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CHILD SEAT AND RESTRAINT SYSTEMS TEST PROGRAM

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16. Abstract

The three objectives of this research program were to: (1) define the state of the art in child seating and restraint systems; (2) evaluate the various types of devices which are in use; and, (3) recommend performance requirements and compliance test procedures for child seating and restraint systems. After an extensive market survey, 37 devices manufactured by 26 companies were selected for the test programs. These devices were tested in frontal, side, oblique, and rear impact. Oscillographic transducer data and high speed motion picture data were obtained and studied.

The performance criterion which was used in evaluating the test data specified: (1) limitations of body motions; (2) adequate load distribution over the surface of the body; and, (3) limitations on acceleration levels applied to the body. In addition, observations were made concerning: (1) structural integrity of the devices tested; (2) dynamic interaction between the child restraint devices and the adult seat on which they were mounted; and, (3) the means by which the child seats and restraint systems were attached to the vehicle. It was recommended that a dynamic impact test be carried out to determine if a child restraint system offers protection to its occupant and that test results be rated by the performance criterion.

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PART I. INTRODUCTION

The three objectives of this project are:

1. Define the state of the art in child seating and restraint systems
2. Evaluate the various types of devices in use
3. Recommend performance requirements and compliance test procedures for child seating and restraint systems.

The project was begun by studying the current state of the art and by conducting an extensive market survey of available seats and restraint systems, the results of which are discussed in Part II of this report. It was found that little is known about the impact tolerance of children and infants, but that numerous safety devices are being marketed by many manufacturers, both large and small. Specific attention was given to 125 devices being manufactured by 34 corporations. Of these, 37 devices manufactured by 26 of the companies were selected for the test program.

The first step in designing the test program, based on the completion of the market survey, was the selection of performance criteria to be used in evaluating the results. These criteria included the specification that body motions and decelerative g-loadings be limited and that forces applied directly to the body be well distributed.

Using the performance criteria as a guide, the test environment was selected which consisted of a durable bucket seat which could be mounted on the Highway Safety Research Institute's impact sled to simulate front, side, rear, and oblique impacts. The Sierra 3-year child dummy which served as the test subject for the bulk of the tests was instrumented with accelerometers to record head and chest g-loadings. High speed photographic coverage was also provided. A total of 120 dynamic sled tests were carried out.

A discussion of the test program is presented in Part III of this report and the test results are described in Part IV. The raw test data, given in Appendix D which is bound separately from this main report, are summarized in a data table included in the text and in Appendix C which is composed of a discussion of each device tested.

Part V consists of a discussion of performance requirements and compliance test procedures. It is obvious that child restraint devices should limit the motions experienced by a child occupant. However, because of the lack of data on impact tolerance, only preliminary suggestions can be made for allowable loadings which can be safely experienced by the child. The authors of this report believe strongly that a dynamic test procedure using an impact sled or other dynamic device is necessary for a complete evaluation of performance and compliance to the recommendations set forth in this report.

PART II. STATE OF THE ART AND MARKET SURVEY

A review of the state of the art of child seating and restraint systems can include several areas such as the hardware marketed, user tolerance to impact loadings, the anthropometry of infants and children, and total system design. Each of these subjects is generating considerable interest at the present time.

The most general discussion of the protection of children in an automobile crash can be found in a report by Siegel, et al.[1], which covers the frequency of various types of injury and child anthropometry as it relates to seating design. Based on accident cases, they recommended the use of lap belts for children over 3-4 years of age. In addition, they evaluated several of the devices which were being marketed at the time.

Burdi[2] and King[3] have presented excellent discussions which are anthropologically and medically oriented. After discussing the anatomy of children, Burdi gave several guidelines for the design and selection of child restraint systems. Great importance was placed on head motions, particularly the snapping which can occur because of the lack of strength in children's neck muscles. He suggested that any head contact with the interior of a vehicle should be avoided due to a child's relatively weak braincase. Also, the danger in using an adult lap belt was mentioned in that the iliac crests are not sufficiently developed to act as belt anchor locations, and caution was suggested in applying restraint loads to the chest, due to both its highly compressible nature and the vulnerability of the internal organs to nonpenetrating injuries. Finally, distribution of restraint loads over wide areas of the body was suggested as an important design criterion.

The discussion presented by King[3] was similar in that a thorough discussion of child anthropometry was followed by a set of design criteria. For children under 50 lbs., he suggested that a stable support platform be provided for any device. He noted that extreme motion is not desirable due to the danger of contact with interior vehicle structures. Requirements for distribution of load over wide areas of the body, the importance of the location of the center of gravity in dynamic design, and the vulnerability of internal organs were also mentioned as important considerations. For children weighing more than 50 lbs., a stiff seat booster cushion, a stable mounting platform, and an adult lap belt were recommended.

Other authors have suggested rear-facing children's seats. This concept has been applied in marketed designs and appeared to be valid in the current test program. In a recent paper, Van Kirk[4] suggested a restraint net as a concept worthy of attention on the basis of gentle rides experienced by primates in dynamic tests.

In two papers concerned with the design, testing and production of children's seat-restraint systems, Head[5] discussed the widely publicized Ford Tot-Guard and Feles[6] discussed the General Motors Infant Carrier. The development and test programs surrounding the introduction of these two devices to the market are the most thorough known to the present authors.

All of the concepts and devices mentioned in the foregoing discussion have been submitted to scrutiny in this test program, and it was found that most of the design criteria suggested in the literature were very important. In addition, several other criteria related to occupant kinematics, structural design strength, and occupant loading have been found to be equally important and will be documented later in this report.

The first step in organizing the experimental phase of this research project involved determining what seats and restraint systems were available on the market. It became immediately clear that many devices were being marketed and that the market changed rapidly from month to month. The devices tested and studied were available between February and August 1969.

In all, 125 devices marketed by 34 different companies were studied. Of these, 37 devices from 26 of the companies were selected for testing. These are listed in Appendix A of this report.

At first glance, this seems to be a rather large collection of devices. However, the need for evaluation of this many tests resulted from the survey of the different techniques used to restrain the child or to attach the seat to the vehicle. Consider the following classifications:

1. Basic restraint concepts.
   a. Device classified as a seat.
   b. Device classified as a harness.
2. Normal attitude of occupant.
   a. Sitting forward-facing.
   b. Sitting rearward-facing.
   c. Standing.
   d. Reclining.
   e. Semi-reclining.
3. Technique of attachment of device to vehicle.
   a. Hookover seat.
   b. Hookunder seat.
   c. Tiedown with adult lap belt.
   d. Tiedown with strap around adult seat back.
   e. Tiedown with strap over or around adult seat back which is anchored to the vehicle.

4. Head restraint.
   a. High-back seat with integral head rest.
   b. No head restraint.
   c. Automotive type adjustable head rest.
   d. Lateral structures to provide head restraint.
5. Seat structure.
   a. Tubular framework.
   b. Molded plastic shell.
   c. Fabric.
6. Integral restraint devices.
   a. Integral lap belt.
   b. Integral belly strap.
   c. Integral horizontal chest strap.
   d. Diagonal chest strap.
   e. Integral double diagonal harness.
   f. Crotch strap.
   g. Vest.
   h. Padded rail.

Several more subclasses could easily be specified; for instance, the webbing material, the techniques of stitching, the buckles, or the structural class of the various tubular frameworks used to support the seats. It should be observed that each of the major classes above, as well as the subclasses mentioned, proved to be important in evaluating the seats selected for this series of tests.

In reducing the number of devices to be tested to 37 and the companies to 26, certain major producers were omitted. It was often found that two or more companies were marketing devices similar in most respects. In these cases, the selection of one particular company was determined by local product availability. The 37 devices selected for testing appeared to be the minimum number capable of providing a reasonably complete evaluation of the restraint concepts being incorporated into actual hardware at the present time.

It was also necessary to determine the age or size group which could use the seats selected for testing. This information was provided with only a few of the devices, which specified either an age group or an upper limit on weight. In only one case were both an age and a weight group specified (K.L. Jeenay). Because of this, the other manufacturers were contacted directly by phone. The average minimum age recommended for use of seat devices was that age at which the occupant could sit unattended. Specific minimum ages ranged from about 3 months to a few over 1 year. The maximum age recommendations averaged over 3 years, with a range from 2 1/2 years to 6 years. Five devices were in the 2 1/2 year class, with eleven in the class of 4 years or over. In the six cases where a maximum weight was given, all recommendations were between 30 and 40 lbs.

The harnesses generally were recommended for use by infants who could sit unattended, up through 6-year olds. Maximum weight limitations, often specified with the device, ranged from 50-75 lbs.

PART III. TEST PROGRAM

The basic objective of the test program described in this section of the report is to obtain an experimentally determined estimation of the protective potential which the 37 devices described previously can offer to the child occupant. In order to achieve this, it was necessary to:

1. Develop a performance criterion for evaluating the various devices;
2. Select an occupant for use in the test program;
3. Select a test environment including an adult seat capable of being oriented so that impacts from various directions could be studied;
4. Select instrumentation and data-handling procedures to determine forces and motions experienced by the occupant in the test in order to provide data for performance evaluation;
5. Select a test matrix; and,
6. Conduct the test program and gather data.

Performance Criterion

The criterion which is generally used in estimating the ability of a restraint system to provide occupant protection consists of three parts. The first is concerned with a limitation of body motions. In order for a restraint system to provide protection, it is obvious that the user must remain within a certain protective envelope inside the vehicle and avoid contact with vehicle interior elements which potentially could cause injury. Occupant motions were studied by means of high speed film analysis, and the excursion was given a rating from 1 to 4 defined as follows:

4 = less than 4 inches of motion of any body segment in any direction and small relative rotations of one body segment with respect to another.

3 = large motions of the various body segments but confined to the environment of the adult seat.

2 = large body motions beyond the confines of the adult seat and possibility of contact with vehicle interior structures such as the door or the dashboard. Also, relative body motions are considered to be large enough to lead to possible injuries.

1 = large body motions with contact with vehicle interior structures certain. This classification can be considered as ejection from the confines of the adult seat.

The second part of the performance criterion consists of a limitation of the acceleration levels experienced by the head and torso. Tolerance levels for adults which have received some acceptance are:

head impact: 80 g's for less than 3 ms;

chest impact: less than 40 g's.

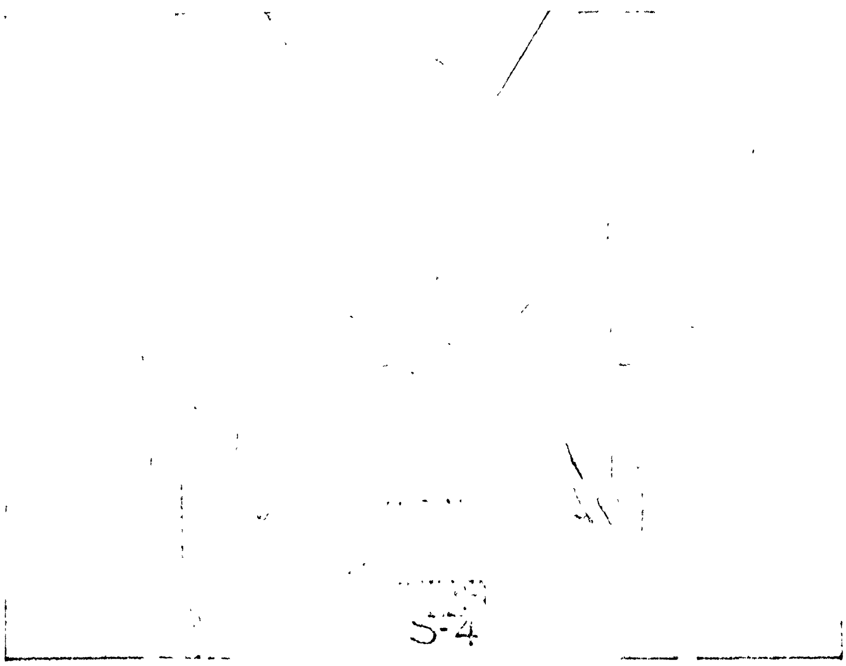
Equivalent data for children are not yet available. Therefore, until such time as new biomechanical data become available,it was decided to hold head and chest acceleration levels within these limits.

The third part of the performance criterion concerns distribution of loads over the body. The various restraint systems showed great variety in the means used to transfer the impact loadings to the subject. The movies were studied and the restraint system and dummy were examined carefully after each test to look for evidence of harness straps slipping into soft abdominal areas,of thoracic compression, etc. No experimental means are currently available for studying contact stresses in detail.

In addition to this performance criterion it was decided to observe design-related features of restraint system performance. These included: (1) structural integrity; (2) dynamic interaction between the child restraint system and the adult seat; and, (3) performance of the various means for attaching the devices to the vehicle.

