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RAIL PASSENGER EQUIPMENT COLLISION TESTS: ANALYSIS OF OCCUPANT PROTECTION MEASUREMENTS

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ABSTRACT

The Federal Railroad Administration has been conducting research on occupant protection in train collisions. As part of this research, computer simulations have been performed, passenger seats have been sled tested, and two full-scale collision tests of rail passenger cars have been conducted. The passenger equipment collisions tests that have been performed to date are:

1. Single car impact into a fixed barrier at 35 mph
2. Two coupled car impact into a fixed barrier at 26 mph

As part of these tests, the cars were instrumented to measure the deformations of critical structural elements; the vertical, lateral, and longitudinal deceleration of the carbody and trucks; and the suspension displacements. The cars were also equipped with instrumented anthropomorphic test devices (test dummies) in three interior arrangements:

1. Forward-facing unrestrained occupants seated in rows, compartmentalized by the forward seat in order to limit the motions of the occupants.
2. Forward-facing restrained occupants with lap and shoulder belts.
3. Rear-facing unrestrained occupants.

This paper describes the vertical and lateral motions of the cars during the two-car impact test, and discusses their influence on the responses of the instrumented dummies. The lateral motions of the cars appear to have had little influence on the response of the test dummies. The vertical motions of the cars may have had an influence on the forward facing unrestrained test dummies seated in rows. Such experiments were conducted in both the leading and trailing cars, and in both these experiments, the heads of the test dummies rose above the seatback ahead, allowing high neck loads.

INTRODUCTION:

Passengers striking the interior of trains during collisions and derailments account for approximately 7% of the fatalities and 57% of the serious injuries occurring on passenger railroads [1]. The Federal Railroad Administration (FRA) has been conducting research to develop strategies for reducing the number of fatalities and injuries associated with occupant impacts with the interior during train accidents. As part of this research, simulation studies of occupant protection strategies have been conducted [2, 3] and dynamic sled tests with test dummies in mock-ups of train interiors have been performed [4].

Modeling and testing to date of occupant interactions with the interior of cars during train collisions have limited the interior environment to longitudinal motion. Analysis of occupant dynamics during train collisions have been limited by initial modeling of train to train collisions, which, until recently, have also been one dimensional. (Subsequent models of train-to-train collisions have been developed which are three-dimensional.) In essence, only the longitudinal motion of the train has been considered in studies of occupant protection to date – the influence of the pitch and yaw motions of the car on occupant response have been neglected. However, pitch motions of the car during a collision may be significant – large vertical accelerations can arise when the car bottoms out on its suspension. The influence of the vertical and lateral car accelerations on occupant response and the effectiveness of occupant protection in the better-defined secondary collision environment need to be determined.

Currently, the FRA is conducting full-scale testing of rail passenger equipment [5, 6, 7, 8]. As part of these tests, the environment that occupants would experience is being measured, and the response of instrumented test dummies is being recorded. (A companion paper describes the requirements and implementation of these tests.) Figure 1 shows a schematic of the two-car test conducted on April 4, 2000. During this test, two coupled cars impacted a fixed wall at 26 mph.

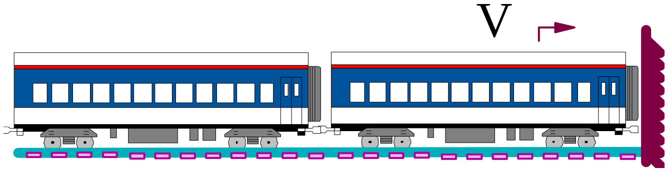

Figure 1 Schematic of Two-Car Test

Figure 2 shows the interior experiments carried out as part of the two-car test. Three interior configurations were tested:

1. Forward-facing unrestrained occupants seated in rows, compartmentalized by the forward seat in order to limit the motions of the occupants.
2. Forward-facing restrained occupants with lap and shoulder belts.
3. Rear-facing unrestrained occupants.

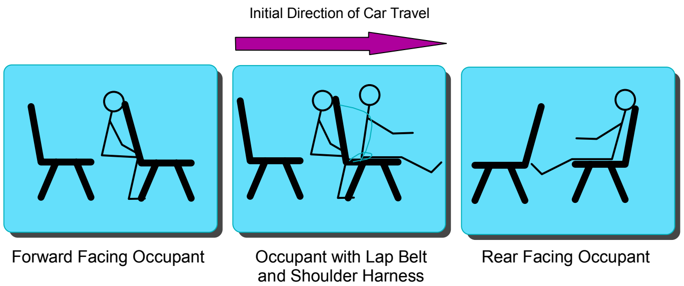

Figure 2. Schematics of Interior Configurations

The forward facing occupant interior configuration was tested in both the lead and trailing cars, while the forward facing restrained occupant and rear facing occupant configurations were tested only in the lead car. Figure 3 shows the placement of the interior configurations in the two-cars.

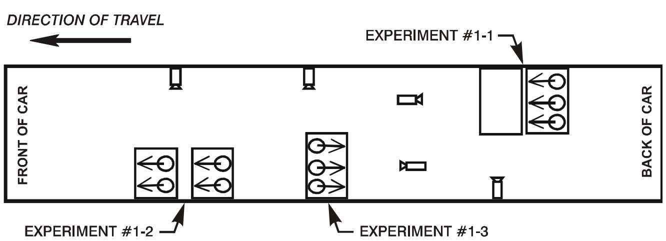

Figure 3.a. Location of Interior Test Configurations in Leading Car

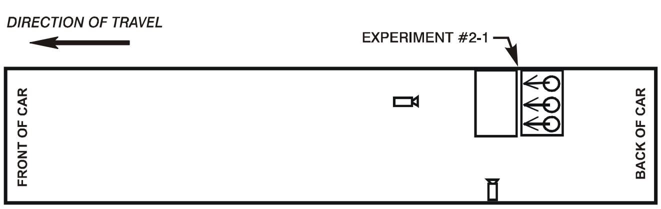

Figure 3.b. Location of Interior Test Configurations in Trailing Car

This paper describes the measurements of the occupant environment made during the two-car test, as well with the measurements made with the instrumented dummies. More detailed descriptions of the test requirements and implementation are included in a companion paper [8] and information on the structural portion of the test is presented in another companion paper [7].

