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TRAIN-TO-TRAIN IMPACT TEST: OCCUPANT PROTECTION EXPERIMENTS

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ABSTRACT

This paper describes the results of the occupant protection experiments included as part of the train-to-train impact test conducted at the Transportation Technology Center in Pueblo, Colorado on January 31, 2002. In this test, a cab car-led train, initially moving at 30 mph, collided with a standing locomotive-led train. The initially moving train included a cab car, three coach cars, and a trailing locomotive, while the initially standing train included a locomotive and two open-top hopper cars. The hopper cars were ballasted with earth such that the two trains weighed the same, approximately 635 kips each. The cars were instrumented with strain gauges, accelerometers, and string potentiometers, to measure the deformation of critical structural elements, the longitudinal, vertical, and lateral car body accelerations, and the displacements of the truck suspensions. As part of the test, the cars were equipped with instrumented test dummies seated 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. Forward-facing unrestrained occupant seated in the locomotive operator seat.

The longitudinal, vertical, and lateral motions of the cars during the train-to-train impact test are discussed in the paper, as well as their influence on the responses of the instrumented dummies. The lateral motions of the cars had some influence on the response of the test dummies, however the vertical motions of the cars had a greater influence on their response. During the test, the cab car overrode the locomotive. This large upward vertical motion of the cab car helped the test dummies in the cab car remain in their seats. The longitudinal motions of the cars during the train-to-train test had lower injury potential than the longitudinal motions of the cars in the previously conducted single- and two-car impact tests. (In these tests, a single car impacted a fixed barrier and two coupled cars impacted a fixed barrier, respectively. Test dummies were also included in both of these tests.) In the train-to-train test the test dummies endured a much longer crash pulse, with a lower average longitudinal acceleration than in the single-car and two-car impact tests. In the train-to-train test only one unrestrained test dummy landed in the aisle after impacting the seat in front of it. All injury criteria values remained below threshold values.

INTRODUCTION

The in-line tests were organized in order of increasing complexity, both in terms of the tests themselves and in terms of the information gathered. The first test was of a single car, the second test was of two coupled cars, and the third test was of two colliding trains [1]. Figure 1 shows schematics of the single-car test [2, 3, 4], the two-car test [5, 6, 7], and the train-to-train test, in which a cab-car-led train impacts a standing locomotive-led train. All of the tests included experiments to measure the response of test dummies in selected interior configurations. The objectives of the single-car test were to observe the failure modes of the major structural components, to measure the gross motions of the car, and to measure the force/crush characteristic. The two-car test had the added objective of measuring the interactions between the coupled cars. The train-to-train test further added the objective of measuring the interactions between the colliding locomotive and cab-car.

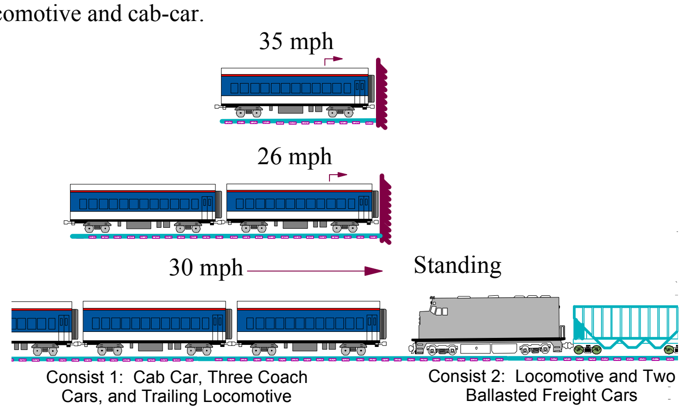

Figure 1. Schematic of Single Car, Two Car, and Train-to-Train Tests

Figure 2 shows schematics of the occupant-protection experiments included as part of the single-car, two-car, and train-to-train tests. Forward-facing commuter passenger seats, rear-facing commuter passenger seats, and forward facing inter-city passenger seats with lap and shoulder belts were tested in the single-car test and in the leading car in the two-car test. The trailing car in the two-car test also tested the forward-facing commuter passenger seats. Forward facing commuter passenger seats were tested in the cab car in the train-to-train test, as well as in the first coach car. Inter-city passenger seats with lap and shoulder belts in the first coach car and the operator's seat in the impacted locomotive were also tested. Test dummies were used in all the occupant protection experiments. The objective of these tests is to observe the kinematics of the test dummy, as well as to measure the test-dummy response and evaluate the potential for occupant injury.

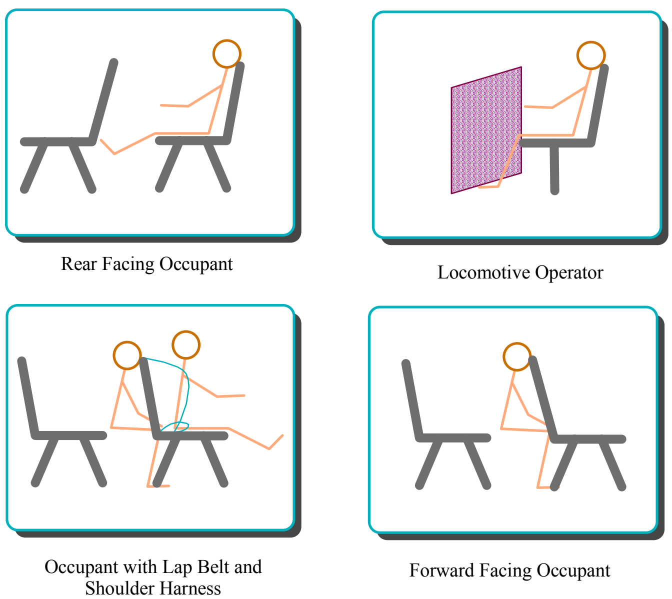

Figure 2. Schematics of Occupant Protection Experiments Included as Part of Fullscale Tests

Table 1 summarizes the critical measurements for each of the three in-line tests. While the overall objective of these tests is to demonstrate the effectiveness of improved-crashworthiness equipment, the test data are also being used for comparison with analyses and modeling results. The measurements will be used to refine these analyses' approaches and models, and to ensure that the factors influencing the response of the equipment and test dummies are taken into account. The table lists the measurements that are critical to ensuring the appropriate modeling and analysis of the equipment and test dummies.

