corresponding variation attributable to experimental repeatability. General results were as follows:

Parameter	General Effect
Lap Belt Angle	Slight effect over range found in today's rear seats.
Seat Cushion Stiffness	Some effect, but FMVSS 213 cushion is representative of today's rear seats.
Seat Geometry	Some responses increased due to new "generic" geometry, but only HIC in the Tot Guard increased substantially.
Acceleration Pulse	All responses decreased substantially due to the new, softer "average car" pulse.

Velocity Change	Nearly all responses increased substantially due to the 39 mph delta-V (35 mph barrier crash velocity).
Lap Belt Pretension	A few responses increased slightly due to the low belt pretension (simulating typical retractor force).
Seat Geom/Belt Pretension	Some responses increased due to the combination of new generic geometry and low belt tension -- HIC and peak chest g's in the Tot Guard increased substantially.
Pulse/Delta-V	Responses increased slightly due to softer average car pulse at higher delta-V (39 mph).
Overall Configuration	Head and chest responses increased substantially in both child seats due to overall test configuration at new revised levels.

1.0 OBJECTIVE/INTRODUCTION

The objective of this project was to re-examine the dynamic test procedure for evaluating child safety seats relative to Federal Motor Vehicle Safety Standard No. 213. The requirement for this procedure was that it represent the environment a child in a safety seat would be exposed to in the rear seat of a late model automobile in a frontal crash.

The FMVSS 213 sled test procedure was developed prior to 1979 using the characteristics of the front seat of a 1974 Chevrolet Impala and an approximation of a square wave crash acceleration pulse with a 30 mph velocity change. Since that time, many aspects of automobile seating systems, crash responses, and the way child safety seats are used have changed. The National Highway Traffic Safety Administration has recommended placing children in the rear seat because the probability of a restrained occupant surviving a frontal impact is greater there than in the front seat [1]. The geometric and structural differences between the typical front seat of the mid 1970's and the typical rear seat of 1988 including their respective restraint systems could have an effect on child safety seat performance. It was the intent of this project to consider the effects of current rear seat parameters and different crash conditions on child safety seat performance and whether that would affect the 213 standard.

2.0 TEST METHODOLOGY

2.1 Overview

The following steps were required in developing the test methodology:

1 Establish test parameters to be simulated. This included identifying parameters to be varied, and setting appropriate values for both fixed and variable parameters.

2 Select a variety of child safety seats to use in the sled test matrix.

3 Develop a sled buck to be used on the HYGE crash simulator incorporating the desired rear seat parameters, including the capability to vary those parameters to be investigated.

4 Develop and execute a sled test matrix to investigate the effect of the variable rear seat design parameters on child safety seat performance as measured through dummy responses. Included in this matrix are tests similar to the FVMSS 213 procedure for comparison with the new procedure.

2.2 Test Parameter Selection

The test parameters were divided into five categories: seat parameters, restraint parameters, crash dynamics, child seat types, and child age/anthropometry. The following is a list of the parameters in each of these categories:

1 Seat parameters

- a Seat back angle
- b Seat bottom angle
- c Seat cushion length
- d Seat cushion thickness
- e Seat back flexibility
- f Seat cushion stiffness

2 Restraint parameters

- a Seat belt lengths, inboard & outboard
- b Seat belt angles, inboard & outboard
- c Lateral distance between inboard and outboard anchors
- d Static pretest belt tension (pretension)

3 Crash dynamics

a Acceleration pulse

b Velocity change (ΔV)

4 Child Safety Seats

a Infant

b Toddler

c Convertible

d Booster

5 Child age & anthropometry

a 6 month old

b 3 year old

c 6 year old

Figure 2.1 illustrates the seat and restraint geometry parameters.

2.2.1 Seat & Restraint Parameters

A representative sample of late model automobiles was chosen for the purpose of collecting the rear seat data that was needed to design the sled buck. The sample was based on 1986 passenger car sales figures in the U.S. (domestic and foreign automobiles) in each of five weight (curb weight) classes. This method is explained in more detail in Reference 2. However, in the course of surveying the vehicles selected for this study, additional vehicles not in the original sample were included. The reason they were included was interesting rear seat characteristics were observed in these vehicles which were not found in the original sample. For example, some automobiles were chosen because the belt angles were near the extremes allowed by FMVSS 210, Seat Belt Assembly Anchorages.

Table 2.1 shows the list of vehicles which were used for this study. Included in this data table are corresponding measurements from the 213 sled buck

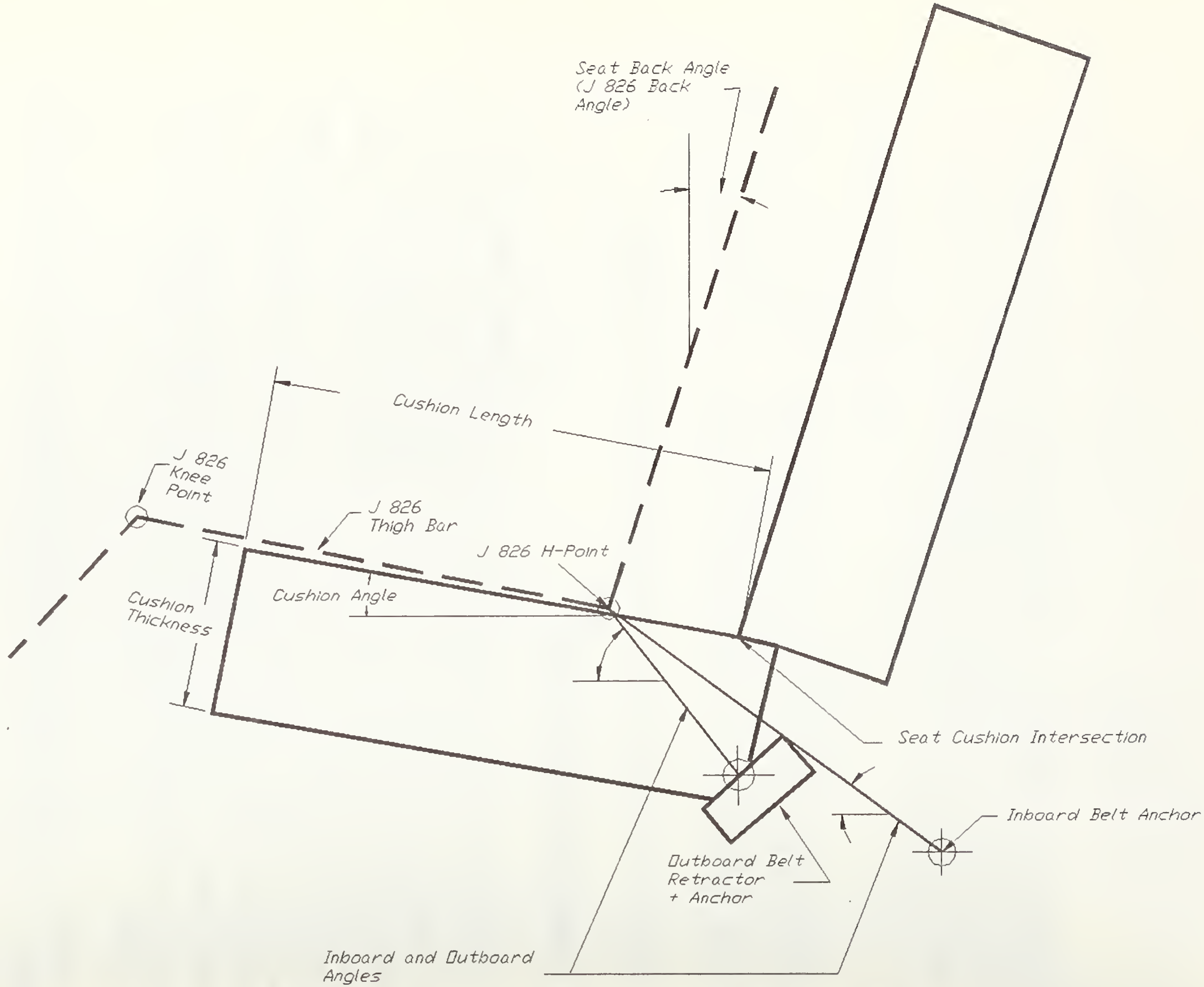


FIGURE 2.1 -- Rear Seat and Restraint Geometry Parameters

TABLE 2.1 -- Vehicle Survey: Rear Seat Parameter Measurements

MAKE OF AUTOMOBILE	INBRD BELT ANGLE	OUTBRD BELT ANGLE	RATIO IN-OUT ANGLES	INBRD BELT LENGTH	OUTBRD BELT LENGTH	ANCHOR WIDTH	SEAT BACK ANGLE	CUSHN LENGTH	CUSHN ANGLE	CENTER CUSHN THICK	FRONT CUSHN THICK	HIP ANGLE
DOMESTIC												
1985 Cutlass Ciera	34.0	67.5	2.0	8.3	4.5	18.5	24.5	17.5	16.7	6.0	4.8	109.0
1988 Olds Delta 88	42.5	49.0	1.2	9.0	6.0	18.0	26.0	15.5	16.8			110.0
1985 Pontiac Sunbird	54.0	50.0	0.9	7.5	6.0	16.5	25.0	18.0	17.0	5.8	4.8	101.0
1985 Pontiac Grand Am	34.0	40.0	1.2	8.5	6.0	16.5	25.0	17.5	16.0	4.5	3.5	99.0
1988 Ford Taurus	26.0	66.0	2.5	10.3	6.5	20.0	28.0	19.8	17.3	6.3	6.0	103.0
1985 Mercury Lynx	28.0	24.0	0.9	8.5	8.3	15.8	26.0	19.3	13.3	4.0	3.3	102.0
1985 Dodge Omni	31.0	73.0	2.4	8.5	5.0	16.3	23.0	16.0	13.6			101.0
1988 Chev Monte Carlo	30.0	29.0	1.0	7.0	6.0	14.0	24.0	16.3	15.4			96.0
1986 Buick Electra	49.0	52.0	1.1	8.0	5.5	17.5	28.0	18.8	17.0	7.5	7.4	101.0
1985 Plymouth Reliant	31.0	75.4	2.4	8.3	5.5	20.5	25.0	15.8	7.2	6.4	5.6	110.0
1987 Ford Tempo GL	25.0	31.5	1.3	8.5	7.3	15.0	27.0	17.5	12.0	5.0	5.0	102.0
1985 Chev Camaro	56.0	71.0	1.3	5.0	1.0	18.5	27.0	17.0	19.0			87.0
1987 Ford Thunderbird	20.0	39.0	2.0	8.0	6.5	15.0	24.0	18.0	19.0	4.8	5.5	97.0
1984 Ford Mustang SVO	21.0	50.0	2.4	8.3	5.0	18.0	24.0	15.5	9.8	6.3	6.0	94.0
DOMESTIC AVERAGE	34.4	51.2	1.6	8.1	5.6	17.1	25.5	17.3	15.0	5.6	5.2	100.9
DOMESTIC STD. DEV.	11.2	16.6	0.6	1.1	1.6	1.8	1.5	1.3	3.3	1.0	1.2	6.1
IMPORT												
1985 Honda Accord	23.5	36.7	1.6	8.5	7.0	15.0	31.0	17.0	15.0	4.0	6.5	96.0
1985 Honda Civic	26.0	48.5	1.9	8.5	6.5	16.5	31.0	15.5	12.0	3.5	6.5	
1987 Nissan Sentra	36.4	68.0	1.9	7.5	6.0	16.0	28.5	15.5	19.5	5.3	5.6	
1987 Hyundai Excel	38.5	47.5	1.2	6.0	6.3	15.0	27.0	17.0	15.0	5.5	7.5	103.5
1987 Toyota Camry	48.5	62.0	1.3	7.5	6.5	15.0	28.5	17.5	19.0	4.0	3.0	104.5
1987 Nissan Maxima	30.0	63.0	2.1	8.0	7.0	16.3	29.0	18.3	9.6			104.5
1983 Volvo GL	25.5	63.0	2.5	7.5	2.0	17.0	22.0	17.5	20.5	5.8	8.3	
IMPORT AVERAGE	32.6	55.5	1.8	7.6	5.9	15.8	28.1	16.9	15.8	4.7	6.2	102.1
IMPORT STD. DEV.	8.3	10.5	0.4	0.8	1.6	0.8	2.8	1.0	3.8	0.9	1.7	3.6
TOTAL AVERAGE	33.8	52.7	1.7	8.0	5.7	16.7	26.4	17.2	15.3	5.3	5.6	101.1
TOTAL STD. DEV.	10.4	15.0	0.6	1.0	1.6	1.7	2.4	1.2	3.5	1.1	1.5	5.7
FMVSS 213 SEAT	49.0	52.0	1.1	19.5	11.3	25.0	18.0	16.0	9.4	6.0	6.0	97.0

seat. As stated earlier, some of the tests were run with seat and restraint parameters set as per FMVSS 213 specifications. Discussion in the following paragraphs is limited primarily to the selection of parameters (both fixed and variable) for the sled buck representing the updated rear seat. There are two important notes regarding the rear seat and restraint parameters: 1) symmetry of the right and left seating positions was assumed and spot checked, and 2) center seat positions were not considered in this study.

The seat cushion bottom lengths were taken from the forward end of each cushion to the approximate intersection of the two cushions. This group of measurements showed little variation in the survey population. This parameter was fixed at a value near the overall vehicle total average of approximately 17 inches.

The seat back angle was measured relative to vertical using the SAE J826 mannequin and its standard placement procedure. This parameter was fairly consistent in the vehicles of this survey and was fixed at the vehicle total average value of approximately 26 degrees.

The seat bottom angle was measured at the center of the occupant's position relative to horizontal using a 1 foot by 1 foot plywood board and a digital inclinometer. The dimensions of the board were intended to approximate the dimensions of the base of a typical child seat. The SAE J826 mannequin was not used to measure the seat bottom cushion angle because the angle of its thigh bar relative to ground (which is what would be measured, see Figure 2.1) can be influenced by more than just the angle of the cushion. The back angle of the mannequin, however, is significantly less sensitive to this factor. The seat bottom angle showed little variation in most of the vehicles measured and was fixed at 15 degrees.

The cushion thickness was measured using a long, thin needle that was pushed through the cushion to the support below. This measurement was taken near the front edge and near the center (front to back) of the occupant's position on the cushion. These measurements showed relatively large percent variations. The test values for this parameter were established in conjunction with the cushion stiffness' parameter.

From the results of Reference 2 it was expected that cushion stiffness might have a significant effect on child seat performance; it was desired, therefore, to vary this parameter. Cushion stiffness data was available in Reference 2. Figures 2.2 and 2.3 show the force/deflection curves (at two locations on each seat) for a variety of seat cushions including the 213 seat. Even though these curves are very nonlinear, it was observed that cushion stiffness correlated with cushion thickness. As one would expect, a thinner cushion is stiffer, in general, than a thick cushion of the same type of foam.

The representative soft and stiff cushions (i.e. thick and thin cushions) chosen in Reference 2 were from the Buick Electra and Toyota Camry respectively. It was decided to use the same seat cushions in this program. The 213 seat cushion was included with them in the matrix; its thickness and stiffness were generally between the extremes represented by the Electra and Camry. The cushion is a simple block of foam approximately 6 inches thick with a vinyl cover.

The seat back flexibility refers to the fact that the majority of rear seat backs are much more rigidly supported than front seat backs. This is of interest because the compliance of the front seat back was simulated in the 213 seat frame. Because none of the selected child seats used tethers, it was decided to fix the seat back as rigid for the entire test program. The child seat would not be influenced by the seat back after the instant of impact unless it was very compliant or the child seat was attached to it by means of a tether.

The seat belt lengths (inboard and outboard) were measured relative to the SAE J826 mannequin's H-point. The measurements were taken from the lap belt anchor (or the last 'hard' structural surface that the belt bore against) to the H-point. This parameter varied in the survey sample; however, physical limitations in the sled buck seat construction made it impractical to vary the belt lengths in the test matrix. Consequently, they were held constant at values greater than the total average inboard and outboard belt lengths: both inboard and outboard belts were approximately 10 inches long.

The seat belt angles were measured in the same manner as the belt lengths using the SAE J826 mannequin H-point as a reference. These measurements were taken in a longitudinal, vertical plane (see Figure 2.1). In this sample of cars, the outboard belt angle was generally greater than the inboard belt angle. There was also a significant amount of variation in these measurements. Also, in Reference 2 belt angle was found to significantly affect adult responses in rear seats. Consequently, they were varied in the test matrix in the following way: for all tests except the belt angle sensitivity tests and the tests following FMVSS 213 specifications, the inboard and outboard belt angles were fixed at the approximate average values of 34 and 53 degrees respectively. In the belt angle sensitivity tests, the inboard and outboard angles were varied independantly by ± one standard deviation (± 1σ) or approximately 11 and 15 degrees respectively. In tests ran according to FMVSS 213, inboard and outboard angles were set at 52°.

The anchor separation is the lateral distance between the lap belt anchors and was fairly consistent in the sample of vehicles. It was fixed at approximately 17 inches centered about the midline of the occupant seating position.