OCCUPANT ENVIRONMENT

The occupant environment during a collision is defined as the interior configuration and its associated engineering details, and the deceleration imparted to that configuration. During an in-line train collision, the greatest decelerations are longitudinal. However, significant lateral and vertical accelerations that influence the kinematics of the occupants can arise. This section describes the longitudinal, vertical, and lateral accelerations measured during the two-car test. The crash pulses described here were measured at the center of the floor in both the leading and trailing cars.

Figure 4 is a plot of the longitudinal deceleration time-histories of the leading and trailing cars during the two-car test. The longitudinal deceleration time-history, or crash pulse, of the lead car is characterized by a high initial peak with a short duration, followed by oscillations around zero, followed by a fairly steady deceleration. The initial peak is owing to the high load required to initiate collapse of the car structure impacting the wall, the oscillations about zero are owing to the impact of the trailing car with the leading car, and the final steady deceleration is both cars riding down the collision as the structure of the lead car crushes. The trailing car crash pulse is characterized by a peak that is substantially lower (less than half) than the peak of the lead car, followed by a fairly steady deceleration. The trailing car's peak deceleration occurs when the lead car's deceleration is oscillating about zero. The average deceleration for the lead car over the 0.4 seconds shown in Figure 4 is 3.1 g's, while it is 3.2 g's for the trailing car.

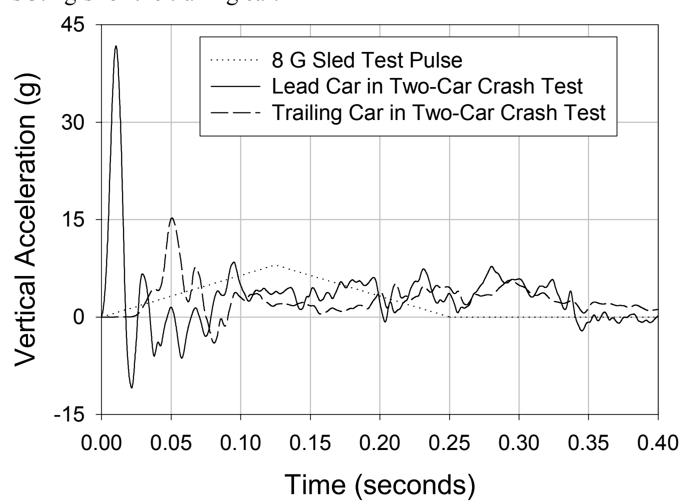

Figure 4. Longitudinal Carbody Accelerations vs Time

For comparison, the plot shown in Figure 4 includes the 8 g triangular pulse used in previous sled testing [4]. This pulse has a significantly different characteristic from the longitudinal decelerations measured during the test. The average value of this pulse, however, is 4 g's, which is greater than averages for the pulses measured during the test. The influence of the shape, or characteristic, on the likelihood of injury depends upon the interior configuration. The average deceleration is greatest for the 8 g triangular pulse and consequently, for unrestrained forward facing occupants seated in rows, the likelihood of injury is probably greatest for this pulse. For restrained occupants the principal concern is the loads imparted to the neck. Since, in effect, the occupant 'impacts' the restraints earlier for the crash pulse measured in the leading car, owing to its initial peak, than for the other two crash pulses, it is expected that the leading car crash pulse is most likely to result in injury. Similarly, for rear facing occupants the crash pulse of the leading car is likely to be most severe because of the initial peak.

Figures 5a and 5b shows the vertical accelerations of the leading and trailing cars in the two-car test, respectively. Both plots show the vertical accelerations at the leading body bolster, at the center of the floor, and at the trailing body bolster. The measurements include the influence of the pitch and bounce of the cars, as well as the elastic vibrations of the carbodies and accelerometer mountings.

Observation of the high-speed film taken during the test indicates that both cars essentially rotated about a point near the trailing body bolster while they pitched upward. This motion resulted in a maximum elevation of approximately 6 inches at the front body bolster for the leading car, and 3 inches for the trailing car. The elastic vibrations of the carbody dominate the vertical accelerations of both cars – the acceleration signatures appear to oscillate about zero for the duration of the impact.