Selection of Occupant

The selection of an occupant was difficult in one respect, but easy in another. It was found that 3-year and 6-year anthropometric dummies were marketed by Sierra Engineering Corporation. Two views of the Sierra 3-year dummy are shown in Figure 1 before two different tests. No dummies of any other size were found to be available. However, several serious



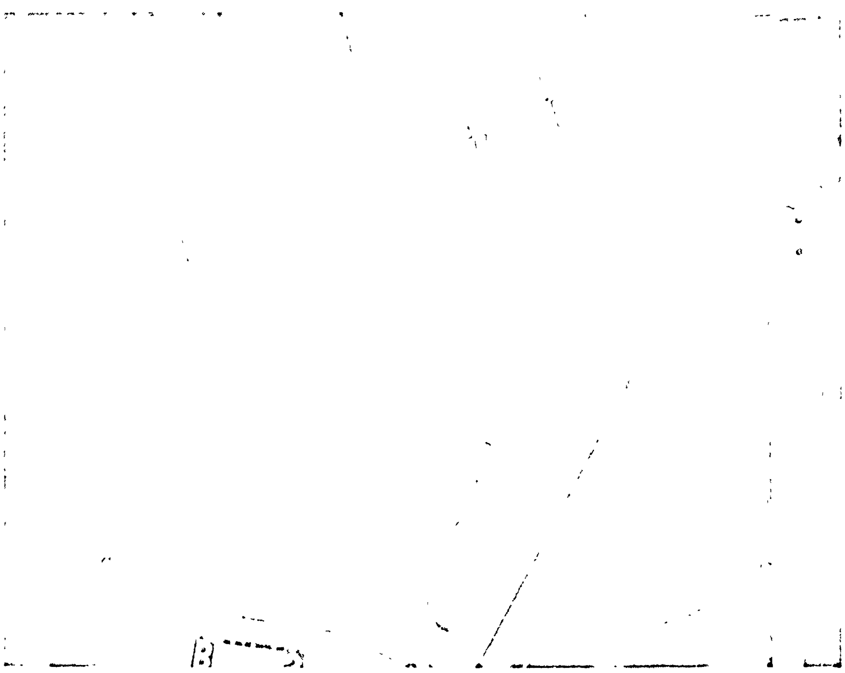


Figure 1. Sierra 3-year old dummy.

questions became obvious at this point: (1) do the available dummies effectively duplicate human kinematics; (2) what about babies; (3) and is the 3-year dummy a proper size to be used in this testing program?

No complete answer can yet be given to the question concerning the accurate duplication of human kinematics by dummies. Although the spine, torso, and neck have flexibility, it is very difficult to adjust.The body of a dummy does not appear to be as compliant as would be the case for a child. One of the most likely problem areas is the neck. One of the major advantages of the dummy is that the weight distribution is nearly correct, although the 3-year dummy is a bit tall. If the weights are distributed nearly correctly, then an experiment should yield approximately the same motions as would be found with a living subject. It should at least be possible to estimate gross body motions such as ejection and excessive excursion. On this basis, it was decided to use the Sierra dummies for the present experiments.

This whole problem demonstrates the substantial lack of data on children and babies. To start with, adequate anthropometric data necessary to construct human simulators for children are only just now becoming available. This leads to the hope that better control of body segment size and weight distribution can be attained in future child dummies. Few data are available on impact tolerance of children. Some medical people are of the opinion that the greater compliance of a child leads to better resistance to impact. Others state that this same lack of development of body structures creates lessened resistance.

Even if the dummy chosen provides a rough estimation of body kinematics, it is still necessary to decide whether it is the right size for a fair testing of the 37 devices. It should be recalled that the 3-year size and weight represents the upper end of suggested usage for most of the devices. Thus this dummy would tend to define the worst cases of dynamic loading which these seats and restraint systems could be expected to withstand in normal service as a protective device. On this basis, it appears that the 3-year dummy would offer the best available selection for the bulk of the test series.

Two of the devices selected for testing were clearly not useable by a three-year old child and were intended only for reclining or semireclining infants under about one year of age. In order to test these devices a doll with the approximate dimensions of an average three-month old baby was disassembled. The two legs, torso, two arms, and head were weighted with lead shot to simulate the body segment weights for a baby this size. The doll was then reassembled. This technique has been used by General Motors in developing their infant carrier and other devices.

Selection of Test Environment

With the selection of the occupants completed it was necessary to consider the test environment. A stable and durable bucket seat manufactured by Bostrom of Miluawkee was chosen for the series. The structure was a pressed steel frame with wire springs and the whole seat was cast in urethane foam and then covered with vinyl. It is felt that this seat is firmer than most of those in current use. Two views of this seat are also shown in Figure 1. The bucket seat concept was believed to offer slight advantages in side impact due to the climb at the edge of the seat. The height of the seat back was 23 inches. This seat was mounted on the sled (Figure 2) in a standard

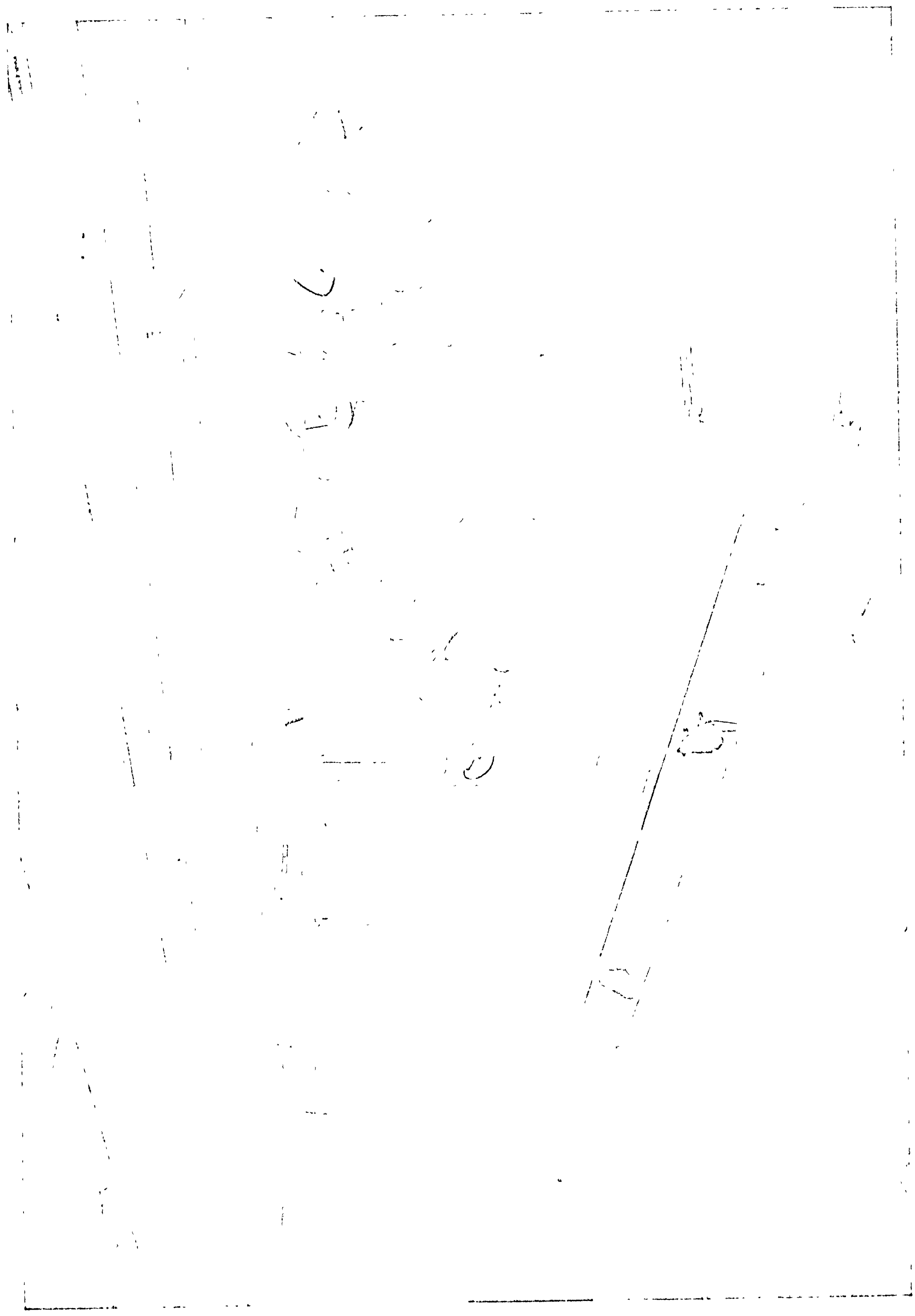


Figure 2. HSRI impact sled.

automotive configuration without a surrounding body buck except in a few cases. Attachment points for seatbelt hardware represented a late-model intermediate-sized vehicle. Because of the necessity to simulate impacts from the front, 45° oblique, 90° lateral, and rear end, this entire seat and restraint system was designed to be oriented in any attitude with respect to the direction of travel of the sled.

Selection of Instrumentation and Data-Handling Procedures

The 3-year dummy was instrumented with triaxial accelerometer packs in the head and in the chest. The individual accelerometers were Kistler [illegible]. A Statham strain-gage accelerometer was used to sense sled deceleration. Belt forces were recorded using Lebow seat belt force transducers if an adult lap belt was used with the child seat or restraint system or if separate tiedown had been provided consisting of standard automotive belt material. Timing signals and impact velocity were also recorded, using a Honeywell 1612 light-beam oscillograph. Hard copy of these records was assured in that each record was photographed shortly after the test.

High-speed motion pictures were also taken for each test. A Photosonics 16-mm camera was located directly to the side of the impact area, and another directly overhead. The frame rate normally used was 500 fps. These motion pictures were supplemented by slides taken before and after each test. Also, a Graph-chek sequence camera was used in the later stages of the test program to provide an instantaneous evaluation of the test as a high-speed sequence of eight frames on a 3 x 5-in. Polaroid sheet.

Test Matrix

The test matrix for this program was designed to include forward impact, side impact, rear impact and oblique impact. Four factors determined the number of tests to which each selected device was subjected: (1) availability; (2) structural integrity; (3) performance; and (4) logistics. Some systems such as the Ford Tot-Guard (C-1), the Sears harness (C-31), and the General Motors seat (C-3), were readily available to the project, so were subjected to more tests than others in order to provide a baseline of data on which to base tests of other systems. Unfortunately, some systems such as the K.L. Jeeny Child Safety Seat (C-26) and the General Motors Infant Carrier (C-25), both of which were observed to provide a high level of protection, became available within a few days of the conclusion of the scheduled tests and thus did not undergo extensive testing.

The second factor which determined the number of tests carried out on a system was its structural integrity. If a system was destroyed in a test, as was the case with most seats of tubular structure, it was necessary to obtain a new device before proceeding. Hence durable devices were subjected to more tests as they could be reused without the delays of reordering.

The third factor which limited testing was disqualification due to bad performance based on the performance criterion. If a system failed badly in a 20 mph forward test, the test series was usually discontinued.

The fourth and final factor which determined the test matrix was the logistics of carrying out the test program. The first test series consisted of front-facing tests. When all available systems had been tested, the sled laboratory was deactivated while the sled was remounted to simulate side impact. Again testing was carried out on all available systems. Similar down time occurred in changing to oblique, rear, and finally back to forward impact. In short, testing continued as rapidly as possible to evaluate as many systems as possible in their various configurations.

The result of this was 117 tests which are summarized as follows:

Forward facing. Fifty-three tests were carried out. Essentially all of the devices were subjected to this test, as it represents the most common type of accident.

Side facing. A total of twenty-seven tests were carried out in side impact. Especially of interest was the behavior of bail hooks, bottom support structures, various belting arrangements, dummy attitude (sit, stand, lie), and side structures if the seat possessed any.

Rear facing. A total of twenty-seven tests were also run representing rear impact. Of particular interest were headrests, sitting height, and interaction with the back of the adult seat.

45° oblique. Only ten tests were performed. It became apparent after a few of these tests that behavior reminiscent of both forward and side impact was occurring.

Data Gathered in Test Program

The data from all tests are summarized in Table I. The tests are grouped by device (Column 1). For most tests a choice of 20 mph or 30 mph was made for the velocity. Devices which performed well at 20 mph (or had unusual kinematics) were also subjected to a 30 mph test. The deceleration level for most tests was about 16 g on the average. A number in parentheses refers to a deceleration spike occurring superimposed on the overall waveform. This was applied in the form of a nearly trapezoidal deceleration pulse.

