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School Bus Passenger Protection

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THREE THOUSAND SEVEN HUNDRED CHILDREN were injured in school bus accidents during the year 1965, representing an increase of 75% over 1960. During this same period, there was only a 45% increase in the number of pupils being transported by school buses. Prior to these experiments no organized research program had been established to determine design criteria for school bus body structures and for safety equipment included within the bus to reduce passenger injuries during collision

During the past sixteen years, ITTE-UCLA has conducted ninety full-scale automobile collision experiments and several hundred related laboratory experiments; additionally, the Research Staff has investigated school bus and passenger bus accidents during the past ten years (1)* for the purpose of gaining background information on the factors accounting for passenger injuries, as well as accident causation.

A series of school bus crash tests using store-type mannequins without instrumentation was conducted at Little Rock and Conway, Ark. in 1964. This pioneering work provided only generalized observations owing to lack of instrumentation and the application of research techniques. In another effort, a commercial intercity bus was crashed by General Motors (2) and carried a moderate amount of instrumentation; this GM test represents the only known sophisticated experiment conducted on bus collision performance prior to the UCLA study, but did not concern school bus conditions.

*Numbers in parentheses designate References at end of paper.

OBJECTIVE

The purpose for conducting a series of school bus collision experiments was to provide specific and practical solutions for those responsible for school bus passenger safety, to wit: the federal and state legislators, state and local law enforcement agencies, local school districts, bus manufacturers, school bus transportation agencies, and the many organizations here and abroad actively seeking safer ways to transport school children.

ABSTRACT

This paper contains findings from the first series of comprehensive school bus collision experiments. Three full-scale collision experiments involving a school bus were conducted using research techniques and engineering methodology designed to provide realistic and objective findings relating to school bus passenger safety. The experiments conducted were: A head-on collision between two fully loaded, moderate-sized school buses, each traveling 30 mph; a stationary bus rear-ended by a passenger car traveling 60 mph; a stationary bus impacted on its right side by a passenger car traveling 60 mph.

The following categories relating to passenger injury causation were studied: location and type of impact, structural integrity of vehicles, vehicle size, seat design, type of restraint or force moderator, type of safety glass, passenger size, standing versus seated passengers, passenger kinematics and interactions, forces sustained by passengers, and many related factors.

Electronic instrumentation consisted of 61 transducers positioned in the anthropometric dummy passengers, on the safety belts, and on the vehicles to record accelerations and forces during collision. Photographic instrumentation included thirty-three high speed motion picture cameras and special photographic devices that were arranged within, around, and above the colliding vehicles to provide detailed observation of all aspects of these collision experiments.

FACILITIES AND EQUIPMENT

The field station, utilized by ITTE-UCLA for collision research during the past ten years, consists of the north-south runway of a decommissioned airstrip at the U. S. Naval Station, Long Beach, Calif. An aluminum monorail guide track was installed on the level asphalt runway to provide means for controlling the direction of the crash vehicles.

Other operational techniques, incorporated in recent years, are reported in prior publications (3-5) relating to head-on, intersection, and rear-end type collision experiments. Four mobile vans provided research support facilities as follows: machine shop, electronic shop, photographic shop, and project control center.

The 1944 Mack-Superior Coach 60-passenger school bus was donated by the Los Angeles County Board of Supervisors; the 1965 GMC-Superior Coach 60-passenger school bus was donated through the National Safety Council, Chicago. The 1960 Plymouth used to rear-end the school bus, two recording instrument station wagons and two 1966 Plymouth tow vehicles were donated by Chrysler Corp. The 1966 Chevrolet used in the intersection collision was donated by General Motors Corp.

Other equipment and facilities required for this research were provided by the University of California's continued support of this project, facilitated by a contribution of funds through the National Safety Council and, in substantial measure, by a research grant from the U. S. Public Health Service.

METHODOLOGY

RESEARCH TECHNIQUES AND ENGINEERING METHODOLOGY - Procedures were devised that provided the opportunity to observe as many phenomena as practicable for each experiment. This approach was necessary because of the high cost in research time and funds required for each full-scale experiment. Methodologies not involving full-scale collisions may provide constructive findings but their usefulness is limited both as to their reliability and their scope. Where findings govern the life and safety of school bus passengers, more economical or expeditious approaches appear inadvisable.

High-speed photography, electronic transducers, and automatic recording systems were used to study the injury-producing movements and forces for the anthropometric dummy passengers during collision.

TYPES OF ACCIDENTS STUDIED - Bus collisions that frequently occur relate to impacts with fixed objects, such as utility poles, bridge railings and trees, as well as head-on impact with other vehicles. For this experiment, the 1965 GMC-Superior school bus was traveling 30 mph when it was struck squarely head-on by a 1944 Mack-Superior school bus also traveling 30 mph (Fig. 1 (a)).

Owing to the many stops made each day by school buses, the rear-end collision is the most frequently occurring type of school bus accident. For this experiment, the 1965 GMC-Superior school bus was stationary as though stopped on the highway for passengers and was squarely impacted in the rear by a 1960 Plymouth 4-door sedan traveling 60 mph (Fig. 1 (b)). This is the second experiment reported in this paper.

Because of the number of intersections passed each day by school buses, it is not surprising that the side impact accident occurs frequently. The third experiment reported in this paper concerns a stationary school bus impacted in the side by a 1966 Chevrolet 4-door sedan traveling 60 mph (Fig. 1 (c)).

Essentially the same seating and passenger assignments were made for each of these three experiments, so that conclusions could be reached on the general collision protection afforded passengers by the many different protective systems under evaluation.

EXPERIMENTAL PROCEDURE - The method of controlling the vehicles so they will crash in the manner planned and at the desired speeds has been described in detail by prior publications. (3, 4) Therefore, it will only briefly be mentioned: Each vehicle is directionally controlled by a front-bumper mounted phenolic-shoe that slides within a 600 ft monorail guide track, secured to the asphalt pavement. Speed control of the colliding vehicles and synchronization

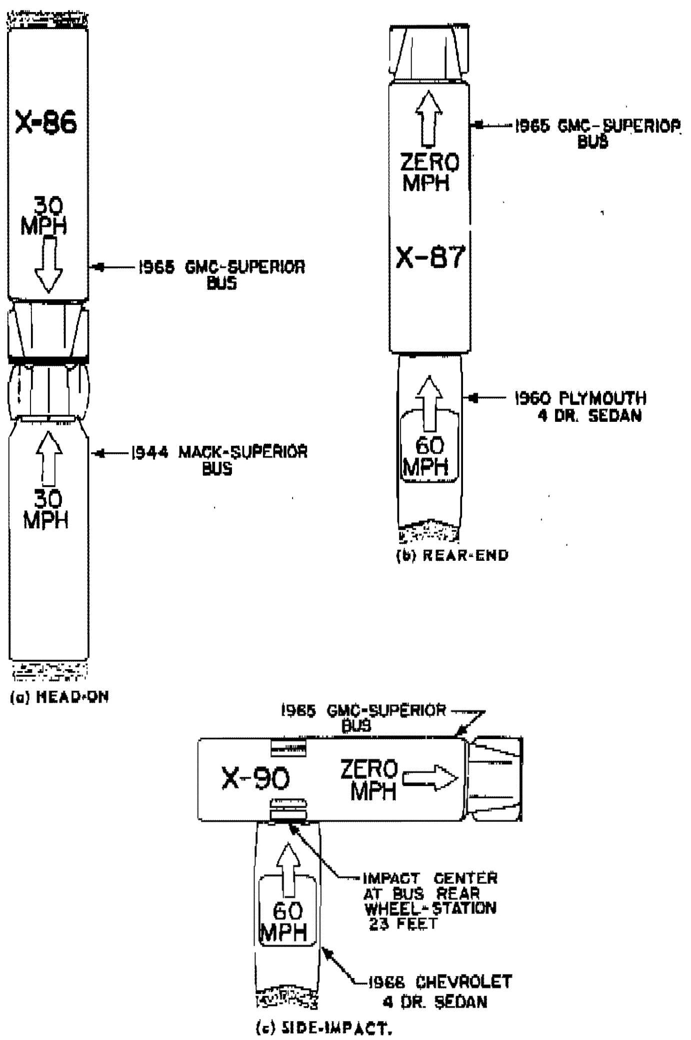

Fig. 1 (a), (b), (c) - Collision configurations of their relative positions was achieved by means of steel cables from the tow vehicles passing about an appropriate sheave arrangement as shown in Fig. 2. Two high performance Plymouths towing in tandem were required to accelerate the crash vehicles to the assigned impact speeds for the three experiments.

The recording oscillograph for the Mack school bus was mounted in a shock attenuating chamber located inside the bus at the rear seat. In a similar manner, the shock mounted recording oscillograph was located in the trunk of the striking passenger vehicles for the rear-end and side-impact collision experiments. In order to accommodate the extensive and complex instrumentation for the head-on collision, both buses moving, two station wagons, each with recording oscillographs, were required to pace the new bus (Fig. 2). For the other two collision exposures, the new bus was stationary.

Remotely controlled brake systems were installed on the crash vehicles for emergencies arising during the experiment. To provide additional operational safety, radio communication was maintained between master control and all mobile units. This communication link was also useful during the preparation period.

VARIABLES UNDER STUDY - Full scale collision experiments are complicated and expensive to conduct. However, they provide a realistic basis for studying a multitude of conditions taking place during the crash. For these reasons, as many variables as practical are introduced into the experiment, with preference given to those factors regarded as most likely to provide useful information. The introduction of dependent variables should follow sound methodological procedures so that the investigator doesn't unknowingly impose secondary or tertiary variables governing a single phenomenon under observation. When this occurs, conclusions cannot be said to relate to a specific factor under observation but, rather, to several without a basis to judge their relative influence.

The larger seating capacity of buses, as contrasted to passenger cars, clearly provides an opportunity to study many more areas of interest. The authors were especially gratified at the number of different factors that could be studied simultaneously during the bus collision (Table 1).

1. Description of Seats - Seats were assigned type designations (Seat Type Code, Table 1), to facilitate identification and comparisons.

a. Seat Type A, a conventional Superior seat (Fig. 3 (a)). This seat was the standard reference for the seating configuration in the bus when other variables, such as dummy size, restraint type, and proximity to impact, were to be evaluated. Some of these standard seats had crash pads installed along the top of the backrest. However, this padding did not change

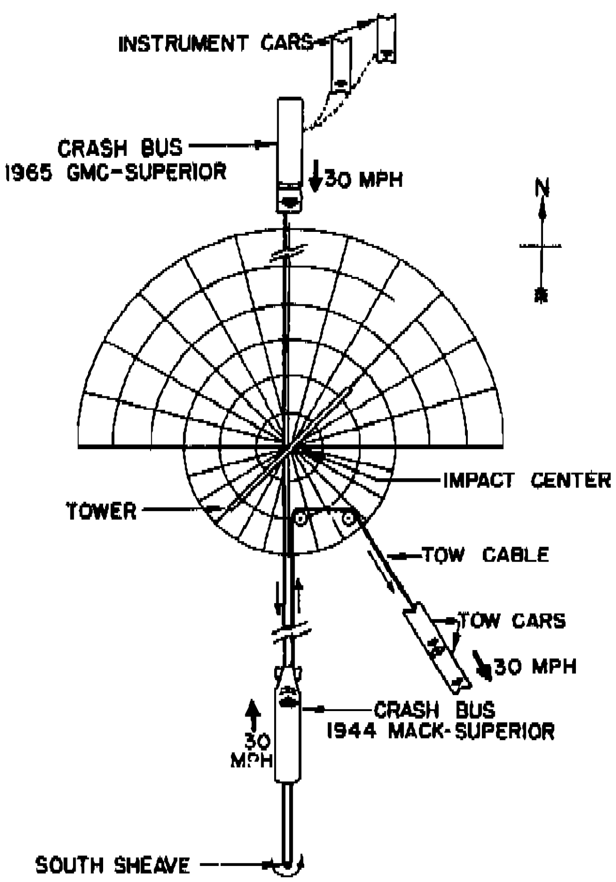

Fig. 2 - Vehicle control systems

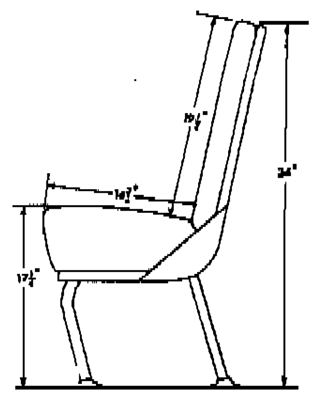

Fig. 3 (a) - Seat type A, conventional Superior seat (Part #612247). This seat was the reference standard for these bus collision studies

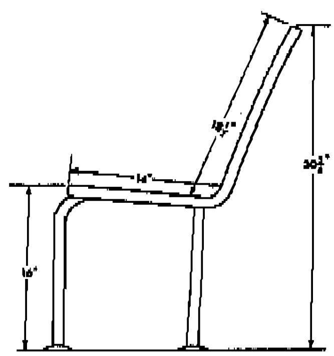

Fig. 3 (b) - Seat type B, a fiberglass seat (Part #12136), manufactured by Superior Coach Corp., Lima, Ohio the configuration sufficiently to designate them as a separate seat type.

b. Seat Type B, a fiberglass Superior seat (Fig. 3 (b)). It is slightly smaller than the standard, Type A seat, and is a one-piece shell molding reinforced with a metal frame.

c. Seat Type C, a high back Superior seat (referred to as an activity seat) is similar to the Type A seat, except that it has a backrest that extends 6-1/2 in. above that of the Type A conventional seat. A handrail extends out from the back of the seat (Fig. 3 (c)).

d. Seat Type D, the ABC Unified School District seat, is a conventional design having a thinner backrest cushion than Type A (Fig. 3 (d)). It was manufactured by the LeVan Specialty Co., Whittier, Calif.

e. Seat Type E, the Rapid Transit seat, manufactured by the American Seating Co., Grand Rapids, Mich. It is a low back seat similar in design to the Type A seat, except that

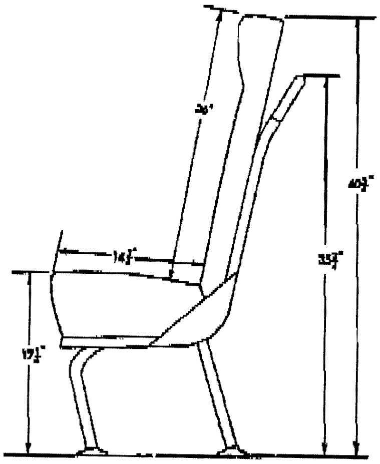

Fig. 3 (c) - Seat type C, a high back seat (activity seat Part #31718), manufactured by Superior Coach Corp.

Table 1 - Variables Under Study

Category	Specific Description	Number of Variations	Reference Figure
Crash Experiment Configuration	Head-On, Rear-End Collision, Side-Impact	3	Fig. 1(a)-(c)
Type of Bus Construction	1944 Mack-Superior versus 1966 GMC-Superior	2	
Seat Types and Assignment	Types A through K*	11	Fig. 3 (a)-(k), 4 (a)-(c)
Surface Padding	Padded or unpadded surfaces to be impacted	2	Fig. 8
Safety Glass	Laminated and Tempered	2	Fig. 8
Restraint Types	Types 1 through 5**	6	Fig. 4 (a)-(c), 5 (a)-(h)
Passenger Size	Adult, 13 yr, 6 yr, 3 yr, and Special	5	Fig. 6 (a), (b)
Passenger Interactions	Adjacent restrained or more remote unrestrained passengers	2	Fig. 4(a)-(c); Fig. 8
Proximity of Seated Passengers to Impact	Adjacent - Remote, long, axis; aisle-window, at or opposite striking car for side impact	6	Fig. 8
Proximity of Standing Passengers to Impact	Close - Remote	2	Fig. 8

*Code For Seat Types	Number Used
A. Conventional Superior	7
B. Fiberglass Superior	2
C. Highback Superior	2
D. ABC School District	1
E. Rapid Transit	1
F. National Seat Co.	1
G. American Seating Co.	1
H. Cox Safety Seat	1
I. United Airlines	1
J. Martin Air Seat	1
K. No Seat	

**Code For Restraint Types	Number Used
1. No Restraint	18
2. Lap Belt Only	11
3. Lap Belt and Diagonal Shoulder Strap	3
4. Air Bag	2
5. Restraint Bar	3

it has a handrail that extends above the back of the seat (Fig. 3 (e)).

f. Seat Type F, manufactured by the National Seat Co., is a high back seat, with integral seat belts, individually adjustable backrests, and with armrests on the aisle and window sides (Fig. 3 (f)). This seat is primarily designed for use in the large, cross-country buses.

g. Seat Type G, manufactured by the American Seating Co., is similar in design and purpose to the Type F seat. It also has individually adjustable backrests, built-in seat belts, and armrests on both sides (Fig. 3 (g)).

h. Seat Type H, the Cox-Hilton seat (Fig. 3 (h)), is an automotive-type "bucket" seat with headrest and integral three-point, shoulder-lap belt restraint system. This system has an inertia reel inside the backrest and is attached to upper end of the diagonal chest strap.

i. Seat Type I, United Airlines Siesta seat, was manufactured by Douglas Aircraft Co. (Fig. 3 (i)). It has a high backrest, individually adjustable, with armrests provided for each passenger.

j. Seat Type J, Martin Air seat, is an inflated air-bag design with lap belt restraint sewn into the seat material

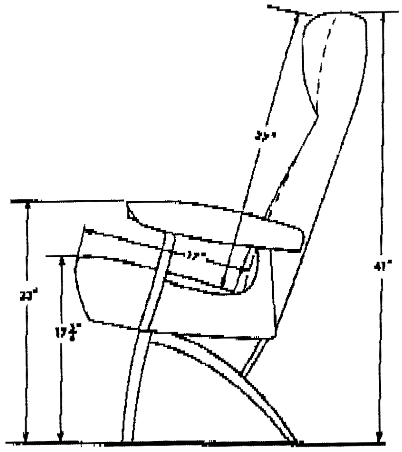

Fig. 3 (f) - Seat type F, manufactured by the National Seating Co., Mansfield, Ohio (Model 1030)

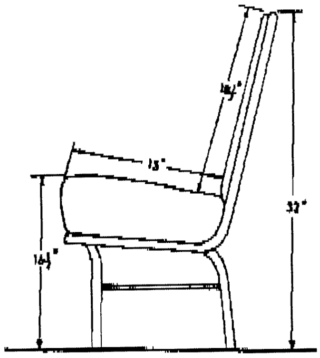

Fig. 3 (d) - Seat type D, the ABC Unified School District seat, Model 539-137, manufactured by the Le Van Specialty Co., Whittier, Calif.

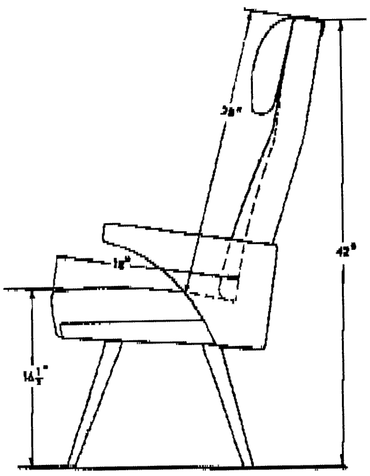

Fig. 3 (g) - Seat type G, Model 6602-C, manufactured by the American Seating Co., Grand Rapids, Mich.

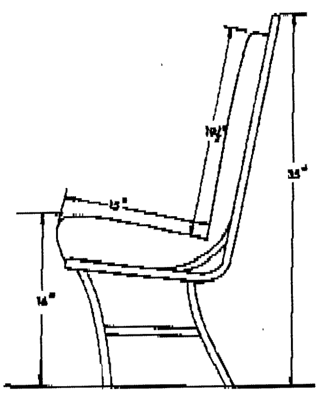

Fig. 3 (e) - Seat type E, the Rapid Transit seat, manufactured by the American Seating Co., Grand Rapids, Mich. (Model 1749)

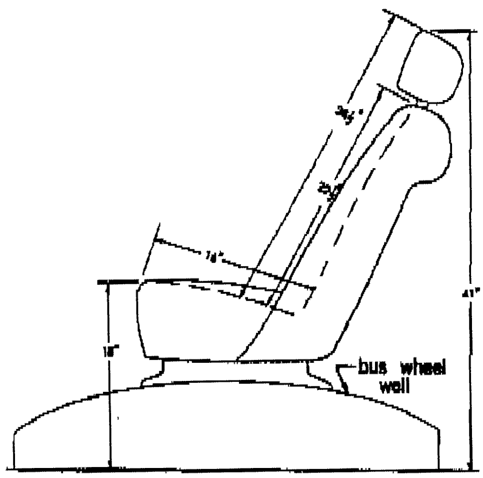

Fig. 3 (h) - Seat type H, the Cox safety seat (G. T. Cortina seat) manufactured by Cox of Watford Ltd., Watford, Hertfordshire, England

(Fig. 3 (j)). The absence of structural members in the seatback made it necessary to position the occupant in an upright seated posture because the seatback did not provide support as a backrest.

k. Designation Type K refers to positions where seats were not installed. This condition applies to standees and seat ahead designations for driver and other occupants behind open spaces.

The driver's seat (Fig. 3 (k)), was not assigned a seat type because it was not included for passenger seat comparisons. Ten different seat types were assigned to specific locations for the purpose of evaluating their performance with respect to the following variables: proximity to impact, interactions by passengers, and structural performance for various seat anchor and safety belt restraint systems (Fig. 4 (a)-(c)). For purposes of identifying locations of seats, proximity of passengers to impact, etc., the bus was assigned reference stations. These stations were marked with targets at one foot increments, starting with zero feet at the front bumper. One of the principal variables under study was the influence of seatback height on passenger safety. Accordingly, seats were positioned to provide optimum passenger interactions with seats having high and low backrests. The methodology used was based on prior collision experiments and accident investigation data.

For the head-on collision experiment (Table 2), the seatback ahead was the primary consideration because it generally was the object initially contacted by both the unrestrained and the partially restrained passengers. In the rear-end collision experiment (Table 3), the seatback height was the principal variable governing the occurrence of whiplash injuries. Side-impact collisions usually force passengers into direct contact with compartment structures or side-window glass. Therefore, in the side-impact experiment, the presence or absence of restraint systems and armrests represented the most important consideration (Table 4).

2. Description of Restraint Systems - Any structure incorporated in a vehicle that inhibits in some manner the movements of passengers, other than the usual seats and enclosure structures, represents a restraining device. Some devices are obviously ineffective, either because they impose injury-producing forces on the occupant or they provide inadequate functional restraining forces. Restraint systems considered practical for school bus passengers were evaluated in this study.

a. Designation Type 1, Table 1, indicates that no restraint was used. Standing passengers were also included in this category.

b. Restraint Type 2 refers to the two-point, lap belt (Fig. 5 (a)). The method by which a particular lap belt was anchored, however, is not specified by this code number but may be determined by referring to Figs. 4 (a-c). Some of the restraints had conventional floor anchorages. Other methods of seat belt attachment are shown in Figs. 5 (b) and 5 (c).

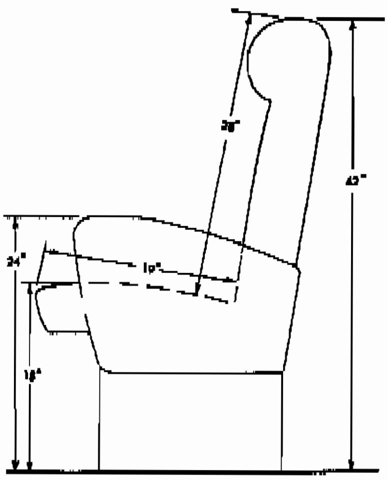

Fig. 3 (i) - Seat type I, the United Airlines Siesta seat, manufactured by Douglas Aircraft Co., Santa Monica, Calif.

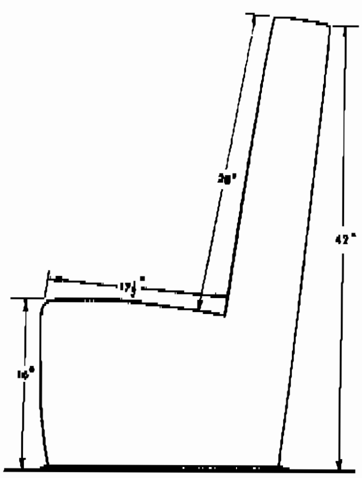

Fig. 3 (j) - Seat type J, the Martin Air seat, prototype model, manufactured by Martin Co., Baltimore, Md.

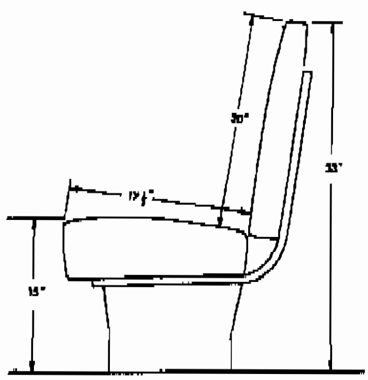

Fig. 3 (k) - Pedestal mounted driver's seat, Superior Coach Corp. (Part #G 11588)

HEAD ON COLLISION, X-86

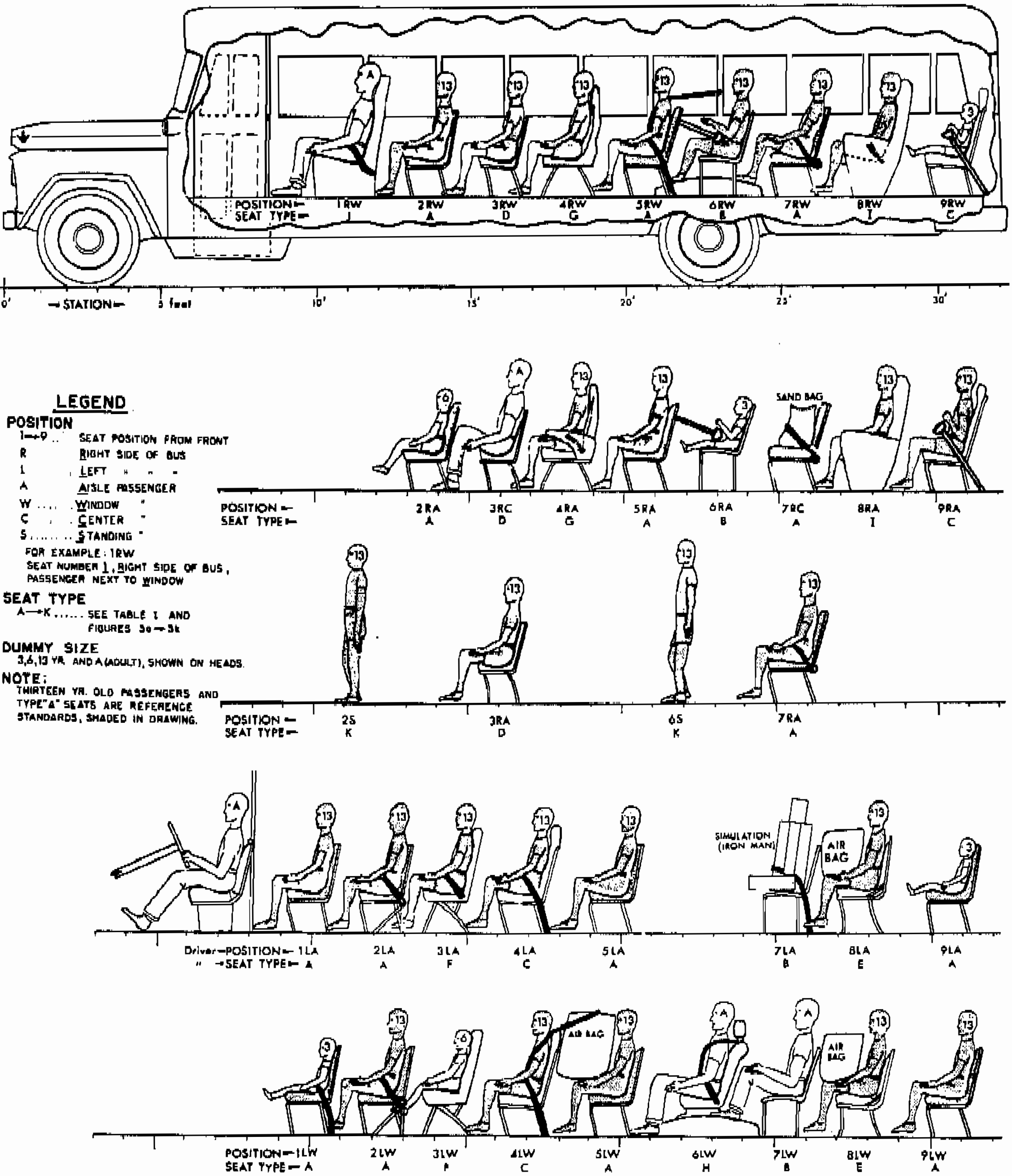

Fig. 4(a) - Head-on collision: seat assignment showing seat location, passenger sizes, and restraint systems

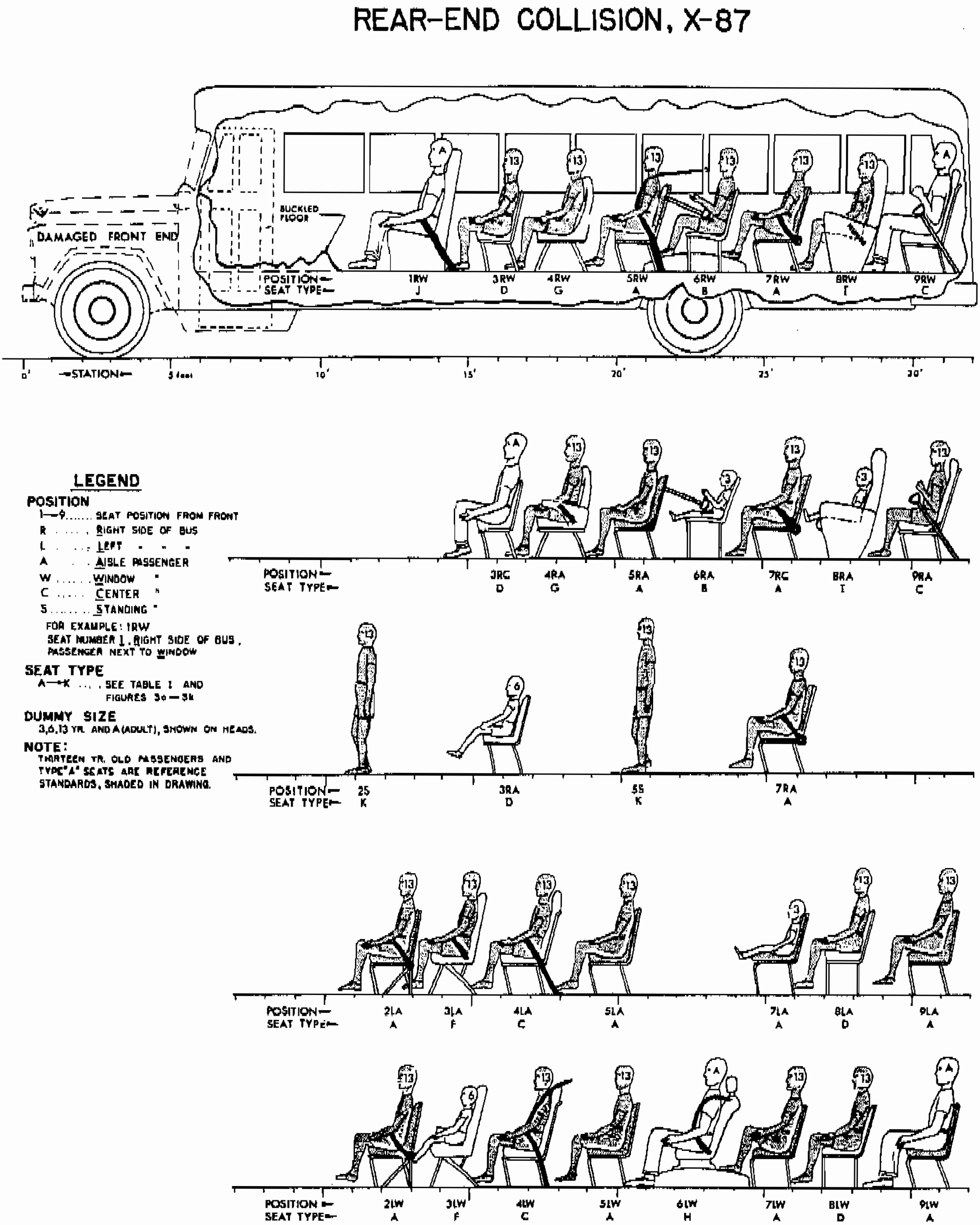

Fig. 4(b) - Rear-end collision: seat assignment showing seat locations, passenger sizes, and restraint systems

SIDE-IMPACT COLLISION, X-90

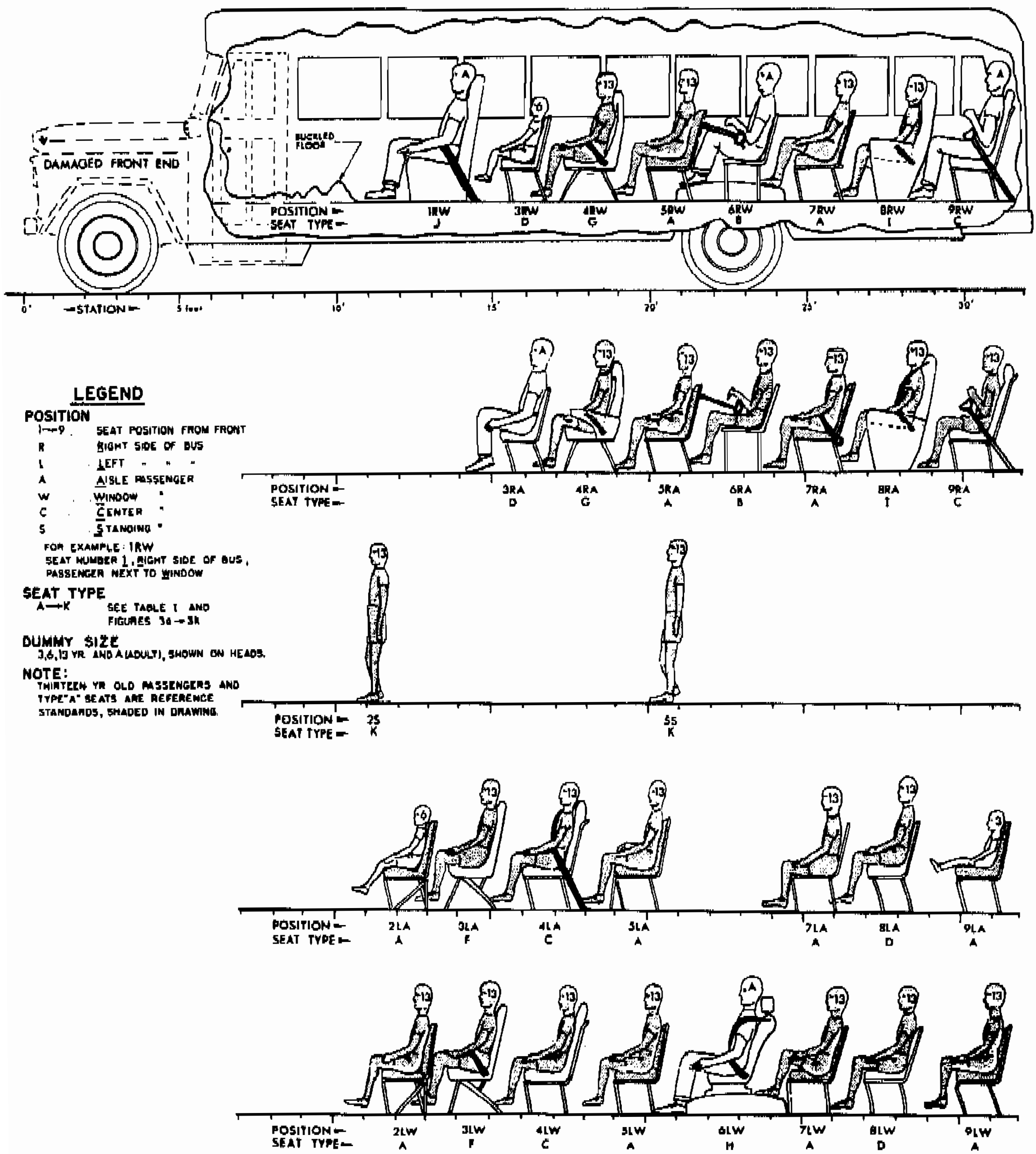

Fig. 4(c) - Side-impact; seat assignment showing seat location, passenger sizes, and restraint systems

c. Restraint Type 3 (Fig. 5 (d)), refers to the three-point, diagonal shoulder strap and lap belt combination. The method of attachment is not specified by this designation. However, this information can be determined from Figs. 4 (a-c).

d. Restraint Type 4 refers to single and double passenger preinflated air bags which were placed between the passengers and the seatback ahead (Fig. 5 (e)). The problems associated with quick inflation of these bags were not investigated. However, it may be possible to inflate them during the period between onset of collision and significant occupant displacement without injury from the abrupt inflation action.

e. Restraint Type 5 includes all special restraint bars that were used in these experiments (Figs. 5(f) and 5 (g)); in addition, a special padded armrest-restraint was added to one of the standard seats for the side-impact collision experiment (Fig. 5 (h)). Some of the seats had conventional

Table 2 - Passenger Assignment Variables, Head-On Collision Experiment

Seat Station	Occupant Type	Seat Type	Restraint Type	Seat Type Ahead
Driver	A	A	1	K
1L Window (1LW)	3	A	2	A
1L Aisle (1LA)	13	A	1	A
2L Window (2LW)	13	A	2	A
2L Aisle (2LA)	13	A	2	A
3L Window (3LW)	6	F	1	A
3L Aisle (3LA)	13	F	2	A
4L Window (4LW)	13	C	3	F
4L Aisle (4LA)	13	C	2	F
5L Window (5LW)	13	A	4	C
5L Aisle (5LA)	13	A	1	C
6L Window (6LW)	A	H	3	A
7L Window (7LW)	A	B	1	H
7L Aisle (7LA)	S	B	2	K
8L Window (8LW)	13	E	4	B
8L Aisle (8LA)	13	E	4	B
9L Window (9LW)	13	A	1	E
9L Aisle (9LA)	3	A	1	E
1R Window (1RW)	A	J	2	K
2R Window (2RW)	13	A	1	J
2R Aisle (2RA)	6	A	1	J
3R Window (3RW)	13	D	1	A
3R Center (3RC)	A	D	1	A
3R Aisle (3RA)	13	D	1	A
4R Window (4RW)	13	G	1	D
4R Aisle (4RA)	13	G	2	D
5R Window (5RW)	13	A	3	G
5R Aisle (5RA)	13	A	1	G
6R Window (6RW)	13	B	5	A
6R Aisle (6RA)	3	B	5	A
7R Window (7RW)	13	A	2	B
7R Center (7RC)	S	A	2	B
7R Aisle (7RA)	13	A	2	B
8R Window (8RW)	13	I	2	A
8R Aisle (8RA)	13	I	1	A
9R Window (9RW)	3	C	5	I
9R Aisle (9RA)	13	C	5	I
2S Standee	13	K	1	K
6S Standee	13	K	1	K

Table 3 - Passenger Assignment Variables, Rear-End Collision Experiment

Seat Station	Occupant Type	Seat Type	Restraint Type	Seat Type Ahead
Driver	-	(Removed)*	-	-
1L Window (1LW)	-	(Removed)	-	-
1L Aisle (1LA)	-	(Removed)	-	-
2L Window (2LW)	13	A	2	K
3L Window (3LW)	6	F	1	A
3L Aisle (3LA)	13	F	2	A
4L Window (4LW)	13	C	3	F
4L Aisle (4LA)	13	C	2	F
5L Window (5LW)	13	A	1	C
5L Aisle (5LA)	13	A	1	-
6L Window (6LW)	A	H	3	A
7L Window (7LW)	13	B	1	H
7L Aisle (7LA)	3	B	1	H
8L Window (8LW)	13	D	1	B
8L Aisle (8LA)	13	D	1	B
9L Window (9LW)	A	A	1	D
9L Aisle (9LA)	13	A	1	D
1R Window (1RW)	A	J	2	K
2R Window (2RW)	-	(Removed)	-	-
2R Aisle (2RA)	-	(Removed)	-	-
3R Window (3RW)	13	D	1	J
3R Center (3RC)	A	D	1	J
3R Aisle (3RA)	6	D	1	J
4R Window (4RW)	13	G	1	D
4R Center (4RC)	-	G	-	D
4R Aisle (4RA)	13	G	2	D
5R Window (5RW)	13	A	3	G
5R Center (5RC)	-	A	-	G
5R Aisle (5RA)	13	A	-	G
6R Window (6RW)	13	B	5	A
6R Center (6RC)	-	B	-	A
6R Aisle (6RA)	3	B	5	A
7R Window (7RW)	13	A	2	B
7R Center (7RC)	13	A	2	B
7R Aisle (7RA)	13	A	2	B
8R Window (8RW)	13	I	2	A
8R Aisle (8RA)	3	I	1	A
9R Window (9RW)	A	C	5	I
9R Aisle (9RA)	13	C	5	I
2S Standee	13	K	1	K
5S Standee	13	K	1	K

*Seats were removed owing to collision intrusion from prior head-on collision experiment armrests as a part of their original design and these acted as restraints for the side-impact collisions.

