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Occupant Protection Experiments in Support of A Full-Scale Train-to-Train Crash Energy Management Equipment Collision Test

Office of Research
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Washington, DC 20590

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Final Report
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13. ABSTRACT (Maximum 200 words)
The Federal Railroad Administration sponsored a full-scale train-to-train crash energy management (CEM) technology test that was conducted on March 23, 2006, at the Transportation Technology Center in Pueblo, Colorado. The Volpe National Transportation Center directed and coordinated the contractors who implemented the test and developed the technical requirements for the test, including the conditions, the equipment tested, and the measurements made. This report describes the installation details and the results of the five occupant protection experiments conducted as part of Task Order Contract DTR S57-04-D-30008/TO6. The five experiments were conducted on board two commuter rail cars as part of the full-scale train-to-train CEM equipment collision test.

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Occupant protection, train-to-train, full-scale, strain gage, accelerometer, occupant configurations, head-on collision, Crash Emergency Management (CEM), Anthropomorphic Test Devices (ATDs), seat configuration loads, accelerations, displacements.

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

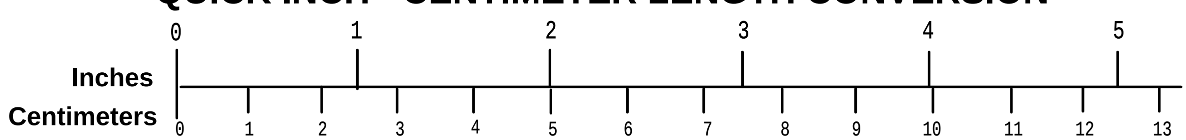
VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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Preface

The work described in this report was performed as part of the Federal Railroad Administration's rail equipment crashworthiness research under contract with the Volpe National Transportation Systems Center (Volpe Center). David Tyrell, Senior Engineer at the Volpe Center, managed the program. Daniel Parent and Kristine Severson, Project Engineers at the Volpe Center, developed the test requirements. This report describes the results of occupant protection experiments conducted on board during a full-scale train-to-train crash energy management collision test.

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Executive Summary

A full-scale train-to-train collision test of crash energy management (CEM) equipment was conducted on March 23, 2006, at the Transportation Technology Center (TTC) in Pueblo, Colorado. The CEM passenger train was subjected to a head-on collision with a stationary locomotive-led train at a speed of 30.8 mph. One of the objectives of this test was to carry out a number of occupant protection experiments that were placed on the first two cars of the cab car-led consist comprising five passenger cars and a locomotive.

Five occupant protection experiments were conducted. Two of these experiments tested the crashworthiness performance of a newly designed commuter seat. Another two tested the crashworthiness performance of a newly designed crushable workstation table between facing seats. The fifth experiment tested the crashworthiness performance of modified intercity seats. Each experiment included instrumented Anthropomorphic Test Devices (ATDs), measurement of occupant impact loading parameters, and high-speed digital cameras and lights to capture the occupant kinematics during the collision. Crashworthiness performance was based upon occupant compartmentalization and injury measurements. Ideally, the seats and tables should remain attached to the car body, the ATDs should be compartmentalized between rows of seats or between the seat and table, and the injury criteria calculated for the head, chest, neck, femur, and abdomen should be below accepted threshold values. The results of these experiments are summarized in Table 1.

Three of the five experiments were conducted in the lead cab car (#9357). The experiments tested the following components:

- Experiment 1.1–Rear-facing newly designed commuter passenger seat,
- Experiment 1.2–Facing-seat pairs with newly designed workstation table and H3RS ATD, and
- Experiment 1.3–Facing-seat pairs with newly designed workstation table and THOR ATD.

Two experiments were conducted in the first coach car (#9358):

- Experiment 2.1–Forward-facing intercity passenger seat, and
- Experiment 2.2–Forward-facing newly designed commuter passenger seat.

Table 1. Summary of Experiment Results

Experiment No.	Experiment Description	Structural Crashworthiness Performance of Equipment	Injury Criteria Met?	ATDs Compartmentalized?
1.1	Rear-Facing Commuter Seat	Seat attachment failed at base of pedestal	Yes	No
1.2	Crushable Table between Facing Seats with Hybrid 3RS	Table crushed as designed to 6.125 in	Yes	Yes
1.3	Crushable Table between Facing Seats with THOR	Table crushed as designed to 4.75 in	Yes	Yes
2.1	Forward-Facing Intercity Seat	E/A actuated as designed by 0.75 in	No	Yes
2.2	Forward-Facing Commuter Seat	Seat attachment partially failed at base of pedestal	Yes	Yes

1. Introduction

The Federal Railroad Administration sponsored a full-scale train-to-train crash energy management (CEM) technology test. The Volpe National Transportation Systems Center (Volpe Center) directed and coordinated the contractors who implemented the test. The Volpe Center also developed the technical requirements for the test, including the conditions, the equipment that was tested, and the measurements that were made..

This report describes the installation details and the results of the five occupant protection experiments conducted as part of Task Order Contract DTR S57-04-D-30008/TO6 on board two commuter rail cars as part of the full-scale train-to-train CEM equipment collision test. The test was conducted on March 23, 2006, at the Transportation Technology Center (TTC), a U.S. Department of Transportation test site located in Pueblo, Colorado. TIAX, LLC, and its subcontractors, Armor Holdings Aerospace & Defense Group, CVID Consulting Services, GMH, and Itronx (the TIAX team), coordinated the occupant protection test effort in collaboration with Transportation Technology Center, Inc. (TTCI), the operating manager of TTC, who was responsible for the overall coordination of the collision test (the structural portion in particular). The structural portion of testing included preparing the cars and their strain gage and accelerometer instrumentation, and reporting the measurements made with such instrumentation.

The five experiments included two commuter seat experiments, two crushable table experiments, and one intercity seat experiment. The TIAX team provided technical services and support as the occupant protection contractor. In this role, the TIAX team's major duties included setting up and preparing the car interiors and their table/seat/occupant configurations, and reporting the data produced by the Anthropomorphic Test Devices (ATD) as well as the selected table and seat configuration loads, accelerations, and displacements.

2. Program Objectives

The objective of this program was to implement the five occupant protection experiments described in the test requirements document provided by the Volpe Center as part of the full-scale train-to-train CEM equipment collision test task order request (TOR) for proposals. The five experiments were conducted on the first two cars of a cab car-led consist of five cars equipped with CEM crush zones and a locomotive. This consist was subjected to a head-on collision with a stationary locomotive-led consist at a speed of 30.8 mph. Figure 1 shows a pretest photograph of the CEM equipment.

Figure 1. Pretest Photograph of the CEM Passenger Train

As a part of this effort, the TIAX team's responsibilities included:

- Installation of the interior table and seat configurations and other components for the test,
- Coordination with the government for the instrumented ATD types (provided as government-furnished equipment [GFE]), GFE seats, and instrumentation,
- Planning, preparation, and execution of the occupant protection experiments, and
- Reporting the occupant protection data gathered during the test.

The data reported describe the occupant environment during the test and the corresponding occupant dynamics and injury likelihood. The objectives of the test included measurement of the secondary collision environment, such as the vertical, lateral, and longitudinal accelerations of the occupant volume at selected locations in the cars and determination of the effectiveness of each seat and table configuration in protecting the occupants.

3. Test Information

Five occupant protection experiments conducted. Two experiments examined the crashworthiness performance of a newly designed commuter seat. Two experiments examined the crashworthiness performance of a newly designed crushable workstation table between facing seats. One experiment examined the crashworthiness performance of previously modified intercity seats. Each experiment included instrumented ATDs, measurement of occupant impact loading parameters, and high-speed digital cameras and lights to capture the occupant kinematics during the collision. Three of the five experiments were conducted in the lead cab car (#9357). The experiments tested the following components:

- Experiment 1.1–Rear-facing newly designed commuter passenger seat,
- Experiment 1.2–Facing-seat pairs with newly designed workstation table and H3RS ATD, and
- Experiment 1.3–Facing-seat pairs with newly designed workstation table and THOR ATD.

Two experiments were conducted in the first coach car (#9358):

- Experiment 2.1–Forward-facing intercity passenger seat, and
- Experiment 2.2–Forward-facing newly designed commuter passenger seat.

Figure 2 illustrates the locations of the five occupant protection experiments.

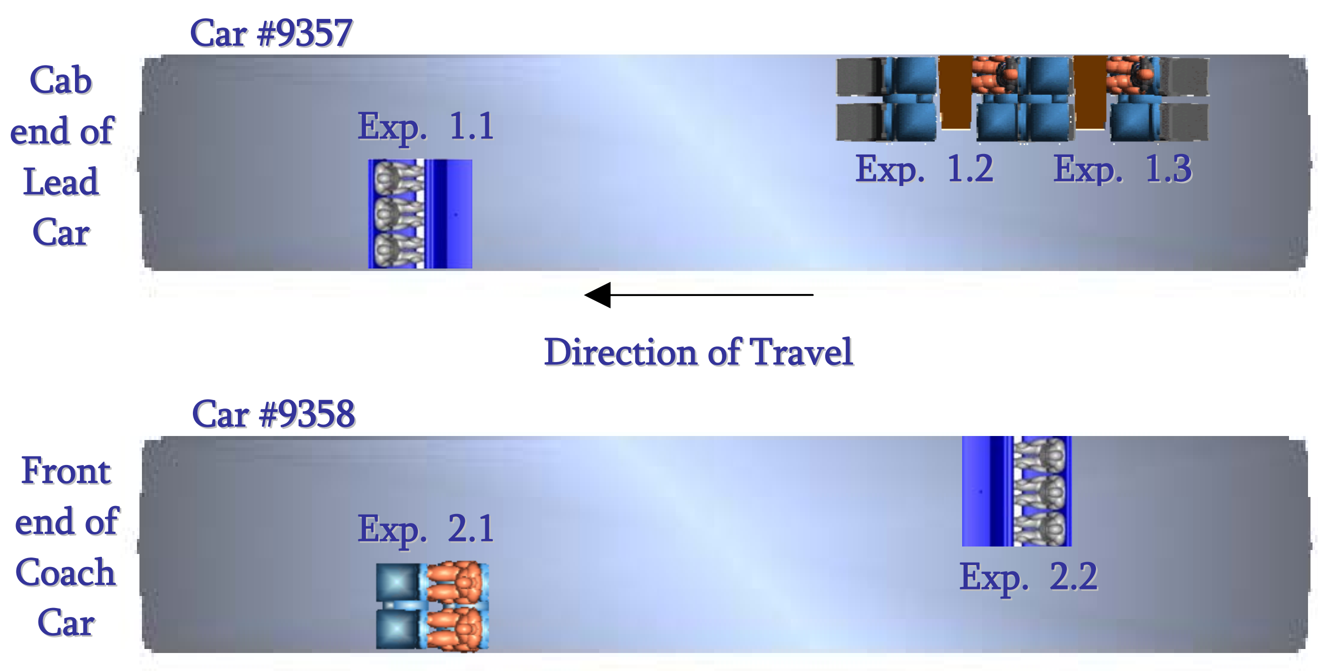

Figure 2. Schematic Showing the Locations of the Five Occupant Protection Experiments

3.1 Seat and Table Installation

The placement of each experiment was determined based on the location of structural attachment areas of the car, the location of the cameras (which were mounted on a heavy structure between the windows for the side views), and avoiding interferences (both structural and with instrumentation) on the car's floor, walls, and ceiling. All references to seat locations are made with respect to their positions in the rail car.

In general, for each experiment, steel bars were welded onto structures in the walls and the floor of the car to provide locations for mounting seat/table/load-cell attachments and to allow access to other structures as required. An existing mountable structure was not available as in previous full-scale tests due to the broad spacing between the structural beams in the floor of the rail cars. For example, the spacing between the 4.25-inch hat sections and the 1.5-inch right-angle sections was 2.5 ft, limiting the structural integrity of a steel bar bolted to these sections. Therefore, steel bars (6-inches wide x 3/8-inches thick) were welded onto these stringers (hat sections and right-angle sections) in the floor to provide a mountable structure for the seats. Steel load-cell adapter plates (4-inches wide x 0.75-inches thick) and attachment plates were then match-drilled to these welded bars and bolted in place. For each load cell, four 0.5-inch grade 8 bolts were used to mount the load-cell attachments to the bars. A 0.50-inch-thick backing plate was used to secure the bolts wherever possible. The seats were then mounted to these steel plates. A false floor was then installed for each experiment to raise the feet of the ATD to the same level that each seat base was installed. Because of the additional mounting hardware, the floor in each experiment was raised, requiring the feet of the ATD to be raised as well.

3.2 Data Acquisition

In total, the experiments (including the ATDs) used 23 accelerometers, 10 displacement transducers, and 36 load cells. Together, these sensors required a data acquisition system that collected data from 155 data channels. Appendix A provides the instrumentation matrix that was used to track the data acquisition requirements.

To collect 155 channels of data, 20 calibrated data bricks were installed, each with the capability of acquiring up to eight channels. Each data brick was set to acquire data for a minimum of 0.1 second (s) before impact and 4 s after impact. A class 1,000 anti-aliasing presample filter and a minimum sample rate of 10 kHz were selected to collect data in accordance with the Society of Automotive Engineers (SAE) J211/1, Revision March 1995, Sections 9.1 and 9.2. Table 2 lists the instrumentation and filter classes that were used. All transducers that were used were calibrated within the 12-month period before the test.

Of the 155 data channels that were set up, 152 successfully recorded and downloaded data. Information will be provided in later sections on the channels that failed to record.

Table 2. Instrumentation and SAE J211 Filter Classes

Instrumentation	Filter Class
Rail Car Accelerations	60
ATD Head Accelerations (x, y, and z)	1000

Upper Neck Transducer–Forces	1000
Upper Neck Transducer–Moments	600
Chest Accelerations (x, y, and z)	180
Femur Axial Loads	600
Table Attachment Loads (x, y, and z)	60

3.3 Lights and Cameras

Rugged fixtures were fabricated and installed inside the rail cars to support the lights and cameras. The light arrays were custom-fabricated on site using a combination of unistrut and slotted-steel angle iron and were bolted and welded as required to hard-point structures on the walls and ceilings. The lights and cameras were mounted in predesignated areas to best capture the response of the seat/table configurations and the ATDs during impact.

A total of 11 high-speed cameras were used for the occupant experiments. Each experiment was installed with two high-speed digital cameras, one providing an overhead view and one providing a side view. An additional camera was installed to provide a combined front view of the two workstation table experiments (Experiments 1.2 and 1.3). The video cameras operated at a rate of 500 or 1,000 frames per second and were set to record 0.5 s before impact and up to 4 or 6 s after impact. The high-speed video cameras and the accompanying strobe lights used to indicate barrier impact were triggered using closure switches (tape switches). These were installed on the leading cab car's coupler and triggered when this coupler made initial contact with the coupler of the stationary locomotive. Table 3 describes the cameras that were used and the parameters for each.

All of the cameras were DC-powered with 12-volt batteries. One battery with an operational life of 5.6 hours powered the two cameras for Experiment 1.1. Two batteries powered the five cameras for Experiments 1.2 and 1.3: one, with an operational life of 6.0 hours, powered the front-view and two overhead cameras, and the other, with an operational life of 6.4 hours, powered the two side cameras. One battery with an operational life of 3.6 hours was used to power the four cameras installed for Experiments 2.1 and 2.2.

Seven of the 11 cameras that were installed collected data effectively. Appendix B provides a report explaining the failure of the remaining four cameras. These camera failures resulted in a complete loss of footage for Experiment 2.1 (the forward-facing intercity passenger seat).

One hundred-eighty 12-volt DC-powered floodlights (each 100 watts) provided the lighting for the experiments. Each experiment was equipped with 36 lights: 12 overhead lights and 24 side-mounted lights. The power source for each group of 12 lights consisted of a 12-volt DC battery and a trigger circuit containing three solid-state trigger relays (one relay for each set of four lights) and a trip that, when opened, supplied voltage to all 12 lights. The trigger circuit and the 12-volt battery were mounted together on a fixture located as close as possible to each light array. A total of 15 of these systems were refurbished from previous tests and installed in the rail cars. Each battery pack was individually tested for all 12 lights by simultaneously tripping all three of its trigger relays. The cabling from the light arrays to the power supplies was carefully routed and secured in a manner to prevent them from being damaged before or during the test.

The trigger/relay cabling was installed from the lights to the side of each car. The lights were switched on manually before the train left its starting point. This approach is different from that used in previous tests in which the lights were automatically switched on just seconds before impact while the train was traveling down the track. (A blade was strategically positioned on the side of the track to break the wire circuit on the rail car as it passed by, turning on the lights.) The lights were switched on manually at the starting point of this test because the cameras did not need to be triggered before impact as they were in previous tests. Since the cameras used in this test were all digital and did not require spool-up before impact as is the case with film cameras, they could be triggered immediately upon impact. The battery power for the lights lasted at least 15 minutes, which easily provided enough time for them to remain lit during the experiment. All lights were successfully turned on and stayed on during impact.

