U.S. Department of Transportation

Federal Railroad Administration

Workstation Table Crashworthiness Tests

Office of Research
and Development
Washington, DC 20590

DOT/FRA/ORD-13/48

Final Report
December 2013

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	December 2013	Final Report June 2009

4. TITLE AND SUBTITLE
Workstation Table Crashworthiness Tests

5. FUNDING NUMBERS

6. AUTHOR(S)
Richard Stringfellow*, Jay Nutting**

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Department of Transportation
Research and Innovative Technology Administration
John A. Volpe National Transportation Systems Center
55 Broadway
Cambridge, MA 02142-1093

8. PERFORMING ORGANIZATION REPORT NUMBER
DOT-VNTSC-FRA-XX-XX

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Department of Transportation
Federal Railroad Administration
Office of Research and Development
1200 New Jersey Avenue, SE
Washington, DC 20590

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
DOT/FRA/ORD-13/XX

11. SUPPLEMENTARY NOTES
*TIAX LLC
15 Acorn Park
Cambridge, MA 02140

**MGA Research Corporation
5000 Warren Road
Burlington, WI 53105

12a. DISTRIBUTION/AVAILABILITY STATEMENT
This document is available to the public through the FRA Web site at http://www.fra.dot.gov.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

This report describes results from the Option C component of a research program aimed at improving crashworthiness of passenger train workstation tables. Research conducted in the Base, Option A, and Option B components of the program was focused on developing a prototype design for a crashworthy workstation table, constructing a number of tables, and testing them. A prototype crashworthy workstation table was successfully tested as part of the full-scale train-to-train test of CEM equipment conducted in March of 2006. The Option C activities described here were focused on characterizing the quasi-static and dynamic force-crush behavior of the prototype workstation table in order to define performance requirements for future workstation table designs.

14. SUBJECT TERMS
Crashworthiness, workstation table, full-scale train-to-train test, crash energy management, crush zones, rail cars, occupant survivability, collision, injury, impacts

15. NUMBER OF PAGES
95

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102

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

Inches: 0 1 2 3 4 5

Centimeters: 0 1 2 3 4 5 6 7 8 9 10 11 12 13

QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSIO

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

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

Updated 6/17/98

Contents

Illustrations

Executive Summary

In support of the Federal Railroad Administration's (FRA) Equipment Safety Research Program, the Volpe Center has been conducting research to improve structural crashworthiness of passenger rail cars and enhance occupant protection for rail car passengers. As a part of this work, crash energy management (CEM) strategies in the form of deformable crush zones built into the ends of passenger cars have been developed and tested with the aim of preserving the occupant volume in passenger cars in the event of a collision. One consequence of the use of CEM in rail cars is the increased level of accelerations experienced by the rail cars in collision scenarios, which also potentially increases the risk of severe injury to occupants from secondary impacts. Additionally, accident investigations have identified the risk of severe injury caused by workstation tables in accidents involving conventional (non-CEM) equipment [1, 2].

This report describes results from the Option C component of a research program aimed at improving crashworthiness of passenger train workstation tables. Research conducted in the Base, Option A, and Option B components of the program was focused on developing a design for a prototype crashworthy workstation table, constructing a number of tables, and testing them [3]. A prototype crashworthy workstation table was successfully tested as part of the full-scale train-to-train test of CEM equipment conducted in March of 2006. The Option C activities described here were focused on characterizing the quasi-static and dynamic force-crush behavior of the prototype workstation table in order to define performance requirements for future workstation table designs.

A set of test requirements was first established. A preliminary set of requirements was drafted by MGA Research Corporation (MGA), reviewed by TIAX LLC, and ultimately reviewed and approved by the Contracting Officer's Technical Representative (COTR). This document defines the test conditions, includes a description of the required fixtures, the means by which the quasi-static or dynamic loads were imparted to the tables, and the critical information to be measured.

A set of test implementation plans was also created. A preliminary set of plans was drafted by MGA, reviewed by TIAX LLC, and ultimately reviewed and approved by the COTR. The test implementation plans include a description of the test setup and the instrumentation and data acquisition system (DAS) that specify how the tests are to be conducted.

The quasi-static test was conducted on October 9, 2007, at MGA's facilities in Burlington, WI. Forces were applied to the table via two hydraulic actuators that loaded the side of the table through two torso-shaped, rigid rams. Prior to the test, a finite element (FE) model was used to generate an estimate of the force-crush performance characteristics of the table. Test results indicated that the table crushed at force levels that were about 15 percent less than pre-test predictions. Accordingly, the material model for the honeycomb elements that serve as the primary energy absorbers for the table top was modified for future use in dynamic test simulations. Test results further showed that most of the reaction load was transmitted to the upper two tabletop connections to the wall and that the wall connection was more resilient than expected.

The first of three dynamic pendulum tests was also conducted on October 9, 2007. The same two identical torso-shaped impactor elements were mounted to the front of pendulums that were suspended from the ceiling of the test bay, having a mass of approximately 170 pound-mass

(lbm) each, and dropped from a height of 59 inches (in) so as to impart 10,000 inch-pound-force (in-lbf) of energy to the table with an initial impact speed of 12 mph. Predicted pendulum displacement-time histories were consistent with measured values, as were both corresponding lateral and axial forces. Deceleration data measurements revealed a high-frequency oscillation that likely was due to excitation of the natural elastic deformation modes of the table support structure. Post-test video revealed that the table support structure had considerably more compliance than was modeled. For this reason, despite the fact that the *peak* displacement of the impactors was very close to the value predicted by the model, the measured *permanent* deformation of the table top (4.75 to 5.5 in) was less than the predicted value of about 5.9 in. It appears that more of the energy imparted to the table by the impacting masses was dissipated elastically in the test than in the model.

For the second dynamic pendulum test conducted on June 17, 2008, each impactor mass was reduced to 75 lbm to be more representative of the *effective* mass of the occupant, rather than the *total* mass. (Because the occupant's body has considerable flexibility and typically extends well above and below the table top, only part of the inertia of the occupant is transmitted to the table top.) The effective mass was determined by running MADYMO models comparing dummy and pendulum masses. The results of this test indicated that the smaller impactor masses caused the pendulums to be less stable laterally than they were with the heavier masses. This caused the edge of the window-side impactor to strike the wall support, resulting in a much larger deceleration pulse than predicted on the window-side impactor and causing the table to rotate away from the aisle-side impactor, so that it experienced smaller than expected levels of deceleration. Finally, the stiff impact between the impactor and the wall support caused the table to 'ring', exciting the natural frequencies of the table structure such that the deceleration signal was very noisy. In short, the lateral stability issue resulted in a test outcome that was not ideal.

For the third and final dynamic pendulum test, also conducted on June 17, 2008, a conventional workstation table was impacted under the same conditions used for the second test. As expected, the table did not absorb much energy upon impact. Instead, the screws connecting the table top to the wall sheared off, as did an aisle-side pedestal connecting the table to the floor. The collision of the stiff window-side impactor and the relatively stiff and unyielding table top led to very high deceleration levels—higher even than the levels that arose when the impactor struck the wall support in the second test—prior to failure. In contrast, the aisle-side impactor experienced relatively small deceleration levels, as the table edge was already moving away from it as it collided, and little force build-up occurred prior to failure.

In summary, it appears that both the quasi-static and dynamic test methods employed for this program are effective in characterizing the energy-absorbing capacity of the tested workstation tables. It appears also that models can be effectively used in conjunction with quasi-static tests to predict the consequences of the dynamic tests. While it appears that the dynamic test method can be effective, the lateral stability of the pendulums during their free fall is an issue that must be addressed further. The stability issue is complicated by the fact that the two falling pendulums must be independent. The cables that guide the pendulum cannot be placed in optimal configurations because they would interfere with one another. The ability to control the pendulums appears to be further compromised when using smaller masses. Such masses may be more representative of the conditions that govern the collision of a seated occupant with a workstation table, but they appear to make it more difficult to control the impact during testing. Further study that demonstrates the feasibility of using larger masses and smaller drop heights to produce the same level of applied kinetic energy is warranted.

1. Introduction

The Volpe Center has been supporting FRA by conducting research and development studies to improve rail equipment crashworthiness. This research has included the development of CEM systems, comprising crush zones at the ends of rail vehicles, as a means of potentially improving occupant survivability during a collision. Studies have shown that a consequence of using CEM strategies is a possible increase in the risk of severe injury to occupants due to secondary impacts during a collision.

Among the various occupant protection strategies, increasing the crashworthiness of workstation tables has been identified as having the potential to significantly reduce the risk of serious and fatal injuries on passenger rail cars. The vulnerability of the occupants and the need to improve the crashworthiness of workstation tables was highlighted by an inline collision between a passenger train and a freight train that occurred April 2002 in Placentia, CA. This accident resulted in two fatalities and several injuries for occupants seated at workstation tables [1, 2].

In response to concerns regarding the safety of passengers seated at workstation tables, the Volpe Center and FRA contracted TIAX LLC to develop a design for a workstation table that would, ideally, reduce passenger injury risk by compartmentalizing the occupants and minimizing the contact forces [3, 4]. Four prototype workstation tables were built as part of the Option B component of this program. Two tables were previously tested in experiments on the March 23, 2006, CEM train-to-train test and successfully performed as designed [5, 6]. The tests conducted on the two remaining tables are the subject of this report.

The research reported here was conducted as part of Option C of this same research program. The principal objective of the Option C research was to characterize, through testing, the force-crush behavior of the prototype table in order to define performance requirements for an industry workstation table safety standard. Both quasi-static and dynamic pendulum tests of the prototype workstation tables were conducted. In addition, a dynamic pendulum test of a conventional workstation table was conducted for comparison.

The static and dynamic tests were conducted October 2007 and June 2008 at the MGA Research Corporation facilities in Burlington, WI.

In order to better understand how the table would behave during the quasi-static and dynamic tests, and to continue to improve its predictive capabilities, an FE model that was developed as part of the Base program was used to simulate the tests. Some of the model predictions are compared with test results in the main body of this report. A complete description of the model and more comprehensive discussion of model predictions are presented in Appendix D.

2. Test Requirements and Implementation Plans

A test requirements document and a test implementation plan were created at the beginning of the program. Both documents were reviewed by the Volpe Center and then finalized. These documents were later modified to reflect a change of scope that facilitated the testing of a conventional workstation table, as well as a change to the mass and drop height of the pendulums.

2.1 Test Requirements

A test requirements document was created in order to detail the specifications for one quasi-static loading test and three dynamic pendulum tests. The complete document is attached to this report as Appendix A. It defines test conditions and includes a description of the required fixtures, the means by which the quasi-static or dynamic loads are imparted to the tables, as well as the critical information to be measured. The document was reviewed and approved by the Volpe Center prior to development of the test implementation plans.

The following fixturing and loading requirements were specified for both the quasi-static and dynamic pendulum tests:

- The workstation table shall be mounted to an effectively rigid support in the same manner in which it is mounted in a rail car—i.e., at two locations along a stiff rail that is located at the window side of the table top and at one location that is at the end of a support beam that extends downward at a 45-degree angle from a bracket located about 8 in away from the wall on the underside of the table top.
- The table shall be loaded by two effectively rigid blocks, as depicted in Figure 1. One block is centered on the aisle half of the table, (~30 in from the wall mounting bracket) and the other is centered on the window half of the table, (~10 in from the wall mounting bracket).

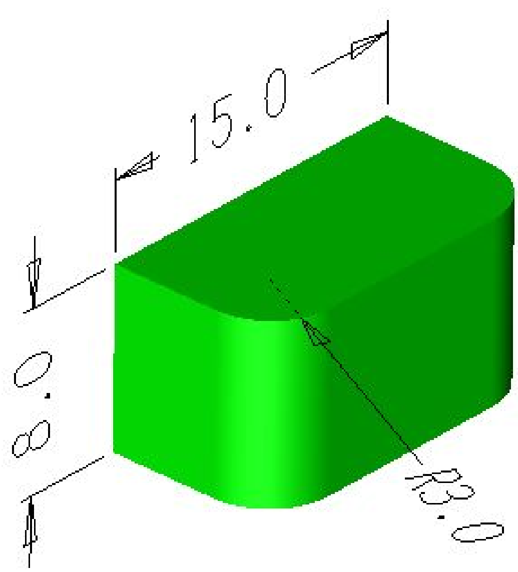


Figure 1. Impactor Geometry (Dimensions are in Inches)

For the quasi-static test, load application was specified to occur through actuation of the loading blocks using hydraulic rams, as depicted in Figure 2.

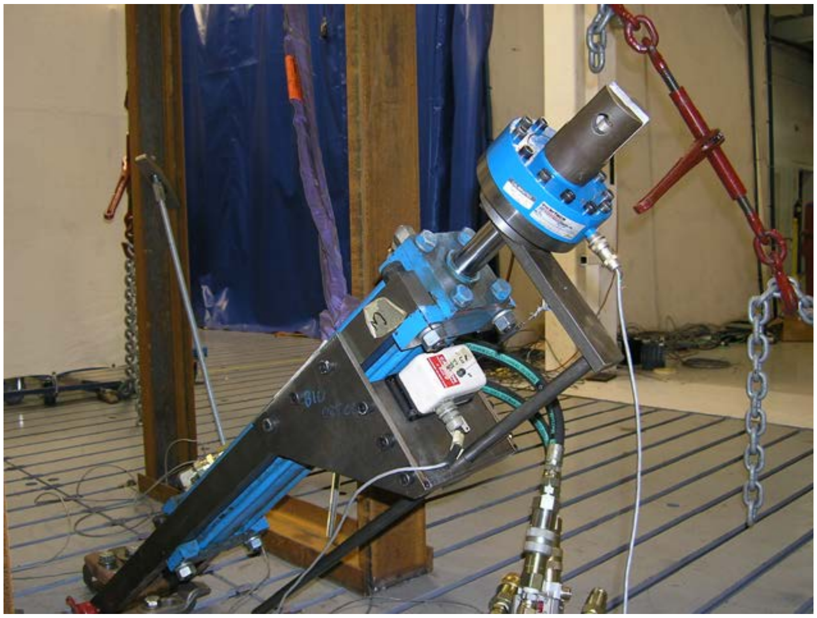


Figure 2. Hydraulic Loading Ram

Data collection requirements for the quasi-static test include:

- Pre-test and post-test photographs;
- Applied load versus time for both hydraulic rams (load cells);
- 3-axis reaction loads versus time between table and wall (load cells);
- Displacement versus time at each loading block (string potentiometers);
- Displacement versus time at each of the locations opposite the two loading blocks (string potentiometers);
- Real-time digital video recordings of the test from at least two locations—from above and from across the aisle.

For the dynamic pendulum tests, load application was specified to occur by means of the impact of two appropriately weighted, freely swinging pendulums suspended from the ceiling by cables, raised to a predetermined height, and then simultaneously released.

The impactor blocks were specified to be the same as those used in the quasi-static test, but now mounted to the front of a weighted ‘shuttle’, as depicted in Figure 3. As shown in the figure, a load cell is mounted between the impactor and the shuttle and is used for measuring the impact load.

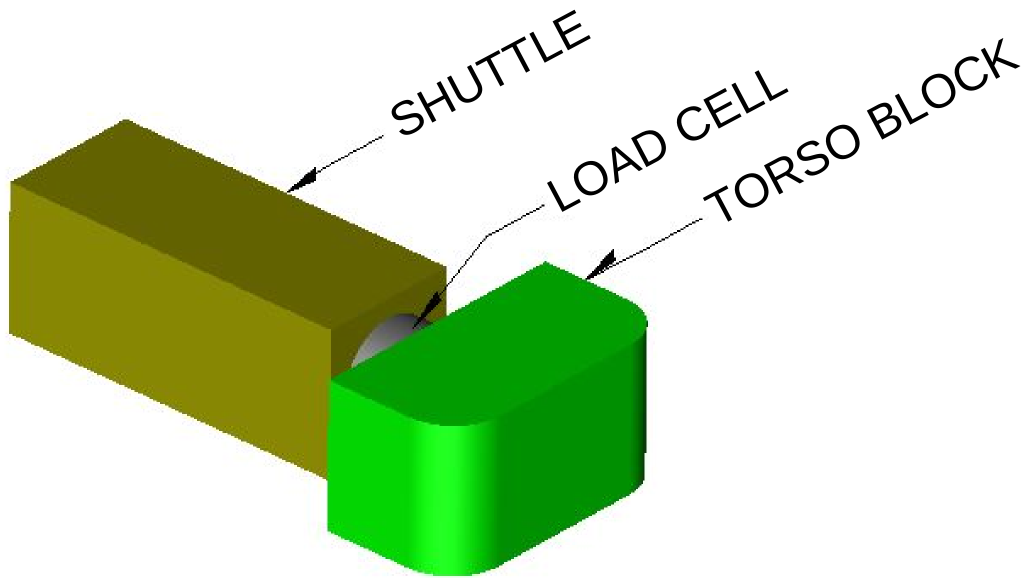


Figure 3. Illustration of Pendulum Shuttle with Attached Load Cell and Torso Block

The following data collection requirements were imposed for each dynamic pendulum test:

- Pre-test/post-test photographs;
- Applied load versus time at each impact location (load cells);
- 3-axis reaction loads versus time between table and wall (load cells);
- 3-axis acceleration versus time for each torso block (accelerometers);
- Displacement versus time at each location opposite the two impact points (string potentiometers);
- High-speed digital video recordings of the test from two perspectives—one view from above and one from across the aisle.

2.2 Test Implementation Plans

Test implementation plans for one quasi-static loading test and three dynamic pendulum tests were also created. The complete test implementation plan documents are included in this report as Appendix B. The test implementation plans specify how the tests are to be conducted, including a description of the test setup, the instrumentation, and the DAS. The test implementation plan was reviewed and approved by the Volpe Center prior to the test.

The procedures that were set forth in the test implementation plan for the two types of tests are summarized below:

<u>Quasi-static test:</u>

- Install the test article onto the test fixture;
- Install the torso block onto the cylinder with the required load cell;
- Install the linear displacement transducers (string potentiometers);
- Set up the video equipment;

- Check and zero all instrumentation;
- Take pre-test photographs;
- Verify setup with test lab engineers and witnesses;
- Start the video equipment;
- Apply the required load;
- Release the load;
- Take post-test photographs;
- Conduct post-test visual inspection of test article;
- Complete quasi-static test data witness sheets (report).

Dynamic pendulum tests:

- Install the test article onto the test fixture with the required load cells;
- Install the torso block onto the shuttle with the required load cell;
- Install the accelerometer onto the torso block;
- Install the string potentiometers on the table;
- Set up the video equipment;
- Check and zero all instrumentation;
- Take pre-test photographs;
- Raise the impactor masses (suspended from the ceiling with cables) to the desired height;
- Verify setup with test lab engineers and witnesses;
- Arm the video equipment and data acquisition system;
- Release the shuttles/masses;
- Take post-test photographs;
- Conduct post-test visual inspection of test article;
- Complete dynamic test data witness sheets (report).

3. Quasi-Static Test

The quasi-static test was conducted on October 9, 2007, at MGA's facilities in Burlington, WI.

MGA provided a complete summary of the test results in a final report attached to this report as Appendix C. The quasi-static test results are presented in Section A of Appendix C.

The test was conducted at a displacement rate of 2 in/min. Figure 4 shows the instrumented table and the rigid loading blocks mounted on the front of the hydraulic cylinders prior to testing.

Figure 4. The Instrumented Workstation Table Prior to the Quasi-Static Test

3.1 Test Results

The measured load-displacement curves for each loading block are shown in Figure 5. The load is a measure of the force in each loading ram. The displacement is a measure of the translation of the loading ram. The window- and aisle-side blocks were actuated together up to a displacement of 7 in. At approximately 6 in of displacement, the load on the window-side block began to increase rapidly, indicating that the honeycomb block on that side of the table had bottomed out. The measured load for the window-side block reached approximately 4,800 lbf at a displacement of 7 in. The load on the aisle-side block was still only around 2,200 lbf at this displacement. This difference is clearly attributable to the elastic deformation of the table support structure, which behaves like a cantilevered beam. At 7 in of block displacement, string potentiometer data indicate that the displacement opposite the aisle-side loading point was approximately 0.8 in, while that opposite the window-side loading point was only approximately 0.3 in.

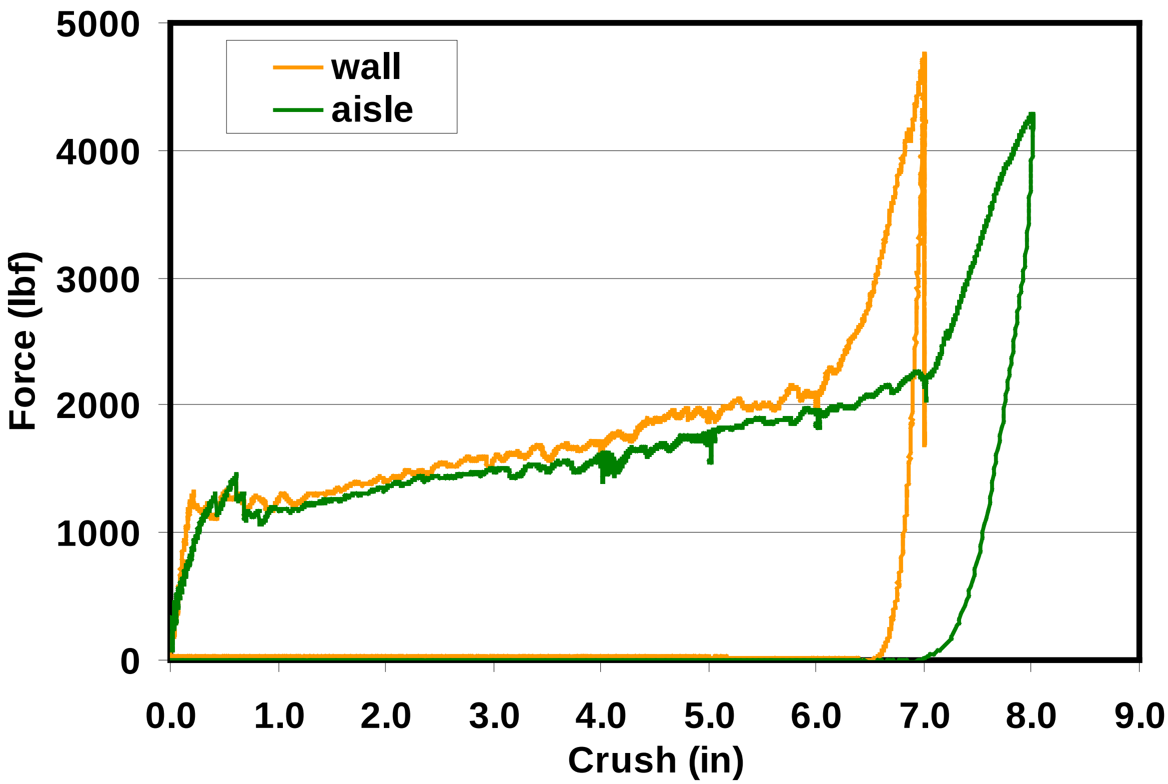


Figure 5. Measured Load-Displacement Curves for the Quasi-Static Test

At this juncture of the test, the displacement of the loading block on the window side of the table was held steady at 7 in, and the aisle-side block was displaced an additional inch. The load on the aisle-side block increased rapidly as the total displacement increased from 7 to 8 in, reaching about 4,300 lbf. The load on the window-side impactor decreased. A post-test photograph of the table is shown in Figure 6. The permanent crush distances on the aisle- and window-sides of the table are 7 and 6.6 in, respectively. Due to the elastic deformation of the table support structure, there is more spring-back on the aisle-side of the table (~1.0 in) than there is on the window-side (~0.4 in).

Figure 6. The Instrumented Workstation Table Following the Quasi-Static Test

3.2 Model versus Test Comparisons

An FE model of the workstation table was developed during the Base component of this research program. In order to better understand how the table would behave during testing, the model was used to simulate both the quasi-static and dynamic pendulum tests. A description of the model and a complete summary of model predictions for both the quasi-static and dynamic pendulum tests can be found in Appendix D of this report.

Pre-test Finite Element Analysis (FEA) predictions of load-crush behavior for the quasi-static test are compared with test results in Figure 7. As is evident, the model generally over-predicts the crush force of each side of the table. In addition, the model under-predicts the displacement at which the response begins to stiffen due to exhaustion of the crushable honeycomb. This latter difference is largely attributable to the assumption in the model that the connection of the table to the wall is perfectly stiff. According to the model, the final displacement of a point on the table opposite the aisle-side load block is 0.45 in, much smaller than the measured value of 0.8 in.

Based upon this comparison of pre-test model versus test load levels, the material model for the honeycomb was adjusted so that it better captured test behavior. A revised analysis was performed using this model, and its predictions for load-crush behavior are compared with test results in Figure 8. As is evident, the adjustment to the honeycomb crush characteristics improved the agreement with the test results. The revised honeycomb material model was subsequently used in the simulations of the dynamic pendulum tests.