TABLE I. HSRI CHILD RESTRAINT TEST SUMMARIES

Device	Test Number	Velocity (mph)	Deceler-ation(g's)	Dummy	Attitude	Impact Direction	Left Seat Belt (lbs)	Right Seat Belt (lbs)	Head a-p(g's)	Chest a-p(g's)	Head s-i(g's)	Chest s-i(g's)	Head l-r(g's)	Chest l-r (g's)	Excursion
C-1	A-020	16	5(8)	3	S	f	-	-	-	-	-	-	-	-	4
C-1	A-021	16	4(7)	3	S	f	110	110	>10	14	-	-	-	-	4
C-1	A-040	30	15	3	S	f	-	-	-	-	-	-	-	-	3
C-1	A-041	30	15(37)	3	S	f	825	825	>77	50	28	>40	-	-	3
C-1	A-042	30	15(42)	3	S	f	825	825	72	44	29	37	-	-	3
C-1	A-058	21	16(33)	3	S	f	660	660	67	40	25	27	-	-	3
C-1	A-060	20	18	3	S	f	625	625	59	48	30	24	-	-	-
C-1	A-073	20	16	3	S	f	600	750	42	22	20	22	-	-	4
C-1	A-074	20	16	3	S	f	600	750	64	41	22	25	6	2	-
C-1	A-089	20	16	3	S	l	1000	300	24	10	45	10	5	5	-
C-1	A-112	20	16	3	S	r	100	100	35	50	29	17	15	30	2
C-1	A-136	30	16	3	S	r	100	90	43	52	27	11	5	3	4
C-1	A-148	30	16	3	S	l	800	1110	32	11	53	21	5	7	3
													85 Spike	32	2
C-1	A-152	20	16	3	S	o	760	500	35	26	41	5	19	25	3
C-3	A-017	16	3(8)	D	S	f	-	-	-	-	-	-	-	-	4
C-3	A-023	16	4(7)	3	S	f	100	100	20	14	-	-	-	-	3
C-3	A-111	20	16	3	S	r	300	250	12	34	27	17	2	2	2
C-3	A-133	30	16	3	S	r	340	290	12	25	100	23	6	3	1
C-3	A-153	20	16	3	S	o	690	510	33	23	85	10	42	35	3
C-4	A-059	20	16	3	S	f	525	525	45	34	73	25	-	-	3
C-4	A-090	20	16	3	S	l	200	260	15 Spike 100+	20	48	23	25 Spike 100+	20	1
C-4	A-091	20	16	3	S	l	660	220	35	10	46	25	122	15	1
C-4	A-094	30	16	3	S	l	1150	2300	[illegible]	25	55	30	35	20	1
C-5	A-049	20	15(26)	3	S	f	-	-	-	-	-	-	-	-	2
C-5	A-050	20	18(32)	3	S	f	650	650	[illegible]	20	110	22	-	-	2
C-5	A-072	20	16	3	S	f	400	700	[illegible]	25	20	23	20	[illegible]	-
C-5	A-092	20	16	3	S	l	630	160	[illegible]	11	43	22	32	20	1
C-5	A-093	30	16	3	S	l	850	350	25	13	95	38	25	20	1
C-5	A-114	20	16	3	S	r	300	200	[illegible]	25	33	12	2	[illegible]	2

TABLE I. HSRI CHILD RESTRAINT TEST SUMMARIES (2)

Device	Test Number	Velocity (mph)	Deceleration (g's)	Dummy	Attitude	Impact Direction	Left Seat Belt (lbs)	Right Seat Belt (lbs)	Head a-p(g's)	Chest a-p(g's)	Head s-i(g's)	Chest s-l(g's)	Head l-r(g's)	Chest l-r (g's)	Excursion
C-5	A-134	30	16	3	S	r	140	140	12	23	33	13	4	1	1
C-5	A-135	30	16	3	S	r	150	120	13	24	35	8	2	2	1
C-6	A-055	21	16(29)	3	S	f	-	-	18	20	31	16	-	>25	1
C-6	A-099	20	16	3	S	l	-	-	10	7	35	10	11	20	1
C-6	[illegible]	20	16	3	S	r	-	-	37	38	48	10	12	5	2
C-6	[illegible]	30	16	3	S	r	-	-	40	30	33	8	3	2	44
C-6	A-149	30	16	3	S	l	-	-	14	12	63	28	15	19	1
C-7	A-024	16	4(7)	3	S	f	-	-	17	15	-	-	-	-	3
C-7	A-096	20	16	3	S	l	-	-	10	7	18	6	7	~50	1
C-8															
C-9	A-054	20	18(28)	3	S	f	43[illegible]	430	64 (109)	25 (65)	52	14	-	-	3
C-10	A-052	20	16(36)	3	S	f	360	450	24	25	45	20	11	5	2
C-11	A-020	16	4(7)	3	S	f	-	-	Spike	Spike	Spike	Spike	Spike	Spike	1
C-12	A-02[illegible]	16	4(7)	3	S	f	-	-	12	13	21	18	-	-	3
[illegible]	A-076	20	16	3	S	f	-	-	-	10	12	10	8	12	2
[illegible]	A-115	20	16	3	S	r	-	-	53	53	35	10	6	0	3
C-14	A-051	20	18(36)	3	S	f	425	425	40	20	55	20	-	-	2
C-14	A-116	20	18	3	S	r	320	300	50	40	58	20	5	0	1
C-14	A-131	30	18	3	S	r	140	110	10	26	37	16	2	3	1
C-14	A-138	20	18	3	S	l	370	100	25	5	48	14	40	28	1
C-15	A-053	20	18(32)	3	S	f	535	535	32	35	53	16	-	-	3
C-16	A-057	21	16	3	S	f	-	-	37	22	38	8	-	-	4
C-16	A-095	20	16	3	S	l	-	-	20	15	18	10	13	22	1
C-16	A-118	20	16	3	S	r	-	-	42	30	17	10	5	25	4
C-16	A-132	30	16	3	S	r	-	-	39	30	17	10	8	5	4
C-16	A-142	20	16	3	S	l	-	-	23	10	16	8	30	47	3
C-17	A-075	20	16	3	S	f	-	-	33	30	22	10	0	0	3
C-17	A-154	20	16	3	S	o	-	-	-	-	-	-	-	-	1

TABLE 1. HSRI CHILD RESTRAINT TEST SUMMARIES (3)

Device	Test Number	Velocity (mph)	Deceler-ation(g's)	Dummy	Attitude	Impact Direction	Left Seat Belt (lbs)	Right Seat Belt (lbs)	Head a-p (g's)	Chest a-p (g's)	Head s-i (g's)	Chest s-i (g's)	Head l-r (g's)	Chest l-r (g's)	Excursion
C-17	A-156	20	16	3	S	o	80	50	19	17	16	7	13	15	2
C-18	A-067	20	16	3	S	f	200	200	25 Spike >100	35 Spike >100	32 Spike >100	15 Spike >100	5 Spike >100	15	1
C-18	A-079	20	16	3	S	f	1500	-	>100	>100	>100	>100	>100	10	1
C-19	A-068	20	16	3	S	f	250	500	20	12	28	15	15	10	2
C-19	A-113	20	16	3	S	r	50	0	20	30	45	23	3	3	2
C-19	A-130	30	16	3	S	r	100	110	17	27	35	27	3	3	2
C-19	A-139	20	16	3	S	l	600	-	15	8	20	6	17	21	1
C-20	A-071	20	16	3	S	f	50	150	22	30	30	13	8	7	2
C-20	A-155	20	16	3	S	o	-	-	13	15	14	3	7	13	1
C-21	A-056	21	16	3	S	f	-	-	13	24	18	10	-	-	1
C-22	A-144	20	16	3	S	l	570	200	30	10	45	25(70)	25 (70)	20	1
C-23	A-098	20	16	3	S	l	-	-	25	4	15	7	50	60	1
C-23	A-100	20	16	3	S	l	400	180	25	7	25	8	75	50	4
C-23	A-117	20	16	3	S	r	-	-	40	40	23	15	5	-	2
C-23	A-129	30	16	3	S	r	-	-	40	28	16	15	8	3	4
C-23	A-150	30	16	3	S	r	1130	230	24	10	17	12	30	41	3
C-24	A-158	20	16	3	S	o	-	-	13	15	20	11	7	15	1
C-25	A-097	20	16	D	1/2	l	350	300	-	-	-	-	-	-	3
C-25	A-123	20	16	D	1/2	r	100	120	-	-	-	-	-	-	3
C-25	A-127	30	16	D	1/2	r	200	200	-	-	-	-	-	-	3
C-25	A-161	20	16	D	1/2	o	1280	890	-	-	-	-	-	-	3
C-26	A-181	20	16	3	S	f	-	-	+35 Spike -48	31	27	20	+8 -12	+2 -10	3
C-26	A-182	30	16	3	S	f	-	-	+30 Spike -40	20	29	10	+5 -11	+3 -6	3
C-26	A-143	20	16	3	S	l	-	-	15	12	-	8	20	35	2
C-26	A-157	20	16	3	S	o	-	-	24	25	25	10	6	11	2
C-27															
C-28	A-119	20	16	3	S	r	100	-	33	42	25	12	4	2	2
C-28	A-145	20	16	3	S	l	780	320	67	20	45	23	Spike (92)	20	1

TABLE I. HSRI CHILD RESTRAINT TEST SUMMARIES (4)

Device	Test Number	Velocity (mph)	Deceler-ation (g's)	Dummy	Attitude	Impact Direction	Left Seat Belt (lbs)	Right Seat Belt (lbs)	Head a-p (g's)	Chest a-p (g's)	Head s-i (g's)	Chest s-i (g's)	Head l-r (g's	Chest l-r (g's)	Excursion
C-30	A-080	20	16	3	S	f	2600	-	25	23	37	11	7	4	4
C-31	A-018	16	3(11)	D	S	f	-	-	-	-	-	-	-	-	4
C-31	A-022	16	4(7)	3	S	f	-	-	>15	23	23	-	-	-	3
C-31	A-043	30	15(41)	3	S	f	-	-	50	-	-	-	-	-	3
C-31	A-101	20	16	3	D	l	-	-	30	60	33	18	8	5	1
C-31	A-104	20	16	3	U	f	-	-	-	-	-	-	-	-	3
C-31	A-105	20	16	3	D	f	-	-	25	20	35	12	13	18	3
C-31	A-120	20	16	3	U	r	-	-	15	10	41	17	5	5	1
C-31	A-121	20	16	3	S	[illegible]	-	-	29	40	10	20	5	5	4
C-31	A-137	30	16	3	S	[illegible]	-	-	29	40	10	20	3	3	2
C-31	A-140	20	16	3	S	l	-	-	25	25	45	15	45	25	1
C-31	A-141	20	16	3	S	l	-	-	22	22	43	18	45	25	1
C-31	A-151	20	16	3	U	l	-	-	35	23	58	12	32	40	1
C-31	A-160	20	16	3	S	o	-	-	22	25	50	13	30	23	1
C-32															
C-33	A-078	20	16	3	S	f	2250	-	35	28	28	9	00	0	4
C-34	A-106	20	16	3	S	f	420	450	28(40)	35(8)	28(20)	25	12	10	1
C-35	A-081	20	16	3	S	f	-	-	118	20	65	15	45	5	3
C-35	A-082	30	16	3	S	f	-	-	120	38	82	33	5	5	3
C-35	A-122	20	16	3	S	r	-	-	25	20	11	40	5	5	4
C-35	A-146	20	16	3	S	l	-	-	47	13	39	13	22	44	1
C-35	A-147	30	16	3	S	l	-	-	61	15	53	22	22	46	1
C-35	A-159	20	16	3	S	o	-	-	20	13	37	8	Spike 85	27	1
C-36	A-107	20	16	3	S	f	360	-	15	22	33	12	4	4	3
C-36	A-108	20	16	3	U	f	520	-	22	20	40	12	10	3	2
C-36	A-109	20	16	3	D	f	270	-	24 (85)	18 (15)	30 (50)	15	5 (35)	12	3
C-38															

TABLE I. HSRI CHILD RESTRAINT TEST SUMMARIES (5)

Device	Test Number	Velocity (mph)	[illegible]	Dummy	Attitude	Impact Direction	Left Seat Belt (lbs)	Right Seat Belt (lbs)	Head a-p(g's)	Chest a-p(g's)	Head s-i(g's)	[illegible]	[illegible] l-r(g's)	Chest l-r(g's)	Excursion
C-41	A-124	20	16	D	D	r	50	50	-	-	-		-	-	3
C-41	A-128	30	16	D	D	r	-	-	-	-	-		-	-	3

The occupant used in a particular test represented either an infant or a three-year old child. A "3" in this column indicates the dummy and a "D", the doll. Attitude refers to the position of the dummy in the devices. The key for this column is:

S = sitting

1/2 = semi-reclining

U = standing up

D = lying down

Four impact directions were used. They are represented by:

f = forward impact

ℓ = lateral or side impact

r = rear impact

σ = oblique impact

The belt loads are self-explanatory. However, for the accelerometers, "a-p" refers to an anterior-posterior direction, "s-i" to superior-inferior mount, and "ℓ-r" to a left-right mount. The word "spike" is used to refer to a short-duration deceleration (<5 ms) peak. If

25
spike
100+

occurs, this indicates that the average acceleration was 25 g's and that this was interrupted by a pulse exceeding 100 g's.