Table 3. Camera Information

Experiment	View	Camera	Lens (mm)	F-stop (Aperture)	Shutter Speed (1/s)	Frame Rate (fps)
1.1–Rear-Facing	Side	Ultima APX-1 Color	12.5	2.8 (8.0)	1/1500	500
	Overhead	Ultima 512-1 Mono	4.8	1.8	1/4500	500
1.2–Facing-Seat H3RS	Front	Ultima APX-RS-1 Mono	25.0	5.6	1/2000	500
	Side	Ultima APX-RS-2 Color	12.5	1.4	1/1500	1000
	Overhead	Ultima 512-2 Mono	4.8	1.8	1/2000	1000
1.3–Facing-Seat THOR	Side	Ultima APX-RS-3 Mono	12.5	5.6	1/3000	1000
	Overhead	Ultima 512-3 Mono	4.8	Wide open	1/2000	1000
2.1–Intercity Seats	Side	Ultima APX-2 Color	12.5	2	1/1000	1000
	Overhead	Ultima 512-4 Color	4.8	1.8	1/2000	1000
2.2–Forward-Facing	Side	Ultima 512-5 Color	7.5	1.2	1/1000	500
	Overhead	Ultima 512-6 Color	4.8	Wide open	1/1000	500

3.4 ATDs

Ten ATDs were used to evaluate occupant response characteristics. All ATDs were generously provided as GFE for the test. ATDs were in accordance with Title 49 Code of Federal

Regulations Part 572, Subparts B & E, and positioned in their seats in accordance with SAE AS8049. The ATDs were equipped with the required accelerometers, load cells, and displacement transducers. The ATDs were delivered directly to TTC from the following sources:

Vehicle Research and Test Center (VRTC)/National Highway Traffic Safety Administration (NHTSA):

- Four Hybrid III 50th percentile (instrumentation provided by VRTC),
- Two Hybrid III 95th percentile (instrumentation provided by VRTC), and
- Two Hybrid II 50th percentile (not instrumented).

Rail Safety and Standards Board (RSSB) in the UK:

- One Hybrid 3RS (instrumentation provided by GMH).

GESAC:

- One THOR (instrumentation provided by GESAC, arms and legs provided by GMH, femur load cells provided by Armor Holdings).

Before the ATDs were positioned in the cars, they were given a functional check to ensure proper joint motion during the test. The ATDs in each experiment were clad in tight-fitting white stretch garments with shoes.

Once the ATDs were installed at the correct locations for each experiment, the cables linking the ATD transducers to the data acquisition systems were bundled together to form an umbilical cable that was routed down the ATD's back, along a leg to a knee, and then away from the ATD. Damage to the cables was avoided by tethering the ATDs to an attachment structure that was welded to the floor, thereby restraining the ATDs before they reached the end of the instrumentation umbilical cables or contacted other, unrelated test equipment/instrumentation. The tethers allowed enough slack so as not to interfere with the action of the ATDs. The ATDs in the experiments that were equipped with tables were not tethered.

Yellow and black 3-inch-diameter targets were placed on the ATDs at points of interest, including the head, shoulders, knees, and ankles. Just before the test, the ATDs were individually secured with duct tape to their respective seats to prevent their inadvertent movement while the rail cars approached the stationary locomotive during the test. To do so, duct tape was wrapped around the seat back and across the chest region of each ATD in each experiment. The duct tape was wrapped around both ATDs in the intercity seat experiment (Experiment 2.1). To ensure that this tape wrap released upon impact, it was notched with a 1-inch cut between the ATDs and the seats.

To determine if and at what location the ATDs contacted the interior of the cars during the impact, a light coat of transfer chalk was applied to specific areas of the ATDs. Three colors were used to represent different ATD body locations: blue chalk was used to apply a 2-inch stripe to the forehead, orange chalk to apply a 6- x 8-inch patch to the chest region, and red chalk to apply a 2-inch stripe to the knees and shins.

4. Experiments

This section describes the objective and configuration of each experiment, along with the installation details, including information about the data acquisition equipment, lights, cameras, and ATDs.

4.1 Experiment 1.1: Rear-Facing Commuter Seats

4.1.1 Objective

This experiment was designed to evaluate the crashworthiness performance of a newly designed version of the commuter seat with improved force/deflection. The experiment was intended to:

- Measure the injury criteria from the instrumented ATDs,
- Verify that the rear-facing commuter seat configuration can withstand secondary impact without significant structural failure,
- Verify if the ATDs remain compartmentalized, and
- Record ATD motion with a high-speed digital video camera.

4.1.2 Configuration

The interior configuration consisted of two rear-facing, newly designed, three-passenger commuter seats located in the forward left-hand-side of the lead cab car. The seats were designed with higher backs and a stiffened tubular frame to provide more energy-absorbing capability during impact. CR Safguard™ fire-resistant cushioning was incorporated. The seat design was the same as that used in Experiment 2.2 (forward-facing, newly designed commuter passenger seats). The seat pitch was set at 32 in. Seat-mounting hardware was consistent with in-service hardware. Three ATDs were used in this experiment: two instrumented Hybrid III 50th percentile ATDs were seated in the aisle and window positions, and one uninstrumented Hybrid II 50th percentile was seated in the middle position. The ATDs were seated in the forward-most seat relative to the front (cab) end of the car. The seat located behind the occupied seat (relative to the cab end of the car) remained unoccupied. Figure 3 illustrates the location of the experiment. Figure 4 shows a pretest photograph of the experiment.

4.1.3 Installation

Seat Attachment to Floor: A steel bar measuring 96 x 6 x 0.375 in was welded to the stringers in the floor of the car, spanning two 4.25-inch-wide hat sections and two 1.5-inch-wide right-angle sections. A 70.75 x 4 x 0.75-inch attachment plate was bolted onto the welded bar with four pairs of bolts along its length. For the occupied front-row seat, two load cells were bolted onto the attachment plate. For the unoccupied rear-row seat, two spacer blocks were bolted onto the attachment plate. The spacer blocks were used to keep the aft-row seat the same height as the front-row seat. The bolt holes in the attachment plate were predrilled so that the spacing between the seats was 32 in when installed. Two rows of seats were then bolted at the bases of their pedestals to the top surfaces of the load cells, and the spacer blocks were bolted through smaller attachment plates. Figure 5 shows a photograph of the load cells and the spacer blocks.

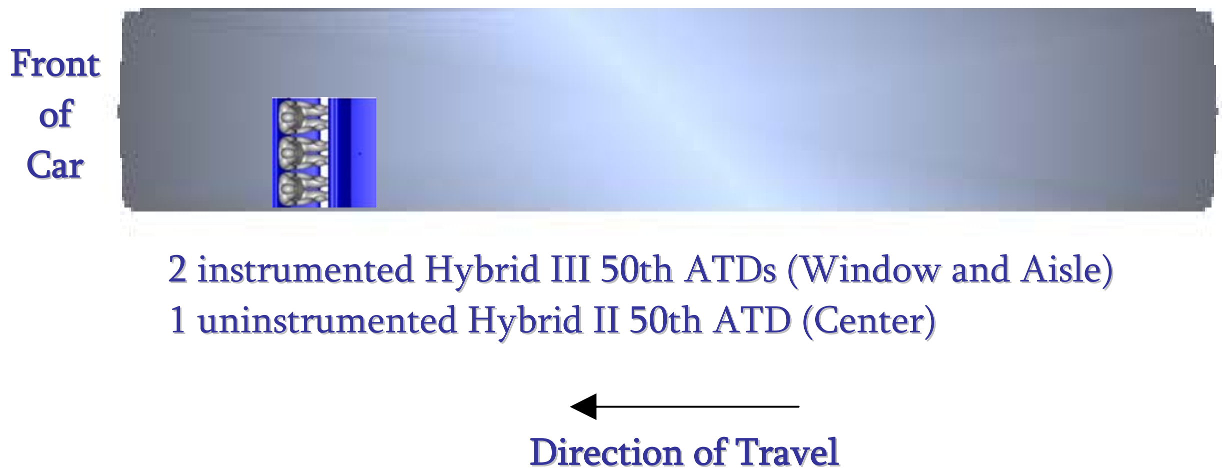

Figure 3. Schematic Showing the Positioning of the Rear-Facing Commuter Seat in the Lead Cab Car (#9357) in Experiment 1.1

Figure 4. Pretest Photograph of Experiment 1.1

Figure 5. Floor-Attachment Spacer Blocks for Unoccupied Rebound Seat (left) and Load Cells for Occupied Front-Row Seat (right) in Experiment 1.1

Seat Attachment to Wall: A steel bar measuring 78 x 3 x 0.25 in was bolted onto the heater rail along the side of the rail car. For the occupied front-row seat, two load cells were bolted onto the attachment plate. For the unoccupied aft-row seat, two spacer blocks were bolted onto the attachment plate to keep this row the same height as the occupied row. The bolt holes in the attachment plate were predrilled to provide the required 32-inch seat pitch. Figure 6 shows a photograph of the load cells and the spacer blocks. A T-shaped load-cell attachment plate was bolted to the load cells through a four-hole bolt pattern that had been drilled to the flat surface of the upside-down T. A piece of rugged angle iron was bolted to the vertical piece of the T-shaped load-cell attachment plate, which was then bolted to the C-channel that formed the base of the seat assembly, as shown in Figure 7.

Figure 6. Wall-Attachment Spacer Blocks for Unoccupied Seat (left) and Load Cells for Occupied Seat (right) in Experiment 1.1

Figure 7. Rugged Angle Iron Bolted to the Vertical Piece of the T-Shaped Load-Cell Attachment Plate and Bolted to the C-Channel That Formed the Base of the Seat Assembly

The forward-most rear-facing seat was equipped with load cells because it would be occupied. The seat behind it, which was unoccupied, was installed with spacers so that the two rows of seats were at equal heights above the floor. Additionally, a plywood floor was built around the seats and attachment points so that the ATD feet would be at the correct height (Figure 8).

4.1.4 Data Acquisition

Four data bricks were installed to collect 29 channels of data from five accelerometers (head, chest, and floor) and six load cells (neck, floor, and wall attachments). Table 4 lists the instrumentation requirements for Experiment 1.1. Figure 9 shows a photograph of the four data bricks installed on the floor closest to and in front of the experiment.

Figure 8. Plywood Floor Installed around the Seat Installation Raising the Floor to the Level Where the Pedestal Base is Installed in Experiment 1.1

Table 4. Instrumentation Requirements for Experiment 1.1

ATD/Object	ATD Location	Transducers	Measurement	Channel Count
HIII 50th	Window Seat	Triaxial Accelerometer	Head G (x, y, z)	3
HIII 50th	Window Seat	Triaxial Accelerometer	Chest G (x, y, z)	3
HIII 50th	Window Seat	6-Axis Load Cell	Upper Neck Forces (x, z) and Extension/Flexion Moment (M_y)	3
HIII 50th	Aisle Seat	Triaxial Accelerometer	Head G (x, y, z)	3
HIII 50th	Aisle Seat	Triaxial Accelerometer	Chest G (x, y, z)	3
HIII 50th	Aisle Seat	6-Axis Load Cell	Upper Neck Forces (x, z) and Extension/Flexion Moment (M_y)	3
Floor	Acceleration	Triaxial Accelerometer	Floor G (x, y, z)	3
Floor	Attachment Loads	3-Axis Load Cells (4)	Force (x, z) at 4 Attachment Points	8
Total Data Channels				29
Total Data Bricks				4

Figure 9. Four Data Bricks Installed behind the Aft-Facing Seating Experiment to Collect 29 Channels of Data in Experiment 1.1

4.1.5 Lights and Cameras

Two cameras were installed to capture footage of Experiment 1.1. Table 5 lists the specifications of these cameras and their respective fields of view.

Table 5. Cameras and Respective Fields of View for Experiment 1.1

View	Camera	Lens (mm)	F-stop (Aperture)	Shutter Speed (sec)	Frame Rate (frames/sec)	Working Distance (ft)	Field of View (X by Y, ft)*
Side	Ultima APX-1 Color	12.5	2.8 (8.0)	1/1500	500	5	6.96 x 6.96
Over-head	Ultima 512-1 Mono	4.8	1.8	1/4500	500	3	5.12 x 5.12

*X is the distance along the length of the car, and Y is the distance along the width of the car (in feet).

Thirty-six 12-volt DC-powered floodlights (12 overhead lights and 24 side-mounted lights) provided the lighting for this experiment (of 100 watts each). Three 12-volt DC batteries and their trigger circuits (each battery had three solid-state trigger relays) were installed to light the experiment. The light arrays were custom-fabricated on site using a combination of unistrut and slotted-steel angle iron and were bolted and welded to hard-point structures on the walls and ceilings of the car. Figure 10 shows how the lights and cameras were configured for Experiment 1.1.

Figure 10. Configuration of Lights and Cameras for Experiment 1.1

4.1.6 ATDs

Three ATDs were seated facing aft in the forward-most (relative to the cab end) commuter seat. Instrumented Hybrid III ATDs were placed in the aisle and window seats, and an uninstrumented Hybrid II ATD was placed in the middle seat. The instrumentation in the ATDs included a triaxial head accelerometer, a triaxial chest accelerometer, and a six-axis load cell in the neck that recorded F_x, F_z, and M_y. The ATDs were seated with their feet flat on the floor and their arms on top of their legs. They were each marked with blue, orange, and red chalk on their faces, chest, and knees, respectively. Reference targets were placed on each ATD at their head, shoulder, elbow, and knee, and on the seats along the edge of the headrest and seat back, as shown in Figure 11. Appendix C illustrates the relative dimensions that were measured between the targets for Experiment 1.1 before the test.

Figure 11. Reference Targets Placed on Each ATD at the Head, Shoulder, Elbow, and Knee Locations, and on the Seats along the Edge of the Headrest and Seat Back

4.2 Experiments 1.2 and 1.3: Workstation Table Occupant Experiments

4.2.1 Objective

Experiments 1.2 and 1.3 were identical in every aspect except for the ATD type and the position of the seat/table in the car. One experiment was installed with an RSSB Hybrid 3RS and the other with a THOR. The experiments were designed to estimate the crashworthiness performance of a newly designed workstation table for a facing-seat arrangement and were intended to support ongoing crashworthiness testing of common interior configurations. One ATD occupied the window seat in the forward-facing direction in each experiment. Each experiment was intended to:

- Measure the force-displacement characteristic of the workstation table,
- Measure the force-penetration characteristics of the table interaction with the abdomen of the ATD,
- Obtain injury criteria from the ATD as part of a whole-vehicle-dynamics crash test program,
- Allow comparison of the kinematics and injury criteria outcomes between the RSSB Hybrid 3RS ATD and the THOR ATD,
- Measure the table attachment loads and accelerations,
- Measure the table displacement with respect to the car,
- Measure the table-edge displacement with respect to the table,
- Film the ATD kinematics, and
- Verify whether the ATD remained compartmentalized.

4.2.2 Configuration

The configuration for each experiment consisted of a four-place facing seating system. Each facing pair of two-passenger seats comprised a welded aluminum base frame and a preassembled fiber-reinforced thermoplastic seat pan/back structure. A newly designed workstation table was installed between the two facing seats. The table was designed with a steel I-beam backbone along its centerline and a 3.5-inch-thick aluminum honeycomb core, potted to the I-beam with a two-part epoxy and sandwiched between two grooved melamine sheets, each 0.048-inch thick. Contact cement was used to bond the melamine to the honeycomb, which provided additional vertical strength to the table. The melamine was intended to fold at precut grooves and move out of the way as the table crushed so that the honeycomb could absorb the impact energy of the occupant. The edge of the table was designed with a protective 1/8-inch-thick layer of neoprene. The table was secured as a cantilever to the wall of the rail car through three attachment plates that formed a triangle on the wall.

The front edge of the facing seat pan in each experiment was modified with a rubber bumper to help reduce the femur loads when the knees or shins of the forward-facing ATD (THOR or Hybrid 3RS) collided with the facing seat pan. The facing seat pan was modified by cutting off the front 2 in, leaving the edges intact. A rubber pad measuring 9 x 15.625 x 0.75 in was then wrapped around the cut front edge of the seat pan so that it extended beyond the cut edge by 2 in. Four 0.25-inch bolts secured the rubber bumper in place at the cut edge of the seat pan. Two steel plates, each measuring 15.5 x 1.0 in, sandwiched the rubber pad to the seat pan and were secured with the four bolts.

The two experiments were located in the rear right-hand-side of the leading cab car. The launch seat of Experiment 1.2 was adjoined to the rear-facing seat of Experiment 1.3 behind it. The seat pitch was set to 65 in, with the workstation table centered between the facing seats. An ATD was positioned in the forward-facing window seat of each experiment in accordance with SAE AS8049. The seats did not incorporate occupant restraint belts. Figure 12 shows a schematic that illustrates the positioning of the workstation tables in the cab car. Figure 13 shows an overall view of both experiments. Figures 14 and 15 are pretest photographs.