The rear seat lap belt pretension was expected to have some effect on child safety seat performance. The 213 standard requires 12 to 15 pounds of static tension in the belt before testing. This is significantly higher than the approximately 2 to 4 pounds that a typical retractor assembly could provide. Therefore, it was decided to include these 'borderline misuse' conditions in some of the tests by allowing no other pretest static tension in the belt other than what the retractor could provide.

In practice, lap belt tension was probably lower than 15 pounds for the 213-type condition. The output signal for loads of that magnitude was very low relative to the belt webbing load cell's full scale. The best estimate of the actual lap belt tension is roughly 10 to 15 pounds. This condition was used for the majority of the tests.

The above parameters, with the exceptions of cushion thickness and stiffness, belt angles, and belt pretension, were treated collectively as 'seat geometry' and fixed at the average values for those tests with the updated "generic" rear seat (as opposed to the FMVSS 213 seat) in the sled test matrix.

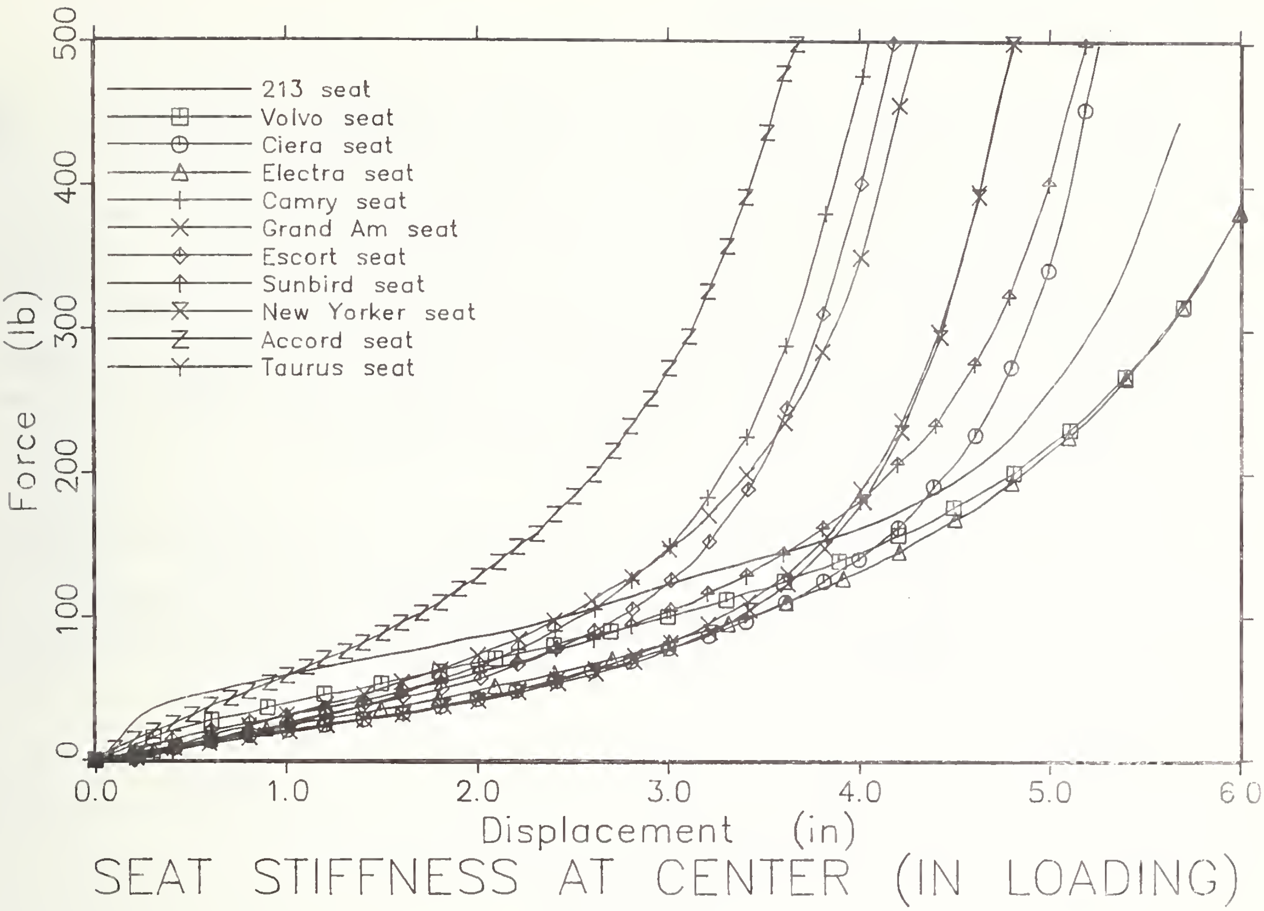


FIGURE 2.2

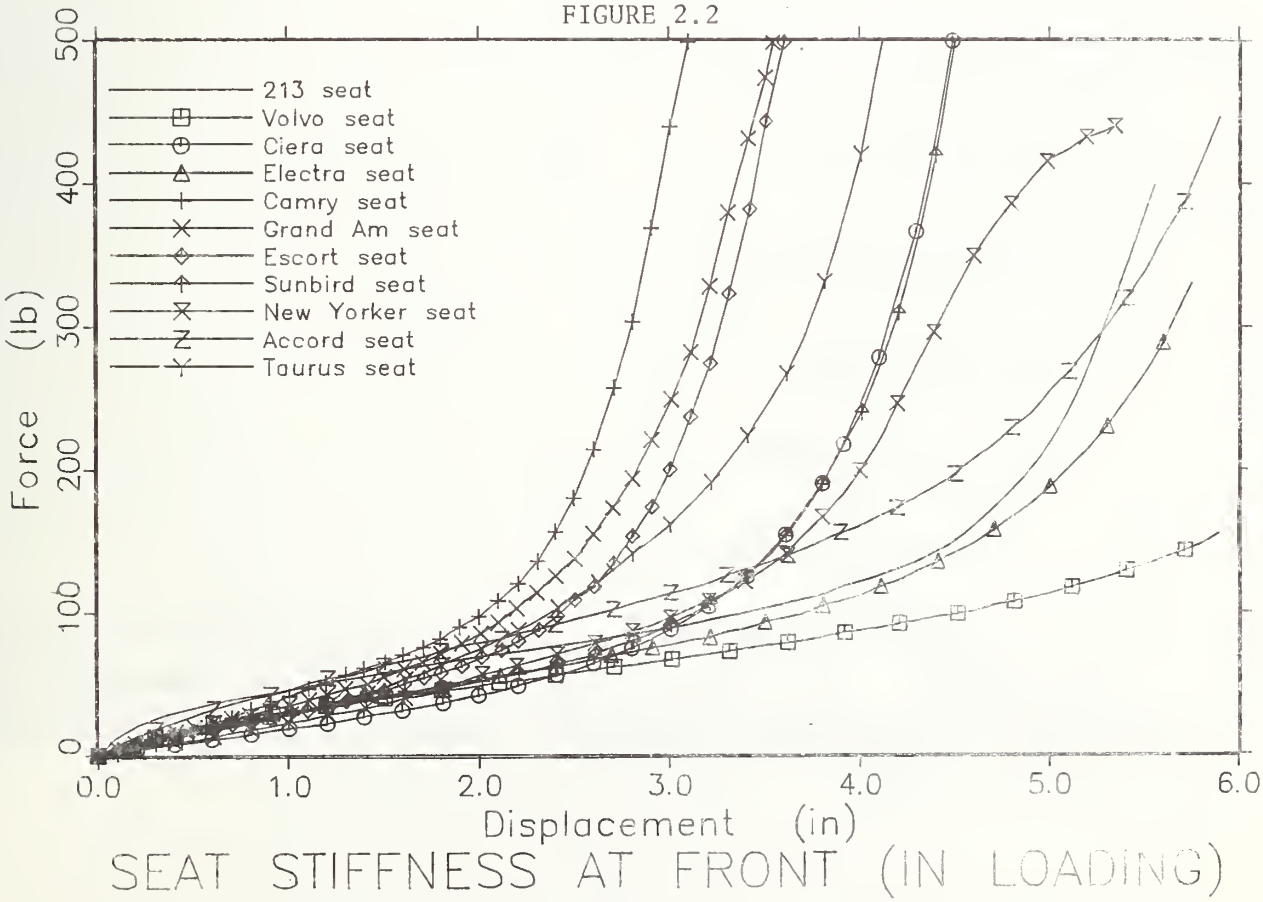


FIGURE 2.3

2.2.2 Crash Dynamics Parameters

The project objective states that the test procedure should reflect the environment of a rear seat in a late model automobile during a frontal crash. The 213 standard uses an acceleration pulse that was an attempt to achieve a square waveform which has a relatively severe onset and was designed for use at a ΔV of 30 miles/hour on the sled. The effect of substituting an acceleration pulse which better represented the crash response of today's cars was desired. Also, there was interest within the Agency in examining the effect of a more severe crash environment (i.e., a 35 mph barrier collision).

One source of recent car crash response data is the New Car Assessment Program (NCAP), which specifies a 35 mile/hour frontal barrier crash test. A composite crash pulse was derived from the following eight mid-1980's automobiles tested in this program:

1985 Buick Electra

1984 Oldsmobile Cutlass

1984 Pontiac Parisiene

1984 Ford LTD

1984 Dodge Daytona

1984 Ford Tempo

1984 Toyota Corolla

1984 Chevrolet Celebrity

Figure 2.4 shows this pulse (which results in a 39 mph ΔV) and the 213 pulse (at a ΔV = 30 mph). Also shown is the acceleration pulse generated by an available HYGE sled metering pin, which is a composite of many crash pulses of late 1970's automobiles.

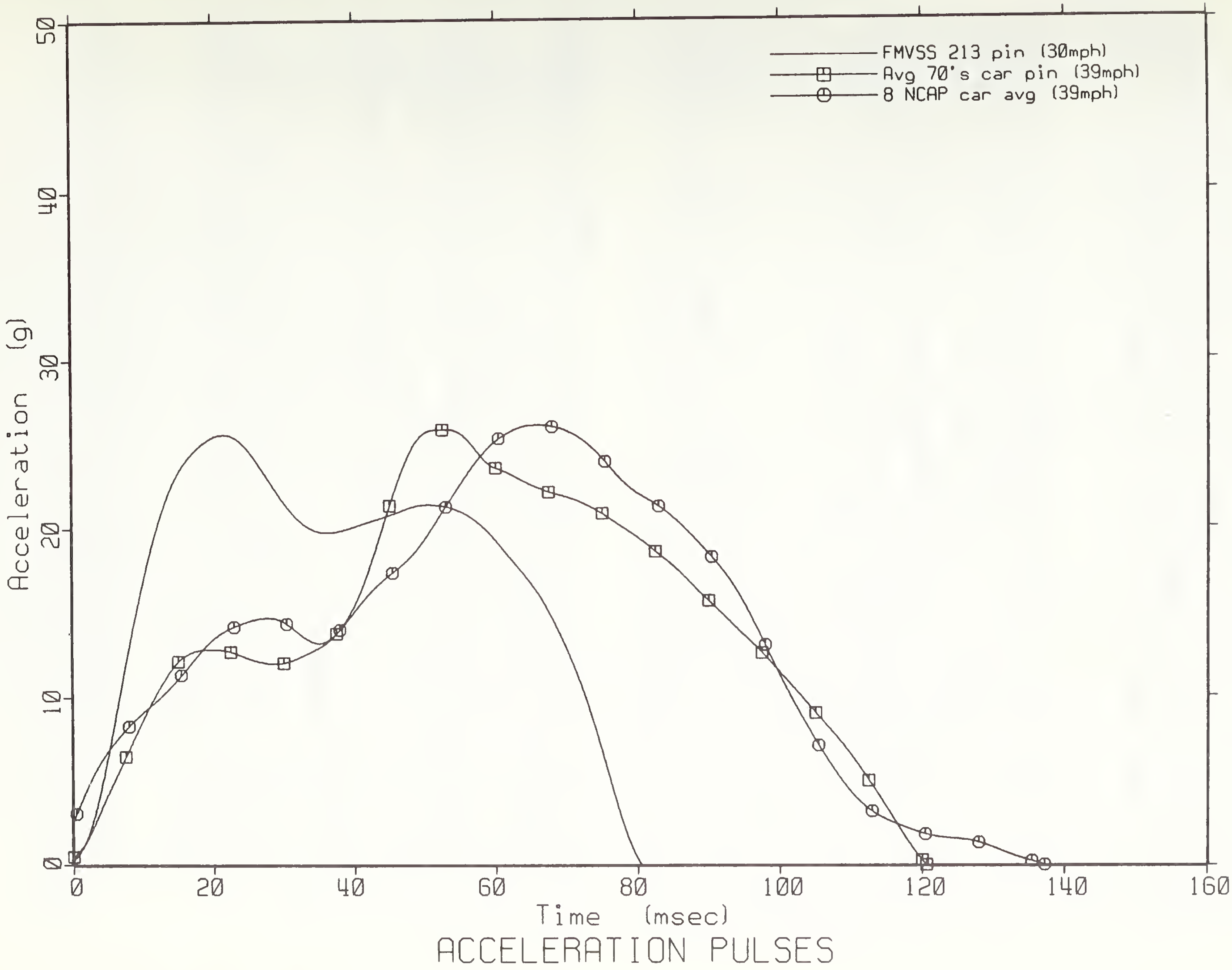


FIGURE 2.4 -- Acceleration Pulses

The two composite pulses were similar enough that it was considered reasonable to use that metering pin to represent a typical car crash response in the test procedure. Hereafter, this pulse is referred to as the "average car" crash pulse. The effect of both acceleration pulses (average car and FMVSS 213) and both crash severities (ΔV's of 30 and 39 mph) were examined in the test matrix.

An important point should be made regarding the 'ΔV': there is some rebound when a car strikes a barrier wall. To accurately simulate this on the HYGE sled, the buck is accelerated to a velocity equal to the crash test incoming plus rebound velocities. It has already been noted that the 39 mph velocity change represents a 35 mph barrier collision. Similarly, the 30 mph velocity change would result from a barrier crash speed of approximately 26-27 mph.

2.2.3 Child Seat Selection

Child seats on the market are essentially categorized by use and the size of the child (as recommended by the Society of Automotive Engineers (SAE) and the American Academy of Pediatrics (AAP) [3,4]) as follows:

Infant Safety Seats: For children from birth to 20 pounds (SAE and AAP recommendations); used rearward facing.

Toddler Seat: For children 20 to 43 pounds (SAE recommendations); used forward facing.

Booster Seat: For children 30 to 60 pounds (SAE and AAP recommendations); used forward facing.

Convertible Seats: For children 20 to 40 pounds (SAE and AAP recommendations); can be used rearward facing as an infant seat and forward facing as a toddler seat.

In general, these seats are intended for children from birth to approximately 4 years old; however, the appropriate seat is also governed by anthropometry of the child as well as the age.

The seats chosen for testing were three boosters, one infant and one convertible. The three boosters selected were the Kolcraft Quikstep, Ford Tot-Guard, and Evenflo Booster Car Seat. The infant and convertible seats chosen were the Century 570 and Fisher Price (selected for use as a toddler seat).

These seats were chosen because they appeared to be durable enough to withstand a moderately rigorous exposure to impact accelerations. They also represented a wide variety of seat designs.

The infant seat (Century 570) was much like others on the market but appeared sturdier (see Figure 2.5). The convertible seat (Fisher Price) was actually chosen for use in the toddler mode rather than as an infant seat (see Figure 2.6). Two of the booster seats (Kolcraft Quikstep and Evenflo Booster) had what are referred to as 'short shields': small restraint shields positioned near the occupant's abdomen (see Figures 2.7 and 2.8). The Ford Tot-Guard was chosen for its 'long shield' design: a shield which is large enough for the child's head to strike (see Figure 2.9).

2.2.4 Child Dummies

The anthropomorphic dummies used for this program were the SA-103C (3 year old), the SA-106C (6 year old), and the 6 month old infant (CAMI) dummy. The anthropometry of each of these dummies was quite suitable for the seats that were selected. The pertinent anthropometric dimensions and which seats each dummy was used to test are presented in Table 2.2.

The 3 and 6 year old dummies are both instrumented with triaxial accelerometers in the head and torso. The infant dummy is an uninstrumented inertial surrogate only.

