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of Transportation
**Federal Railroad
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Passenger Rail Train-to-Train Impact Test Volume II: Summary of Occupant Protection Program

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Washington, DC 20590

Rail Passenger Equipment Impact Tests

DOT/FRA/ORD-03/17.II

Final Report
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13. ABSTRACT (Maximum 200 words)
On January 31, 2002, a train-to-train collision test was conducted involving a cab-car-led consist with three coach cars, all of conventional design, and a trailing locomotive traveling at 30 mph into a stationary locomotive coupled with two ballasted freight cars. The objective of this test was to determine the corresponding level of occupant safety for that impact scenario. In this test, the two leading cars and locomotive were equipped with instrumented anthropomorphic test devices (ATDs) in four interior seating arrangements as follows:

1. Two forward-facing M-style seats, each with three unrestrained ATDs in the back-row seat (one set in the lead cab car, one in the trailing car)
2. Two forward-facing intercity seats with two unrestrained ATDs in the back-row seat and two restrained ATDs in the front-row seat that was modified with seat belts and energy absorbing devices
3. One unrestrained ATD in a locomotive operator seat.

The principal goal of this full-scale rail car and locomotive test and the overall test program was to obtain scientific data to define a realistic rail car crash pulse, structural response, and corresponding level of occupant safety.

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PREFACE

The work described in this report was performed as part of the Equipment Safety Research Program at the Volpe National Transportation Systems Center (Volpe Center), sponsored by the Federal Railroad Administration (FRA). Dr. Tom Tsai, Program Manager, and Claire Orth, Division Chief, Equipment and Operating Practices Research Division, Office of Research and Development, Federal Railroad Administration directed this program. David Tyrell, Senior Engineer, Volpe Center, developed the test requirements and initiated and monitored this work. Gunars Spons, FRA Resident Engineering Manager at the Transportation Technology Center, directed and coordinated the activities of all the parties involved in the test. Dr. Barrie Brickle, Senior Engineer, Transportation Technology Center, Inc. (TTCI), implemented the equipment-related portions of the test.

The author would like to thank: Edward Murphy, Chief Mechanical Officer, Southeastern Pennsyvania Transportation Authority, for arranging the donation of the cars in the test effort; Doug Karan of Amtrak for arranging the donation of the intercity passenger seats; Gordon Campbell, Senior Engineer, LDK Engineering, Inc., for securing a copy of the Pioneer car structural drawings from Bombardier, Inc.; Michael Lorenzen of General Motors/ElectroMotive Division (GM/EMD) and George Binns of Amtrak for donation of F-40 locomotives; and Seats, Inc. for the donation of the locomotive operator seat.

The author would like to acknowledge the assistance of the United States Department of Transportations's (US DOT's) National Highway Transportation Safety Administration (NHTSA) and Simula, Inc., which provided anthropomorphic test devices (ATDs), and the US DOT's Federal Aviation Administration (FAA), which provided the load cells.

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

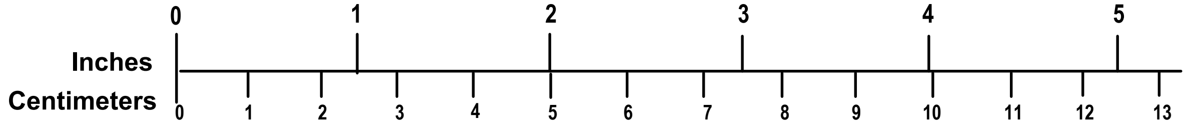
VOLUME (APPROXIMATE)

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
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TABLE OF CONTENTS

Section Page

LIST OF FIGURES

LIST OF TABLES

ACRONYMS AND ABBREVIATIONS

ATD	anthropomorphic test device
APTA	American Public Transportation Association
CCEC	Coach and Car Equipment Corporation
CFR	Code of Federal Regulations
DOT	U.S. Department of Transportation
FMVSS	Federal Motor Vehicle Safety Standard
FRA	Federal Railroad Administration
GE	General Electric
HIC	Head Injury Criterion
LIRR	Long Island Rail Road
MNRR	Metro North Railroad
MARC	Maryland Rail Commuter
NHTSA	National Highway Transportation Safety Administration
NICTD	Northern Indiana Commuter Transportation District
OEM	original equipment manufacturer
SAE	Society of Automotive Engineers
SEPTA	Southeast Pennsylvania Transit Authority
TTC	Transportation Technology Center
TTCI	Transportation Technology Center, Inc.
Volpe	Volpe National Transportation Systems Center
VRTC	Vehicle Research and Test Center

EXECUTIVE SUMMARY

A series of full-scale passenger rail impact tests is being conducted in support of the Federal Railroad Administration's (FRA's) Occupant Protection Research Program. This test was a train-to-train test involving a cab-car-led consist with three coach cars and a trailing locomotive traveling at 30 mph into a stationary locomotive coupled with two ballasted freight cars. The test was conducted on January 31, 2002 at the FRA's Transportation Technology Center. In addition to instrumenting the cars for structural deformation and car interaction evaluation, the cars were equipped with instrumented anthropomorphic test devices (ATDs) in four interior seating arrangements, as follows:

1. Two forward-facing M-style seats with three unrestrained ATDs in the back-row seat (one set of seats in the lead cab car, and one set in the first trailing coach car).
2. Two forward-facing intercity seats with two unrestrained ATDs in the back-row seat and two restrained ATDs in the front-row seat, which was modified by the addition of lap and shoulder belts plus an energy-absorbing device in the seat back (first trailing coach car).
3. One unrestrained ATD in a locomotive operator seat.

These seat/occupant configurations comprised the occupant protection experiments that were conducted to add to a baseline of seated occupant safety data. In general, the desirable outcome would be to show that the seats are able to sustain the inertial loads, as well as the occupant impact loads, and remain intact, providing the occupants with effective compartmentalization (i.e., the occupants sustain minimal injuries and remain between the two seat rows). Protection with an automotive-type lap and shoulder belt (i.e., a three-point restraint) was also evaluated. This report describes the interior seat/occupant experiments, including the seat hardware, appropriate instrumentation, data acquisition equipment, and the test results showing the occupants' motions, the impact forces, and the seats' performance.

The results of this train-to-train impact test scenario showed that the occupants were effectively compartmentalized and the sustained injury loads did not exceed the injury criteria. The vertical vehicle accelerations experienced inside the passenger car may have helped contain the ATDs in their seats. The lateral vehicle accelerations forced the ATDs into the sidewalls and, in one case, the aisle. The ATD in the locomotive operator seat endured the collision by grazing its shoulder against the sidewall of the locomotive and then rebounding into a forward slumped position. This ATD did not impact the console or the window in the front of the locomotive. Much of the locomotive operator's interaction was with the seat back during the collision.

The results of this train-to-train test better model typical passenger rail car collisions than that of the previous train collision tests (rail cars into a rigid barrier). The collision pulse was long (at least 6 seconds) and oscillating; and both lateral and vertical accelerations were notably present. These lateral and vertical accelerations need to be accounted for in a standardized test crash pulse, which currently only incorporates a longitudinal acceleration.

1. INTRODUCTION

The Office of Research and Development of the Federal Railroad Administration (FRA) is currently researching the crashworthiness and occupant safety of rail equipment by: reviewing relevant accidents; identifying options for design modifications; and applying analytical tools and testing techniques to evaluate the effectiveness of these options.

As part of this research, seat/occupant experiments were incorporated into the full-scale rail car and train-to-train impact tests. Anthropomorphic Test Devices (ATDs) were set up in various seating arrangements, and placed in various locations within the rail passenger car and locomotive compartments. Each experiment included different sized ATDs (5th-percentile female, and 50th- and 95th-percentile male ATDs) to obtain a spectrum of data both from sensors in the ATDs and the seats that accounted for extremes in size and mass. Each experiment tested a seating arrangement that included: one of three seat types (three-person M-style seats, two-person intercity seats, or one-person locomotive operator seats); a restraint condition within that type of seat (no restraint as in current seats or a two- or three- point belt restraint installed on some seats – as a test); orientation (facing toward the crash or away from the crash); and location within the rail passenger car or locomotive compartment. The specific experiment setups are explained in Section 3, "Test Configuration and Equipment" of this report.

In addition to placing sensors and load cells in ATDs, load cells were placed below them to determine the integrity of existing M-style (commuter) seats and intercity seats (some of which were modified to include lap and seat belt restraints). The current-production M-style seats were not designed to meet the recently published FRA safety standards [1]. The data from these experiments were compared to baseline data from dynamic sled tests [2], to determine the correlation between sled based and "real-world" force and acceleration levels measured.

These experiments have been incorporated into a series of tests planned to measure the crashworthiness performance of conventional-design equipment. These tests, conducted at FRA's Transportation Technology Center (TTC) near Pueblo, Colorado, simulate two collision situations. One is based on a head-on collision situation, in which a cab car-led train collides with a locomotive-led train. Figure 1 shows a schematic representation of the in-line collision situation. Examples of such collisions include the Prides Crossing, Massachusetts collision between a commuter train and a freight train [3] and the Silver Spring, Maryland collision between a commuter train and an intercity passenger train [4].

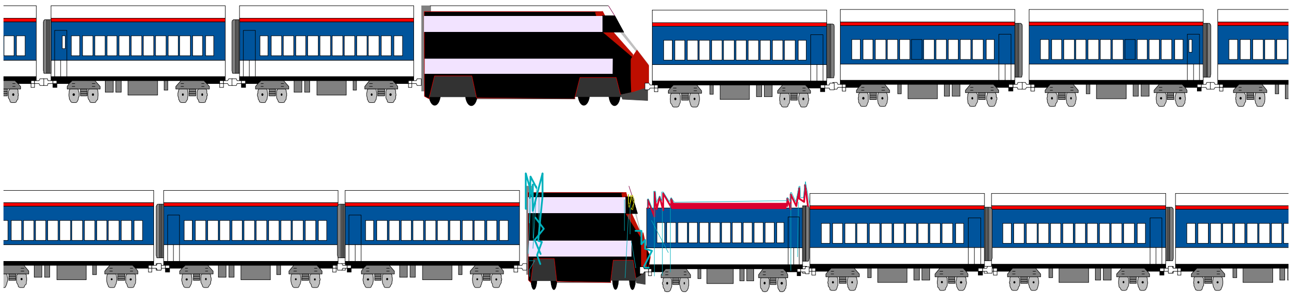

Figure 1. Schematic of In-Line Collision Situation

Figure 2 shows a schematic representation of the grade-crossing collision situation. Examples of such collisions include the Portage, Indiana collision between a cab-car led commuter train and a tractor-tandem trailer carrying coils of steel [5] and the Yardley, Pennsylvania collision between a cab-car-led commuter train, and a tractor semi-trailer carrying coils of steel [6].

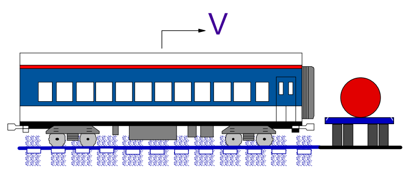

Figure 2. Schematic of Grade-Crossing Collision Situation

Eight total tests are currently planned, a pair in each of four test conditions:

Train-to-train:
1. Single-car impact into a fixed barrier
2. Two-coupled-car impact into a fixed barrier
3. Cab-car-led train collision with standing locomotive-led train

Train-to-vehicle:

4. Single-car impact with a steel coil

These tests are described in Section 2, "Planned Program Tests."

1.1 HOW THIS REPORT IS ORGANIZED

This report describes the occupant/seat experiments within Test 3, a cab-car-led train collision with a standing locomotive-led train and with conventional design equipment (here in this report referred as the "train-to-train test") and summarizes the results, organized as follows:

Section 1 (This): "Introduction" – generally describes the collision test program and the organization of this report

Section 2:	"Planned Program Tests" – generally describes the tests within the collision program
Section 3:	"Train-to-Train Collision Test" - contains a description of the train-to-train test conducted at the TTC on January 31, 2002, and a brief account of the occupant/seat experiments within the passenger car and locomotive compartments
Section 4:	"Test Configuration and Equipment" – describes the seats and Antrhopomorphic Test Devices (ATDs) used in the experiment, and the locations of the experiments within the passenger car and locomotive compartments
Section 5:	"Test Implementation" – describes how the ATDs, seats, cameras, lights and other fixtures were installed, including specific modifications made to either equipment or compartment structure and pre-test and post-test activity
Section 6:	"Test Results and Observations" - discusses the results of the test, by visually observing and describing the collision aftermath, comparing data collected with established injury criteria, and comparing data obtained in this test with data obtained in previous tests
Section 7:	"M-Style Test Data Comparisons" - compares observations between the M-style (commuter) seats tested in the two impact tests previously conducted and this train-to-train test
Section 8:	"Observations, Conclusions, and Recommendations" - describes general observations summarized from the previous section, conclusions drawn from this test, and recommendations to be used in future tests
Appendix A:	"Test Equipment Summary – Train-to-Train Test – January 31, 2002" - contains a summary of the load cells, ATD types, and data channels used in the test
Appendix B:	"Seat Attachment Loads – Train-to-Train Test – January 31, 2002" - contains figures that show the maximum seat attachment loads recorded for each experiment
Appendix C:	"Seat Attachment – Load-Time Histories – January 31, 2002" - contains the data plots of the seat attachment loads
Appendix D:	"Occupant Injury Load-Time Histories – January 31, 2002" - provides the data plots for all the occupant injury loads
Appendix E:	"Shoulder Belt Load-Time Histories on Experiment No. 2-1 – January 31, 2002" - consists of the data plots for the shoulder belt load-time histories of the restrained ATDs in the intercity seats.

2. PLANNED PROGRAM TESTS

Currently, eight tests are planned to obtain data over a wide range of test conditions. The condition and the sequence of these tests are listed in Table 1. The first series (Tests 1 – 4) measure and benchmark the crashworthiness of conventional equipment in the in-line and grade-crossing collision scenarios. Once modifications have been made to the equipment based on the results observed in the first series, the second series (Tests 5-8) measure the performance of improved-crashworthiness equipment under the same conditions. In the train-to-train test situation, the in-line collision tests are intended to measure the crashworthiness of a single car, then the interactions of two such cars when coupled, and finally the behavior of complete trains, including the interactions of the colliding cars. The requirements for the in-line collision tests are described in Appendix A. In the grade crossing test situation, the tests are intended to measure the effectiveness of the car end structure in preventing intrusion during a grade-crossing collision.

Table 1. Planned Sequence of Full-Scale Passenger-Equipment Impact Tests

Test Conditions	Conventional -Design Equipment	Improved-Crashworthiness Design Equipment
Single-Car Impact with Fixed Barrier	Test 1	Test 6
Two-Coupled-Car Impact with Fixed Barrier	Test 2	Test 7
Cab-Car-Led Train Impact with Locomotive-Led Train	Test 3	Test 8
Single-Car Impact with Steel Coil	Test 4	Test 5

2.1 SUMMARY DESCRIPTION OF TESTS

Figure 3 shows a schematic of the "Single-car impact with fixed barrier" test condition. The objectives of this condition are to observe the failure modes of the major structural components, to measure the gross motions of the car, to measure the force/crush characteristic, and to evaluate selected occupant-protection strategies. Test 1 was conducted in November 16, 1999, using a conventional-rail passenger car, which was traveling at 35.1 mph (56.1 km/h) when it impacted the wall [7, 8, 9].

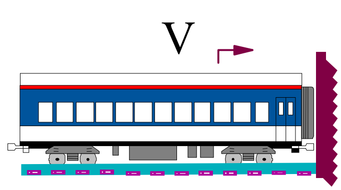

Figure 3. Schematic of Single-Car Test Condition

Figure 4 shows a schematic of the two-coupled-car impact with fixed barrier test. The objectives of this test condition are the same as the objectives as the single-car test conducted on November 16, 1999, with the addition of measuring the interactions between the coupled cars. Test 2 was conducted April 4, 2000, using conventional-rail cars, which were traveling at 26.25 mph (42 km/h) when they impacted the wall [10, 11, 12].

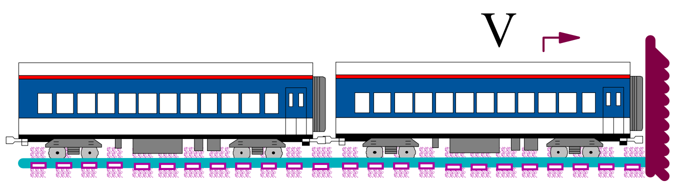

Figure 4. Schematic of Two-Car Test Condition

Figure 5 shows a schematic of the cab car-led train impact with locomotive-led train test. In this test, a cab-car-led train impacts a standing locomotive-led train. The locomotive is backed up by ballasted freight cars. This test has the same objectives as the two-car test, with the addition of measuring the interactions between the colliding locomotive and cab-car. Test 3, which this report documents, was conducted on January 31, 2002, using conventional-rail cars, which were traveling at 30 mph (45 km/h) when they impacted the standing locomotive.

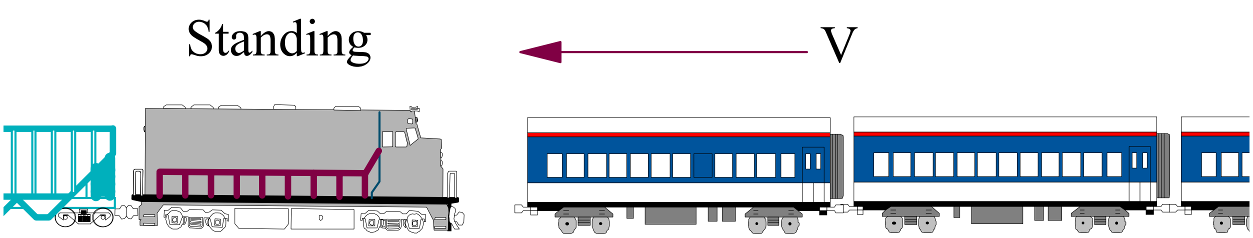

Figure 5. Schematic of Train-to-Train Test Condition

Figure 6 shows a schematic of the single-car impact with steel coil test. In Test 4, a cab car with collision and corner post designs typical of practice in the 1990's was used, and in Test 5 a cab car with collision posts and corner posts compliant with current FRA regulations and industry standards was used.

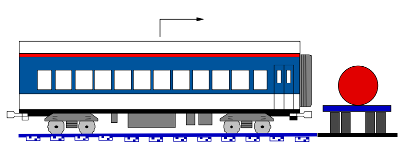

Figure 6. Schematic of Grade-Crossing Collision Condition

2.2 DESCRIPTION OF OCCUPANT PROTECTION EXPERIMENTS

Figure 7 shows schematics of the passenger-protection strategies tested in the single-car and two-car tests. All three strategies were tested in the single-car test and in the leading car in the two-car test. The trailing car in the two-car test also tested the forward-facing unrestrained occupant-protection strategy.

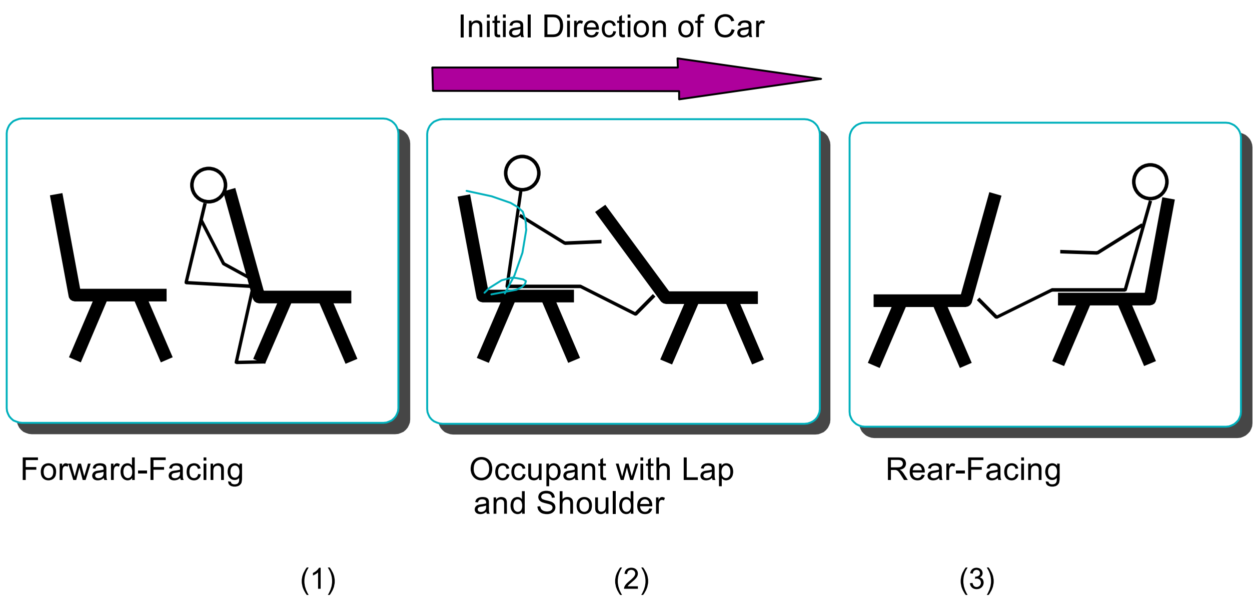

Figure 7. Schematics of Passenger-Protection Strategies

Figure 8 shows a schematic of the locomotive operator's interior environment to be tested during this train-to-train test. The objective of this test is principally to observe the kinematics of the ATD, as well as to measure the ATD response and evaluate the potential for occupant injury.

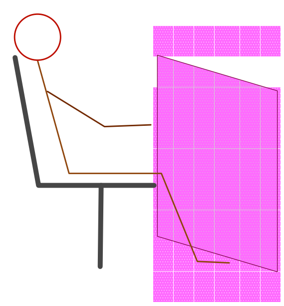

Figure 8. Schematic of Locomotive Operator Interior Test

Table 2 summarizes the critical measurements for each of the three tests. While the overall objective of these tests is to demonstrate the effectiveness of improved-crashworthiness equipment, the test data are also being used for comparison with analyses and modeling results. The measurements will be used to refine these analyses' approaches and models, and to ensure that the factors influencing the response of the equipment and ATDs are taken into account. The table lists the measurements that are critical to ensuring the appropriate modeling and analysis of the equipment and test dummies.

Table 2. Test Descriptions and Critical Measurements

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

3. TRAIN-TO-TRAIN COLLISION TEST

The train-to-train test was conducted on January 31, 2002, at the US Department of Transportation (DOT) Transportation Technology Center (TTC) in Pueblo, CO. This test involved a cab-car-led consist with three coach cars trailed by a locomotive (Figure 9). At a speed of approximately 30 mph, this five-car consist impacted a standing locomotive that was coupled to two ballasted freight cars. The pre-test impact site with the cab car and locomotive is shown in Figure 10.

The seating configurations and ATDs were installed with the appropriate fixtures, power sources, instrumentation, data acquisition equipment, and filming equipment to quantify the occupant impact forces and seat loads. These data were then used to evaluate the injury potential and strength of the seating systems tested.

Figure 9. The Cab-Car-Led Consist with Three Trailing Coach Cars and a Locomotive

Figure 10. Pre-Test Impact Site - Leading Cab Car and Stationary Locomotive

Three different seat/occupant experiments were identified and installed in the test, with some modifications made to the original equipment manufacturer (OEM) intercity seats used in the test The three seat/occupant configurations evaluated were:

1. Two forward-facing M-style seats with three unrestrained occupants in the back-row seat
2. Two forward-facing intercity seats with two unrestrained occupants in the back-row seat and two restrained occupants in the front-row seat, which was modified by the addition of lap and shoulder belts, plus an energy-absorbing device in the seat back
3. One locomotive operator seat with an unrestrained occupant

Each seat type and modifications made to the seats or floor are described in the next section, “Test Configuration and Equipment.”

4. TEST CONFIGURATION AND EQUIPMENT

One of the objectives of the full-scale rail car testing is to determine the potential impact tolerance of the existing M-style seats and their occupants. The seat/occupant experiments included in the test program were selected in part to be compared to baseline data previously produced in dynamic sled tests, as well as to the data produced during the two previous full-scale collision tests: the single-car impact test and the two-car impact test. This train-to-train test was a more realistic representation of a collision and provided new information about seat/occupant responses in such an environment (compared to the controlled test environment provided by sled tests and the previous full-scale tests). The desired outcome for occupants and their seating environment during a collision should include the following safety measures:

- Seat assemblies remain attached to the car
- Seat components remain attached to the seat assembly
- The seat effectively compartmentalizes the occupants
- The seat does an effective job of minimizing human injury

A key safety measure is compartmentalization, which is a strategy for seat design in which the seat provides enough stiffness to absorb all, or a substantial portion of, the kinetic energy of a passenger, thus preventing a tertiary impact. An occupant is compartmentalized when the torso is confined within the perimeter defined by the front edge of the front-row seat pan, the full width of the aisle, and the seat back surface of the launch seat. The seat/occupant experiments that were incorporated into the full-scale rail car impact test represented typical M-style and intercity seat row-to-row configurations, designed with the intent to provide occupant compartmentalization. Each seat configuration included a range of seated occupants (5th-percentile female and 50th- and 95th-percentile male ATDs) in the aft-row seat. The seat configurations and locations are described in the next subsection, while the ATDs, cameras and other fixtures used to gather information are described in the subsection after.

4.1 TEST CONFIGURATION

The Train-to-Train test had several experiments related to occupant/seat analysis. Each experiment was a unique configuration of the type of seat used and the experiment location.

4.1.1 SEATS USED IN THE EXPERIMENTS

Three seats were used in the experiments, two in the passenger rail car experiments and one in the locomotive experiment.

4.1.1.1 Intercity Seat

The intercity seat/occupant experiment was designed to provide information about restraint systems in rail seats. This experiment involved an intercity seat modified with three-point restraints (there is no seat like the modified seat in service today). Amtrak provided the intercity seats from their discarded, used-seat inventory.

The seats were modified by replacing the seat back panel and strengthening the hinge-point between the seat pan and the seat back to increase the load-bearing capacity required by the lap and shoulder belts, as well as the load of the unrestrained occupants impacting the seat from behind. Energy-absorbing devices were also incorporated into the movable back of the modified seat to absorb some of the impact load. Figure 11 is a schematic showing the intercity seat modifications.

The seats used in this test were previously used in both the single- and two-car impact tests, and refurbished again for the train-to-train test. Seat refurbishment included replacing both energy-absorbing devices, the seat back panel, the seat cushions, and the restraints with new components for this test.

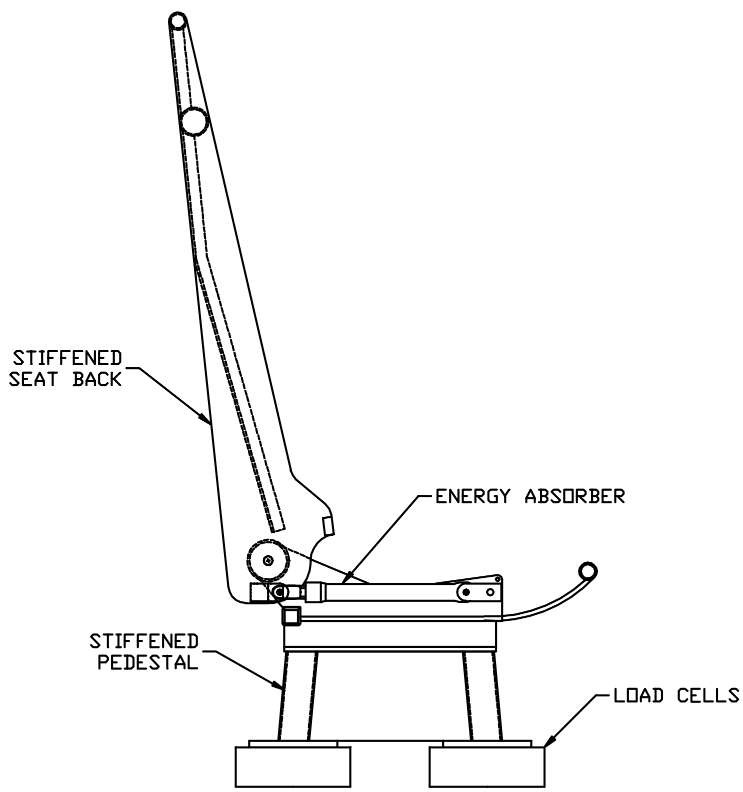

Figure 11. Modifications Made to the Intercity Seat

4.1.1.2 M-Style Seat

The M-style seat experiments were designed to provide information about typical seat/occupant responses, including information about compartmentalization effectiveness. These seats are currently in use by commuter transit authorities such as Metro North Railroad (MNRR), Long Island Rail Road (LIRR), Southeast Pennsylvania Transit Authority (SEPTA), Northern Indiana Commuter Transportation District (NICTD), New Jersey Transit, and Maryland Rail Commuter (MARC).

The seats used for the row-to-row tests were installed as manufactured at the time of purchase in late 1999. At that time, none of the production rail seats were designed to meet the FRA regulations that contain the new dynamic testing standards for seats. Plus, due to the delay in testing, the seats were exposed to ultraviolet radiation while they were stored outdoors in the Arizona summer heat at a contractor's facilities. This prolonged exposure to the sun may have caused the thermoplastic back panel to become more brittle than would normally have been expected. A schematic of the three-passenger M-style seat is shown in Figure 12.

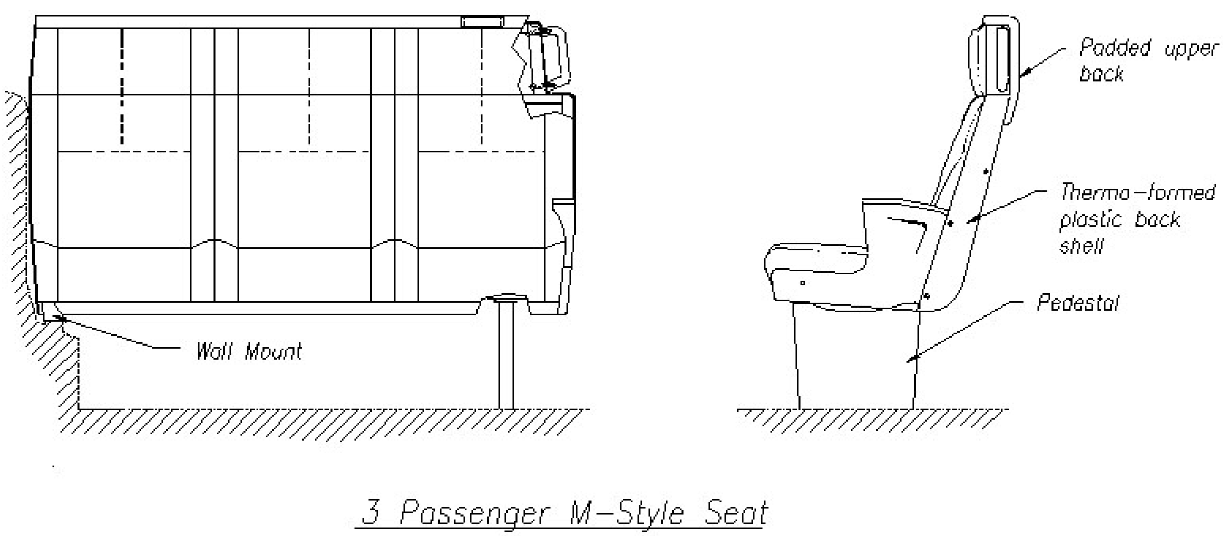

Figure 12. The M-Style Three-Passenger Seat Tested

4.1.1.3 Locomotive Operator Seat

Locomotive operator seat experiments were designed to determine the occupant kinematics by observing the ATD's interaction with the console and front windshield. High-back, pedestal-mounted operator seat replaced the sidewall mounted operator seat originally installed in the locomotive. This seat is typical for locomotives currently being manufactured. A photo of the seat is provided in Figure 13.

Figure 13. Locomotive Operator, High-Back Seat

4.1.2 Experiment Locations

Three different seat/occupant experiments were identified and installed, and one experiment was duplicated, for a total of four seat/occupant experiments. These four seat/occupant experiments, along with their respective high-speed cameras, were installed as shown in Figures 14, 15, and 16. Nomenclature for these four experiments is X-Y and describes the car location (X) and the experiment number in that car (Y). The car location designation "L" is for the locomotive.

1. Experiment No. 1-1 - Two unmodified, row-to-row, three-passenger M-style seats in the leading cab car.
2. Experiment No. 2-1 - Two modified (the modifications are the same as in the previous full-scale collision tests, with lap and shoulder belts), row-to-row, two-passenger intercity seats in the first trailing coach car.
3. Experiment No. 2-2 - Two unmodified, row-to-row, three-passenger M-style seats in the first trailing coach car.

4. Experiment No. L-1 - One single-person locomotive operator seat.

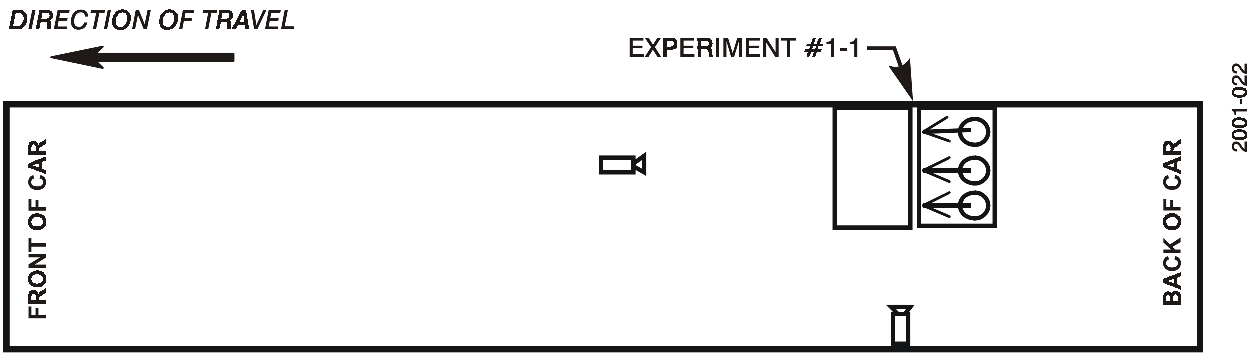

Figure 14. Location of Experiment No. 1-1 in the Leading Cab Car

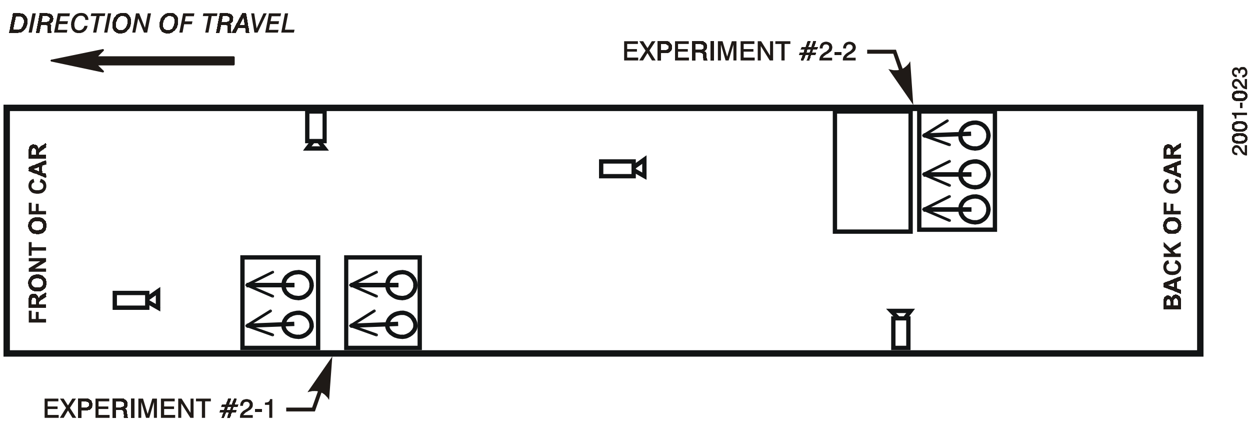

Figure 15. Location of Experiments No. 2-1 and 2-2 in the First Trailing Coach Car

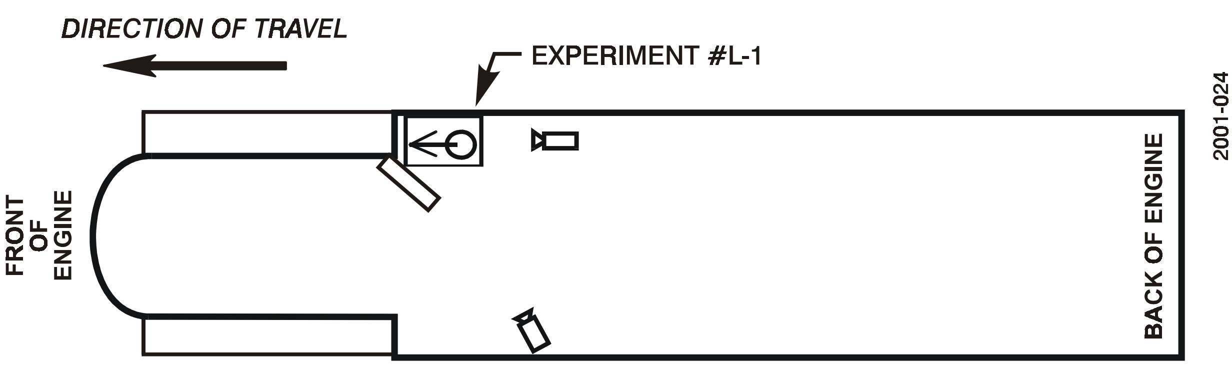

Figure 16. Location of Experiment No. L-1 in the Locomotive

Specific seat placement was determined predominantly by the structural framework of the car. The side cameras of each test had to be mounted on the heavy structure located between the windows; therefore, the center of interest of each experiment was located directly opposite the camera, between the windows. The position of the seats was shifted slightly if there was any side structure present, or if there was any structure present that interfered with the wall-mounted load cells.

In addition to the structural framework of the car, results of a computer modeling analysis effort performed previously at the Volpe National Transportation Systems Center (The Volpe Center) (predicting the acceleration pulse and structural response of the car during impact) were used to help determine the preferred location for each seat/occupant experiment. In the previous full-scale tests, these experiments were installed between the body bolsters of each car (to allow the ends of the car to crush without damaging any of the interior experiments). The seat/occupant experiments in the first trailing coach car of the train-to-train test, however, were installed directly above the body bolsters. This deviation was primarily due to the nature of the car's structural framework, which was different from the cars used previously. The vestibules in the first trailing coach car were not located at the ends of the car, as they were in the cars used in the first tests, but rather they were located toward the center of the car. Generally, the seat/occupant experiments would be installed where the vestibules were, but when the vestibule walls were removed, the remaining structure was not sufficient for seat/occupant experiment installation. Therefore, in this train-to-train test, the experiments in the first trailing coach car were installed closer to the ends of the car. Figure 17 is a schematic of the floor removal configuration in the first trailing coach car.

In anticipation of a catastrophic failure in the front end of the leading cab car, it was desirable to install the seat experiment toward the aft section of that car. The ATD data would not be meaningful if the seat experiment was installed where the occupiable volume of the car was lost and the ATDs were damaged. It is desirable to analyze survivability within the survivable regime of an accident.

4.1.2.1 Experiment No. 1-1, Forward-Facing Row-to-Row M-style Seats

Experiment No. 1-1 was installed in the right, aft section of the leading cab car (orientations are made with respect to a forward-facing occupant, facing the impacting front end of the rail car), in front of the rear body-bolster. This experiment was installed in a rail car that had been previously used as the trailing car in the two-car test; and the experiment was installed in the same location as a previous experiment in that same car. The seats in Experiment 1-1 were installed with a 32-inch seat pitch. The rear seat was occupied by three (unbelted) 50th-percentile ATDs (one instrumented Hybrid III, and two uninstrumented Hybrid IIs).

The focus of this experiment was on the rear-seat occupants impacting the front-row seat and observing the reaction of the front-row seat (the floor and sidewall attachment loads and the seat structural response). A pre-test photo of Experiment 1-1 is provided in Figure 18.

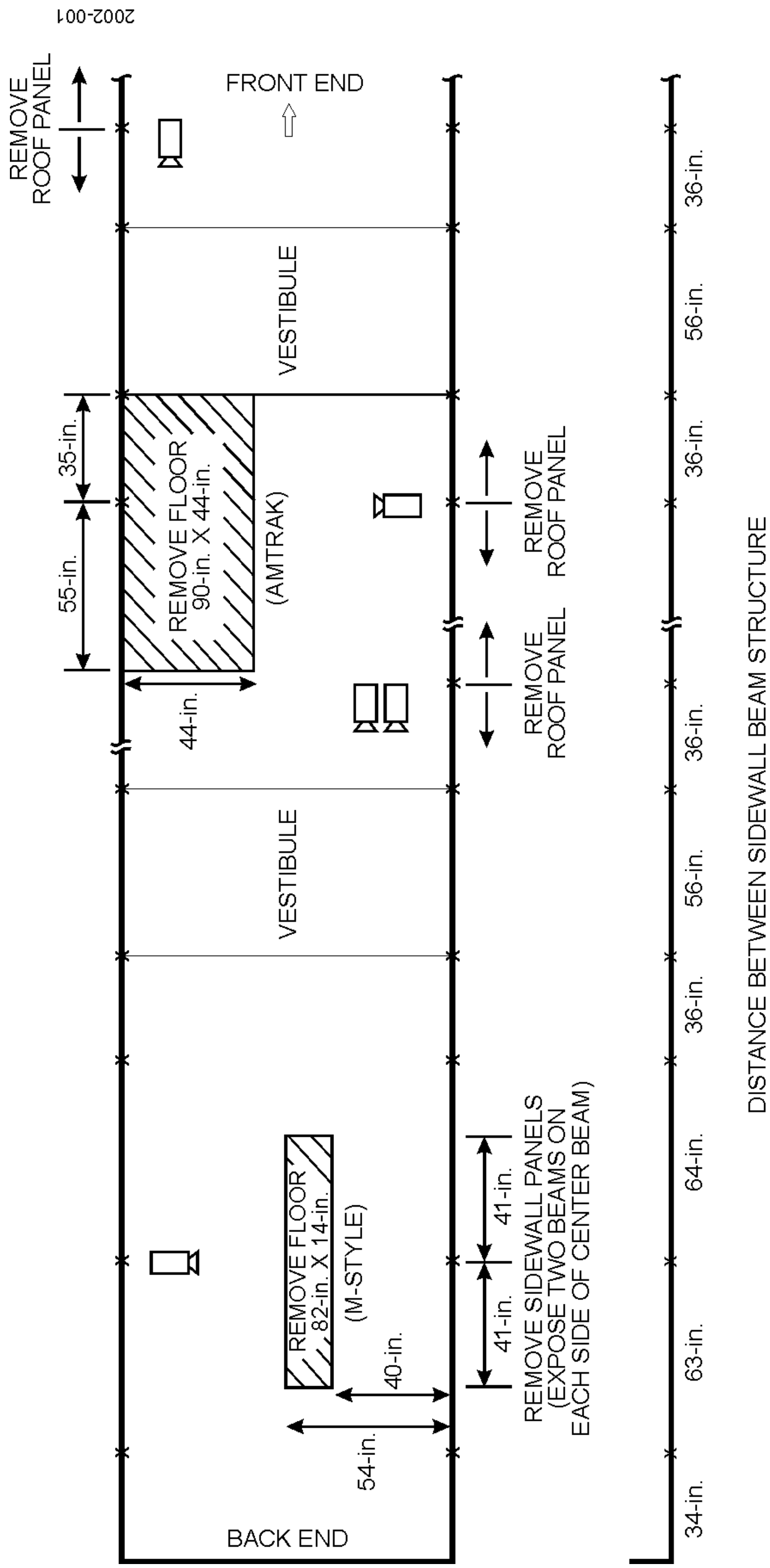

Figure 17. Floor Removal Plan for Experiments No. 2-1 and 2-2 in the First Trailing Coach Car

Figure 18. Pre-Test Photo of Experiment No. 1-1, Row-to-Row M-Style Seats

4.1.2.2 Experiment No. 2-1, Forward-Facing Row-to-Row Intercity Seats with Restraints
Experiment No. 2-1 was installed toward the front, left section of the first trailing coach car. The floor attachment of the front-row seat was approximately 23 feet from the front-most panel of the car. The seats were installed with a 42-inch seat pitch. The front-row seat was occupied by two restrained ATDs: a 5th-percentile ATD in the aisle seat (instrumented with a neck load cell), and a 95th-percentile ATD in the window seat (also instrumented with a neck load cell). The back-row seat was occupied by two unrestrained 95th-percentile ATDs (the aisle-seated ATD was fully instrumented).

The focus of this experiment was on the rear-seat occupants impacting the front-row seat occupied by the restrained ATDs, and on observing the reaction of the front-row seat, the restrained occupants in the seat, and the unrestrained ATDs impacting the seat from behind. A pre-test photo of Experiment 2-1 is provided in Figure 19.

Figure 19. Pre-Test Photo of Experiment No. 2-1, Row-to-Row Intercity Seats with Front-Row Restraints

4.1.2.3 Experiment No. 2-2, Forward-Facing Row-to-Row M-style Seats

Experiment No. 2-2 was installed in the right, aft section of the rail car, 9 feet from the aft-most panel of the car. These seats were installed with a 32-inch seat pitch, similar to Experiment 1-1.

Unlike previous tests, there were no seat design modifications incorporated into the seat; they were installed as manufactured. The focus of this experiment was on the rear-seat occupants impacting the front-row seat and observing the reaction of the front-row seat (floor and wall attachment loads and seat structural response). A pre-test photo of Experiment 2-2 is provided in Figure 20.

Figure 20. Pre-Test Photo of Experiment No. 2-2, Row-to-Row M-Style Seats

4.1.2.4 Experiment No. L-1, Locomotive Operator Seat

Experiment No. L-1 consisted of an unrestrained, 95th-percentile ATD seated upright and facing forward in a current-production operator seat.

The focus of this experiment was on the occupant kinematics and the ATD's interaction with the console and front windshield. The inertial forces on the seat would also be measured through the seat/floor attachment load cells. A pre-test photo of Experiment L-1 is provided in Figure 21.

4.2 TEST EQUIPMENT

The test equipment used in the train-to-train test included 11 ATDs, instrumentation for 5 of the ATDs requiring 56 data channels, 15 seat attachment load cells (4 load cells per experiment with two-seat rows, and three load cells for the locomotive operator seat experiment) requiring 45 data channels, and 2 shoulder belt load cells. A total of 103 channels of data were collected from these transducers using a data-brick acquisition system of 14 data bricks. Also used were 91 ruggedized automotive floodlights, each 100W and 12V (ranging from 12 – 31 lights per experiment), 8 cameras (2 per experiment), AC and DC power sources, and the appropriate mounting fixtures required to fully support the test equipment. The equipment that was used in the train-to-train test experiments is listed in Appendix A in Tables A-1 through A-7.

Figure 21. Pre-Test Photo of Experiment No. L-1, Locomotive Operator Seat

4.2.1 ATDS AND INSTRUMENTATION

The ATDs used were seated in the rear-row seats of all three passenger rail car experiments. Two ATDs were also seated in the front-row seat of the intercity seat experiment. The ATDs were used to produce an applied load to the back of the front-row seats and to measure the reaction of representative occupants to the collision environment. Ultimate seat strength is tested when the 95th-percentile ATDs of a fully occupied aft-row seat apply loads to the seat row in front of them. Occupant survivability is predicted by the impact loads measured by these ATDs, as well as by their post-impact location (compartmentalized or not). It is expected that a stiff seat system occupied by 5th-percentile ATDs could cause the small occupants to bear high impact loads that indicate an injurious situation. To assess the likelihood of injuries, some ATDs were selectively instrumented to measure applied loads in the head, chest, femurs, and the neck. A cross-section of an instrumented Hybrid III ATD is shown in Figure 22, with the basic instrumentation locations highlighted.

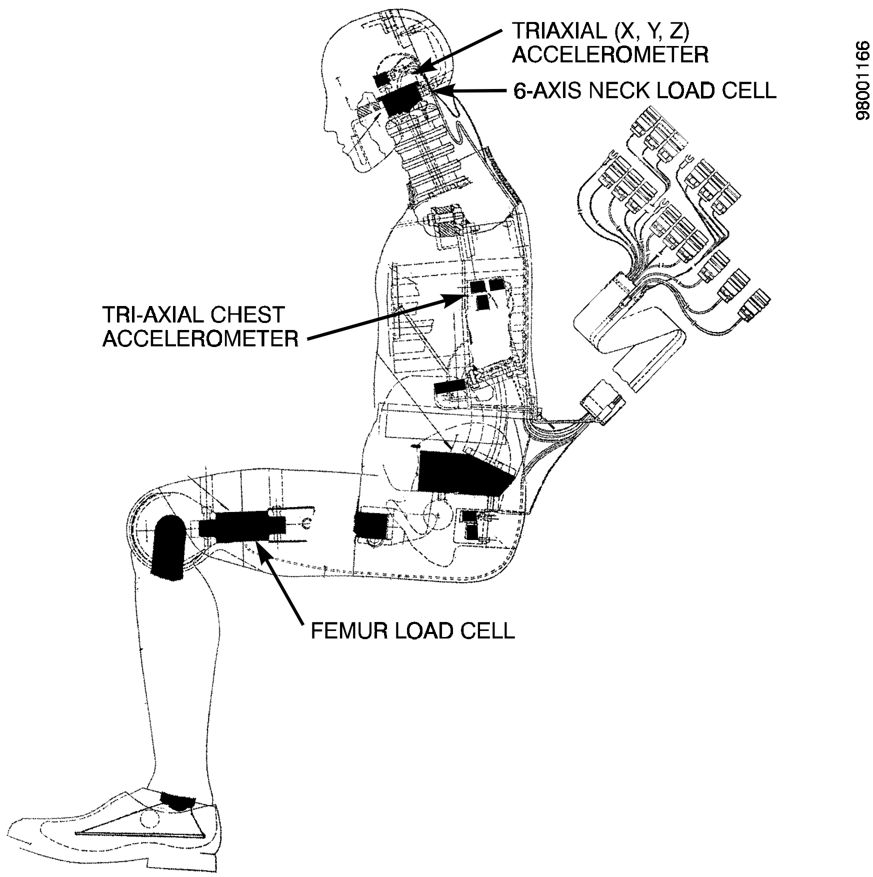

Figure 22. Cross-Section of a Fully Instrumented Hybrid III ATD

The ATDs used in these tests met the standards and requirements to comply with 48 CFR Part 572, Subparts B and E. The adjustment, positioning, and care of the ATDs used in the testing processes was performed in accordance with the standards and requirements needed to comply with SAE AS8049. Each ATD was clothed in a form fitting, cotton stretch garment with short shirtsleeves and mid-thigh-length legs. The ATDs were also fitted with shoes weighing approximately 2.5 lb. The friction in each limb joint was adjusted to support a 1-G weight when extended horizontally prior to testing.

Instrumentation requirements included floor load cells that measured the longitudinal, lateral, and vertical loads imparted by the seats to the floor panel. High-speed cameras recorded the motions of the seats and ATDs during the test. The associated triggering capability and power required to operate the lights, cameras, and data acquisition system was provided. The transducers used in these tests are identified in Appendix A in Table A-6.

4.2.2 DATA ACQUISITION SYSTEM

A high-speed, self-contained data acquisition system was installed on board the rail cars to collect the data from the 103 data channels. A "data brick" data acquisition system was used because it is a small, extremely rugged (capable of sustaining 100 G) and lightweight system. It consisted of a number of "brick" modules; specifically, 14 were used in this test, each consisting of 8 data channels. Each eight-data-channel module is battery-operated, and provides transducer power, signal conditioning, filtering, triggering, and offset compensation via a host computer software program. The data bricks are self-calibrating for all radiometric transducers. Each data channel can sample at a rate of up to 12,800 samples/sec.

All data collected was required to comply with SAE J211 filter class requirements. The typical instrumentation and filter classes for the rail seat testing are listed in Appendix A in Table A-7.

4.2.3 CAMERAS AND LIGHTING

High-speed, high-G-force-tolerant cameras were used to capture the motions of the ATDs and the seats during the collision. Two cameras per experiment were used: one to capture the front view and one to capture the side view of the seats. In the case of the locomotive operator seat experiment, the cameras were positioned to capture an oblique side view, and the aft view of the seat. A camera was not positioned to capture the front view, due to the high possibility of its being damaged during the test. The cameras were all ruggedly installed to withstand the collision. The camera speeds were set to run at a minimum of 500 frames/sec. The positioning of the cameras with respect to each experiment is provided in Appendix A in Table A-5, along with the lens focal length.

The lighting provided by a number of ruggedized automotive floodlights was sufficient for optimum viewing under the dusty conditions that were anticipated during the collision of these old rail cars. The lighting was also ruggedly installed to withstand the collision. The time of impact was marked in each camera by capturing the flash of a strobe light that was installed near each camera and triggered when the front end of the leading cab car impacted the stationary locomotive. Cameras and lights were simultaneously and remotely triggered 10 seconds prior to impact to completely capture the effects of the collision.

5. TEST IMPLEMENTATION

The train-to-train collision test was conducted at the Transportation Technology Center (TTC), which is an FRA test site located in Pueblo, Colorado. Weather conditions, specifically snowfall, delayed the test by one day, from January 30, 2002, as indicated in the photo documentation, to the actual date of testing on January 31, 2002. The operating manager of the TTC coordinated the test sequence of the occupant/protection test effort with contracted vendors that prepared data acquisition and video equipment, provided the on-site photography, and on-site data acquisition. Prior to testing, the seat/occupant experiments and accompanying cameras, lights, and power equipment were designed, selected, and prepared off-site at the contractor's facilities located in Phoenix, Arizona. The test equipment was then transported by truck to the TTC where it was installed in the rail cars during the designated time period prior to testing.

5.1 PRE-TEST SEQUENCE DOCUMENTATION

A sequence of pre-test events was developed and a list of items needed for the test was compiled. This equipment list consisted of test instrumentation, hardware, tools, etc., and included the serial numbers and part numbers of each article. The transducer list identified the specific experiment and location for each load cell, including the serial numbers, experiment numbers, and installation locations. All references to location were made with respect to the rail car, with "forward" referring to the front (impact end) of the car, and "left" and "right" defined in relation to facing forward inside the car. A pre-test checklist was developed to ensure that all required steps were taken to properly prepare for the test.

5.2 SEAT INSTALLATION

Experiment No. 1-1 consisted of two forward-facing row-to-row three-place passenger M-style seats. In each row-to-row M-style seating experiment, there was a sidewall attachment and a floor attachment that needed to be located at a structural point. The seats were bolted onto retrofitted steel bars that replaced the original wooden floor of the rail car. The seat/car interface at the floor consisted of a 4.00- x 0.75- inches steel plate approximately 72 inches in length (longitudinal in the car) that was attached to each horizontal structural floor member or "zee" section with 0.38 inch bolts. A 0.50-inch-thick backing plate was used to secure the bolts whenever possible. These steel bars represented the retrofit floor design in SEPTA's Silverliner 3 rail car. Two floor load cells provided an interface between the seat pedestal and the steel floor bar. At the sidewall mounting points, two load cells provided an interface between the seat attachment and the heater guard, which is a lip that extends horizontally from the wall of the car. The wall-mount interface consisted of a pre-drilled, longitudinal plate that accommodated both sidewall attachment load cells. This plate was installed onto the sidewall shelf with 0.38 inch bolts. Each load cell was bolted to the seat at its attachment point. The rear-row seat was similarly installed, but instead of load cells, spacer blocks of equivalent height were used as the interface. With the addition of the floor load cells and spacer blocks underneath the original-manufactured pedestals, the seat height was increased a few inches. Therefore, a mock-up wood floor was placed between the seats to raise the ATDs' feet to the normal floor height. The row-to-row M-style seat tests required a mock-up raised wood floor that was 4.25 (0.5 inches above the "zee" sections. Experiment No. 2-2, installed in the first trailing coach car, was similar to Experiment No. 1-1.

Experiment No. 2-1 consisted of two forward-facing, row-to-row, two-place passenger intercity rail car seats. The seat pitch between the seats was 42 inches. Both seats were fitted with modified pedestals that, when bolted to floor load cells, brought the seat height to its original dimension. The front-row seat had additional modifications that included three-point lap and shoulder belts. The intercity seats were floor-mounted and were bolted onto steel bars (4.00 x 0.75 inches) that replaced the original wooden floor of the rail car. The row-to-row intercity seat experiment did not require a sidewall mount, but rather two seat/floor interfaces. Four floor load cells provided an interface between the two seat pedestals and the steel bars to which they were attached. The back-row seat was similarly installed, but instead of load cells, spacer blocks of equivalent height were used as the interface. Because the intercity seats were fitted with modified pedestals that had been designed to provide the original seat height when bolted to the load cells and/or the spacer blocks, a raised floor was not needed. Instead, a mock-up wood floor, flush with the existing floor in the rail car, was placed in front of both seats, upon which the ATDs' feet rested.

In each of these experiments, tethers were used to secure the seats (and the ATDs) to the car in the event of a catastrophic structural failure. A single 2.0 inches wide, 3-feet long tether was used to secure the seats to the cars.

The seat/car attachment requirements for the Experiment L-1 locomotive operator seat were different from those of the row-to-row seating experiments. A review of the operator seat installation requirements led to the realization that the locomotives currently in operation have floors that are substantially stronger than the floor installed in the test locomotive. Drawings from General Motors/Electromotive Division (GM/EMD) showed that the floor in the test locomotive could be strengthened to support the floor-mounted operator seat without compromising the results of the experiment. TTCI determined the floor areas that needed to be removed and replaced with more substantial support structure and floor (Figure 23). TTCI provided the technical services needed to remove the existing floor and replace it with the stronger floor. A schematic of the pedestal mount was prepared for the operator seat (Figure 24) and its interface with the modified locomotive floor (Figure 25).

5.3 ATD INSTALLATION

Eleven ATDs were used to evaluate occupant response. The aisle-side ATD in each M-style seat experiment was instrumented, and three ATDs were instrumented (one fully instrumented) in the intercity seat experiments. The ATDs were provided by the contractor and the National Highway Transportation Safety Administration (NHTSA) Vehicle Research and Test Center (VRTC). These ATDs were instrumented and prepared for testing at the contractor's facility prior to transferring them to the TTC test site. Before placing the ATDs in the rail cars, a joint function check was performed on each ATD to ensure proper joint motion during the test. The joint function checks were done on the elbow, shoulder, and knee joints of each ATD.

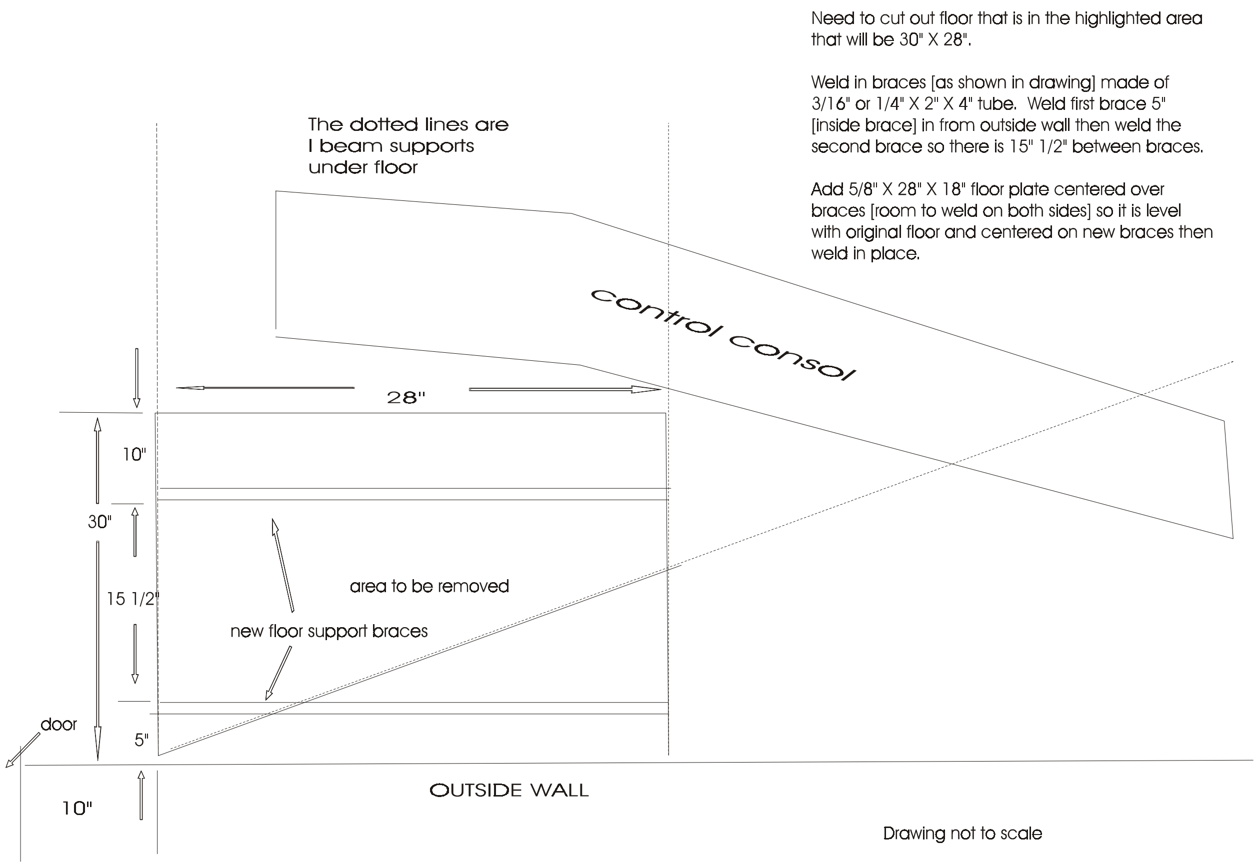

Figure 23. Schematic of Locomotive Floor Modification

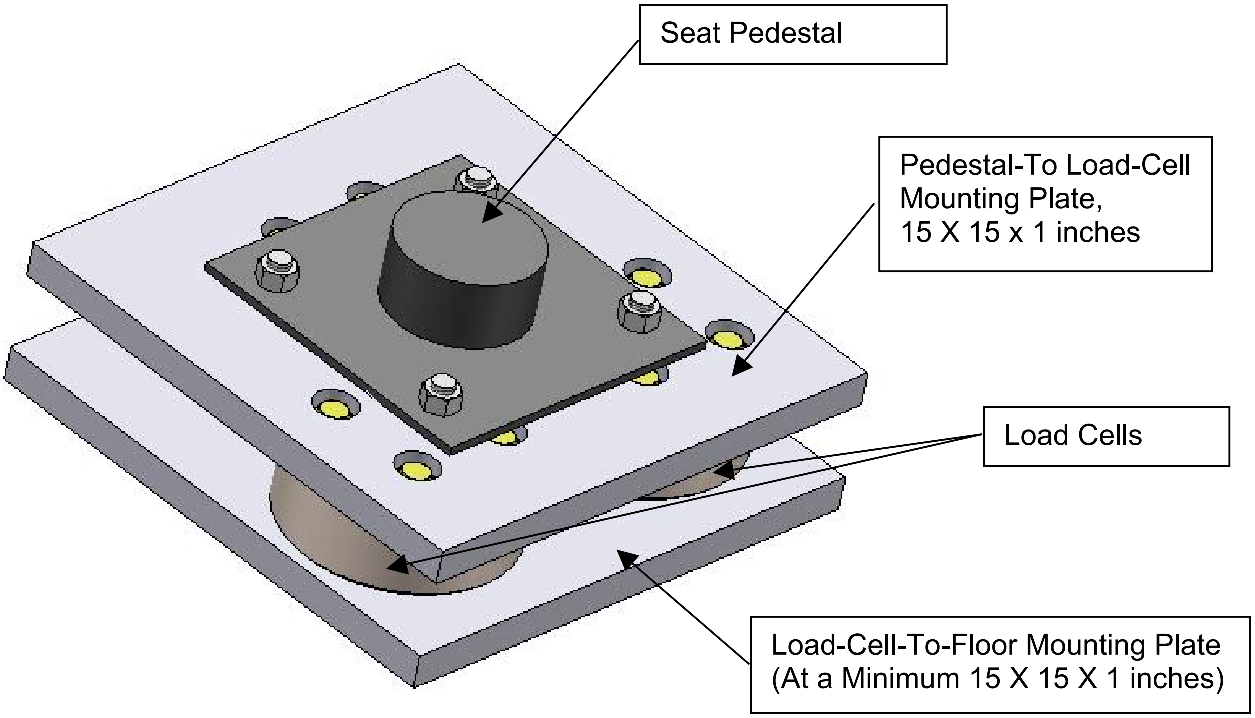

Figure 24. Locomotive Operator Seat Floor Mounting Hardware

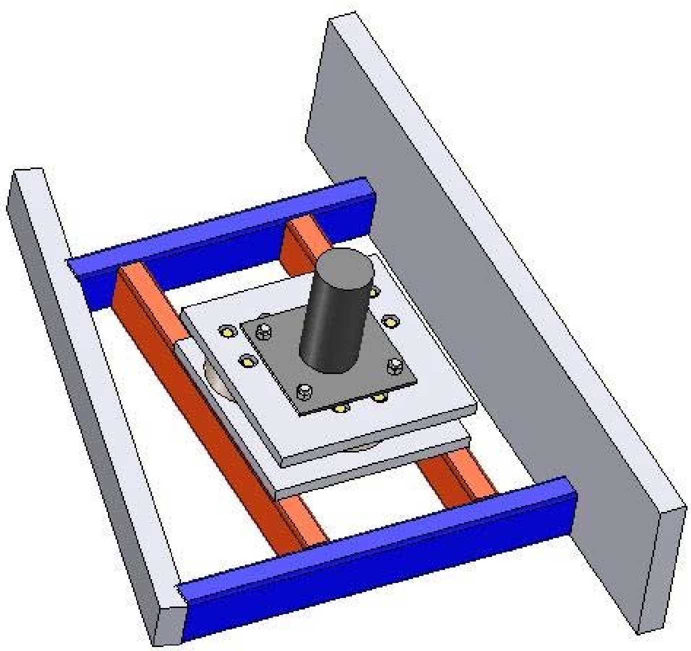

Figure 25. Locomotive Operator Seat Floor Mounting Hardware and Interface with Modified Locomotive Floor

The cables that linked an ATD's instrumentation to the data acquisition bricks were taped together to form an umbilical that was at least 15 feet in length. Once the ATDs were seated, this umbilical was typically routed down the ATD's back, then down its leg to the knee, where it was routed away from the ATD and coiled just behind the ATD's feet using duct tape. Immediately beyond the coil, the cable was securely taped to the floor. It was necessary to ensure that the cables were routed in low-foot-traffic areas to avoid damage prior to and during the test. Damage to the cables was also avoided by tethering the ATDs to eyelets that were bolted to the floor of the car. These tethers were shorter than the instrumentation cables by at least 18 inches; thus, the tethers allowed each ATD approximately 13 feet of unrestrained motion. The instrumentation cables were routed to the data acquisition system, where the leads were connected to the appropriate data bricks. Information coding was critical to the success of the data acquisition process and required direct communication and full understanding between the technician who installed the instrumentation and the cable and the technician who installed the data bricks. Every instrumented ATD was manipulated to determine the sign convention of all of the transducers. The load traces were read one-by-one on the laptop computer that was connected to each data brick.

The lap and shoulder belts on the intercity seats were tightened so that only two fingers could be fit snugly between the ATDs' pelvis or chest and the belt. The unbelted ATDs were tethered only enough to limit their motion to prevent damage to the instrumentation cables. The final position of each ATD was defined by measuring a fist's worth of space between the ATDs' knees, placing the ATDs' hands on their knees, and positioning the buttocks and back firmly in contact with the seat back. The ATDs were positioned so that they were not leaning to either side when viewed from the front or back. If it was not possible to keep the ATDs from leaning (especially if the ATDs' shoulders were in contact with one another), then all the ATDs in the same seat row were made to lean the same amount, but preferably not so far that the aisle-side ATD would miss or glance off of the side of the forward-row seat frame. Standard yellow and black targets, 2 inches in diameter, were placed on the ATDs and the seats at points where they could be observed during the test.

Just prior to the test, the ATDs were strapped to the seats with duct tape to prevent them from moving in their seats as the rail car traveled down the track. The duct tape was wrapped two or three times around the seat back and across the sternum (or chest area) of all the ATDs in each seat. To ensure that the tape would release upon impact, it was notched with a 0.5 inch cut between the ATDs and between the ATDs and the seat. The ATD in the locomotive operator seat was not taped into position. A light coat of chalk was applied to specific parts of each ATD to determine where it contacted the interior of the car. Three colors were used to represent the different body locations: blue for the face, orange for the chest; and red for the knees and upper shins. A 1- to 2-inches wide line of chalk was applied from the top surface of the head to the chin, and from the top surface of the knee to the middle of the shin. A duct tape patch, approximately 6 inches square, was placed on the middle of the ATDs' chest and covered with chalk. The patch was not placed over the restraining tape.

5.4 FIXTURES, LIGHTS, CAMERAS, POWER, TRIGGERS, AND DATA ACQUISITION

Rugged fixtures were installed in the rail car to support the lights and the cameras. The lights and cameras were mounted in strategic areas to capture the response of the seats and ATDs during impact. Power sources for both the lights and the cameras were designed and installed to supply the required power. A trigger mechanism was set up to activate the power supplies, turning on the lights and the cameras just prior to impact. A total of eight cameras were used; six DC cameras and two AC cameras. Two cameras were used to record each experiment: one from the side view and one from the front view of each seat; except in the locomotive where an oblique side/aft view and an aft view were recorded. All three side-view cameras for the row-to-row seat experiments were high-G cameras. All but one of the eight cameras successfully recorded data; unfortunately, the side-view camera on Experiment 2-2 failed.

5.4.1 FIXTURES

The front-view camera of each experiment was mounted on a dovetail mount that was attached to the top of a uni-strut fixture built in front of each seat/occupant experiment. The side-view cameras were installed level and perpendicular to the centerline of the car on rugged frames constructed of slotted angle iron. In the locomotive, the side-view camera was restricted to a side-angled aft-view of the seat, and the front-view camera was replaced with an aft-view camera. Figures 26, 27, 28, and 29 are photographs of the lights installed for each experiment.

Twenty-four lights, 12 in front and 12 to the side, were installed for two of the three row-to-row experiments. In Experiment 2-2, the M-style seating experiment in the first trailing coach car required more lights, 31 in total, because there was a large distance between the seats and the camera fixture. The seats and camera fixture were far apart in this case to accommodate the car’s structural framework around the vestibule. The locomotive operator seat experiment required only 12 lights in total; 4 to the side and 8 behind the experiment. The area inside the locomotive was painted white and helped illuminate the experiment. All lights were mounted in groups of four (maximum) on slotted angle iron and were strategically placed to provide proper light balance. Front-view lights were installed on a large frame constructed of uni-strut slotted angle that also supported the front-view camera. All uni-strut and slotted angle iron was installed to span at least two structural sections on the rail car's floor or wall.

5.4.2 LIGHTS AND POWER

A total of 91 ruggedized automotive floodlights, each 100W and 12V, were installed to cover all of the experiments in this test. The power source for each set of 4 lights consisted of a single 12V battery and a trigger circuit that contained 3 solid-state triggers (for 3 sets of 4 lights) and a single trip wire which, when broken, supplied power to all 12 lights. The trigger circuit and 12V battery were mounted together on a small frame located as near to the lights as possible, and energy-absorbing foam was inserted in each mount to protect the battery. Six 12V power supply units were built and installed in the rail cars. Each battery pack was individually tested for a full set of lights by simultaneously tripping all three of its triggers. The wires from the lights to the power supply were routed and taped in a manner that prevented them from being damaged either before or during the test.

Figure 26. Experiment No. 1-1, Front-View Lights and Fixtures

Figure 27. Experiment No. 2-1, Front-View Lights and Fixtures

Figure 28. Experiment No. 2-2, Front- and Side-View Lights and Fixtures

Figure 29. Experiment No. L-1, Aft-View and Oblique-Side-View Lights and Fixtures

5.4.3 CAMERAS AND POWER

The cameras used in the tests were AC-powered in the leading cab car and DC-powered everywhere else. The DC cameras were powered by 28V batteries. One such battery pack was installed directly on one of the DC cameras, and another 28V battery pack was installed as much as 10 feet away from the two cameras that it powered. The batteries were mounted on solid structure and padded with foam. A tape switch was used to trigger the DC cameras 10 seconds prior to impact.

A DC inverter powered the two AC cameras in the leading cab car, supplying enough power for the two cameras (although it was designed to provide power for up to three cameras). The inverter was mounted on an energy-absorbing "sled" that limited its deceleration during the impact. This sled was mounted near the center of gravity of the leading cab car to minimize the magnitude of deceleration. The trip wire used to trigger the AC cameras was bundled with all of the light trigger trip wires. The power supply cables for both the lights and cameras were separated from the instrumentation cables by stringing them above the roof rail of the car. The instrumentation cables were placed below the roof rail.

5.4.4 TRIGGERS AND TIMING

After the power supply units were attached to the car, the units' triggering wires were bundled together and held by a small frame that was mounted to the outside of the car. The wires were fitted with "quick disconnects" designed to separate easily when a trip bar passed through the frame holding the wires. The lights were triggered 10 seconds before impact at a trigger point 438 feet from the front impacting surface of the stationary locomotive. A hole was cut through the side of the car large enough to accommodate all of the trip wires. Special care was taken to protect the wires from the sharp edges of the hole. The flash of a strobe light (signifying the moment of impact) was visible in each camera view. These strobes were triggered when the coupler, upon which the trigger wires were taped, contacted the impact surface between the locomotive and the cab car. To ensure that all strobes flashed simultaneously upon impact, a trigger relay system was designed. This system was not needed in the previous full-scale tests, because the distance between the impact surface and the strobes was not quite as far as it was for the strobes in the first trailing coach car of this test.