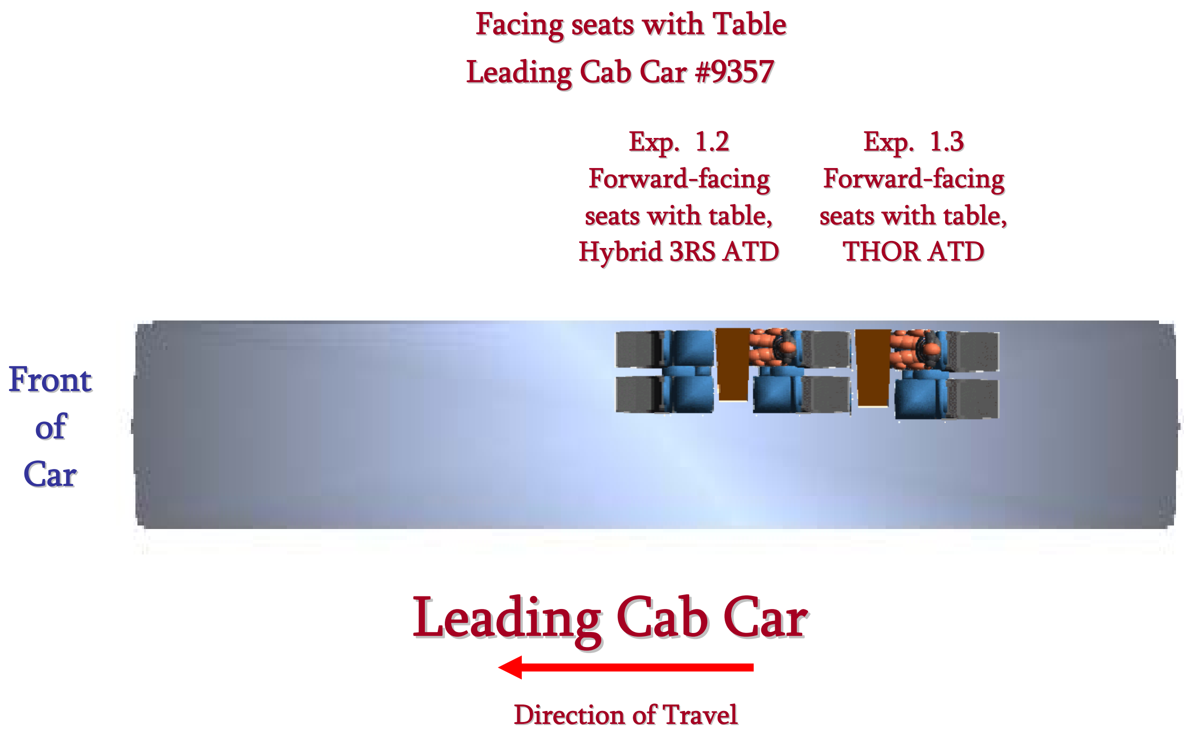

Figure 12. Schematic Showing the Positioning of Facing Seats with Improved Workstation Table in the Cab Car (#9357) in Experiments 1.2 and 1.3

4.2.3 Installation

Seat Attachment to Floor: In Experiments 1.2 and 1.3, the seats were attached only to the floor of the car. Two parallel steel bars, each measuring 15.5-feet long x 6-inches wide x 0.375-inch thick, were welded to the stringers in the floor of the car—one along the window side and one along the aisle side. These parallel bars were long enough to support the installation of three sets of back-to-back seats, as required for the two facing-seat experiments. In lieu of installing the seats directly to the wall of the rail car, three wall-side mounts were fabricated so the seats could be installed in a position that was aligned with the workstation tables, which were installed offset from the wall due to the load cells. The base of each wall-side mount was 36 x 4 x 0.75 in and the top of each mount was 27.5 x 2 x 0.75 in. The bases of these wall-side mounts were bolted to the welded bar. The metal tabs protruding from the bases of the seat pans were bolted to the tops of the wall mounts. On the aisle side, the bases of the pedestals were bolted to two smaller 2 x 3 x 0.75-inch plates that were bolted to the welded bar along the aisle. Figure 16 shows a photograph of the floor attachments.

Figure 13. Overall View of Experiment 1.2 (background) and Experiment 1.3 (foreground)

Figure 14. Pretest Photograph of Experiment 1.2

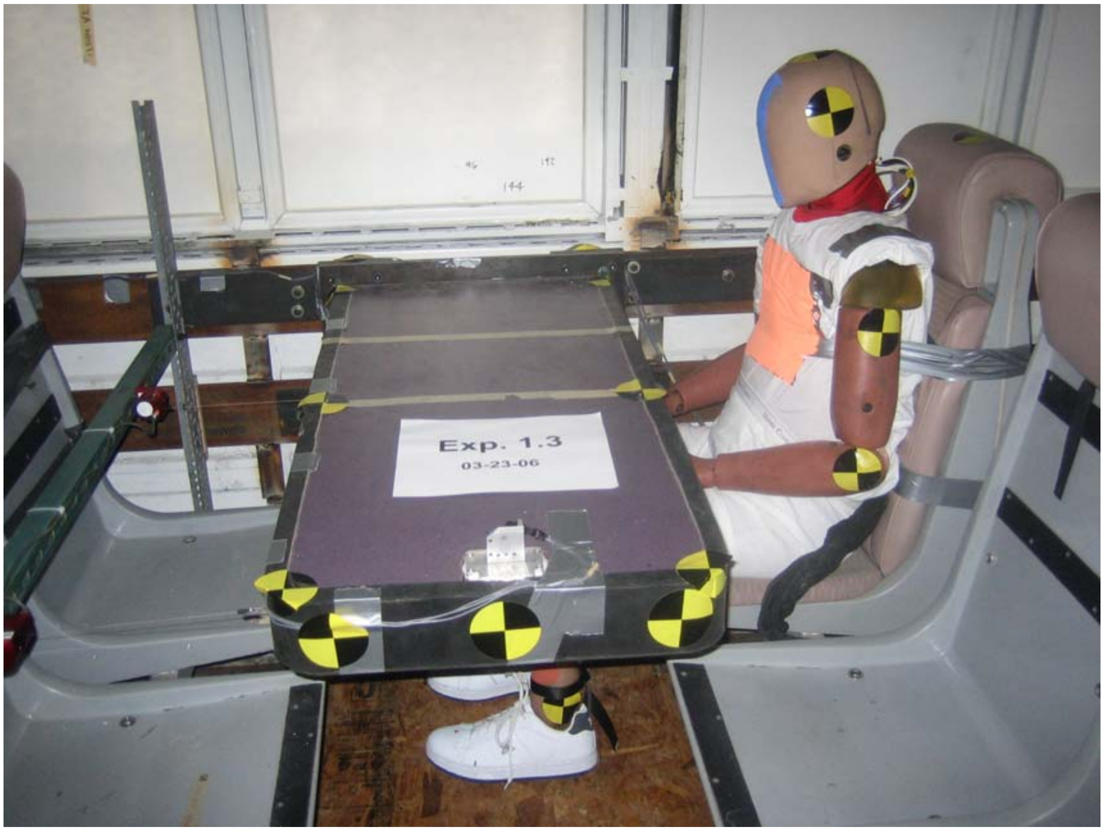

Figure 15. Pretest Photograph of Experiment 1.3

Table Attachment to Wall: In Experiments 1.2 and 1.3, the workstation tables were attached only to the wall of the car. Along the window-side of the rail car, two parallel bars, each measuring 20-feet long x 5-inches wide x 0.375-inch thick, were welded to a series of nine vertical bars that had been welded to existing structural members in the wall. These vertical bars were each 22 x 2 x 0.25 in and were spaced at intervals of 29 or 32 in, except at the center, where a 10-inch spacing occurred. The two 20-foot bars were welded 4-inches apart on top of these vertical bars, as shown in Figure 17.

Each table attachment included an upper attachment plate measuring 50 x 4 x 0.5 in bolted to the upper welded bar and a lower attachment plate measuring 32 x 3.75 x 0.5 in bolted to the lower welded bar. Before installation, the upper attachment plate was predrilled with two load cells bolted to it, and the lower attachment plate was predrilled with one load cell bolted to it. Together, the load cells formed a triangle that matched the bolt pattern of the cantilevered/table wall attachments. The table was then bolted to three individual attachment plates, each measuring 7 x 7 x 1 in, which were bolted to the load cells, as shown in Figure 18.

Figure 16. Window-Side Facing Seat Installation (left), and Aisle-Side Installation (right) for Experiments 1.2 and 1.3

Figure 17. Two 20-Foot Bars were Welded Four Inches Apart on Top of Vertical Bars

Figure 18. Table Bolted to Three Individual Attachment Plates which were Bolted to the Load Cells

4.2.4 Data Acquisition

Nine data bricks were installed to collect 70 channels of data from a combined total of eight accelerometers (head, chest, upper abdomen in Experiment 1.3, floor, and table tops), 14 load cells (neck, femur, and table attachments to the wall), and 10 potentiometers (lower abdominal CRUX, upper abdomen in Experiment 1.3, occipital condyle in Experiment 1.3, and tables). Figure 19 shows a photograph of the data bricks installed on the floor behind the two experiments. Tables 6 and 7 list the instrumentation requirements for Experiments 1.2 and 1.3, respectively.

Figure 19. Nine Data Bricks Installed to Collect Data from 70 Channels Linked to Experiments 1.2 and 1.3

A triaxial accelerometer was attached to each table top at its center along the aisle edge to measure table accelerations. A small piece of the melamine table surface was removed, and the accelerometer was bonded to the cleaned surface adhesive as shown in Figure 20.

Two potentiometers were installed to measure table crush and table displacement. The table crush was measured with one string potentiometer, attached between a unistrut fixture that stretched across the length of the opposing seat and the underside of the table at the crush initiation point. At this location, a strip of the melamine table undersurface was removed and a metal hook was inserted and bonded into the honeycomb core with adhesive. The potentiometer cord stretched from the unistrut fixture, underneath the table, then attached to the hook (left-side photograph, Figure 21). A second string potentiometer was installed to measure the table displacement. This potentiometer was also attached to the unistrut fixture and the cord was stretched to the surface edge of the table, where a hook was inserted and bonded into the rubber protective covering and honeycomb core (Figure 20 and right-side photograph, Figure 21).

Table 6. Instrumentation Requirements for Experiment 1.2

ATD/Object	ATD Location	Transducers	Measurement	Channel Count
HIII RS 50th	Window Seat	Triaxial Accelerometer	Head G (x, y, z)	3
HIII RS 50th	Window Seat	Triaxial Accelerometer	Chest G (x, y, z)	3
HIII RS 50th	Window Seat	6-axis Load Cell	Upper Neck Forces (x, z) and Extension/Flexion (M_y)	3
HIII RS 50th	Window Seat	Triaxial Displacement	Abdomen, Left, Lower CRUX	3
HIII RS 50th	Window Seat	Triaxial Displacement	Abdomen, Right, Lower CRUX	3
HIII RS 50th	Window Seat	Uniaxial Load Cell	Femur, Left, Axial Load (F_z)	1
HIII RS 50th	Window Seat	Uniaxial Load Cell	Femur, Right, Axial Load (F_z)	1
Floor	Acceleration	Triaxial Accelerometer	Floor G (x, y ,z)	3
Table	Wall-Attachment Loads	6-axis Load Cell (3)	Force (x, y z) at 3 Wall-Mount Locations (forward, aft, lower mid) (z Channel Expendable)	9
Table	Table Top Acceleration	Triaxial Accelerometer	Table G (x, y, z)	3
Table	Linear Displacement	Uniaxial Displacement	2 String Pots	2
Total				34
Total Data Bricks (9 Total Data Bricks Shared between Experiments 1.2 and 1.3)				5

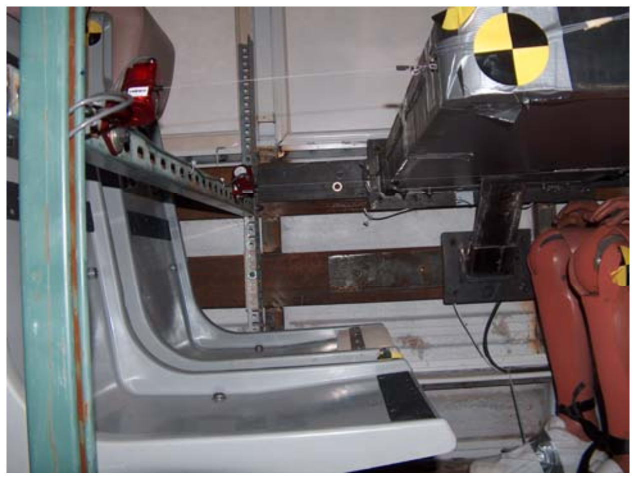

Figure 20. Table Acceleration was Measured with an Accelerometer, and Table Crush and Displacement were Measured with Two Potentiometers

Table 7. Instrumentation Requirements for Experiment 1.3

ATD/Object	ATD Location	Transducers	Measurement	Channel Count
THOR	Window Seat	Triaxial Accelerometer	Head G (x, y, z)	3
THOR	Window Seat	Triaxial Accelerometer	Chest G (x, y, z)	3
THOR	Window Seat	Uniaxial Upper Abdomen	Abdomen, Upper	1
THOR	Window Seat	6-Axis Load Cell	Upper Neck Forces (x, z) and Extension/Flexion (M_y)	3
THOR	Window Seat	Single-Axis Load Cell	Front Neck Cable	1
THOR	Window Seat	Single-Axis Load Cell	Rear Neck Cable	1
THOR	Window Seat	Potentiometer	Occipital Condyle Pos. Sensor	1
THOR	Window Seat	Triaxial Displacement	Abdomen, Left, Lower CRUX	3
THOR	Window Seat	Triaxial Displacement	Abdomen, Right, Lower CRUX	3
THOR	Window Seat	Uniaxial Displacement	Upper Abdomen	1
THOR	Window Seat	Uniaxial Load Cell	Femur, Left, Axial Load (F_z)	1
THOR	Window Seat	Uniaxial Load Cell	Femur, Right, Axial Load (F_z)	1
Floor	Acceleration	Share Triaxial Accelerometer Identified in Exp. 1.2	Floor G (x, y, z)	0
Table	Wall Attachment Loads	3-axis Load Cell (3)	Force (x, y, z) at 3 Wall-Mount Locations (fwd, aft, lower mid) (z Channel is Expendable)	9
Table	Table Acceleration	Triaxial Accelerometer	Table G (x, y, z)	3
Table	Linear Disp.	Uniaxial Displacement	2 String Pots	2
Total				36
Total Data Bricks (9 total Data Bricks Shared between Experiments 1.2 and 1.3)				4

 

Figure 21. Potentiometer Cord for Table Crush, Stretched under Table to a Hook Bonded into the Honeycomb Where a Melamine Strip was Removed (left). Cord for Table Displacement, Stretched from the Unistrut to a Hook Bonded into the Facing Edge of the Table (right) in Experiments 1.2 and 1.3

4.2.5 Lights and Cameras

Five cameras were installed to capture footage of Experiments 1.2 and 1.3. Table 8 lists those cameras and their respective fields of view. A total of 72 12-volt DC-powered floodlights (each 100 watts) provided the lighting for these two experiments (48 side-mounted lights and 12 above each experiment). Six 12-volt DC batteries and their trigger circuits (each battery had three solid-state trigger relays) were installed to light the two experiments. These light arrays were custom-fabricated on site using a combination of unistrut and slotted-steel angle iron and were bolted and welded to hard-point structures on the walls and ceilings. Figures 22 and 23 show how the overhead and side lights and cameras were configured for Experiments 1.2 and 1.3. Figure 24 shows the front-view camera.

Table 8. Cameras and Respective Fields of View for Experiments 1.2 and 1.3

View	Camera	Lens (mm)	F-stop (Aperture)	Shutter Speed (sec)	Frame Rate (frames/sec)	Working Distance (ft)	Field of View (X by Y, ft)*
1.2 Front	RS-1 Mono	25.0	5.6	1/2000	500	10	6.96 x 6.96
1.2 Side	RS-2 Color	12.5	1.4	1/1500	1000	5	6.96 x 6.96
1.2 Over-head	U512-2 Mono	4.8	1.8	1/2000	1000	3	5.12 x 5.12
1.3 Side	RS-3 Mono	12.5	5.6	1/3000	1000	5	6.96 x 6.96
1.3 Over-head	U512-3 Mono	4.8	Wide open	1/2000	1000	3	5.12 x 5.12

*X is the distance along the length of the car, and Y is the distance along the width of the car.

Figure 22. Forty-Eight Flood Lights were Installed along the Wall (left), with Two RS Cameras (right) Covering Both Experiments 1.2 and 1.3

Figure 23. Twelve Flood Lights and One U512 Camera, were Installed above for Experiment 1.2 (left) and Experiment 1.3 (right)

Figure 24. One RS Front View Camera was Installed to Capture the Combined Front View of Experiments 1.2 and 1.3

4.2.6 ATDs

For each experiment, one ATD was seated in the forward-facing window seat. In Experiment 1.2, the ATD was an instrumented Hybrid 3RS. The instrumentation in the Hybrid 3RS included:

- A triaxial head accelerometer,
- A triaxial chest accelerometer,
- A six-axis load cell in the neck that recorded F_x, F_z, and M_y,
- Two uniaxial femur load cells, and
- A triaxial lower CRUX (abdomen) displacement transducer.

The ATD used in Experiment 1.3 was an instrumented THOR. The instrumentation in the THOR included:

- A triaxial head accelerometer,
- A triaxial chest accelerometer,
- A uniaxial upper abdominal accelerometer,

- A six-axis load cell in the neck that recorded F_x, F_z, and M_y,
- Two uniaxial neck cable load cells,
- Two uniaxial femur load cells,
- A triaxial lower CRUX (abdomen) displacement transducer,
- A uniaxial upper abdominal displacement transducer, and
- A uniaxial occipital condyle potentiometer.

Both ATDs were seated with their feet flat on the floor and their arms on their legs. They were each marked with blue, orange, and red chalk on their faces, chests, and knees, respectively. Reference targets were placed on each ATD at the head, shoulder, elbow, and knee, and on the aisle-side edge of each table. Figure 25 shows photos of the ATDs situated at the tables. Appendix C illustrates the relative dimensions between the targets that were measured before the test for Experiments 1.2 and 1.3.