The complete set of data gathered in this series of tests is included as Appendix D to this report. Each test is described and summarized on a separate introductory sheet. A description of the performance of the device in protecting the dummy is contained in this summary.

Also included in each individual test report is a photograph of the accelerometer and force transducer traces as originally recorded on a light beam oscillograph. In addition, four frames have been removed from the high-speed movies and are printed on another page. One of these shows initial position, one shows the beginning of motion, one shows maximum excursion (this frame was used in the preparation of Table I), and the final one shows any rebound. If the Graph-chek camera was used, a print of this view is also included. A sample of these data sets is bound with the present volume as Appendix B.

PART IV. DISCUSSION OF TEST RESULTS

The data gathered in this test program have been assembled and evaluated in several different ways. The first and simplest was to summarize each individual test independently. This is the method used to compile Appendix D of this report, "Data from Individual Tests," which consists of test observations, oscillographic transducer data, and photographic documentation. The peak accelerometer readings, belt loads, velocity, excursion, and other data from all tests were then summarized in Table I, "Child Restraint Test Summaries."

Based on the assembled data, the test results were then evaluated. Each of the devices selected for the test program were studied independently and all tests evaluated. This technique has been used to prepare Appendix C, "Child Restraint Test Evaluations by Device."

Finally, the test results were evaluated to determine the performance of the various design, structural, and protective concepts which are embodied in the 37 devices. In addition to limiting body motions and body accelerations as well as avoiding the application of concentrated loads to delicate body organs as outlined in performance criteria specified in Part III of this report, it has been found that three additional design factors should be considered from the viewpoint of providing protection. The device should: (1) possess structural integrity, (2) avoid dynamic interaction with the adult seat, and (3) attach securely to the vehicle. These considerations are discussed and examples given in the next several paragraphs as they relate to front, side, and rear collision.

Several observations can be made on performance of the devices in forward impact. Problems with ejection, structural collapse, and gross dynamic interactions with the adult seat structure were observed. Some concepts offered considerable protective potential.

Motions large enough to constitute ejection were observed in several tests. Typical examples are tests A-026 and A-055. In the first case, a hook-under seat slipped from its attachment under the seat back, folded up, and then flew from the adult seat. In the second case, the seat was attached to the adult seat by bail hooks and straps attached to the vehicle structure. The amount of elastic and plastic deformation experienced by the tiedown system was sufficient to allow the head of the dummy to move forward approximately 32 inches.

A typical example of structural collapse is shown in Test A-067. This general type of failure occurred over 30 times in the test program as documented in the appendices. In this case, a tubular structure was not able to resist the loads placed on it during the test. On many devices similar to the one used in this test, the adult lap belt was used to provide tiedown. It was ineffective as large occupant motions occurred as the seat pitched forward upon collapse. (See Figure 3.)

Gross interaction with adult seat is shown in Test A-059. This seat responded in a manner similar to others selected for this program, which might be classified as booster seats. In this case, the seat exerted a large force over a small area of the adult seat. The result was that the front of the child seat dug into the adult seat, allowing the head and torso of the occupant to whip forward and receive a large superior-inferior g-loading. (See Figure 4.)

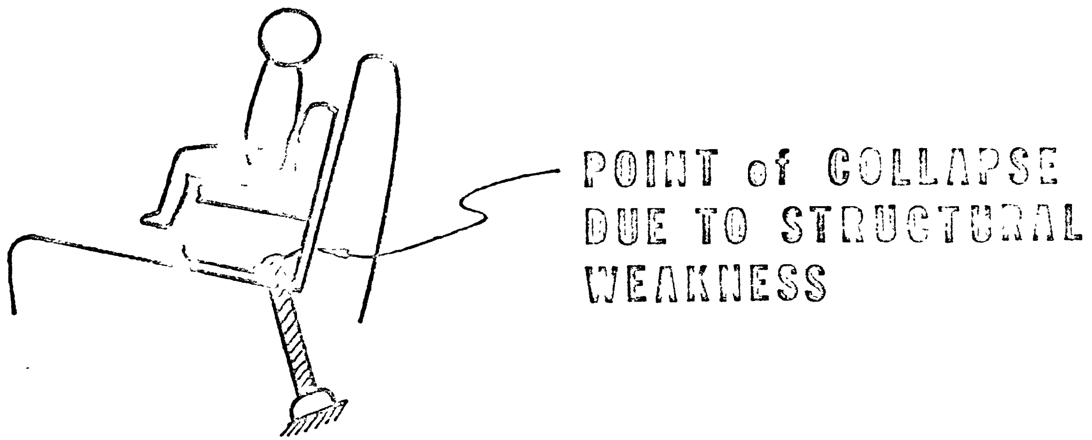


FIGURE 3. STRUCTURAL COLLAPSE of TUBULAR FRAMEWORK

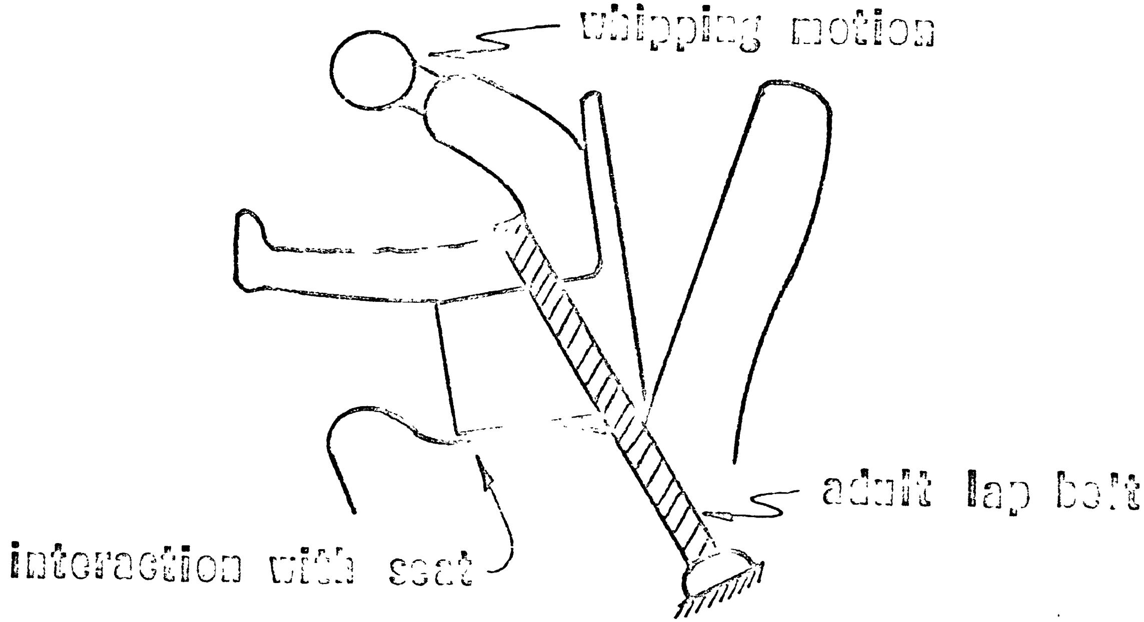


FIGURE 4. GROSS INTERACTION of BOOSTER SEAT with ADULT SEAT

This action points out the extreme importance of matching the design of child seats and restraint systems to the adult seat. One manufacturer of a prototype booster-type seat (not one whose device was tested in this program) suggested to us that his device could qualify for a standard if the surface on which the seat were mounted was a board. Otherwise, the amount of forward pitching in either a static or dynamic qualification test would be too large. However, a static test would not be capable of demonstrating the violent relative motion occurring at the head-neck junction.

Examples of a fair degree of protection in forward impact are shown in Tests A-040 and A-107. The first of these shows a Ford Tot-Guard and the second, a Sears harness. In both cases the load appears to be distributed quite evenly over the torso. It should be noted, however, that the occupants were positioned ideally in the devices prior to impact. With the Tot-Guard some problems in positioning the occupant occurred, leading to a tendancy to submarine. Also, the value of the force applied to the abdominal area is not known in either case, and the tolerances of children to loads of this type are also not known. Not all harnesses distributed the load as evenly as the Sears Harness, and there was a tendancy with some harnesses for individual straps to slide down into the abdominal area. However, both of these devices were quite capable of keeping the child dummy within the environment of the adult seat. The GM Infant Carrier also performed well in this test using the 3-month doll.

There was little evidence of protective potential in side impact for most of the devices tested. Either the devices did not possess sufficient side structures or else the structure of the device failed due to the dynamic loading.

An example of a lack of lateral restraint is shown in Test A-148 of the Ford Tot-Guard. The low side of this device allowed the occupant to rotate sideways over the edge of the rail far enough to cause likely contact with a vehicle's side structures. Many devices suffered this shortcoming. It should be noted that there is little room for movement toward the doors of a car in the event of a side impact, making design of the protective environment much more difficult.

Tests of many of the devices resulted in ejection of the occupant in lateral impact. This poor performance was due to the simple fact that most devices are not designed with the express purpose of providing protection in a side impact. If an adult lap belt was used with the device, the entire assembly slid to the side, under the belt and out of the seat. Bail hooks rarely offered any resistance to side impact and broke off. Harnesses tended to allow the occupant to move far to the side indicating that the techniques used for tiedown and resistance to motion in the forward direction did not hold the occupant securely in position in side impact. The tubular structures used to support many seats showed failures similar to those experienced in forward impact.

It was interesting to note that the two devices with substantial side structures (C-16 and C-23) suffered from the same type of failure. In both cases, the technique used to tie the system to the seat broke causing ejection. In one test, A-100, the Volvo seat was given auxiliary support by the adult lap belt in an attempt to overcome the inherent weakness in its own tiedown system and also in an attempt to evaluate the potential of side structures in preventing the excessive excursion observed in most of other tests. The results were encouraging as relative motion between adjacent body segments was nearly eliminated and the occupant did remain in the seat.

Protection in side impact seemed, then, to be related to the inclusion of side structures on the seat or restraint system to prevent motion to the side. This was accomplished by the General Motors Infant Carrier.

Several observations can be made regarding the tests simulating a rear-end collision. The first is concerned with sitting height. Booster seats ususally placed the head of the child just above the top of the adult seat back, presumably so he can see. This indicates that the top of the child's shoulders coincides with top of the seat back. If no head restraint was provided severe whiplash was observed in several cases. (See Test A-133, for example). This type of problem should decrease as a greater percentage of cars with head rests are found on the roads. However, it is still necessary for the head rest to be adjusted properly and for the distance between the head and the head rest to be as small as possible at initiation of impact.

Some booster seats provided high backs or head rests. These worked with varying degrees of success depending on structural strength and design shape.

When the harnesses were used with lower seats the problem of whiplash did not occur, in that the dummy interacted primarily with the adult seat back and received gentle rides. However, certain harnesses allow the child to stand in the seat. A test (A-120) using this configuration in a simulated rear-end impact resulted in the dummy being vaulted over the seat back. It is our recommendation that children not be allowed to stand in a moving vehicle.

The Volvo seat requires special attention in that it is intended for use in a rear-facing seat. Hence, a rear-end impact simulation represents a front-end collision. The dummy receiveda very gentle ride in this test, proving the potential for protection in rear-facing seats. The motions experienced by the dummy were small, relative rotations of adjacent body segments were minimal, and [illegible] requires substantial interaction with the adult seat back. The success of this test was diminished by the fact that on rebound the dummy broke the restraint straps holding him in the seat, and bounced out of the adult seat onto the floor of the sled.

In conclusion, after reviewing all the individual tests, it is suggested that from the viewpoint of providing protection three performance considerations should be made in designing child seats and restraint systems. In addition, three design-related considerations are proposed which can influence the performance substantially.

Performance Considerations

1. Limitation of body motions. As excursion forward, rearward, or to the side has proved to be a major problem with many of the devices, this factor should be a major consideration in the redesign of current seats or in new designs. Of equal importance is the minimization of relative motion between adjacent body segments.

2. Distribution of the load over the body. Some devices distributed load over wide areas of the abdomen, rib cage, and shoulders. However, there was a tendancy on the part of many devices to use dangerous belly straps, harnesses which slip down leading to high abdominal loading, and chest straps placed such that there is likelihood of thoracic compression.

3. Body acceleration tolerance. Tolerance levels which have received acceptance are:

head impact: 80 g's for less than 3 ms.

chest impact: less than 40 g's.

These data have been applied to adults. Equivalent data are not yet available for children. Therefore, until such time as new data become available, accelerations applied to the head and chest should be held within these limits.