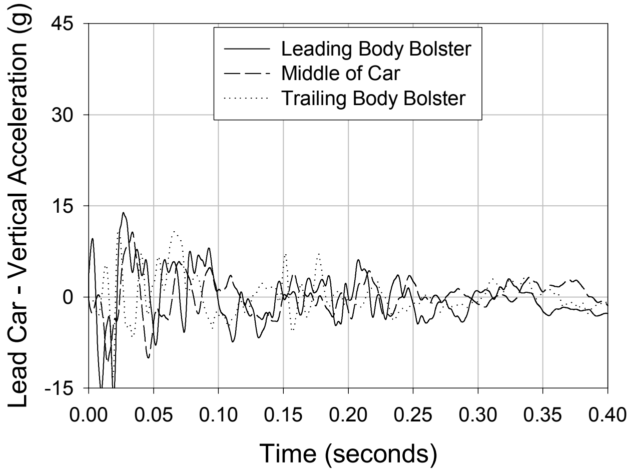

Figure 5a. Vertical Carbody Accelerations vs Time, Leading Car

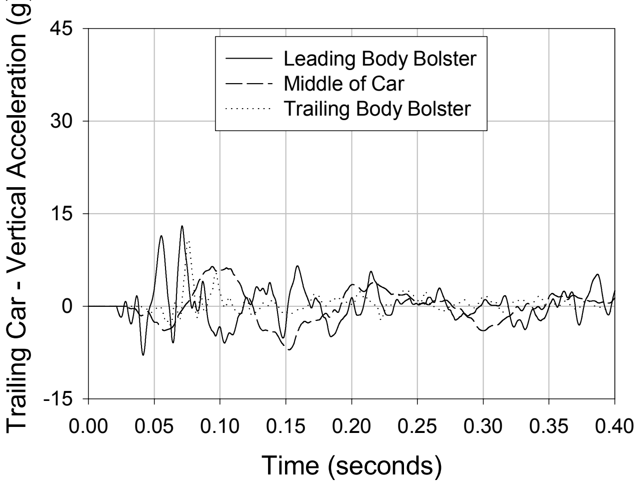

Figure 5b. Vertical Carbody Accelerations vs Time, Trailing Car

The lateral accelerations measured in the leading and trailing cars in the two-car test are shown in Figures 6a and 6b, respectively. The lateral acceleration for the leading car has an initial peak whose timing corresponds with the impact from the trailing car. The trailing car lateral acceleration is smaller than the leading car lateral acceleration. Similar to the vertical acceleration measurements, the lateral acceleration measurements include the influence of the yaw and sway of the cars, as well as the elastic vibrations of the carbodies and accelerometer mountings. During the test, both cars yawed in a counter clockwise direction, which resulted in a 'sawtooth' lateral buckle of the coupled cars. From the high-speed film, both cars apparently yawed about their trailing body bolster.

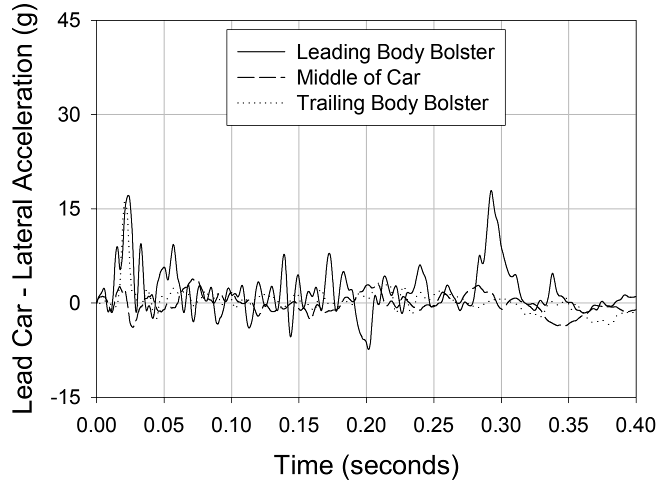

Figure 6a. Lateral Carbody Accelerations vs Time, Leading Car

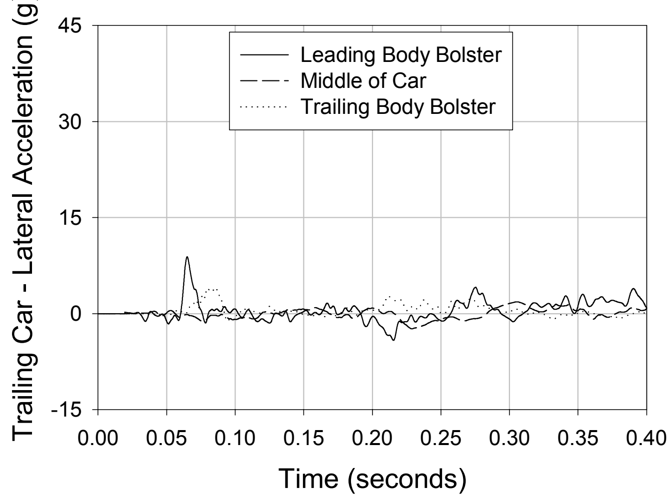

Figure 6b. Lateral Carbody Accelerations vs Time, Trailing Car

Table 1 lists the average longitudinal, vertical, and lateral accelerations in the leading and trailing cars during the two-car test. It can be seen in the table that except for the lead body bolster sensors, the longitudinal deceleration is nearly an order of magnitude larger than lateral and vertical accelerations. For the rear facing and restrained occupants, the influence of the lateral and vertical accelerations on the occupant response, and consequently, their influence on the likelihood of injury, is expected to be small. For the rear facing occupants, the longitudinal deceleration, in combination with the friction between the occupant and seat, prevents much lateral and vertical motion of the occupants during the most severe portion of the primary impact. For the restrained occupants, the restraints prevent much vertical and lateral motion of the occupants. For unrestrained occupants that travel some distance before their secondary impact, however, the lateral and vertical motions of the car may potentially influence the occupant motion and influence their likelihood of injury. In particular, for unrestrained forward facing occupants seated in rows, there is a possibility of relative vertical and lateral displacement between the seat ahead and the occupant. These displacements may result in an occupant's head missing the seat ahead, and the neck impacting the top of the seatback. If this does occur, then there is potential for high neck loads and consequent injury.

Table 1. Average Longitudinal, Vertical, and Lateral Accelerations, Leading and Trailing Cars

Average Acceleration 0 to 0.4 seconds	Leading Car	Trailing Car	8 g Pulse[1]
Longitudinal	3.1 g	3.2 g	4 g
Vertical, Leading Body Bolster	2.37 g	0.19 g	NA
Vertical, Middle of Car	0.11 g	0.04 g	NA
Vertical, Trailing Body Bolster	0.16 g	0.46 g	NA
Lateral, Leading Body Bolster	1.88 g	0.44 g	NA
Lateral, Middle of Car	-0.08	-0.04 g	NA
Lateral, Trailing Body Bolster	0.34 g	0.46 g	NA

Figure 7 shows a plot of the time-history of the displacement, relative to the interior of the cars, of the head of an unrestrained forward facing occupant. This plot is derived from the test data and the assumption that the occupant is in free-flight during the impact [3]. The distance from the front of an occupant's head to the seatback ahead is approximately 2 feet for typical commuter seat spacing and approximately 2.5 feet in typical inter-city seat spacing. The plot indicates that the head of a forward facing unrestrained occupant seated in rows of seats would impact the back of the seat ahead at 0.18 to 0.20 seconds after the leading car impacts the wall; the secondary impacts occurs at about the same time in both the trailing and leading cars.