3. Passenger Size - The nature and severity of collision injury is size dependent, whether it relates to the sizes of the colliding vehicles or to the sizes of occupants within these vehicles. A selection of dummy sizes was made to represent this variation (Table 5). These anthropometric dummies correspond to the ages of 3-, 6-, 13-year-old and adult. It is evident, with respect to a rear-end collision exposure that a seat providing satisfactory head support for a

Table 4 - Passenger Assignment Variables, Side-Impact Collision Experiment

Seat Station	Occupant Type	Seat Type	Restraint Type	Seat Type Ahead
Driver	-	(Removed)*	-	-
1L Window (1LW)	-	(Removed)	-	-
1L Aisle (1LA)	-	(Removed)	-	-
2L Window (2LW)	13	A	1	K
2L Aisle (2LA)	6	A	1	K
3L Window (3LW)	13	F	2	A
3L Aisle (3LA)	13	F	1	A
4L Window (4LW)	13	C	1	F
4L Aisle (4LA)	13	C	3	F
5L Window (5LW)	13	A	1	C
5L Aisle (5LA)	13	A	1	C
6L Window (6LW)	A	H	3	A
7L Window (7LW)	13	B	1	H
7L Aisle (7LA)	13	B	1	H
8L Window (8LW)	13	D	1	B
8L Aisle (8LA)	13	D	1	B
9L Window (9LW)	13	A	1	D
9L Aisle (9LA)	3	A	1	D
1R Window (1RW)	A	J	2	K
2R Window (2RW)	-	(Removed)	-	-
2R Aisle (2RA)	-	(Removed)	-	-
3R Window (3RW)	6	D	1	J
3R Aisle (3RA)	A	D	1	J
4R Window (4RW)	13	G	2	D
4R Aisle (4RA)	13	G	2	D
5R Window (5RW)	13	A	1	G
5R Aisle (5RA)	13	A	1	G
6R Window (6RW)	A	B	5	A
6R Aisle (6RA)	13	B	5	A
7R Window (7RW)	13	A	1	B
7R Aisle (7RA)	13	A	2	B
8R Window (8RW)	13	I	2	A
8R Aisle (8RA)	13	I	3	A
9R Window (9RW)	A	C	5	I
9R Aisle (9RA)	13	C	5	I
2S Standee	13	K	1	K
5S Standee	13	K	1	K

*Seats were removed owing to collision intrusion from prior head-on collision experiment

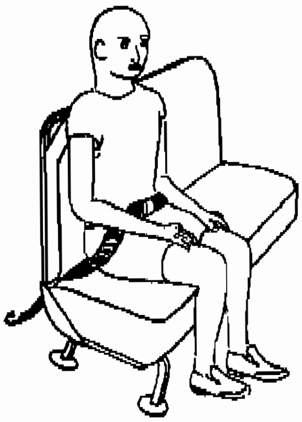

Fig. 5(a) - Type 2 lap belt installation with passenger car floor attachments

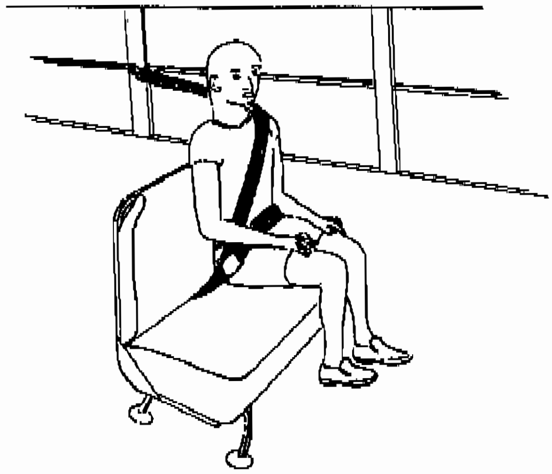

Fig. 5(d) - The three-point belt provides head and upper torso restraint

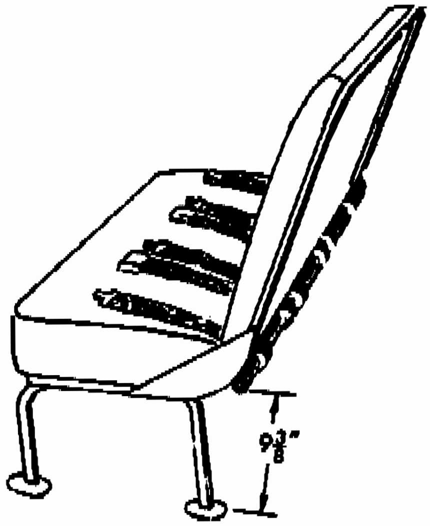

Fig. 5(b) - Seat belt manifold anchor bar; a useful device if the seat legs are sufficiently strong to sustain the added stresses

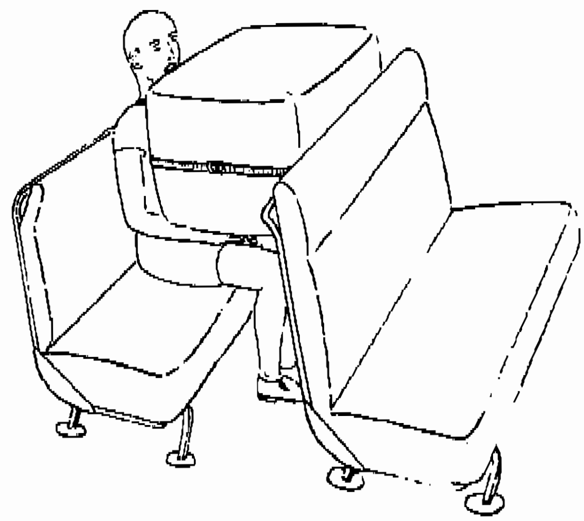

Fig. 5(e) - Air bag restraint. The bag would not be inflated until the collision was underway. The complication air bags could add to expeditious evacuation in the event of post-crash fire should not be overlooked

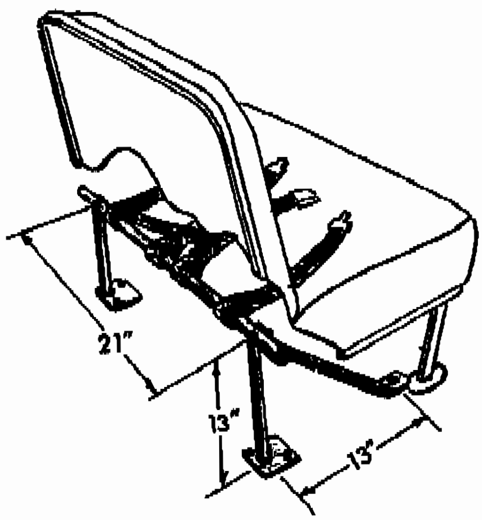

Fig. 5(c) - Floor supported manifold anchor bar provides the required strength without need for modifying seat

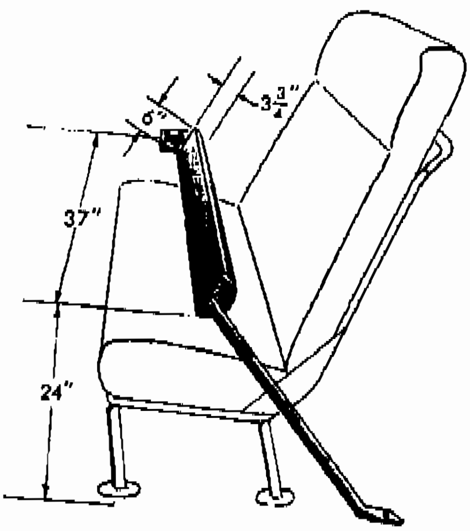

Fig. 5(f) - Floor side-wall anchored restraint bar

3-year-old, may present a compromise for a 6-year-old and provides no whiplash protection for the majority of school bus passengers represented by the 13-year-old as well as larger sizes (Fig. 6 (a)).

The Experimental Findings, a later section of this paper, also provides data indicating that there are problems of a serious nature relating to seat design when considering passenger size, variation in restraining devices, and so forth.

Sixteen million school children are transported daily by buses over the city streets and rural highways of our country. The range in size of this very special population is from pre-kindergarten (nursery school) to young adults. Realistic simulation of this extreme size range, as typified by Fig. 6 (b) was necessary. Description of construction of adult and small child dummies is provided by Ref. 6. A pilot study of a new technique was made resulting in development of a prototype 6-year-old solid-pour anthropometric dummy.

Subsequently, based on the favorable performance of this prototype dummy, the solid-pour technique was selected as the procedure for manufacturing twenty-six 13-year-old solid-pour anthropometric dummies (Fig. 7 (a)).

The development and manufacturing procedure, briefly stated, was as follows: Considering the lower size range, kindergarten child's weight of 40 lb, and the upper range of high school young adult's weight of about 190 lb, it was determined that a 115 lb child was most representative of

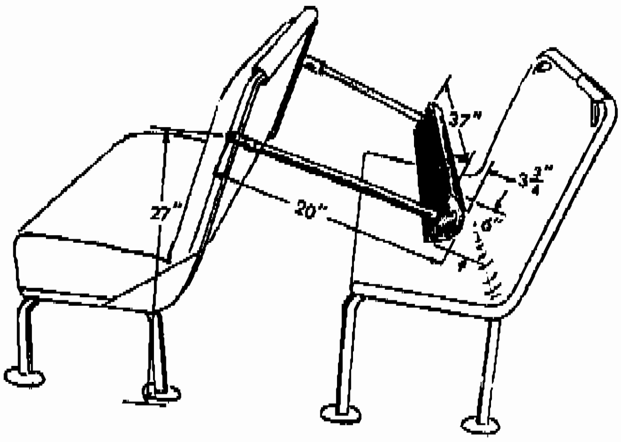

Fig. 5(g) - Seat backrest anchored restraint bar

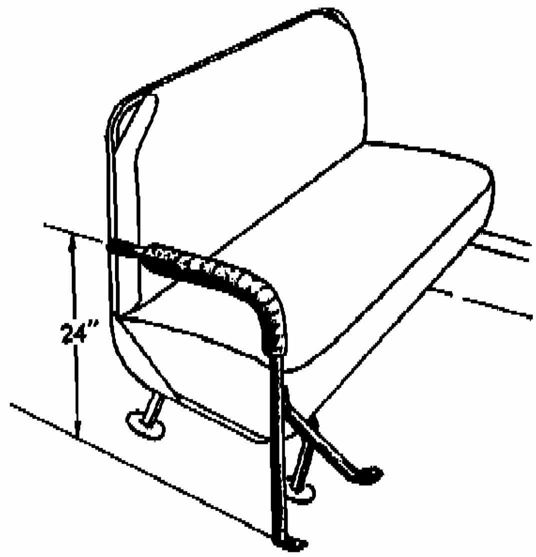

Fig. 5(h) - Special padded armrest restraint added to one of the standard seats shown in Fig. 3(a)

Table 5 - Anthropometric Dummy Passenger Specifications

Ref. No.	Manufacturer	Model No.	Ht., in.	Wt., lb	Age Group
1	Sierra Engr. Co.	120	72	195	Adult
2	Sierra Engr. Co.	15	68	200	Adult
3	Sierra Engr. Co.	15	68	200	Adult
4	Sierra Engr. Co.	135	68	175	Adult
5	Sierra Engr. Co.	262	69	170	Adult
6	Sierra Engr. Co.	292	72	195	Adult
7	Sierra Engr. Co.	292	72	195	Adult
1-26	UCLA	13-SP*	61	115	13-yr
1	Sierra Engr. Co.	492-06	46	42	6-yr
2	Sierra -- UCLA	492-SP	46	55	6-yr
1-4	Sierra -- UCLA	492-01	38	32	3-yr
1	UCLA	Simulation (Iron Man)**	--	173	Special
		Sandbag**	--	100	Special

*13-SP, 13-year-old, Solid-Pour construction, anthropometric dummy

**Nonanthropometric

these extremes. This weight is representative of a 13-year-old.

After determining the required size and weight categories, a review of publications on anthropometrical data by the project's medical scientist provided necessary measurements for accurate construction of a 13-year-old dummy (Table 6).

Fig. 6(a) - Comparison of passenger size range to reference standard seat for anthropometric dummies used in bus study

Using these measurements, a commercial sculptor was retained to develop the corresponding human form. Subsequently, the limbs were dismembered from this clay figure and, following certain modifications necessary to provide accommodation for a skeleton, molds were made for the head-torso unit and each of the limbs. The aluminum molds were designed to facilitate hand-pouring operations of heated polyvinyl-chloride thermoplastic. While these operations were underway, arrangements were made for production of the required limb skeletal components, as well as their torso anchor plates. Collectively, the 13-year-old dummy components before assembly appeared as shown in Fig. 7(b)).

The exceptional performance of this dummy in more faithfully representing forced human kinematics indicates a substantial advance in the field of human simulation (Fig. 7(c)).

4. Proximity to Impact of Passengers - In general, other factors remaining the same, the more remote a passenger is from the point of impact, the less likely he is to be injured. The basis for this assertion concerns the intervening action of collapsing structures between two passenger positions. Thus, in head-on collisions, deceleration rates for passengers toward the rear tend to be lower than for passengers in the front, owing to the intervening of buckling structures between these locations. Where no significant collapse action of passenger compartment occurs, as in many rear-end collisions, the acceleration exposure of all subjects is approximately uniform; an exception would be a specialized con-

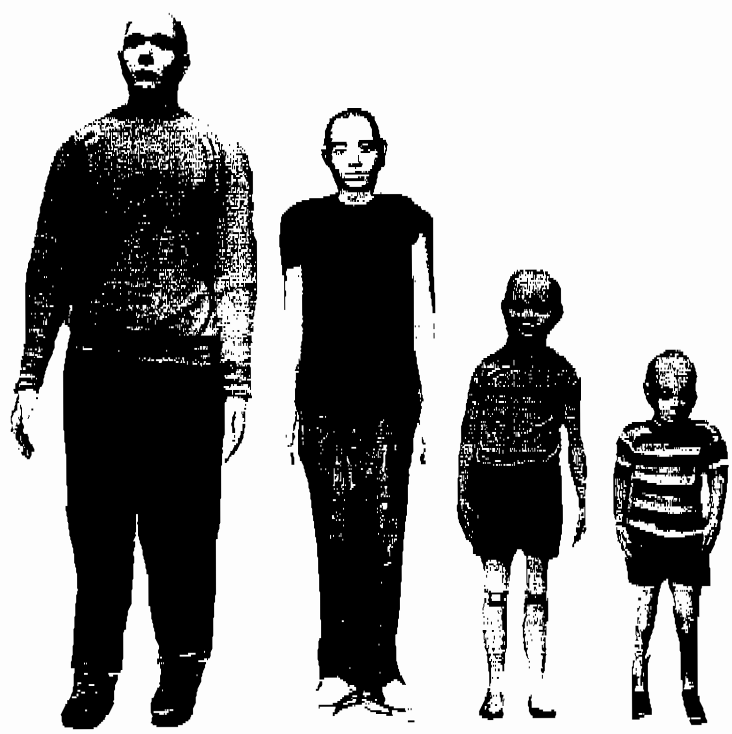

Fig. 6(b) - Anthropometric dummy passengers in UCLA school bus experiments dition encountered by the rear-seated passengers exposed to collapsing structures.

Owing to the lack of symmetry characteristic with side-impact exposures, the proximity of the passenger to the impacting vehicle does have a significant bearing on the direction and magnitude of his forced movements. Thus, at the rear of the bus directly in line with the striking vehicle, tangential accelerations are very high for adjacent passengers, causing them to be pitched sideways. Contrasted to this, unrestrained passengers near the front would be hurled forward and to the side less violently, due to lower rotational forces. A mathematical analysis of vehicle rotational dynamics influencing passengers' force magnitudes is described in a prior publication. (7)

To control against the variable of proximity to impact, the standard reference 13-year-olds and conventional Superior seats were distributed throughout the bus (Fig. 8).

5. Categories of Data Recorded - The large number of

Fig. 7(a) - Assembly line for twenty-six 13-year-old dummies

Table 6 - UCLA-ITTE Anthropometric Data for 13-Year-Old Dummy

Measurement, in.	Location
10.9	Top of head to shoulder pivot
17.8	Shoulder pivot to hip pivot
14.7	Hip pivot to knee pivot
13.9	Knee pivot to ankle pivot
3.2	Ankle pivot to bottom of foot
28.7	Top of head to hip pivot ("H" point)
32.7	Top of head to base of buttocks (sitting)
27.8	Crotch to heel
15.0	Width between shoulders
5.8	Transverse diameter of skull
12.5	Transverse diameter between shoulder pivots
11.0	Transverse diameter of chest
12.3	Transverse diameter of hips
3.5	Transverse diameter of knee
10.7	Shoulder pivot to elbow pivot
15.6	Elbow pivot to tip of fingers
2.8	Transverse diameter of 4 lateral fingers compressed together
6.6	Longitudinal diameter of chest
9.0	Long diameter of foot (heel to toe)
60.5	Height, in.
115.0	Weight, lb

transducers and cameras used for these experiments, as well as other provisions made for scientific observations, account for the many categories of data possible for each collision experiment; these are indicated in Table 7.

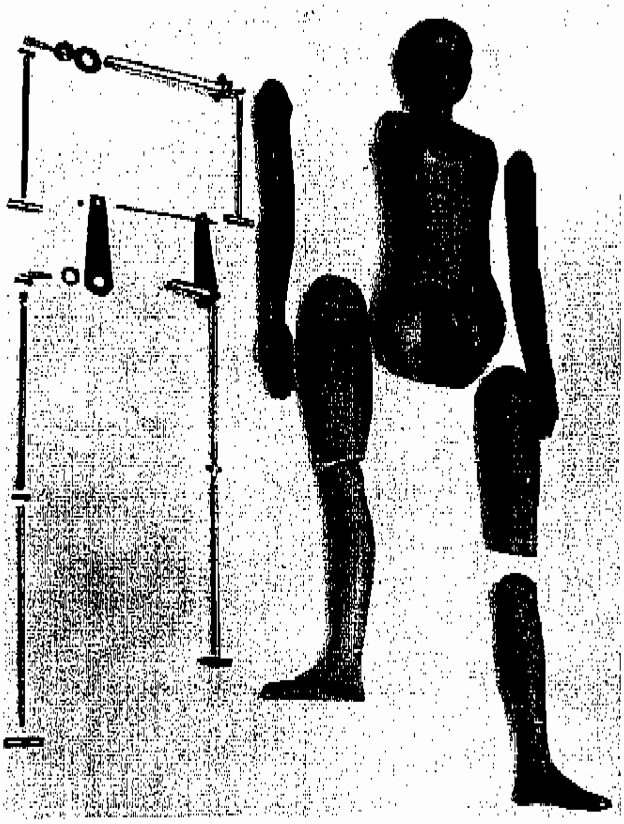

Fig. 7 (b) - Component parts of UCLA-ITTE 13-year-old anthropometric dummy

6. Instrumentation - A photographic record of the sequence of events occurring during the collision experiment was obtained using specialized photographic systems strategically positioned (Fig. 9). Owing to the extremely short duration of the collision event, usually less than 1/4 sec, it was necessary to use high-speed photography, operated automatically by electronic timing devices; motion picture photography was valuable in determining collision phenomena that would otherwise be lost. Therefore twelve moderately high-speed motion picture cameras, positioned along the roof rail of the new bus, viewed the passengers while four high-speed exterior cameras recorded structural collapse

Table 7 - Categories of Data Recorded

1. Kinematics of passengers with respect to the following variables:
   a. Size of passenger.
   b. Type of seat.
   c. Form of restraint.
   d. Proximity to impacting vehicle, to other passengers, to seatbacks and other fixed objects.
   e. Seated without restraint versus standing in aisle.
   f. Type of safety glass.
2. Forces sustained by passengers.
3. Loading of restraint systems.
4. Relative injury exposure for passengers in different seating arrangements undergoing the same collision.
5. Vehicle collision dynamics.
6. Vehicle structural performance.

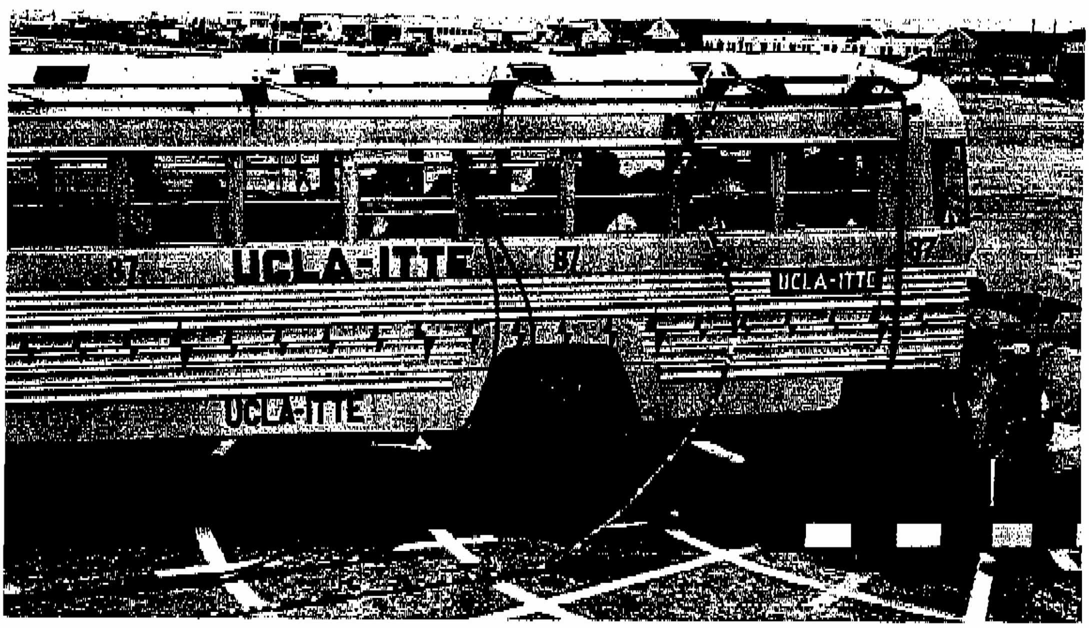

Fig. 7 (c) - Realistic whiplash action of 13-year-old passengers

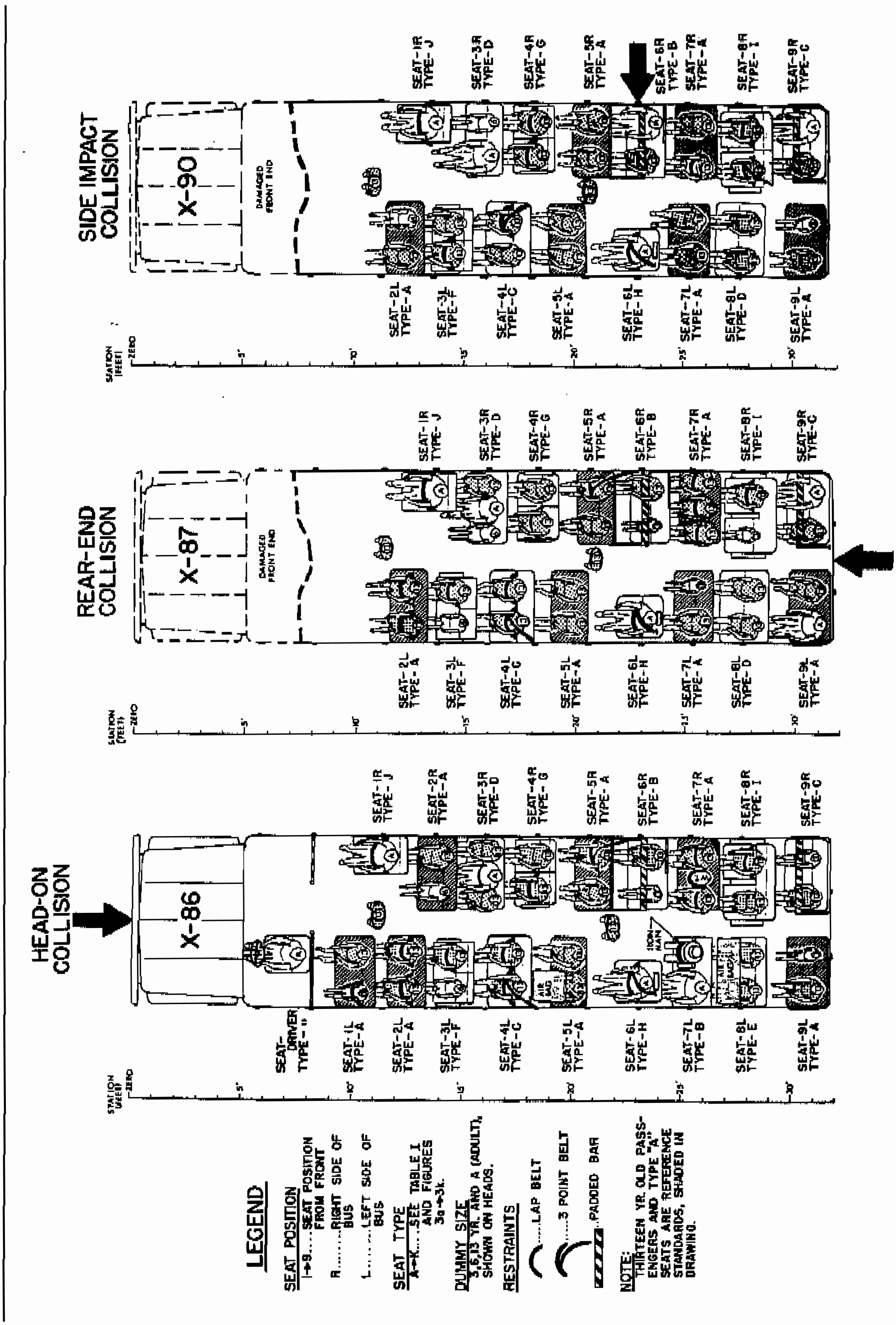

Fig. 8 - Proximity to impact for specific sized passengers, seat types, and restraint systems

Table 8 - Instrumentation

Device	To Provide	Location	Specifications
High Speed Motion Picture Cameras	Vehicle collision dynamics and passenger kinematics	Cameras 1, 2, 3, and 4, Fig. 9	2-Eastman, High speed; 2-Fastax WF-3; 600-1700 frames/sec; 16mm Kodak ER 7257 Film
Moderately High Speed Motion Picture Cameras	Vehicle collision dynamics and passenger kinematics	Cameras 5-20, Fig. 9	15-Photosonics 1B, Traid, Engr; 1-GSAP MBH 200-16, high G tolerance 200 f/s 16mm Kodak Ektachrome 7257
Standard Motion Picture Cameras	General photographic coverage	Cameras 21-24, Fig. 9	1-K100 @ 64 FPS; 1-Arriflex 16mm, Model 16 S; 1-Bolex, 16mm; 1-GSAP, 16mm
Special Motion Picture Cameras	Sequential, large format photographs of collision events	Cameras 25-28, Fig. 9	2-Hulcher Model 102, 20 f/s 70mm (Camera rotated 90 deg to permit cine-reduction); 1-Bell & Howell Eyemo, 48 f/s Ektachrome ER 5257; 1-Foton 35mm rapid fire, Bell & Howell
Still Camera	Precision-timed photographs	Cameras 29-33, Fig. 9	5-Super Speed Graflex 4 X 5 Ektachrome 1/1000 sec electronically controlled to fire at pre-calculated msec after contact
Calibrated References	Fixed ground reference points for micro-motion analysis	Near the impact center	8 ft longitudinal reference boards and 4 ft vertical posts calibrated with yellow and black at alternate 1 ft increments
Reference Targets	Precision photographic references for micro-motion analysis	At strategic positions on the vehicles and their occupants	Diamond shaped yellow and black targets
Electrical Accelerometers	Acceleration measurements	Within dummy passengers, body of bus at two locations, and on striking vehicle	B & F-LF 50-50 and LF 50-100; Statham A 38a-60-350, A6-100-350, AJ43-100-350, F 100-300, F 50-350 and A6 9TC-500-350
Seat Belt Tensiometers	Measurement of belt loads	On belt webbing	Thread-through type, special UCLA construction
Recording Oscillograph	Amplitude-time records of transducer signals	Carried by instrument recording vehicles	2-18 Channel Consolidated Type 5-114 P2; 1-50 Channel CEC, Type 5-119; 1-12 Channel CEC, Type 5-118
Electronic Time Delays	Precision timing for still photography	Electric pressure pads near impact center	100, 200 and 500 msec time delay devices built by UCLA
Photographic Oscillographic Synchronization Units	Zero time (vehicle contact); flash bulb for film and pulse for oscillograph	Pressure switches between contacting surfaces of vehicles, photocell and flashbulb on vehicle	Foil contacts with spacers
Strain Gages	Measurement of passenger interaction with safety glass	On side-windows near position of impact	SR-4 bonded strain gages
Pulse Generators	Timing for high-speed and moderate-speed cameras	Between camera and power source	Wollensak, 100 cps, 1000 cps and special 100 cps solid-state devices
Auxiliary Timer	Backup timing	Near impact center in view of all cameras	Rotating yellow-black drum; constant speed 1740 rpm motor

(cont'd.)

Table 8 - (cont'd)

Device	To Provide	Location	Specifications
Speed Counter	Car speed data	On guide yoke	Induction pickup for oscillograph. Measures time-displacement of vehicle
Tire-Skid Mark Tracer	Identification of skids	On each tire-rib, 1/4 in. from road surface	Artist-type oil paint deposits
Polar Coordinate Grid	Position data for vehicles from point of impact to positions of rest	On asphalt surface at test site	Yellow traffic marker paint on asphalt, per Fig. 9

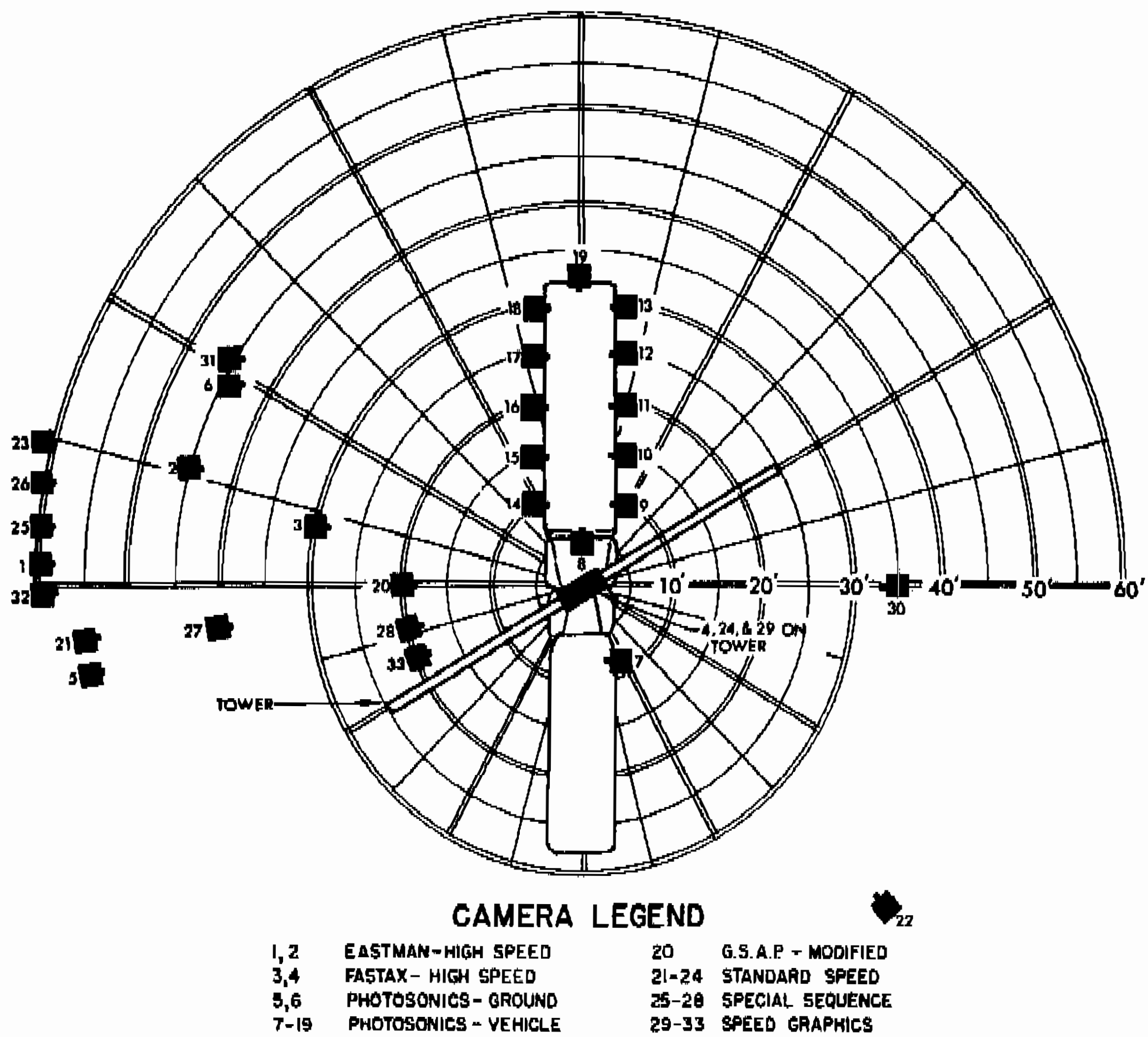

Fig. 9 - Location of photographic instrumentation

of the vehicles. In addition, three regular speed motion picture cameras provided backup documentary coverage. Other precision-timed still cameras and rapid-fire, sequential-frame cameras accurately portrayed specific events and related observations.

In addition to the extensive photographic coverage, effective evaluation of the variables under study required strategic positioning of the numerous electronic sensing devices. Accelerometers were placed in the chests of unrestrained passengers to monitor their violent interactions with interior surfaces, seats, and other occupants: the more limited displacements of restrained individuals made it advisable to use head accelerometers, to determine the magnitude of head contact with injury-producing structures, for those situations where a lap-belted passenger would jackknife and slam his head against improperly designed seat structures. Exact specifications and functions of the numerous instrumentation systems are described in Table 8.

FINDINGS - HEAD-ON COLLISION

EXPERIMENT 86 - A head-on collision was conducted between a 1944 Mack bus and a 1965 GMC bus, each vehicle traveling 30 mph at impact (Fig. 10 (a)). The 1944 Mack and the 1965 GMC chassis each carried Superior school bus bodies. This initial inquiry into school bus passenger safety is identified as Experiment 86. The front ends of the buses were in line and directly opposing each other at impact (Fig. 10 (b)). As the collision intrusion progressed, the front end of the 1965 GMC bus was pushed inwards by the overriding structure of the 1944 Mack (Figs. 10 (c)-10

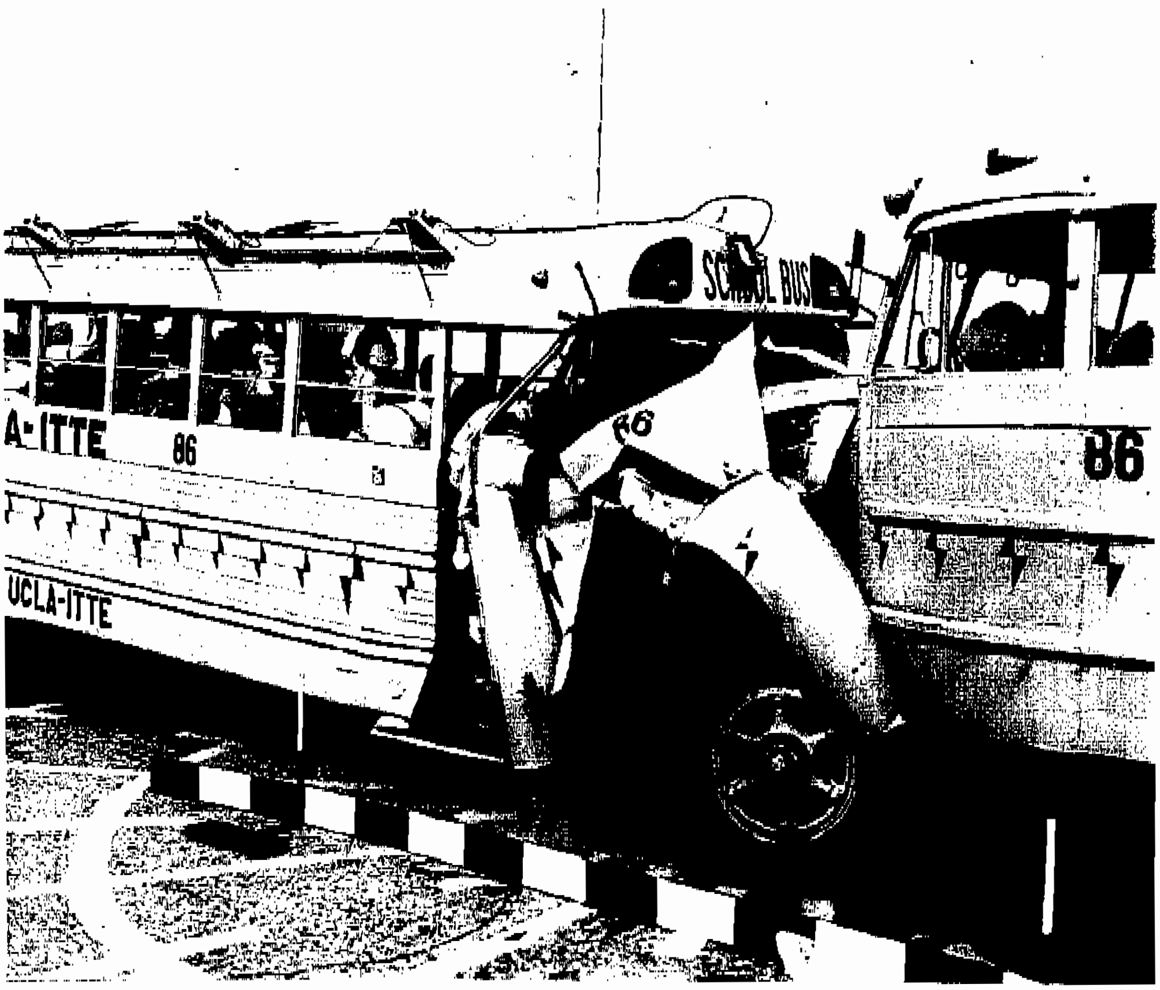

Fig. 10(a) - Head-on collision, school buses, each vehicle traveling 30 mph at impact

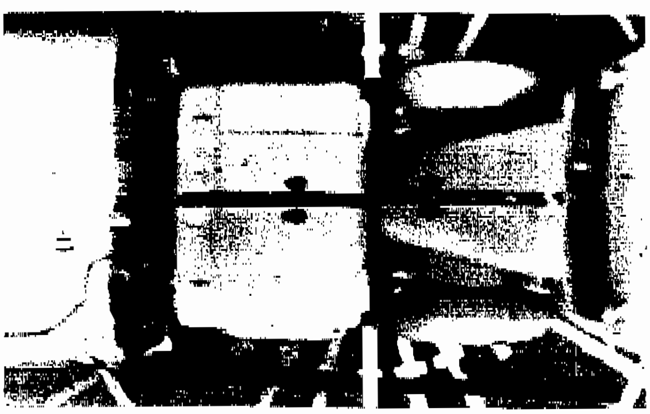

Fig. 10(b) - Position of buses at contact

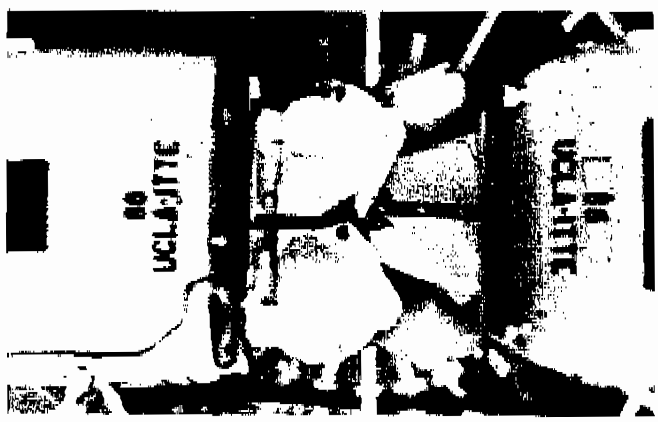

Fig. 10(c) - Intermediate collapse action during impact (e)). This unbalanced condition was intensified by slippage forward, relative to its frame, of the 1965 Superior bus body. Within the first 1/10 sec after contact, the front engine compartment of the new bus had been entirely crushed in. Further discussion concerning the structural performance of the buses will be reserved for a later section of Findings.

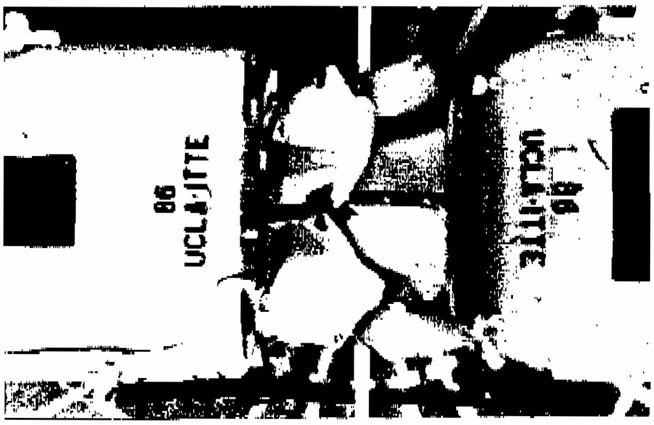

Fig. 10 (d) - Continuing encroachment of old Mack-Superior bus (right) into engine cowl structure of 1965 GMC-Superior (left)

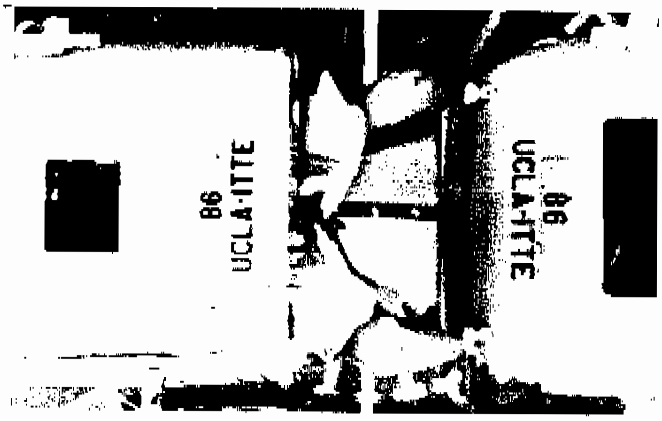

Fig. 10 (e) - Maximum collapse of two bus structures

1. The 1944 Mack Superior Bus Passenger Compartment - Because of the cost of anthropometric dummies and their instrumentation, only two adult-type occupants were used in the old bus and unrestrained sandbags (see Table 5) were positioned in the remaining seats (Fig. 11). Although these sandbags simulated the load condition of a fully occupied bus, their use was not intended to provide seat collision performance information.

a. Driver's position was occupied by an adult-type anthropometric dummy (No. 2, Table 5), secured in a chair-type

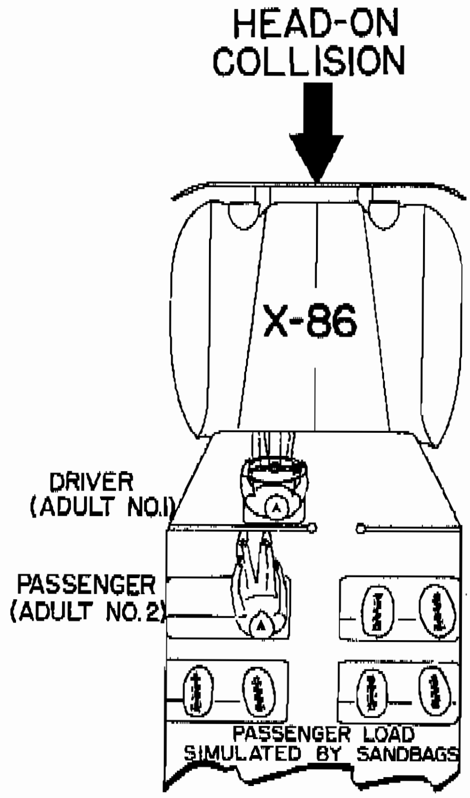

Fig. 11 - Seat assignment, 1944 Mack-Superior bus

Fig. 12 - (a) Driver of Mack bus crushed against steering wheel, at 137 ms; (b) nonrestrained passenger forced against driver's seatback, at 250 ms

HEAD ON COLLISION, X-86

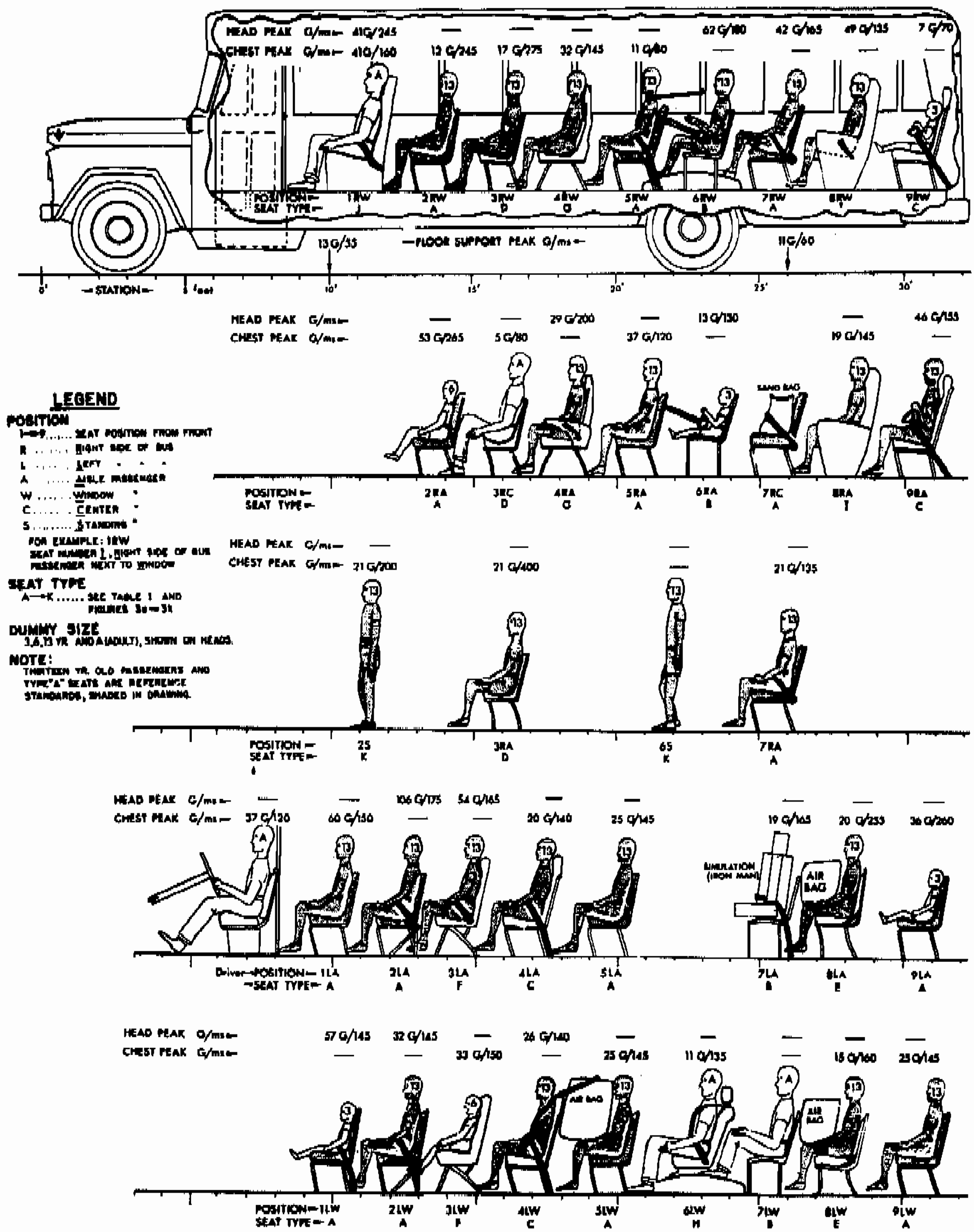

Fig. 13(a) - Passenger assignment, 1965 GMC-Superior bus, showing also seat types, restraint systems, and peak accelerometer values seat by a lap belt. The passenger, adult No. 1, seated on a bench-type seat behind the driver, had no restraint. As collision intrusion progressed, the steering wheel was not extended toward the driver at all; instead, the driver's chest was thrown against the steering wheel to collapse the lower portion of the wheel rim downward. This action is seen at the right side of Fig. 12 (a). The relatively small amount of front-end collapse for this older bus explains why the steering column remained fixed for this head-on collision. Next, the driver's head flexed forward and struck the top rim of the steering wheel, while his right arm flailed against the instrument panel. These injury-producing forces were augmented by the unrestrained passenger, seated directly behind him, who was thrown forward against the driver's seatback, thereby crushing him between it and the steering wheel (Fig. 12 (b)).

b. Passenger, adult No. 1, was thrown against the horizontal separation bar between him and the driver's seatback. The vertical handhold that anchored this separation bar was likewise collapsed forward. The passenger's head then pitched to the left of the driver and snapped downward as he flexed over the driver's seatback; his knees buried into the seatback causing him to pivot past the driver with his head close to the windshield.