Table 1. Test Descriptions and Critical Measurements

Test	Critical Measurement
Single-Car Test	Dynamic crush force Occupant volume deceleration Effectiveness of compartmentalization, rear-facing seats, and seats with lap and shoulder belts
Two-Car Test	"Sawtooth" lateral buckling of coupled cars Influence of trailing car on maximum occupant volume deceleration Effectiveness of compartmentalization, rear-facing seats, and seats with lap and shoulder belts
Train-to-Train Test	Override of colliding cars Lateral buckling of coupled cars Effectiveness of compartmentalization, and seats with lap and shoulder belts Measurement of operator secondary-collision environment and test dummy response

TRAIN-TO-TRAIN TEST

Interior experiments have been included in the in-line fullscale tests in order to observe the motions (kinematics) of the test dummies under collision conditions and to measure the forces and decelerations imparted to the dummies. Four occupant protection experiments were included as part of the train-to-train test. (The structural aspects of the train-to-train test are discussed in a companion paper [8].) Each of these experiments included instrumented test dummies, to make the measurements necessary to compute values for comparison with injury criteria. Load cells were used to measure the loads imparted to the seats during the test. Each occupant protection experiment also included two high-speed film cameras. The four occupant protection experiments were:

1. Test dummy in the operator's seat of the initially standing, impacted locomotive,
2. Test dummies unrestrained in forward facing rows of commuter passenger seats in the cab car,
3. Test dummies unrestrained in forward facing rows of commuter passenger seats in the first coach car,
4. Test dummies restrained by lap and shoulder belts in forward facing inter-city passenger seats in the first coach car.

Figure 3 shows the locations of the interior experiments inside the locomotive, cab car, and first coach car.

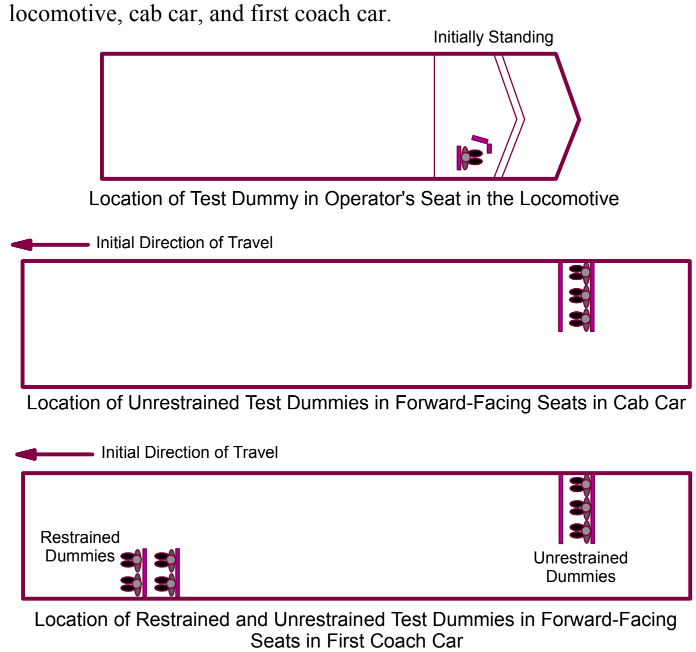

Figure 3. Locations of Interior Experiments

RESULTS OF OCCUPANT PROTECTION EXPERIMENTS

During the train-to-train test, for the unrestrained dummies in the forward-facing inter-city passenger seats in the first coach car, the vertical and lateral motions led to one dummy's head becoming wedged in between the sidewall of the car and the seatback ahead, and the adjacent test dummy being thrown into the aisle. For the unrestrained dummies in the forward-facing three-position commuter passenger seats in the first coach car, the vertical motions of the car resulted in the heads of the dummies missing the seatback ahead, and the chests impacting the seat. The unrestrained dummies in the forward-facing three-position commuter passenger seats in the cab car experienced a similar mode. The effects of the lateral and vertical motions of the cars on unrestrained occupants can cause them to impact the interior in an unfavorable manner, which can potentially lead to a greater likelihood of injury, even at a relatively low longitudinal deceleration. The injury criteria values computed from the test measurements all remained below NHTSA threshold values.

Occupant Environment

The longitudinal, vertical, and lateral decelerations of the cars, along with the interior features, make up the occupant environment during a collision. The average lateral and vertical decelerations are small compared with the longitudinal deceleration; however, the lateral and vertical decelerations have a strong influence on unrestrained test dummy response.

Figure 4 shows the longitudinal, vertical, and lateral decelerations of the cab car, measured near the trailing body bolster, i.e., close to the test dummies unrestrained in forward facing rows of commuter passenger seats. There are some variations to about 0.2 seconds, after which the character of all three measurements is similar. The longitudinal deceleration has the greatest peak, just above 20 G's, occurring before 0.1 seconds. The lateral deceleration has the lowest peak. The vertical deceleration's peak is nearly as great as the longitindal; this peak occurs about 100 milliseconds after the longitudinal peak and is associated with the suspension of the rear truck bottoming out as the cab car overrode the locomotive.