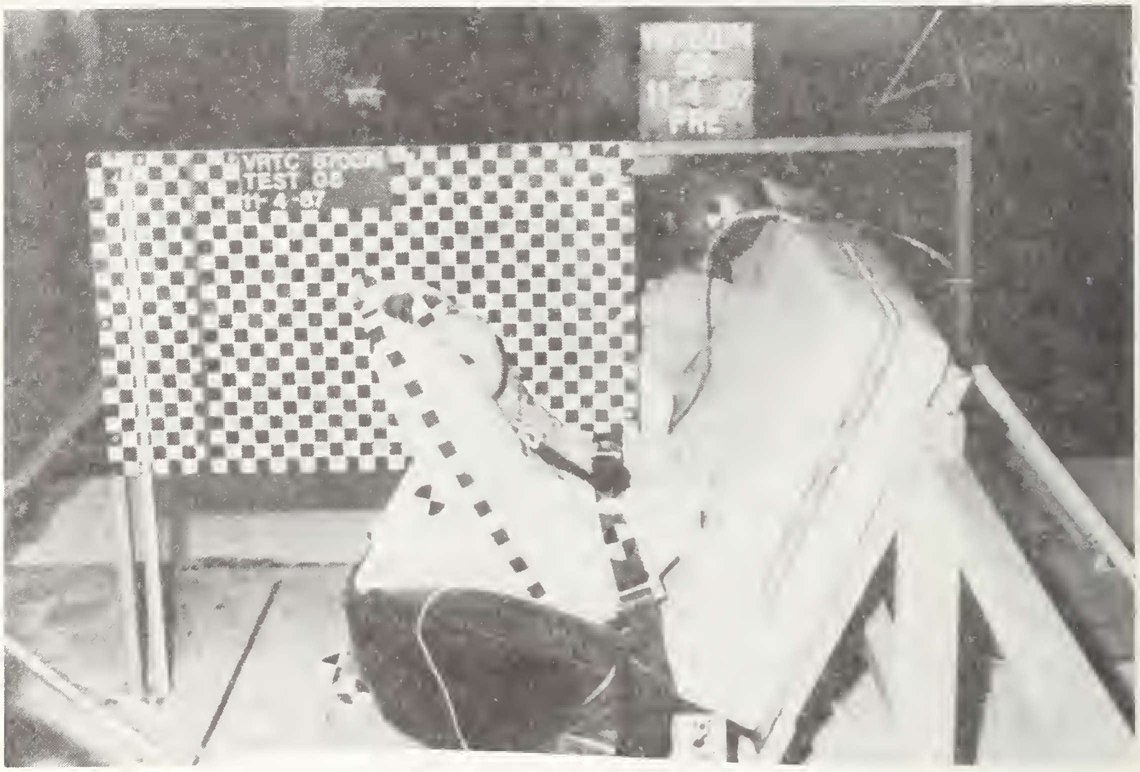


FIGURE 2.5 -- Century 570 - Infant Seat

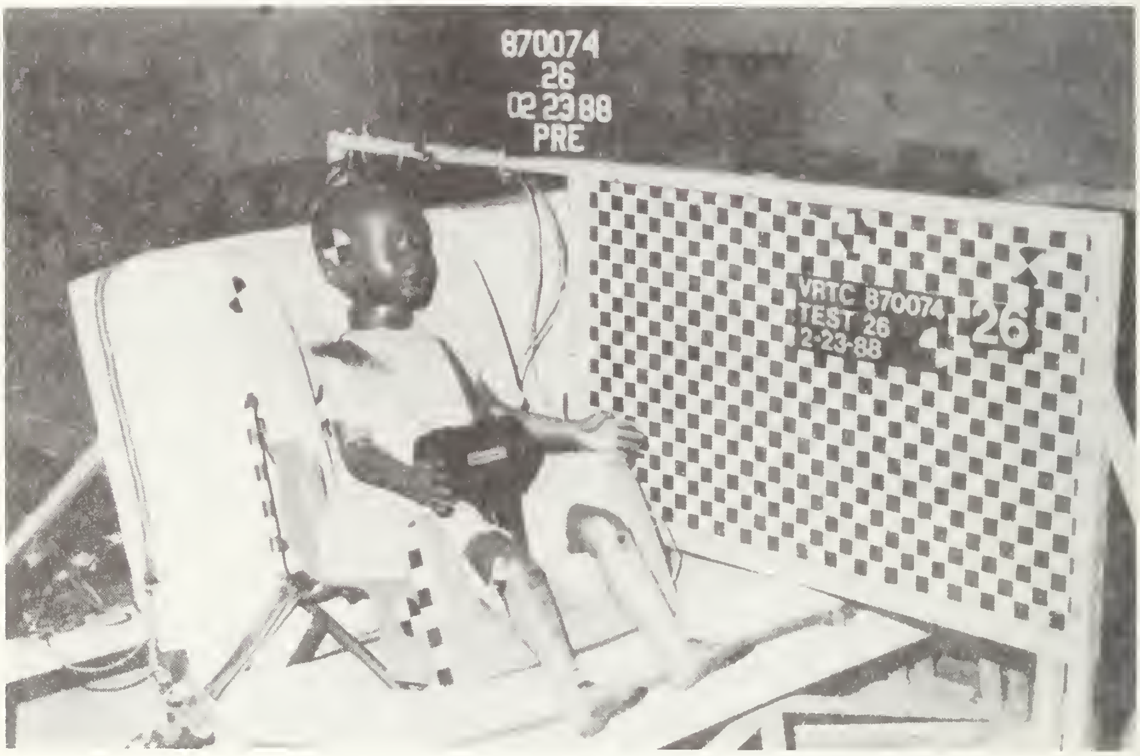


FIGURE 2.6 -- Fisher Price Toddler/Convertible Seat

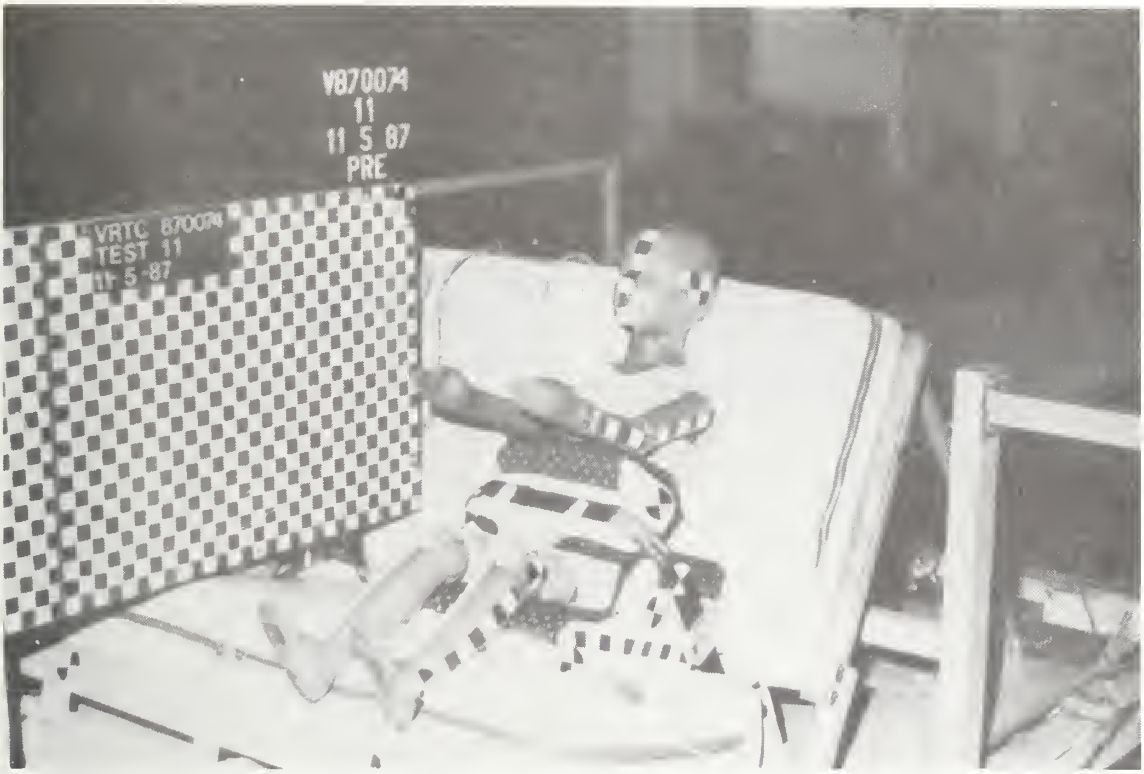


FIGURE 2.7 -- Kolcraft Quikstep Booster Seat

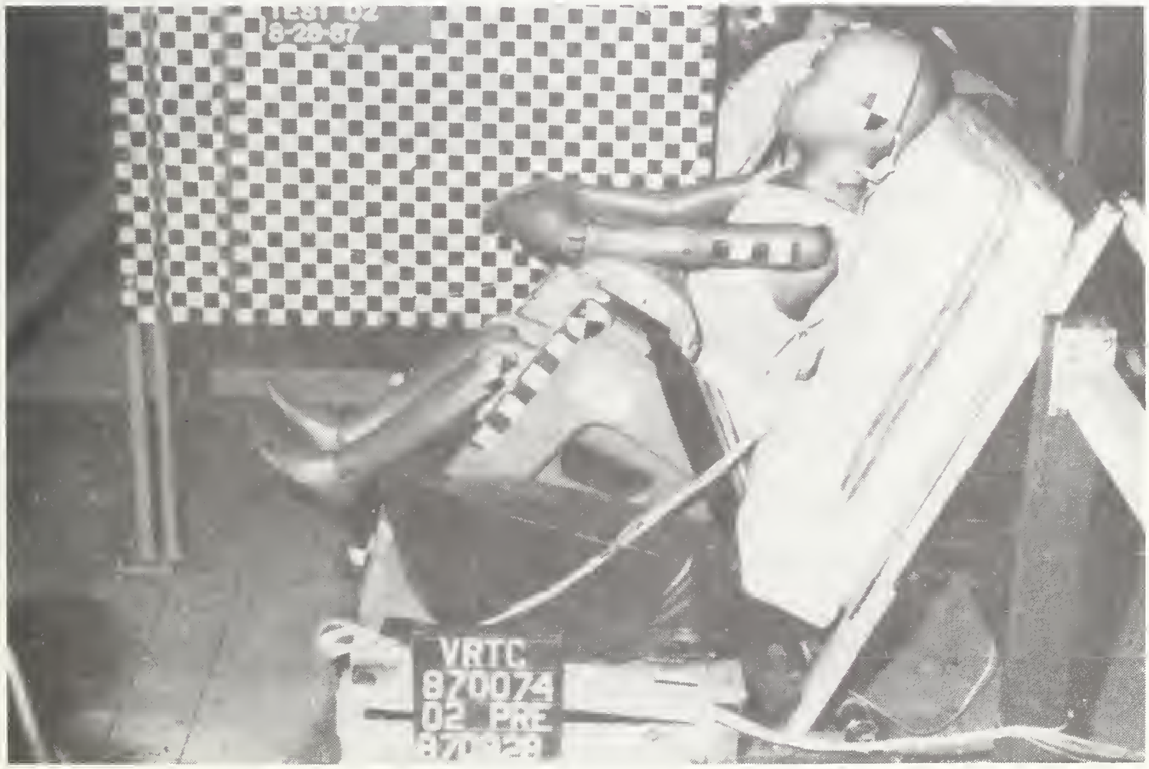


FIGURE 2.8 -- Evenflo Booster Seat

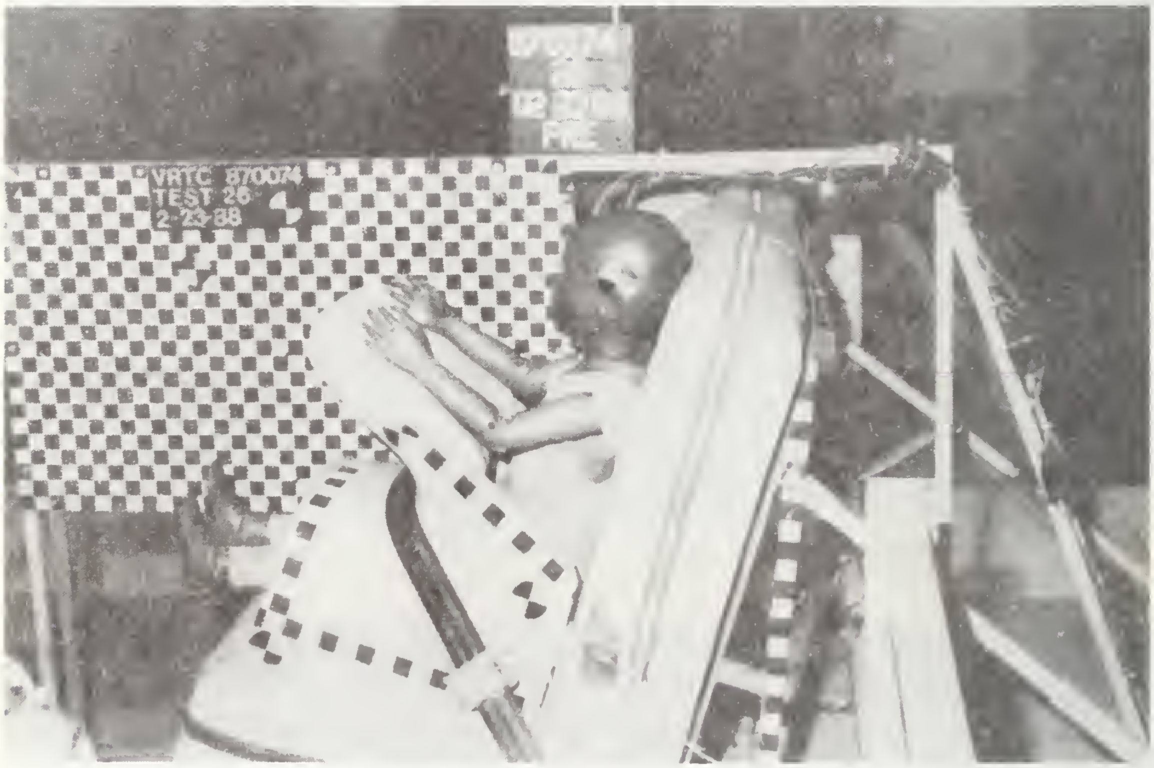


FIGURE 2.9 -- Ford Tot Guard Booster Seat

TABLE 2.2

CHILD DUMMY	STANDING HEIGHT (inches)	SEATED HEIGHT (inches)	WEIGHT (pounds)	CHILD SEAT
6 YEAR (SA-106C)	47.5	25.6	45.5	Quikstep Evenflo Tot-Guard
3 YEAR (SA-103C)	38.4	22.5	33.2	Fisher Price Evenflo
6 MONTH INFANT (CAMI)	~26	~17	17	Century 570

2.3 Sled Test Buck

The sled tests were done using the test fixtures from Reference 2 and from the 213 standard procedure (see Figures 2.10 and 2.11). This bench style seat can accommodate two child safety seats for each test run (see Figure 2 12). The seat frame from Reference 2 was used primarily as the developmental model on which most of the modifications were made. This was done to avoid permanently modifying the 213 seat frame until the choices of parameters for the final design were clear.

The tests that were done with the 213 seat and geometry actually differed from the specified test procedure in two ways. First, the belts used in this program had automatic locking retractors (ALR's) rather than the manually adjusted buckles. The second was that the seat back was fixed rather than deformable. The aluminum energy absorbing rods in the clevis near the seat back pivot were replaced with steel ones and stays were mounted securing the seat frame to the buck frame (see section 2.2.1 and Figure 2.11).

2.4 Test Matrix Development

The test parameters are summarized below:

1. Crash pulse: 'average car' pulse or 213 pulse
2. Velocity (ΔV): 30 or 39 mph

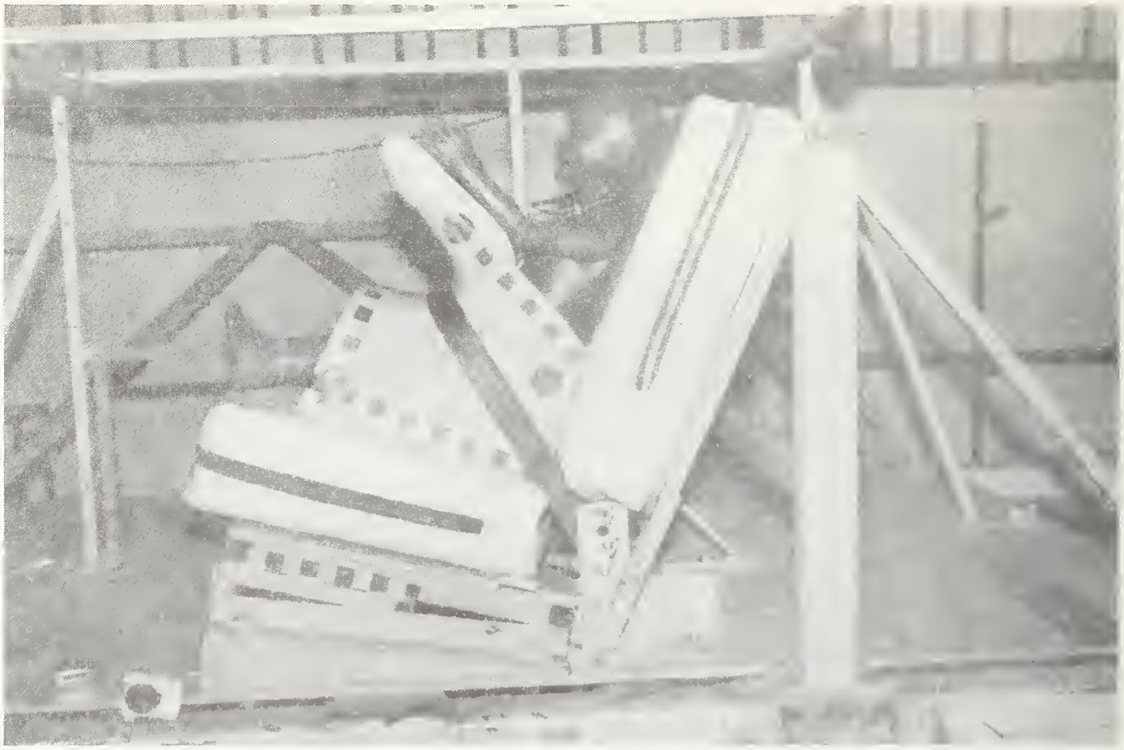


FIGURE 2.10 -- Generic Seat

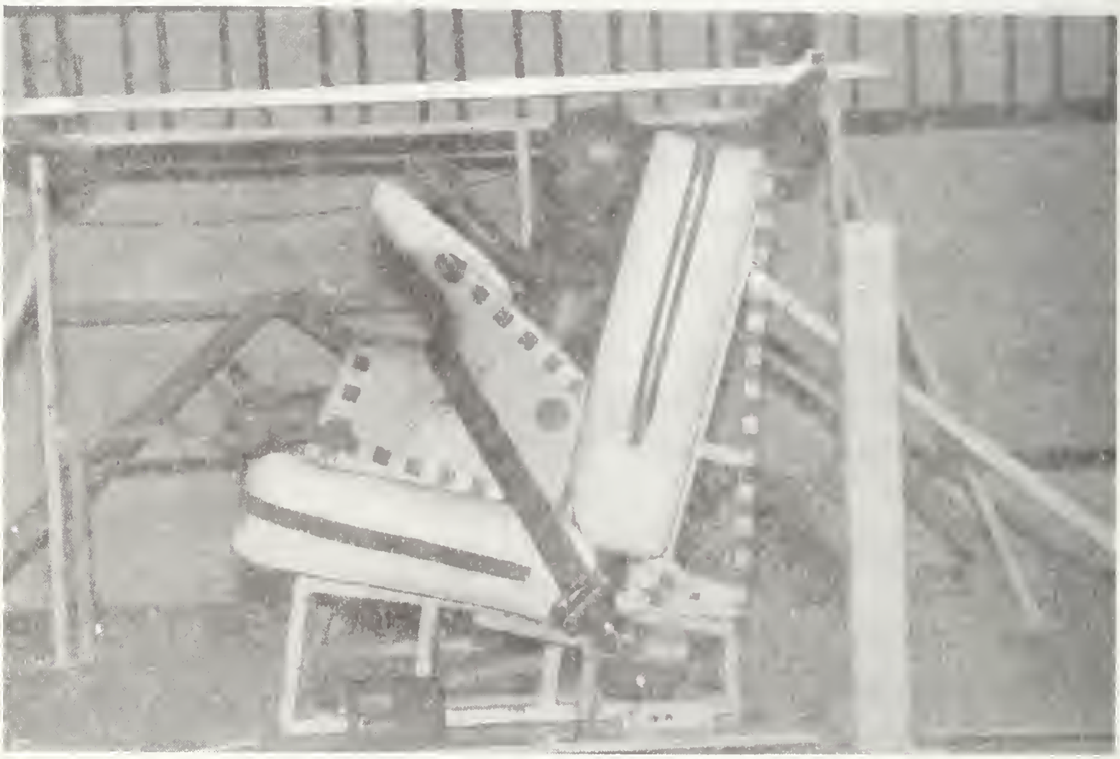


FIGURE 2.11 -- FMVSS 213 Seat

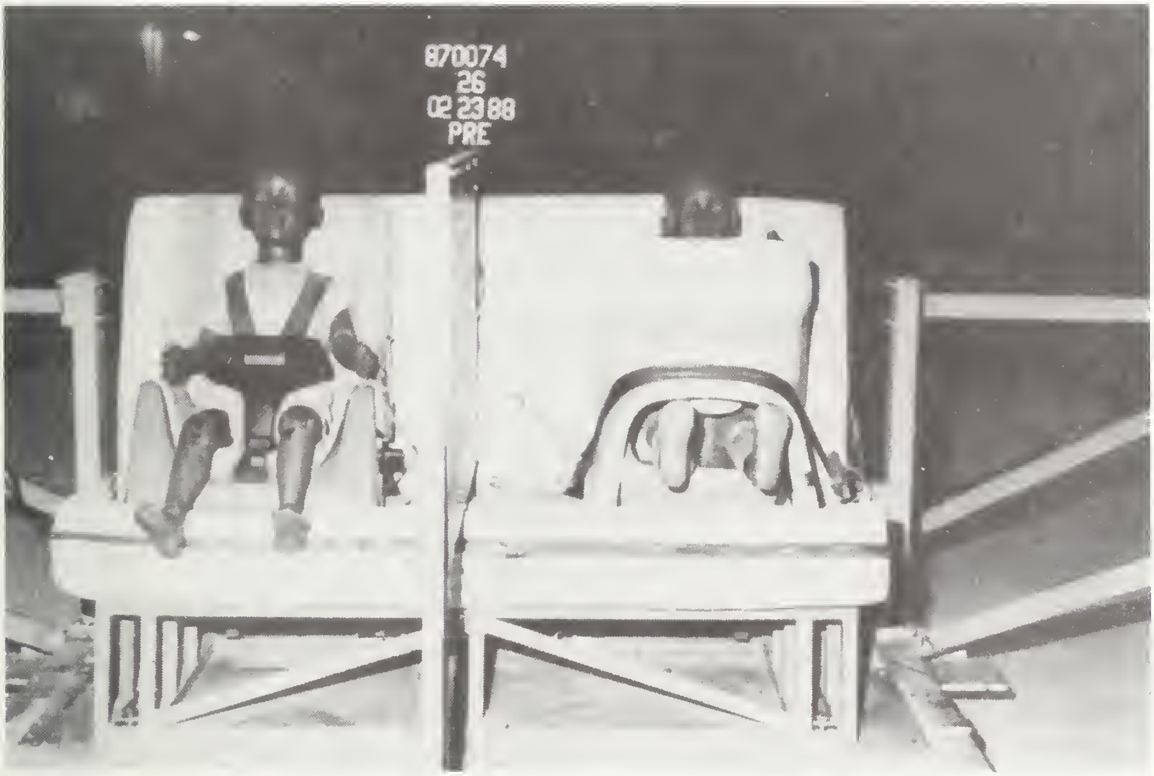


FIGURE 2.12 -- Two Seat Per Test Configuration

3. **Child safety seat:**

Boosters: Ford Tot-Guard, Evenflo Booster or Kolcraft Quikstep

-or-

Toddler/convertible: Fisher Price

-or-

Infant: Century 570

4. **Child age/anthropometry**: 6 month, 3 year or 6 year

5. **Seat Cushion**: Stiff (Toyota Camry), soft (Buick Electra) or 213 (straight block foam with vinyl cover).

6. **Seat geometry**: average ('generic' in Table 2.3) or 213

7. **Lap belt angles**: average $\pm$ 1σ or 213

8. **Lap belt pretension**: high (~213: 10-15 lb) or low (2-4 lb)

The test matrix was progressively developed segment by segment in blocks of tests ranging in number from 3 to 15 at a time. They were grouped as follows:

Test #	PURPOSE
Tests 1-3:	"Shakedown" tests for child seats, seat cushions & other hardware
Tests 4-18:	Belt angles, seat cushion stiffness, and repeatability
Tests 19-24:	Seat cushion stiffness, and repeatability
Tests 25-31:	Geometry, seat cushion stiffness, and repeatability
Tests 32-39:	Geometry, lap belt pretension, acceleration pulse, velocity change (ΔV), and repeatability

The parameters, as they were varied in the testing, are presented in Table 2.3.

TABLE 2.3 -- Test Conditions

TEST NO.	CRASH PULSE	DV mph	POSITION 3 (RIGHT REAR) CHILD RESTRAINT	POSITION 3 (RIGHT REAR) DUMMY	POSITION 4 (LEFT REAR) CHILD RESTRAINT	POSITION 4 (LEFT REAR) DUMMY	SEAT CUSHION	GEOMETRY	OUTBOARD BELT ANGLE DESIGN	OUTBOARD BELT ANGLE ACTUAL	INBOARD BELT ANGLE DESIGN	INBOARD BELT ANGLE ACTUAL	LAP BELT TENSION (L side/R side)
1	Average Car	39	Fisher Price	3	Evenflo Booster	6	Camry	FMVSS 213	---	(1)	---	(1)	High
2	Average Car	39	Fisher Price	3	Evenflo Booster	6	Electra	FMVSS 213	---	(1)	---	(1)	High
3	Average Car	39	Fisher Price	3	Evenflo Booster	6	FMVSS 213	FMVSS 213	(2)	53.0	(2)	49.0	High
4	Average Car	39	Fisher Price	3	Quikstep Booster	6	Camry	Generic	53	51.5	34	34.5	High
5	Average Car	39	Ford Tot-Guard	3	Century 570 Infant	1/2	Camry	Generic	53	51.5	34	34.5	High
6	Average Car	39	Fisher Price	3	Quikstep Booster	6	Camry	Generic	53	51.5	34	34.5	High
7	Average Car	39	Fisher Price	3	Quikstep Booster	6	Electra	Generic	53	56.0	34	33.0	High
8	Average Car	39	Ford Tot-Guard	3	Century 570 Infant	1/2	Electra	Generic	53	56.0	34	33.0	High
9	Average Car	39	Ford Tot-Guard	3	Century 570 Infant	1/2	FMVSS 213	Generic	53	50.5	34	34.5	High
10	Average Car	39	Fisher Price	3	Quikstep Booster	6	FMVSS 213	Generic	53	50.5	34	34.5	High
11	Average Car	39	Fisher Price	3	Quikstep Booster	6	FMVSS 213	Generic	38	40.0	23	23.0	High
12	Average Car	39	Ford Tot-Guard	3	Century 570 Infant	1/2	FMVSS 213	Generic	38	40.0	23	23.0	High
13	Average Car	39	Ford Tot-Guard	3	Century 570 Infant	1/2	FMVSS 213	Generic	68	68.0	44	49.0	High
14	Average Car	39	Fisher Price	3	Quikstep Booster	6	FMVSS 213	Generic	68	68.0	44	49.0	High
15	Average Car	39	Fisher Price	3	Quikstep Booster	6	FMVSS 213	Generic	53	50.5	23	23.0	High
16	Average Car	39	Ford Tot-Guard	3	Century 570 Infant	1/2	FMVSS 213	Generic	53	50.5	23	23.0	High
17	Average Car	39	Ford Tot-Guard	3	Century 570 Infant	1/2	FMVSS 213	Generic	68	68.0	34	34.5	High
18	Average Car	39	Fisher Price	3	Quikstep Booster	6	FMVSS 213	Generic	68	68.0	34	34.5	High
19	Average Car	39	Fisher Price	3	Ford Tot-Guard	3	Camry	Generic	53	43.0	34	33.0	High
20	Average Car	39	Fisher Price	3	Ford Tot-Guard	3	Electra	Generic	53	47.0	34	35.0	High

(1) Although not measured, belt anchors were at the Standard 213 locations.
(2) Belt angles were determined using SAE J826 procedure rather than seat design drawings.

TABLE 2.3 -- Test Conditions (Continued)

TEST NO.	CRASH PULSE	DV mph	POSITION 3 (RIGHT REAR) CHILD RESTRAINT	DUMMY	POSITION 4 (LEFT REAR) CHILD RESTRAINT	DUMMY	SEAT CUSHION	GEOMETRY	OUTBOARD BELT ANGLE DESIGN	OUTBOARD BELT ANGLE ACTUAL	INBOARD BELT ANGLE DESIGN	INBOARD BELT ANGLE ACTUAL	LAP BELT TENSION (L side/R side)
21	Average Car	39	Fisher Price	3	Ford Tot-Guard	3	Camry	Generic	53	43.0	34	33.0	High
22	Average Car	39	Fisher Price	3	Ford Tot-Guard	3	Electra	Generic	53	47.0	34	35.0	High
23	Average Car	39	Fisher Price	3	Ford Tot-Guard	3	FMVSS 213	Generic	53	45.0	34	32.0	High
24	Average Car	39	Fisher Price	3	Ford Tot-Guard	3	FMVSS 213	Generic	53	45.0	34	32.0	High
25	Average Car	39	Fisher Price	3	Ford Tot-Guard	3	FMVSS 213	FMVSS 213	(2)	53.0	(2)	49.0	High
26	Average Car	39	Fisher Price	3	Ford Tot-Guard	3	FMVSS 213	FMVSS 213	(2)	53.0	(2)	49.0	High
27	Average Car	39	Fisher Price	3	Ford Tot-Guard	3	FMVSS 213	FMVSS 213	(2)	53.0	(2)	49.0	High
28	Average Car	39	Fisher Price	3	Ford Tot-Guard	3	Electra	Generic	53	47.0	34	35.0	High
29	Average Car	39	Fisher Price	3	Ford Tot-Guard	3	Electra	Generic	53	47.0	34	35.0	High
30	Average Car	39	Fisher Price	3	Ford Tot-Guard	3	Camry	Generic	53	43.0	34	33.0	High
31	Average Car	39	Fisher Price	3	Ford Tot-Guard	3	FMVSS 213	Generic	53	45.0	34	32.0	High
32	FMVSS 213	30	Fisher Price	3	Ford Tot-Guard	3	FMVSS 213	FMVSS 213	(2)	53.0	(2)	49.0	High
33	FMVSS 213	30	Fisher Price	3	Ford Tot-Guard	3	FMVSS 213	Generic	53	52.0	34	32.0	Low
34	FMVSS 213	30	Fisher Price	3	Ford Tot-Guard	3	FMVSS 213	Generic	53	52.0	34	32.0	Low
35	Average Car	39	Fisher Price	3	Ford Tot-Guard	3	FMVSS 213	Generic	53	52.0	34	32.0	High
36	Average Car	39	Fisher Price	3	Ford Tot-Guard	3	FMVSS 213	Generic	53	52.0	34	32.0	Low
37	Average Car	39	Evenflo Booster	3	Evenflo Booster	3	FMVSS 213	Generic	53	52.0	34	32.0	Low/High
38	Average Car	30	Fisher Price	3	Ford Tot-Guard	3	FMVSS 213	FMVSS 213	(2)	53.0	(2)	49.0	High
39	Average Car	30	-----	---	Ford Tot-Guard	3	FMVSS 213	FMVSS 213	52	53.0	52	49.0	High

3.0 RESULTS

Presented in Table 3.1 are the filtered peak measurements recorded from the insrumentation and films in each test. Also presented are the values for head and chest injury criteria, as specified in FMVSS 213. Head resultant velocities were calculated by filtering, then differentiating, head excursion time histories obtained from digitized films. Head and knee excursions were measured relative to initial rest position.

3.1 Test Notes and Anomalies

Reasons for missing data for individual and groups of tests are presented in Table 3.2.

Tests 1 and 2 were conducted primarily to check out the generic sled buck, using the average car pulse at a 39 mph ΔV, and to ensure satisfactory performance of two of the child seats (particularly, with the 6-yr old dummy) in the more severe test environment. Results from these tests were not used in subsequent analyses.

3.2 Repeatability

Repeatability was examined for responses of the 3-yr old dummies in the Fisher-Price and Ford Tot-Guard child seats in several test configurations. Table 3.3 defines five repeatability test groups and shows the test conditions. Table 3.4 presents the repeatability test results. The degree of variation for each response (head resultant g's, HIC, etc.) was quantified by calculating half-ranges as percentages of means [half-range/mean, where half-range = (maximum - minimum)/2]. For each response in each child seat (Fisher-Price, Ford Tot-Guard), the average of the half-range/mean values from the five test groups was calculated, and is shown at the bottom of the table. Average repeatability values were similar for the two child seats. They ranged from 2.5% to 11.7%; the highest were for head accelerations and HIC values, and the lowest, for chest accelerations.