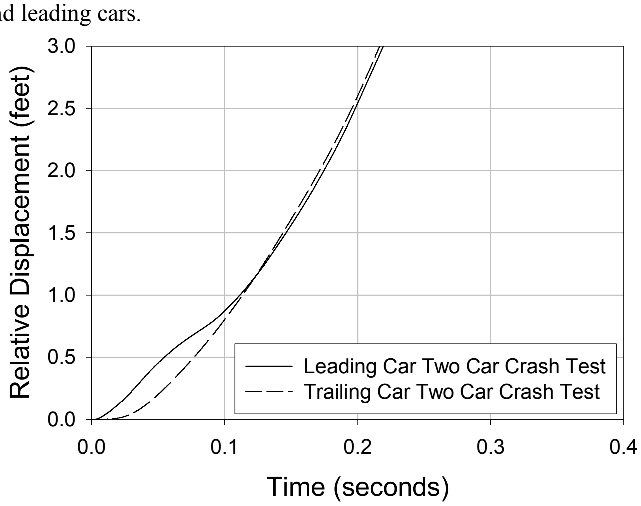

Figure 7. Forward-Facing Unrestrained Occupant Longitudinal Relative Displacement Time History

Since the cars are pitching during the impact, the vertical displacements vary along the lengths of the cars. The maximum vertical upward displacement of the carbody after 0.20 seconds is approximately 2 inches near the lead body bolster and the maximum displacement downward is approximately 1 inch near the trailing body bolster. The upward displacement of the carbody results in the downward relative displacement of the occupant; at this location the point of contact of an unrestrained occupant's head would move down the seat back ahead, closer to the floor by several inches. Such motions are not likely to influence the likelihood of injury. At the rear body bolster, however, relative displacement is upward, and the occupant's head may miss or only partially impact the seat ahead. Such motions may significantly increase the head load, increasing the likelihood of injury.

Relative lateral motion greater than 1 foot is required for the head of the aisle-side occupant to miss the back of the seat ahead, and similar relative displacements are required for the wall-side occupant to strike the wall. Even though the lateral displacements vary along the length of the car, for the initial 0.20 seconds, these displacements remained significantly less than 1 foot. (The lateral motions of the cars did indeed exceed 1 foot some time after 0.20 seconds. It is assumed that, once the occupant contacts the interior, that the longitudinal deceleration in combination with friction is sufficient to keep the occupant in contact with the interior. The lateral accelerations are nearly an order of magnitude less than the longitudinal accelerations.)

Figure 8 shows a plot of the longitudinal velocity of an unrestrained occupant relative to the interior of the car as a function of that occupant's longitudinal displacement relative to the interior of the car. The greater the relative velocity of the secondary impact is, the greater the likelihood of occupant injury. The plot shows the relative velocity for test dummies in the leading and trailing cars, the longitudinal velocity associated with the 8 g triangular crash pulse used in previous sled testing, as well as the relative velocity measured in the single-car test conducted in November, 1999. The 8 g triangular pulse results in a secondary collision velocity that is approximately 30% greater than the pulses measured during the two-car test. The 8 g crash pulse is more likely to result in passenger injury than the crash pulses measured during the two-car test, for forward facing unrestrained occupants.

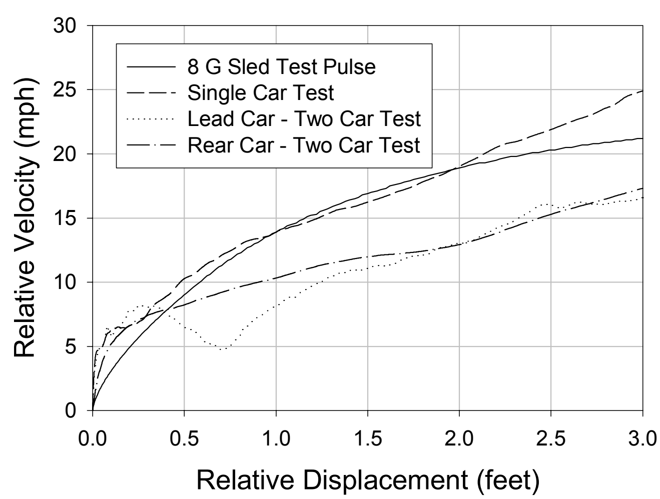

Figure 8. Relative Longitudinal Velocity of an Unrestrained Occupant as a Function of Relative Longitudinal Displacement

[1] Averaged over 0.25 seconds.

RESULTS OF OCCUPANT PROTECTION EXPERIMENTS

Test dummies were used in the four interior experiments included in the two-car test to measure the loads and decelerations imparted during the two-car impact test, high-speed cameras were used to record the kinematics of the dummies, and load cells were used to measure the forces supported by the seats. In all four experiments, only the aisle-side dummy was instrumented. Similar loads and decelerations were expected for all test dummies initially seated in the same seat. This section briefly describes each of the experiments, the kinematics of the dummies, and the values of injury criteria computed from the instrumented dummy measurements.

To interpret and evaluate dummy response measurements from simulation and testing, occupant injury criteria or injury assessment values are specified for the various types of occupant injuries in terms of measured dummy responses. The injury criteria values refer to a human response level below which a specified significant injury is considered unlikely to occur for a given individual. If a dummy response measurement is below its corresponding injury criteria value, then the occurrence of the associated injury for that size occupant is considered unlikely for the accident environment being tested. Exceeding an occupant injury value does not imply that its human counterpart would experience that injury if exposed to the same test condition since the occupant injury criteria are only lower bounds of the level of human response below which a specified injury does not occur.