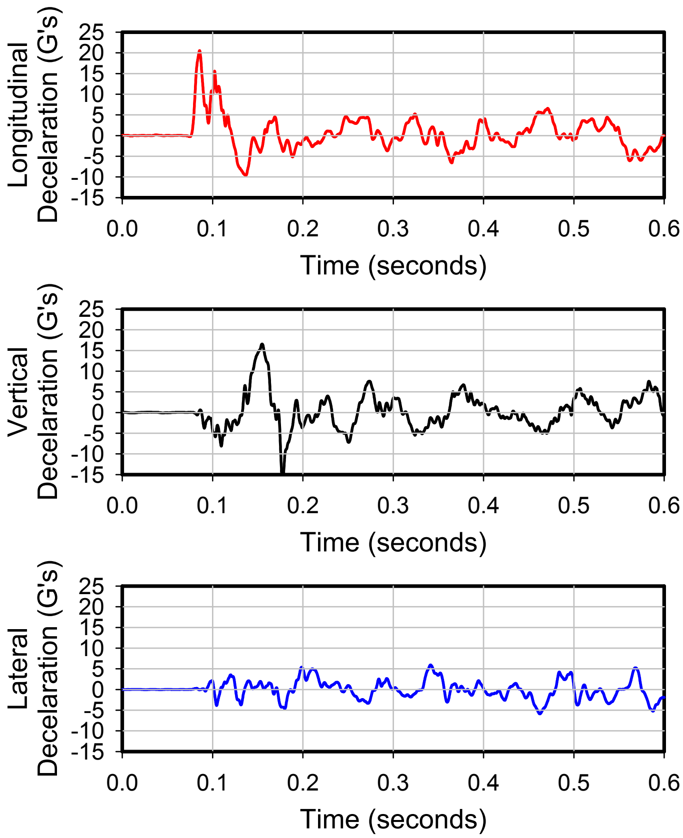

Figure 4. Longitudinal, Vertical, and Lateral Deceleration Time Histories, Cab Car Location C6

Table 2 lists the average decelerations for the first 0.6 seconds for the locomotive, cab car, and first coach car. The average longitudinal decelerations are largest, and are associated with the cab and first coach car slowing from 30 mph to approximately 15 mph, and the locomotive speeding up from approximately 0 to 15 mph. The average lateral and vertical decelerations are small because the net lateral and vertical displacements are small. The net vertical displacements are essentially zero, as are the net lateral displacements for the locomotive and first coach. The cab car did move vertically and laterally during the test, however, this lateral displacement was small compared with its longitudinal displacement.

Table 2. Average Longitudinal, Vertical, and Lateral Decelerations for the Locomotive, Cab Car, and First Coach Car

0.6 s Average Deceleration	Locomotive	Cab Car	First Coach Car
Longitudinal	0.71 G's	0.48 G's	0.55 G's
Lateral	0.12 G's	0.01 G's	0.42 G's
Vertical	0.01 G's	0.32 G's	0.10 G's

Figure 5 shows the longitudinal decelerations for the car in the single car test, the lead car in the two car test, the cab car in the train-to-train test, and the 8 G crash pulse that has been used in dynamic sled testing of passenger seats [9]. The peak longitudinal deceleration of the cab car in the train-to-train test was about half the peak deceleration of the car in the single car test and the lead car in the two-car test. The duration of the crash pulse is longest for the cab car in the train-to-train test and shortest for the car in the single car test.

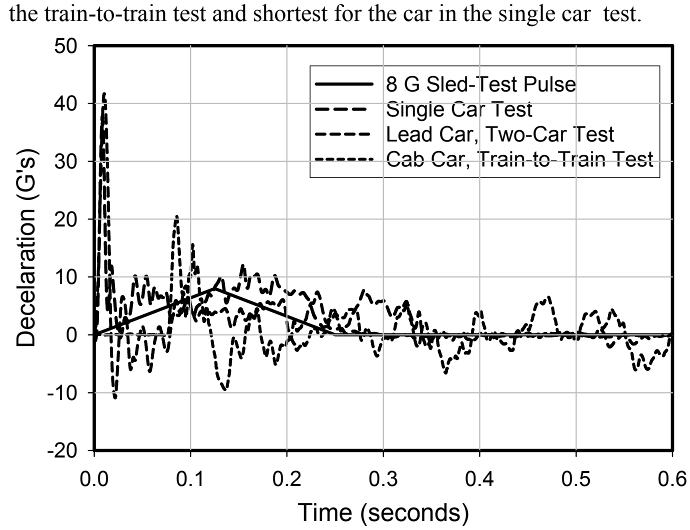

Figure 5. Longitudinal Deceleration Time Histories, Single-Car Test, Lead Car from Two-Car Test, Cab Car from Train-to-Train Test, and 8G Sled Test Pulse

It is difficult to make distinctions between the longitudinal deceleration time histories based only on the graph shown in Figure 5. From the figure it is not clear which is the most severe pulse, or if the 8 G pulse has any relationship to the test measurements. The deceleration-time history can contain high values for a very short duration, which have little influence on the occupant response, but can make a deceleration time history appear to be severe when it is not. Conversely, a deceleration-time history may have a relatively high average value, and relatively low peak value, appearing to be benign, when in fact it is severe. Secondary impact velocity gives some indication of the relative severity of the occupant environment, although it is an incomplete measure for an unrestrained occupant because it does not take into account vertical and lateral accelerations. The secondary impact velocity is the velocity at which an unrestrained occupant would impact the interior. The secondary impact velocity is computed from the deceleration-time history of the car, but provides a more appropriate means of comparison.

Figure 6 shows the velocity of an unrestrained occupant relative to the car, for the distance the occupant has traveled inside the car, for the single-car test, two-car test leading car, and the train-to-train test cab car. The plot shows that the occupant environment in the single car test was the most severe, and the environment in the train-to-train test was least severe. The 8 G crash pulse results in similar secondary impact velocities as the crash pulse measured in the single car test, for forward facing occupants seated with 2.0 to 2.5 feet to the seatback or bulkhead ahead of them. The 8 G crash pulse results in secondary impact velocities greater than those associated with the crash pulses measured in the two car and train-to-train tests.