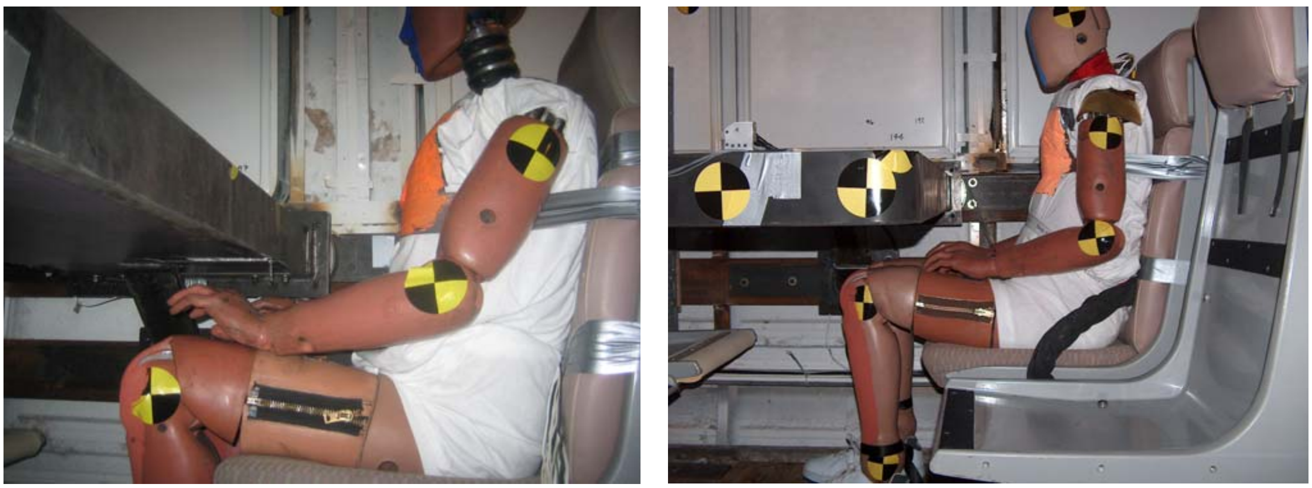

Figure 25. One Instrumented Hybrid 3RS Occupied the Forward-Facing Window Seat in Experiment 1.2 (left) and One Instrumented THOR Occupied the Forward-Facing Window Seat in Experiment 1.3 (right)

4.3 Experiment 2.1: Forward-Facing Intercity Seats

4.3.1 Objective

This experiment was designed to estimate the crashworthiness performance of Amtrak intercity seats that were tested in four previous in-line full-scale conventional and CEM collision tests. Specifically, this experiment was conducted to:

- Measure the injury criteria from the instrumented ATDs,
- Verify that the impact seat can withstand secondary impact without significant structural failure,
- Verify if the ATDs remain compartmentalized, and
- Record ATD motion with high-speed digital video cameras.

4.3.2 Configuration

The interior configuration for this experiment consisted of two rows of modified, forward-facing, two-passenger Amtrak intercity seat pairs located in the front left-hand-side of the first coach car (second car in the consist). The seats used in the previous full-scale testing were refurbished with the same original modifications that were made to the intercity seat, with one exception: the upper seat back was modified with additional foam padding with the intent of reducing head impact loading. The seat pitch was 41 in. Seat-mounting hardware was consistent with in-service hardware. Two instrumented Hybrid III 95th percentile male ATDs were seated and unbelted in the rear launch seat. The seat in front remained unoccupied. Figure 26 illustrates the location of the experiment. Figure 27 shows a pretest photograph.

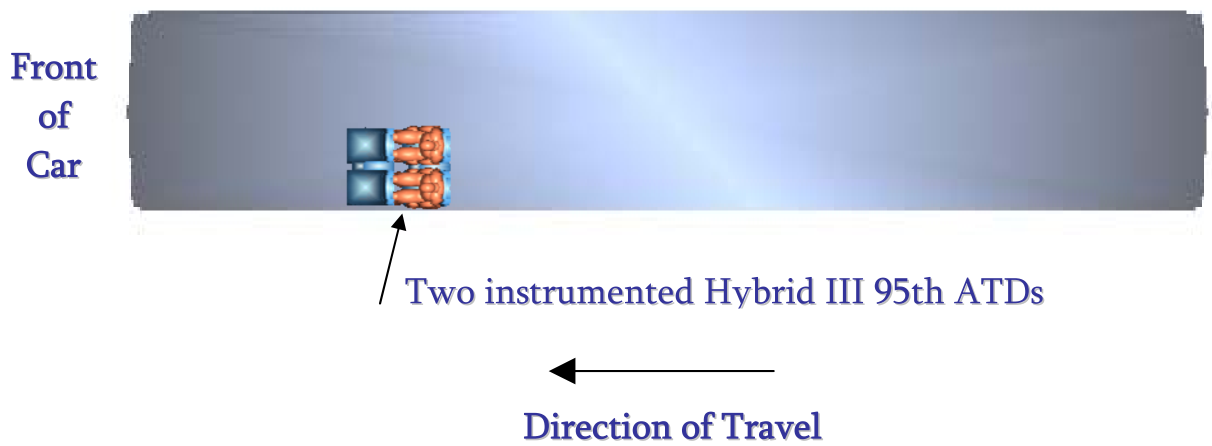

Figure 26. Schematic Showing the Location of Experiment 2.1

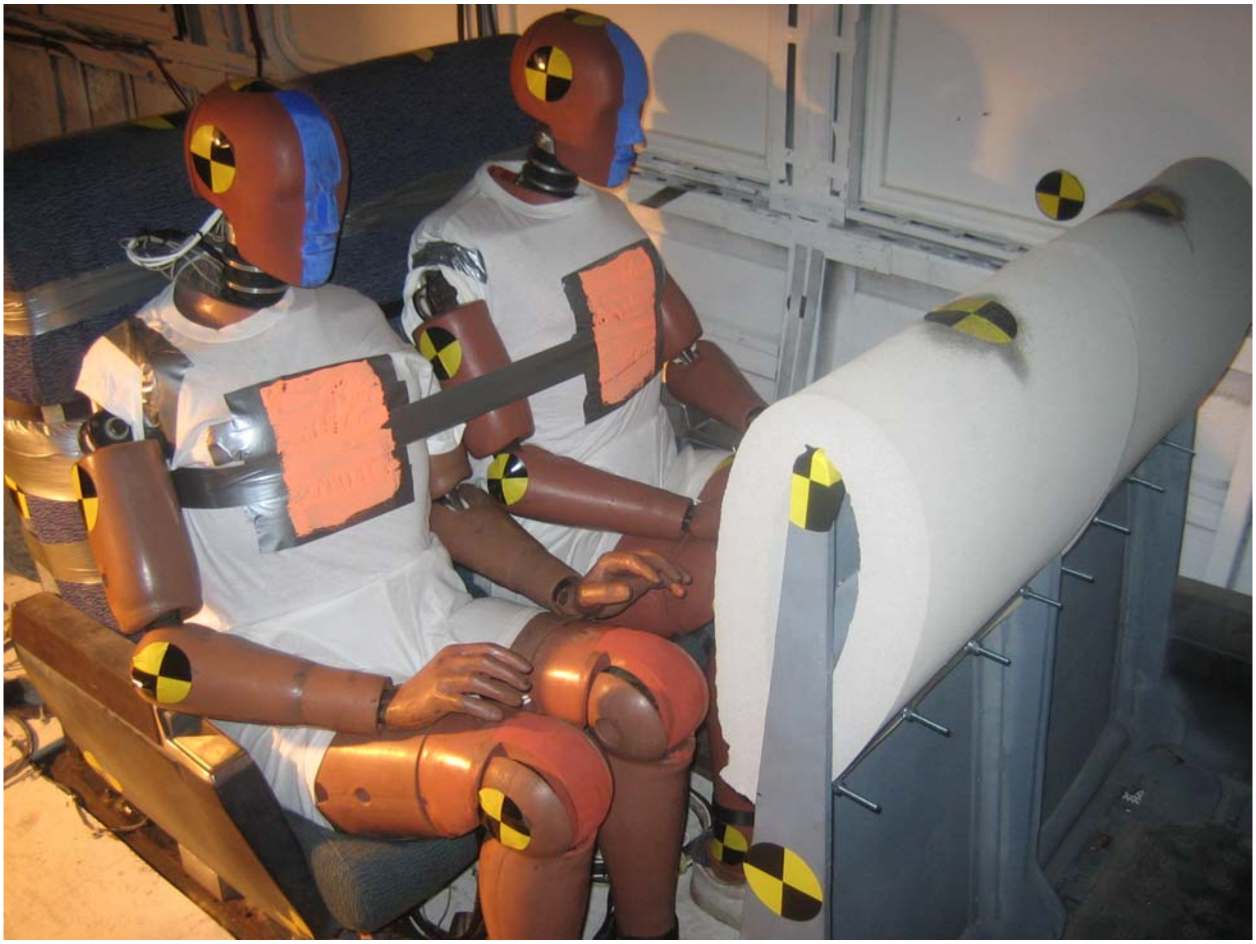

Figure 27. Pretest Photograph of Experiment 2.1

4.3.3 Installation

Seat Attachment to Floor: Two steel bars measuring 98 x 6 x 0.375 in were welded to the stringers in the floor of the car, each spanning two 4.25-inch-wide hat sections and two 1.5-inch-wide right-angle sections. An 84 x 4 x 0.75-inch attachment plate was bolted onto each welded bar with four pairs of bolts along its length. Four spacer blocks were bolted onto each attachment plate where they had been predrilled with inset holes to fit the attachment points on the spacer blocks. In previous tests, load cells were installed to raise the level of the seats. To maintain consistency with previous tests and with the other tests on board this consist, spacer blocks were installed to keep the floor level as shown in Figures 28 and 29. When installed, the spacing between the seats was 41 in. A plywood floor was built around the seats and attachment points so that the ATD feet would be at the correct height as shown in Figure 30.

Figure 28. Launch-Seat Installation for Experiment 2.1

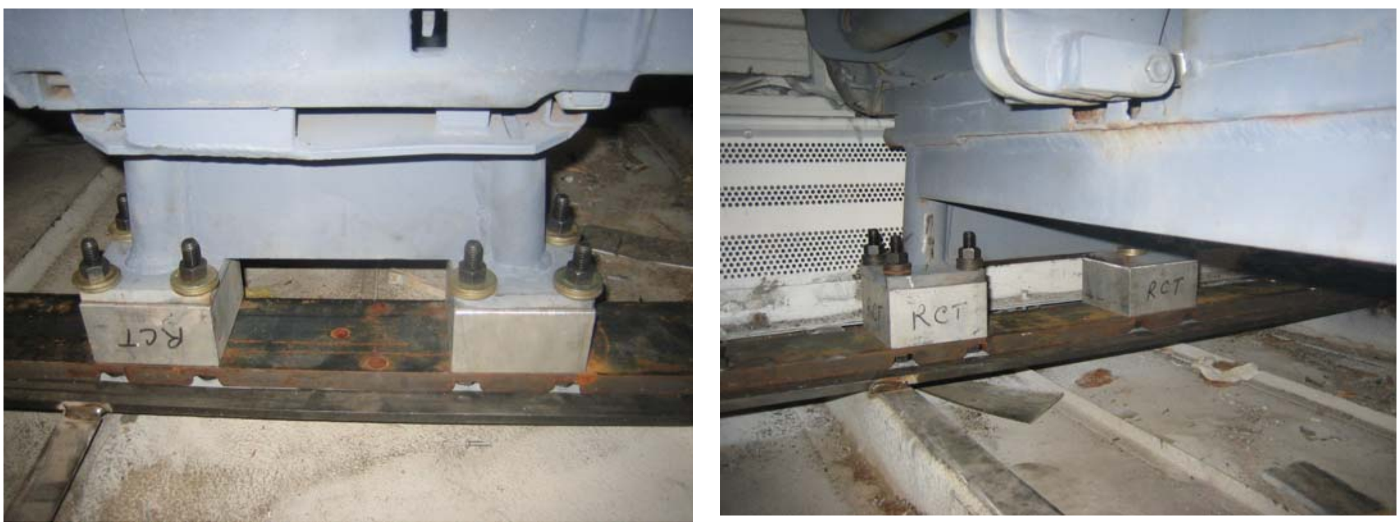

Figure 29. Impact-Seat Installation for Experiment 2.1 Aisle Side (left) and Window Side (right)

Figure 30. Plywood Floor Installed around Experiment 2.1

4.3.4 Data Acquisition

Three data bricks were installed to collect 24 channels of data from five accelerometers (head, chest, and floor) and six load cells (neck and femur). Table 9 lists the instrumentation used in Experiment 2.1. Figure 31 shows a photograph of the three data bricks and the single accelerometer that were installed on the floor behind the experiment.

4.3.5 Lights and Cameras

Two cameras were installed to capture video footage of Experiment 2.1. Table 10 lists these cameras and their respective fields of view. Thirty-six 12-volt DC-powered floodlights (12 overhead lights and 24 side-mounted lights) provided the lighting for this experiment (each 100 watts). Three 12-volt DC batteries and their trigger circuits (each battery had 3 solid-state trigger relays) were installed to light the experiment. These light arrays were custom-fabricated on site using a combination of unistrut and slotted-steel angle iron and were bolted and welded to the interior car hard-point structures on the walls and ceilings. Figure 32 shows how the lights and cameras were configured for Experiment 2.1.

Table 9. Instrumentation Requirements for Experiment 2.1

ATD/Object	ATD Location	Transducers	Measurement	Channel Count
HIII 95th	Window Seat	Triaxial Accelerometer	Head G (x, y, z)	3
HIII 95th	Window Seat	Triaxial Accelerometer	Chest G (x, y, z)	3
HIII 95th	Window Seat	6-axis Load Cell	Upper Neck Forces (x, z) and Extension/Flexion Moment (M_y)	3
HIII 95th	Window Seat	Uniaxial Load Cell	Femur, Left, Axial Load (F_z)	1
HIII 95th	Window Seat	Uniaxial Load Cell	Femur, Right, Axial Load (Fz)	1
HIII 95th	Aisle Seat	Triaxial Accelerometer	Head G (x, y, z)	3
HIII 95th	Aisle Seat	Triaxial Accelerometer	Chest G (x, y, z)	3
HIII 95th	Aisle Seat	6-axis Load Cell	Upper Neck Forces (x, z) and Extension/Flexion Moment (M_y)	3
HIII 95th	Aisle Seat	Uniaxial Load Cell	Femur, Left, Axial Load (F_z)	1
HIII 95th	Aisle Seat	Uniaxial Load Cell	Femur, Right, Axial Load (F_z)	1
Floor	Acceleration	Triaxial Accelerometer	Floor G (x, z)	2
Total				24
Total Data Bricks				3

Figure 31. Three Data Bricks and One Accelerometer, Installed behind Experiment 2.1

Table 10. Cameras and Respective Fields of View for Experiment 2.1

View	Camera	Lens (mm)	F-stop (Aperture)	Shutter Speed (sec)	Frame Rate (frames/sec)	Working Distance (ft)	Field of View (X by Y, ft)*
Side	APX-2 Color	12.5	2	1/1000	1000	5	6.96 x 6.96
Over-head	Ultima 512-4 Color	4.8	1.8	1/2000	1000	3	5.12 x 5.12

*X is the distance along the length of the car, and Y is the distance along the width of the car.

Figure 32. One APX Camera and 24 Flood Lights were Installed along the Wall (left) and One U512 Camera and 12 Lights were Installed along the Ceiling (right) in Experiment 2.1

4.3.6 ATDs

Two instrumented Hybrid III 95th percentile ATDs occupied the aft row of this experiment. The instrumentation in the ATDs included a triaxial head accelerometer, a triaxial chest accelerometer, a uniaxial load cell in each femur, and a six-axis load cell in the neck that recorded F_x, F_z, and M_y. The ATDs were seated with their feet flat on the floor and their arms on their legs. They were each marked with blue, orange, and red chalk on their faces, chest, and knees, respectively. Reference targets were placed on each ATD at their head, shoulder, elbow, and knee and on the seats along the edge of the headrest and seat back. Figure 33 shows a photograph of the experiment. Appendix C illustrates the relative dimensions between the targets that were measured before the test for Experiment 2.1.

Figure 33. Two Instrumented Hybrid III 95th Percentile ATDs Occupied the Two-Place Passenger Intercity Seat in Experiment 2.1

4.4 Experiment 2.2: Forward-Facing Commuter Seats

4.4.1 Objective

This experiment was designed to estimate the crashworthiness performance of a newly designed version of the commuter seat with improved force/deflection. Specifically, the experiment was conducted to:

- Measure the injury criteria from the instrumented ATDs,
- Verify that the impact seat can withstand secondary impact without significant structural failure,
- Verify whether the ATDs remain compartmentalized, and
- Record ATD motion with a high-speed digital video camera.

4.4.2 Configuration

This interior configuration consisted of two forward-facing, newly designed, three-passenger commuter-seats located in the aft right-hand-side of the first coach car (second car in the consist). The seats tested in this experiment were identical to the seats tested in the rear-facing commuter seat experiment, Experiment 1.1. In this experiment, however, the seats faced forward. The seat pitch was set to 32 in, the same as that for the rear-facing commuter seat experiment. Seat-mounting hardware was consistent with in-service hardware. Three ATDs were used in this experiment. Instrumented Hybrid III 50th percentile ATDs were seated in the aisle and window positions, and an uninstrumented Hybrid II 50th percentile ATD was seated in the middle position. These ATDs were seated in the aft seat of the two seat rows, and the seat in front remained unoccupied. Figure 34 illustrates the positioning of the experiment in the first coach car. Figure 35 shows a pretest photograph of the experiment.