A manual triggering mechanism was used for the lights and cameras in the locomotive. Rather than building a breakaway trigger on the opposite side of the track with which the oncoming consist would interact, a hand-held switch was manually turned on when the oncoming car passed a specific point along the track. While this mode of operation was appropriate for triggering the lights and cameras in the locomotive, it may have been preferable if the switch itself was one that stays on when turned on, rather than needing to be continually held open.

5.4.5 DATA ACQUISITION

Fourteen data bricks, each with 8 channels, were installed to collect 103 channels of data. Data from the experiments were recorded for a minimum of 0.1 seconds prior to impact and for 6.0 seconds after impact. A Class 1,000 anti-aliasing pre-sample filter and a minimum sample rate of 10 kHz was used in accordance with SAE J211/1, Rev. March 1995 (J211), Sections 9.1 and 9.2. Only transducers that had been calibrated within the 12-month period prior to the test were used. A calibration record for each transducer was compiled, and a copy of the record accompanied the transducer list.

5.5 MOCK TEST IMPLEMENTATION

Prior to the test, a mock triggering test was performed to ensure that all of the lights and cameras triggered in time without overloading the power supplies and without adversely triggering the data acquisition system. Unlike previous collision tests, when the mock triggering test could be performed at the desired speed on a parallel track, this time the mock test was conducted while the cars were stationary and inside the test preparation building. The cameras were loaded with dummy film, allowing the cameras to run the same amount of time as they would for the actual test. All of the camera and light triggers were tripped at the same time to simulate the actual load on the power supplies. The data acquisition system was tested to make sure it was not adversely affected when the cameras and lights were triggered. The data bricks were set and waiting for trigger (upon impact) when the cameras and lights were tripped, verifying that the electronic noise emitted by the relatively high-power photography equipment did not prematurely trigger the data acquisition system. While the cameras and lights were still on, the tape switches on the leading coupler were all tripped by lightly pressing them with a crowbar, triggering the data bricks to collect data.

5.6 PRE-TEST (TEST DAY) ACTIVITY

The pre-test sequence of events on the test day was controlled by TTCI personnel. Due to the cold temperatures – outside temperatures were at or below 32° F (0° C) – a propane heater was installed near each experiment inside every car and locomotive. The goal was to keep the ATDs and cameras near room temperature (the temperature recorded inside the heated cars was approximately 60° F (16° C)) to allow more realistic ATD responses during the impact scenario and to keep the cameras functional. At very cold temperatures, the cameras become difficult to operate, the high-speed film becomes brittle, and the ATDs become stiff and hard to manipulate. The four heaters were all removed immediately prior to the start of the test, after the pre-test activity was completed.

While the car was still connected to the locomotive and staged to accelerate down the track, all of the trigger cables were checked to confirm that power would be supplied to the lights, cameras, and strobes. Each trigger was tested individually. With one person stationed at the trip wire and another at the camera or light array, each trip wire was unplugged and proper operation of the camera or light was verified, and then the trip wire was reconnected.

To check the camera triggers, the cameras were loaded with film and the camera frame rate was slowed down so that when the camera triggers were tripped a significant amount of film was not used. After the camera triggers were checked, the camera frame rate was re-set to the test speed of 500 frames/second, and double-checked by another test technician. The strobes were turned on and charged, and the all of the data acquisition equipment was set to collect data. The 9V batteries that powered the DC camera triggers were replaced with fresh batteries just prior to checking the trigger.

For each strobe light, the tape switch was pressed, and a technician inside the car verified that the respective strobe light flashed properly. After the strobe triggers were tested, each strobe was checked to ensure that the "Ready" light was lit and that the flash was charged.

Finally, the triggers for the data acquisition system were checked by pressing the respective tape switches at the coupler. Each module was reset after the trigger check. A test technician was stationed at the coupler to ensure that none of the tape switches on the coupler were disturbed prior to the test.

When all of the trigger checks were completed, and all of the equipment was re-set and then checked to ensure that it was properly set, the occupant protection portion of the test was ready. The TTC was responsible for releasing the rail car(s) at the designated speed and distance from the impact site, i.e., the stationary locomotive.

5.7 POST-TEST ACTIVITY

Immediately after the rail car impacted the locomotive, a representative of TTCI boarded every rail car and the locomotive, and inspected each one for safety. The power supplies were disconnected. Care was taken not to disturb any of the experiments. The data was uploaded from the data acquisition system to a personal computer while the film was removed from the cameras. When all the data and film had been removed, the post-test inspection of the experiments began.

6. TEST RESULTS AND OBSERVATIONS

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

Table 3 lists the injury criteria to which the test data was compared. The head injury, chest, and femur criteria values in Federal Motor Vehicle Safety Standard (FMVSS) Regulation No. 208, Occupant Crash Protection [13] were used. The objective of a motor vehicle crash test for Federal Motor Vehicle Safety Standard (FMVSS) No. 208 is to measure how well a passenger vehicle would protect its occupant in the event of a serious real world frontal crash (a.k.a. crashworthiness of a passenger vehicle). The human performance requirements (injury criteria) the standard uses was developed to evaluate seated occupants in motor vehicle barrier crash tests. The injury criteria were developed in terms that address the mechanical response of crash test dummies in terms of risk to life or injury to a living human. Some of the types of injuries that occur in train accidents are similar to the types of injuries that occur in highway vehicle accidents. For these types of injuries, there are generally accepted criteria for evaluating the likelihood of injury from test dummy measurements. There are types of serious injuries in rail vehicle accidents which are not as likely in motor vehicle accidents, such as abdominal injuries, that can not be evaluated using the criteria in Table 3. These additional injury criteria are currently under consideration to be included in future occupant injury studies of rail vehicle crashworthiness.

Table 3. Injury Criteria

ATD Percentile	**5th Percentile Female**	**50th Percentile Male**	**95th Percentile Male**
Head Injury Criteria (HIC_{15})	700	700	700
Neck Fz (lbf)	+589 / -566	+937 / -899	+1131 / -1086
Neck (Nij)	Nij < 1.0 (loading mode of max)	Nij < 1.0 (loading mode of max)	Nij < 1.0 (loading mode of max)
Chest (G)	60	60	55
Femur (lb)	-1,530	-2,250	-2,857

Reproducible plots of the collected data were compiled for each test. High-speed film (and video), still photographs, and records of the data were generated. Calculations from the data, such as the HIC calculations, were completed in accordance with SAE AS8049. All test data was reported in full-range scale (0 – 6.0 seconds) and in a zoomed scale (0 – 1.0 seconds). The test data plots are provided in Appendix C, D, and E of this report.

The data collected includes:

1. ATD Measurements
   - Head acceleration versus time (x, y, z)
   - Head resultant acceleration and HIC
   - Chest acceleration versus time (x, y, z)
   - Chest resultant acceleration
   - Neck loads and moments versus time (x, y, z, and My)
   - Neck injury time-dependent thresholds (where applicable)
   - Axial femur loads versus time (where applicable)
   - Shoulder belt loads (where applicable).

2. Seat Attachment Loads
   - Left front load cell
   - Left rear load cell
   - Right front load cell
   - Right rear load cell.

6.1 TEST RESULTS

The train-to-train test was conducted on January 31, 2002. A five-car consist (leading cab car, three coach cars and a trailing locomotive) impacted a stationary locomotive (coupled with two ballasted freight cars) at 30 mph. The post-test residue is shown in Figures 30, 31, and 32.

Figure 30. Post-Test Impact Site

Figure 31. Post-Test View of the Impacted Locomotive

Figure 32. Post-Test View of Leading Cab Car, Right Side, Through the Broken Windshield of the Impacted Locomotive

The leading cab car overrode the stationary locomotive, climbing on top and over half of the front end of the locomotive, tearing off the front end and the front half of the cab car's understructure, and losing all survivable volume from the front third of the cab car. The front truck on the cab car was completely severed from the main body, and the trailing coach cars derailed as a result of lateral buckling. The severity of the damage to the leading cab car, combined with the energy absorbed by the impacted locomotive when it moved backward along the track, plus the continuing forward acceleration provided by the trailing cars of the moving consist, all contributed to the reduced collision acceleration and occupant injury severity recorded in the test.

This collision produced an acceleration pulse in the leading cab car that had an initial peak of 20 G at approximately 0.03 sec, followed by an oscillating acceleration of approximately +/- 5 G. The trailing cars acted to minimize the deceleration of the leading car (from 38 G in the single-car test, and 32 G in the two-car test to 20 G in this test) during the first 100 msec. Plus, the stationary locomotive became a moving barrier when it was impacted, unlike the rigid barriers of the previous two tests (Figure 31). And, while the leading car was decelerating due to its impact with the locomotive, the trailing cars were simultaneously trying to accelerate the leading car. Figure 33 shows the acceleration pulses for the leading cab car in this train-to-train test and compares it to the pulses of the leading cars on the previous two full-scale collision tests, and with the 8-G triangular sled test pulse currently required in the American Public Transportation Association (APTA) and FRA seating standards.

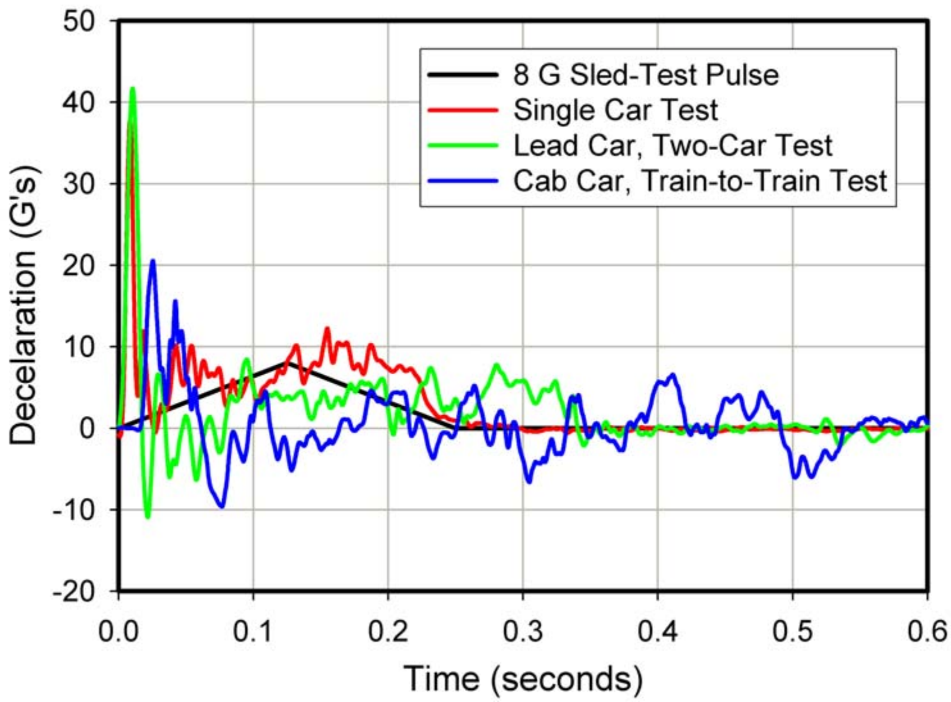

Figure 33. Deceleration Crash Pulse for the Sled Test and the Impacting Rail Car in the Three Full-Scale Collision Test Scenarios

While the collision caused severe damage to the leading cab car, which lost one third of its survivable volume, all of the experiments were installed in the survivable volume of the rail cars. The outcome of these experiments in the train-to-train collision appeared, at first sight, to be somewhat benign. All but one of the ATDs were still seated within their original seating area. The relative longitudinal velocity was calculated by the Volpe Center from the deceleration pulse of the crash test. Shown in Figure 34, the relative velocity for the unrestrained occupants in this train-to-train collision scenario was less than that produced by the 8 G, 250 millisecond-triangular crash pulse and also less than both the single-car and two-car impact tests. In the train-to-train test, the unrestrained occupants seated in a 32 inch pitch seat system likely impacted the seat in front of them at approximately 7 mph (compared to 13 mph in the two-car test and 19 mph in the sled test and the single-car test). The intercity seat experiment was not installed in the leading cab car for which the secondary velocity calculations were made. However, one could deduce that the secondary velocity in the second car (the first trailing coach car) may be less than that predicted in the leading cab car. Unrestrained occupants in the intercity seat system, which had a 42 inch pitch, would likely be traveling in the leading cab car at approximately 5 mph upon impacting the seat in front of them. Since this experiment was in the first trailing coach car, it may be less. This secondary velocity of 5 mph compares to the 16 mph predicted for passengers in the two-car test and 22 mph in the single-car test.

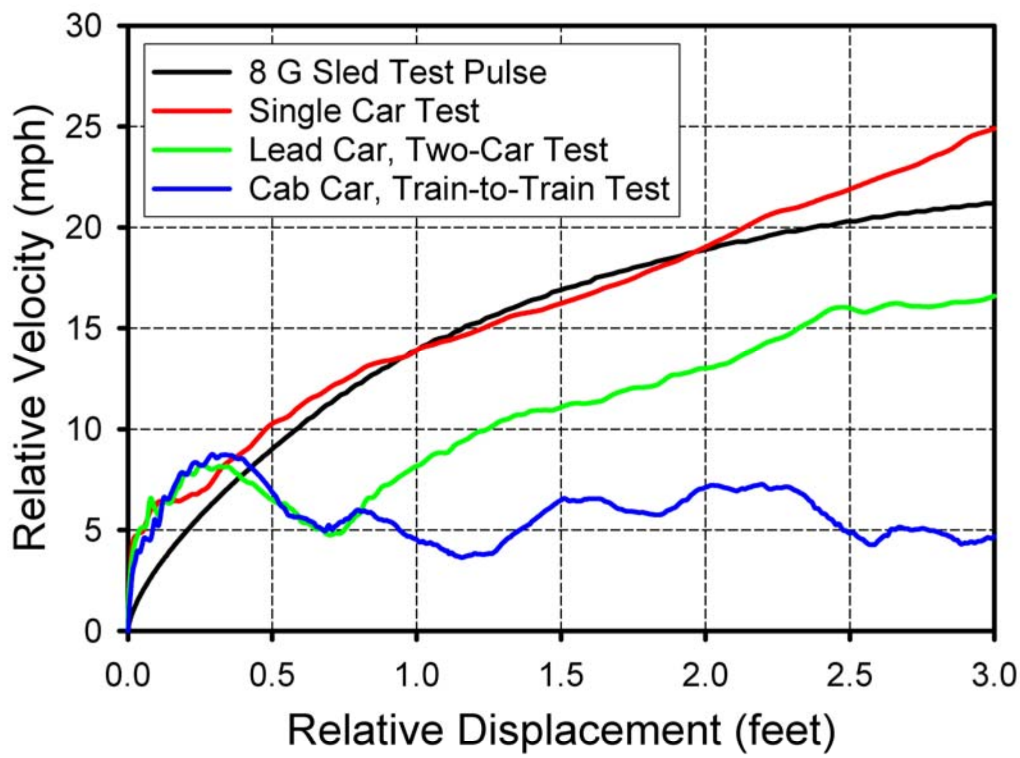

Figure 34. Relative Longitudinal Velocity of an Unrestrained Occupant as a Function of Relative Longitudinal Displacement

Post-test inspection showed that none of the seats deformed; all of them remained attached to the floor and/or wall, thereby successfully compartmentalizing the ATDs. Of the 103 data channels that were installed, 102 channels of data were collected. Data analysis shows that no ATD measured injury loads that exceeded the injury criteria. Of the eight cameras that were installed, only the lateral camera on Experiment 2-2 failed.

6.1.1 EXPERIMENT NO. 1-1, FORWARD-FACING ROW-TO-ROW M-STYLE SEATS, LEADING CAB CAR

The seats used in this experiment were not modified; they were OEM M-style seats and were identical to the seats used in the single-car test, although they were more aged. All of the M-style seats were purchased prior to the first single-car test in November 1999, and were stored outdoors during the period before the train-to-train test took place in January 2002. The ATDs in this experiment were compartmentalized; and the loads measured on the instrumented ATD (aisle seat) did not exceed any of the injury criteria. There was no deformation of the pedestal nor of the seat frame; however, the shroud on the seat back failed when the knees from the occupants behind penetrated this seat back panel (Figures 35 and 36).

Figure 35. Experiment No. 1-1 – Front and Aft Views, Post-Test

6.1.1.1 Experiment No. 1-1, Seat Outcome

There was no observable deformation in the aft-row seat; however, the back cushion in the aft-row detached from the frame.

There also was no observable deformation in the front-row seat. The secondary velocity of the ATDs from the aft-row seat was lower than in past tests. In addition, there was a much higher vertical acceleration that precluded the ATD's from traveling forward as much as they had in previous collision scenarios. The front-row seat and the floor attachments of the seat to the

Figure 36. Experiment No. 1-1 – Occupants Remain Compartmentalized

pedestal remained intact. The load cell attachment of the front-row seat to the sidewall remained intact. The seat back cushion on the front-row seat detached when the ATDs impacted the seat from behind. The seat attachment loads are provided in Appendix B in Figure B-1, and the seat attachment data plots are provided in Appendix C in Figures C-1 to C-12.

6.1.1.2 Experiment No. 1-1, ATD Outcome

The occupant loads in this experiment were measured from instrumentation installed inside the 50th-percentile Hybrid III ATD seated in the aft row, in the aisle seat. Upon impact, the ATDs in this experiment slid forward along the seat pan cushion until their knees impacted the seat in front at approximately 76 milliseconds. At this time, the ATDs rose vertically upward while maintaining some forward momentum; allowing the head and upper torso to travel over the top of the seat back. At this point, the chest impacted the seat back (approximately 300 milliseconds) and the ATDs rebounded back into their seats, catching their chins on the top of the seat back (approximately 440 milliseconds). This interaction between the ATDs' chins and the top of the seat back forced their necks into extension, but not enough to exceed the injury criteria. The ATDs returned to their seated positions before reacting to lateral loading which, at 500 milliseconds, caused them all to lean toward the window side of the seat. The aisle-side ATD leaned so far laterally that its buttocks were completely lifted off of the seat. Once the collision pulse was over, the ATDs resumed fairly orderly seated positions. Table 4 lists the injury loads recorded for the aisle-side, 50th-percentile ATD. The ATD injury data plots are provided in Appendix D in Figures D-1 to D-14.

Table 4. Experiment No. 1-1, Row-to-Row M-Style Seats – Occupant Injury Loads

	Hybrid III 50th Percentile , Aisle-Seat Unrestrained Forward Facing Occupant	
	50th Percentile Injury Criteria	Recorded Loads
HIC_{15}	< 700	16
Neck Fz (lbf)	+937 / -899	+199 / -100
Neck Nij	Nij < 1.0	0.13 (tension-flexion)
Chest (G)	60	6
Left Femur (lbf)	-2,250	-183
Right Femur (lbf)	-2,250	-43

6.1.2 EXPERIMENT NO. 2-1, FORWARD-FACING ROW-TO-ROW INTERCITY SEATS WITH RESTRAINTS, FIRST TRAILING COACH CAR

The intercity seats used in this two-car test were refurbished seats from the single-car test and the two-car test, including new seat cushions that were donated by Amtrak for the program. The ATDs in this experiment were compartmentalized, and the loads measured by the unrestrained, instrumented ATD, which was seated in the aft row on the aisle side, did not exceed any of the injury criteria. The ATD seated in the aft row on the window side was not instrumented; however, the ATD was found at the end of the test with its head stuck between the front row seat and the sidewall. There was no seat deformation; only the cushions from the aft-row seat detached (Figures 37 and 38).

Figure 37. Experiment No. 2-1 - Front and Aft Views, Post-Test

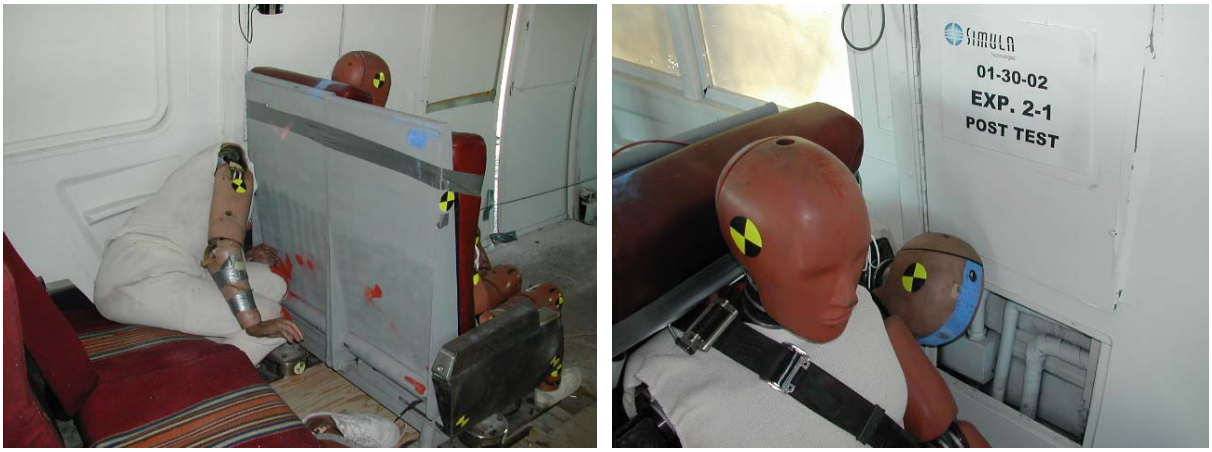

Figure 38. Experiment No. 2-1 - Post-Test Position of Unrestrained, Window-Side 95th-Percentile ATD

6.1.2.1 Experiment No. 2-1 Seat Outcome

The forward motion of the front seat's back panel was greatly reduced from the previous two tests. The seat back motion observed was due primarily to the shoulder restraint systems pulling the seat backs forward as the occupants leaned into the restraints. None of the seat back motion was due to the unrestrained ATDs' knees; the ATDs' knees impacted the seat back very lightly late in the deceleration pulse. There was some seat back movement that could be attributed to the unrestrained ATDs' heads impacting the top of the seat back from behind. The aft-row seat cushions detached. The seat attachment loads are provided in Appendix B in Figure B-2, and the seat attachment data plots are provided in Appendix C in Figures C-13 to C-24.

6.1.2.2 Experiment No. 2-1, ATD Outcome

Unlike the previous two full-scale tests where the longitudinal accelerations were predominant, it appears that the vertical and lateral accelerations played a more influential role in the ATDs' kinematic response. The unrestrained ATDs did not begin to move forward until approximately 90 milliseconds after initial impact. The heads of the unrestrained ATDs impacted the seat in front first, before the knees did. The instrumented, aisle-side ATD hit its head first against the seat back in front of it at approximately 400 milliseconds. The ATD then rose vertically upward, leaving its head still stuck against the seat back, causing the neck to rotate in flexion. As the ATD's head began to rebound off of the seat back, its knees impacted the seat back, and its head separated from the seat back, straightened forward, and then hit against the seat back again at approximately 650 milliseconds. The ATD rebounded from the seat back, and then reacted to the lateral accelerations that caused it to land head-first onto the aisle floor at approximately 5.8 seconds. The ATD measured its peak head acceleration at this time. This ATD's chest never contacted the seat back.

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

The restrained occupants in the front row remained seated, and loaded their shoulder restraints at approximately 90 milliseconds. After loading their restraints, the ATDs notably leaned toward the window side of their seats in response to the lateral forces in the car. Both restrained ATDs were instrumented in the neck and both of them recorded loads that were below the respective injury criteria. Table 5 lists the injury loads recorded for the instrumented ATDs. The ATD injury data plots are provided in Appendix D, Figures D-15 to D-36. The shoulder belt loads are in Appendix E in Figures E-1 and E-2.

Table 5. Experiment No. 2-1, Row-to-Row Intercity Seats, First Trailing Coach Car - Occupant Injury Loads

	5th Percentile	**5th Percentile Hybrid III, Aisle Seat, Front-Row Restrained Occupant**	**95th Percentile**	**95th Percentile Hybrid III, Aisle Seat, Back-Row Unrestrained Occupant**	**95th Percentile Hybrid III, Window Seat, Back-Row Unrestrained Occupant**
	Injury Criteria	**Recorded Loads**	**Injury Criteria**	**Recorded Loads**	**Recorded Loads**
HIC_{15}	700	(not measured)	700	44	(not measured)
Neck Fz (lbf)	+589 / -566	+67 / -64	+1131/-1086	+75 / -418	+107 / -60
Neck Nij	Nij < 1.0	0.32 (tension – extension)	Nij < 1.0	0.29 (compression – flexion)	0.20 (tension – extension)
Chest (G)	60	(not measured)	55	5	(not measured)
Left Femur (lbf)	-1,530	(not measured)	-2,857	-599	(not measured)
Right Femur (lbf)	-1,530	(not measured)	-2,857	-76	(not measured)

6.1.3 EXPERIMENT NO. 2-2, FORWARD-FACING ROW-TO-ROW M-STYLE SEATS, FIRST TRAILING COACH CAR

The seats used in this experiment were OEM M-style seats and were identical to the seats used in the single-car test, although they were more aged. The aft row seat was tested without a shroud covering the back of the seat frame. The ATDs in this experiment were compartmentalized.

There was no deformation of the pedestal nor of the seat frame; however, the shroud on the front-row seat back failed when the knees from the ATDs behind penetrated the seat back panel (Figures 39, 40, and 41).

Figure 39. Experiment No. 2-2 - Front and Aft Views, Post-Test

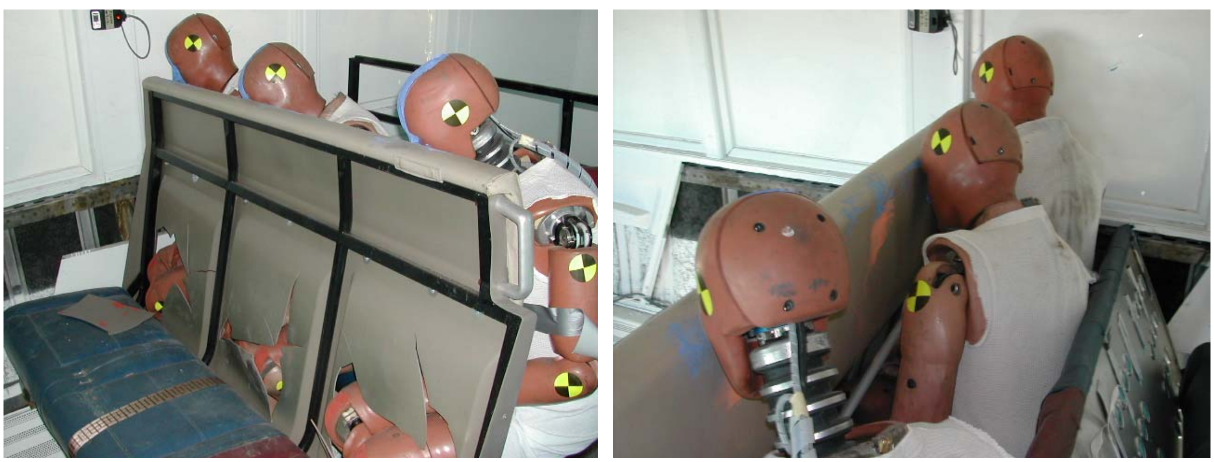

Figure 40. Experiment No. 2-2 - ATDs Remain Compartmentalized

Figure 41. Experiment No. 2-2 - Post-Test Close-Up View Shows No Seat Frame Deformation

6.1.3.1 Experiment No. 2-2, Seat Outcome
There was no observable deformation in the aft-row seat. The seat back cushion and the headrest cushion detached from the frame and appear to have impacted the aisle-side ATD's head from behind, causing a neck flexion moment that exceeded the injury criteria.

The front-row seat did not deform, but the seat cushions detached when the knees from the ATDs behind penetrated the shroud cover on the seat back. The floor load cell attachments remained intact between the pedestal and sidewall mounts. The seat attachment loads are provided in Appendix B in Figure B-3, and the data plots are provided in Appendix C in Figures C-25 to C-36.

6.1.3.2 Experiment No. 2-2, ATD Outcome
The occupant loads in this experiment were measured from instrumentation installed in the 50th-percentile Hybrid III ATD seated in the aft row in the aisle seat. This ATD slid forward in the seat until its knees impacted the seat back at approximately 100 milliseconds. After knee impact, the ATD rebounded, never hitting its head against the seat back. Instead, as the ATD rebounded back into the seat, the detached headrest impacted the ATD's head from behind. As the aisle-side ATD rebounded, the window- and middle-seat ATDs wedged the headrest between them and the seat back, forcing the aisle-side ATD to impact the headrest two times. This blow

to the head produced the highest neck loads in this experiment, but the neck injury criteria was not exceeded. The blow to the head from behind then forced the ATD forward again, where it ultimately came to rest with its head against the seat back in front. Unfortunately, the side-view camera of this experiment did not capture any footage of this experiment due to camera failure upon impact. Table 6 lists the injury loads recorded for the instrumented ATDs, and the injury data plots are provided in Appendix D in Figures D-37 to D-50.

Table 6. Experiment No. 2-2, Row-to-Row M-Style Seats, First Trailing Coach Car – Occupant Injury Loads

	Hybrid III 50th Percentile , Aisle-Seat Unrestrained Forward Facing Occupant	
	50th Percentile Injury Criteria	**Recorded Loads**
HIC_{15}	< 700	10
Neck Fz (lbf)	+937 / -899	+139 / -59
Neck Nij	Nij < 1.0	0.18 (tension-flexion)
Chest (G)	60	5
Left Femur (lbf)	-2,250	-185
Right Femur (lbf)	-2,250	-179

6.1.4 Experiment No. L-1, Operator Seat, Stationary Locomotive

This was the first time that a locomotive operator seat with an occupant was incorporated into a full-scale collision test for occupant protection evaluation. A pedestal-mounted, high-back seat with armrests was installed, and a 95th-percentile ATD was seated, unrestrained, in the seat. Despite the amount of damage that occurred inside the locomotive (Figure 42), the seat was not damaged and it did not fail under the inertial loads of the collision. Surprisingly, the ATD remained in the seat after sliding forward toward the seat edge. The ATD's post-test position was slumped forward, and its feet had slipped forward off of the footrest that had been installed to replace the original footrest. There were no markings at all on any of the interior components (See Figures 42, 43, and 44).

Figure 42. Experiment No. L-1 - Post-Test View of the Locomotive Interior

Figure 43. Experiment No. L-1 - Post-Test View of the ATD in the Operator Seat

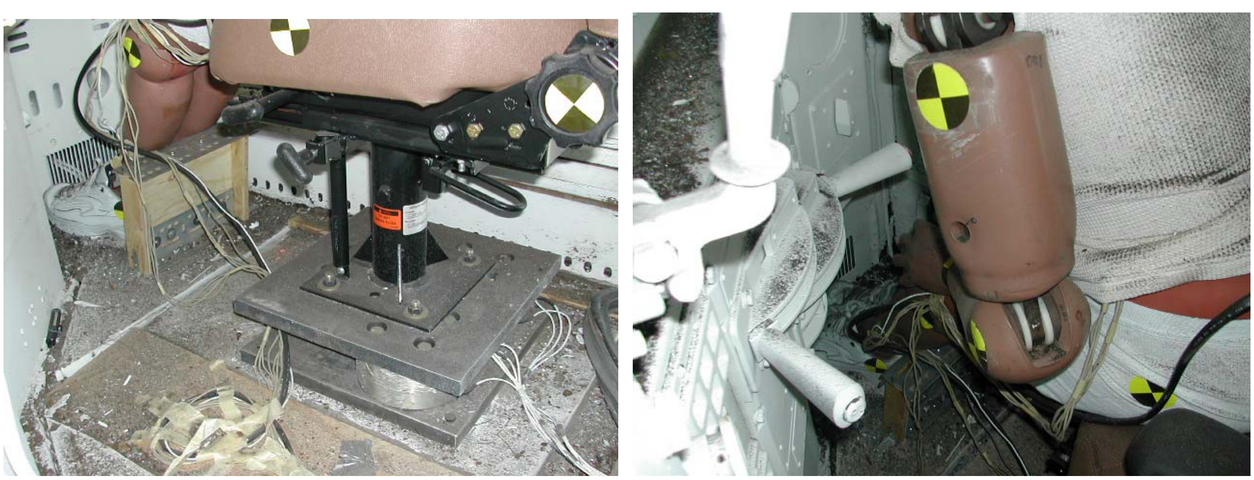

Figure 44. Experiment No. L-1 - Post-Test Close-Up Views of Operator Seat/Floor Mount, and ATD Feet and Body Placement

6.1.4.1 Experiment No. L-1, Seat Outcome

There was no damage or structural failure observed during the post-test evaluation of the seat. Nonetheless, the seat experienced considerable motion during the collision as both the seat and the ATD reacted to the crash pulse, and the seat reacted to the moving ATD. A slow-motion view of the film footage shows the seat back reacting first to the inertial loads by moving forward, and then rebounding back. When the seat back reaches its back stopping point, it moves forward again, this time colliding with the ATD, which is rebounding backward. None of this activity appears to have caused any damage or seat failure. The seat attachment loads are provided in Appendix B in Figure B-4, and the data plots are provided in Appendix C in Figures C-37 to C-45.

6.1.4.2 Experiment No. L-1, ATD Outcome

A 95th-percentile ATD was seated facing forward with its hands on its thighs and its feet on the footrest. Upon initial impact, the ATD slid forward in the operator seat, and the seat back followed the ATD's forward motion. The ATD continued to slide forward in the seat, even though the seat back stopped moving forward. The ATD stopped sliding forward and reacted to some lateral acceleration by leaning toward the right window. At approximately 180 msec, the ATD's right shoulder contacted the window. At this point, the seat back rebounded forward again, colliding into the back of the ATD, and forcing the ATD away from the window. The ATD then slumped forward, the upper torso bending over, and the head traveling toward the console. There was no evident contact between the head or torso with the front interior of the locomotive. The ATD did not rebound back into the seat after the collision, but rather stayed slumped forward in the seat. Table 7 lists the injury loads that were recorded for the ATD in this experiment. Injury data plots are provided in Appendix D in Figures D-51 to D-64.

Table 7. Experiment No. L-1, Operator Seat, Stationary Locomotive – Occupant Injury Loads

	Hybrid III 95th Percentile , Unrestrained Forward Facing Occupant in Locomotive Drivers Seat	
	95th Percentile Injury Criteria	**Recorded Loads**
HIC_{15}	700	5
Neck Fz (lbf)	+1131/-1086	+219 / -24
Neck Nij	Nij < 1.0	0.05 (compression-flexion)
Chest (G)	55	5
Left Femur (lbf)	-2,857	-304
Right Femur (lbf)	-2,857	-86

7. M-STYLE SEAT TEST DATA COMPARISONS

This train-to-train test was the third in a series of FRA-funded full-scale passenger rail collision testing with occupant protection experiments. The first test was a single-car collision against a rigid barrier, and the second test was a two-car collision against the same rigid barrier. This train-to-train test represented a more realistic scenario, because it involved a five-car collision against a stationary locomotive-led two-car consist that moved when it was impacted. The energy of the collision was dissipated by the severe destruction of the front end of the leading cab car, the moving impacted locomotive, and the continued forward acceleration of the trailing cars in the consist. This impact scenario contributed to the lower seat attachment loads and reduced occupant injury potential.

The M-style seat/occupant experiments installed in this and all previous collision tests are compared in this section. The seat attachment and occupant loads of each experiment in all previous tests are compared along with the seat deformation characteristics and the occupant kinematics. In addition to the three full-scale collision scenarios, results from seat tests on a dynamic sled using the standard 8 G peak, 250 millisecond triangular crash pulse are compared.

7.1 SEAT ATTACHMENT LOAD COMPARISONS

The magnitude of the resultant attachment loads measured in the load cells are correlated to the severity of the collision in Table 8. Time histories of the longitudinal, lateral, and vertical components of the load cell forces are included in Appendix C. The data shows that the M-style seat attachment loads measured in the train-to-train test were much lower in magnitude than those produced in the other tests. Similarly, the predicted relative occupant velocity was also lower, at a distance of 2.0 feet from the initial seated position. Higher vertical and lateral forces were a contributing cause of the reduced occupant velocity in the train-to-train test, as these forces compromised the forward motion of the occupants.

The data produced previously in the sled tests suggests that the seats are capable of bearing up to at least 16,131 lb in the one-dimensional loading environment provided by the sled tests. However, the sled tests did not incorporate vertical or lateral motion in the vehicle; these motions were produced by the vehicles in the collision tests. Vertical motion was produced in all the vehicle tests and was most pronounced in the train-to-train test. Lateral motion was produced in the two-car test and the train-to-train test, but it was not evident in the single-car collision test.

Table 8. Total M-Style Seat Attachment Load Versus Occupant Velocity

	Relative Occupant Velocity at 2.0 feet Displacement (mph)	Total Resultant Attachment Load (lb)
Sled Test	19	16,131
Single-Car Test	19	13,820
Two-Car Test (Leading Car)	13	12,084
Two-Car Test (Trailing Car)	~13	12,548
Train-to-Train Test (Leading Cab Car)	7	7,838
Train-to-Train Test (Trailing Coach Car)	~7	7,294

Table 9 lists the floor attachment and resultant loads for all of the tests. The comparison shows that the wall attachment loads in the sled test were higher than they were in the collision tests. This difference may suggest that the wall mounting provided by the railcar is not as strong as the fixture that had been built for the sled test. Also, there was no sidewall in the sled test fixture. It is possible that the sidewall of the rail car may have borne some of the occupant's impact load, which in the sled test was applied entirely on the seat. Of the three full-scale collision tests, the train-to-train test produced loads measured in the load cells of the M-style seats that were much lower than those measured in the other full-scale tests; as much as 40 percent lower.

Table 9. Resultant Floor Attachment Loads at Each Load Cell for Each M-Style Seat/Occupant Experiment (lb)

Test	Wall Attachment, Aft	Wall Attachment, Forward	Floor Attachment, Aft	Floor Attachment, Forward	Total Resultant Attachment Load
Sled Test	5,586	4,085	4,075	2,385	16,131
Single-Car Test	1,889	2,057	4,961	4,913	13,820
Two-Car Test (Leading Car)	2,067	1,819	3,744	4,454	12,084
Two-Car Test (Trailing Car)	2,056	2,178	4,057	4,257	12,548
Train-to-Train Test (Leading Cab Car)	1,462	1,571	2,007	2,798	7,838
Train-to-Train Test (Trailing Coach Car)	1,494	1,211	2,286	2,303	7,294

7.2 SEAT RESPONSE

The mode of failure of the seat in each collision environment is outlined in Table 10. While failure modes appeared to be similar; any variability was primarily a function of the severity of the collision. The severity level of seat failure in the train-to-train test was much lower than that of the other two tests, as none of the seat frames failed. A more detailed description of the seat failure modes is provided in the Final Report for the single- and two-car collision tests.

Table 10. Mode of Failure for the M-Style Seat in Each Collision Environment

Test	Pedestal	Wall Attachment	Seat Frame	Cushions
Sled Test	Pedestal collapsed under load	Wall attachments buckled	Square beam frame buckled, less severe than single-car test; seat pan frame bowed	Detached
Single-Car Test	Pedestal collapsed under load	Wall attachments buckled, wall mounts sheared completely at the weldment	Square beam frame that bends to form the seat pan failed; seat pan frame bowed	Detached
Two-Car Test (Leading car)	Minimal deformation	Attachments buckled forward, but did not fail	Some forward bending of the seat frame	Detached
Two-Car Test (Trailing car)*	No deformation	No deformation	Some forward bending of the seat frame	Detached
Train-to-Train Test (Leading Cab Car)	No deformation	No deformation	No deformation	Detached
Train-to-Train Test (Trailing Coach Car)	No deformation	No deformation	No deformation	Detached

*The seat in this experiment was modified

8. OBSERVATIONS, CONCLUSIONS, AND RECOMMENDATIONS

The train-to-train collision test was successful, producing useful information and data on occupant safety that could be compared with the results obtained from previous tests. The results of this test will be compared with those of future tests as the understanding and technology for providing occupant protection improves. Observations, conclusions, recommendations resulting from the train-to-train test occupant experiments are provided in this section.

8.1 OBSERVATIONS

The peak deceleration of the leading cab car was less than that measured for the leading cars of the single-car test and the two-car test. This reduction in initial peak deceleration was due to a moving impact barrier (the locomotive, rather than the rigid barriers used in the previous two tests), and the trailing cars in the consist that continued to accelerate the leading cab car forward with the moving barrier, thus countering the deceleration of impact. In addition, the front-end destruction of the cab car absorbed much of the energy.

Two forward-facing rows of unmodified, production, three-place M-style passenger seats were installed in the leading cab car. While the survivable volume was completely lost in the front third of the cab car, the seats installed in the aft third of the car performed well, as they did not fail, structurally, and the occupants were effectively compartmentalized.

Two forward-facing rows of unmodified, production, three-place M-style passenger seats were installed in the first trailing coach car. This car derailed from the track. The seats in this experiment performed well, as they did not fail structurally, and the occupants were effectively compartmentalized. However, the cushions that detached in this experiment severely impacted the aisle-side ATD.

Two forward-facing rows of two-place intercity passenger seats were installed in the first trailing coach car. The seats in this experiment performed well, as they also did not fail structurally, and the occupants were effectively compartmentalized. However, the unrestrained aisle-side ATD landed headfirst in the aisle at the end of the 6 second deceleration pulse, producing the maximum head and neck loads of that time series. The unrestrained window-side ATD was found with its head stuck between the front row seat and the wall.

There were no seat structural failures in the train-to-train test. Only the shrouds covering the seat backs failed in the M-style seating experiments. This failure is most likely due to the brittleness developed by the material as it aged in the sun in storage during the months prior to testing.

An intercity seat was modified with lap and shoulder belts and stronger load-carrying members to support these restraints. There was no damage to the seats in this test.

8.2 CONCLUSIONS

The velocity of the five-car consist was 30 mph when it collided head-on into the standing locomotive. This velocity differed from the 26 mph of the two-car test and the 35 mph of the single-car test, both of which collided head-on into a rigid barrier. The moving barrier involved in the train-to-train test appears to have reduced the overall severity of the collision, as measured by the occupant experiments.

In this collision environment, all seat configurations provided the occupants with effective compartmentalization.

The upward motion of the cab car during the collision forced the ATDs to remain in their seats, minimizing the impact load of the occupants on the seat back.

The train-to-train test produced a safer environment to occupants, compared to that produced in the single-car and two-car impact tests. For example, the secondary-impact velocities for the unrestrained, forward-facing ATDs seated in the M-style seats (where the occupant travels approximately 2 feet before impacting the seat in front of it) in the single-car and two-car tests were 19 mph and 13 mph, respectively. The corresponding value for these same ATDs in the train-to-train test (leading cab car) was 7 mph. Thus, occupants in the single-car test had more than seven times the kinetic energy than occupants in the leading cab car of the train-to-train test, and those in the two-car test had over three times more.

The secondary-impact velocities for the unrestrained, forward-facing ATDs seated in the intercity seats (where the distance the occupant travels is approximately 2.5 feet) in the single-car and two-car tests were 22 mph and 16 mph, respectively. The corresponding value for these same ATDs in the train-to-train test – for an experiment in the leading cab car - was 5 mph. However, the intercity seats were not installed in the leading cab car; instead, they were installed in the first trailing coach car, which is likely to have a lower deceleration pulse than the leading cab car. Even if this experiment had been installed in the leading cab car, it could be calculated that the occupants in the single-car test had almost 20 times more kinetic energy than the occupants in the leading cab car of the train-to-train test, and those in the two-car test had over 10 times more.

While the distance traveled is greater for occupants seated in the intercity seats (where the seat pitch is 42 inches) than it is for the occupants seated in the M-style seats (where the seat pitch is 32 inches), the predicted relative velocity for occupants in the intercity seats is less than that for occupants in the M-style seats. During the longer traveling distance, the railcars from behind pushed the front railcars forward, thereby reducing the relative velocity for the ATDs traveling a longer distance. Therefore, when they impacted the seat in front of them, they were traveling at a slower relative speed than the occupants traveling a shorter distance, who impacted the seat before the rail car was pushed forward.

The unbelted 95th-percentile ATD in the intercity window seat was not instrumented, so no injury loads were recorded. However, this ATD was stuck in its seat, with its head wedged between the front-row seats and the wall. Emergency egress for an occupant in this situation would likely not have been possible.

Both the belted 5th-percentile and 95th-percentile ATDs in the modified intercity seat recorded neck loads that were below the injury criteria. This is unlike the neck loads that exceeded injury criteria during the single- and two-car tests. One reason the recorded neck loads were below the injury criteria is that the unrestrained ATDs behind them did not collide into their seats.

In previous full-scale testing, the neck and knees were the most frequent body areas where measured loads exceeded the injury criteria. In the train-to-train test, the knees were rarely impacted. The neck recorded higher loads. The Nij for that particular measurement was below the Nij criterion. The most probable cause for this high neck load was due to a detached headrest cushion that impacted the ATD's head from behind (Experiment 2-2).

The intercity seats could not be installed flush against the sidewall of the car in this test, which may have contributed to the head of one of the unrestrained ATDs getting wedged between the seat and the wall. The interior construction of the test car was designed for sidewall-mounted seats, not double-pedestal-mounted seats like the intercity seats.

The results from these tests will be used to continue refining the analytical models of the rail cars and seats and to address the practicality of the current sled-test requirements, in particular the test pulse criterion.

8.3 RECOMMENDATIONS

Future collision tests are planned that will duplicate the three full-scale collision scenarios conducted to date, but will involve passenger cars with front-end structures that have been upgraded to provide crash energy management.

At least one unmodified, forward-facing M-style seat experiment should continue to be included in each one of the next series of tests.

Occupant protection against longitudinal accelerations (through compartmentalization and possibly seat belts) should continue to be addressed.

Additionally, occupant protection against lateral and vertical accelerations should be considered in at least one seating experiment per test.

The test sled crash pulse should be re-defined considering the effects of sled lateral, vertical, and longitudinal accelerations. Accurate replication of all the axes is particularly important in evaluating compartmentalization strategies.

Seat cushion attachments should be strengthened to prevent loose cushions from becoming projectiles capable of causing serious injury.

It is essential to ensure that all seats are installed in rail cars so that they are flush against the sidewall to avoid any chance of occupants getting stuck between the seat and the sidewall.

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APPENDIX A

TEST EQUIPMENT SUMMARY
TRAIN-TO-TRAIN TEST – JANUARY 31, 2002

Table A-1. Floor/Wall Attachment Load Cells Used and Number of Data Channels Needed

Exp. No.	Description	Seat Requirements	Load Cells[1]	Data Channels
1-1	Two row-to-row, three-place passenger M-style seats (Leading Cab Car)	Three-place M-style (back row) Three-place M-style (front row)	0 4	0 12
2-1	Two row-to-row, two-place passenger intercity seats (First Trailing Coach Car)	Two-place intercity seat without restraints (back row) Two-place intercity seat with lap and shoulder belts (front row)	0 4	0 12
2-2	Two row-to-row, three-place passenger M-style seats (First Trailing Coach Car)	Three-place M-style (back row) Three-place M-style (front row)	0 4	0 12
L-1	One locomotive operator seat	One-person seat	3	9
Total	**4 Experiments**	**7 Seats**	**15**	**45**

[1] Three data channels per load cell.

Table A-2. Train-to-Train Test Experiment Configurations and Number of ATD Data Channels

Exp. No.	Description		ATD Data Channels				
	Seats	**ATDs**	**Head**	**Neck**	**Chest**	**Femur**	**Total**
1-1	Three-place M-style (back row), leading car	Hybrid III 50th (aisle seat)	3	4	3	2	**12**
		Hybrid II 50th (middle seat)	0	0	0	0	**0**
		Hybrid II 50th (window seat)	0	0	0	0	**0**
	Three-place M-style (front row), leading car	Empty	-	-	-	-	**-**
2-1	Two-place intercity seat, no restraints (back row), trailing car	Hybrid III 95th (aisle seat)	3	4	3	2	**12**
		Hybrid III 95th (window seat)	0	0	0	0	**0**
	Two-place intercity seat, with restraints (front row), trailing car	Hybrid III 5th F (aisle seat)	0	4	0	0	**4**
		Hybrid III 95th (window seat)	0	4	0	0	**4**
2-2	Three-place M-style (back row), trailing car	Hybrid III 50th (aisle seat)	3	4	3	2	**12**
		Hybrid II 50th (middle seat)	0	0	0	0	**0**
		Hybrid II 50th (window seat)	0	0	0	0	**0**
	Three-place M-style (front row), trailing car	Empty	-	-	-	-	**-**
L-1	Locomotive seat	Hybrid III 95th	3	4	3	2	**12**
Total	**7 Seats**	**11 ATDs**	**12**	**24**	**12**	**8**	**56**

Table A-3. Train-to-Train Test - Total Number of Data Bricks Required

Experiment	Floor	ATD	Shoulder Belts	Total Channels	No. of Bricks (Chan. avail.)
Experiment 1-1	12	12	0	**24**	**3** (24)
Experiment 2-1	12	20	2	**34**	**5** (40)
Experiment 2-2	12	12	0	**24**	**3** (24)
Experiment L-1	9	12	0	**21**	**3** (24)
Total Channels	**45**	**56**	**2**	**103**	**14** (112)

Table A-4. Lighting(1) and Camera Equipment Used in Testing

	Front View		Side View		
Experiment	**No. of Lights**	**Camera (500 fr/sec)**	**No. of Lights**	**Cameras (500 fr/sec)**	**Total Lights**
1-1 (M-Style, fwd)	12	AC, LoCam	12	AC, Hi-G LoCam	**24**
2-1 (Intercity)	12	DC, LoCam	12	DC, Hi-G LoCam	**24**
2-2 (M-Style, fwd)	19	DC-DBM5 (Milliken)	12	DC, Hi-G LoCam	**31**
L-1 (Operator Seat)	6	DC-DBM5 (Milliken)	6	DC-DBM5 (Milliken)	**12**
TOTAL	**49**	**3 DC/1 AC**	**42**	**3 DC/1 AC**	**91**

(1) Light bulbs are ruggedized automotive floodlights, each 100W and 12V

Table A-5. Lens Focal Lengths and Camera Location with Respect to the Seats

	Front-view Camera				Side-view Camera			
Exp. No.	**Camera (500 fr/sec)**	**Lens Focal Length (mm)**	**Dist. to Seat (ft)**	**Ht Above floor (ft)**	**Cameras (500 fr/sec)**	**Lens Focal Length (mm)**	**Dist. to Seat (ft)**	**Ht Above floor (ft)**
Exp. 1-1	AC, LoCam	10.00	11.00	5.75	AC, Hi-G LoCam	5.70	6.00	2.25
Exp. 2-1	DC, LoCam	10.00	11.00	5.50	DC, Hi-G LoCam	5.70	6.00	3.00
Exp. 2-2	DC-DBM5 (Milliken)	16.00	16.00	5.50	DC, Hi-G LoCam	5.70	6.00	2.25
Exp. L-1	DC-DBM5 (Milliken)	5.70	4.50	-	DC-DBM5 (Milliken)	9.00	7.50	-

Table A-6. Instrumentation Used

Instrumentation	Manufacturer	Model	Range	Response
Tri-Axial Floor Load Cell	Denton	2177A	10,000 lb	DC-1,250 Hz
Tri-Axial Floor Load Cell	GSE	T-3152-D	5,000 lb	DC-1,250 Hz
Uni-Axial Load Cell (Seat Belt)	Denton	1910	3,000 lb	DC-1,250 Hz
Tri-Axial Head Accelerometer	IC Sensor	3031-500	500 G	DC-2,000 Hz
Tri-Axial Head Accelerometer	Endevco	7264C	200 G	DC-2,000 Hz
Six-Axis Neck Transducer	Denton	1716	2-3,000 lb 2,500 lb/in.	DC-1,250 Hz
Chest Tri-Axial Acelerometer	IC Sensor	3031-500	500 G	DC-2,000 Hz
Chest Ti-Axial Accelerometer	Endevco	7264C	200 G	DC-2,000 Hz
Uni-Axial Femur Load Cells	GSE	2430	0-3,000 lb	DC-1,250 Hz
Uni-Axial Femur Load Cells	Denton	2121	0-3,000 lb	DC-1,250 Hz

Table A-7. Rail Seat Dynamic Testing Instrumentation and SAE J211 Filter Class

Instrumentation	Filter Class
Vehicle Accelerations	60 or 180
ATD Head Acceleration (x, y, and z)	1,000
Neck Transducer	600 (moments) - 1,000 (forces)
Chest Acceleration (x, y, and z)	180 (at spine)
ATD Femur Loads (z)	600
Floor Reaction Loads (x, y, and z)	60

APPENDIX B

SEAT ATTACHMENT LOADS
TRAIN-TO-TRAIN TEST – JANUARY 31, 2002

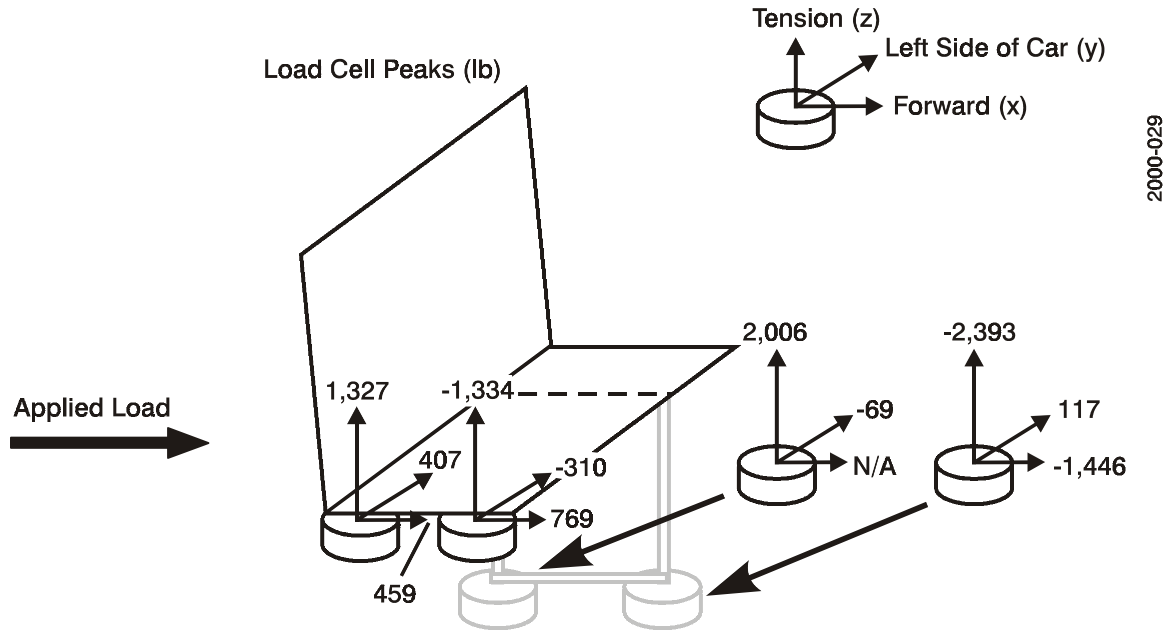


Figure B-1. Experiment 1-1 – Forward-Facing Row-to-Row M-Style Seats, Leading Cab Car - Front-Row Seat Attachment Loads (Maximums)

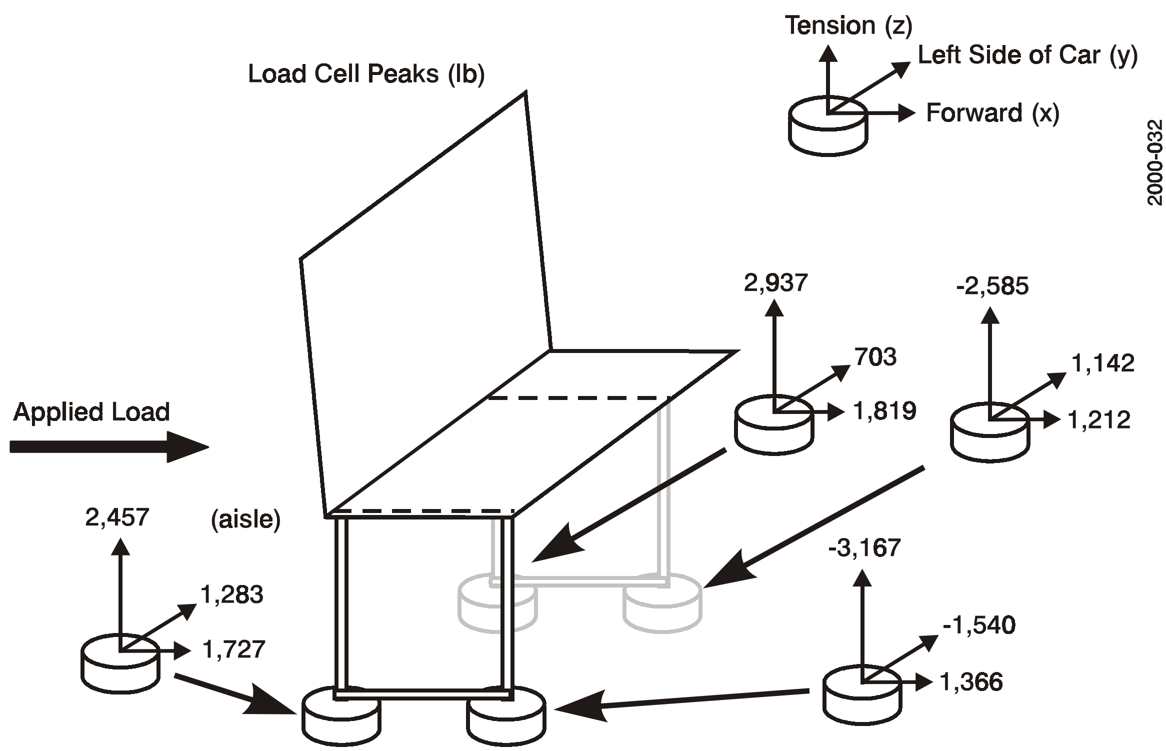


Figure B-2. Experiment 2-1 – Forward-Facing Row-to-Row Intercity Seats with Restraints, First Trailing Coach Car - Front-Row Seat Attachment Loads (Maximums)

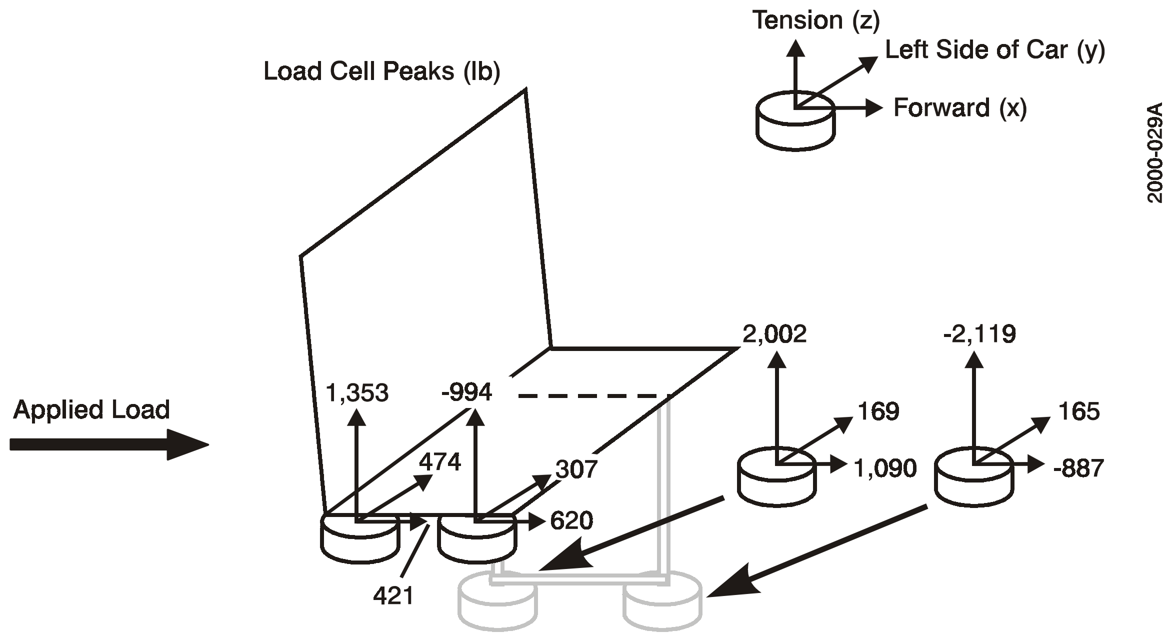


Figure B-3. Experiment 2-2 – Forward-Facing Row-to-Row M-Style Seats, First Trailing Coach Car - Front-Row Seat Attachment Loads (Maximums)

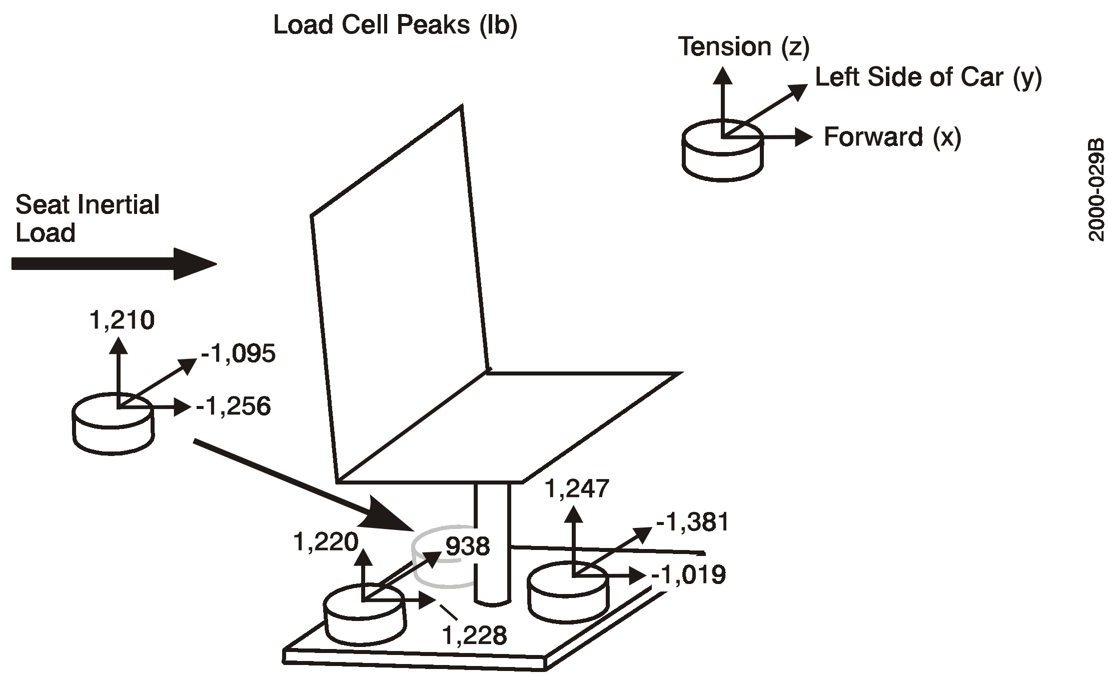


Figure B-4. Experiment L-1 – Locomotive Operator Seat, Seat Attachment Loads (Maximums)

APPENDIX C

SEAT ATTACHMENT LOAD-TIME HISTORIES – JANUARY 31, 2002

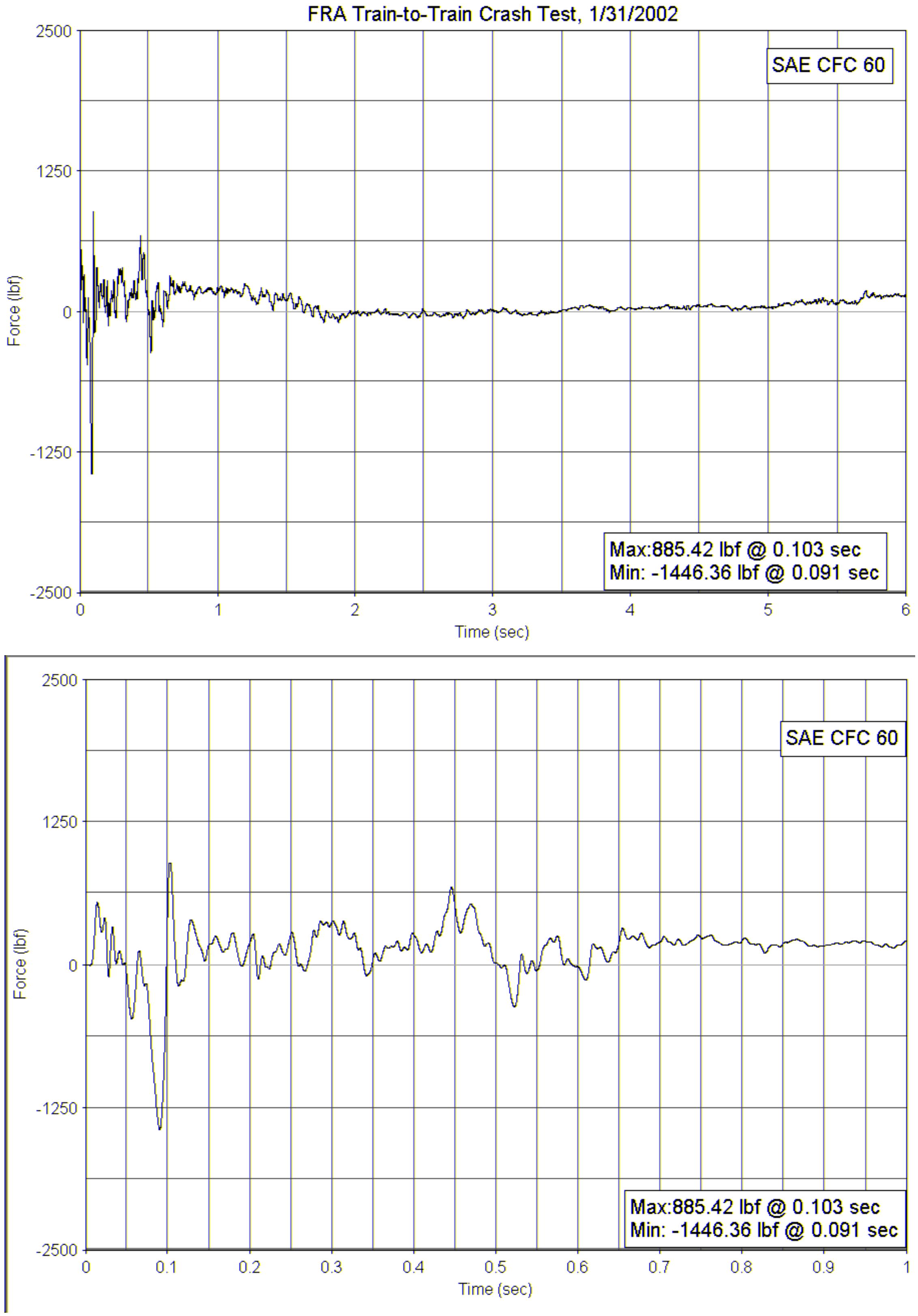


Figure C-1: Experiment No. 1-1 M-Style Seat, Forward Row, Left Front Leg, X-Axis Force

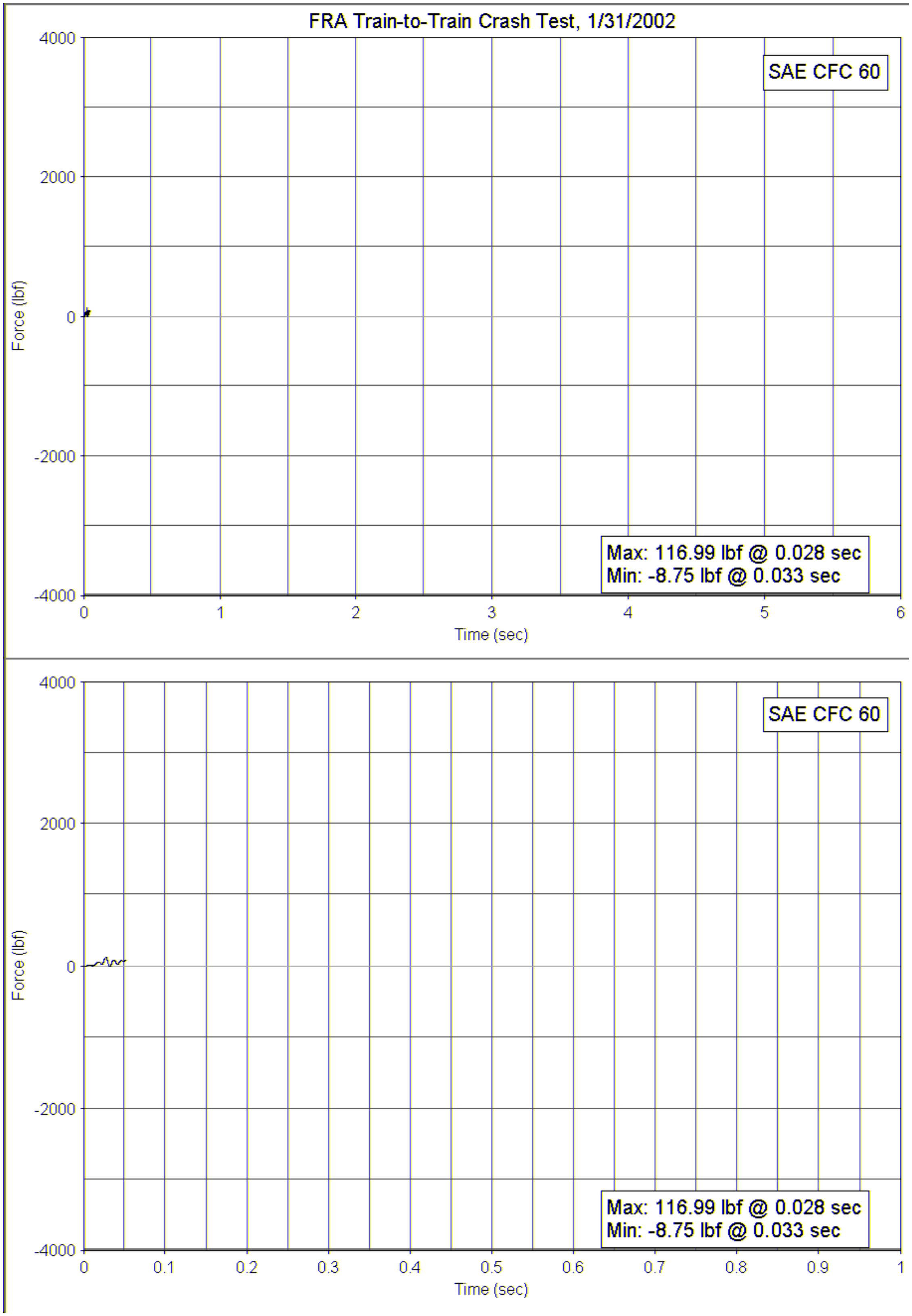


Figure C-2: Experiment No. 1-1 M-Style Seat, Forward Row, Left Front Leg, Y-Axis Force

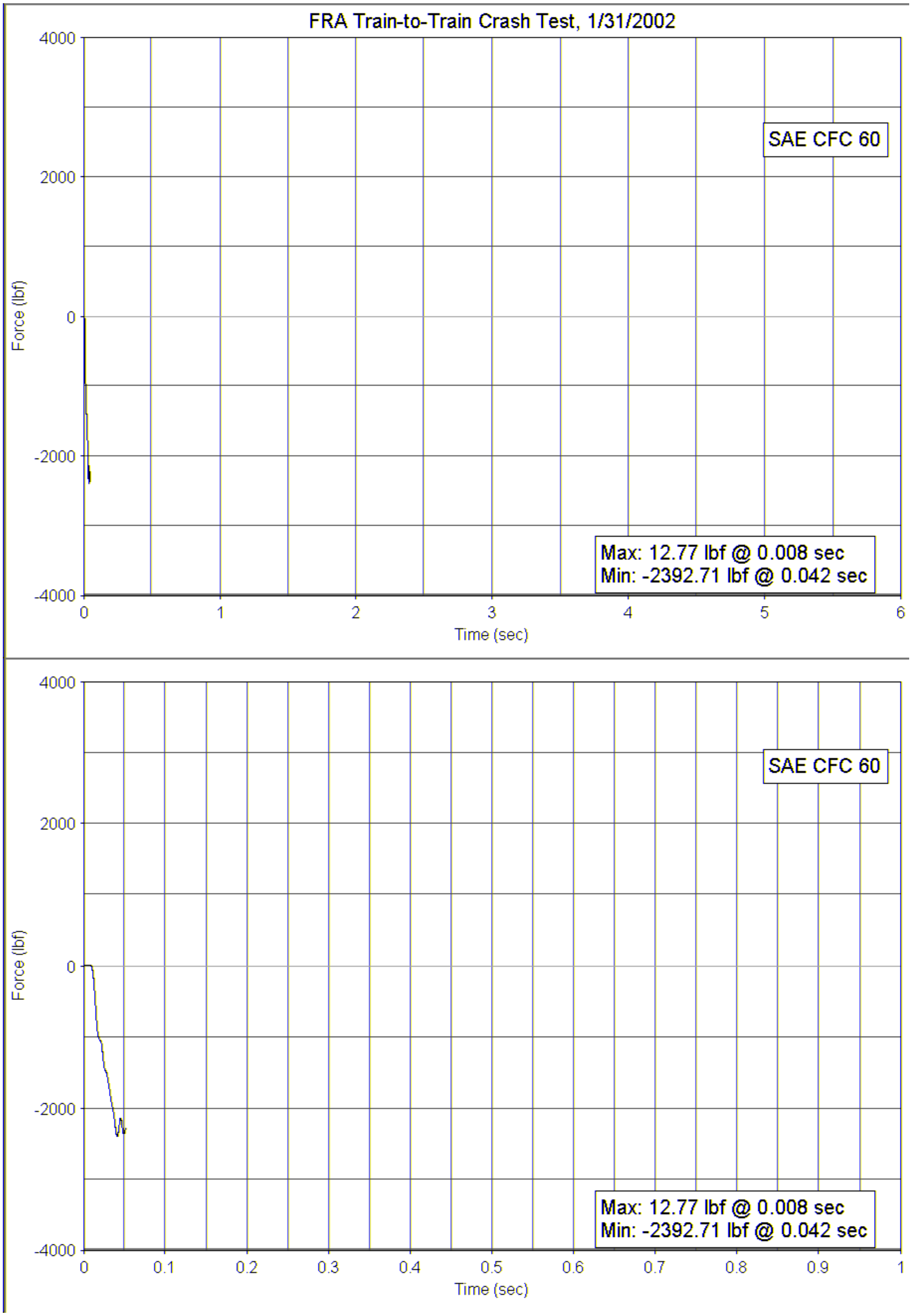


Figure C-3: Experiment No. 1-1 M-Style Seat, Forward Row, Left Front Leg, Z-Axis Force