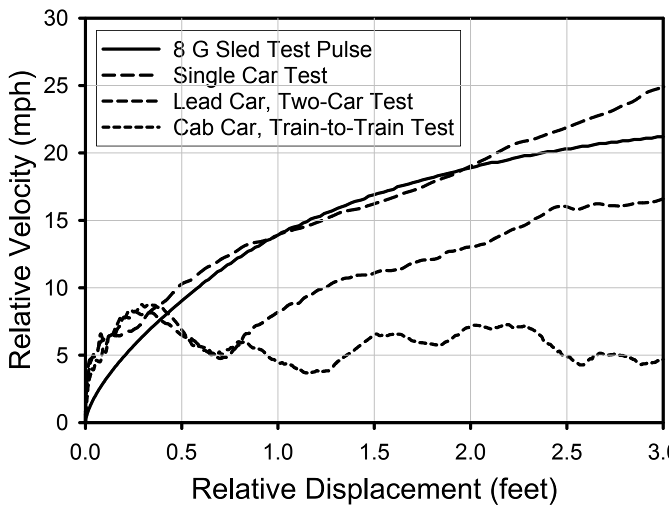

Figure 6. Secondary Impact Velocity, Single Car Test, Two-Car Test Leading Car, and Train-to-Train Test Cab Car, Computed from Test Measurements

Figure 7 shows the train-to-train test results for the secondary impact velocities for all of the cars in the cab car led consist, and the impacted locomotive. For all the cars and the impacted locomotive, the secondary impact velocities are all very similar. For the cab car led train, this similarity is the result of the structural crush being focused on the cab car. The weight of the locomotive-led train influenced the secondary impact velocity for the impacted locomotive. If the locomotive led train had been heavier than the cab car led train, then the secondary impact velocity would have been lower, and if the locomotive-led train had been lighter, than the secondary impact velocity would have been greater.

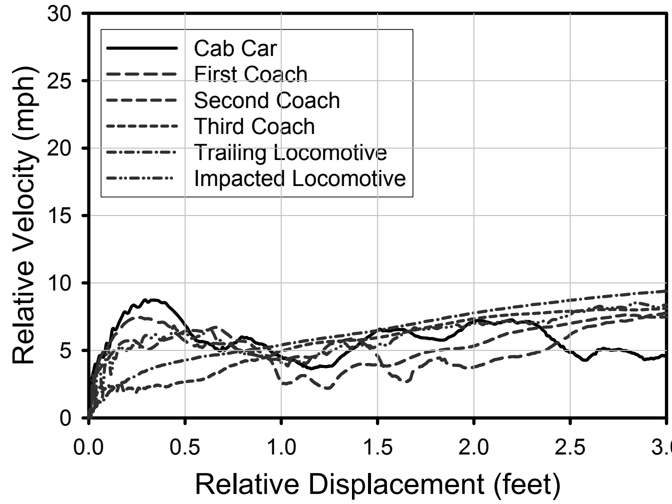

Figure 7. Secondary Impact Velocities, Cab Car Led Train and Impacted Locomotive, Train-to-Train Test

Occupant Protection Experiments

The test results presented in this section include a post-test description of each experiment, the seat outcome, and the test dummy outcome. These results were determined from the occupant kinematics recorded on film by the on-board cameras and from the loads recorded by the seat attachment load cells and instrumented test dummies. To interpret and evaluate the test dummy response measurements from the tests, occupant injury criteria are specified. These injury criteria values refer to a human response level, below which a specified significant injury is considered unlikely to occur for a given individual.

Test dummies were used to measure accelerations and loads, and load cells were used to measure loads between seats and their attachment structures. High-speed film (and video), still photographs, and records of the data were generated. Calculations from the data, such as the HIC calculations, were completed in accordance with SAE AS8049 [10]. The test dummy data collected includes:

- Head acceleration versus time (x, y, z)
- Chest acceleration versus time (x, y, z)
- Neck loads and moments versus time (x, y, z, and My)
- Axial femur loads versus time (where applicable)
- Shoulder belt loads (where applicable).

Table 3 lists the injury criteria to which the test data was compared. The head injury, chest, and femur criteria values used in this report are from the NHTSA Final Rule that modifies the Federal Motor Vehicle Safety Standard (FMVSS) Regulation No. 208, Occupant Crash Protection [11]. The neck injury Nij values are also taken from the FMVSS 208.

Table 3. Injury criteria

Test Dummy Percentile Size	5th (F)	50th (M)	95th (M)
Head Injury Criterion (HIC)	700	700	1,000
Neck Nij	Nij<1.0	Nij<1.0	Nij<1.0
Chest (G)	60	60	60
Femur (lb)	-1,530	-2,250	-2,594

Experiment No. L-1, Locomotive Operator's Seat

Figure 8 shows the interior experiment in the impacted locomotive, before the test. This experiment include a Hybrid III test dummy of 95th percentile male stature. None of the NHTSA injury criteria threshold values were exceeded for this dummy and the seat remained attached and intact.

Figure 8. Pre-test photo of Experiment No. L-1, locomotive operator seat

The seat used in this experiment was a Seats, Inc., pedestal mounted locomotive operator's seat. A photo of the seat is shown in Figure 9. Load cells were mounted between the seat pedestal and the floor. The adjustment range of the seat allowed lowering the seat to the appropriate level, even with the load cells between the base and the floor.

Figure 9. Locomotive operator, high-back seat, manufactured by Seats, Inc.

Upon initial impact, the test dummy slid forward in the operator seat, and the seat back followed the test dummy's forward motion. The test dummy continued to slide forward in the seat, even though the seat back stopped moving forward. The test dummy stopped sliding forward and reacted to some lateral acceleration by leaning toward the right window. At approximately 180 milliseconds, the test dummy's right shoulder contacted the window. At this point, the seat back rebounded forward, colliding into the back of the test dummy, and forcing the test dummy away from the window. The test dummy then slumped forward, the upper torso bending over, and the head traveling toward the console. There was no evident contact between the head or torso with the front interior of the locomotive. The test dummy did not rebound back into the seat after the collision, but rather stayed slumped forward in the seat. Table 4 lists the injury loads that were recorded for the test dummy in this experiment.