The passenger's seat and backrest cushions were loosened during the initial phase of the impact and added additional forces to both him and the driver. One of the sandbags behind the passenger's seat was hurled through his seatback and continued forward into the driver's compartment. Other sandbags ruptured and propelled their contents forward during the latter phases of the collision.

The passenger's seat frame remained partially fastened to the floor, although the back yielded substantially forward during the impact.

2. The 1965 GMC-Superior Bus Compartment - The assignment of passenger types, seat types and restraint systems complete with peak accelerometer values for the passengers of the new bus is shown by Fig. 13 (a). In addition, each passenger's forced movements and positions of rest were plotted for this head-on collision (Fig. 13 (b)); these and other related findings will be discussed individually for each seat location.

a. The driver, unrestrained adult No. 3, was seated in a bucket type seat (see Fig. 3 (k)). As the front-end collapse commenced, the steering column was thrust axially rearward, and the lower rim of the steering wheel buried into the driver's abdominal area. This penetration was moderated for the dummy because of his stiffer abdominal structure which grossly deformed the steering wheel rim. The horn button was then projected rearward to strike the right side of the driver's face above the temple. At this instant, the steering column was deflected upward and the wheel hub struck the base of the nose, shearing it from his face (Fig. 14 (a)). The peak chest deceleration of 36 G occurred 120 ms after the front bumpers contacted each other (Fig. 14(b)). At 145 ms, the intrusion by the striking bus and the forward movement of the driver had proceeded sufficiently to close the 30 in. gap, bringing the instrument panel forcibly against his chest. As the driver was pitched forward, his seatback was forced forward by the 13-year-old thrown against it (Fig. 14 (c)). All indicators for inferred injury precluded the possibility of survival for this individual.

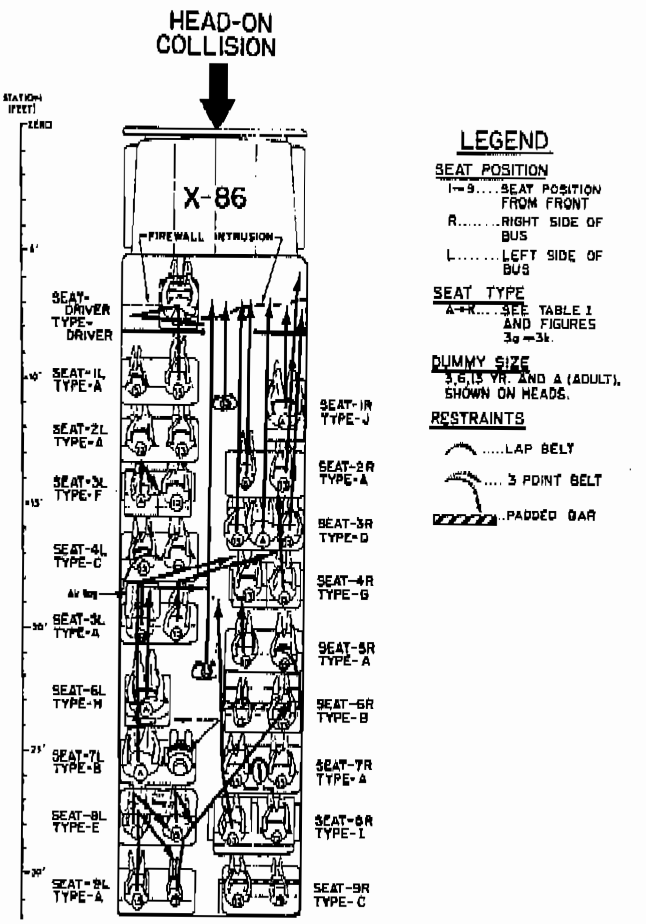

Fig. 13(b) - Forced movements of passengers in new bus during collision along with their positions of rest

Fig. 14 (a) - Driver struck above mouth by steering wheel hub at 100 ms after vehicles contact

The action of the entire seat unit rotating forward was augmented by floorpan distortion immediately behind his seat (Fig. 15). The floor buckling occurred behind the driver's seat because of strong longitudinal floorpan members that terminated at the end of the driver's seat. However, this buckling tendency was primarily related to the lack of proper attachments for the bus body to the frame.

b. Seat 1L, a conventional Superior seat (see Fig. 3 (a)), was occupied by a lap-belted 6-year-old and an unrestrained 13-year-old. This 13-year-old passenger was seated directly behind the driver in the number 1 seat, Left side, Aisle position (1LA) (see Figs. 8 and 13). During the collision, he buried his knees into the driver's seatback but continued to maintain a normal erect posture, rotating only slightly forward as his chest came against the horizontal bar which was lightly padded. The bar deformed forward and his movement was momentarily restrained causing him to flex over the horizontal bar. However, his head and torso maintained an erect posture as he slammed against the back of the driver, sustaining a 60 G chest deceleration at 150 ms (Fig. 16 (a)). The crushing forces applied by this 13-year-old to the driver's back occurred at the same time as the engine was intruding into the firewall, pushing the dashboard rearward against the driver. He flexed over the right shoulder of the driver, elevating 1-1/2 ft. before reversing his heading; thereafter, he rotated his feet 90 deg in a clockwise direction pointing them toward the side windows and finally came to rest laying across the lap of the driver with his head toward the aisle (Fig. 16 (b)).

The 3-year-old, sitting in seat 1, Left side, Window position (1LW) was restrained by a lap belt and rode out the crash rather well until his head hit the rearward intruding heater enclosure at the left of the driver (Fig. 17). At this time, 145 ms after bumper contact, he received a peak head deceleration of 57 G.

In spite of other complications that occurred as a result of unrestrained individuals thrown against him, had it not been for the gross intrusion of the school bus body, this child simulation would have ridden out the crash with relatively

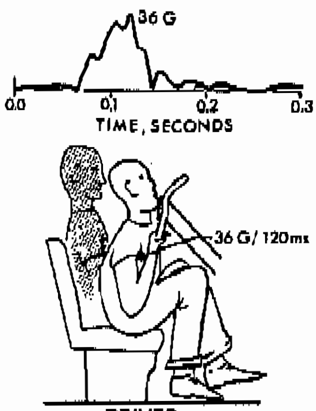

Fig. 14(b) - Driver of 1965 GMC-Superior bus. (Note: Chest (long.) indicates that chest transducer was sensitive in direction of bus's longitudinal axis and refers to driver's precrash seated posture.)

Fig. 14(c) - Instrument panel at 145 ms crushed against driver's chest

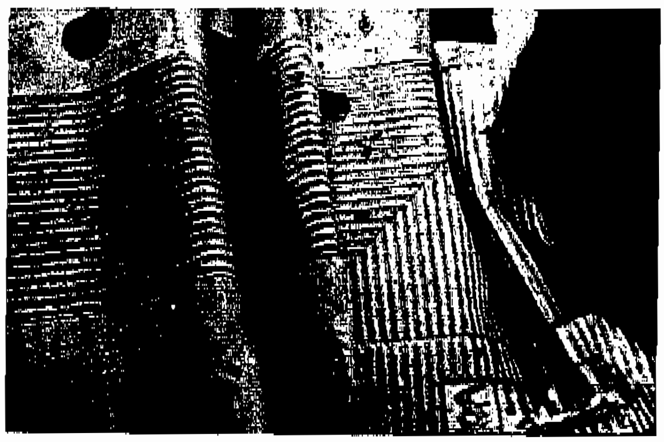

Fig. 15 - Buckling of floor directly behind driver's seat in 1965 GMC-Superior bus

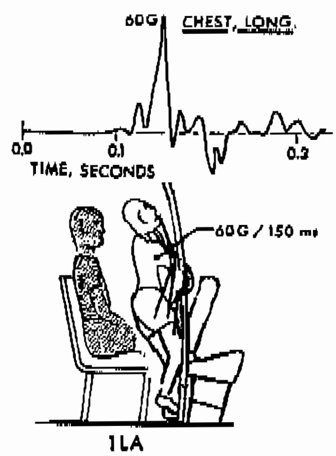

Fig. 16(a) - Thirteen-year-old thrown against horizontal handbar and against driver's seatback minor inferred injuries despite his closeness to the front of the bus. The medical data relating to his inferred survival were inconclusive and his injuries were listed as severe. Following the crash, he was still belted and leaning forward because his seat had tilted forward owing to floor buckling. His right leg indicated an inferred fracture caused by the intruding structure.

c. Standee 2S, a 13-year-old standing in the aisle opposite seats 1 and 2 (see Fig. 13), was thrown forward against the front of the bus, maintaining his standing posture all the way. His peak chest deceleration of 21 G occurred at 200 ms as he impacted the front portion of the passenger compartment (Fig. 18). Just before this impact he rotated to his left; therefore, his single chest accelerometer was not aligned with the direction of impact and his actual peak deceleration was considerably higher than indicated. The post-collision medical analysis indicated that he would have sustained serious injuries.

d. Seat 2L was a conventional Superior seat with two 13-year-old occupants, each restrained by lap belts. These lap belts were attached to a special anchorage system (see Fig. 5 (c)). The performance of this anchorage system appeared to be entirely satisfactory. The kinematics for the passengers at the aisle and window positions are essentially identical, both going through the typical jackknife motion in a forward direction as a result of the lap belt restraining action. The 2LA occupant, however, struck his head against the upward moving buttocks of the passenger 1LA ahead, and at this time, 175 ms, received a peak head deceleration of 106 G (Fig. 19 (a)). Due to the severity of this head impact, this occupant was regarded as a potential fatality.

The 2LW occupant, who impacted the seatback ahead, received a head deceleration of 32 G at 145 ms (Fig. 19 (b)); as his head extended over the seat his neck received a critical injury from the seatback. The passengers in 2L then returned to a normal seated position after which there was some rearward overshoot of their heads. Thereafter their body postures assumed a slumped-forward final rest position.

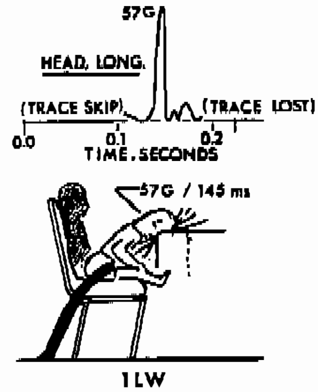

Fig. 17 - Lap-belted 3-year-old struck his head against intruding heater structure

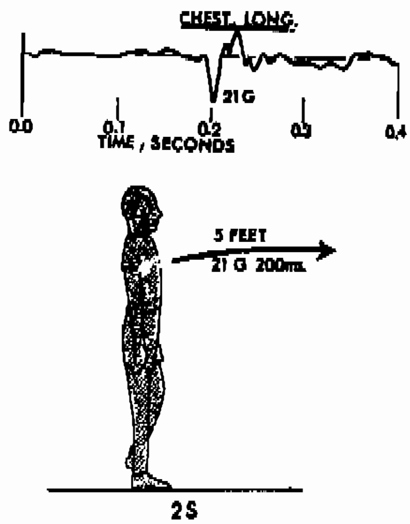

Fig. 18 - Standee at front of bus was hurled against door operation lever forcing it deeply into his waist

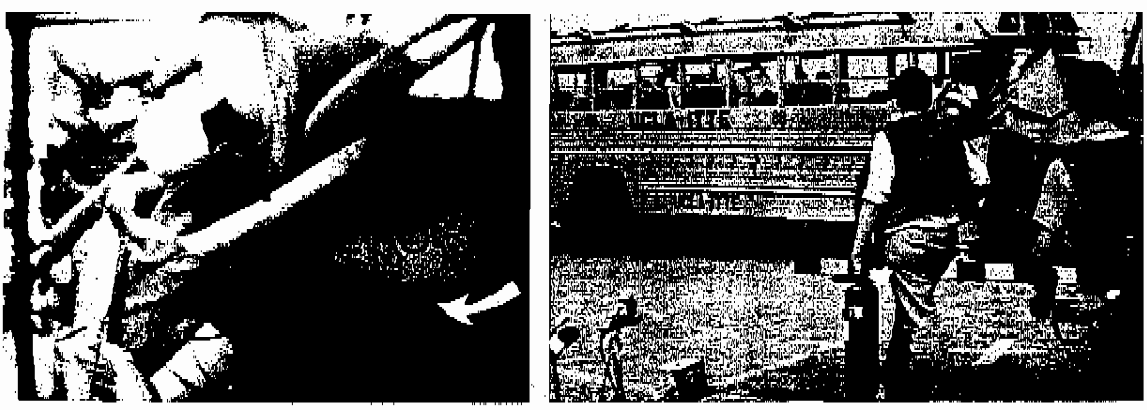

Fig. 16(b) - Thirteen-year-old lands on driver at 1250 ms. Smoke from a post-crash fire starts to enter passenger compartment on right. Prompt action by UCLA crew extinguished this engine compartment fire eliminating hazard to passenger compartment. An important consideration is the almost hopeless problem of promptly evacuating a bus load of unconscious and dazed children through inadequate escape routes

e. Seat 3L was a National seat (see Fig. 3 (f)), occupied by a lap-belted 13-year-old, 3LA, and an unbelted 6-year-old, 3LW. As the collision progressed, the belted 13-year-old jackknifed about his belt and struck the seatback of 2L with enough force to give his chest a 54 G impact at 160 ms (Fig. 20(a)); his head then whipped over the top of the seatback (Fig. 20 (b)). This action caused a neck injury considered fatal by the medical scientist who conducted the post-collision analysis.

In a similar manner, the 6-year-old was thrown forward, and because of his lesser height and his unbelted condition, struck his chest in an almost identical manner against the top of seatback 2L, thereby receiving a 33 G impact at 150 ms (Fig. 20(c)). His head flexed over the top of the seatback bringing extreme manipulation to the neck (Fig. 20

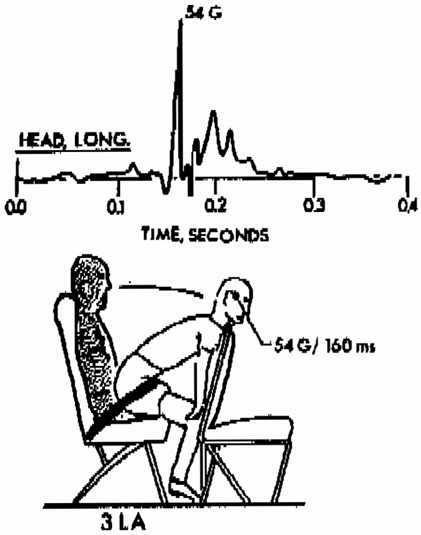

Fig. 20 (a) - Belted 13-year-old, 3LA, jackknifed about lap belt striking chest against seatback

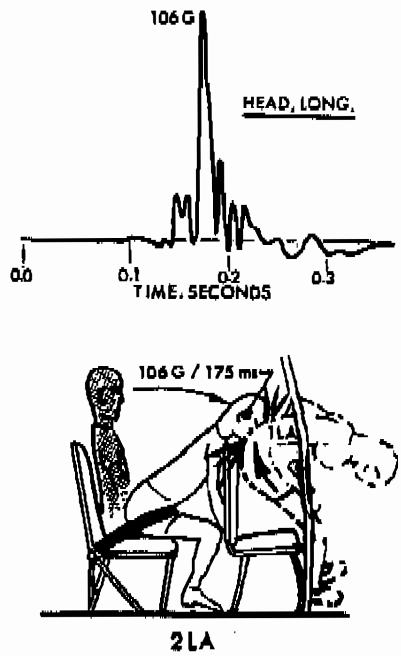

Fig. 19 (a) - Belted passenger 2LA jackknifed over seatback striking unbelted passenger

Fig. 20 (b) - Passengers from seat 3L flex their necks over seatback rail during collision. Note extreme neck traumatization for 13-year-old, 3LA, in foreground

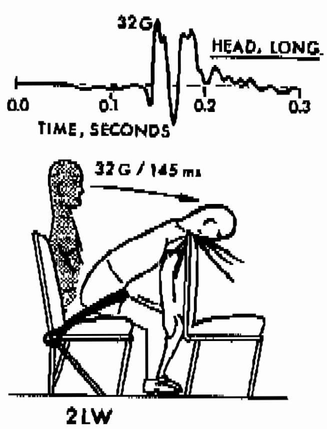

Fig. 19 (b) - Exposure comparable to his companion, 2LA, except passenger struck no one in front of him

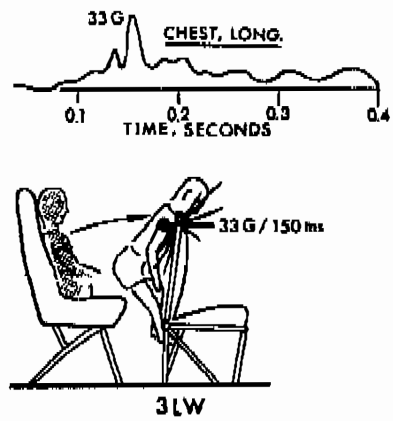

Fig. 20 (c) - Unbelted 6-year-old pitched against seatback (d)). This inferred neck injury was considered critical to fatal. Substantially higher seatbacks would avoid this type of extreme injury exposure. The height of the seatback he struck (2L) was only 19-1/2 in.

After the two occupants from seat 3L were thrown over seatback 2L, they rebounded to a relatively normal posture. Finally, the 13-year-old 3LA slumped over into the aisle and the 6-year-old 3LW slumped forward and to his right.

f. Seat 4L was a high back Superior seat (see Fig. 3 (c)), with the aisle 13-year-old 4LA lap-belted, and the window 13-year-old 4LW restrained by a three-point belt. Occupant 4LW lunged forward against this three-point restraint and rotated to his left, counterclockwise, owing to the nonsymmetrical application of restraining forces by the diagonal chest strap. This rotation appeared to be 90 deg, which essentially freed him from his upper torso restraint (Fig. 21 (a)). As he rotated, his head flailed to the right, striking the seatback of 3L with a peak deceleration of 26 G at 140 ms. In addition to this forceful head impact, the extreme rotation of his upper torso may have caused back injuries. The inferred injury level for this occupant was moderate.

The 4LA 13-year-old pivoted about his lap belt, striking his head and shoulders against the high-padded seatback of National seat, 3L. The peak chest deceleration of 20 G occurred at 140 ms (Fig. 21(b)). His inferred injury level was also considered moderate.

g. Seat 5L was a conventional Superior seat with a 13-year-old dummy, 5LA, unbelted, and another 13-year-old passenger, 5LW, protected by an air bag. The two 13-year-olds in seat 5L were thrown forward, with passenger 5LW plunging squarely into the air bag; the resulting distortions of the bag clearly indicated that he was receiving good energy dissipation and force distribution (Fig. 22 (a)). His chest accelerometer registered a peak of 25 G at 145 ms. The 5LW dummy at this time is shown in Fig. 22 (b). As he

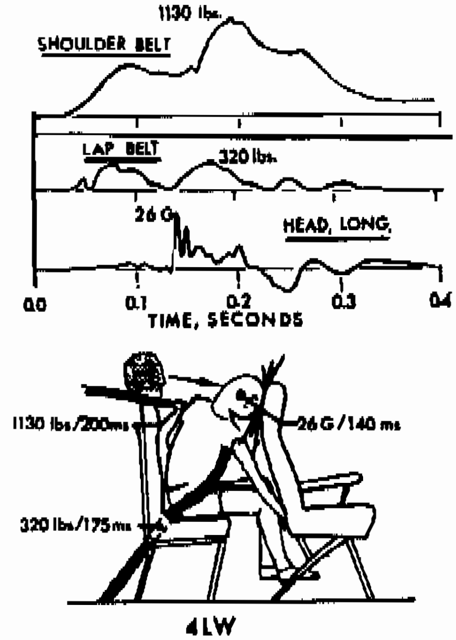

Fig. 21(a) - Thirteen-year-old restrained by combination cross-chest and lap belt rotates out of chest restraint

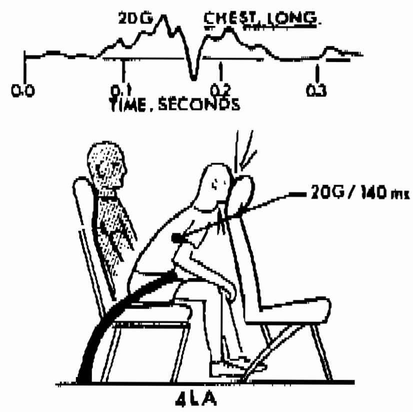

Fig. 21(b) - Thirteen-year-old pivots about lap belt striking padded seatback ahead

Fig. 20(d) - Six-year-old passenger, 3LW, flexes head completely over seatback rail, directing extremely abusive forces to his neck

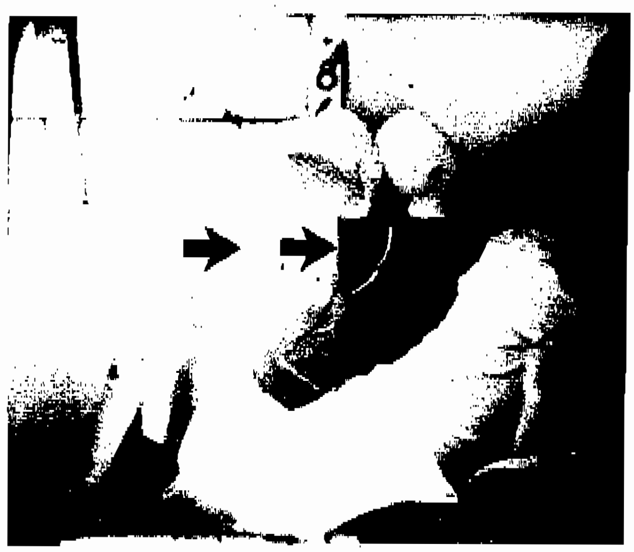

Fig. 22(a) - Seat 5L passengers thrown against air bag, 175 ms after start of collision crushed into the air bag, the bag bulged sideways and provided some protection for 5LA seated beside him.

Passenger 5LA buried his head into the bag after it had been displaced sideward into his pathway (Fig. 22 (c)). Note pressure elongation of bag vertically as a result of passenger impacts, also, the diagonal belt anchor point for the chest restraint portion of the three-point belt restraining 13-year-old 4LW, ahead of the air bag. The air bag attenuation of 5LA's chest held the peak acceleration to 25 G at 145 ms (Fig. 22 (d)). This was partially attributed to the even force distribution of the air bag and the effect of the seatback structure ahead deflecting forward.

The 5L seat cushion dislodged and followed the two 13-year-olds forward and actually added to their collision forces by pressing against their buttocks as they crushed into the air bag. The aisle seat and window seat passengers were rebounded towards the aisle as the restitutional forces of the compressed air bag prevailed. Subsequently, on rebound, the 13-year-olds were displaced toward the aisle when two adults from behind their seated position were thrown forward. Adult 6LW, with the Cox seat belted to him, buried his head into the same air bag after 13-year-olds 5LW and 5LA were rebounded sidward from it: moments later adult 7LW buried his head into the same air bag (Fig. 22 (e)).

The fact that this single-passenger type air bag served four passengers represented an unexpected series of events that couldn't ordinarily be depended on. For example, if the 5LA passenger had preceded, instead of following, the 5LW passenger, the bag would have popped forcibly into the side of the head of 5LA, instead of becoming a cushion in front of him. Similarly, if the individuals pitched from behind the 5L seat had been properly restrained, they wouldn't

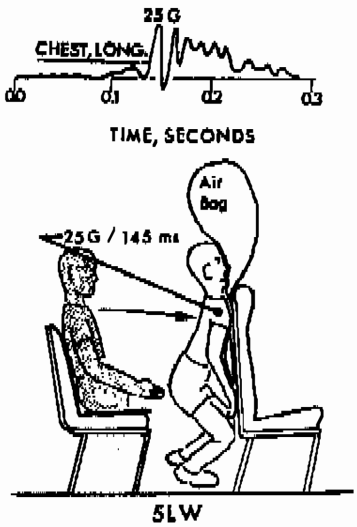

Fig. 22(b) - Thirteen-year-old squarely impacts air bag

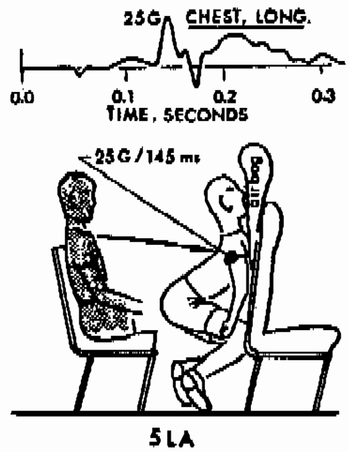

Fig. 22(d) - Elongation of air bag, formerly at shoulder level, stretched approximately 2 ft above this point, 145 ms

Fig. 22(c) - Air bag in seat 5L elongated from impact, primarily by window seat occupant (not shown), and secondarily by aisle seat passenger shown plunging his face and chest into bag, 125 ms after buses contact

Fig. 22(e) - Passenger 7LW is thrown forward through area formerly occupied by seat 6L and buries his head in 5LW air bag after three prior passengers, 5LW, 5LA, and 6LW, have rebounded sequentially from this same air bag have been pitched forward to strike the 5L seat area. As the 5L passengers were thrown forward, they yielded the 4L seatback, thereby directing greater forces to the diagonally restrained 4LW passenger. This interaction shows the importance of not allowing both restrained and unrestrained individuals within the same passenger compartment.

h. Seat 6L was a Cox seat (see Fig. 3 (h)). It was occupied by an adult anthropometric dummy (No. 6, Table 5). This passenger was restrained by a three-point belt attached to the seat (Fig. 23 (a)). As collision forces increased, the adult passenger strained forward with the chest restraint remaining effectively positioned; however, the extremely limited forward movement of the upper torso allowed the lower limbs to pull his body under the lap belt, thereby causing him to submarine considerably. In addition, the slightly reclined position of the seatback also facilitated this tendency (Fig. 23 (b)). While in this position, he received a peak chest deceleration of 11 G at 135 ms (Fig. 23 (c)). The extent of submarining was checked at this instant by failure of the rear seat floor attachments. The entire seat 6L rotated forward about its front anchorages, thereby eliminating further restraint evaluation (Fig. 23 (d)). The 6L seat, with its belted adult was pitched, backrest forward, over the back of the seat 5L and continued forward until its occupant, 6LW, plunged his head into the 5L air bag. Moderate injuries were inferred from his forward motion and subsequent loadings. The adult, 7LW, seated directly behind him, was likewise thrown forward following the ejected 6L seat, and struck the air bag after 6LW had been displaced from it (see Fig. 22 (e)).

In connection with the detachment of the 6L Cox seat,

Fig. 23(a) - Cox seat 6L in its pre-crash position

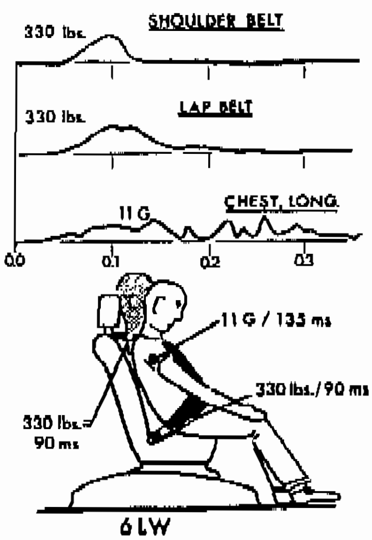

Fig. 23(c) - Peak G occurs before seat anchors fail

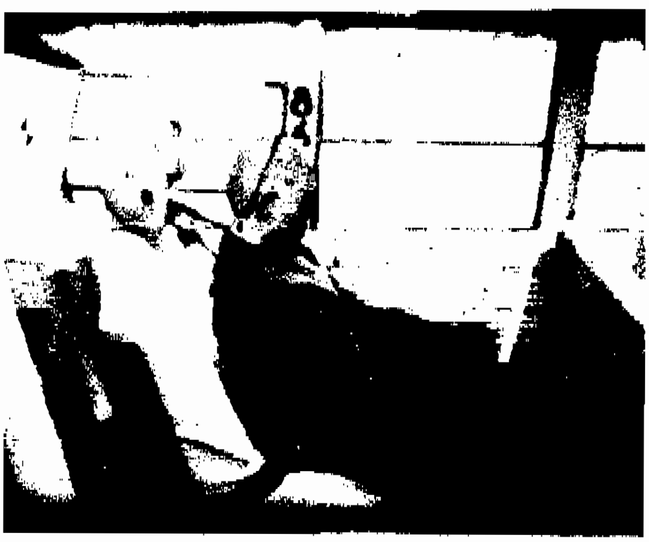

Fig. 23(b) - Seat 6L, showing diagonal chest belt restraining upper torso; hips start submarining action before seat anchors fail

Fig. 23(d) - Seat 6L shown after seat anchorage detachment, its slumped-in-seat passenger is still restrained, but both seat and passenger are being hurled forward. For this Cox seat installation restraint system is fastened to strengthened seat unit a study of the motion picture film covering this sequence indicated that the adult seated behind seat 6LW was thrown forward in time for his knees to contact the backrest of seat 6L, but this seat had already commenced anchorage detachment, indicating that a failed condition existed before the 7LW passenger applied significant force to the seatback. The left arm of the "iron man" device, 7LA, grazed the rear of the seat 6L but not until it had already started to pitch forward following detachment of the anchorage (Fig. 23 (d)). Before the 6L rear anchorage detached, however, the upper torso restraint, with its built-in inertial reel, took hold and restricted forward movement of the chest until the entire seat unit detached. Thereafter, the seat caught up with the upper torso and the belt retracted into the automatic inertia reel. The performance of this inertia reel appeared to be completely satisfactory. The seat 6L detached, but not with assistance from behind.

i. Standee 6S, a 13-year-old standing in the aisle opposite 6L, was thrown forward, still maintaining a standing posture, until he impacted the front of the passenger compartment (Fig. 24). This passenger did not have instrumentation; however, post-crash analysis by the medical scientist indicated that his inferred injuries were probably fatal.

j. Seat 7L, a fiberglass Superior seat (see Fig. 3 (b)), was occupied by a highly simplified mechanical simulation of an adult passenger, dubbed "iron man," in position 7LA, secured by a lap belt, and an adult dummy (No. 7, Table 5) seated in position 7LW. During the collision this unrestrained adult was thrown forward over position 6L to crush into the air bag in front of the 5L passengers. Post-crash analysis indicated that 7LW received moderate injuries.

The mechanical adult simulation was included in this study to develop further computer solutions of forced kinematics for the lap-belted human undergoing collision deceleration. His peak chest deceleration was 19 G at 165 ms (Fig. 25(a)). The pre-crash seated posture of the iron man was slightly reclined to the rear of vertical; during collision, he rotated forward beyond the vertical reference 52 deg (Fig. 25 (b)).

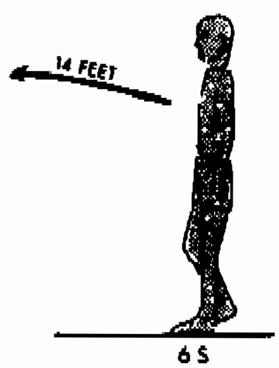

Fig. 24 - The 13-year-old standing occupant, 6S, was thrown forward 14 ft to front of bus

k. Seat 8L was a Rapid Transit seat (see Fig. 3 (e)), and was occupied by two 13-year-old passengers who were unrestrained, except for a double air bag between them and the seat ahead. During the collision, they were pitched forward into the air bag (Fig. 26 (a)).

Upon impacting the air bag, the chest deceleration of 13-year-old 8LW, reached its peak of 15 G at 160 ms (Fig. 26 (b)). The passenger next to him, 8LA, received a chest deceleration of 12 G at this same time; however, he was later hit in the back by occupant 9LA and received

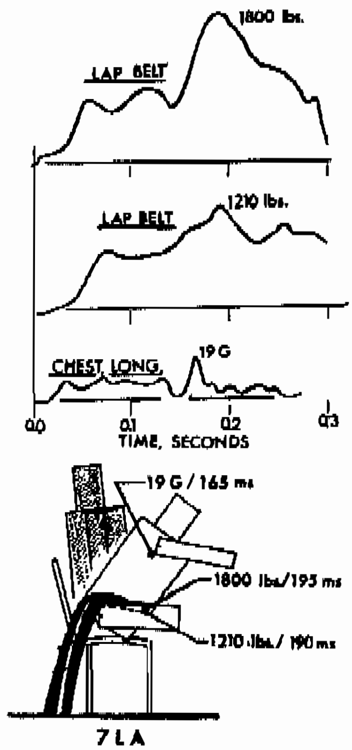

Fig. 25(a) - Mechanical analog of belted human subject provided data for theoretical calculations

Fig. 25(b) - "Iron man," shown in his most forward position, 52 deg forward of vertical his peak acceleration at this later time, 20 G at 255 ms (Fig. 26 (c)).

The passengers in the seat 9L were thrown against the horizontal seatback handbar of 8L (Figs. 26 (a) (left side), and 26 (d)). The 8L seatback failed from the forces provided by the 9L passengers. The seat cushion the 9L passengers were seated on was also thrown forward and, collectively, the seat cushion and 9L passengers struck the backs of the 8L passengers. Because of this passenger interaction, the inferred injuries for the 13-year-olds in seat 8L were listed as moderate.

l. Seat 9L was a conventional Superior seat, with a 3-year-old Sierra dummy (Table 5) seated in position 9LA, and a 13-year-old in position 9LW. Both passengers were unrestrained.

The 3-year-old passenger, 9LA, struck his head on the horizontal bar of 8L after the 13-year-old beside him crushed his knees into the backrest of seat 8L, deflecting the seat padding forward and buckling the masonite backing (Fig. 26 (d)). Subsequently, the entire seatback deflected forward allowing the 3-year-old, 9LA, to be thrown forward 9 ft, ending up in seat 6R after striking the backs of passengers in 8L (Fig. 27 (a)). The 3-year-old received his peak chest deceleration of 36 G at 260 ms (Fig. 27(b)), when he dealt the 13-year-old passenger, 8LA, a blow with his head and body. His injuries were considered to be serious but survivable.

Occupant 9LW received his peak chest deceleration of 25 G at 145 ms (Fig. 27(c)), corresponding to his impact with seatback 8L (Fig. 26 (a)). This 13-year-old in 9LW, after crushing into the backs of the passengers in 8L, was deflected toward the ceiling and subsequently came down head first into the aisle. The medical examination that followed indicated that he was a possible fatality due to the severity of these injuries.

m. Seat 1R was a Martin air seat (see Fig. 3 (j)). It was occupied by an adult anthropometric dummy (No. 5, Table

Fig. 26(a) - Two 13-year-olds in seat 8L impact air bag; 13-year-old, 9LW, strikes chin a crushing blow against the horizontal bar of seatback 8L

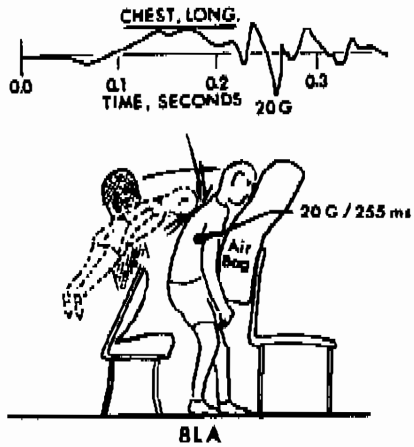

Fig. 26(c) - This passenger's chest deceleration of 12 G into air bag was subsequently increased to a 20 G peak when struck from behind by dummy 9LA

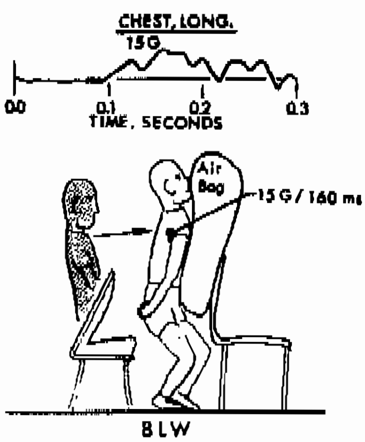

Fig. 26(b) - Peak chest deceleration was only 15 G for impact with this air bag

Fig. 26(d) - Three-year-old, 9LA, strikes head against horizontal bar of 8L backrest before it flailed forward

Fig. 27(a) - Three-year-old (arrow) was pitched, head first, 9 ft ahead, landing in seat 6R

5). He was restrained by a lap belt that formed a continuous loop around the seatback and was sewn into the seat fabric. His peak chest deceleration was 41 G at 160 ms, which occurred when he impacted the intruding front-end structure although still restrained by the lap belt (Fig. 28 (a)); however, his peak head acceleration of 41 G occurred at 245 ms, at which instant he was rebounding from a lap-belted, jack-knifed position when struck by the right shoulder of 2RW being hurled partially through the windshield area (Fig. 28 (b)).

During the collision, the seat frame was partially torn loose from the floor and the belt stitching was ripped out of the seat fabric, allowing the belt to slip up the seatback (Fig. 28 (c)), thus permitting the occupant to shift violently forward.

n. Seat 2R, a conventional Superior seat (see Fig. 3 (a)), was occupied by a 6-year-old anthropometric dummy (No. 1, Table 5), in position 2RA, and a 13-year-old dummy in

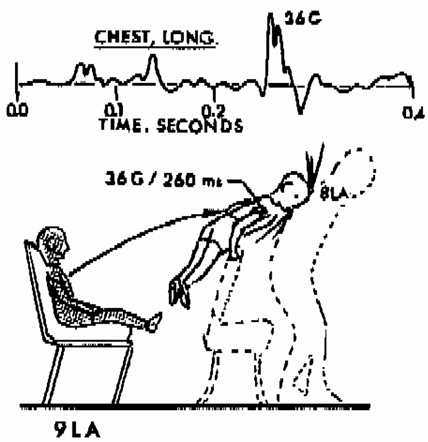

Fig. 27(b) - Three-year-old, 9LA, struck back of 13-year-old, 8LA

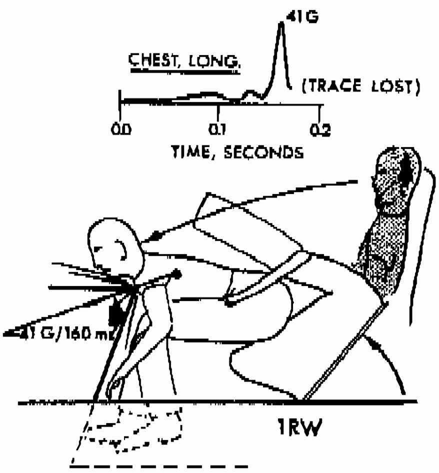

Fig. 28(a) - Adult, lap-belted to Martin air seat; both lap belt and seat ripped free of anchorages, adult struck intruding front-end structure

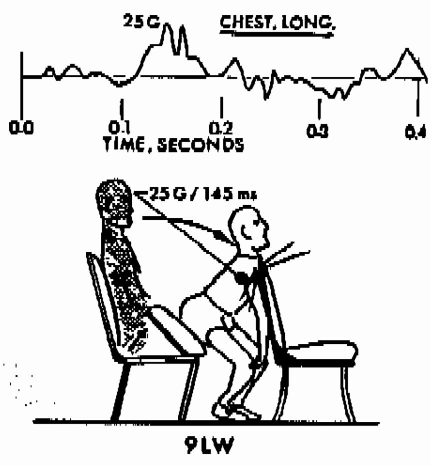

Fig. 27(c) - Thirteen-year-old, unbelted, thrown against backs of passengers ahead of him, deflects toward ceiling, subsequently coming down head first into aisle

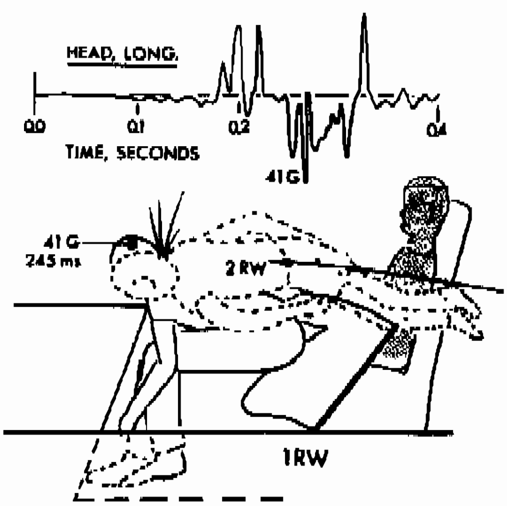

Fig. 28(b) - Thirteen-year-old from 2RW hurled forward to strike his shoulder against the adult's head from 1RW

2RW. Both were unrestrained and during collision were projected forward against the collapsing front cabin structure.

The 6-year-old passenger, 2RA, received a 53 G chest deceleration at 265 msec (Fig. 29 (a)), but the other passenger, the 13-year-old, 2RW, recorded his chest deceleration in the vertical axis only, which reached 12 G at 245 ms (Fig. 29 (b)); the longitudinal axis was electrically disconnected during collision. The unbelted 2R passengers had already vacated their seat (Fig. 28 (b)), when their backrest was crushed forward by the three onrushing occupants from the seat behind them; therefore, they did not receive the extreme abusive forces from these 3R occupants (Fig. 29 (c)). However, the critical forces encountered by not being belted and being thrown forward were probably fatal.

o. Seat 3R, an ABC Unified School District seat (see Fig. 3 (d)), was occupied by three unrestrained passengers. Two 13-year-olds were located in the 3RA and 3RW positions, with an adult (No. 4, Table 5), between them in position 3RC.

Their unrestrained forces during collision flattened the 2R seatback (Fig. 29 (c)), as they crushed on over 2R and continued being hurled forward. Similarly, the Martin air-seatback 1R offered no significant resistance to the forward movement of individuals being thrown from their seats against it (Fig. 30 (a)).

Fig. 30 (b) shows the 13-year-old occupant, 3RA (arrow), sailing through the aisle head first toward the dash. He received his peak longitudinal chest deceleration of 21 G at 400 ms (Fig. 30(c)). The adult, 3RC, reached his peak longitudinal chest deceleration of 5 G at 80 ms (Fig. 30 (d)). The 13-year-old in position 3RW recorded his peak longitudinal chest deceleration of 17 G at 275 ms (Fig. 30 (e)). All three of these occupants, however, could have experienced higher decelerations in another axis, since they had time to rotate considerably before contacting the forward portion of the passenger compartment.

Fig. 28 (c) - Seat belt on seat 1R after it has torn loose and is starting to slide up seatback (arrow)

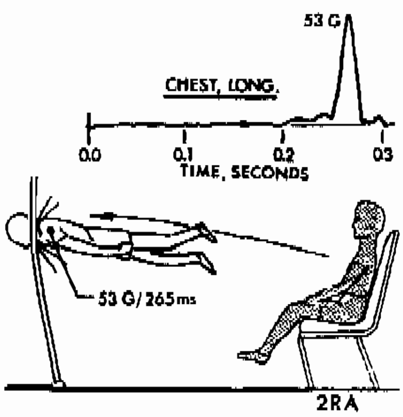

Fig. 29 (a) - Six-year-old, unrestrained, hurled against collapsing structure

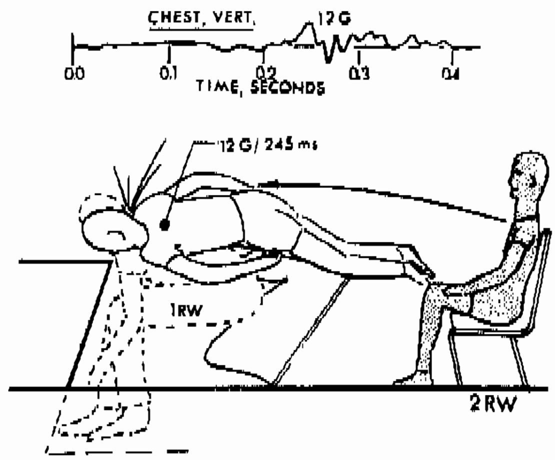

Fig. 29 (b) - Unrestrained 13-year-old pitched over air seat and against collapsing front structure

Fig. 29 (c) - Three passengers of seat 3R were forced against seatback of 2R crushing it towards a horizontal position; seat pad was rotated vertically ahead of it

Fig. 30(a) - Three unrestrained passengers crushed flat seatback ahead of them as they were hurled to collapsing front section of passenger compartment

Fig. 30(b) - Looking front to rear during head-on collision, 13-year-old, 3RA, being hurled toward front of bus (arrow). Air bag, 5LW, has been vertically inflated from impact (upper right)

p. Seat 4R, an American seat (see Fig. 3 (g)), was occupied on the left by a 13-year-old, 4RA, restrained by a lap belt, and on the right by another 13-year-old, 4RW, who was unrestrained.

The restrained 13-year-old, 4RA, pivoted forward, slammed his chest into the 3R seatback and pushed it forward. At this time, 200 ms, he received a peak head deceleration of 29 G (Fig. 31 (a)). This seat was again struck and pushed further forward by the unrestrained 13-year-old from 4RW, whose position of impact was higher on the seatback which his chest struck with a peak chest deceleration of 32 G at 145 ms (Fig. 31(b)). The higher impact position provided an opportunity for this occupant to be thrown over the seatback (Fig. 31 (c)). His injuries were considered moderate to severe whereas his companion, 4RA, was regarded as a probable fatality due to the critical neck blow with the seatback ahead.