Design-related Considerations

1. Structural integrity. The seat should not collapse or suffer extensive deformation during dynamic tests unless collapse has been designed in for a specific purpose. The design of tubular structures such as bail hooks, hookunder structures, and other tubular support structures should be improved. In many cases, the failure of tie-down support straps, buckles, hooks, rings, rivets, etc., indicated that criteria should be established for the techniques of attaching the seat or harness to the vehicle. Although many seats collapsed, there was a tendancy to reduce the g-loadings as the excursion increased. Thus, designed controlled deformation could be useful.

2. Dynamic interaction with the adult seat. In forward impact, some booster seats dug into the seat cushion leading to occupant motion which could be potentially injurious. Sitting height is a serious consideration particularly in rear-end impact, and especially to avoid whiplash.

3. Attachment to the vehicle. In many cases auxiliary straps supplied by the manufacturers either failed or placed a load on a part of the adult seat back incapable of resisting a load. Some attempt should be made to determine whether a shoulder harness can be used to hold the upper portion of the child seats in place.

PART V. RECOMMENDED PERFORMANCE REQUIREMENTS AND COMPLIANCE TEST PROCEDURES

Based on the HSRI test program, several conclusions can be stated which relate to performance requirements and compliance test procedures for child restraint systems. It has been suggested that three factors are extremely important in order to provide impact protection for the user of the device. These are:

1. The extent of body motions experienced by the occupant;
2. Distribution of the load over the body of the occupant; and,
3. Tolerance of the occupant to impact loading.

Recommendations for Performance Requirements

It is recommended that the motion experienced by the occupant be limited to a volume above the seat cushion of the adult seat. In Figure 5 a volume is sketched out which is 24 inches wide and which extends above the top of the adult seat back for 12 inches. It extends from the front of the seat cushion to the top of the seat back. If motion is limited to this range, there is little danger of occupant contact with vehicle interior structures to the front, side, or rear.

The distribution of loads over the child's body surface which occurs as a result of interactions with the various types of restraint devices, is equally important. The growth patterns of children are such that their pelvic structure is not as effective in picking up belt loadings as it is for adults due to the immature structure of the iliac crests. In the case of many child seats and belt restraint systems which are currently marketed, belts which may act in the pelvic region have a nearly horizontal configuration as well as line of action for the application of forces. The proposed standard does not reflect the fact that a horizontal loading in the pelvic region or in the abdominal area could

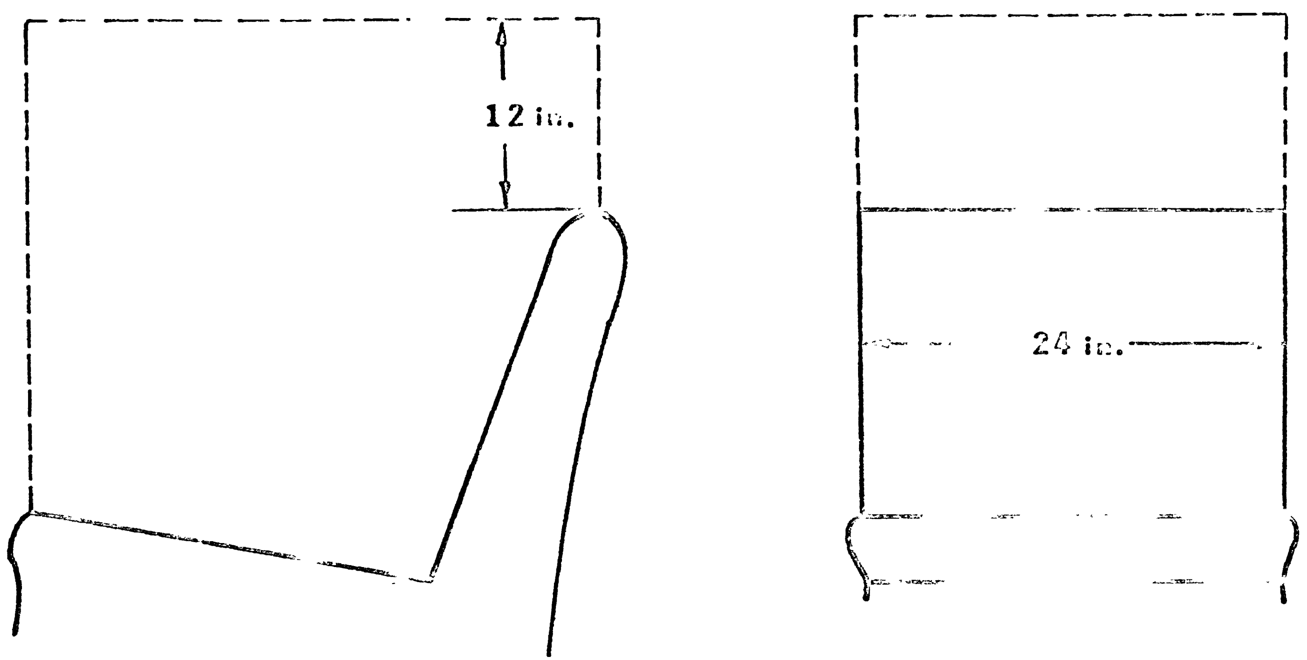


FIGURE 5. SUGGESTED RESTRICTION of OCCUPANT MOTION

be extremely dangerous. Therefore, we recommend a performance requirement that the angle of action of any pelvic restraint be 45° - 75° from horizontal at the time of peak loading. Also, it is recommended that no restraint system elements apply loadings to the abdominal area between the pelvic structures and the bottom of the rib cage unless the primary load bearing elements distribute the bulk of the impact loads to these two regions.

In order to clearly define a requirement for the restraint of the torso, it is necessary to possess knowledge of its load carrying ability based on human tolerance data. Little data is available for adults (40 g limit to chest loads in forward impact) and there is none for children.

It is possible to suggest means by which performance requirements can be generated when sufficient data is available. For example, if it is assumed that: (1) a 40 g tolerance level for chest impact is applicable to children; and, (2) adequate restraint is provided by a properly positioned two-inch wide lap belt combined with two-inch straps over each shoulder; then it is possible to compute an average pressure level acting under the restraint system based on child body dimensions and weights.

TABLE II. Child Size Data (6-year male)

Torso Length	- 13.0 inches
Torso Breadth	- 7.1 inches
Body Weight	- 48.2 pounds

For a six-year old child, the value is approximately 33 psi. This decreases to approximately 20 psi for an infant of six months. This type of an analysis can be applied to other restraint systems such as the airbag and contact panels (Ford Tot-Guard) where a contact area between user and restraint system can be estimated from high speed motion pictures in the case of a dynamic test procedure or a still photo in the case of a static test.

The major problems with this type of specification are a lack of tolerance data and a lack of instrumentation techniques for the measurement of contact pressures between surfaces. First, the 40 g chest tolerance level was determined for an adult and only represents forward impact. Before suitable tolerance data can be obtained for children, tolerance scaling techniques must be developed either from adult data to the child or from laboratory animal data to the child. Second, a pressure specification, such as the example given in the previous paragraph, defines a uniformly distributed loading. Even if the loading were uniform, which is unlikely, tolerance data for the impact pressure loadings which are likely to cause injury to each individual organ under the contact area of the restraint system are unknown. Third, in order to validate the performance criterion the actual contact pressure levels should be measured. Dynamic pressure transducers are not yet available for this purpose. Before a pressure loading performance specification can be recommended with confidence, it is suggested that research be carried out in three areas: (1) tolerance data for children; (2) pressures applied to particular body areas causing injury; and, (3) development of dynamic contact pressure sensors.

The <u>tolerance to impact</u> remains relatively unknown for children as has been mentioned previously. On one hand, some medical experts believe that children are more compliant than adults and thus can safety resist higher loads. In this case, one might tend to feel safe in using an 80-g, 3 ms. limit to direct head impact, a 40-g limit to chest impact, and a 20-g limit to vertical acceleration of the torso. In addition, one could estimate that this greater compliance could allow a greater degree of relative motion between adjacent body segments.

On the other hand, this greater compliance is related to the fact that the bony, load-carrying structure of the body is not fully developed in children. The skull is soft and the bones are not yet fully connected to one another, making this area of the body extremely vulnerable. Also, the rib cage is readily compressed, leading to a potential for other internal injuries. Therefore, until such time as new data become available, accelerations applied to the head and chest should not exceed the values listed above in any dynamic test.

As a supplement to this recommendation, it is suggested that a restriction be placed on the relative motions which can occur between the major body elements such as head, torso, and lower extremities. The head should be limited to 45° rotation rearward or forward rotation relative to the torso and a similar value to the side. Also, a value of sideways rotation of the legs relative to the lower torso should be limited to 45° as long as the body does not extend outside the protective environment defined in Figure 5. These values represent the voluntary rotation limits which can be accomplished without forcing joint structures beyond their normal range of flexibility. The possibility of injury exists if these limits are exceeded.

Observations on Restraint System Performance in a Dynamic Environment

Several additional observations can be made which could be helpful in the preparation of new or improved standards. These are based on observations of the dynamic tests and are concerned primarily with the performance of various design features found in devices which are currently marked. Hence, these observations can not be directly included in performance requirements.

Structural collapse should be avoided, but limited controlled deformation can be used effectively in restraint system design. The major problem is to avoid impingement of the child occupant on the collapsing structures.

The method of attachment of the child restraint device to the adult seat has been found to be extremely important. The use of the adult seat belt proved to be the most effective means of tie-down observed during the course of the test program, but some other auxiliary straps which were supplied by the manufacturers of child seats also were effective. A number of tests which were carried out used bail hooks over the adult seat back, or a non-rigid restraint strap looped over the top of the adult seat back, under the seat back, and hooked to a common auxiliary bracket mounted on the floor of the vehicle. In several of these tests the fixed seat back (which meets Federal requirements on seat back strength) was broken and deformed forward as much as 24 inches. This led to a redesign of the HSRI sled fixture such that the seat back was braced to avoid this problem. It is thus observed that the seat back should not be used as an attachment point for bail hooks, auxiliary straps, or other devices unless it is especially strengthened to take a load of at least 1000 lbs applied at the top of the seat back, in front, side, and rear directions without permanent deformation.

Dynamic interaction between the adult seat, child restraint device, and occupant has also been observed to be important and is one reason that a dynamic sled test is recommended in the next section on test procedures. The dynamics and inertial loads acting on the three parts of the system are difficult to duplicate in a static test. Also, the fact that the loads are being applied at a high rate affects the physical properties of many non-metallic materials such as the foams used in padding, cushions, and plastic shell structures. Also, possibly injurious rebound has been observed in some seats, sometimes caused by "springy" adult lap belts and other components which do not absorb energy. This property would not be observed in a static test. The coupling between the properties of the auto seat and child seat must also be considered. In the sled tests, distinct differences have been observed between hard and soft seat cushions. In fact, one manufacturer remarked that he could qualify his seat on a hard board but it would never qualify when tested on a soft seat structure.

In some seats restrained by an adult lap belt, the occupant sits on a pedestal several inches above the seat cushion. It is possible for the child occupant to pitch forward with velocities amplified by the fact that the center of gravity of the child-seat system is so high. This dynamic response, dependent on inertial forces, would not be reflected in a static test. Finally, body segments such as the head are capable of providing rather complex inertial loadings on the other body segments and also on the seat and restraint system. It is thus recommended that the test procedure be a dynamic one and that a test occupant be segmented in at least three flexible parts (head, torso, lower extremities) in order to adequately simulate the performance of the child restraint system in a dynamic environment.

Test Procedures

In order to meet the performance requirements which have been discussed in the previous section of this report, a series of three impact sled tests is recommended. The four features of this test procedure are the occupant, the means of fastening the restraint device to an adult bucket seat, the acceleration profile which simulates the actual crash, and the test instrumentation.

It is recommended that a flexible articulated dummy be used as the test device. For restraint devices intended for use by children weighing up to 30 lbs., a 3-year human simulator is recommended. For infants it will be necessary to develop a new test device similar to the doll which has been used in the present test program (3-month infant) or to the doll used by General Motors Corp.

in their development program. These test devices should be segmented in at least three parts (head, torso, and lower extremities) in order to simulate dynamic body motions, and should be able of carrying accelerometers in both the head and torso.

The child restraint device should be fastened to an adult seat representative of current design and manufacturing techniques and meeting Federal standards for seat back strength. A seat belt assembly should be provided to allow tie-down by this technique if its use is recommended by the manufacturer of the child restraint device. This belt should be mounted to the sled structure so that a 50th percentile male occupant in the seat would be restrained in the following manner. The angle of the belt should be 60° from the horizontal and not more than 10° out from a plane passing from the front to the rear of a hypothetical vehicle. If an adult seat belt is not to be used, any auxiliary straps should be fastened to the sled structure as recommended by the manufacturer in their instructions to the user.