The test dummy instrumentation enabled measurement of head accelerations, select head/neck interface forces and moments, chest accelerations, and femur axial force. The National Highway Transportation Safety Administration (NHTSA) defines the injury criteria, along with maximum values for the criteria, for use in setting regulatory standards for highway vehicles. The head injury, chest, and femur criteria and values used in this paper are from the NHTSA interim final rule modifying the Federal Motor Vehicle Safety Standard (FMVSS) No. 208 (Occupant Crash Protection) [9]. The neck injury values are from reference [10].

The NHTSA interim final rule does prescribe neck injury criteria. As part of the development of this rule a number of neck injury criteria were proposed. The neck injury criteria used in this paper are different from the criteria in the NHTSA interim final rule. The proposed neck injury criteria, along with the criteria used in this paper and in the NHTSA interim final rule, are being evaluated for their applicability to the rail passenger equipment occupant protection environment. The criteria prescribed in the NHTSA interim final rule are less restrictive than the criteria used in this paper, and it is likely that test dummy measurements which result in marginal exceedance of the criteria used in this paper would not result in exceedance of the NHTSA interim final rule criteria.

Experiment 2-1, Forward Facing Rows of Seats, Trailing Car

Figure 9 shows the forward-facing unrestrained test dummies seated in rows in the trailing car. This experiment included three 50th percentile male test dummies.

Figure 9. Experiment 2-1, Forward Facing Rows of Seats, Trailing Car, Pre-Test

The rear seat in this test was a conventional M-style seat from Coach and Car Equipment Corporation. The forward seat in this experiment was a modified M-style Seat. The modifications consisted principally of a stronger seat pedestal, reinforcement to the frame in the area where the seat back and seat pan join, and additional gussets on the wall mounting lugs. Only the difference in the floor pedestal can be observed when the seat is fully assembled. Figure 10 shows the areas of the seat frame that were modified.

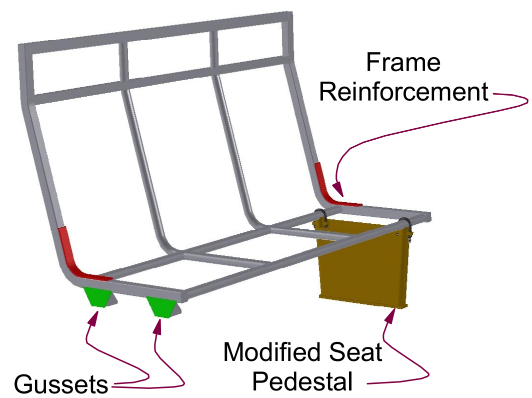

Figure 10. Modifications to M-Style Seat Frame

All of the injury load measurements were made from instrumentation installed in the Hybrid III 50th-percentile test dummy seated in the aft row, in the aisle seat. This test dummy's knees impacted the seat back ahead of it, followed by head and chest impacts which resulted in some deformation of the upper portion of the seat back. In this particular experiment, the test dummy's face impacted the upper seat back, followed by the head going over the top of the seat. Upon returning to its seated position, the chin caught on the top of the seat back causing an excessive moment in the neck. Table 2 lists the values for the occupant injury criteria for this experiment. Three photographs, taken from the side-view high-speed film, are shown in Figure 11. The middle photograph shows all three of the dummies' heads above the top of the seatbacks.

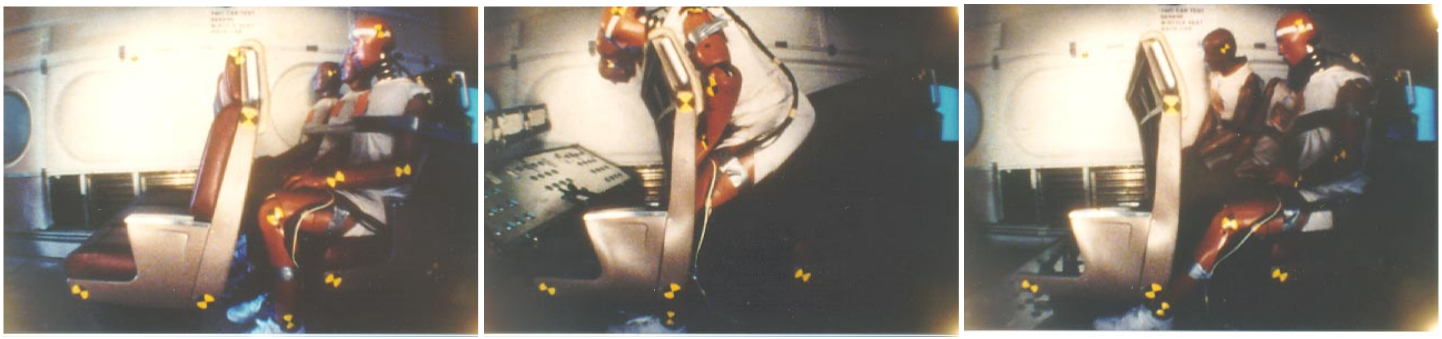

Figure 11. Time-Sequence for Experiment 2-1, Forward Facing Rows of Seats, Trailing Car

Table 2. Experiment No. 2-1, Forward Facing Rows of Seats, Trailing Car, Occupant Injury Criteria Values

Injury Criteria	**Hybrid III 50th-percentile, aisle seat occupant**	
	Criteria	**Recorded Loads**
HIC	1,000	118
Neck Fx (lb)	+/-697	+350/-4
Neck Fy (lb)	+/-697	+26/-9
Neck Fz (lb)	+742/-900	+323/-261
Upper Neck My (ft-lb)	+140/-42	+91 (0.203 sec) / **-42 (0.638 sec)**
Chest (g)	60	15
Left Femur (lb)	-2,250	-646
Right Femur (lb)	-2,250	-532

In previous sled testing of the M-style seat the dummies' heads impacted the seatback near the top, but did not rise above the seatback. (A report on those sled tests is currently in draft.) The dummies' heads going over the seat top, and the dummies chins catching on it appear to be caused by the vertical motion of the car. In this location, the downward vertical motion of the car apparently influenced the dummies heads' rising above the seatback.