TABLE 3.1 -- Test Results

TEST #	POSITION (R or L)	AGE	RESTRAINT TYPE	PEAK BELT TENSION OUTBOARD (lb)	PEAK BELT TENSION INBOARD (lb)	HEAD RESULTANT ACCEL. (g)	HIC	HEAD X EXCURSION (in)	HEAD RES VELOCITY (ft/sec)	CHEST RESULTANT ACCEL. (g)	3 msec CHEST CLIP (g)	KNEE X EXCURSION (in)
1	R	3	Fshr Price	789	1320	56.7	489	20.2	32.1	40.1	39.3	12.8
	L	6	Evenflo	980	996	70.2	946	24.9	38.2	42.7	40.8	7.3
2	R	3	Fshr Price	1043	1229	65.2	624	28.0	38.6	52.6	50.8	18.1
	L	6	Evenflo	896	1092	79.4	1037	30.3	44.7	44.0	41.3	12.7
3	R	3	Fshr Price	976	1444	59.8	626	24.6	35.2	44.4	43.5	14.2
	L	6	Evenflo	1251	1414	75.4	917	31.0	44.4	56.5	51.1	13.6
4	R		----	NA	NA	NA	NA	NA	NA	NA	NA	NA
	L		----	NA	NA	NA	NA	NA	NA	NA	NA	NA
5	R	3	Ford Tot Grd	1063	NA	86.5	858	21.0	38.9	45.5	44.9	14.8
	L	1/2	Century 570	308	NA	---	---	8.1	20.1	---	---	---
6	R	3	Fshr Price	1005	NA	61.5	547	19.6	31.6	44.7	43.4	11.6
	L	6	Quikstep	920	NA	48.1	350	26.4	36.0	30.8	29.4	9.3
7	R	3	Fshr Price	1015	NA	66.1	655	23.5	37.4	48.8	46.6	15.3
	L	6	Quikstep	885	NA	55.7	612	28.2	42.5	39.8	35.2	11.0
8	R	3	Ford Tot Grd	1072	NA	103.6	1260	24.6	45.6	59.6	57.4	14.3
	L	1/2	Century 570	339	NA	---	---	12.6	25.0	---	---	---
9	R	3	Ford Tot Grd	987	NA	95.6	1015	20.9	37.5	52.2	50.7	12.1
	L	1/2	Century 570	247	NA	---	---	9.0	15.9	---	---	---
10	R	3	Fshr Price	845	NA	53.5	436	17.6	27.5	46.6	45.7	10.2
	L	6	Quikstep	1012	NA	49.6	321	26.8	36.0	32.1	31.5	9.6

TABLE 3.1 -- Test Results (Continued)

TEST #	POSITION (R or L)	AGE	RESTRAINT TYPE	PEAK BELT TENSION OUTBOARD (lb)	PEAK BELT TENSION INBOARD (lb)	HEAD RESULTANT ACCEL. (g)	HIC	HEAD X EXCURSION (in)	HEAD RES VELOCITY (ft/sec)	CHEST RESULTANT ACCEL. (g)	3 msec CHEST CLIP (g)	KNEE X EXCURSION (in)
11	R	3	Fshr Price	918	NA	64.7	623	20.2	32.3	45.0	43.8	12.4
	L	6	Quikstep	756	NA	51.8	377	22.9	33.9	38.2	35.1	6.9
12	R	3	Ford Tot Grd	1131	NA	88.5	843	20.0	38.4	42.3	41.9	12.4
	L	1/2	Century 570	335	NA	---	---	8.3	17.1	---	---	---
13	R	3	Ford Tot Grd	1075	NA	115.0	1111	25.0	42.7	56.9	55.5	14.8
	L	1/2	Century 570	375	NA	---	---	13.1	22.4	---	---	---
14	R	3	Fshr Price	677	NA	64.2	573	21.2	31.7	47.8	45.9	12.5
	L	6	Quikstep	648	NA	48.2	324	30.8	40.2	37.2	33.5	11.6
15	R	3	Fshr Price	854	NA	60.9	519	19.1	31.1	44.4	43.5	11.0
	L	6	Quikstep	2052	NA	57.5	372	27.9	39.4	32.7	27.5	9.8
16	R	3	Ford Tot Grd	858	NA	89.8	895	18.9	35.0	46.3	46.1	10.8
	L	1/2	Century 570	429	NA	---	---	8.5	16.7	---	---	---
17	R	3	Ford Tot Grd	1217	NA	101.5	880	21.3	36.4	49.4	48.7	13.5
	L	1/2	Century 570	254	NA	---	---	9.2	16.4	---	---	---
18	R	3	Fshr Price	774	NA	67.7	577	21.6	33.2	48.6	47.2	13.0
	L	6	Quikstep	889	NA	49.8	414	26.5	37.6	32.7	31.1	10.3
19	R	3	Fshr Price	894	1189	48.5	406	20.4	30.3	42.6	40.4	10.5
	L	3	Ford Tot Grd	1026	1002	123.5	959	18.8	32.7	51.5	47.9	11.1
20	R	3	Fshr Price	838	1119	68.5	610	24.4	36.4	49.2	47.8	13.9
	L	3	Ford Tot Grd	1032	984	122.0	1170	24.5	42.7	58.6	54.7	12.7

TABLE 3.1 -- Test Results (Continued)

TEST #	POSITION (R or L)	AGE	RESTRAINT TYPE	PEAK BELT TENSION OUTBOARD (lb)	PEAK BELT TENSION INBOARD (lb)	HEAD RESULTANT ACCEL. (g)	HIC	HEAD X EXCURSION (in)	HEAD RES VELOCITY (ft/sec)	CHEST RESULTANT ACCEL. (g)	3 msec CHEST CLIP (g)	KNEE X EXCURSION (in)
21	R	3	Fshr Price	954	1188	62.2	597	22.4	34.0	42.7	42.6	11.1
	L	3	Ford Tot Grd	859	969	100.9	897	17.6	32.9	43.8	42.4	11.0
22	R	3	Fshr Price	829	1205	69.5	596	24.1	35.8	51.6	49.7	13.5
	L	3	Ford Tot Grd	970	898	149.2	1156	23.4	44.1	55.8	54.0	13.0
23	R	3	Fshr Price	789	1362	65.0	639	23.2	34.5	43.3	42.3	12.3
	L	3	Ford Tot Grd	979	526	143.9	1219	20.4	40.9	44.6	43.4	10.1
24	R	3	Fshr Price	827	1192	62.4	540	20.0	30.8	43.3	42.0	10.5
	L	3	Ford Tot Grd	956	818	110.6	1138	20.6	38.2	44.8	43.8	10.7
25	R	3	Fshr Price	1084	1383	63.6	637	24.6	37.1	45.4	44.3	13.1
	L	3	Ford Tot Grd	910	882	76.1	647	25.9	41.0	38.4	37.1	9.9
26	R	3	Fshr Price	1116	1399	65.0	634	22.5	34.5	44.7	44.3	12.0
	L	3	Ford Tot Grd	904	906	74.1	739	26.5	41.7	39.0	36.6	9.9
27	R	3	Fshr Price	1002	1436	61.8	588	21.6	33.8	43.0	41.7	11.2
	L	3	Ford Tot Grd	927	889	NA	NA	27.0	45.2	39.6	37.9	9.0
28	R	3	Fshr Price	907	1227	70.4	627	22.7	34.5	53.9	51.6	12.7
	L	3	Ford Tot Grd	NA	NA	NA	NA	NA	NA	NA	NA	NA
29	R	3	Fshr Price	819	1223	67.7	573	22.6	34.0	52.1	49.8	12.9
	L	3	Ford Tot Grd	946	516	111.0	1210	20.3	38.0	60.3	56.2	11.0
30	R	3	Fshr Price	857	1288	60.0	590	21.3	33.2	44.5	42.1	10.6
	L	3	Ford Tot Grd	823	911	101.0	889	17.1	32.9	42.9	41.2	10.4

TABLE 3.1 -- Test Results (Continued)

TEST #	POSITION (R or L)	AGE	RESTRAINT TYPE	PEAK BELT TENSION OUTBOARD (lb)	INBOARD (lb)	HEAD RESULTANT ACCEL. (g)	HIC	HEAD X EXCURSION (in)	HEAD RES VELOCITY (ft/sec)	CHEST RESULTANT ACCEL. (g)	3 msec CHEST CLIP (g)	KNEE X EXCURSION (in)
31	R	3	Fshr Price	795	1588	62.4	537	21.0	32.2	42.8	42.1	11.0
	L	3	Ford Tot Grd	952	310	82.2	722	18.0	31.6	47.1	46.3	9.5
32	R	3	Fshr Price	936	1164	47.9	354	20.8	33.3	45.2	43.8	13.4
	L	3	Ford Tot Grd	468	1032	56.7	575	23.8	39.7	43.0	34.8	10.3
33	R	3	Fshr Price	453	853	NA	NA	NA	NA	NA	NA	NA
	L	3	Ford Tot Grd	1075	1246	81.1	916	23.2	42.7	53.0	47.1	12.1
34	R	3	Fshr Price	817	1679	53.6	349	21.5	33.8	47.6	46.0	12.8
	L	3	Ford Tot Grd	1007	1168	88.5	904	21.0	39.9	49.4	47.6	10.9
35	R	3	Fshr Price	850	1313	63.1	608	23.3	36.1	47.7	46.7	13.0
	L	3	Ford Tot Grd	1053	1212	87.4	1021	23.4	40.3	48.4	44.6	11.5
36	R	3	Fshr Price	1002	1414	70.7	835	25.8	39.4	51.3	49.3	14.1
	L	3	Ford Tot Grd	1122	1198	91.0	1097	23.7	41.1	53.6	49.9	11.2
37	R	3	Evenflo	798	1064	113.0	1174	28.3	47.0	37.7	37.4	9.7
	L	3	Evenflo	1033	1211	86.8	859	NA	NA	38.6	38.0	NA
38	R	3	Fshr Price	646	781	35.5	163	15.4	19.8/20.7	28.9	28.4	8.5
	L	3	Ford Tot Grd	NA	NA	NA	NA	NA	NA	NA	NA	NA
39	R	---	----	NA	NA	NA	NA	NA	NA	NA	NA	NA
	L	3	Ford Tot Grd	590	662	50.1	330	21.4	29.4	28.2	27.9	7.4

NOTES: * All excursions are measured from the segment's rest or initial position

TABLE 3.2
TEST NOTES AND ANOMALIES

TEST NO.	DESCRIPTION
4	Both positions (right and left sides)The lap belt retractors were incorrectly mounted and spun around upon loading. All channels were unusable.
4-18	Both positions (right and left sides): The inboard lap belt tension was not measured in either position because the belt routing through the seat would not allow proper placement of the belt tension load cells.
27	Position 4 (left side): The neck of the dummy was probably damaged in this test; the head accelerations were somewhat higher than expected, and in test no. 28 the head of this dummy severed completely from the torso (see below).
28	Position 4 (left side): The neck failed in the dummy, and the head severed completely from the torso. It is likely that the neck began to fail in the previous test (test no. 27).
33	Position 3 (right side): The seat belt latch buckle and tongue were bearing directly against the tubular metal frame of the Fisher-Price seat and apparently failed in bending when loading occurred. The seat and dummy were ejected completely from the sled buck. The only data recoverable in this test were the maximum belt loads at failure.
37	Position 4 (left side): The dummy's lumbar spine apparently failed when the torso flexed over the Evenflo booster seat shield. Although not known at the time, it is believed that the spine was completely severed, leaving only the torso flesh to contain upper and lower torso assemblies. All channels were unusable.
38	Position 4 (left side): This test was run using the dummy with the spine that had failed in the previous test. The broken spine was not discovered until the conclusion of this test. All channels were unusable.

Table 3.3 -- Repeatability Test Conditions

TEST GROUP	TEST NUMBERS	PULSE	DV	SEAT CUSHION	SEAT GEOMETRY	LAP BELT ANGLE OUTBOARD / INBOARD	LAP BELT PRETENSION	NUMBER OF TESTS IN SAMPLE FISHER PRICE	FORD TOT GUARD
I	3, 25, 26, 27	AVG CAR	39	213	213	51.2-53 / 49-51.2	HIGH	4	2/3
II	33, 34	213	30	213	213	52 / 32	LOW	1	2
III	19, 21, 30	AVG CAR	39	CAMRY	GENERIC	43 / 33	HIGH	3	3
IV	23, 24, 31	AVG CAR	39	213	GENERIC	45 / 32	HIGH	3	2
V	20, 22, 28, 29	AVG CAR	39	ELECTRA	GENERIC	47 / 35	HIGH	4	3

TABLE 3.4 -- Repeatability Test Results

FISHER PRICE								
TEST GROUP		HEAD R ACCEL. (g)	HIC	HEAD X EXCURSION (in)	HEAD VELOCITY (ft/sec)	CHEST R ACCEL (g)	3 ms CHEST CLIP (g)	KNEE X EXCURSION (in)
I	Mean	62.6	619	23.3	35.2	44.4	43.7	12.6
	1/2 R/M *	4.2%	3.9%	6.2%	4.7%	2.7%	3.0%	11.8%
II	Mean	NA	NA	NA	NA	NA	NA	NA
	1/2 R/M	NA	NA	NA	NA	NA	NA	NA
III	Mean	56.9	531	21.4	32.5	43.3	41.7	10.7
	1/2 R/M	12.0%	18.0%	4.7%	5.7%	2.2%	2.6%	3.0%
IV	Mean	63.3	571	21.4	32.5	43.1	42.1	11.3
	1/2 R/M	2.1%	8.9%	7.5%	5.7%	0.6%	0.4%	8.0%
V	Mean	69	602	23.5	35.2	51.7	49.7	13.3
	1/2 R/M	2.0%	4.5%	3.9%	3.4%	4.5%	3.8%	4.3%
Average 1/2 R/M		5.1%	8.8%	5.6%	4.9%	2.5%	2.5%	6.8%

FORD TOT GUARD								
TEST GROUP		HEAD R ACCEL. (g)	HIC	HEAD X EXCURSION (in)	HEAD VELOCITY (ft/sec)	CHEST R ACCEL (g)	3 ms CHEST CLIP (g)	KNEE X EXCURSION (in)
I	Mean	75.1	693	26.5	42.6	39	37.2	9.6
	1/2 R/M *	1.4%	6.6%	2.1%	4.9%	1.5%	1.7%	4.8%
II	Mean	84.8	910	22.1	41.3	51.2	47.4	11.5
	1/2 R/M	4.4%	0.7%	5.0%	3.5%	3.5%	0.5%	4.9%
III	Mean	108.5	915	17.8	32.8	46.1	43.8	10.8
	1/2 R/M	10.4%	3.8%	4.8%	0.4%	9.3%	7.6%	3.1%
IV	Mean	127.3	1179	20.5	36.9	44.7	43.6	10.4
	1/2 R/M	27.5%	24.2%	6.6%	12.5%	2.7%	3.3%	6.1%
V	Mean	127.4	1179	22.7	41.6	58.2	55.0	12.2
	1/2 R/M	15.0%	2.3%	9.3%	7.3%	3.9%	2.0%	8.2%
Average 1/2 R/M		11.7%	7.5%	5.6%	5.7%	4.2%	3.0%	5.4%

* 1/2 R/M = Half-range [(max-min)/2] as a percentage of the mean

3.3 Parameter Sensitivity

As described in Section 2.0, there are several vehicle and crash parameters which were examined. Individual parameters are listed below, along with "Parameter Identification Numbers" (for future reference).

Parameter Identification No.	Parameter
1	Lap Belt Angle
2	Seat Cushion Stiffness
3	Seat Geometry
4	Acceleration Pulse
5	Velocity Change
6	Lap Belt Pretension

In addition, the following parameter combinations were investigated:

Parameter Identification No.	Parameter Combination
7	Seat Geometry / Lap Belt Pretension
8	Acceleration Pulse / Velocity Change
9	Overall Test Configuration

In the remainder of this section, test results are presented and discussed in order of the Parameter Identification Number. To determine the effect of a parameter (or parameter combination), response differences were compared to variations seen in the repeatability tests. This was done by calculating the half-range between responses at the two (or more) levels and dividing by the mean of the responses. These values were then compared with the half-range/mean values which were calculated from the repeatability test results (Table 3.4). If a parameter half-range/mean value greatly exceeded the repeatability half-range/mean value, then that parameter was judged to be "significant". If the parameter half-range/mean value was less than the repeatability half-range/mean value, then the variation between the two parameter levels could be attributed to experimental variability, and the effect of that parameter was not considered to be significant. If the parameter half-range/mean value was between one and two times the repeatability half-range/mean value there was some uncertainty about the parameter's significance, so it was judged to be "marginally" significant.

3.3.1 Lap Belt Angle

The effects of lap belt angle on the dummy responses in the Ford Tot Guard, Fisher Price, Kolcraft Quikstep, and Century 570 child seats are shown in Table 3.5. As described above, half-ranges are presented as percentages of the means, for comparison with the repeatability data. Some of the dummy responses are plotted against average belt angle [(outboard belt angle + inboard belt angle) / 2] in Figures 3.1 - 3.5.

Peak head resultant accelerations and HIC values for the 3-yr old dummy in the Ford Tot Guard for the different belt angle combinations resulted in half-range/mean values of 13.5% and 14.1%, respectively. These are somewhat higher than the repeatability half-range/mean values of 11.7% and 7.5% for peak head resultant acceleration and HIC in the Tot Guard, and indicate a marginally significant effect of lap belt angle on head response. Figure 3.1 confirms this, showing a slight effect of average belt angle on HIC. Similarly, lap belt angle significantly affected the peak chest acceleration of the 3-yr old in the Tot Guard; variation was 14.0% as compared with only 3.0% in the repeatability tests, and the effect is seen in Figure 3.2. Both head and knee excursions were also significantly affected by lap belt angle, as indicated by the percent variations in Table 3.5 and the curves of Figures 3.3 and 3.5.

In the Fisher Price seat, most of the response variations were marginally significant, and trends (from Figures 3.1--3.5) were barely, if at all, discernable.

In general, increasing the average lap belt angle from approximately 30 to 60 degrees slightly increased some of the 3-yr old dummy responses in both the Ford Tot Guard and the Fisher Price seats. The largest effects were in the Tot Guard; HIC increased from 840 to 1100, maximum chest acceleration (3 msec clip) increased from 42 to 56, head excursion increased about 4 inches, and knee excursion increased about 2.5 inches.