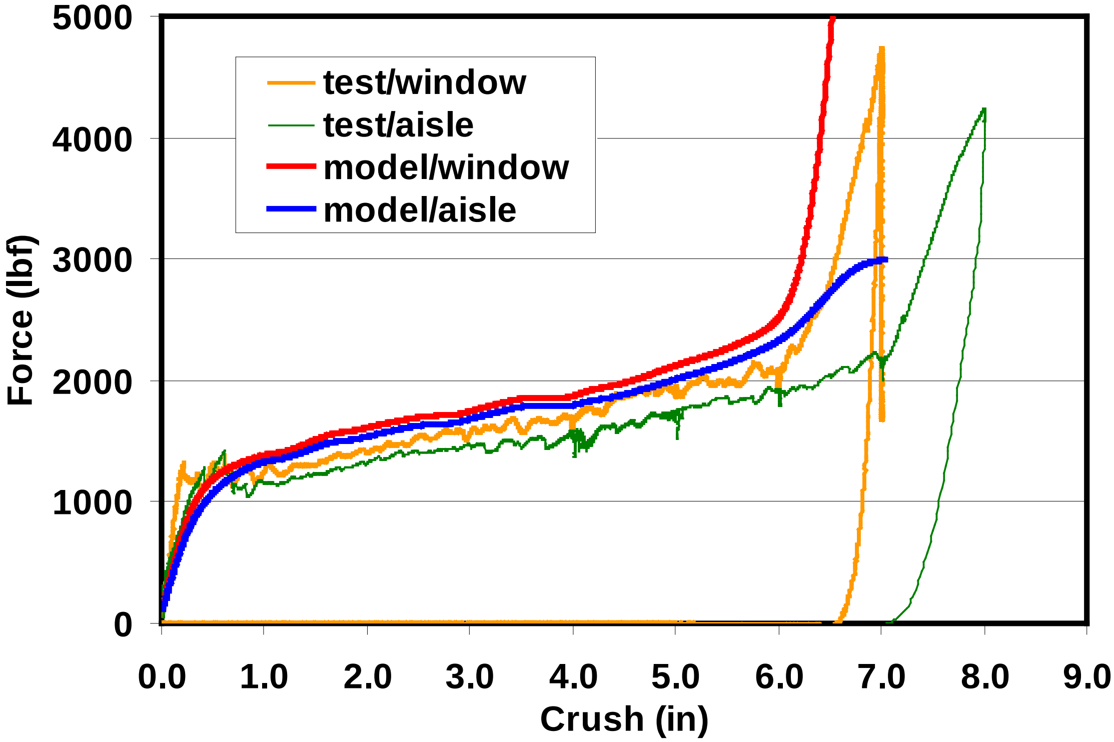


Figure 7. Comparison of Pre-Test Model Prediction of Load-Crush Response with Test Results

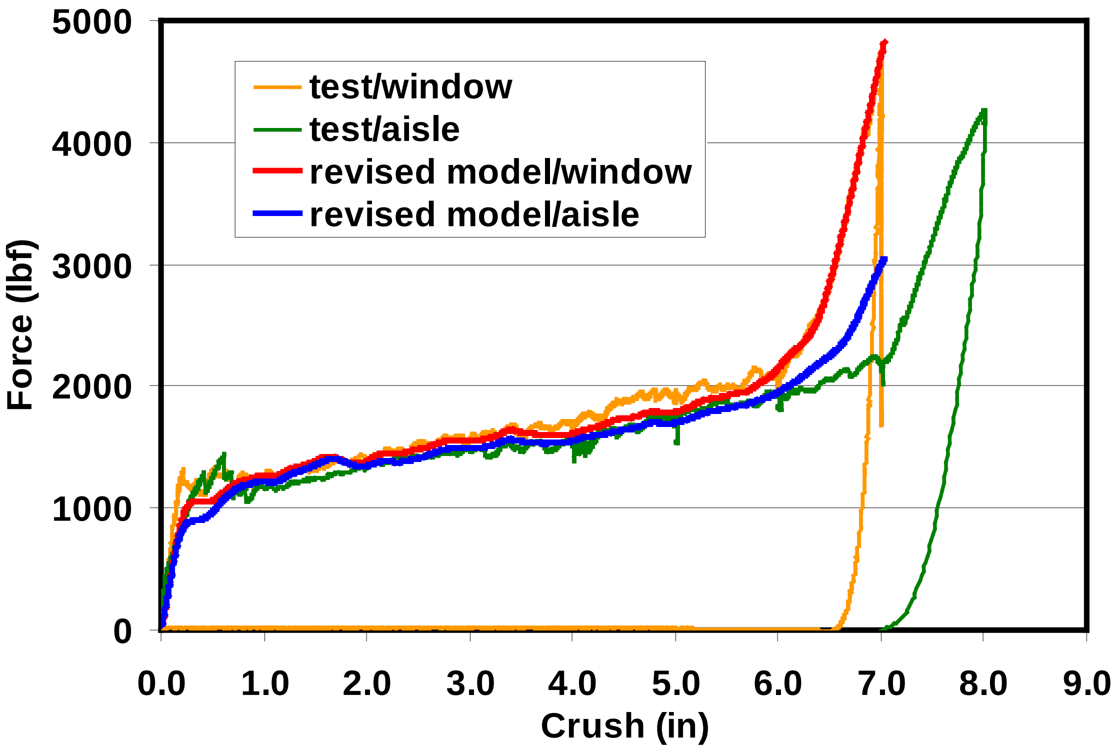


Figure 8. Comparison of Revised Model Prediction of Load-Crush Response with Test Results

4. Dynamic Pendulum Tests

The first dynamic pendulum test was conducted on October 9, 2007, at MGA's facilities in Burlington, WI. The second and third dynamic pendulum tests were conducted on June 17, 2008. A complete summary of the dynamic pendulum test results are presented in Sections B, C, and D of Appendix C.

Each pendulum mass was suspended from the ceiling of the test bay by a set of eight cables that were attached to the pendulum shuttle. As shown in Figure 9, each pendulum has eight cables, four attached to the front of the shuttle and four attached near the back. The outboard cables are suspended at an angle of approximately 30 degrees with respect to the vertical direction, to provide stability. The inside cables are suspended vertically so that the cables do not interfere with one another during the drop.

For the first pendulum test, the mass of each block was approximately 170 lbm; this mass was later decreased to 75 lbm for the second and third pendulum tests. The 170–pound-mass caused more table crush than a 50th percentile anthropomorphic test device (ATD) under similar collision conditions. The mass was reduced to 75 lbm for subsequent tests to better approximate the effective mass of an ATD impacting the table. The drop height for the first pendulum test was specified to produce a total impact energy of 10,000 in-lbf. For a 170–pound-mass, this corresponds to a drop height of approximately 59 in, with a resulting impact speed of 213 in/sec or 12.1 mph. For the second and third pendulum tests, the impact energy was decreased to 6,000 in-lbf. For the smaller 75 lbm mass, this corresponds to a drop height of 80 in and an impact speed of 249 in/sec or 14.1 mph.

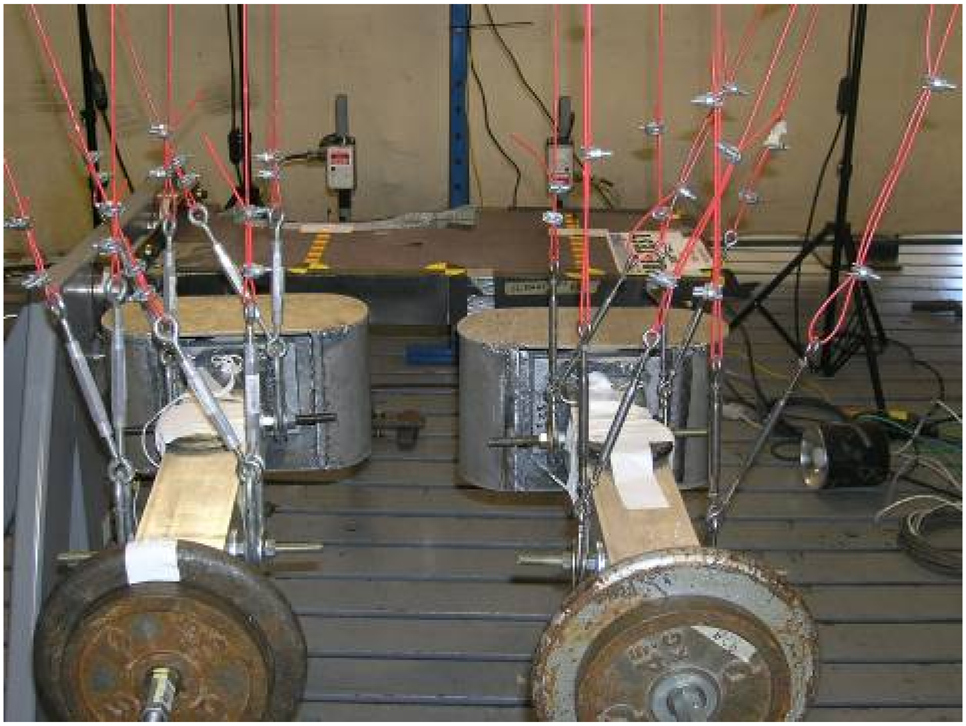


Figure 9. Arrangement of Pendulum Cables

4.1 Dynamic Pendulum Test #1

The first dynamic pendulum test was also conducted on October 9, 2007. For this test, the mass of each pendulum was 172 lbm and the pendulum was released from a height of 59.6 in. The complete results for this test are reported in Section B of Appendix C.

4.1.1 Test Results

Figure 10 and Figure 11 show photographs of the instrumented table and the pendulum shuttles before and after the first test. (Note that the far side of this table had been previously crushed during another test.)

Figure 10. Side View of the Instrumented Workstation Table Prior to the First Dynamic Pendulum Test

Figure 11. Side View of the Instrumented Workstation Table Following the First Dynamic Pendulum Test

The impact of the pendulums produced about 5 to 5.5 in of permanent deformation on the window-side of the table and about 4.75 to 5.25 in on the aisle-side of the table. The variation is due not only to elastic bending of the cantilever support, as was seen in the quasi-static test, but also to rotation of the impacting masses about a vertical axis. On the wall side of the table, the deformation appears to be slightly greater closer to the fixture. In contrast, on the aisle-side of the table, the deformation is slightly greater closer to the end of the table.

The measured deceleration of the impactors is shown in Figure 12. The plateau level of about 8 to 12 Gs is consistent with the quasi-static load levels of 1,400 to 2,000 lbf shown in Figure 5. Note that the window-side deceleration level appears to be increasing more rapidly near the end of the pulse, consistent with the initial stages of stiffening in the window-side table response. In contrast, the aisle-side response remains fairly steady, consistent with the delay in the stiffening response shown in Figure 5, and appears to be the result of elastic bending of the table support. The somewhat smaller total deformation on the aisle-side is also consistent with the table support bending. The plastic deformation on that side does not need to be as great to stop the impactor because some of the energy is dissipated through elastic deformation.

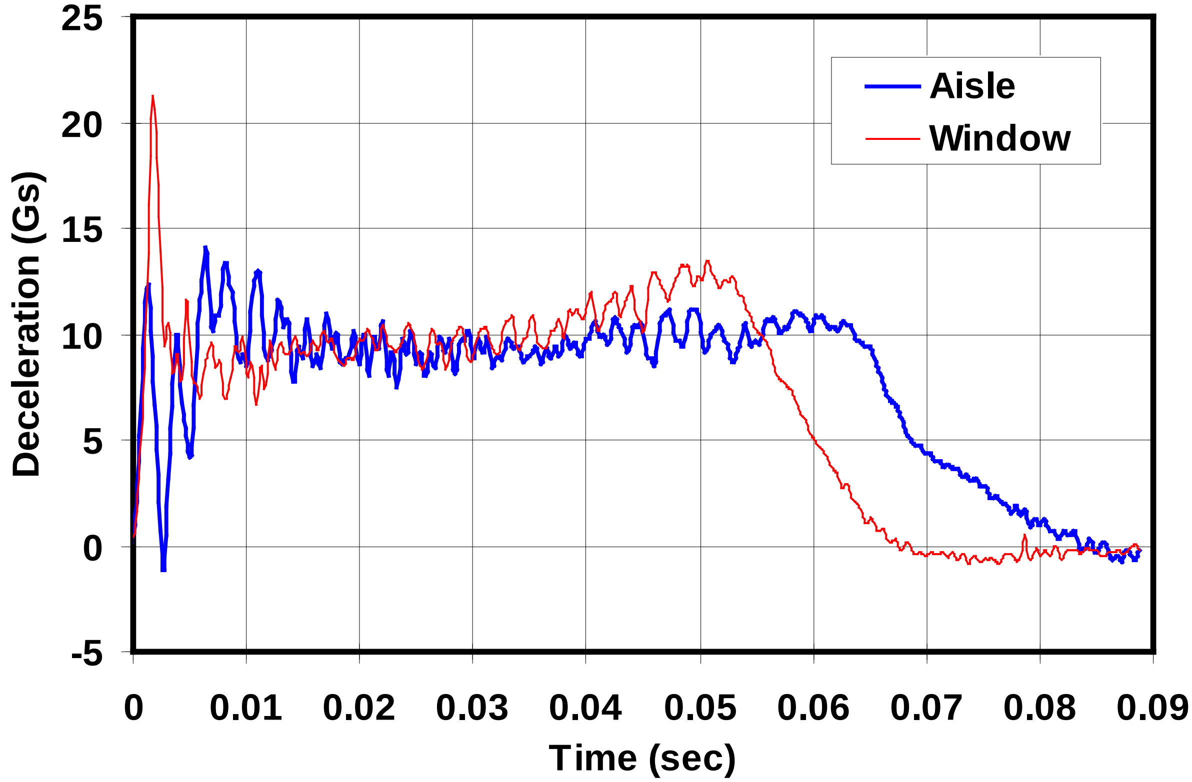


Figure 12. Measured Deceleration of Impacting Masses

4.1.2 Model versus Test Comparisons

FEA model predictions of impactor displacement-time histories are compared with test results in Figure 13. The displacement-time history of the test impactors was calculated by double-integrating the measured acceleration-time history. As is evident, there is very good agreement overall. The peak measured displacements are slightly greater than those predicted by the model. However, the total permanent deformation of the honeycomb table top is lower. As noted above, the measured displacement ranges from about 4.75 to 5.5 in. The predicted permanent deformation is about 5.9 in. It is likely that this difference is, once again, attributable to the additional elastic deformation of the table that occurs because the wall support exhibits some compliance.

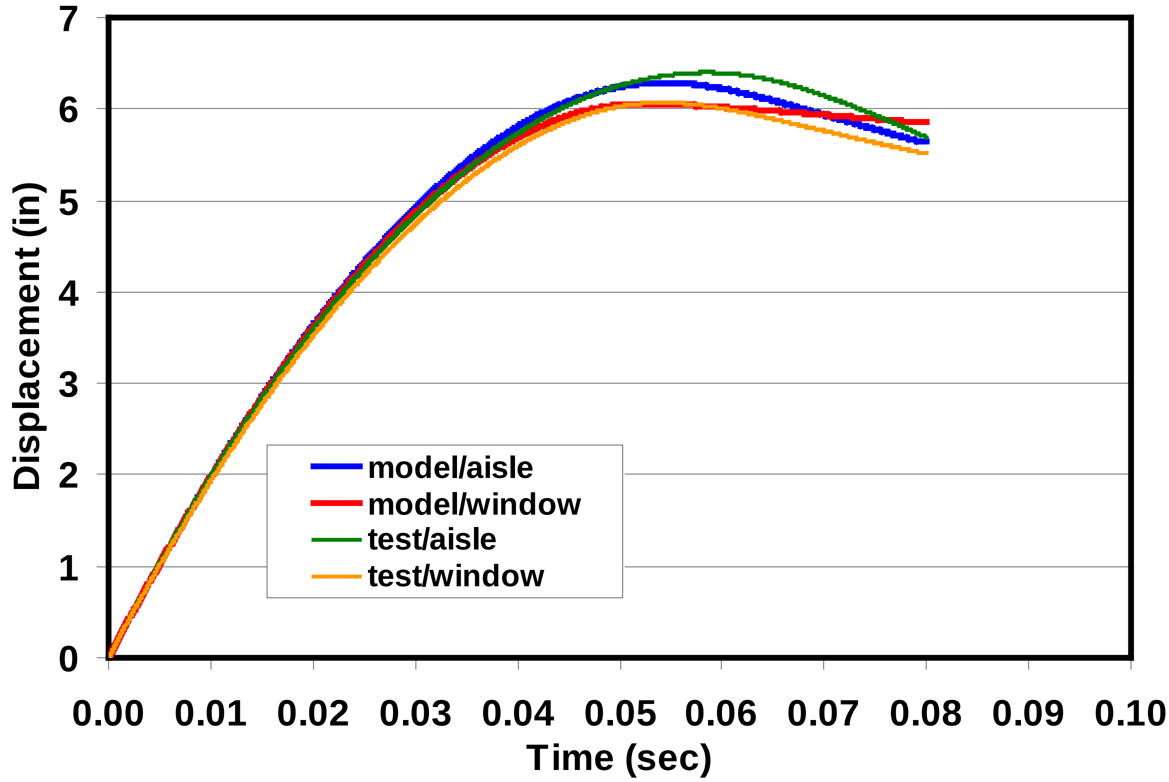


Figure 13. Comparison of Measured and Predicted Impactor Mass Longitudinal Displacements

The measured and predicted table top longitudinal and lateral reaction forces are compared in Figure 14 and Figure 15, respectively. In general, the predictions are in excellent agreement with measurements. The frequency of the oscillations of the system is lower for the tests. This is likely also due to the additional compliance in the supports that is not captured by the model—the added compliance lowers the effective spring stiffness of the system and therefore increases the period of the oscillations. The lateral forces on the upper two table top supports form a force couple that is necessary to carry the applied bending moment. Because of the large moment, the magnitudes of the lateral reaction forces are actually greater than the total longitudinal reaction force. Note, also, that the model does not accurately predict the distribution of longitudinal reaction forces that is likely due to the elastic compliance not captured in the model between the two top connections; therefore, the sum of these two reaction forces is plotted in Figure 14.

The measured results further indicate that the bottom support carries very little of the impact load since it was designed primarily to help carry vertical loads.

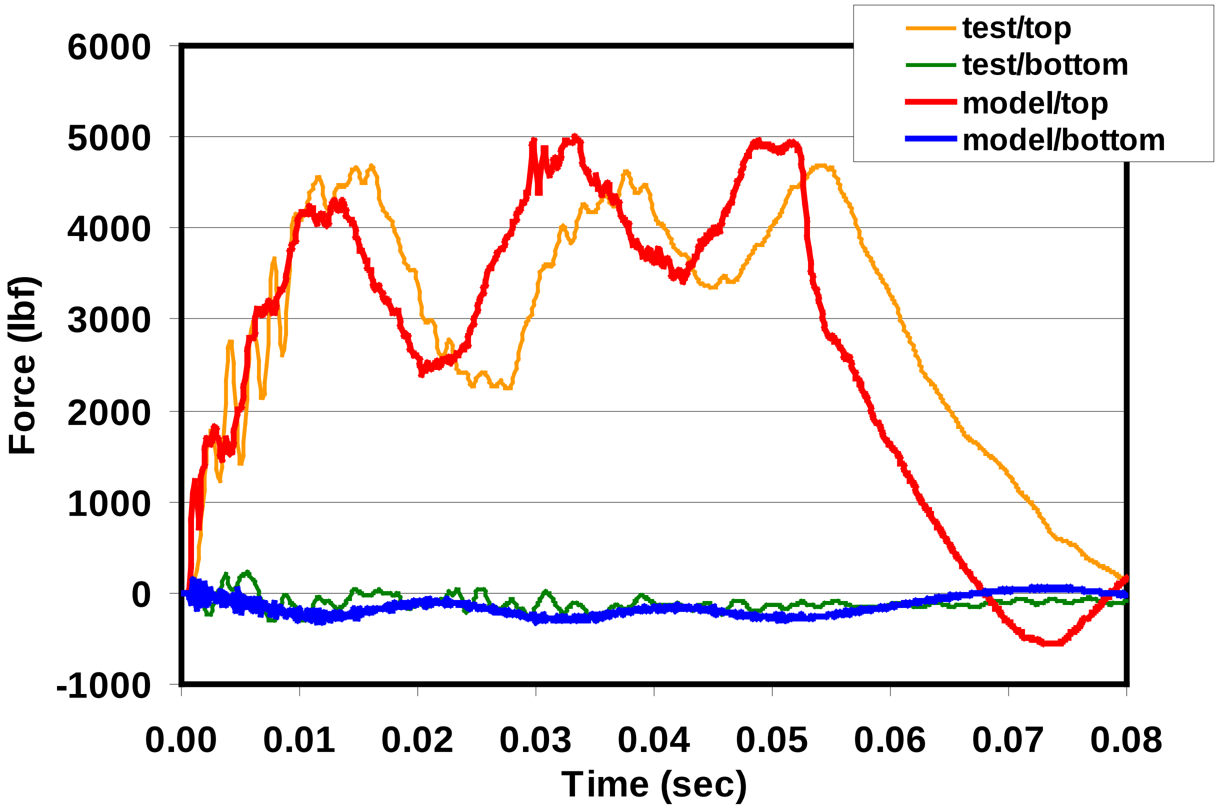


Figure 14. Comparison of Measured and Predicted Longitudinal Reaction Forces

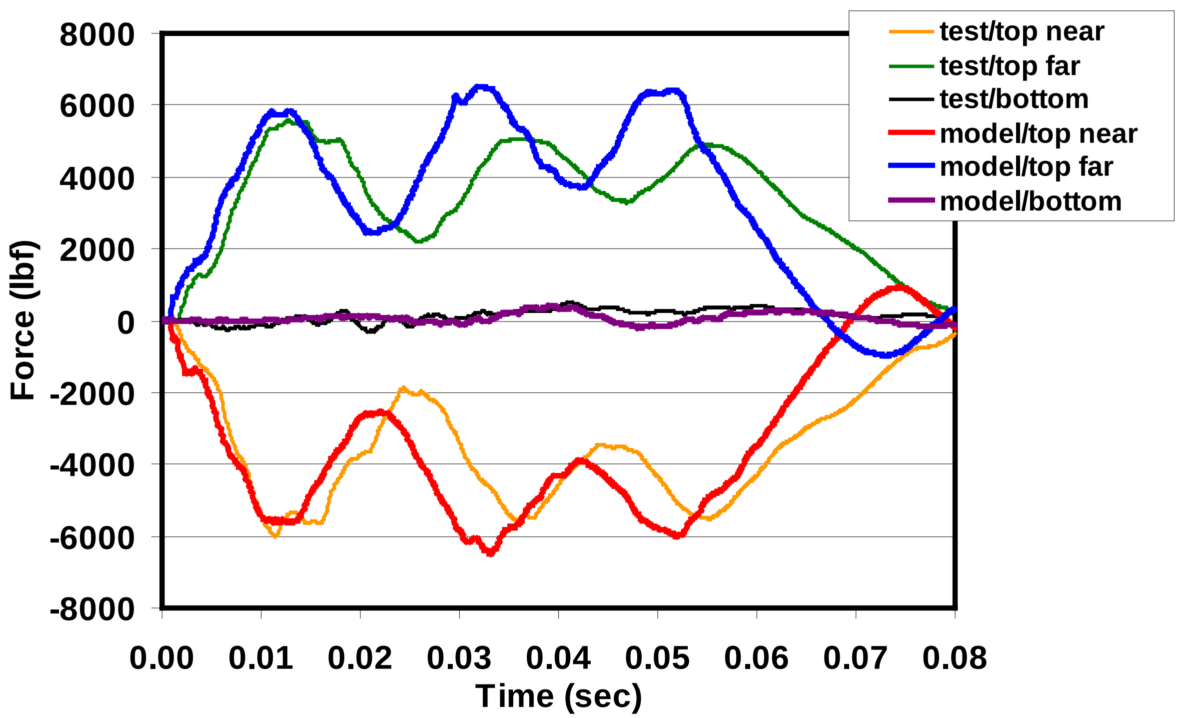


Figure 15. Comparison of Measured and Predicted Lateral Reaction Forces

4.2 Dynamic Pendulum Test #2

The second dynamic pendulum test was conducted on June 17, 2008. One side of the test article used in this test had been crushed during a previous test. However, the opposite side of the table was undamaged, permitting the table to be reused in the second pendulum test. The target energy for this test was 6,000 in-lbf. The mass of each pendulum was reduced to 75 lbm and the pendulums were released from a height of approximately 80 in above the table top. The complete results for this test are reported in Section C of Appendix C.

The measured deceleration-time histories for this test are shown in Figure 16. Compared with the deceleration curves shown in Figure 12 for pendulum test #1, the deceleration levels that were reached in this test are much higher and the curves are generally much noisier. These higher levels of deceleration were expected due to the lighter impactor masses; however, the values for the window-side impactor are much greater than would be necessary to account for the reduction in mass from 170 lbm to 75 lbm. For example, even when these data are filtered at CFC 60 (i.e., channel frequency class of 60 Hz), the peak window-side deceleration is approximately 44 Gs. This corresponds to a force of approximately 3,300 lbf, which is much greater than the 1500–2000 lbf force that might be expected based on the quasi-static force-displacement curve shown in Figure 5.

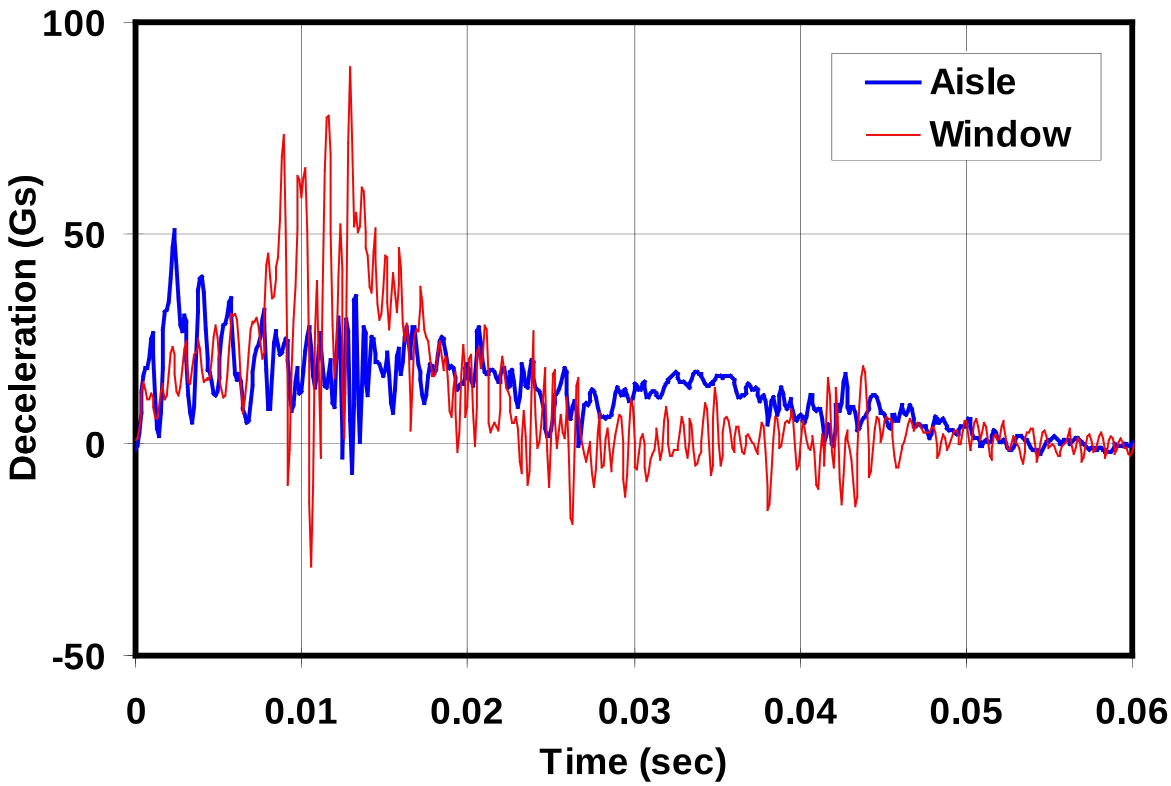


Figure 16. Measured Deceleration of Impacting Masses for Pendulum Test #2

A post-test examination of the table and review of the high-speed film helps to explain this greater than expected deceleration level. Figure 17 shows an overhead view of the table taken just prior to impact. The center of the window-side impactor should have been lined up with the red and white striped tape. Instead, because of the excessive lateral sway of the impactor during the drop, it impacts the table approximately 3 in closer to the wall support than it was meant to. This causes the window-side edge of the impactor to strike the stiff support structure at the end of the table after 0.008 seconds, leaving a large scratch mark. The impact between the two stiff structures causes a large deceleration spike followed by a high-frequency oscillation that occurs because the natural frequencies of the table support structure are excited. For this reason, much of the energy of the window-side impactor was transferred directly to the table support structure.