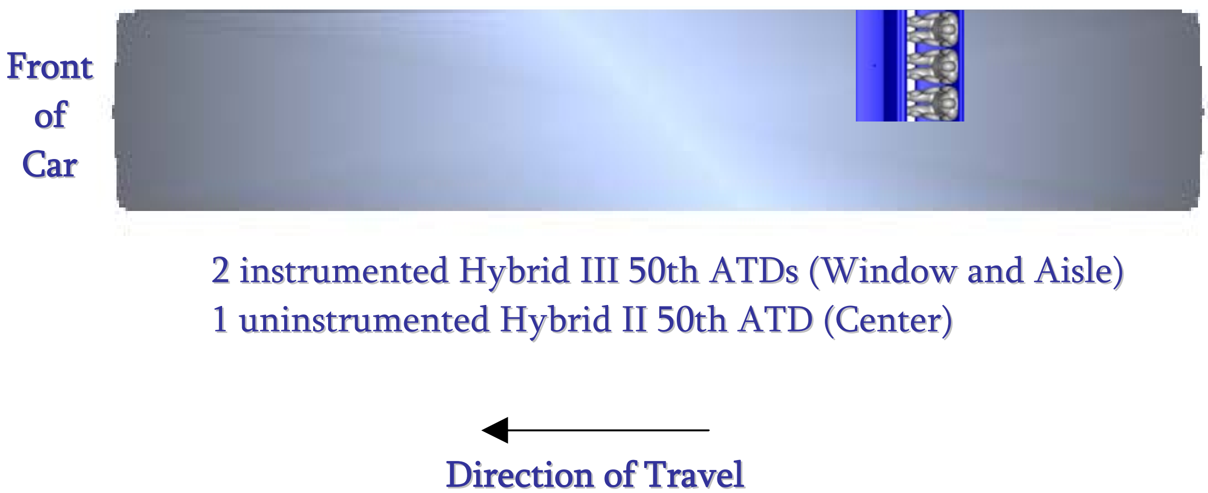

Figure 34. Schematic Illustrating the Positioning of the Forward-Facing Commuter Seat in the First Coach Car (#9358) in Experiment 2.2

Figure 35. Pretest Photograph of Experiment 2.2

4.4.3 Installation

Seat Attachment to Floor: A steel plate measuring 96 x 6 x 0.375 in was welded to the stringers in the floor of the car, spanning two 4.25-inch-wide hat sections and two 1.5-inch-wide right-angle sections. A 70.75 x 4 x 0.75-inch attachment plate was bolted onto the welded plate with four pairs of bolts spaced along its length. For the unoccupied front-row seat, two load cells were bolted onto the attachment plate. For the occupied aft-row seat, two spacer blocks were bolted onto the attachment plate. The spacer blocks were used to keep the aft-row seat the same height as the front-row seat. The bolt holes in the attachment plate were predrilled so that the spacing between the seats was 32 in when installed. Two rows of seats were then bolted at the bases of their pedestals to the top surfaces of the load cells and the spacer blocks through smaller attachment plates. Figure 36 shows a photograph of the load cells and the spacer blocks.

Figure 36. Floor Attachment Load Cells for the Impact Seat (left) and Spacer Blocks for the Launch Seat (right) in Experiment 2.2

Seat Attachment to Wall: A steel attachment plate measuring 78 x 3 x 0.25 in was bolted onto the heater rail along the side of the rail car. For the occupied front-row seat, two load cells were bolted onto the attachment plate. For the unoccupied front-row seat, two spacer blocks were bolted onto the attachment plate to keep this row the same height as the occupied row. The bolt holes in the attachment plate were predrilled to provide the required 32-inch seat pitch. Figure 37 shows top and side photographs of the load cells and spacer blocks. A T-shaped load-cell attachment plate was bolted to the load cells through a 4-hole bolt pattern that had been drilled into the flat surface of the upside-down T. A piece of rugged angle iron was bolted to the vertical piece of the T-shaped load-cell attachment plate, which was then bolted to the C-channel that formed the base of the seat assembly, as shown in Figure 38.

Figure 37. Top View of the Wall-Attachment Load Cells on the Unoccupied Impact Seat (left), and Underside View of Spacer Blocks on the Launch Seat (right) in Experiment 2.2

The launch seat with the three occupants was equipped with spacer blocks. The impact seat in front of the launch seat was unoccupied and was equipped with load cells. The spacer blocks were installed so that the two rows of seats were at an equal height above the floor. A plywood floor was built around the seats and attachment points so that the ATD feet would be at the correct height, as shown in Figure 39.

4.4.4 Data Acquisition

Figure 40 shows four data bricks that were installed to collect 32 channels of data from five accelerometers (head, chest, and floor) and ten load cells (neck, femur, floor, and wall attachments). Table 11 lists the instrumentation used for Experiment 2.2.

4.4.5 Lights and Cameras

Two cameras were installed to capture video footage from Experiment 2.2. Table 12 lists the characteristics of these cameras and their respective fields of view.

Thirty-six 12-volt DC-powered floodlights (12 overhead lights and 24 side-mounted lights) provided the lighting for this experiment (each 100 watts). Three 12-volt DC batteries and their trigger circuits (each battery had three solid-state trigger relays) were installed to light the experiment. These light arrays were custom-fabricated on site using a combination of unistrut and slotted-steel angle iron and were bolted and welded to the interior car hard-point structures on the walls and ceilings. Figure 41 shows how the lights and cameras were configured for Experiment 2.2.

Figure 38. Rugged Angle Iron was Bolted to the Vertical Piece of the T-Shaped Load-Cell Attachment Plate, Then Bolted to the C-Channel That Formed the Base of the Seat Assembly

Figure 39. Plywood Floor Built around the Seat Installation Raising the Floor to the Level Where the Pedestal Base was Installed in Experiment 2.2

Table 11. Instrumentation Requirements for Experiment 2.2

ATD/Object	ATD Location	Transducers	Measurement	Channel Count
HIII 50th	Window Seat	Triaxial Accelerometer	Head G (x, y, z)	3
HIII 50th	Window Seat	Triaxial Accelerometer	Chest G (x, y, z)	3
HIII 50th	Window Seat	6-Axis Load Cell	Upper Neck Forces (x, z) and Extension/Flexion Moment (M_y)	3
HIII 50th	Window Seat	Uniaxial Load Cell	Femur, Left, Axial Load (F_z)	1
HIII 50th	Window Seat	Uniaxial Load Cell	Femur, Right, Axial Load (F_z)	1
HIII 50th	Aisle Seat	Triaxial Accelerometer	Head G (x, y, z)	3
HIII 50th	Aisle Seat	Triaxial Accelerometer	Chest G (x, y, z)	3
HIII 50th	Aisle Seat	6-Axis Load Cell	Upper Neck Forces (x, z) and Extension/Flexion Moment (M_y)	3
HIII 50th	Aisle Seat	Uniaxial Load Cell	Femur, Left, Axial Load (F_z)	1
HIII 50th	Aisle Seat	Uniaxial Load Cell	Femur, Right, Axial Load (F_z)	1
Floor	Acceleration	Triaxial Accelerometer	Floor G (x, y, z)	2
Floor	Attachment Loads	3-Axis Load Cells (4)	Force (x, z) at Four Locations	8
Total				32
Total Data Bricks				4

Figure 40. Four Data Bricks Installed Behind Experiment 2.2 to Collect 32 Channels of Data

Table 12. Cameras and Respective Fields of View for Experiment 2.2

View	Camera	Lens (mm)	F-stop (Aperture)	Shutter Speed (sec)	Frame Rate (frames/sec)	Working Distance (ft)	Field of View (X by Y, ft)*
Side	Ultima 512-5 Color	7.5	1.2	1/1000	500	5	5.46 x 5.46
Over-head	Ultima 512-6 Color	4.8	Wide open	1/1000	500	3	5.12 x 5.12

*X ft. is along the length of the car, and Y ft. is along the width of the car.

Figure 41. One U512 Camera and 24 Flood Lights Were Installed along the Wall and One U512 Camera and 12 Lights Were Installed along the Ceiling

4.4.6 ATDs

Three ATDs were seated facing forward in the aft row of this experiment. Instrumented Hybrid III ATDs were placed in the aisle and window seats. An uninstrumented Hybrid II ATD was placed in the middle seat. The instrumentation in the ATDs included a triaxial head accelerometer, a triaxial chest accelerometer, a uniaxial load cell in each femur, and a six-axis load cell in the neck that recorded F_x, F_z, and M_y. The ATDs were seated with their feet flat on the floor and their arms on their legs. They were each marked with blue, orange, and red chalk on their faces, chest, and knees, respectively. Reference targets were placed on each ATD at its head, shoulder, elbow, and knee and on the seats along the edge of the headrest and seat back, as shown in Figure 42. Appendix C illustrates the relative dimensions between the targets that were measured before the test for Experiment 2.2.

Figure 42. Instrumented Hybrid III ATDs Occupied the Aisle and Window Seats. An Uninstrumented Hybrid II ATD Occupied the Middle Seat in Experiment 2.2

5. Test Implementation

5.1 Pretest Preparation

After the experiments were completely installed, a dry run was successfully conducted. The results of the dry run ensured that all of the lights and digital cameras would trigger without overloading the power supplies or prematurely triggering the data acquisition system before impact of the passenger train with the stationary locomotive. Lighting and camera views were adjusted to account for the outdoor ambient light, and the trigger systems were verified to confirm that power would be supplied to the light arrays, cameras, strobes, and data-brick modules.

The day before the test, a pretest inspection of each experiment and its related equipment was conducted and pretest photos were taken. Propane heaters were placed inside the cars to keep the ATDs as close to room temperature as possible. In the early morning of the test day, the passenger train was moved to the test site for final inspection and exterior camera setup. After inspection, it was pulled back to its starting point, where the cameras and the data bricks were set and armed and the lights were triggered. The impact with the stationary locomotive occurred at approximately 10:30 a.m. on Thursday, March 23, 2006.

5.2 Post-Test Activity

Immediately after the impact of the passenger train with the stationary locomotive, a representative of TTCI boarded the cars to inspect them for unsafe conditions and hazards. Once the cars were confirmed to be safe, Armor Holdings personnel boarded the rail cars and disconnected the power supplies. Extreme care was taken not to disturb the experiments. The data was uploaded from the data-brick modules, and the videos were downloaded onto laptop computers. Difficulties downloading images from some of the digital cameras occurred, which resulted in the loss of one camera view in Experiments 1.1 and 2.2 and both camera views of Experiment 2.1. Appendix B provides a report on the loss of this footage. Each experiment was examined and photographed. Notes were taken on the post-test condition of each experiment.

6. Results

The five-car cab car-led passenger train impacted the stationary locomotive (coupled with two ballasted freight cars) at approximately 30.8 mph. Figure 43 shows the post-test impact interface.

Figure 43. Post-Test Photograph of the Impact Interface

The collision conditions for the ATD experiments are determined by the crash pulse, i.e., the deceleration-time history of the rail cars, and the configuration of the interior seats and tables. The crash pulse affects the velocity at which the ATDs impact the interior structures. The severity of the crash pulse can be assessed more easily by plotting the relative velocity of an unrestrained ATD with respect to the car against the relative displacement of that ATD, assuming that the ATD continues to travel at the speed before impact. This plot approximates the velocity of the secondary impact over a range of occupant travel distances. The difference among crash pulses is more apparent when plotted in this manner, rather than comparing the acceleration-time histories.

The crash pulse for the 1st coach car in the CEM train-to-train impact test is similar to the 8g, 250-millisecond triangular crash pulse, which is specified in the American Public Transit Administration

(APTA) SS-C&S-016-99, Rev. 1, Standard for Row-to-Row Seating in Commuter Rail Cars. The crash pulse for the cab car is more severe than that of the first coach. The cab car crash pulse is approximated by a 12G, 250-millisecond triangular crash. The relative velocity versus relative displacement plots associated with the crash pulses for the cab car and first coach car are plotted in Figure 44, along with the comparable curves for an 8G and 12G 250-millisecond crash pulses.

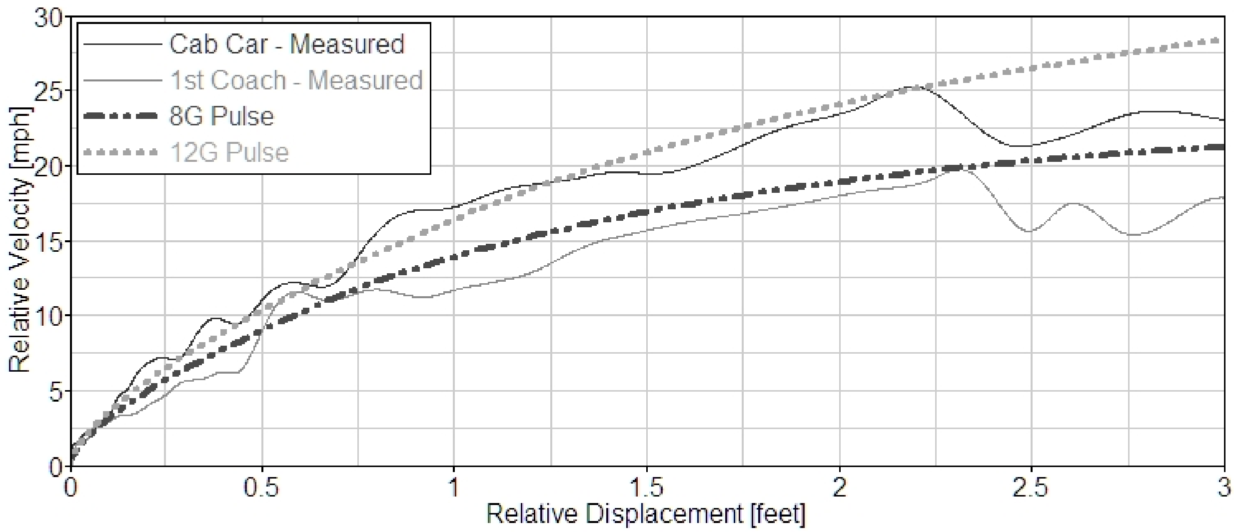

Figure 44. Plots of Relative Velocity versus Relative Displacement

Test results presented in this section include a post-test description of each experiment, the seat/table outcome, and the ATD outcome. These results were obtained from the occupant kinematics recorded on video by the onboard cameras and from the loads recorded by the seat and table attachment load cells and instrumented ATDs.

6.1 Experiment 1.1: Rear-Facing Commuter Seats

This experiment consisted of two rear-facing, newly designed, three-passenger commuter seats located on the forward left-hand-side of the leading cab car. Due to a failure of the pedestal that attached the seats to the floor, which caused the seats to collapse forward as shown in Figure 45, the ATDs in this experiment were not compartmentalized.

6.1.1 Seat Outcome–Experiment 1.1

The outcome of this experiment was a catastrophic failure of the seat-to-floor attachment and the wall, which caused the occupied seat to collapse under the inertial loading of the seats and ATDs. Specifically, the weld at the base of the pedestal failed, which caused the pedestal to separate from its base, as shown in Figure 46. Bolted attachments between the base of the seat pan and the C-channel and between the C-channel and the wall separated as shown in Figure 47. This was caused by the load that was transferred when the pedestal welds failed.

Figure 45. Post-Test Photograph of Experiment 1.1

Figure 46. Weld Failure at the Pedestal Base, which Caused the Seat to Collapse in Experiment 1.1

Figure 47. The Bolt Holding Seat Base at the C-Channel Pulled through. The Connection Holding the C-Channel to the Wall also Failed

The seat-attachment load data indicates that, at 0.080 s, the pedestal bottom plate peeled away from the pedestal body in tension (+6,277 lbf) from the aft side of its attachment, producing a high compressive force (-5,563 lbf) at the front end of the pedestal as shown in Table 13. On pedestal failure, the load was transmitted to the wall attachment, resulting in failure of the seat pan at both a wall attachment bolt and a seat-frame attachment bolt.

Table 13. Floor Attachment Loads and Accelerations in Experiment 1.1

Description	Position Relative to Car	Maximum	Minimum
Floor Attachment Loads (lbf)	Aisle–Fwd F_x*	1842	-9
	Aisle–Fwd F_z	1970	-5563 @ 0.080 sec
Wall Attachment Loads (lbf)	Window–Fwd F_x	1751	-1361
	Window–Fwd F_z	195	-2005 @ 0.143 sec
Floor Attachment Loads (lbf)	Aisle–Aft F_x	2351	-1056
	Aisle–Aft F_z	6277 @ 0.080 sec	-227
Wall Attachment Loads (lbf)	Window–Aft F_x	2823 @ 0.104 sec	-517
	Window–Aft F_z	2712 @ 0.152 sec	-185
Floor Acceleration (*g*)	G_x	33.2	-48.7
	G_y	6.3	-6.9
	G_z	45.6	-63.1

*Fwd is relative to the rail car, nearer the front end.

6.1.2 ATD Outcome–Experiment 1.1

Due to the failure of the seat pedestal, the ATDs in this experiment were not compartmentalized. These rear-facing ATDs simply fell backward toward the front of the car, in unison with the seats that fell backward when their attachments to the rail car failed. The aisle ATD Neck F_z data channel failed to record; therefore, the Neck N_{ij} could not be calculated for this ATD. Table 14 lists the ATD measurements.