TABLE 3.5 -- Belt Angle Sensitivity - Test Results

FORD TOT GUARD

TEST #	(ACTUAL) OUTBOARD BELT ANGLE (degrees)	INBOARD BELT ANGLE (degrees)	BELT ANGLE RATIO	TENSION OUTBOARD (lb)	HEAD RESULTANT ACCEL. (g)	HIC	HEAD X EXCURSION (in)	HEAD RES VELOCITY (ft/sec)	CHEST RESULTANT ACCEL. (g)	3 msec CHEST CLIP (g)	KNEE X EXCURSION (in)
9	50.5	34.5	1.46	987	95.6	1015	20.9	37.5	52.2	50.70	12.1
12	40.0	23.0	1.74	1131	88.5	843	20.0	38.4	42.3	41.90	12.4
13	68.0	49.0	1.39	1075	115.0	1111	25.0	42.7	56.9	55.50	14.8
16	50.5	23.0	2.20	858	89.8	895	18.9	35.0	46.3	46.10	10.8
17	68.0	34.5	1.97	1217	101.5	880	21.3	36.4	49.4	48.70	13.5
	MEAN			1054	98.08	949	21.2	38.0	49.4	48.58	12.7
	1/2 RANGE / MEAN			17.0%	13.5%	14.1%	14.4%	10.1%	14.8%	14.0%	15.8%

FISHER PRICE

TEST #	(ACTUAL) OUTBOARD BELT ANGLE (degrees)	INBOARD BELT ANGLE (degrees)	BELT ANGLE RATIO	TENSION OUTBOARD (lb)	HEAD RESULTANT ACCEL. (g)	HIC	HEAD X EXCURSION (in)	HEAD RES VELOCITY (ft/sec)	CHEST RESULTANT ACCEL. (g)	3 msec CHEST CLIP (g)	KNEE X EXCURSION (in)
10	50.5	34.5	1.46	845	53.5	436	17.6	27.5	46.6	45.7	10.2
11	40.0	23.0	1.74	918	64.7	623	20.2	32.3	45.0	43.8	12.4
14	68.0	49.0	1.39	677	64.2	573	21.2	31.7	47.8	45.9	12.5
15	50.5	23.0	2.20	854	60.9	519	19.1	31.1	44.4	43.5	11.0
18	68.0	34.5	1.97	774	67.7	577	21.6	33.2	48.6	47.2	13.0
	MEAN			814	62.20	546	19.9	31.2	46.5	45.22	11.8
	1/2 RANGE / MEAN			14.8%	11.4%	17.1%	10.0%	9.1%	4.5%	4.1%	11.8%

TABLE 3.5 -- Belt Angle Sensitivity - Test Results (Continued)

CENTURY 570

TEST #	(ACTUAL) OUTBOARD BELT ANGLE (degrees)	INBOARD BELT ANGLE (degrees)	BELT ANGLE RATIO	TENSION OUTBOARD (lb)	HEAD RESULTANT ACCEL. (g)	HIC	* HEAD X EXCURSION (in)	* HEAD RES VELOCITY (ft/sec)	CHEST RESULTANT ACCEL. (g)	3 msec CHEST CLIP (g)	KNEE X EXCURSION (in)
9	50.5	34.5	1.46	247	NA	NA	9.0	15.9	NA	NA	NA
12	40.0	23.0	1.74	335	NA	NA	8.3	17.1	NA	NA	NA
13	68.0	49.0	1.39	375	NA	NA	13.1	22.4	NA	NA	NA
16	50.5	23.0	2.20	429	NA	NA	8.5	16.7	NA	NA	NA
17	68.0	34.5	1.97	254	NA	NA	9.2	16.4	NA	NA	NA
	MEAN			328	NA	NA	9.6	17.7	NA	NA	NA
	1/2 RANGE / MEAN			27.7%	NA	NA	24.9%	18.4%	NA	NA	NA

KOLCRAFT QUIKSTEP

TEST #	(ACTUAL) OUTBOARD BELT ANGLE (degrees)	INBOARD BELT ANGLE (degrees)	BELT ANGLE RATIO	TENSION OUTBOARD (lb)	HEAD RESULTANT ACCEL. (g)	HIC	HEAD X EXCURSION (in)	HEAD RES VELOCITY (ft/sec)	CHEST RESULTANT ACCEL. (g)	3 msec CHEST CLIP (g)	KNEE X EXCURSION (in)
10	50.5	34.5	1.46	1012	49.6	321	26.8	36.0	32.1	31.5	9.6
11	40.0	23.0	1.74	756	51.8	377	22.9	33.9	38.2	35.1	6.9
14	68.0	49.0	1.39	648	48.2	324	30.8	40.2	37.2	33.5	11.6
15	50.5	23.0	2.20	2052	57.5	372	27.9	39.4	32.7	27.5	9.8
18	68.0	34.5	1.97	889	49.8	414	26.5	37.6	32.7	31.1	10.3
	MEAN			1071	51.38	362	27.0	37.4	34.6	31.74	9.6
	1/2 RANGE / MEAN			65.5%	9.1%	12.9%	14.6%	8.4%	8.8%	12.0%	24.3%