The use of a lap belt with low back seats exposed passengers to extreme hazards of the seatback acting as a fulcrum across the neck when they were jackknifed down across the horizontal surface of the seatback ahead of them (Fig. 31 (d)). Accordingly, where low seatbacks are installed, little benefit, if any, will be derived from use of seat belts

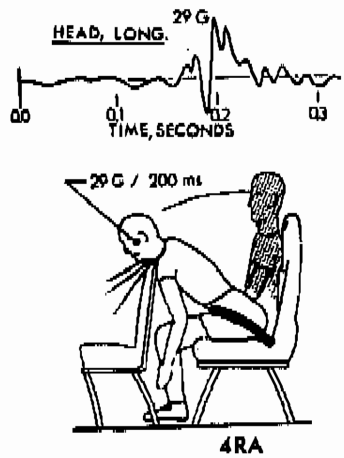

Fig. 31(a) - Even though restrained by a lap belt, chest of 13-year-old forcibly struck seat ahead and thereafter his head flailed the neck against seatback with a critical blow

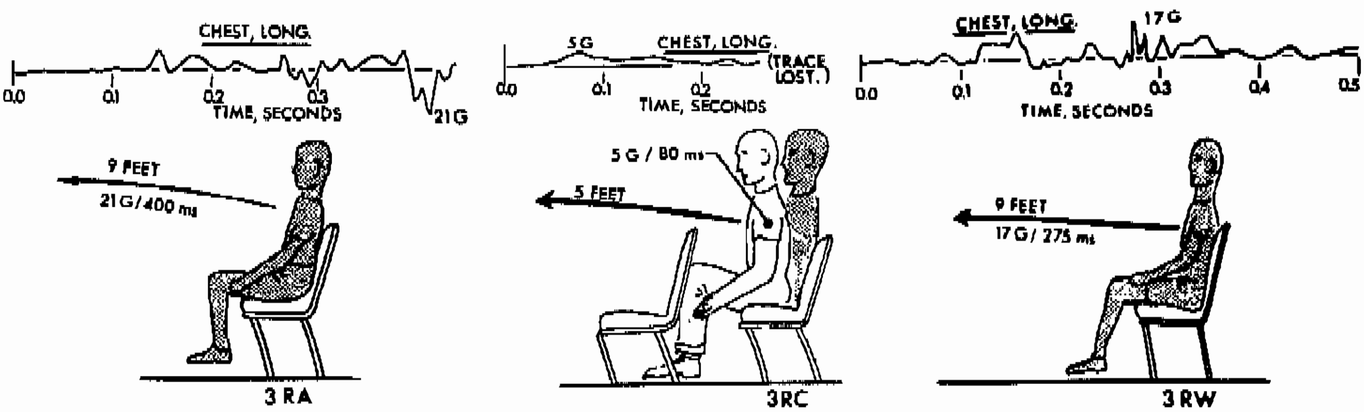

Fig. 30(c), (d), (e) - Thirteen-year-old (aisle), adult (center), and 13-year-old (window), respectively, all unrestrained, were pitched over seat ahead of them

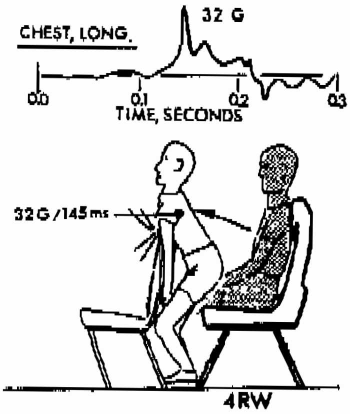

Fig. 31(b) - After striking seatback, this unrestrained 13-year-old is pitched head first over it

Fig. 31(c) - At 800 msec, 13-year-old (with dark shirt) is pitched head first over 3R seatback while other 13-year-old is rebounded from 5L air bag across aisle

Fig. 31(d) - Even though held by a seat belt, low seatback ahead provides a dangerous impact surface for neck of this 4RA 13-year-old

for the typical front-end impact. Therefore, it is strongly recommended that seat belts not be installed in school buses unless higher seatbacks are also provided, with appropriate padding on all surfaces, and with seatback frame members that provide broad deformable surfaces and with adequate anchorages to prevent failure when passengers are thrown against them, even though restrained at the hips.

q. Seat 5R, a conventional Superior seat, was occupied by two 13-year-olds. The passenger in 5RW was restrained by a three-point belt, and 5RA was unrestrained.

The passenger in 5RW remained in a good seated posture throughout the collision. He was restrained against the collision forces in a very effective manner, except that his seatback was pushed forward against him, adding to his restraint loadings as a result of direct loading through the swing-bar restraint by the passengers to his rear. His peak chest deceleration was 11 G at 80 ms (Fig. 32(a)). His lap belt tensiometer registered 210 lb at 85 ms and his shoulder strap tension was 330 lb when he received his peak chest deceleration, building up to 580 lb at 180 msec when loaded from the rear.

The unrestrained 13-year-old, 5RA, struck the high back American seat ahead where he received a chest deceleration of 37 G at 120 ms (Fig. 32(b)). He then rebounded back into his seat. This high back seat provided significant restraining action by preventing the unrestrained 13-year-old from being pitched to the front of the bus where his impact forces would have been considerably higher. His high chest loading with the seatback ahead could have inflicted serious injuries because he contacted framework with insufficient padding. His injuries were diagnosed as a probable survival.

r. Seat 6R, a fiberglass Superior seat (see Fig. 3 (b)), was occupied by a 13-year-old in position 6RW, and a 3-year-old child simulation (Table 5), in 6RA. A swing-type horizontal padded bar was attached to the seatback ahead pro-

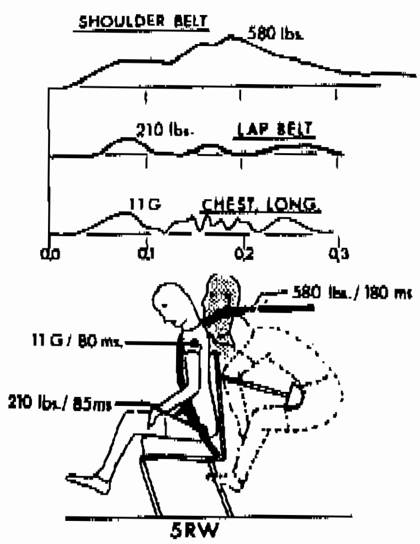

Fig. 32(a) - Cross-chest belt forces were increased by inertial forces from dummies to his rear viding restraint for the 6R passengers at their laps, similar to the unit to be described in connection with seat 9R.

Both passengers strained forward during the impact and the aisle seated 3-year-old was adequately restrained from striking the forward structure by the horizontal padded bar (Fig. 33 (a)). He received a head deceleration of 13 G at 130 ms (Fig. 33(b)), and his injuries were considered relatively minor.

The 13-year-old, 6RW, on the other hand, flexed over the bar and struck his head a critical blow at the bridge of the nose, on the horizontal portion of seatback 5R (Fig. 33 (a)). The extreme deformation of his head is shown as well as the buckling of his arms from flailing against the seatback. This impact gave him a 62 G head deceleration at 180 ms (Fig. 33(c)). His violent interaction with the seatback ahead indicated severe to fatal injuries.

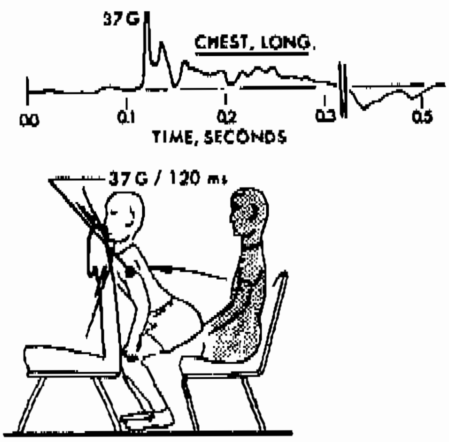

Fig. 32(b) - High back seat prevented this 13-year-old from being hurled to front of passenger section

Fig. 33(a) - Three-year-old, 6RA, held by horizontal padded bar but 13-year-old, 6RW, strikes head a critical blow against 5R seat backrest (arrow)

The reason the seatback did not push further forward from this force is partially attributed to the shoulder restraint that is holding the 5RW passenger in place. This strap may be seen attached to the vertical window post, opposite seat 6R. This severe to fatal injury exposure for 6RW demonstrated the design error of having a low seatback onto which restrained passengers could flex and strike their heads and over which the unrestrained passengers would be thrown. The seat ahead had padding along the top but this narrow and shallow padding was of little significance considering the level of force at which the head contacted the horizontal bar of the backrest.

s. Seat 7R, a conventional Superior seat, was occupied by two 13-year-olds in positions 7RA and 7RW both lap-belted, with a 100-lb sandbag in position 7RC (Fig. 34 (a)). This sandbag, restrained by a two-point belt, was included to simulate the additional loading of a third passenger which this seat was designed to carry and to evaluate the performance of the manifold anchor bar system (see Fig. 5 (b)).

Upon impact, the three passenger simulations were thrown forward, each restrained by their belts. Occupant 7RW received a 42 G head deceleration at 165 ms (Fig. 34(b)) when he impacted the seat ahead with his chest. He did not

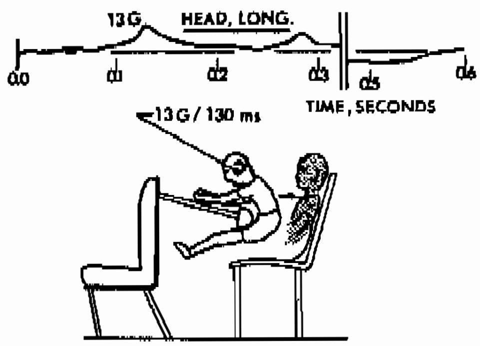

Fig. 33(b) - Three-year-old flexed about padded bar during impact without striking other objects

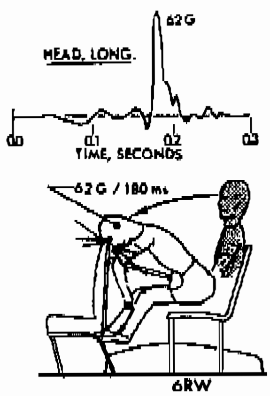

Fig. 33(c) - Restraining bar, as with restraining belt, provides an unsatisfactory solution for school passengers unless seatback ahead is high and properly constructed to minimize head, neck, and chest impact injuries wrap his head over the backrest due to the fact that as his neck started to touch the top of the seatback, his head contacted the passenger ahead who was elevating about his swing-bar restraint. For this head impact his injuries were diagnosed as severe.

Occupant 7RA sustained a 21 G chest deceleration at 135 ms (Fig. 34(c)). As he continued his forward rotation about his lap belt, he slammed his head downward completely over the low seatback ahead, dealing a probable lethal blow to his neck (Fig. 34 (d)). This exposure, typical of findings from these studies, points out the danger of reaching "arm-chair conclusions" based on somewhat unrelated findings of other seat belt experiments. Seat belts should not be added to buses unless attention is also given to the seatback height and design.

Fig. 34(a) - This seat was additionally loaded by a 100-lb belted sandbag

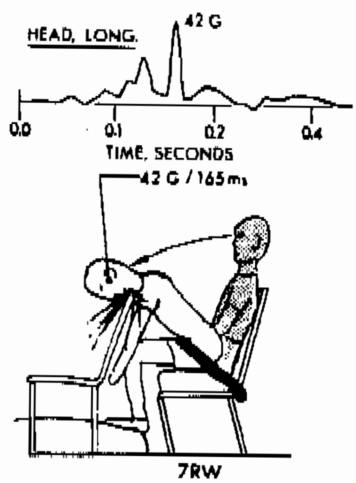

Fig. 34(b) - Belted 13-year-old snapped head downward receiving critical blow to his neck

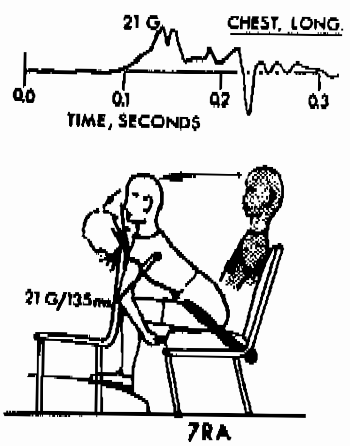

Fig. 34(c) - Although sustaining only a 21 G chest acceleration, a probable fatal blow was applied to his head and neck when he struck top of seatback ahead

The 7R seatback collapsed forward to a 45 deg angle from the 8R passengers' impacts. Seat 7R restraints were attached to a back bar; the bar was not attached to the floor but was anchored to the seat frame. Consequently, this restraint system depended on the strength of the seat frame and anchorages. This system differs in seat stress applications from the 2L installation in that the belts of 2L were anchored to a manifold bar secured to the floor.

t. Seat 8R was a United Airlines seat (see Fig. 3 (l)), occupied by two 13-year-olds. Passenger 8RW was restrained by a lap belt and 8RA was unrestrained.

When passenger 8RA started to push the 7R seatback forward (Fig. 35 (a)), the window-seated passenger rotated about his lap belt, striking the top of the seatback and sustaining a peak head deceleration of 49 G at 135 ms (Fig. 35 (b)). After the seatback was pushed from his reach, he received a second head deceleration, 40 G at 270 ms, as he slammed his head against the rigid seat belt manifold bar ahead of him (Fig. 35 (c)). His lap belt built to a peak of 900 lb at 186 ms as the seatback was pushed from his reach. The medical scientist concluded these head injuries were severe to fatal. Following impact, passenger 8RW returned to a normal seated posture. Except for the design deficiencies of the 7R seatback ahead of him, this lap-belted passenger would have ridden through this crash in a relatively uneventful manner.

The unrestrained 13-year-old, 8RA, was thrown into the 7R seatback. As he crushed it forward he sustained a peak chest deceleration of 19 G at 145 ms (Fig. 35(d)). Thereafter the conventional-type seatback ahead yielded and

Fig. 34(d) - Head and neck (arrows) 7RA dealt critical blow by 6R seatback. Seat belts should not be added to seats of unacceptable heights and design deflected him forward into the aisle beside seat 5L (see Fig. 13 (b)), where adult 7LW was rebounded from the air bag on top of him.

u. Seat 9R was a high back Superior seat (see Fig. 8 (c)). Three-year-old 9RW was seated beside a 13-year-old, 9RA; both passengers were restrained by a padded gate-bar device that passed horizontally across their laps (see Fig. 5 (f)). During collision, the 13-year-old flexed over the gate-bar in a manner suggesting that forces were primarily directed to his lap, whereas the 3-year-old, because of his shorter torso measurements, tended to receive these forces at the viscera as he flexed over the restraint. The gate-bar was, however, padded and provided a broad distribution of forces. This restraint, for the 3-year-old, prevented him from contacting the forward structure during this impact and he received a head deceleration only 7 G at 70 ms (Fig. 36 (a)). The 13-year-old, on the other hand, because of his substantially longer head-to-hip length, flailed forward and struck his head against the 8R seatback; although this aircraft-type seatback was partially padded, the frame was exposed at the side where his head struck, causing him to receive a head deceleration of 46 G at 155 ms (Fig. 36 (b)).

The rebounded occupants returned to a normal seated position, still restrained by their gate-bar systems. The 3-year-old's injuries were considered minor, while the aisle seat occupant's inferred head injury was moderate to serious.

Fig. 35(a) - Four 13-year-olds, lap belted, except for unbelted lower right passenger 8RA who is shown striking his chest against the seatback of 7R. Unrestrained passenger 8RA in foreground strikes his chest against the seatback ahead as contrasted to jackknifing companion

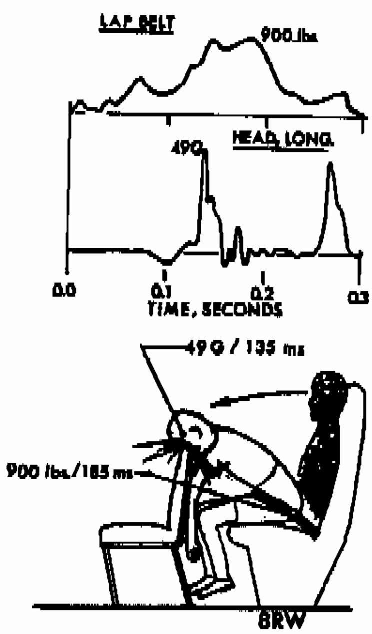

Fig. 35(b) - Injury-producing rigid structures must be kept from contact of passengers during collisions

Fig. 35(c) - Thirteen-year-old flexes over his lap belt and strikes seat belt manifold bar ahead because seatback was collapsed forward by unbelted passenger to his left

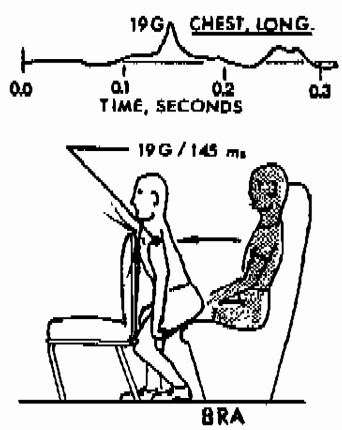

Fig. 35(d) - Unrestrained 13-year-old 8RA strikes seatback ahead with chest

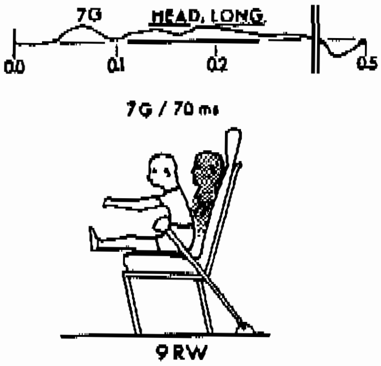

Fig. 36(a) - Three-year-old adequately restrained by gate-bar

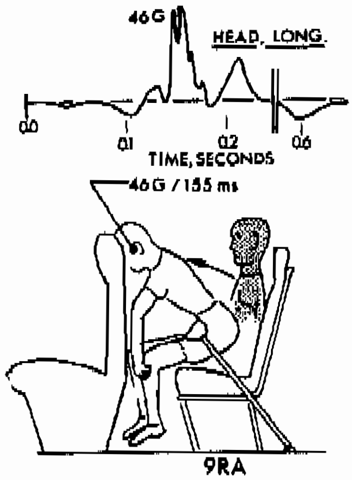

Fig. 36(b) - Even high back seats can deal serious blows to partially restrained passengers when rigid frame members are contacted

Fig. 36(c) - Thirteen-year-old in 9RA flexing severely over gate-bar restraint of 9R, buried his head into 8R United Airlines seatback

In addition to an appropriate use of padding, seatbacks should be constructed based on design evolving from full-scale impact experiments. It should be evident that considerable improvement is possible over the seatback performance indicated for the 8R (United Airlines) seatback when unpadded frame structures are contacted (Fig. 36 (c)).

3. Collision Performance - Head-on collisions represent one of the most severe types of vehicle-to-vehicle accidents. With increased use of divided highways and protective median barriers, each serving to separate opposing traffic, some progress in avoidance of head-on collisions has been made. Notwithstanding, head-on collisions continue to be a common type of accident and vehicles striking fixed objects or other vehicles at intersections, for example, sustain collision forces than can be comparable in nature and magnitude to head-on impacts. It is very important, therefore, that considerable attention be given to the vehicular collision performance for front-end type impacts.

Experiment 86 involved two buses of comparable size and weight* each traveling 30 mph when they met head-on in perfect alignment (Figs. 37 (a) and 37 (b)). It is evident, even from these photographs, that certain design modifications are needed to improve the collision performance of buses. In this head-on collision, the excessive overriding action of the 1944 Mack-Superior bus allowed it to penetrate the passenger compartment, completely crushing and overriding the engine compartment of the 1965 GMC-Superior bus. Vertical misalignment of vehicle frames, whether bus-to-bus, bus-to-truck, or bus-to-passenger car, is a condition that can be corrected through standardization.

A head-on collision between two vehicles that approached one another, each traveling 30 mph, represents an extremely destructive and a very dangerous collision. A 30 mph head-on, nevertheless, is only a moderately severe accident, considering the highway speeds likely to involve school buses. In addition, a school bus striking a concrete fixed abutment or similar fixed object will sustain collision forces higher than the above-mentioned head-on collision. It is for this reason that school bus passenger protection for the 30 mph head-on collision was regarded as a practical and necessary exposure.

In the construction of vehicles, consideration must be given to the height and strength of structures likely to be impacted by opposing vehicles. Such design considerations should include structures that will transmit collision forces to the strong members of the vehicle, and particularly design considerations that avoid an overriding or underriding characteristic during a collision with other vehicles or barriers. Bus bumper design should bring the strong components of the respective vehicles into direct opposition, thus providing a greatly increased measure of protection for the pas-

*The 1965 GMC-Superior, as crashed, has a gross weight of 17,500 lb; sandbags were placed in seats of the 1944 Mack-Superior bus to bring its weight to 17,500 lb.

sengers in either vehicle since this would reduce the collapse of the passenger compartment. Such a design admittedly may increase the impact peak acceleration for the passenger compartment, but, with appropriate passenger protective devices, this approach provides a substantially greater measure of safety than the current conditions of allowing the passenger compartment to be directly collapsed.

Two biaxial accelerometer units measured the deceleration of the 1965 GMC-Superior bus. Each unit measured acceleration in the longitudinal and vertical axis; one was positioned on the bus body floor cross-members at 10 ft from the front bumper and the other biaxial unit was bolted to a similar body frame member 26 ft from the front bumper. These stations recorded 13 G at 55 ms and 11 G at 60 ms respectively (Fig. 38). A second peak acceleration of 21 G at 175 ms occurred at the 10 ft station. This larger second peak was floorpan buckling in the immediate area of the vertical axis accelerometer. In fact, this accelerometer case was rotated 90 deg and entrapped in one of the floor convolutions. This buckling of the floorpan was

Fig. 37(a) - Two school buses of comparable size and weight, each traveling 30 mph, striking squarely head-on but demonstrate grossly different collision performances

Fig. 37(b) - Following collision, driver's compartment for bus on right shows little change; by contrast, gross intrusion to driver's compartment for vehicle on left forced driver completely rearward of his normal position

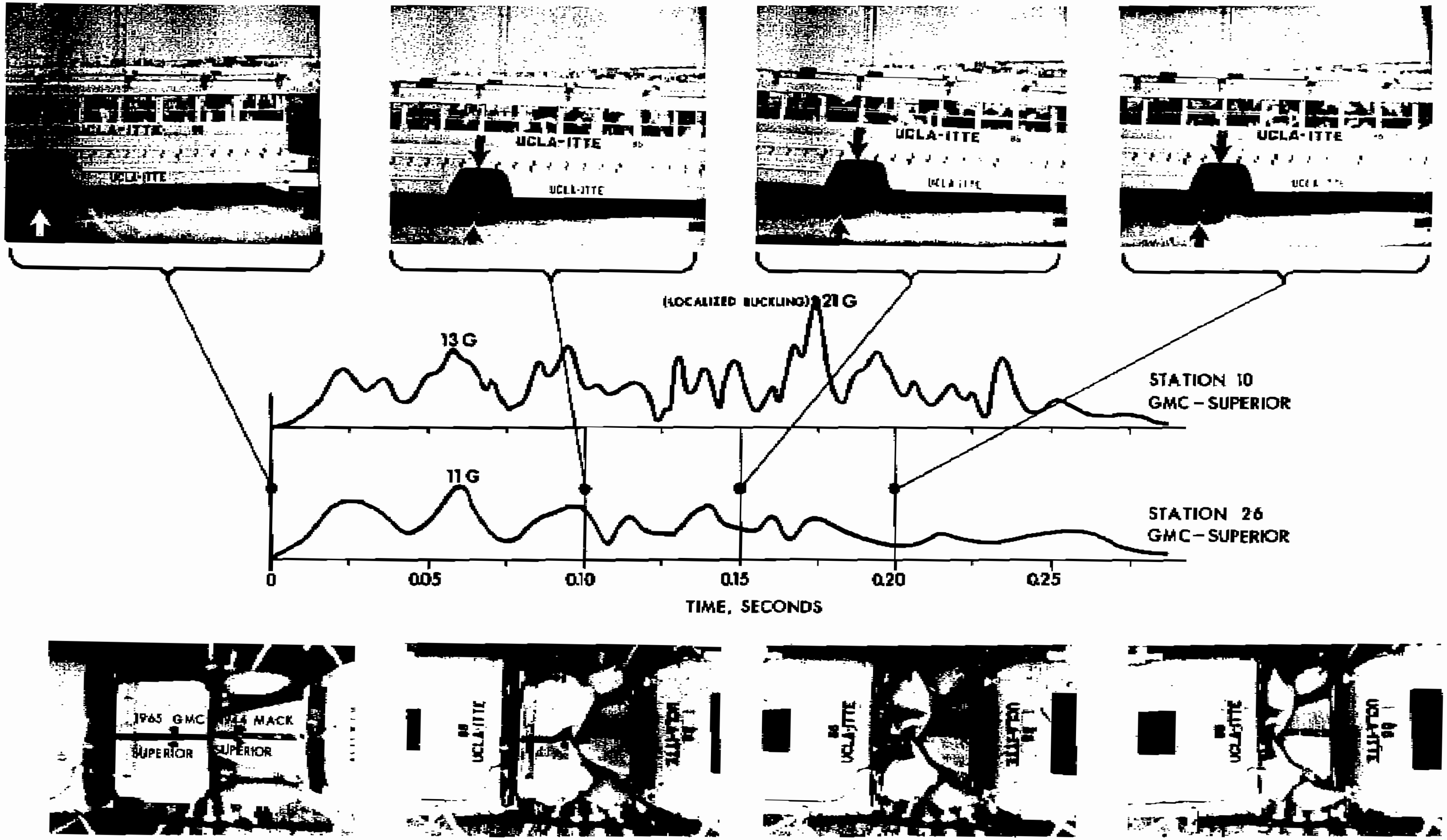

Fig. 38 - 1965 GMC-Superior bus body deceleration pattern during a 30 mph head-on collision

caused by the body shifting forward 17 in., as observed in the sequence photos (Fig. 38).

Steering column intrusion into the passenger compartment for this bus was similar to observations for the passenger vehicle steering column performance of earlier studies (3). During the initial phase of the collision, the steering wheel rim pierced the driver's abdominal area, deflecting the upper rim into the face as the steering column crushed into the chest and was deflected upward under the chin along the face, carving his nose and eyes as it swept upwards. This abusive action is even more severe for bus and truck drivers than for drivers of passenger vehicles, owing to the significantly stronger structure common to these heavier vehicles. The design improvements being considered for passenger vehicles, that prevent a steering column from being thrust rearward into the passenger compartment during impact, increase the size of the hub so that impact forces are distributed over a more reasonable area of the body, and limit the axial forces required to deflect the steering wheel relative to the hub, and should be included with the design specifications of buses and other heavy vehicles.

During the collision, the instrument panel of the 1965 GMC-Superior bus was thrust 2-1/2 ft rearward into the passenger compartment, crushing against the driver. The significance of this observation relates to the need for greater front-end structural integrity for bus-type vehicles. The exceptional length of these vehicles provides a columniated weight which, if not properly structured, will "accordion" the forward section of the passenger compartment. Collapsing of the passenger compartment applies injury-producing collision forces directly to the driver and passengers, even when adequately restrained. It is for this reason that violations of the structural integrity of the passenger compartment must be designed out of the vehicle, to the extent practical.

Following collision, there was an 11-in. permanent displacement between the frame and the 1965 GMC-Superior bus body (Fig. 39(a)). This is important to note, with respect to observations of the driver's movements, because the motion picture camera that was directed at the driver was actually moving forward with the collapsing bus body and roof structure, whereas the driver's seat was anchored to the portion of the bus floorpan that did not have a similar 11-in., collapse. This situation occurred because buckling of the floorpan developed approximately three vertical convolutions directly behind the driver's seat (see Fig. 15). The 30 in. foreshortening of the passenger compartment represented by the convolutions was made up of the 11 in. body shift and the balance attributed to front end intrusion. Inadequate anchoring of floor sills to the frame allowed the inertial load of the entire bus body to be concentrated on the forward sill under the driver. This slippage between the bus body and frame occurred when the four shear bolts at the front failed to prevent this differential motion. The buckling tendency related to the use of clamp attachments between body and frame, thus allowing the body to shift longitudinally, relative to the frame (Fig. 39(a)). With respect to Fig. 39(a), note also unrestrained passengers being pitched forward during collision.

Within 1/10 sec following contact of the two vehicles in this head-on collision, two unrestrained 13-year-olds from seat 1L landed on top of the driver, rendering his constructive efforts to facilitate evacuation of these children an impossibility, assuming he wasn't killed during the onset of collision forces owing to the unexpected front-end collapse around him. In addition, at this same time, smoke had

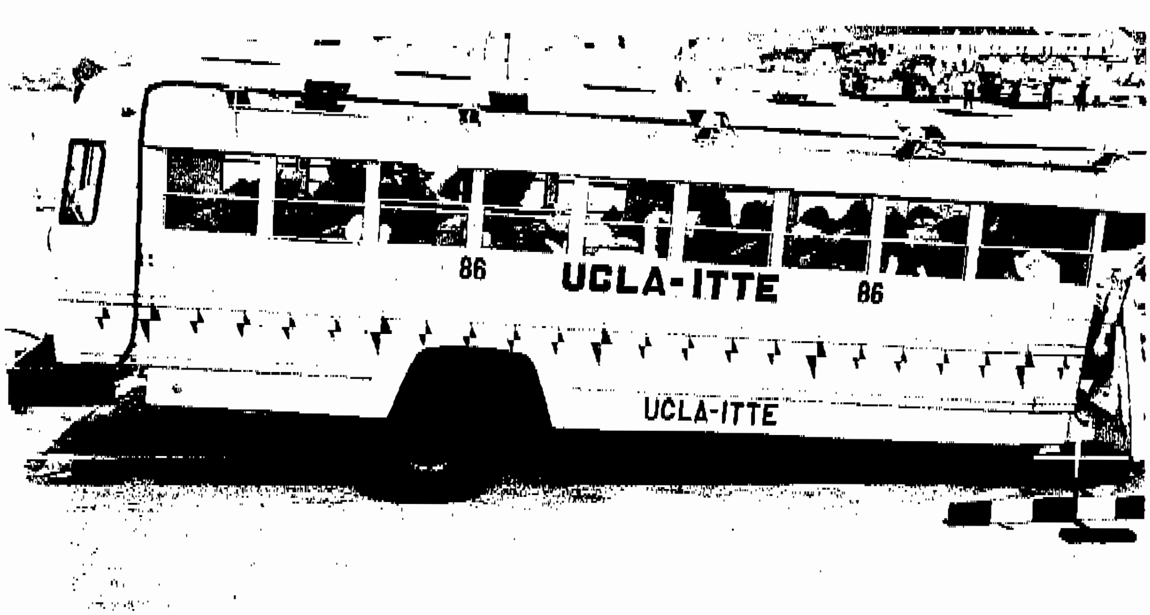

Fig. 39(a) - Unrestrained passengers may be seen being pitched forward during collision started to enter the passenger compartment at the front from an electrical short that, if allowed to progress, might have resulted in a devastating fire. Although this fire was extinguished promptly by project personnel assigned to this task, the event indicates the almost hopeless task of promptly evacuating a bus load of unconscious and dazed children, especially considering the inadequate escape routes and the present condition of no restraints being worn by school children (Fig. 39 (b)). The moderate size school bus, as typified by the 1965 GMC-Superior bus crashed for these experiments, should be provided with a minimum of four clearly marked and wide escape hatches. In addition to the front right and center rear exits, there should be an exit at or near the center right side and center left side. The right and left center-side exits should comply with the Federal Aviation Agency specification for emergency exits used on passenger aircraft as to labeling, lighting, size, protection against inadvertent openings, and protection against mischievous manipulations of escape levers. In this connection, it would be advisable to have a buzzer sound off for the driver when either of the emergency escape hatches have their sequential protective device moved in order to discourage misdirected use or accidental opening of the escape hatches.

Inside the bus the horizontal handbar located behind the driver does not provide an effective restraining device either with respect to preventing the passenger behind him from striking the driver in a serious, injury-producing manner, or from the point of view of restraining the passenger effectively against the collision forces occurring during a head-on impact. To the extent that this bar provides restraint, it is an injury-producing device and a structure more closely simulating a padded seatback should be designed and installed in the area behind the driver, as well as in the area requiring the modesty panel between the entrance and the first seat at the right front. The thin padding applied to the horizontal bar was considered to be of practically no value owing to the short radius of curvature of the bar and to the force concentration attending such a shape, regardless of the superficial padding. As with passenger vehicles, angular sections as well as small radii surfaces should be avoided in the driver's area. In this connection, the 3-year-old sitting in the window seat immediately behind the driver, although restrained by a lap belt and though riding out the crash rather well, did strike his head against the rearward protruding heater enclosure at the left side of the driver's section, sustaining a severe head impact. This sharp protruding section is readily susceptible to redesign to minimize the injury for any passenger or the driver thrown against it.

The vertical tubular struts used for bracing the modesty panel at the entrance, as well as the kick-panel behind the driver and in front of the first seat, should not run from floor to ceiling owing to the difficulty of making these tubes both strong enough to be functional, slender enough not to be an obstruction to vision, and collapsible enough not to cause head and other body injuries for the passengers that may be thrown against them. Such structures should be floor anchored and provide a measure of human body impact protection comparable to the properly constructed well-padded high back seat. In the head-on collision, nonbelted passengers, especially when seated behind the usual low seatbacks, were hurled forward, striking these bars (Fig. 40). The front passengers in any bus are in a position of substantial vulnerability by comparison with the other passengers and their safety should not be further compromised by the obvious injury-producing structures immediately in front of them.

Fig. 39(b) - Entrance was completely blocked by collapsed structure and unrestrained occupants

FINDINGS - REAR-END COLLISION

EXPERIMENT 87 - A rear-end collision between a 1965 GMC-Superior school bus and a 1960 Plymouth Savoy 4-door sedan was conducted; the 17,500-lb stationary school bus was struck by the 4400-lb sedan traveling 60 mph (Fig.

Fig. 40 - Passengers without safety belts seated behind low back seats were hurled forward collapsing low seatbacks and vertical handbars to form this crushed pile of passengers, 10 deep

41). Seated in the school bus were three 3-year-olds, two 6-year-olds, twenty-two 13-year-olds and five adults. In addition, there were two 13-year-olds standing in the aisle. The striking car had two adults seated in front and two 13-year-olds seated in the rear.

1. 1960 Plymouth - The driver and front seat passenger were adult-type anthropometric dummies seated on a conventional passenger car bench seat. The driver was unrestrained and the front seat passenger was restrained in the direction of forward motion by an air bag (Fig 42 (a)). Two 13-year-old solid-pour dummies were seated in the rear on a bench seat. The left rear passenger was unrestrained; the right rear passenger was restrained with a lap belt. At impact with the rear-end of the bus, the driver and front seat passenger were sandwiched between the crushed-back instrument panel and their seat, which was being thrown forward. The air bag restraining the right front seat passenger ruptured during collision; the passenger sustained 109 G at 110 ms following vehicle contact (Fig. 42 (b)).

This high G indicates the air bag offered little protection, considering the striking car only reached a peak deceleration of 18 G at 45 ms after contact. This low frame deceleration was attributed to the relatively long deceleration distance provided by this rear-ending car underriding the high rear bumper until the bus bumper reached the car's windshield (Fig. 41). The steering column showed no evidence of having been extended rearward, but was severely damaged from the driver crushing around the steering wheel as he was thrown forward. The constant position of the steering column, notwithstanding the collapse-action of the front end, is attributed to the lack of contact by the opposing bus structure with the car front bumper and frame. The steering column is attached to the frame and would have been forced rearward had the frame encountered opposing bus structures. (Figs. 43(a)-(c)).

The unrestrained left rear passenger struck the front seatback head first, sustaining 86 G at 145 ms. After this head

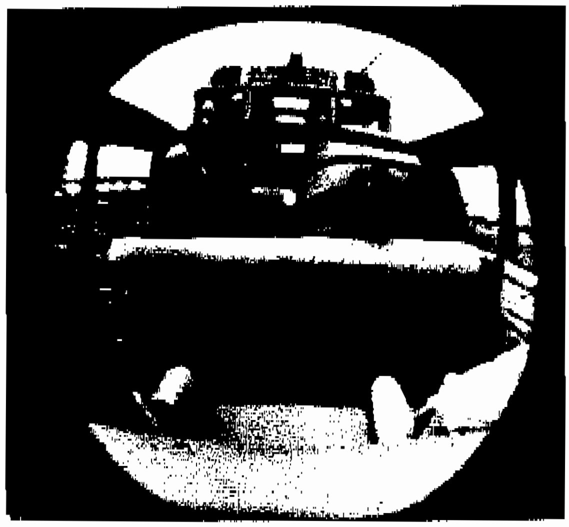

Fig. 42(a) - Air bag positioned ahead of front-seat passenger

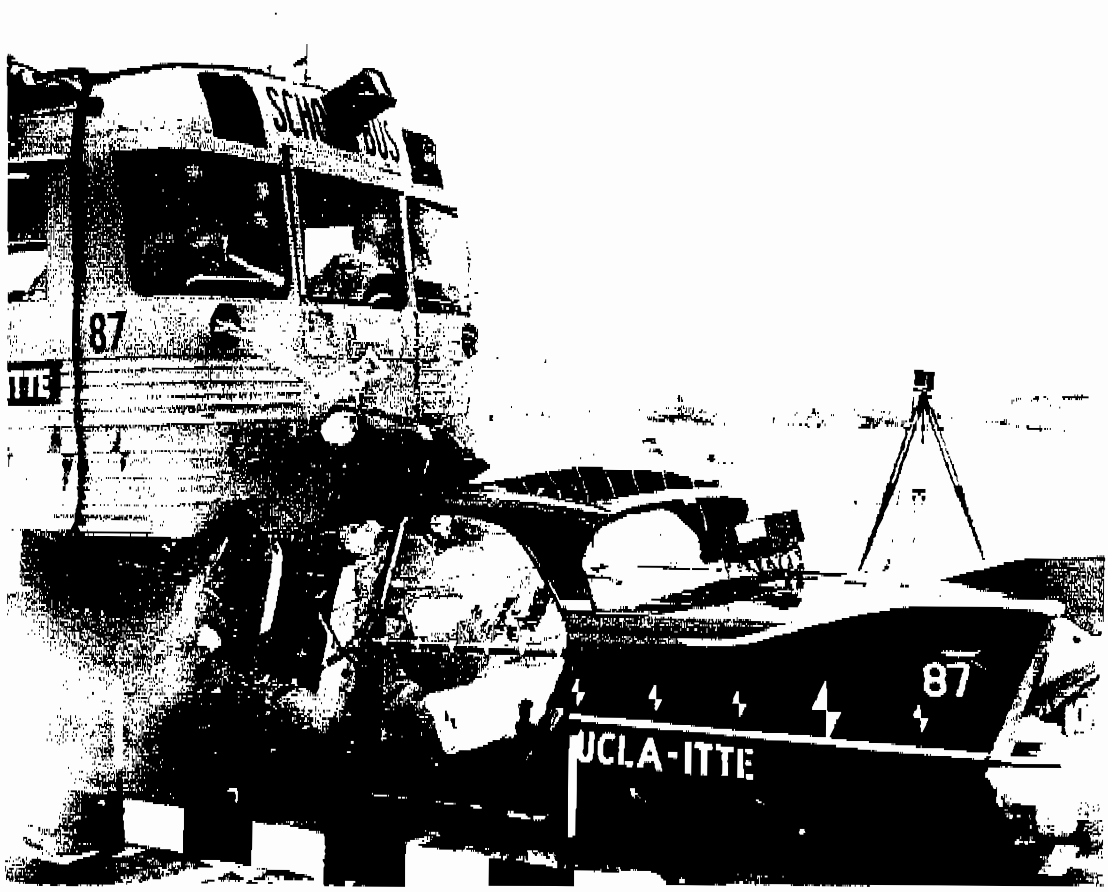

Fig. 41 - Stationary school bus rear-ended by 1960 Plymouth sedan traveling at 60 mph

impact, his arms and legs flailed in rapid succession into the seatback, resulting in gross intrusion to the seatback (Fig. 41). This left rear seat passenger subsequently came to rest between the front and rear seat, doubled up on the floor. Even though the front seat crushed forward, the lap belt, restraining the right rear passenger, elongated sufficiently to allow the passenger to jackknife over the belt and impact his face against the top edge of the front seatback, 54 G at 135 ms (Fig. 44). This was followed by additional flexion of this belted passenger over the seatback and he subsequently came to rest slumped forward, still sustained by his lap belt.

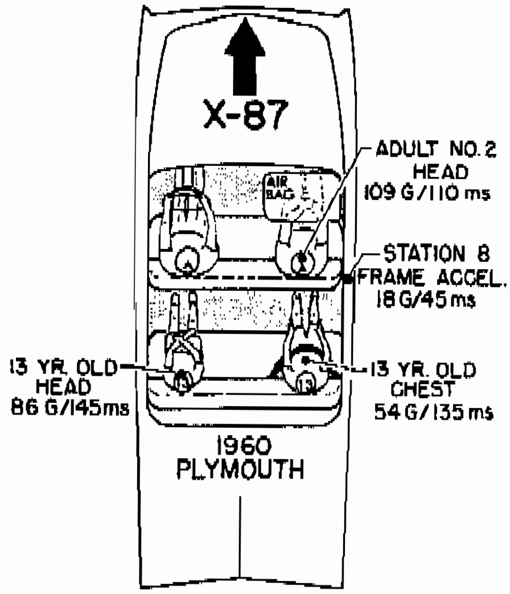

Fig. 42(b) - Striking car seating assignment and peak deceleration values recorded for occupants and car frame

2. The 1965 GMC-Superior Bus Passenger Compartment - Certain front seats of the bus were removed for this collision experiment owing to front-end damage resulting from the prior head-on collision experiment. Because of this compartment damage the driver's seat was removed, air seat 1R was relocated in seat location 2R, and the damaged 2R seat was deleted. The air seat, however, in this experiment is described as being in seat position 1R. The original 1L seat was also removed owing to prior collision damage (floor buckling), and, consequently, there is no seat in this position. Passenger types, seat types, restraint systems and peak accelerometer values are shown in the passenger assignment (Fig. 45 (a)). The seat assignment and location, by right or left side, were designated by numbers starting from the front of the bus, as, for example, 1R, 1L, 2R, 2L. The locations of passengers were further defined by the seat position, relative to W-window, C-center, A-aisle, or S-standing, as, for example, 2RW, 2LA, 2S, and so forth. In addition, the forced movements and positions of rest are represented in Fig. 45 (b).