Table 14. ATD Measurements on Hybrid III 50th Percentile ATDs in Experiment 1.1

Measure	Injury Criteria 50th (M)$^{+}$	Window 50th (M)	Aisle 50th (M)
Upper Neck Tension / Compression Force (F_z) (lbf)	+937 (4170N) / -899 (4000N)	131.8 / -40.0	Unreliable Data
Head Injury Criterion (HIC_{15})	700	23.3	11.8
Neck N_{ij}–Tension-Flexion	1.0	0.086	Unreliable Data
Neck N_{ij}–Tension-Extension	1.0	0.245	Unreliable Data
Neck N_{ij}–Compression-Flexion	1.0	0.037	Unreliable Data
Neck N_{ij}–Compression-Extension	1.0	0.218	Unreliable Data
Chest Deceleration (G_x) over a 3msec Clip$^{(1)}$	60	10.2	7.4

$^{+}$ Code of Federal Regulations, Title 49, Part 571, Standard 208 Occupant Crash Protection, October 2002.

6.2 Experiment 1.2: Workstation Table Occupant Experiment Using the RSSB Hybrid 3RS

This experiment was one of the two workstation table experiments located in the cab car, each with one ATD seated in the forward-facing window seat. The Hybrid 3RS ATD in this experiment successfully impacted the workstation table, which caused the table to crush as expected during the collision. Figure 48 shows a post-test photo.

6.2.1 Table Outcome–Experiment 1.2

The outcome of this experiment was a successful crushing of the table when the ATD impacted it during the collision. A maximum crush of 6.125 in was measured after the test. The wall attachment load cells measured forces that were relatively evenly distributed. The two upper attachment points carried loads that were slightly higher than the loads that the lower wall attachment carried, as shown in Table 15. The table remained attached to the wall and kept the ATD compartmentalized.

Figure 48. Post-Test Photograph of Experiment 1.2 (with Hybrid 3RS ATD)

Table 15. Table Attachment Loads, Displacements, and Floor Accelerations in Experiment 1.2

Description	Position Relative to Car	Maximum	Minimum
Table Attachment Loads (lbf)	Near Wall, F_x	2063	-2248
	Near Wall, F_y	3103	-2762
	Near Wall, F_z	914	-949
Table Attachment Loads (lbf)	Far Wall, F_x	1961	-3025
	Far Wall, F_y	2125	-2386
	Far Wall, F_z	890	-725
Table Attachment Loads (lbf)	Lower Wall, F_x	1394	-1595
	Lower Wall, F_y	770	-1356
	Lower Wall, F_z	1065	-908
Table Crush Displacement (inches)		6.1	-
Table Edge Displacement (inches)		1.3	-
Table Top Acceleration (*g*)	G_x	82.2	-83.3
	G_y	12.5	-14.4
	G_z	27.9	-25.9
Floor Acceleration (*g*)	G_x	49.4	-38.8
	G_y	5.8	-7.2
	G_z	15.4	-16.9

6.2.2 ATD Outcome–Experiment 1.2

The Hybrid 3RS in this experiment measured a chest deceleration of 63G. No indication was found that the head impacted the top of the table. The knees of the Hybrid 3RS, however, did impact the seat pan on the other side of the table. In anticipation of this interaction between the knee/shin of the ATD and the facing seat pan, a rubber bumper was installed around the edge of the facing seat pan. This bumper was intended to mitigate the femur loads experienced by the ATD. Table 16 lists the ATD injury data. Figure 49 shows how the knees interacted with the facing-seat rubber bumper.

The value for the Upper Abdomen V*C was calculated by converting the average of the left and right CRUX measurements into a compression-time history. The compression-time history of the upper abdomen was divided by the undeformed depth of the abdomen and then multiplied by the compression velocity-time history. The maximum value of the resulting curve was scaled by 1.3 to determine the Upper Abdomen V*C value.

Table 16. ATD Measurements on Hybrid 3RS in Experiment 1.2

Measure	Injury Criteria 50th (M)[+]	Hybrid 3RS–Window 50th (M)
Upper Neck Tension / Compression Force (F_z) (lbf)	+937 (4170N) / -899 (4000N)	264 / -208
Head Injury Criterion (HIC_{15})	700	157
Neck N_{ij}–Tension-Flexion	1.0	0.283
Neck N_{ij}–Tension-Extension	1.0	0.360
Neck N_{ij}–Compression-Flexion	1.0	0.248
Neck N_{ij}–Compression-Extension	1.0	0.363
Chest Deceleration (G_x) over a 3msec Clip (*g*)	60	22.7
Femur Load (Right) (lbf)	-2250	-795
Femur Load (Left) (lbf)	-2250	-226
Upper Abdomen V*C (inches/sec)[*]	78	37.8
Upper Abdominal Compression Ratio (%)[++]	50	29

[+] Code of Federal Regulations, Title 49, Part 571, Standard 208 Occupant Crash Protection, October 2002.
[*] Wallace, W.A. and Srinivasan, S.C.M., “Rail Passenger & Crew Survivability Studies–Part 2,” November 2002.
[++] Rouhana, S.W., Viano, D.C., Jedrzejczak, E.A., and McCleary, J.D., “Assessing Submarining and Abdominal Injury Risk in the Hybrid III Family of Dummies,” Proc. 33rd Stapp Car Crash Conference, pp. 257-279, SAE Technical Paper No. 892440, October 1989.

Figure 49. Interaction of the Knees with the Facing Seat Rubber Bumper Occured in Experiment 1.2

6.3 Experiment 1.3: Workstation Table Occupant Experiment Using the THOR ATD

This experiment was the second of the two workstation table experiments located in the cab car. The THOR ATD in this experiment successfully impacted the workstation table, causing it to crush as expected during the collision. Figure 50 shows a post-test photograph.

Figure 50. Post-Test Photograph of Experiment 1.3 (with THOR ATD)

6.3.1 Seat Outcome–Experiment 1.3

The outcome of this experiment was a successful crushing of the table caused by the ATD impact. A maximum crush of 4.75 in was measured after the test. The wall attachment load cells measured forces that were relatively evenly distributed. Two upper attachment points carried loads that were slightly higher than loads carried by the lower wall attachment as shown in Table 17. The table remained attached to the wall and kept the ATD compartmentalized.

Table 17. Table Attachment Loads, Displacements, and Floor Accelerations for Experiment 1.3

Description	Position Relative to Car	Maximum	Minimum
Table Attachment Loads (lbf)	Near Wall, F_x	1769	-2421
	Near Wall, F_y	2884	-3499
	Near Wall, F_z	619	-641
Table Attachment Loads (lbf)	Far Wall, F_x	2589	-3097
	Far Wall, F_y	3647	-3135
	Far Wall, F_z	819	-582
Table Attachment Loads (lbf)	Lower Wall, F_x	1312	-1542
	Lower Wall, F_y	680	-1111
	Lower Wall, F_z	1053	-864
Table Crush Displacement (inches)		4.7	–
Table Edge Displacement (inches)		1.4	–
Table Top Acceleration (*g*)	G_x	95.3	-78.9
	G_y	9.9	-8.6
	G_z	21.3	-19.4

6.3.2 ATD Outcome–Experiment 1.3

Despite neck loads that were higher in this experiment than in Experiment 1.2, no indication was seen that the head impacted the top of the table. The knees of the THOR, however, did impact the seat pan on the other side of the table. In anticipation of this interaction between the knee/shin of the ATD and the facing seat pan, a rubber bumper was installed around the edge of the seat pan. This bumper was intended to mitigate the femur loads experienced by the ATD. Table 18 lists the ATD injury data. Figures 51 and 52 show how the knees interacted with the facing-seat rubber bumper.

The value for the Upper Abdomen V*C was calculated by converting the average of the left and right CRUX measurements into a compression-time history. The compression-time history of the upper abdomen was divided by the original depth of the abdomen and then multiplied by the compression velocity-time history. The maximum value of the resulting curve was scaled by 1.3 to determine the Upper Abdomen V*C value.

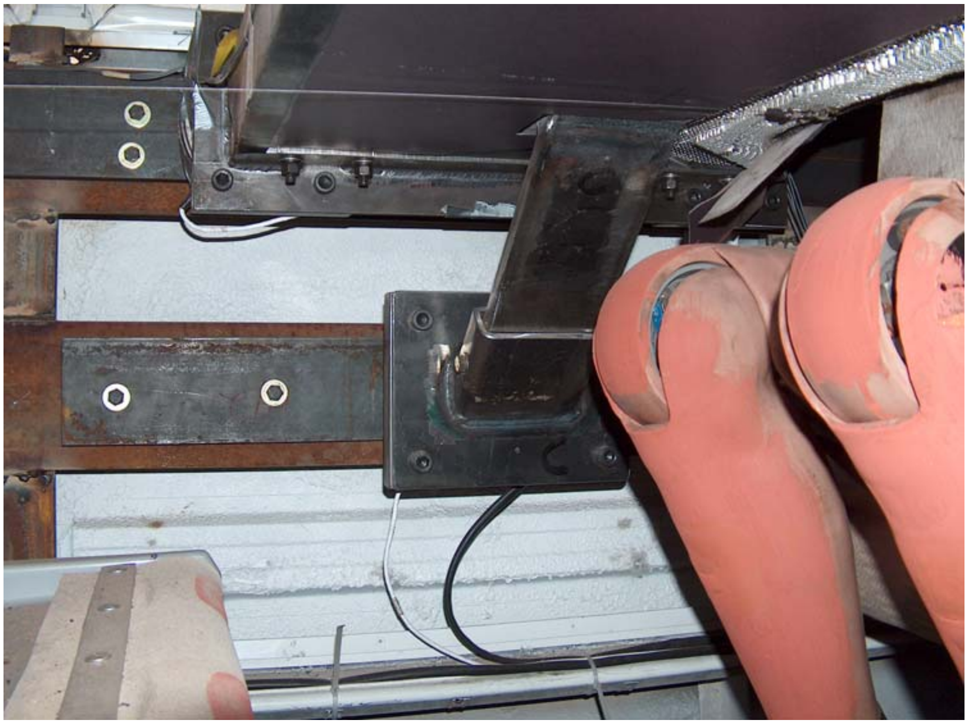

Figure 51. Evidence of Knee Interaction with the Facing-Seat Rubber Bumper in Experiment 1.3

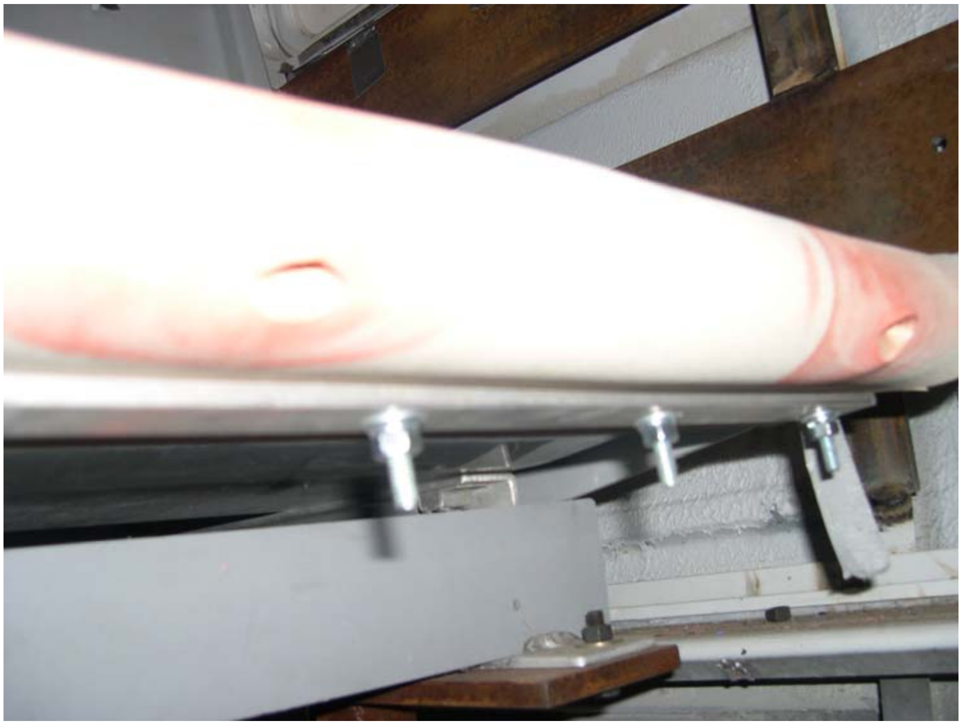

Figure 52. Tears in the Rubber Bumper from Knee Interaction with the Facing Seat in Experiment 1.3

Table 18. Injury Criteria Calculated for THOR ATD in Experiment 1.3

Measure	Injury Criteria 50th (M)[+]	THOR–Window 50th (M)
Upper Neck Tension / Compression Force (F_z) (lbf)	+937 (4170N) / -899 (4000N)	376 / -96
Head Injury Criterion (HIC_{15})	700	166
Neck N_{ij}–Tension-Flexion	1.0	0.246
Neck N_{ij}–Tension-Extension	1.0	0.289
Neck N_{ij}–Compression-Flexion	1.0	0.059
Neck N_{ij}–Compression-Extension	1.0	0.118
Chest Deceleration (G_x) over a 3msec Clip (*g*)	60	33.7
Femur Load (Right) (lbf)	-2250	-1219
Femur Load (Left) (lbf)	-2250	-968
Upper Abdomen V*C (inches/sec)[*]	78	44.5
Upper Abdominal Compression Ratio (%)[++]	50	26

[+] Code of Federal Regulations, Title 49, Part 571, Standard 208 Occupant Crash Protection, October 2002.
[*] Wallace, W.A. and Srinivasan, S.C.M., "Rail Passenger & Crew Survivability Studies–Part 2," November 2002.
[++] Rouhana, S.W., Viano, D.C., Jedrzejczak, E.A., and McCleary, J.D., "Assessing Submarining and Abdominal Injury Risk in the Hybrid III Family of Dummies," Proc. 33rd Stapp Car Crash Conference, pp. 257-279, SAE Technical Paper No. 892440, October 1989.

6.4 Experiment 2.1: Forward-Facing Intercity Seats

This experiment consisted of two rows of modified, forward-facing, two-passenger Amtrak intercity seat pairs located in the front left-hand-side of the first coach car (second car in the consist). The ATDs in this experiment were compartmentalized as shown in the post-test photograph in Figure 53. No seat attachment loads were recorded in this experiment.

Figure 53. Post-Test Photograph of Experiment 2.1

6.4.1 Seat Outcome–Experiment 2.1

The aft-row seats (launch seats) used in this experiment were the original Amtrak seats from previous tests. The impact seats were the same refurbished seats that were used in previous full-scale testing for assessing the suitability of restraint systems. The seat pitch was 41 in, considerably longer than the 32-inch seat pitch of the commuter seats tested in Experiment 1.1 and Experiment 2.2. The impact seats in this experiment were the original two-place passenger Amtrak seats whose backs had been modified to withstand the high forces produced by two occupants in 3-point restraints. The seats were also equipped with energy-absorbing (E/A) struts to help minimize the impact force on the head. Without occupants, all movement in the impact seats was caused by the impact of the occupants from the launch seats and the seat's relatively smaller self-weight inertia loads. To help reduce the potential for high head-injury loads, a cushioned headrest was installed on the rear face of the impact seats. The E/A struts extended approximately 0.75 in each, indicating they performed as designed by reacting to the impact of the knees from behind as shown in Figure 54. Table 19 lists the recorded floor accelerations for Experiment 2.1.

Figure 54. Energy-Absorbing Struts Before the Test (left), Actuated Approximately 0.75 in (right) to Help Reduce the Force of the Head Impacting the Seat Back

Table 19. Floor Accelerations in Experiment 2.1

Direction (Relative to Car)	Maximum (*g*)	Minimum (*g*)
X-direction (G_x)	38.5	-65.2
Z-direction (G_z)	26.5	-28.9

6.4.2 ATD Outcome–Experiment 2.1

Both 95th percentile ATDs were compartmentalized for this experiment. Failure to collect high-speed footage for this experiment prevented the observation of the kinematic response of the ATDs during the collision. The HIC_{15} criteria was exceeded for both the aisle and window ATDs. Table 20 lists the injury data that was recorded for Experiment 2.1.

Table 20. Injury Criteria Calculated for Hybrid III 95th Percentile ATDs in Experiment 2.1

Measure	Injury Criteria 95th (M)[+]	Window 95th (M)	Aisle 95th (M)
Upper Neck Tension / Compression Force (F_z) (lbf)[*]	+1131 (5033N) / -1089 (4846N)	217 / -600	153 / -603
Head Injury Criterion (HIC_{15})	700	1478	1305
Neck N_{ij}–Tension-Flexion	1.0	0.542	0.599
Neck N_{ij}–Tension-Extension	1.0	0.307	0.259
Neck N_{ij}–Compression-Flexion	1.0	0.806	0.959
Neck N_{ij}–Compression-Extension	1.0	0.359	0.361
Chest Deceleration (G_x) over a 3msec Clip (*g*)	55	17.1	15.0
Femur (Right) (lbf)	-2850	-815	-769
Femur (Left) (lbf)	-2850	-799	-515

[*] Nahum and Melvin, *Accidental Injury: Biomechanics and Prevention*, New York: Springer-Verlag, 1993, pp. 82-83.
[+] Eppinger, R., Sun, E., Kuppa, S., and Saul, R., "Development of Improved Injury Criteria for the Assessment of Advanced Automotive Restraint Systems–II," Supplement to NHTSA Docket No. 1998-4405-9, 2000.

6.5 Experiment 2.2: Forward-Facing Commuter Seats

This experiment consisted of two forward-facing, newly designed, three-passenger commuter seats located in the aft right-hand-side of the first coach car (second car in the consist). The ATDs were compartmentalized in this experiment, as shown in a post-test photograph in Figure 55.