Table 4. Experiment No. L-1 Occupant injury loads

Criteria	95th-percentile Criteria Value	Test Dummy Loads
HIC	1,000	5
Neck Nij, Tens-Flex	Nij<1.0	0.044
Neck Nij, Tens-Ext	Nij<1.0	0.030
Neck Nij, Comp-Flex	Nij<1.0	0.048
Neck Nij, Comp-Ext	Nij<1.0	0.028
Chest (G)	60	5
Left Femur (lb)	-2,594	-304
Right Femur (lb)	-2,594	-86

A portion of the roof of the cab car intruded into the operator's cab of the locomotive during the test, through the forward window on the conductor's side of the cab. Figure 10 shows a time-sequence of photographs taken from a high-speed movie of this experiment. The middle frame, in the lower left, shows the roof intruding through the conductor's windshield. If the cab car had deflected to its right, rather than its left as it did in the test, it appears likely that a portion of the cab car roof would have intruded into the cab on the operator's side. If this had happened, there would have been contract between the roof and the test dummy, likely resulting in damage to the test dummy.

There was no damage or structural failure observed during the post-test evaluation of the seat. Nonetheless, the seat experienced considerable motion during the collision as both the seat and the test dummy reacted to the crash pulse, and the seat reacted to the moving test dummy. A slow-motion view of the film footage shows the seat back reacting first to the inertial loads by moving forward, and then rebounding back. When the seat back reaches its back stopping point, it moves forward again, this time colliding with the test dummy, which is rebounding backward. None of this activity appears to have caused any damage or seat failure.

Figure 10. Time-Sequence for Experiment L-1, Locomotive Operator's Seat

Experiment No. 1-1, Forward-Facing Commuter Rail Passenger Seats in cab car

Figure 11 shows the test dummies in the three-position commuter passenger in the rear of the cab car. The window-side and center test dummies were Hybrid II test dummies with 50th percentile male stature, while the aisle-side test dummy was a Hybrid III test dummy with a 50th percentile male stature. (One difference between the Hybrid II and Hybrid III dummies is the neck. The Hybrid III includes a flexible neck with load cells, while the Hybrid II does not. This difference can be seen in the before test photo in Figure 11.) The occupant loads in this experiment were measured from instrumentation installed inside the 50th-percentile Hybrid III test dummy. None of the NHTSA injury criteria threshold values were exceeded in this experiment during the test. The seats remained attached to the car, although some of the cushions detached.

The seats tested were M-Style seats currently in use by transit authorities such as Metro North Railroad, Long Island Railroad, Southeast Pennsylvania Transit Authority, Northern Indiana Commuter Transportation District, New Jersey Transit, and Maryland Rail Commuter. Coach and Car Equipment Corporation manufactured the M-Style seat. These seats have been previously dynamically sled tested in the same configuration [12]. Experiments with the same configuration were also included in the single car and two car tests [3, 6]. A schematic of the three-passenger M-Style commuter rail seat is shown in Figure 12.

Figure 11. Pre-test photo of Experiment No. 1-1, Forward-Facing Commuter Rail Passenger Seats in Cab Car

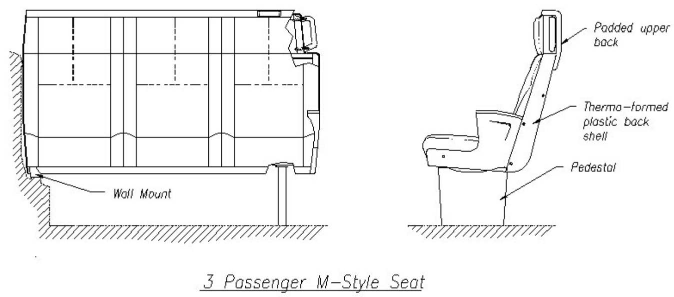

Figure 12. The M-Style Commuter Rail Passenger Seat, manufactured by Coach and Car Equipment Corporation, Inc.

Figure 13 shows a time-sequence taken from the high-speed film. Upon impact, the test dummies in this experiment slid forward along the seat pan cushion until their knees impacted the seat in front at approximately 76 milliseconds. At this time, the test dummies rose vertically upward while maintaining some forward momentum; allowing the head and upper torso to travel over the top of the seat back. At this point, the chest impacted the seat back (approximately 300 milliseconds) and the test dummies rebounded back into their seats, catching their chins on the top of the seat back (approximately 440 milliseconds). This interaction between the test dummies' chins and the top of the seat back forced their necks into extension, but not enough to exceed the injury criteria.

The test dummies returned to their seated positions before reacting to lateral loading which, at 500 milliseconds, caused them all to lean toward the window side of the seat. The aisle-side test dummy leaned so far laterally that its buttocks were completely lifted off of the seat. Once the collision pulse was over, the test dummies resumed fairly orderly seated positions. Table 5 lists the injury loads recorded for the aisle-side, 50th-percentile test dummy.