Three dynamic tests should be carried out on a device. The first is a "moderate" collision of 30 mph representing a frontal crash. The g-level should be approximately 20 g's, possess a sinusoidal shape, and have a duration of about 100 ms. This is a fairly good approximatation of most barrier crashes at this speed. The other two tests should be 30-mph side and rear-end collisions. Although published experimental vehicle compartment data are limited on side and rear collisions, the deceleration levels are lower due to the crushability of the rear of most vehicles and the intrusion and whole-vehicle motion to the side in lateral collisions. A level of 12 g's is recommended for the side and rear test simulations.

The instrumentation consists of photographic and transducer devices. Transducer devices should be chosen to determine sled g-pulse, impact velocity, acceleration loads applied to the occupant's head and chest, and belt loads on the adult belt system if it is used. High-speed motion picture cameras should be located where they can best record the motions experienced by the occupant. In most cases this will be to the side and above the impact site.

A test procedure such as this can be carried out within one day on any one of the several governmental, industry, university, and private research organization operated sleds which are located in this country. It is felt that a dynamic test requirement is required to determine child occupant restraint performance and that enough information is available to write a dynamic test standard.

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APPENDIX A

DEVICES SELECTED FOR TEST PROGRAM

TABLE III. DEVICES SELECTED FOR HSRI CHILD RESTRAINT SYSTEM EVALUATION (1)

CODE	MANUFACTURER	SEAT NAME	DESCRIPTION
C-1	Ford Motor Company	Tot-Guard	Molded plastic shell encapsulating child. Uses adult lap belt.
C-3	General Motors Corporation	Standard Seat	Molded plastic pedestal-type seat. Hooks under seat back. Horizontal chest strap. Adult lap belt.
C-4	Sears, Roebuck, and Co. (Made by General Motors)	#28A6400C	Same as C-3 with addition of plastic hand rail.
C-5	Sears (Made by International Manufacturing Company)	#5516	Molded vinyl shell filled with foam. Pedestal type. Adult lap belt.
C-6	S & W Corporation	George B. Walker Safety Seat	Padded plywood high back seat. Aluminum bar stock is used to mount this as a bail seat and to provide a hand rail. A fabric loop around the seat back in conjunction with a floor mount anchors the seat. Integral lap belt and crotch strap.
C-7	Wards (Made by Trimble Products, Inc.)	#821	Tubular frame with padded cushion, back and head rest. Bail mounted. Belly, suspender and crotch straps.
C-8	Thayer, Inc.	#34936	Tubular frame with padded cushion and back. Unpadded hand bar with plastic and metal steering wheel. Bail mounted. Belly straps.
C-9	Century Products, Inc.	#4625	Tubular frame with padded cushion and high back. Padded hand bar. Bail mounted. Belly and crotch straps.

TABLE III. DEVICES SELECTED FOR HSRI CHILD RESTRAINT SYSTEM EVALUATION (2)

CODE	MANUFACTURER	SEAT NAME	DESCRIPTION
C-10	Century Products, Inc.	#4865	Tubular frame with padded cushion and high back. Padded hand bar. Hookunder mounted. Belly and crotch straps.
C-11	Five-Filer Bros. Co.	hookunder type	Tubular frame with padded cushion and high back. Padded hand bar. Belly strap. Hookunder mounted.
C-12	Five-Filer Bros. Co.	hookover type	Tubular frame with padded cushion and back. Padded hand bar. Bail mounted. Belly and crotch straps.
C-13	Peterson Baby Products	Swinger Model #60EC	Tubular frame with padded cushion and high back. Padded hand bar. Bail mounted. Diagonal chest and crotch straps.
C-14	International Mfg. Co.	#4613	Molded padded high back shell. Hookunder mounted. Lap, crotch and chest straps. Seat restrained by adult belt. Padded hand bar.
C-15	International Mfg. Co.	#4513	Molded padded high back shell. Padded hand bar. Bail mounted. Uses lap, crotch and chest straps. Seat restrained by adult belt.
C-16	AB Bröderna Ottosson & Co.	Klippan Safety Seat	Molded shell with heavy padding. Integral contoured head rest offering side restraint. Rear-facing configuration uses dash-board. Forward configuration uses straps to floor and shelf behind rear seat. Integral lap and shoulder straps.

TABLE III. DEVICES SELECTED FOR HSRI CHILD RESTRAINT SYSTEM EVALUATION (3)

CODE	MANUFACTURER	SEAT NAME	DESCRIPTION
C-17	Strolee of California	#509	Tubular bail-type frame with padded seat and back. Adjustable contoured head rest. Padded hand bar. Nylon vest in combination with suspender type nylon straps. Crotch strap.
C-18	Strolee of California	#587	Tubular pedestal-type frame with padded seat and back. Adjustable contoured head rest. Padded hand bar. Crotch and belly straps. Straps around adult seat frame anchor seat to automobile; adult lap belt can also be used.
C-19	Strolee of California	#589	Essentially the same as C-18, except uses same vest as C-17.
C-20	Bunny Bear	#T8905H	Tubular frame with padded, contoured back and cushion. Padded hand bar with steering wheel. Adjustable contoured head rest. Hookunder and bail mounted. Belly, crotch, and diagonal straps. Seat restrained by adult lap belt.
C-21	Bunny Bear	#3505	Essentially same as C-20, minus bail mount and diagonal strap; includes contoured head rest.
C-22	Hamilton Cosco, Inc.	Go-Seat	Steel frame pedestal under molded shell. Seat and child are restrained by adult lap belt.
C-23	Volvo	Child Safety Seat	Heavy, contoured, high-back shell; rear facing; mounted to rear-facing adult seat by straps around seat back; lap belt restrains child.

TABLE III. DEVICES SELECTED FOR HSRI CHILD RESTRAINT SYSTEM EVALUATION (4)

CODE	MANUFACTURER	SEAT NAME	DESCRIPTION
C-24	Union Carbide	Hi-back sports car seat	Combined tubular and molded shell seat with high back. Padded hand bar. Bail mounted. Crotch and belly straps.
C-25	General Motors Corp.	Infant Carrier	Molded plastic shell. Restrained by adult lap belt. Occupant rests in a semi-reclining position rearward facing. Shoulder straps.
C-26	K L Automotive Products, Ltd.	K L Jeenay Child Safety Seat	Royalite shell, Bri-nylon webbing and expanded PVC [illegible]. Contoured high back. Straps over and under seat belt to floor. Integral lap, belly and double diagonal belts.
C-27	Beam's Mfg. Co.	Tot Booster Cushion	7-inch plastic booster cushion to be used by child in conjunction with adult lap belt.
C-28	Spiegel(Walter E. Kelly & Sons, Inc.)	Kiddy Kaddy	Contoured plastic shell to be used as booster cushion by child in conjunction with adult lap belt.
C-30	Wards (Made by Market-Forge)	#61B12890 (Mark Fore Monitor Harness)	Harness with two shoulder straps, belly strap and strap through crotch. Restraining strap over seat back is anchored to the floor.
C-31	Sears	Auto Harness, Small	Small size harness with vest, crotch strap, shoulder strap, strap over seat back and floor bracket. (Up to 50 [illegible]).

TABLE III. DEVICES SELECTED FOR HSRI CHILD RESTRAINT SYSTEM EVALUATION (5)

CODE	MANUFACTURER	SEAT NAME	DESCRIPTION
C-32	Sears	#6402	Same as C-31 for 40-75 lb. child.
C-33	Vogt Mfg. Co.	Voplex Child's Seat Belt-Harness #C-2000	Waist, crotch and shoulder straps pass through plate in back. Strap over seat back attaches to floor.
C-34	Life Mfg. Co., Inc.	Auto-babe nylon car harness	Waist and shoulder straps attach to zipper back. Device restrained by adult lap belt.
C-35	American Motors (Made by Safety Equipment Corp.)	#AMC 8992185	Vest, waist strap and shoulder straps. Device attaches to floor by strap from hip. Made by American Safety Equipment Corp.
C-36	Irvin Industries, Inc. (Purchased as Penny's #2037)	Irvin Auto Safety Harness #CH-102	Zipper vest, waist strap, crotch strap and shoulder straps. Device restrained by strap over seat back to floor bracket.
C-38	Wards	#60B6053	Waist and shoulder straps restrained by strap over seat back.
C-41	Circle Square Mfg. Co.	Ba-be Safe	Two shoulder straps attach at a three-point ring to a crotch strap. Foam pad is placed around profile of occupant which rests reclining on auto seat cushion with head forward. Adult lap belt rests across lap.

APPENDIX B

SAMPLE TEST RESULTS

HSRI SUMMARY DATA SHEET (FH-11-6962)

Test No:	A-095
Test Date:	11 July 1969
Restraint Code No.:	C-16
Restraint Description:	Klippan Safety Seat

Dummy:	3 year
Sled Velocity:	20 mph
Sled G-level:	18
Impact Direction:	Side impact
Dummy Attitude:	Sitting

Test Observation:

The dummy received an extremely gentle ride in this test. However, the lefthand strap retaining the Klippan seat to the adult seat tore out of the molded resin fiberglass shell. The spring on the upper rear retaining strap was deformed somewhat. The seat needs better anchoring of the side retaining straps. Both the seat and the dummy were ejected in this test.

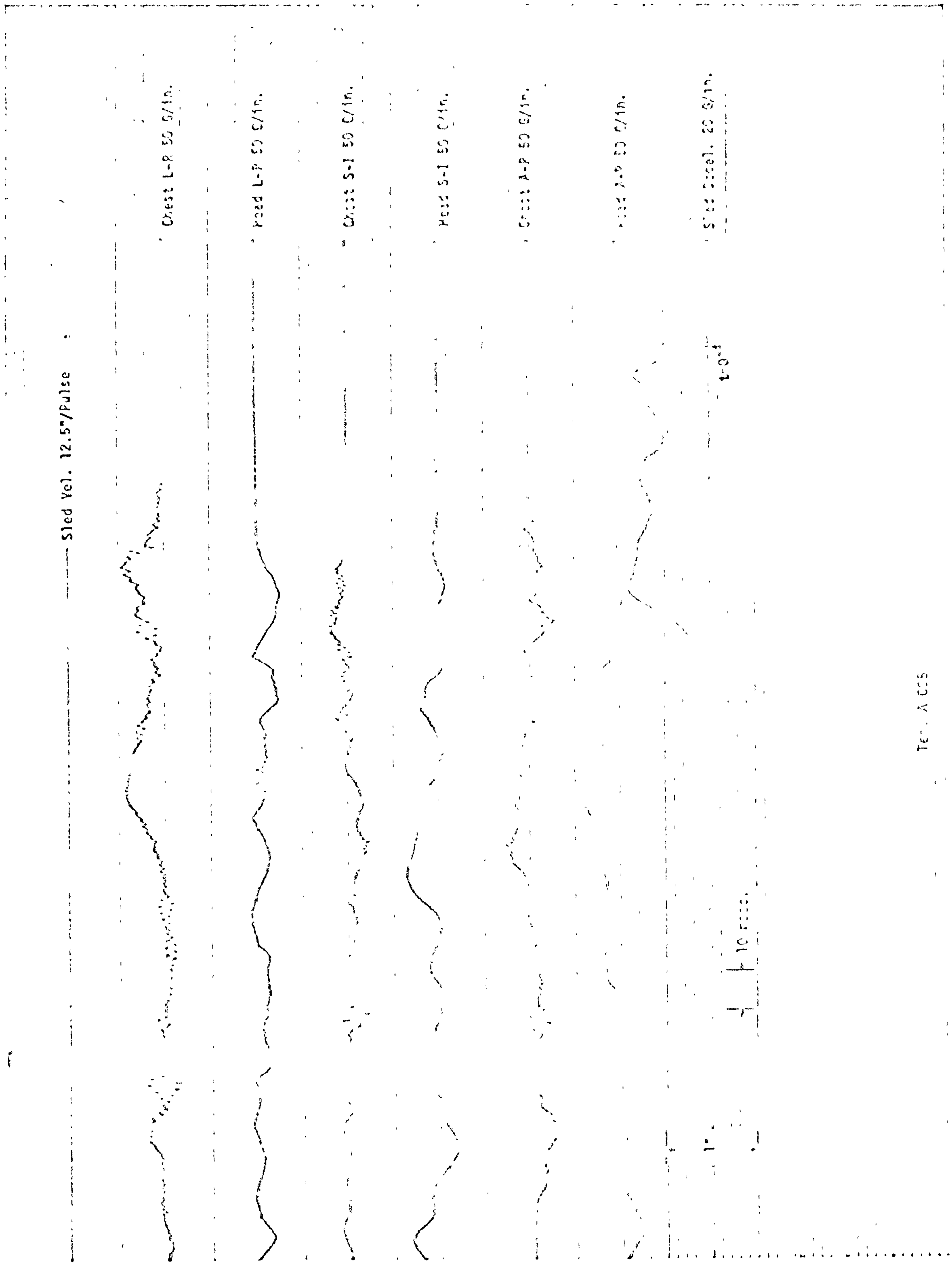

Figure 6. Oscillographic recording, Test No. A-095.