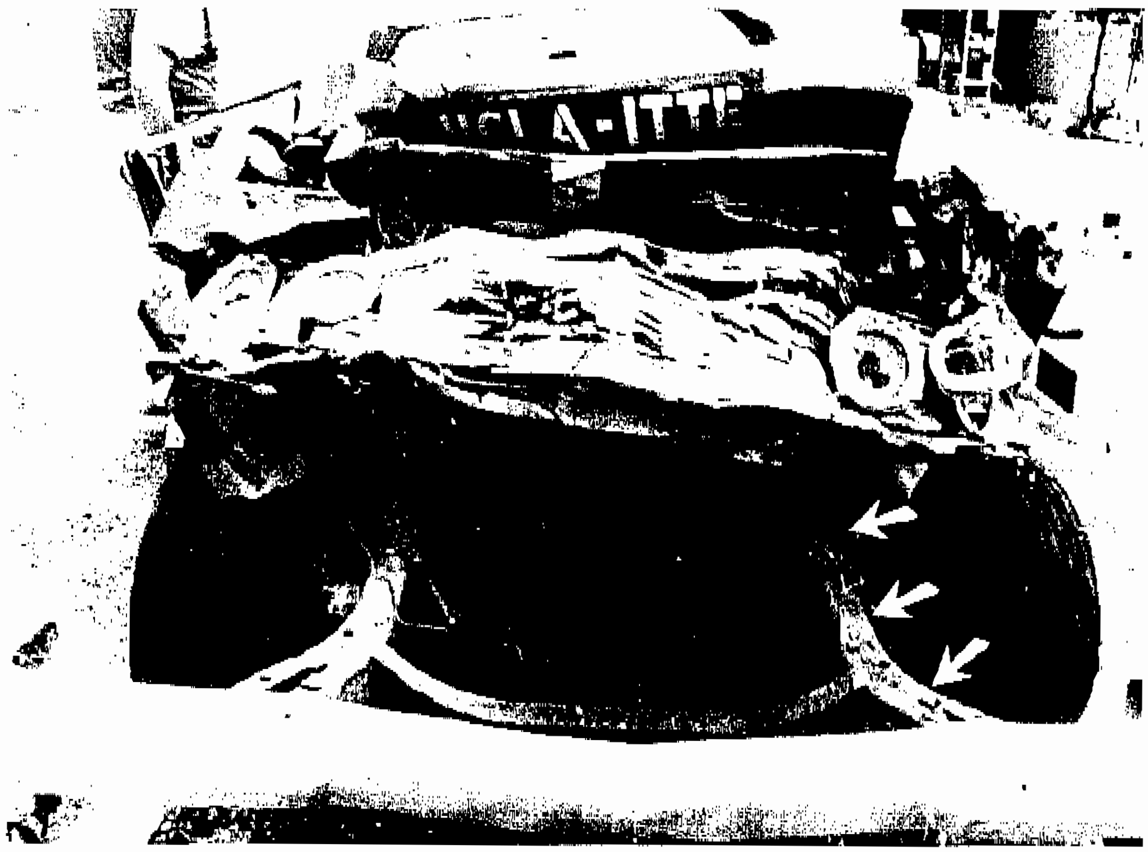

Fig. 43(a) - Frame, 1960 Plymouth, undamaged by high rear bumper of 1965 GMC-Superior bus

a. Seat 1R, a Martin air seat (see Fig. 38), was occupied by an adult (No. 5, Table 5), restrained by a lap belt. During the collision this adult first rotated to a prone position as the seatback was forced rearward, still retained by the lap belt (Fig. 46 (a)). When the seatback bottomed out against the passengers to his rear, he sustained a 29 G head deceleration at 235 ms (Fig. 46(b)). The seatback reclined under the inertial forces of the adult and maintained his head and torso in a normal posture. The elastic rebound from the air pressure in the seat catapulted him forward with considerable force against his still properly positioned lap belt (Fig. 46 (c)). All observations indicated that lap-belted passengers in air seats receive adequate support against rear-end collisions, except for their heads striking passengers behind them. His injuries were considered minor to moderate for these restrained movements.

b. Standee 2S - A 13-year-old was standing in the aisle between seats 1R and 2L (Fig. 47 (a)). The rear-end collision forces propelled him 7 ft rearward before striking the bus floor where he sustained a 14 G chest deceleration at 555 ms (Fig. 47(b)). Passenger 2S came to rest in the aisle beside seat 4R. The post-collision medical analysis indicated moderate injuries.

c. Seat 3R, an ABC Unified School District seat (see Fig. 3 (d)), was occupied by a 13-year-old in position 3RW, an adult (No. 3, Table 5) in position 3RC, and a 6-year-old (No. 1, Table 5) in position 3RA; all three passengers were unrestrained. The 13-year-old and the adult underwent severe whiplash, owing to the low seatback height (Fig. 48 (a)). However, the 6-year-old's head was supported against whiplash and his biaxial chest accelerometers recorded only 5 G at 405 ms (Fig. 48(b)). Subsequently, 6-year-old 3RA was thrown between seats 3L and 3R, coming to rest in a prone position, crossways in the aisle. The medical scientist diagnosed this 6-year-old occupant's injuries as minor. The adult in the center seat position did not have accelerometer instrumentation. His head flexed rearward but did not assume as extreme a forced posture as a human under the same conditions because of the mechanical neck stops,

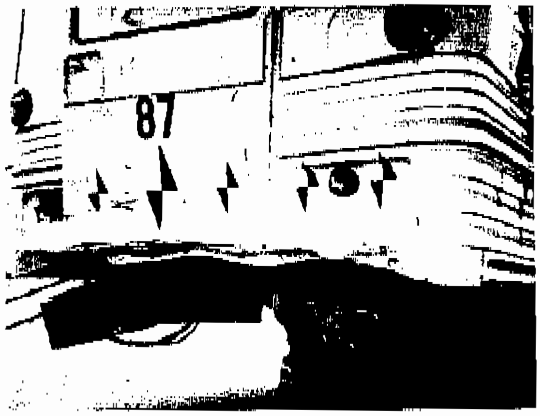

Fig. 43(c) - Passenger car underrode bus

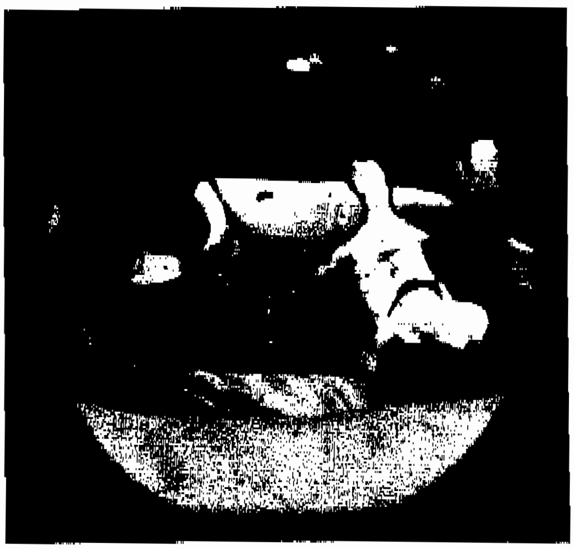

Fig. 44 - Belted passenger slams head into front backrest, sustaining a 54 G head deceleration

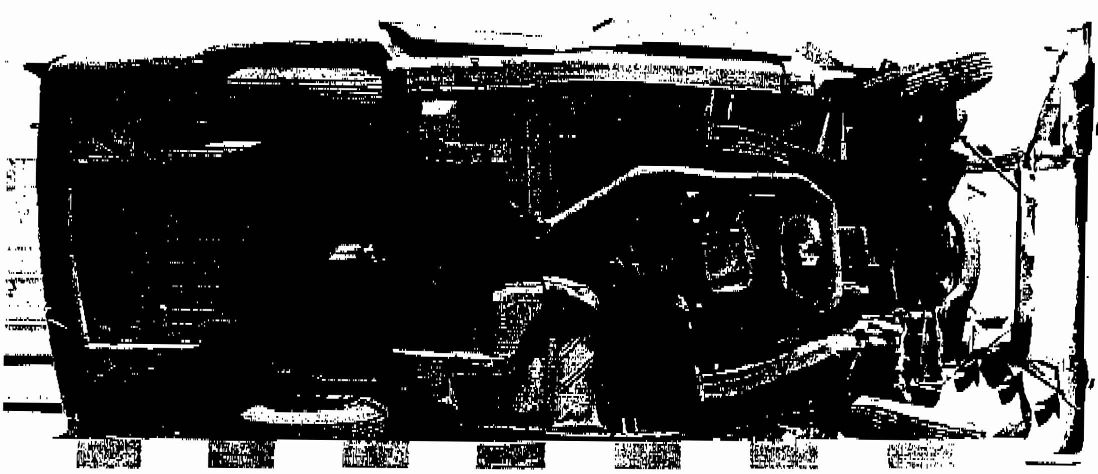

Fig. 43(b) - Frame, 1960 Plymouth, underrode rear bumper of bus

REAR-END COLLISION, X-87

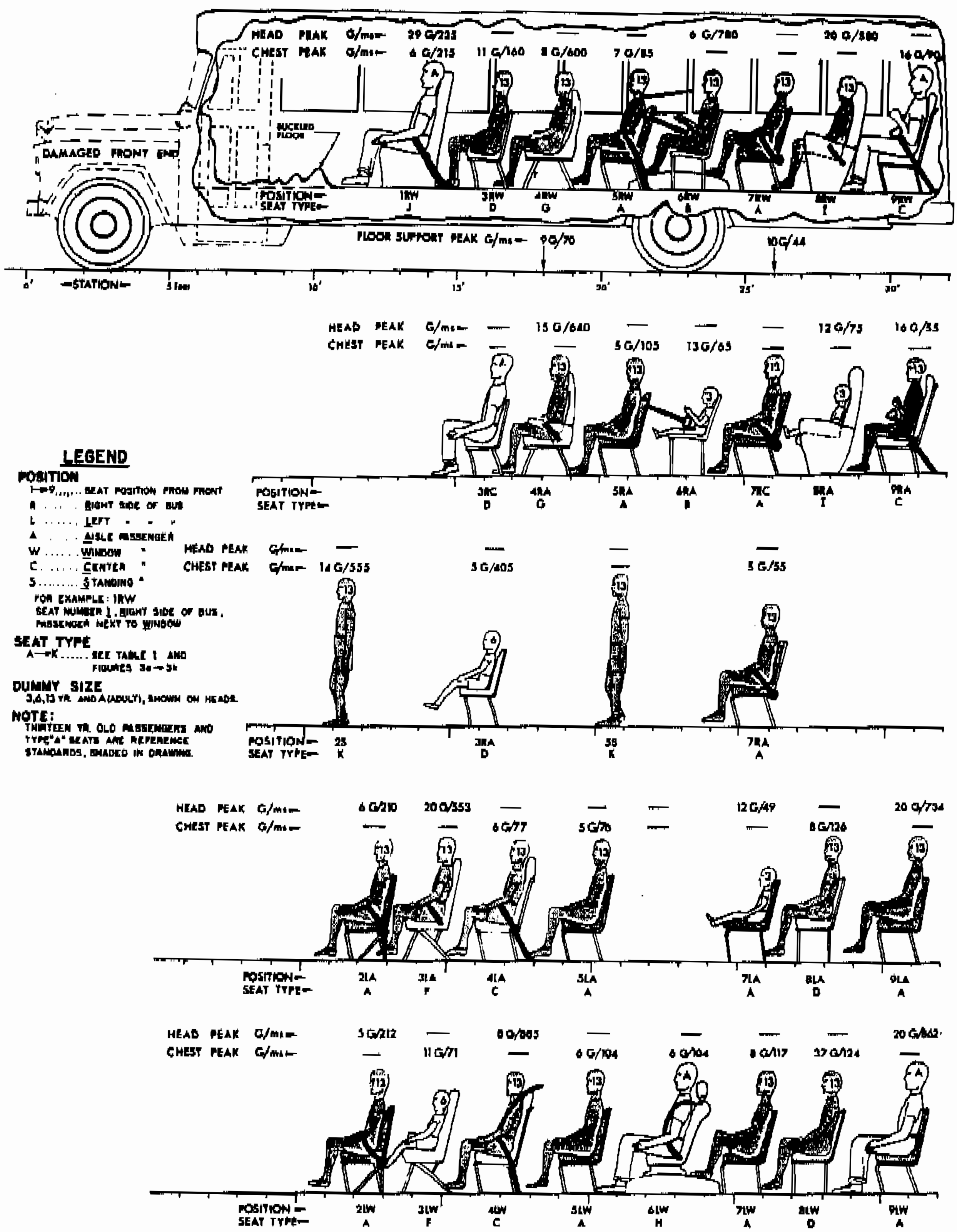

Fig. 45(a) - Passenger assignment, 1965 GMC-Superior bus, showing also seat types, restraint systems, and peak accelerometer values serving to limit head motion regardless of the level of forces acting on the head. A greater rearward head movement of the 13-year-old is apparent, since he is a solid-pour type of construction with a homogeneous neck lacking specific stops. The inferred whiplash injuries for adult 8RC were moderate

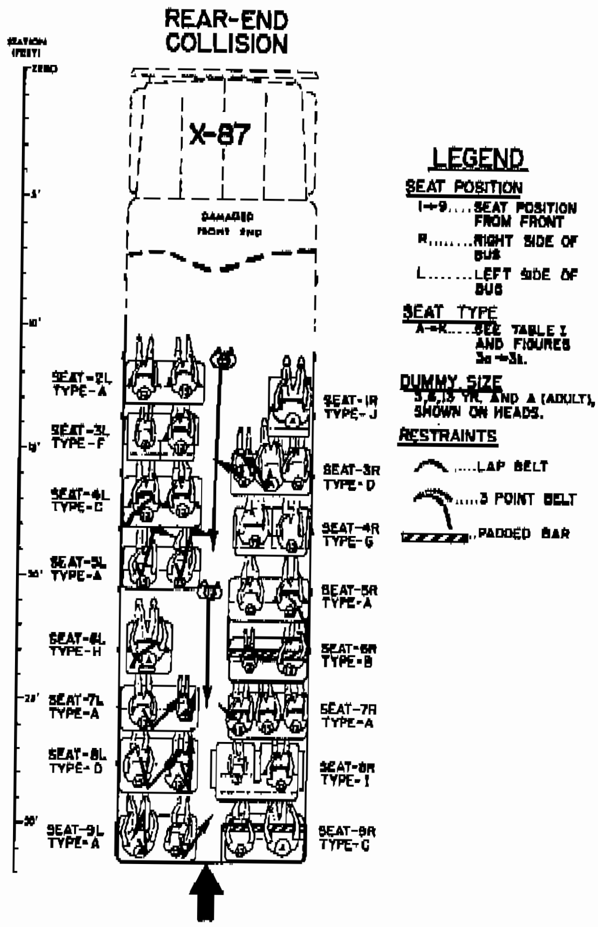

Fig. 45(b) - Forced movements of passengers during rear-end collision, and their positions of rest

Fig. 46(a) - Seatback yields but high back holds adult head in good posture with torso

to severe because of this low seatback condition. During the rear-end collision, the 13-year-old sustained an 11 G chest acceleration at 160 ms (Fig. 48(c)). He received a severe whiplash and then rebounded to a semi-reclined position on the front edge of the seat.

Inertial action of upper torsos force seatbacks rearward and this action tends to reduce the injury-producing forces for the passengers undergoing collision accelerations. High speed photography measured the deflection of seatback 3R from its normal position of 12 deg to the rear of vertical, rearward to 40 deg; then it rebounded about 1/4 of the way toward normal. Even if this seatback had not deflected rear-

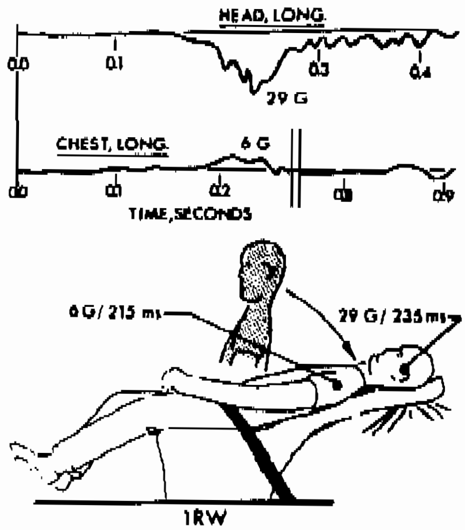

Fig. 46(b) - The lap-belted passenger in an air seat is protected against whiplash; lack of proper seatback support allows seatback to lay back against knees of passenger to his rear

Fig. 46(c) - Seat belt, a must for air seat when a passenger is undergoing a rear-ender, to avoid sliding over seatback rearward or subsequently being rebounded dangerously forward

ward, the occupants seated to the rear would still have abusively struck the low backrest.

d. Seat 4R, an American seat (see Fig. 3 (g)), was occupied by two 13-year-olds; 4RW was unrestrained, and 4RA was restrained by a lap belt. Although both occupants in seat 4R were identical human simulations, the difference in their kinematics was attributed to the lap belt worn by the aisle seat passenger, and the absence of a lap belt for the window seat passenger. The unrestrained 13-year-old, 4RW, elevated in his seat and this action reduced neck flexion over the seatback, but there was sufficient elastic action to rebound him, causing his head to strike the head of the passenger in the seat ahead, 3RW, as shown at top center of Fig. 49(a). This 13-year-old received an 8 G chest deceleration at 600 ms (Fig. 49(b)). His inferred injuries were minor.

The 13-year-old in position 4RA rebounded, and was thrown forward sufficiently to cause his chest to strike the top horizontal bar of seatback 3R, and his neck to flex over the bar bringing the head hard against the front of seatback 3R, sustaining a severe inferred injury (center, Fig. 49 (a)). This 13-year-old, 4RA, sustained a 15 G head deceleration at 640 ms (Fig. 49(c)).

The seatback of 4R was forced rearward during the impact approaching a semi-reclined position. The high back well-padded design of this seat provided very effective head support for both occupants so that neither experienced any whiplash. This retention is in direct contrast to the inadequacy

Fig. 47 (a) - Front standee between seats 1R and 2L

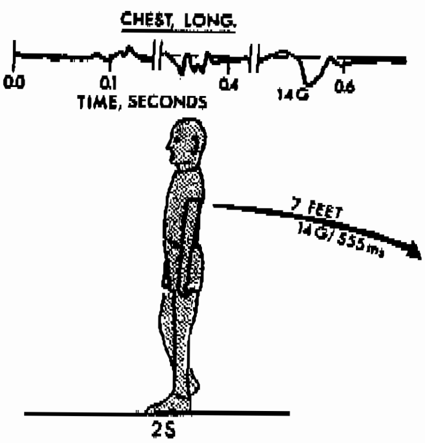

Fig. 47 (b) - Standee is thrown 7 ft to rear before landing on aisle floor

Fig. 48 (a) - Adult head (arrow) snapped rearward against mechanical stops

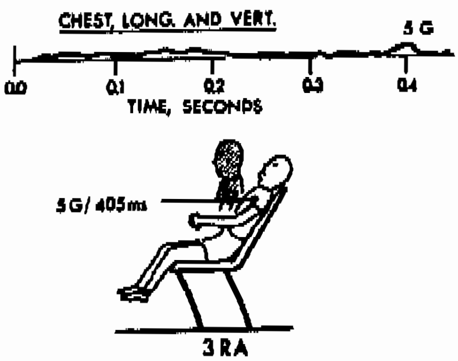

Fig. 48 (b) - This 6-year-old's head was pitched against horizontal bar of his seatback

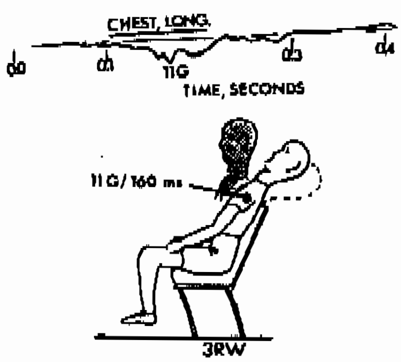

Fig. 48 (c) - Low seatback allowed head to flail rearward

Fig. 49(a) - After riding out collision acceleration satisfactorily, this 13-year-old (foreground) rebounded against a dangerous low back seat sustaining a serious head-snap action

of seat 3R design, where abusive whiplash forces are being applied to an identical 13-year-old passenger during the same exposure.

e. Seat 5R, a conventional Superior seat (see Fig. 3(a)), with a thin plastic padding on the top horizontal bar of the backrest, was occupied by two 13-year-olds. The 13-year-old in seat position 5RW was restrained with a three-point belt and the 13-year-old in 5RA was unrestrained. During the onset of the rear-end collision, both passengers underwent severe whiplash such that at maximum neck flexion their eyes were directed slightly to the rear of vertical (Fig. 50(a)). Both 13-year-old passengers were the same size and postured the same, suggesting that, regardless of the type of safety belt restraint, when no head support is provided, the whiplash action will occur with nearly the same severity. The 13-year-old in position 5RW sustained a 7 G chest acceleration at 85 ms (Fig. 50(b)), and the 13-year-old in 5RA sustained a 5 G chest acceleration at 105 ms (Fig. 50(c)). On rebound, 5RW rotated from under the chest strap, consequently the diagonal restraint carried no load; the lap belt carried only an 80 lb load at 310 ms for this

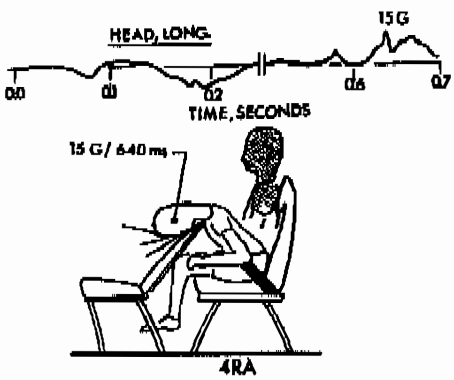

Fig. 49(b) - Excellent head support provided this 13-year-old during rear-end collision acceleration was seriously compromised by his rebounding into low back seat ahead of him

Fig. 50(a) - Two 13-year-olds seated in a conventional Superior seat, undergoing severe whiplash

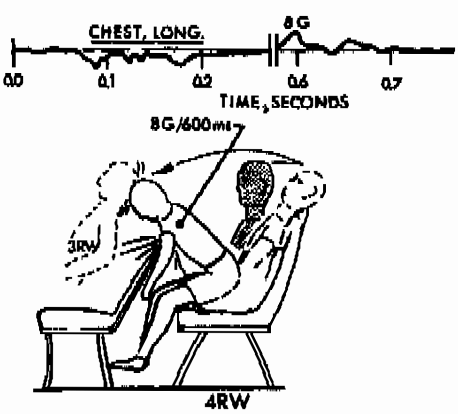

Fig. 49(c) - This high back American seat provided excellent head support during rear-end collision

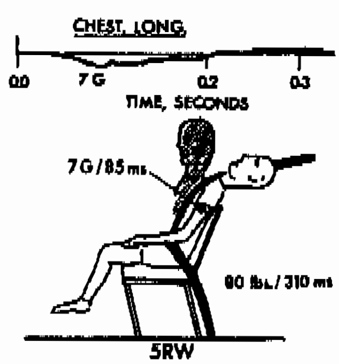

Fig. 50(b) - Restrained 13-year-old in low back seat, whiplashed rebound. Both passengers struck the back of seat 4R, a well-padded high back American seat. The 5RW passenger came to rest in a normal seated posture and the 5RA passenger came to rest in a seated posture leaning ahead against the seatback of 4R.

f. Seat 6R, a fiberglass Superior seat (see Fig. 3(b)), was occupied by a 13-year-old in position 6RW and a 3-year-old in position 6RA. Both passengers were restrained by a padded swing-type bar restraint. This restraint was hinge-anchored to each side of 5R seatback ahead (Fig. 51 (a)), and swung down onto the laps of the passengers in 6R. As the hips elevate, the swing-bar responds and does not limit vertical movement of the hips. This feature would be eliminated if the bar locked down when in proper restraining position. Freedom of the bar to elevate tends to reduce the severity of the neck flexion somewhat in this rear-end collision because 6R has no head support; however, hip elevation is an unsatisfactory solution to the whiplash problem and this freedom would allow passengers to be released during other types of collisions, such as upsets. The seatback was sufficiently high to prevent the 3-year-old from flailing his head rearward, relative to his shoulders, as he sustained a 13 G chest acceleration at 65 ms (Fig. 51(b)). When the 13-year-old 6RW reached his maximum whiplash excursion his longitudinal axis accelerometer could not record this higher vertical acceleration. Upon rebound he was elevated 1 ft off the seat and returned downward, striking his head on the window post, sustaining a 6 G head deceleration at 780 ms (Fig. 51(c)). Both passengers came to rest in a normal seated posture. Because the hips were permitted to elevate, 6RW sustained whiplash injuries which were considered less severe than belted occupants in low-back seats. The 3-year-old, 6RA, passenger's inferred injuries were considered minor.

If bus occupants were provided with an adequate head support, this type of swing-bar restraint appears to be satisfactory with respect to rear-end collisions.

g. Seat 7R, a conventional Superior seat, was occupied by three 13-year-olds, each restrained by a lap belt. Owing to the additional seat inertial forces, extra rearward flexure of seatback 7R delayed the whiplash movement of these three 13-year-olds, as contrasted with the occupant in seat 6RW whose neck had reached maximum rearward extension (upper left of Fig. 52 (a)). The 7RA 13-year-old was the only one of the three with accelerometer instrumentation and he

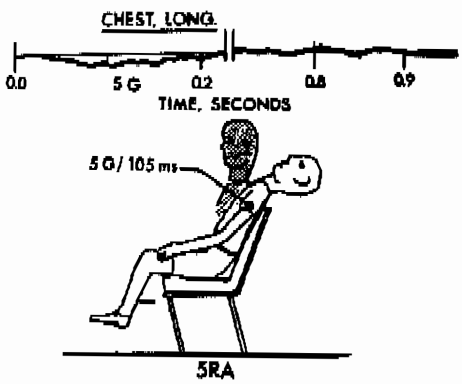

Fig. 50(c) - Unrestrained 13-year-old in low back seat, whiplashed

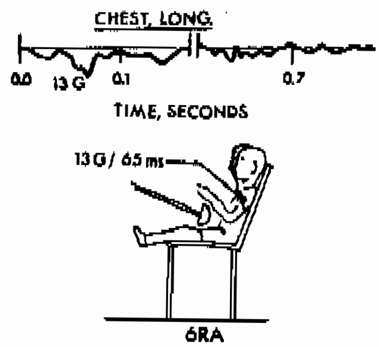

Fig. 51(b) - This low back seat did provide satisfactory head support for tiny 3-year-old, even though average size school child would be injured riding in this seat during a rear-ender

Fig. 51(a) - Swing-bar allowed hips to elevate during this rear-end collision

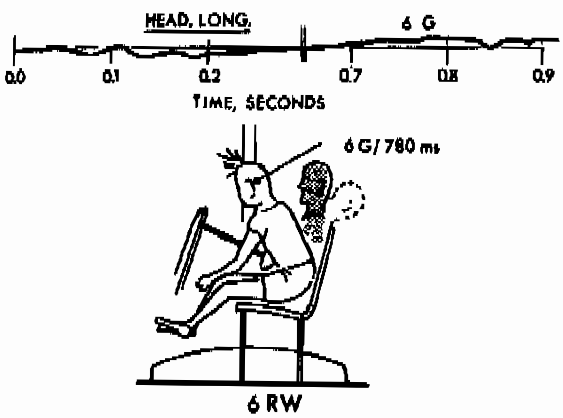

Fig. 51(c) - On rebound, 13-year-old strikes his head a glancing blow on window post received a 5 G chest acceleration at 55 ms (Fig. 52(b)). The lap belt restraining 7RC allowed the hips to elevate vertically, permitting the shoulders and upper torso to press against the seat in a semi-prone position, accounting for a delay in the onset of the severe whiplash. On rebound this occupant loaded his lap belt to less than 50 lb (Fig. 52 (c)). Passengers 7RC and 7RW returned to a normal seated posture and 7RA slumped over into the aisle still restrained by his lap belt. All three 13-year-olds received severe whiplashes during this collision exposure.

The deforming of this 7R backrest to the rear, not only delayed the whiplash movement, but it did measurably reduce the magnitude of the rebound in that these lap-belted occupants did not rotate past a vertical posture, thus avoiding the injury-producing low seatback ahead of them.

h. <u>Seat 8R</u>, a United Airlines seat, was occupied by a 13-year-old restrained by a lap belt in position 8RW, and an unrestrained 3-year-old in position 8RA. The heads and torsos of both occupants in seat 8R were provided excellent support against rearward movement during the acceleration phase of the collision (Fig. 53 (a)). Owing to the elastic characteristics of this high seatback, however, the 13-year-old in 8RW was thrown out of synchrony with the rearward

Fig. 52(a) - Delayed onset of severe whiplash for two 13-year-olds in conventional seat

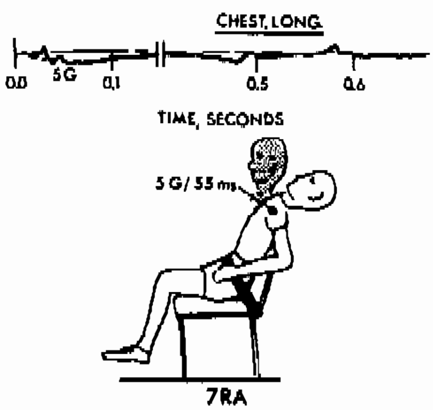

Fig. 52(b) - This 13-year-old, third occupant on conventional Superior seat, did not receive effective support from his backrest

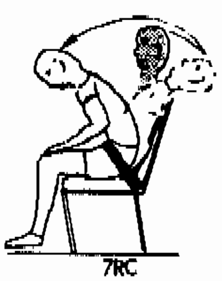

Fig. 52(c) - Lap belt loading (less than 50 lb) occurred on rebound from seat for this rear-end collision

Fig. 53(a) - Passenger heads and upper torsos received excellent support from United Airlines high back, well-padded seatback

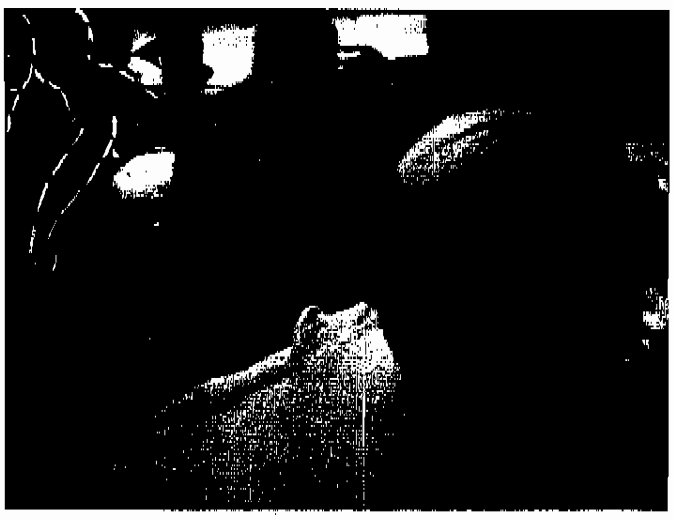

Fig. 53(b) - Thirteen-year-old rebounded from high backrest to bump heads with whiplashed passenger in front of him movement of the 13-year-old in seat 7RW, and their heads bumped together forcibly (upper left, Fig. 53 (b)). Immediately after these heads bumped, 8RW continued forward and struck the top edge of seat 7RW with his face, sustaining an inferred severe injury from this 20 G head blow at 580 ms (Fig. 53 (c)).

After receiving an initial head acceleration of 12 G at 75 msec, the 3-year-old in 8RA was not rebounded from his seat because his lighter body mass had not deflected the seat frame, as occurred with the 13-year-old. Owing to his size, the 3-year-old in seat 8RA was well supported, and did not sustain any whiplash action; additionally, he received no rebound effect, but registered a 12 G head acceleration (Fig. 53 (d)), derived from seatback acceleration rather than an actual blow. Both passengers came to rest in a normal seated posture.

i. Seat 9R, a high back Superior seat (see Fig. 3 (c)), was occupied by an adult (No. 7, Table 5), in position 9RW, and a 13-year-old in position 9RA. Seat 9R was at the rear of the bus on the right side. Both passengers were restrained by a horizontal padded gate-bar lap-type restraint (see Fig. 5 (f)), as shown on the right side of Fig. 53 (a). The head of the adult passenger in seat 9RW was forced rearward during the collision, first fracturing then pushing out the entire right rear-end window. Owing to the gate-bar restraining action, his vertical hip movement was restricted, but he did elevate in his seat sufficiently to contact the top frame of the window. A minor whiplash was received when his head punched the window out. This 9RW adult sustained a 16 G chest acceleration at 90 ms (Fig. 54(a)), and came to rest in a normal seated posture. The 13-year-old in position 9RA had his head snapped rearward against the right rear doorpost, abruptly stopping the onset of whiplash action; he elevated slightly in his seat before coming to rest in a normal seated posture. He received a 16 G head blow at 55 ms (Fig. 54(b)). Only a subtle rebound action occurred for these 9R passengers.

j. Seat 2L, a conventional Superior seat, was occupied by two 13-year-old passengers, each restrained by a lap belt. Both passengers underwent extreme whiplash action, as shown in the background of Fig. 55 (a). The medical scientist diagnosed their injuries as severe.

The passenger in 2LA sustained a 13 G chest acceleration at 66 ms and a 6 G head acceleration at 210 ms (Fig. 55 (b)). The passenger in 2LW sustained a 5 G head acceleration at 210 ms (Fig. 55(c)). The rebound action pitched the upper trosos of these two 13-year-olds violently forward, as in a frontal type impact, but did not dislodge them from their seats owing to their lap belts. Their heads flailed

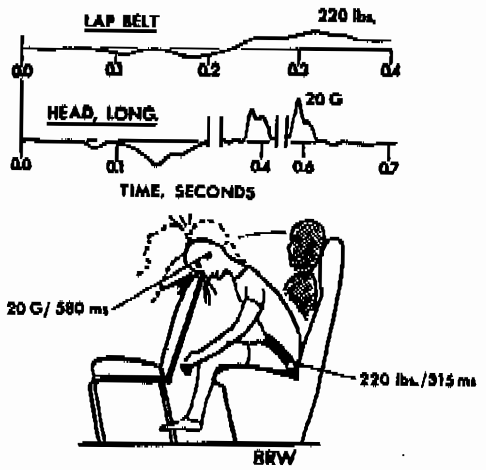

Fig. 53 (c) - Rebound from backrest caused head injury with low back seat in front of this 13-year-old

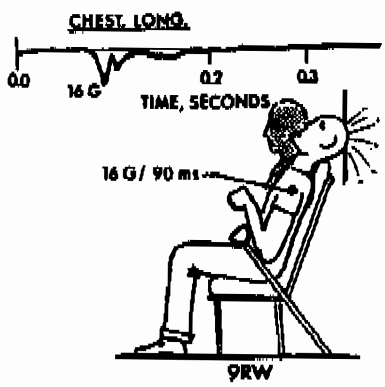

Fig. 54 (a) - Whiplashed adult punched his head through rear window

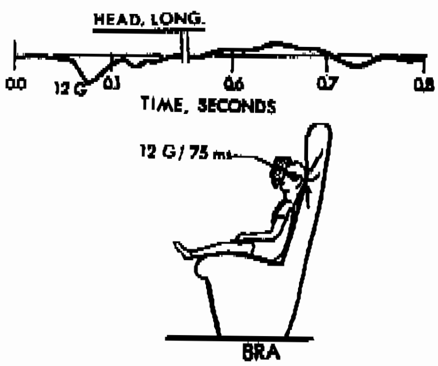

Fig. 53 (d) - Three-year-old rode out this rear-end collision in an uneventful manner

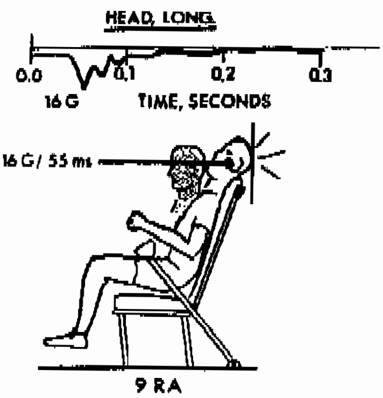

Fig. 54 (b) - Onset of whiplash action for 13-year-old abruptly stopped by head impact with doorpost behind his seat forward and would have impacted the next seat or the bar behind the driver if these items had not been removed for this experiment. In the absence of a seatback or other object to strike, the 13-year-olds jackknifed over their lap belts bringing their heads to a position below their knees before reaching their extreme forward movement; then they rebounded to a somewhat normal seated posture. Except in those seats having high backs, or conventional seats occupied by very small children, a similar whiplash effect occurred for all passengers in this bus (Fig. 55 (d)).

k. Seat 3L, a National seat with a high back (see Fig. 3 (f)), was occupied by a 13-year-old in position 3LA, restrained by a lap belt, and an unrestrained 6-year-old, (No. 2, Table 5), seated at the window position. The 13-year-old, after riding out the acceleration with good head support, flexed forward over his lap belt and forcibly struck his face against the top horizontal bar of low back seat 2L, sustaining a 20 G blow at 555 ms (Fig. 56(a)). This would definitely have been a severe injury-producing impact, possibly causing a broken jaw, loss of teeth or other facial injuries (Fig. 56(b)). The 6-year-old unrestrained passenger, in position 3LW, sustained an 11 G chest acceleration at 70 ms, without injury (Fig. 56(c)). On rebound he remained in a relatively normal seated posture (Fig. 56(b)).

Fig. 55(a) - Two lap-belted 13-year-old passengers in seat 2L undergoing severe whiplash, 175 ms; standee in foreground is being forced abruptly rearward

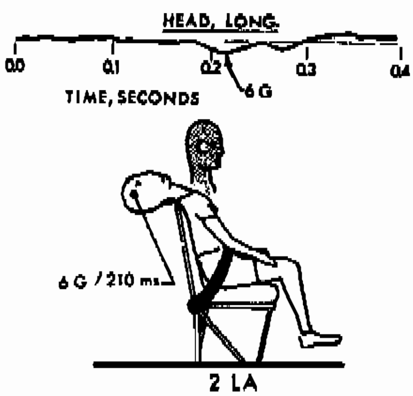

Fig. 55(b) - Whiplash of lap-belted 13-year-old

Fig. 55(d) - Except where heads were supported, passengers were whiplashed; standee in aisle was hurled rearward to floor

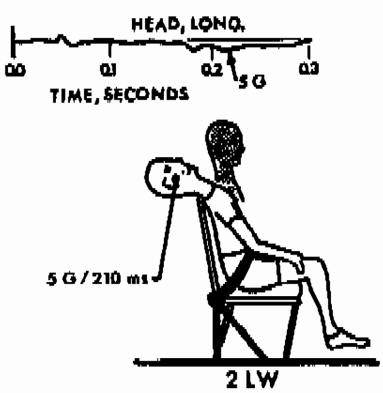

Fig. 55(c) - Replication: this 13-year-old sustained whiplash acceleration with his co-occupant having same restraint configuration

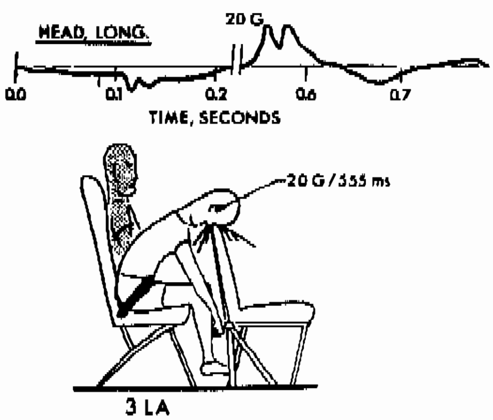

Fig. 56(a) - Protective qualities of high seatback 3L were compromised by rebound impact with low back seat ahead, causing injury-producing forces

The difference in kinematics for these two passengers occupying the same type seat was attributed to their relative heights and weights; the 13-year-old applied considerable force at a higher level and developed sufficient elastic rebound from his individual backrest to pitch him forward. This rebound caused him to impact the top horizontal bar of the seat ahead. Both 3L passengers had satisfactory head support and were not exposed to the usual whiplash associated with this type of collision.

1. Seat 4L was a high back Superior seat; the passenger in seat position 4LA was a 13-year-old, restrained by a lap belt, and position 4LW was occupied by a 13-year-old, restrained by a three-point chest-lap belt combination.

At the onset of collision forces both occupants loaded the backrest and consequently deformed it rearward. Thirteen-year-old 4LA received a 6 G chest acceleration at 75 ms (Fig. 57 (a)). However, the window seated 13-year-old did not record his peak head acceleration until he rebounded and cycled into his backrest for the second time. At this time he sustained 8 G head acceleration at 885 ms as his head struck his backrest and the shoulder of the rebounded 13-year-old to his rear (Fig. 57 (b)). The three-point restraint for 4LW carried tensiometers, but, owing to the deflecting seatback, belt loads were too low to be significant (less than 50 lb).

During collision, the seatback was forced rearward approximately 20 deg; this action minimized the rebound of the occupants. The disadvantage of this situation is that it places the seatback in a position where it is more likely to be contacted by passengers in the seat directly behind. The high seatback of 4L appeared to provide a reasonably adequate head support against whiplash for 13-year-olds.

The kinematics for both passengers were substantially the same even though restrained differently. For this rear-end collision, and for 13-year-olds in the high back 4L seat, both the lap belt and the three-point belt minimized the undesirable movements of the passengers; both passengers maintained their postures, received no whiplash manipulation, and did not sustain contacts that would have been injury producing.

Although this high back Superior seat did appear adequate for 13-year-old passengers during a rear-end collision, the seatback height (26 in.) allowed slight contact with the back of their necks; high school students need higher seatback heights (28 in. or higher) for adequate protection.

Fig. 56(b) - Even though well protected from whiplash by high seatback, lap-belted 13-year-old rebounded and struck his face forcibly against low seatback ahead

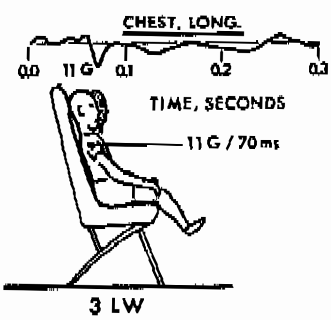

Fig. 56(c) - Unrestrained 6-year-old rode out crash in an uneventful manner owing to his shorter torso height and well-padded, high back National seat

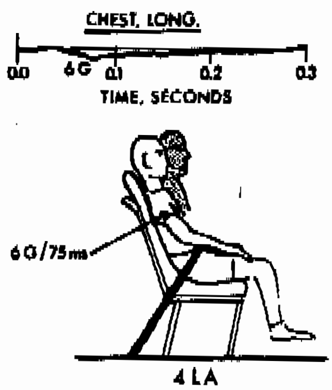

Fig. 57(a) - Head and torso inertia of this lap-belted 13-year-old contributed to deforming backrest rearward

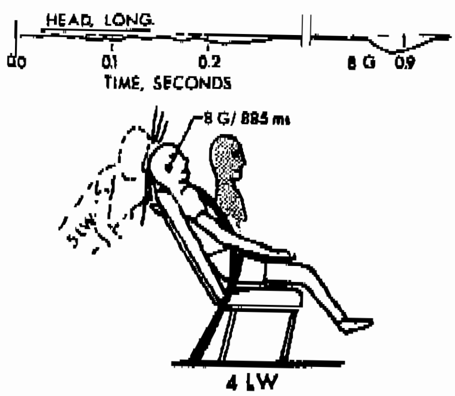

Fig. 57(b) - Thirteen-year-old with cross-chest lap-belt combination rode out rear-end collision without sustaining inferred injuries

m. Seat 5L was occupied by two 13-year-olds, both unrestrained. Owing to the low seatback design of 5L, both passengers received severe whiplash, with their heads forced rearward until they faced 30 deg to the rear of vertical, representing an extreme whiplash position prior to rebound (Fig. 58 (a)). The passenger in 5LA sustained a 5 G chest acceleration at 75 ms (Fig. 58(b)). He came to rest on the floor between seats 4L and 5L. Co-occupant 5LW sustained a 6 G chest blow at 105 ms (Fig. 58(c)), and came to rest in a seated position on the floor beside 5LA. On rebound, both occupants forcibly struck the handrail and seatback ahead (Fig. 58 (d)).

n. Rear Standee 5S, a 13-year-old standing between seats 5L and 5R, did not have accelerometer instrumentation. He was hurled to the rear in much the same manner as the front standee. He struck the flailing arm of the 3-year-old passenger in seat 7L, and then fell to the aisle floor at the base of the 7L seat, 4 ft behind his original position. His injuries were considered moderate for the back impact he received with the edge of the 7L seat. As would be expected during a rear-end collision, the passengers standing in the aisle of the bus are thrown rearward head first, exposing their heads, shoulders, and buttocks to impact with seats and other passengers.

o. Seat 6L, a Cox seat (see Fig. 3 (h)), was occupied by an adult dummy (No. 6, Table 5), restrained with a three-point cross-chest lap belt combination. The built-in head support and belt anchorages appeared quite adequate; the normal seated posture of this passenger was correctly maintained throughout the rear-end collision (left side, Fig. 58 (a)). At the onset of collision, adult 6LW started to forcibly press rearward against his seatback and later sustained a 6 G chest acceleration at 105 ms (Fig. 59). Thereafter, on rebound, he loaded his lap belt to 95 lb at 285 ms. There was minimal rebound action for this adult passenger and the Cox seat performance was excellent for this rear-end collision exposure.

p. Seat 7L, a conventional Superior seat, was occupied by a 13-year-old in position 7LW and a 3-year-old in 7LA, both unrestrained. During the collision the 13-year-old was

Fig. 58(a) - At 180 ms, 13-year-olds undergo extreme whiplash over conventional height Superior seatback as contrasted with head-supported adult to their rear

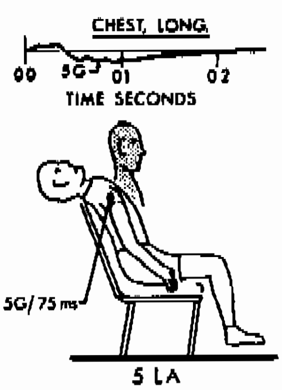

Fig. 58(b) - Whiplashed 13-year-old unrestrained in conventional Superior seat

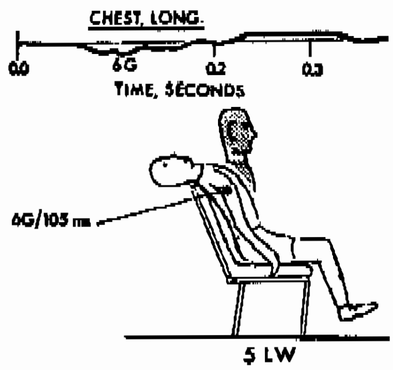

Fig. 58(c) - Unrestrained 13-year-old received whiplash identical to his co-occupant

Fig. 58(d) - Thirteen-year-olds rebound from conventional Superior seat to strike heads forcibly against seatbacks and handrail ahead, 525 ms forced against his backrest receiving an 8 G chest acceleration at 115 ms (Fig. 60(a)). His head flailed rearward to an extreme whiplash position (Fig. 60 (b)). The unrestrained 3-year-old appeared to receive satisfactory support from the seatback owing to his shorter torso height. Because his head was supported by the backrest, he sustained a head acceleration of 12 G at 50 ms, considerably earlier than other whiplashing passengers (Fig. 60 (c)).