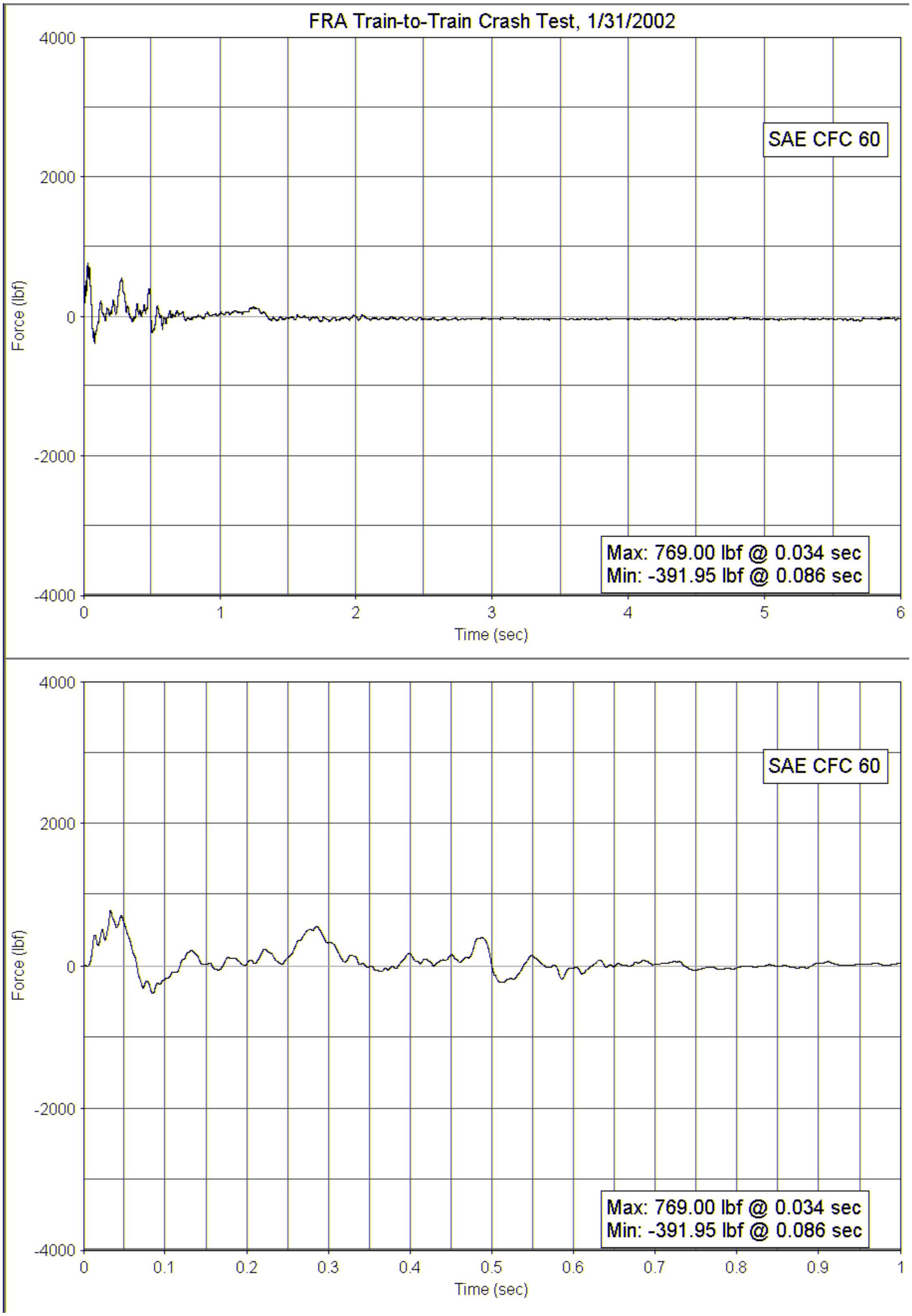


Figure C-4: Experiment No. 1-1 M-Style Seat, Forward Row, Right Front Leg, X-Axis Force

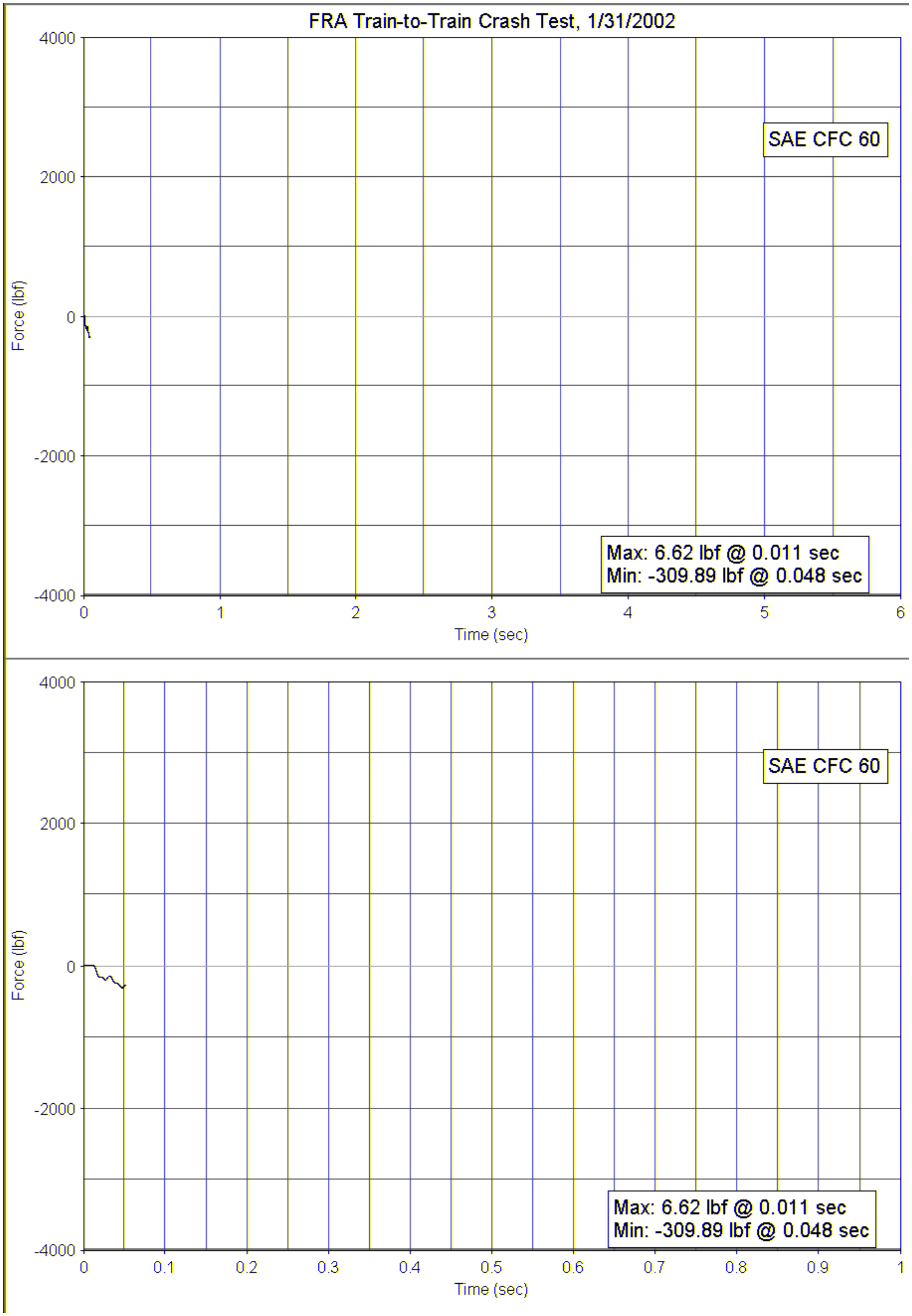


Figure C-5: Experiment No. 1-1 M-Style Seat, Forward Row, Right Front Leg, Y-Axis Force

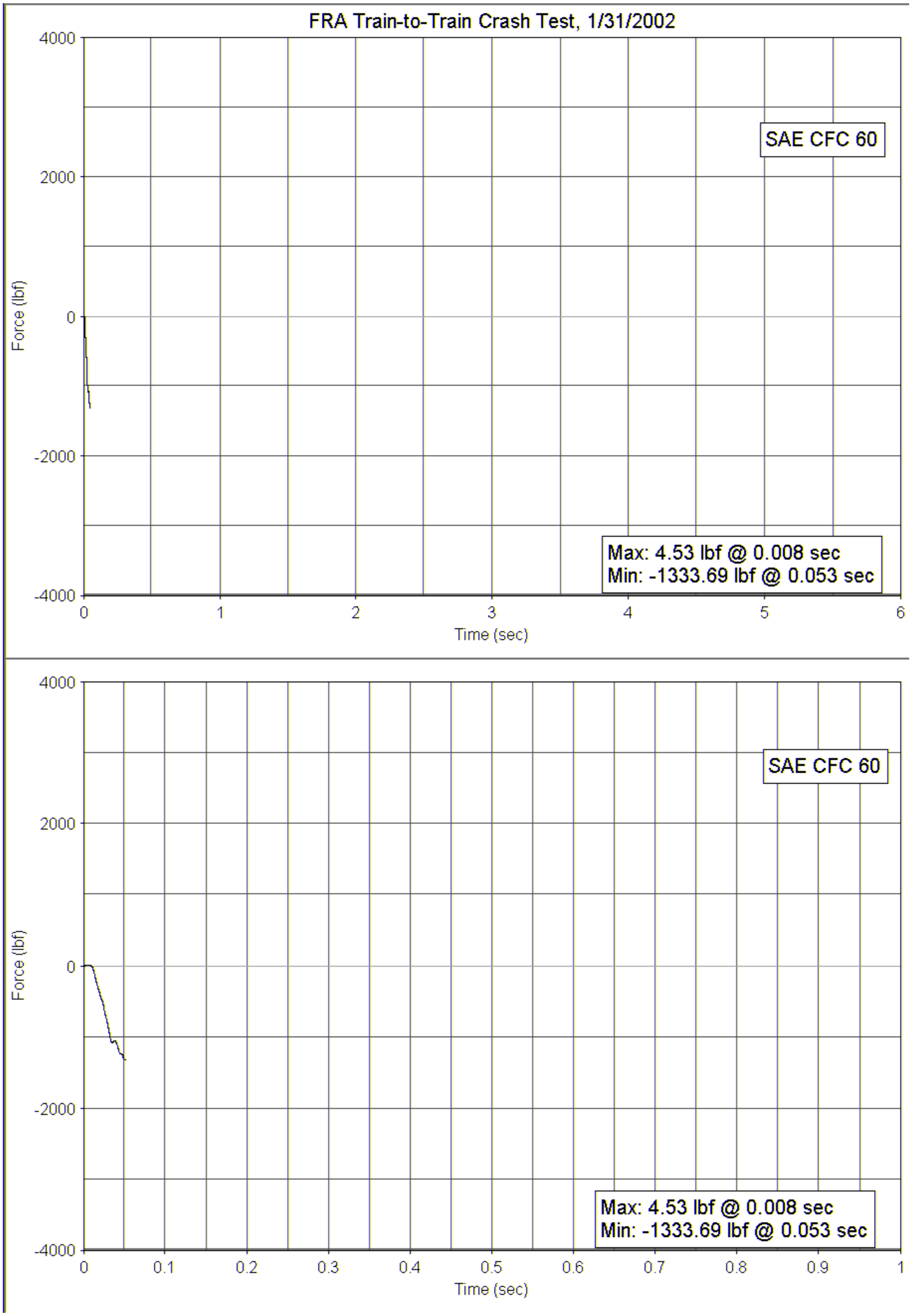


Figure C-6: Experiment No. 1-1 M-Style Seat, Forward Row, Right Front Leg, Z-Axis Force

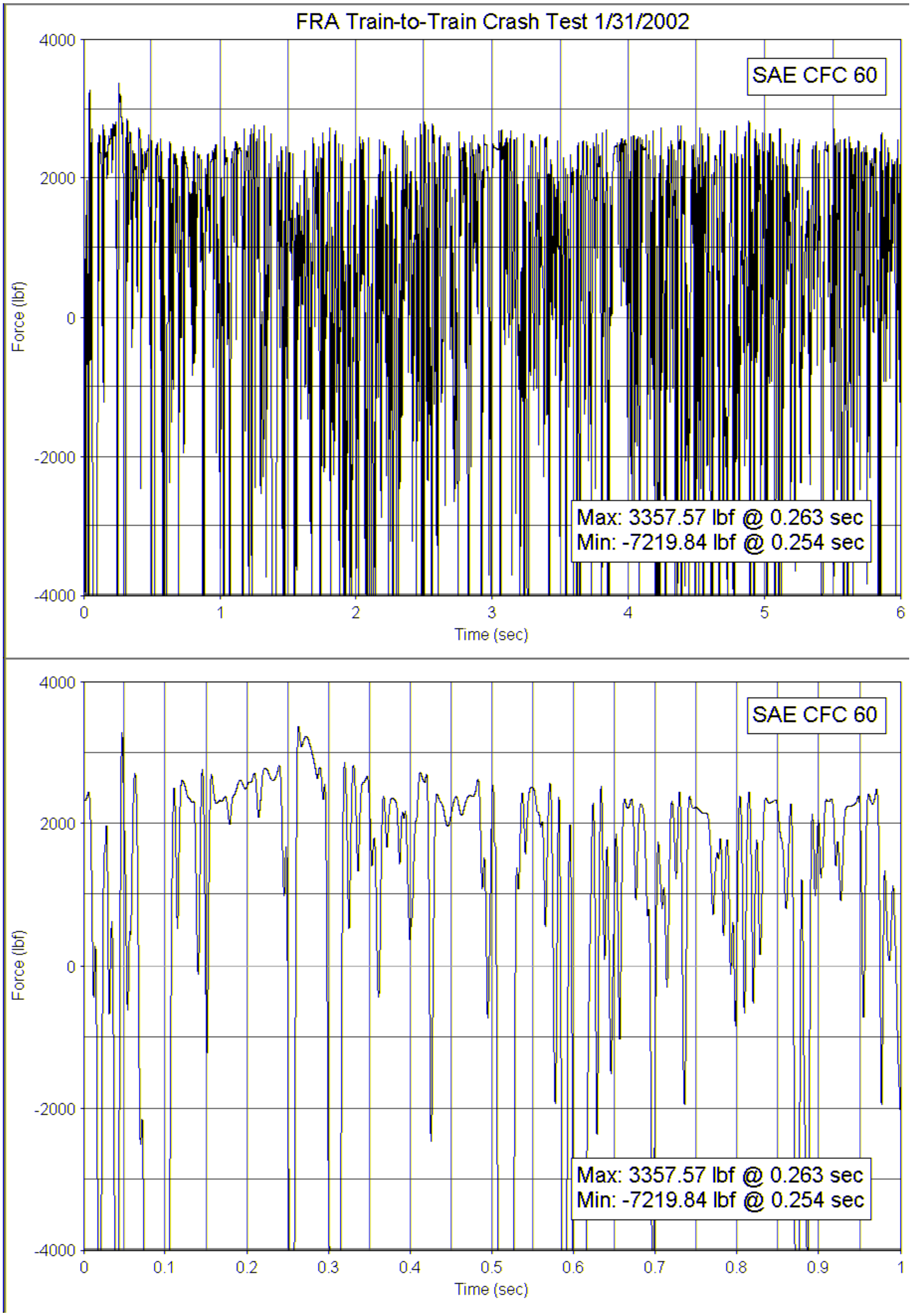


Figure C-7: Experiment No. 1-1 M-Style Seat, Forward Row, Left Rear Leg, X-Axis Force

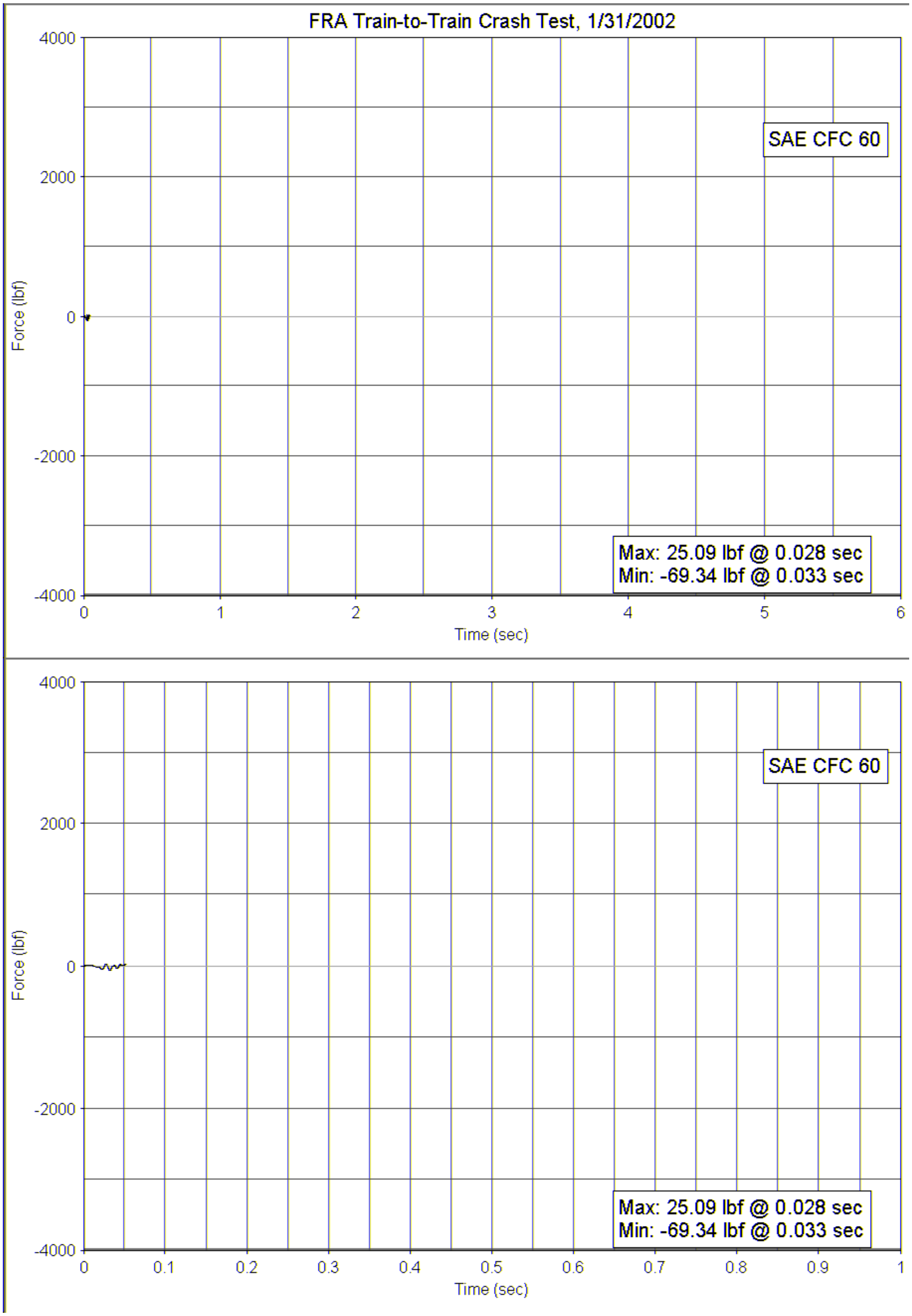


Figure C-8: Experiment No. 1-1 M-Style Seat, Forward Row, Left Rear Leg, Y-Axis Force

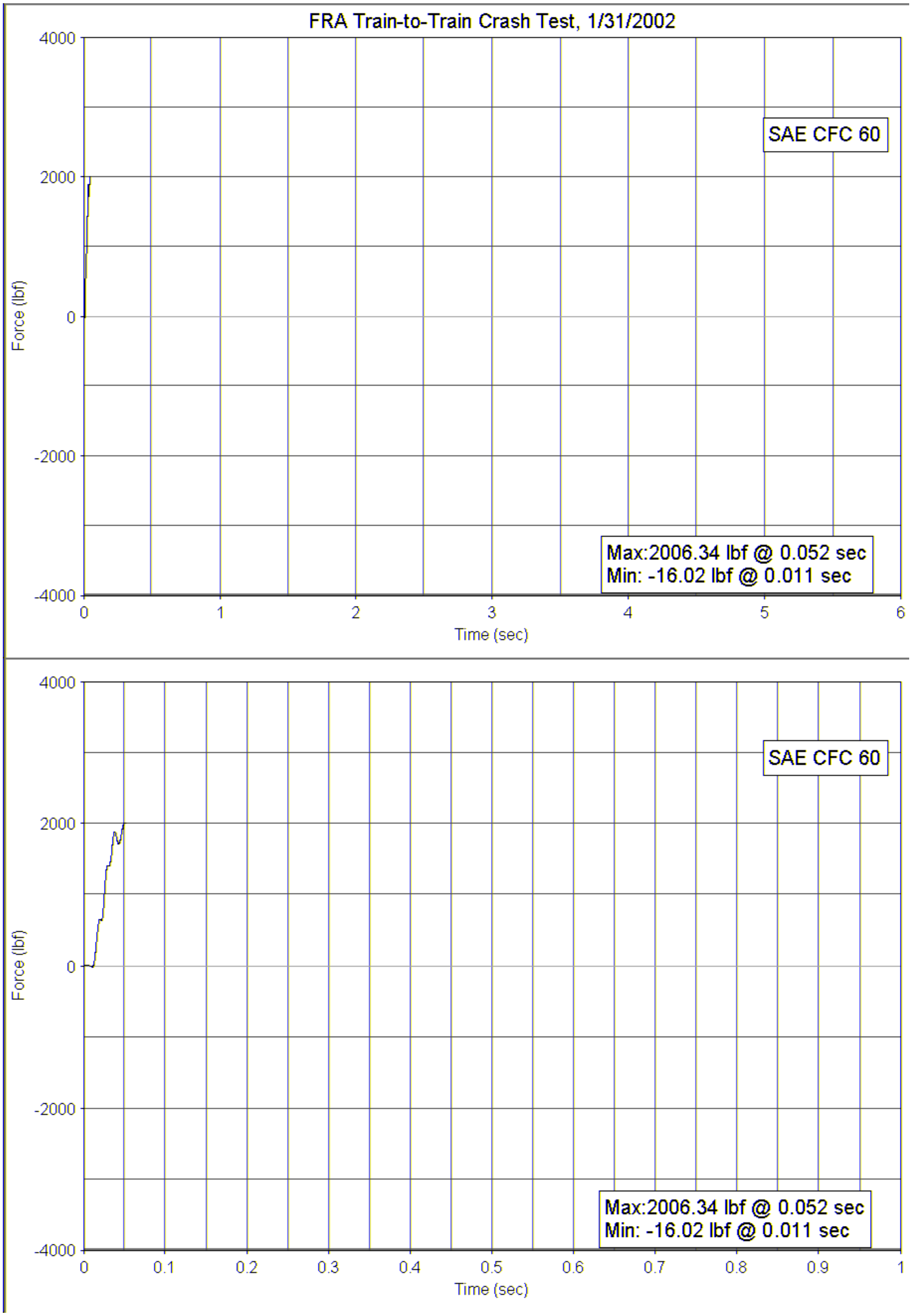


Figure C-9: Experiment No. 1-1 M-Style Seat, Forward Row, Left Rear Leg, Z-Axis Force

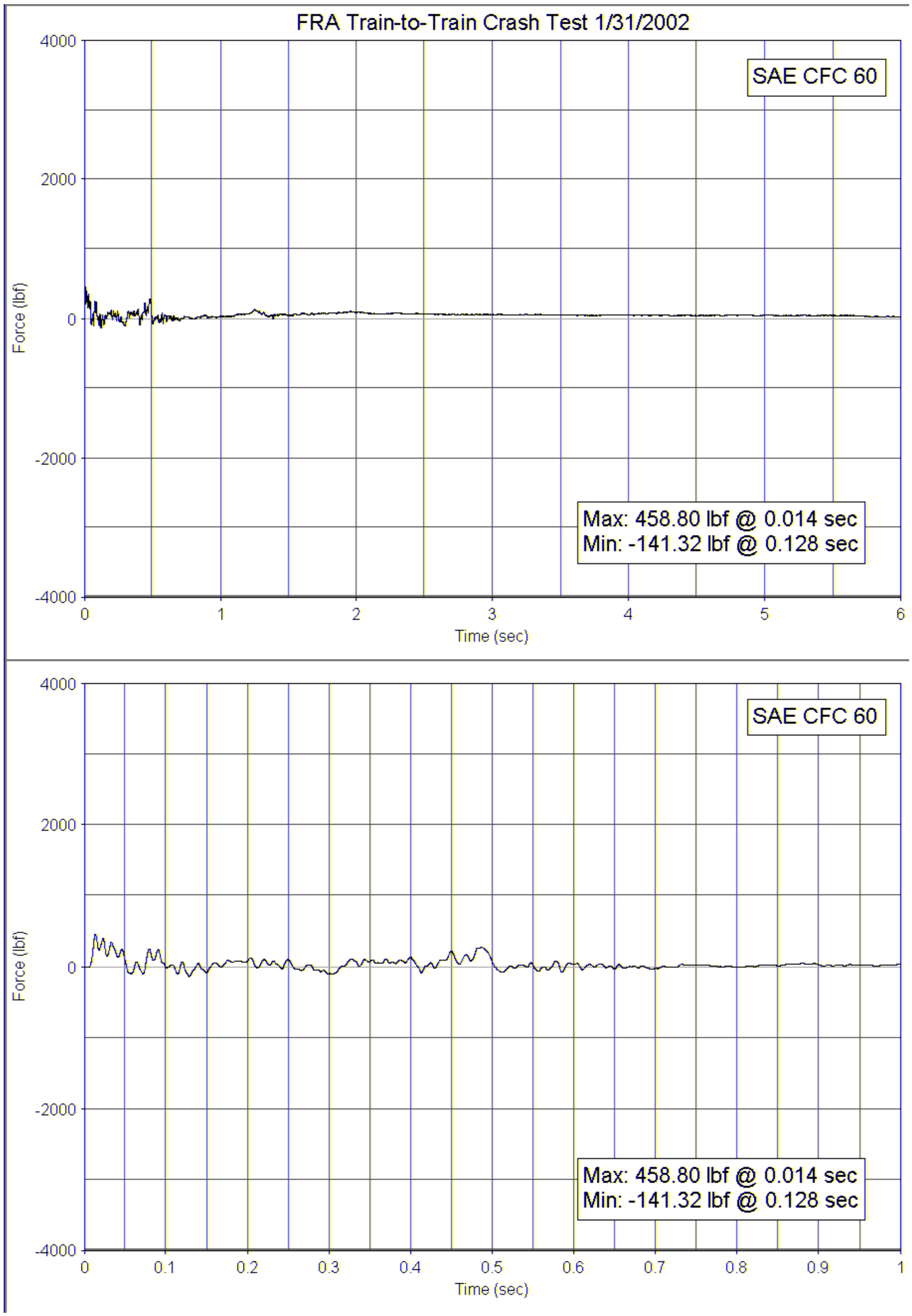


Figure C-10: Experiment No. 1-1 M-Style Seat, Forward Row, Right Rear Leg, X-Axis Force

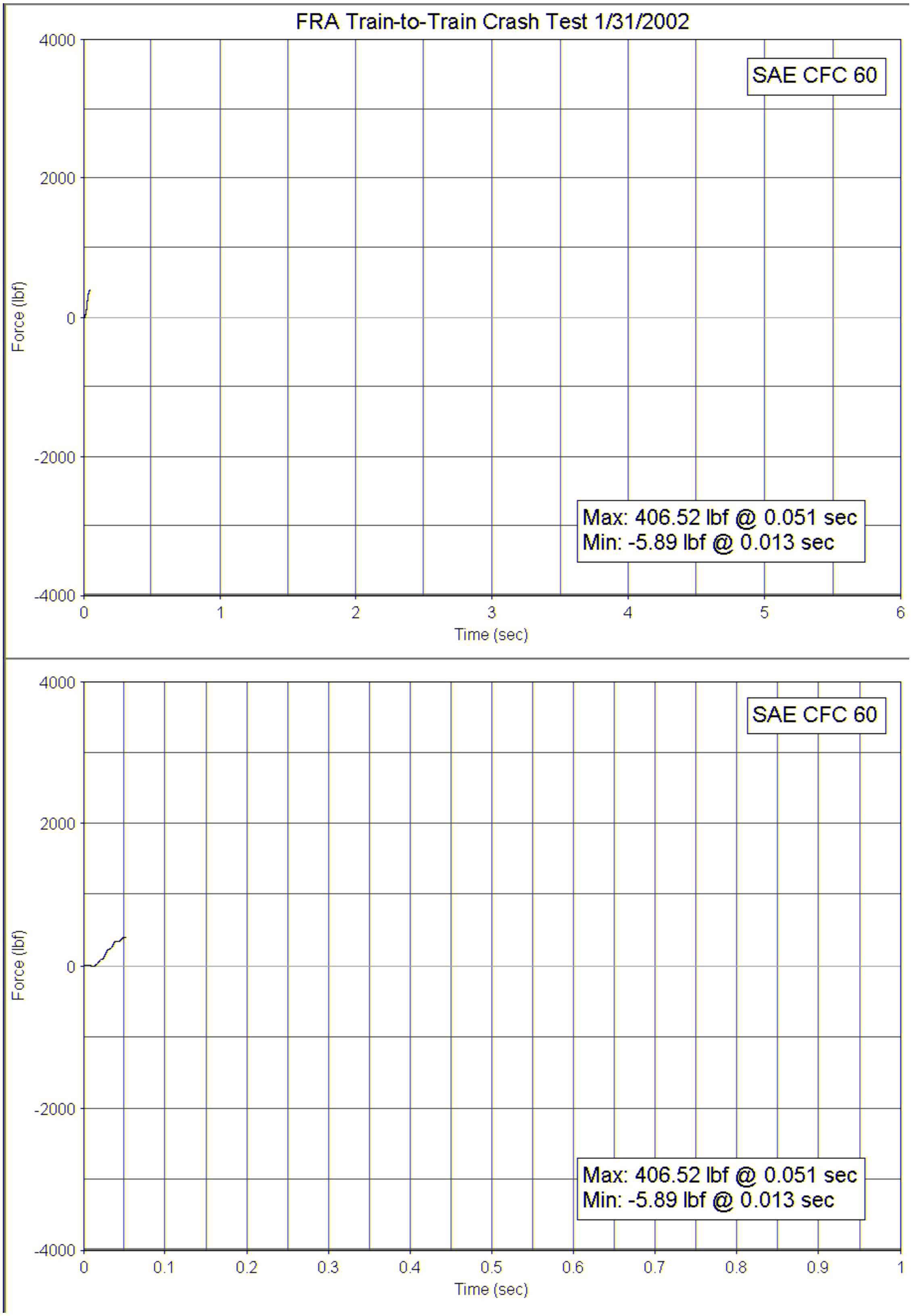


Figure C-11: Experiment No. 1-1 M-Style Seat, Forward Row, Right Rear Leg, Y-Axis Force

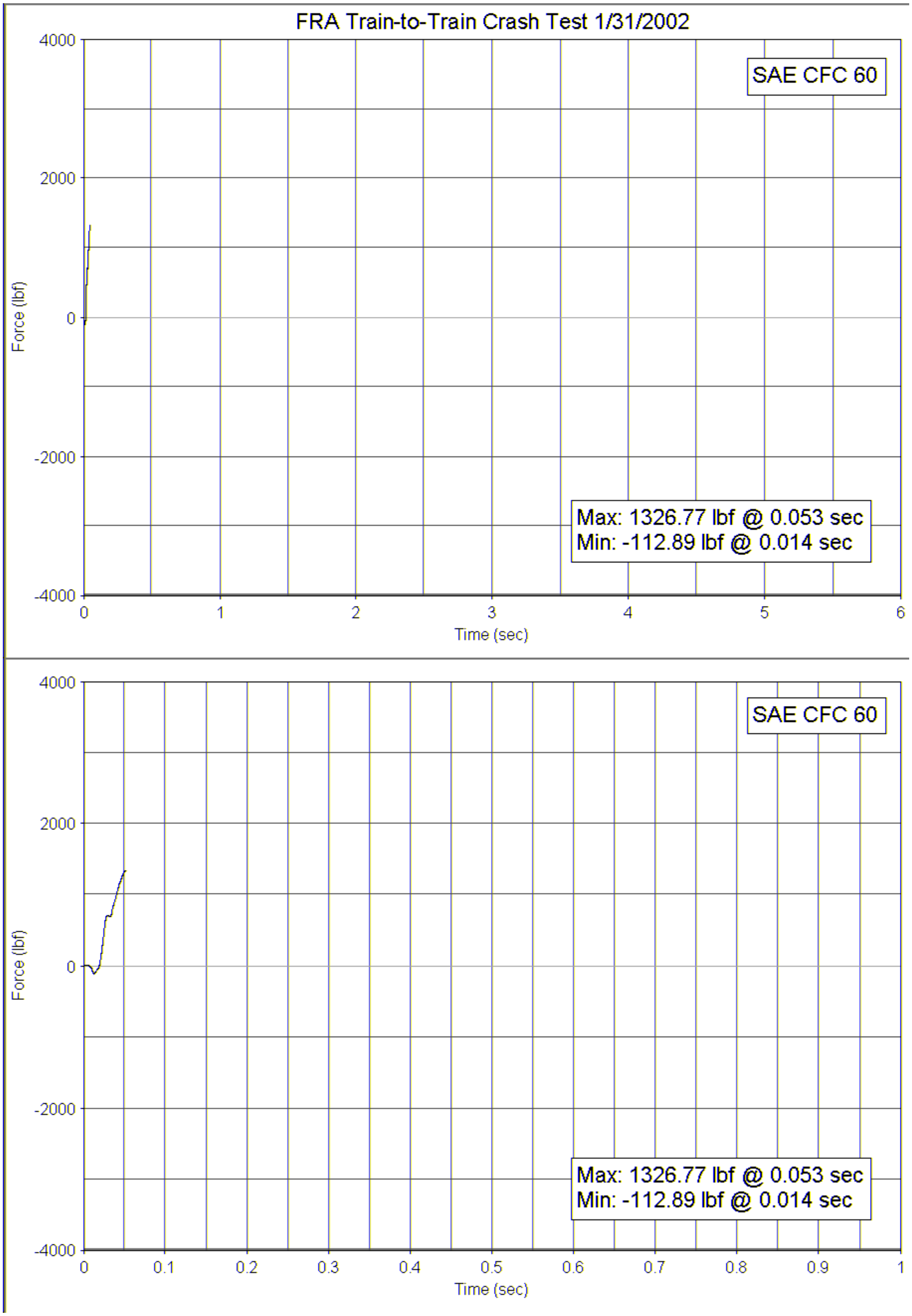
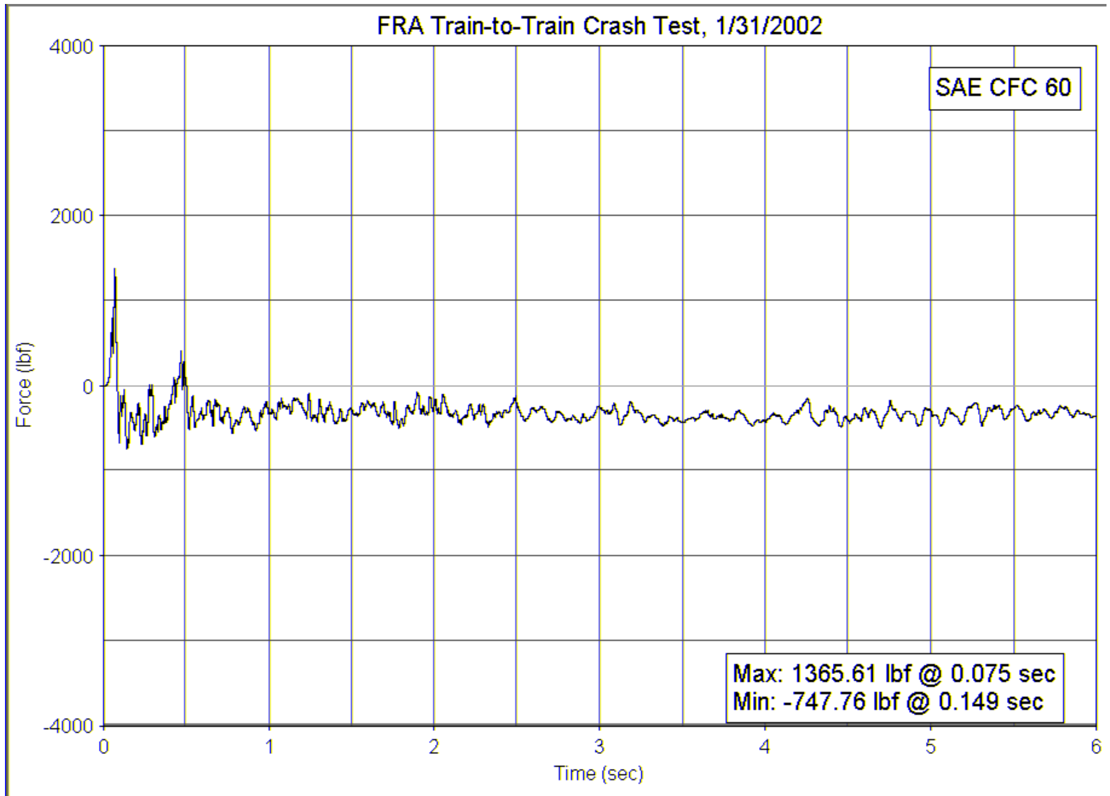


Figure C-12: Experiment No. 1-1 M-Style Seat, Forward Row, Right Rear Leg, Z-Axis Force



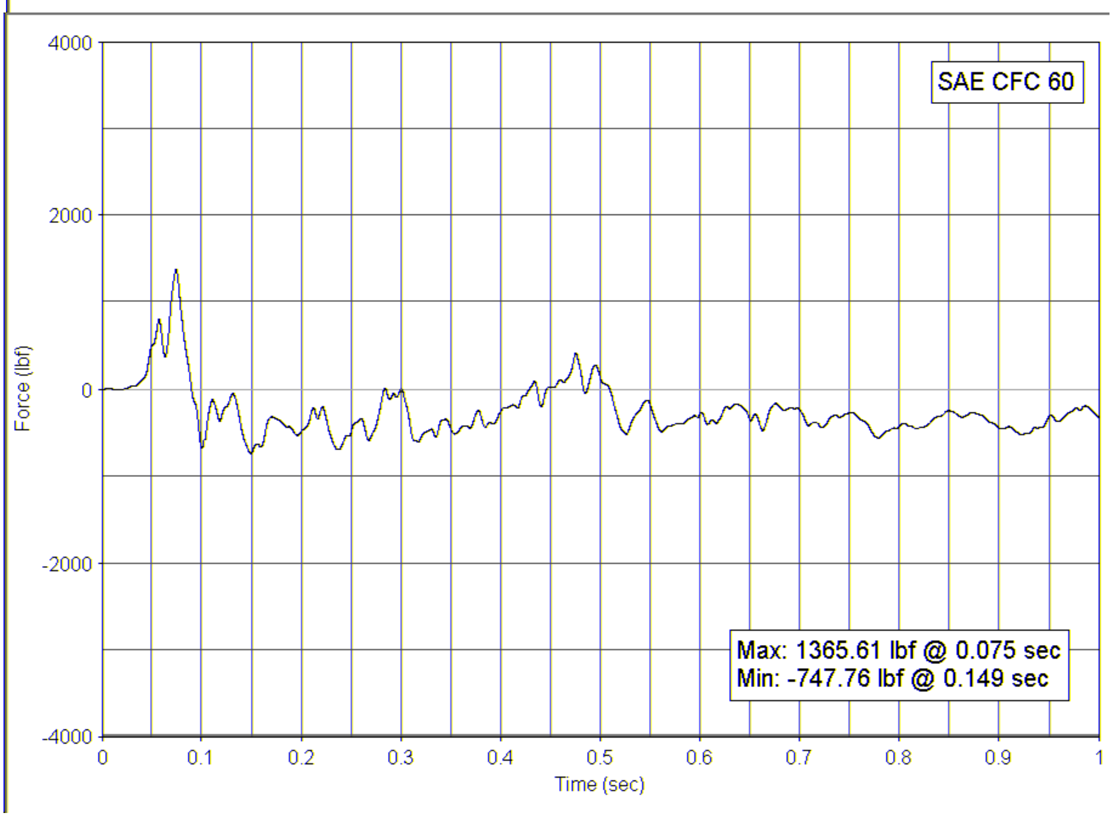


Figure C-13: Experiment No. 2-1 Intercity Seat, Forward Row, Right Front Leg, X-Axis Force

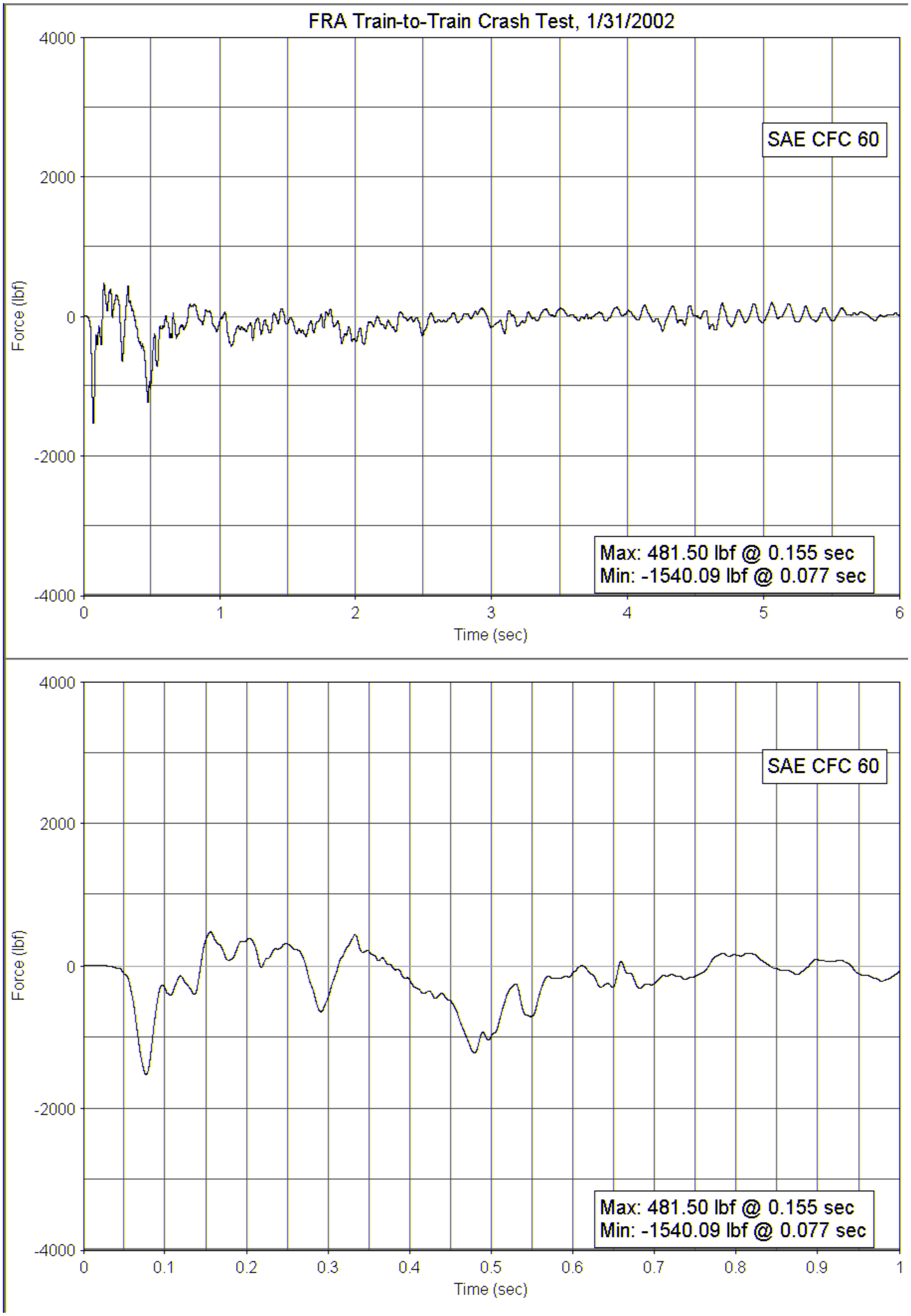
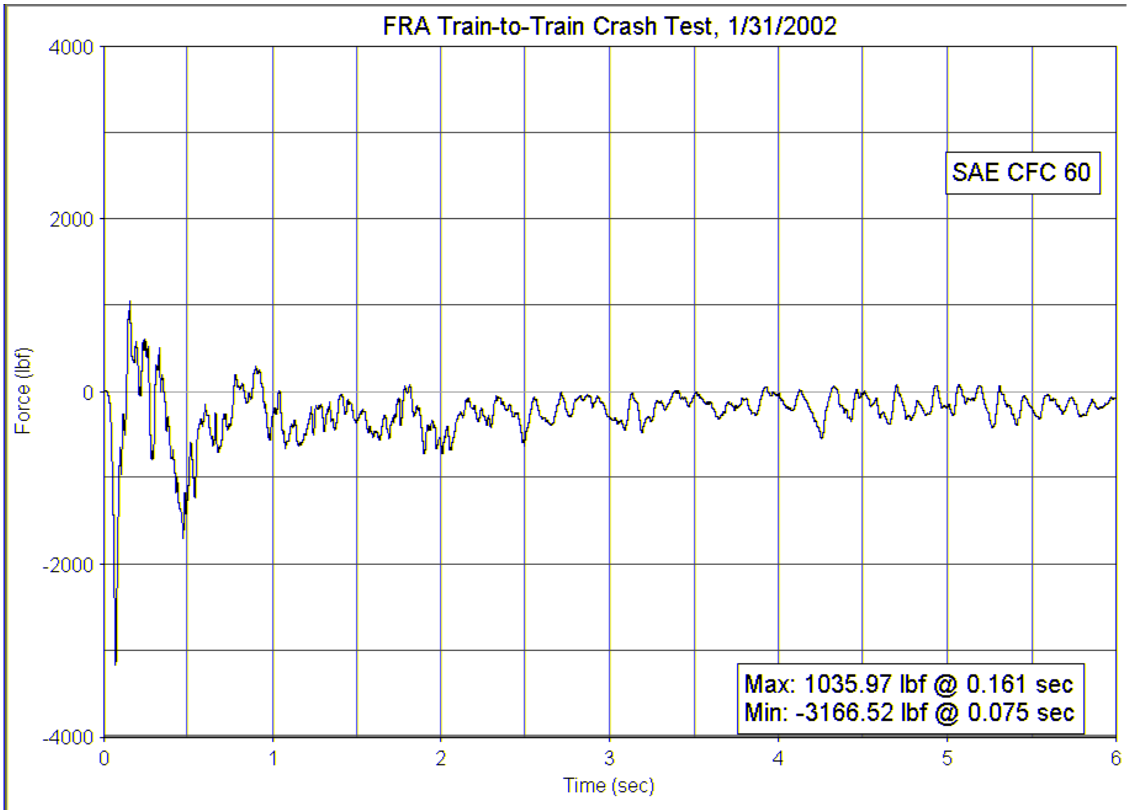


Figure C-14: Experiment No. 2-1 Intercity Seat, Forward Row, Right Front Leg, Y-Axis Force



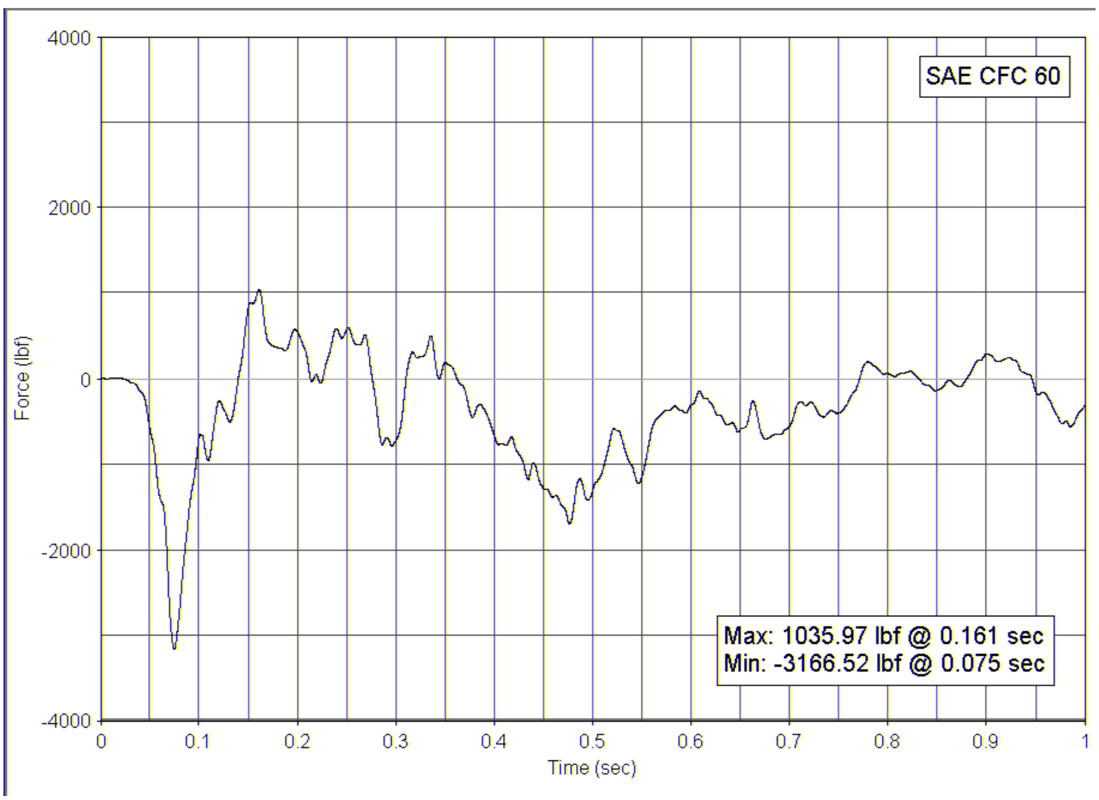


Figure C-15: Experiment No. 2-1 Intercity Seat, Forward Row, Right Front Leg, Z-Axis Force

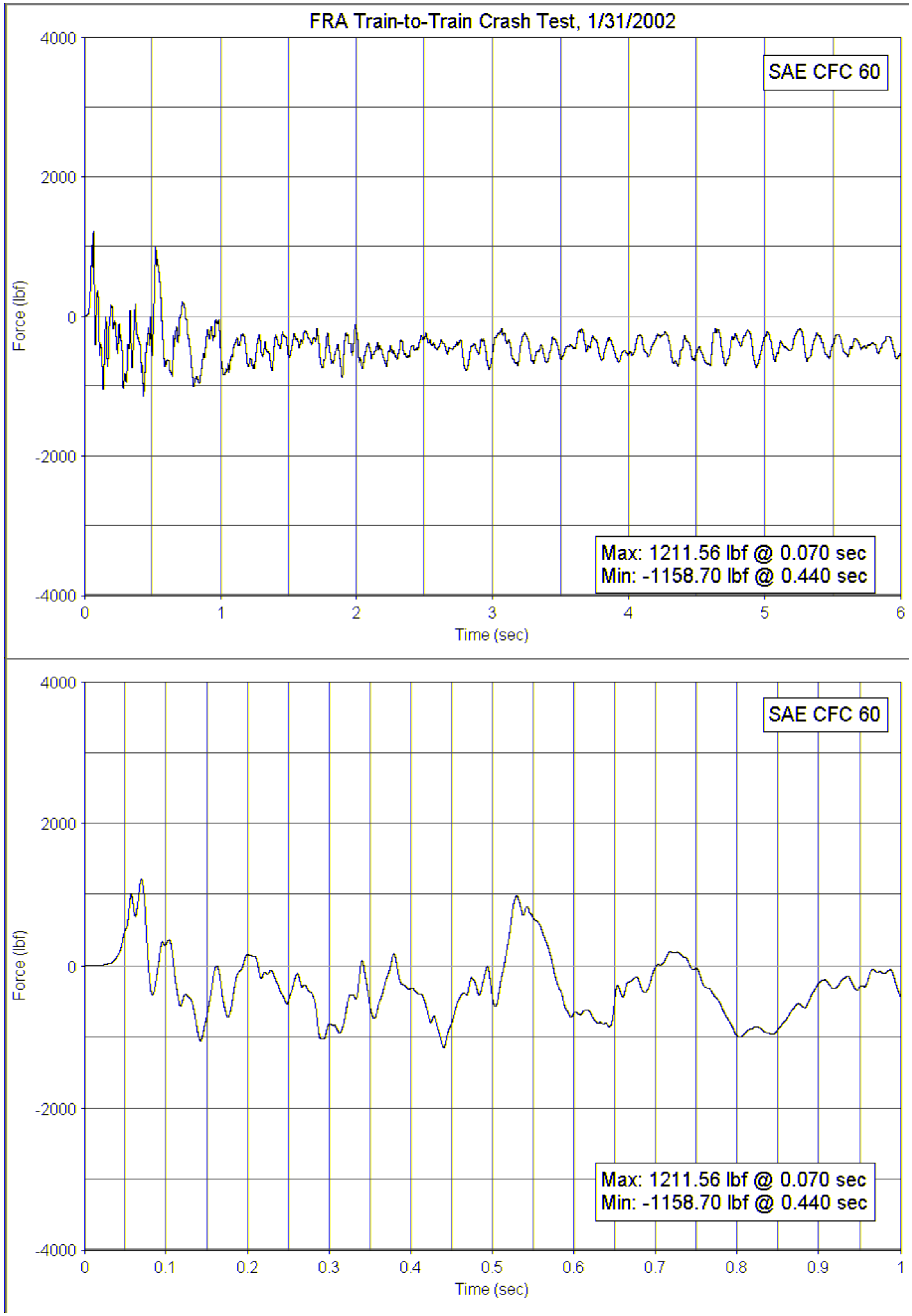


Figure C-16: Experiment No. 2-1 Intercity Seat, Forward Row, Left Front Leg, X-Axis Force

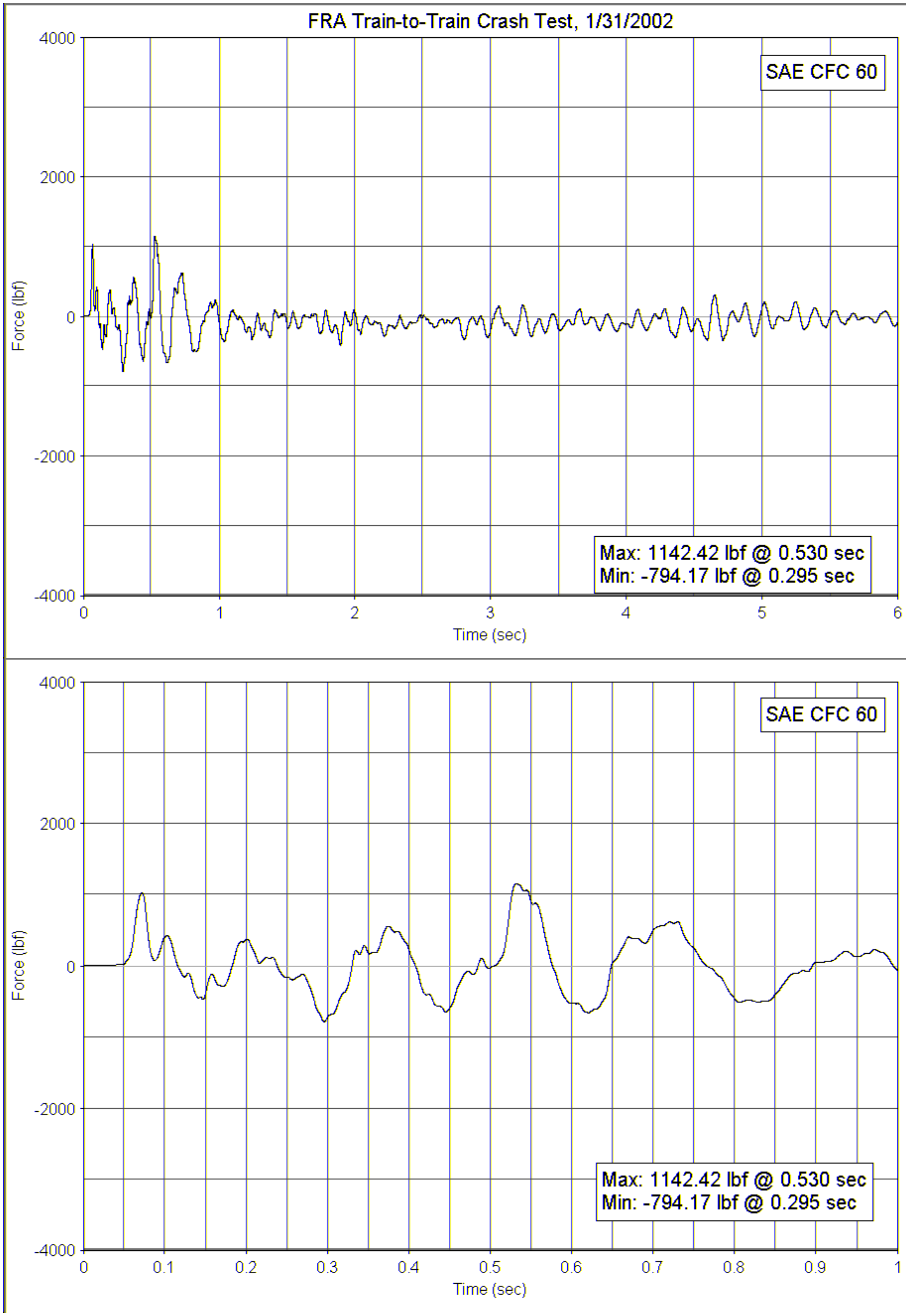


Figure C-17: Experiment No. 2-1 Intercity Seat, Forward Row, Left Front Leg, Y-Axis Force

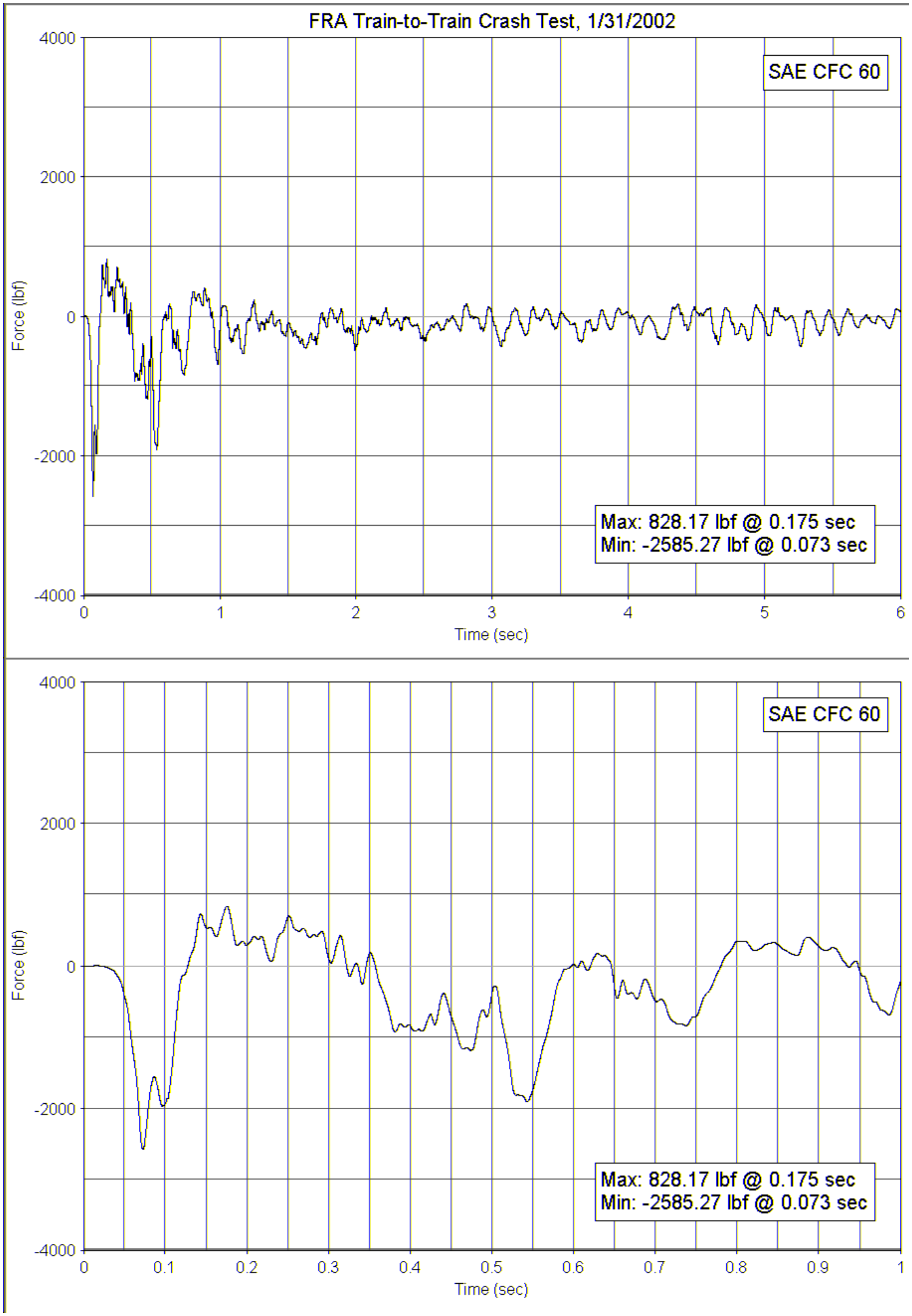


Figure C-18: Experiment No. 2-1 Intercity Seat, Forward Row, Left Front Leg, Z-Axis Force

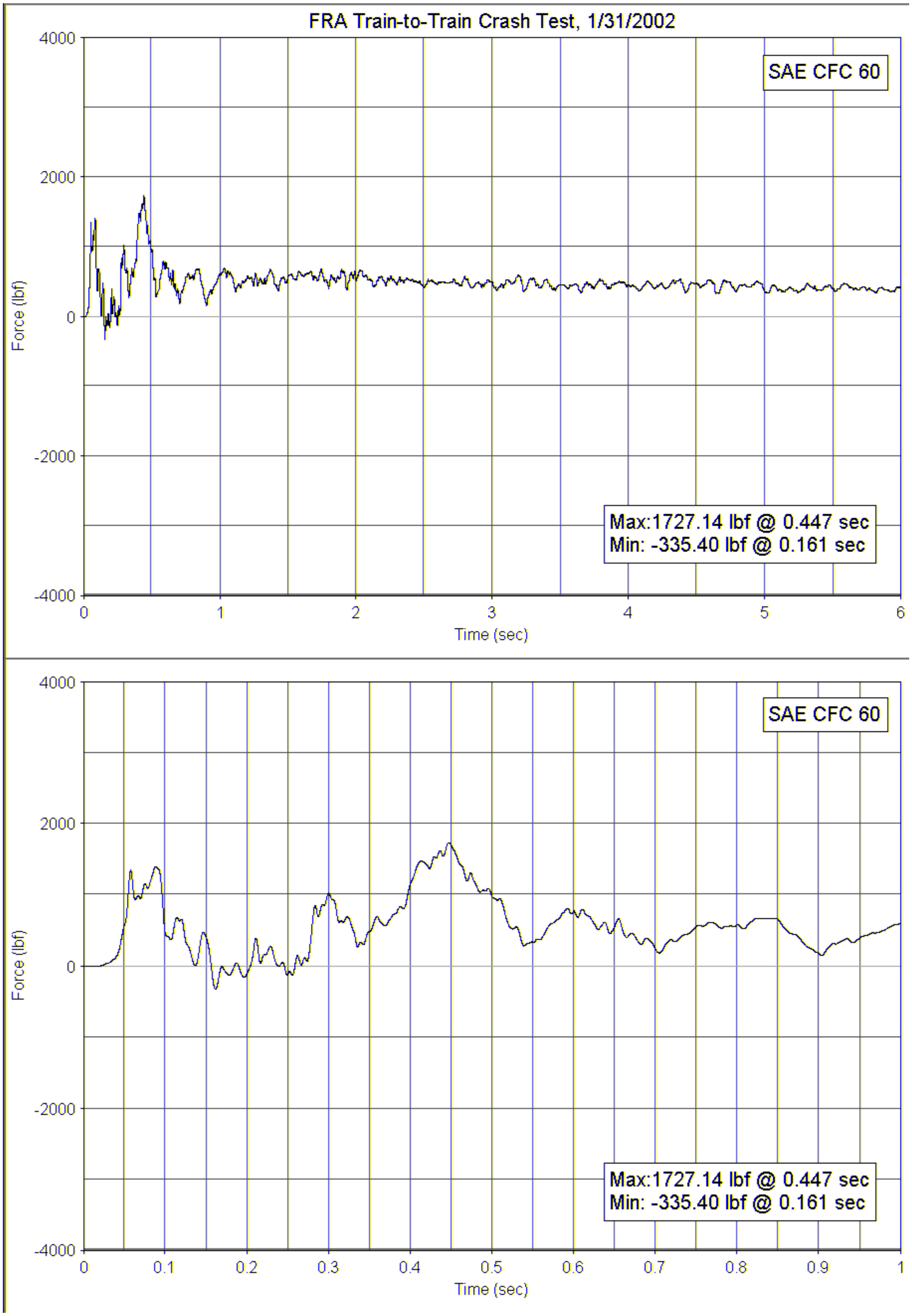


Figure C-19: Experiment No. 2-1 Intercity Seat, Forward Row, Right Rear Leg, X-Axis Force

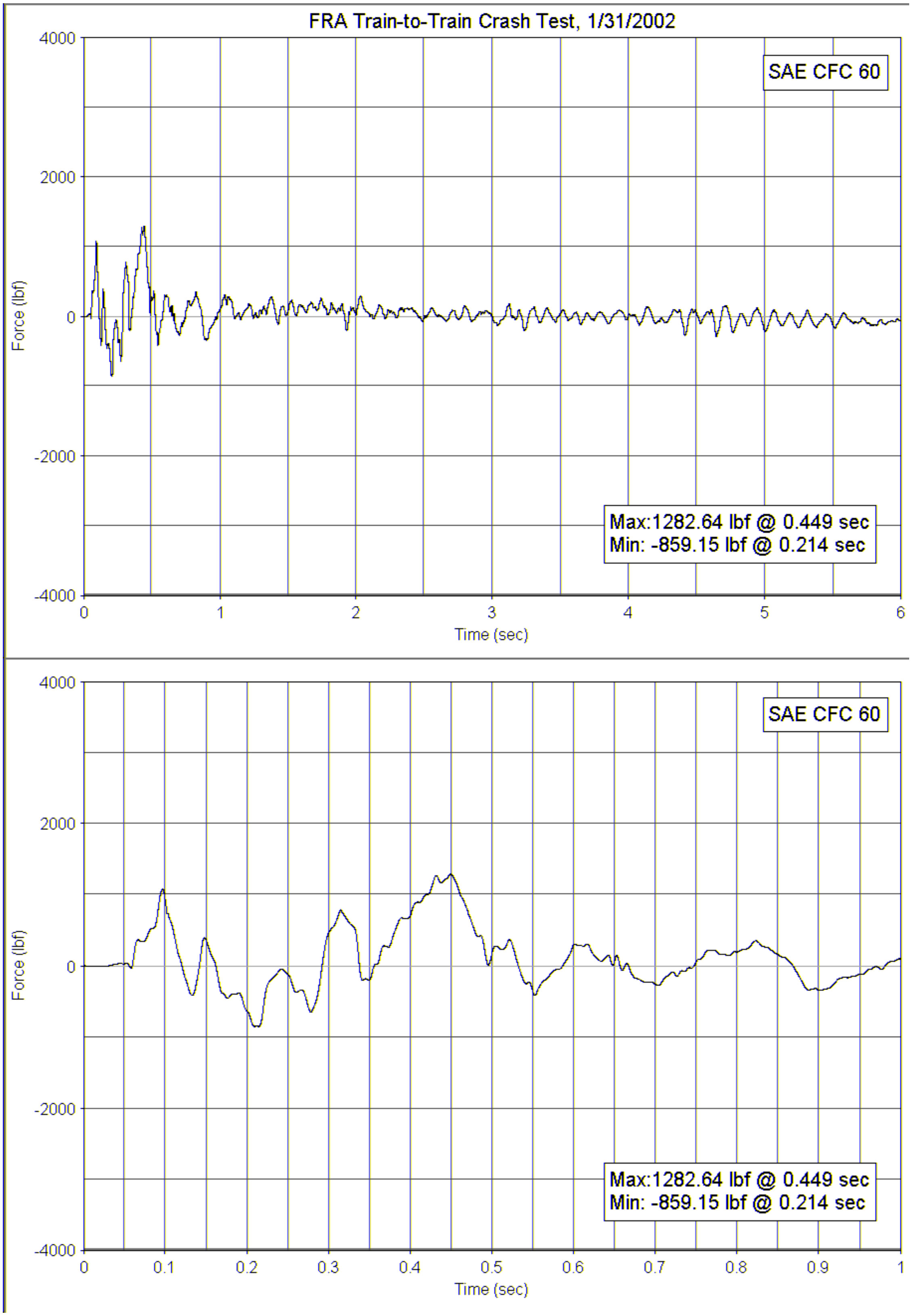


Figure C-20: Experiment No. 2-1 Intercity Seat, Forward Row, Right Rear Leg, Y-Axis Force

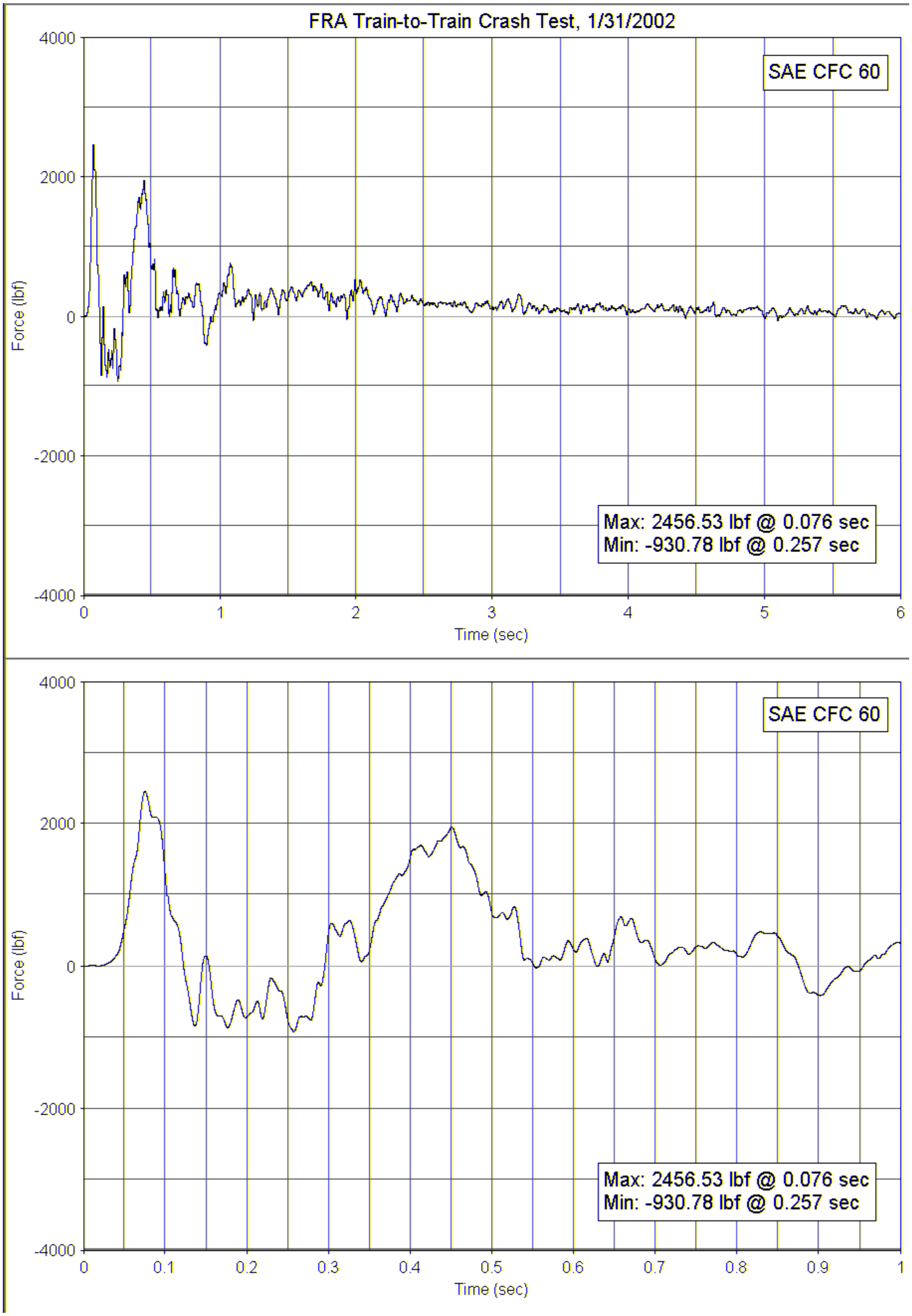


Figure C-21: Experiment No. 2-1 Intercity Seat, Forward Row, Right Rear Leg, Z-Axis Force