Figure 7. Graph-chek sequence photograph, Test No. A-095.

Figure 8. Film clips, Test No. 1-355.

APPENDIX C

EVALUATION OF TEST RESULTS BY DEVICE

INTRODUCTION

It should be noted in reviewing this test program that some devices received more testing than others. First, the Ford Tot-Guard (C-1) and Sears harness (C-31) were tested more extensively than any other devices. Many of these tests were carried out early in the test program in order to check out the sled, dummy, instrumentation, and cameras to insure that useful and reproducible test results could be obtained. In addition, they represented the two basic types of devices which were tested in the program - a harness and a seat - and were readily available on the market. Second, several bail type seats received limited testing because the large loads placed by the device on the back of the adult seat caused two types of damage in the majority of cases: either the seat back broke loose and moved forward or the bail hooks failed. The potential for damage to the seat, dummy and sled system was believed to be quite high and hence testing at speeds above 20 mph was limited. (See device C-13.) Third, several harness systems received limited testing, particularly those devices which were attached to the vehicle by a strap over the back of the adult seat. The kinematics of the occupant were similar with all these devices and hence extensive testing was deemed unnecessary. In some cases harness belts were observed to slide into the abdominal area, a feature believed to be dangerous and included in the performance evaluation criteria. Fourth, and finally, some devices were difficult to obtain or were obtained near the completion of the scheduled test program. In cases where damage occurred during a test it was not possible to obtain a replacement in a short period of time.

EVALUATION OF T... RESULTS BY DEVICE

Device - C-1 (Ford Tot-Guard)

There were a total of 14 tests carried out on this device: nine front impact, two side impact, two rear impact, and one oblique. Several of these tests were used to check impact sled and dummy instrumentation and can be regarded as duplicates. In tests A-040 and A-041 the Tot-Guard was not positioned properly on the adult seat, so the test was repeated until the problem was solved. In frontal impact, this device shows great potential for preventing contact between the occupant and the vehicle environment. There are several interesting features of the interaction between the dummy and device, however. The dummy first moves forward taking up the slack in the system as the deceleration pulse begins. This slack appears to be quite variable. It is not possible to adjust the seat for an individual subject although it was designed to fit a range of child sizes. The seat lacks adjustability, a prime feature in eliminating system slack. Initial contact was observed in the tests in the upper portion of the abdominal region. As this area picked up load, the body flexed around the protective shield. Finally, the head was observed to make a rather strong contact with the shield. Both chest and head g-loadings were moderately high in these tests compared with others in this series presumably caused by the rather abrupt stop affected by the shield. However, relative rotation between head and upper torso was decreased. It can be presumed that the distribution of forces offered by this system is quite efficient although the pressures applied in the abdominal area are unknown.

The Tot-Guard is not nearly as efficient in providing lateral protection as excursion over the low side bar would make contact with the vehicle interior quite likely. G-loadings in side impacts are moderately high.

In rear-end impact, the dummy interacted primarily with the vehicle seat. However, the protective shield was observed to rotate upward and rearward giving the dummy a sharp slap in the face. This phenomenon is probably related to vehicle seat angle and restraint system geometry.

One can conclude that the Ford Tot-Guard is one of the better designed devices on the market although the level of protection offered in lateral impact is low.

Device - C-3 (General Motors Standard Seat)

C-4 (Sears Seat No. 28A6400c. This seat is manufactured by General Motors and resembles C-3 closely in its kinematic response.)

There were nine tests carried out on these devices: three forward impact, two rear impact, one oblique impact and three side impact. In forward impact, the device appears to limit motion sufficiently to prevent contact with the interior of the vehicle. However, there are several features of the kinematics worthy of consideration. The first is the interaction of the bottom of the child seat with the vehicle seat cushion. As the deceleration pulse begins, the child occupant begins to move forward. The upper torso places a forward acting force on the back of the child seat. In addition to this, a downward acting force is placed on the bottom of the child seat by the buttocks of the dummy due to interaction with the adult lap belt. The action of these two forces rotates the child seat downward into the seat cushion of the car seat. The extent of this action is very dependent on the material and structural properties of the adult seat cushion. In the HSRI test series, the front of the GM seat dug into the vehicle seat as much as five inches in a 20 mph, 16 g frontal impact. Because of the "softness" of most automobile seats, it is anticipated that this behavior is not unique.

The effect of this action on the dummy is to magnify the body superior-inferior acceleration loadings. The seat and dummy rotate forward until resistance in the adult seat is found. At this point, the upper part of the upper torso and the head whip forward over the chest restraint strap causing the dummy to flex at this point and causing high acceleration loadings. It should be noted that the head of the dummy traces out an arc during this motion of about 24 inches forward.

This problem exists to a similar degree in the side impact tests, where the side of the child seat digs deeply into the adult seat cushion and the dummy pitches to the side. A 24-inch excursion of the head to the side would most likely insure contact with the vehicle interior structure.

A problem of a different nature was observed in the rear collision simulations. When the GM seat was mounted on the sled, its seat back was nearly the same height as the 23-inch seat used as the adult seat for the test series. Because the dummy was sitting essentially on a pedestal, his shoulder level was also approximately at seat back top level. Thus, severe whiplash of the dummy was observed. It is possible that an adult head rest could have prevented this extensive rearward rotation of the head. However, it appears that seat back height of child seat-restraint systems is important and should be carefully studied in relation to current seat back height and head rest designs for adult seats.

Device - C-5 (Sears Seat No. 5516. Manufactured by International Mfg. Co. as "Jumbo" seat.)

This seat is essentially a booster armchair mounted on the adult seat. It is held in place by the adult lap belt mounted across the lap of the child. A series of eight tests were carried out on this device: three front impact, two side impact, and three rear impact.

The behavior of this system was similar in many ways to that of the other booster and pedestal-type seats examined in this test series. In forward impact, the dummy pitched forward over the seat belt. Because of the flexible foam interior of the Sears seat, it was compressed and pushed downward by the dummy's g-weight and the action of the seat belt. Because there is no upper torso restraint provided with this device, the torso and head continued to pitch forward until violent contact occurred between the dummy's head and the lower front portion of the adult seat structure.

In side impact, the upper torso and head pitched to the side compressing the Sears seat structure and allowing motion sufficient to insure contact with any adjacent side structures. The sitting height of this booster seat was again high enough to lift the dummy's head above the back of the adult seat. Severe whiplash was observed.

Device - C-6 (George B. Walker Safety Seat)

A series of five tests was carried out on this device: one front impact, two side impacts, and two rear impacts.

One positive feature of this seat was the use of energy-absorbing structures which led to low dummy g-loadings in all the tests. However, the space required for absorbing the energy was too large and contact with vehicle interior structures would have been assured in most cases.

In the forward facing test, the bail hooks were straightened out as they pulled over the adult seat back. In addition, the lap belt slipped allowing the dummy to slide forward into the padded aluminum bar stock hand rail which was also extensively deformed. The head of the dummy moved foward about 32 inches.

In side impact, the excursions experienced by the dummy were extreme with ejection occurring in the 30 mph impact. In this case, the bail hooks slid towards the side of the adult seat and finally the restraint strap used to anchor the bails to the floor failed. The bail system would appear to offer little protection in side impact and requires a great deal from the adult seat on which they are mounted.

Performance was considerably improved in rear-end collision. The seat back was high enough to prevent whiplash (except in the one test where the head slid off the side of the rather narrow structure), and well enough padded to prevent high g-loadings to the head.

Device - C-7 (Montgomery Wards Seat No. 821. Manufactured by Trimble Products, Inc.)

Two tests were carried out on this seat: one forward impact and one rear impact.

In the mild, low-g, forward impact, the bail hooks and the adult seat back held and the dummy was prevented from moving forward to any excessive degree. The kinematics observed with this device were similar to other bail-mounted seats. No higher speed tests were carried out as it was presumed that the loading applied by the bail hooks to the top of the adult seat back would cause it to fail. (See devices C-13 and C-31.) In the side impact, the bail hooks failed and the seat and dummy were ejected. The head rest appears to be capable of preventing excessive whiplash in the event of a rear-end collision.

Device - C-9 (Century Products, Inc. Seat No. 4625)

One forward facing test was carried out on this device which used bail hooks plus an adult lap belt across the lap of the dummy. Although the bail hooks held, some bending of the structure was noted. The excursion of the dummy was significant as it pitched over and into the hand rail but not sufficient to allow contact with vehicle interior structures. Chest and head g-loadings were quite high as the torso pitched into the hand rail with a resultant head g-loading of over 80 g's for at least 5 ms. The test series was discontinued.

Device - C-10 (Century Products, Inc. Seat No. 4865)

One forward facing test was carried out on this device which features a tubular framework supporting the seat. In addition, an adult lap belt is placed across the lap of the dummy. No restraint is provided for the back of the seat. As the deceleration pulse began, the dummy moved forward into the lap belt. As a result, a large downward force component was exerted on the front of the seat structure, causing the tubular framework to collapse in the manner typical of seats of this type of construction. When the seat collapsed, the dummy continued to move forward and down in the arc allowed by the adult lap belt. This excursion was sufficiently large to make contact with the vehicle interior structures likely.

Device - C-11 (Five-Filer Brothers Hook-Under Seat)

One forward facing test was performed on this device. The only attachment provided to retain this tubular-supported pedestal seat in the adult seat is a hook which is placed under the adult seat back. During the test the dummy began to move forward into the hand rail. The tube hooking under the back of the adult seat slipped out from under its attachment. Finally, the whole framework folded up as it would if the device were being prepared for storage and the dummy and device were ejected.

Device - C-12 (Five-Filer Brothers Bail Seat)

One low level forward facing test was carried out on this bail seat. The seat was observed to swing up during the deceleration as the bail hooks picked up the load. However, the seat retained structural integrity and no undue motions were observed. The kinematics observed with this device were similar to other bail-mounted seats. No higher speed tests were carried out as it was presumed that the loading applied by the bail hooks to the top of the adult seat back would cause it to fail. (See devices C-13 and C-31.)

Device - C-13 (Peterson Swinger Model No. 60 EC)

Two tests were performed on this bail seat, one forward and one rear collision simulation. In the forward-facing configuration, the bail hooks produced a load on the adult seat back sufficiently large to cause it to break away and move forward thus allowing the dummy large excursion. This points out the fact that if the adult seat back is to be used as an attachment point for child restraint systems, it must have strength beyond the current requirements. For instance, a 30 lb. child subjected to a 20 g crash could place a load of 600 lbs. on the top of the seat back, a total moment of 12,600 in. lb. on a 21-inch seat back. This is well beyond the requirement of Motor Vehicle Safety Standard No. 207 which requires a 20 g inertial loading applied at the center of gravity of the seat back. The seat back was high enough so that on rear-end impact, whiplash was minimal.

Device - C-14 (International Seat No. 4613)

Four tests were carried out on this seat: one forward impact, two rear impact, and one side impact. This seat features a tubular structure supporting a molded plastic shell surrounding the child's buttocks and lower torso. The adult seat belt is placed over the lap of the child.

In the forward facing test, the dummy moved forward into the adult lap belt and, as in other devices using this structure, the tubular framework collapsed. The dummy rode down the ineffective chest strap and hand rail and the head traced an arc ending about eight inches in front of the adult seat cushion indicating large excursion.

In the rear impact simulation, the head of the dummy was observed to experience whiplash because the device seat back and the adult seat back heights matched.

In side impact, the lower torso, buttocks, and legs of the dummy were very effectively prevented from moving by the contoured plastic shell. However, the unrestrained upper torso and head flexed over the hand rail to the side allowing fairly large excursion. The flexing occurred at a point approximately at the level of the bottom of the rib cage. The tubular structure supporting the seat was deformed but not collapsed by the impact.

Device - C-15 (International Seat No. 4513)

One forward facing test was carried out on this bail mounted seat utilizing the adult seat belt across the dummy's lap. This seat differs from International Seat No. 4613 (C-14) in that there is no tubular support structure under the molded shell. However, the fact that the bail supports broke loose in this test, produced kinematics primarily dominated by the adult lap belt and the adult seat cushion. These results were similar to the tests on C-14 where the tubular support structure under the seat failed to provide support.

Device - C-16 (Klippan Safety Seat)

Five tests were performed on this seat: one forward impact, two lateral impact, and two rear impact.

This seat features a contoured molded shell with heavy padding. Straps are provided to attach the seat to the vehicle structure at two points on the bottom of the shell, and also at a point on the top of the shell. This strap goes to an energy absorbing spring assembly. In addition, an integral harness arrangement is provided to tie-down the child to the system. In concept, this system uses advanced safety design for occupant protection quite effectively.