After the collision, 13-year-old 7LW was leaning toward the center aisle of the bus against the 3-year-old 7LA, who was also leaning toward the center aisle. This aisle-seated 3-year-old remained on the edge of his seat with his right arm protruding into the aisle.

q. Seat 8L, an ABC Unified School District seat (see Fig. 3 (d)), was occupied by two 13-year-olds, both unrestrained. During the impact the 13-year-old passenger in position 8LA sustained an 8 G chest acceleration at 125 ms (Fig. 61(a)). At this same time his companion, 8LW, received a peak chest acceleration of 37 G (Fig. 61 (b)). This large acceleration variation between like occupants in seat 8L was attributed to the kinematics of the adult dummy seated directly behind 8LW. The backrest of seat 9L, the most rearward left side seat, was up against the rear interior structure of the bus which did not allow the 9LW adult to be forced rearward at impact, but instead he transferred the impact

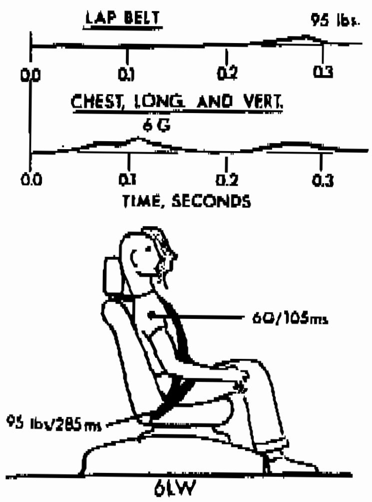

Fig. 59 - Adult in Cox seat undergoing rear-end collision acceleration, rode out collision in an uneventful manner owing to excellent performance of seat and restraints

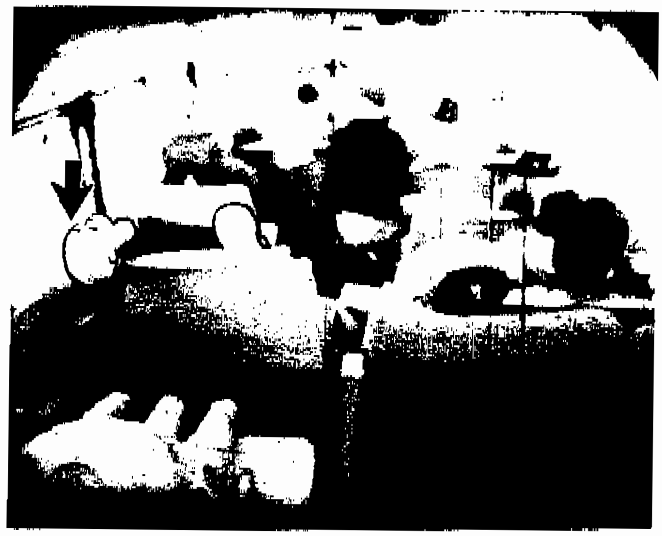

Fig. 60(b) - Thirteen-year-old experiencing extreme whiplash; 3-year-old beside him rode out crash in an uneventful manner owing to backrest providing adequate support for his tiny body

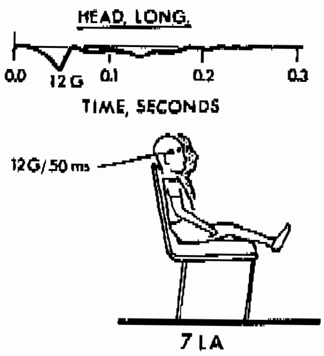

Fig. 60(c) - Because of shorter torso, 3-year-old received adequate support from conventional Superior backrest

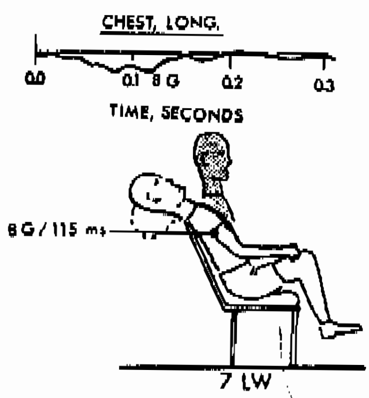

Fig. 60(a) - Thirteen-year-old receives an 8 G peak chest acceleration and a severe whiplash

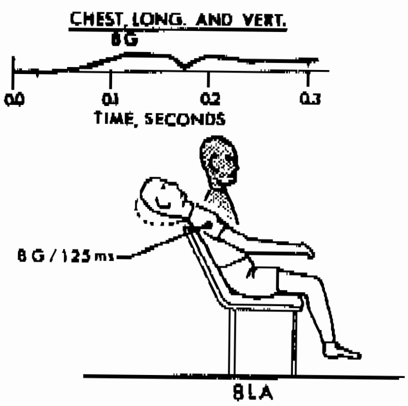

Fig. 61(a) - Unrestrained 13-year-old sustained a severe whiplash force of the striking car directly to the 8LW occupant ahead of him.

The 8L seatback deformed about 10 deg rearward as both 13-year-old occupants received a severe whiplash. Because of the close proximity to impact, the occupants were rebounded violently into the air approaching almost standing posture against the seatback ahead (Fig. 61 (c)). Then they slumped rearward, with 8LW coming to rest across the cushion of his seat, and 8LA rebounded to the floor ahead of his original seated position.

r. Seat 9L, a conventional Superior seat, was occupied by a 13-year-old in position 9LA, and by an adult (No. 1, Table 5), in position 9LW, both unrestrained. During impact, the 9LW adult's head whiplashed against the rear window directly behind him but did not fracture the tempered glass window. The 9LW adult was then thrown vertically, still maintaining his seated posture, impacting the top of the window frame with his head, receiving only minor injuries. Thereafter he came to rest in a normal seated posture. When the adult rebounded vertically, he came down striking the seatback ahead and sustained a 20 G head blow at 860 ms (Fig. 62(a)).

The passenger in position 9LA reacted substantially the same as the passenger in 9LW; during impact he also contacted the left rear-end tempered glass window and also struck the adjacent doorpost, receiving only minor injuries. Neither passenger received a whiplash since their heads were supported by the tempered glass window and frame. The 13-year-old came to rest in a doubled-over posture lying on his right side on the floor, between seats 9L and 9R. He sustained a 20 G head blow at 735 ms (Fig. 62(b)).

3. Collision Performance - The stationary 1965 GMC-Superior bus was rear-ended by a 1960 Plymouth Savoy* traveling at 60 mph. The 1965 GMC chassis carried a Superior school bus body; the 1960 Plymouth was of unitized body construction, with a stub-frame from the firewall to the front bumper. The rear end of the bus and the front end of the

*1965 GMC-Superior Coach school bus gross weight, as crashed, was 17,500 lb; the 1960 Plymouth Savoy 4-door sedan at time of crash had a gross weight of 4400 lb.

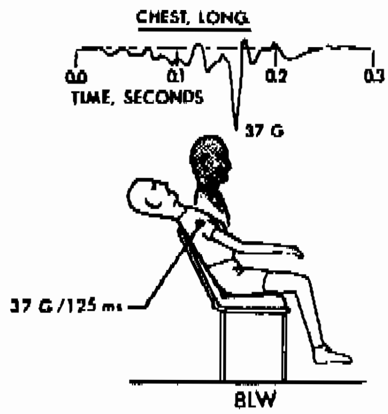

Fig. 61(b) - Unrestrained 13-year-old, whiplashed, sustains an exceptionally high chest acceleration from impact by the adult passenger in the seat directly behind him

Fig. 61(c) - The rebounding 13-year-old, seat position 8LA, is thrown to his feet approaching a standing posture

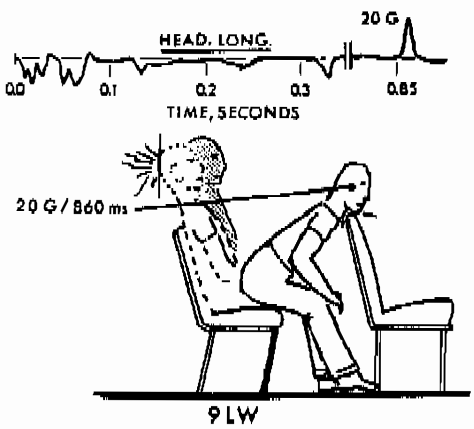

Fig. 62(a) - Adult strikes rear window before his head impact with seatback ahead

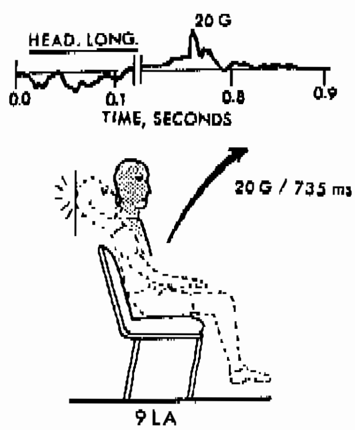

Fig. 62(b) - Thirteen-year-old impacts rear window, accelerates violently upward, then slumps forward striking his head

Plymouth were directly opposing each other at impact (Fig. 63).

The Plymouth front frame structure and front bumper showed no contact with the rear bumper of the bus because the bumpers were of different heights (Fig. 64 (a)). The Plymouth front bumper retained its original shape; there was no damage to the bumper supports attached to the frame or the frame itself. When the Plymouth reached its maximum underriding position, the car's instrument panel had advanced to the crash center, the point the bus's rear bumper had been over before the bus began to accelerate from collision forces (Fig. 64 (b)). This underriding condition was further facilitated by the 8-in. forward slippage of the 1965 Superior bus frame, relative to the bus body (Fig. 64 (c)). The underriding action of the striking passenger vehicle forced the car against the pavement; this accounted for the

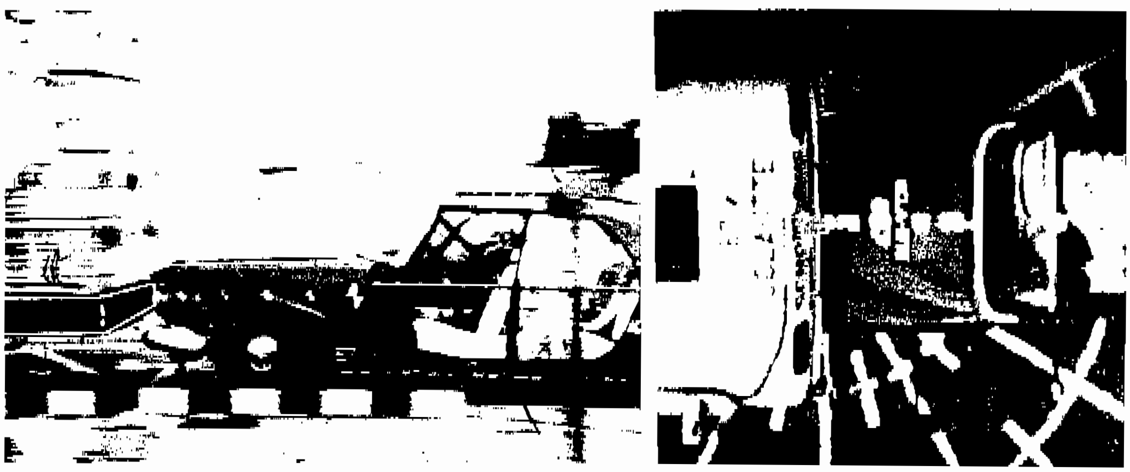

Fig. 63 - Position of vehicles just prior to impact

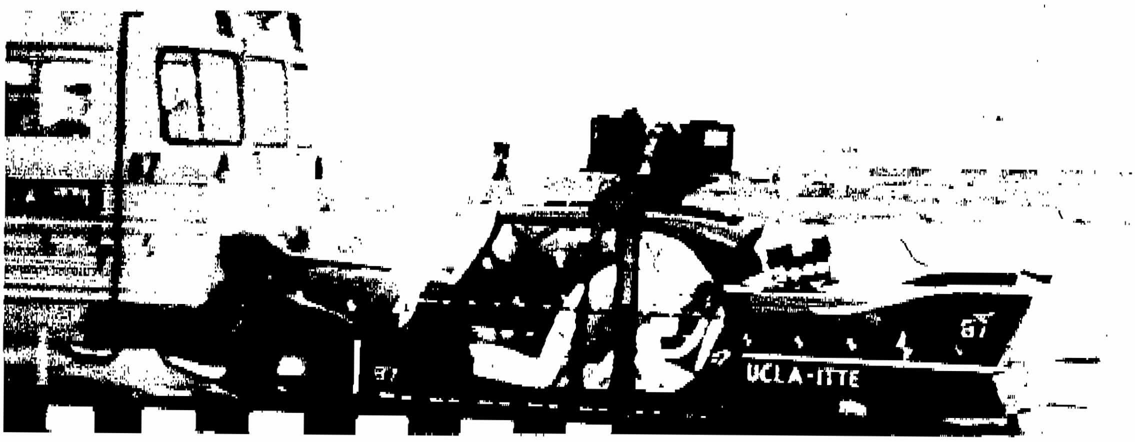

Fig. 64(a) - 1960 Plymouth at start of underriding

Fig. 64(b) - Maximum penetration of two colliding vehicles lack of follow-through movement for the striking vehicle commonly associated with rear-end collisions (Fig. 64 (d)). No braking was applied to the bus; however, the bus's forward movement following impact was resisted by a collision-distorted front end and eccentric front wheels. The position of rest for the bus following collision roll-out was 143 ft forward and 8 ft to the left of the point of impact, and the position of rest for the 1960 Plymouth was 16 ft forward and 1-1/2 ft to the right of the point of impact.

The top surface of the Plymouth front bumper had scrape marks from front to rear and the trim had been stripped from the bumper. The radiator and engine both were shifted rearward. The hood leading edge was forced rearward 4 ft from its original position. Because of the extreme shift to the rear of all forward components above the frame toward the passenger compartment, the instrument panel was deflected downward. The left fender was collapsed rearward to the windshield; the right fender was similarly crushed rearward to within 1-1/2 ft of the windshield. Neither door on the right side was forced open but the right front door was buckled outward 14 in. at the rear edge of the wing vent. Both left doors had been removed for better ground camera viewing and in their place, compression struts were installed to retain the structural rigidity of the vehicle. All tires remained inflated except the left front. The right front door window was shattered and the right rear door glass remained intact (Fig. 64 (d)). All external lights were on and the headlights exhibited the characteristic indications of the heated filament distortion and failure. The rearward section of the engine pan was forced against the pavement 5 ft after the start of impact. Other gouges were located further from the position of contact. The rear seat anchorages were strengthened and the seatback did not break loose during impact. The right front armrest was torn off. The right front wing vent was not distorted and the glass remained intact. The rear of the engine tilted downward approximately 30 deg by the underriding action of the front end. Parts and debris dislodged from the Plymouth during collision were distributed to 70 ft ahead of the point of impact.

The school bus rear bumper was damaged most at its center with a 22 in. permanent indentation caused by the underriding Plymouth engine. A pattern from the right dual headlights of the Plymouth was embossed on the rear of the bus body sheet metal, 20 in. to the left of the right side. The bus frame was displaced 8 in. forward, relative to the chassis. The rear door of the bus was dented; dents and paint transfers were observed 10 in. above the base of the door, or 43 in. above the pavement. The bus was accelerated by this rear-end collision reaching a peak of 10 G at 45 ms.

Fig. 64(c) - The 4,400-lb striking car's position of rest, 16 ft from contact; 17,500-lb school bus rolled to a stop 143 ft after impact

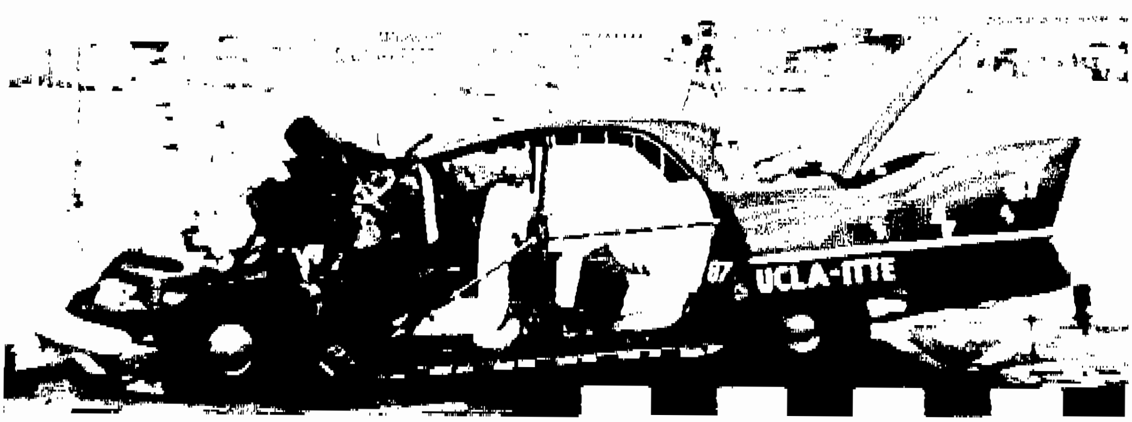

Fig. 64(d) - Striking car's position of rest, showing collision damage sustained

FINDINGS - SIDE-IMPACT COLLISION

EXPERIMENT 90 - The side-impact collision involved a car traveling at 60 mph striking the right side of a stationary school bus. A 60-passenger, 1965 GMC-Superior school bus simulating a condition of crossing a divided highway was struck at the right rear duals by a 1966 Chevrolet Bel Air 4-door sedan* (Figs. 65 (a) and 65 (b)). During this intersection collision, electronic and photographic instrumentation recorded passenger decelerations, safety belt loads, passenger forced movements (whether restrained or unrestrained), seat performance, restraint effectiveness, safety glass performance and structural collapse of the vehicles.

Thirty-two anthropometric dummy passengers in the bus (five adults, twenty-four 13-year-olds, two 6-year-olds, and one 3-year-old) provided the basis for evaluation of 10 seat configurations and 5 types of restraining devices. Additional information on the dummy passengers, seat construction, restraint systems, photographic coverage, instrumentation and recording devices, is listed under Methodology.

1. 1966 Chevrolet - The striking car had four passengers, two adults in the front seat, and two 13-year-olds in the rear seat. The seating assignment (Fig. 66 (a)), shows the peak accelerometer loads and restraint systems.

As the vehicles collided, the unrestrained adult driver (No. 4, Table 5) was thrown against the steering wheel. His biaxial chest accelerometers registered a 36 G peak at 95 ms. The peak deceleration of the Chevrolet frame was 26 G at 65 ms.* The steering wheel was collapsed bringing the driver's head against the windshield header. With his knees in the instrument panel, his upper torso rotated causing his head to glance from the windshield header into the glass with a shearing movement. Thereafter, he rebounded to a normal seated posture, except that he was slightly to the right of his original seated position. Owing to his abusive contact with the steering wheel, the driver's inferred injuries were considered severe to fatal.

The right front adult passenger (Dummy No. 2, Table 5), was also unrestrained. His initial dash-to-knee deceleration resulted in upper torso rotation in a forward direction. This jackknifing action caused his head to strike the windshield header and glass a glancing blow. The biaxial accelerometers mounted in the front seat passenger's head recorded 43 G

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*1965 GMC-Superior Coach school bus gross weight, as crashed, was 17,500 lb; the 1966 Chevrolet Bel Air 4-door sedan at time of crash had a gross weight of 4500 lb.

*Collision dynamics for the 1966 Chevrolet Bel Air sedan striking the side of the 1965 GMC-Superior Coach bus are presented at the end of this section.

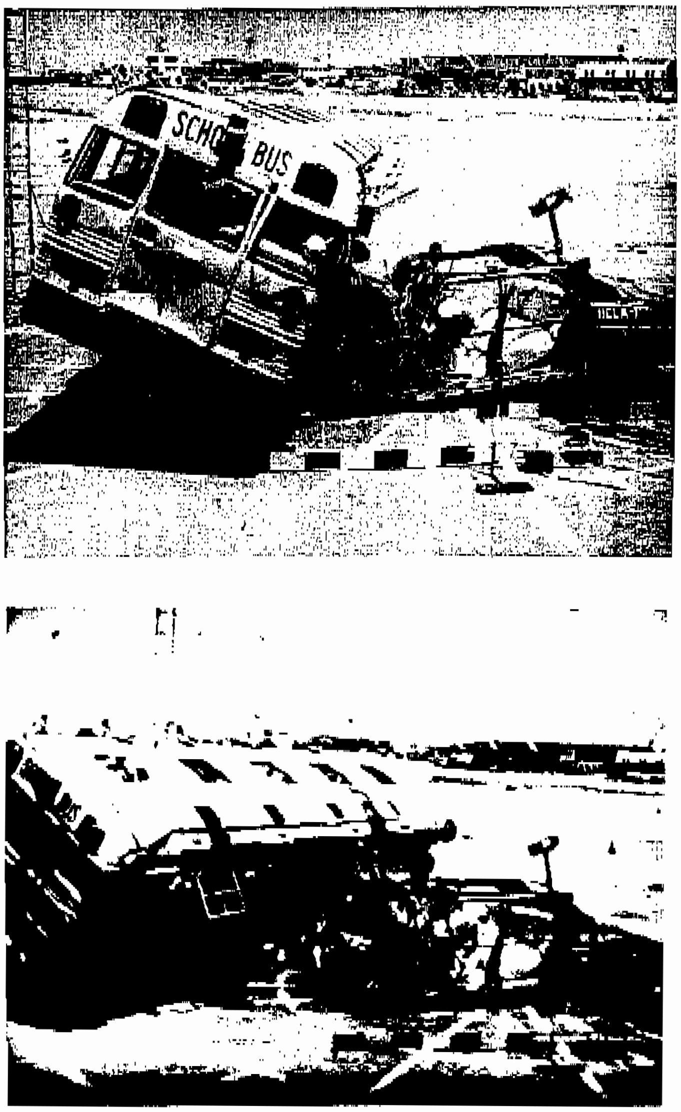

Fig. 65 (a), (b) - Sixty mph into the side of a 60-passenger school bus nearly topples it

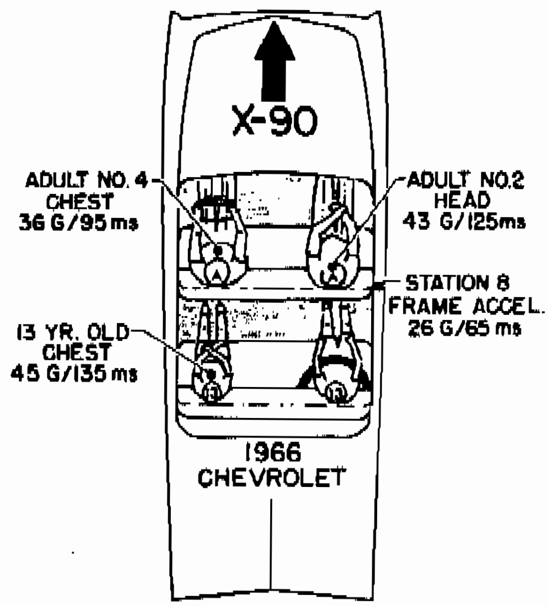

Fig. 66 (a) - Striking car seat assignment and peak accelerometer loads peak at 125 ms. This impact by the front seat passenger contributed to the tearing of the plastic interlayer of the windshield after it had been punctured by the car hood. The puncture was small and did not allow entrapment of the head, representing a very significant improvement in windshield collision performance compared with pre-1966 windshields. Following the windshield and instrument panel impacts, he rebounded to his seat; the seat developed sufficient deflection to rebound him into the windshield a second time. His final position of rest was slumped down in the seat to the right of his original seated position with his head leaning out the right front window. He was diagnosed as severely injured from this unrestrained abusive impact with the windshield.

The left rear 13-year-old passenger was unrestrained. He was thrown forward as the car crashed until his knees penetrated the back of the front seat; then he rotated about the hips, striking his chest 45 G at 135 ms against the back of the front seat (Fig. 66 (b)). During his contact with the front seat, the left side seat anchorage failed, causing the seat to shift diagonally forward at the left side. This seat action allowed the 13-year-old to rotate to the left, around the seat, to strike the left doorpost and steering wheel. His position of rest was with his buttocks out the left front door opening, resting on the reinforcing strut replacing the door. The left side of the front seat had shifted almost to the steering wheel, and he came to rest with his chest on the top of the front seatback. His injuries were severe considering his high chest deceleration from impacting the front seat.

The right rear 13-year-old passenger was restrained by a lap belt. He did not have head or chest instrumentation. As the lap belt loaded up, the usual jackknifing over the belt allowed the head and torso to be forced into the back of the front seat, with his head behind his flailing hands and his head contacted the top of the front seatback. He continued elongating the belt until his chest was forced against the back of the front seat. At this time, 140 msec after impact, the lap belt failed and he was thrown completely against the seatback striking it with his knees and hips (Fig. 66 (c)). He came to rest slumped to the center of the floor between the front and rear seats in a semi-kneeling, but upright, position. Although the belt failed,* it had adequately restrained most of the kinematic energy of this 13-year-old. His injuries were considered moderate because of his restraint and his subsequent moderate impact with the seatback.

2. The 1965 GMC-Superior Bus Compartment - Thirty-two anthropometric dummies were used to study passenger kinematics during the 60 mph side-impact collision experiment. The seating assignment identifies occupant size, restraint type and seat type. Seat location is identified by right or left side numbers, starting from the front as, for example, 1R, 1L, 2R, 2L, and so forth. Seat station is given as the number of feet from the front bumper. These data along with the passengers' forced movements and positions of rest are shown in Fig. 67 (a). The location of passengers was further defined by seat position, relative to W-window, C-center, A-aisle or S-standing as, for example, 2RW, 2LA, 2S, and so forth. Cross section views of passenger positions to scale for each seat station, portray occupant size versus seatback height and bus interior size, restraint systems, seat types, belt loads and accelerometer peak readings for dummies carrying instrumentation (Fig. 67 (b)).

*Belt tensiometers and accelerometers were not applied owing to the more important application for data on school bus children collision performances. The belt was designed to sustain 5000 lb (loop load), and, considering the 26 G peak deceleration sustained by the car frame and the latency-amplification of peak G characteristic for restrained occupants, it is considered that the belt restrained approximately 5000 lb before failing.

Fig. 66 (b) - Unrestrained left rear 13-year-old received peak deceleration against front seat which had already torn loose from inertial forces

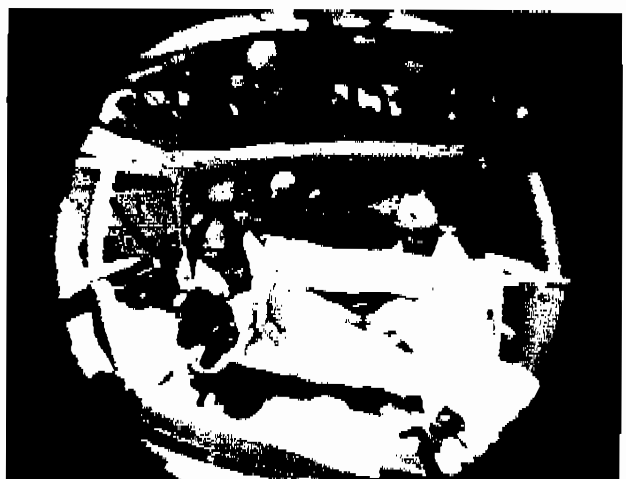

Fig. 66 (c) - Right rear 13-year-old passenger loaded lap belt to failure as he contacted front seatback

The driver's seat, the first seat on the left side, and the second seat on the right side were removed because of prior damage to this area from the head-on collision experiment. The first seat on the right side 1R, the Martin air seat, was moved to position 2R because of extreme floor buckling at its former location from the prior head-on collision experiment.

a. Seat 1R, a Martin air seat (see Fig. 3 (j)), was occupied by an adult (No. 3, Table 5), restrained by a lap belt that was anchored to the floor. At the onset of impact the adult was thrown to his right against the side of the bus, sustaining an 8 G chest blow at 120 ms (Fig. 68). His head grazed the window with a flailing motion and the elastic rebound forced him toward the aisle. After coming to rest, he was still restrained at the hips by the lap belt but leaning into the aisle over the left edge of his seat.

Because of the forward position of this seat and the remoteness from the impact, the lateral movement against the side of the bus for this adult was moderate. Neither the adult's initial impact with the side of the bus nor his rebound was cushioned by the air seat-lap belt combination, since, by design, the seat provides protection only for impacts in the front and rear directions. This adult received minor injuries from his limited contact with the window and his somewhat uneventful rebound.

b. Standee 2S, a 13-year-old standing in the aisle beside seat 2L, did not have accelerometer instrumentation. The impact forces from this collision hurled this 13-year-old through the open door at the right front entrance (Fig. 69). This door was removed for an earlier experiment in order to photograph the driver with exterior ground cameras. After ejection, the 13-year-old passenger came down striking the pavement head first. From this violent head blow, his injuries were diagnosed as severe to fatal. Although this 13-year-old probably would not have ejected if the door were closed, the rapidity with which he was ejected indicates the dangerous condition that prevails when passengers are permitted to stand in bus aisles.

c. Seat 2L, a conventional Superior seat (see Fig. 3 (a)), had a 6-year-old (No. 1, Table 5) in position 2LA, and a 13-

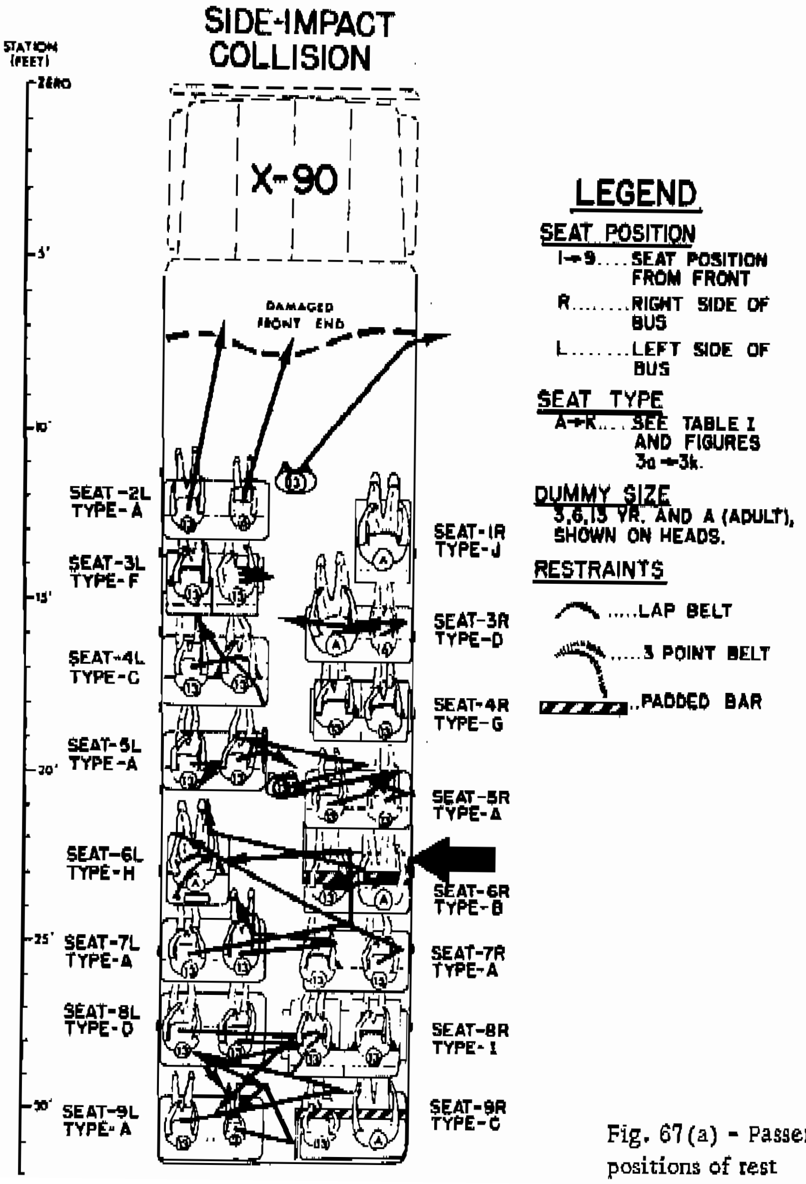

Fig. 67 (a) - Passenger assignment, including forced movements and positions of rest

SIDE-IMPACT COLLISION, X-90

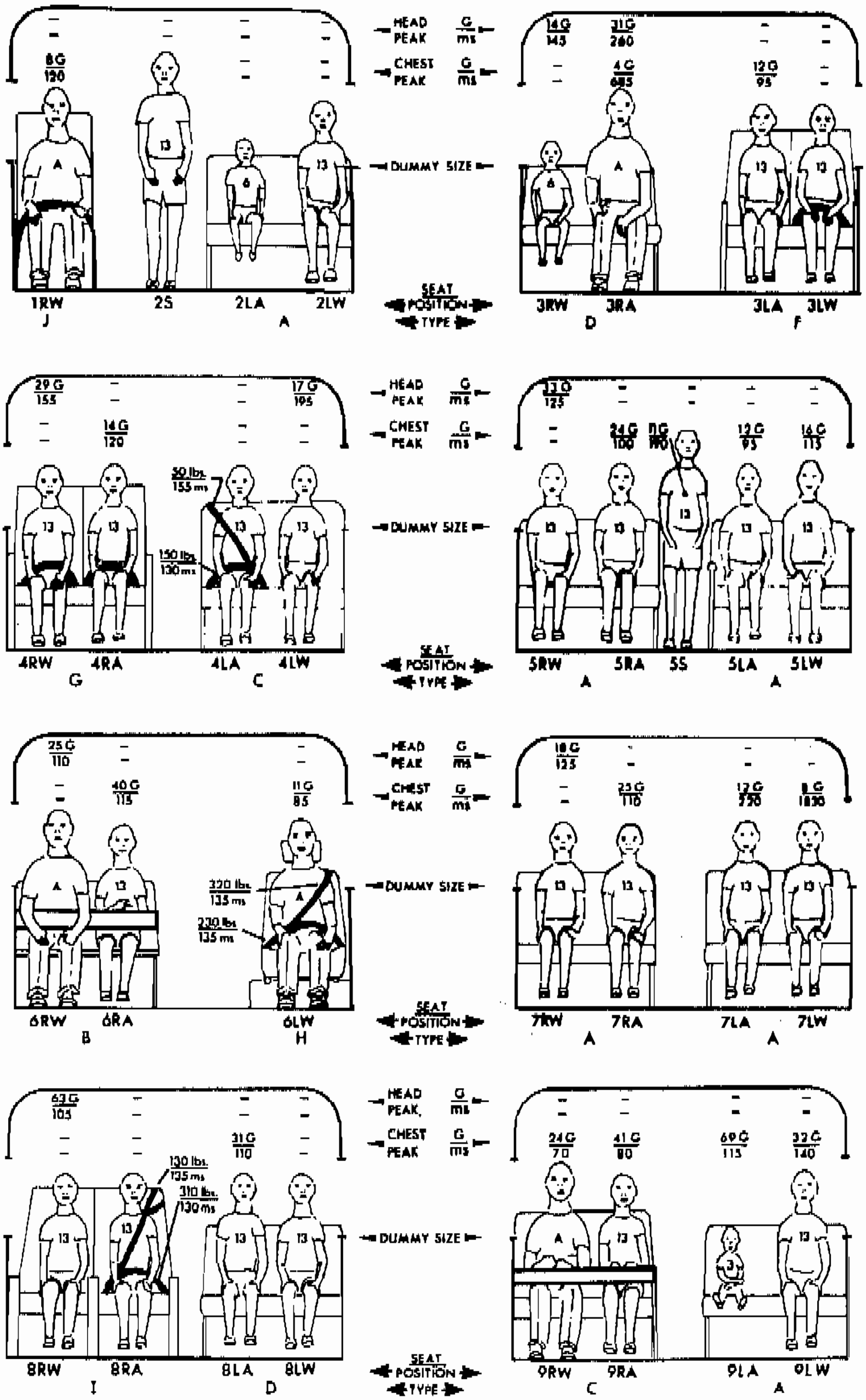

Fig. 67 (b) - Seat stations with occupant's accelerometer and belt load values year-old in position 2LW, both unrestrained. Although lateral forces were not nearly as great for this forward position, as contrasted with stations nearer the impact, both passengers were violently shifted to their right from their pre-crash seated positions.

The 6-year-old in position 2LA was pitched, head first, transversely across the bus to the right front area. In flight, he did a somersault before landing head first, face up, near the stairwell (Fig. 70), receiving severe inferred injuries.

The 13-year-old in position 2LW was thrown obliquely to the floor area adjacent to the driver's location. He impacted the floor, in a prone position, and came to rest under the steering wheel. His injuries were considered moderate for this impact with the floor, in view of the distributed blow he received on contacting the floor.

d. Seat 3R, an ABC Unified School District seat (see Fig. 3(d)), was occupied by a 6-year-old (No. 2, Table 5), and an adult (No. 5, Table 5), both unrestrained. The striking car impact was to the rear of this seat position and both passengers were thrown to their right. The solid-pour type 6-year-old in position 3RW struck the window with his head. His biaxial head accelerometers recorded 14 G at 145 ms (Fig. 71(a)). At 120 ms later, he was forcibly struck by the adult in 3RA shifting laterally. Owing to this pinning action against the side by the adult, the 6-year-old remained substantially in his normal seated position. He then rebounded to a prone position in his seat. His injuries were considered moderate for this head contact and impact by adult 3RA. At the time of impact with the 6-year-old, the adult received a head blow of 31 G at 260 ms (Fig. 71 (b)). He did not, however, receive his peak chest acceleration at this time since he was cushioned by the 6-year-old. His peak chest deceleration of 4 G occurred at 685 ms, when he rebounded back to his seat with a rotational motion about the hips and struck his head against the seat across the aisle. He remained in this reclined position across the aisle with his buttocks in his original seat position. His injuries were judged moderate to severe from the head blow with the window.

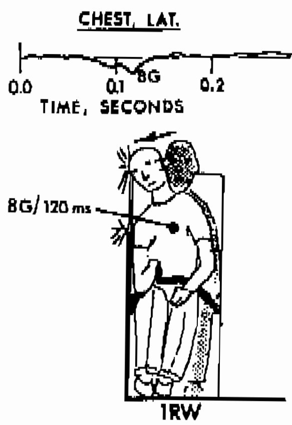

Fig. 68 - Adult in air seat impacted right side of bus and struck window as a result of flailing head motion

Fig. 70 - Six-year-old 2LA somersaults to floor and lands head first near stair well

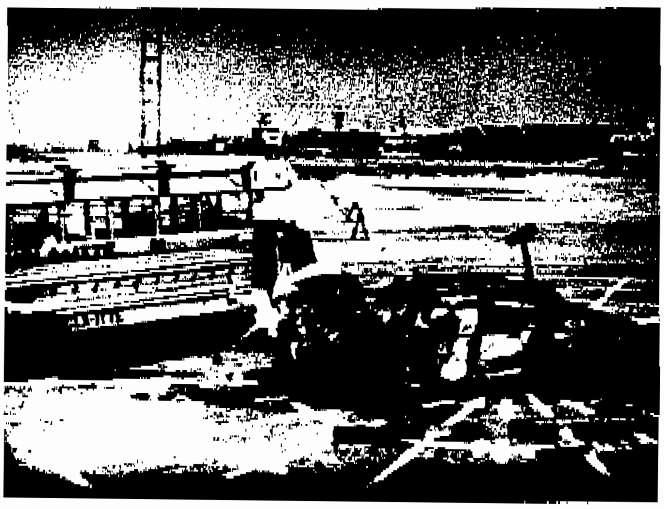

Fig. 69 - Collision rotational movement ejects 25 standee from open door

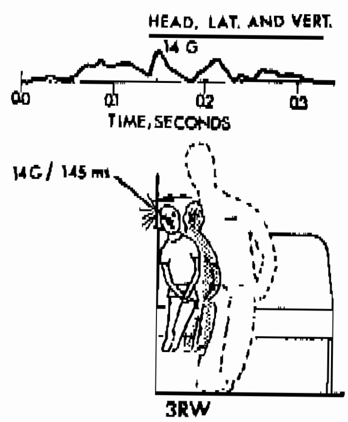

Fig. 71(a) - Six-year-old impacts window with his head and is subsequently crushed by adult No. 5, thrown against him

e. Seat 3L, a National seat (see Fig. 3(f)), had two 13-year-old passengers. Aisle-seated passenger 3LA was unrestrained and window-seated passenger 3LW was restrained by a lap belt attached to the seat. There was an armrest to the right of 3LA and another to the left of 3LW. Owing to the forward location of this seat relative to the side impact forces, the armrest effectively prevented the unrestrained 3LA from sliding laterally to the right into the aisle (Fig. 72 (a)). While partially restrained by the armrest, 13-year-old 3LA sustained a chest acceleration of 12 G at 95 ms (Fig. 72 (b)). Later he received a minor blow on the back by the jackknifing 13-year-old companion. On rebound, 3LA rocked slightly forward but maintained a nearly normal seated posture. He sustained only minor injuries that were attributed to the restraining action of the armrest and the location of this seat near the bus center-of-rotation.

Occupant 3LW did not have accelerometer instrumentation. At the onset of the collision he flailed to his right about his lap belt and struck 3LA in the back with his shoulder. Following the impact, he returned to a normal seated posture. His injuries were considered negligible for this exposure.

f. Seat 4R, an American seat (see Fig. 3 (g)), had two 13-year-old occupants, both restrained by lap belts anchored to their seat frame. During the initial phase of the impact the upper torsos and heads were flailed to the right. The occupant in seat position 4RW rotated slightly to his right, then his companion in position 4RA struck him in the back (Fig. 73 (a)). Thirteen-year-old 4RW struck his head against the window and windowpost, sustaining 29 G at 155 ms. Since he had a single axis (lateral) accelerometer and his head had rotated 60 deg into the window, his head acceleration would have been double, or 58 G, for this impact (Fig. 73 (b)). Before he attained this peak deceleration, he was struck in the back by his co-occupant, thereby augmenting the head impact forces. Thereafter, 4RW was flailed in the opposite direction toward the aisle but remained in an almost normal seated posture. His head injuries were considered severe and in some measure may have been increased by jackknifing owing to the lap belt.