The associated rapid buildup in load causes the table to rotate away from the impactors. This rotation decreases energy transfer on the aisle-side of the table. The net result is that the permanent deformation of the table top is smaller than expected. Pre-test model predictions called for permanent honeycomb crush of about 4 in on each side of the table, with a bit more expected on the window-side of the table. The measured values are only about 1¾ to 2⅝ in on the window-side of table and approximately 1½ to 2¼ in on the aisle-side of the table. The high-speed film also shows that the aisle-side impactor rebounds much faster than the window-side impactor, consistent with the return of the elastic energy that has built up in the central I-beam support of the table top.

Because of the unexpected mode of load transfer, the predicted results are not in as good agreement with the measured values for this test as they were for the first pendulum test. For example, a total longitudinal reaction load of 4,300 lbf was predicted, but the measured total longitudinal reaction load was about 5,700 lbf. (For pendulum test #1, the peak total longitudinal load was predicted to be 4,750 lbf, and the measured value was 4,710 lbf).

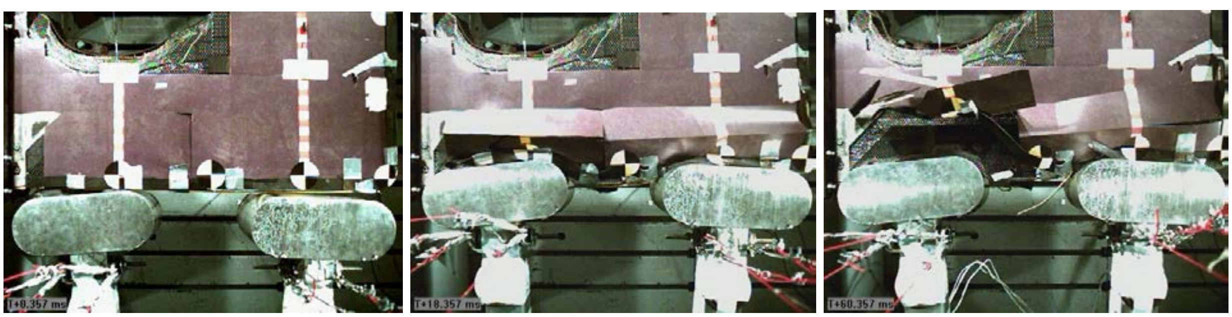


Figure 17. Overhead Views of Table during Impact of Pendulum Masses during Pendulum Test #2

4.3 Dynamic Pendulum Test #3

The third and final dynamic pendulum test was also conducted on June 17, 2008. A conventional workstation table was tested. A pre-test photograph of the table is shown in Figure 18. This table is approximately 34 in long and 16 in wide. It is supported along its wall edge as well as a pedestal near the aisle. It is constructed primarily from plywood, with melamine top and bottom surfaces and a rubber edge, and is approximately 1-inch thick.

As with pendulum test #2, the target energy for this test was 6,000 in-lbf using the same 75-pound-mass pendulum shuttles and an 80-inch drop height. The complete results for this test are reported in Section D of Appendix C.

Figure 18. Pre-Test Photograph of the Conventional Workstation Table

A post-test photograph of the conventional workstation table is shown in Figure 19. The table top was essentially torn away from the wall supports, with three sets of screws that connect the end of the table top to the wall support shearing off. The floor pedestal sheared away from its base, as shown in Figure 20.

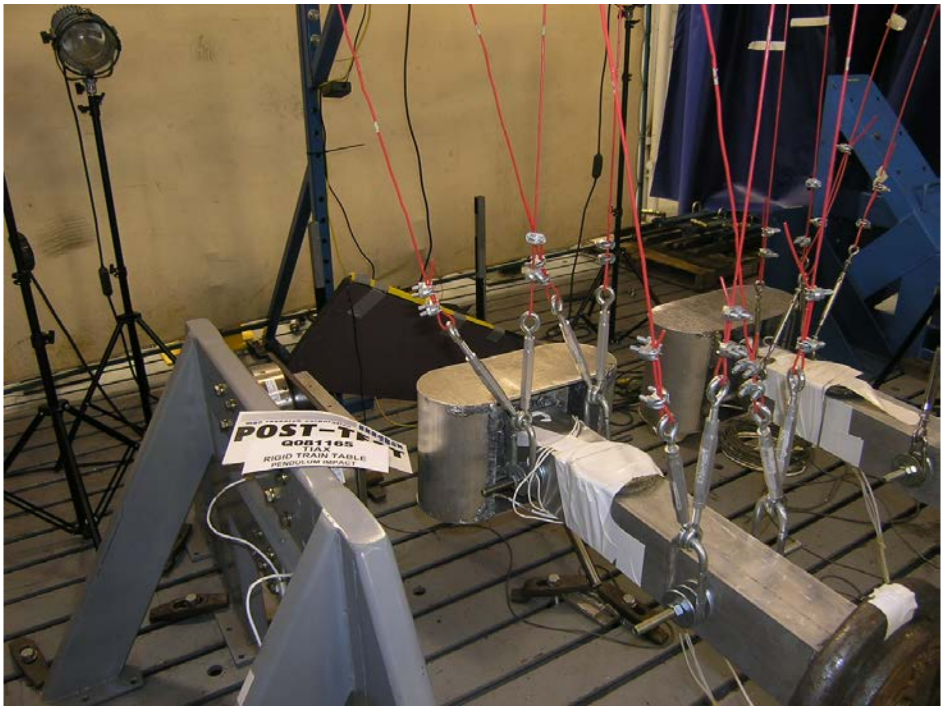


Figure 19. Post-Test Photograph of the Conventional Workstation Table

Figure 20. Post-Test Photograph of Sheared-Away Floor Pedestal

The measured deceleration-time histories for this test are shown in Figure 21. These curves indicate that the aisle-side impactor deceleration levels are extremely high, consistent with the collision of two stiff bodies that are unable to undergo large deformation prior to failure. The window-side deceleration levels are low because the aisle-side impactor effectively pushes the table edge away from it, so that it barely interacts with the table prior to failure.

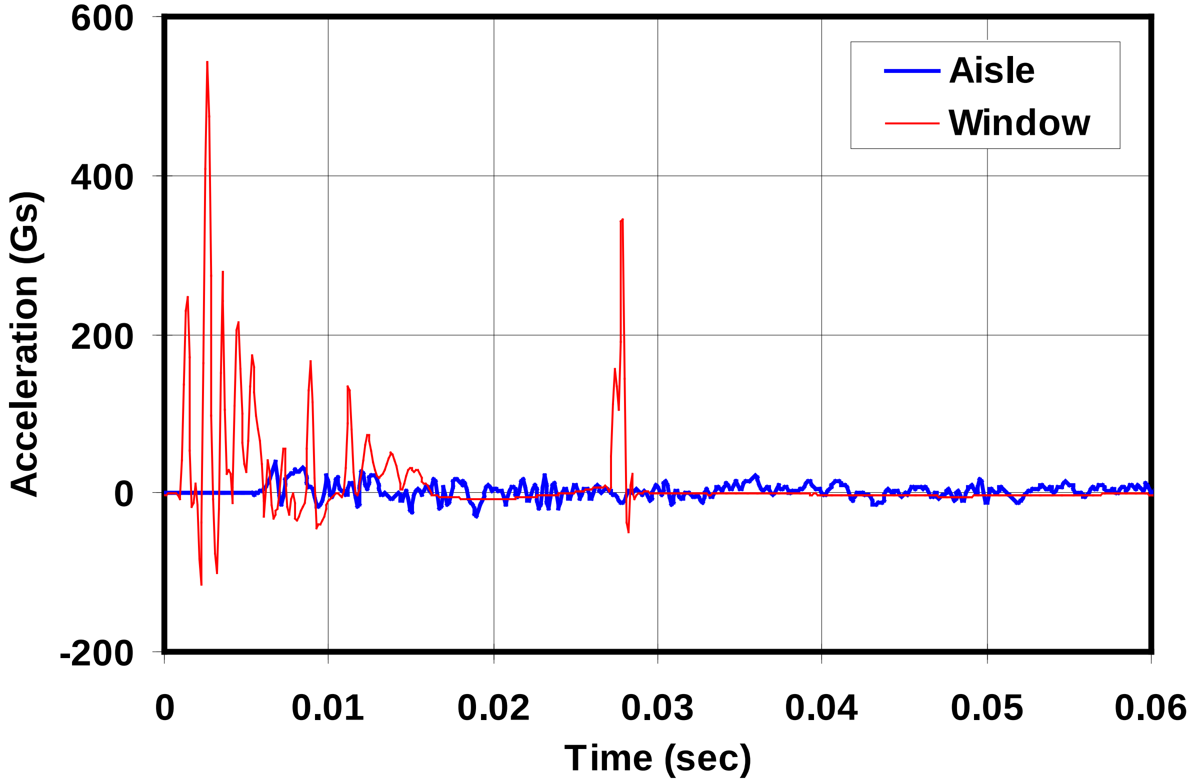


Figure 21. Measured Acceleration of Impacting Masses for Pendulum Test #3

5. Summary and Conclusions

The testing conducted under this research program had two primary objectives: to evaluate the effectiveness of the testing methods that were used, and to help establish a standard for qualifying the crashworthiness of workstation tables when subjected to the longitudinal impact associated with a seated occupant.

The quasi-static test was successful. The load-displacement characteristics of both the aisle- and window-sides of the table top matched expectations based on earlier tests and the results of FE models. Test results did, however, reveal that the crush of the honeycomb core of the table top occurred at a load level that was approximately 15 percent lower than the models had predicted. Based on this result, the honeycomb material model was modified. In addition, the test results indicated that the connection of the table to the wall was much more compliant than was modeled. For this reason, the rotation (with respect to a vertical axis) of the table under load was greater than expected. Accordingly, the displacement at which the aisle-side honeycomb bottoms out increases, resulting in an approximately 1-inch difference between the bottoming-out displacements for the aisle- and window-sides. The model, however, features a very stiff connection at the wall (i.e., does not capture rotation at the wall connection) and therefore predicts a difference of only about half an inch.

The first dynamic pendulum test was also quite successful. The results of this test were generally very consistent with model predictions with respect to both the deformation of the table and the magnitude and timing of the reaction loads. However, while the displacement-time histories of both impactors behaved in a manner consistent with model predictions, the permanent deformation of the table top was less than expected. This difference was determined to be largely attributable to the fact that the model does not capture the noted compliance in the wall connection.

In the second dynamic pendulum test, the mass of each impactor was reduced to 75 lbm to represent the effective mass of a seated occupant. This test was not as effective as the first, for two reasons. First, the 75 lbm impactor mass is very close to the mass of the table itself. As a result, not only were the measured accelerations higher (due to the lower impact mass), but in addition, there was significantly more noise in the acceleration signal due to excitation of dynamic modes of the table structure. Second, because of their smaller mass and the larger drop height, the pendulum masses exhibited much less stability than did the heavier masses used for the first test. During free fall, in particular, they rotated significantly about a vertical axis. The window-side impactor rotated so much that it impacted the stiff table support—a full 3 in away from its target impact point.

The third impact test was performed on a conventional workstation table—one that was not designed to absorb energy upon impact. Not surprisingly, this table behaved in a very stiff manner and failed almost immediately after impact. The screws holding the table top to the wall support sheared off completely.

The close agreement between the predictions of the FEA model and the outcome of the first dynamic test is encouraging and suggests that once the force-displacement behavior of the key energy-absorbing elements is well characterized, it possible to predict dynamic behavior with much accuracy. Accurate predictions are possible when the elastic vibrational modes of the system are not strongly excited and when the mode of impact is as expected. If these conditions are not met, as was the case for the second pendulum test when the mass inadvertently made contact with the stiff support structure, the predictive capability of the model becomes more dependent on details, such as the compliance of the key connections, which may be difficult to capture.

In summary, it appears that both the quasi-static and dynamic test methods employed for this program can be effective in characterizing the energy-absorbing capacity of workstation tables. However, the quasi-static test appears to be safer, more reliable, and easier to conduct. It appears also that FEA models can be used effectively in conjunction with quasi-static tests to predict the consequences of the dynamic tests. While it appears that the dynamic test method can be effective, the lateral stability of the pendulums during their free fall is an issue that must be addressed further. The stability issue is complicated by the fact that the two falling pendulums must be independent. The cables that guide the pendulum cannot be placed in optimal configurations because they would cross. The ability to control the pendulums appears to be further compromised by using smaller masses. Such masses may be more representative of the conditions that govern the collision of a seated occupant with a workstation table, but they appear to make it harder to control the impact. Further study that demonstrates the applicability of using larger masses and smaller drop heights to produce the same level of applied kinetic energy is warranted.

6. References

1. National Transportation Safety Board, “Collision of Burlington Northern Santa Fe Freight Train with Metrolink Passenger Train, Placentia, California, April 23, 2002,” Railroad Accident Report NTSB/RAR-03-04, adopted on 10/7/2003.
2. Parent, D., Tyrell, D., Perlman, A.B., “Crashworthiness Analysis of the Placentia, CA, Rail Collision,” International Journal of Crashworthiness, Volume 9, Issue 5, pp. 527–534, March 8, 2004.
3. Stringfellow, R., Rancatore, R., “Workstation Table Engineering Model Design, Development, Fabrication and Testing,” U.S. Department of Transportation, DOT/FRA/ORD-12/06, May 2012.
4. Parent, D., Tyrell, D., Rancatore, R., Perlman, A.B., “Design of a Workstation Table with Improved Crashworthiness Performance,” American Society of Mechanical Engineers, Paper No. IMECE2005-82779, November 2005.
5. Severson, K., Parent, D., “Train-to-Train Impact Test of Crash Energy Management Passenger Rail Equipment: Occupant Experiments,” American Society of Mechanical Engineers, Paper No. IMECE2006-14420, November 2006.
6. Rancatore, B., Llana, P., Van Ingen-Dunn, C., and Bradney, C., “Occupant Protection Experiments in Support of a Full-Scale Train-to-Train Crash Energy Management Equipment Collision Test” U.S. Department of Transportation, DOT/FRA/ORD-09/14, July 2009.

Appendix A
Test Requirements Document

A.1. Introduction

A prototype workstation table has been developed that potentially reduces the injury risk to rail vehicle occupants during a collision by compartmentalizing the occupants to prevent impact with other objects or passengers seated across from them, and limiting the contact forces. The effectiveness of the workstation table design was successfully demonstrated using instrumented anthropomorphic test devices (ATDs) in a full-scale test of a passenger train outfitted with crash energy management (CEM) technology colliding into a standing locomotive and two ballasted freight cars.

This Test Requirements document details requirements for quasi-static and dynamic testing of prototype workstation tables that are aimed at characterizing the mechanical behavior of the tables during simulated collision conditions in order to define performance requirements for future workstation table designs. One quasi-static test and three dynamic pendulum tests are planned.

The single quasi-static test and the three dynamic pendulum tests will be conducted at MGA Research Corporation test facilities in Burlington, WI. This document describes the tests that will be conducted, including a description of the required fixtures, the conditions under which the tests will be conducted, and the critical information to be measured.

A companion Test Implementation Plan that describes how the tests will be conducted is included in Appendix B of this report.

A.2. Program Objectives

The overall objective of the testing is to characterize the mechanical behavior of the tables to define performance requirements for future workstation table designs. The single quasi-static test will be conducted to measure the force-crush characteristics of the table under collision loads and the reaction forces at the attachments to the car body. The three pendulum tests will be conducted to measure the acceleration- and force-time histories of the pendulums and the table-to-wall reaction loads under dynamic conditions. The dynamic tests will also be used to determine appropriate test conditions for future qualification tests.

A.3. Quasi-Static Testing

The quasi-static test will be conducted to measure the force-crush characteristic of the table under collision loads and the reaction forces at the attachments to the car body.

A.3.1 Test Description

The quasi-static test will be conducted using MGA Research Corporation's static structural loading frame and a test fixture designed to accommodate the proper attachment points and representative attachment mechanisms for the table. The test fixture will act as a rigid mounting point for the table. An example of a loading frame that could be used for the testing is shown in Figure A1.

Figure A1. Example Structural Loading Frame

The test loads will be applied to the test article using two hydraulic cylinders arranged horizontally on a single structure. Each hydraulic cylinder will be capable of applying a load independent of the other hydraulic cylinder. A feedback control loop will be used to allow precise control over the amount of displacement or loads being applied by each cylinder. Figure A2 shows an example of a hydraulic cylinder used at MGA, along with the necessary attachments.

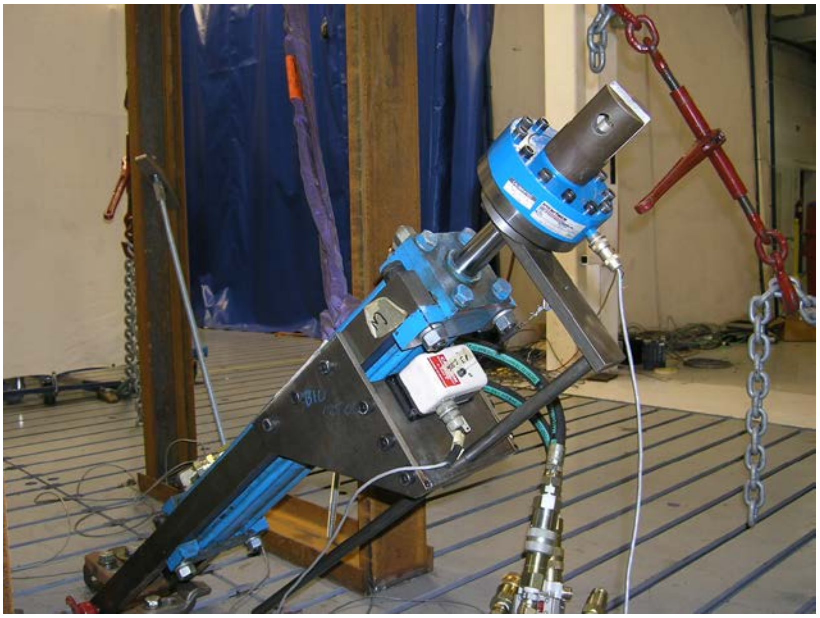


Figure A2. Example MGA Hydraulic Cylinder

An effectively rigid block that simulates, in a simplified manner, the dimensional characteristics of a colliding human torso will be mounted to the front of each cylinder ram. The simulated torso block will have a width of 15 in, corner radii of 3 in, and a height of 8 in. It will be constructed so that its deformation is minimal. Figure A3 is a schematic illustration of the simulated torso block.

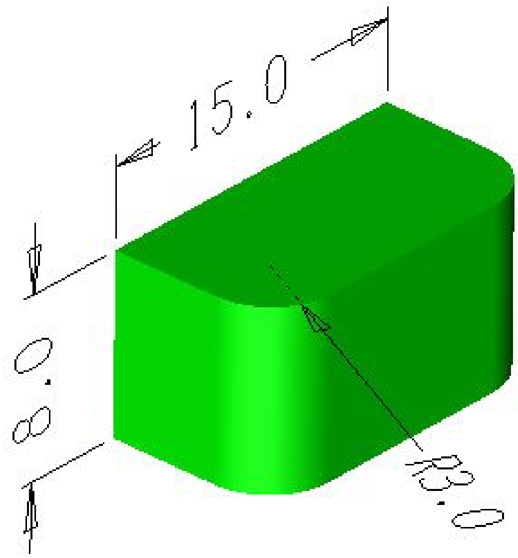


Figure A3. Simulated Torso Block

A.3.2 Instrumentation

Each cylinder setup will have the means to record torso block load and displacement. A load cell will be placed in between the cylinder and the block. In addition to the load cell, each cylinder will have a string potentiometer attached to the block for displacement measurement.

The table setup will also have means of recording loads and displacements. Three triple-axis load cells will be attached to the table wall-mounting plates. Two string potentiometers will be attached to the side of the table opposite the side that is crushed, in line with the two loading blocks.

A.3.3 Data Collection

A.3.3.1 Instrumentation

All instrumentation used during the quasi-static tests shall be calibrated and maintained in accordance with SAE J211.

A.3.3.2 Still Photographs

Still photographs of the test setup before and after each test will be taken with a digital camera. All post-test photographs shall be taken immediately following release of the required load and before moving the table and energy absorber.

A.3.3.3 Video

Real-time video of each test shall be recorded using two digital video cameras, one placed above the table and one placed in front of the table (i.e., looking toward the table from across the aisle).

A.3.3.4 Minimum Requirements

At a minimum, the following data shall be collected during each static test, included in the test report, and supplied electronically:

1. Pre-test and post-test photos (at least four of each)
2. Applied load versus time for both hydraulic rams
3. Three-axis reaction loads versus time between table and wall
4. Displacement versus time at each loading block
5. Displacement versus time at each of the locations opposite the two loading blocks
6. Two real-time digital video recordings of the test (view from above and from across the aisle)

A.4. Pendulum Testing

The pendulum tests will be conducted to determine the force-crush characteristics of the table and the table-to-wall reaction loads under dynamic conditions. The tests will also be used to determine the energy absorption requirements to be specified in future qualification tests.

A.4.1 Test Description

Dynamic impact testing will be conducted using a pendulum that is suspended from the ceiling by cables. It will be mounted with a rigid impactor sized and weighted specifically to represent a 50th percentile male occupant colliding with the table and a fixture designed to accommodate the proper attachment points and representative attachment mechanisms for the table. The test fixture will be made of structural steel and will act as a rigid mounting point for the table. (Note: the test fixture used for the quasi-static testing will also be used for pendulum testing.)

The required dynamic loads will be applied to the test article using a swinging pendulum with two simulated torso blocks spaced the same as they were for the quasi-static test. The pendulum masses will be raised to a height that will provide a specified initial velocity on impact. Figure A4 is an example of a pendulum device used at MGA.

Figure A4. Example of MGA Pendulum

A simulated torso block will be mounted to the front of each pendulum "shuttle" (see Figure A5). The shuttles will each bear the mass of a moving 50th percentile male (approximately 170 lbm). The simulated torso blocks will have a width of 15 in, with corner radii of 3 in, and a height of 8 in (same as the quasi-static test torso blocks).

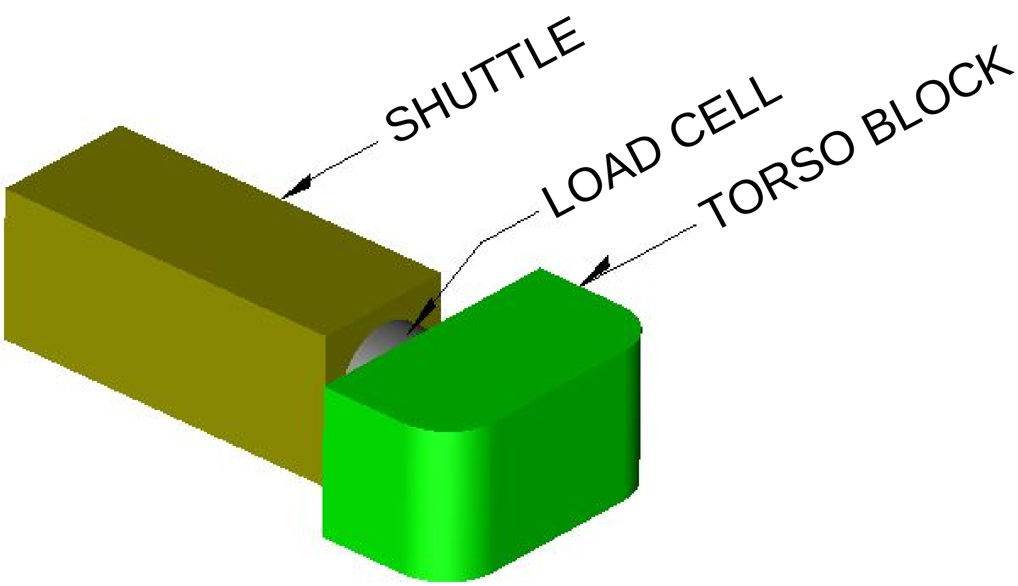


Figure A5. Example of a Pendulum Shuttle and Torso Block

A.4.2 Test Instrumentation

Each pendulum shuttle setup will have the means of recording torso block deceleration. A 2,000 g accelerometer will be placed on the back side of the torso block to reduce the risk of impacting the accelerometer. In addition to the accelerometer, a load cell will be placed in between the torso block and shuttle. The load cell will record the force transferred from the pendulum to the table.

The table setup will also have the means of recording reaction loads and table displacements. Three 10,000 lbf, three-axis load cells will be attached to the table wall-mounting plates. Two string potentiometers will be attached, in line with the two torso blocks, to the side of the table opposite the side that will be crushed, to measure longitudinal displacement of the table top.

A.4.3 Data Collection

A.4.3.1 Instrumentation

All instrumentation used during the dynamic tests will be calibrated and maintained in accordance with SAE J211.

A.4.3.2 Still Photographs

Several still photographs of the test setup before and after each test will be taken with a digital camera. All post-test photographs shall be taken immediately following the test and before moving the table.

A.4.3.3 Video

High-speed video of each test will be recorded at a minimum of 500 frames per second using two high-speed digital video cameras, one placed above the table and one placed in front of the table (i.e., looking toward the table from across the aisle).