Figure 12. Experiment 2-1, Forward Facing Rows of Seats, Trailing Car, Post-Test

After the test, there was no observable deformation in the aft-row seat, nor did the aft-row cushions detach from the frame. The modified pedestal in the front-row seat did not deform. The side wall frame and its shroud both deformed slightly on the window side of the seat. The side arm on the aisle side did not deform. The upper part of the seat back absorbed much of the energy from the impacting test dummies. The side wall and the floor attachments of the seat to the car remained intact. All of the front-row seat cushions detached. Figure 12 shows a post-test photograph of this experiment.

Experiment 1-1, Forward Facing Rows of Seats, Leading Car

Figure 13 shows experiment 1-1, the forward facing rows of seats in the leading car. The differences with experiment 2-1 include being in different cars, and the forward seat used in this experiment was not modified, but simply an off-the shelf M-Style commuter seat.

Figure 13. Experiment 1-1, Forward Facing Rows of Seats, Leading Car, Pre-Test

All injury load measurements were made from instrumentation installed in the Hybrid III 50th-percentile test dummy seated in the aft row, in the aisle seat. This test dummy's knees impacted the seat back ahead of it and peaked at approximately 70 msec and then again at approximately 120 msec and 200 msec. After the knees impacted the seat back, the test dummy began to stand and travel forward, catching its chin on the upper seat back, causing the neck to measure a neck flexion moment that exceeded the injury criterion. The side arm of the seat deformed primarily as a result of the test dummy's upper body impacting the seat rather than the knees' initial impact, which appeared to have little effect on the initial seat deformation. Table 3 lists the values for the occupant injury criteria for this experiment. Three photographs, taken from the side-view high-speed film, are shown in Figure 14. The middle photograph shows the aisle-side dummy's head above the top of the seatback. (The heads of the other two dummies are not clearly visible in the photograph, although the front-view high-speed film shows these heads also were above the top of the seatback.)

Like experiment 2-1, the test dummies' heads rose above the seatback ahead, and consequently the chins caught on the seatback. As a result, a neck injury criterion was exceeded for the instrumented dummy. The dummy motions appear to have been influenced by the vertical motion of the car, which sank at the location of this experiment.

Table 3. Experiment No. 1-1, Forward Facing Rows of Seats, Trailing Car, Occupant Injury Criteria Values

Injury Criteria	Hybrid III 50th-percentile, aisle seat occupant	
	Criteria	**Recorded Loads**
HIC	1,000	69
Neck Fx (lb)	+/-697	+437/-27
Neck Fz (lb)	+742/-900	+164/-258
Upper Neck My (ft-lb)	+140/-42	**+148**/-8
Chest (g)	60	15
Left Femur (lb)	-2,250	-556
Right Femur (lb)	-2,250	-555

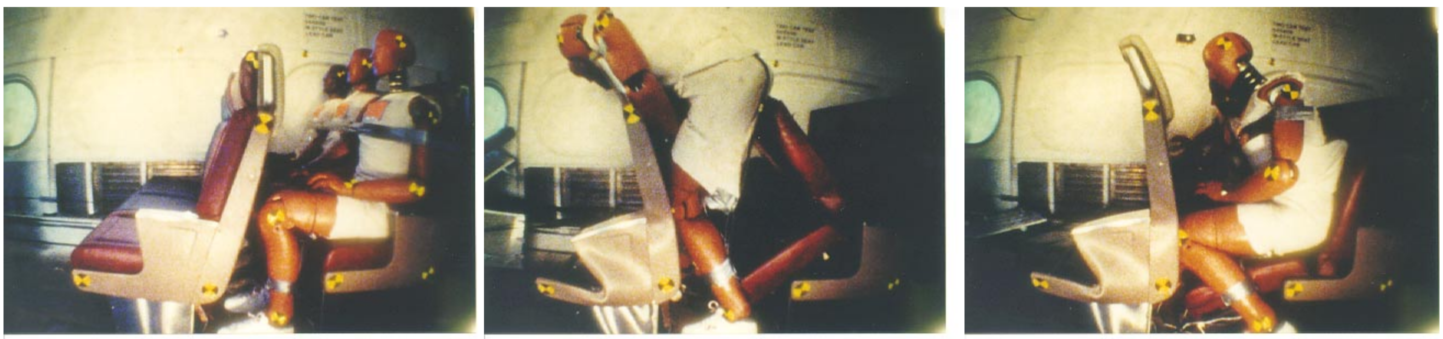

Figure 14. Time-Sequence for Experiment 1-1, Forward Facing Rows of Seats, Leading Car

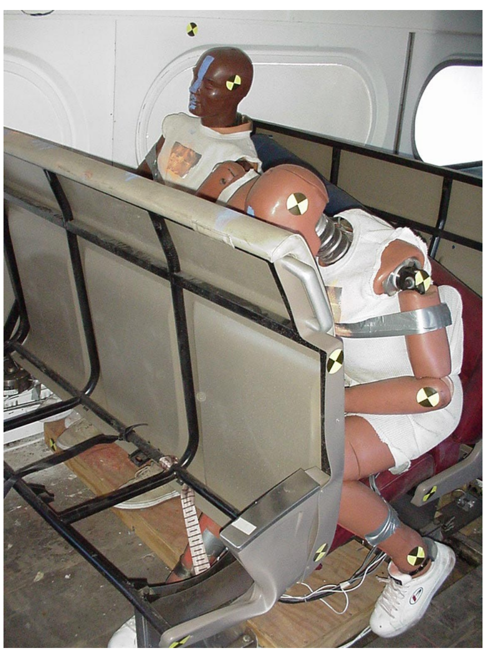

Figure 15. Experiment 1-1, Forward Facing Rows of Seats, Leading Car, Post-Test

After the test, there was no observable deformation in the aft-row seat, however, all of the aft-row cushions detached from the frame. The pedestal in the front-row seat deformed a small amount. The side arm frame and its shroud both deformed slightly on the aisle side of the seat, while the side wall attachments rotated forward under the impact load from the occupants in the row behind it. The seat back rotated forward, but not enough to cause the test dummies to travel over the seat back. The seat and the floor attachments of the seat to the pedestal remained intact. The load cell attachment of the seat to the side wall remained intact. All of the front row seat cushions detached. Figure 15 shows a post-test photograph of this experiment.