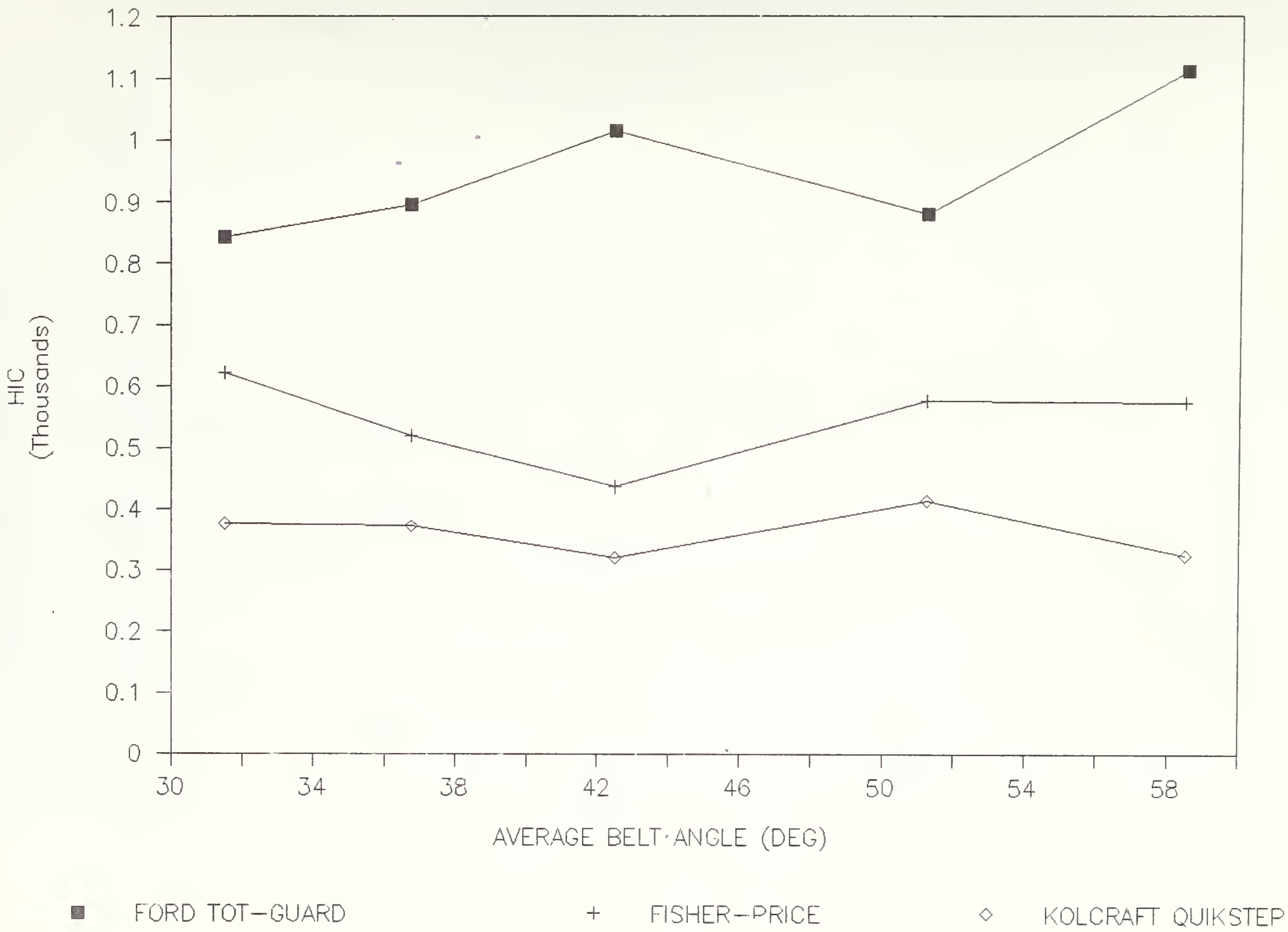


FIGURE 3.1 -- Effect of Average Belt Angle on Hic

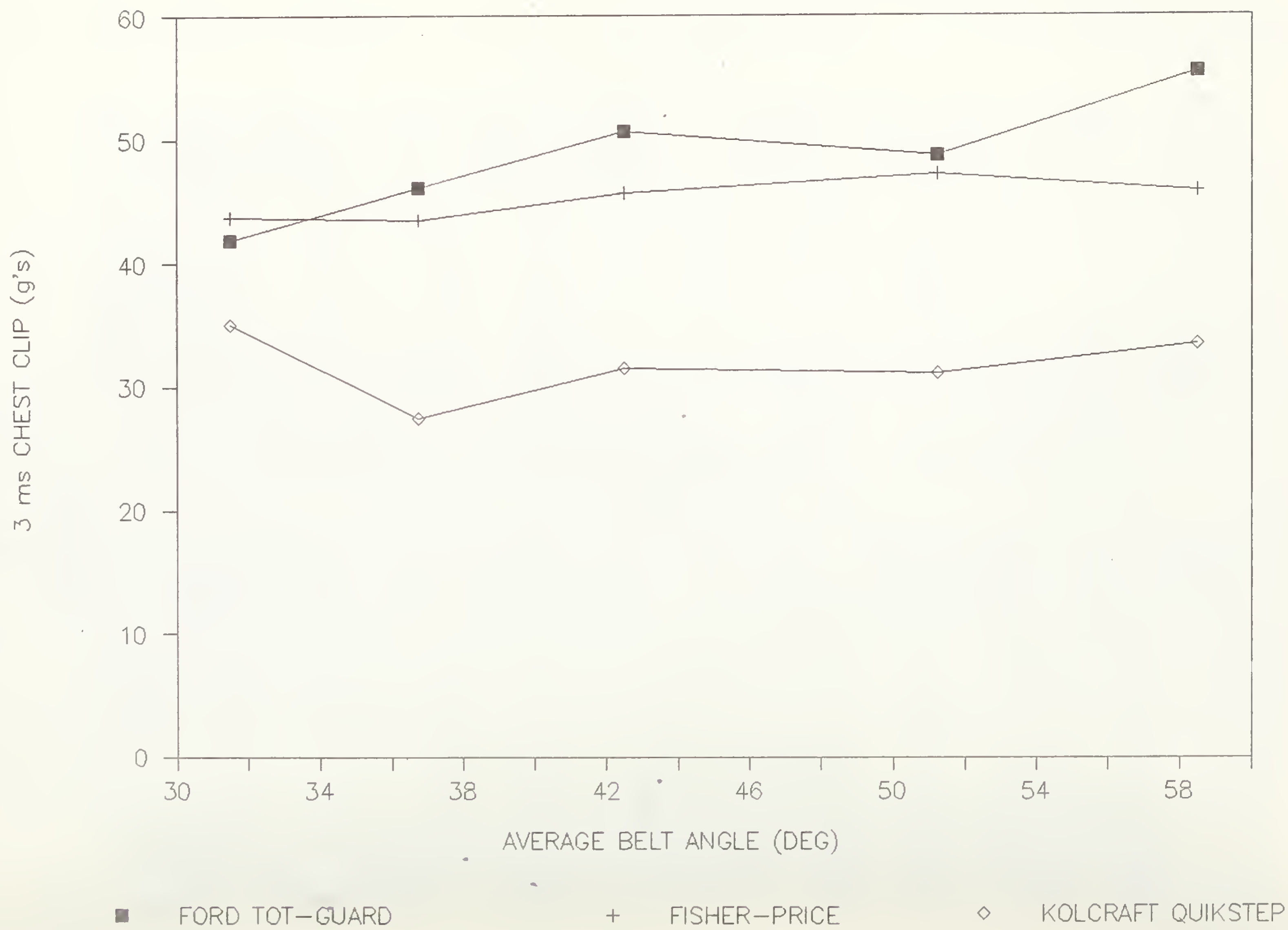


FIGURE 3.2 -- Effect of Average Belt Angle on Chest Acceleration

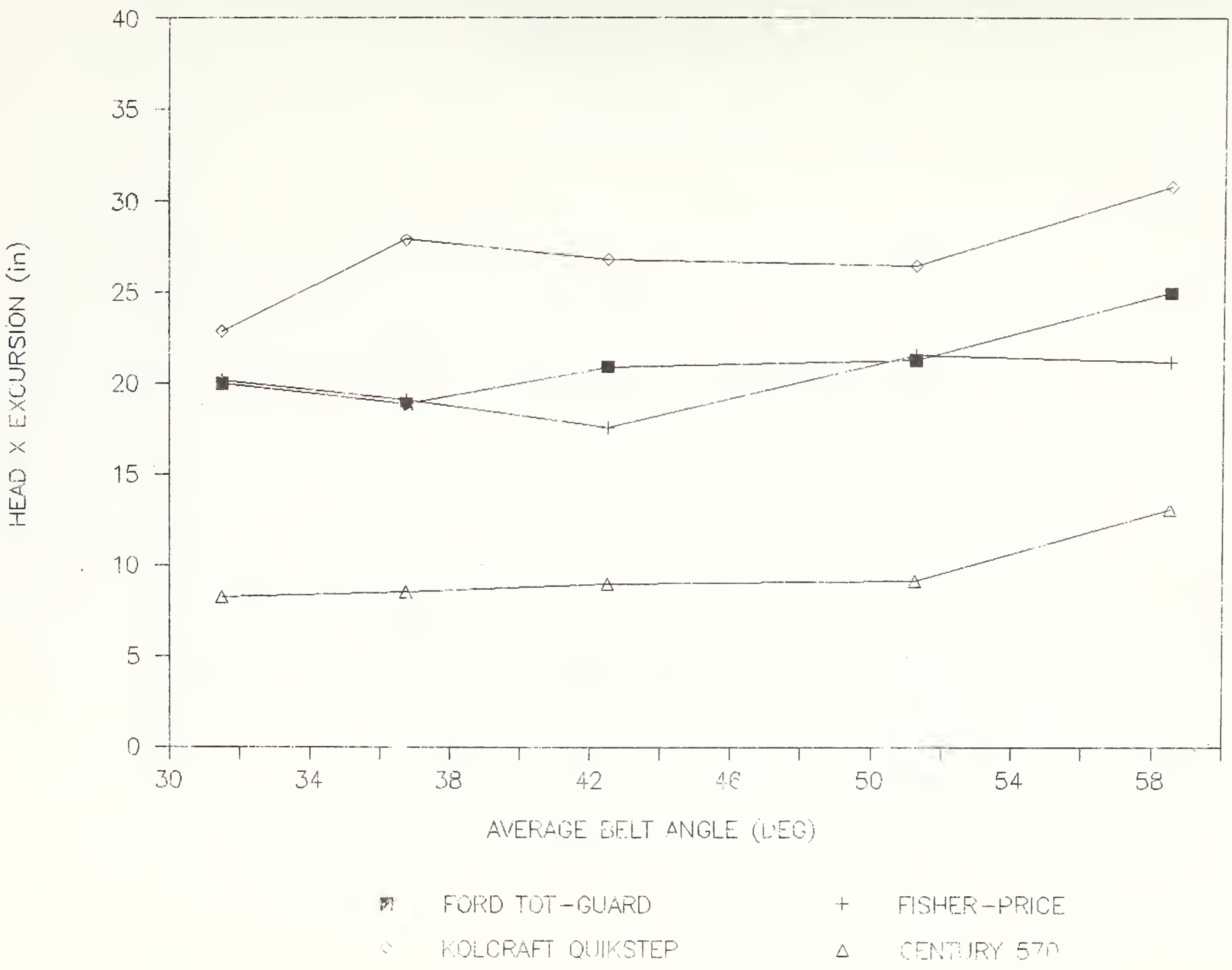


FIGURE 3.3 -- Effect of Average Belt Angle on Head Excursion

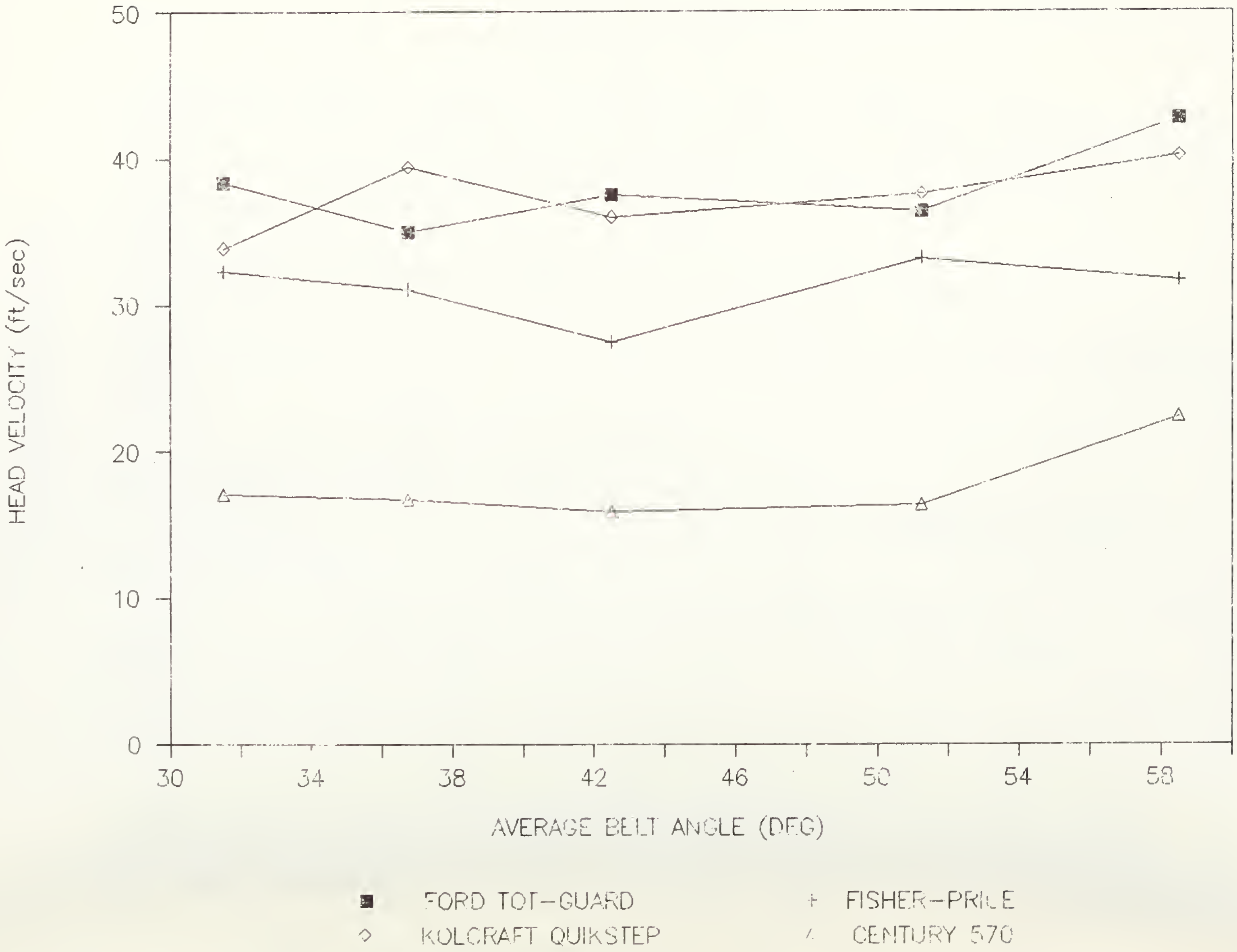


FIGURE 3.4 -- Effect of Average Belt Angle on Head Velocity

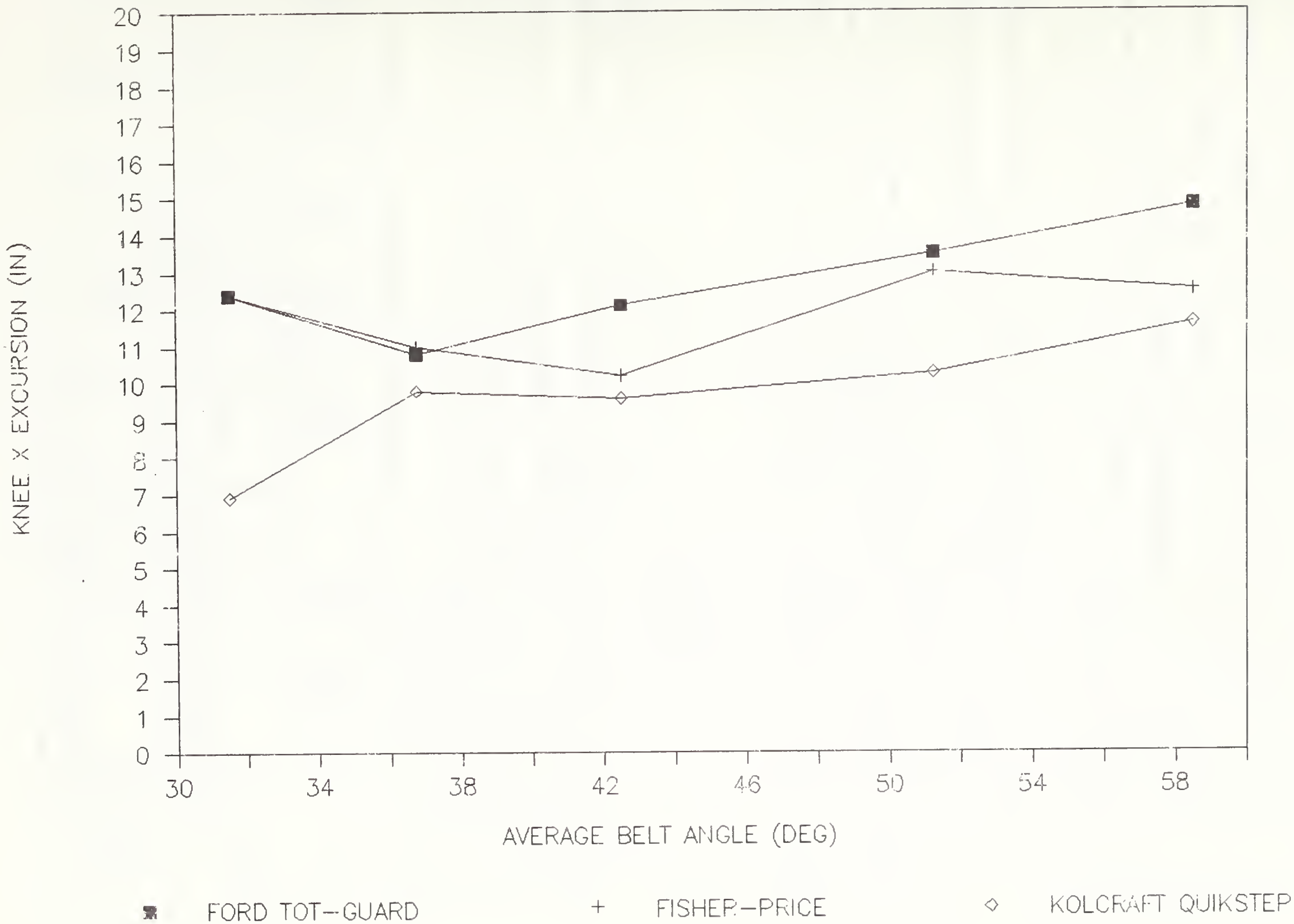


FIGURE 3.5 -- Effect of Average Belt Angle on Knee Excursion

Variations due to lap belt angle for the 6-year old in the Kolcraft Quikstep and the 6-month old in the Century 570 seat appeared to be comparable to those in the Tot Guard and Fisher Price; slight increases for some of the responses -- in particular, head and knee excursions -- were seen with increasing belt angle. Since no repeatability data were obtained for these seats, very little can be said regarding the significance of these variations. However, it is reasonable to expect similar repeatability in these child seats as in the Tot Guard and Fisher Price seats.

In subsequent tests, the results of which were used to evaluate the remaining parameters (parameters 2 through 9), lap belt angles were essentially fixed at average values. Although some variation occurred in lap belt angles (as described in Section 2.2.1), these variations were small compared with the total range of angles over which the belt-angle-effect tests were conducted. Therefore, this variation was not considered to influence subsequent parameter evaluations.

3.3.2 Seat Cushion Stiffness

Tests were conducted with the Fisher Price and Ford Tot Guard child seats to determine the effects of seat cushion stiffness. Results of these tests are presented in Table 3.6. The "stiff" cushion was from the Toyota Camry, the "soft" cushion was from the Buick Electra, and "213" refers to the standard foam cushion specified in the FMVSS 213 test procedure. Test Groups III, IV, and V are defined in Table 3.3.

TABLE 3.6 -- Seat Cushion Stiffness Sensitivity Test Results

CHILD SEAT	STIFFNESS	TEST GROUP	HEAD R ACCEL (g)	HIC	HEAD X EXCURSION (in)	HEAD VELOCITY (ft/sec)	CHEST R ACCEL (g)	3 ms CHEST CLIP (g)	KNEE X EXCURSION (in)
FISHER-PRICE	STIFF	III	58.0	535	22.0	32.5	45.4	41.7	10.7
FISHER-PRICE	SOFT	V	69.0	602	23.4	35.2	51.7	43.7	13.3
FISHER-PRICE	213	IV	63.3	572	21.4	32.5	43.1	42.1	11.3
	1/2 RANGE/MEAN %		7.8%	5.9%	4.5%	4.0%	3.2%	9.0%	10.7%
FORD TOT GUARD	STIFF	III	115.5	1106	20.1	32.8	51.0	43.8	10.8
FORD TOT GUARD	SOFT	V	127.4	1179	22.7	41.6	58.3	55.0	12.2
FORD TOT GUARD	213	IV	127.2	1178	20.5	36.9	44.7	44.5	10.1
	1/2 RANGE/MEAN %		4.8%	3.2%	6.2%	11.3%	13.2%	11.7%	9.6%

For the Fisher Price seat, the only response whose variation exceeded the repeatability variation by more than a factor of two was the maximum chest acceleration. For the Tot Guard, only head velocity and maximum chest acceleration variations exceeded twice the corresponding repeatability variations. Although the two significant Tot Guard response variations were fairly large (12% to 13%), no consistent trends were observed. The "soft" Electra and FMVSS 213 cushions have similar stiffnesses, yet in many cases the dummy response for the 213 cushion was closer to that of the "stiff" Camry than it was to the Electra. It was also observed that dummy responses from the FMVSS 213 cushion fell either between responses from the stiff and soft cushions or very close to one of them.

Consequently, seat cushion stiffness, over a representative range, was considered to have relatively little effect on dummy responses, and the FMVSS 213 cushion was judged to be representative of the rear seats of current cars. Therefore, the remaining parameters (parameters 3 through 9) were evaluated from tests done exclusively with the FMVSS 213 cushion.

3.3.3 Test Conditions for Parameters Three through Nine

The test conditions for the remaining parameters and parameter combinations are summarized in Table 3.7. (In subsequent discussions, the term "parameter" is used to refer to parameter combinations as well as individual parameters.) For example, the first row of the table contains information on parameter 3, seat geometry. It shows that the seat geometry in Test Condition I was as per FMVSS 213, and in Test Condition II was the new generic design. It also shows that the tests for evaluating parameter 3 were conducted with the other parameters at the following levels:

Acceleration pulse = Average car pulse
Velocity change = 39 mph
Seat cushion = FMVSS 213 cushion
Seat belt pretension = High (i.e., as per FMVSS 213)

Note that two of the parameters -- parameters 7 and 8 -- were compared under two different sets of test conditions.

TABLE 3.7 -- Test Conditions for Evaluation of Parameters 3-9

PARAMETER IDENTI-FICATION NO.	PARAMETER	Test Condition I					Test Condition II				
		PULSE	DV	CUSHION	SEAT GEOMETRY	BELT TENSION	PULSE	XV	CUSHION	SEAT GEOMETRY	BELT TENSION
3	SEAT GEOMETRY	AVG CAR	39	213	213	HIGH	AVG CAR	39	213	GENERIC	HIGH
4	PULSE	213	30	213	213	HIGH	AVG CAR	30	213	213	HIGH
5	DELTA V	AVG CAR	39	213	213	HIGH	AVG CAR	30	213	213	HIGH
6	BELT PRETENSION	AVG CAR	39	213	GENERIC	HIGH	AVG CAR	39	213	GENERIC	LOW
7*	SEAT GEOMETRY BELT PRETENSION	AVG CAR	39	213	213	HIGH	AVG CAR	39	213	GENERIC	LOW
7*	SEAT GEOMETRY BELT PRETENSION	213	30	213	213	HIGH	213	30	213	GENERIC	LOW
8*	PULSE DELTA V	213	30	213	213	HIGH	AVG CAR	39	213	213	HIGH
8*	PULSE DELTA V	213	30	213	GENERIC	LOW	AVG CAR	39	213	GENERIC	LOW
9	PULSE DELTA V SEAT GEOMETRY BELT PRETENSION	213	30	213	213	HIGH	AVG CAR	39	213	GENERIC	LOW

* Note that parameters 7 and 8 each were evaluated under two different test conditions sets

The test results for parameters 3 through 9 are summarized in Tables 3.8 and 3.9 for the Ford Tot Guard and Fisher Price child seats, respectively. The third column of each of these tables, "Level", lists the two conditions under which tests were conducted for each parameter. In the fourth column are the numbers of those tests that were used for making the comparison. The test numbers lie on the same line as the corresponding level for the parameter. For some test conditions there were more than one test conducted, while for others there was only a single test. The next seven columns contain the filtered peak measurements and injury criteria values (averages where more than one test were available).

As previously defined, a parameter had a "significant" effect if its variation exceeded twice the repeatability variation. It was "marginally significant" if the response variation was greater than, but less than twice, the repeatability variation. For convenience in comparing parameter and repeatability variations, the average repeatability half-range/mean values from Table 3.4 are reproduced in Tables 3.8 and 3.9; they appear at the top of the tables, directly beneath the headings, "Head R Accel", "HIC", etc.

A detailed examination of Tables 3.8 and 3.9 can be made to determine the specific effect (and its significance) of each parameter on each response (head resultant accelerations, HIC, etc.) In the following paragraphs, results are summarized for each parameter.

3.3.3.1 Seat Geometry

As stated in Section 2.2.1, the seat (and restraint) geometry was defined by:

1. Seat back cushion angle.
2. Seat bottom cushion angle.
3. Seat cushion length.
4. Inboard and outboard lap belt lengths.
5. Inboard and outboard lap belt angles.
6. Lateral distance between inboard and outboard anchors.

TABLE 3.8 -- Test Results for Evaluation of Parameters 3-9 - Fisher Price Child Seat

PARAMETER IDENTI-FICATION NO.	PARAMETER	LEVEL	REPEATABILITY HALF-RANGE/MEAN → / TEST NUMBERS	HEAD R ACCEL (g)	HIC	HEAD X EXCURSION (in)	HEAD V (ft/s)	CHEST R ACCEL (g)	3ms CHEST CLIP (g)	KNEE X EXCURSION (in)
				5.1%	8.8%	5.6%	4.9%	2.5%	2.5%	6.8%
3	SEAT GEOMETRY	213	3, 25, 26, 27	62.6	621	23.3	35.2	44.4	43.7	12.6
		Generic	35	63.1	608	23.3	36.1	47.7	46.7	13
			1/2 range/mean (%)	0.4%	1.1%	0.0%	1.3%	3.6%	3.3%	1.6%
4	PULSE	213	32	47.9	354	20.8	33.3	45.2	43.8	13.4
		Average car	38	35.5	163	15.4	19.8	28.9	28.4	8.5
			1/2 range/mean (%)	14.9%	36.9%	14.9%	25.4%	22.0%	21.3%	22.4%
5	DELTA V	39	3, 25, 26, 27	62.6	621	23.3	35.2	44.4	43.7	12.6
		30	38	35.5	163	15.4	19.8	28.9	28.4	8.5
			1/2 range/mean (%)	27.6%	58.4%	20.4%	28.0%	21.1%	21.2%	19.4%
6	BELT PRETENSION	High	35	63.1	608	23.3	36.1	47.7	46.7	13
		Low	36	70.7	835	25.8	39.4	51.3	49.3	14.1
			1/2 range/mean (%)	5.7%	15.7%	5.1%	4.4%	3.6%	2.7%	4.1%
7	SEAT GEOMETRY & BELT PRETENSION	213/High	3, 25, 26, 27	62.6	621	23.3	35.2	44.4	43.7	12.6
		Generic/Low	36	70.7	835	25.8	39.4	51.3	49.3	14.1
			1/2 range/mean (%)	6.1%	14.7%	5.1%	5.6%	7.2%	6.0%	5.6%
7	SEAT GEOMETRY & BELT PRETENSION	213/High	32	47.9	354	20.8	33.3	45.2	43.8	13.4
		Generic/Low	34	53.6	349	21.5	33.8	47.6	46	12.8
			1/2 range/mean (%)	5.6%	0.7%	1.7%	0.7%	2.6%	2.4%	2.3%
8	PULSE & DELTA V	213/30	32	47.9	354	20.8	33.3	45.2	43.8	13.4
		Average Car/39	3, 25, 26, 27	62.6	621	23.3	35.2	44.4	43.7	12.6
			1/2 range/mean (%)	13.3%	27.4%	5.7%	2.8%	0.9%	0.1%	3.1%
8	PULSE & DELTA V	213/30	34	53.6	349	21.5	33.8	47.6	46	12.8
		Average car/39	36	70.7	835	25.8	39.4	51.3	49.3	14.1
			1/2 range/mean (%)	13.8%	41.0%	9.1%	7.7%	3.7%	3.5%	4.8%
9	PULSE, DELTA V, SEAT GEOMETRY, & BELT PRETENSION	213/30/213/High	32	47.9	354	20.8	33.3	45.2	43.8	13.4
		A.C./39/Gen/Low	36	70.7	835	25.8	39.4	51.3	49.3	14.1
			1/2 range/mean (%)	19.2%	40.5%	10.7%	8.4%	6.3%	5.9%	2.5%

(1) 213 Standard Seat Geometry & restraint configuration
(2) New, generic seat geometry & restraint configuration with low belt pretension