A.4.3.4 Minimum Requirements

At a minimum, the following data will be collected during each dynamic test, included in the test report, and supplied electronically:

1. Pre-test and post-test photos (at least four of each)
2. Applied load versus time at each impact location
3. Three-axis reaction loads versus time between table and wall
4. Acceleration versus time for each torso block
5. Displacement versus time at each impact point
6. Displacement versus time at each location opposite the two impact points
7. Two high-speed digital video recordings of the test (one view from above and one from across the aisle)

Appendix B
Test Implementation Plans

B.1. Introduction

A prototype workstation table has been developed that potentially reduces the injury risk to rail vehicle occupants during a collision by compartmentalizing the occupants to prevent impact with other objects or passengers seated across from them, and limiting the contact forces. The effectiveness of the workstation table design was successfully demonstrated using instrumented ATDs in a full-scale test of a passenger train outfitted with CEM technology colliding into a standing locomotive and two ballasted freight cars.

A single quasi-static test and three dynamic tests of prototype workstation tables have been planned. The tests will be conducted at MGA Research Corporation test facilities in Burlington, WI, with the purpose of characterizing the crush behavior of the tables during simulated collision conditions and defining performance requirements for future workstation table designs. This Test Implementation Plan describes how these tests will be conducted.

A companion Test Requirements document, included in Appendix A of this report, outlines the requirements for the tests, including a description of the required fixtures, the conditions under which the tests will be conducted, and the critical information to be measured.

B.2. Program Objectives

The overall objective of the testing is to characterize the mechanical behavior of the tables to define performance requirements for future workstation table designs. The single quasi-static test will be conducted to measure the force-crush characteristics of the table under collision loads and the reaction forces at the attachments to the car body. The three pendulum tests will be conducted to measure the acceleration- and force-time histories of the pendulums and the table-to-wall reaction loads under dynamic conditions. The dynamic tests will also be used to determine appropriate energy absorption requirements for future qualification tests.

B.3. Test Facility

The testing described herein will be conducted at the MGA Proving Grounds and Crash Test Center. The MGA test facility is located at 5000 Warren Road, Burlington, WI, 53105. The MGA point of contact for the test facility is the project manager, Jay Nutting. The MGA facility has both static and dynamic testing capabilities and has been accepted by several government bodies to perform compliance testing. MGA has all of the resources necessary to conduct the testing described herein.

B.4. Quasi-Static Test

B.4.1 Test Equipment

B.4.1.1 Frame

The static test frame will provide sufficient rigidity of the mounting structure so that test component deflection measurements can be taken without the need to correct for loading frame deformation. MGA will design and assemble the proper loading frame to mount two cylinders capable of meeting the quasi-static test requirements.

B.4.1.2 Test Article

A single table is required for quasi-static testing. An existing prototype table manufactured by TIAX LLC will be shipped to MGA for testing. MGA will design and manufacture a rigid structure to simulate the side of the railcar. In addition to the rigid frame, the interface plates needed to mount the load cells and table to the fixture will be supplied by MGA. Note: for the quasi-static test, the table should be oriented with the wall mounting brackets on the right hand side of the table when viewed from the perspective of the loading blocks.

B.4.1.3 Hydraulic Cylinders

The required loads will be applied to the test article using two hydraulic cylinders arranged horizontally on a single structure. Each hydraulic cylinder is capable of applying a load independent of the other hydraulic cylinder. The cylinders that will be used will have a capacity of 10,000 lbf and a stroke of 24 in. A feedback control loop allows precise control of the amount of displacement being applied by each cylinder. The hydraulic cylinders are computer-controlled by a remote console. The console, fed by a single, electronically driven hydraulic pump, provides for directional control, pressure regulation, and flow rate control. Figure B1 illustrates the hydraulic cylinder equipment setup for displacement control.

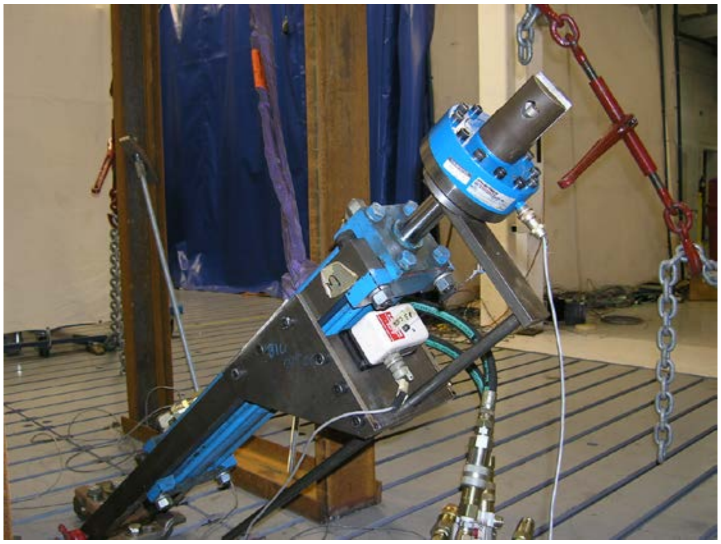


Figure B1. MGA Hydraulic Cylinder

A simulated torso block will be mounted to the front of each cylinder ram. The simulated torso block will have a width of 15 in, height of 8 in, and corner radii of 3 in. (The 15-inch length is based on standardized body blocks used in the automotive and aircraft industries—see SAE AS8049 Rev. B.) The block will be made of steel and designed to act as a rigid article. There will effectively be no deformation of the torso block during the tests.

B.4.1.4 Instrumentation

Strain gage load transducers (load cells) with either a 10,000 lbf or 25,000 lbf range will be used for the static testing. Two uniaxial 25,000 lbf load cells will be placed on the cylinder to record input loads for the table crush. Three triaxial 10,000 lbf load cells will be placed on the table mounting locations of the test article.

Potentiometer displacement transducers (string pots) will be used to record displacements during the test. Four transducers will be used, one on each cylinder and two on the test article. The two string pots on the test article will be attached to the side of the table opposite the side that will be loaded, in line with the hydraulic cylinders. Table B1 lists some information pertaining to the instrumentation that will be used for the quasi-static test. (This instrumentation will also be used for the dynamic pendulum test.)

Table B1. Quasi-Static Test Instrumentation Specifications

Instrumentation for Quasi-static Test				
Instrumentation	**Manufacturer**	**Model**	**Range**	**Response Limit**
Tri-axial load cells	Denton	2177A	10,000 lbf	1,250 Hz frequency response
Uni-axial load cells	Interface	1210	25,000 lbf	1,250 Hz frequency response
Potentiometers	Celesco	PT-101-20C	Various	100 g max. retraction rate

B.4.1.5 Data Acquisition System

The required data will be collected electronically. The instrumentation setup will be in accordance with SAE J211/1. Instrumentation will be selected to provide sufficient range for the data being measured. A minimum sample frequency of 20 Hz will be used for all static test instrumentation. However, at the discretion of the MGA Project Engineer, the sample rate may be changed to facilitate test setup or accommodate instrumentation limitations. The system will use an individual analog to digital (A/D) converter for each channel, and a six-pole anti-aliasing filter with a software controlled corner frequency.

Prior to the start of testing, a "calibration run" will be performed to ensure that all instrumentation is properly configured and all data channels are responding and recording appropriately. At a minimum, the pre-test calibration run will be performed prior to the start of the quasi-static test, and, if needed, after significant changes to the instrumentation setup have been made (i.e., replacement of an instrument, reconfiguration of the instrumentation setup, etc.).

B.4.1.6 Photographic Documentation

Still photographs will be taken with a digital camera of the test setup before and after each test. All post-test photographs will be taken immediately following release of the required load and before moving the table.

The camera will have a minimum resolution of 4.0 megapixels. Digital images will be saved in jpg format.

B.4.1.7 Video Documentation

Real-time video of each test will be recorded using two digital video cameras, one placed above the table and one placed in front of the table (i.e., looking toward the table from across the aisle). The real-time video camera (camcorder) will have a minimum resolution of 2 megapixels and record at a minimum of 15 frames per second. The imager of the camera will have a minimum illumination of 0.5 lux. Digital video will be saved in .mpeg format.

B.4.2 Test Procedures

During the test, both hydraulic cylinders and torso blocks will crush the table simultaneously based on displacement. A crush depth of 7 in will be reached by means of an intelligent controller. The controller will subtract table displacement from cylinder displacement to ensure a full crush of 7 in on the table edge. The displacement rate of the cylinder will be 2 in/min.

A recommended procedure for the quasi-static tests is bulleted below.

- Install the test article onto the test fixture.
- Install the torso block onto the cylinder with the required load cell.
- Install the linear displacement transducers.
- Set up the video equipment.
- Check and zero all instrumentation.
- Take pre-test photographs.
- Verify setup with test lab engineers and witnesses.
- Start the video equipment.
- Apply the required displacement/load.
- Release the load.
- Take post-test photographs.
- Conduct post-test visual inspection of test article.
- Complete quasi-static test data and witness sheets (report).

The quasi-static test will be a destructive test to measure the deformation behavior of the tabletop and any other deformable components in the table design.

B.5. Pendulum Test

B.5.1 Test Equipment

B.5.1.1 Pendulum Assembly and Test Frame

The test article will be loaded by means of a moving rigid pendulum suspended from the ceiling of the test facility with cables. The moving mass of the pendulum will consist of a shuttle, load cell, accelerometer, and simulated torso block. All items will have a total mass of 170 lbm for each shuttle assembly. The simulated torso block will have a width of 15 in, with corner radii of 3 in, and a height of 8 in (the same as the quasi-static block).

The test frame developed for the quasi-static test to simulate the attachment of the table to the side of the rail car will be used for the dynamic pendulum test as well.

B.5.1.2 Test Article

Three workstation tables will be required for dynamic pendulum testing. The table used for the quasi-static test will be reused for a dynamic pendulum test. Two additional prototype tables will be shipped to MGA for testing. (Note that each of these two tables was used in the full-scale collision test, so that one side has already been crushed. The third table will have been crushed during the quasi-static test. Each of the tables will have been crushed such that, from the viewpoint of the object that has crushed them, the wall mounting brackets are on the right hand side of the table. Therefore, for the pendulum tests, all tables should be oriented with the mounting brackets on the left hand side when viewed from the perspective of the colliding mass.) MGA will reuse the rigid structure that it developed for the quasi-static test to simulate the side of the railcar. In addition to the rigid frame, the interface plates needed to mount the load cells and table to the fixture will be supplied by MGA.

B.5.1.3 Instrumentation

Each pendulum shuttle setup will have the means of recording torso block deceleration. A 2,000 g accelerometer will be placed on the back side of the torso block. The deceleration will be integrated to calculate velocity and displacement. In addition to the accelerometer, a 25,000 lbf load cell will be placed in between the torso block and shuttle. The load cell will record the force transferred from the pendulum to the table.

The table setup will also have the means of recording loads and displacements. Three 10,000 lbf three-axis load cells will be attached to the table wall-mounting plates. The two string pots on the test article will be attached to the side of the table that is opposite the side that will be impacted, in line with the colliding block. See Table B2 for instrumentation specifications.

Table B2. Pendulum Test Instrumentation Specifications

Instrumentation for Pendulum Test				
Instrumentation	**Manufacturer**	**Model**	**Range**	**Response Limit**
Tri-axial load cells	Denton	2177A	10,000 lbf	1,250 Hz frequency response
Uni-axial load cells	Interface	1210	25,000 lbf	1,250 Hz frequency response
Potentiometers	Celesco	PT-101-20C	Various	100 g max. retraction rate
Accelerometers	Entron (MSI)	64	2,000 Gs	DC to 2,000 Hz

B.5.1.4 Data Acquisition System

The required data will be collected electronically. The instrumentation setup will be in accordance with SAE J211/1. Instrumentation will be selected to provide sufficient range for the data being measured. The DAS should be capable of recording at 10,000 Hz for the dynamic impact of the pendulum. The system will use an individual analog-to-digital (A/D) converter for each channel and a six-pole anti-aliasing filter with a software controlled corner frequency. The DAS will have both primary and backup event triggers.

B.5.1.5 Photographic Documentation

Still photographs will be taken with a digital camera of the test setup before and after each test. All post-test photographs will be taken immediately following the test, prior to moving the table.

The camera will have a minimum resolution of 4.0 megapixels. Digital images will be saved in .jpg format.

B.5.1.6 Video Documentation

High-speed video of each test will be recorded at a minimum of 500 frames per second using two high-speed digital video cameras, one placed above the table and one placed in front of the table (i.e., looking toward the table from across the aisle).

B.5.2 Test Procedures

During each test, both shuttles will be released simultaneously and contact the table at the same time.

A recommended procedure for each dynamic pendulum test is bulleted below.

- Install the test article onto the test fixture with the required load cells.
- Install the torso block onto the shuttle with the required load cell.
- Install the accelerometer to the torso block.

- Install the string potentiometers on the table.
- Set up the video equipment.
- Check and zero all instrumentation.
- Take pre-test photographs.
- Raise the pendulum arm to the desired height.
- Verify setup with test lab engineers and witnesses.
- Arm the video equipment and DAS.
- Release the shuttle.
- Take post-test photographs.
- Conduct post-test visual inspection of test article.
- Complete dynamic test data and witness sheets (report).

The pendulum test will be a destructive test to validate the deformation behavior of the tabletop and any other deformable components in the table design.

B.6. Deliverables

A final test report will be submitted to TIAX LLC by MGA Research Corporation detailing the results of the testing program, including the following items:

- Data plots:
    - Acceleration-time histories
    - Displacement-time histories
    - Force-time histories
- Summary of test setup and conclusions, including deviations if applicable
- Photographic documentation
- Videographic documentation (real-time and high-speed)

B.7. Schedule

The quasi-static test and the first pendulum test have been tentatively scheduled for October 9, 2007. The second and third pendulum tests are expected to take place two to three weeks later.

Appendix C
MGA Test Report

Summary

Testing was conducted using the Test Implementation Plan developed by MGA Research Corporation. Any deviations from the implementation plan were either at the customer's request or approved by the customer at the time of testing and are noted in this report where applicable.

The overall objective of the testing is to characterize the mechanical behavior of the tables to define performance requirements for future workstation table designs. The single quasi-static test will be conducted to measure the force-crush characteristics of the table under collision loads and the reaction forces at the attachments to the car body. The orientation of the load cells is shown in the figure below. The three pendulum tests will be conducted to measure the acceleration- and force-time histories of the pendulum and the table-to-wall reaction loads under dynamic conditions. The dynamic tests will also be used to determine appropriate impact velocities for future qualification tests.

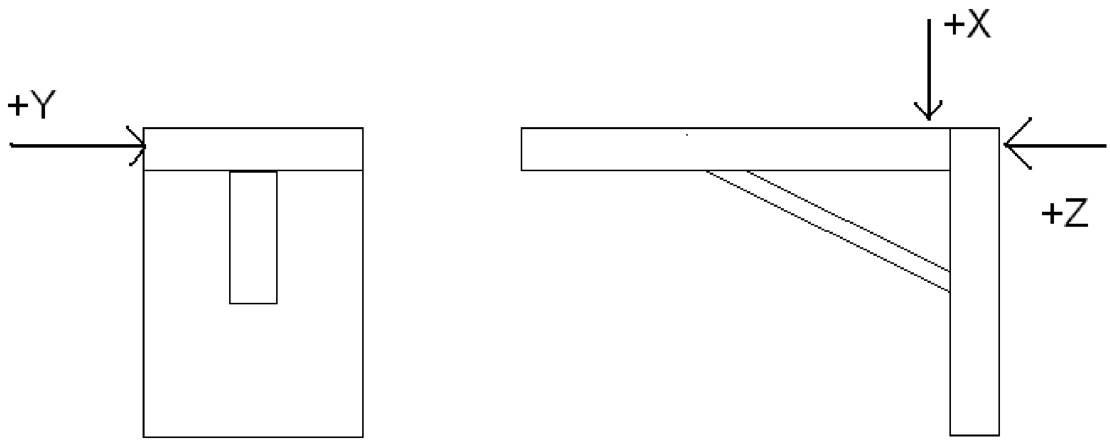


Figure C1. Schematic Depicting Load Cell Orientation and Sign Convention

C.1. MGA Test: Q07614 Quasi-Static Test

Test Date:	10/09/07
Test Procedure:	Test Implementation Plan
MGA Test Number:	Q07614
Test Description:	Quasi Static—Horizontal

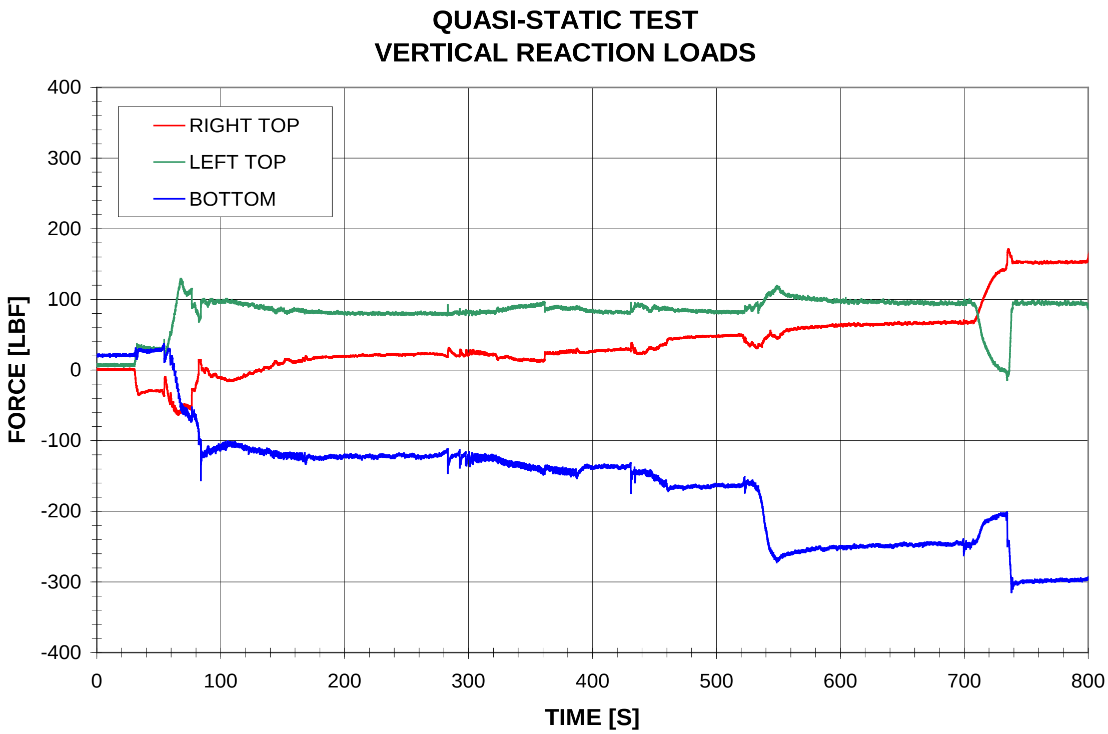
C.1.1 Summary

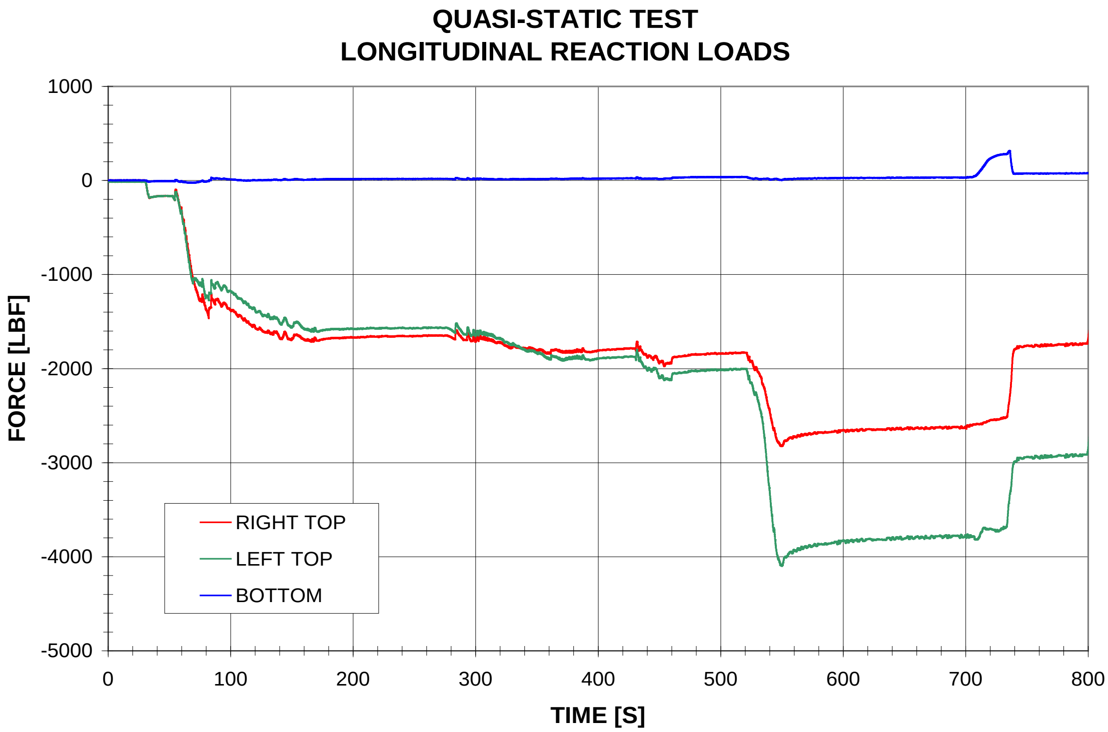
The displacement rate of the cylinder was set at 2 in/min. The initial crush took place with 4 in of displacement, followed by a 2 min holding period. After the first holding period, the table was crushed at 1 in increments to observe deformation. Total displacement reached 7 in before the cylinders were retracted.

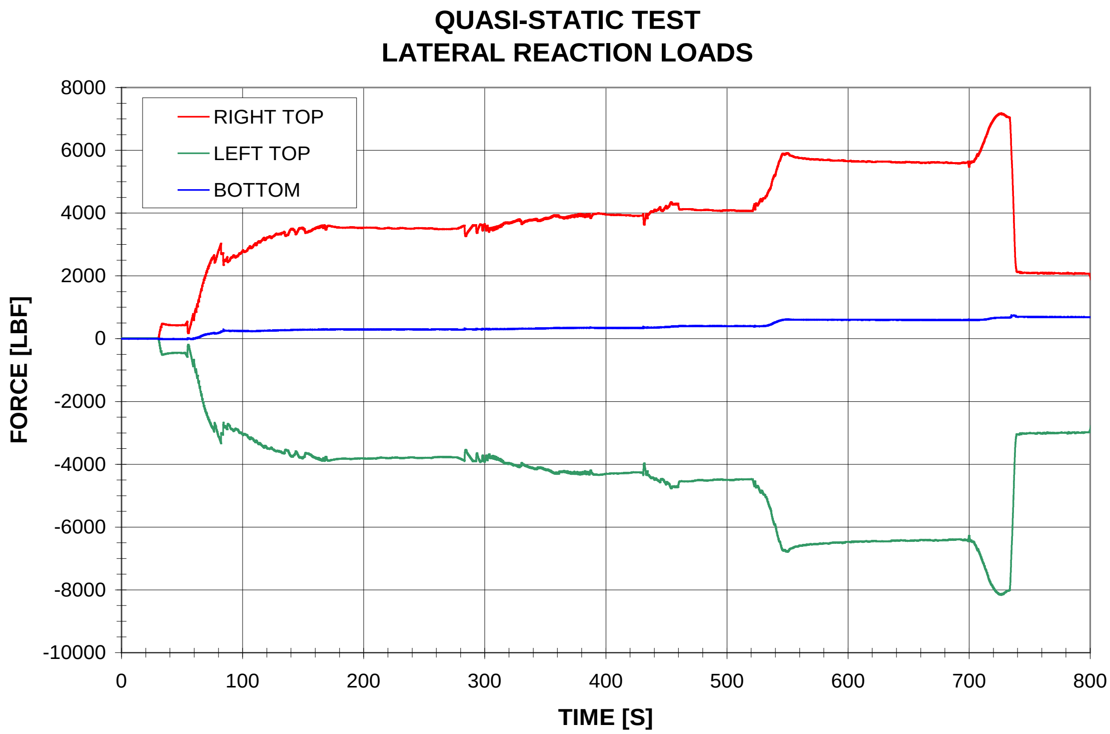
C.1.2 Equipment and Calibration

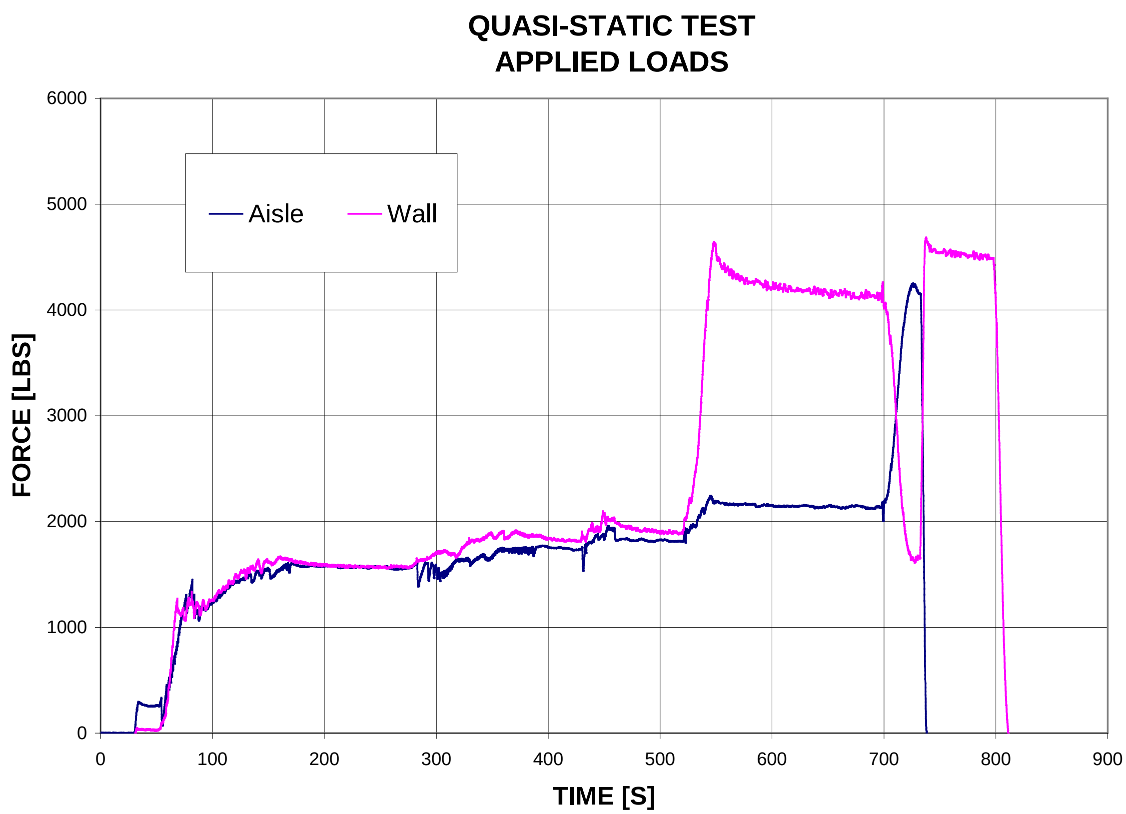
Equipment	**Description**	**Manufacturer**	**Model No.**	**Range**	**Serial No.**	**Cal. Date**
String Potentiometer	Displacement	Ametek	P-50A		17167	6/01/07
String Potentiometer	Displacement	Ametek	P-25A		19183	6/01/07
String Potentiometer	Displacement	Ametek	P-50A		17166	8/28/07
String Potentiometer	Displacement	Ametek	P-25A		19366	2/13/07
3-Axis Load Cell (1)	Force	Denton	2177A	10,000 lbf	105	8/08/07
3-Axis Load Cell (2)	Force	Denton	2177A	10,000 lbf	102	8/08/07
3-Axis Load Cell (3)	Force	Denton	2177A	10,000 lbf	103	8/08/07
Cylinder 1 Load Cell	Force	Interface	1220AF-25K	25,000 lbf	143280	9/28/07
Cylinder 2 Load Cell	Force	Interface	1220AF-25K	25,000 lbf	142051	2/22/07