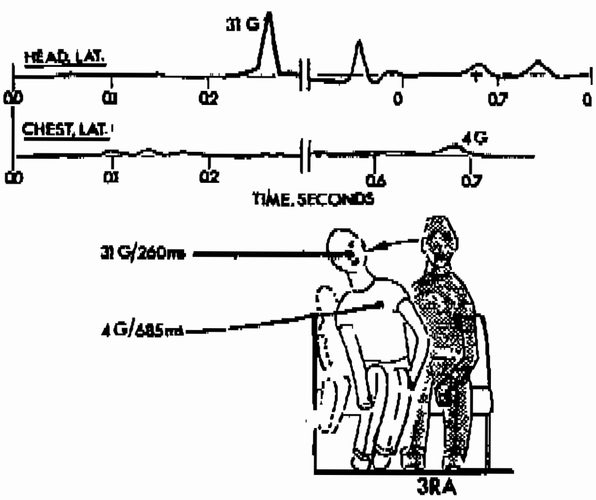

Fig. 71(b) - Adult 3RA forcibly strikes his smaller companion who cushions adult's initial impact

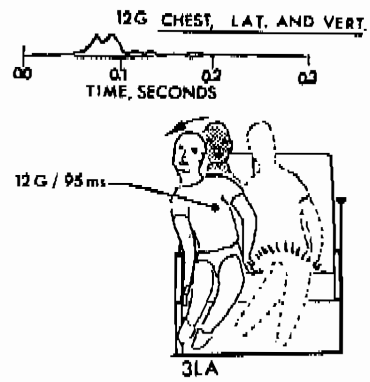

Fig. 72(b) - Partially restrained by armrest, 3LA remains in his seat for this forward seat position

Fig. 72(a) - Armrests provided substantial restraint against side forces during collision

Fig. 73(a) - Restrained by a lap belt, aisle-seated 13-year-old forcibly struck his companion seated next to window

When 4RA struck his companion, he received a chest acceleration of 14 G at 120 ms (Fig. 73(c)). He glanced slightly to the front ahead of 4RW and on rebound struck his head on the seatback of seat 3R. He continued this circular motion about his hips to an almost original seated posture. His injuries were minor as the head blow on the seatback ahead was only a glancing blow; his belt kept him from contacting the seat across the aisle on rebound. Additionally, the rebound action of the 13-year-old's was less violent because of the reduced magnitude of bus acceleration as the bus commenced its skidout to a position of rest.

g. Seat 4L, a high back Superior seat (see Fig. 3 (c)), carried two 13-year-old passengers; 4LA had a type-3 restraint and 4LW was unrestrained. The diagonal strap passed over the right shoulder of 4LA and was anchored to the seatback. The 13-year-old in position 4LA did not have accelerometers but had tensiometers on his three-point belt combination. At 130 msec he loaded the lap belt to 150 lb, and the diagonal strap to 50 lb at 155 ms (Fig. 74(a)). The load on his diagonal cross-chest strap was augmented by his unrestrained companion, 4LW (Fig. 74 (b)). He received abusive lacerative forces to his throat as the belt passed across the neck below the right ear. He remained in his seat without appreciable movement to the right owing to the upper torso restraint. Thereafter, he rebounded to his left from behind the diagonal chest strap and remained in a slightly reclined leftward seated position. His injuries were

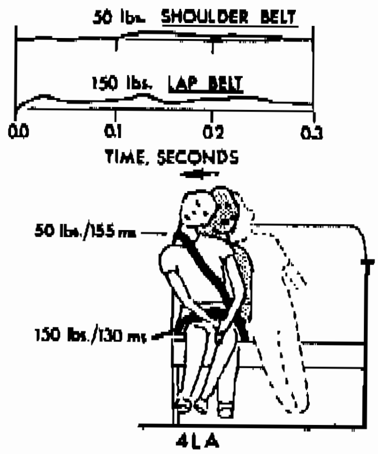

Fig. 74(a) - Diagonal belt loads augmented by impact of unrestrained companion

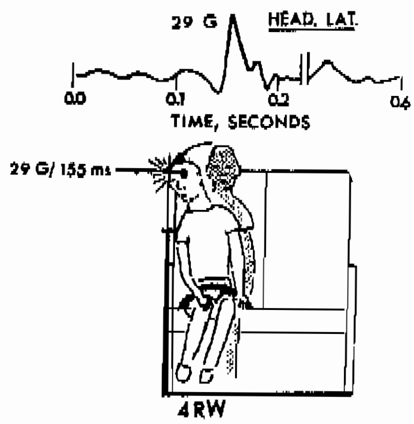

Fig. 73(b) - Before impacting window, this 13-year-old rotates his head 60 deg to his right, owing to his shoulder contacting bus side initially

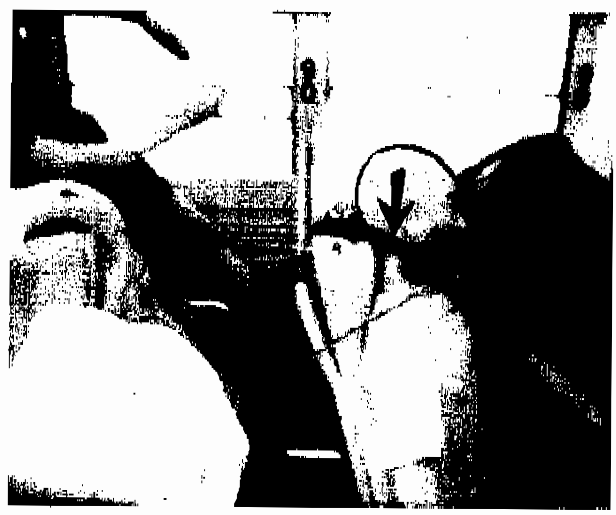

Fig. 74(b) - Loading by 4LW causes abusive contact to throat area of 4LA by diagonal belt

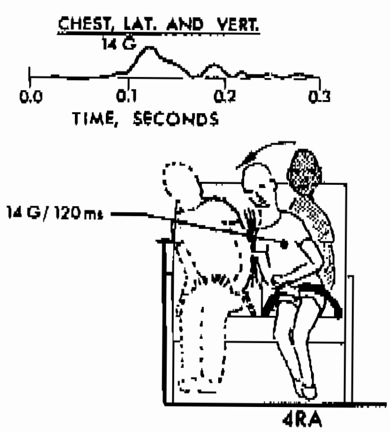

Fig. 73(c) - Restrained by a lap belt, this 13-year-old forcibly struck his companion

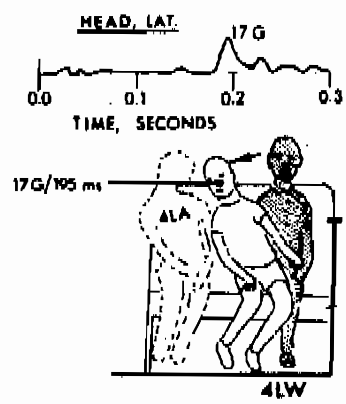

Fig. 74(c) - Unrestrained 13-year-old, cushioned by restrained passenger, struck head-to-head judged minor primarily owing to the effectiveness of this restraint configuration.

The unrestrained passenger in position 4LW was thrown laterally and contacted 4LA head-to-head with a 17 G head blow at 195 ms (Fig. 74(c)). The resistance of his belted companion caused 4LW to rotate with his left side coming forward to a position of rest across the lap of 4LA. Then he rebounded to floor with his head and shoulders remaining on his original seat position. His injuries were minor since his companion's restraint stopped lateral movements for both passengers.

h. Seat 5R, a conventional Superior seat (see Fig. 3 (a)), was occupied by two 13-year-olds, both unrestrained. The impact was slightly behind and below this seat position. At impact, 5RW was hurled violently to his right toward the striking car. He was pinned to the side of the bus by the abrupt acceleration and subsequently loaded by his companion, 5RA. His shoulder fractured the adjacent laminated window. Upon striking this fractured window with his head, 5RW received a 33 G head acceleration at 125 ms (Fig. 75 (a)). He rebounded toward the aisle but remained in a normal seated posture, one foot removed from his original seated position. His injuries were considered moderate for this exposure.

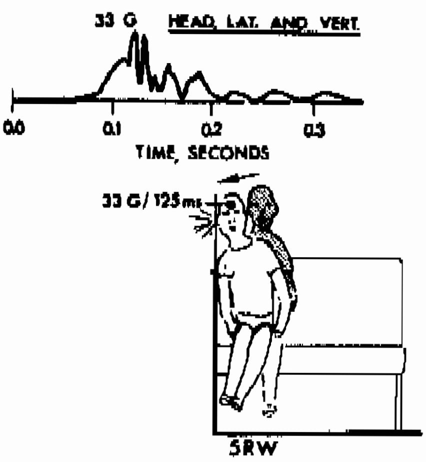

Fig. 75 (a) - Thirteen-year-old strikes his head against already fractured laminated side window

The aisle-seated occupant, 5RA, was hurled violently to his right and glanced off the left shoulder of 5RW passing in front of him. Thirteen-year-old 5RA received a 24 G chest acceleration when he struck his companion at 100 ms (Fig. 75 (b)). He continued his projectile-like movements to the right side of the bus then rebounded toward the aisle. Thereafter, he slumped rearward into the aisle with his buttocks on the inboard edge of his seat cushion. His injuries were diagnosed moderate because he received considerable cushioning from the window-seated passenger.

i. Standee 5S, a 13-year-old standing in the aisle between seats 5L and 5R, was thrown violently to his right and remained almost standing as he went in between seats 5R and 6R. He received an 11 G chest blow as he impacted the 13-year-old, 5RW, at 190 ms (Fig. 76). His rebound was almost as violent because he landed over the armrest of seat 5L in a jackknifed posture. His injuries were unexpectedly minor, considering his rapid movements. However, his actions were exceptional in that he cushioned his impact using another passenger initially and subsequently did not contact any seat frames on rebound.

j. Seat 5L, a conventional Superior seat with an armrest restraint (see Fig. 5 (h)), was occupied by two 13-year-olds, both unrestrained. On impact 5LA was partially restrained by his armrest and received a 12 G chest acceleration at 95 ms (Fig. 77(a)). He then rotated about his left hip, upward and around the armrest as 5LW attained an almost standing position behind him (Fig. 77 (b)). Occupant 5LA continued to his right and struck seat 5R across the aisle. He collapsed face down in the aisle and did not experience the rebound action of the bus. He received minor inferred injuries for his limited movements.

When 5LW shifted to his right he impacted 5LA who was momentarily stopped by the armrest. At 115 ms, 5LW received a chest acceleration of 16 G (Fig. 77 (c)). Then at

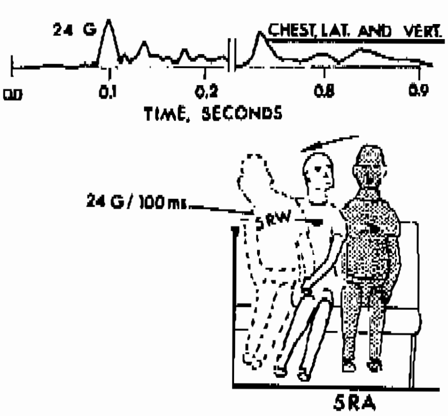

Fig. 75 (b) - Aisle-seated 13-year-old hurled violently to his right, glancing off to back side of window-seated passenger

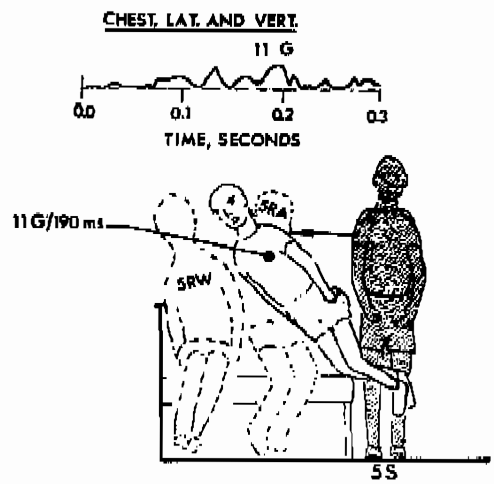

Fig. 76 - Thirteen-year-old standing in aisle pitched violently to his right in an almost upright posture

443 ms the 13-year-old 5LW was essentially in vertical flight. About 1 sec later he came down over his seatback with a rather severe dorsiflex action (Fig. 77 (d)). Thereafter, he came to rest arched over his seatback face up. His injuries were considered moderate to severe.

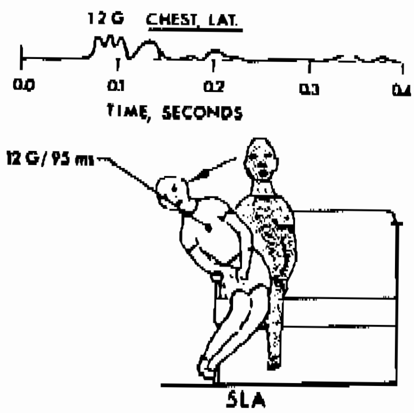

Fig. 77 (a) - Aisle-seated 13-year-old was partially restrained by armrest

Fig. 77 (b) - Thirteen-year-old 5LA rotating about armrest as companion 5LW rebounds vertically

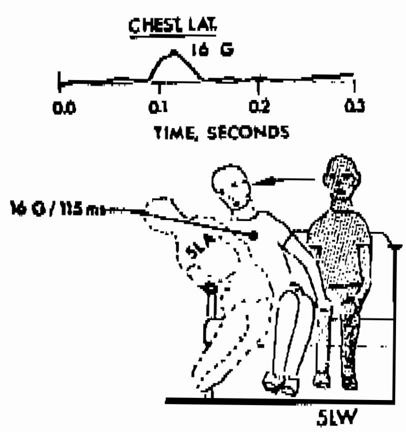

Fig. 77 (c) - Thirteen-year-old 5LW thrown against companion, who was stopped by armrest

k. Seat 6R, a Superior fiberglass seat (see Fig. 3 (b)), was occupied by an adult (No. 1, Table 5), and a 13-year-old, both restrained by a padded swing-bar positioned over their laps. The impact was essentially in line and slightly below this 6R seat position. The violent lateral movement to the right of the passengers in this seat that occurred for this swing-bar restraint also occurred for the gate-bar restraint on seat 9R. Both designs have similar features and offer virtually no lateral restraint. The adult, 6RW, was pinned against the side of the bus and received a 25 G head acceleration at 110 ms (Fig. 78(a)). This head blow fractured the upper laminated glass window shortly after his right shoulder penetrated the lower window glass panel. On rebound, the adult was reclined leftward but remained in the bench seat with his head extending into the aisle area. His injuries were inferred moderate considering his head impact with the window and in part because of his limited rebound.

During the initial phase of this impact, the 13-year-old, 6RA, was hurled against the adult and caused the bar restraint to be elevated to waist height as he rotated over the adult.

Fig. 77 (d) - Thirteen-year-old 5LW falls, striking his back against top edge of seatback 5L

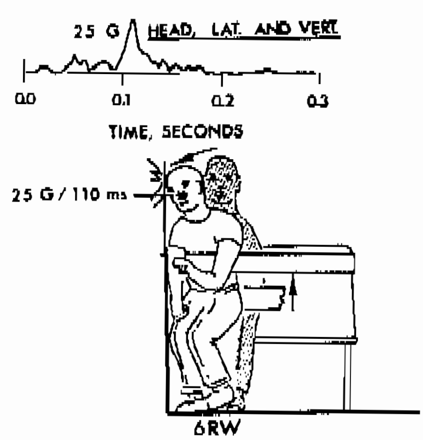

Fig. 78 (a) - Adult No. 1 fractures laminated glass side window by shoulder and head impact

Fig. 78(b) shows the maximum elevation of this swing-bar restraint that allowed 6RA to strike his adult companion violently. Thirteen-year-old 6RA received a 40 G chest acceleration at 115 ms (Fig. 78(c)). During the bus skid-out phase to the side, the acceleration reversed its direction causing the 13-year-old to be rebounded toward the aisle. He also sustained a vertical component of acceleration (Fig. 78 (d)). This lifting of the hinged swing-bar restraint allowed the 13-year-old 6RA to slide out from under this device. He rebounded across the bus, struck adult 6LW and landed on the floor in front of seat 6L. His injuries were considered severe from his initial impact with adult 6RW and his rebound across the bus.

1. Seat 6L, a Cox safety seat (see Fig. 3 (h)), had an adult dummy (No. 6, Table 5) restrained by a three-point shoulder-lap belt combination anchored to the seat. This passenger remained normally seated even though the lateral forces were directed in such a manner as to cause him to shift to the right. The retention of the cross-chest belt against the forces tending to move the passenger out from under the diagonal loop passing over his left shoulder, was attributed to the fact that the belt wraps around the shoulder to its anchor point for this adult size, instead of up to some higher point of attachment, which would allow the individual to slip out from under it more readily. Due to the seat design and the adult dummy's weight, he was pocketed approximately 2 in. into the cushion and this provided lateral restraint sufficient to develop his peak chest acceleration before his three-point belt system was completely loaded (Fig. 79 (a)). His two chest accelerometers recorded 11 G at 85 ms before the lap-belt tensiometer loads increased to 230 lb at 135 ms and the diagonal-strap load, 320 lb at 135 ms (Fig. 79(b). Even though adequately restrained, the adult was struck forcibly by 13-year-old 7LW who rebounded

Fig. 78(b) - Maximum elevation of swing-bar restraint caused by 13-year-old 6RA rotation and absence of a hold-down latch

Fig. 78(d) - Beginning of vertical movement from combination of rebound forces and bus skid-out near-upset

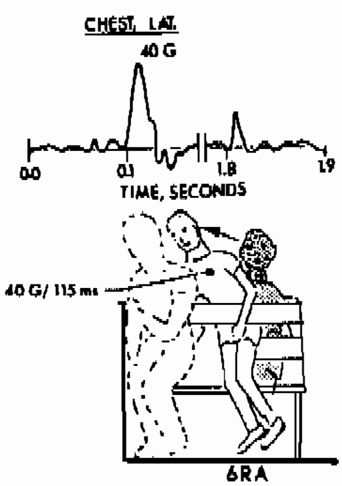

Fig. 78(c) - Thirteen-year-old is thrown to right under swing-bar restraint, striking adult

Fig. 79(a) - Shows effective restraint of adult in special three-point belt anchored to seat from the seat across the aisle, seat 6R. This impact caused 7LW to attain a peak chest deceleration of 8 G at 1830 ms. The inferred injuries for adult 6LW were minor considering the effective performance of this restraint system and the pocketing action of the seat design.

m. Seat 7R, a conventional Superior seat, was occupied by two 13-year-olds; 7RW was unrestrained and 7RA was restrained by a lap belt anchored to the floor. At the onset of impact, both passengers were violently thrown to their right. The passenger in 7RW shifted slightly forward as the restrained passenger in 7RA forced his torso against the back of 7RW, sustaining a peak chest loading of 25 G at 110 ms (Fig. 80 (a)). The occupant in 7RW received an 18 G head acceleration at 125 ms (Fig. 80(b)). This head accelerometer value was lower than impacts sustained by either passenger directly behind or ahead of him, because the emergency exit window latch failed and the window swung open. On rebound, 7RW was pitched so violently to his left that he actually passed sideways in front of the lap-belted 7RA (Fig. 80 (c)). He rebounded to the far side of the bus coming to a position of rest on the lap of the adult in seat 6L. His injuries were judged moderate owing to his head striking the window in the course of swinging open, and because of an unexpected uneventful rebound to the far side of the bus that brought no forcible contact with any injury-producing seat or bus structure. After rebound, 7RA came to rest leaning over into the aisle with his head against the seat across the aisle and his hips still restrained in his seat. His injuries were judged minor to moderate because of his relatively high chest deceleration.

n. Seat 7L, a conventional Superior seat, was occupied by two 13-year-olds, 7LA and 7LW, both unrestrained. At the onset of the impact, both passengers were pitched violently to the right across the aisle until they contacted seat 7R. Next, 7LW rotated head-first over the top of 7LA and at this time 7LA also rotated about the edge of the 7R seat cushion and slammed against the already vacated seat, sus-

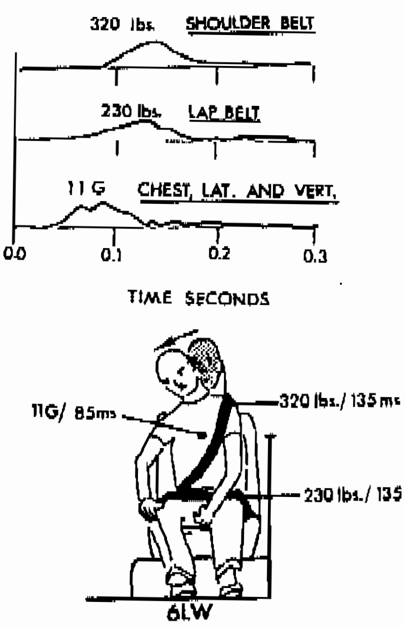

Fig. 79(b) - Adult pocketed in his seat back cushion developed peak acceleration 50 msec before three-point belt loads became maximum

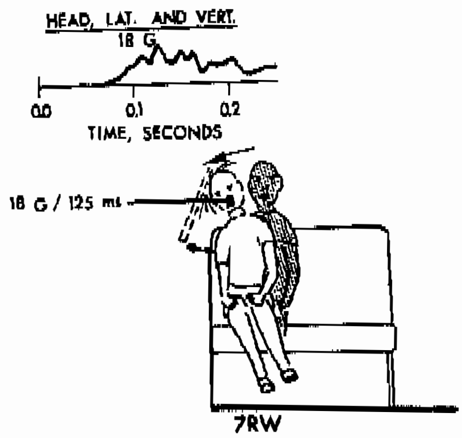

Fig. 80(b) - Thirteen-year-old received a peak head acceleration on striking window causing exit latch to fail

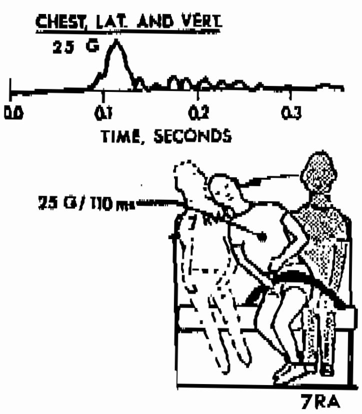

Fig. 80(a) - Although restrained by a lap belt, head and torso of 7RA is thrown against companion

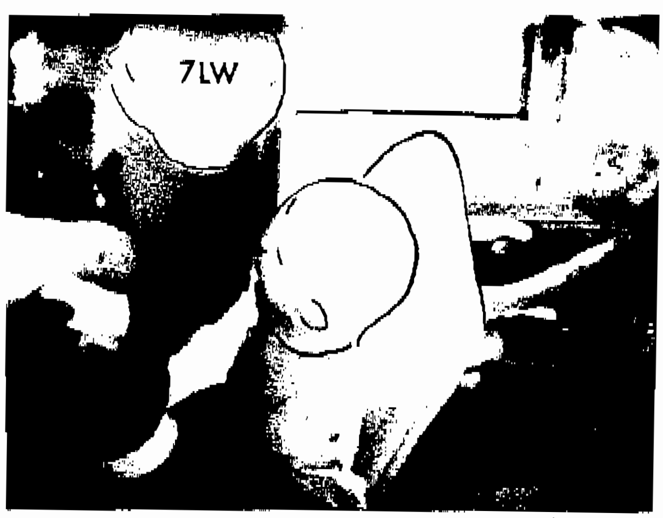

Fig. 80(c) - Violent rebound of unrestrained 7LW hurls him to opposite side of bus taining a 12 G chest accelerometer load at 220 ms (Fig. 81 (a)). When the bus completed its skidding spin-out, it rocked back onto the pavement and caused a shift of all passengers on the right side, throwing them violently to their left. Thirteen-year-old 7LA rebounded to his original seated position, facing slightly to his left. From there he fell forward to the floor between seats 7L and 6L. His injuries were judged minor based on his limited movement and low accelerometer values.

When 13-year-old 7LW impacted and rolled over the top of 7LA he sustained 6 G at 160 ms; this was not his peak acceleration as will be explained. After 7LW rotated over 7LA he was vertically accelerated toward the roof, with his buttocks striking the roof. While the bus was spinning to the left he fell on seat 6R and struck his tibia on the swing-bar restraint in a manner that would probably have resulted in a broken leg (Fig. 81 (b)). On rebound he was violently thrown to the far side of the bus where he struck adult 6LW and recorded an 8 G peak chest deceleration at 1830 ms (Fig. 81 (c)). His injuries were judged severe owing to the abusive contact he sustained with interior structures of the bus.

o. Seat 8R, a United Airlines seat (see Fig. 3 (i)), was occupied by two 13-year-olds; 8RW was restrained by a lap belt, and 8RA was restrained by a three-point shoulder-lap belt combination. The cross-chest strap passed over the left shoulder of 8RA and both restraint systems were anchored to the seat. As the impact occurred 13-year-old 8RW rotated about his lap belt into the tempered glass side window. He received a 63 G head blow at 105 ms (Fig. 82(a)). After impacting the glass he rebounded to a normal seated posture. His head injury was moderate to severe for this violent impact with the window.

Thirteen-year-old 8RA did not have head or chest accelerometers but did have tensiometers on his diagonal chest-lap belt combination. During impact, he loaded the diagonal strap to 130 lb at 135 ms and the lap belt to 310 lb at 130 ms (Fig. 82(b)). Thereafter, he slid out from under the diagonal chest strap and was flailed laterally to the right against the window-seated 13-year-old passenger. As with his companion, he was also rebounded to a normal seated posture. His injuries were considered minor owing to the

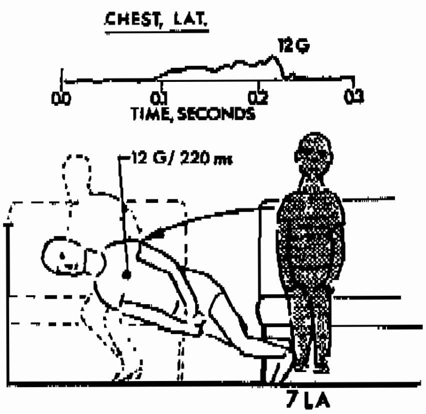

Fig. 81(a) - Thirteen-year-old 7LA impacts seat across aisle and then rotates about its cushion

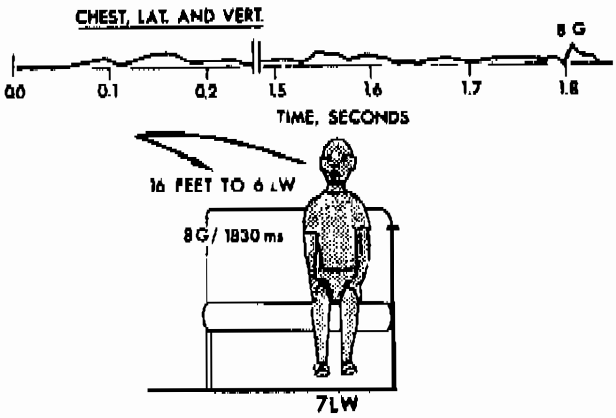

Fig. 81(c) - Thirteen-year-old 7LW received peak chest deceleration on rebound to left side of bus

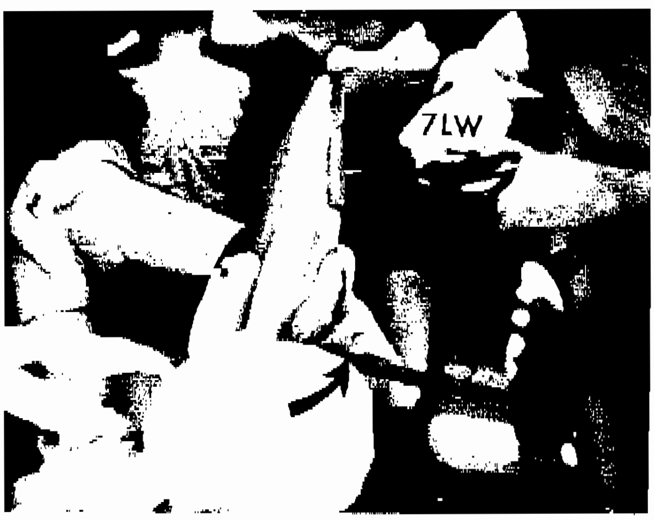

Fig. 81(b) - Thirteen-year-old 7LW falls from roof with leg striking swing-bar restraint on seat 6R

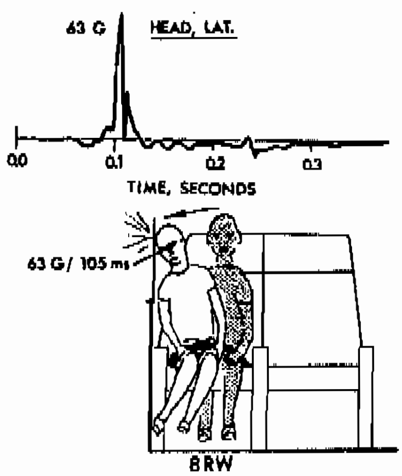

Fig. 82(a) - Restrained 13-year-old receives high head loading from tempered glass side window observation that his armrest provided more effective restraint than his diagonal strap.

p. Seat 8L was an ABC Unified School District seat and was occupied by two 13-year-olds, both unrestrained. At the onset of the collision, they were pitched violently to the right to strike the seat and passengers across the aisle in seat 8R. The 13-year-old 8LA received a 31 G chest acceleration at 110 ms (Fig. 83(a)). After rotating past the seatback, 8LA struck the chest of 8RA and then was vertically accelerated toward the roof. Occupant 8LA rebounded back to his seat and arched over the seatback in a torso dorsiflexed posture (Fig. 83 (b)). Subsequently, he was struck by 9LW from above and then he fell to the floor between seats 8L and 9L. His injuries were diagnosed as severe considering the nature of his exposures.

The unrestrained 13-year-old, 8LW, did not carry accelerometers. As he was projected violently to his right in an almost standing posture he impacted the back of his companion 8LA. This allowed 8LW to develop a vertical component and he deflected violently toward the roof of the bus (Fig. 83 (c)). Thirteen-year-old 8LW was airborne, and as shown in Fig. 83(d), headed toward the viewport, with some of the occupants of the bus also undergoing lesser vertical accelerations toward the roof. On his way down from the roof, 8LW assumed a horizontal position and impacted other passengers in the 8L-9L seat locations (Fig. 83 (e)). Thirteen-year-old 8LW came to rest slumped over seat 9L that had been vacated during the collision. His injuries were considered severe to fatal, considering his violent exposure.

q. Seat 9R, a high back Superior seat, had an adult (No. 7, Table 5) and a 13-year-old restrained by a gate-type padded bar device. At the onset of impact both occupants slid laterally to their right without deriving any significant restraining action from the gate-bar. The adult impacted the side of the bus and received a 24 G chest blow at 70 ms (Fig. 84 (a)). Adult 9RW then rebounded, flailing laterally to his left and received only vertical restraint from the gate-

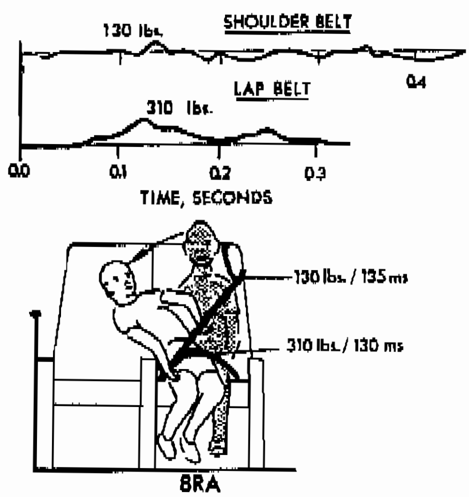

Fig. 82(b) - Thirteen-year-old partially loaded diagonal strap before he slipped from under it and then struck companion

Fig. 83(b) - Thirteen-year-old, 8LA, struck his own seatback a severe blow with his back

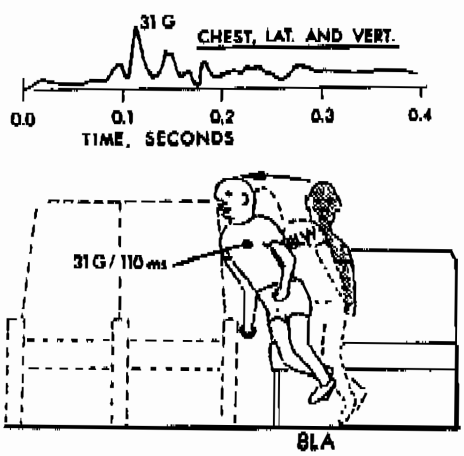

Fig. 83(a) - Thirteen-year-old pitched violently across aisle against seat and passengers

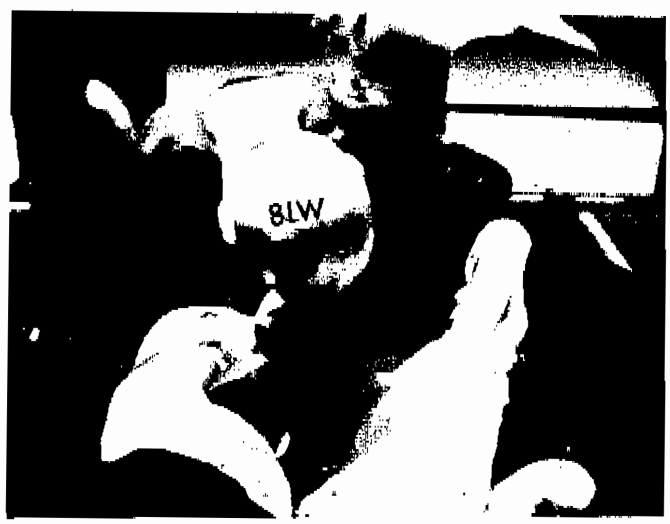

Fig. 83(c) - Start of vertical acceleration for 8LW, after striking companion 8LA bar. He returned to his pre-crash seated posture; his injuries were judged only moderate for this seat position.

Thirteen-year-old 9RA also slid to his right under the gate-bar restraint and impacted the back of adult 9RW. He received a 41 G chest acceleration at 80 ms (Fig. 84(b)). Thirteen-year-old 9RA thereafter rebounded to his left, but remained in his seat. He came to rest slumped over in the aisle. His injuries were considered moderate to severe owing to the high chest accelerations derived on impacting the adult.

r. Seat 9L, a conventional Superior seat, had a 3-year-old, 9LA, and a 13-year-old, 9LW, both unrestrained. They were shifted violently from their seat to the right and then received a vertical acceleration as the bus continued its skidding spin-out on the pavement. Three-year-old 9LA struck the 9R seatback across the aisle and sustained a 69 G chest blow at 115 ms (Fig. 85(a)). He then fell to the aisle floor between seats 9L and 9R and was struck from above by his companion, 13-year-old 9LW. After 9LW landed on top of him, 3-year-old 9LA came to rest under the seat he originally occupied. His injuries were judged severe to fatal because of his high chest accelerations.

When 13-year-old 9LW was pitched violently to his right,

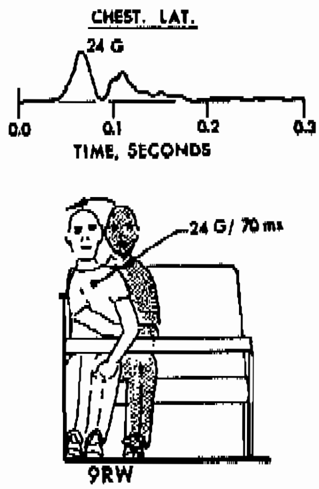

Fig. 84(a) - Adult slides sideways under gate-bar and impacts side of bus

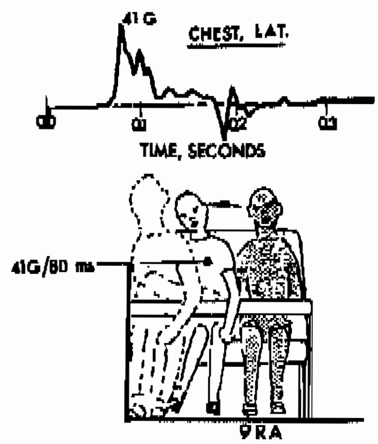

Fig. 84(b) - Thirteen-year-old slides sideways under gate-bar and forcibly impacts his adult companion

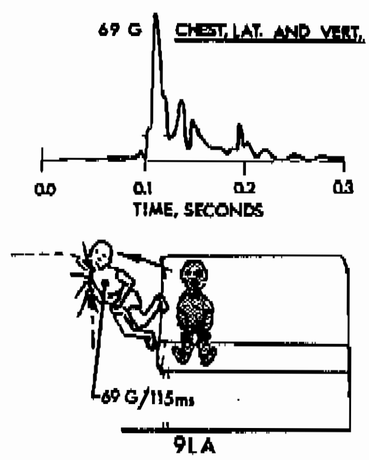

Fig. 85(a) - Three-year-old impacts seatback across aisle

Fig. 83(d) - Thirteen-year-old 8LW airborne and headed for roof view-port

Fig. 83(e) - Downward return of 8LW after contacting roof he impacted the seat and occupants across the aisle in seat 9R. He sustained a 32 G chest acceleration at 140 ms (Fig. 85 (b)). He then assumed an almost lying down position across the seat when he received a vertical acceleration toward the roof. Thereafter, he became airborne and was partially ejected through the roof port, head first. Later he rotated and came vertically downward, head first, striking 13-year-old 8LA who was arched over the back of seat 8L. He then slid from the seatback of 8R and landed on top of his companion, 3-year-old 9LA, on the floor, some 2 sec after initial impact. His injuries were considered severe owing to his airborne impacts and his impact with seatback of 8R. However, his initial impact with this seatback was cushioned somewhat by occupant 8LA.

3. Collision Performance - A 1965 GMC-Superior bus having a gross weight of 17,500 lb was positioned at the impact center with its right side perpendicular to the striking car and its rear dual wheels centered on the path of the striking car (Fig. 86 (a)). A 1966 Chevrolet Bel Air 4-door sedan with a gross weight of 4500 lb, traveling 60 mph struck the right side of the stationary bus, 23 ft behind the front bumper, in a manner corresponding to an intersection-type collision (Fig. 86 (b)). The lower edge of the bus sidesill was 18 in. above the pavement and the leading edge of the front bumper on the striking car was 22 in. above the pavement. The bus rear dual wheels were inset 4 in. relative to its apron side rail.

When the striking car contacted the bus, the car started collapsing and attained almost complete deformation at 50 msec after contact, with no conspicuous movement of the bus. At 15 msec time the two frame accelerometer units on the bus at stations 18 and 26 ft recorded 8 and 11 G, respectively. At this time, the bus side rail apron collapsed inward bringing the rear wheels into direct contact with the striking car; the frame accelerometers on the bus recorded peaks of 13 G at 55 ms for station 18 and 17 G at 51 ms for station 26. The average of 38 ms delay between the consecutive acceleration peaks for the bus frame oscillograph curves was also identifiable from studying the slow motion picture films; initial acceleration resulted from direct contact by the car with the bus side rail apron and delayed acceleration occurred when the heavy dual wheel assembly subsequently transferred the car's kinetic energy through the bus suspension to the bus frame. When most of the car occupants sustained their peak decelerations at 100 ms, the corresponding displacement of the bus at the rear was only 1-1/2 ft sideways from the position of contact. Although the car's frame attained peak deceleration of 26 G at 64 ms, the collapsing action of the car front-end continued until a maximum deformation of 3 ft occurred at 115 ms. The striking car, traveling 60 mph at impact, decelerated to a stop in 12 ft after contacting the bus.

During the rotation and broadside skidding of its rear, the bus violently rolled about its long axis onto its right side to an inclination of 30 deg with the left side attaining a vertical height of 5-1/2 ft off the pavement (Fig. 86 (c)). The drag coefficient of its tires with the pavement arrested its near upset and thereafter rocking back onto its wheels. The bus then rear-end skidded leftward from its original position in a clockwise direction approximately 50 deg. It reached a position of rest with its right rear dual wheels displaced

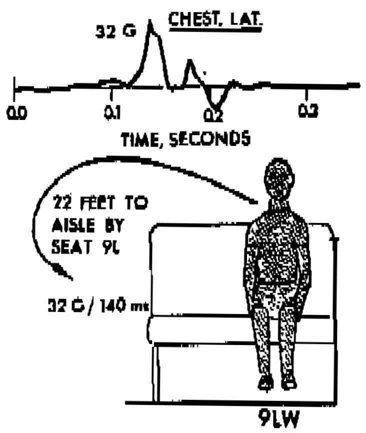

Fig. 85(b) - Window-seated 13-year-old struck passengers across aisle

Fig. 86(a) - Traveling 60 mph, a 1966 Chevrolet contacts right-rear dual wheels of 1965 GMC-Superior bus

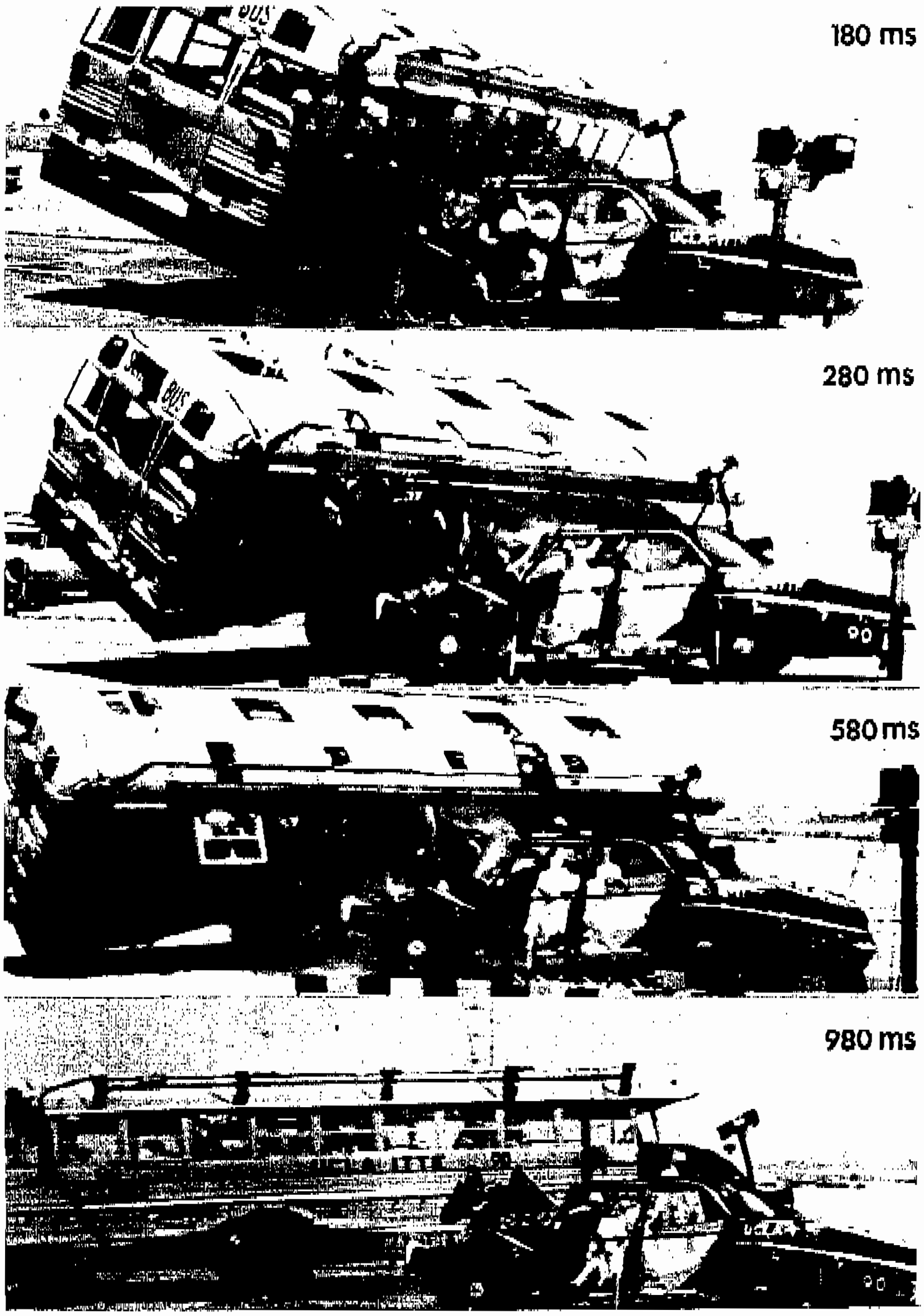

Fig. 86(b) - Vehicle dynamics of intersection collision

Fig. 86(c) - Near upset follows side impact

25 ft from its original position and 1 ft to the left of the path of the striking car.

The bus sustained the following damage: the roof at the rear of the bus was pantographed rightward 4 in. toward the impact; the differential and rear wheels shifted to the left 4 in.; the body moved to the left 1/4 in. relative to the frame, in the vicinity of impact. Three of the laminated side window glass panels fractured, two from passenger impacts and one from bus body deformation (Fig. 87). The left rear tempered glass window panel was ejected from the rubber molding by inertial forces.

The front-end of the striking 1966 Chevrolet collapsed

Fig. 87 - Collision damage to side of bus, with arrows depicting glass breakage

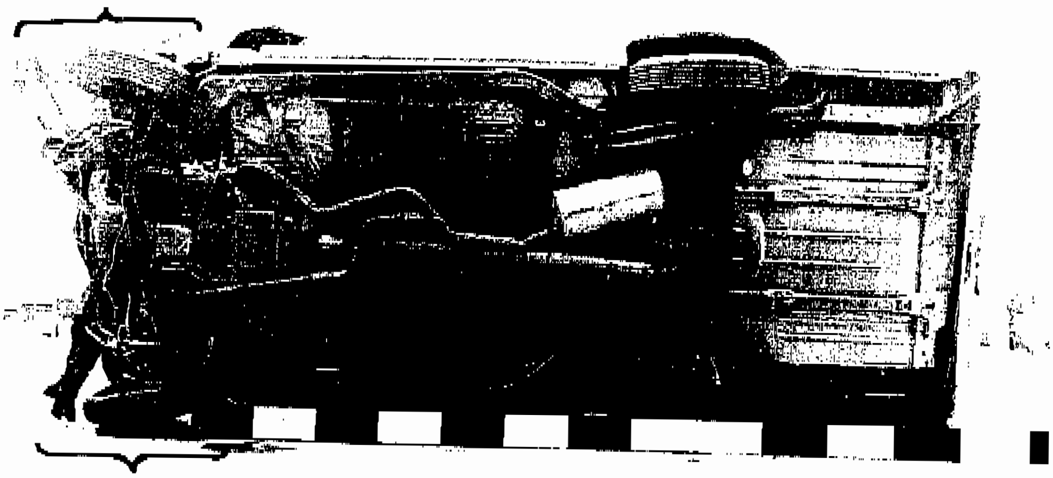

Fig. 88 (a) - Frame damage of 1966 Chevrolet after 60 mph impact into side of bus

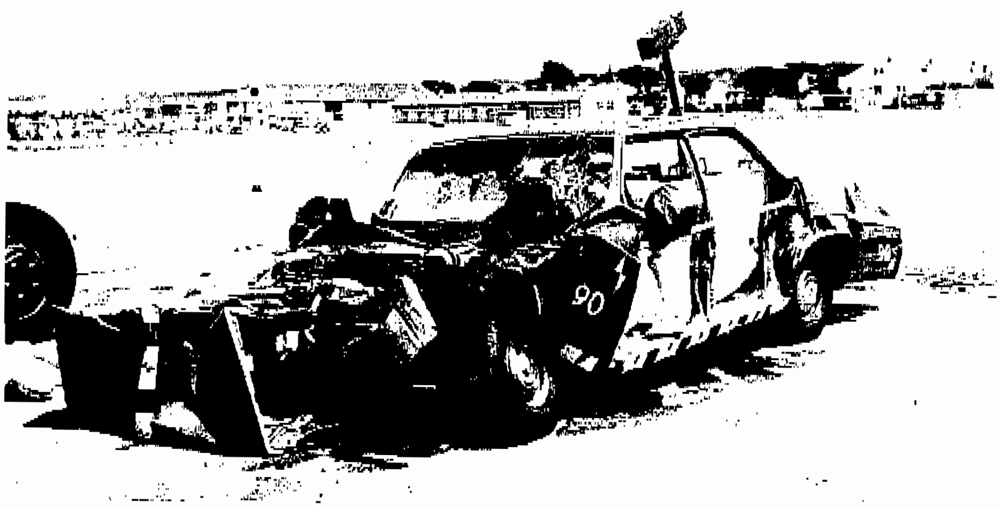

Fig. 88 (b) - 1966 Chevrolet collision damage

Fig. 88(c) - Fractured windshield on striking car

causing the engine and front wheels to be displaced rearward against the firewall (Fig. 88 (a)). The front seat adjustment rail failed at the left side and the rear seat cushion popped up rotating about its prong anchors. The steering wheel column was deformed to a vertical position. Longitudinal compressive forces buckled the right front door 6 in. outward at the window sill, but the latch remained engaged. Initial fracturing of the windshield was caused from penetration by the rear edge of the hood as the hood contacted the bus. The high-impact interlayer of the laminated windshield was ruptured at two points by the car hood and right front passenger but generally maintained its continuity, notwithstanding this unusually severe impact exposure (Figs. 88(b) and 88 (c)).