Table 5. Experiment No. 1-1Occupant injury loads

Criteria	50th Percentile Criteria Values	Test Dummy Loads
HIC	1,000	16
Neck Nij, Tens-Flex	Nij<1.0	0.130
Neck Nij, Tens-Ext	Nij<1.0	0.235
Neck Nij, Comp-Flex	Nij<1.0	0.047
Neck Nij, Comp-Ext	Nij<1.0	0.107
Chest (G)	60	6
Left Femur (lb)	-2,250	-183
Right Femur (lb)	-2,250	-43

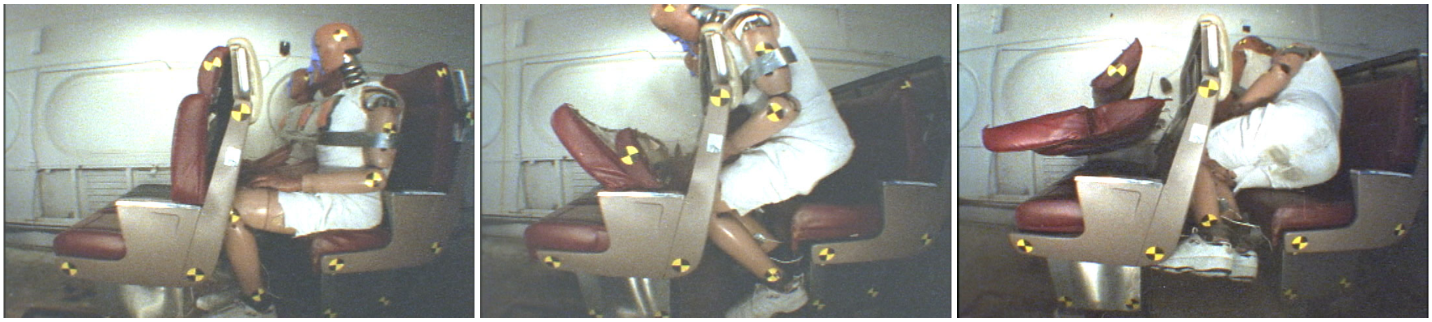

Figure 13. Time-Sequence for Experiment 1-1, Forward-Facing Commuter Rail Passenger Seats in Cab Car

There was no observable deformation in the aft-row seat; however, the back cushion in the aft-row detached from the frame. There also was no observable deformation of the frame in the front-row seat. The front-row seat and the floor attachments of the seat to the pedestal remained intact. The load cell attachment of the front-row seat to the sidewall remained intact. The seat back cushion on the front-row seat detached when the test dummies impacted the seat from behind.

The seats used for the row-to-row experiments were installed as manufactured at the time of purchase in late 1999. At that time, none of the production rail seats were designed to meet the FRA regulations that contain the new dynamic testing standards for seats. Plus, due to the delay in testing, the seats were left exposed to ultraviolet radiation while they were stored outdoors in the Arizona summer heat. This prolonged exposure to the sun may have caused the thermoplastic back panel to become more brittle than would normally have been expected. Figure 14 shows a post-test photograph of experiment 2-1.

Figure 14. Post-Test Photograph of Experiment 1-1

Experiment No. 2-1, Forward-Facing Inter-city Seats with and without Restraints

Figure 15 shows the test dummies in the forward-facing inter-city passenger seats, which were located in the leading end of the first coach car behind the cab car. The test dummies in the leading row were restrained with lap and shoulder belts and the test dummies in the trailing row were not restrained. The test dummy in the aisle-side seat of the leading row was of 5th percentile female stature, and the test dummy in the window-side seat was of 95th percentile male stature. Both dummies in the trailing row were of 95th percentile male stature. None of the NHTSA injury criteria threshold values were exceeded in this experiment.

Figure 15. Pre-test Photograph of Experiment No. 2-1

This experiment involved an inter-city seat modified with three-point restraints (there is no seat like the modified seat in service today). Amtrak provided the inter-city seats from their discarded, used-seat inventory. The inter-city seats used in this test were manufactured by AMI of Colorado Springs, Colorado. Simula modified the seats by replacing the seat back panel and strengthening the hinge-point between the seat pan and the seat back to increase the load-bearing capacity required by the lap and shoulder belts, as well as the load of the unrestrained occupants impacting the seat from behind. Energy-absorbing devices were also incorporated into the movable back of the modified seat to absorb some of the impact load. Figure 16 is a schematic showing the Amtrak seat modifications. The seats used in this test were previously used in both the single- and two-car impact tests, and refurbished again for the train-to-train test. Seat refurbishment included replacing both energy-absorbing devices, the seat back panel, the seat cushions, and the restraints with new components for this test.

The restrained occupants in the front row remained seated, and loaded their shoulder restraints at approximately 90 milliseconds. After loading their restraints, the test dummies notably leaned toward the window side of their seats in response to the lateral forces in the car. Both restrained test dummies were instrumented in the neck and both of them recorded loads that were below the respective injury criteria. Table 6 lists the injury loads recorded for the restrained 5th percentile female stature test dummy, and Table 7 lists the injury loads recorded for the restrained 95th percentile male stature test dummy.

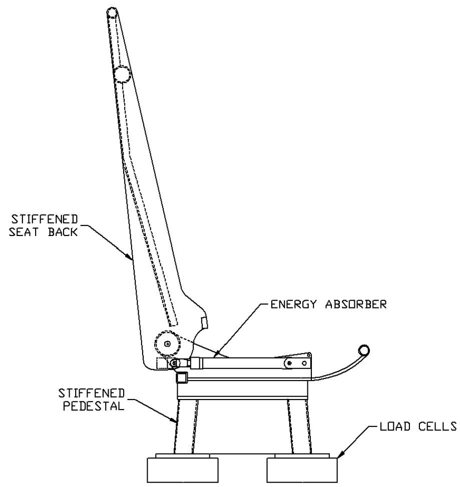

Figure 16. Sketch of Modifications Made to the Inter-city Seat

Table 6. Experiment No. 2-1 5th Percentile Test Dummy Loads

Criteria	5th Percentile Criteria Values	Test Dummy Loads
HIC	1,000	(not measured)
Neck Nij, Tens-Flex	Nij<1.0	0.137
Neck Nij, Tens-Ext	Nij<1.0	0.315
Neck Nij, Comp-Flex	Nij<1.0	0.137
Neck Nij, Comp-Ext	Nij<1.0	0.262
Chest (G)	60	(not measured)
Left Femur (lb)	-1,530	(not measured)
Right Femur (lb)	-1,530	(not measured)
Shoulder belt (lb)	N/A	477