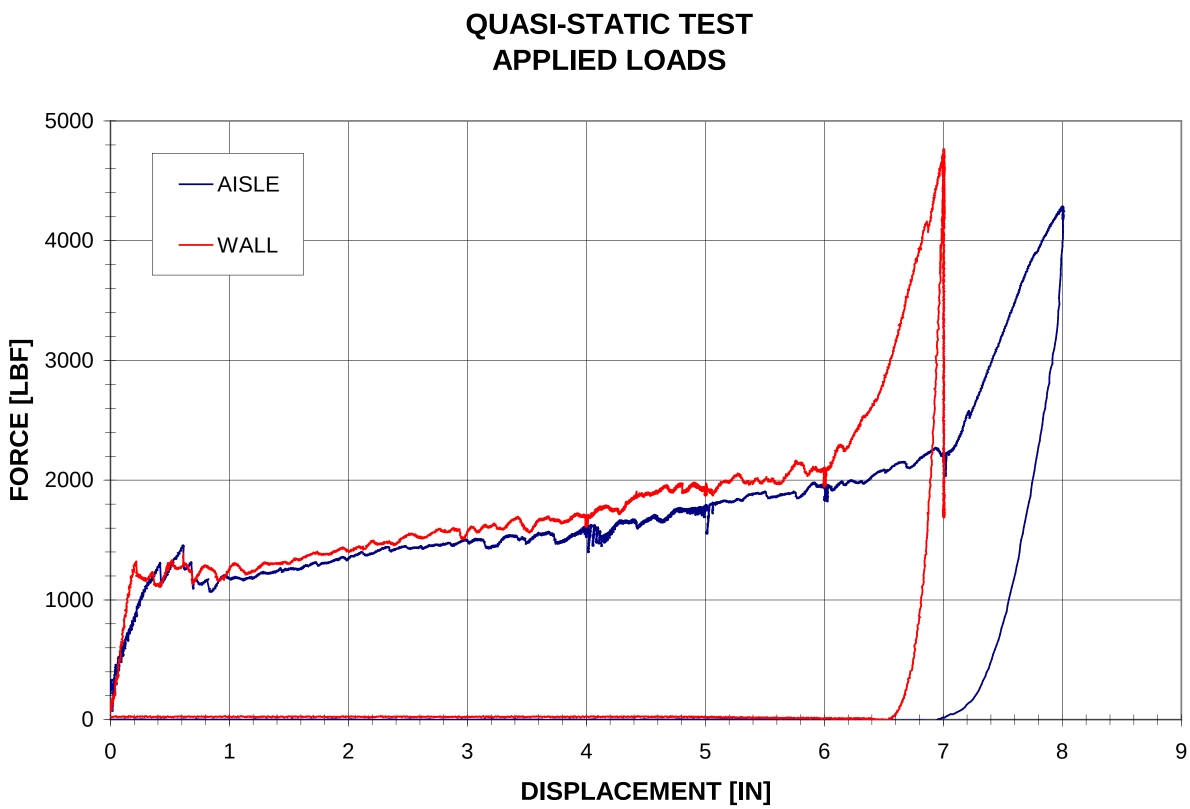
C.1.3 Data Plots






QUASI-STATIC TEST
LATERAL REACTION LOADS
RIGHT TOP
LEFT TOP
BOTTOM
FORCE [LBF]
TIME [S]
8000
6000
4000
2000
0
-2000
-4000
-6000
-8000
-10000
0
100
200
300
400
500
600
700
800

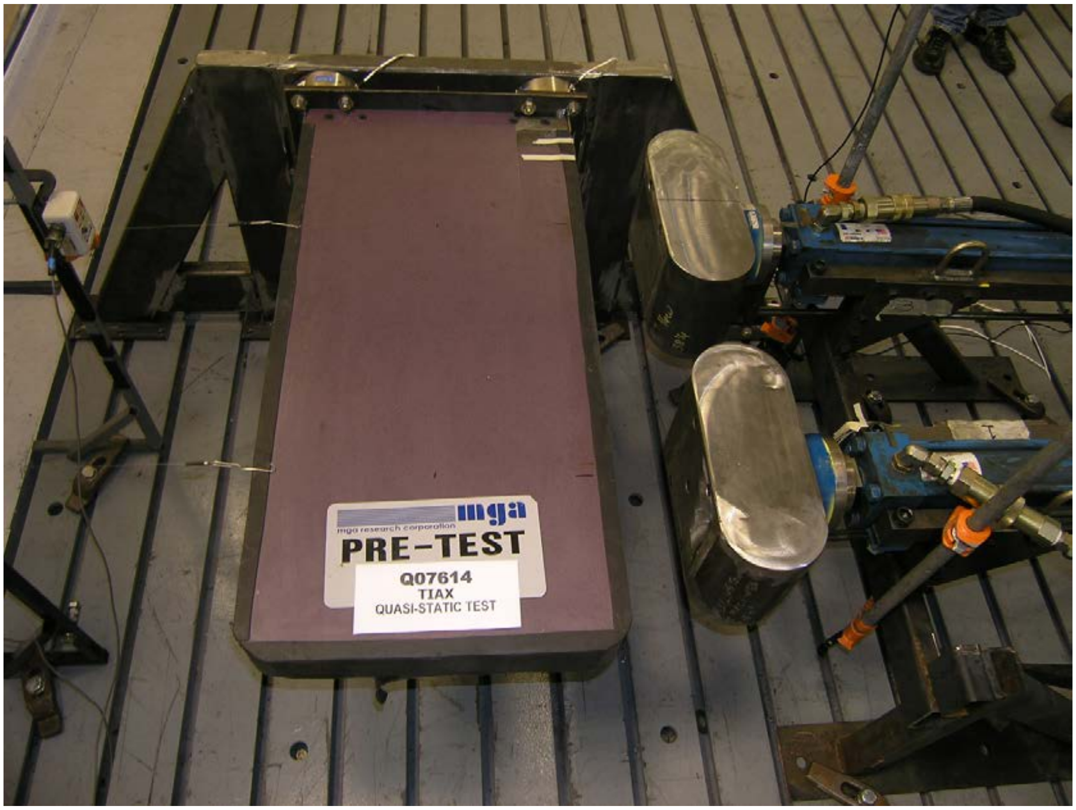

QUASI-STATIC TEST
APPLIED LOADS
Aisle
Wall
FORCE [LBS]
TIME [S]
6000
5000
4000
3000
2000
1000
0
0
100
200
300
400
500
600
700
800
900

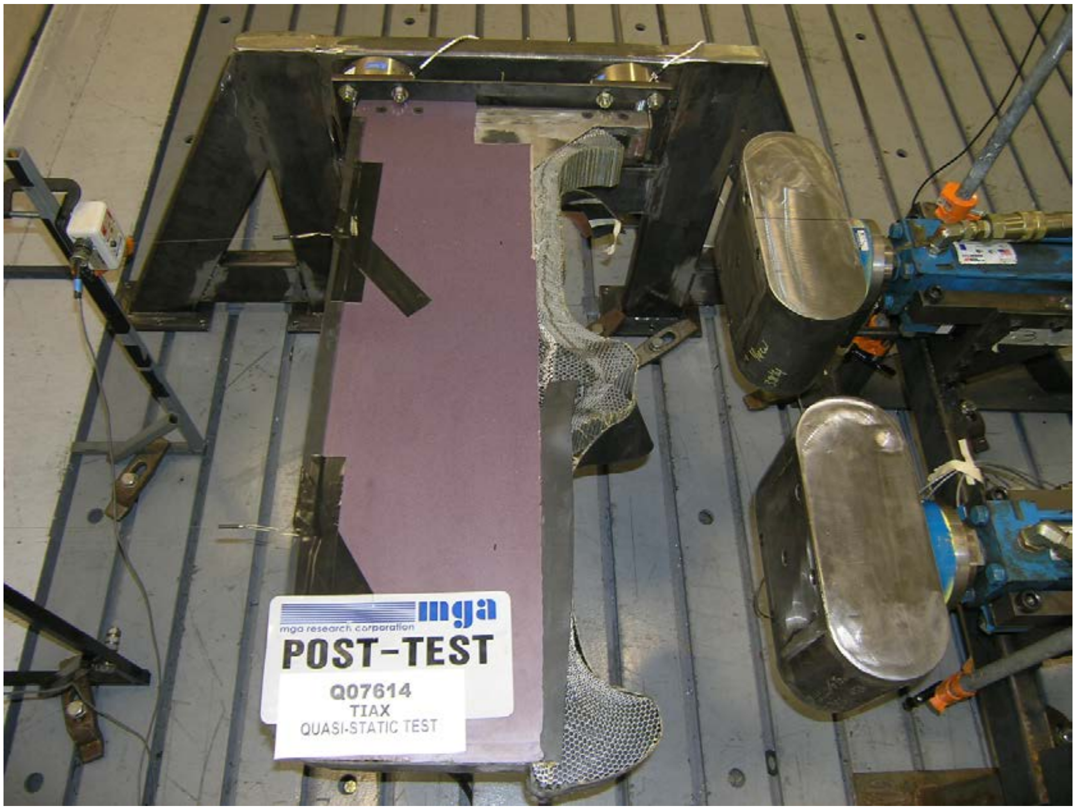

QUASI-STATIC TEST
APPLIED LOADS
AISLE
WALL
FORCE [LBF]
5000
4000
3000
2000
1000
0
0
1
2
3
4
5
6
7
8
9
DISPLACEMENT [IN]

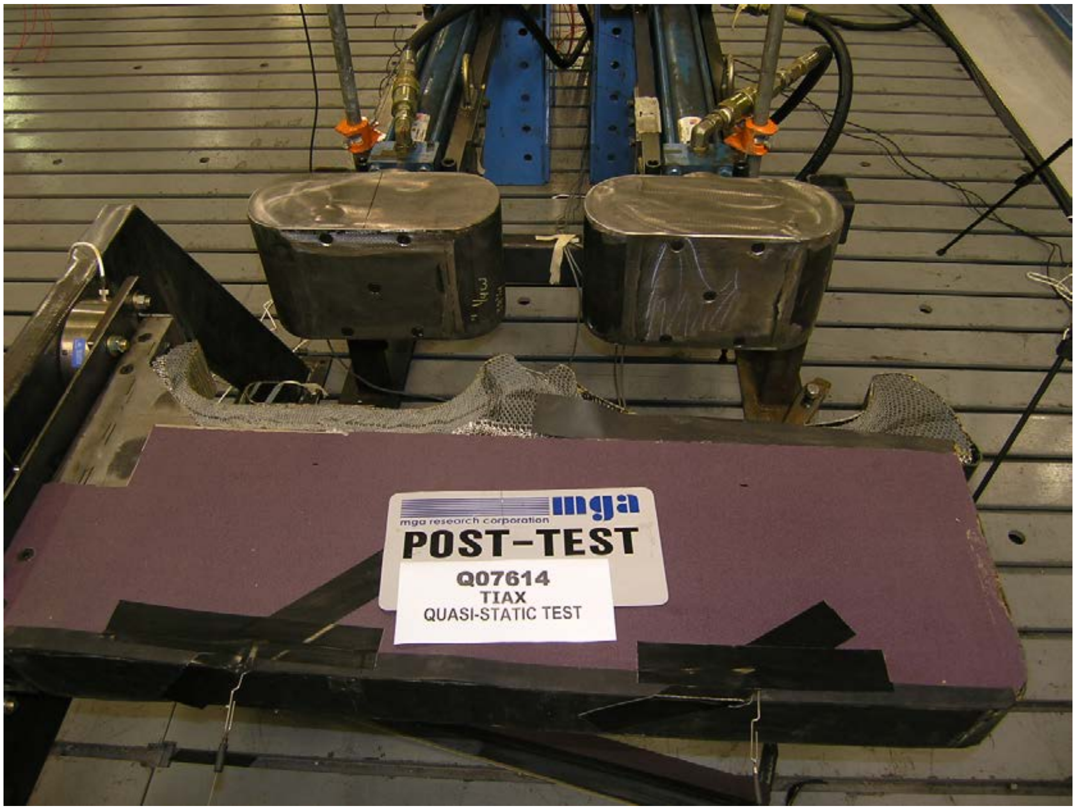
C.1.4 Photographs


mga research corporation
mga
PRE-TEST
Q07614
TIAX
QUASI-STATIC TEST


mga research corporation
mga
POST-TEST
Q07614
TIAX
QUASI-STATIC TEST


mga
mga research corporation
PRE-TEST
Q07614
TIAX
QUASI-STATIC TEST


mga
mga research corporation
POST-TEST
Q07614
TIAX
QUASI-STATIC TEST


mga research corporation
mga
POST-TEST
Q07614
TIAX
QUASI-STATIC TEST


mga research corporation
mga
POST-TEST
Q07614
TIAX
QUASI-STATIC TEST

C.2. MGA Test: Q07615 Pendulum Test

Test Date:	10/09/07
Test Procedure:	Test Implementation Plan
MGA Test Number:	Q07615
Test Description:	Pendulum

C.2.1 Summary

This pendulum test was conducted on a deformable table with two 172-pound shuttles. Both shuttles were dropped simultaneously by a mechanical release mechanism at an approximate effective release height of 59.6 in.

C.2.2 Post Test Comments

The lateral accelerometer for the wall shuttle was damaged during impact; therefore, no valid data were collected.

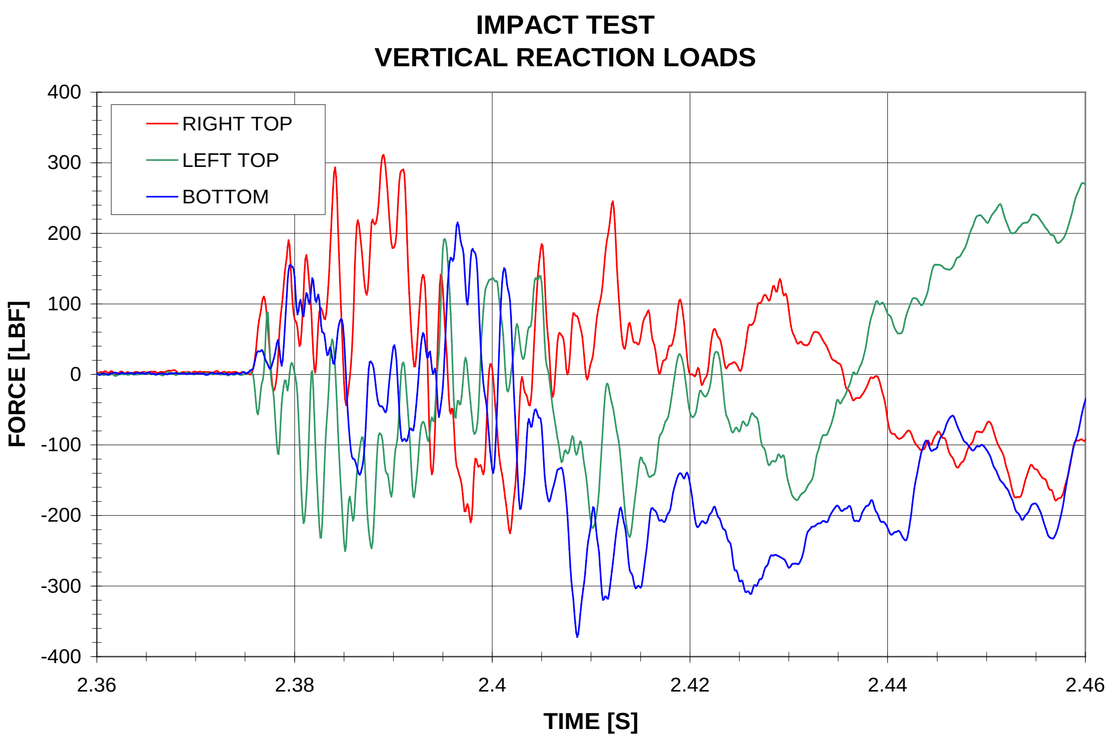
Data collected for the table displacement string pots showed no change in displacement; therefore, the assumption is made that there was no valid data.

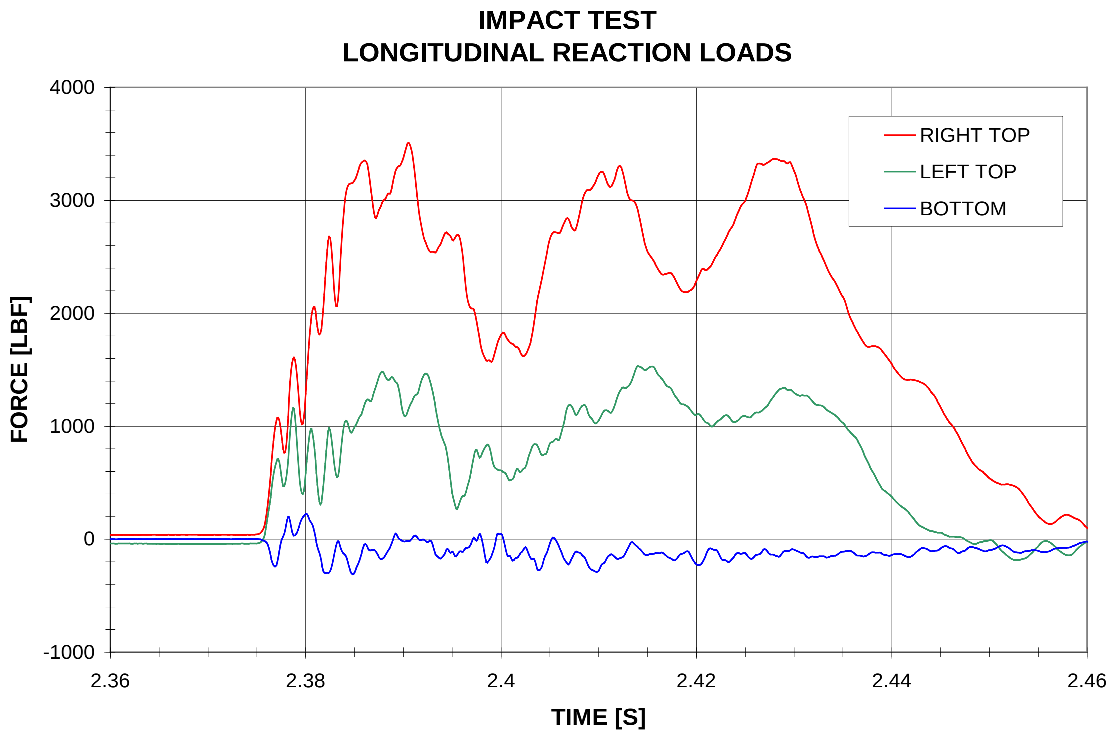
C.2.3 Equipment and Calibration

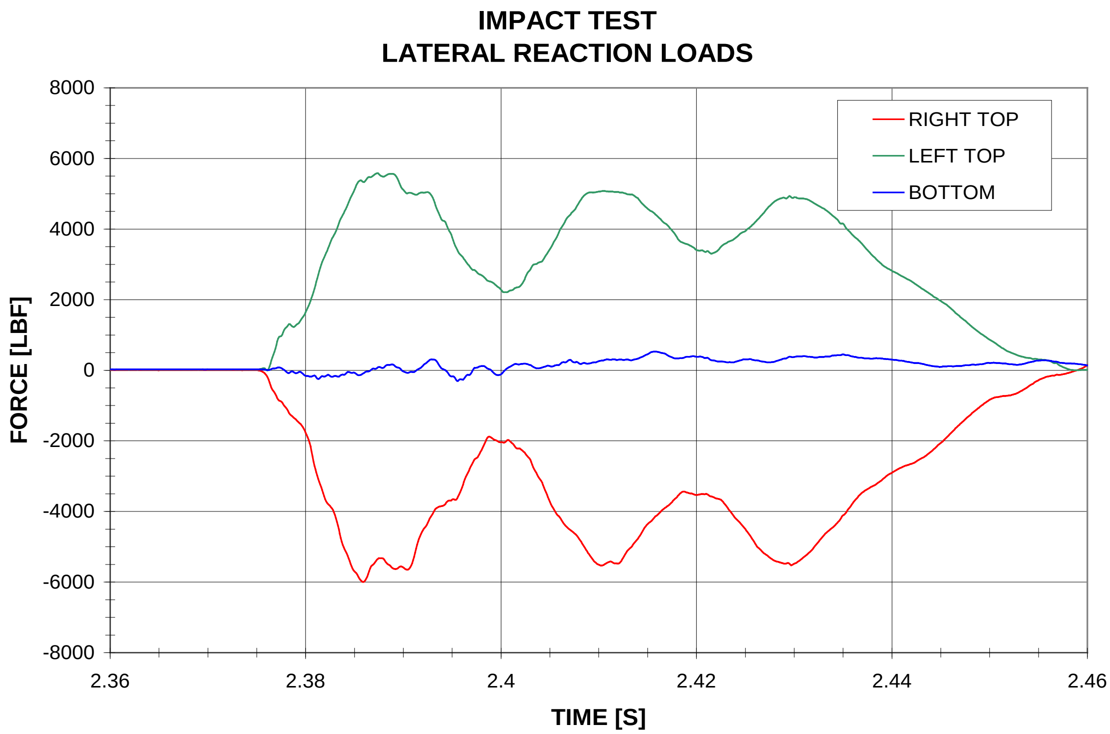
Equipment	**Channel**	**Manufacturer**	**Model No.**	**Range**	**Serial No.**	**Cal. Date**
String Potentiometer	Displacement	Ametek	P-50A		17167	6/01/07
String Potentiometer	Displacement	Ametek	P-25A		19183	6/01/07
3-Axis Load Cell (1)	Force	PCB	1316-01A	10,000 lbf	607	7/13/07
3-Axis Load Cell (2)	Force	Denton	2177A	10,000 lbf	105	8/08/07
3-Axis Load Cell (3)	Force	Denton	2177A	10,000 lbf	102	8/08/07
3-Axis Load Cell (1)	Force	PCB	1316-01A	10,000 lbf	607	7/13/07
3-Axis Load Cell (2)	Force	Denton	2177A	10,000 lbf	103	8/08/07

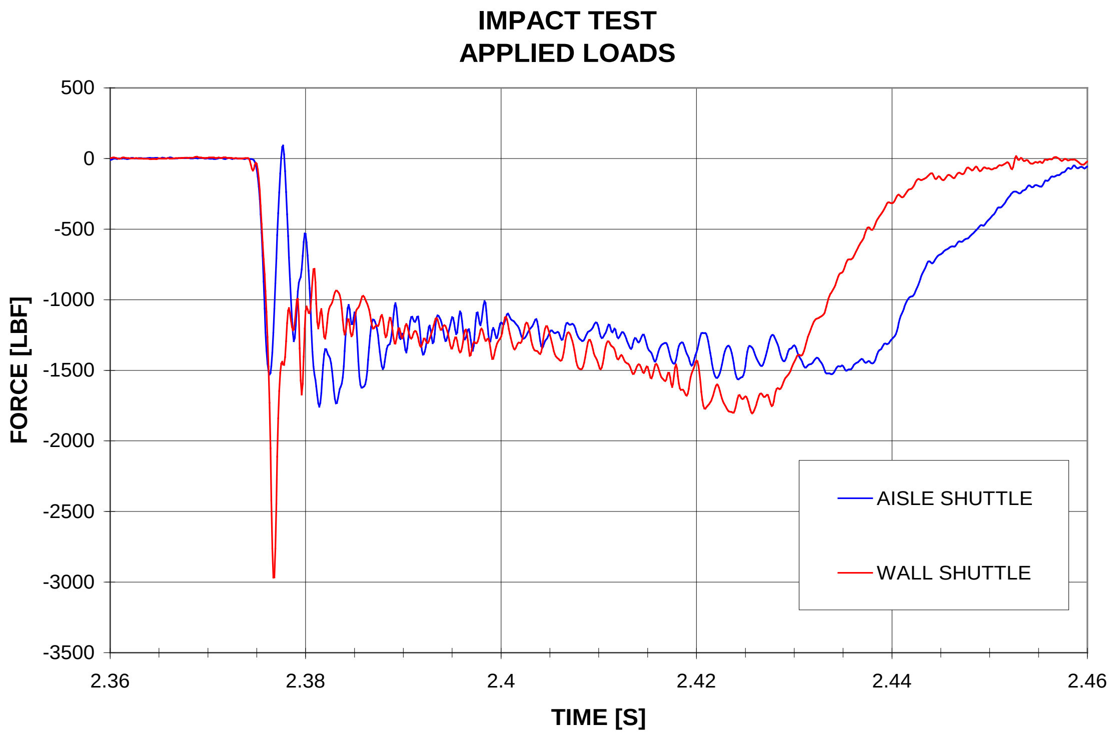
Inboard Pendulum X	Acceleration	Entran	EGE-73B6Q-2000JF	2,000 g	G15-B09	6/15/07
Inboard Pendulum Y	Acceleration	Entran	EGE-73B6Q-2000JF	2,000 g	A07-R09	6/15/07
Inboard Pendulum Z	Acceleration	Entran	EGE-73B6Q-2000JF	2,000 g	A05-A09	6/15/07
Outboard Pendulum X	Acceleration	Entran	EGE-73B6Q-2000JF	2,000 g	J24-H12	8/25/07
Outboard Pendulum Y	Acceleration	Entran	EGE-73B6Q-2000JF	2,000 g	J04-J11	8/25/07
Outboard Pendulum Z	Acceleration	Entran	EGE-73B6Q-2000JF	2,000 g	G25-Z09	8/25/07