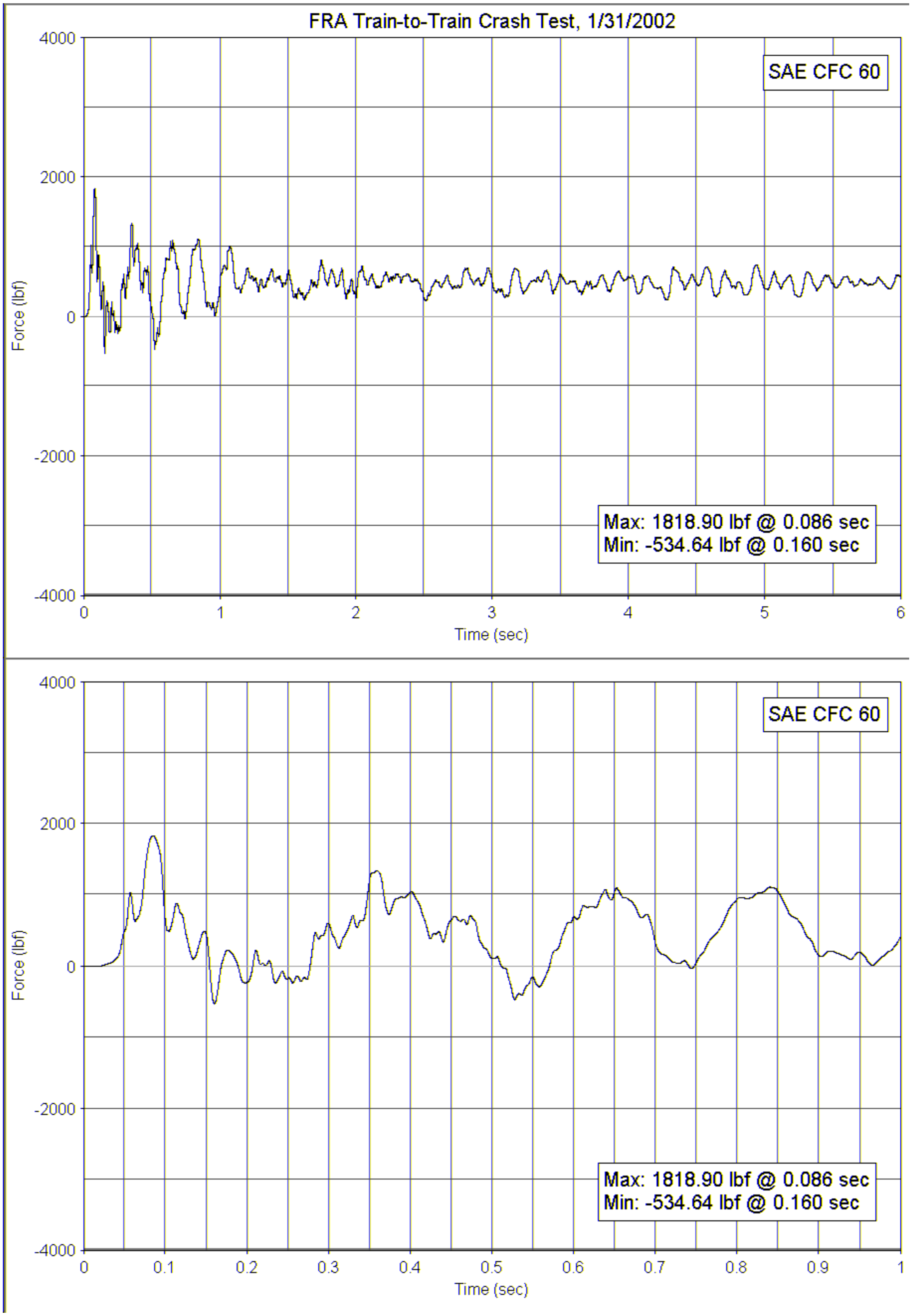
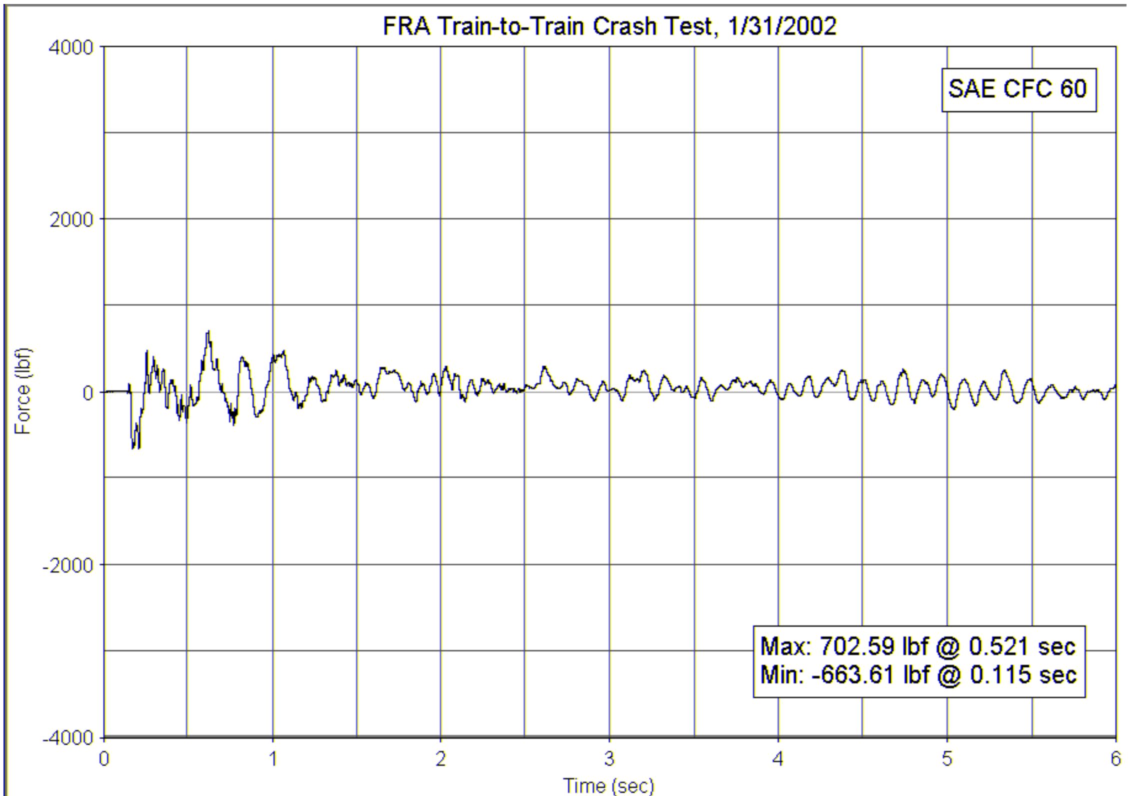


Figure C-22: Experiment No. 2-1 Intercity Seat, Forward Row, Left Rear Leg, X-Axis Force



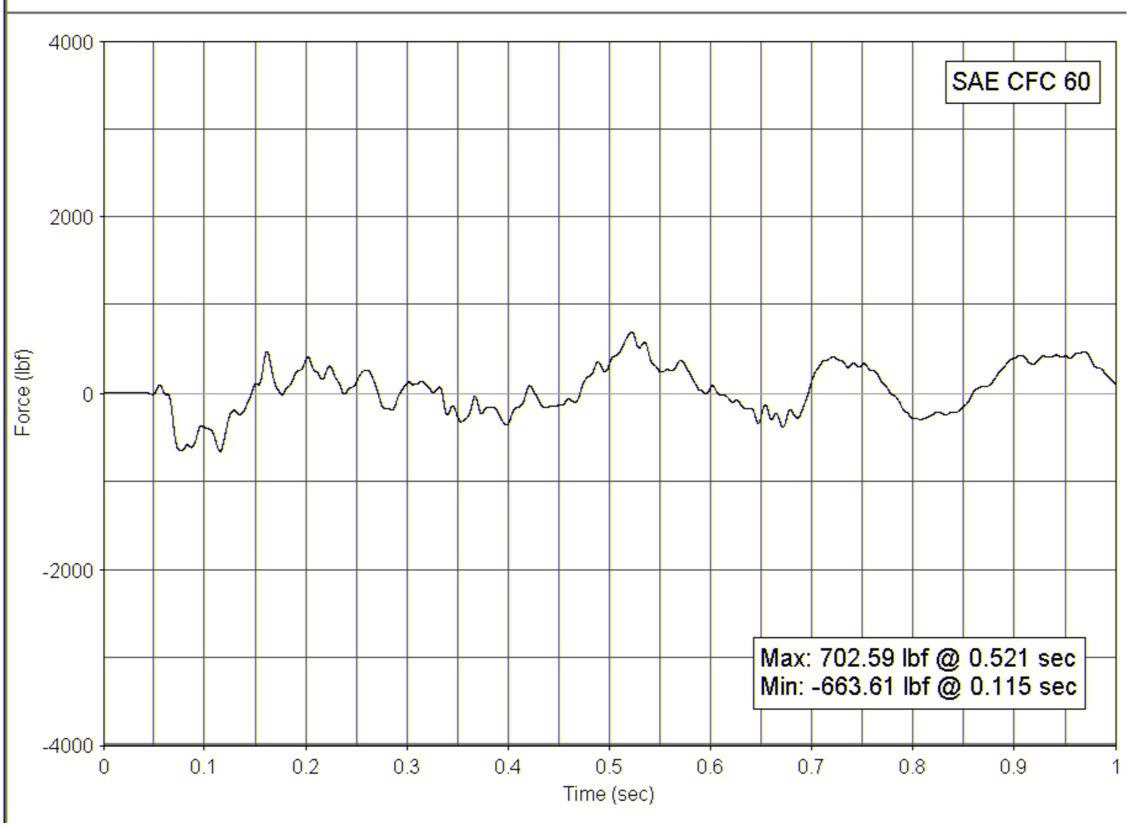


Figure C-23: Experiment No. 2-1 Intercity Seat, Forward Row, Left Rear Leg, Y-Axis Force

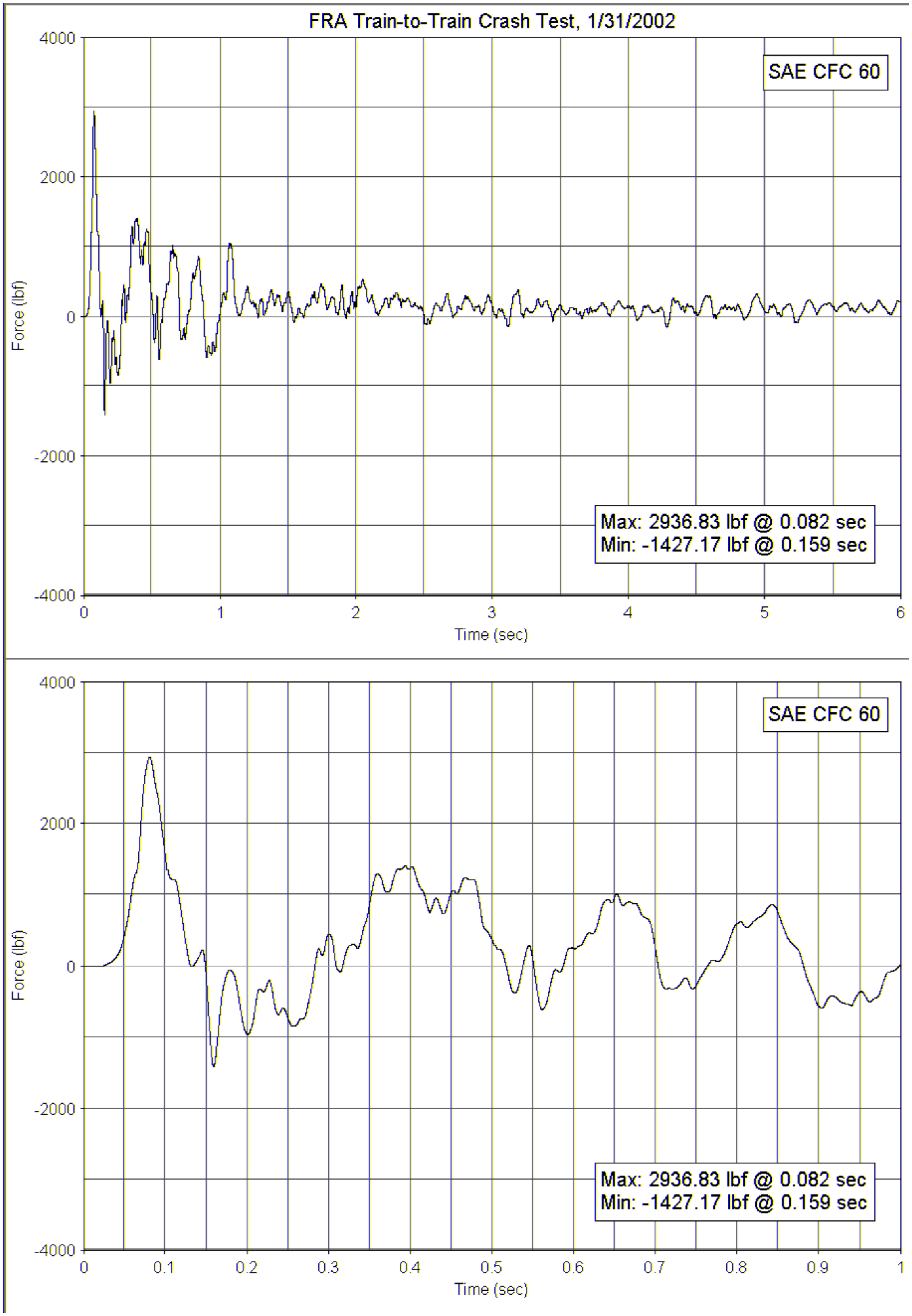


Figure C-24: Experiment No. 2-1 Intercity Seat, Forward Row, Left Rear Leg, Z-Axis Force

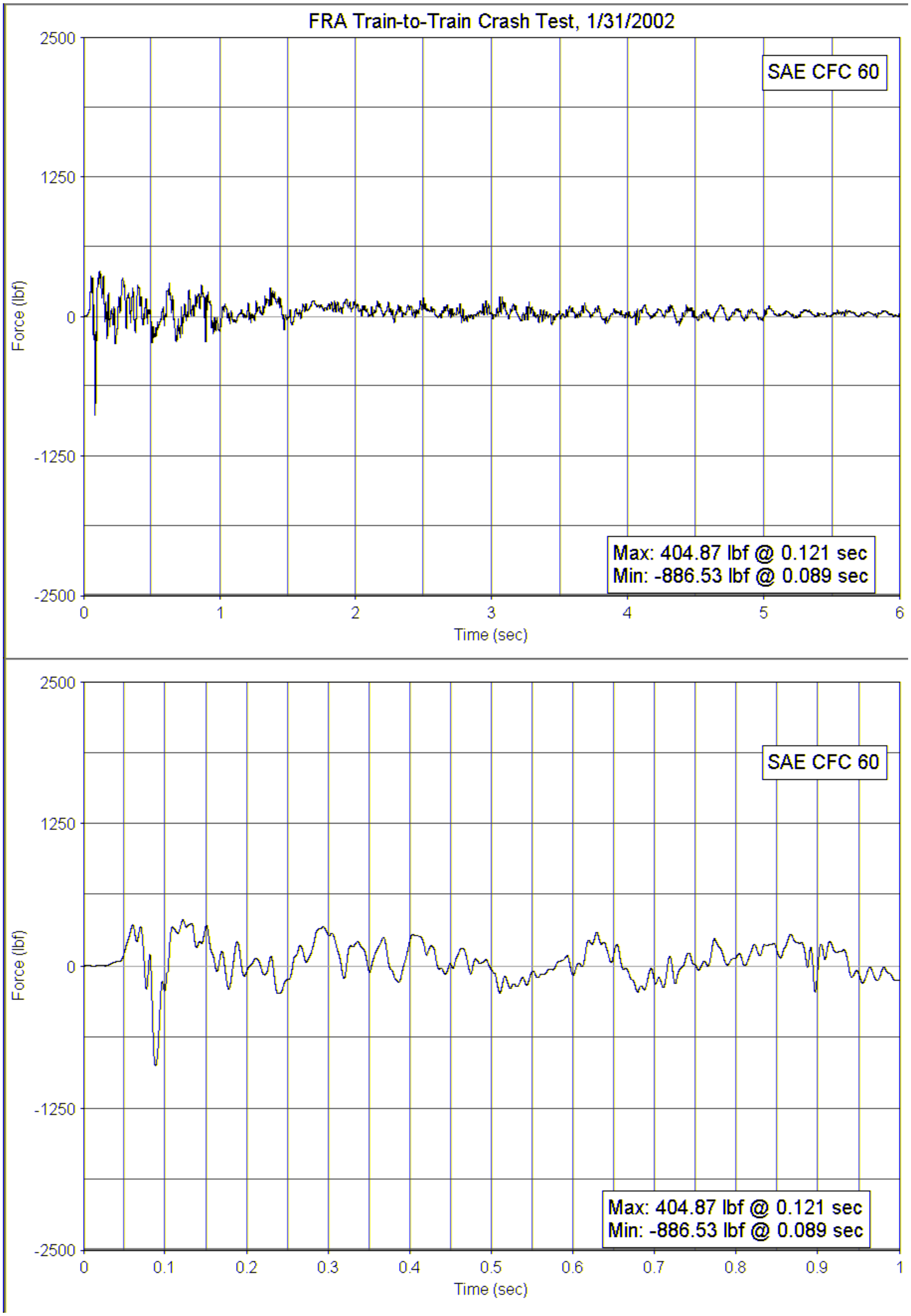


Figure C-25: Experiment No. 2-2 M-Style Seat, Forward Row, Left Front Leg, X-Axis Force

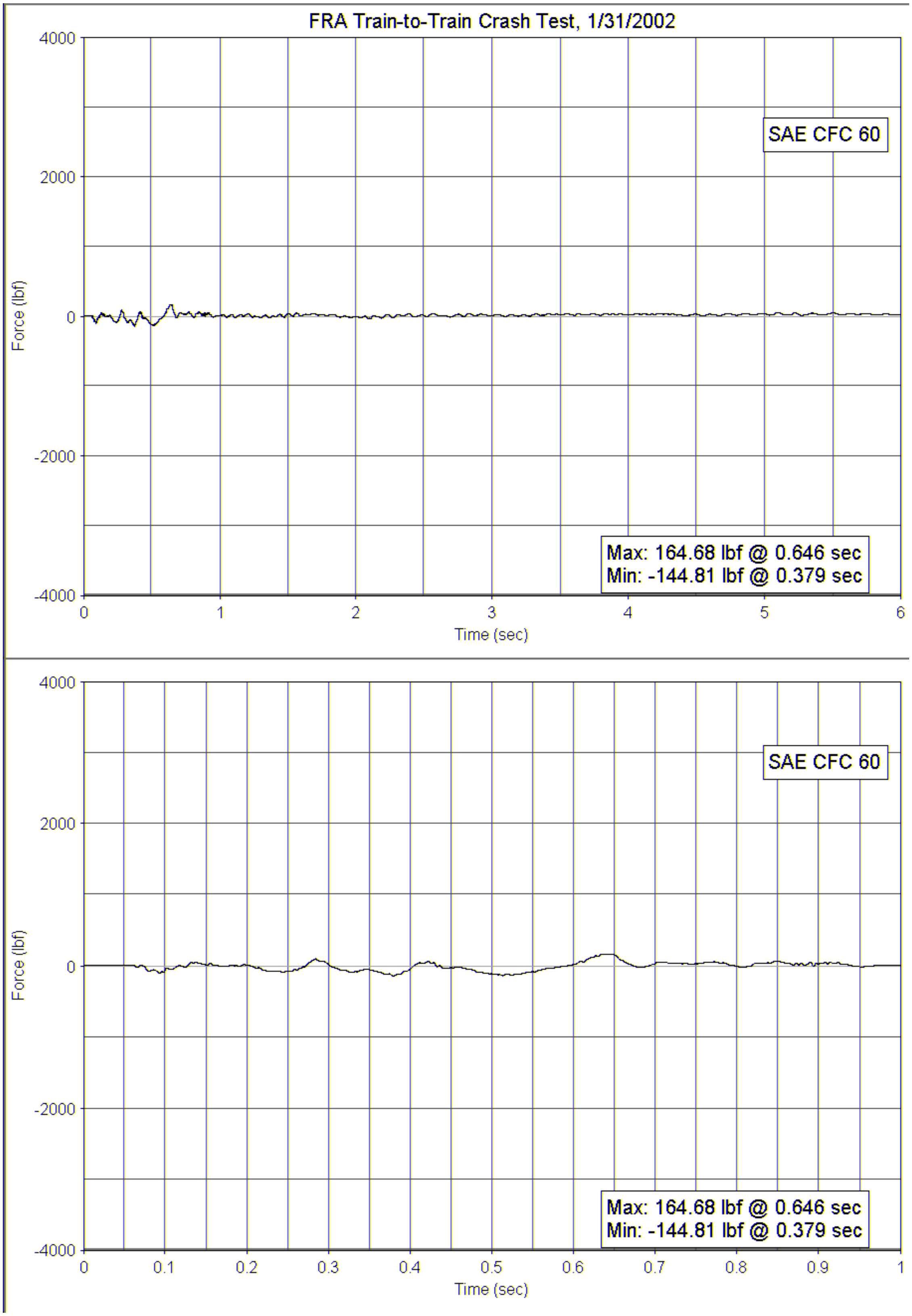
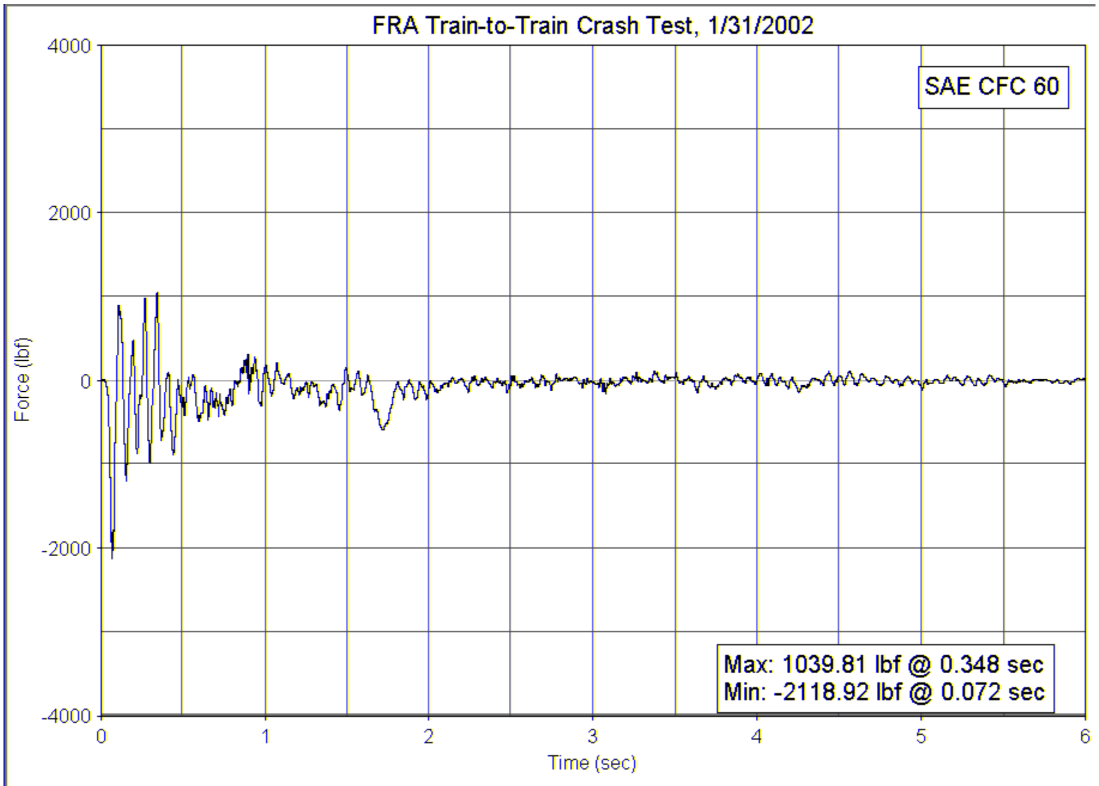


Figure C-26: Experiment No. 2-2 M-Style Seat, Forward Row, Left Front Leg, Y-Axis Force



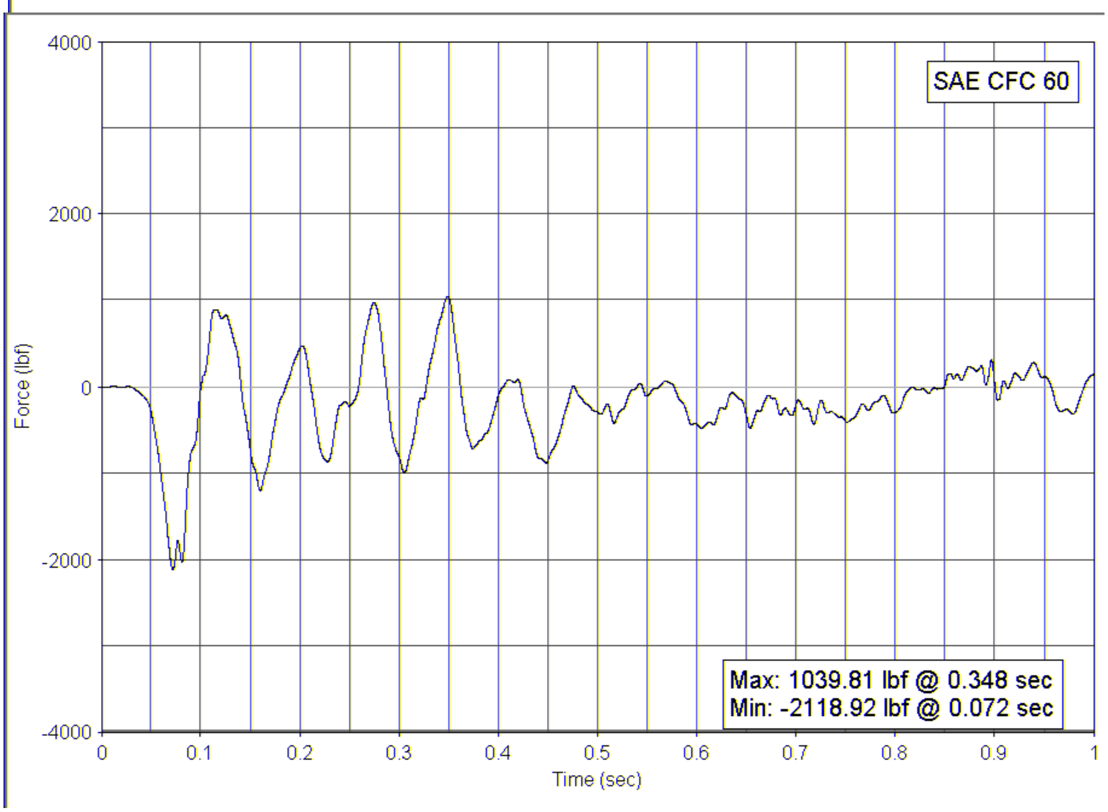


Figure C-27: Experiment No. 2-2 M-Style Seat, Forward Row, Left Front Leg, Z-Axis Force

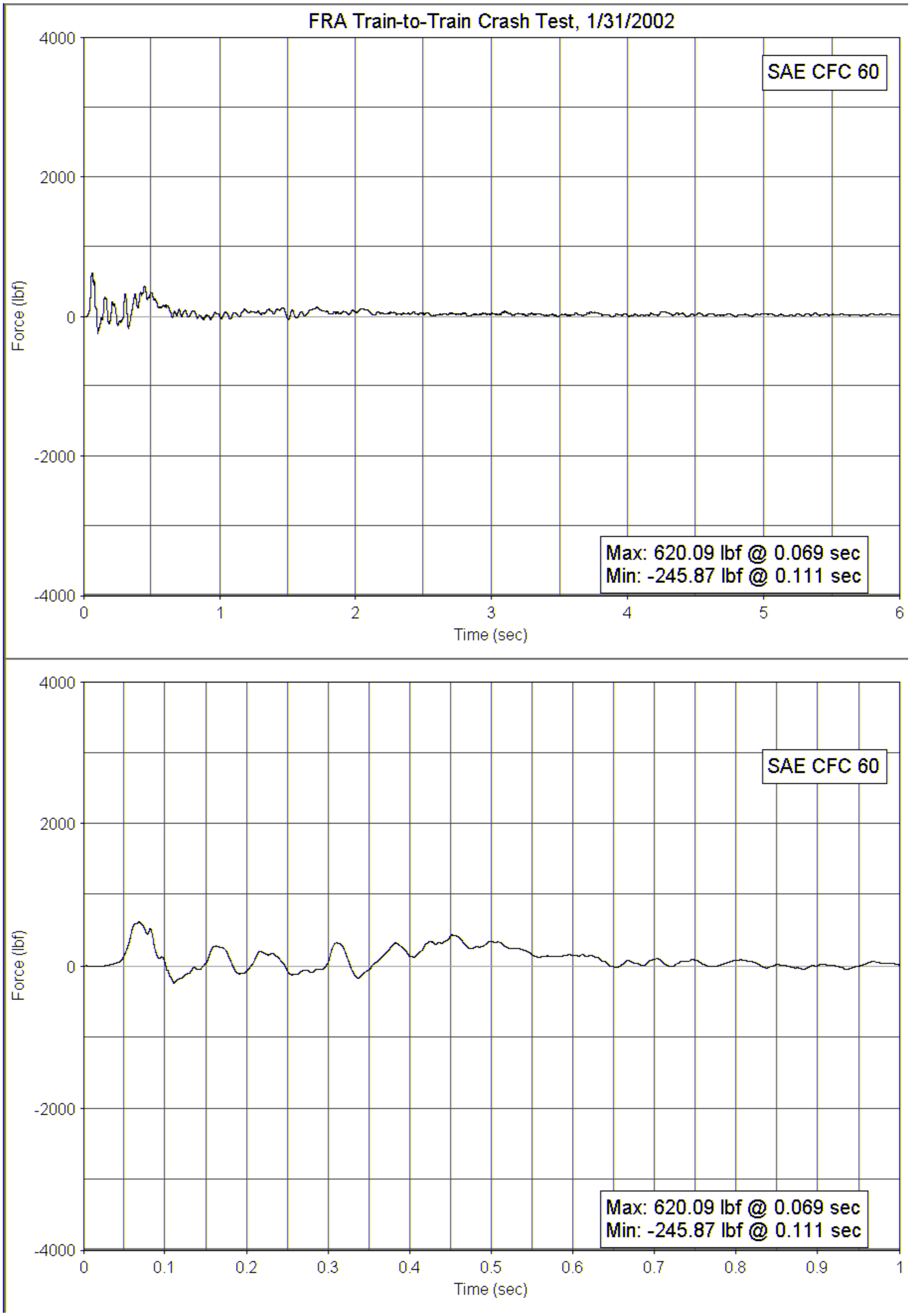


Figure C-28: Experiment No. 2-2 M-Style Seat, Forward Row, Right Front Leg, X-Axis Force

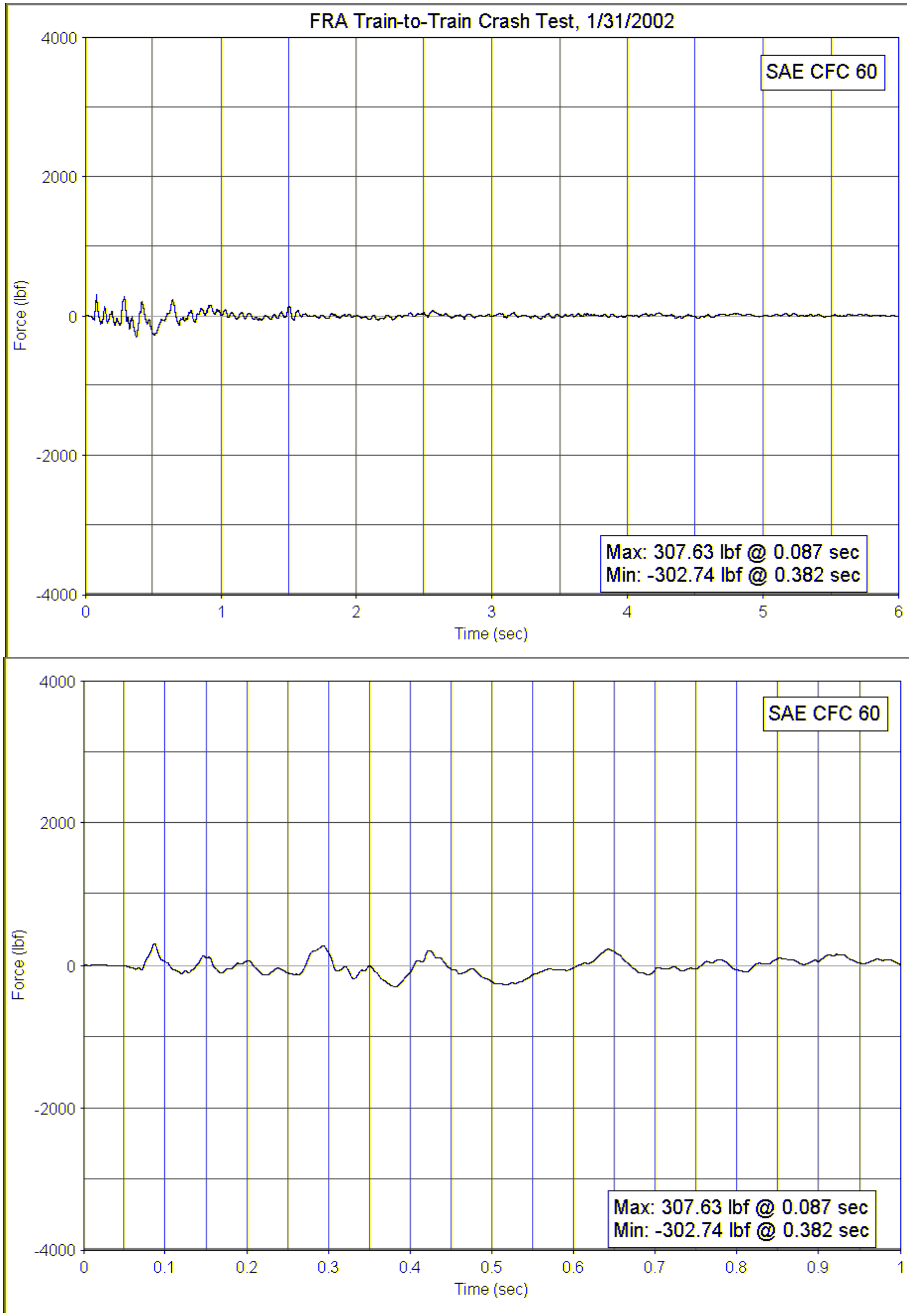


Figure C-29: Experiment No. 2-2 M-Style Seat, Forward Row, Right Front Leg, Y-Axis Force

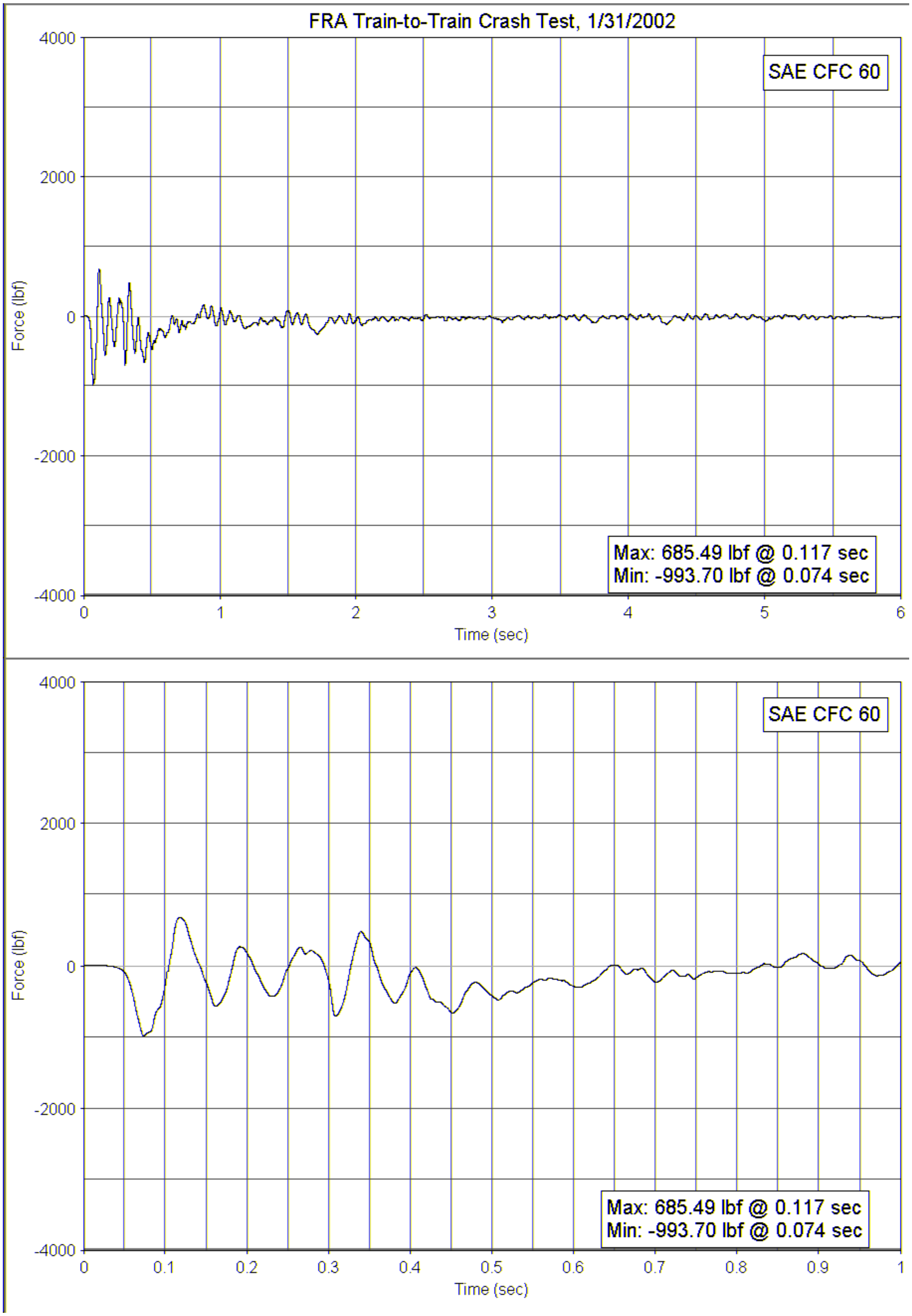


Figure C-30: Experiment No. 2-2 M-Style Seat, Forward Row, Right Front Leg, Z-Axis Force

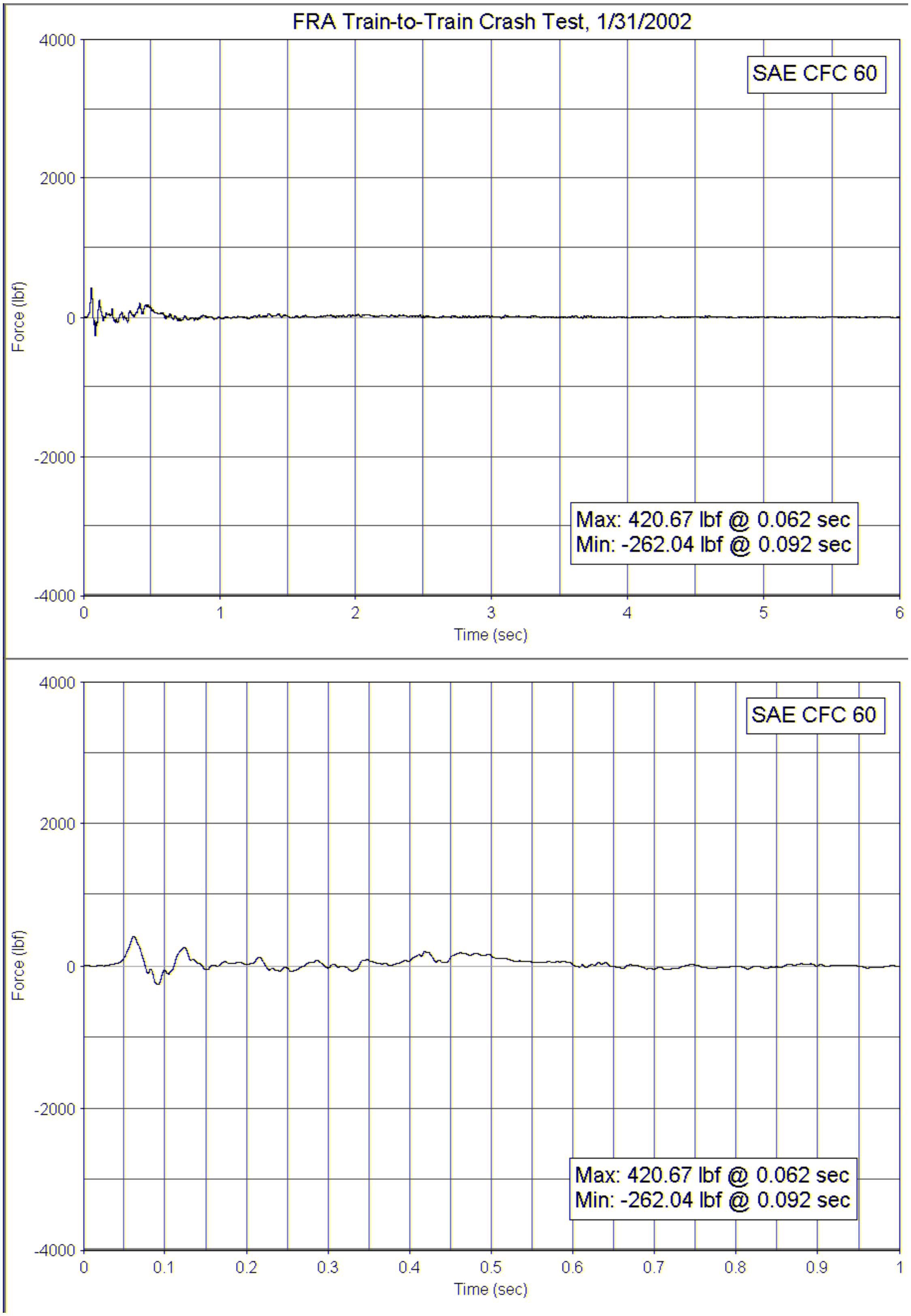


Figure C-31: Experiment No. 2-2 M-Style Seat, Forward Row, Right Rear Leg, X-Axis Force

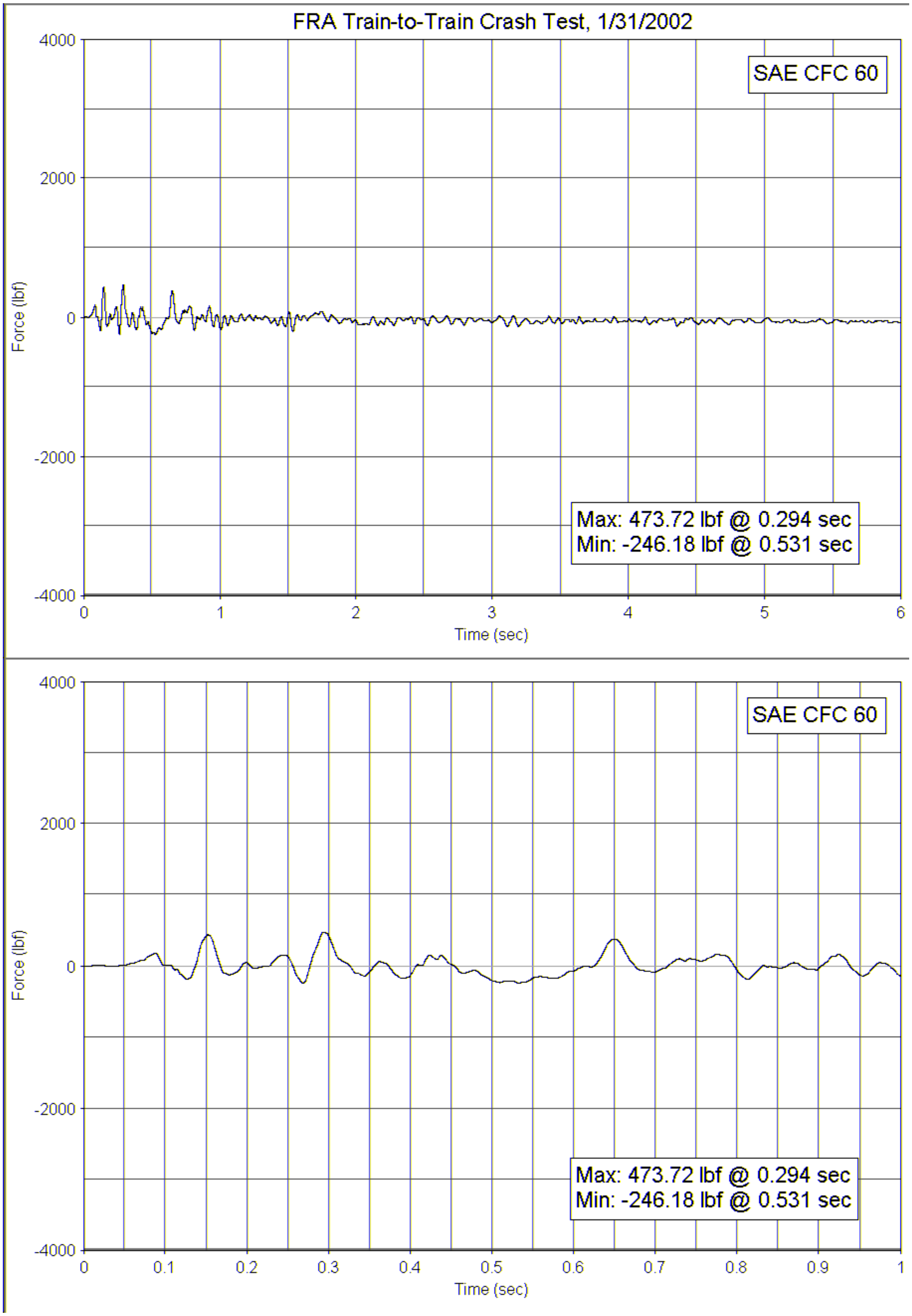


Figure C-32: Experiment No. 2-2 M-Style Seat, Forward Row, Right Rear Leg, Y-Axis Force

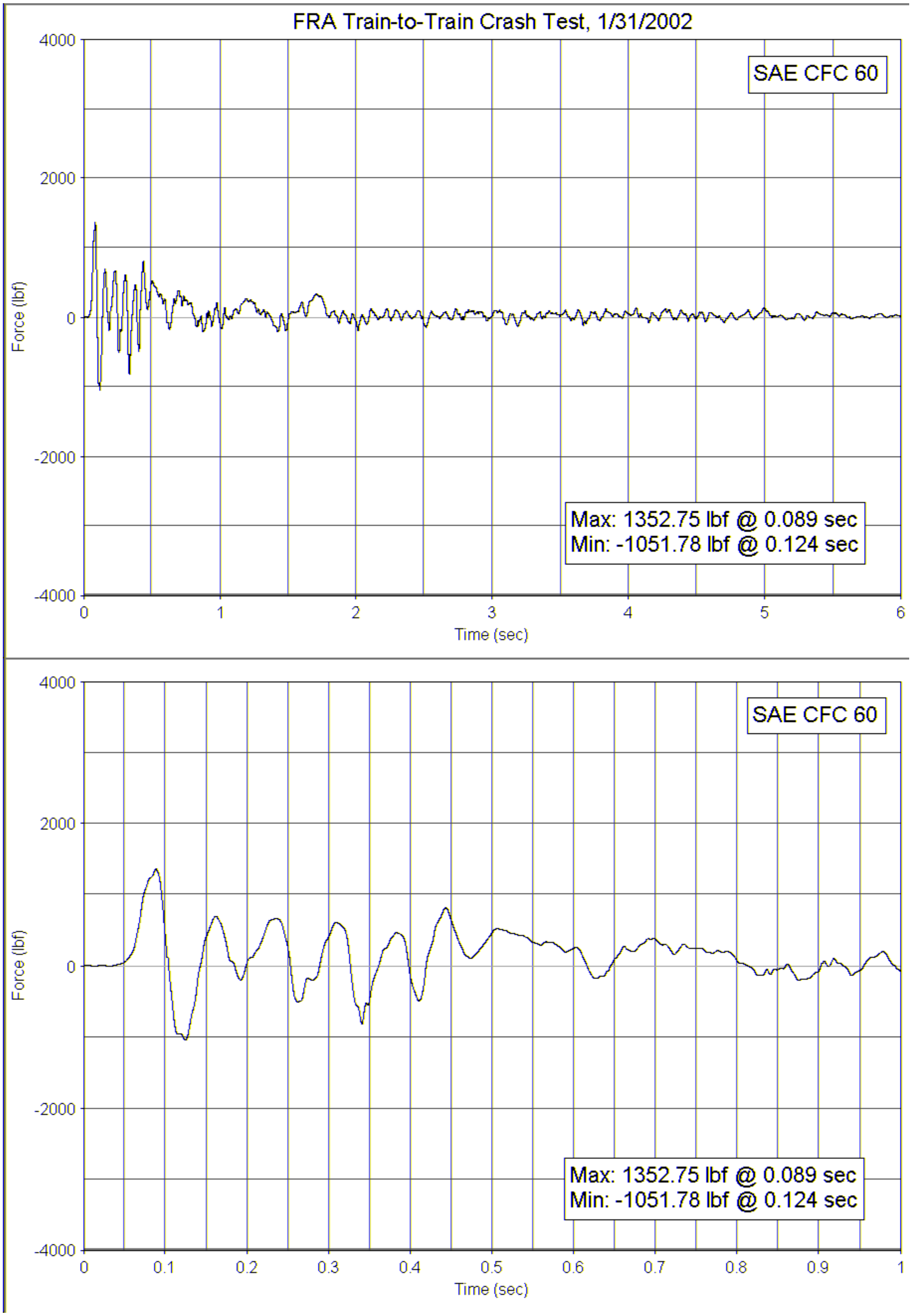


Figure C-33: Experiment No. 2-2 M-Style Seat, Forward Row, Right Rear Leg, Z-Axis Force

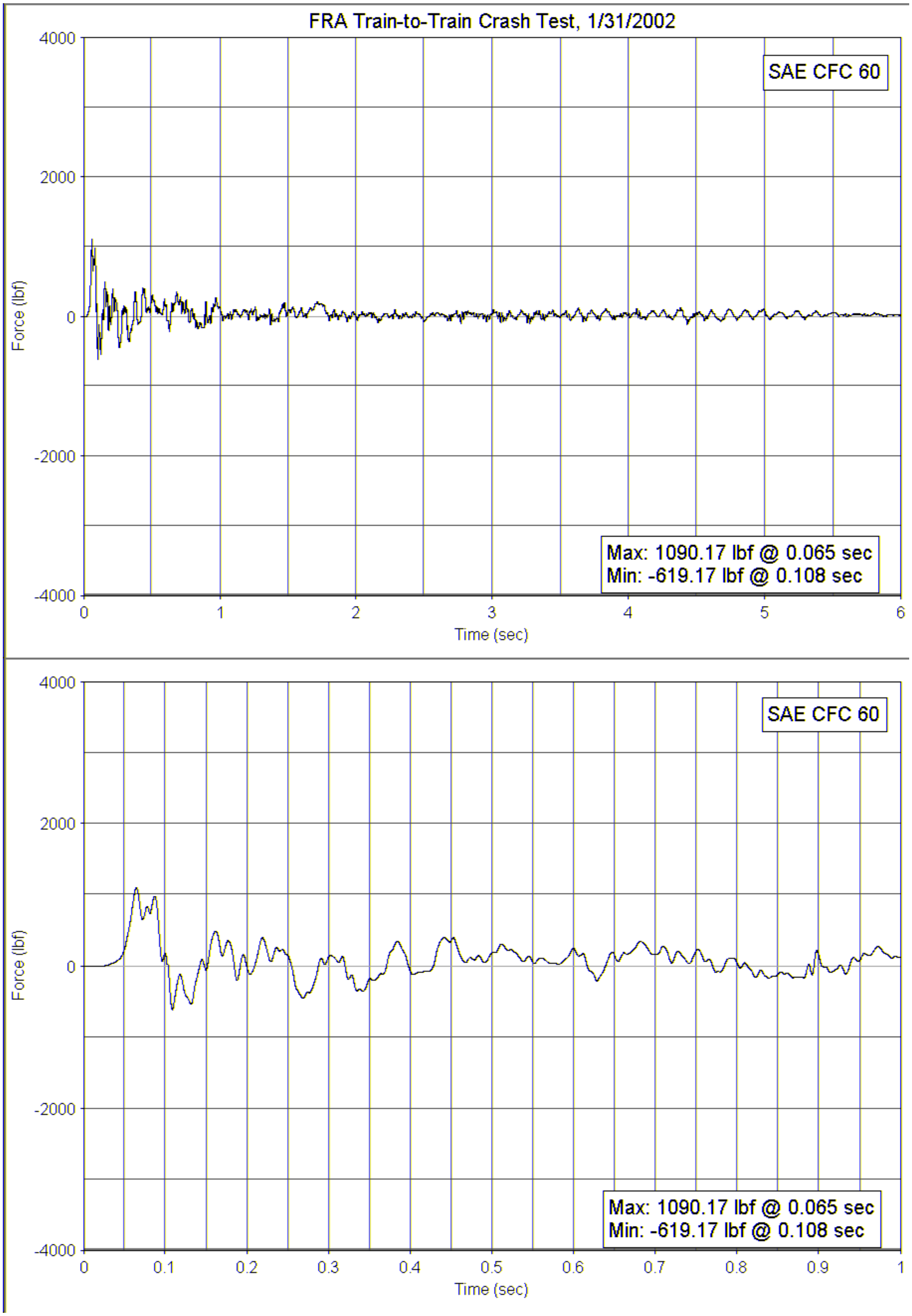


Figure C-34: Experiment No. 2-2 M-Style Seat, Forward Row, Left Rear Leg, X-Axis Force

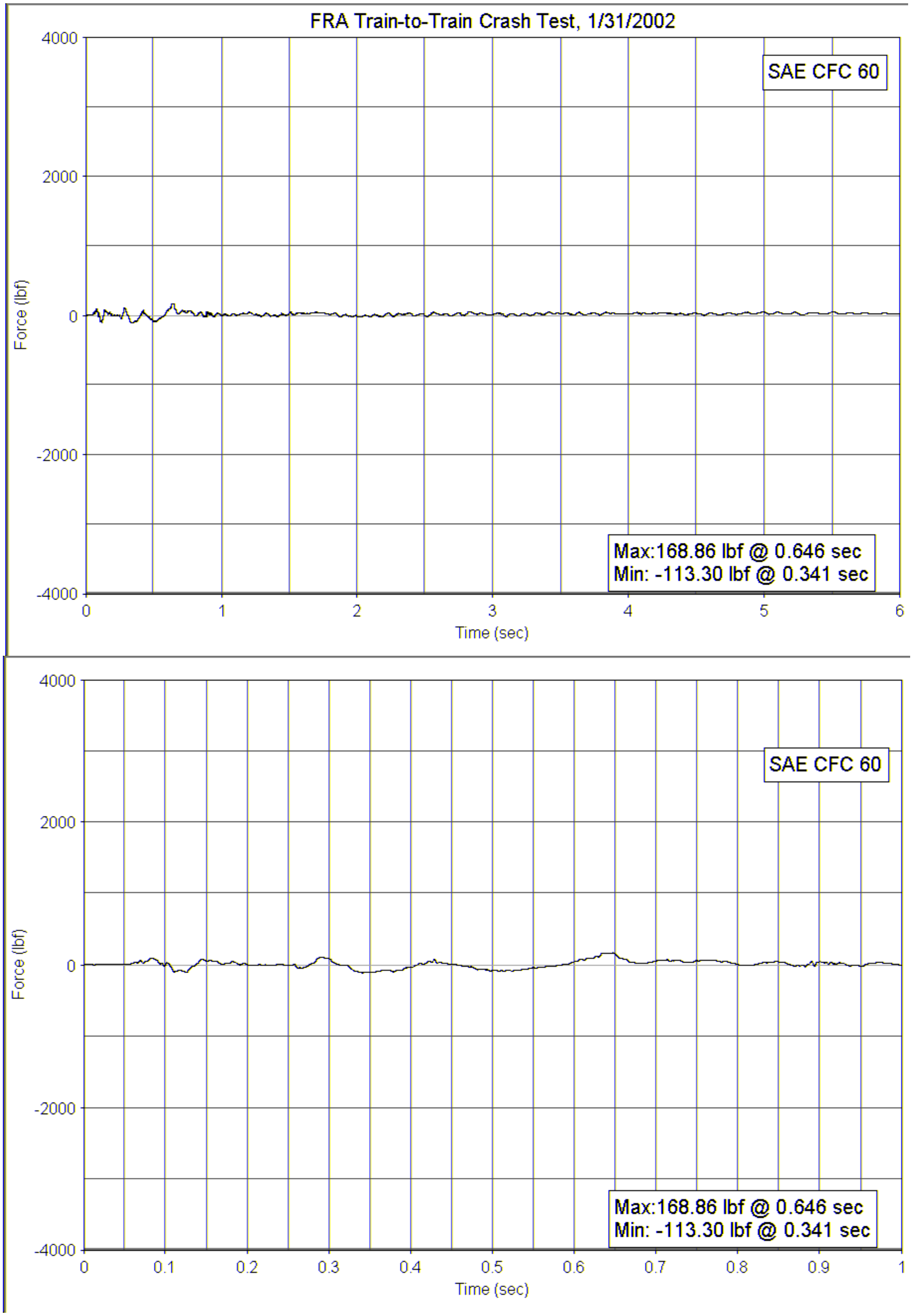


Figure C-35: Experiment No. 2-2 M-Style Seat, Forward Row, Left Rear Leg, Y-Axis Force

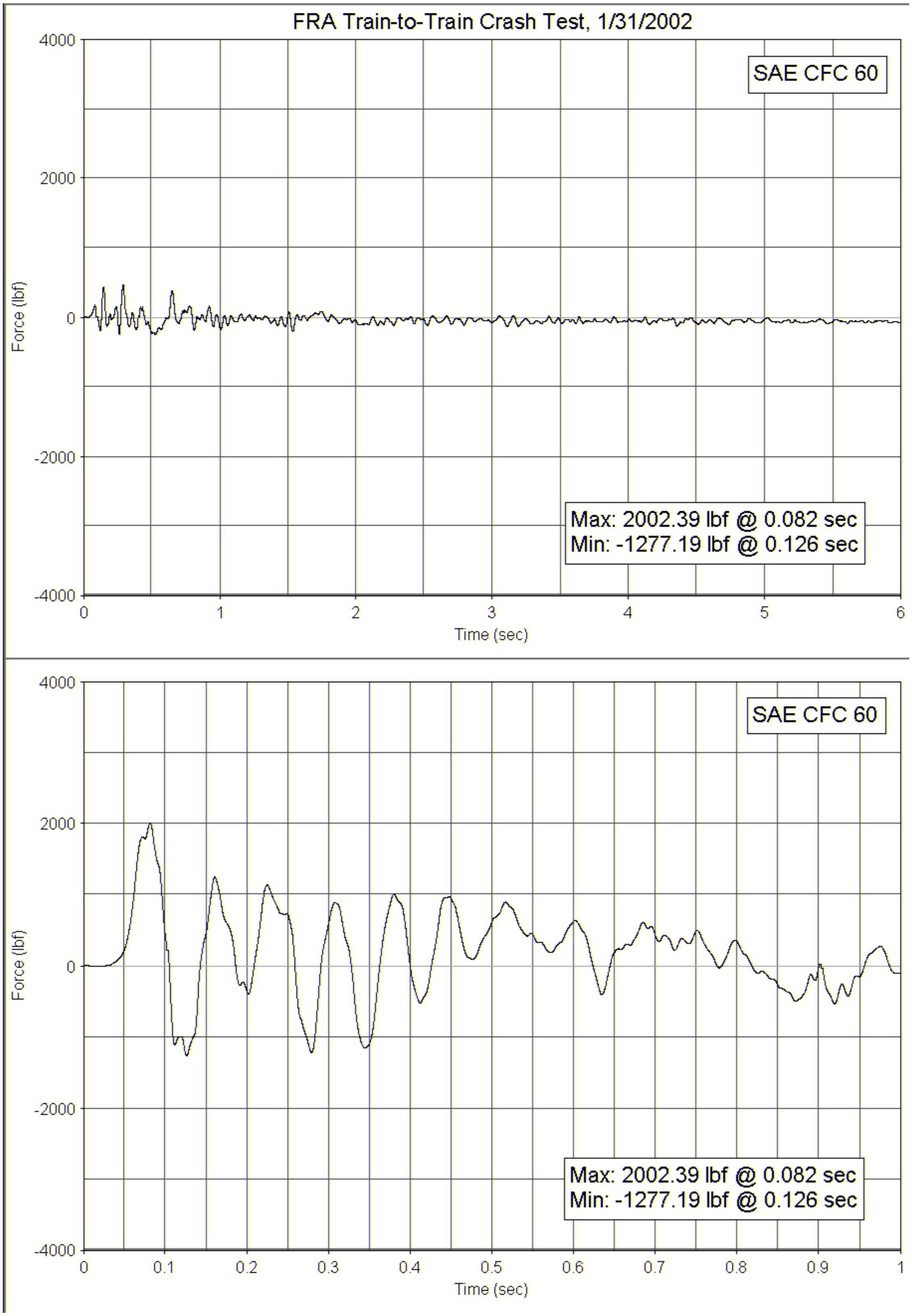


Figure C-36: Experiment No. 2-2 M-Style Seat, Forward Row, Left Rear Leg, Z-Axis Force

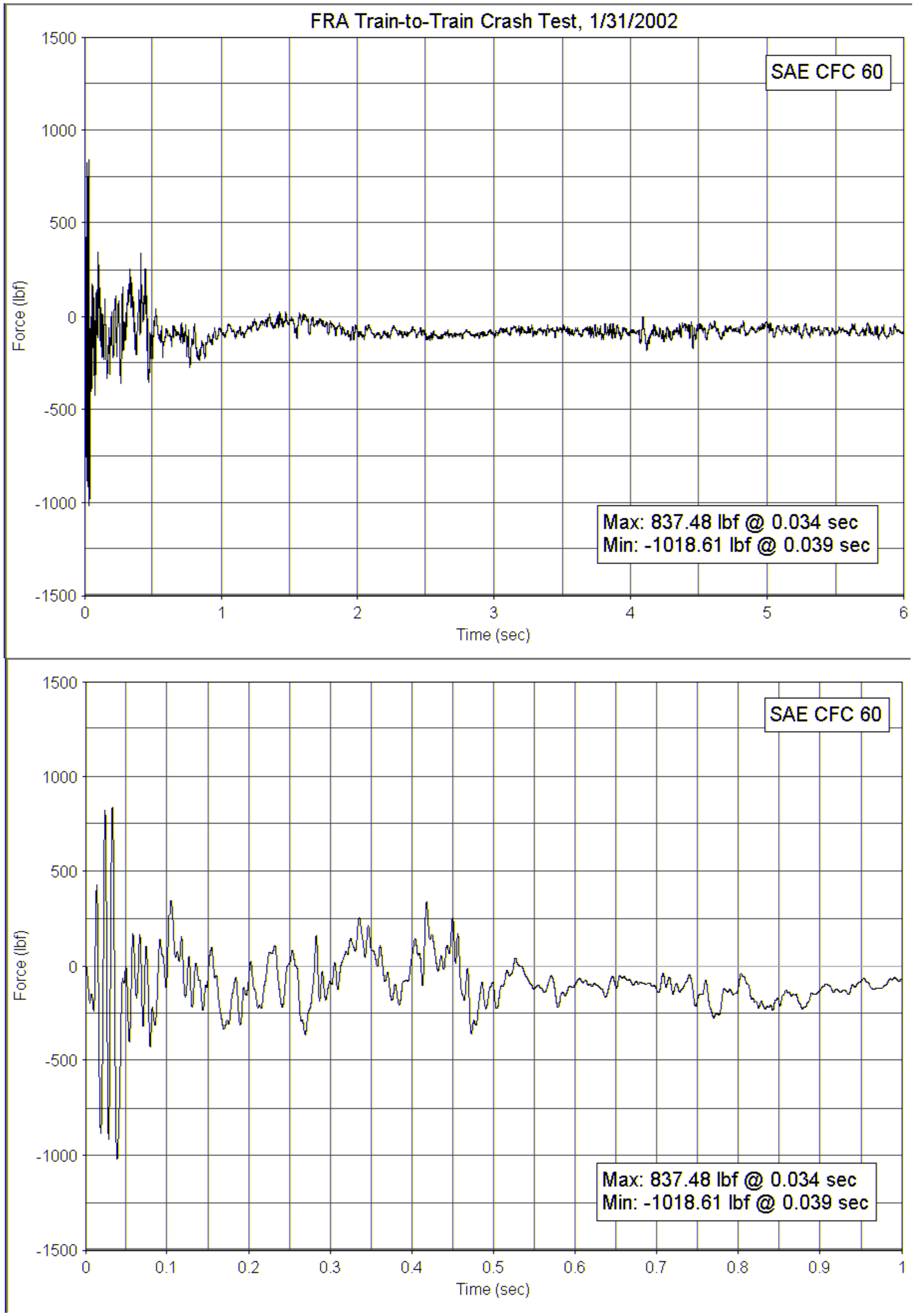


Figure C-37: Experiment No. L-1 Operator Seat, Front Leg, X-Axis Force

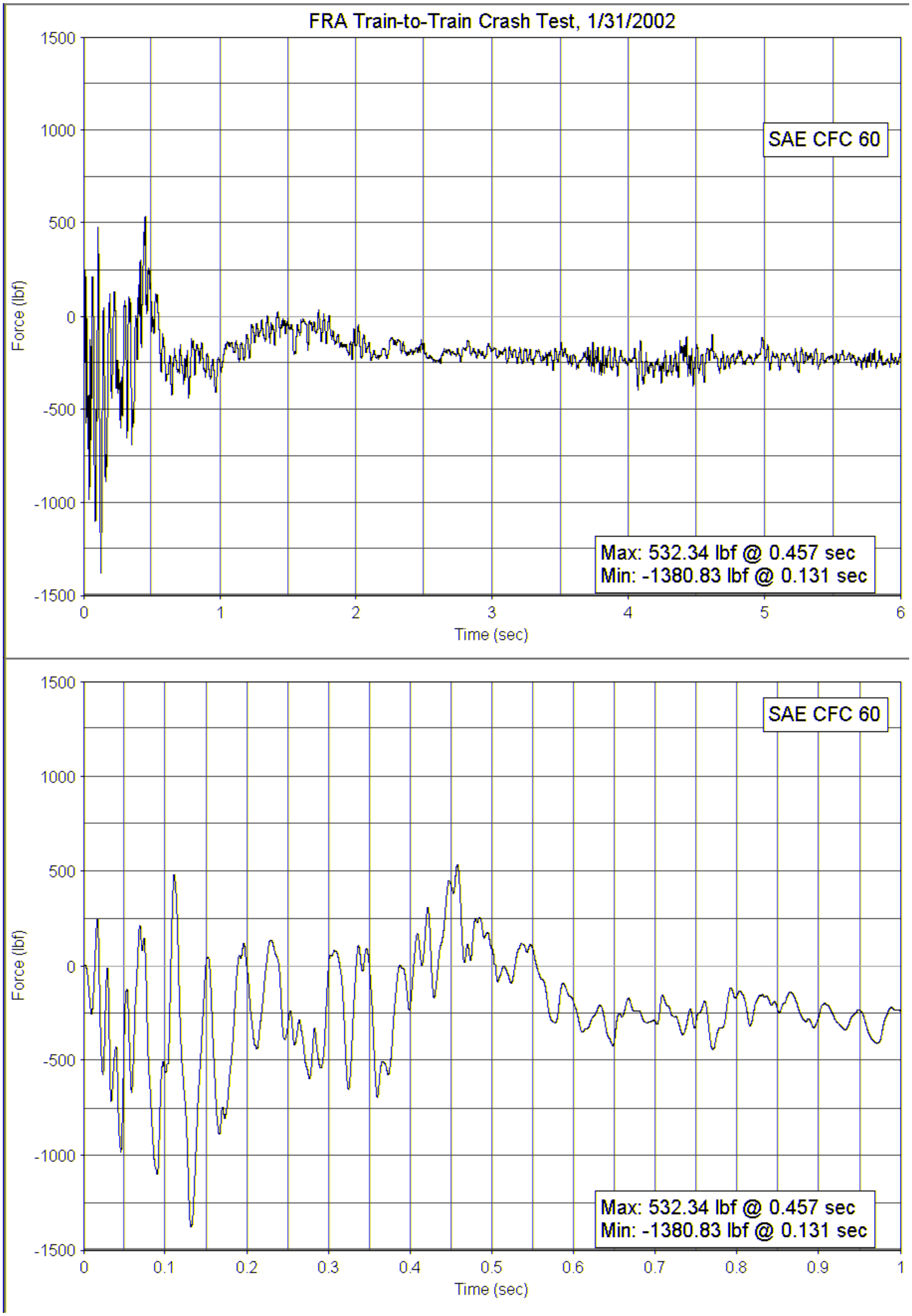
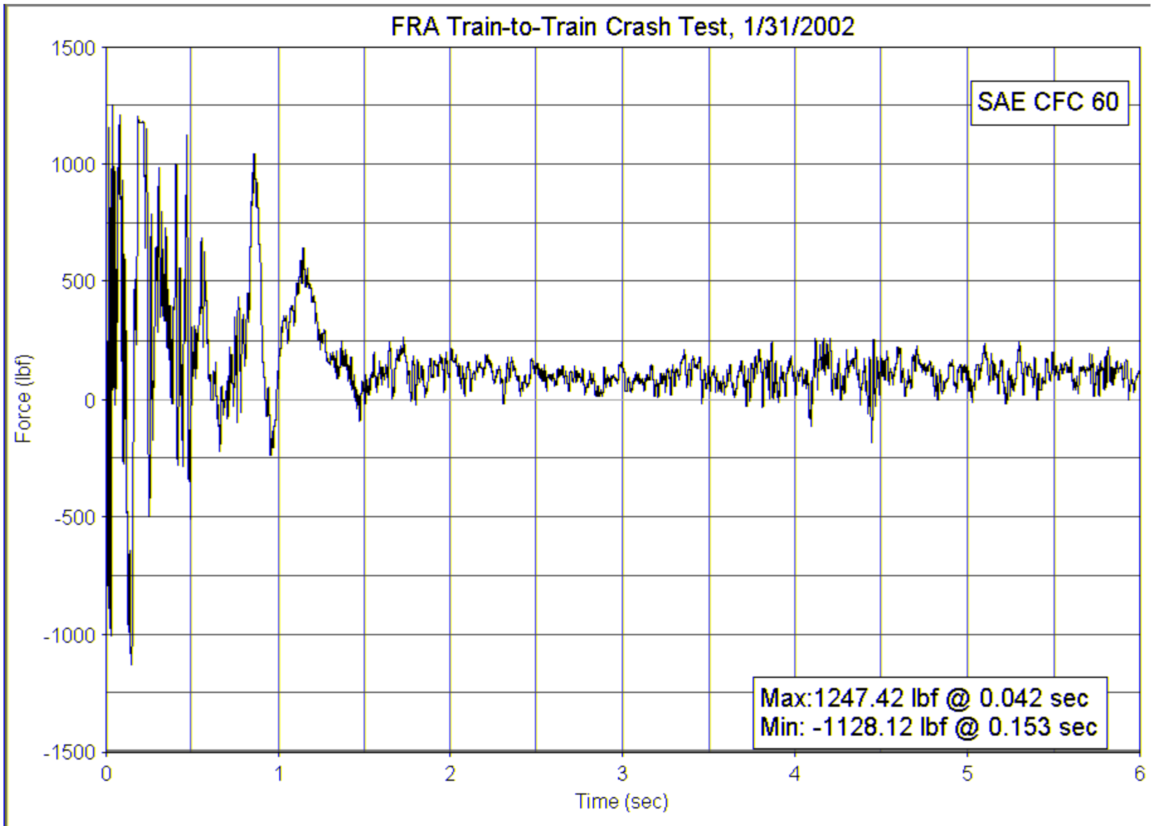