The unrestrained test dummies did not begin to move forward until approximately 90 milliseconds after initial impact. The heads of the unrestrained test dummies impacted the seat in front first, before the knees did. The instrumented, aisle-side test dummy hit its head first against the seat back in front of it at approximately 400 milliseconds. The test dummy then rose vertically upward, leaving its head still stuck against the seat back, causing the neck to rotate in flexion. As this test dummy's head began to rebound off of the seat back, its knees impacted the seat back, and its head separated from the seat back, straightened forward, and then hit against the seat back again at approximately 650 milliseconds. The test dummy rebounded from the seat back, and then reacted to the lateral accelerations that caused it to land head-first onto the aisle floor at approximately 5.8 sec. Figure 17 shows a time sequence from a high-speed movie of experiment 2-1. The last frame shown in the figure shows the unrestrained aisle-side test dummy falling into the aisle. The test dummy measured its peak head acceleration at this time. This test dummy's chest never contacted the seat back. Table 7 lists the injury loads recorded for the unrestrained 95th percentile male stature test dummy.

Table 7. Experiment No. 2-1 95th Percentile Test Dummy Injury Loads

Criteria	95th Percentile Criteria Values	Unrestrained Test Dummy Loads	Restrained Test Dummy Loads
HIC	1,000	44	(not measured)
Neck Nij, Tens-Flex	Nij<1.0	0.101	0.085
Neck Nij, Tens-Ext	Nij<1.0	0.038	0.195
Neck Nij, Comp-Flex	Nij<1.0	0.287	0.096
Neck Nij, Comp-Ext	Nij<1.0	0.186	0.139
Chest (G)	60	5	(not measured)
Left Femur (lb)	-2,594	-599	(not measured)
Right Femur (lb)	-2,594	-76	(not measured)
Shoulder belt (lb)	N/A	(Unrestrained)	746

The unrestrained test dummy on the window side of the aft row slid forward in its seat as it leaned toward the center of the two seats in the front row. The test dummy's knees do not appear to have impacted the seat back in front of it. At approximately 400 milliseconds, the test dummy's head impacts the seat back. As the test dummy's torso follows, it pushes the test dummy's head and chin over the seat back at approximately 550 milliseconds. At 600 milliseconds, the head retracts back over the seat back and the test dummy rebounds toward the window side of the seat. The detached seat back cushions tended to force the test dummy toward the space between the wall and the front-row seat where, at 1,300 milliseconds, the test dummy's head gets wedged.

The forward motion of the front seat's back panel was greatly reduced from the previous two tests. The seat back motion that was observed was due primarily to the shoulder restraint systems pulling the seat backs forward as the occupants leaned into the restraints. None of the seat back motion was due to the unrestrained test dummies' knees; the test dummies' knees impacted the seat back very lightly late in the deceleration pulse. There was some seat back movement that could be attributed to the unrestrained test dummies' heads impacting the top of the seat back from behind. The aft-row seat cushions detached.

Figure 17. Time-Sequence for Experiment 2-1, Forward-Facing Inter-city Seats with and without Restraints

During the test, the dummy in the trailing row aisle-side seat fell into the aisle, and the head of the dummy in the window-side seat wedged in between the wall and the side of the seat ahead. The test dummies in the forward seat remained in their seats. Figure 18 shows a post-test photograph of experiment 2-1.

Figure 18. Post-Test Photograph of Experiment 2-1

Experiment No. 2-2, Forward-Facing Row-to-Row Commuter Seats

Figure 19 shows the test dummies in the forward-facing rows of a three-position commuter seat in the trailing end of the first coach car behind the cab car, before and after the test. The arrangement of this experiment was the same as the arrangement of the experiment in the cab car; the window-side and center test dummies were Hybrid II test dummies with 50th percentile male stature, while the aisle-side test dummy was a Hybrid III test dummy with a 50th percentile male stature. Like the experiment in the cab car, review of the high-speed movies taken during the test does show that the heads did rise over the seatbacks during the test, with the chests impacting the top of the seat backs. In addition, the backs of the heads of the dummies were struck by the headrest pad, caused the greatest neck loads in this experiment.

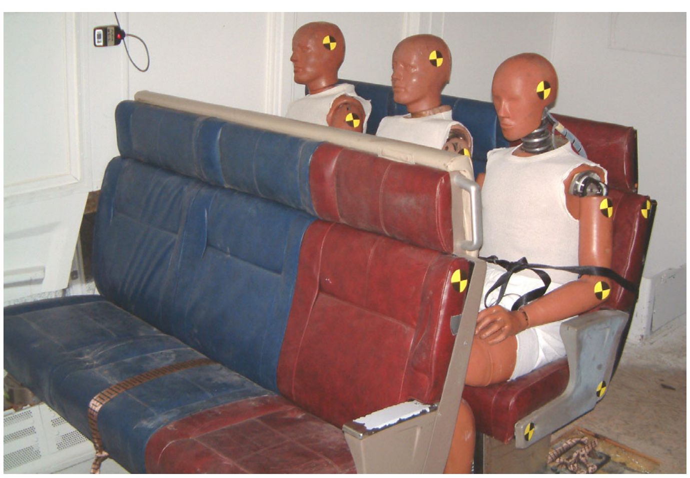

Figure 19. Pre-test Photograph of Experiment No. 2-2

The occupant loads in this experiment were measured from instrumentation installed in the 50th-percentile Hybrid III test dummy seated in the aft row in the aisle seat. This test dummy slid forward in the seat until its knees impacted the seat back at approximately 100 milliseconds. After knee impact, the test dummy rebounded, never hitting its head against the seat back. Instead, as the test dummy rebounded back into the seat, the detached headrest impacted the test dummy's head from behind. As the aisle-side test dummy rebounded, the window- and middle-seat test dummies wedged the headrest between them and the seat back, forcing the aisle-side test dummy to impact the headrest two times. The blow to the head from behind then forced the test dummy forward again, where it ultimately came to rest with its head against the seat back in front. Unfortunately, the side-view camera of this experiment did not capture any footage of this experiment due to camera failure upon impact. The front view camera did work, and Figure 20 shows a time sequence taken from the film recorded with this camera. The first frame shows the detached headrest, and the middle frame shows the headrest impacting the aisle-side dummy in the back of the head. The influence of the car lateral accelerations can be seen in the middle and last frames in the figure. In the middle frame, the test dummies are moving toward the wall, and in the last frame the dummies are moving toward the aisle. Table 8 lists the injury loads recorded for the instrumented test dummy.