In the frontal collision, the restraint system performed well with minimal motion and rebound. Some elongation of the energy-absorbing spring assembly and damage to the points on the seat where system tie-down straps are located was observed. In the rear facing tests, the dummy received a gentle ride and the system performed its function well.

This system appears to be designed with side impact protection in mind. An integral head rest and other side structures are provided which could offer considerable protection. However, the system failed in both side impact tests as the straps attaching the Kiropan seat to the vehicle structure tore completely out of the molded shell. With some minor structural modifications, the current investigators feel that this device could offer considerable protection in side impact as well as in front and rear collisions.

Device - C-17 (Strolee Seat No. 509)

Three tests were carried out on this seat: one forward impact, and two oblique impact. Attached to this bail seat is an integral vest restraint with attachments over the child's shoulders and on the bottom of the seat. It is recommended by the maker that the adult lap belt be used across the lap of the occupant. In the forward impact the bails were bent and the buckle over the right shoulder which attaches the vest restraint to the seat structure failed. Excursion was quite high but the structure of both the adult seat and child seat remained nearly intact. In the 45° oblique test the left bail hook failed causing ejection of the seat and dummy. The dummy was restrained somewhat by the action of the adult lap belt.

In setting up these tests it appeared that the seat was too small for the three-year old dummy. The vest straps over the shoulder could have caused spinal compression and the head rest would not stay at the proper height due to the lack of support structure.

Device - C-18 (Strolee Seat No. 587)

This seat was subjected to two forward facing impacts. It is a pedestal-type seat with a tubular and bar steel support structure. The adult lap belt secures the lower part of the pedestal.

In both tests the structural supports collapsed in the region of tie-down to the adult lap belt. This allowed the dummy to move forward about this pivot point and interact violently with the dashboard assembly on the body buck in use during these tests.

Device - C-19 (Strolee Seat No. 589)

Four tests were carried out on this device: one forward impact, two rear impact and one lateral impact. This seat is the same as seat C-18 except that a strap is supplied by the manufacturer which is intended to secure the upper part of the device to the adult seat back.

In the forward impact the pedestal structure collapsed about the adult lap belt allowing the dummy to pitch forward toward the dash assembly. The strap around the seat back supplied no support.

In the rear-end impacts, the dummy experienced whiplash even though the seat includes a contour head rest. The structure supporting the headrest was deformed severely in the test.

The side impact was accompanied by lateral collapse of the tubular support frame. The dummy was essentially ejected.

Device - C-20 (Bunny Bear Seat No. T 8905H)

Two tests were carried out on this device: one forward impact and one oblique impact. This seat features bail hooks and tie-down of the tubular pedestal support structure by the adult lap belt. Integral belly, crotch, and shoulder straps are provided.

In the tests the bail hooks, tubular support structure and integral restraint straps failed and the dummy pitched forward encountering the very large excursions usually observed in the seats possessing this type of support structure.

Device - C-21 (Bunny Bear Seat No. 3505)

One forward facing test was carried out on this seat which is similar to C-20 minus the bail mount and chest strap. As with C-20, the tubular support structure failed and the dummy pitched forward and experienced very large excursion.

Device - C-22 (Hamilton Cosco "Go-Seat")

One side impact was carried out on this seat. A molded shell seat is supported by a support structure of rather substantial steel rods. The adult lap belt is placed across the child's lap to restrain both seat and occupant. This device was obtained late in the testing program and it was not possible to carry out extensive tests. However, due to the fact that the base of the seat distributes the load over a very small area, it is likely that the device would deform the seat cushion extensively in forward impact as was the case in side impact.

As the dummy moved to the side into the lap belt, the support structure dug deeply into the adult seat and the upper torso and head pitched over the belt to the side. At maximum excursion the head of the dummy was about 18 inches to the side of the adult seat. The child seat structure was not damaged.

Device - C-23 (Volvo Child Safety Seat)

Five tests were performed on this seat: three side impact and two rear impact. This seat features a heavy molded shell with a high back and side restraint panels from head to hip. Auxiliary straps are supplied by the manufacturer for tying the restraint to the adult seat. An integral lap belt is included. It is intended that this system be mounted in a Volvo seat which has been re-mounted in the car in a rear-facing direction. Hence, a rear-facing impact simulation on the sled represents a front-end collision.

In this rear-facing configuration, the dummy experienced a smooth ride-down of the deceleration pulse in the 20 mph test. However, on rebound, the integral seat back buckle pulled loose and the dummy was ejected to the floor of the sled. In the 30 mph test, this strap held and the dummy received a very gentle ride. These tests should be compared with forward facing tests of the other systems. In addition to the relatively low g-loadings (influenced, of course, by the soft springy nature of the seat back used in the tests) experienced by the dummy, there was little relative motion between the various body parts contributing substantially to the gentleness of the ride.

In the first side impact test the integral lap belt again failed and the seat and dummy were ejected. In order to test the lateral restraint features of this device, it was decided to restrain the dummy by the adult lap belt in addition to the straps provided by the manufacturer for 20 and 30 mph tests. This technique worked and any substantial side motion was prevented. The g-loadings experienced by the dummy were moderately low and there was no pitching out of the seat. Rather, the dummy moved into the paneled side of the restraint device and relative rotation between body parts was prevented.

An additional problem in the construction of this seat should be mentioned. The Volvo seat has pointed sheet metal screws attaching the integral straps to the side of its shell. The points protrude through the shell towards the inside approximately 3/8 inch. These appear to be aimed at the head of the occupant and are covered only by a thin layer of foam. The seats purchased for these tests were ordered through an area Volvo distributor.

<u>Device</u> - C-24 (Union Carbide Hi-back sports car seat)

This seat was tested once in the 45° oblique direction. It possesses a high-backed molded shell construction and is attached to the adult seat back by bail hooks. The bail hooks failed and both dummy and remaining seat structure were ejected.

<u>Device</u> - C-25 (General Motors Infant Carrier)

Four tests were carried out on this device: one side impact, two rear impact and one oblique impact. This molded shell is attached to the adult seat by the adult lap belt. The infant (up to about 12 months) rests in a semi-reclining position with head towards the front of the vehicle. He is restrained against motion by straps integral to the device which are placed over the shoulders. This device was obtained late in the test program and did not receive a complete series of tests.

In the lateral and oblique tests, the doll appeared to experience a gentle ride although the infant carrier experienced considerable elastic deformation during the tests. In the rear collision simulations, the seat pitched up towards the rear projecting the doll into the seat back. Given the cushiony structure of most seat backs, it is possible that this interaction would not be injurious.

<u>Device</u> - C-26 (K.L. Jeenay Child Safety Seat)

Four tests were carried out with this seat: frontal impacts at 20 mph and 30 mph, and side and 45° oblique impacts at 20 mph.

The contoured high-back plastic shell seat is mounted in the rear seat of the vehicle with two upper straps which anchor to the package shelf and a lower strap which anchors to the floor behind the seat. The harness which is integral to the child seat structures includes a strap over each shoulder, around each side of the abdomen, and through the crotch, all joining in the region of the child's navel to a pin-type buckle resembling those used in Air Force harnesses.

The Jeenay seat performed well in the tests. In the frontal impact, the dummy decelerations were moderate, with those at 30 mph being actually of slightly lower levels than at 20 mph, but of considerably longer duration. Peak resultant acceleration, occurring in the head, was about 43 g for only about 2 msec. There was a sharp acceleration spike in the head anterior-posterior direction in both tests, which occurred upon rebound of the dummy into the seat back. It reached approximately 52 g for only about 1 msec. Excursions were small and controlled in both tests; however, there was a considerable degree of head flexion (approximately 80°) with respect to the torso, in both tests. Although some sideways excursion occurred in the side impact test, the shoulder harness prevented excessive side motion. This seat system appears to offer lateral impact protection the equal of any currently marketed device. It also performed well in oblique impact. The harness appears to distribute the load effectively. Also, the tie-down, or anchor, structure retained its integrity, although slight damage to the seat occurred in the 30 mph frontal impact, in the form of a crack in the plastic shell around one of the rivets fastening the lower anchor strap to the shell.

Device - C-28 (Kelly Kiddy-Kaddy)

Two tests were carried out on this device, one side impact and one rear impact. This seat is a booster cushion for the child and should be used in conjunction with an adult lap belt.

In the rear-end collision, there was no evidence of whiplash as in previous tests in that the seat is rather low. In the lateral impact simulation, the usual interaction between a child pedestal seat and an adult seat was observed. The dummy pitched far to the side and the head bent down far enough to be on the level of the vehicle floorboard at maximum excursion.

Device - C-30 (Mark Fore Monitor Harness)

One forward impact test was performed on this device. This harness has two shoulder straps, a belly strap, and a crotch strap. It is anchored by a strap over the seat back which ties down to the floor of the vehicle. The forward excursions and g-loadings experienced by the dummy were moderate. The harness did appear to slip down into the abdominal area the result of which could be a high localized load. The restraint strap adequately carried the 2,600 lb. dynamic load to which it was subjected. Additional tests were not carried out due to the similarity of kinematics with other harness devices and due to the sliding of the belt into the abdominal area.

Device - C-31 (Sears small harness)

This device was subjected to thirteen tests: five forward impact, four lateral impact, three rear impact, and one oblique impact. This harness is supplied with a vest, crotch strap, and shoulder straps and is anchored to the vehicle by a strap over the back of the adult seat which is attached to the floorboard by a bracket.

In the forward impacts at low speed (20 mph) the performance of the system was adequate in sitting, standing, and reclining attitudes. Excursion and g-loading were not excessive and the load appeared to be well-distributed over the torso of the dummy. In the test at 30 mph the adult seat back broke away due to the load imposed by the restraint system tether. This allowed the dummy to move forward far enough to cause a potential contact with the vehicle interior.

In side impact tests, the dummy again experienced extremely large excursions and wild body contortions as it flew from the sled. Contact with vehicle interior structures seems likely in standing, sitting, and reclining configurations.

In rear impact, the ride was quite gentle when the dummy was seated. In these cases, the interaction was primarily with the soft seat back. However, when the dummy was standing, rearward bending occurred at the hips, and the dummy was vaulted head first into the rear seat location. The results of this test indicate that it is very unwise to allow children to stand on a car seat whether they are restrained or not.

In oblique impact, restraint performance was adequate until rebound. The dummy rebounded from the initial deceleration off the side of the adult seat into the sled structure.

<u>Device</u> - C-33 (Voplex Child's Seat Belt-Harness)

This device was subjected to one forward facing-impact. Waist, crotch, and shoulder straps attach to a plate on the back of the harness. A strap through the plate is hooked over the adult seat back and fastened to the vehicle floor board. In the test, excursion and g-loading were moderately low and the load appeared to be well distributed between the various straps. The kinematics were similar to other harness restraint systems and the device was not tested further.

Device - C-34 (Life Auto-babe nylon car harness)

This device was subjected to one forward-facing impact. Waist and shoulder straps attach to a zippered back piece. The adult lap belt is looped through the back piece as a tie-down. The fabric material ripped upon impact. As the dummy was ejected, it was hung by the neck by the remaining intact strap.

Device - C-35 (American Motors harness manufactured by American Safety Equipment Corporation)

This device was subject to six tests: two forward impact, two side impact, one rear impact, and one oblique impact. This device consists of a vest with waist and shoulder straps. The straps join at either side of the dummy's waist and are attached to individual floor-mounted brackets on either side.

Because the tie-down arrangement for this system was different from the other harnesses there was more flexing of the dummy at the waist than with other systems. High g-loadings to the head were observed as it interacted with the front portion of the adult seat cushion.

In the rear collision simulations, the dummy received a gentle ride. The interaction was primarily with the adult seat back.

In the side and oblique impacts the dummy slid to the side and off the adult seat experiencing large excursion. The harness was ripped in one test. The vest did not appear to serve much function in any of the tests carried out on this restraint device.

Device - C-36 (Irvin Auto Safety Harness No. CH-102)

This device was subjected to three forward facing impacts. Waist, crotch, and shoulder straps are attached to a zipper vest. The device is anchored to the floor of the vehicle by a strap over the back of the seat. In the tests where the dummy was sitting and standing, the restraints appeared to slide down into the abdominal area producing high loads in the area. In the case where the dummy was reclining, g-loadings and excursion were moderate on the initial interaction but quite high on rebound. Kinematics were similar to other harness systems where the device was tied to the vehicle by a strap over the seat back and the series was discontinued after these three tests.

Device - C-41 (Circle Square Manufacturing Company "Ba-be Safe")

Two rear impacts were carried out on this device which places the baby in a reclining position on the auto seat with head towards the front of the vehicle. The load in a forward impact is carried by the shoulders. In the rear impacts the doll was vaulted into the seat back without experiencing any obviously damaging g-loadings or excursion. This device was obtained near the end of the test program and it was not possible to test it completely because some damage to the straps occurred. Replacements were not readily available.