Figure C-38: Experiment No. L-1 Operator Seat, Front Leg, Y-Axis Force



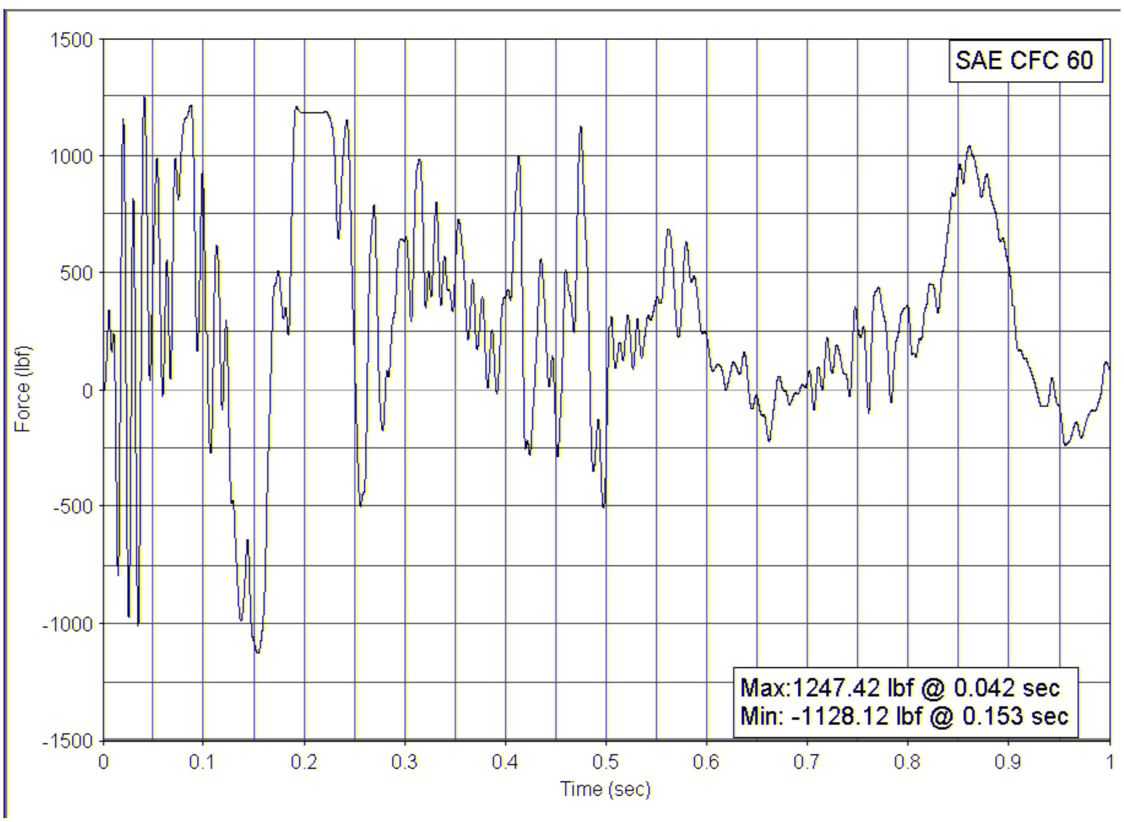


Figure C-39: Experiment No. L-1 Operator Seat, Front Leg, Z-Axis Force

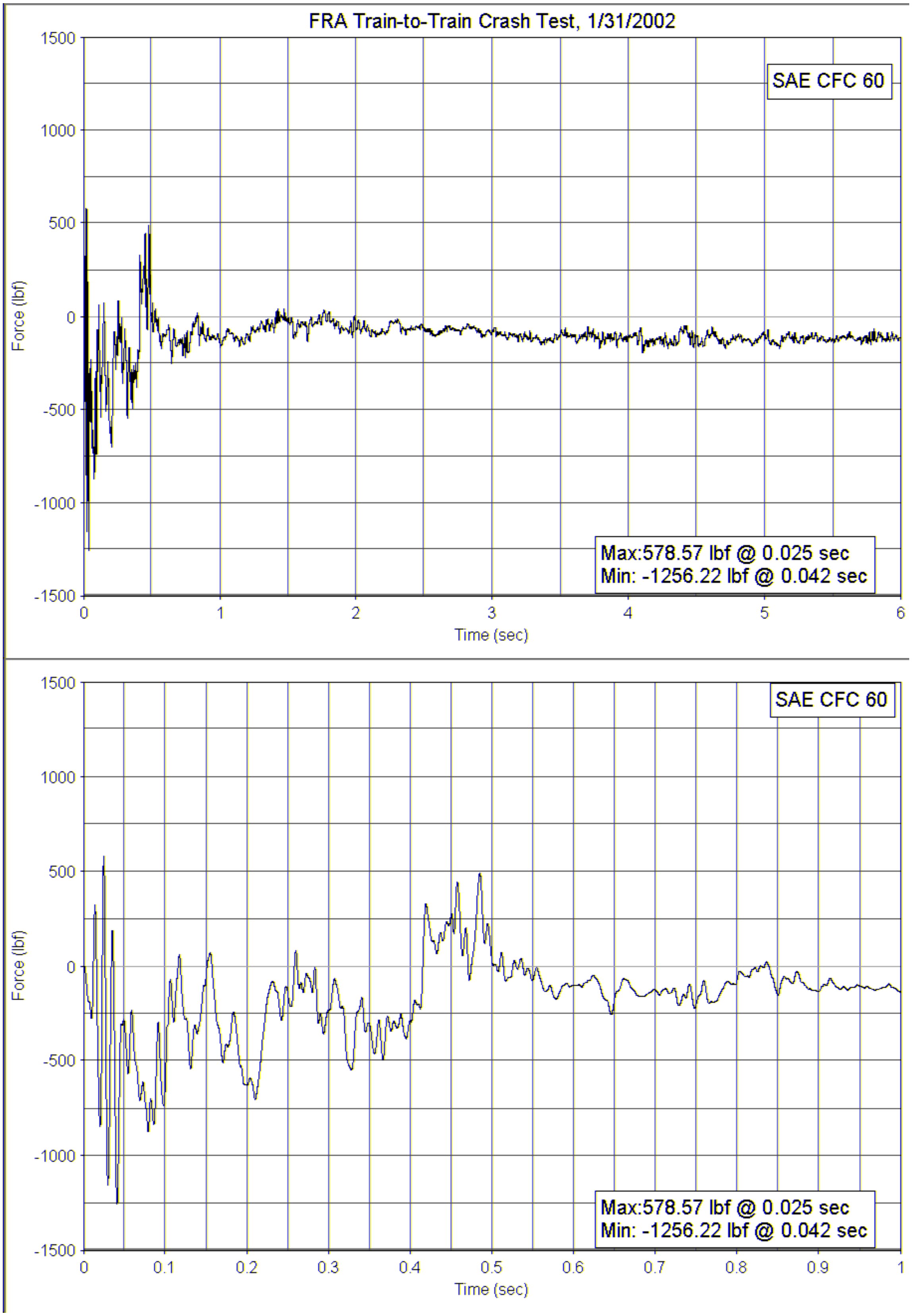


Figure C-40: Experiment No. L-1 Operator Seat, Left Rear Leg, X-Axis Force

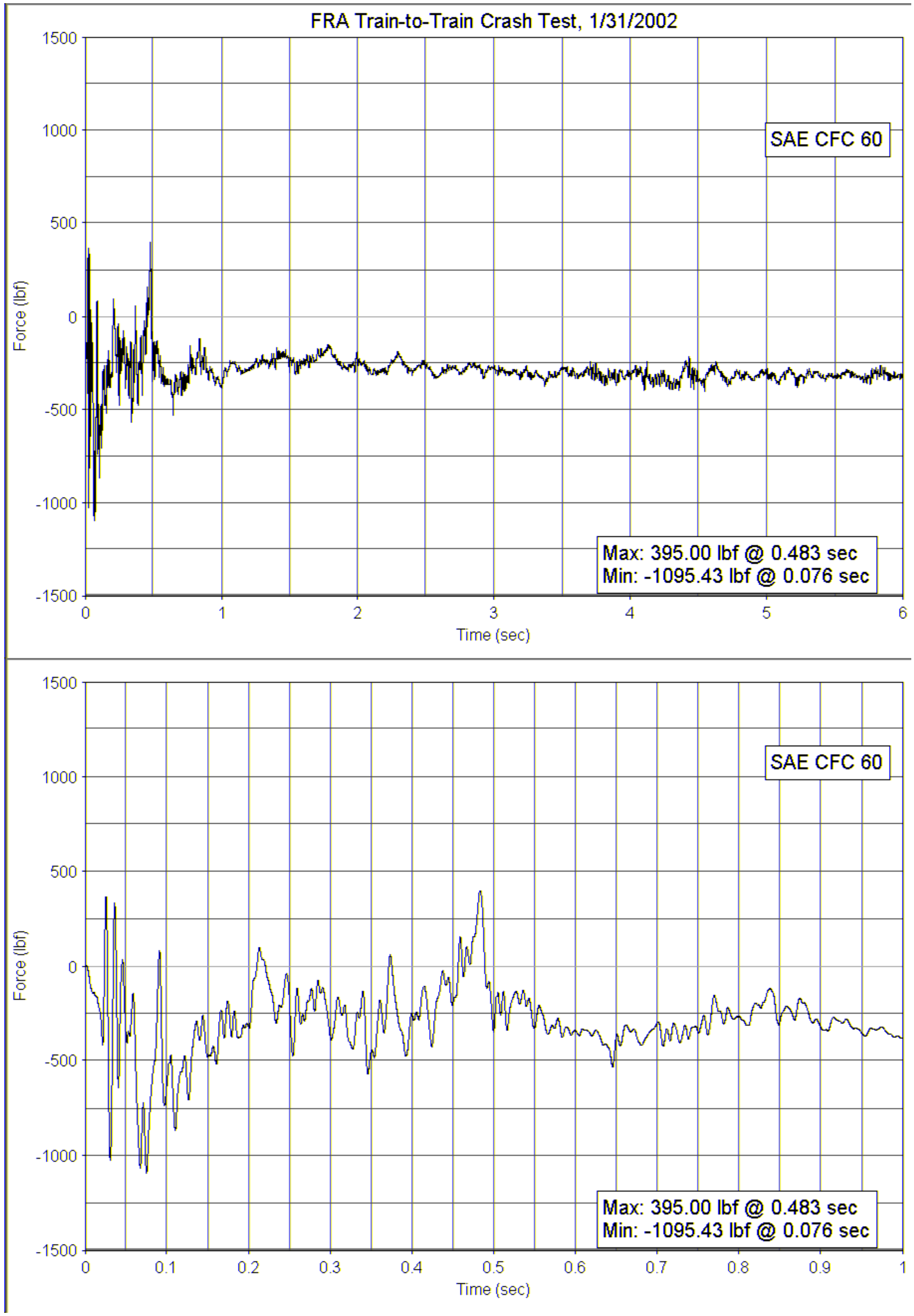


Figure C-41: Experiment No. L-1 Operator Seat, Left Rear Leg, Y-Axis Force

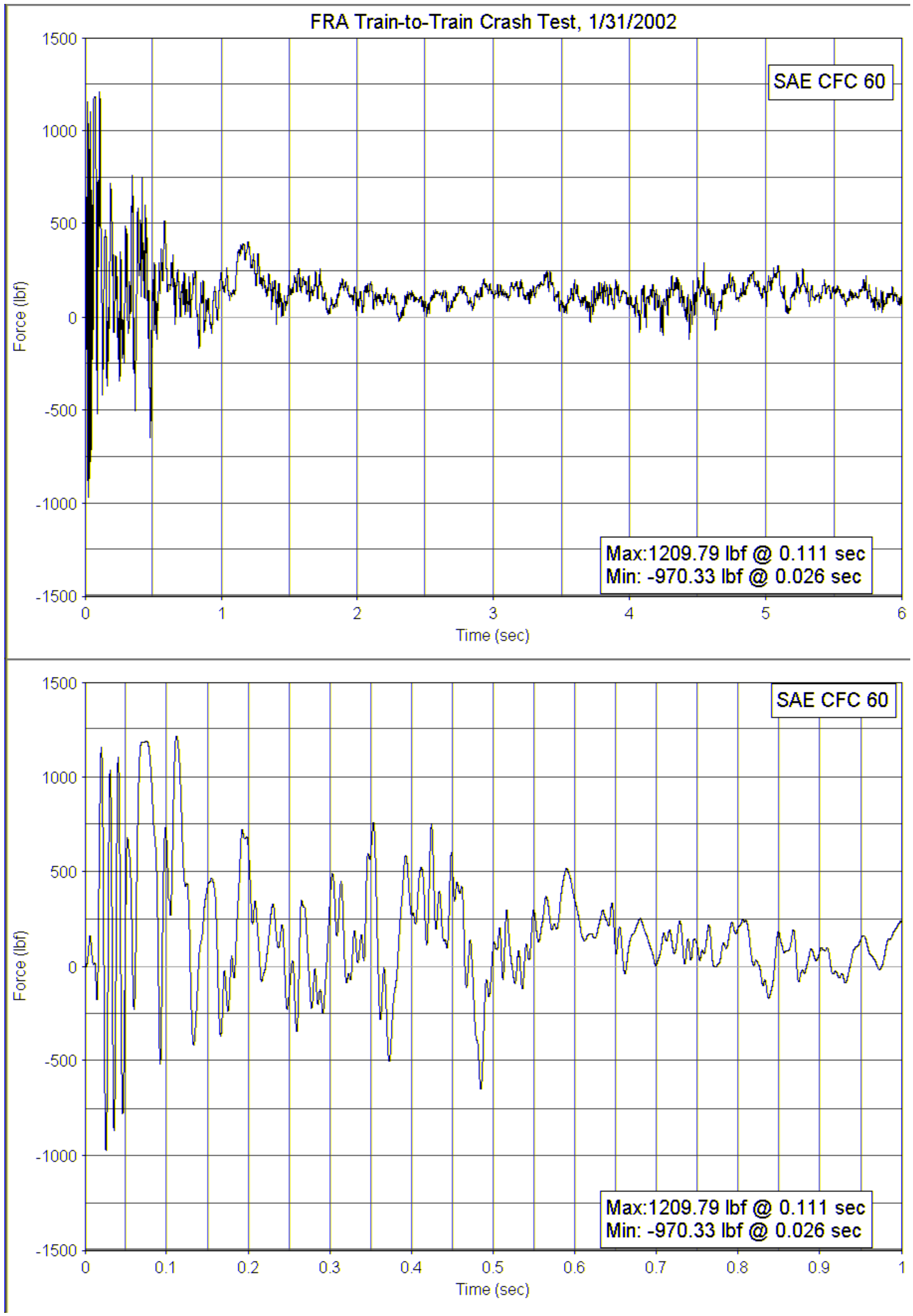


Figure C-42: Experiment No. L-1 Operator Seat, Left Rear Leg, Z-Axis Force

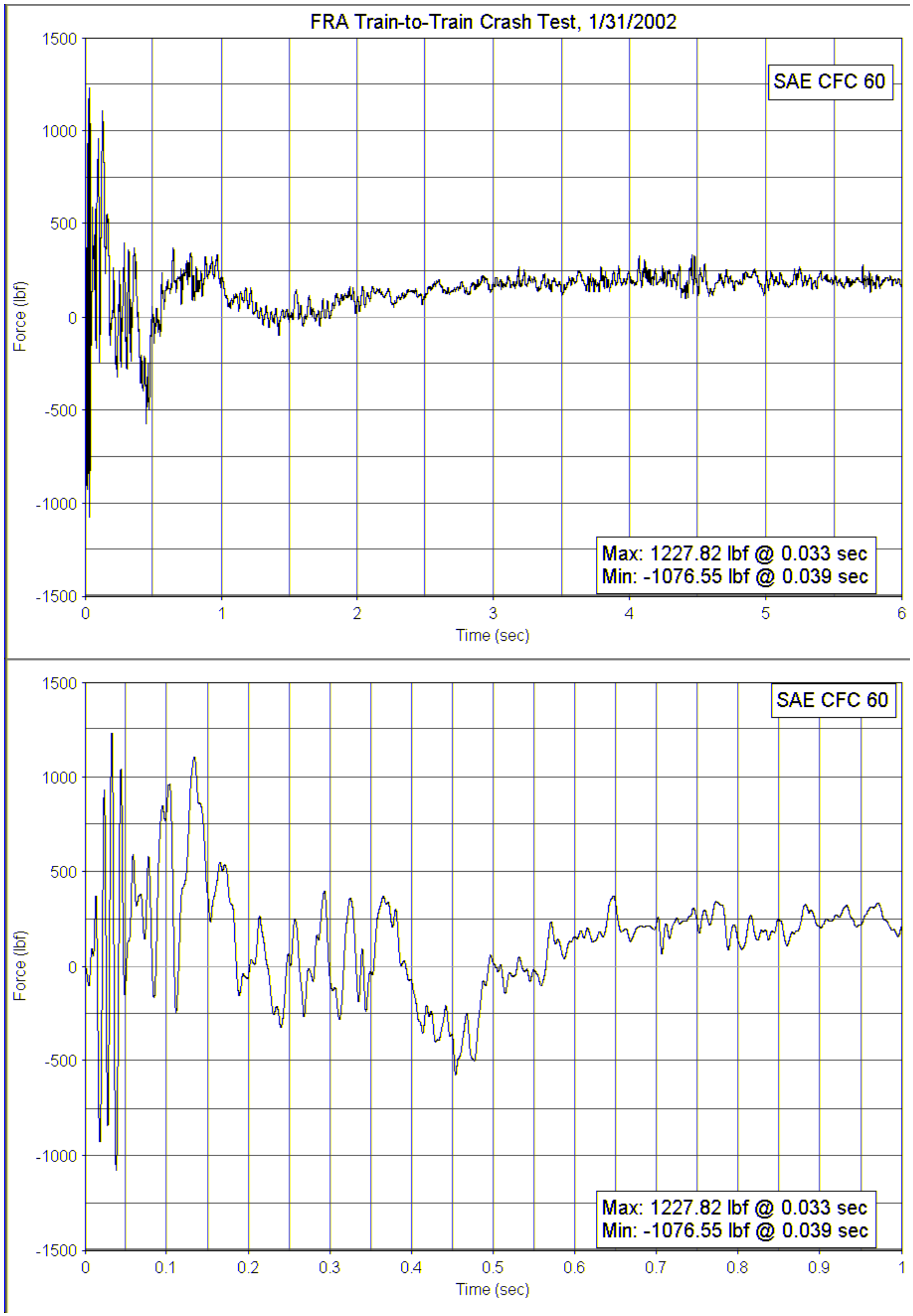


Figure C-43: Experiment No. L-1 Operator Seat, Right Rear Leg, X-Axis Force

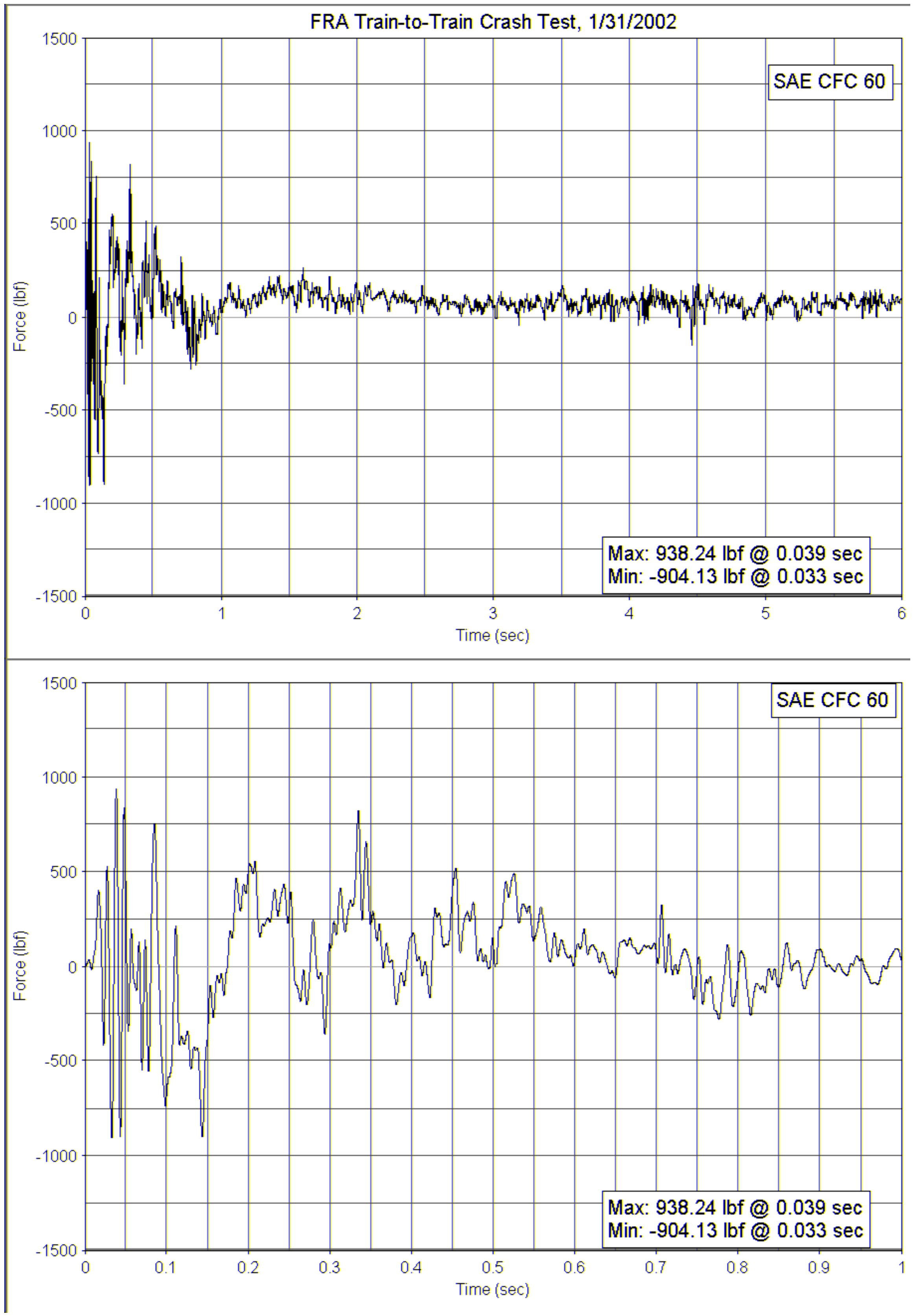


Figure 44: Experiment No. L-1 Operator Seat, Right Rear Leg, Y-Axis Force

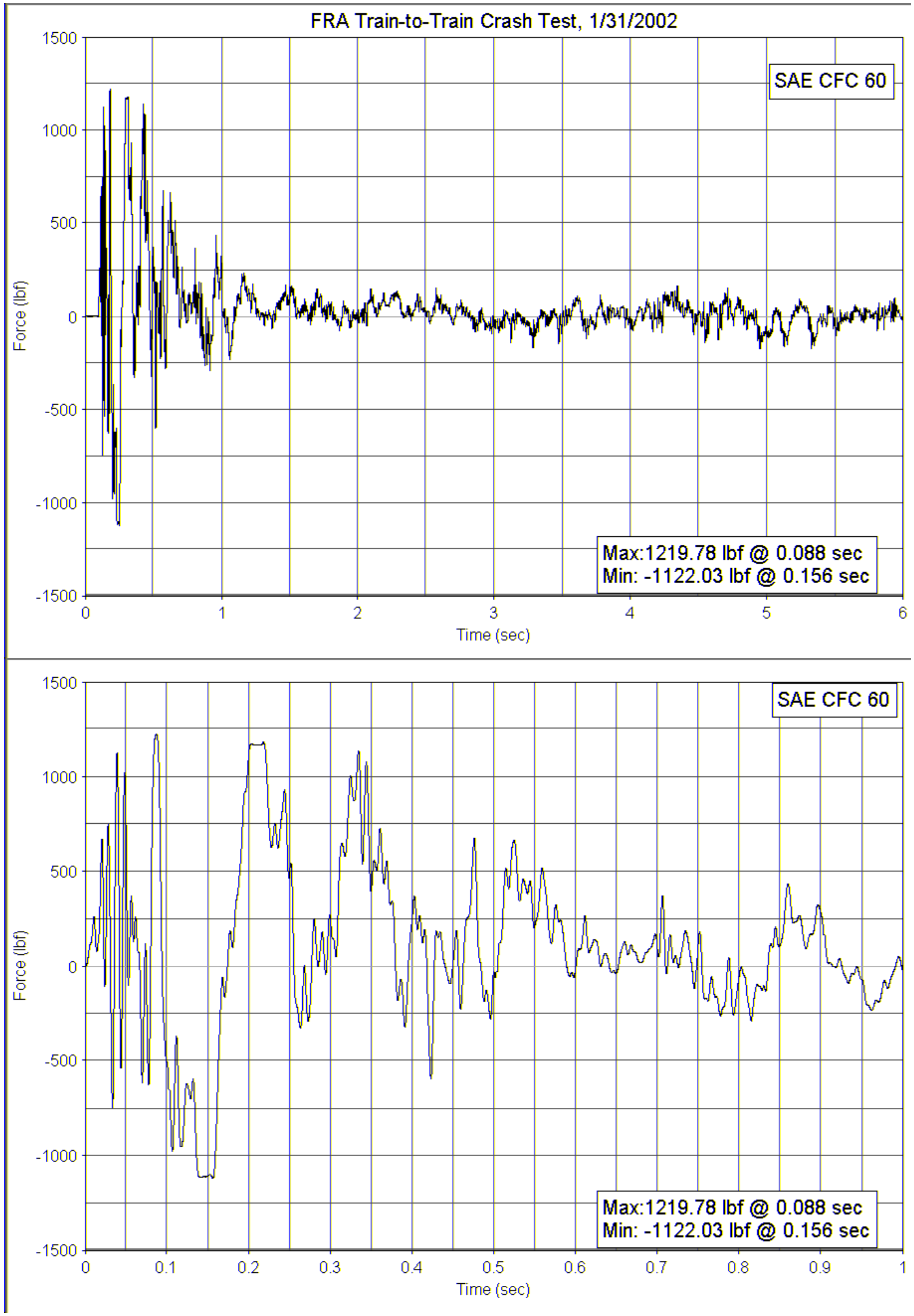


Figure C-45: Experiment No. L-1 Operator Seat, Right Rear Leg, Z-Axis Force

APPENDIX D

OCCUPANT INJURY LOAD-TIME HISTORIES – JANUARY 31, 2002

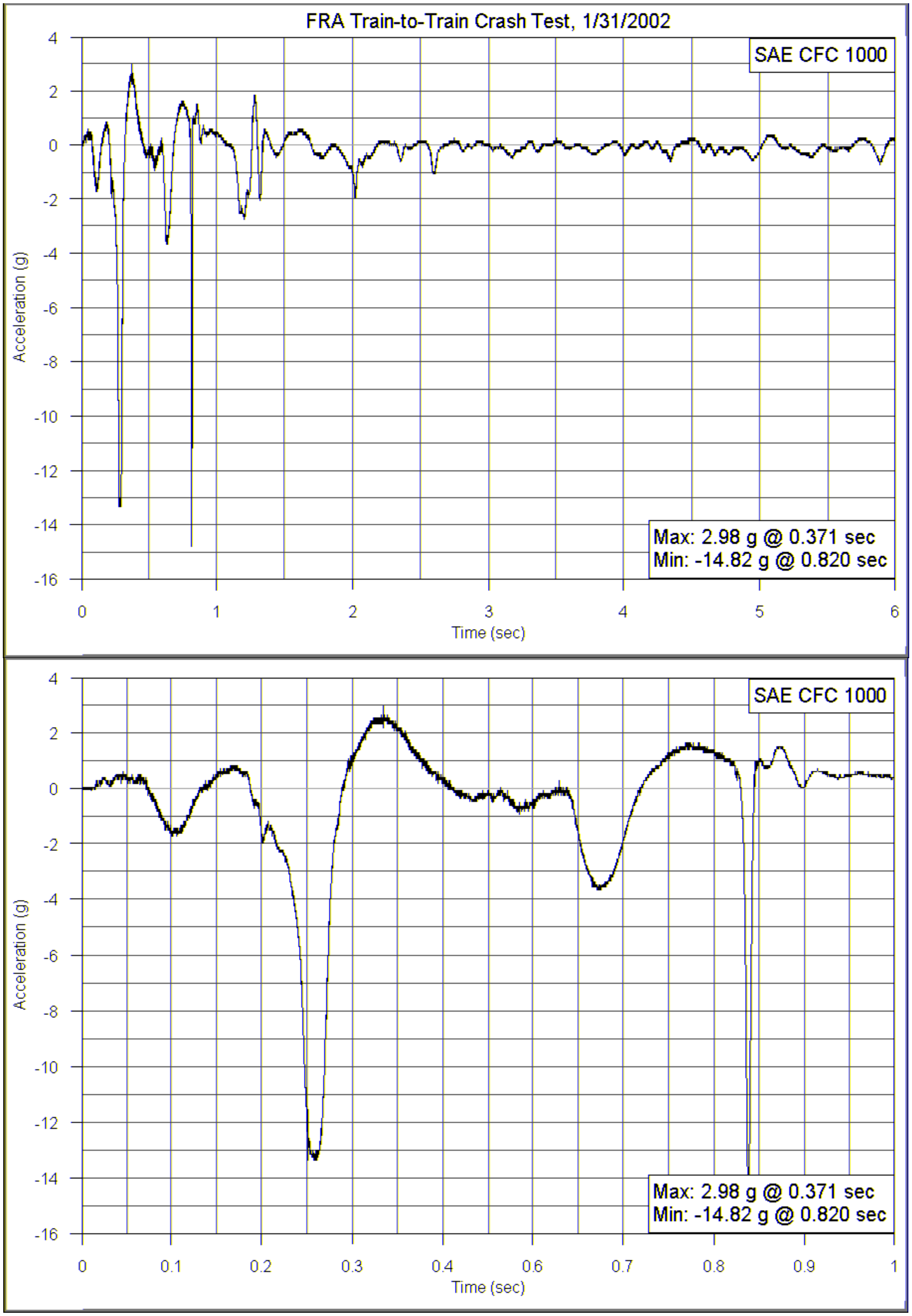


Figure D-1: Experiment No. 1-1 M-Style Seat, Aft Row, Aisle Seat, Hybrid III 50th Head X-axis Acceleration

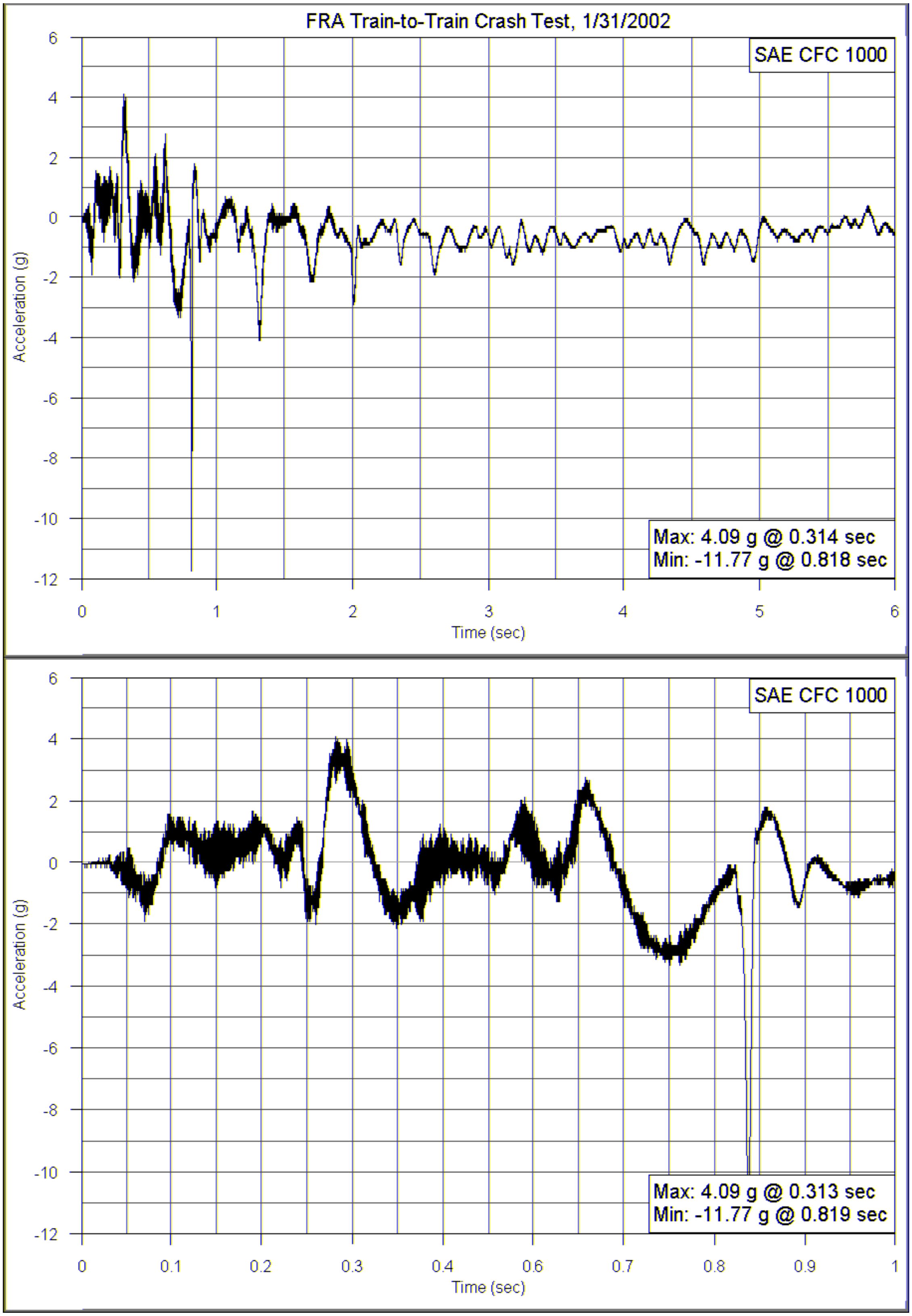


Figure D-2: Experiment No. 1-1 M-Style Seat, Aft Row, Aisle Seat, Hybrid III 50th Head Y-axis Acceleration

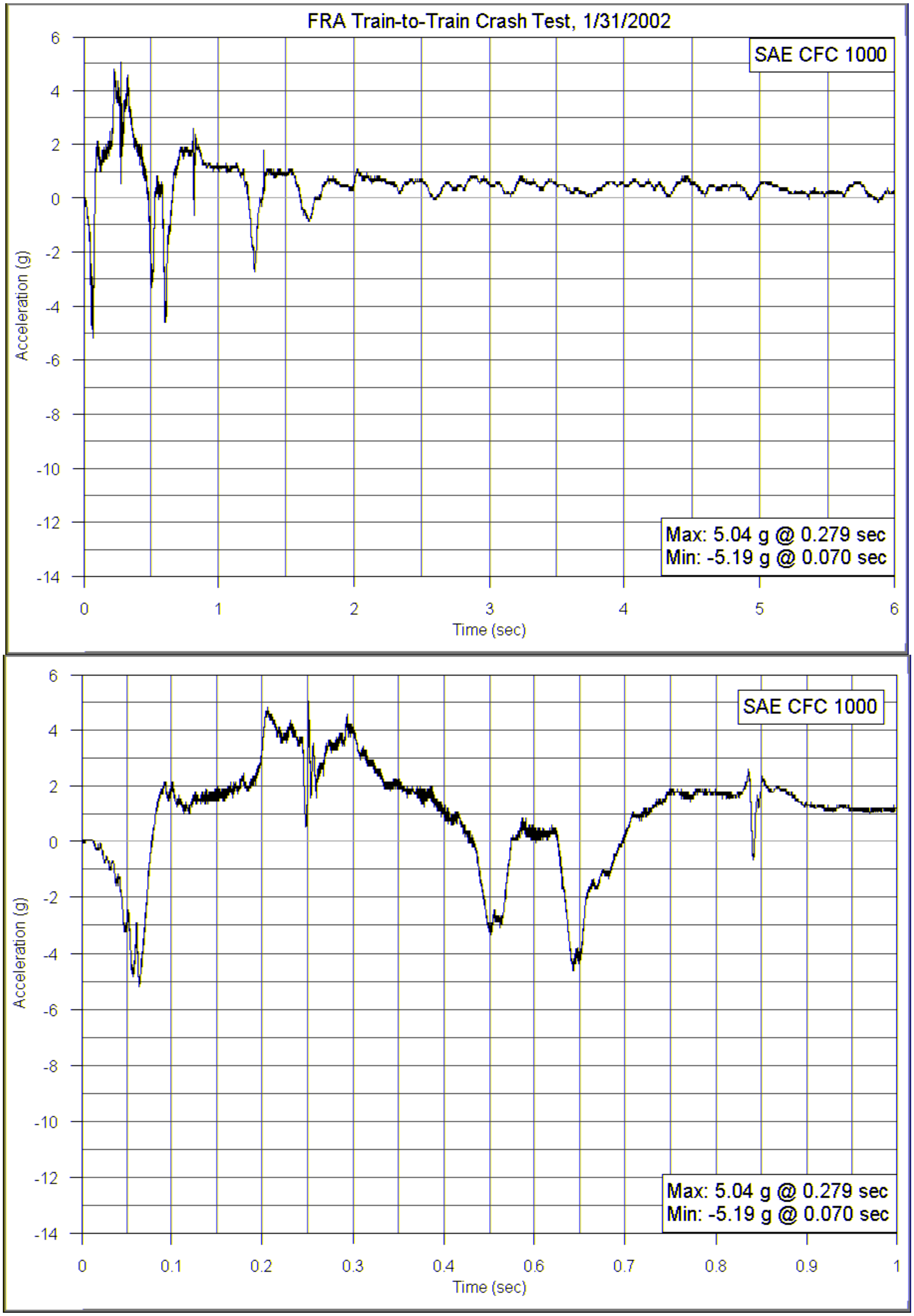


Figure D-3: Experiment No. 1-1 M-Style Seat, Aft Row, Aisle Seat, Hybrid III 50th Head Z-axis Acceleration

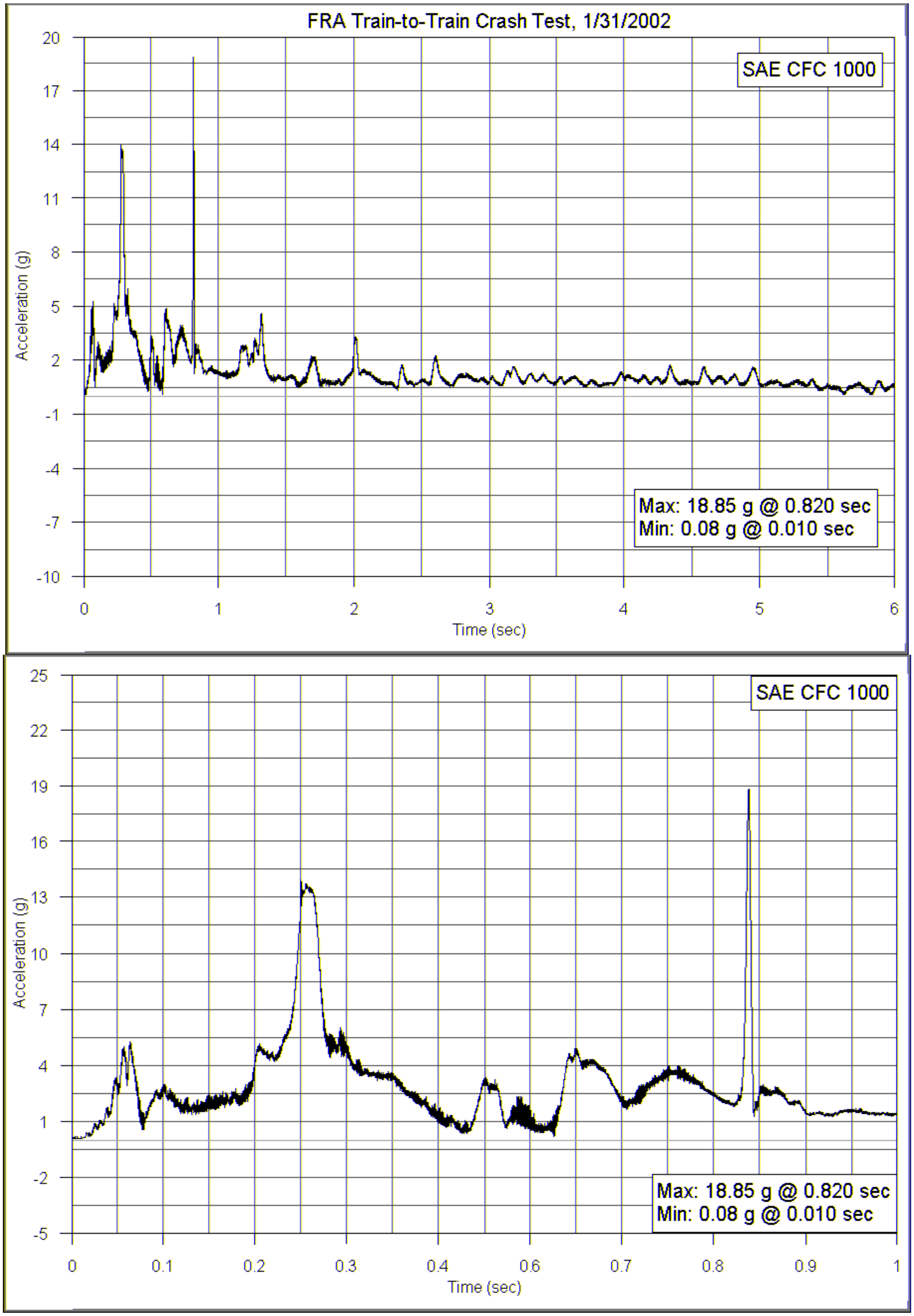


Figure D-4: Experiment No. 1-1 M-Style Seat, Aft Row, Aisle Seat, Hybrid III 50th Head Resultant Acceleration

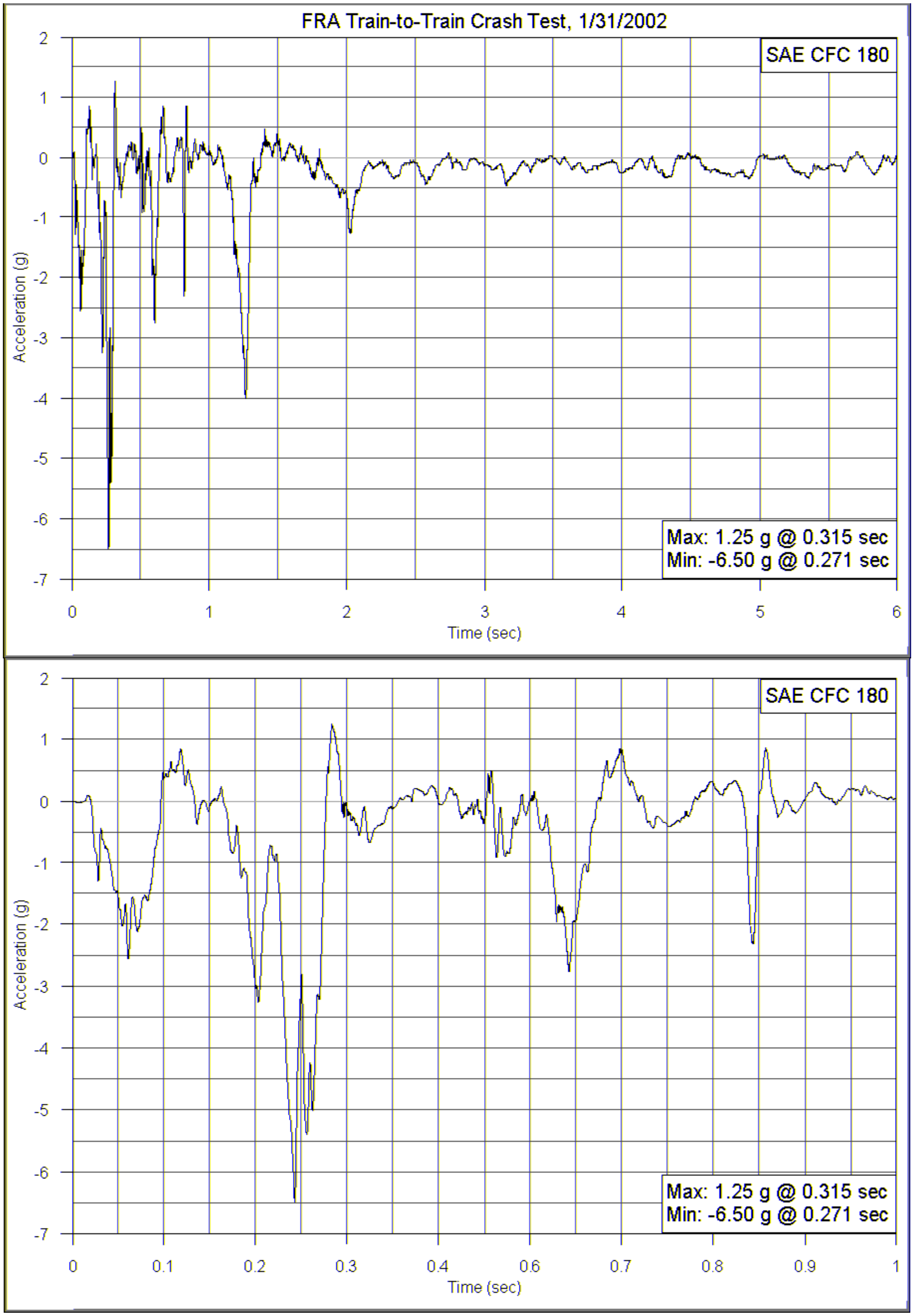


Figure D-5: Experiment No. 1-1 M-Style Seat, Aft Row, Aisle Seat, Hybrid III 50th Chest X-axis Acceleration

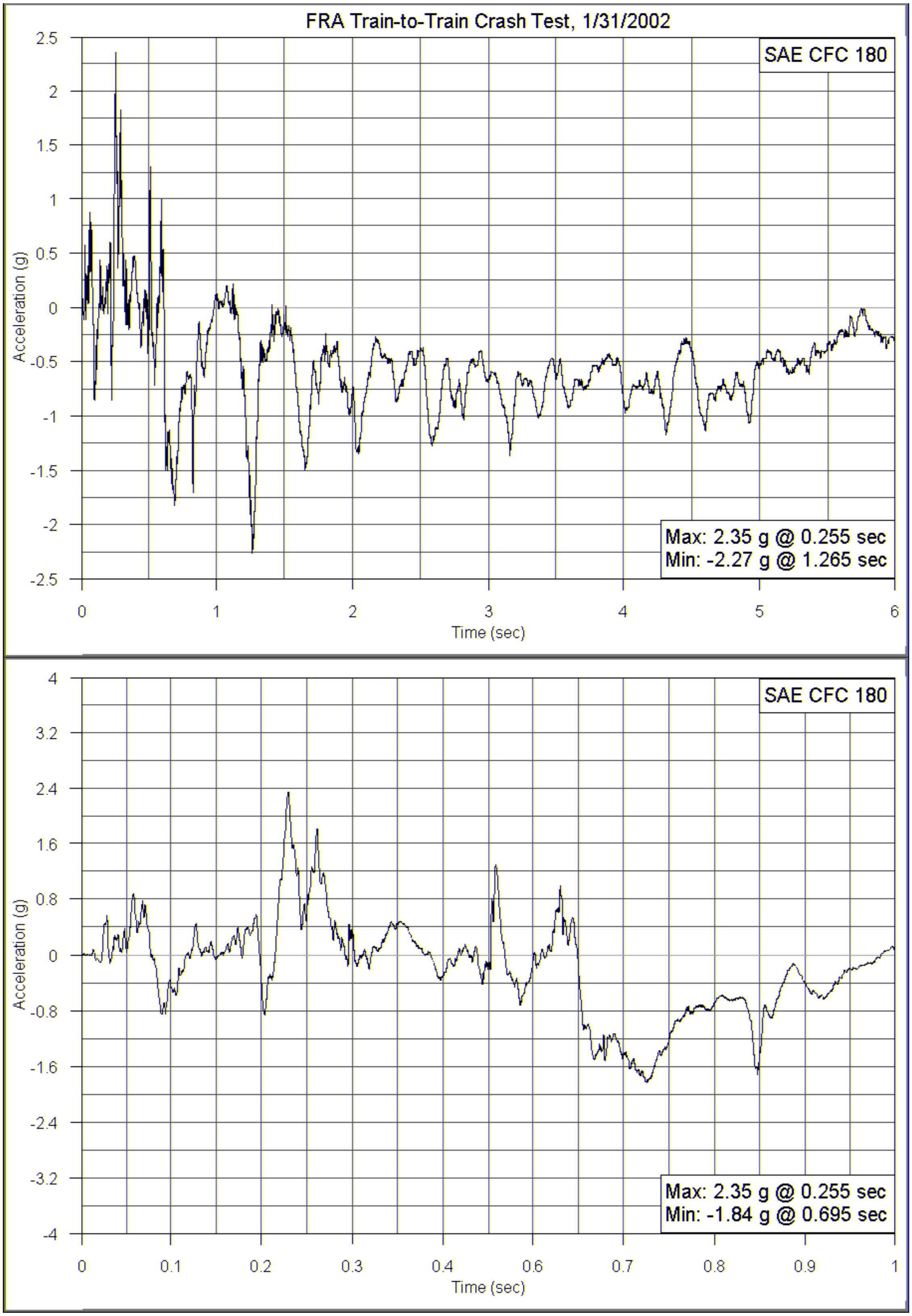


Figure D-6: Experiment No. 1-1 M-Style Seat, Aft Row, Aisle Seat, Hybrid III 50th Chest Y-axis Acceleration

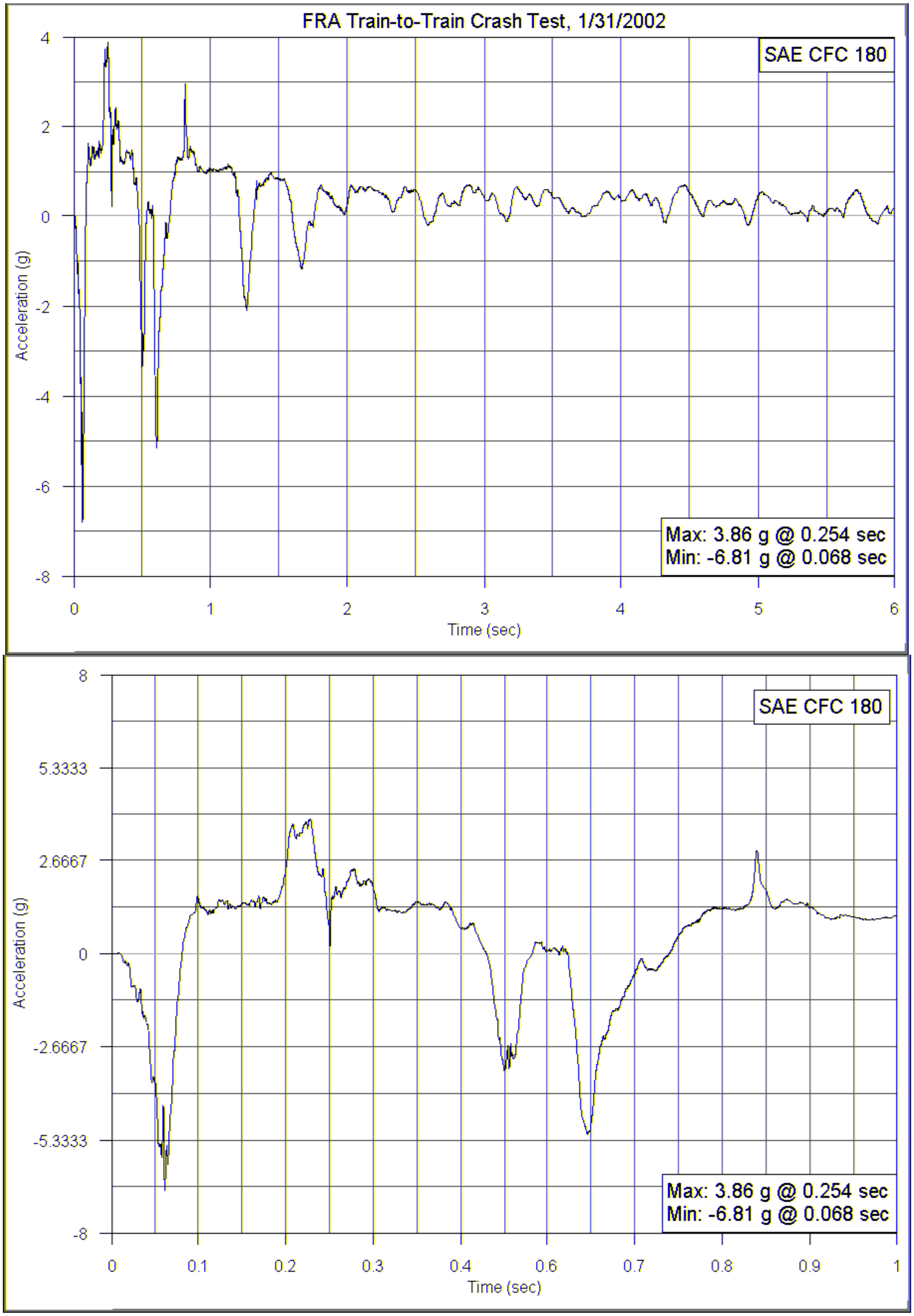


Figure D-7: Experiment No. 1-1 M-Style Seat, Aft Row, Aisle Seat, Hybrid III 50th Chest Z-axis Acceleration

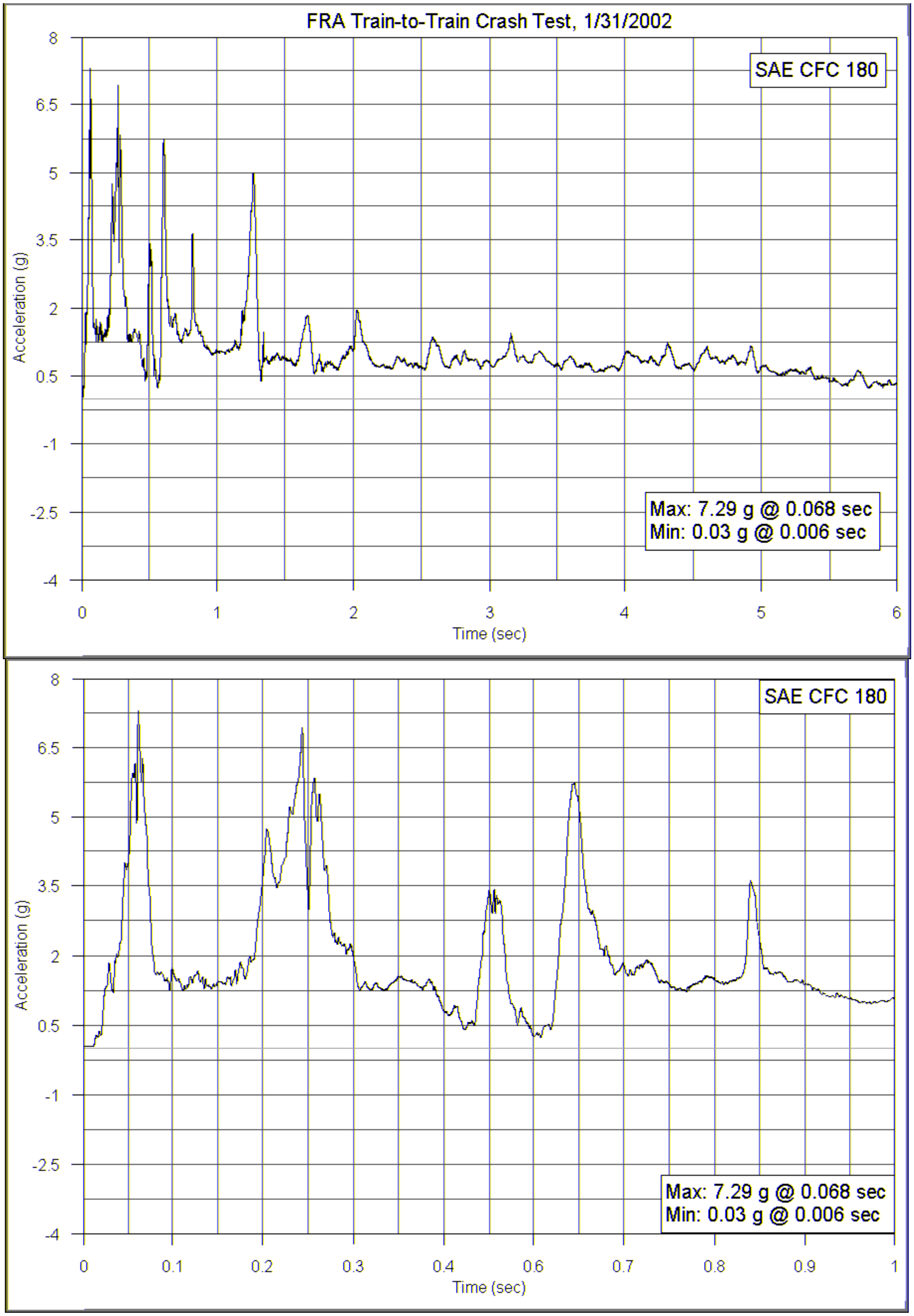


Figure D-8: Experiment No. 1-1 M-Style Seat, Aft Row, Aisle Seat, Hybrid III 50th Chest Resultant Acceleration

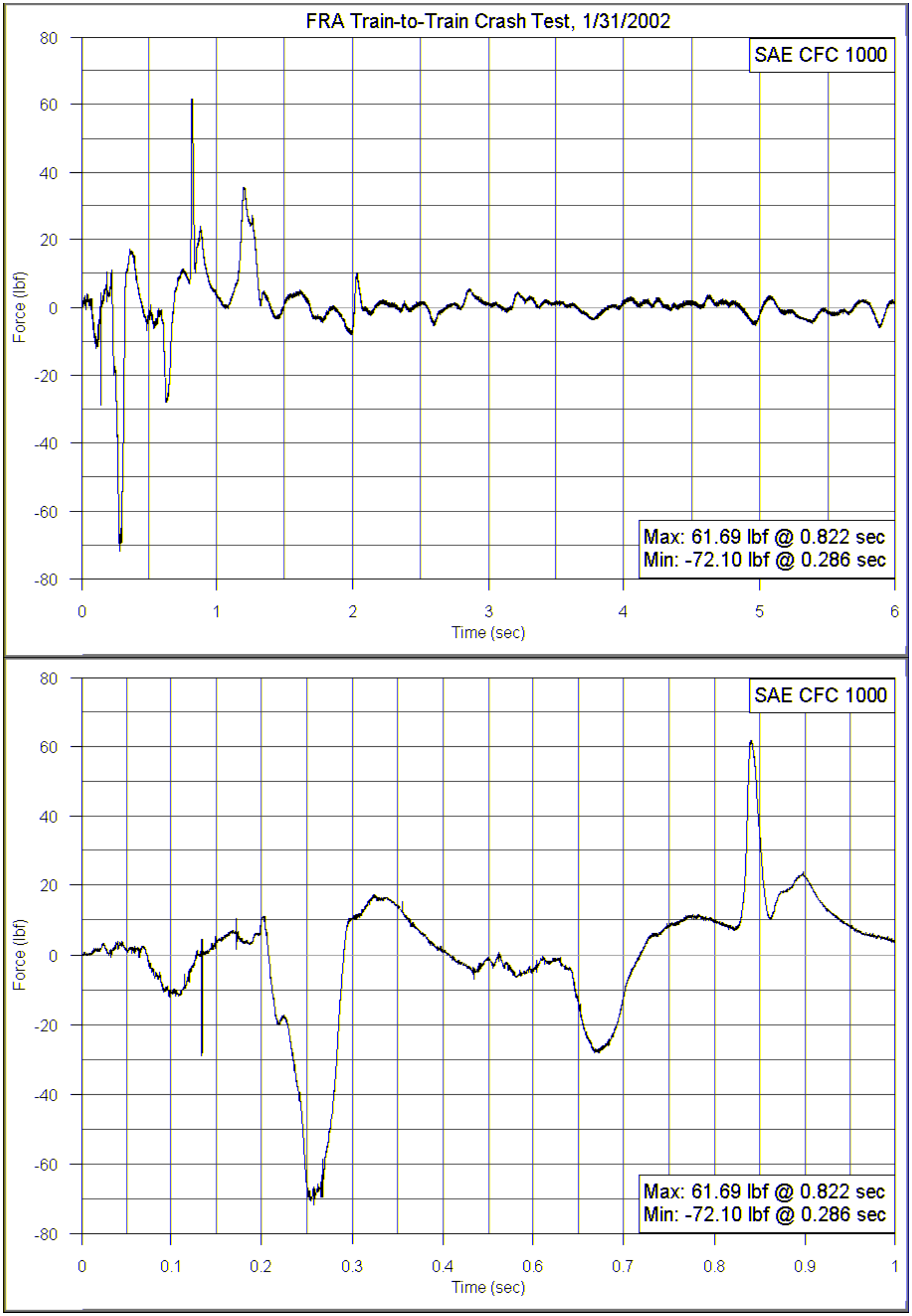


Figure D-9: Experiment No. 1-1 M-Style Seat, Aft Row, Aisle Seat, Hybrid III 50th Upper Neck X-axis Shear Force

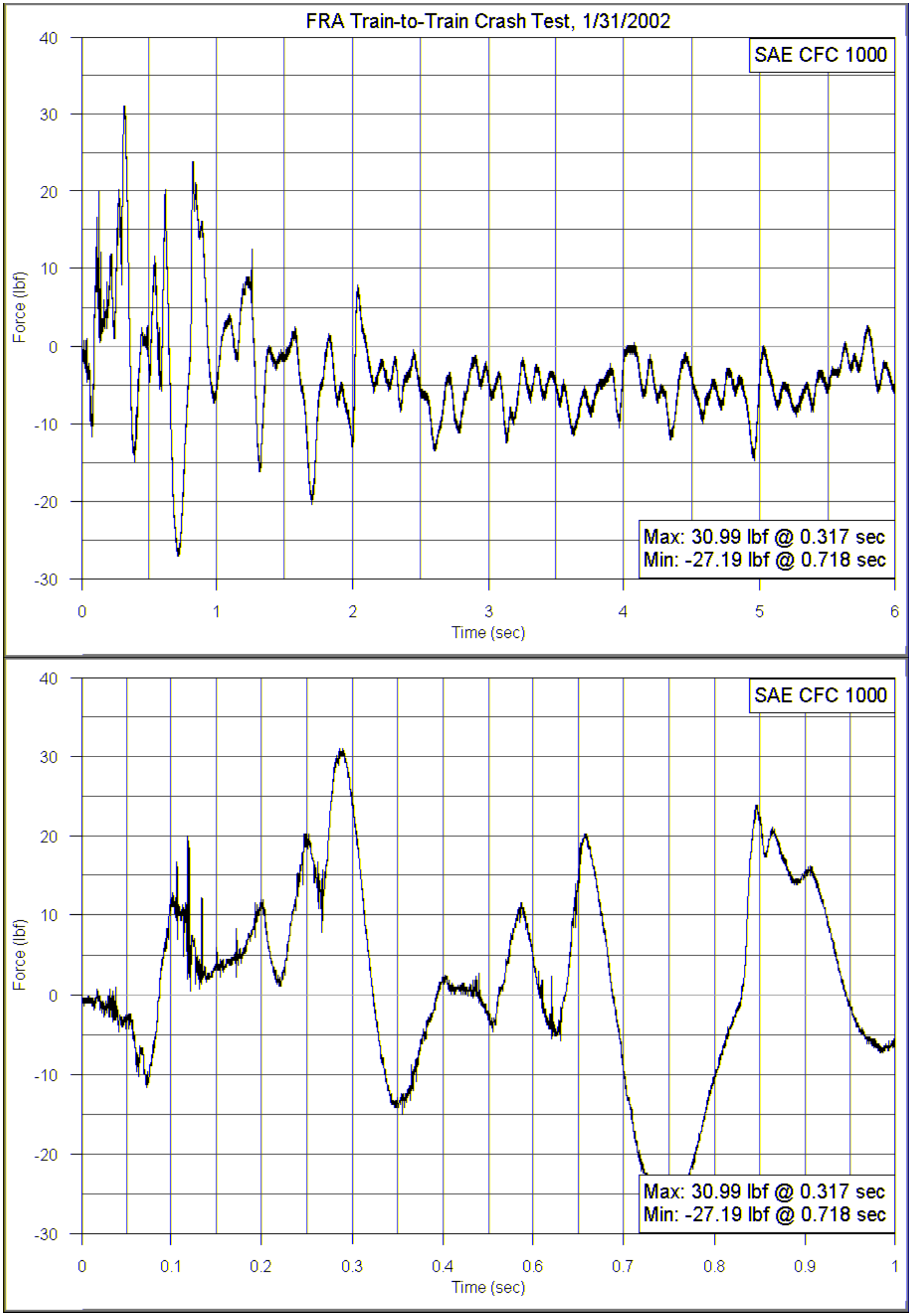


Figure D-10: Experiment No. 1-1 M-Style Seat, Aft Row, Aisle Seat, Hybrid III 50th Upper Neck Y-axis Shear Force

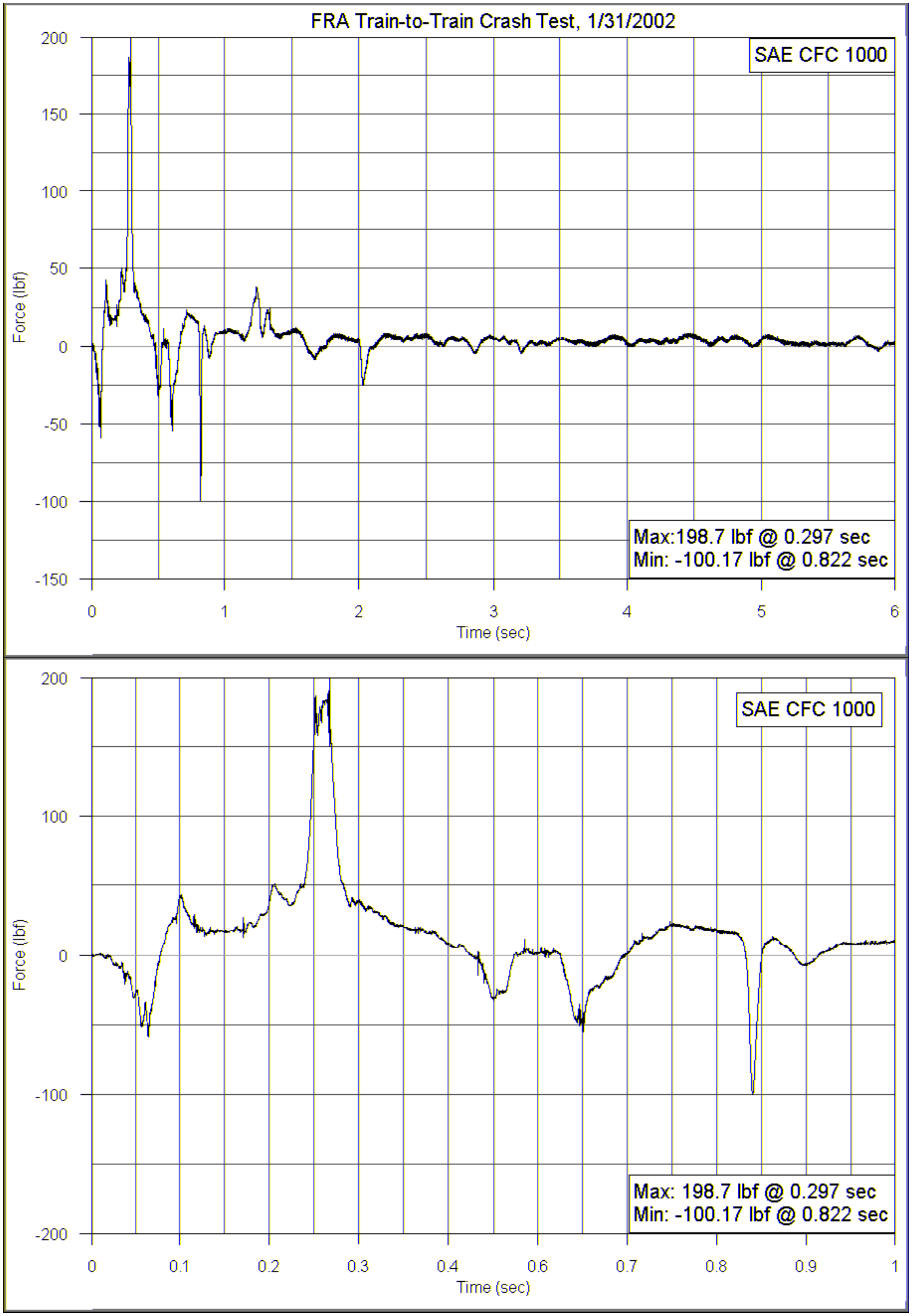


Figure D-11: Experiment No. 1-1 M-Style Seat, Aft Row, Aisle Seat, Hybrid III 50th Upper Neck Z-axis Axial Force

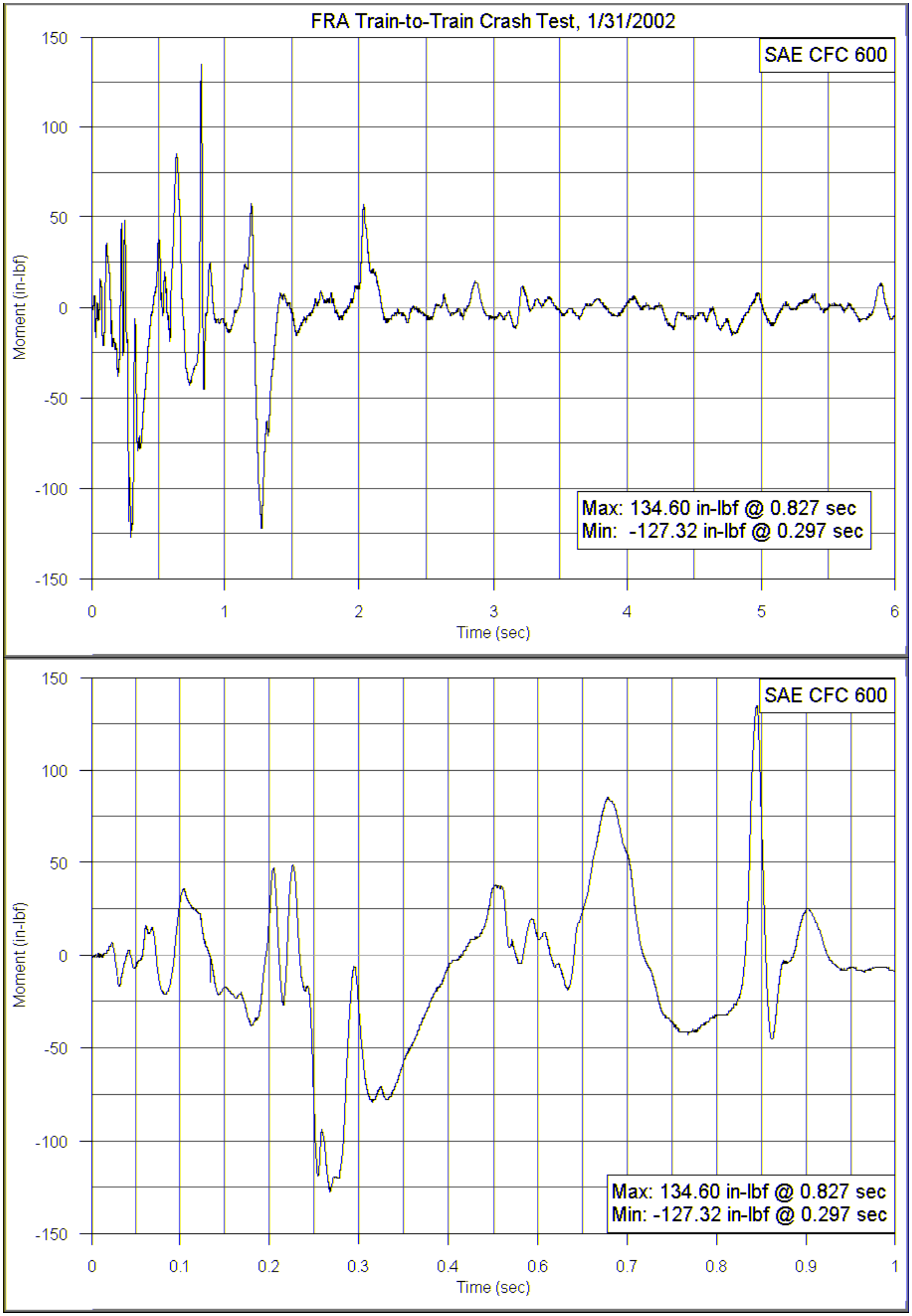


Figure D-12: Experiment No. 1-1 M-Style Seat, Aft Row, Aisle Seat, Hybrid III 50th Upper Neck Y-axis Moment