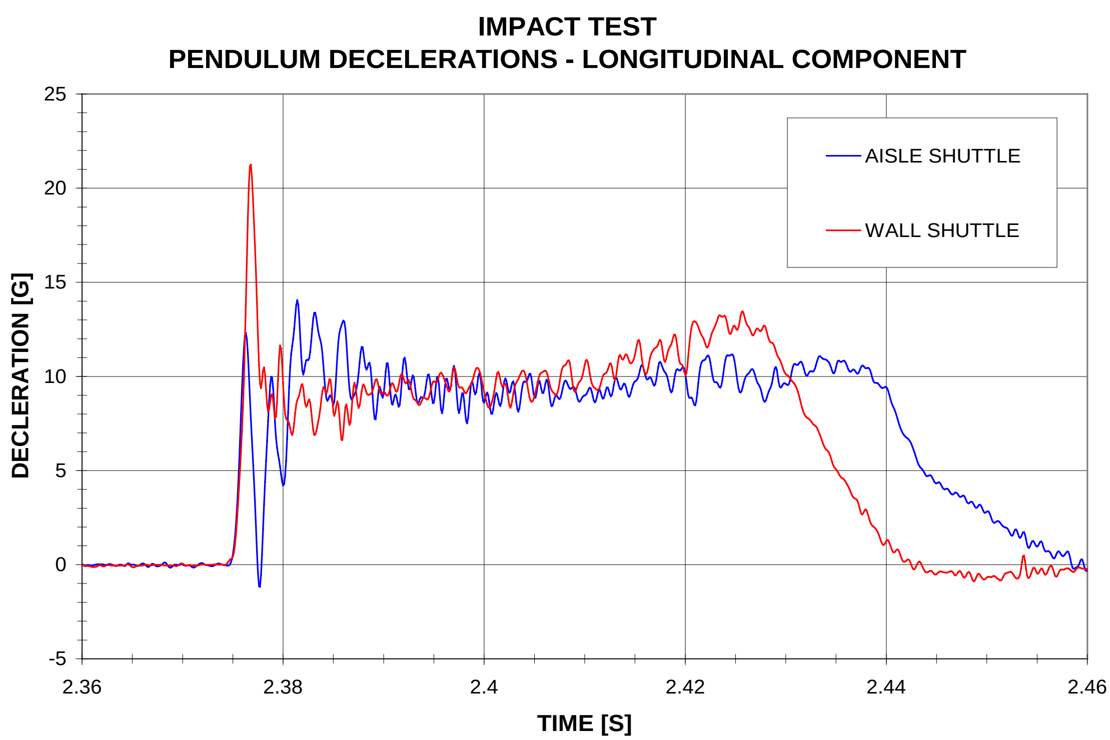
C.2.4 Data Plots

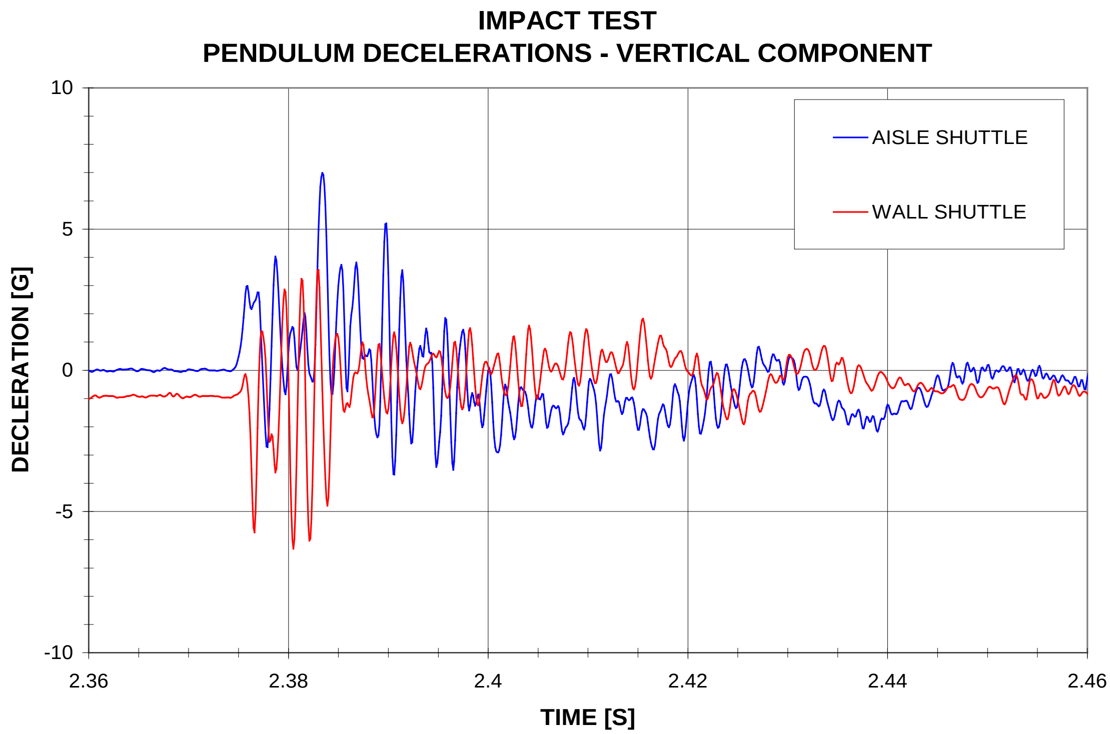


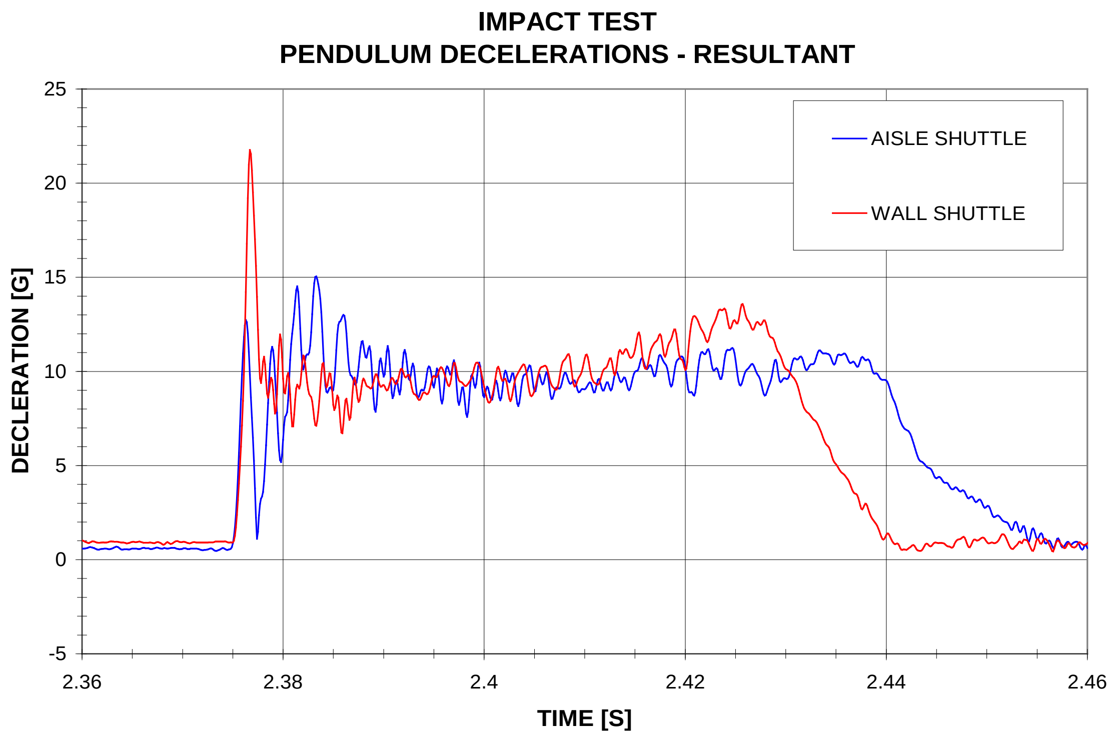

IMPACT TEST
LONGITUDINAL REACTION LOADS
FORCE [LBF]
TIME [S]
RIGHT TOP
LEFT TOP
BOTTOM
4000
3000
2000
1000
0
-1000
2.36
2.38
2.4
2.42
2.44
2.46


IMPACT TEST
LATERAL REACTION LOADS
FORCE [LBF]
TIME [S]
RIGHT TOP
LEFT TOP
BOTTOM
8000
6000
4000
2000
0
-2000
-4000
-6000
-8000
2.36
2.38
2.4
2.42
2.44
2.46

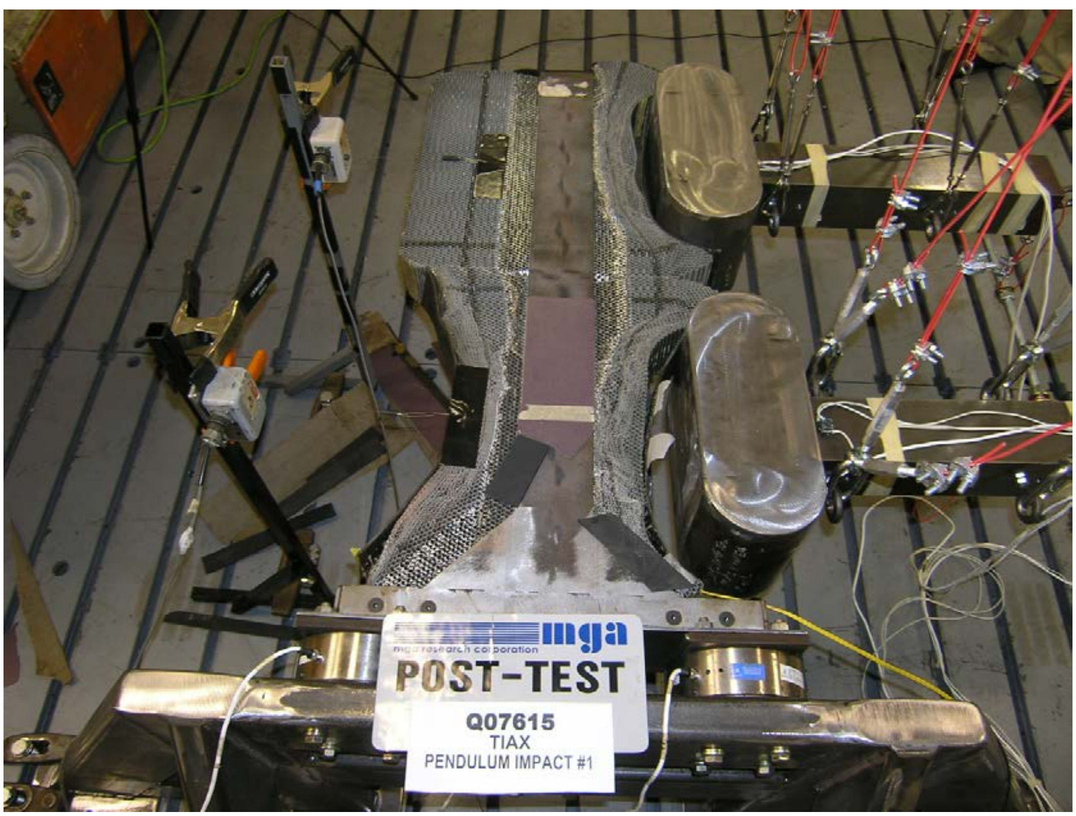

IMPACT TEST
APPLIED LOADS
FORCE [LBF]
500
0
-500
-1000
-1500
-2000
-2500
-3000
-3500
2.36
2.38
2.4
2.42
2.44
2.46
TIME [S]
AISLE SHUTTLE
WALL SHUTTLE


IMPACT TEST
PENDULUM DECELERATIONS - LONGITUDINAL COMPONENT
DECLERATION [G]
25
20
15
10
5
0
-5
2.36
2.38
2.4
2.42
2.44
2.46
TIME [S]
AISLE SHUTTLE
WALL SHUTTLE


IMPACT TEST
PENDULUM DECELERATIONS - VERTICAL COMPONENT
AISLE SHUTTLE
WALL SHUTTLE
DECLERATION [G]
10
5
0
-5
-10
2.36
2.38
2.4
2.42
2.44
2.46
TIME [S]


IMPACT TEST
PENDULUM DECELERATIONS - RESULTANT
AISLE SHUTTLE
WALL SHUTTLE
DECLERATION [G]
25
20
15
10
5
0
-5
2.36
2.38
2.4
2.42
2.44
2.46
TIME [S]

C.2.4 Photographs




mga
mga research corporation
PRE-TEST
Q07615
TIAX
PENDULUM IMPACT #1


mga
mga research corporation
POST-TEST
Q07615
TIAX
PENDULUM IMPACT #1


mga
mga research corporation
POST-TEST
Q07615
TIAX
PENDULUM IMPACT #1


mga
mga research corporation
POST-TEST
Q07615
TIAX
PENDULUM IMPACT #1

C.3. MGA Test: Q081164 Pendulum Test

Test Date:	06/16/08
Test Procedure:	Test Implementation Plan
MGA Test Number:	Q081164
Test Description:	Pendulum

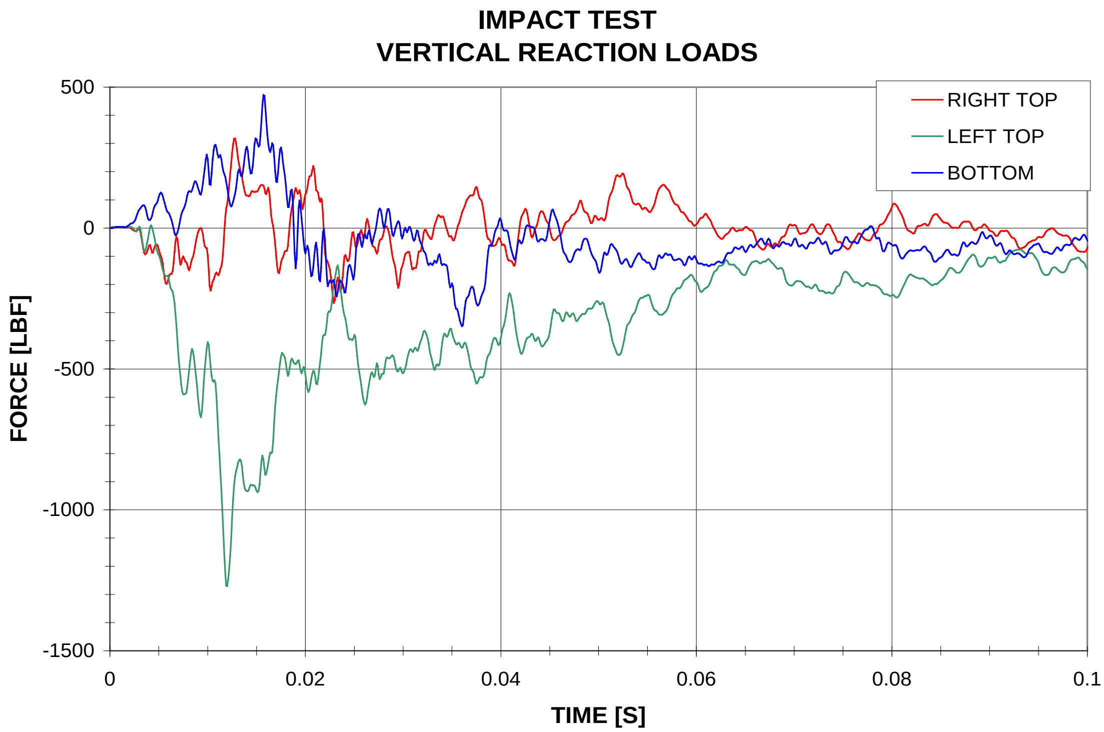
C.3.1 Summary:

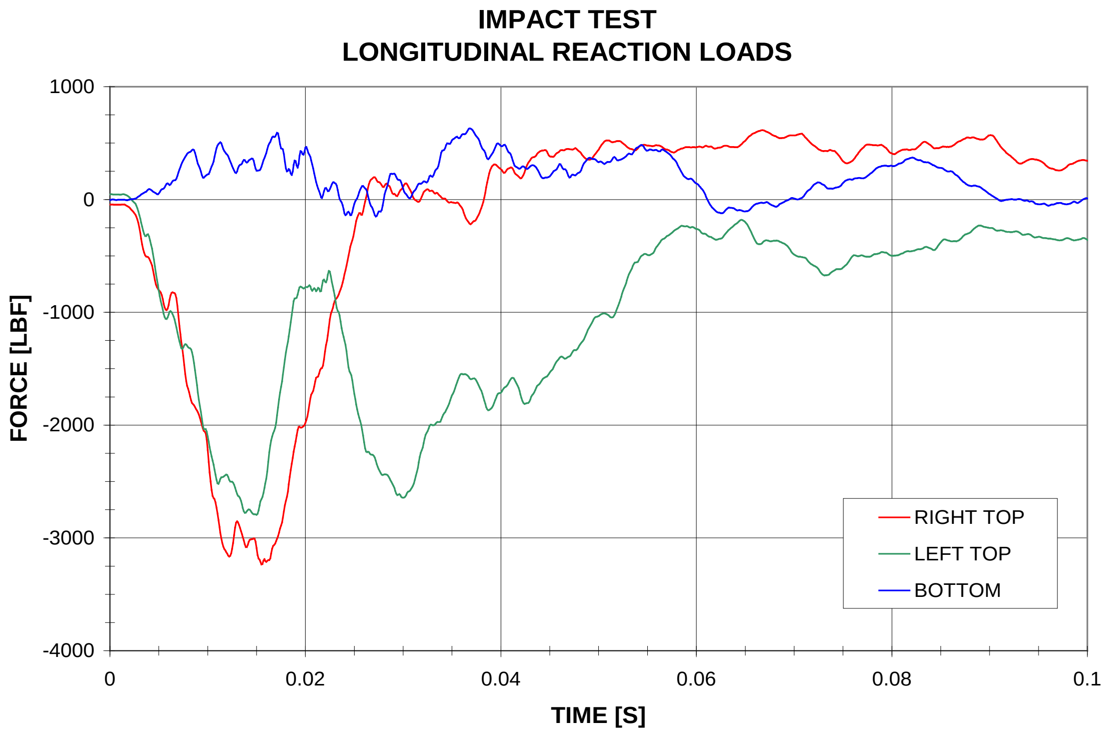
This pendulum test was conducted on a deformable table with two 75-pound shuttles. Both shuttles were dropped simultaneously by a mechanical release mechanism at an approximate effective release height of 79.8 in.

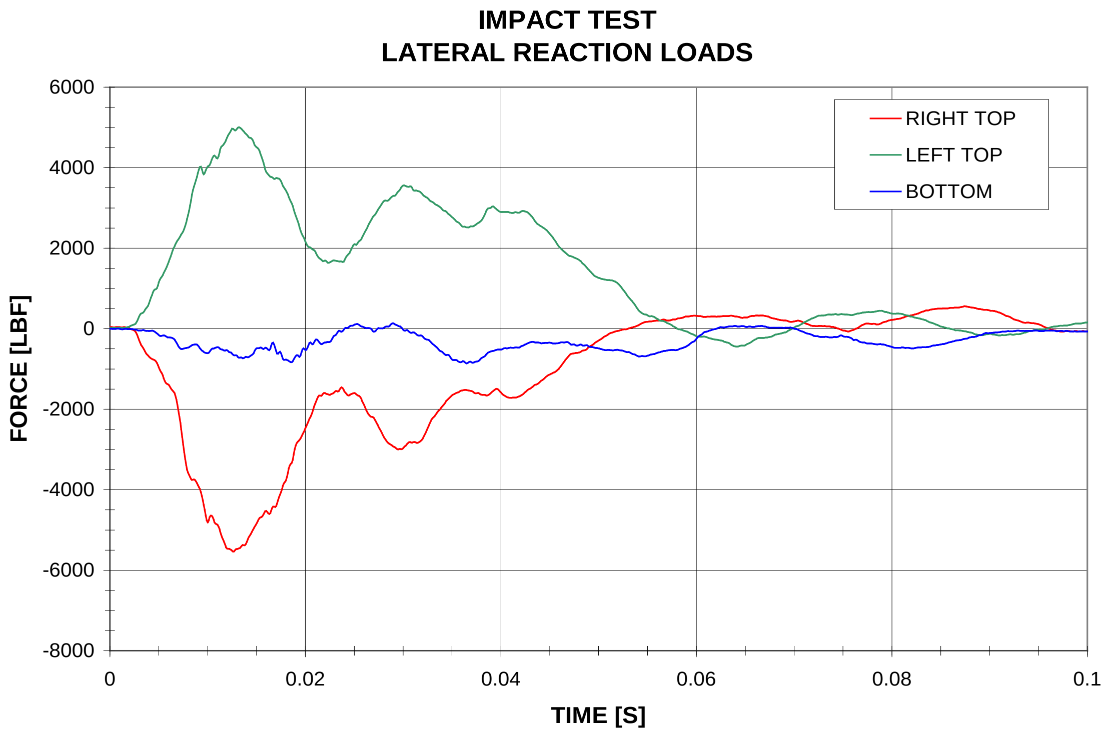
C.3.2 Equipment and Calibration

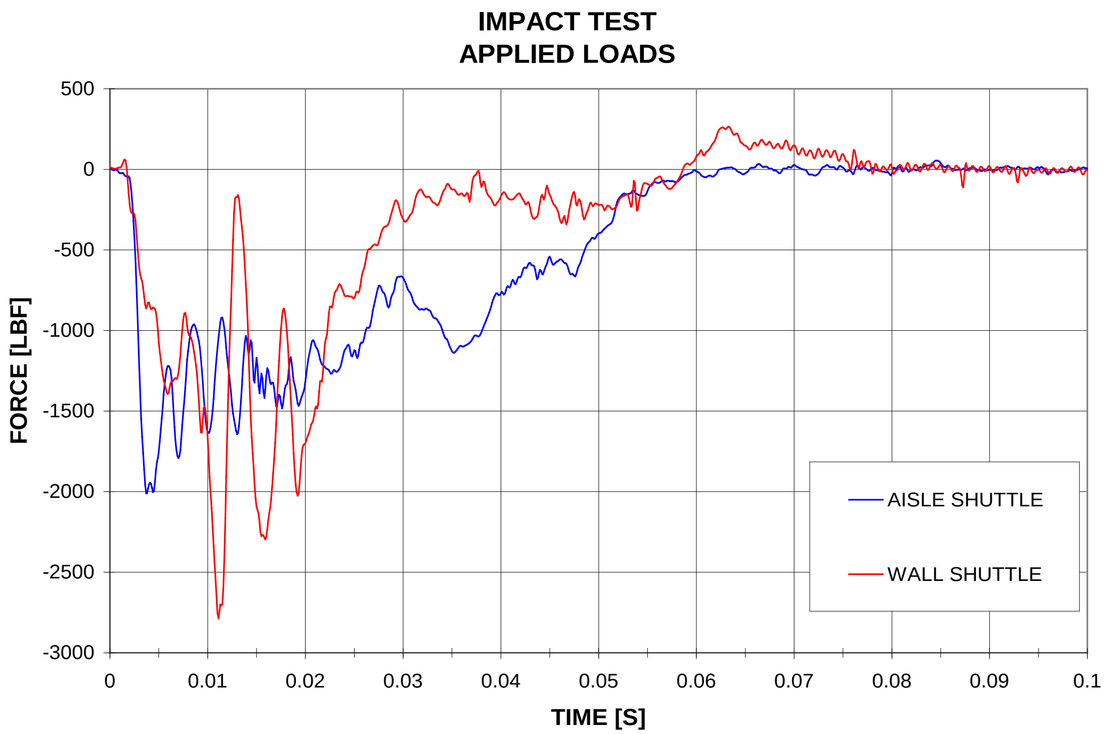
Equipment	**Description**	**Manufacturer**	**Model No.**	**Range**	**Serial No.**	**Cal. Date**
String Potentiometer	Displacement	Ametek	P-40A		0304-2163102	2/18/08
String Potentiometer	Displacement	Ametek	P-40A-HT		21954	2/18/08
3-Axis Load Cell (1)	Force	Denton	2177A	10,000 lbf	105	3/17/08
3-Axis Load Cell (2)	Force	Denton	2177A	10,000 lbf	102	2/20/08
3-Axis Load Cell (3)	Force	Denton	6224-03	10,000 lbf	1101	5/05/08
3-Axis Load Cell (4)	Force	Denton	2177A	10,000 lbf	103	2/20/08
3-Axis Load Cell (5)	Force	Denton	2177A	10,000 lbf	104	3/17/08
Inboard Pendulum X	Acceleration	Entran	EGE-73B6Q-2000JF	2,000 g	G16-Z10	6/09/08
Inboard Pendulum Y	Acceleration	Entran	EGE-73B6Q-2000JF	2,000 g	A07-R09	6/09/08
Inboard Pendulum Z	Acceleration	Entran	EGE-73B6Q-2000JF	2,000 g	A05-A09	6/09/08
Outboard Pendulum X	Acceleration	Entran	EGE-73B6Q-2000JF	2,000 g	J26-H14	2/21/08
Outboard Pendulum Y	Acceleration	Entran	EGE-73B6Q-2000JF	2,000 g	B05-J14	2/21/08
Outboard Pendulum Z	Acceleration	Entran	EGE-73B6Q-2000JF	2,000 g	A27-Z05	2/21/08