TABLE 3.9 -- Test Results for Evaluation of Parameters 3-9 -- Ford Tot Guard Child Seat

PARAMETER IDENTI-FICATION NO.	PARAMETER	LEVEL	TEST NUMBERS / REPEATABILITY HALF-RANGE/MEAN	HEAD R ACCEL (g)	HIC	HEAD X EXCURSION (in)	HEAD V (ft/s)	CHEST R ACCEL (g)	3ms CHEST CLIP (g)	KNEE X EXCURSION (in)
				11.7%	7.5%	5.6%	5.7%	4.2%	3.0%	5.4%
3	SEAT GEOMETRY	213	25, 26, 27	75.1	693	26.5	42.6	39	37.2	9.6
		Generic	35	87.4	1021	23.4	40.3	48.4	44.6	11.5
		1/2 range/mean (%)		7.6%	19.1%	6.2%	2.8%	10.8%	9.0%	9.0%
4	PULSE	213	32	56.7	575	23.8	39.7	43	34.8	10.3
		Average Car	39	50.1	330	21.4	29.4	28.2	27.9	7.4
		1/2 range/mean (%)		6.2%	27.1%	5.3%	14.9%	20.8%	11.0%	16.4%
5	DELTA V	39	25, 26, 27	75.1	693	26.5	42.6	39	37.2	9.6
		30	39	50.1	330	21.4	29.4	28.2	27.9	7.4
		1/2 range/mean (%)		20.0%	35.5%	10.6%	18.3%	16.1%	14.3%	12.9%
6	BELT PRETENSION	High	35	87.4	1021	23.4	40.3	48.4	44.6	11.5
		Low	36	91	1097	23.7	41.1	53.6	49.9	11.2
		1/2 range/mean (%)		2.0%	3.6%	0.6%	1.0%	5.1%	5.6%	1.3%
7	SEAT GEOMETRY & BELT PRETENSION	213/High	25, 26, 27	75.1	693	26.5	42.6	39	37.2	9.6
		Generic/Low	36	91	1097	23.7	41.1	53.6	49.9	11.2
		1/2 range/mean (%)		9.6%	22.6%	5.6%	1.8%	15.8%	14.6%	7.7%
7	SEAT GEOMETRY & BELT PRETENSION	213/High	32	56.7	575	23.8	39.7	43	34.8	10.3
		Generic/Low	33, 34	84.8	910	22.1	41.3	51.2	47.4	11.5
		1/2 range/mean (%)		19.9%	22.6%	3.7%	2.0%	8.7%	15.3%	5.5%
8	PULSE & DELTA V	213/30	32	56.7	575	23.8	39.7	43	34.8	10.3
		Average car/39	25, 26, 27	75.1	693	26.5	42.6	39	37.2	9.6
		1/2 range/mean (%)		14.0%	9.3%	5.4%	3.5%	4.9%	3.3%	3.5%
8	PULSE & DELTA V	213/30	33, 34	84.8	910	22.1	41.3	51.2	47.4	11.5
		Average car/39	36	91	1097	23.7	41.1	53.6	49.9	11.2
		1/2 range/mean (%)		3.5%	9.3%	3.5%	0.2%	2.3%	2.6%	1.3%
9	PULSE, DELTA V, SEAT GEOMETRY, & BELT PRETENSION	213/30/213/High	32	56.7	575	23.8	39.7	43	34.8	10.3
		A.C./39/Gen/Low	36	91	1097	23.7	41.1	53.6	49.9	11.2
		1/2 range/mean (%)		23.2%	31.2%	0.2%	1.7%	11.0%	17.8%	4.2%

The tests were conducted with the seat geometry in either of two configurations: the FMVSS 213 or the new generic design. (As previously mentioned, the "FMVSS 213" configuration used in this project differed from that of FMVSS 213 in that locking seat belt retractors were used, and the seat and seat back were rigidly attached.)

Ford Tot Guard -- HIC and chest accelerations (peak resultant and 3 msec clip) were significantly higher in the new generic seat geometry. The HIC values were 1021 and 693, and chest acceleration differences were about 10% (half-range/mean values). Head and knee excursion differences were marginally significant and were not large (6% and 9%, respectively). The FMVSS 213 geometry produced a higher head excursion, but a lower knee excursion. Other response differences were not significant.

These differences are due primarily to the greater rearward inclination of the generic seat. In the generic seat, the dummy moved forward from a more inclined initial position, striking its head and chest solidly on the shield (Figure 3.6). In the FMVSS 213 seat, the dummy started its motion from a more nearly upright position. The head nearly passed over the shield, resulting in greater excursion and a less severe impact and the chest also contacted the shield less solidly (Figure 3.7). The dummy experienced more upper body rotation and less knee excursion than in the generic seat.

Fisher Price -- The chest response (peak resultant g's and 3 msec clip) was marginally significant, being higher in the generic design by only 3 g's. All other responses were insignificant.

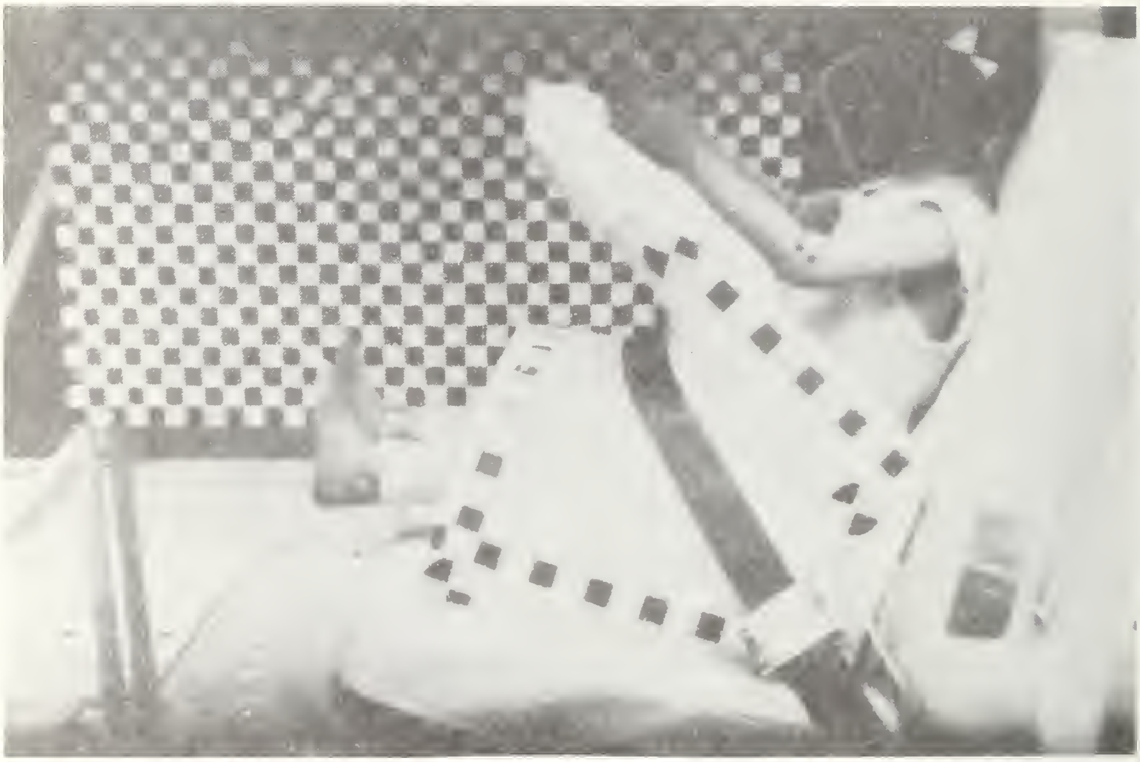
3.3.3.2 Acceleration Pulse

The two levels for this parameter were the standard FMVSS 213 sled pulse and the average car pulse (see Section 2.2.2). The average car pulse was derived from 35 mph crash test data and was run at 30 mph for direct comparison with the 30 mph FMVSS 213 pulse.

Initial Position

At Maximum Excursion

FIGURE 3.6 -- Dummy Trajectory in Generic Seat



Initial Position

At Maximum Excursion

FIGURE 3.7 -- Dummy Trajectory in FMVSS 213 Seat

Ford Tot Guard -- All responses except head resultant acceleration and head excursion were significantly higher due to the stiffer FMVSS 213 pulse. However, HIC values were low (575 and 330), so although the numerical difference was significant, no major difference in predicted injury severity would be expected.

Fisher Price -- All responses were significantly higher due to the stiffer FMVSS 213 pulse. However, HIC values were very low (354 and 163); therefore, HIC differences were meaningless in terms of injury severity prediction.

3.3.3.3 Velocity Change (ΔV)

Tests were conducted at ΔV's of 30 mph (as per FMVSS 213) and 39 mph (the average ΔV for 35 mph barrier crash tests).

Ford Tot Guard -- As expected, all responses were significantly higher in the higher speed tests, except for head resultant acceleration and excursion; and even those two responses had nearly twice the variation seen in the repeatability tests.

Fisher Price -- All responses were significantly higher in the 39 mph ΔV tests. (As before, it should be recognized that HIC differences are not particularly significant in terms of injury severity differences, since values are well below 1000. This is true for the Tot Guard, as well.)

3.3.3.4 Lap Belt Pretension

Tests were conducted with lap belt pretension set as specified in FMVSS 213 ("high" pretension), and set to simulate typical retractor belt tension ("low" pretension).

Ford Tot Guard -- This parameter had very little effect. Only chest acceleration was marginally significant, the low belt pretension resulting in slightly higher chest g's.

Fisher Price -- Head acceleration, HIC, and chest acceleration were marginally significant. The low belt pretension produced slightly higher responses.

3.3.3.5 Seat Geometry / Lap Belt Pretension

The parameter combination of the standard FMVSS 213 seat geometry with high belt tension (both parameter levels as per FMVSS 213) was compared with the combination of the new generic seat geometry and low belt pretension. Referring to Table 3.7, the reader can see that this parameter combination was compared under two different sets of test conditions: 1) using the average car sled pulse at a velocity change of 39 mph, with the FMVSS 213 seat cushion; and 2) using the standard FMVSS 213 sled pulse at a velocity change of 30 mph, also with the FMVSS 213 seat cushion.

Ford Tot Guard -- The two test condition sets gave essentially the same results. For the generic seat geometry and low belt pretension, HIC and peak chest g's were significantly higher, and knee excursion was slightly higher (a marginally significant effect). The differences were due primarily to the greater rearward inclination of the generic seat, as described previously (see Section 3.3.3.1).

Fisher Price -- The effect of this parameter combination was somewhat dependent on the test condition set. A greater effect resulted when the average car sled pulse and higher ΔV were used. Under this test condition set, the generic seat geometry with low belt pretension produced significantly greater chest g's (although the magnitude of the difference was not great), and marginally greater head g's, HIC, and head velocity. In the other test condition set (FMVSS 213 sled pulse at 30 mph), almost no effect was seen -- peak head and chest accelerations were just barely marginally significant.

3.3.3.6 Acceleration Pulse / Velocity Change

The FMVSS 213 acceleration pulse at a 30 mph velocity change was compared with the new average car acceleration pulse at a 39 mph velocity change. As in the previous parameter combination, two sets of test conditions were used: 1) the FMVSS 213 seat geometry with high belt pretension, and 2) the generic seat geometry with low belt pretension.

Ford Tot Guard -- Results were similar for the two test condition sets; the effects of this parameter combination were small. HIC values were marginally significant. (As before, numerical significance does not necessarily imply injury severity significance.) Under one of the test condition sets, peak head and chest accelerations were just barely marginally significant. (In fact, marginal significance for the peak chest acceleration is doubtful, since the average car pulse at 39 mph produced a higher peak acceleration, but lower 3 msec clip value.)

Fisher Price -- As with the Tot Guard, results were similar for the two test condition sets. However, this parameter combination had a much greater effect on head accelerations than occurred with the Tot Guard. Peak head accelerations and HIC values were significantly greater for the average car pulse at 39 mph. (Note, however, that in most of the tests, HIC values were quite low.) Head excursion was marginally greater for this pulse and ΔV in both test condition sets, and head velocity and peak chest acceleration were marginally greater in only one of the test condition sets.

3.3.3.7 Overall Test Configuration

The final comparison was made between two tests -- one conducted with all four parameters as specified in FMVSS 213:

- FMVSS 213 acceleration pulse
- 30 mph velocity change
- FMVSS 213 seat geometry
- High lap belt pretension

and the other conducted with all four parameters at the revised levels:

- Average current car acceleration pulse
- 39 mph velocity change (35 mph barrier crash)
- New generic (current typical) rear seat geometry
- Low lap belt pretension (typical retractor tension)

Ford Tot Guard -- Head and chest accelerations were significantly higher at the revised parameter levels -- HIC was nearly doubled (1097 vs. 575), and peak chest accelerations were 10 to 15 g's greater.

Fisher Price -- As in the Tot Guard, head and chest accelerations were significantly higher at the revised parameter levels. HIC was more than doubled (835 vs. 354), and peak chest accelerations increased by about six g's. Also, head excursion and velocity were marginally greater for the revised parameter levels.

4.0 SUMMARY

Repeatability was examined for responses of 3-yr old child dummies in Fisher Price and Ford Tot Guard child seats. Half-range/mean values ranged from 2.5% to 11.7%; the highest were for peak head accelerations and HIC values, and the lowest were for peak chest accelerations.

The effects of several parameters were determined. Significance of each effect was estimated by comparing response variations from parameter changes with corresponding response variations attributable to experimental repeatability. General results were as follows:

Lap Belt Angle

Increasing average lap belt angle over a range found in current production cars (approximately 30 to 60 degrees) slightly increased some of the child dummy responses in the four child seats tested. The largest and most significant effects were seen in the Ford Tot Guard.

Seat Cushion Stiffness

Response differences among the stiff (Camry), soft (Electra), and FMVSS 213 seat cushions were not sufficiently large or consistent to warrant specifying a different cushion than that currently specified in the FMVSS 213 test procedures. The FMVSS 213 cushion is considered to be representative of the rear seats of current cars.

Seat Geometry

Two responses in the Ford Tot Guard -- HIC and peak chest accelerations -- were significantly higher in the generic car seat geometry, which simulates current car rear seats more closely than the FMVSS 213 test seat geometry. A few other responses (only one in the Fisher Price) were marginally significant. The reason for the difference was the greater rearward inclination of the generic seat, as compared with the FMVSS 213 seat, causing more direct head and chest contact with the Ford Tot Guard shield.

Acceleration Pulse

An average car acceleration pulse was derived from 35 mph crash test data and was scaled to a velocity change of 30 mph for direct comparison with the 30 mph ΔV FMVSS 213 pulse. Almost all the responses in both child safety seats were significantly lower due to the average car pulse. (HIC values, however, were low; therefore, significant numerical differences did not imply significant injury severity differences.)

The FMVSS 213 acceleration pulse provided a significantly more severe environment than the average car barrier crash pulse for a velocity change of 30 mph. (Note that, due to rebound, a 30 mph ΔV would result from a barrier crash velocity of about 26-27 mph.)

Velocity Change

Nearly all responses in both child seats were significantly higher at a velocity change of 39 mph (the average ΔV for 35 mph barrier crash tests) than at 30 mph. (HIC values, however, were well below 1000; therefore, significant numerical differences did not imply significant injury severity differences.)

Lap Belt Pretension

A few responses (only one for the Ford Tot Guard) were marginally significantly higher when low lap belt pretension (simulating typical retractor tension) was used, rather than the pretension specified in the FMVSS 213 test procedures.

Seat Geometry / Lap Belt Pretension

The combination of the generic seat geometry and low belt pretension (more closely simulating the rear seats of today's cars) increased some of the responses in both child seats. The largest differences were for HIC and peak chest acceleration in the Ford Tot Guard, resulting from greater contact with the shield in the generic seat, due to its more rearward inclination. None of the differences in the Fisher Price seat were very large.

Acceleration Pulse / Velocity Change

In comparing the FMVSS 213 acceleration pulse at a 30 mph ΔV with the average car pulse at 39 mph, the effects of the stiffer FMVSS 213 pulse were largely offset by the lower ΔV. Most differences were marginal, the average car pulse at 39 mph generally causing slightly higher responses. (The exception was in the Fisher Price seat, where HIC values were significantly greater due to the new pulse at 39 mph. Most HIC values, however, were well below 1000; therefore, significant numerical differences did not imply significant injury severity differences.)

The generally small observed differences indicate that the existing FMVSS pulse/ΔV combination is comparable in severity to a more representative crash pulse at a higher velocity (slightly less than 35 mph barrier crash velocity).

Overall Test Configuration

With all four parameters (seat geometry, acceleration pulse, velocity change, and belt pretension) at the revised levels, as compared with FMVSS 213 levels, head and chest responses were significantly higher in both child safety seats. (I.e., decreases in responses due to the softer average car pulse were more than offset by changes in the other three parameters.)

Thus, if some of the FMVSS 213 test parameters (specifically, seat geometry, acceleration pulse, and lap belt pretension) were revised to better simulate today's rear seat environment, and the test were conducted at a velocity change representing a 35 mph barrier collision, the test environment would be somewhat more severe than that of the current FMVSS 213.

5.0 REFERENCES

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