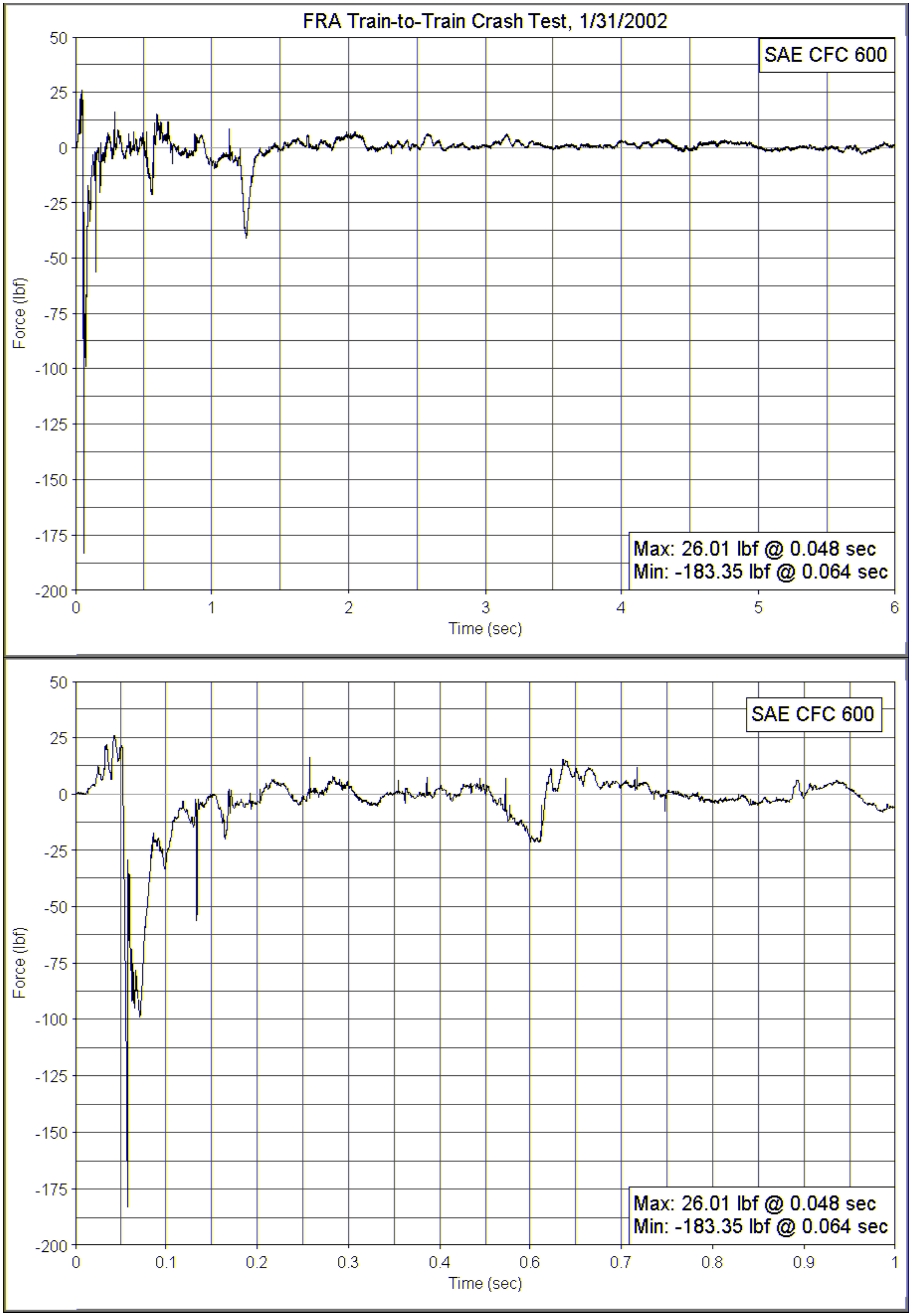


Figure D-13: Experiment No. 1-1 M-Style Seat, Aft Row, Aisle Seat, Hybrid III 50th Left Femur Axial Force

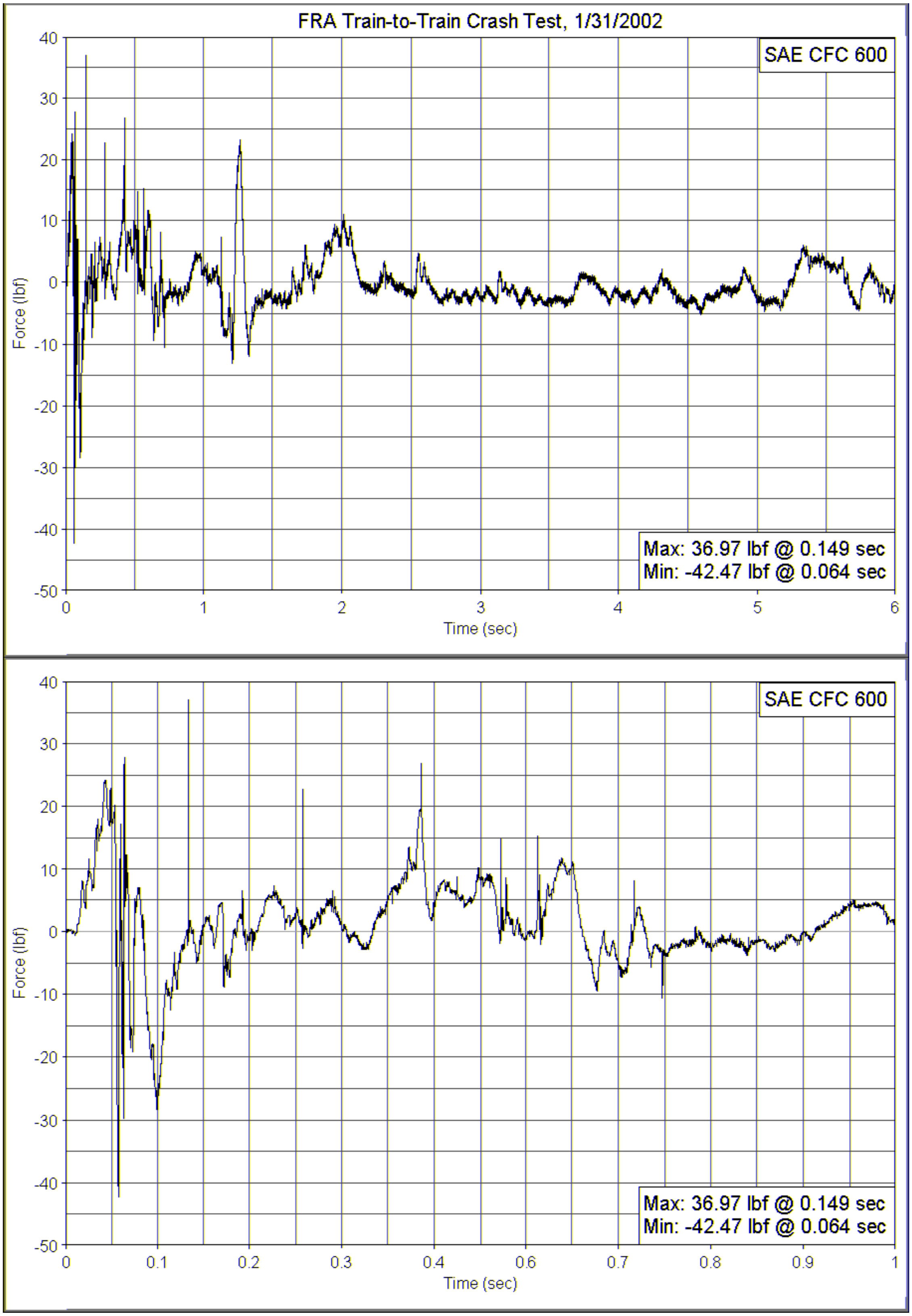


Figure D-14: Experiment No. 1-1 M-Style Seat, Aft Row, Aisle Seat, Hybrid III 50th Right Femur Axial Force

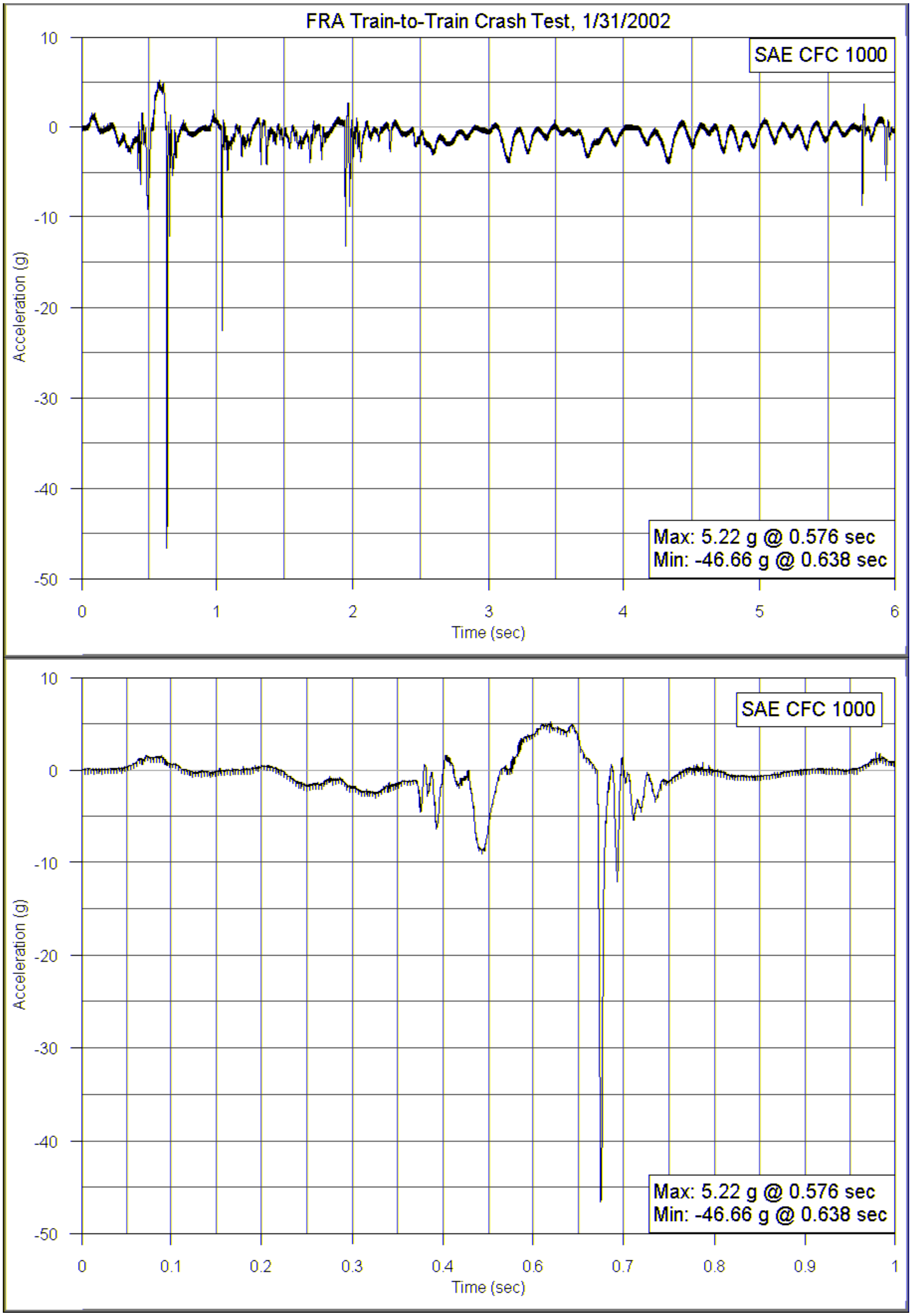


Figure D-15: Experiment No. 2-1 Intercity Seat, Aft Row, Aisle Seat, Hybrid III 95th Head X-axis Acceleration

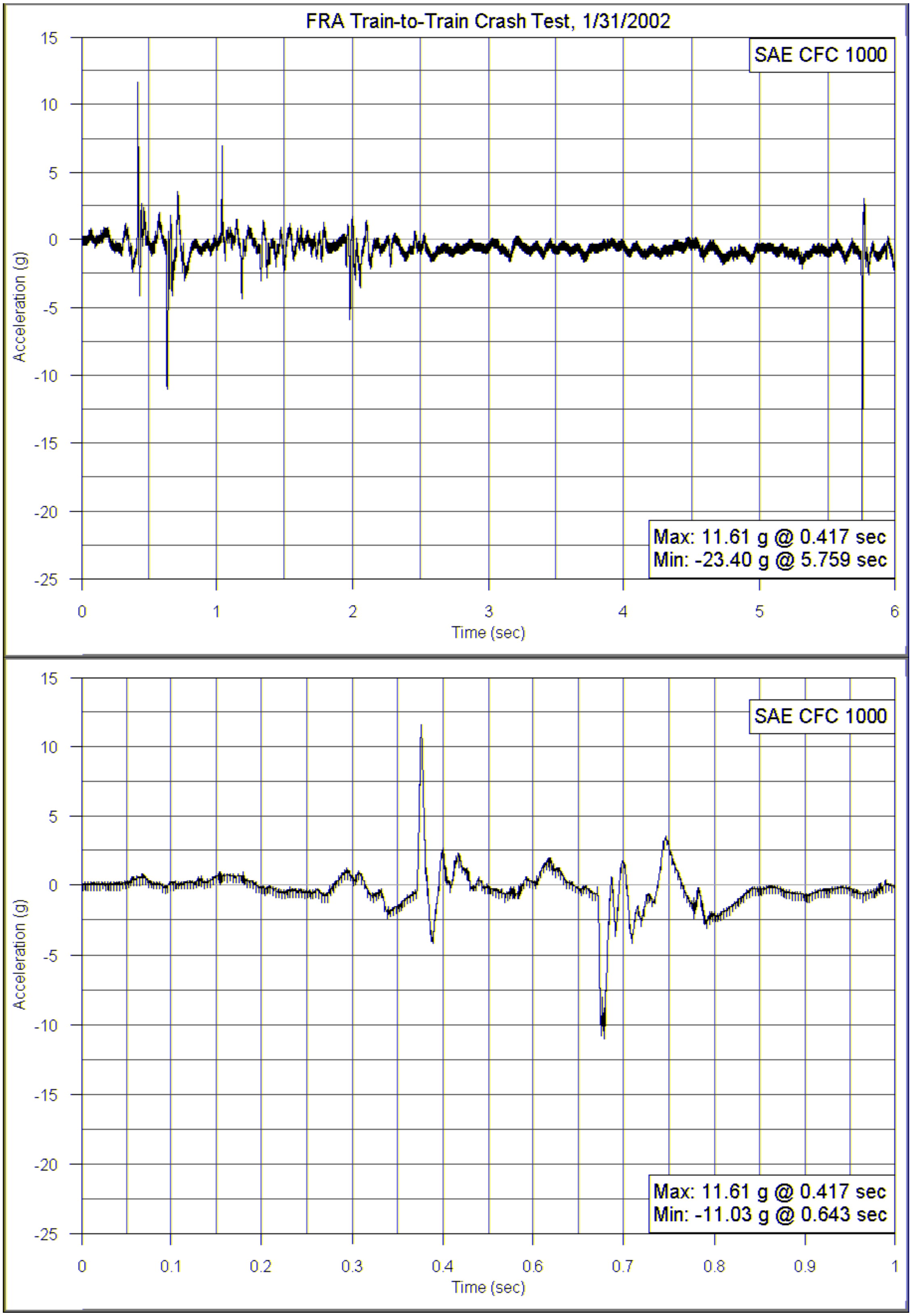


Figure D-16: Experiment No. 2-1 Intercity Seat, Aft Row, Aisle Seat, Hybrid III 95th Head Y-axis Acceleration

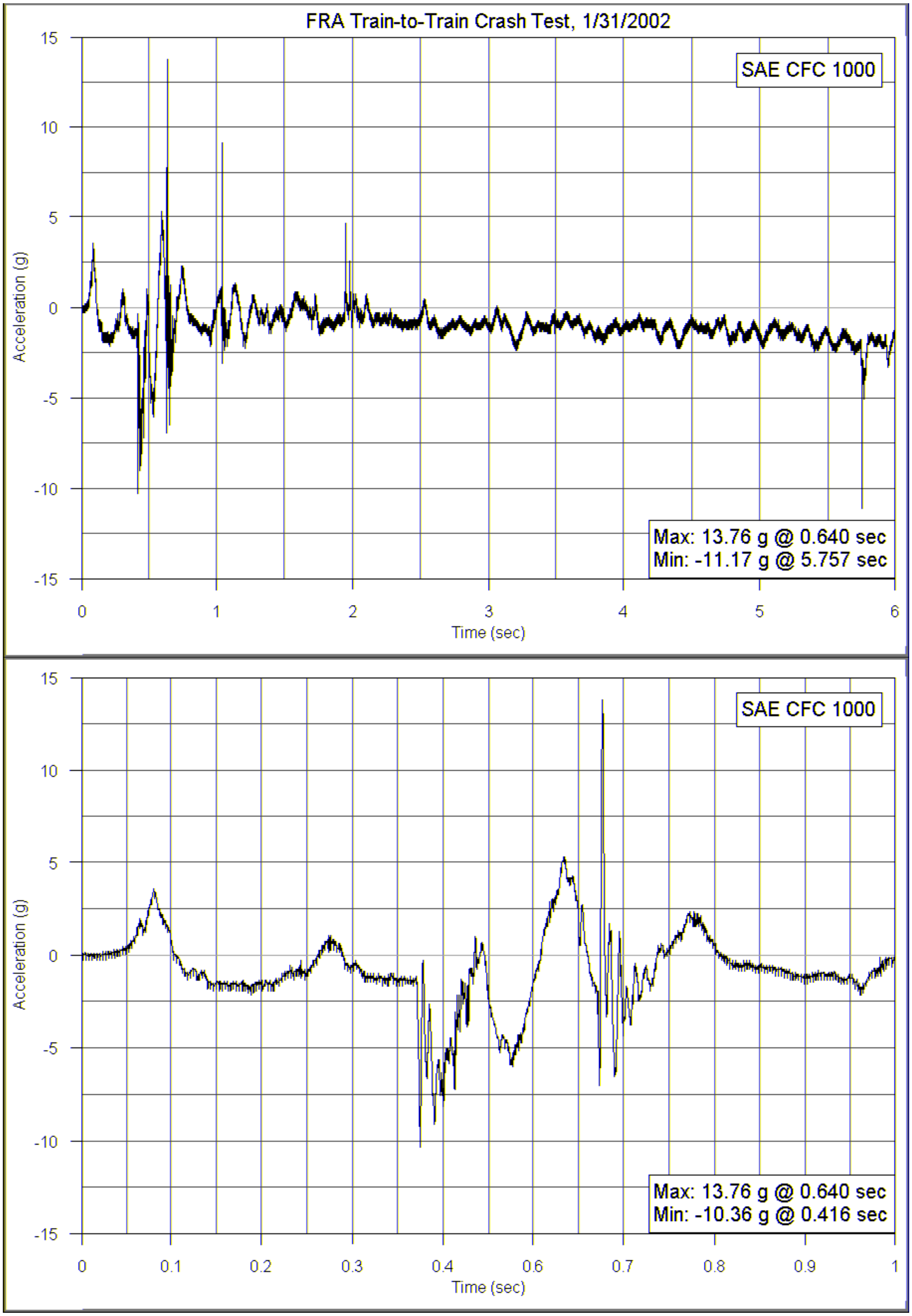


Figure D-17: Experiment No. 2-1 Intercity Seat, Aft Row, Aisle Seat, Hybrid III 95th Head Z-axis Acceleration

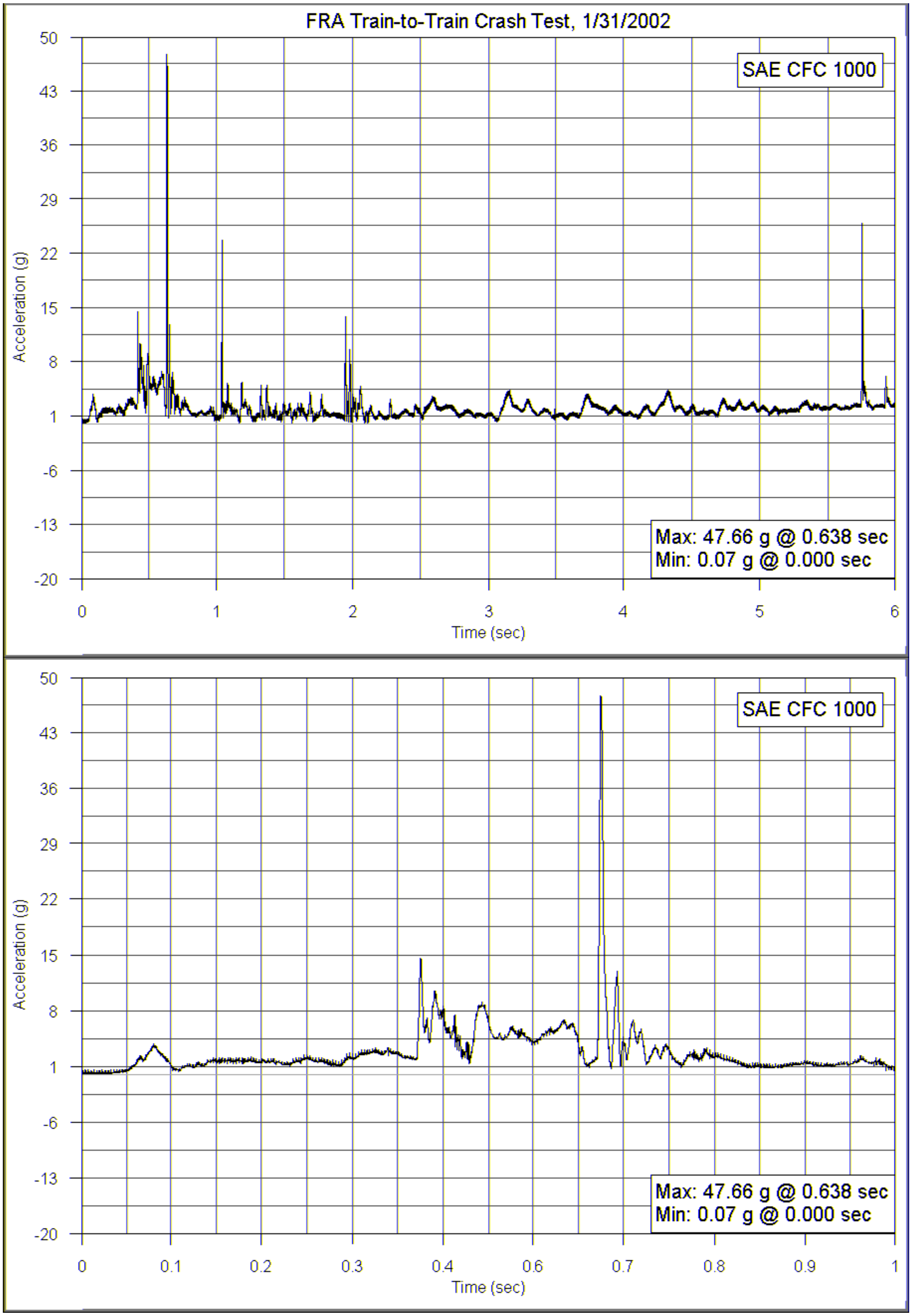


Figure D-18: Experiment No. 2-1 Intercity Seat, Aft Row, Aisle Seat, Hybrid III 95th Head Resultant Acceleration

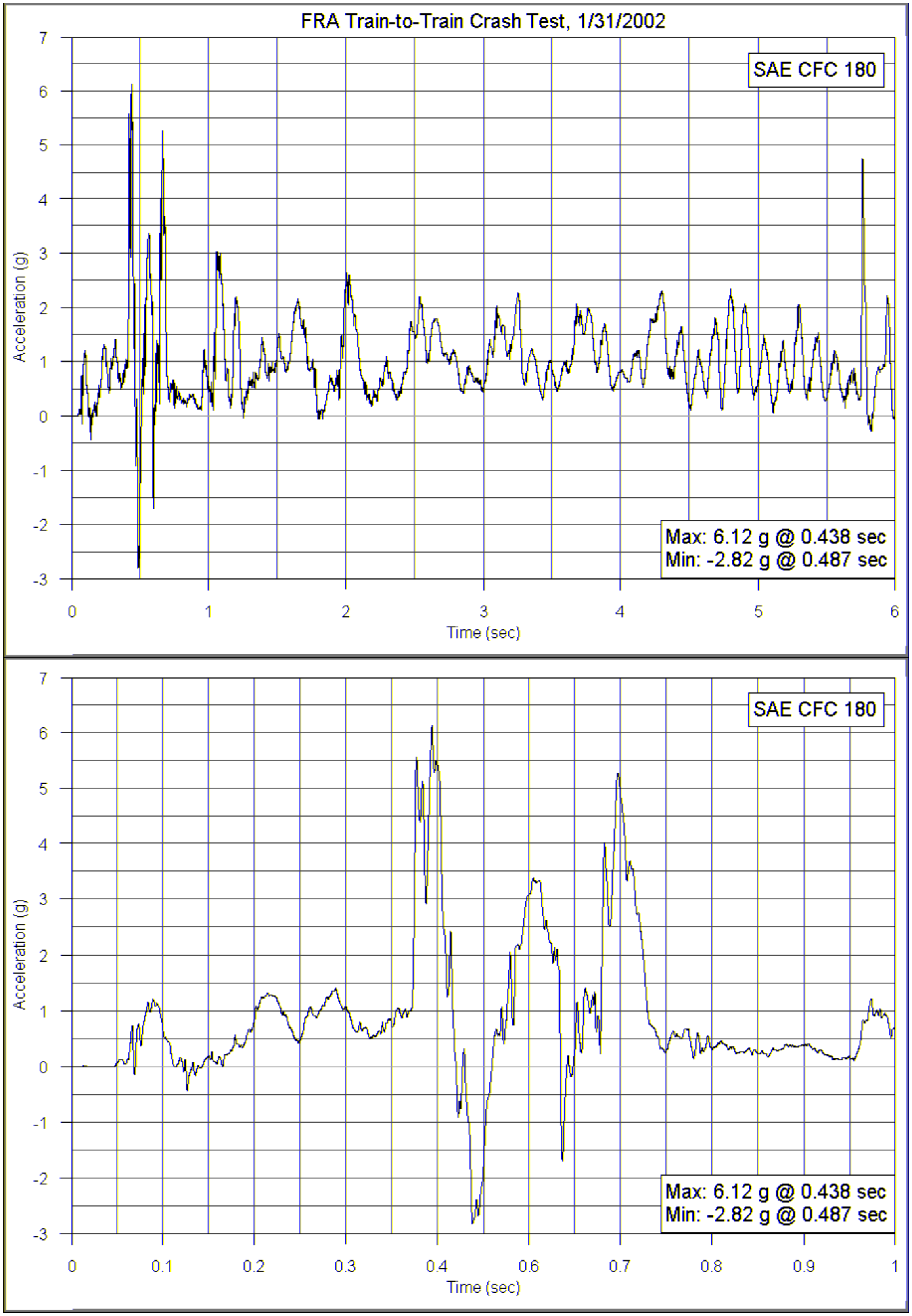


Figure D-19: Experiment No. 2-1 Intercity Seat, Aft Row, Aisle Seat, Hybrid III 95th Chest X-axis Acceleration

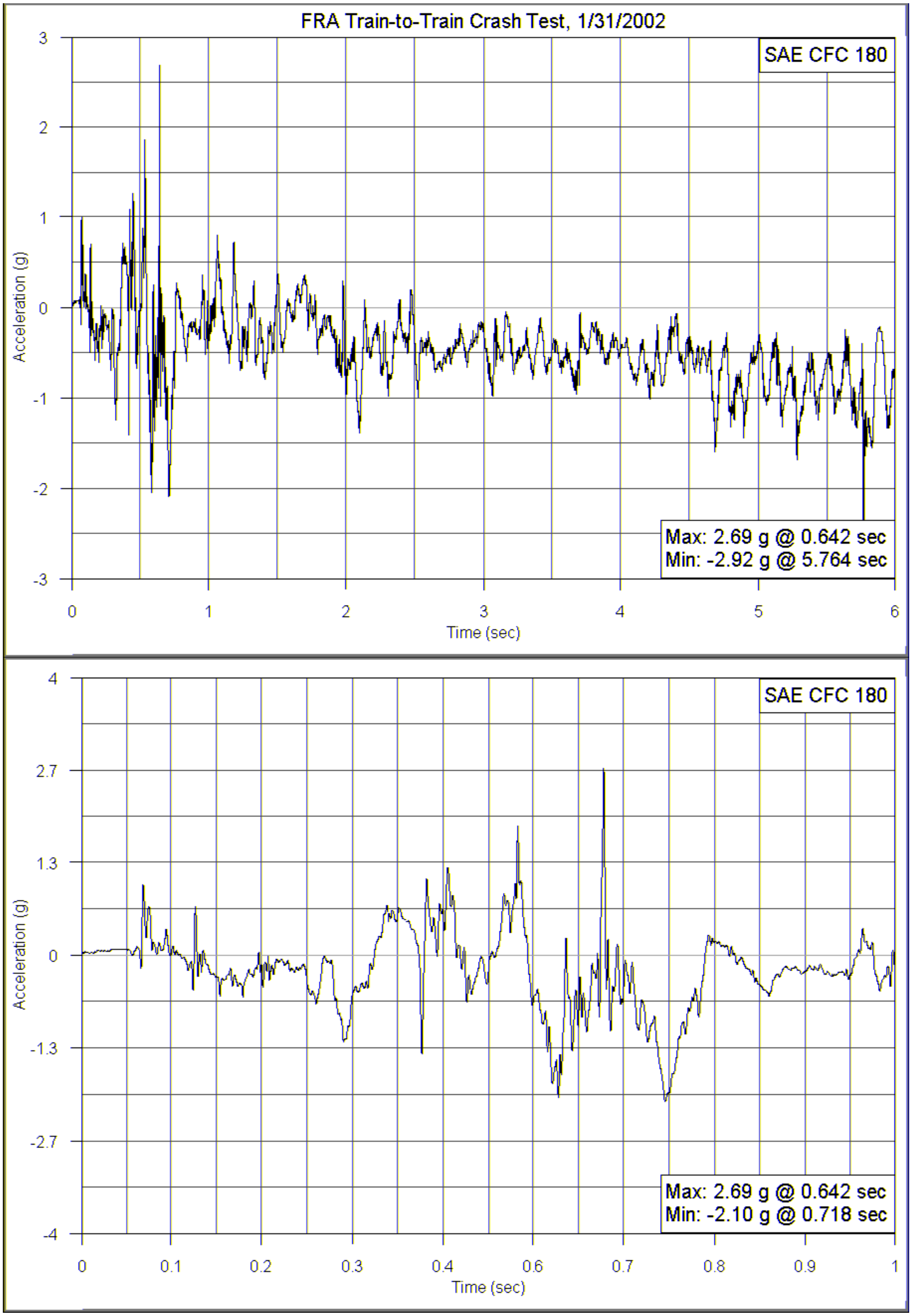


Figure D-20: Experiment No. 2-1 Intercity Seat, Aft Row, Aisle Seat, Hybrid III 95th Chest Y-axis Acceleration

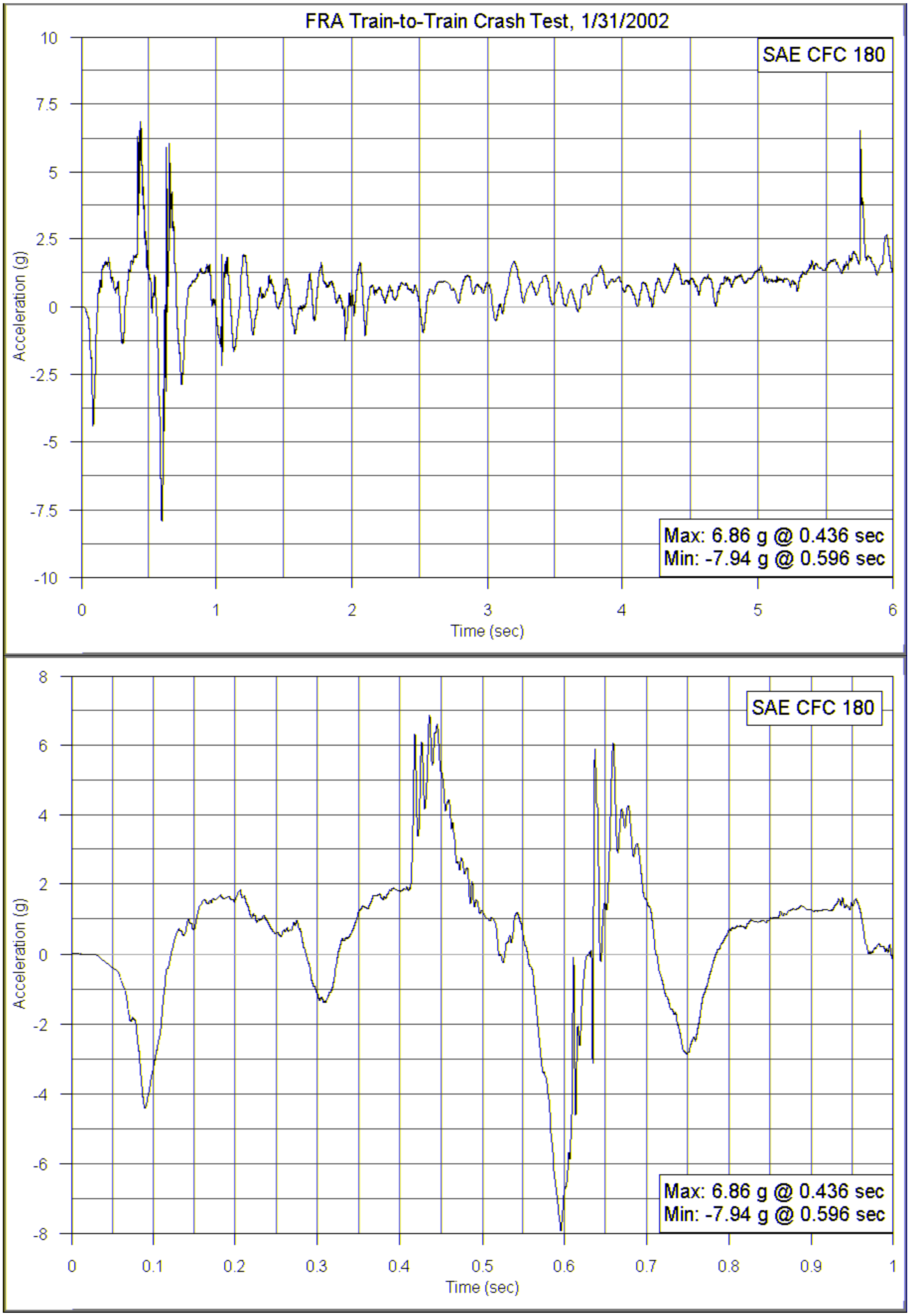


Figure D-21: Experiment No. 2-1 Intercity Seat, Aft Row, Aisle Seat, Hybrid III 95th Chest Z-axis Acceleration

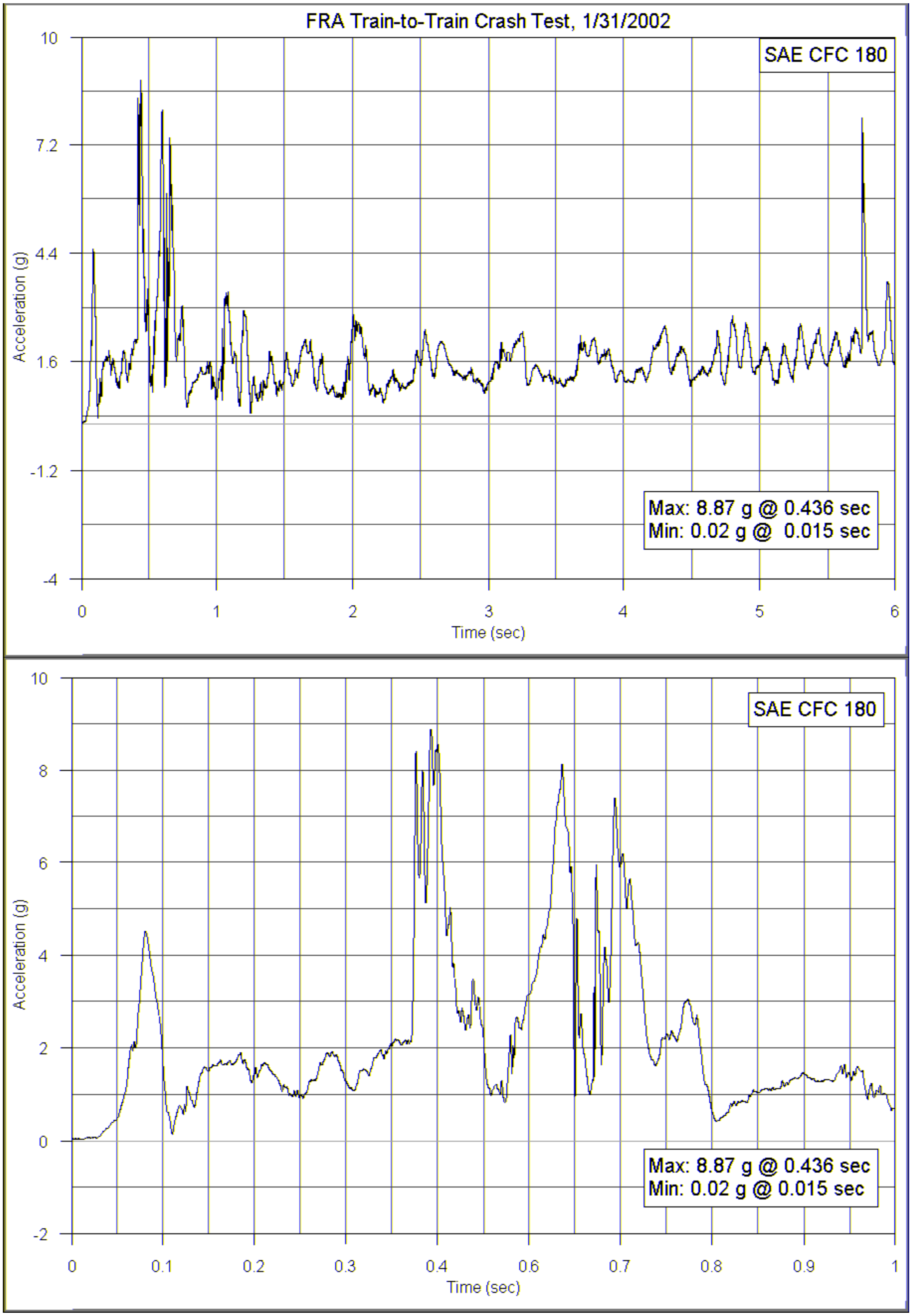


Figure D-22: Experiment No. 2-1 Intercity Seat, Aft Row, Aisle Seat, Hybrid III 95th Chest Resultant Acceleration

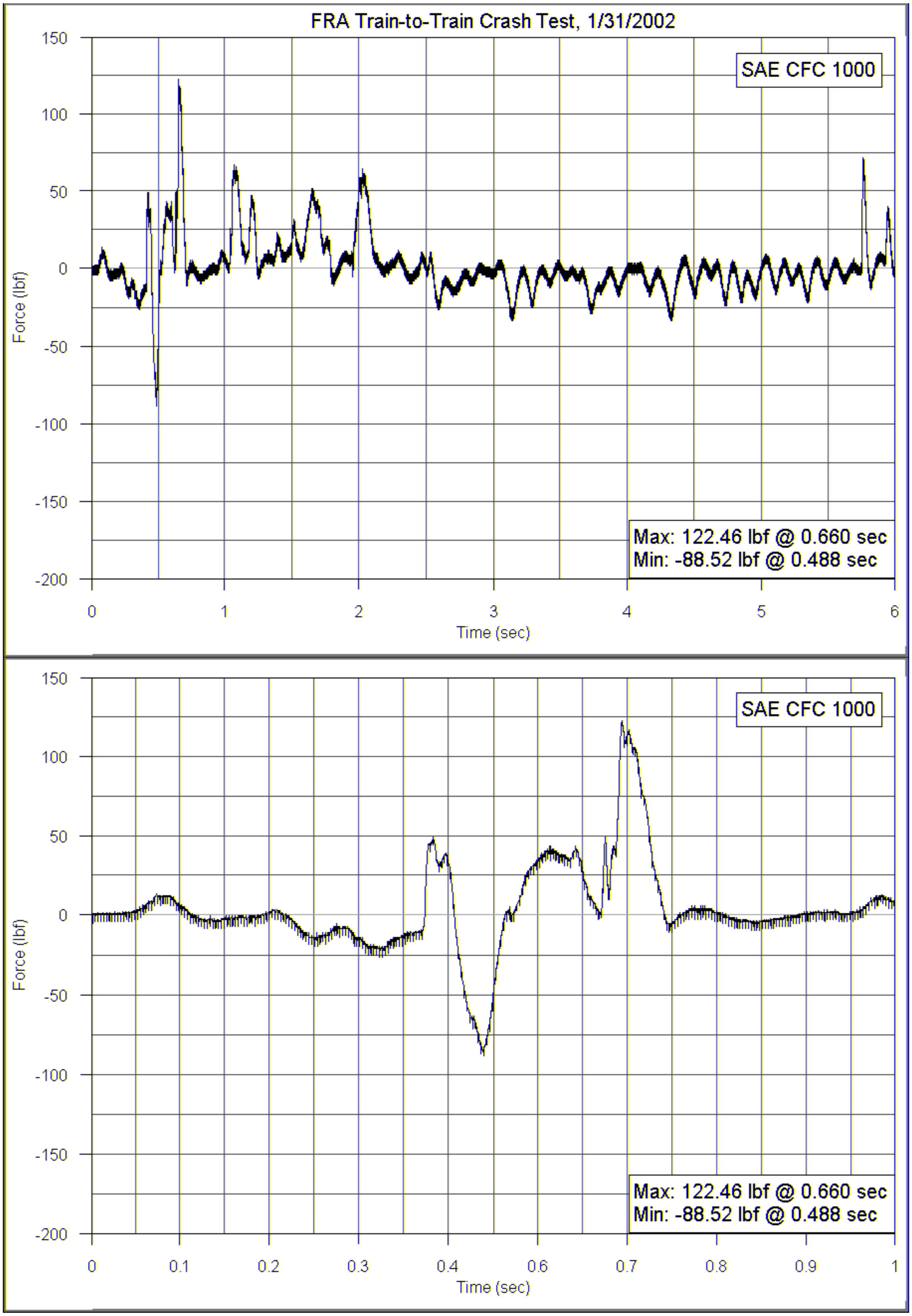


Figure D-23: Experiment No. 2-1 Intercity Seat, Aft Row, Aisle Seat, Hybrid III 95th Upper Neck X-axis Shear Force

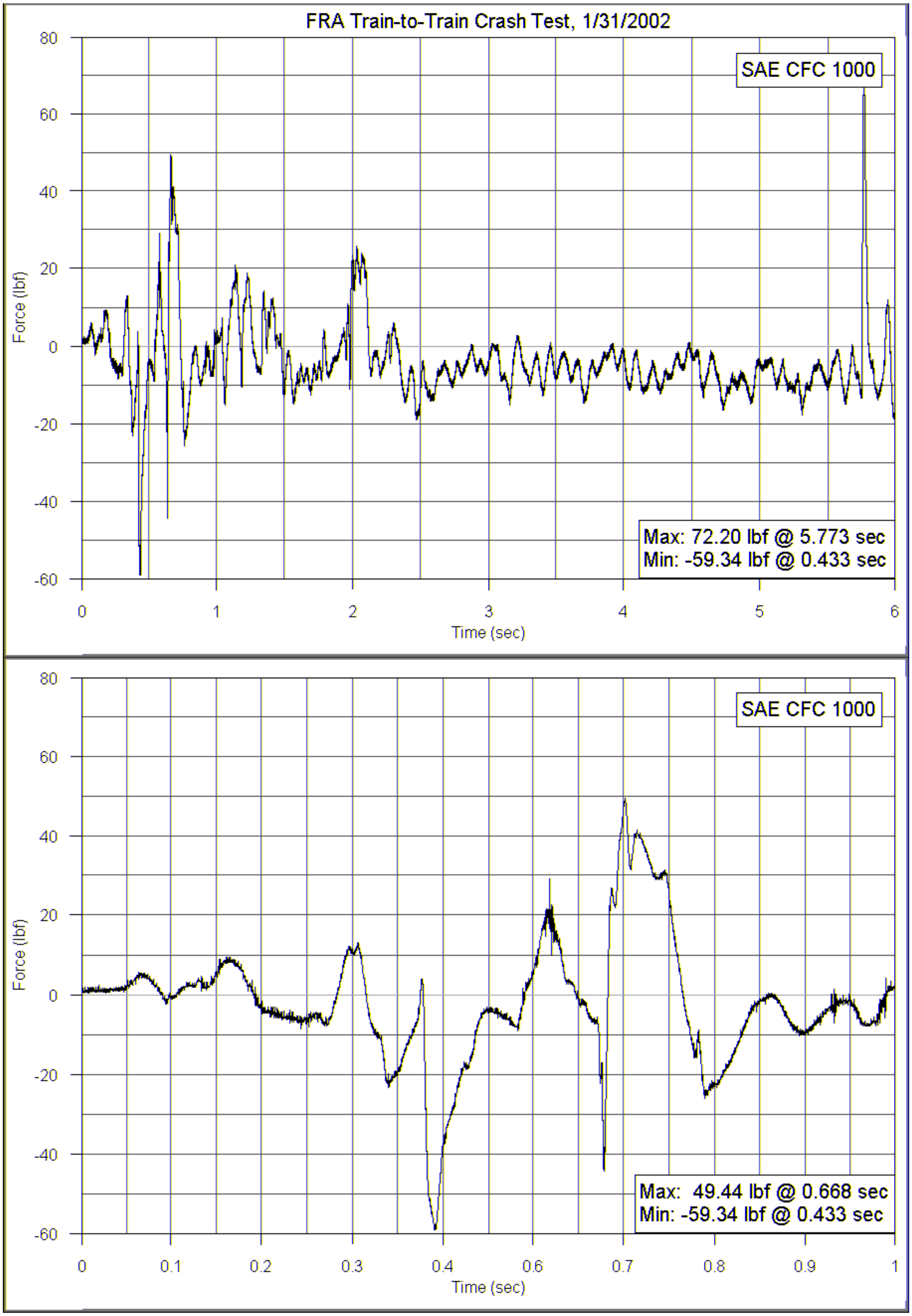


Figure D-24: Experiment No. 2-1 Intercity Seat, Aft Row, Aisle Seat, Hybrid III 95th Upper Neck Y-axis Shear Force

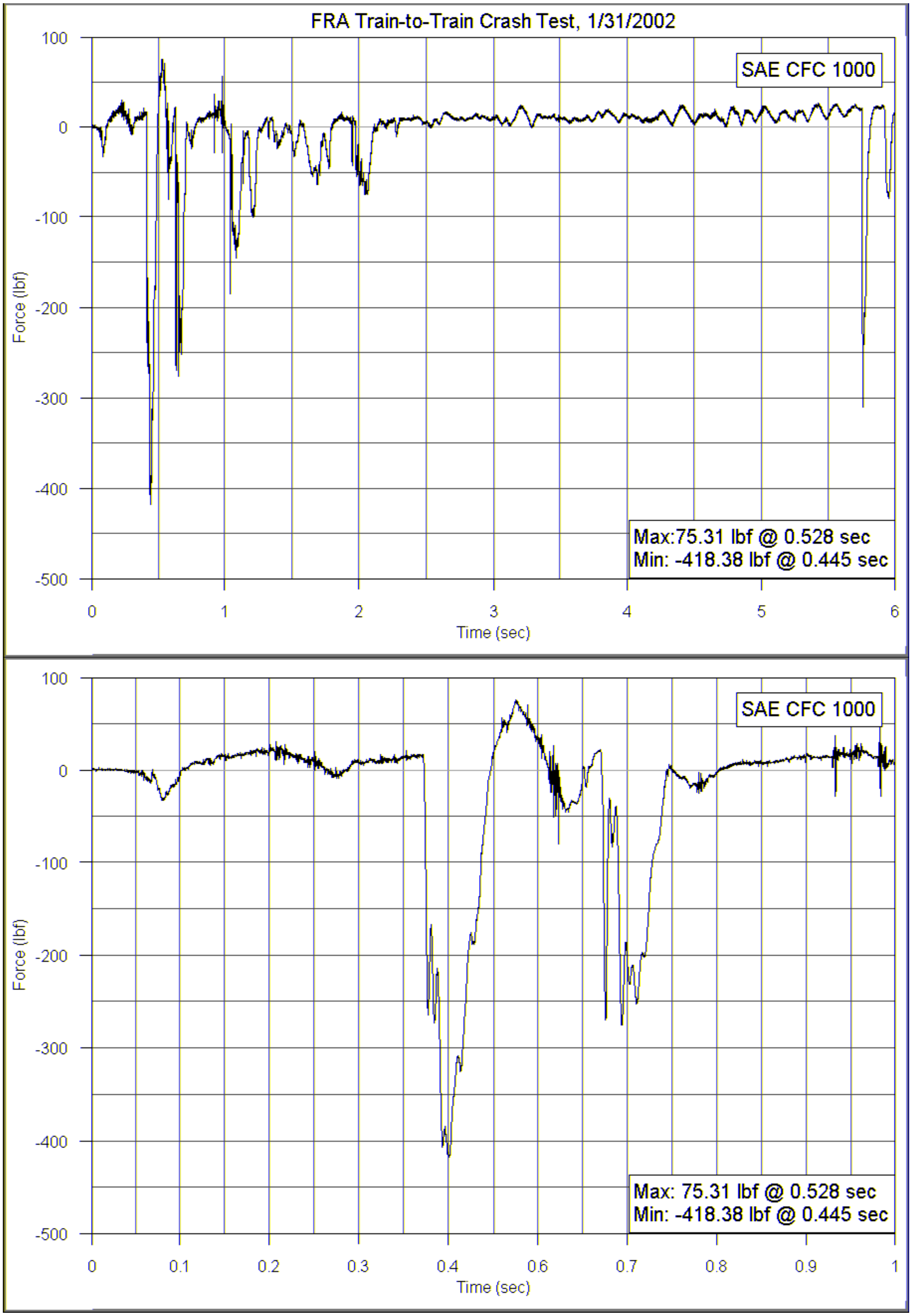


Figure D-25: Experiment No. 2-1 Intercity Seat, Aft Row, Aisle Seat, Hybrid III 95th Upper Neck Z-axis Axial Force

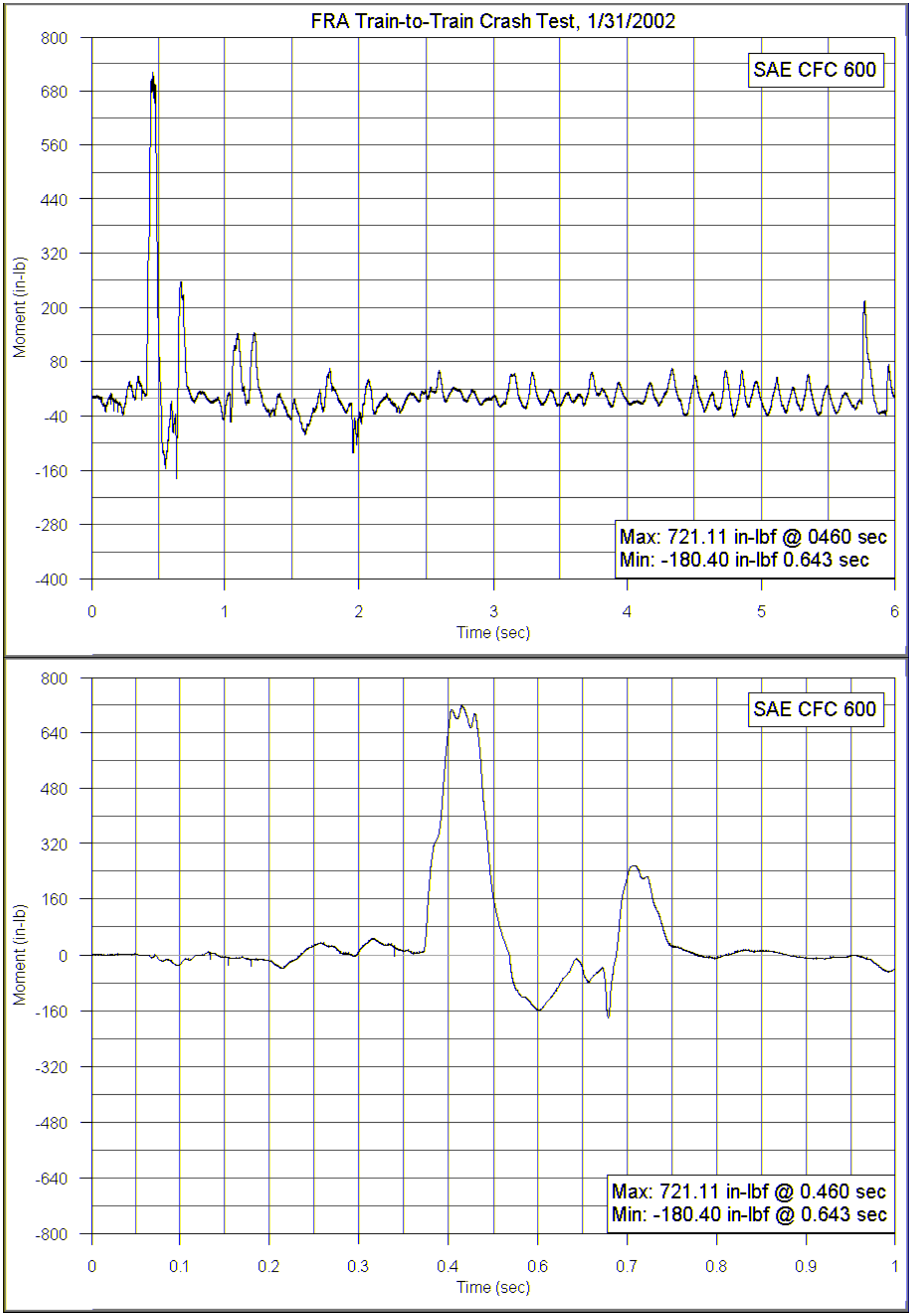


Figure D-26: Experiment No. 2-1 Intercity Seat, Aft Row, Aisle Seat, Hybrid III 95th Upper Neck Y-axis Moment

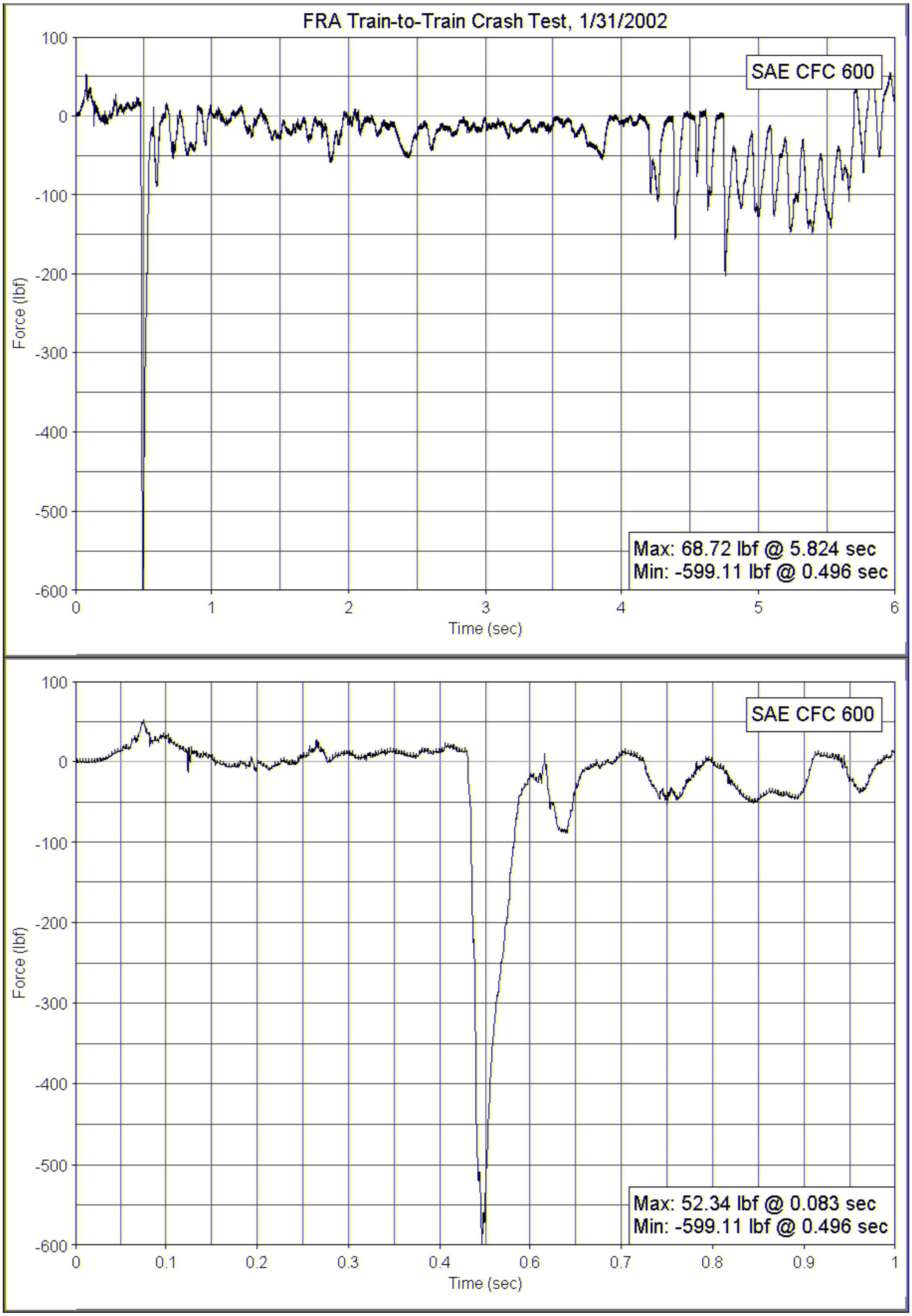


Figure D-27: Experiment No. 2-1 Intercity Seat, Aft Row, Aisle Seat, Hybrid III 95th Left Femur Axial Force

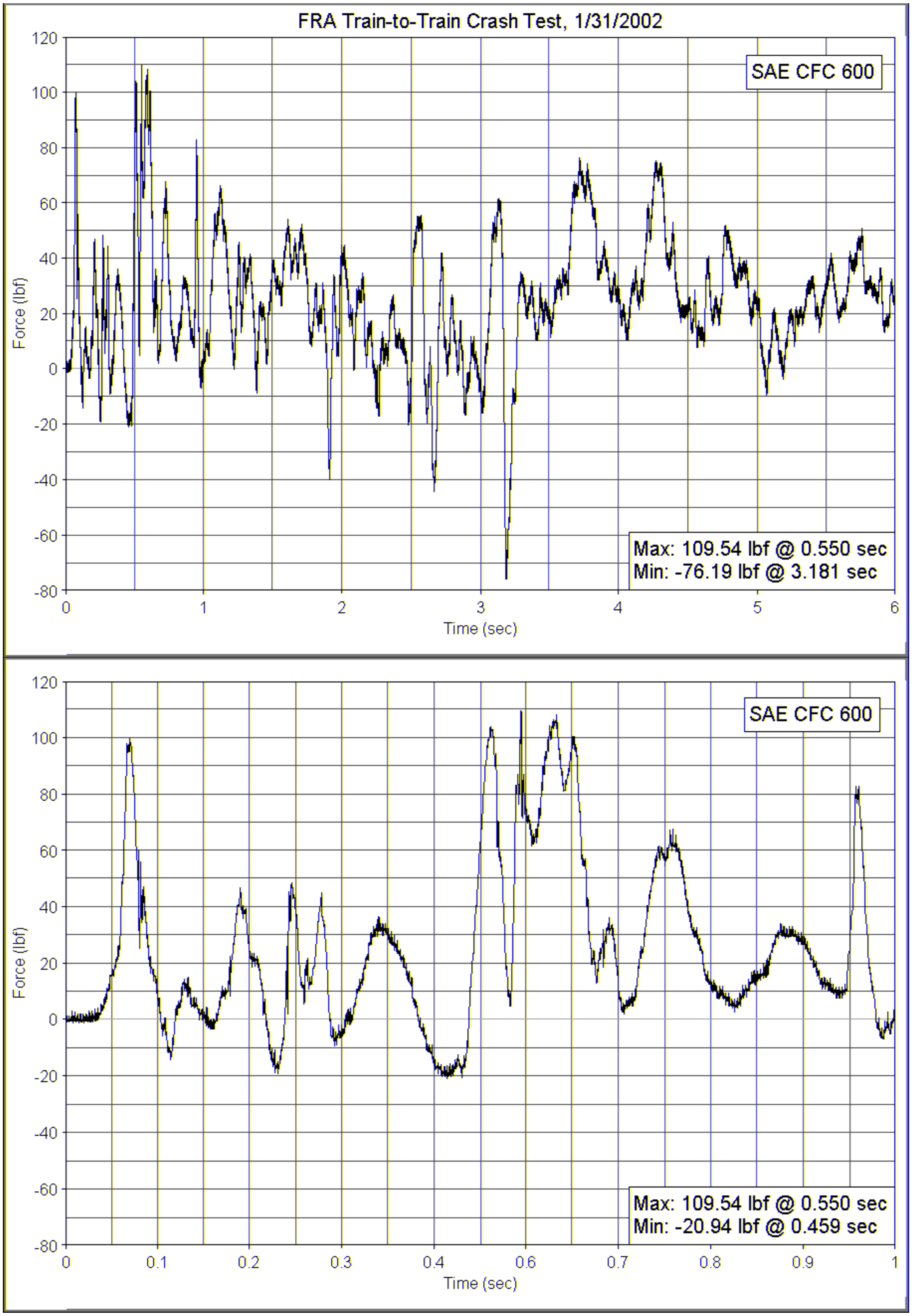


Figure D-28: Experiment No. 2-1 Intercity Seat, Aft Row, Aisle Seat, Hybrid III 95th Right Femur Axial Force

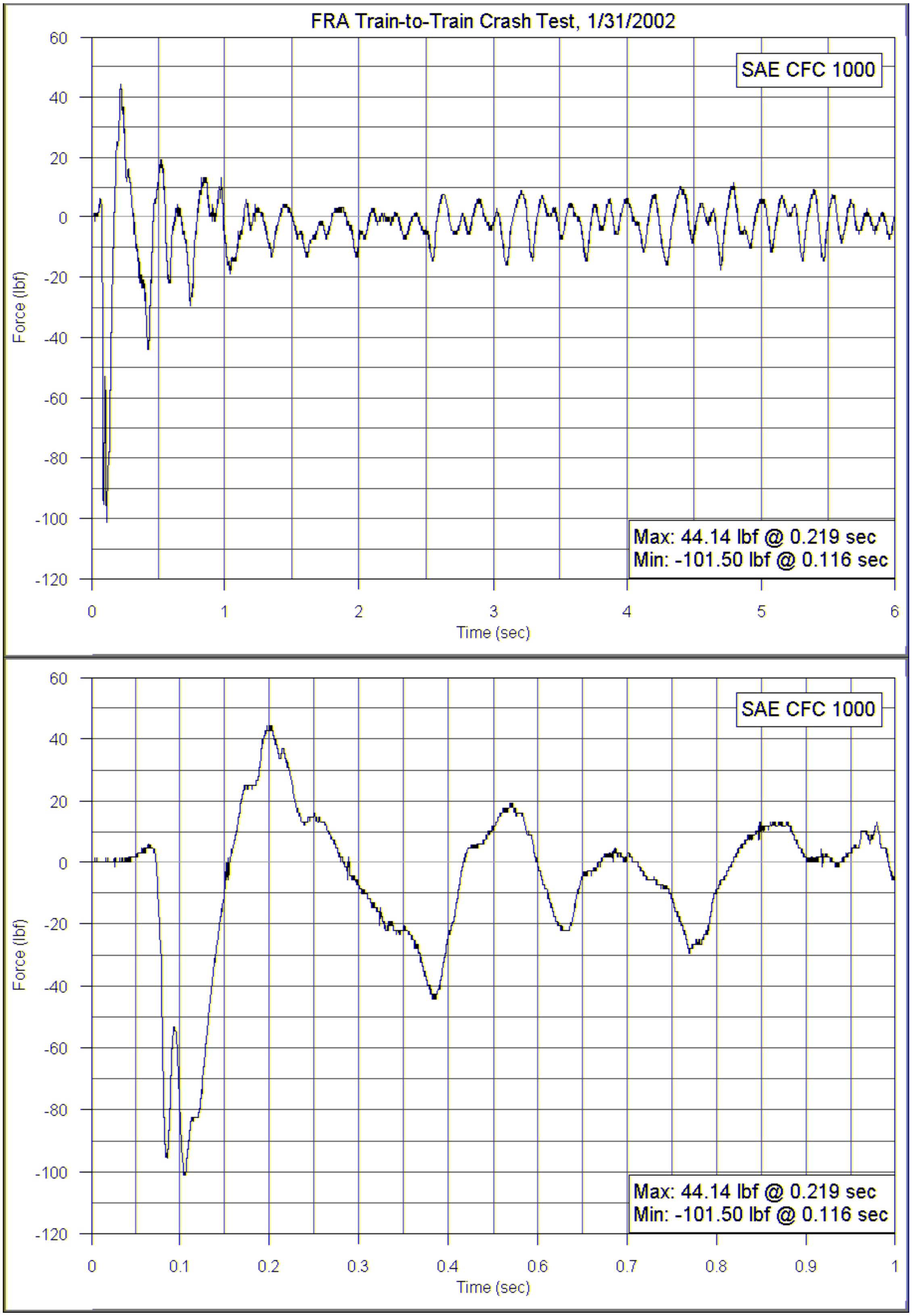
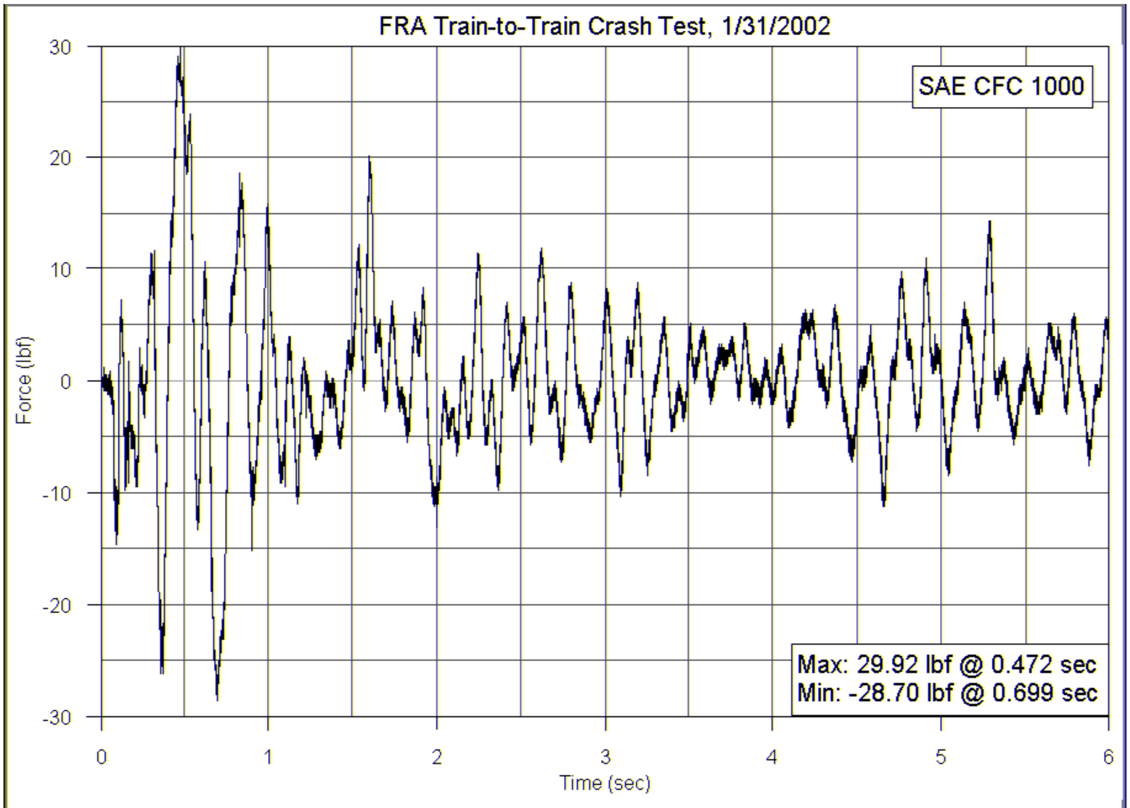


Figure D-29: Experiment No. 2-1 Intercity Seat, Fwd Row, Window Seat, Hybrid III 95th Upper Neck X-axis Shear Force



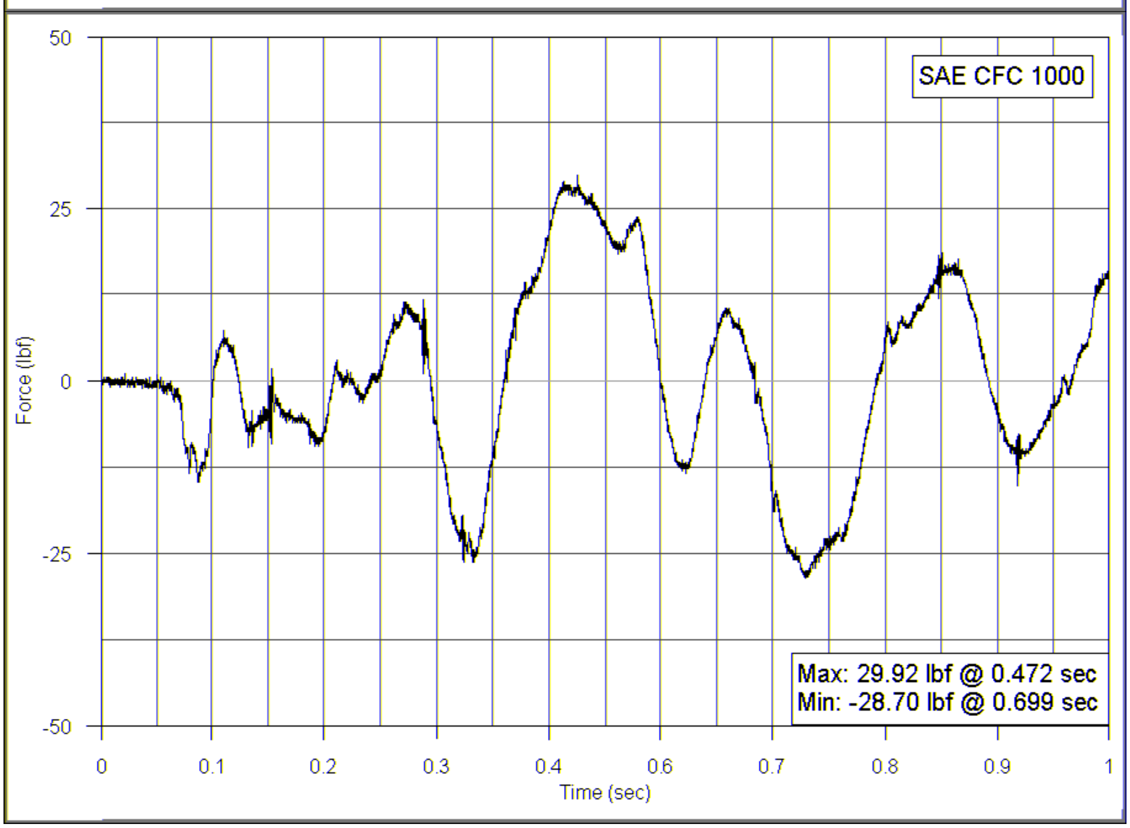


Figure D-30: Experiment No. 2-1 Intercity Seat, Fwd Row, Window Seat, Hybrid III 95th Upper Neck Y-axis Shear Force

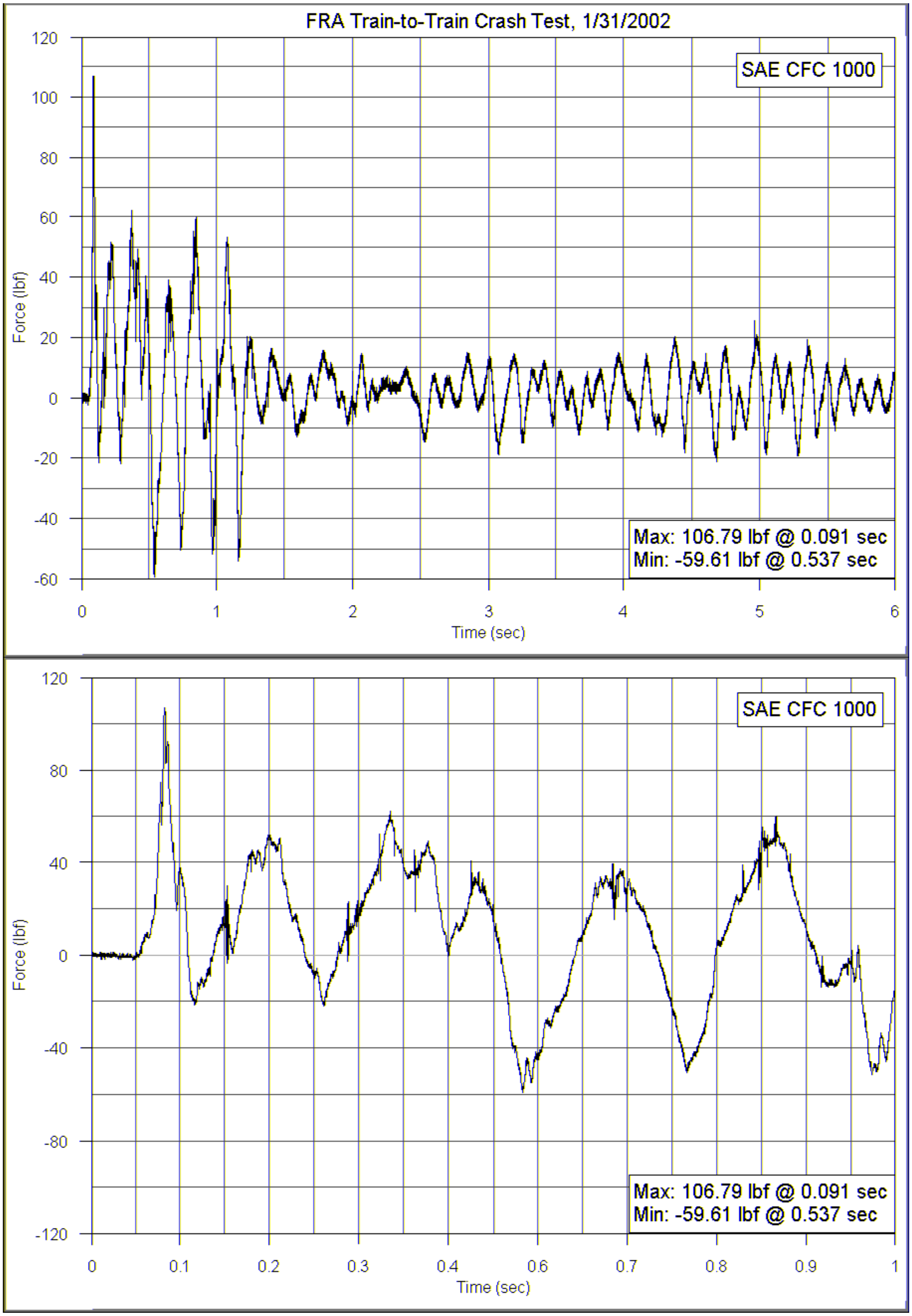


Figure D-31: Experiment No. 2-1 Intercity Seat, Fwd Row, Window Seat, Hybrid III 95th Upper Neck Z-axis Axial Force