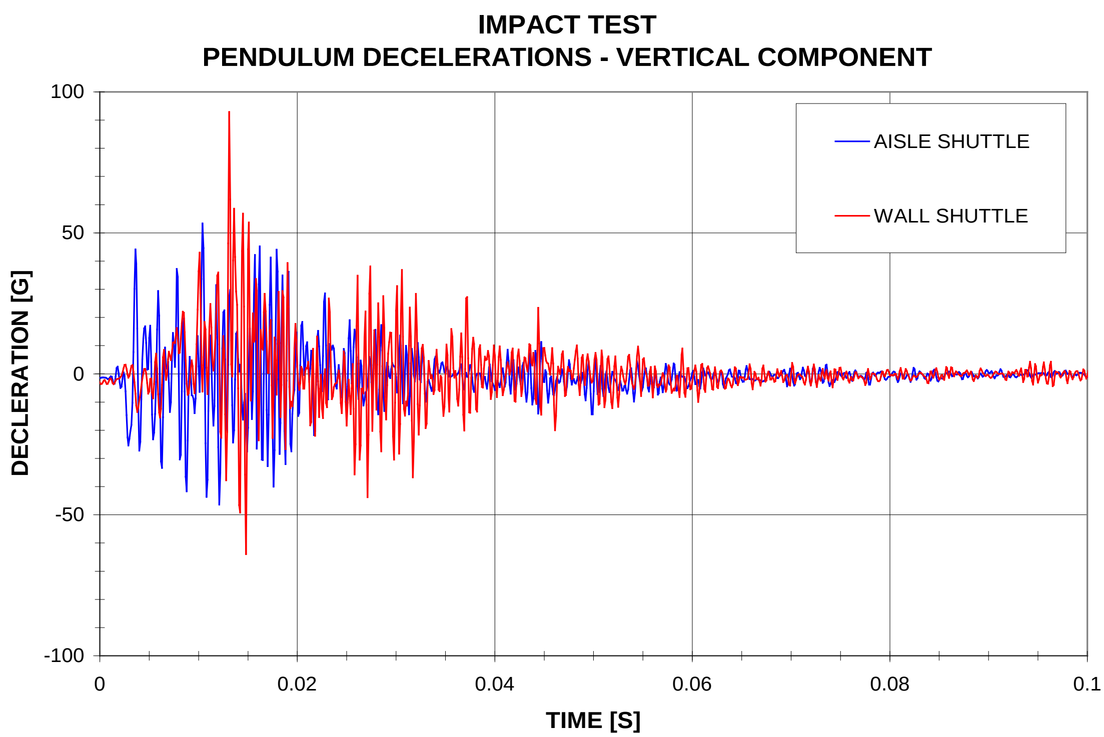
C.3.3 Data Plots

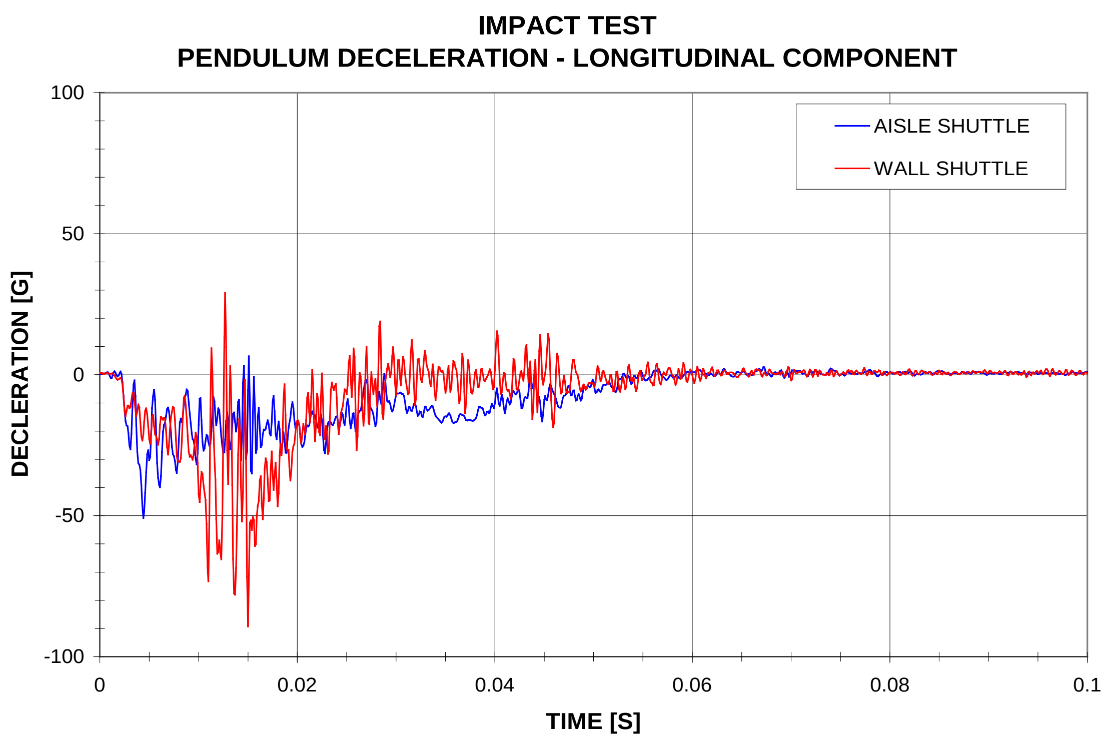


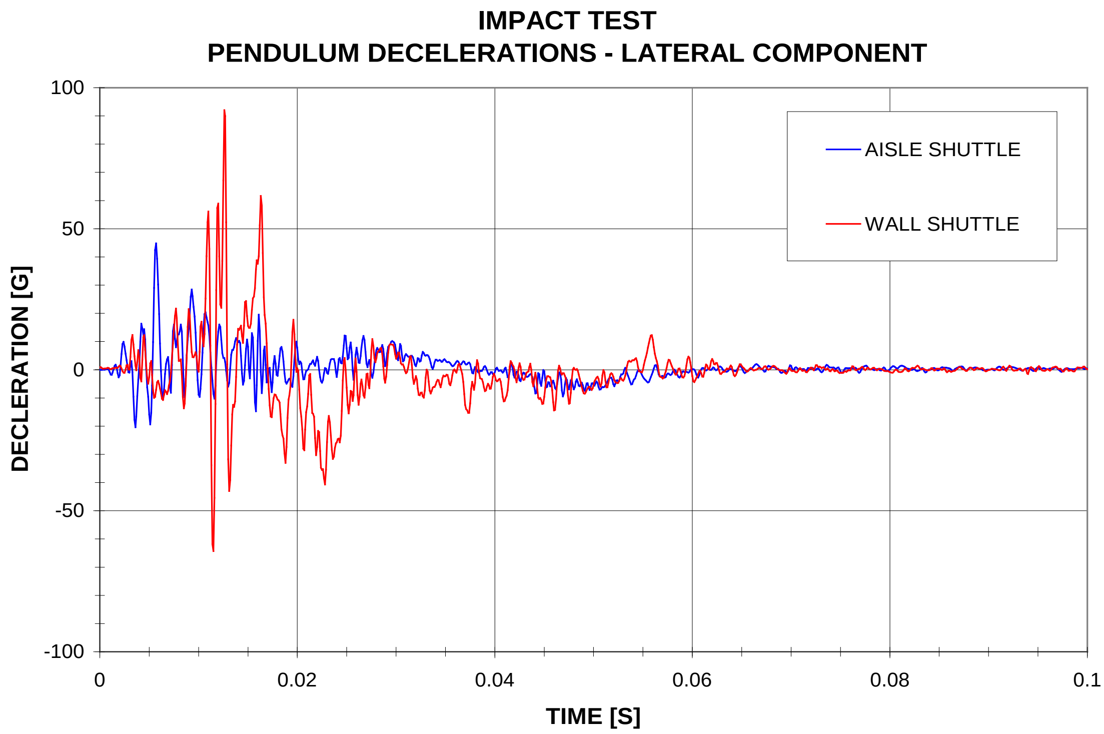


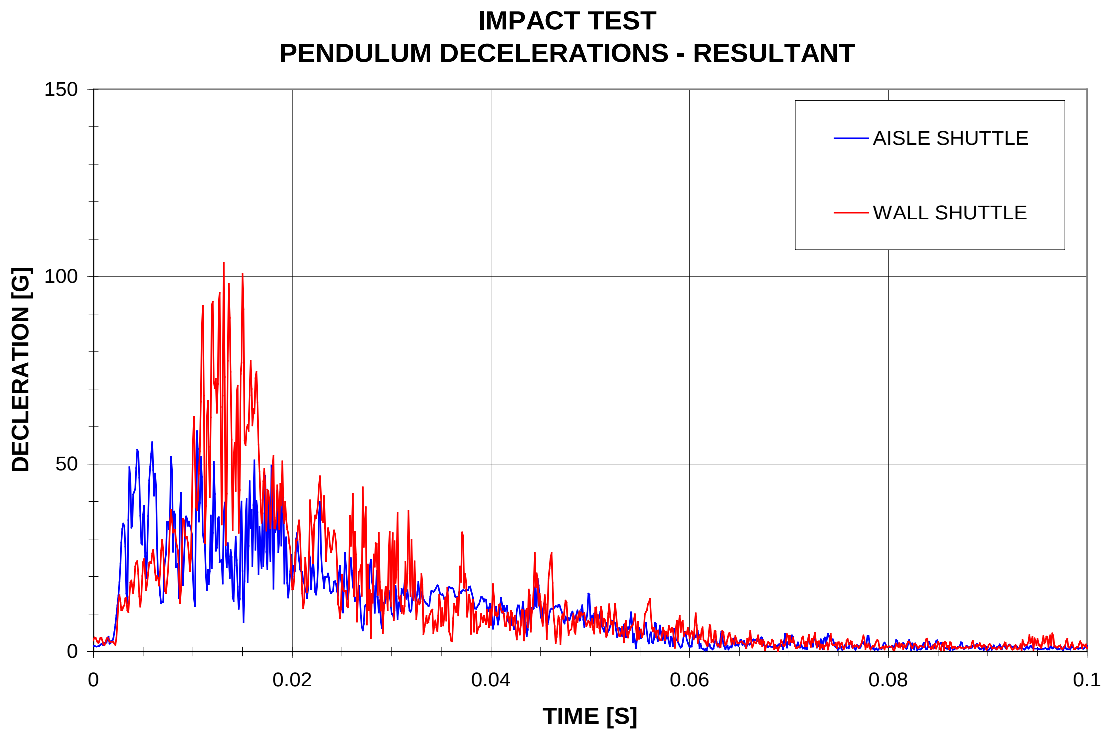

IMPACT TEST
LATERAL REACTION LOADS
RIGHT TOP
LEFT TOP
BOTTOM
FORCE [LBF]
TIME [S]
6000
4000
2000
0
-2000
-4000
-6000
-8000
0
0.02
0.04
0.06
0.08
0.1

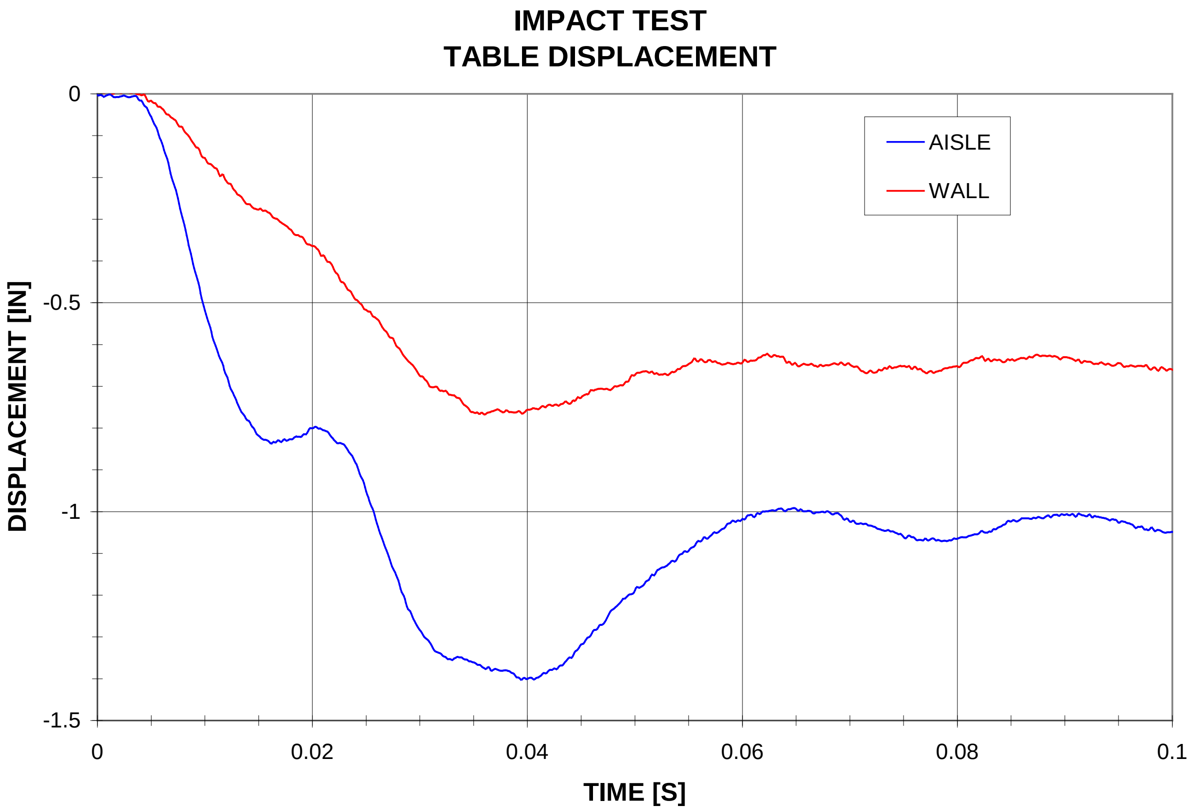

IMPACT TEST
APPLIED LOADS
AISLE SHUTTLE
WALL SHUTTLE
FORCE [LBF]
TIME [S]
500
0
-500
-1000
-1500
-2000
-2500
-3000
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1


IMPACT TEST
PENDULUM DECELERATIONS - VERTICAL COMPONENT
AISLE SHUTTLE
WALL SHUTTLE
DECLERATION [G]
100
50
0
-50
-100
0
0.02
0.04
0.06
0.08
0.1
TIME [S]


IMPACT TEST
PENDULUM DECELERATION - LONGITUDINAL COMPONENT
AISLE SHUTTLE
WALL SHUTTLE
DECLERATION [G]
100
50
0
-50
-100
0
0.02
0.04
0.06
0.08
0.1
TIME [S]

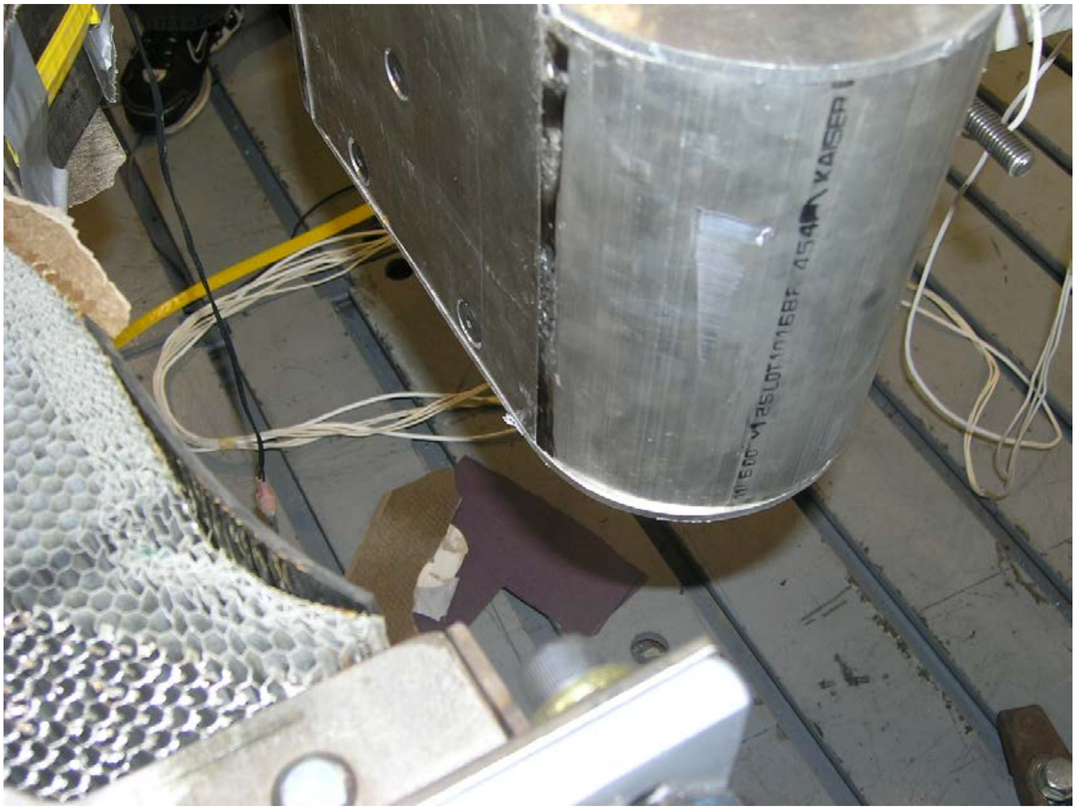

IMPACT TEST
PENDULUM DECELERATIONS - LATERAL COMPONENT
100
50
0
-50
-100
0
0.02
0.04
0.06
0.08
0.1
DECLERATION [G]
TIME [S]
AISLE SHUTTLE
WALL SHUTTLE

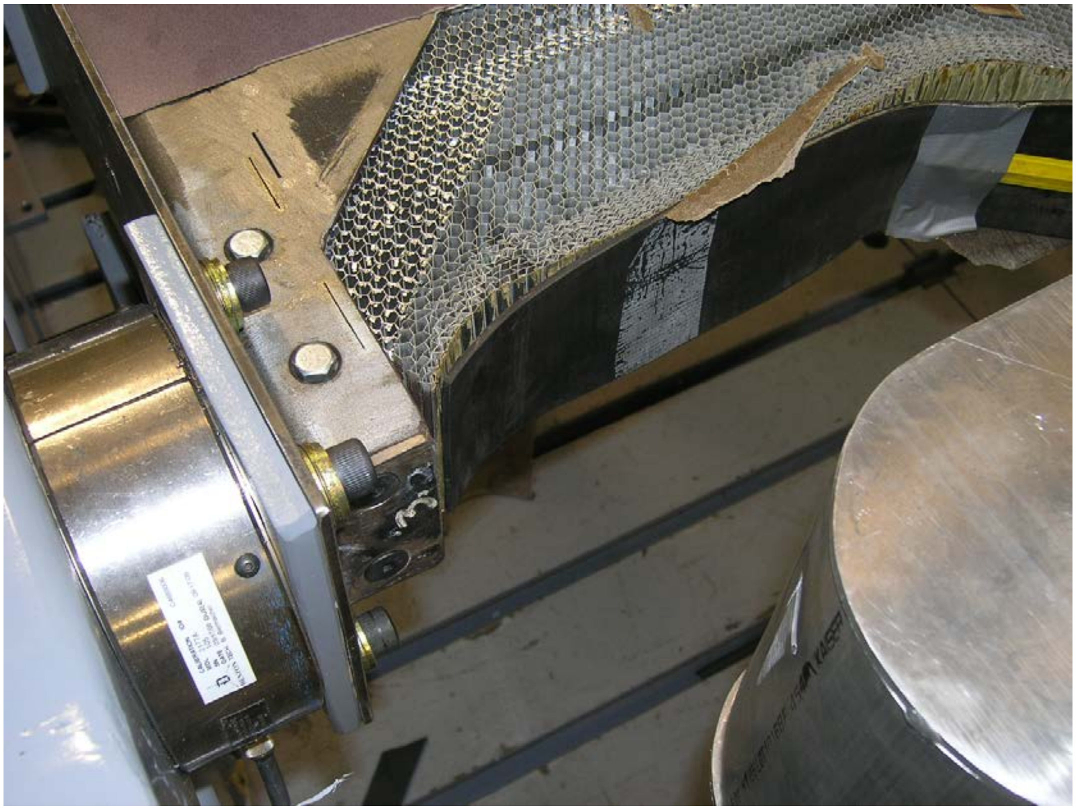

IMPACT TEST
PENDULUM DECELERATIONS - RESULTANT
150
100
50
0
0
0.02
0.04
0.06
0.08
0.1
DECLERATION [G]
TIME [S]
AISLE SHUTTLE
WALL SHUTTLE


IMPACT TEST
TABLE DISPLACEMENT
AISLE
WALL
DISPLACEMENT [IN]
0
-0.5
-1
-1.5
0
0.02
0.04
0.06
0.08
0.1
TIME [S]

C.3.4 Photographs


mga research corporation
POST-TES
Q081164
TIAX
TRAIN TABLE


KAISER


KAISER

C.4. MGA Test: Q081165 Pendulum Test

Test Date:	06/16/08
Test Procedure:	Test Implementation Plan
MGA Test Number:	Q081165
Test Description:	Pendulum

C.4.1 Summary

This pendulum test was conducted on a "rigid" table with two 75-pound shuttles. Both shuttles were dropped simultaneously by a mechanical release mechanism at an approximate effective release height of 79.8 in.

Because of the expectation of table separation during impact, no table displacement measurements were taken.

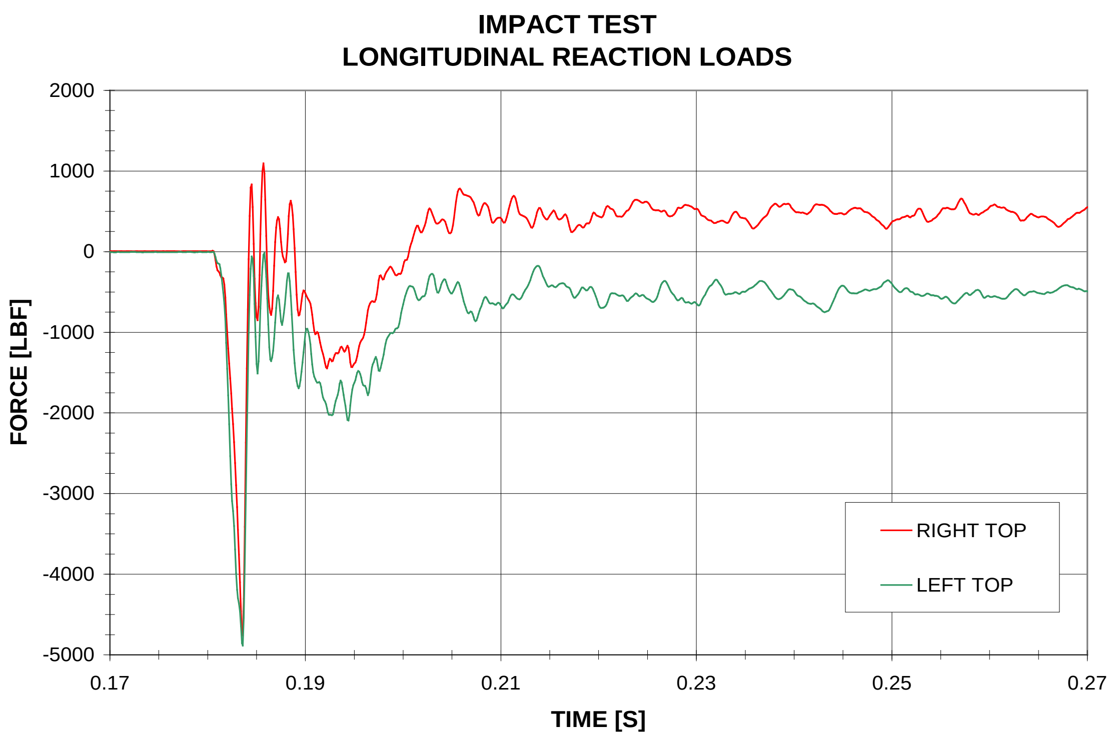
C.4.2 Post-Test Comments

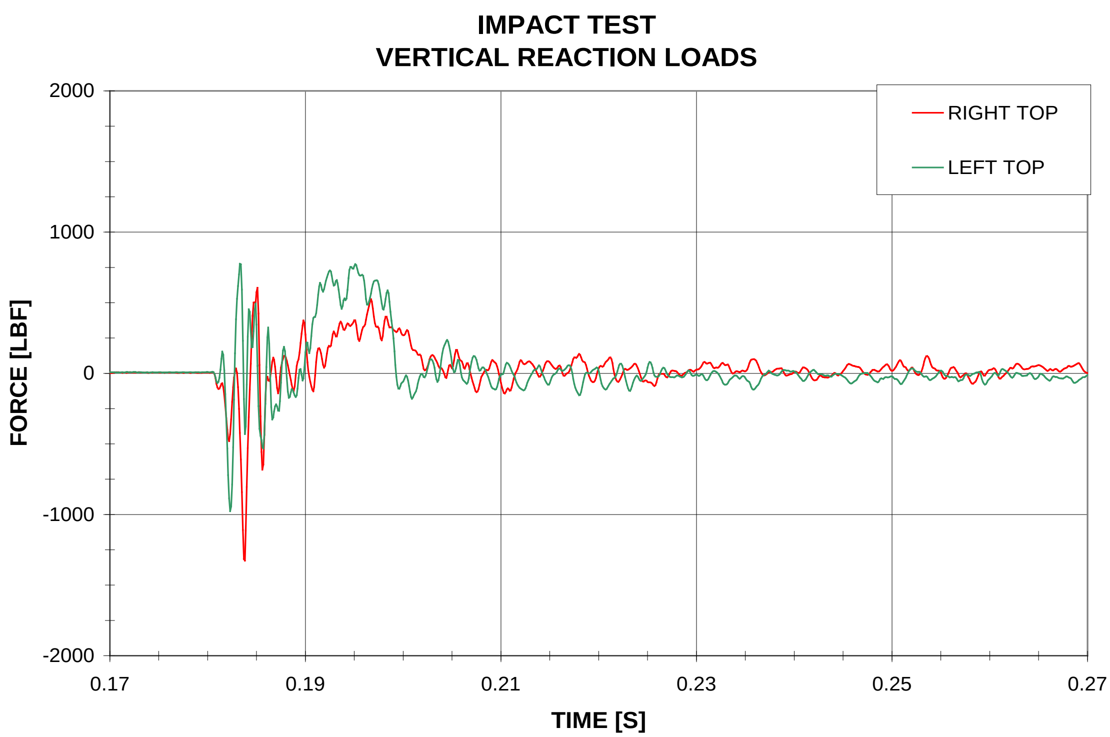
The table support post sheared from the lower (floor) anchor point during impact. The screws that fastened the table top to the wall bracket sheared as well. The table completely detached from both mounting locations.