Table 8. Experiment No. 2-2 Occupant Injury Loads

Criteria	50th Percentile Criteria Values	Test Dummy Loads
HIC	1,000	10
Neck Nij, Tens-Flex	Nij<1.0	0.133
Neck Nij, Tens-Ext	Nij<1.0	0.073
Neck Nij, Comp-Flex	Nij<1.0	0.177
Neck Nij, Comp-Ext	Nij<1.0	0.056
Chest (G)	60	5
Left Femur (lb)	-2,250	-185
Right Femur (lb)	-2,250	-179

There was no observable deformation in the aft-row seat. The seat back cushion and the headrest cushion detached from the frame and appear to have impacted the aisle-side test dummy's head from behind, causing the maximum neck flexion moment. The front-row seat did not deform, and the seat cushions detached when the knees from the test dummies behind penetrated the shroud cover on the seat back. The floor load cell attachments remained intact between the pedestal and sidewall mounts.

SUMMARY AND CONCLUSIONS

Four interior experiments were performed as part of a train-to-train impact test. During this test, a moving cab car-led train impacted a standing locomotive-led train. Test dummies were included in the locomotive, the cab car, and in the first coach car. The locomotive test dummy was seated in a conventional locomotive seat and not restrained. The test dummies in the cab car were seated in a forward facing three-place commuter seat, and also not restrained. Restrained test dummies were included in modified inter-city passenger seats in the first coach car. Unrestrained dummies were seated behind the restrained test dummies. Also included in the first coach car were unrestrained test dummies seated in a forward facing three-place commuter seat. None of the NHTSA injury criteria threshold values were exceeded in any of the experiments, and the seats remained attached in all the experiments, although seat cushions did detach in some of the experiments.

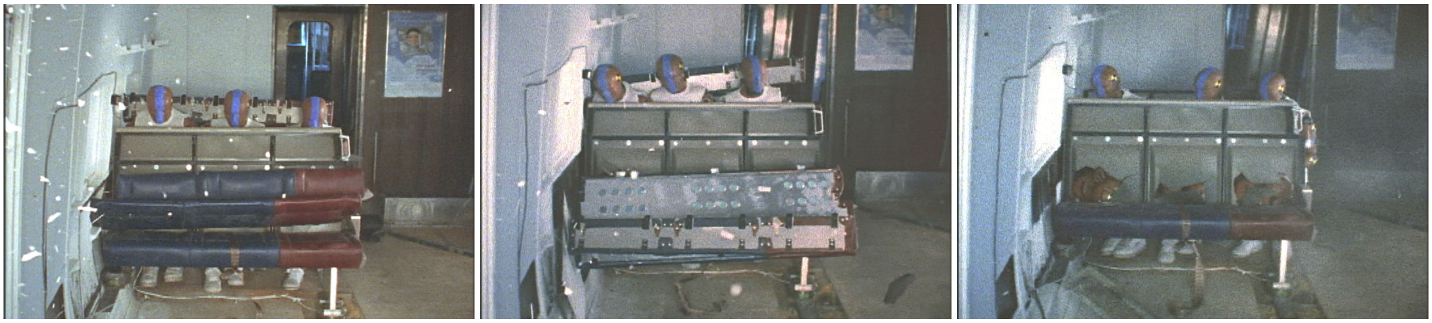

Figure 20. Time-Sequence for Experiment 2-2, Forward-Facing Commuter Rail Passenger Seats in First Coach Car

The results of these test show that the influence of the lateral and vertical car motions is greater than previously assumed. The kinematics of the unrestrained test dummies in the forward facing three-place commuter seats in both the cab and first coach car were significantly different from the kinematics of similarly placed dummies during dynamic sled tests. This difference in kinematics is attributable to the lateral and vertical motions of the cars in the train-to-train test.

The seatbelts were effective in limiting the motions of the restrained dummies. One of the unrestrained dummies seated in the intercity passenger seat had its head wedged in between the seatback ahead and the car sidewall. The other dummy landed in the aisle. The restrained dummies remained in their seats. The injury criteria values remained below threshold values for both restrained and unrestrained dummies.

The forces and decelerations imparted to the test dummy in the locomotive operator's position were within survivable limits, and the kinematics of the test dummy do not appear to be threatening. However, a portion of the roof of the cab car penetrated the locomotive through the conductor's side windshield; if the operator's side windshield had been penetrated instead, it is likely that there would have been damage to the test dummy.

A large amount of data has been gathered from the occupant protection experiments conducted as part of the single-car, two-car, and train-to-train fullscale tests. Plans are being developed to synthesize this data, along with data gathered from previously conducted sled tests of rail passenger seats. The data measured in the fullscale tests will be compared with simulation model predictions, used to evaluate the influence of the lateral and vertical car motions, seat position inside the car, and occupant size on occupant response, and to evaluate current rail passenger seat sled-test procedures. The test data will also be used to develop and evaluate potential modifications to rail passenger seats to improve the effectiveness of compartmentalizing occupants during impacts.

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