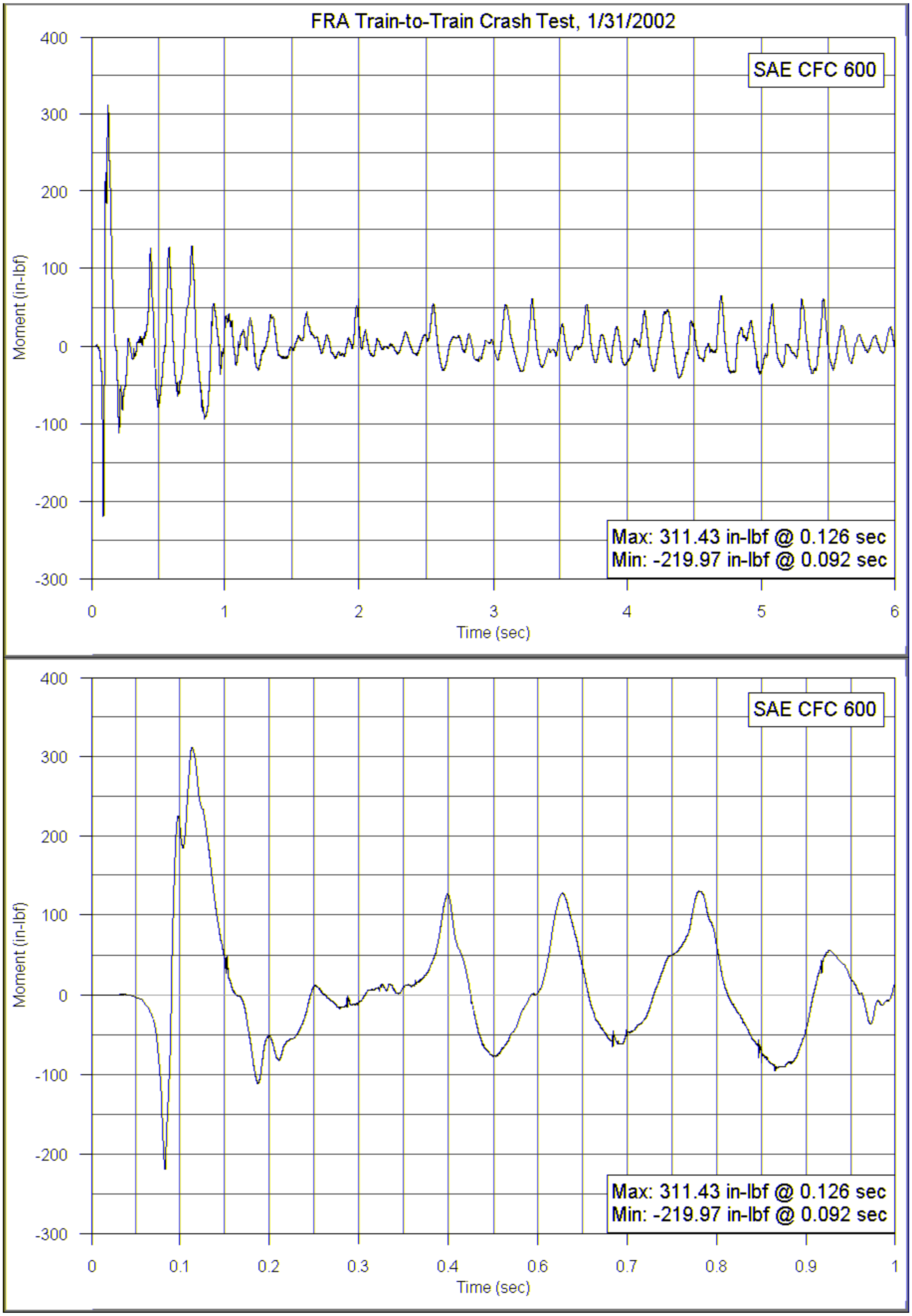


Figure D-32: Experiment No. 2-1 Intercity Seat, Fwd Row, Window Seat, Hybrid III 95th Upper Neck Y-axis Moment

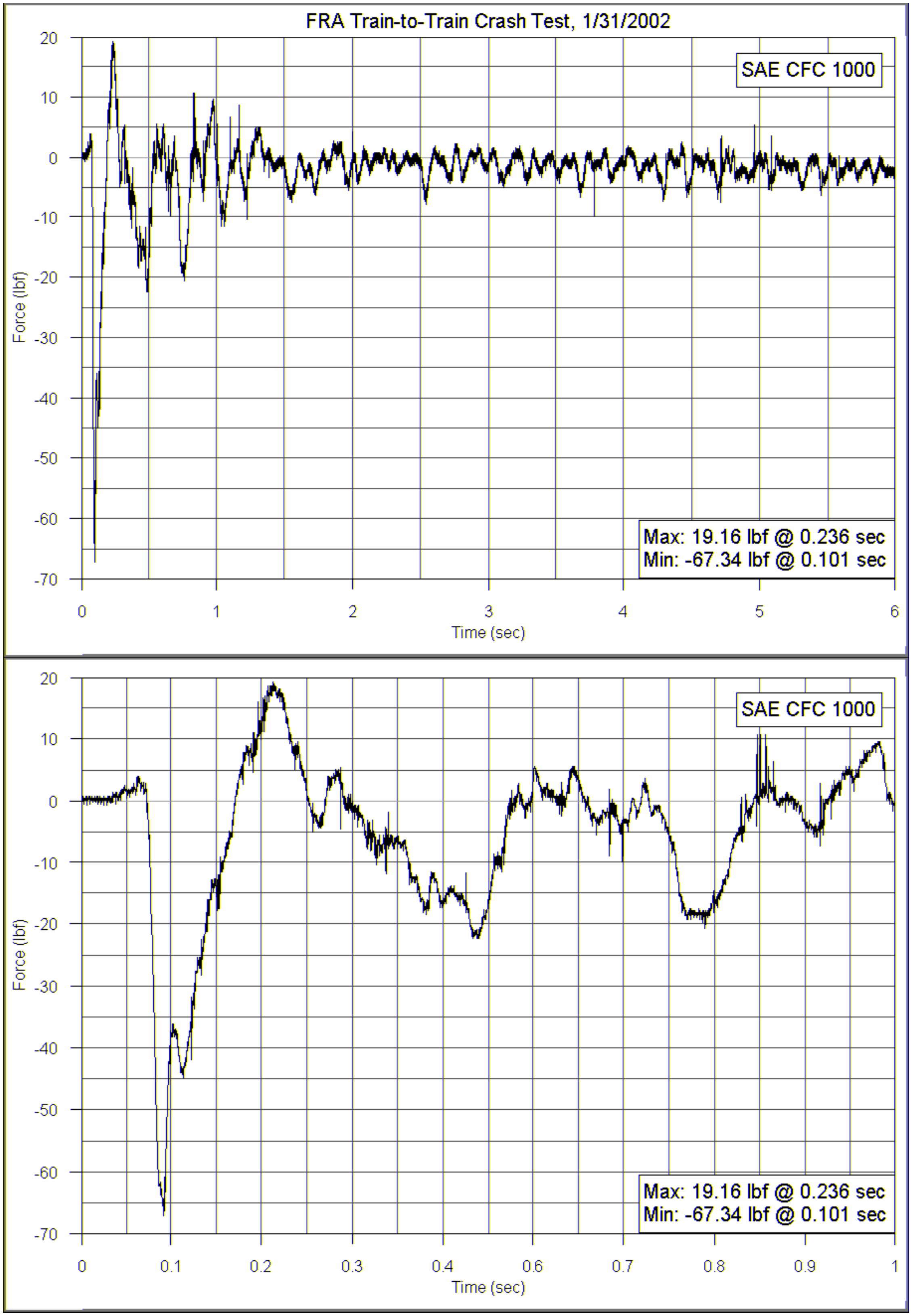


Figure D-33: Experiment No. 2-1 Intercity Seat, Fwd Row, Aisle Seat, Hybrid III 5th Upper Neck X-axis Shear Force

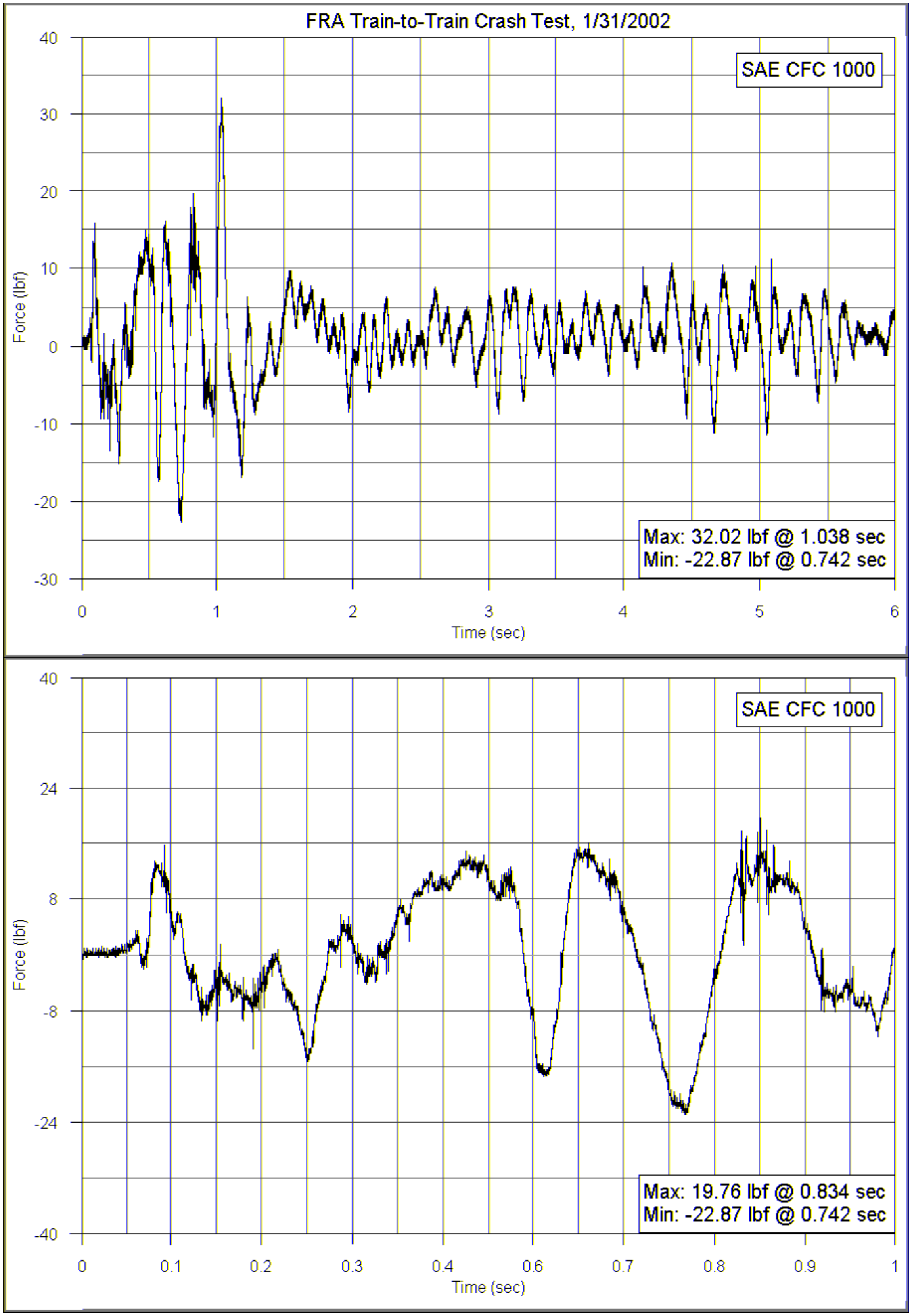
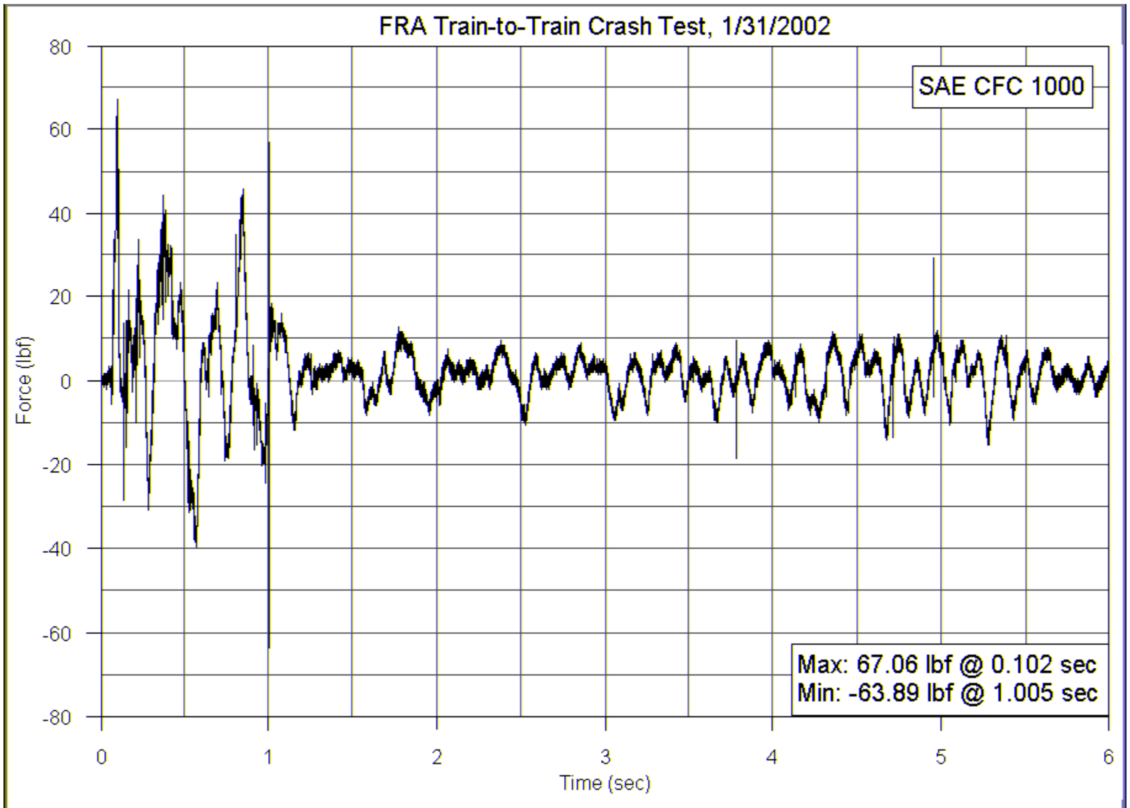


Figure D-34: Experiment No. 2-1 Intercity Seat, Fwd Row, Aisle Seat, Hybrid III 5th Upper Neck Y-axis Shear Force



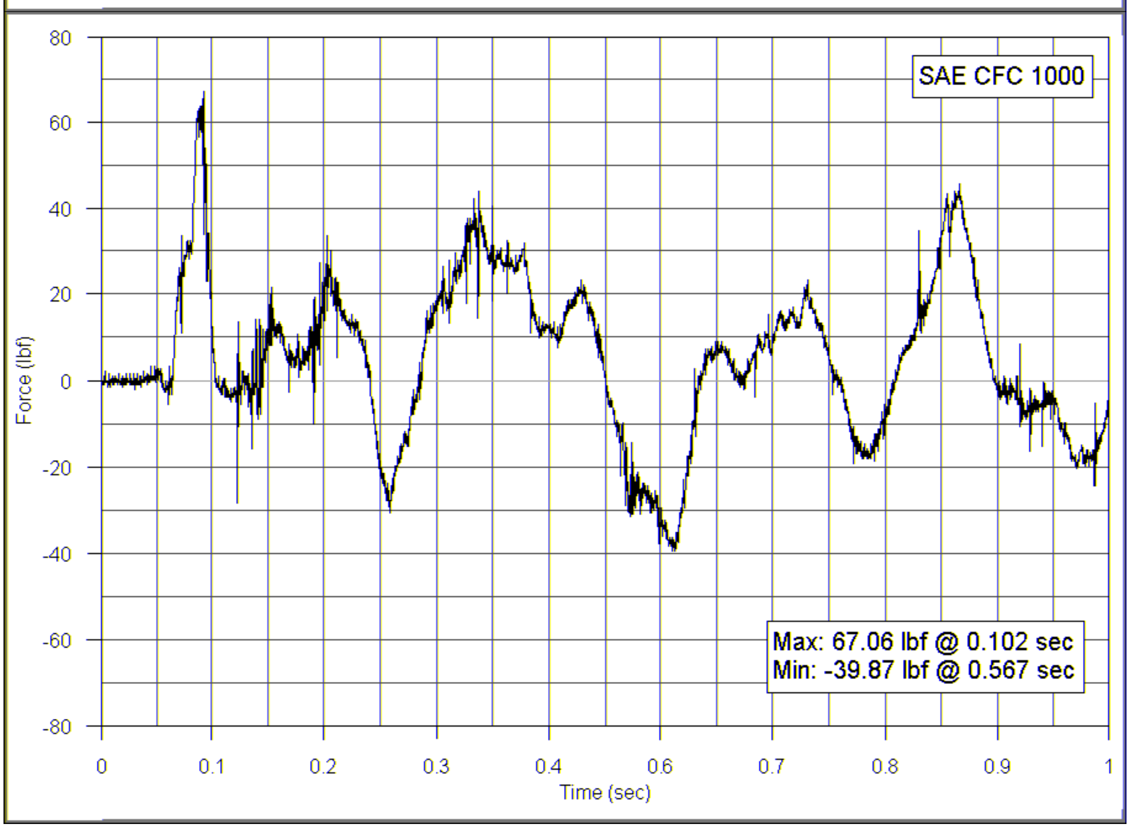


Figure D-35: Experiment No. 2-1 Intercity Seat, Fwd Row, Aisle Seat, Hybrid III 5th Upper Neck Z-axis Axial Force

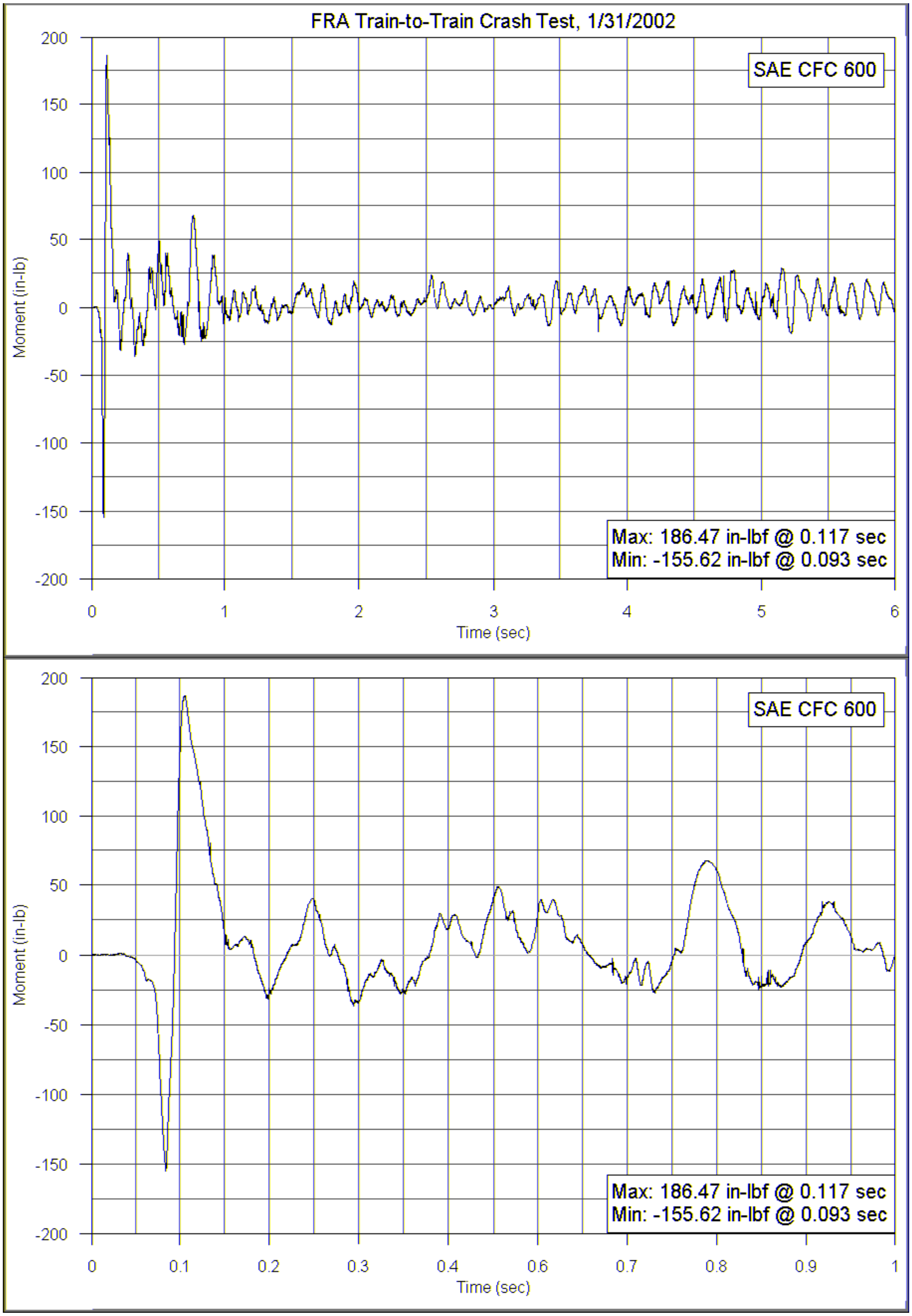


Figure D-36: Experiment No. 2-1 Intercity Seat, Fwd Row, Aisle Seat, Hybrid III 5th Upper Neck Y-axis Moment

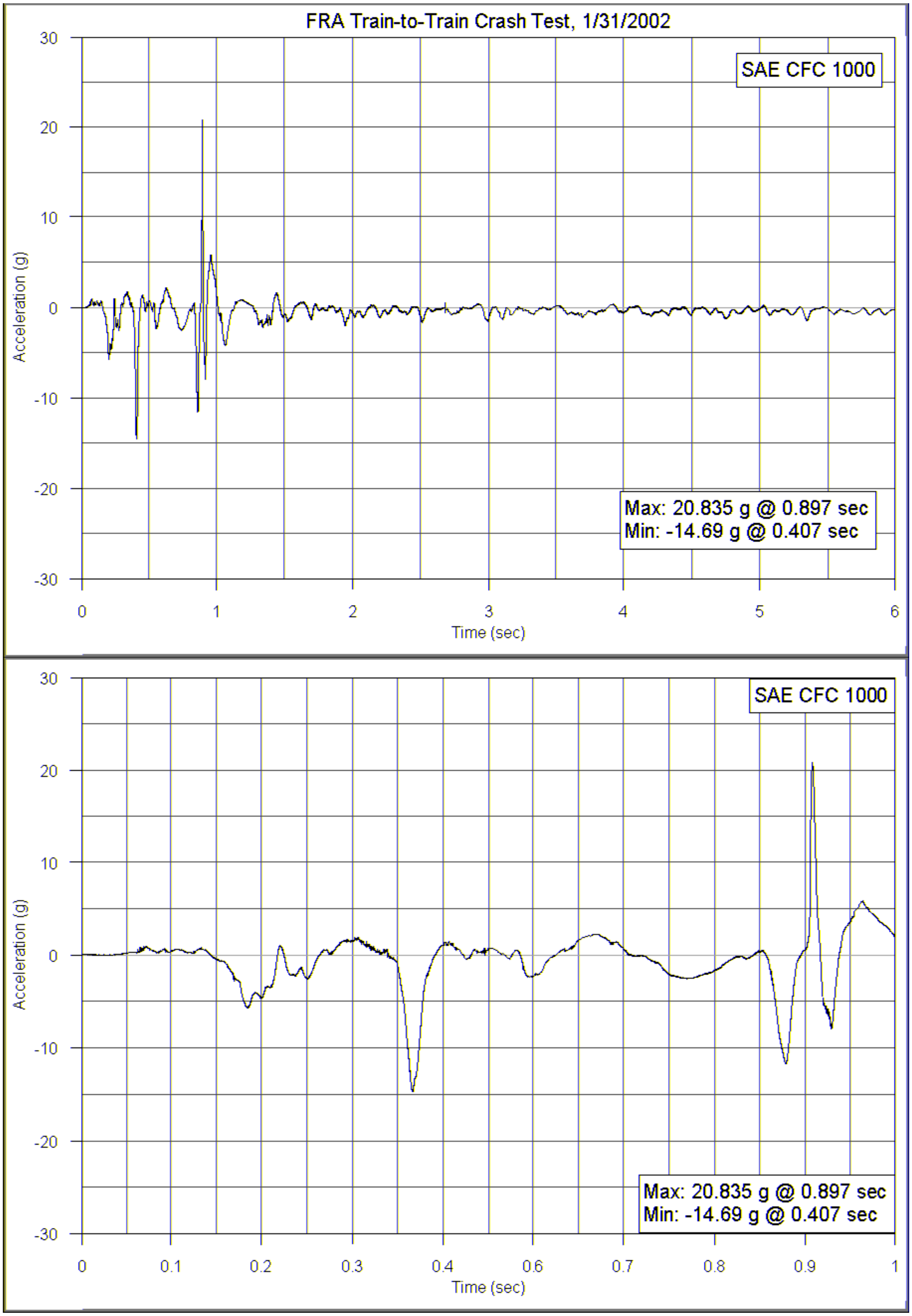


Figure D-37: Experiment No. 2-2 M-Style Seat, Aft Row, Aisle Seat, Hybrid III 50th Head X-axis Acceleration

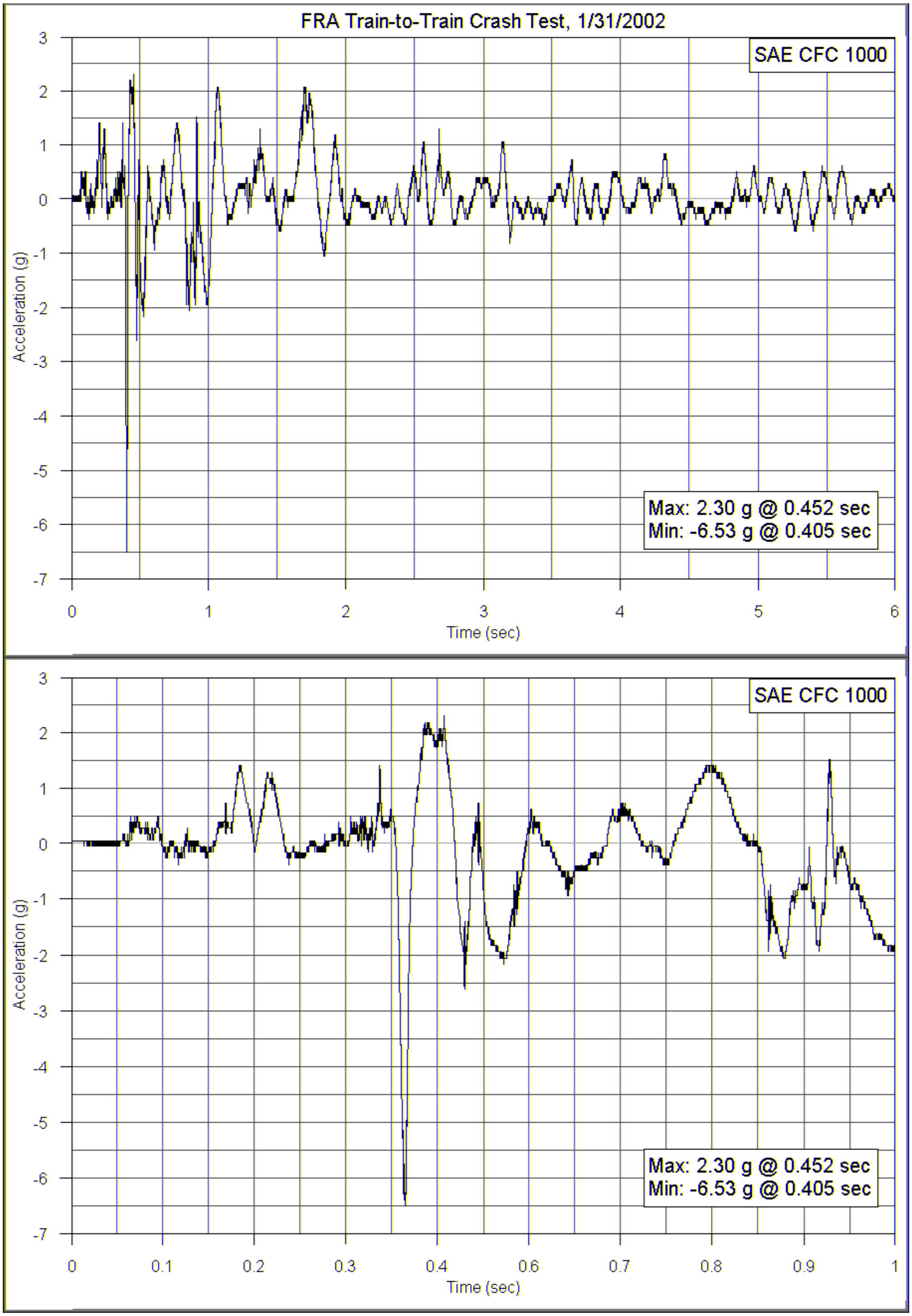


Figure D-38: Experiment No. 2-2 M-Style Seat, Aft Row, Aisle Seat, Hybrid III 50th Head Y-axis Acceleration

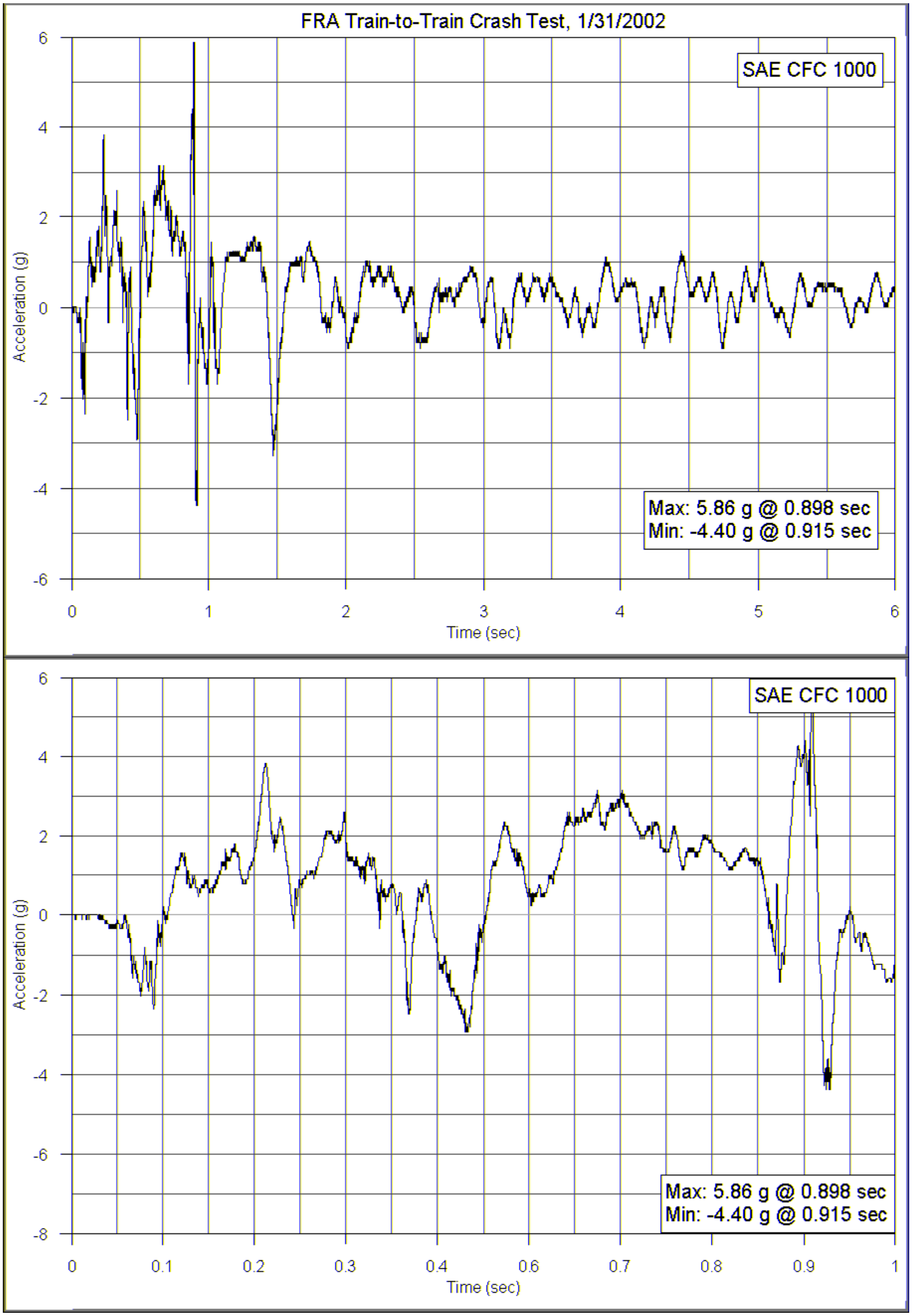


Figure D-39: Experiment No. 2-2 M-Style Seat, Aft Row, Aisle Seat, Hybrid III 50th Head Z-axis Acceleration

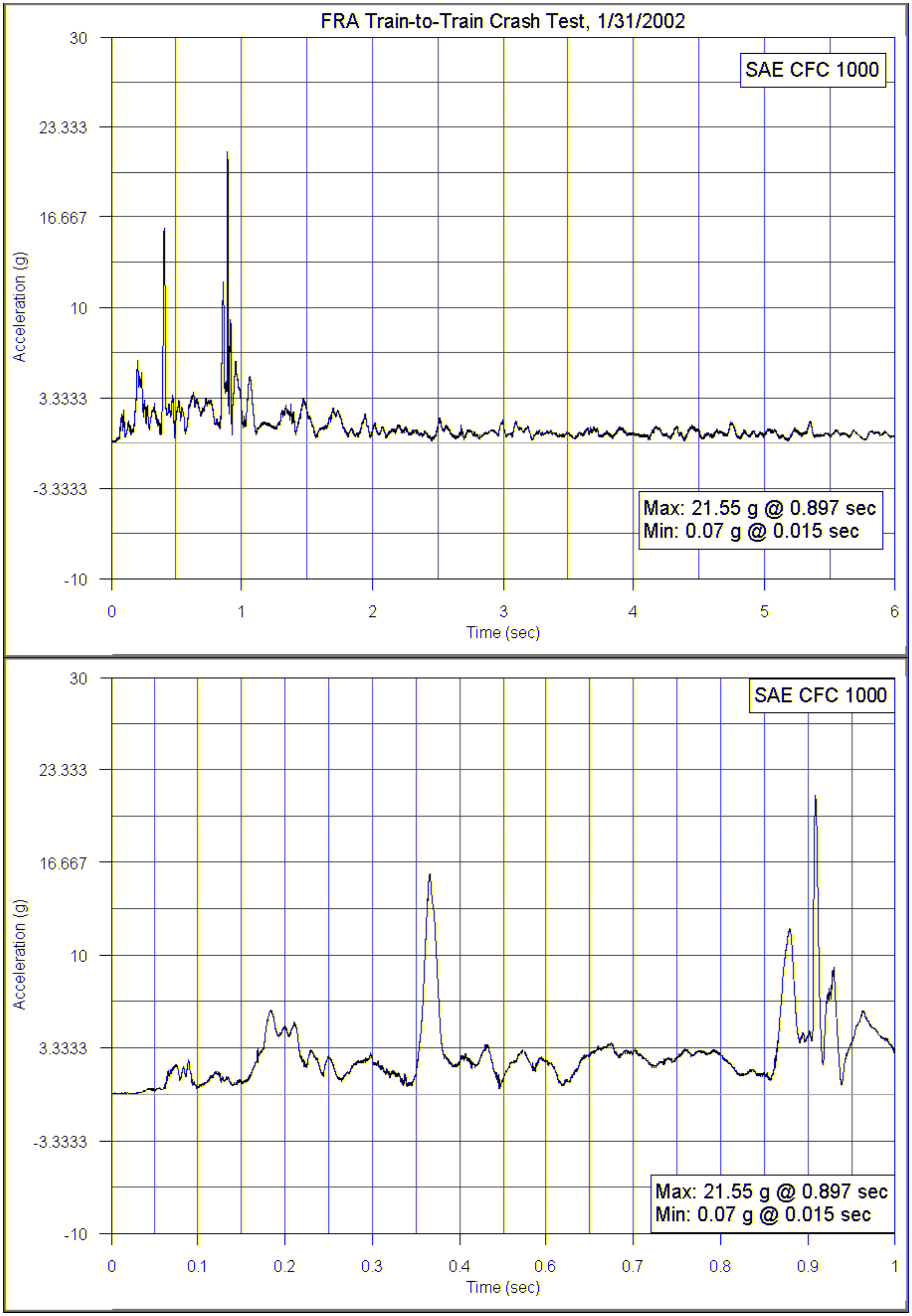


Figure D-40: Experiment No. 2-2 M-Style Seat, Aft Row, Aisle Seat, Hybrid III 50th Head Resultant Acceleration

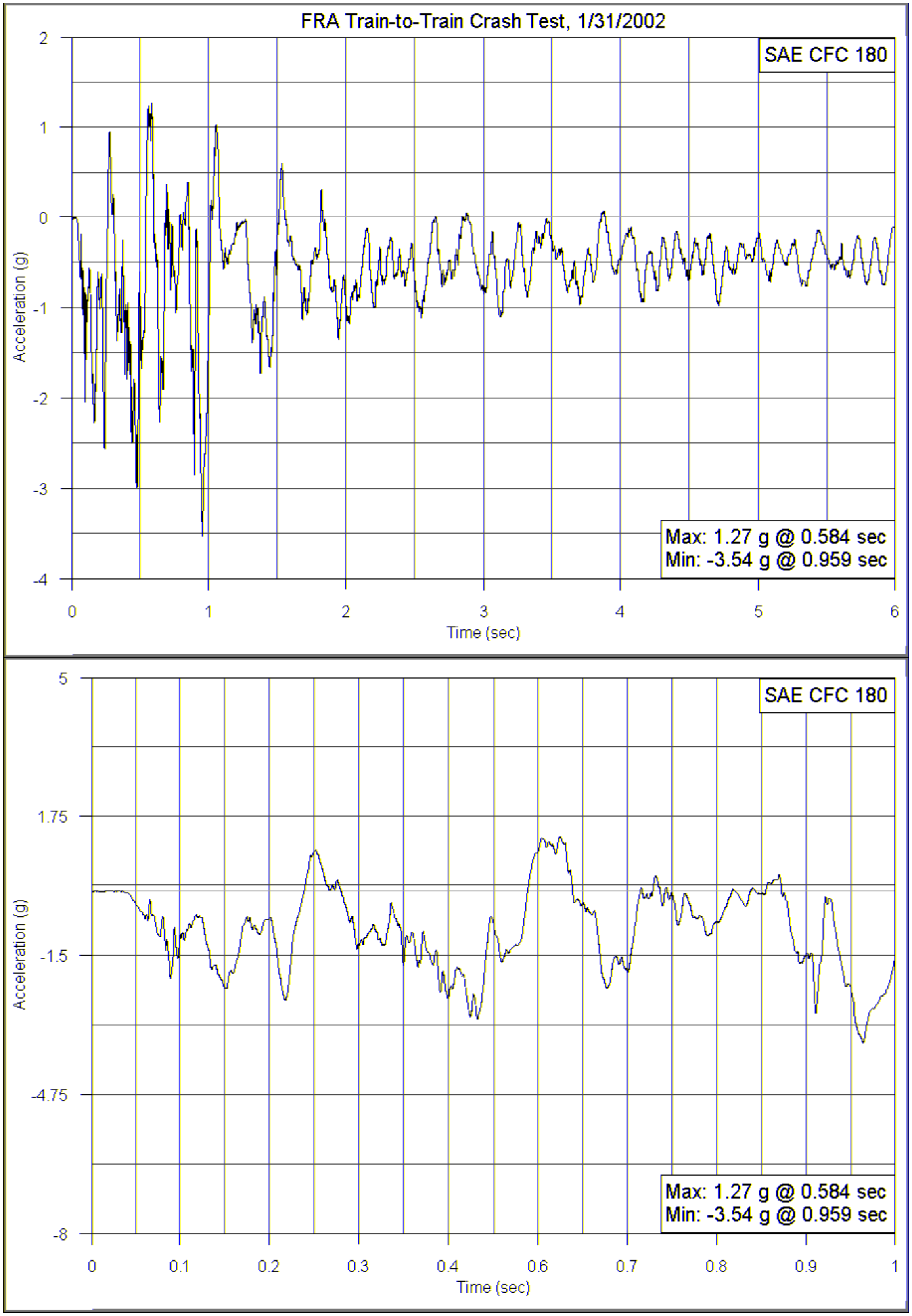


Figure D-41: Experiment No. 2-2 M-Style Seat, Aft Row, Aisle Seat, Hybrid III 50th Chest X-axis Acceleration

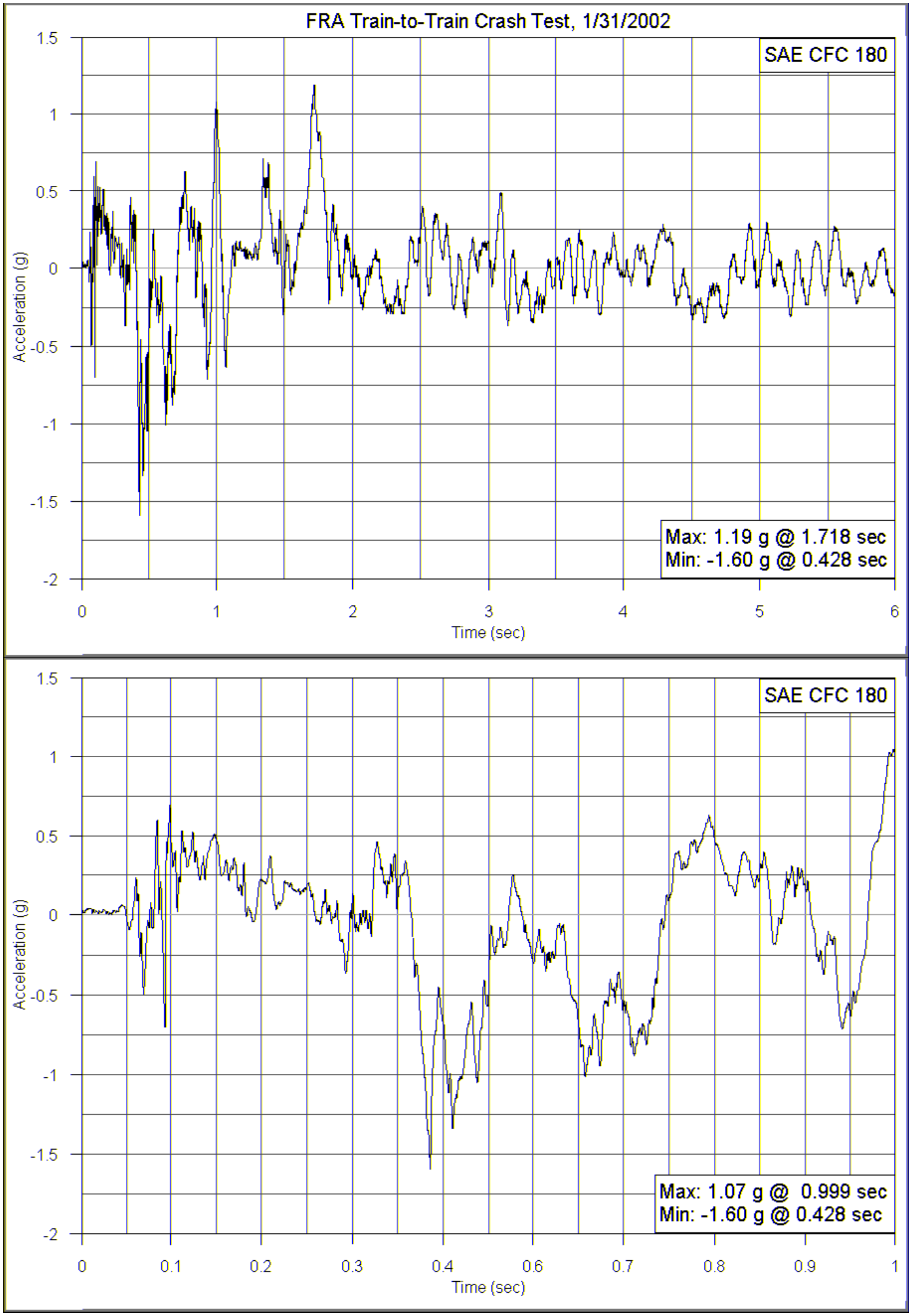


Figure D-42: Experiment No. 2-2 M-Style Seat, Aft Row, Aisle Seat, Hybrid III 50th Chest Y-axis Acceleration

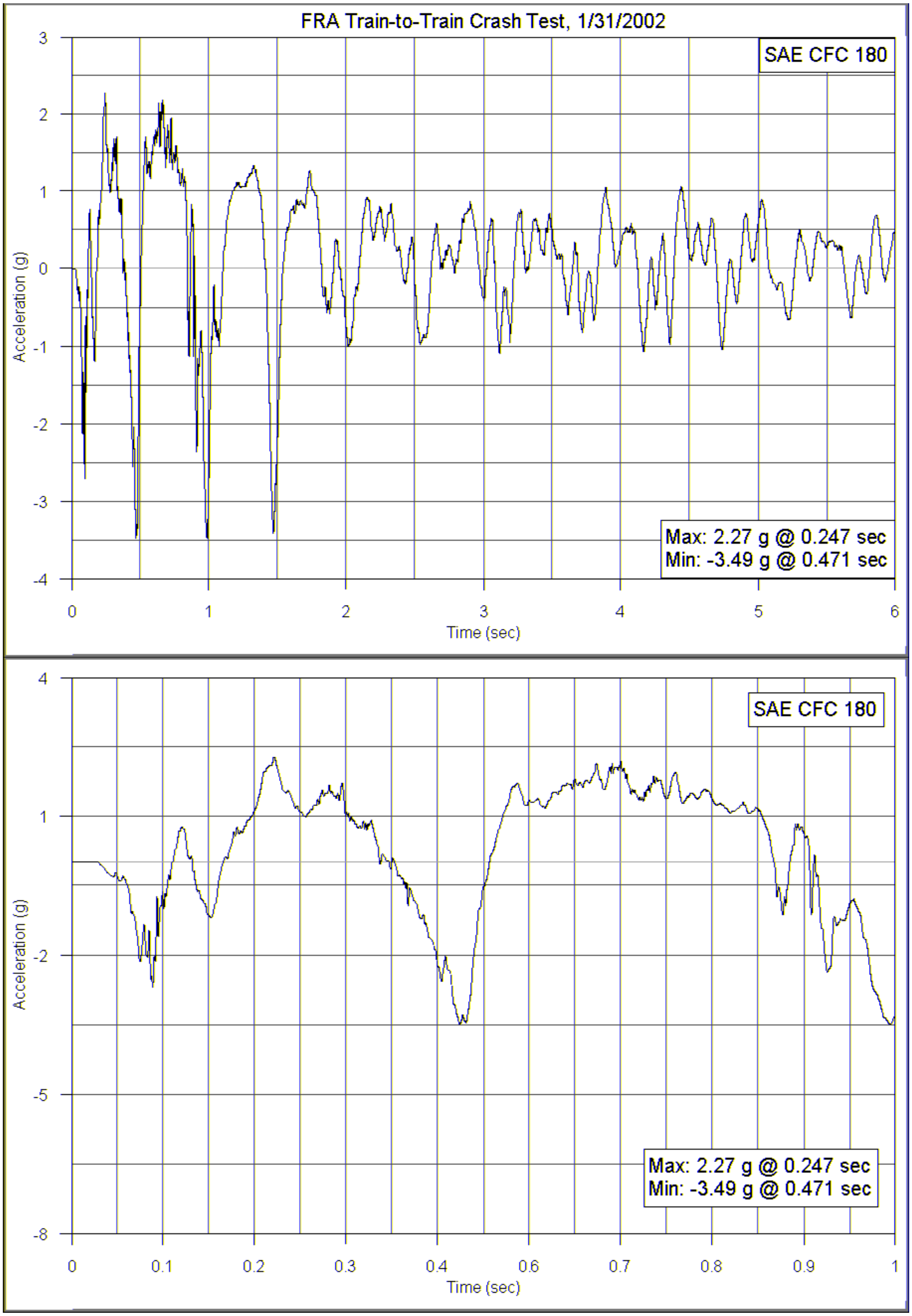


Figure D-43: Experiment No. 2-2 M-Style Seat, Aft Row, Aisle Seat, Hybrid III 50th Chest Z-axis Acceleration

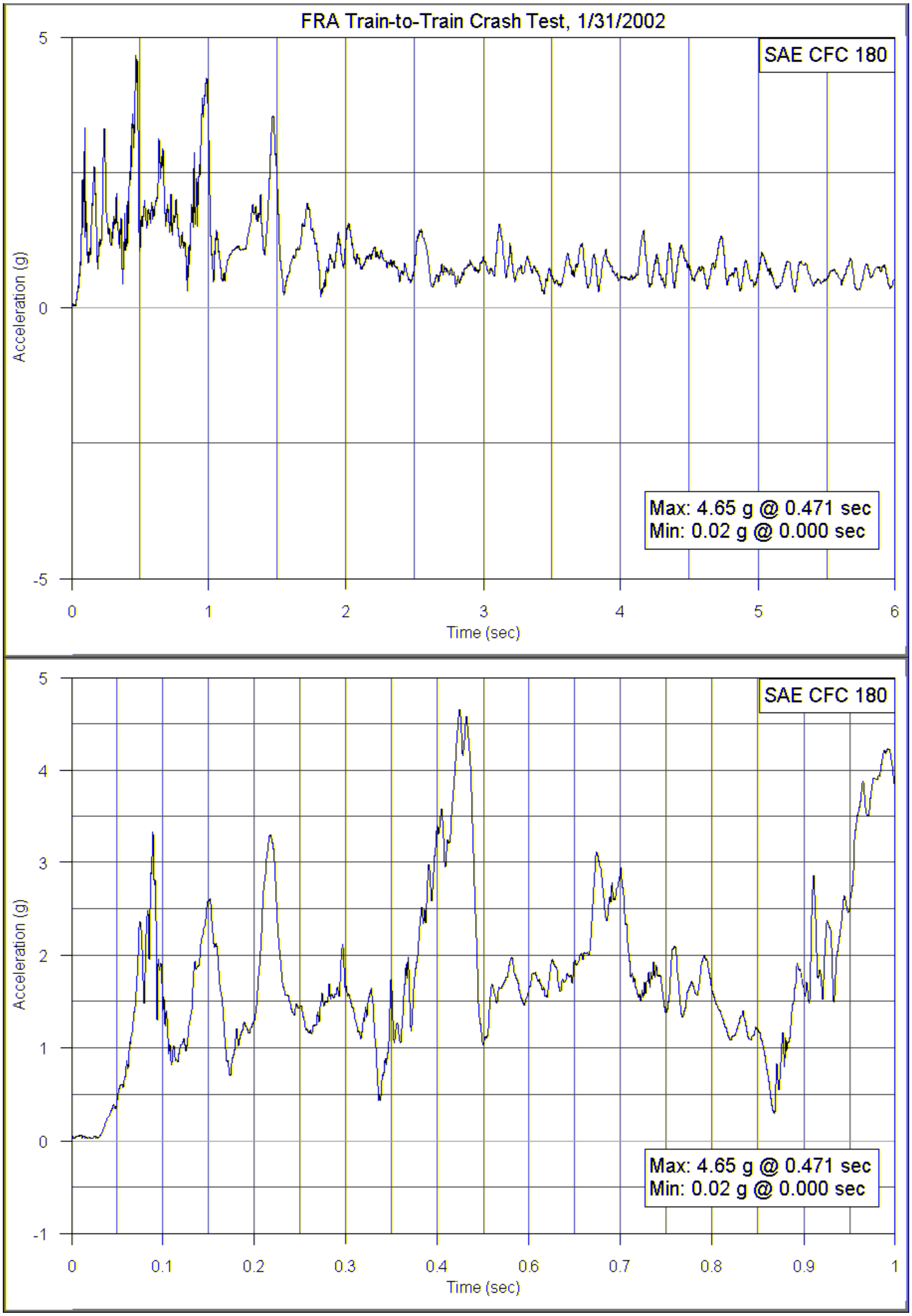


Figure D-44: Experiment No. 2-2 M-Style Seat, Aft Row, Aisle Seat, Hybrid III 50th Chest Resultant Acceleration

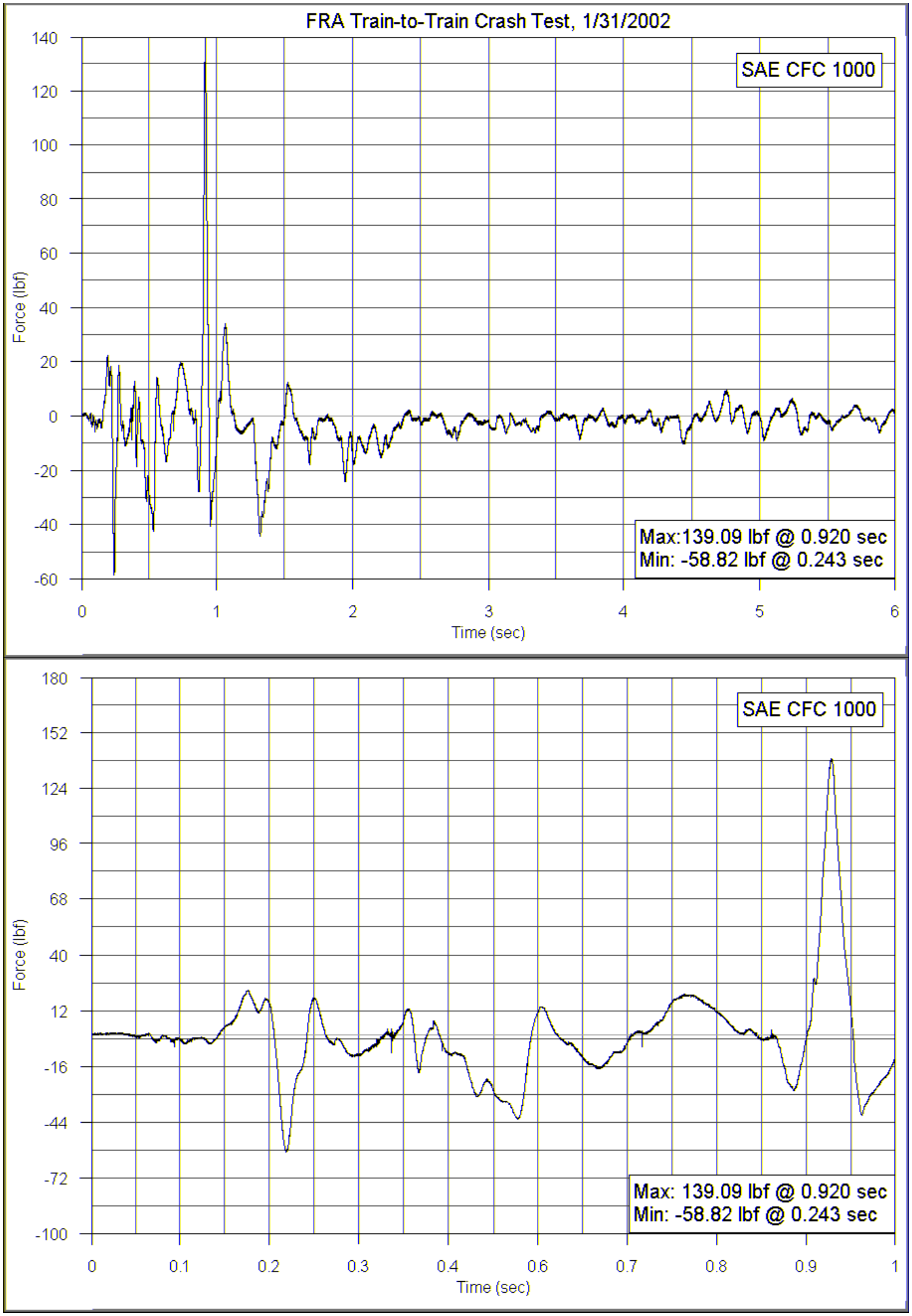


Figure D-45: Experiment No. 2-2 M-Style Seat, Aft Row, Aisle Seat, Hybrid III 50th Upper Neck X-axis Shear Force

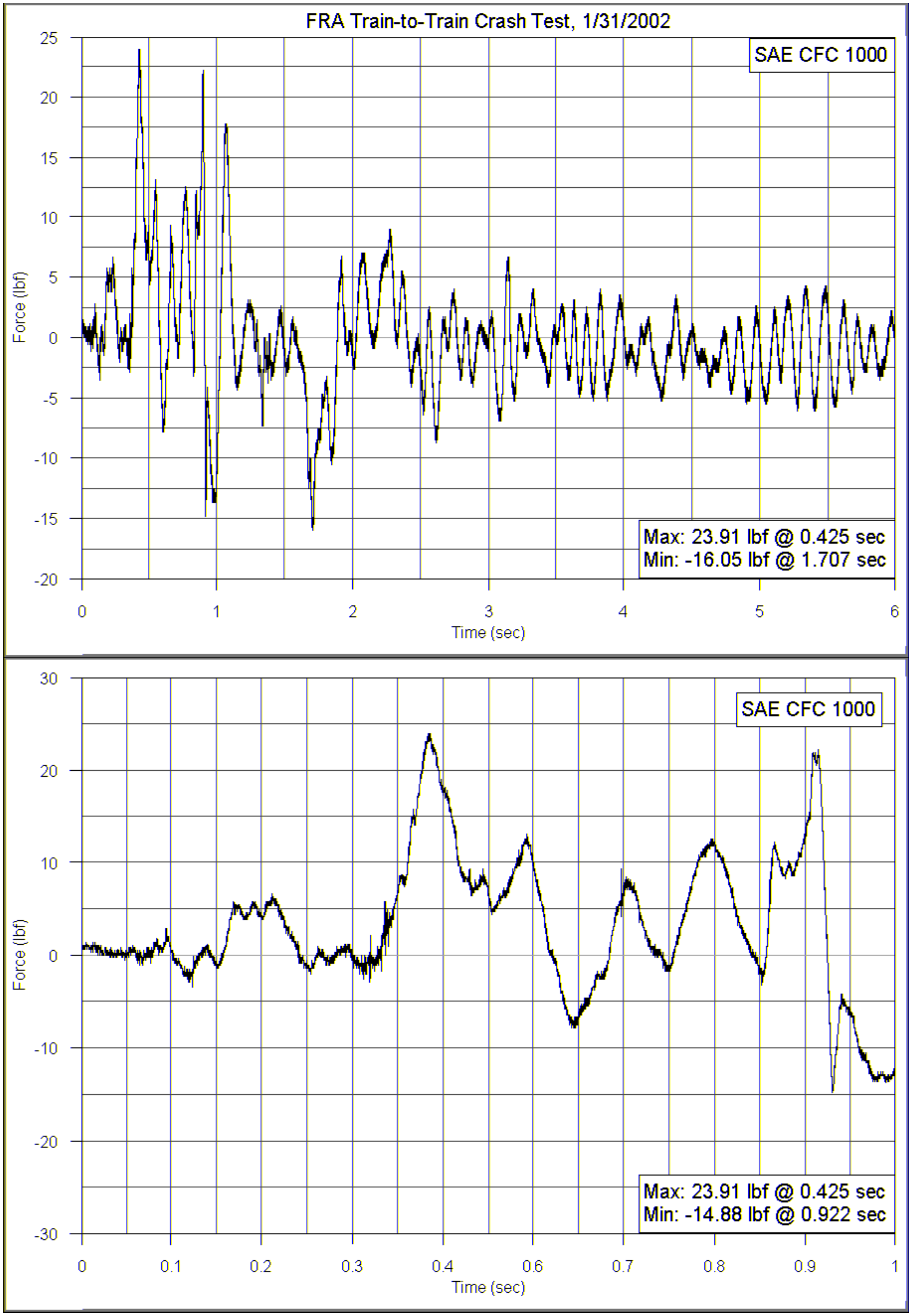
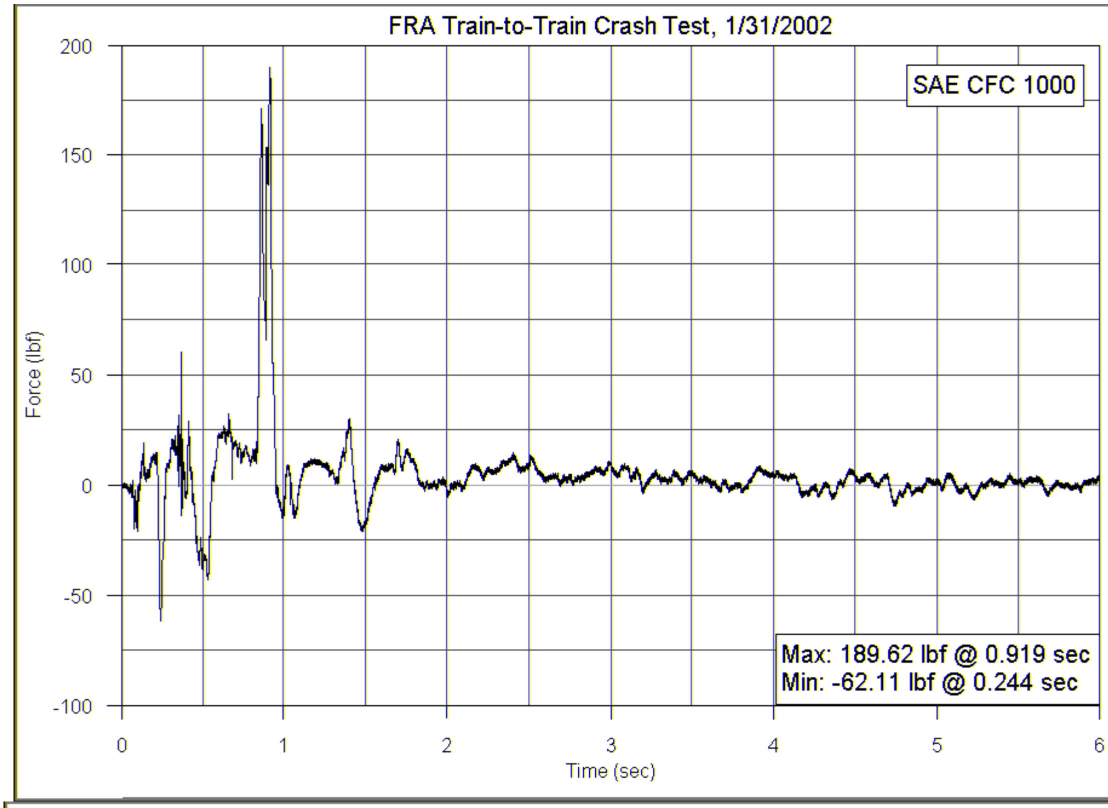


Figure D-46: Experiment No. 2-2 M-Style Seat, Aft Row, Aisle Seat, Hybrid III 50th Upper Neck Y-axis Shear Force



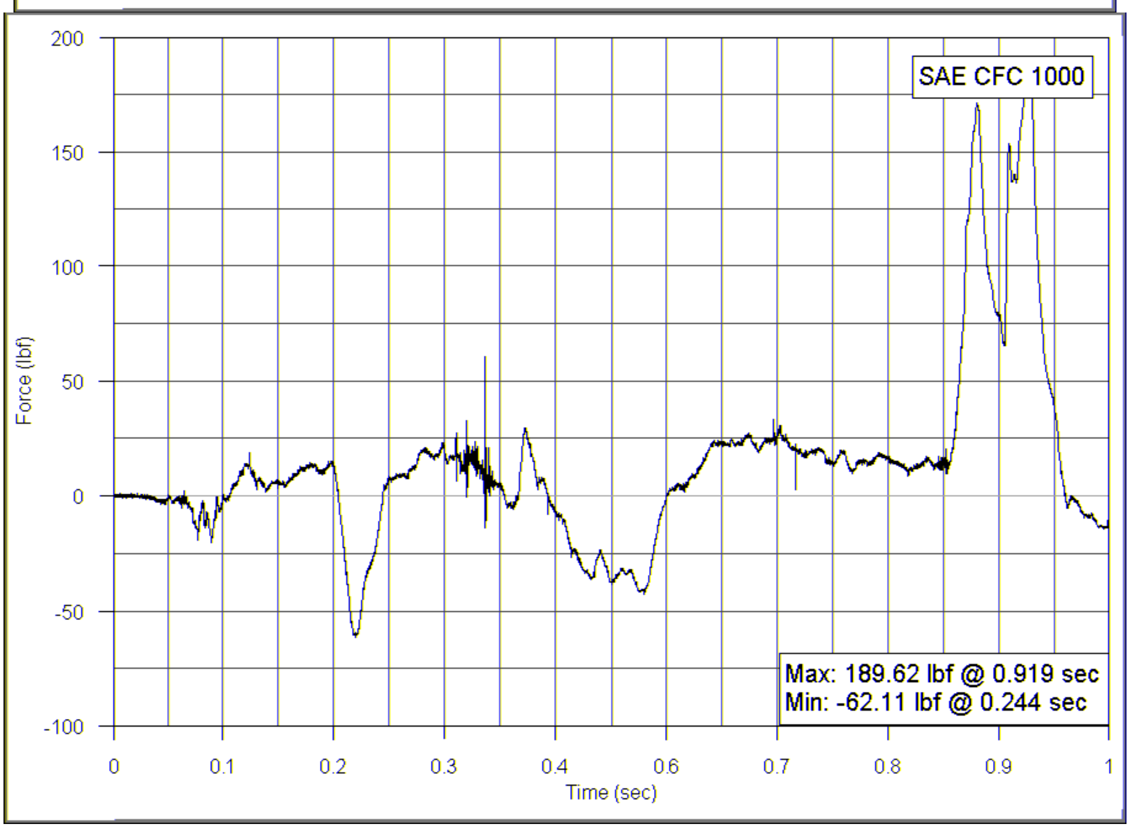


Figure D-47: Experiment No. 2-2 M-Style Seat, Aft Row, Aisle Seat, Hybrid III 50th Upper Neck Z-axis Axial Force

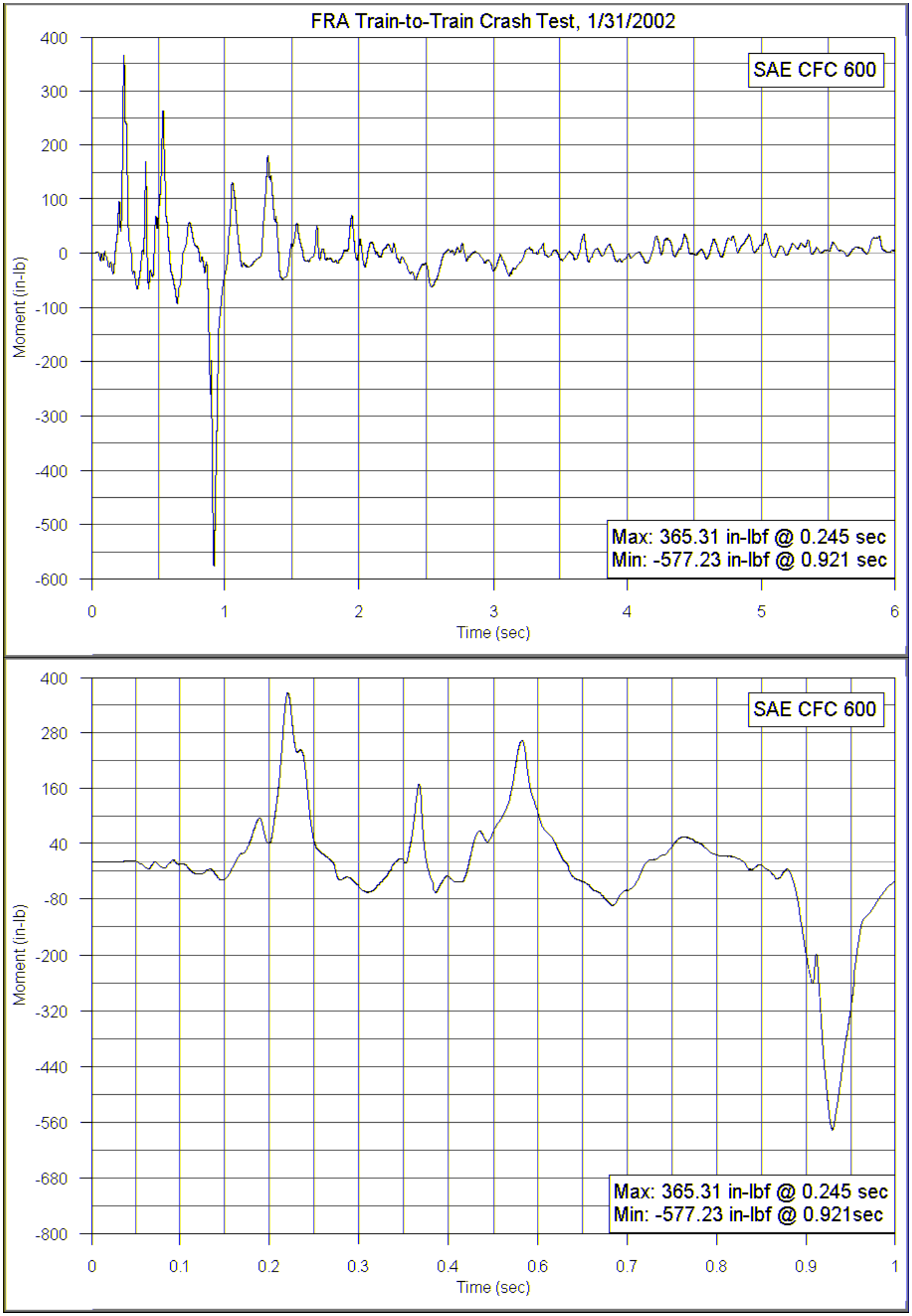


Figure D-48: Experiment No. 2-2 M-Style Seat, Aft Row, Aisle Seat, Hybrid III 50th Upper Neck Y-axis Moment

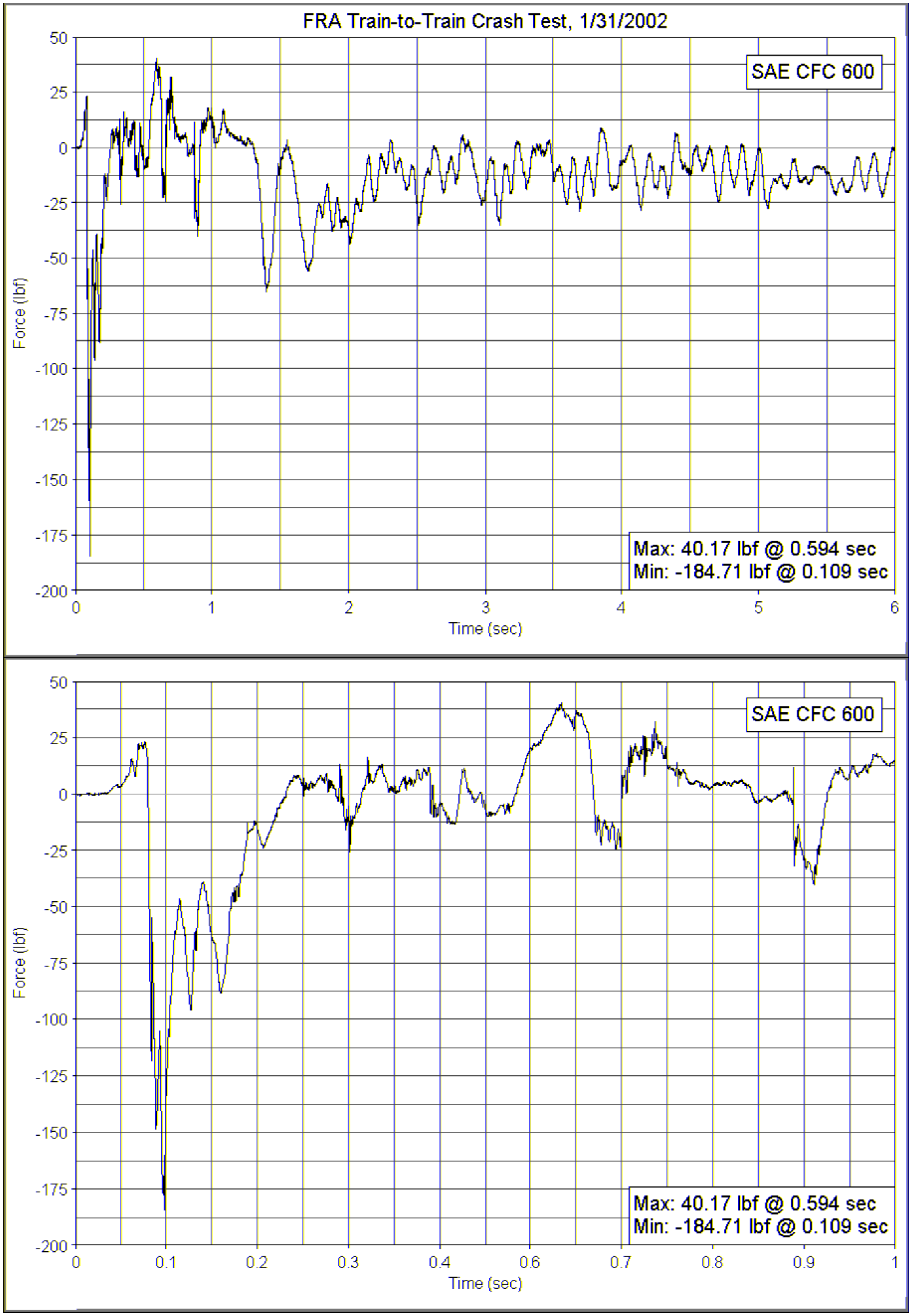


Figure D-49: Experiment No. 2-2 M-Style Seat, Aft Row, Aisle Seat, Hybrid III 50th Left Femur Axial Force