CONCLUSIONS

In the conclusions that follow, the authors wish to point out that these statements are based on specific observations, the majority of which should not be over-interpreted to form generalized conclusions. However, because of the wide variety of conditions evaluated, certain conclusions are broad, not because of a specific observation, but because of a multiplicity of observations that are correlative and that reinforce a specific conclusion, thereby providing foundation for some degree of generalization.

METHODOLOGY - The foundation of scientific inquiry is its methodology. It is the procedures devised for evolving information not commonly available and not readily verifiable. The confidence in the data subsequently developed is dependent on the reputation of the investigators and the soundness of their methodology.

1. The three collision experiments reported in this paper provide conditions sufficiently realistic and severe to adequately evaluate the relative merits of various school bus passenger protective devices and to identify other injury-producing factors. Inferred fatalities were generated by the head-on and side-impact collisions; severe whiplash injuries were inferred from the rear-end collision. These results indicate that a practical level of collision force was obtained for evaluating school bus passenger safety.

2. The three school bus collision experiments reported by this paper are representative of nearly all collision exposures by school bus passengers. School buses travel in a stream of traffic that presents them to essentially the same exposures as passenger cars. Their larger size provides some added protection when impacts involve passenger cars. Frequent passenger stops, however, increase their exposure to collisions. In addition to studying conditions for head-on, side-impact, and rear-enders, the upset type of collision was partially evaluated; during the side-impact experiment, the bus nearly upset and the vertical accelerations sustained were substantially more violent than skid-out roll-over accelerations, owing to their being collision induced. Seventy percent of all injury-producing accidents concern front-end, side, or rear-end collisions. To the extent that upset kinematics can be inferred from the near roll-over condition of the side-impact reported by this paper, this series of experiments evaluated the hazardous factors associated with 95% of school bus accidents.

3. The use of 3-, 6-, 13-year-old, and adult sizes of anthropometric dummies provided a practical evaluation of the effect of passenger size on school bus passenger collision safety. This size range embraces the 5th and 95th percentile of school age children, both as to height and weight. Additionally, the 6- and 13-year-old passengers provided well-spaced intermediate values. Finally, by using 13-year-olds to comprise 72% of the total bus passenger load, a midpoint size provided a standard reference for evaluating variables other than size that contribute to injury causation.

4. On a selective basis, variations in seat types, restraint types and related protective devices were evaluated under realistic conditions. Selection of a wide variety of protec-

tive devices was made to provide objective data useful in making performance judgments concerning units not specifically evaluated to these studies. The realistic characteristic of these studies was described in connection with the first two conclusions.

5. Comprehensive instrumentation was used in these studies to provide detailed specifics required for performance evaluation of school bus passenger safety. The use of 39 anthropometric dummies, 61 transducers and 33 photographic units represented the most comprehensively instrumented collision study conducted to date. The extensive photographic coverage of each human simulation during the entire collision event provided new insight into injury causation.

6. The utilization of instrumented trauma-indicating anthropometric dummies simulating passenger collision, induced movements, high speed motion picture color photography overlapping all collision movements, and full size vehicles providing realistic collision conditions, represents a most practical and reliable method for determining school bus collision performance. An evaluation was made of the several procedures in use by research groups in the U. S. and abroad concerned with accident trauma; the consensus of opinions concurred with this methodological approach (6). While it is true that fatal injury trauma varies greatly from individual to individual, and this range is not understood with any great degree of precision, nevertheless, the procedures used in this study provided an exacting basis for determining the relative performances of safety devices. It is more important to learn which passenger environment provides the most practical and effective improvement to passenger protection than to delve into refinements concerned with the specific traumatic conditions required for permanent injury or death. Progress with the safe transportation of humans will always be a relative matter -- there will never be a practical arrangement for transportation that guarantees no injuries.

7. The presence of double or higher order variables was controlled through appropriate methodology to ensure reliability of findings. In this study, the techniques of redundancy and replication were used as control devices. For example, the distribution of the standard reference seat (conventional Superior) and standard reference subject (the 13-year-old) to several remote locations in the bus provided redundancy to control against variations in impact intensity and direction for different locations. The seating side-by-side of two or more identical dummies with identical restraints in identical seats at essentially the same bus location provided replication as a means of establishing the level of reliability of observations.

COLLISION PERFORMANCE - The susceptibility to passenger compartment encroachment, the comparative resultant accelerations, the influence of vehicle components on injury causation, and the preservation of passenger compartment integrity while undergoing moderate levels of impact acceleration are examples of vehicle collision responses characterizing collision performance. In the ordinary use of a vehicle, these deficiencies do not usually manifest themselves and frequently escape observation by accident investigators owing to the transient nature of these deficiencies or the investigator's lack of familiarity with levels of collision performance. Adequate collision performance provides the passenger with a protective shield from the crashing structures of the primary impact; adequate passenger compartment safety protects the passenger from the injury-producing forces of the secondary impact, the one in which the passenger may be hurled against the compartment interior or ejected. This section relates to the former and the following section, to the latter.

1. All heavy vehicle designs and more particularly those classified as buses, must include provisions for collision-resistant structure at the passenger car bumper height as well as at the heavy truck bumper height. The rear bumper of the 1965 GMC-Superior Coach bus was not effectively contacted by the front bumper of the rear-ending 1960 Plymouth. This striking car wedged under the bus until the bus's rear bumper had reached the windshield. Buses and other heavy vehicles must have bumper structures directly opposing all vehicle bumpers to prevent the dangerous overriding action of trucks and critical underriding action common for collisions with passenger vehicles. In the head-on collision, the gross overriding characteristic of the 1944 Mack-Superior school bus allowed it to deeply penetrate the passenger compartment of the 1965 GMC-Superior Coach bus. The instrument panel of the 1965 GMC-Superior bus was thrust 2-1/2 ft rearward into the passenger compartment, pushing the driver rearward from his normal seated position. Economical considerations necessitate the mixing of vehicles with a forty-fold weight difference into common streams of traffic; not much can be done to correct this abusive mismatch except to prevent overriding actions that deprive the smaller vehicle of impacts directed to their stronger structural components and overriding actions by heavy vehicles that compromise the bus passenger compartment unnecessarily.

2. Bus design should insure that the passenger compartment is securely attached to the frame of the bus by appropriately sized shear bolts at frequent intervals from front to rear and along both frame members. There was a 17 in. displacement between the frame and the bus body for the GMC-Superior Coach bus during the head-on collision. This displacement was caused by slippage between the bus body and frame anchored clamps, which occurred because there were insufficient shear bolts acting to prevent this displacement. The exceptional length of school buses corresponds to a tubular structure which, if not properly designed, will develop compression bellows at the forward section of the passenger compartment during front-end impacts. This buckling tendency was primarily related to the lack of proper attachments for the bus body to the frame allowing the body to shift longitudinally relative to the frame. Collapsing of the passenger compartment applies violent collision forces directly to the driver and passengers, even when they are adequately restrained. It is for this reason that the structural integrity of the passenger compartment must be maintained.

3. The adverse performance of bus steering wheel assem-

blies during front-end collisions corresponds to that of other pre-1967 vehicles. In the 30 mph head-on collision between two moderate sized school buses (17,500 lb each), the 1944 Mack-Superior bus overrode the frame of the 1965 GMC-Superior bus with the result that the steering column of the old bus remained fixed while the steering column of the new bus thrust violently into the driver's chest and face. Steering column intrusion into the passenger compartment for buses was similar to that of the passenger vehicle steering column performance, as identified in Ref. 3. During the initial phase of collision, the steering wheel rim pierces the abdominal area, deflecting the upper rim into the face as the steering column crushes into the chest and is deflected upward either under the chin cutting the throat or along the face carving nose and eyes as it sweeps upwards. This abusive action is even more severe for bus and truck drivers than for drivers of passenger vehicles owing to the significantly stronger structure common to these heavier vehicles. Design improvements currently under consideration for passenger vehicle steering assemblies are:

1. Prevention of a steering column from being thrust rearward into the passenger compartment during impact.

2. Increases in the size of the hub so that impact forces are distributed over a more favorable area of the body.

3. Limitation of axial forces required to deflect the steering wheel rim, relative to the hub.

These design improvements should be included in future design specifications for buses and other heavy vehicles.

4. The new laminated glass having a high-energy interlayer with controlled adhesion, represents a substantial improvement for collision performance of windshields. The 1966 Chevrolet Bel Air traveling 60 mph, striking the side of the 1965 GMC-Superior school bus, sustained only small punctures in the windshield interlayer, representing a very significant improvement in the collision performance of laminated glass windshields when contrasted with pre-1966 windshields undergoing comparable exposures. No passenger head entrapment occurred under collision conditions that would have caused highly injurious exposures for windshields before this improvement.

BUS INTERIOR - The school bus, fundamentally, is a "king-size" passenger car. With minor exceptions, the recommended practices relating to passenger safety developed by the Society of Automotive Engineers, the automotive safety standards evolved by the United States General Services Administration, the Federal Motor Vehicle Safety Standards published by the Department of Commerce, as well as those standards currently under development, should be applied to buses, with very little revision required.

1. Tubular struts, protruding hand grips and similar protruding rigid structures should be eliminated. Inside the bus, vertical tubular struts running from floor to ceiling used for bracing the modesty panel at the entrance, as well as the kick-panel behind the driver and in front of the first seat, should be eliminated owing to the difficulty of making these tubes strong enough to be functional, slender enough not to be an obstruction to vision, and collapsible enough not to cause head and other body injuries for the passengers that may be thrown against them. Kick-panels and similar structures should be floor anchored and provided with a measure of human body impact protection comparable to the properly constructed well-padded high back seat. The first passenger in a bus is in a position of substantial vulnerability in comparison with the other passengers, and his safety should not be further compromised by an obviously injury-producing structure immediately in front of him.

2. Thin padding, less than 1/2 in., applied to tubular struts and similar rigid structures serves little practical value. Design criteria for passenger protection should conform with the standards referenced at the beginning of this section. Fixed objects of this nature should either be recessed, eliminated, or redesigned, rather than attempting to compensate errors of design with superficial and ineffective padding.

3. Force amplifying structures should be relocated, recessed, or eliminated. As with passenger vehicles, angular sections in the bus passenger compartment as well as small radii surfaces represent injury sites that should be eliminated. For example, in the head-on collision, the 3-year-old sitting in the window seat immediately behind the driver, although restrained by a lap belt and otherwise riding out the crash rather well, did strike his head against the rearward protruding heater enclosure at the left side panel of the driver's section, sustaining a severe head impact. This angular protruding section is readily susceptible to redesign, thereby minimizing injuries for any passenger or the driver thrown against it. During the head-on collision the handle-lever assembly used to open and close the door adjacent to the driver shifted outward into the path of the standee and caught him in the waist as he was thrown forward, developing gross intrusion to his torso causing him to be doubled over before striking the front of the bus compartment.

4. Glass should remain in place, even after sustaining head or shoulder impacts. The practice of having side windows pop out, or partially pop out when hinged at the top is not advisable. During a crash, glass serves to keep passengers' heads and limbs from being flailed through windows where they may encounter a far more abusive environment.

5. Window-glass impact performance of buses depend on many factors; the relative performances of laminated and tempered glass for these collisions should not be compared without cautious consideration of the varying circumstances of exposure. Although side-glass geometry was constant, passenger seat position was not; proximity of impact, passenger size, angle of impact with glass, position of passenger relative to the window frame and roof pillar, and the presence of collateral factors such as passenger-shoulder induced stresses that pre-fracture glass before head contact, indicate some of the reasons why direct comparison of head deceleration values and fracture data cannot be made without consideration of related factors.

SEATING UNITS - Seat designs ranging from frameless air seats to nonpadded hard fiberglass shell seats with tubular frames were evaluated; some seats had no head support, no lateral support and no padded backrest (to protect passengers from the rigid knife-like seatback) while some were safety seats, designed and shown substantially to protect the passengers from abusive collision forces, regardless of direction. Properly designed bus seats provide an inner protective shield around their precious cargo while also compartmentalizing the passengers to reduce the possibilities of their interacting with each other during all but the most devastating of collisions. In general, seats in buses are the initial and very frequently the only structure contacted by passengers during collision. Special attention to their construction can contribute very markedly to bus passenger safety.

1. Low back seat units, seatback height less than 28 in., greatly increase chances of injuries during school bus accidents. Seats most commonly encountered in school buses have seatback heights ranging from 18-20 in. These low back units provide no head support except for very young school children and leave the passenger in an extremely vulnerable condition when the vehicle is rear-ended. In addition, for the head-on collision, the lap-belted passenger, even the 3-year-old in some instances, pivoted about the belt and struck the top horizontal edge of the low seatback ahead in a manner that applied extremely dangerous forces to the face, neck, and chest of the individual.

2. School bus seat anchorages and seat cushion fasteners should not fail from forward decelerations under 30 G and should comply with other related performance criteria that become a part of the Federal Motor Vehicle Safety Standards. The fact that most seat anchorages held during the UCLA 30 mph head-on collision is attributed to the following factors: most of the seats were special units and required individualized techniques to anchor them (UCLA engineers made certain these anchorages would sustain the contemplated impacts so that evaluations of restraints, etc., would not be compromised). The fact that approximately half of the passengers were restrained by systems generally independent of the seat reduced the inertia forces sustained by these seats.* The principal factor is that the bus passenger compartment was subjected to a peak deceleration of only 12 G in the head-on collision because of the bumper mismatch and shifting of bus body-to-frame anchorages. This unusually low deceleration was adversely achieved by the front passenger compartment being crushed from bumper mismatch.

3. Seats not designed to accommodate the added stress of multiple lap belts attached to the seat can be retrofitted with a satisfactory structure to accomplish this modified performance. This modification should not be accomplished unless the seatback height is at least 28 in. It was found that bus seats were not designed to withstand multiple loads from belts attached to the seat. Therefore, a tubular structure with a horizontal belt anchorage manifold was installed in such a manner that it would not impose a trip hazard or complicate cleaning problems. This device was evaluated under collision conditions and effectively carried the restraining loads of these belts through separate floor attachments without adding stresses to the existing seat anchorages. It should be pointed out that retrofit of low seatback units with safety belts is strongly discouraged because low seatbacks greatly intensify and channel impact forces to the face, neck, and chest for passengers thrown against them; these installations also intensify whiplash injuries, owing to the absence of effective shoulder and head support.

4. Seatback strength should include allowance for passengers thrown forward against the backrest. Even when a bus is provided with lap belts, not all passengers will use them. Additionally, lap-belted taller persons will flail their heads and chests against the seatbacks ahead of them during collisions. School bus seatback designs should be of sufficient strength to withstand without failure a 30 G deceleration in the forward direction (head-on) and a 20 G acceleration in the forward direction (rear-end); in addition, a 3000-lb force applied to the backrest longitudinally forward at 16 in. above the seat level for the 30 G deceleration exposure and a 2000-lb force, similarly applied, for the 20 G exposure except in the reverse direction.

5. Elastic rebound of seatbacks increased the chances of passengers sustaining multiple impact injuries. On rebounding from his head impact with the Plymouth windshield, during the rear-end collision, the front seat passenger contacted his seatback with sufficient force to rebound him into the now shattered windshield, striking it forcibly for a second time. This rebound into the windshield would not have occurred for a lap-belted passenger and the severity of his first contact would have been significantly less.

6. Plastic deformation of high seatbacks reduce lap-belted passenger's rebound towards seat ahead in rear-end collisions but greatly increase chances of injury for passengers thrown against them. During the rear-end collision, high backed seats offered adequate support for the head and torso and when the seatback yielded rearward approximately 20 deg, rebound was diminished for the lap-belted passenger. A disadvantage, however, of the low seatback being forced into a semi-reclined position is that the passenger to the rear is more likely to strike it on rebound. This rebound hazard would be intensified if a front-end impact occurred, following the rear-end collision.

7. For the moderately severe collision exposures reported in this paper, it was established that a well-designed safety seat would protect passengers from sustaining more than minor injuries. It is apparent that far safer seats can be provided on the basis of performance guidelines established by this paper. School districts quite properly specify for purchase the least expensive, most durable seats available. However, considering that school buses are used more than a decade, a higher initial investment that provides greatly improved safety and comfort is money well spent.

An adequately designed, properly structured and anchored high back contoured seat (28 in. or higher, well-padded back-

*Only the driver was restrained in the 1944 Mack-Superior bus and many more of its seats failed during the head-on collision.

rest) provided with well-padded armrests, harness or a lap belt, built into the seat unit with retractable, inertial-lock mechanism, represents the essential features of a safety seat that provides sufficient protection for a bus passenger to sustain, with probably no more than minor injuries, a 30 mph head-on or 60 mph side and rear-end collisions, as reported in this study. The crash performance of seats designed as safety seats represents a decided improvement over conventional seats. This was borne out in a prior series of experiments designed to evaluate the Liberty Mutual safe-seat configuration. (5) As demonstrated by the Cox 6LW contour safety seat with head support and built-in cross-chest lap-belt restraint, the individual from child to adult size can ride out a severe rear-end collision in an uneventful manner. This seat was equally as effective in protecting its occupant from the side-impact forces and the authors are confident that if the rear anchorages for this seat had been adequately attached for the head-on collision experiment, the occupant would have been protected against injury-producing forces for this exposure as well.

8. Seatback height for all school buses should be at least 28 in. While it may be argued that school buses bought exclusively for pre-school activities or exclusively for grade school use should not be required to include high back seats, the purchaser may have no control over its use for special school functions or over its use after it is sold. In rural areas, it is not even acceptable to have part low back and part high back seating within a given bus even though one bus may carry children from the 1st through 12th grades. The adverse interaction of passengers from high back seats thrown against low back seats is clearly documented in this paper.

The high back Superior 26 in. seatback allowed the head of the 13-year-old to contact the top edge of his backrest during the rear-end collision. High back seats (28 in. or more) greatly contribute to the compartmentalization of passengers thereby reducing the chances of injuries sustained by passengers being hurled against one another, regardless of their size.

9. Seat belts recommended for safety seats.* These bus experiments, the many actual school bus accidents investigated by the authors, the many types of collision experiments conducted during the past 16 years by the authors and investigations by others, clearly establish the value in passenger protection of lap belts when used with high back seats. The greatest single contribution to school bus passenger collision safety is the high strength, high back safety seat. Next in importance is the use of a three-point belt, a lap belt or other form of effective restraint. These restraints can be added to the safety seat at very little added cost and their presence provides the continuity needed for proper training of youth concerning habitual use of restraints when riding in any vehicle.

10. Low back seats (backrest less than 28 in.) common to school buses built in 1966 and earlier should not be retrofitted with lap-type safety belts, unless the low backrests are replaced with adequately designed high backrests. During front-end impacts and following rebound from their seatback for rear-end collisions, the lap-belted passenger pivots about his belt and slams his head, face, and, if tall enough, his chest into the seatback ahead. The low back seat presents dangerous surfaces to the belted or unbelted passenger hurled forward against it during collision. In addition, exposure to serious back and neck injuries results when passengers in low back seats experience a rear-end collision. Forces to the passenger as a result of a rear-end collision are increased if a lap belt is worn because it secures the hips thereby intensifying the fulcrum-like action of the seatback forces.

11. Seatbacks and armrests should be designed using well-padded, broad surfaced metal frames designed to provide the required strength and attenuate head impact forces in accordance with the performance specifications of the Federal Motor Vehicle Safety Standard No. 201, S 3.2. As stated in a prior conclusion, within the school bus passenger compartment, seats are the most important single contribution to collision safety, second to none. The seat requires a strong frame to prevent seat inertial forces and free-body impact forces from breaking it free from its mounts. This strength must be designed into the seat so that small surface areas and rigid structures are not encountered during "bottoming-out" type head impacts.

12. The narrow, thin padding covering rigid tubular structures such as the tops of seatbacks, and so forth, represents an unsatisfactory solution to the problem of an inadequate design. Reference to prior discussions in this section sets up guidelines for eliminating these injury-producing structures.

13. Seats should not be provided with rigid protruding structures such as handgrips, handrails and similar injury-producing fixtures. This conclusion is in keeping with prior conclusions and relates to any structure against which a passenger can be thrown.

14. The air seat did not impress the authors as being a practical approach to school bus passenger protection during collisions. The inflated seat, the Martin Air seat tested in this crash series, represents an interesting variation of passenger protective devices. The air seat is readily deformable and could minimize injuries of passengers thrown against it; however, this readily deformable seat in the head-on collision carried the disadvantages of providing a very inexacting restraint to its occupant as well as an inadequate restraint to those passengers thrown against it. Also, during the rear-end collision, no real back support was provided, although the head and back were kept in a good postural relationship as the entire body of the adult flailed into a fully reclined position, bringing the head hard against the knees of the passenger to his rear. From this reclined position, a passenger could readily slip from under the lap belt and become injured as though he were unrestrained. The air seat provides no significant restraint in the lateral direction against the forces of a side impact even when the occupant is con-

*Safety seat, see discussion for conclusion No. 6 for description.

strained by a lap belt, owing to the ease with which the air seat deflects sideways, allowing the passenger to contact the side panel and window of the bus. Without a safety belt, the air seat may bounce its passenger into injury-producing structures. The durability of an inflated seat is certainly questionable and particularly in the presence of school children who would find it difficult to resist the temptation of puncturing the seats.

15. School bus seats at the time of this study are grossly inadequate for protecting passengers. This conclusion is adequately documented by the preceding conclusions and corresponding discussions.

RESTRAINTS - A list of passenger-protective devices would generally show restraints at the top, with the seat a close second. The reason passenger seats are regarded as more important than individual restraints for the protection of school bus children is the close proximity of the occupants to school bus seats as contrasted to passenger car seats. The compartmentalization provided by school bus seats, if they are high back seats, serves as a very valuable constraint for all horizontal directions of impact. The performance of safety belts and harnesses in this study followed the lines clearly established in prior experiments. (3-5) Properly designed restraining devices direct collision forces to the strong parts of the body in a manner least likely to produce injuries.

1. Lap-type safety belts would provide substantial additional protection to the school bus passengers, seated in high back seats that have efficient padding on the rear panels of its backrests. The use of a lap belt with a low seatback exposed passengers to extreme hazards of the seatback acting as a fulcrum across the face, neck, or chest when they are jackknifed across the horizontal surface of the seatback ahead of them. Accordingly, where seats with low seatbacks are installed, little benefit, if any, will be derived from use of seat belts for the typical front-end impact. In the head-on and side-impact experiments the passengers flexed at the hips, pitching their heads and upper torsos forward or to the side, striking objects within reach.

For the rear-end collision, lap-belted passengers responded slightly differently from unbelted passengers, but this factor was not nearly as important as was the height of the seatback. Lap belts should not be used for low seatback units because their use substantially increases the highly adverse forces to the spinal column resulting from whiplash and they virtually assure severe head or neck impacts with the low backrests ahead.

In the absence of armrests, the lap belt does provide some hip restraint against sideward movement, thereby reducing the forces that a displaced passenger may apply to a companion seated beside him during a side-impact collision. It is strongly recommended that seat belts not be installed in school buses unless higher seatbacks are also included with appropriate padding applied to all sides of the seatback.

2. The cross-chest lap-belt combination when properly fitted provides significantly more passenger protection than does the use of only a lap belt. A comparison was made between performances of three-point and lap belts in the prior conclusion. In contrast with no belt, the three-point belt allows its wearer to sustain but one-third the crash forces received by an unrestrained passenger of the same size seated beside him. More importantly, the forces are directed by the three-point restraint system to strong parts of the passenger's body in a generally noninjury-producing manner, as contrasted with head and chest injuries commonly sustained for unrestrained passengers on direct impact with the structures around them.

3. The cross-chest lap-belt combination restraint is not recommended for use in school buses. As has been found in prior intersection type collisions where the cross-chest belt has an anchor point to the rear and substantially above shoulder level, the belt passes across the throat in a manner which, during side-impact accelerations, applies injury-producing forces of a lacerative nature to the throat; the forces may be sufficient to cause neck injury and back injury as well. The cross-chest belt should have an anchor point, preferably built into the seat at shoulder level to prevent the belt from passing diagonally across the neck.

Passengers rebounding from the school bus side-impact collision slipped from behind their cross-chest belts, except where the upper anchor point was at their shoulder level; this left the passenger without upper torso restraint should any subsequent collision stresses develop, such as an upset.

During the head-on collision, passengers with higher-than-shoulder level anchor points showed evidence of asymmetrical restraining forces that force their upper torsos to rotate from behind the belt. Thus, an important condition with the effective use of the cross-chest lap-belt unit is to make certain the anchor point is at shoulder level in order to reduce the tendency for the cross-chest belt to injure the necks and to provide a more effective restraint for the head and upper torso against lateral and forward collision forces.

Considering the height variation shown in Table 5, representing the size variation common to school bus passengers, it is apparent that adjustments would have to be provided over a wide range in order to accommodate this requirement. The anchorage ladder necessary to achieve this would provide a rigid structure at shoulder and head level that could be struck by all but the shortest child. The potential gain in the use of cross-chest belts for school bus passengers is too questionable to warrant their further consideration. This position in no way should be construed to extend to passenger vehicles where proper anchorage heights can be obtained that would seldom need to be changed. The smaller passenger car does not provide nearly the passenger safety that is common to buses, making it more important to seek the best possible restraint.

4. Seats having strong but well-padded armrests provide important lateral constraint. Although seats with armrests are a little more difficult to enter, sit down in or exit from, they are more comfortable owing to their additional body support. During the bus side-impact experiment, it was observed that armrests provided a significant improvement in passenger safety by first, preventing individuals from being

ejected from their seats laterally to strike passengers across the aisle, and second, preventing the larger passenger from crushing against a smaller passenger who may be seated in his path. As a minimum requirement, each school bus seat should have an armrest on the aisle side.

5. The restraint bar provides acceptable restraining action against front-end type collisions but does not provide restraint against the lateral forces of a side impact. During the head-on collision, passengers jackknifed over the swing bar in a manner similar to lap-belted subjects. In a side impact the hips of passengers seated together "shift" in unison, with the lead-passenger sustaining the full crushing forces of his companions; the restraint bar does not restrain passengers individually against sideward movement. To be effective for rebound in a rear-end collision, the bar should have a positive latch to fix its position just above the passenger's lap, provided this unit is mounted to a seat with a high backrest.

6. The restraint bars of the type tested in these experiments are not recommended for school buses. The swing bar was positioned next to the lap, tending to prevent passengers from shifting forward during a front-end impact but was not considered a satisfactory restraint, particularly for side impact. In addition to allowing the passengers to shift to the right without restraint from the swing bar, this bar, because of its supports, presents a rigid structure, thereby increasing the chances of injury for a passenger flailed against the firm strut that supports the padded bar.

The restraint bar applies a restraining force to the lap-abdominal area. The thickness of the bar, in order to provide adequate force distribution, may develop back injuries and apply forces to the viscera which could be very injury-producing. There is also a possibility that school children would be injured when the bars are thrown up or thrown down by an overly energetic school child. Accordingly, although this device could be designed to provide some measure of protection for the forward impact, it is of little value in a side impact and for the reasons described above, is an impractical solution, considering the advantages of seat-anchored lap safety belts.

7. The air bag provides good impact attenuation for passengers thrown against it; further research is recommended before a decision can be made concerning its practicality for school buses. The air bag continues to be an interesting, somewhat effective impact moderator. The air bag provides a means for moderating impact forces to the passenger thrown against it. There are certain practical problems associated with its use, as typified by the following:

a. Except under exceptional circumstances, their performance is no better than properly structured, properly padded high back seat units.

b. The device for practical purposes would have to be stored in a folded condition with an external covering relatively impervious to the meddling nature of the school child passengers.

c. The device would have to be rapidly inflated during the onset of collision forces and this precludes the possibility of a centrally stored reservoir of compressed air or gas owing to the time lag common to such manifold systems. The cost of electrical operation of individual air valves, even of the simple life vest cartridge configuration, makes such an installation impractically expensive, both as to initial installation and the frequent maintenance.

d. Inadvertent firing of these devices could produce injuries, particularly if the children were in the process of boarding or leaving the bus when such inadvertent firing occurred.

e. Immediately following a collision, these devices would pose a serious impedance to an expeditious evacuation of injured and unconscious children owing to the tremendous volume they displace when fully inflated.

f. Unless the air bag is provided with a device limiting the build-up pressure during a passenger impact, it performs as an almost perfectly elastic restraining system having the serious disadvantage of rebounding the passenger with great force. To the extent that there is a pressure regulator, the effectiveness of the air bag is reduced because it must operate at a specific pressure level; this tends to limit the higher pressures that would effectively resist impact at higher levels.

The air bags used between the passenger head, chest and the feet in front of him for this experiment appeared to provide good impact attenuation for those individuals thrown against them when the bag did not rupture. In an exceptionally fortuitous sequence of events, one air bag was contacted by four different passengers, owing to their sequential contacts and rebound characteristics.

An air bag was also used in the passenger vehicle for Experiment 87. Taking into account the deceleration of the rear-ending Plymouth, reaching a frame peak of 18 G at 44 msec after the vehicles contacted one another, the right front seat passenger received little value from the air bag positioned between him and the instrument panel, considering his 109 G head impact at 112 msec. A three-point safety belt would have restrained him so that no component of his body would have sustained anything approaching the 109 G value he sustained. The air bag apparently ruptured relatively early during the collision, thereby losing its expected protection.

OCCUPANT KINEMATICS - The forced body movements of passengers during collision are not readily predictable, except by reference to observations from full-scale collision research. The complications of relative impacting masses; positions of contact and the resulting dynamic centers of rotation of vehicles; location of passenger and his size in relationship with the constraints he encounters within; and on ejection from the vehicle, each typify the variables that challenge credibility of information not based on full-scale research. An understanding of human body collision kinematics provides the basis for practical and effective design of passenger restraining devices and of vehicle interiors that provide the most protection for the money invested. These experiments have shown that, depending upon the nature and extent of passenger collision protection, school bus occupants may be killed or sustain no injury even though subjected to identical collision conditions. This subject has been extensively investigated by the authors (3-5, 7) and by other investigators (8).

1. Bus drivers and truck drivers should be required to wear at least a lap-type safety belt whenever their vehicle is in motion to assure that they remain "behind the wheel" during an accident. Drivers of all vehicles and particularly those of school buses should be firmly secured in their seat whenever the vehicle is in motion so that, in the event of a collision sufficient to throw the driver from his seat, he will be retained in the operator's position so as to avert a possible second collision with a fixed object or a more serious head-on impact, either through steering, braking, or control combinations, as required. The authors have investigated many bus and truck type collisions where this factor alone would have averted the injury-producing secondary collision event. (1) The practice should be changed where unrestrained drivers of heavy vehicles are placed on polished plastic seats from which they are readily ejected during even minor impacts, only to try to struggle back behind the wheel before a major collision or upset takes place. In the side impact, Experiment 90, the driver's seat in the bus was removed owing to front-end collision damage resulting from the head-on collision experiment. Adjacent to this driver was an unrestrained dummy that was ejected through the right front door. It may be concluded that had a simulated driver been positioned behind the wheel, he would have been thrown from his seat during collision.

2. Passenger collision kinematics are sufficiently varied from crash to crash that there is no "safe seat" and also there is no "death seat." Protective measures must be provided for all passengers and be used by all passengers at all times. Passengers seated close to each other may sustain significantly different injury-producing forces with some undergoing violent impact actions and others appearing to escape serious injuries. These observations correlate with observations of live accidents in which some individuals within a vehicle may escape serious injuries while others are killed. Inasmuch as these collision forces do not lend themselves to predictability as to location or magnitude, it is obvious that respective restraint systems must be uniformly applied to all passengers and be in use at all times.

3. The path the body travels during collision is not definable in simple terms but rather depends on many factors, each including many variations. Investigators in the past have attempted to define path-of-body-travel in terms of the line connecting the position of the passenger at impact with the point of contact by the striking vehicle. Collision dynamics are too complicated to produce simple interactions with occupants.

The path a body travels during a collision is not readily predictable without direct reference to observations of full-scale collision dynamics and related body kinematics. For example, the 6-year-old seated in 2LA during the side impact was thrown ahead and to his right to impact near the stairwell head first, instead of being thrown in the direction of the impact which was rearward and to his right. The side-impacting vehicle struck the bus on its right side to the rear of its center of gravity. This had the effect of skidding the rear wheels to its left and displacing the bus rearward, with the resulting effect of shifting occupants toward the front of the bus and to their right. The previously referenced 6-year-old was judged a possible fatality owing to the severe inferred injuries sustained. This points out that unrestrained passengers, even though remotely positioned from impact, may be critically injured.

4. The practice of transporting bus passengers standing in the aisle is dangerous and should not be permitted, especially for school bus passengers. Individuals standing in the aisle are far more likely to be injured than passengers who are seated, regardless of the lack of quality of the seats. During a collision, they are thrown about the bus passenger compartment striking and injuring other individuals who may be adequately restrained.

The exposure for the standee relative to the head-on and rear-end collision is, understandably, severe, owing to no structure immediately in his path to retard his body being hurled down the aisle to strike the front or rear of the bus forcibly, and often head first. It was found that conditions are or may be as serious for the side impact owing to the abruptness with which the standee is thrown against other passengers and the side of the bus, or, in the instance of the individual standing near the front of the bus, thrown against the opening and ejected head first. The standee's chances of injury during a collision greatly exceed those of seated passengers, even when safety seats are not included in the bus.

Standees thrown to the front of the bus may block the exit with injured and unconscious bodies greatly increasing the evacuation time for those able to move.

EVACUATION - The orderly exiting of many people under emergency conditions poses a problem requiring special measures; this is true whether the evacuation relates to a burning building, a sinking ship, a crashed aircraft, or bus. The adversities of congested space, injured and dazed people should not be complicated by too few and too inadequate escape routes. In addition to evolving more emergency exits for school buses, studies are needed to give direction to design engineers for evolving expeditious yet safe and practical emergency escape systems. In addition, school districts should be required to conduct practice emergency exit demonstrations so that the younger passengers can manage their own escape during an accident that incapacitates the driver. The ever-present hazard of post-crash fire necessitates prompt and orderly evacuation by all able passengers in order to improve the chances of rescue of those unable to help themselves.

1. Because of the hazard of crash-induced fire following moderate to severe collisions, passengers should be evacuated promptly and required to stand remote from traffic and the accident scene. Within 1/10 sec following collision contact between the two buses, smoke entered the passenger compartment at the front from an electrical short that, if allowed to progress, might have enveloped the entire bus

in a devastating fire. Immediately after this head-on collision experiment, the fire was extinguished promptly by project personnel assigned this task. This event indicates, however, the almost hopeless task of promptly evacuating a bus load of unconscious and dazed children, especially considering the inadequate escaped routes and the present conditions of aggravated injuries because of no restraints being worn by school children.

2. Because the driver is generally the only responsible adult in the bus, he should be protected from collision injury by at least a seat belt restraint and a well designed high back safety seat with padded armrests. Within 1/10 sec following the head-on contact of the two school buses, two unrestrained 13-year-olds had struck the driver, landing on top of him. In an actual collision this interference from behind would render his constructive efforts to facilitate evacuation of these children an impossibility, even if he wasn't killed during the onset of collision forces owing to his lack of restraint. Protecting the driver serves to better protect the school children he transports since this provides greater assurance that he will be able to direct an evacuation if one is advisable.

3. School buses need at least four full size emergency escape routes of a standardized design and location. The moderate size school bus typified by the 1965 GMC-Superior Coach bus crashed for these experiments, should be provided with a minimum of four clearly marked and full size exists. In addition to right-front and center-rear exists, there should be exit doors at, or near, the center-right side and center-left side. The right and left center side exits should more than comply with Federal Aviation Agency (FAA) specifications for emergency exits used on passenger aircraft because the school bus passengers do not generally include adults. Emergency exits should comply with the FAA as to labeling, lighting, protection against inadvertent openings, and protection against mischievous manipulation of escape levers. In this connection it would be advisable to have a buzzer sound off for the driver when an emergency escape door handle is moved. The complications that air bags would introduce during an attempted expeditious evacuation of passengers in the event of post-crash fires has been discussed previously.

REGULATORY STANDARDS - Experience has shown that in matters affecting public safety, specific performance and functional guidelines evolved by specialists are necessary to assure that economical considerations do not suppress safety. This section is not intended to be complete; the authors felt that certain conclusions belong under this category but remain hopeful that all findings will be carefully examined by committees that are charged with formulating regulatory standards for buses, including school buses.

1. Safety belts should be worn at all times by the drivers of buses and other heavy vehicles. This requirement is not as much in consideration of the safety of the driver, per se, as it is with the safety of any passengers. Motorists are likely to be injured or killed by a heavy vehicle traveling out of control, following a minor impact; the driver, dislodged from his driving position, will usually not make it back to his seat in time to regain control of his crippled vehicle. The wearing of belts on the part of truck drivers should be necessary in the interest of protection of lives of those motorists forced into the mainstream of traffic in passenger vehicles whose weight may be 1/40 that of a truck. During impact with an out-of-control, heavy vehicle, a passenger car has a disadvantage in terms of weight and vulnerability exceeding that of a 1-year-old toddler on a football field against the 200 lb professional football player. Considering this disadvantage every practical measure must be taken to assure continued dependable performance of heavy vehicles.

2. Safety regulations for school buses should be standardized without allowances for the intended size of school passengers to be hauled. During its operational life, a school bus may have been purchased to haul grade school children, later be assigned for high school use, and subsequently be bought by a religious organization for diversified activities, including hauling of adult passengers. As with private passenger vehicles, standards are needed that apply to school buses to provide adequate collision protection, regardless of the size of the passenger. The 3-year-old, 1LW, in the head-on collision, "rode out the crash rather well (in spite of his close proximity to the front of the bus) until his head hit the rearward intruding heater enclosure." Any structure that is positioned in such a manner that it can become injury-producing, should be designed to comply with Federal Standards for injury minimization as to curvature and head impact force attenuation. This standardization should include protective seat units of one size, unless appropriate regulations are devised that restrict the use of buses to the passenger size range for which the bus has been certified. For reasons already explained, dissimilar passenger seats should be prohibited from buses.

3. The bumpers of all buses (and other large vehicles) should be capable of effectively transferring collision forces to heavier structural members of the bus frame and should be positioned with the base not more than 16 in. above the pavement for the unloaded vehicle. This standard is very much needed to reduce the chances of extreme underriding of heavy vehicles by smaller vehicles. Overhang drag of these heavy vehicles could be eliminated by the use of adjustable air-pressurized leveler shocks to compensate for load variations or the technique of placing the wheels of the heavy vehicle close to each end. This latter arrangement provides dual wheels, axle and differential in a position that further assures no extreme underriding by passenger vehicles. Bumper mismatch contributed considerably to passenger inferred injury, both in the bus head-on and rear-end collision experiments reported by this paper. Most of the underriding action of passenger vehicles rear-ending trucks, buses, and other large vehicles, or of buses and trucks being overridden, is attributed to bumper mismatch. This is an international problem, recognized in England and elsewhere, too long neglected, requiring U. S. leadership to correct.

4. Seatback height for school buses should not be less

than 28 in. High school students would need a seatback 28 in. from the base of the seat to the top of the seatback in order to adequately protect them from the whiplash effects during a rear-end collision.

Seatbacks must extend high enough for the last seat in the bus to provide positive support for the head of a 95th percentile male during a moderately severe rear-end collision to assure that his head is not forced rearward through the rear window.

A seatback 26 in. high provides satisfactory head support during a rear-end collision for passengers under 13 years of age but the 13-year-old is found to sustain slight contact with the back of the neck against the top of the seatback.

5. Built-in or improvised seating in the aisle should not be permitted in buses. This refers to seat structures laid between left and right rows of seats blocking the aisle. This restriction is necessary in order to avoid overloading the bus both as to gross vehicular weight and as to the added complications of effective evacuation of the injured and unconscious in the event of an accident. Additionally, standees, passengers taken aboard beyond the seating capacity of a bus, should not be permitted because these individuals are deprived of the safe transportation accorded seated passengers in a properly designed bus. In addition, they become heavy missiles during a crash, inflicting injury to other passengers as well as to themselves.

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Appendix appears on next page.

APPENDIX

PEAK ACCELEROMETER VALUES

	X-86 Head-on		X-87 Rear-end		X-90 Side-impact	
	Distance from front bumper	Peak G frame	Distance from front bumper	Peak G frame	Distance from front bumper	Peak G frame
Struck Vehicle	10'	13	18'	9	18'	13
	26'	11	26'	10	26'	17
	(New Bus)		(New Bus)		(New Bus)	
Striking Vehicle	-	-	8'	18	8'	26
	-	-	-	-	-	-
	(Old Bus)		(Plymouth)		(Chevrolet)	
Seat Positions	Seat Dummy Type Size	Peak G Head/Chest	Seat Dummy Type Size	Peak G Head/Chest	Seat Dummy Type Size	Peak G Head/Chest
Driver	*-/A	-/37	-/-	-/-	-/-	-/-
1LW	A/3	57/-	-/-	-/-	-/-	-/-
1LA	A/13	-/60	-/-	-/-	-/-	-/-
2S	K/13	-/21	K/13	-/14	K/13	-/-
2LW	A/13	32/-	A/13	5/-	A/13	-/-
†2LA	A/13	106/-	A/13	6/-	A/6	-/-
†3LW	F/6	-/33	F/6	-/11	F/13	-/-
3LA	F/13	54/-	F/13	20/-	F/13	-/12
4LW	C/13	26/-	C/13	8/-	C/13	17/-
4LA	C/13	-/20	C/13	-/6	C/13	-/-
5LW	A/13	-/25	A/13	-/6	A/13	-/16
5LA	A/13	-/25	A/13	-/5	A/13	-/12
6LW	H/A	-/11	H/A	-/6	H/A	-/11
6LA	-/-	-/-	-/-	-/-	-/-	-/-
†7LW	B/A	-/-	A/13	-/8	A/13	-/8
†7LA	B/M	-/18	A/3	12/-	A/13	-/12
8LW	E/13	-/15	D/13	-/37	D/13	-/-
8LA	E/13	-/20	D/13	-/8	D/13	-/31
†9LW	A/13	-/25	A/A	30/-	A/13	-/32
†9LA	A/3	-/36	A/13	20/-	A/3	-/69
1RW	J/A	41/41	J/A	29/6	J/A	-/8
2RW	A/13	‡ -/12	-/-	-/-	-/-	-/-
2RA	A/6	-/53	-/-	-/-	-/-	-/-
†3RW	D/13	-/17	D/13	-/11	D/6	14/-
3RC	D/A	-/5	D/A	-/-	-/-	-/-
†3RA	D/13	-/21	D/6	-/5	D/A	31/4
4RW	G/13	-/32	G/13	-/8	G/13	29/-
4RA	G/13	29/-	G/13	15/-	G/13	-/14
5RW	A/13	-/11	A/13	-/7	A/13	33/-
5RA	A/13	-/37	A/13	-/5	A/13	-/24
5S	-/-	-/-	K/13	-/-	K/13	-/11
6S	K/13	-/-	-/-	-/-	-/-	-/-
†6RW	B/13	62/-	B/13	6/-	B/A	25/-
†6RA	B/3	13/-	B/3	-/13	B/13	-/40
7RW	A/13	42/-	A/13	-/-	A/13	19/-
7RC	-/-	-/-	A/13	-/-	-/-	-/-
7RA	A/13	-/21	A/13	-/5	A/13	-/25
8RW	I/13	49/-	I/13	20/-	I/13	63/-
†8RA	I/13	-/19	I/3	12/-	I/13	-/-
†9RW	C/3	7/-	C/A	-/16	C/A	-/24
9RA	C/13	46/-	C/13	16/-	C/13	-/41

Key

*Driver's seat, Figure 3(k)

†Occupant size was varied between experiments for this seat position

‡Vertical axis only

LEGEND

POSITION: 1–9...Seat position from front, R...Right side of bus, L...Left side of bus, A...Aisle passenger, W... Window passenger, C...Center passenger, S...Standing passenger, M...Mathematical model "Iron Man".

For example: 1RW; seat number 1, Right side of bus, passenger next to Window.

SEAT TYPE: A–K...See Table 1 and Figures 3(a)–3(k).

DUMMY SIZE: 3, 6, 13 year and A (Adult).