Figure 55. Post-Test Photograph of Experiment 2.2

6.5.1 Seat Outcome–Experiment 2.2

The outcome of this experiment was a partial failure of the seat attachment to the floor, which caused the ATDs in the center and aisle seats to fall into the aisle of the car. Specifically, some of the welds at the base of the pedestal failed, which caused the pedestal to partially separate from its base as shown in Figure 56. Unlike the seat in Experiment 1.1, the bolt attachment of the seat base to the wall did not separate, which helped to keep the ATDs compartmentalized.

Figure 56. Weld Failure at Pedestal Base, which Caused the Seat to Rotate Forward and Allowed the ATDs to Fall into the Aisle in Experiment 2.2

The seat attachment loads indicated that, at 0.214 s, some of the pedestal welds failed in tension with the vertical load at the aft attachment point reaching 6,796 lbf, while the vertical load at the forward attachment point reached -7,151 lbf, as shown in Table 21. Upon pedestal failure, the load was transmitted to the wall attachment. Unlike the seat in Experiment 1.1, however, the seat base remained attached to the side wall.

6.5.2 ATD Outcome–Experiment 2.2

All three ATDs in this experiment were compartmentalized. The partial failure of the pedestal attachment allowed the center and aisle-side ATDs to collapse into the aisle after the secondary impact, which is acceptable under the definition of compartmentalization in the APTA Safety Standard SS-C&S-016-99, Rev. 1 Standard for Row-to-Row Seating in Commuter Rail Cars. The data channel tracking the chest acceleration in the G_x direction for the window-side ATD failed to record.

Table 21. Floor Attachment Loads and Accelerations for Experiment 2.2

Description	Position Relative to Car	Maximum	Minimum
Floor Attachment Loads (lbf)	Aisle–Fwd F_x*	2300	-1574
	Aisle–Fwd F_z	1133	-7151 @ 0.213 sec
Wall Attachment Loads (lbf)	Window–Fwd F_x	2890	-448
	Window–Fwd F_z	513	-1967
Floor Attachment Loads (lbf)	Aisle–Aft F_x	2545	-656
	Aisle–Aft F_z	6796 @ 0.214 sec	-552
Wall Attachment Loads (lbf)	Window–Aft F_x	961	-1801
	Window–Aft F_z	1646	-374
Floor Acceleration (*g*)	G_x	86.6	-96.6
	G_z	37.3	-36.2

*Fwd is relative to the rail car, nearer the front end.

Table 22. Injury Criteria Calculated for the Hybrid III 50th Percentile ATDs in Experiment 2.2

Measure	Injury Criteria 50th (M)+	Window 50th (M)	Aisle 50th (M)
Upper Neck Tension / Compression Force (F_z) (lbf)	+937 (4170N) / -899 (4000N)	86 / -201	93 / -144
Head Injury Criterion (HIC_{15})	700	301	220
Neck N_{ij}–Tension-Flexion	1.0	0.346	0.224
Neck N_{ij}–Tension-Extension	1.0	0.205	0.381
Neck N_{ij}–Compression-Flexion	1.0	0.393	0.195
Neck N_{ij}–Compression-Extension	1.0	0.162	0.433
Chest Deceleration (G_x) over a 3 msec Clip* (*g*)	60	Unreliable Data	20.2
Right Femur Load (lbf)	-2250	-444	-633
Left Femur Load (lbf)	-2250	-724	-374

+ Code of Federal Regulations, Title 49, Part 571, Standard 208 Occupant Crash Protection, October 2002.

7. Conclusions

Table 23 provides a summary of results of the occupant protection experiments on board the full-scale train-to-train CEM collision test.

Table 23. Summary of Test Results

Experiment No.	Experiment Description	Structural Crashworthiness Performance of Equipment	Injury Criteria Met?	ATDs Compartmentalized?
1.1	Rear-Facing Commuter Seat	Seat failed at base of pedestal	Yes	No
1.2	Crushable Table between Facing Seats with Hybrid 3RS ATD	Table crushed as designed to 6.1 in	Yes	Yes
1.3	Crushable Table between Facing Seats with THOR ATD	Table crushed as designed to 4.7 in	Yes	Yes
2.1	Forward-Facing Intercity Seat	E/A struts actuated as designed by 0.75 in	No	Yes
2.2	Forward-Facing Commuter Seat	Seat failed at base of pedestal	Yes	Yes

These results indicate that the newly designed crushable table performed as intended. It appears that the Hybrid 3RS in Experiment 1.2 may have crushed the table to the point of bottoming out on the I-beam at the center of the table, which caused the higher chest deceleration. The ATDs of the rear-facing commuter-seat experiments were not compartmentalized due to the failure of the seat-base welds at the floor attachments. The ATDs of the forward-facing commuter seat and intercity seat experiments were effectively compartmentalized.

Appendix A
Test-Equipment Matrix

Table A-1. Distribution of Test Equipment

Test Number	Test Description	Modified Intercity Seats	Commuter Seats	Facing-Seat Pairs	Tables	Hybrid III 50th ATD Instrumented	Hybrid III 95th ATD Instrumented	Hybrid II 50th ATD Not Instrumented	Hybrid III RS ATD	THOR ATD	Digital High-Speed Cameras	Accelerometers	Load Cells	Displacement Transducers	ATD Data Channels	Seats/Table/Floor Data Channels	Total No. of Data Channels		
1.1	Rear-Facing	0	2	0	0	2	0	1	0	0	2	5	6	0	18	11	29		
1.2	H3RS-Facing Seats with Table	0	0	2	1	0	0	0	1	0	3	4	6	4	17	17	34	No. of Data Channels in Leading Cab Car	No. of Data Bricks per Car
1.3	THOR-Facing Seats with Table	0	0	2	1	0	0	0	0	1	2	4	8	6	22	14	36	99	13
2.1	Forward-Facing Intercity Seats	2	0	0	0	0	2	0	0	0	2	5	6	0	22	2	24	No. of Data Channels in First Coach Car	
2.2	Forward-Facing Commuter Seats	0	2	0	0	2	0	1	0	0	2	5	10	0	22	10	32	56	7
	Total	2	4	4	2	4	2	2	1	1	11	23	36	10	101	54	155	Total No. of Data Channels	
								10	ATDs									155	20

Table A-2. Distribution of Instrumentation/ATDs

	#9357			#9358			
	1.1	1.2	1.3	2.1	2.2	TOT	
ATDs							**Source of Equipment**
Hybrid III 50th	1					1	VRTC
Hybrid III 50th	1					1	VRTC
Hybrid III 50th					1	1	VRTC
Hybrid III 50th					1	1	VRTC
Hybrid III 95th				1		1	VRTC
Hybrid III 95th				1		1	VRTC
Hybrid II 50th	1					1	VRTC
Hybrid II 50th					1	1	VRTC
Hybrid 3RS		1				1	RSSB, fully assembled, instrumentation from GMH
THOR			1			1	GESAC, fully instrumented; arms and lower legs from GMH
Total	**3**	**1**	**1**	**2**	**3**	**10**	
Accelerometers							
Triaxial (Head)	2	**1**	1	2	2	8	VRTC, GESAC for THOR, GMH for 3RS dummy
Triaxial (Chest)	2	**1**	1	2	2	8	VRTC, GESAC for THOR, GMH for 3RS dummy
Triaxial (Floor)	1	1	0	1	1	4	Simula
Triaxial (Table top)		1	1			2	Simula
Uniaxial (U-Abdomen)			1			1	GESAC
Total	**5**	**4**	**4**	**5**	**5**	**23**	
Load Cells							
6-axis (Head/Neck)	2	**1**	1	2	2	8	VRTC, GESAC for THOR, GMH for 3RS dummy
Uniaxis Neck Cables			2			2	GESAC
Uniaxial (Femur)		**2**	2	4	4	12	VRTC, GMH for 3RS dummy and THOR
Uniaxial (Table Edge)		0	0			0	Not needed
Triaxial (Table Attachment)		3	3			6	Simula
Triaxial (Seat/Floor Attachment)	4				4	8	Simula
Total	**6**	**6**	**8**	**6**	**10**	**36**	
Displacement Trans.							
Triaxial (LCrux)		2	2			4	RSSB, GESAC
Uniaxial (UAbdomen)			1			1	GESAC
Uniaxial (OC position)			1			1	GESAC
Uniaxial (Table top)		2	2			4	Simula
Total	**0**	**4**	**6**			**10**	

Table A-3. Total Number of Data Channels

	Experiment						
	1.1	1.2	1.3	2.1	2.2	TOT	
Accelerometers							
Triaxial (Head)	6	3	3	6	6	24	
Triaxial (Chest)	6	3	3	6	6	24	
Triaxial (Floor)	3	3	**0**	**2**	**2**	10	
Triaxial (Table top)		3	3			6	
Uniaxial (U-Abdomen)			1			1	
Total	**15**	**12**	**10**	**14**	**14**	**65**	65
Load Cells							
6-axis (Head/Neck)	6	3	3	6	6	24	
Uniaxis Neck Cables			2			2	
Uniaxial (Femur)		2	2	4	4	12	
Uniaxial (Table Edge)		**0**	**0**			0	
Triaxial (Table Attachment)		9	9			18	
Triaxial (Seat/Floor Attachment)	8				8	16	
Total	**14**	**14**	**16**	**10**	**18**	**72**	72
Displacement Trans.							
Triaxial (LCrux)		6	6			12	
Uniaxial (U-Abdomen)			1			1	
Uniaxial (OC Position)			1			1	
Uniaxial (Table top)		2	2			4	
Total	**0**	**8**	**10**			**18**	18
	29	**34**	**36**	**24**	**32**		**155**
Required No. of Data Bricks	3.63	4.25	4.50	3.00	4.00	19.38	
		70					
		8.8					
Actual No. of Data Bricks	**4**	**9**		**3**	**4**	**20**	

Appendix B
Camera Failure Report

This report addresses several problems that occurred with the cameras during the collision test conducted on March 23, 2006.

Test Day Procedures

With instructions that the test was a "go" and to expect the crash to occur at 10:15 a.m., the camera crew (comprised of two people) began to arm and configure the cameras at 9:50 a.m., completing their task at 10:05 a.m. Before leaving the train, the crew checked that each camera was set correctly and armed. This included the cameras for Experiments 1.1, 1.2, 1.3, 2.1, and 2.2. All cameras were operational and armed. Arming the cameras consisted of connecting the positive battery post for each camera group, checking each camera with a video monitor to make sure it booted, setting each camera to pre-trigger 0.5 s before impact, and validating frame rate and shutter speed.

Lesson 1: Conduct a final check of the cameras with lights on to ensure that the lens settings, camera settings, and light level will produce a good image. This can be done during the final check on each camera and takes less than 5 min.

After the crash, the camera crew proceeded to the train and waited for the all-clear signal. A minor detail had been overlooked; the crew had to wait for ladders to board the train. Once on board, the two-person crew worked independently, each with a small battery video monitor and keypad as well as a laptop to download the cameras one at a time.

Camera Issues in the Leading Cab Car

Camera for Experiment 1.1–Side View (Ultima APX Color)
The day before the test, the ambient light from bright sun washed out the image on the side and overhead cameras. The side camera was adjusted from f1.4 to f2.8, and the shutter speed was increased from 1/1000 to 1/1500, with a frame rate of 500 fps. The camera crew reviewed the changes with the test engineer and project engineer. Everyone agreed the image looked good with the lights on after the adjustment.

After the test, images from the side camera (Color APX) were dark. When the lens was checked, it was at f8, not f2.8. One might conclude that it had mistakenly been set to f8. However, the lens setting had been reviewed and then taped. The desired field of view (known as FOV) had been adjusted by changing the pretest 12.5 mm lens to a 7 mm lens. This lens was so long that some concern occurred about stability during the high-G loads of the test. To lower the risk, the lens was secured with duct tape to the camera safety strap. The lens setting could have been accidentally changed at this time. No live test was conducted with lights after this point except during the actual test. It is conceivable that this was a human error that resulted in the side-camera view being underexposed.

Recovery of the image data to a sufficient level may be possible by using the SAI tracking software with pre-image processing set such that color is removed, the image is brightened, and some contrast adjustment may be required. Even with the dark image, quad targets can be seen.

Camera for Experiment 1.1–Overhead View (Ultima 512 Mono)
No issues were found. Good images were obtained. In addition, these images validated that the lights were on during the test.

Camera for Experiment 1.2–Front View(Ultima APX-RS Mono)
No issues were found. Images downloaded without a problem.

Cameras for Experiment 1.2–Side View (Ultima APX-RS Color)
This camera had two issues. The first issue was that the image was soft, meaning it was slightly out of focus. This camera had been reviewed in the same manner as the Experiment 1.1 side camera the day before the test. The lens had been locked with tape and was not touched. After the test, however, the tape on the lens was not as tight as it had been the previous night. This allowed the lens to rotate slightly in a high-G jolt. The lens had been set on infinity, but after the test it was slightly off from this position. The only possible conclusion is that the lens had rotated during the collision and that the use of minimal tape is not sufficient in this high-G test.

Lesson 2: The lens should be locked during a high-*g* test. Supporting a lens in a high-*g* environment is advisable. A recommendation for the future is to provide a lens support similar to the one GMH used on the Vision Research cameras.

The second issue and the most difficult problem was that the camera responded to keypad instructions but did not respond to the PC program. This meant that digital images could not be downloaded. The camera crew worked to gain control of this camera by contacting the manufacturer's customer support to find out if they could troubleshoot the problem. The camera crew called several sales people about the specific camera history and then reloaded interface software. A second communication cable was obtained. Several PCs and I-394 interface cards were tried. However, none of these options worked. Images could be viewed on the video monitor but could not be downloaded. One option was to back up the images with videotape, however, a videotape recorder was not immediately available. More than 30 min of searching was required to locate a videocassette recorder (VCR).

Lesson 3: For a high-G test, it is necessary to have a VCR on site to download analog images as a backup to the digital images.

With the VCR, a video backup of the images was downloaded. At this point, the camera crew was approaching the critical limit on the amp-hour rating of the battery. An AC power and a battery charger were requested at this time; however, none were on site. By the time a generator was provided, an option was present to jumper the battery with one of the light batteries. No means to accomplish this existed however, so one of the DC power cables was cut and jumpered between secondary batteries. At that time, a battery charger arrived. At this point, however, the cameras in the second car needed a backup. A request was made to provide a charger for the battery powering the cameras in the second car.

The camera crew concluded that the communication issue was with the camera and not with the cables or the PC. The camera safety strap was removed and the camera was jolted with minimum force on the side in the direction opposite the *g*-loading. The camera began communicating and the images were downloaded.

Lesson 4: Suggest to the camera manufacturer that they further reinforce the camera by using an RTV sealant on the connectors such that high-*g* loading will not disconnect them.

Cameras for Experiment 1.2—Overhead View (Ultima 512 Mono)
No issues. Images downloaded without a problem.

Camera for Experiment 1.3—Side View (Ultima APX-RS Mono)
Some unexpected trouble occurred getting this camera to communicate through the GigE interface. This interface had been tested and was found to be working the day before the experiment. A specific PC had been assigned to download the data from this camera; however, the images could not be downloaded. The camera crew made many attempts, including using a new cable, reloading software, and reviewing the network connections to the camera. Finally, the Gateway discovered on the camera was different than the PC. Once they were made the same, the camera and the PC were able to communicate with one another and the images from this camera were downloaded and found to be exceptional.

Camera for Experiment 1.3—(Ultima 512 Mono)
No issues. Images downloaded without a problem.

Camera Issues in the Second Car

Two experiments were in the coach car: Experiments 2.1 and 2.2. Each experiment had an overhead and a side-view camera. Experiment 2.1 used an APX camera and a 512 camera. Experiment 2.2 used a pair of 512 cameras. One 12-volt DC battery supplied power to all four cameras, which were armed, rechecked, and working properly before the test.

The camera crew attempted to download the video data after the test with only partial success:

- Experiment 2.1, side view—no data recovered,
- Experiment 2.1, overhead view—no data recovered,
- Experiment 2.2, side view—all data recovered successfully, and
- Experiment 2.2, overhead view—no data recovered.

Cameras for Experiment 2.2—Overhead and Side Views
Experiment 2.2 was considered the more important of the two experiments, and since the 512 cameras would be quicker to download, they were tried first. The top-view camera would not communicate with the computer via the 1394 port. The side-view camera worked normally and images were downloaded.

Cameras for Experiment 2.1—Overhead and Side Views
Neither the APX camera nor the 512 camera for Experiment 2.1 would communicate via the I-394 interface. One (possibly both) of the cameras still had data in memory, which could be displayed on a local NTSC display under keypad control. An NTSC-compatible video recorder

was requested in an attempt to recover the video data without computer communication. As Experiment 2.1 was considered as having the least priority, the VCR was initially used successfully on one of the cab-car cameras, which was experiencing similar problems.

Different software drivers were tried without success. Another computer was used (with a different software revision that had been used in the past successfully with both the 512 and APX systems). By the time the VCR became available, the cameras had stopped responding to keypad commands and it became obvious that the battery power had decayed below limits.

It appears that the problems were due to battery-power decay. Unanticipated delays occurred between the time the cameras were armed and the start of downloading. Battery-power failure was attributed to the following causes:

- The batteries were cold; temperatures before the test were about 40 °F.
- It was some time before AC generator power became available. When the battery charger was connected, it tripped. The reason for this was the battery had decayed significantly and the cameras were trying to run entirely from the charger, which had exceeded its capacity.
- Both cameras (APX and 512) failed; this was the greater power requirement case.