Experiment 1-2, Forward Facing Rows of Seats with Lap and Shoulder Belts, Leading Car

Figure 16 shows experiment 1-2, the forward facing rows of seats with lap and shoulder belts in the leading car. The intercity seats used in this two-car test were the same seats used in the single-car test [6]. Modest changes were made to the front-row seat from the first test. These modifications included lowering the position of the energy-absorbers to increase the effective moment arm between the point of knee impact and the horizontal actuation of the energy absorbers, and moving the seatback stops in order to decrease the maximum rotation of the seatback relative to the seat pan. The change to the energy absorbers was made in order to prevent the energy absorbers from being exhausted by the seatbelt load. The change to the seatback stops was made in order to prevent the seatback from making a ramp that could allow the unrestrained dummies to catapult over.

The restrained occupants in the front row remained seated, and the instrumented 5th-percentile test dummy recorded loads that were all well below the respective injury criteria (See Table 4a.)

Figure 16. Experiment 1-2, Forward Facing Rows of Seats with Lap and Shoulder Belts, Leading Car, Pre-Test

Table 4a. Experiment No. 1-2, Forward Facing Rows of Seats with Lap and Shoulder Belts, Leading Car, Occupant Injury Criteria Values, Restrained Instrumented Dummy

Injury Criteria	Hybrid III 5th-percentile, aisle seat, front-row occupant	
	Criteria	**Recorded Loads**
HIC	1,000	(not measured)
Neck Fx (lb)	+/- 438	+20/-70
Neck Fy (lb)	+/- 438	+21/-25
Neck Fz (lb)	+468 / -567	+168/-68
Neck Mx (ft-lb)		(not measured)
Neck My (ft-lb)	+70 / -21	+22/-14
Chest (g)	60	(not measured)
Left Femur (lb)	-1,530	(not measured)
Right Femur (lb)	-1,530	(not measured)
Aisle-seat shoulder belt (lb)	N/A	445
Window-seat shoulder belt (lb)	N/A	782

The head, chest, and femurs of the unrestrained rear-seat test dummies impacted the front-row seat back, causing some deformation in the seat back. The 95th-percentile test dummy in the rear aisle seat was instrumented and recorded neck flexion and shear loads, as well as a right femur load, which exceeded the injury criteria. The high neck flexion moment occurred as a result of the test dummy's chin impacting the seat back in front, and then "sticking" to the seat back while the test dummy's shoulders and upper body continued to travel forward. While the head continued forward, the chin remained stuck in position, leaving the neck in severe flexion. Both the maximum neck shear and the maximum neck moment occurred at the same time. The peak knee load occurred when the right knee impacted the side frame of the seat in front. (See Table 4b.)

Table 4b. Experiment No. 1-2, Forward Facing Rows of Seats with Lap and Shoulder Belts, Leading Car, Occupant Injury Criteria Values, Unrestrained Instrumented Dummy

Injury Criteria	Hybrid III 95th-percentile, aisle seat, back-row occupant	
	Criteria	**Recorded Loads**
HIC	1,000	593
Neck Fx (lb)	+/-856	**+897**/-60
Neck Fy (lb)	+/-856	+25/-62
Neck Fz (lb)	+910/-1,104	No data
Neck Mx (ft-lb)		
Neck My (ft-lb)	+190/-58	**+209 (0.254 sec)** -12.56 (0.362 sec)
Chest (g)	60	28
Left Femur (lb)	-2,594	-815
Right Femur (lb)	-2,594	**-2,765**

Like experiment 2-1 and 1-1, the unrestrained test dummies' heads rose above the seatback ahead, the chins caught on the seatback and a neck injury criterion was exceeded for the instrumented dummy. In this case however, it was expected that the vertical motion of the car, which rose at the location of this experiment, would tend to cause the head of the unrestrained test dummies to impact the back of the seat ahead. The likely principal cause of the heads not striking the top of the seatback is that the top of the seatback was too low for the stature of the test dummies. The unrestrained test dummies used in this test have the size of the 95th percentile male. In previous sled testing, where the dummies' heads were *not* observed to rise above the seatbacks, the test dummies were of the size of a 50th percentile male. Three photographs, taken from the side-view high-speed film, are shown in Figure 17.

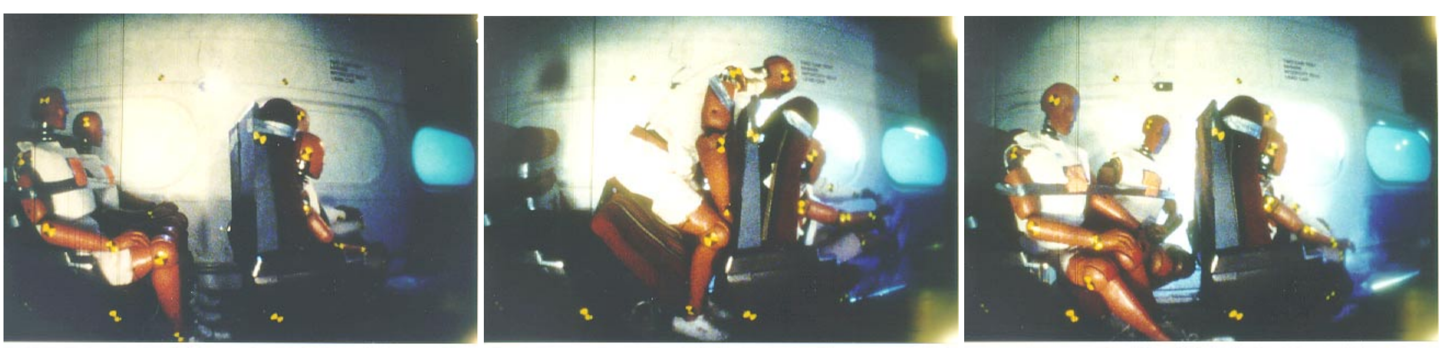

Figure 17. Time-Sequence for Experiment 1-2, Forward Facing Rows of Seats with Lap and Shoulder Belts, Leading Car