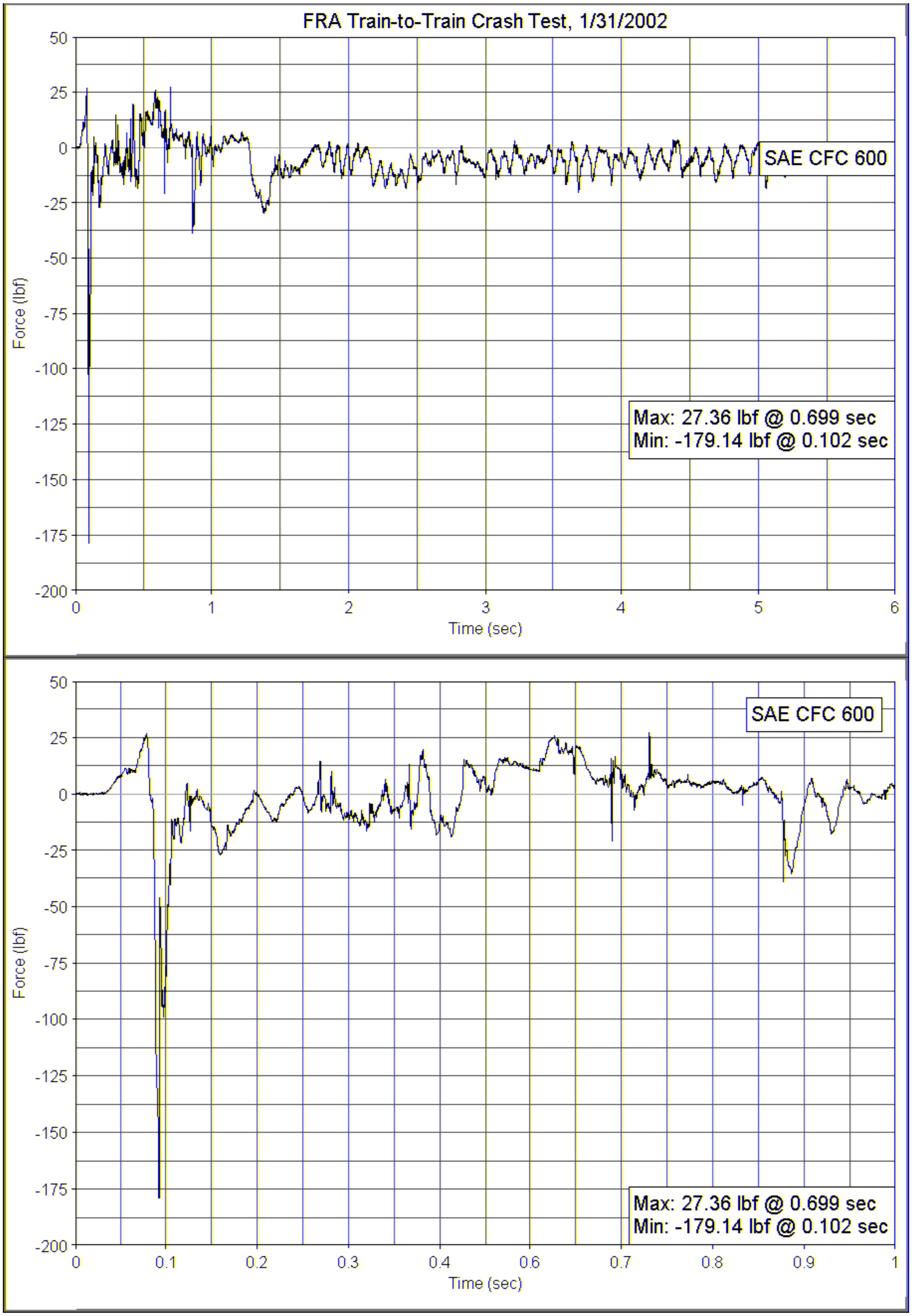


Figure D-50: Experiment No. 2-2 M-Style Seat, Aft Row, Aisle Seat, Hybrid III 50th Right Femur Axial Force

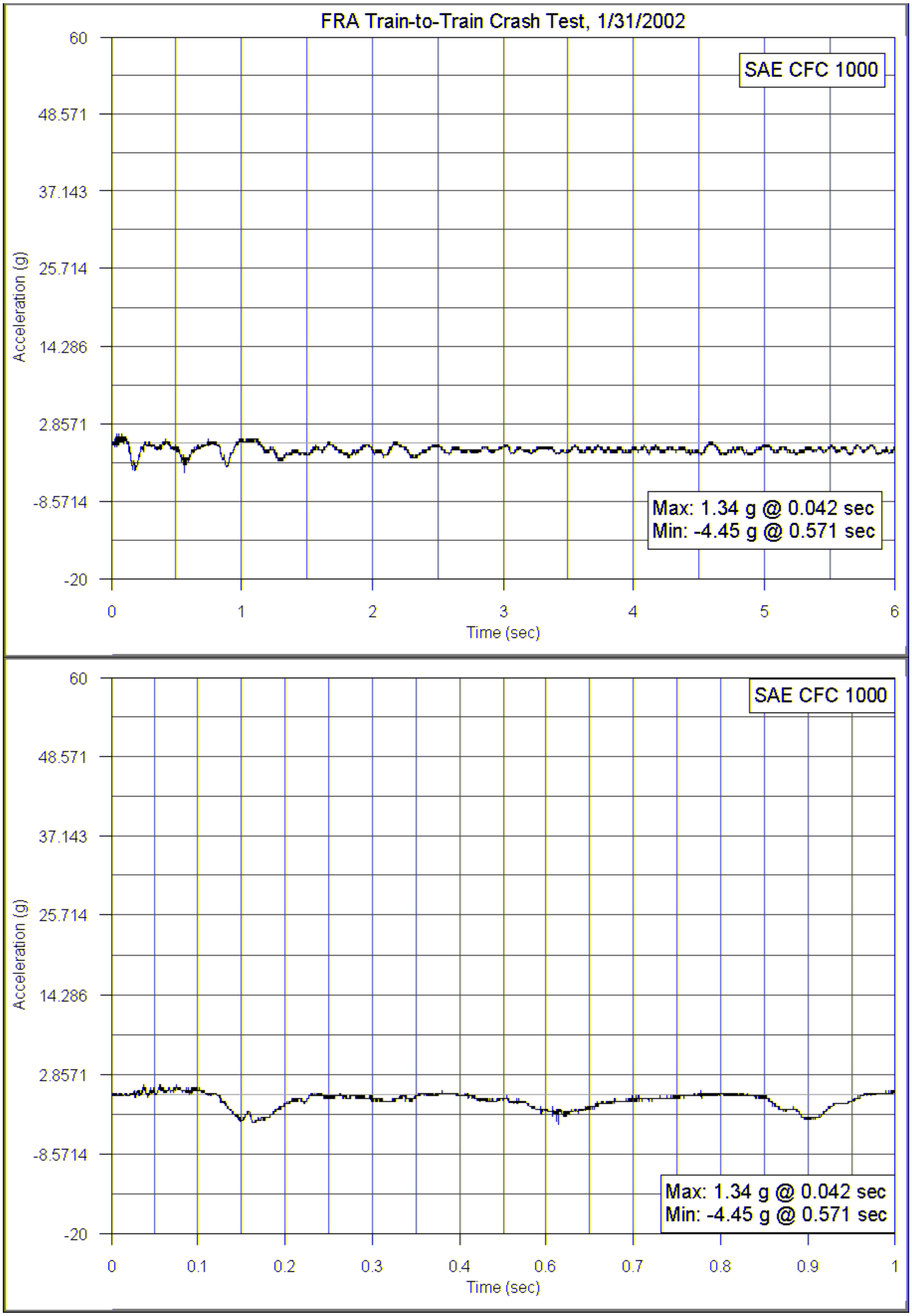
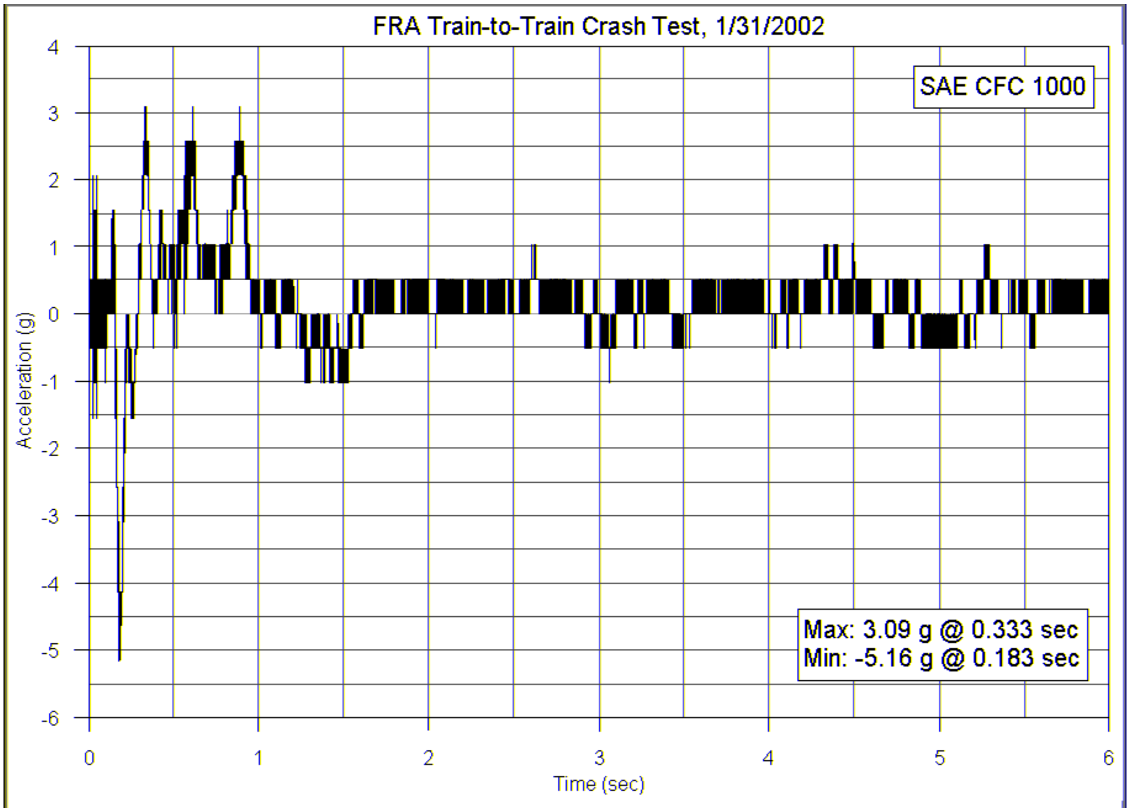


Figure D-51: Experiment No. L-1 Operator Seat,
Hybrid III 95th Head X-axis Acceleration



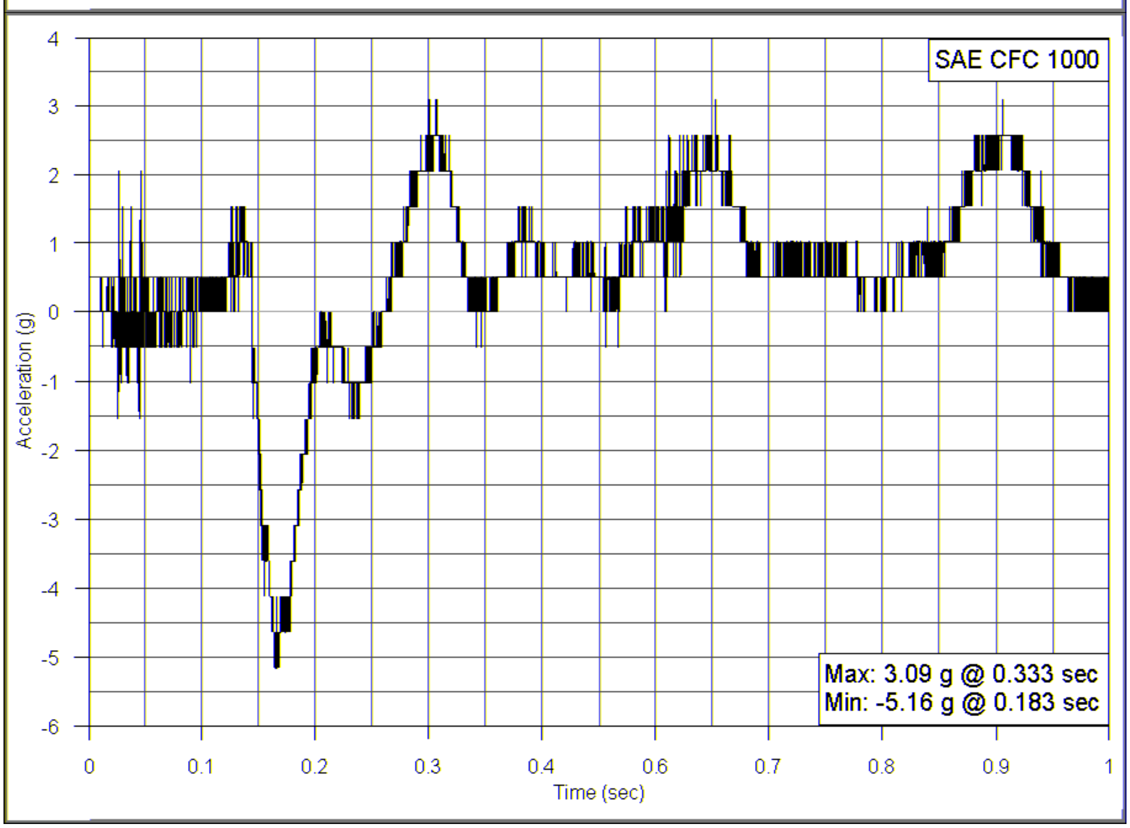


Figure D-52: Experiment No. L-1 Operator Seat, Hybrid III 95th Head Y-axis Acceleration

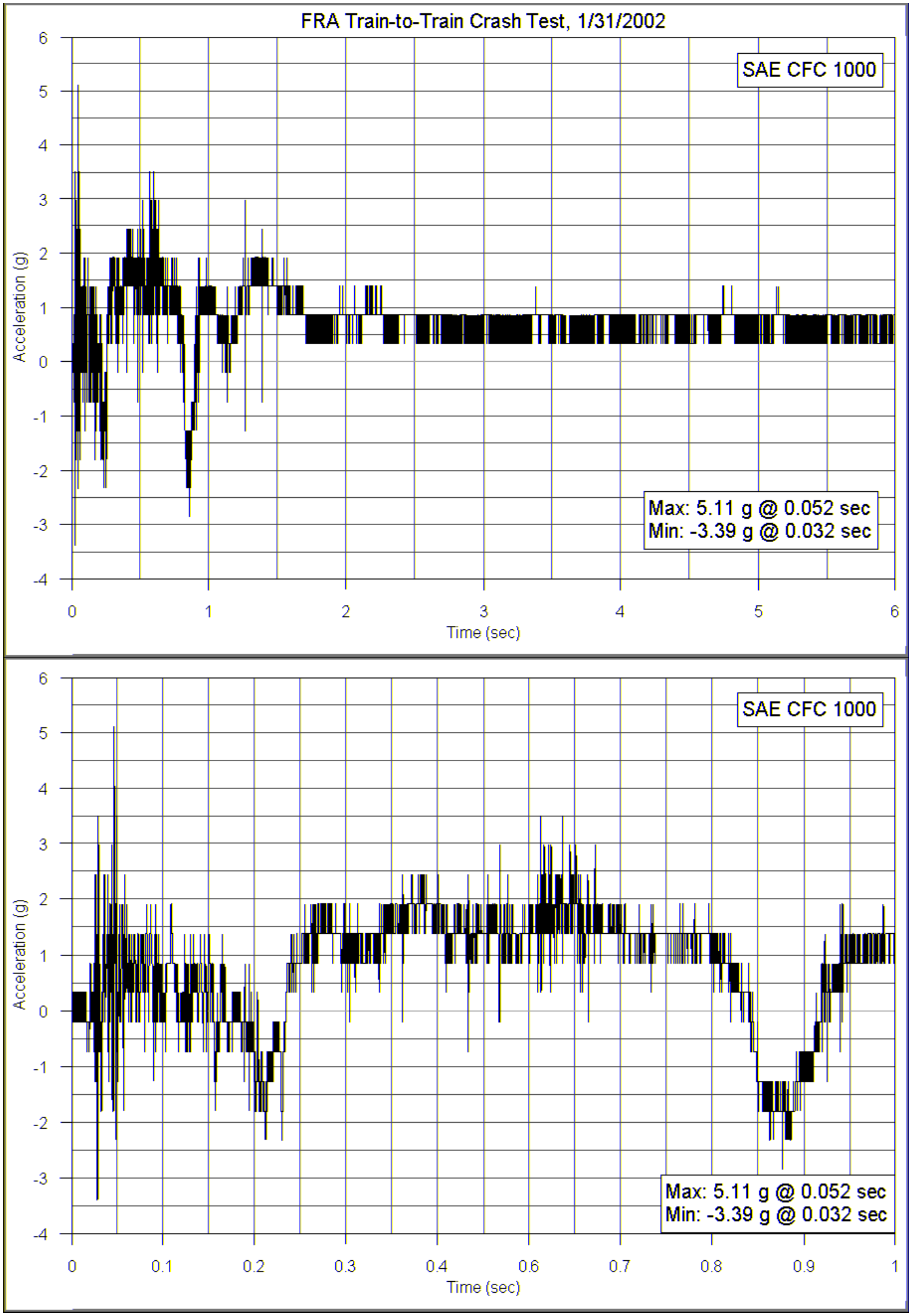


Figure D-53: Experiment No. L-1 Operator Seat, Hybrid III 95th Head Z-axis Acceleration

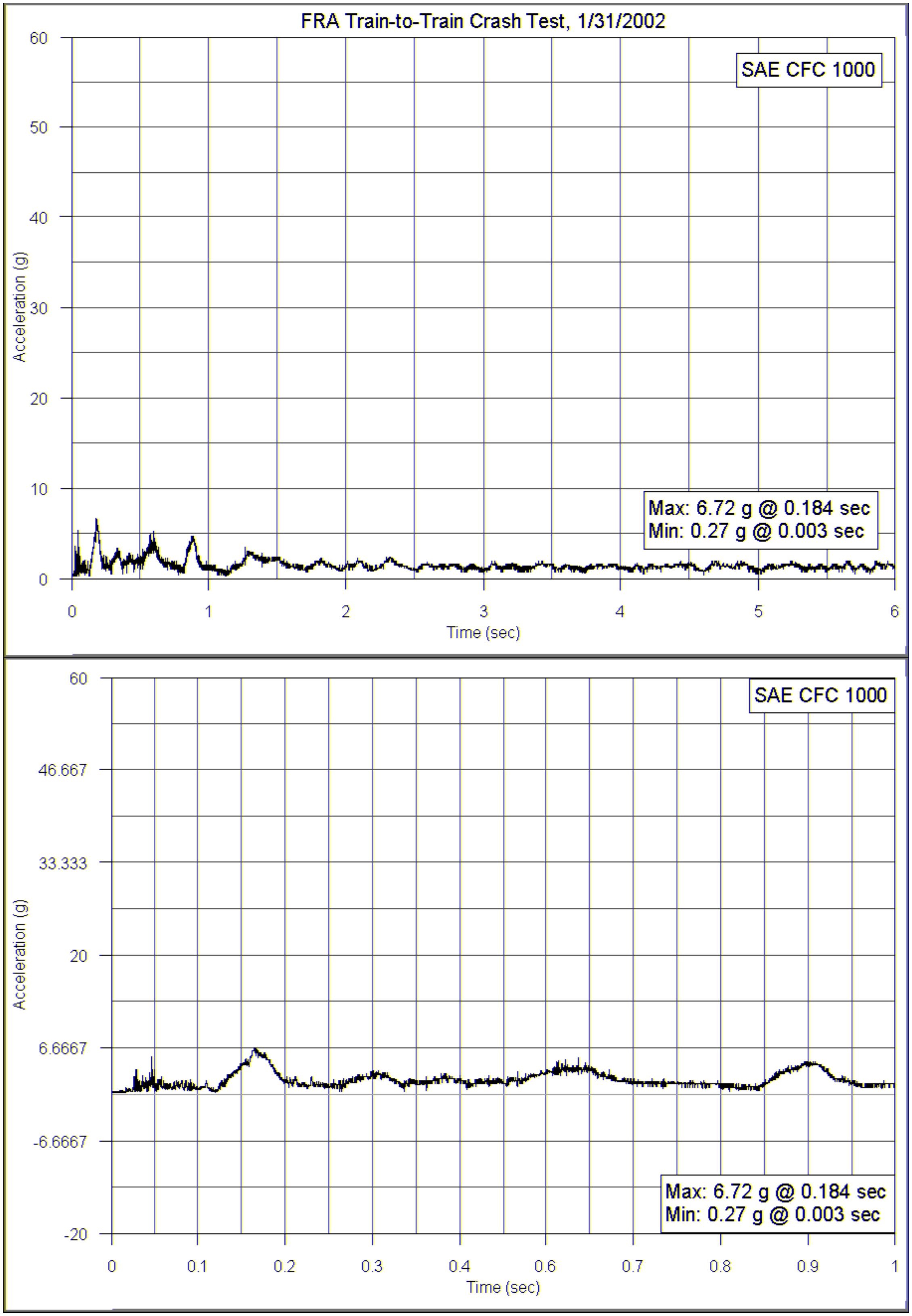
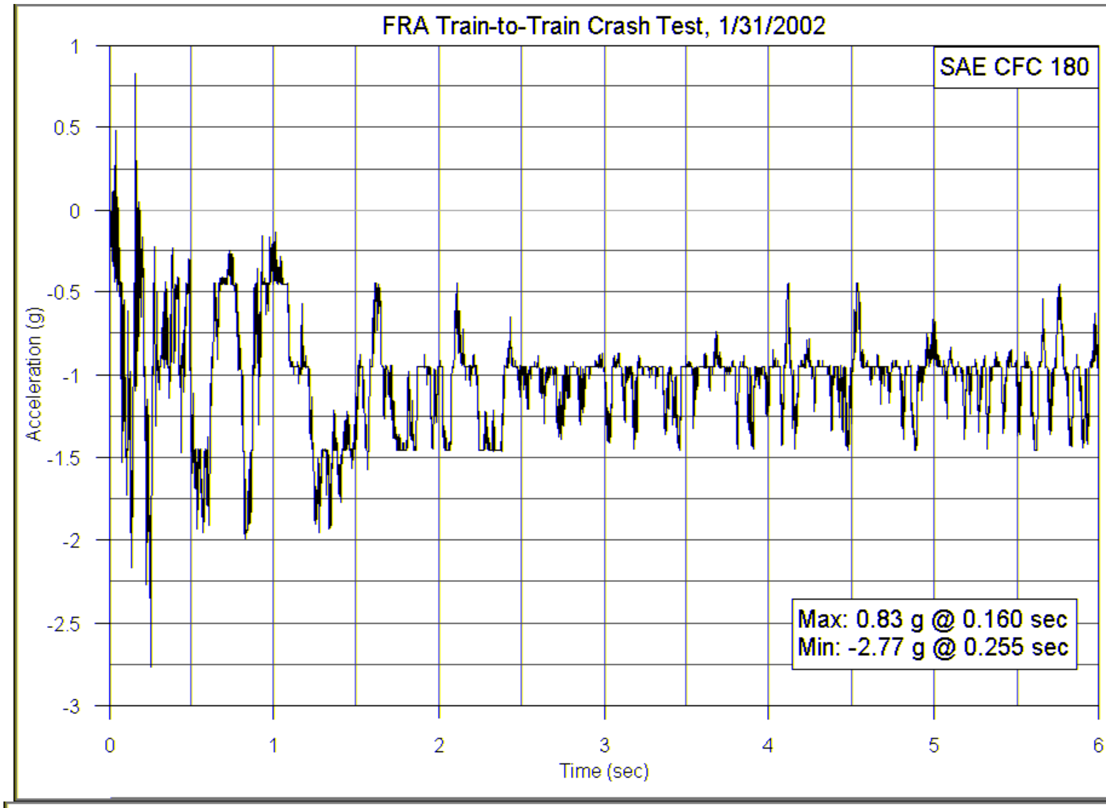


Figure D-54: Experiment No. L-1 Operator Seat, Hybrid III 95th Head Resultant Acceleration



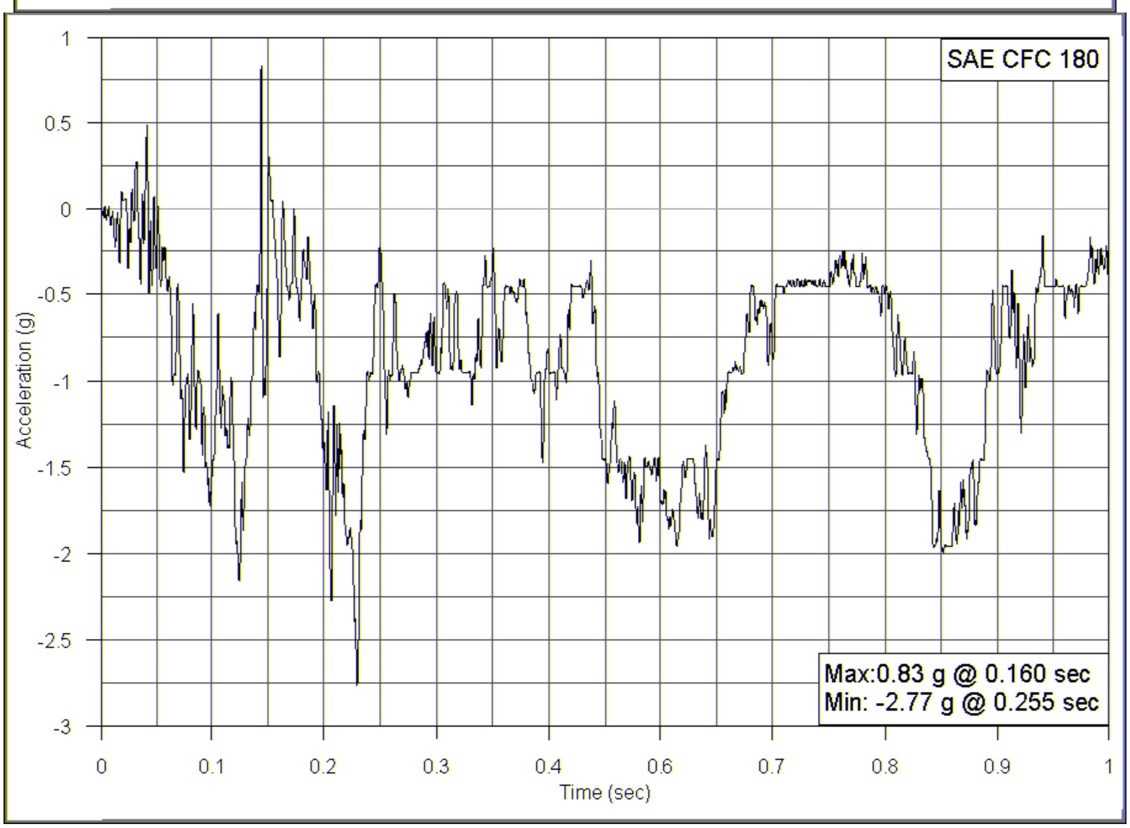


Figure D-55: Experiment No. L-1 Operator Seat, Hybrid III 95th Chest X-axis Acceleration

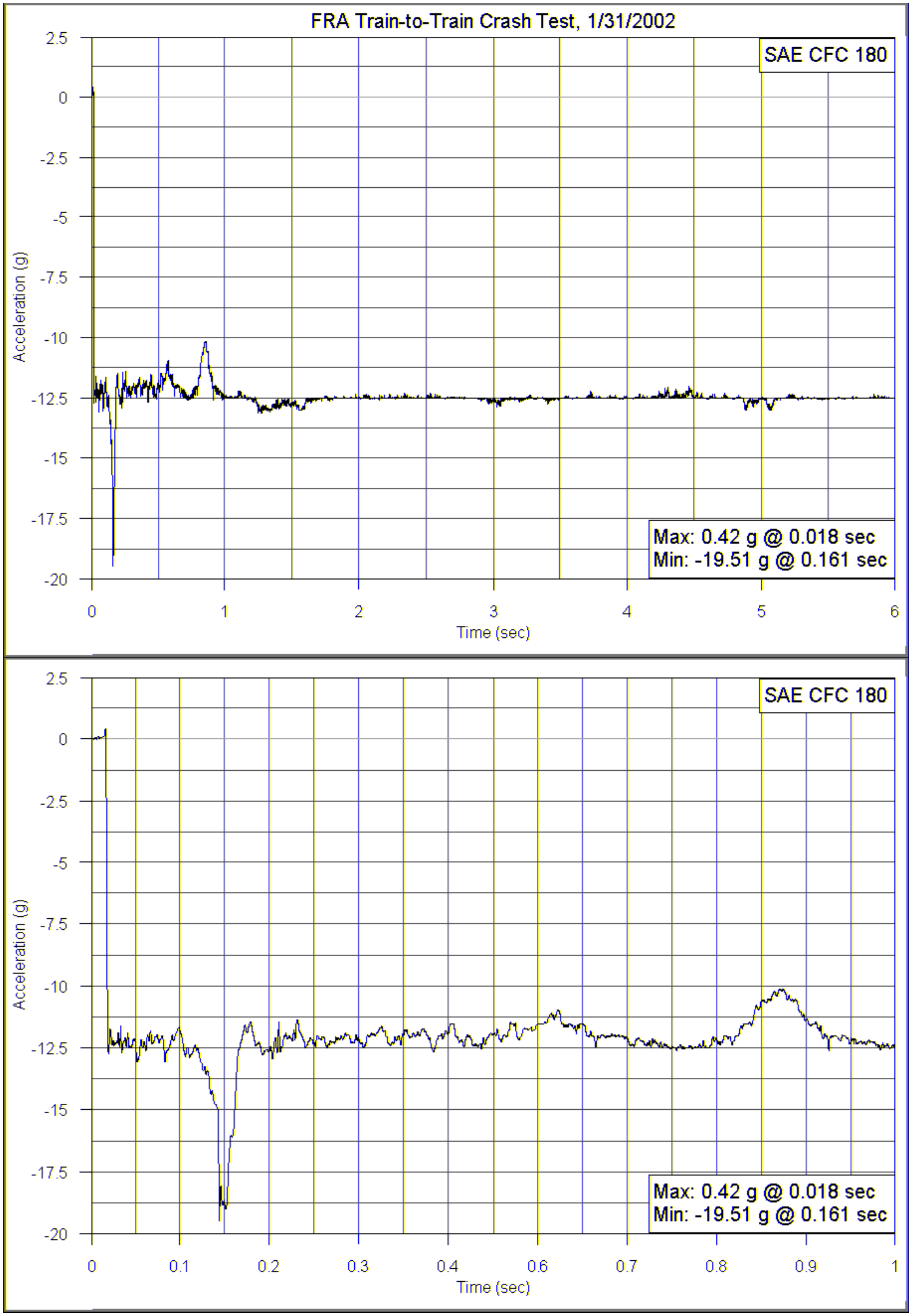


Figure D-56: Experiment No. L-1 Operator Seat, Hybrid III 95th Chest Y-axis Acceleration

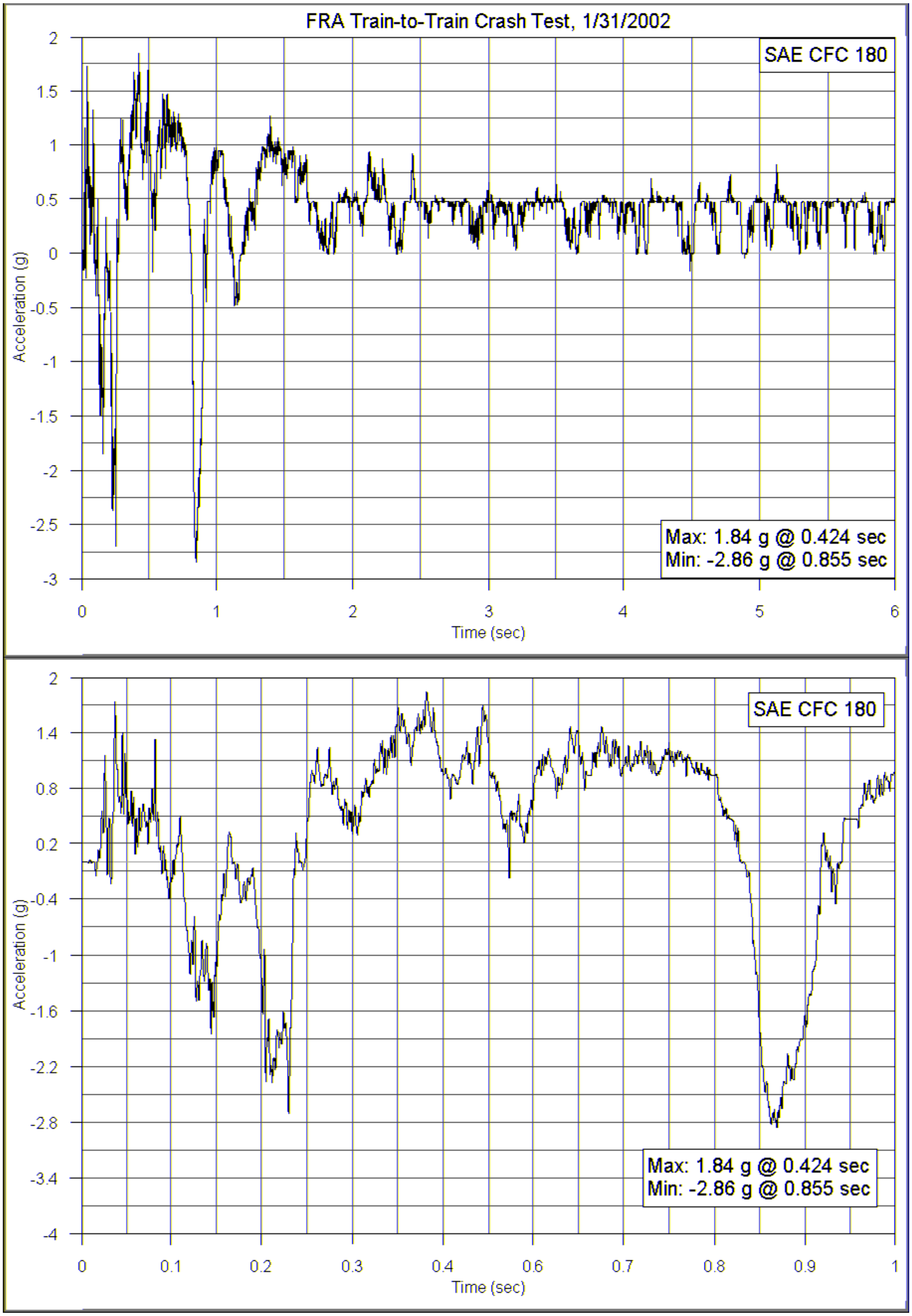
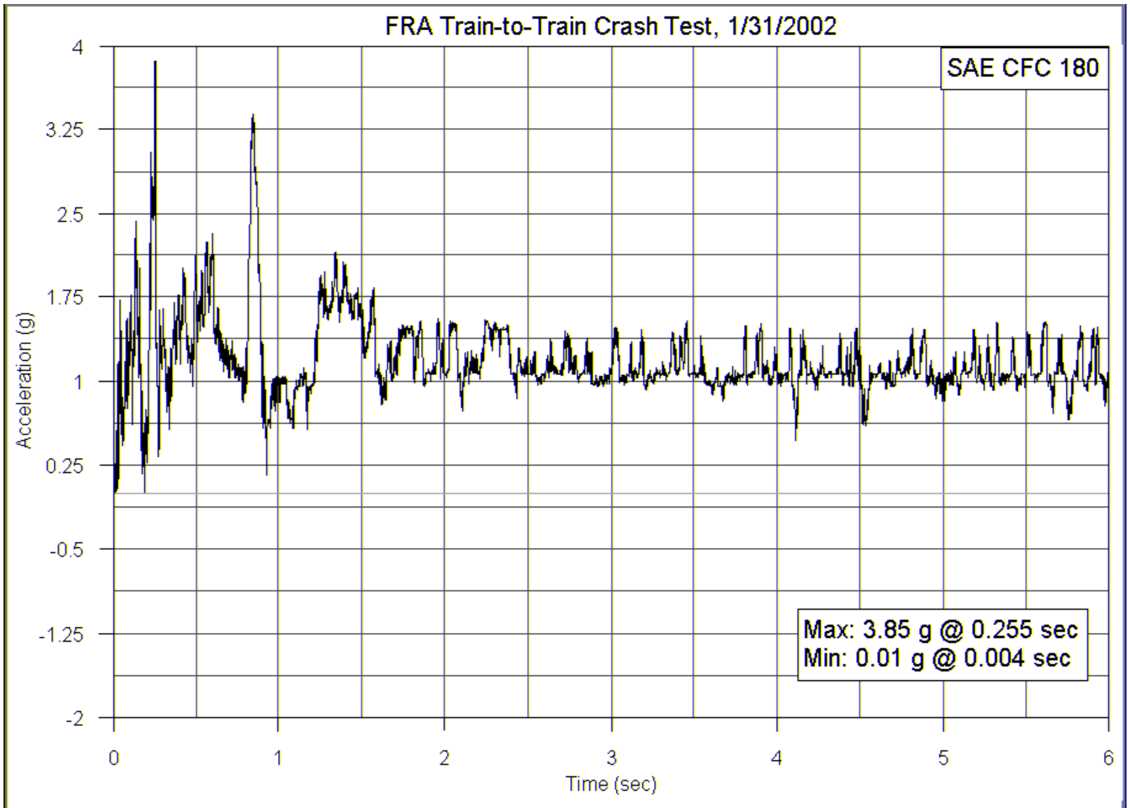


Figure D-57: Experiment No. L-1 Operator Seat, Hybrid III 95th Chest Z-axis Acceleration



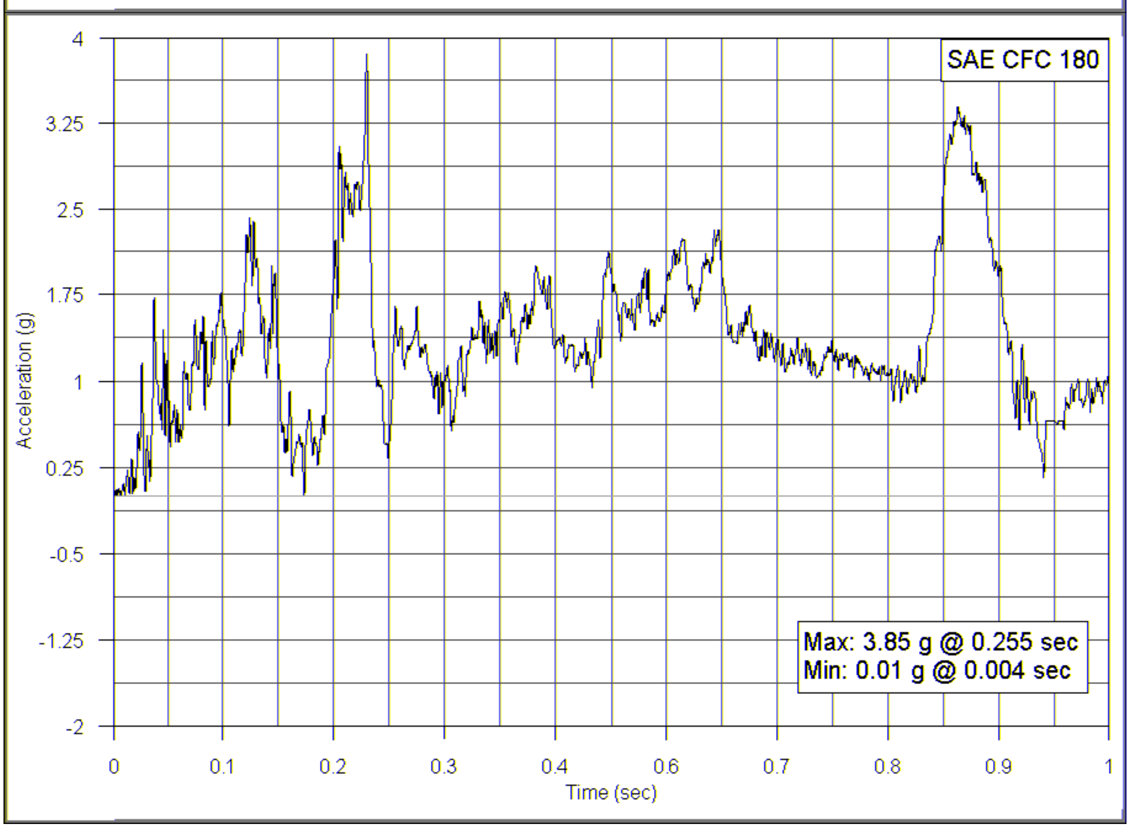


Figure D-58: Experiment No. L-1 Operator Seat, Hybrid III 95th Chest Resultant Acceleration

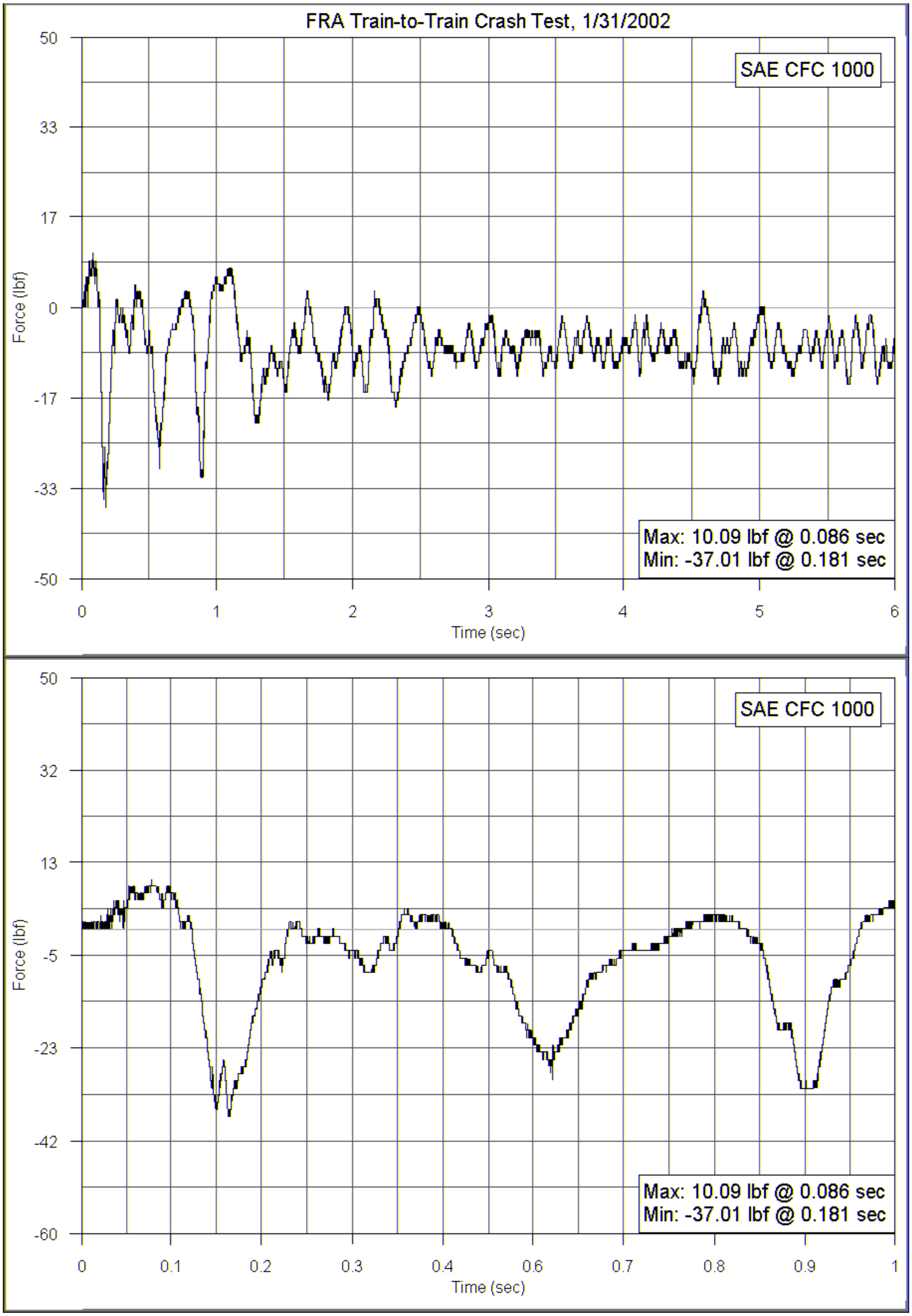


Figure D-59: Experiment No. L-1 Operator Seat, Hybrid III 95th Upper Neck X-axis Shear Force

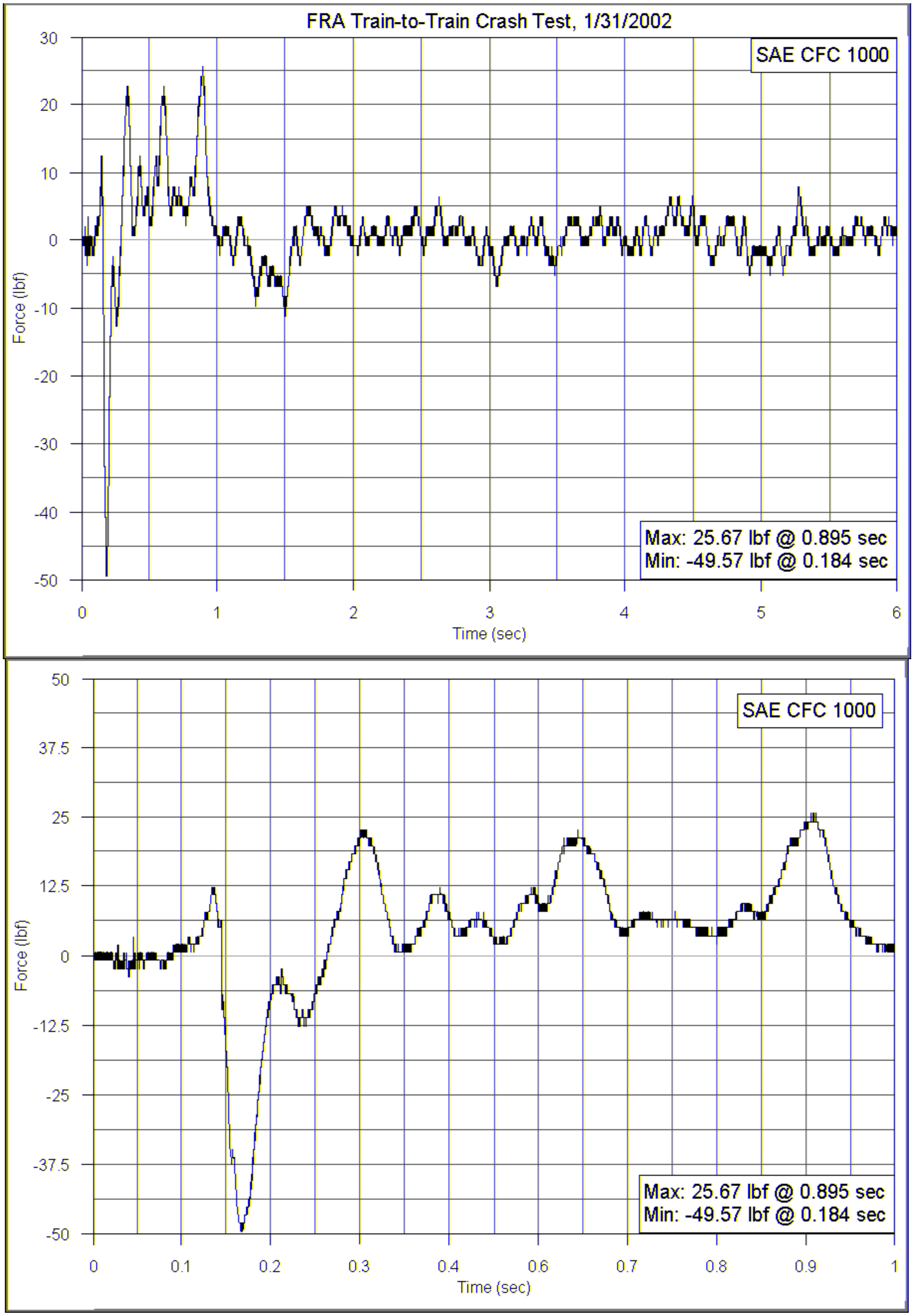


Figure D-60: Experiment No. L-1 Operator Seat, Hybrid III 95th Upper Neck Y-axis Shear Force

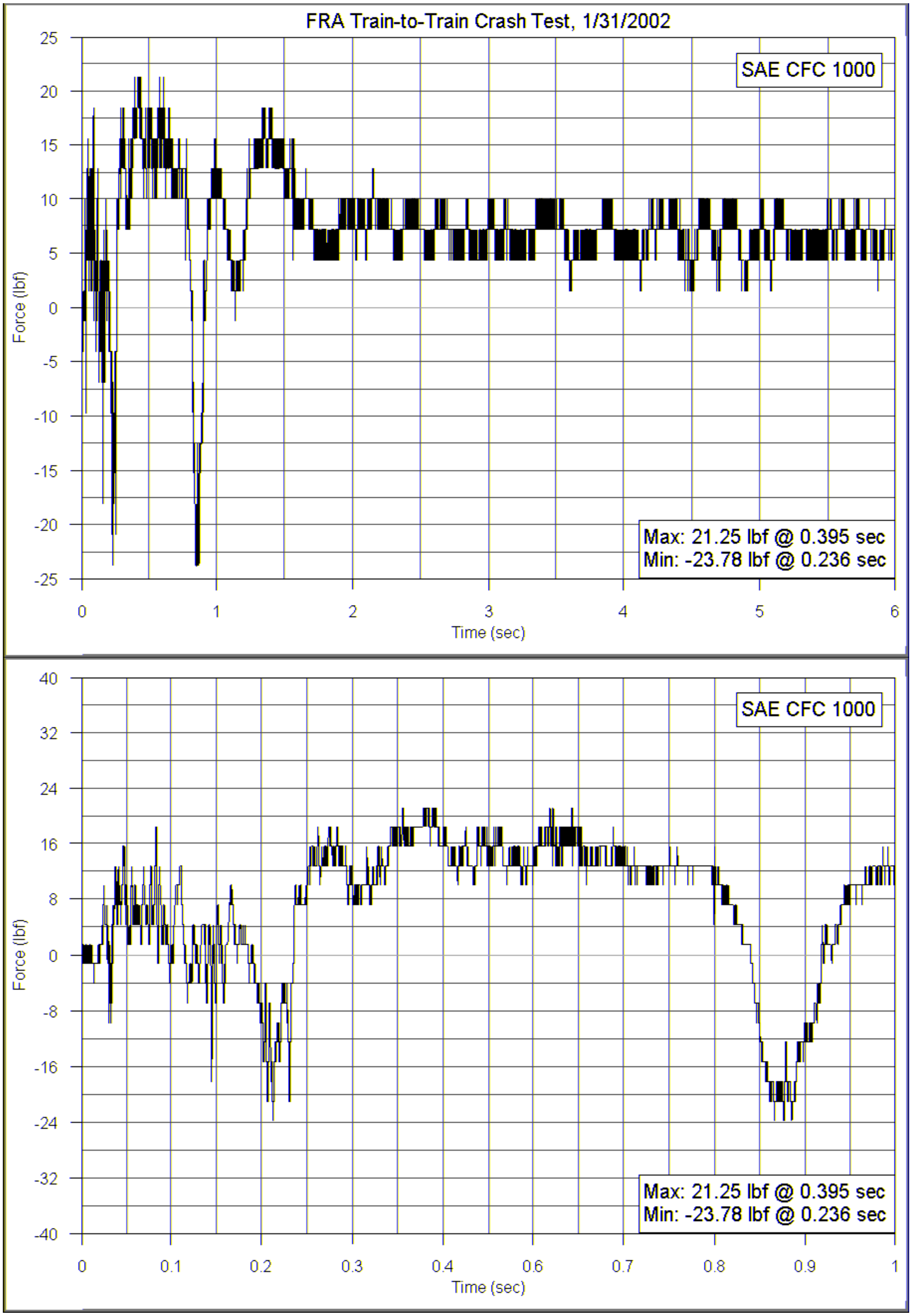


Figure D-61: Experiment No. L-1 Operator Seat, Hybrid III 95th Upper Neck Z-axis Axial Force

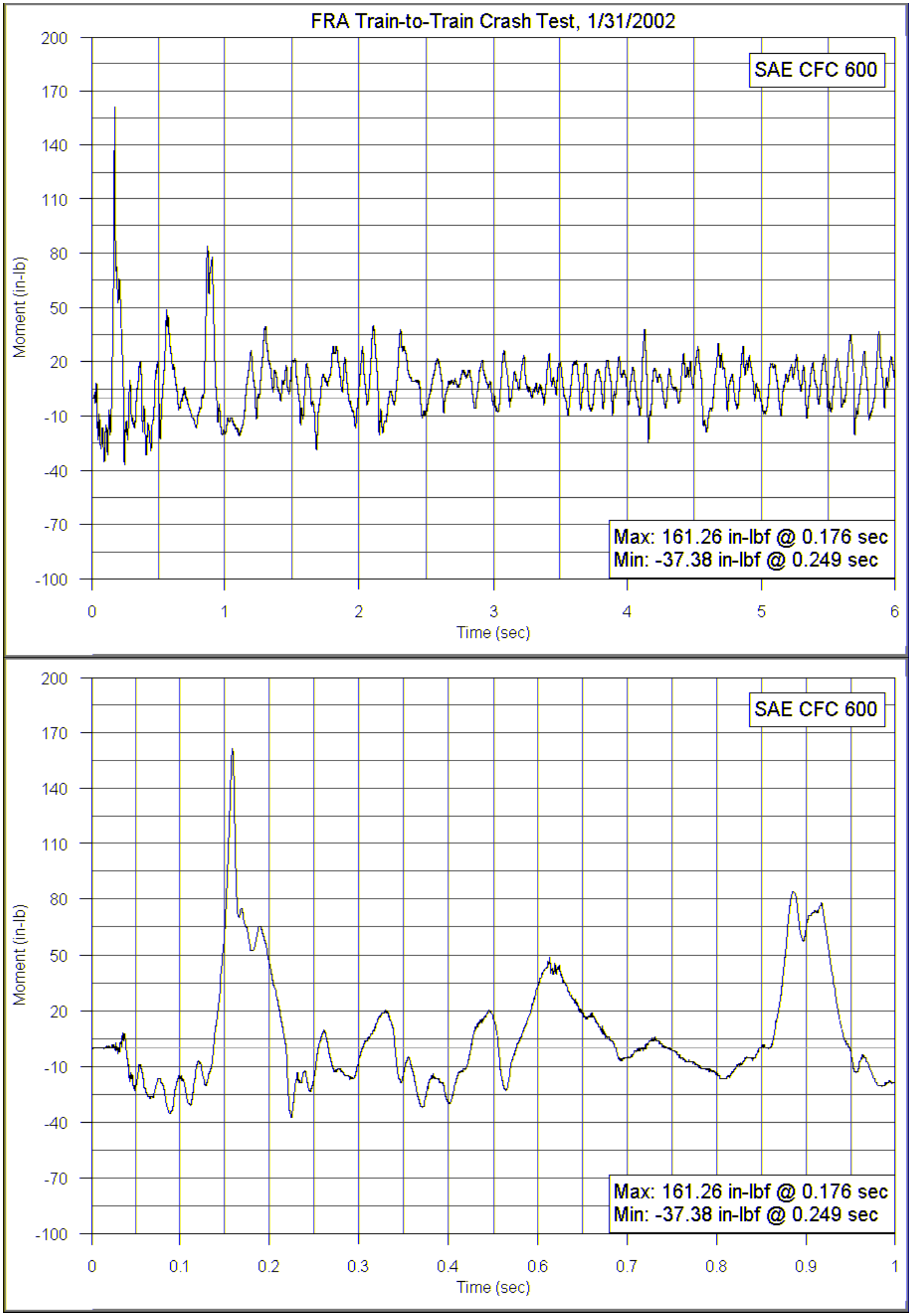


Figure D-62: Experiment No. L-1 Operator Seat, Hybrid III 95th Upper Neck Y-axis Moment

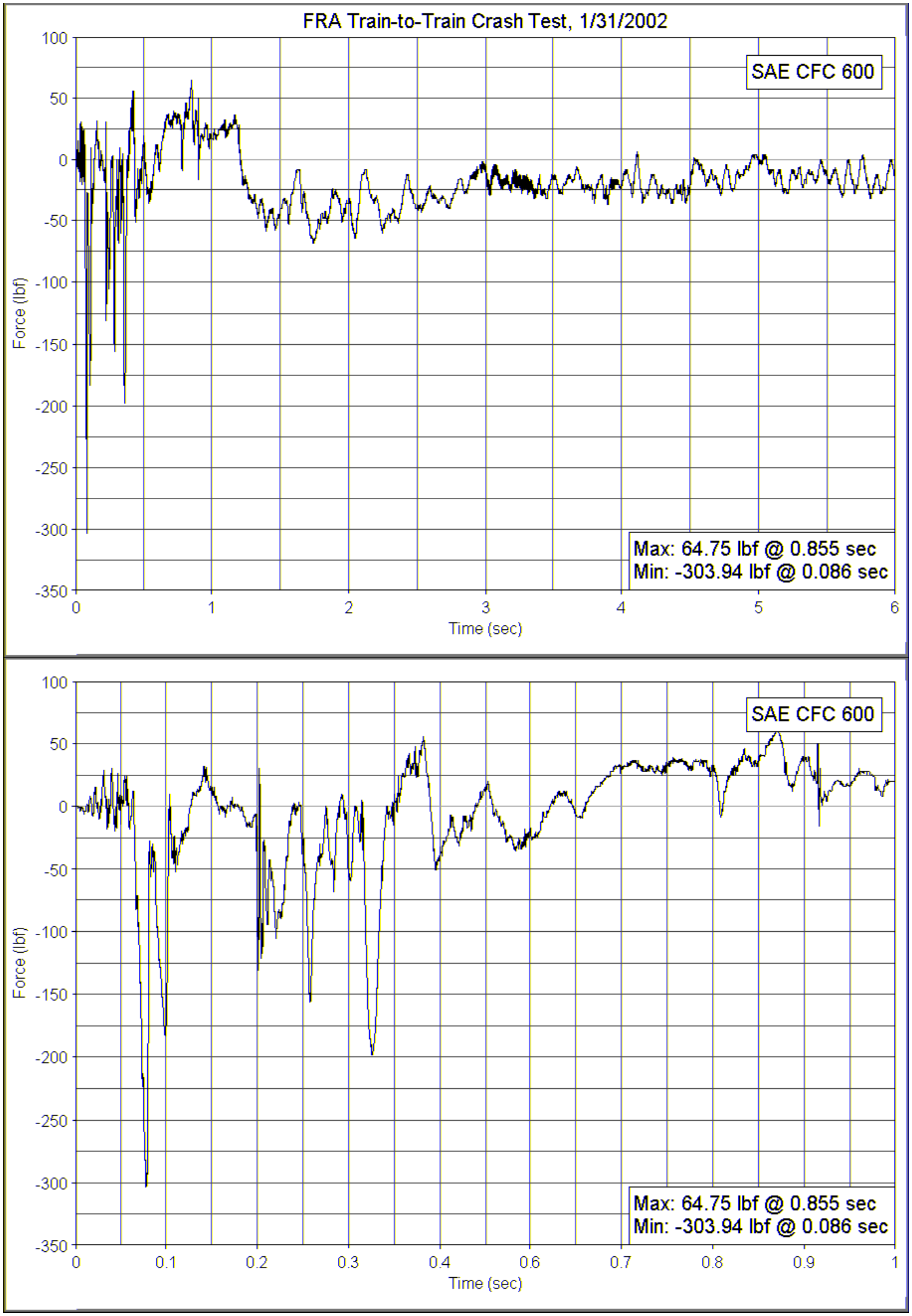


Figure D-63: Experiment No. L-1 Operator Seat, Hybrid III 95th Left Femur Axial Force

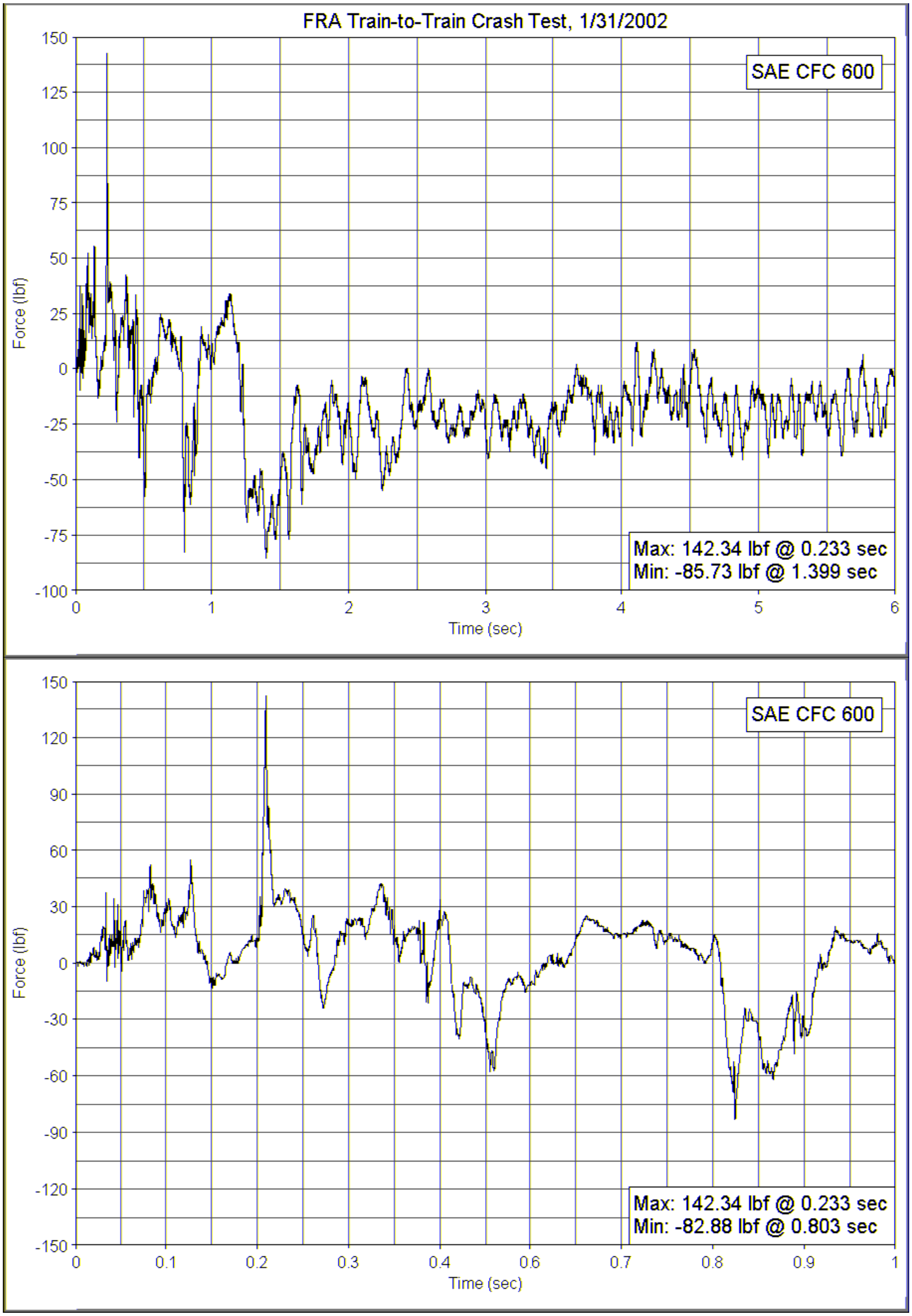


Figure D-64: Experiment No. L-1 Operator Seat, Hybrid III 95th Right Femur Axial Force

APPENDIX E

SHOULDER BELT LOAD-TIME HISTORIES
ON EXPERIMENT NO. 2-1 – JANUARY 31, 2002

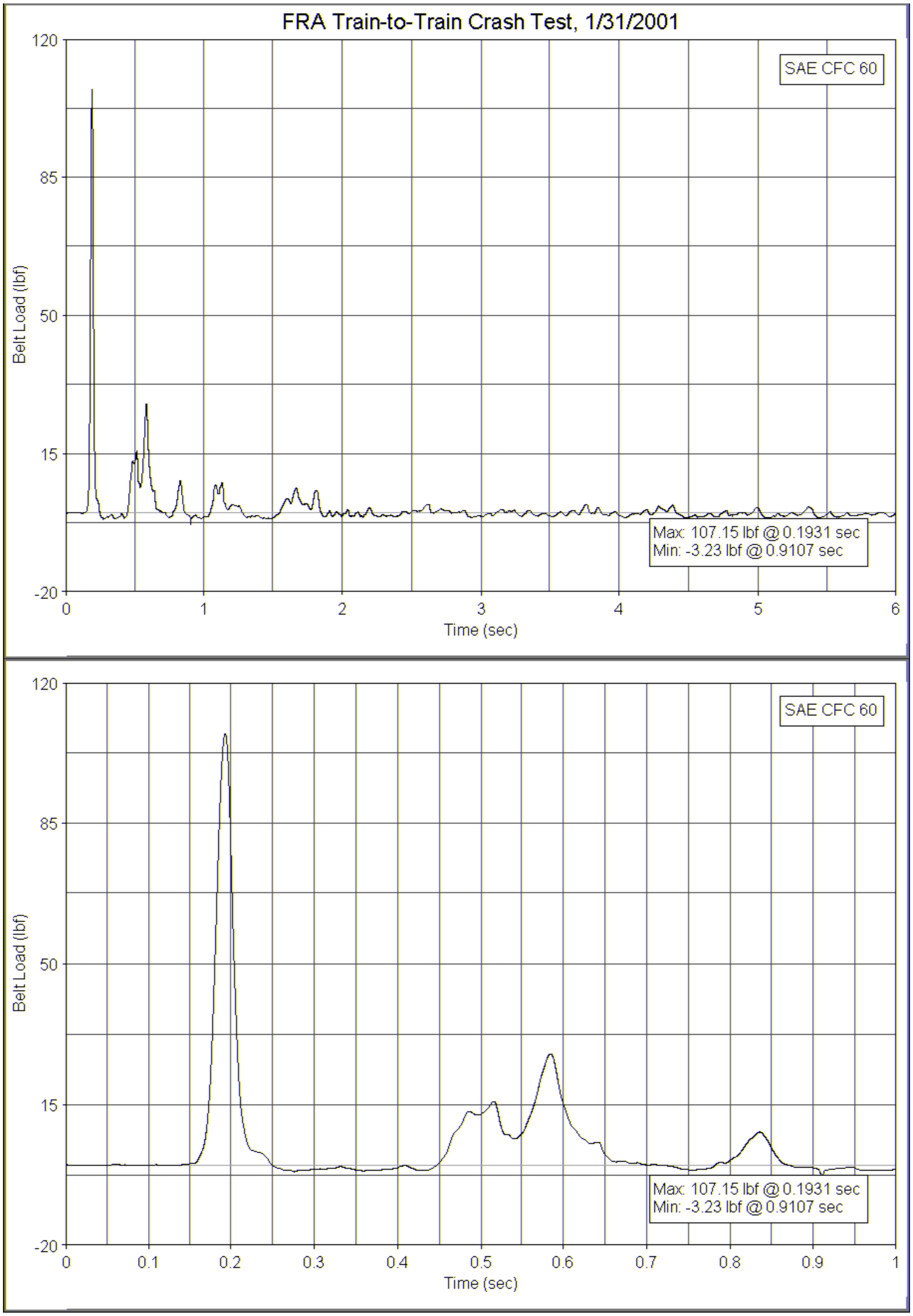


Figure E-1: Experiment No. 2-1 Intercity Seat, Forward Row, Aisle Seat, Hybrid III 5th-Percentile Female, Shoulder Belt Load

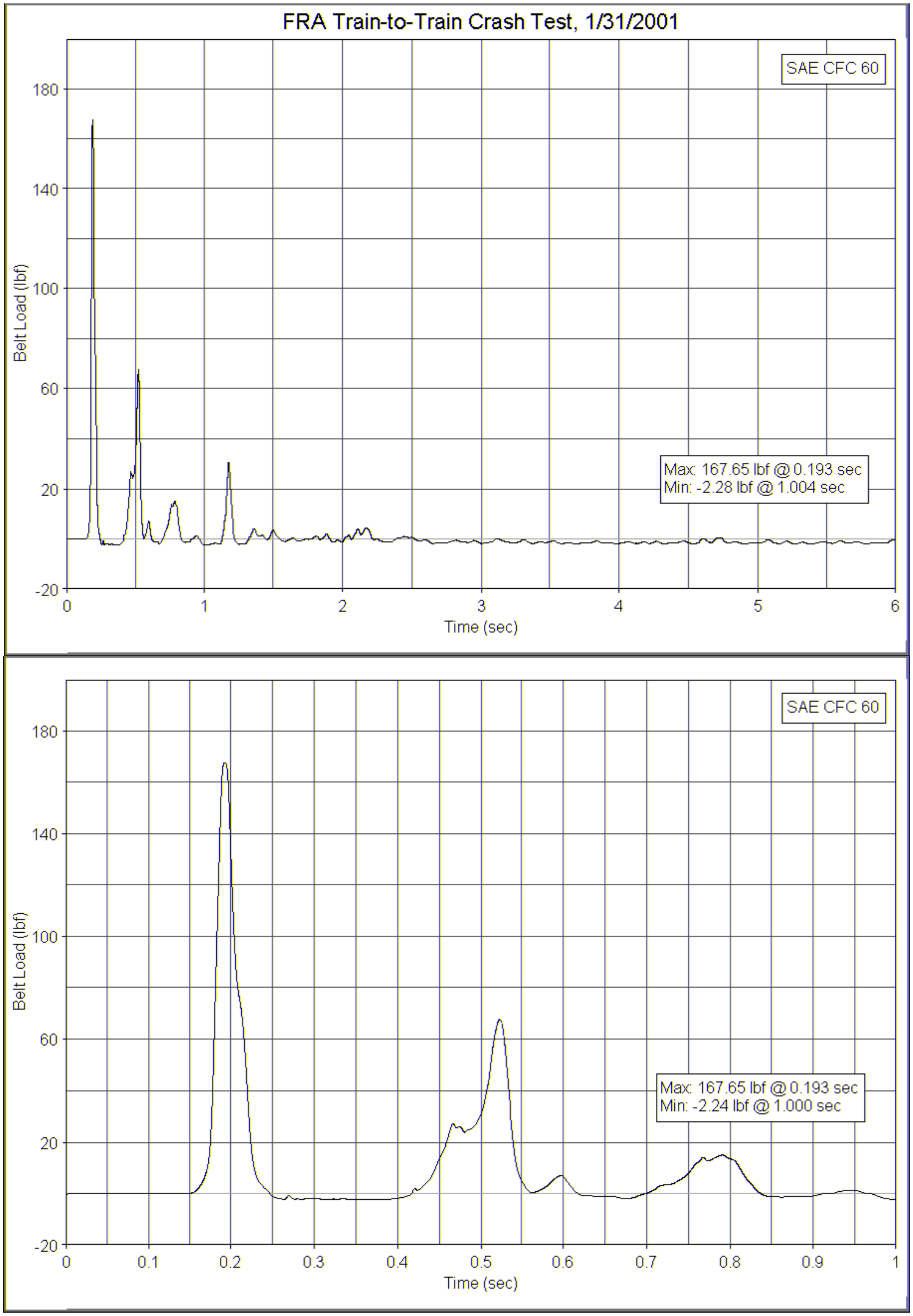


Figure E-2: Experiment No. 2-1 Intercity Seat, Forward Row, Window Seat, Hybrid III 95th-Percentile Male, Shoulder Belt Load