Summary

The lead car had the same type of cameras that were in the second car. The cameras in the lead car functioned properly. Although some difficulty with one of the RS cameras in the lead car occurred, a similar camera did not exist in the second car. The conclusion is that the power drain on the battery in the second car was the highest. The amp-hour calculation for this battery indicated that the battery life was sufficient at over 3 hr. The time between arming the cameras and the collision was 1 hr, which minimized the amount of time available to download the cameras after the test. The attempt to keep the battery charged by hooking up the battery charger may have had a detrimental effect on the voltage output temporarily. This could have caused the cameras to be unresponsive.

Appendix C
Pretest Target Measurements

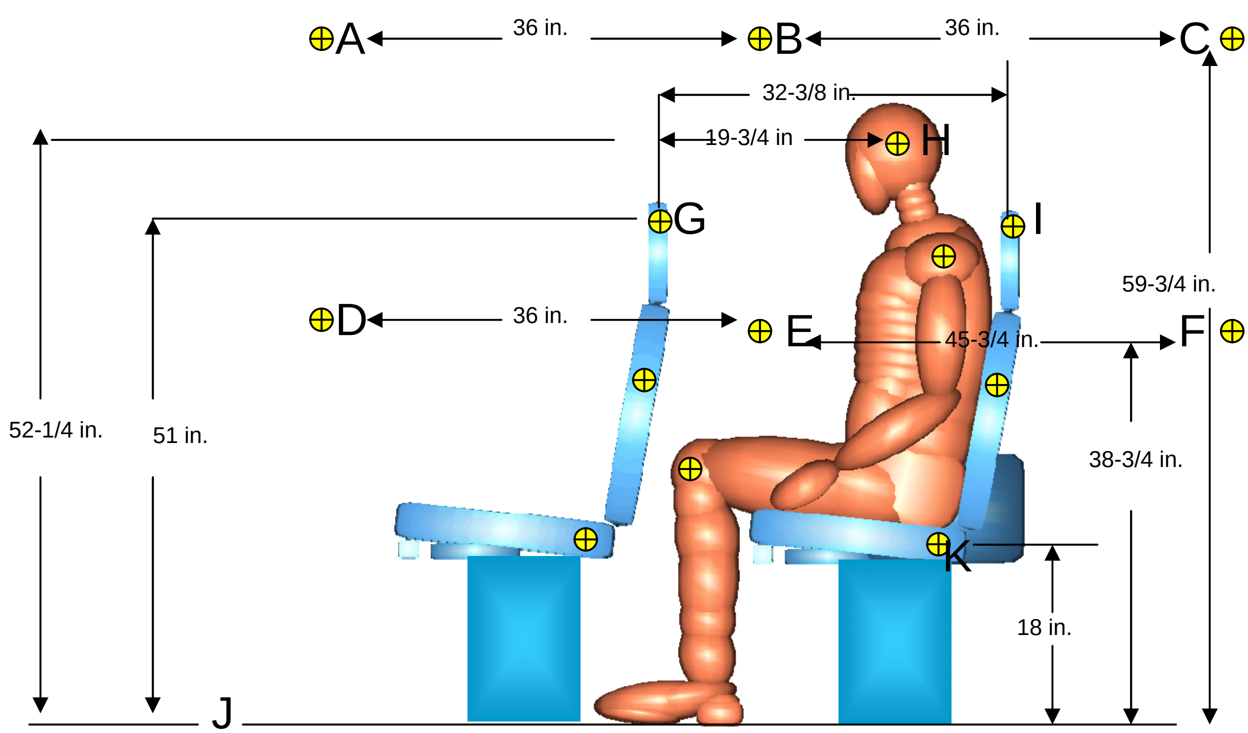

Figure C-1. Target Dimensions for Experiment 1.1

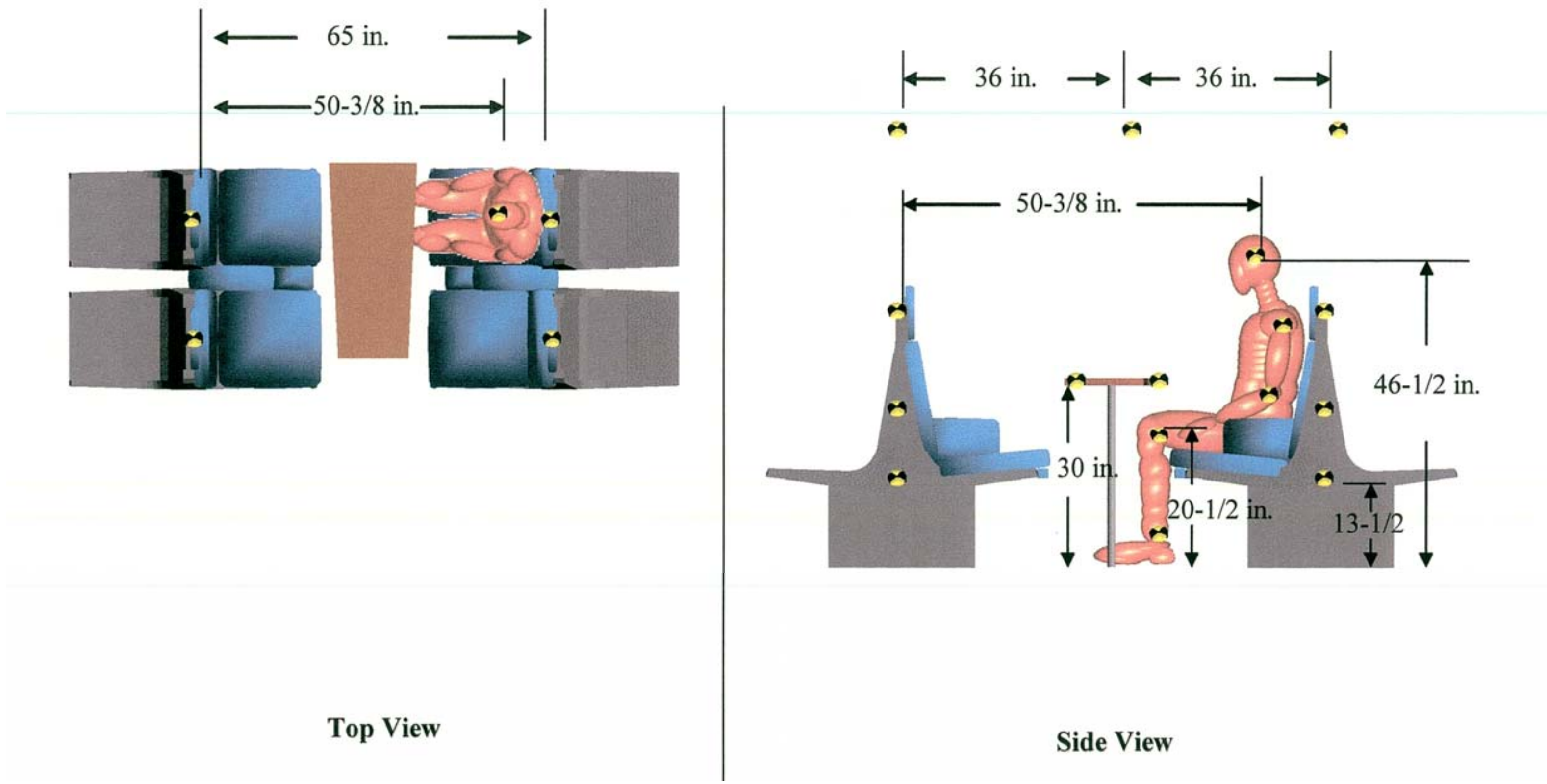

Figure C-2. Target Dimensions for Experiment 1.2

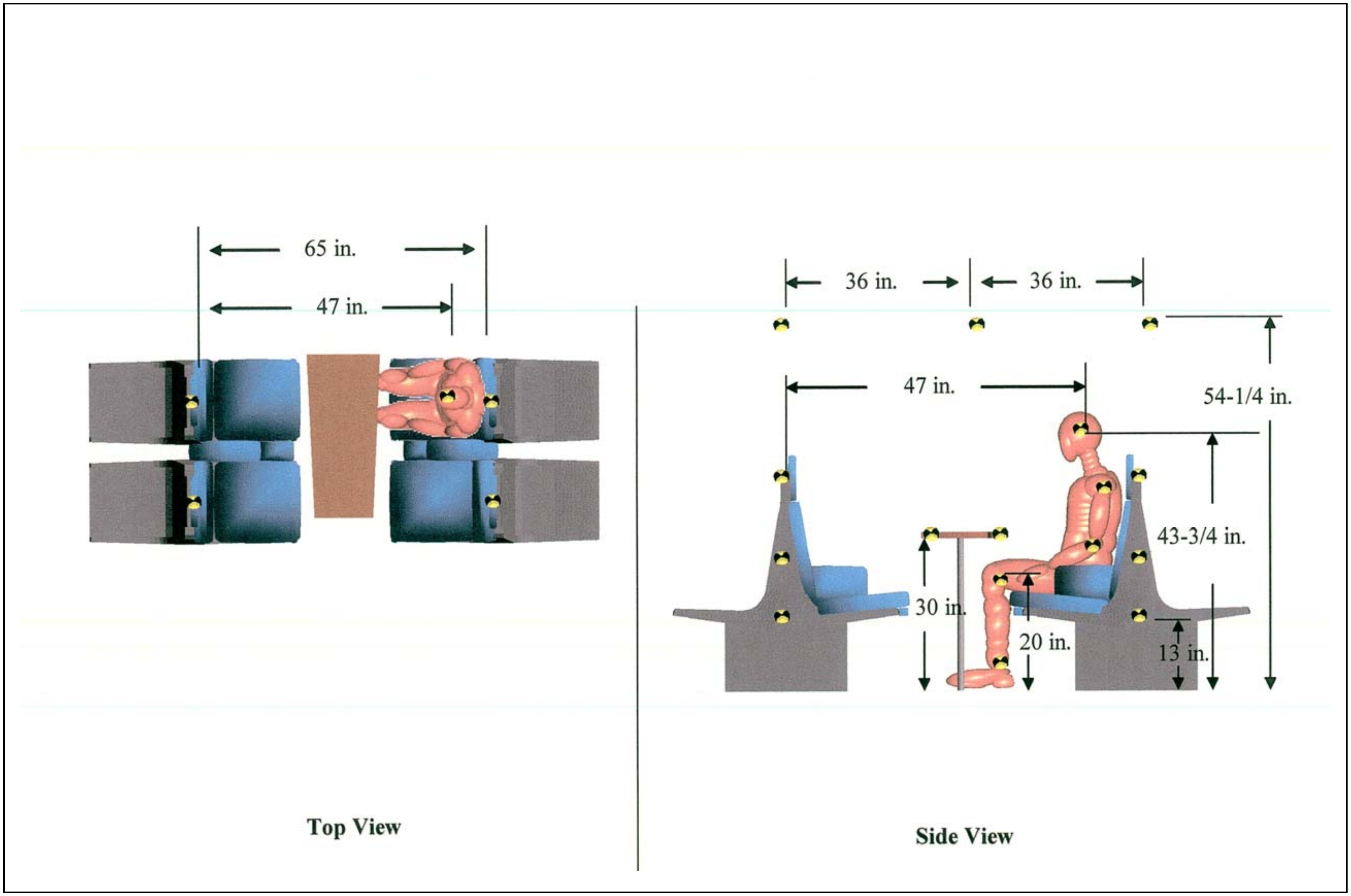

Figure C-3. Target Dimensions for Experiment 1.3

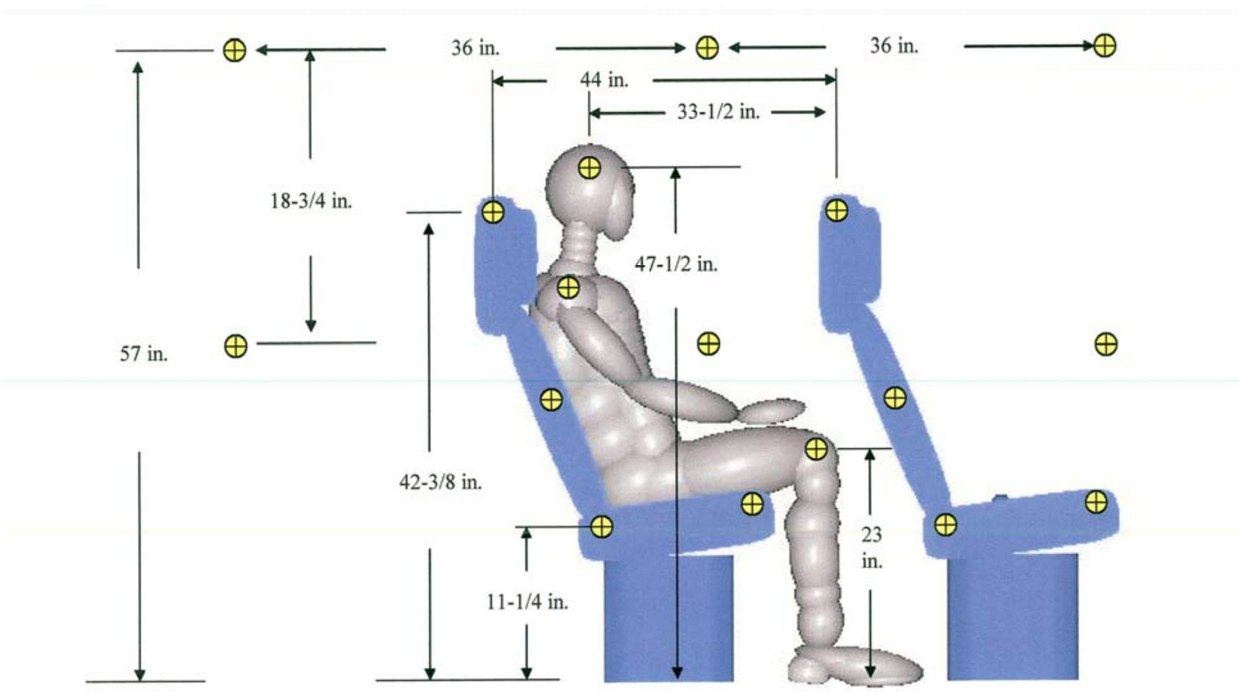

Figure C-4. Target Dimensions for Experiment 2.1

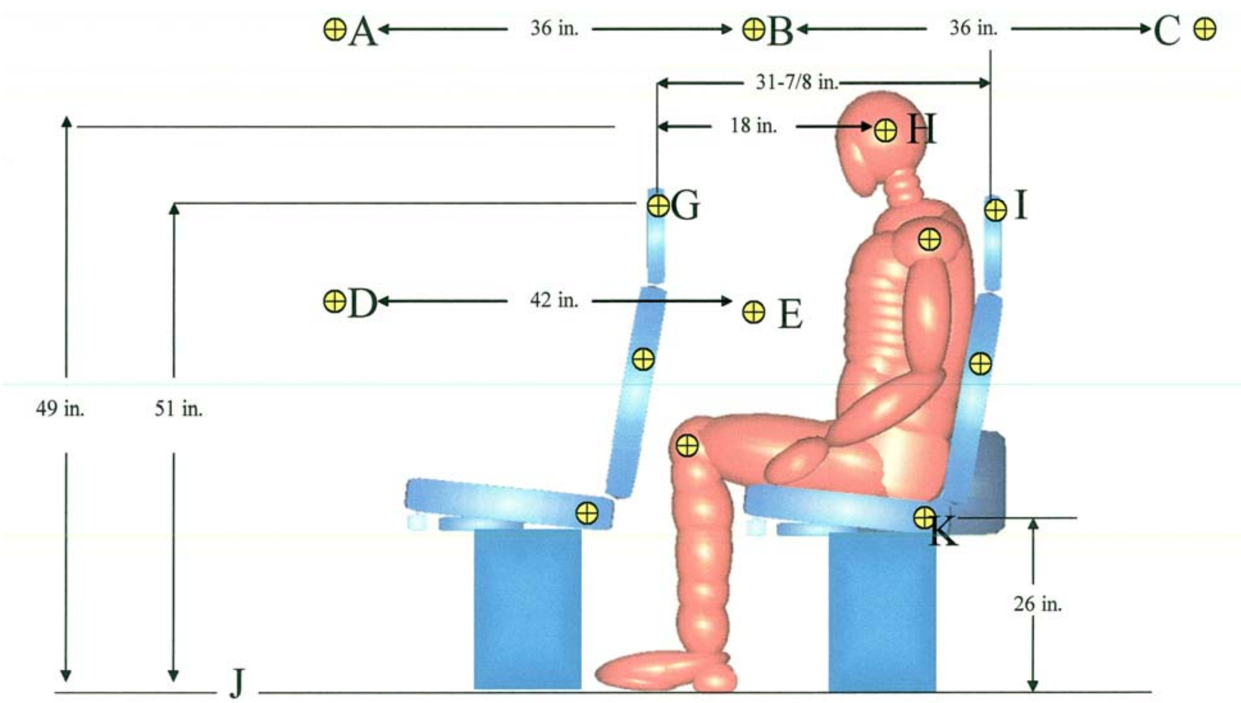

Figure C-5. Target Dimensions for Experiment 2.2

Acronyms and Abbreviations

ATD	Anthropomorphic Test Devices
CEM	crash energy management
E/A	energy absorbing
GFE	Government-Furnished Equipment
NHTSA	National Highway Traffic Safety Administration
RSSB	Rail Safety and Standards Board
SAE	Society of Automotive Engineers
THOR	Advanced crash test dummy developed by NHTSA Research and Development Office
TTC	Transportation Technology Center
TTCI	Transportation Technology Center, Inc.
VNTSC and Volpe Center	Volpe National Transportation Systems Center
VRTC	Vehicle Research and Test Center