The forward motion of the front seat's back panel was greatly reduced from the first test. There was very little seat back panel deformation. What little seat back panel deformation did occur was due to the unrestrained test dummy's knees impacting the seat from behind. While the seat stiffness helped compartmentalize the unrestrained test dummies in the rear seat, it may have contributed to the excessive loads measured in the unrestrained and instrumented test dummy's knees. After the test, there was no notable deformation in the pedestals or in the longitudinal metal floor beams to which the seat was attached (floor beams in single-car test deformed.) The aft-row seat cushions detached during the test. Figure 18 shows a post-test photograph of this experiment.

Figure 18. Experiment 1-2, Forward Facing Rows of Seats with Lap and Shoulder Belts, Leading Car, Post-Test

Experiment 1-3, Rear Facing Seat, Leading Car

Figure 19 shows the rear-facing unrestrained test dummies seated in the leading car. This experiment included three 50th percentile male test dummies. The seat in this experiment was an M-style Seat with the same modifications as the forward seat in experiment 2-1, which are illustrated in Figure 10. The modifications consisted principally of a stronger seat pedestal, and additional gussets on the wall mounting lugs.

The 50th-percentile test dummy in the aisle seat was instrumented with an upper neck load cell that recorded loads and moments that were below the respective injury criteria (See Table 5).

Figure 19. Experiment 1-3, Rear Facing Seat, Leading Car, Pre-Test

Table 5. Experiment No. 1-3 Rear Facing Seat, Leading Car, Occupant Injury Criteria Values

Injury Criteria	Hybrid III 50th-percentile, aisle seat occupant	
	Criteria	Recorded Loads
Neck Fx (lb)	+/-697	+278 (0.458 sec) / -46 (0.107 sec)
Neck Fz (lb)	+742/-900	+87/-33 (0.616 sec)
Neck My (ft-lb)	+140/-42	+10/-16

Minimal to no deformation occurred to the pedestal, and some deformation of the seat back occurred. Deformation occurred in the seat pan frame primarily on the aisle side. It appears that the stiffened pedestal acted as a pivot point about which the aisle side of the seat frame deformed. The aft-facing seat pan rotated toward the front of the car under the inertial loads of the test dummies. Some deformation of the seat back also occurred as it rotated toward the front of the car. Three photographs, taken from the side-view high-speed film, are shown in Figure 20.

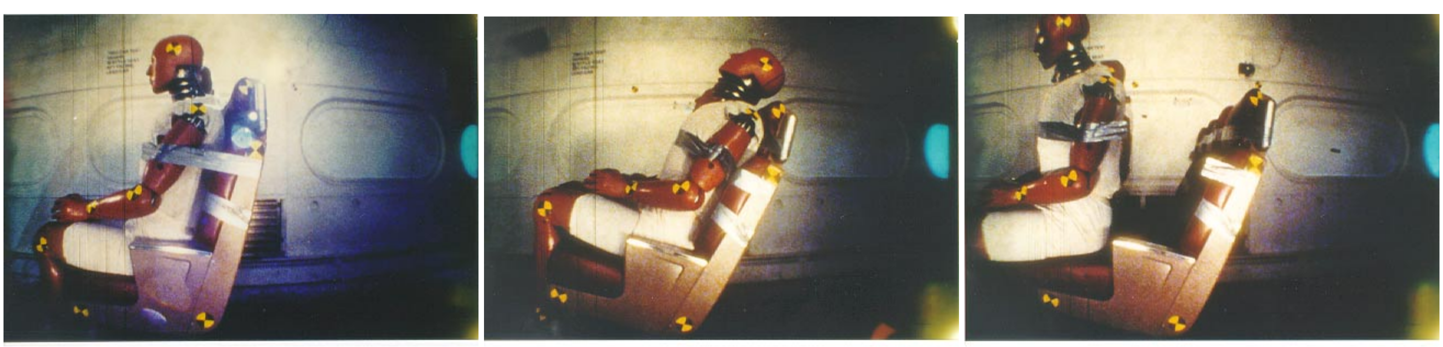

Figure 20. Time-Sequence for Experiment 1-3, Rear Facing Rows of Seats, Leading Car

All three 50th-percentile test dummies were found lying on the floor in front of the seat after the test was over. It is likely that these test dummies may have been found in their seats post-test if there had been a seat installed in front of them. Without the additional row of seats, the test dummies were able to fall to the floor after rebounding in their seat. Most of the test dummies' rebound was likely due to the seat releasing some of the energy it absorbed during the impact. Figure 21 shows a post-test photograph of this experiment.

Figure 21. Experiment 1-3, Rear Facing Rows of Seats, Leading Car, Post-Test

CONCLUSIONS AND FUTURE PLANS

A full-scale test of two coupled rail passenger cars was conducted, during which the occupant secondary collision environment was measured and the response of test dummies in selected interior configurations was measured. The lateral motions of the cars appear to have had little influence on the response of the test dummies. The vertical motions of the cars may have had an influence on the forward facing unrestrained test dummies seated in rows. In both these tests, the heads of the test dummies rose above the seatback ahead, allowing high neck loads. Such motions were not observed in previous sled testing of this interior configuration. This sled testing did not include the influence of the vertical and lateral motions of the car. Efforts are ongoing to simulate the influence of the lateral and vertical car motions on occupant response.

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