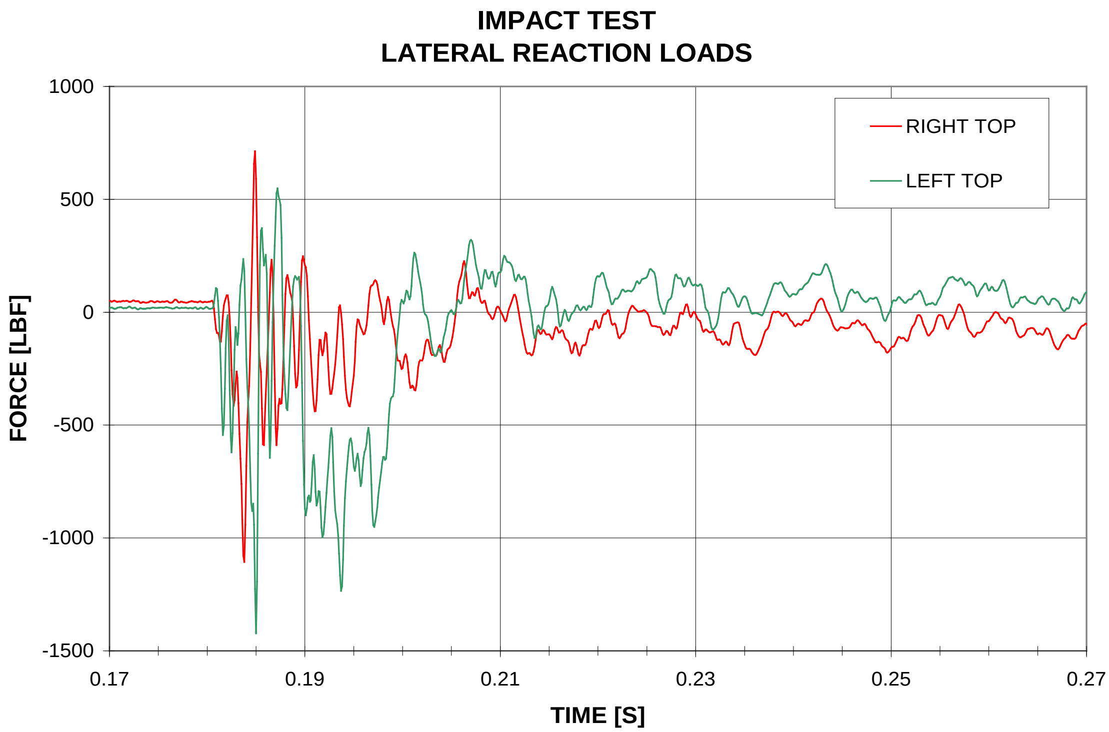
C.4.3 Equipment and Calibration

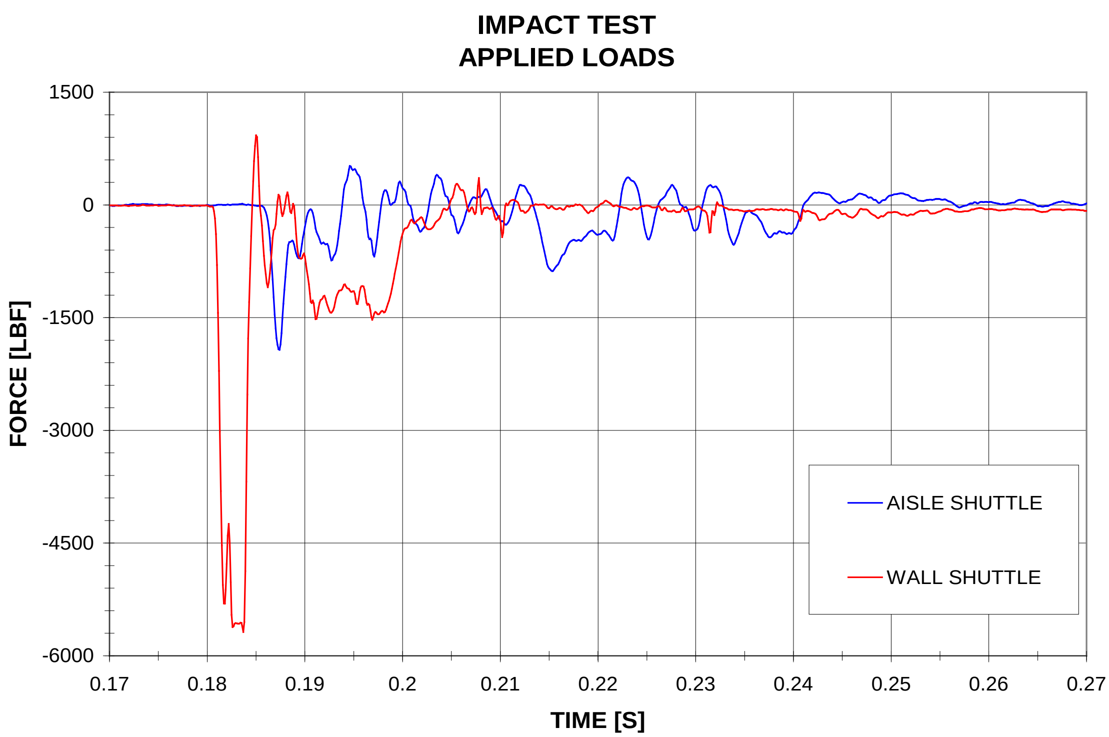
Equipment	Description	Manufacturer	Model No.	Range	Serial No.	Cal. Date
3-Axis Load Cell (1)	Force	Denton	2177A	10,000 lbf	105	3/17/08
3-Axis Load Cell (2)	Force	Denton	2177A	10,000 lbf	102	2/20/08
3-Axis Load Cell (3)	Force	Denton	6224-03	10,000 lbf	1101	5/05/08
3-Axis Load Cell (4)	Force	Denton	2177A	10,000 lbf	103	2/20/08
3-Axis Load Cell (5)	Force	Denton	2177A	10,000 lbf	104	3/17/08
Inboard Pendulum X	Acceleration	Entran	EGE-73B6Q-2000JF	2,000 g	G16-Z10	6/09/08
Inboard Pendulum Y	Acceleration	Entran	EGE-73B6Q-2000JF	2,000 g	A07-R09	6/09/08
Inboard Pendulum Z	Acceleration	Entran	EGE-73B6Q-2000JF	2,000 g	A05-A09	6/09/08
Outboard Pendulum X	Acceleration	Entran	EGE-73B6Q-2000JF	2,000 g	J26-H14	2/21/08
Outboard Pendulum Y	Acceleration	Entran	EGE-73B6Q-2000JF	2,000 g	B05-J14	2/21/08
Outboard Pendulum Z	Acceleration	Entran	EGE-73B6Q-2000JF	2,000 g	A27-Z05	2/21/08

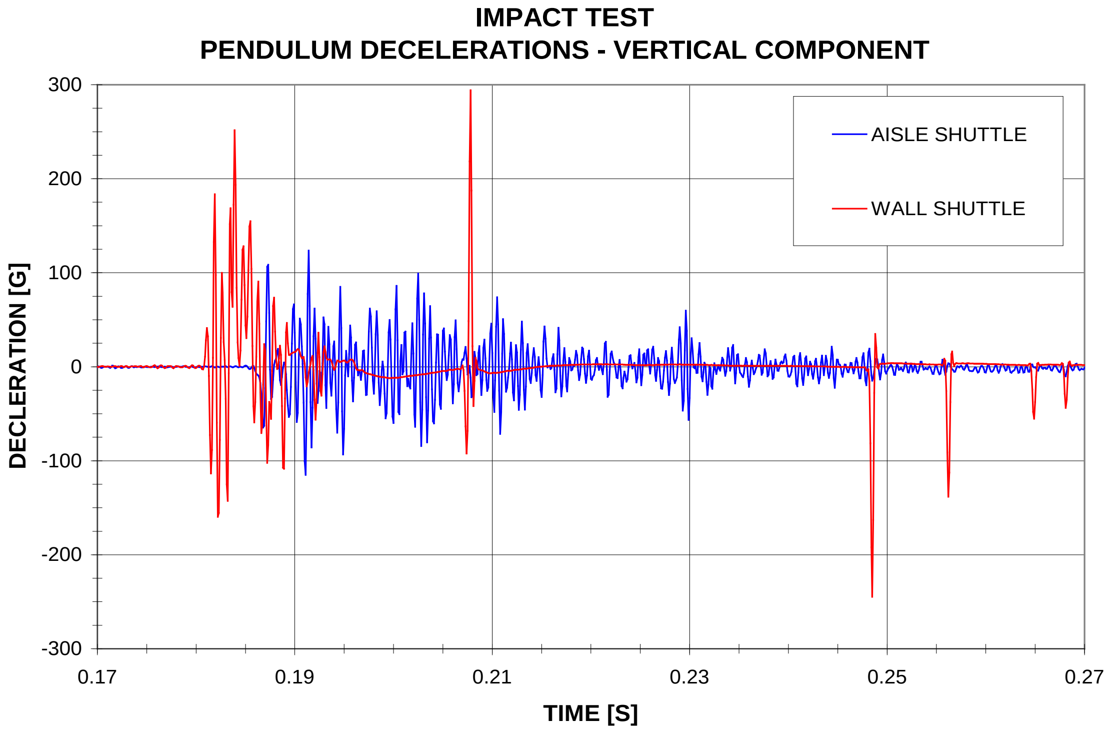
C.4.4 Data Plots

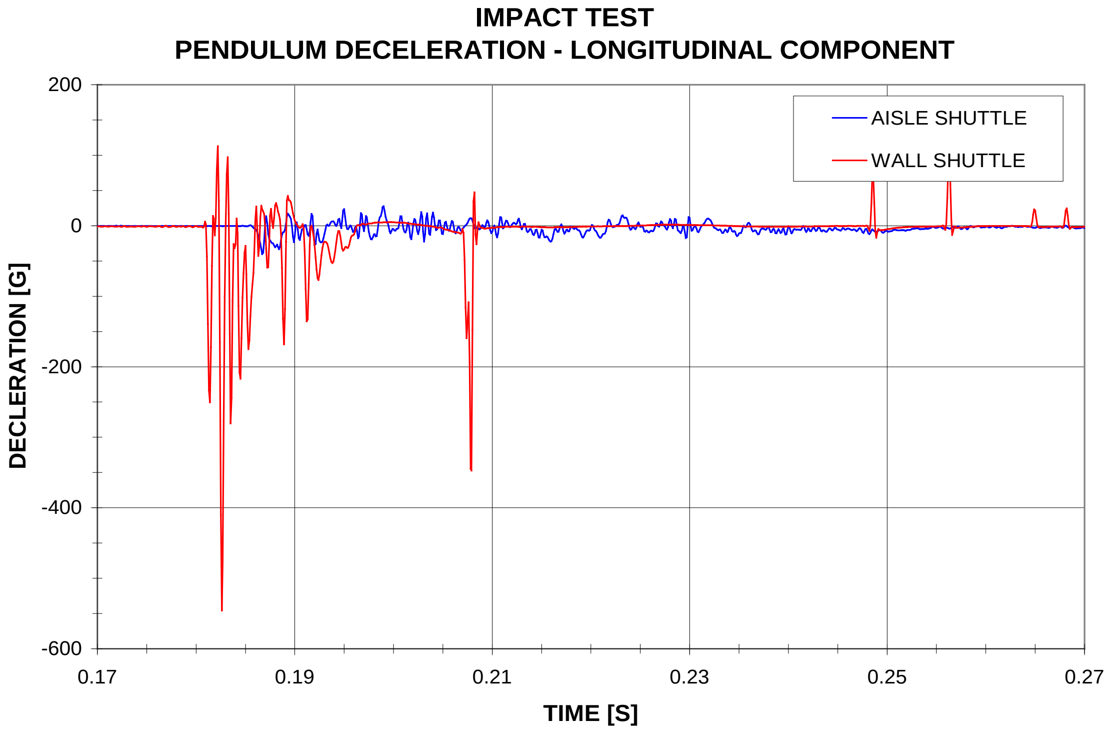


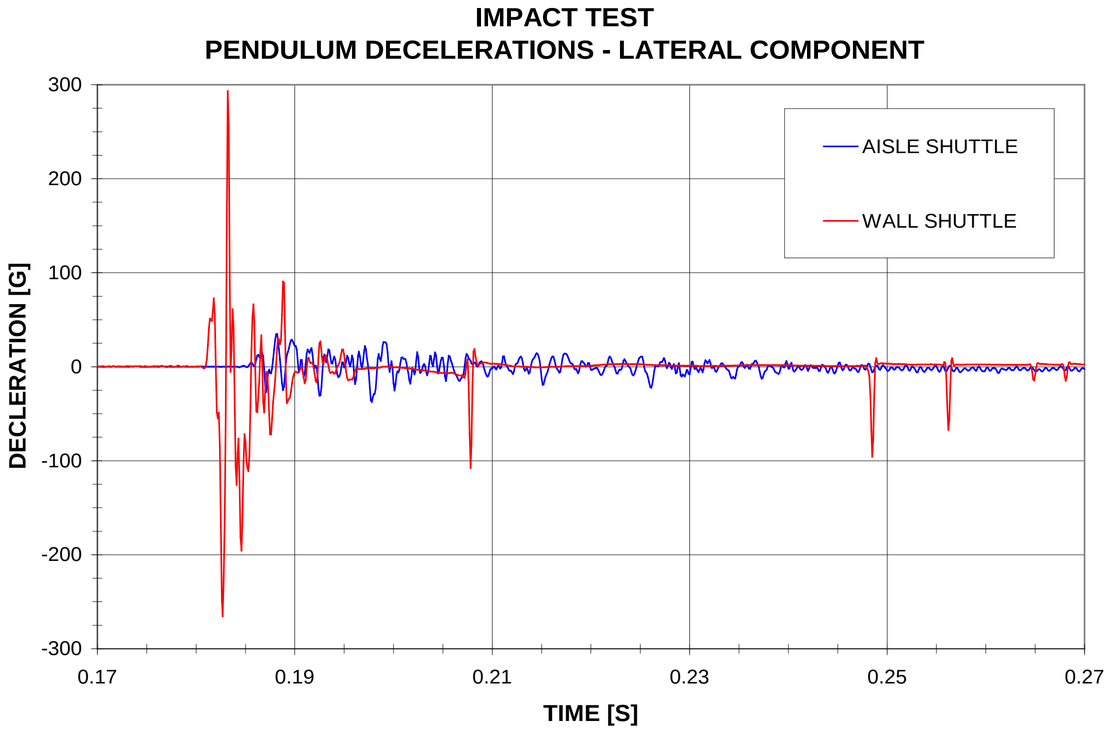


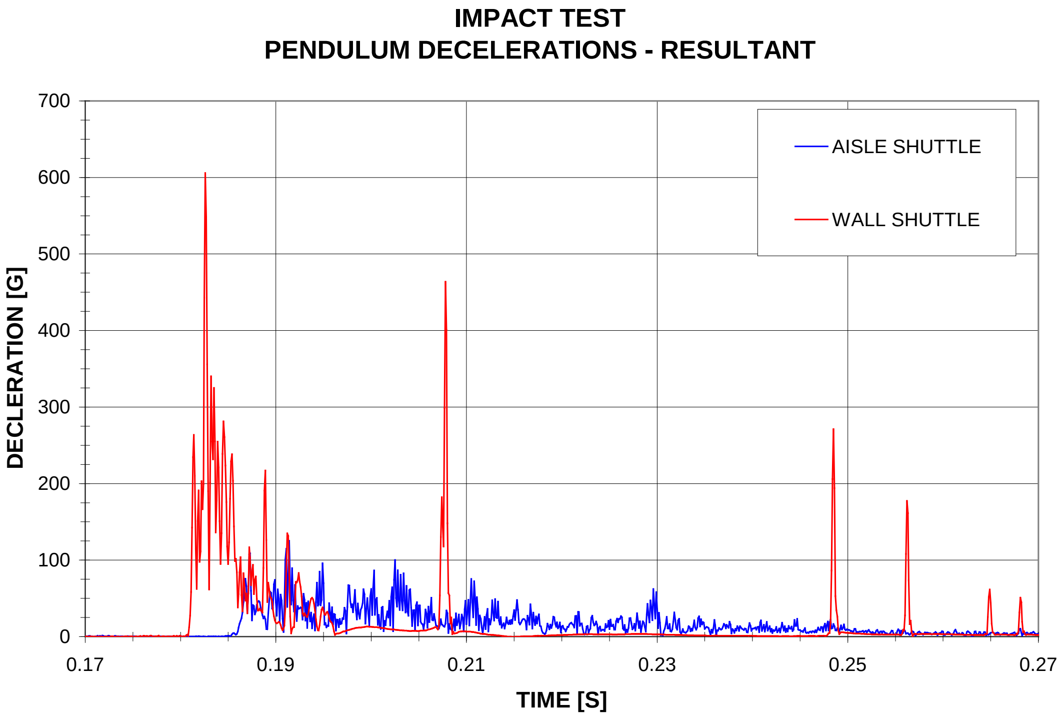

IMPACT TEST
LATERAL REACTION LOADS
RIGHT TOP
LEFT TOP
FORCE [LBF]
TIME [S]
1000
500
0
-500
-1000
-1500
0.17
0.19
0.21
0.23
0.25
0.27


IMPACT TEST
APPLIED LOADS
AISLE SHUTTLE
WALL SHUTTLE
FORCE [LBF]
TIME [S]
1500
0
-1500
-3000
-4500
-6000
0.17
0.18
0.19
0.2
0.21
0.22
0.23
0.24
0.25
0.26
0.27

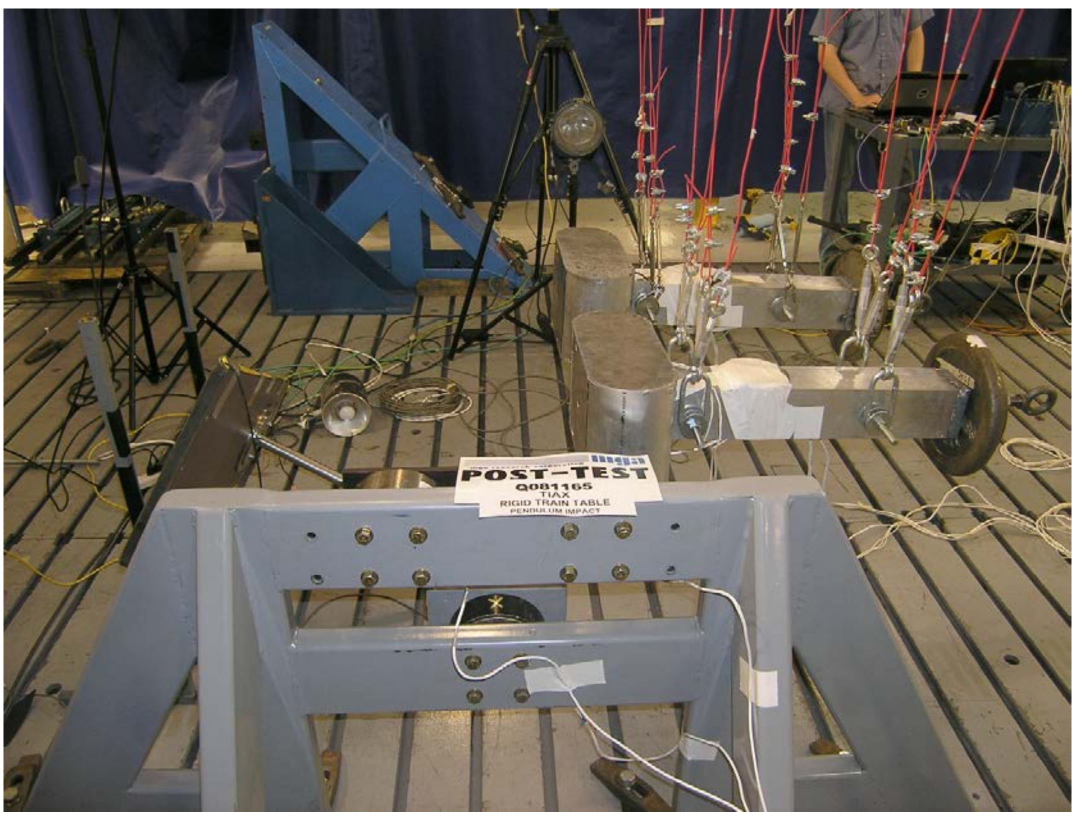

IMPACT TEST
PENDULUM DECELERATIONS - VERTICAL COMPONENT
DECLERATION [G]
300
200
100
0
-100
-200
-300
0.17
0.19
0.21
0.23
0.25
0.27
TIME [S]
AISLE SHUTTLE
WALL SHUTTLE


IMPACT TEST
PENDULUM DECELERATION - LONGITUDINAL COMPONENT
DECLERATION [G]
200
0
-200
-400
-600
0.17
0.19
0.21
0.23
0.25
0.27
TIME [S]
AISLE SHUTTLE
WALL SHUTTLE

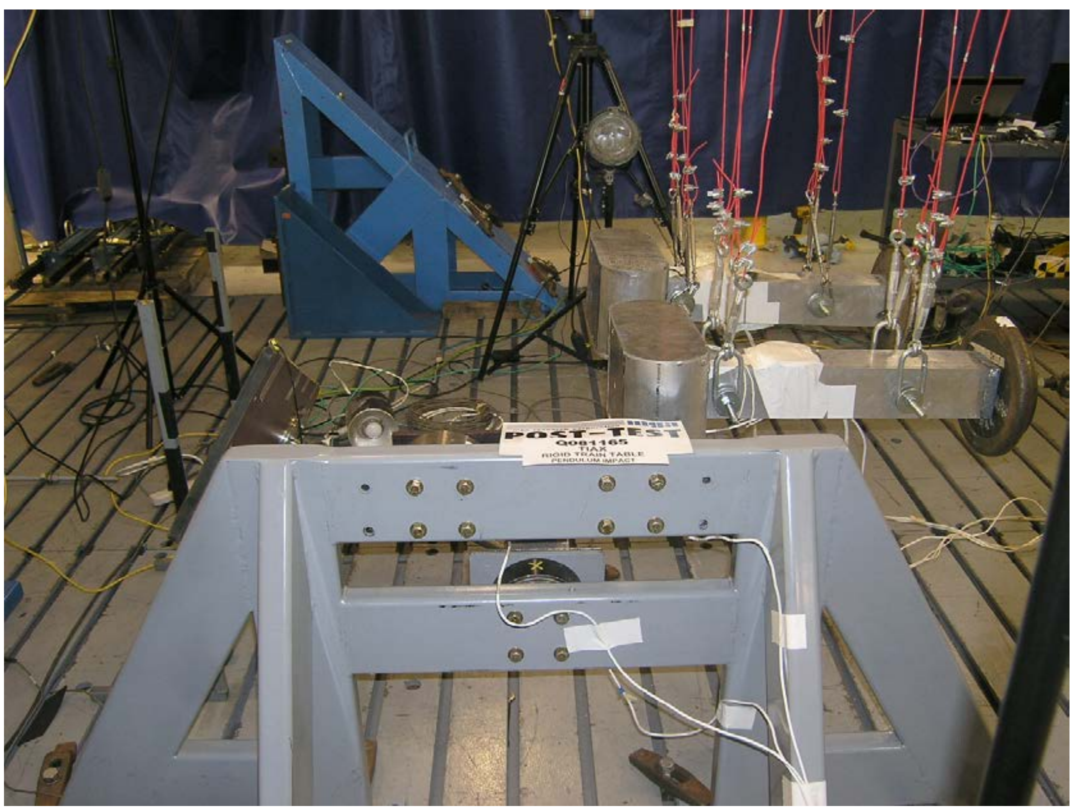

IMPACT TEST
PENDULUM DECELERATIONS - LATERAL COMPONENT
DECLERATION [G]
TIME [S]
AISLE SHUTTLE
WALL SHUTTLE
300
200
100
0
-100
-200
-300
0.17
0.19
0.21
0.23
0.25
0.27

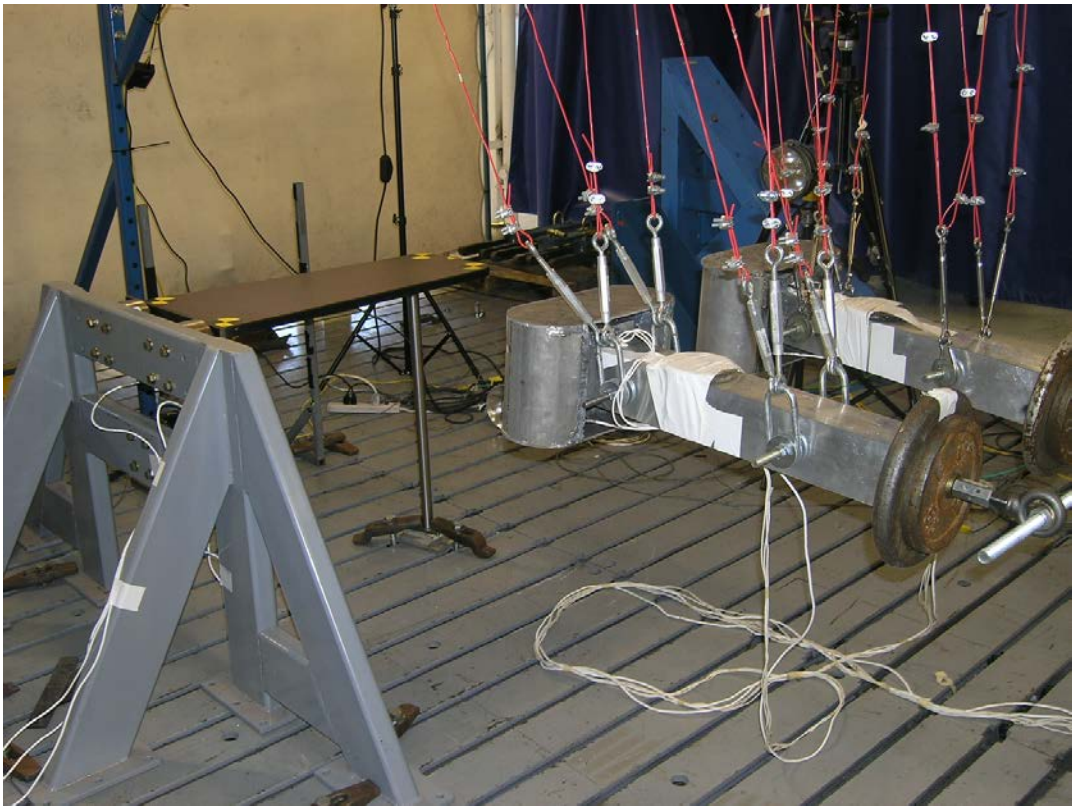

IMPACT TEST
PENDULUM DECELERATIONS - RESULTANT
DECLERATION [G]
TIME [S]
AISLE SHUTTLE
WALL SHUTTLE
700
600
500
400
300
200
100
0
0.17
0.19
0.21
0.23
0.25
0.27

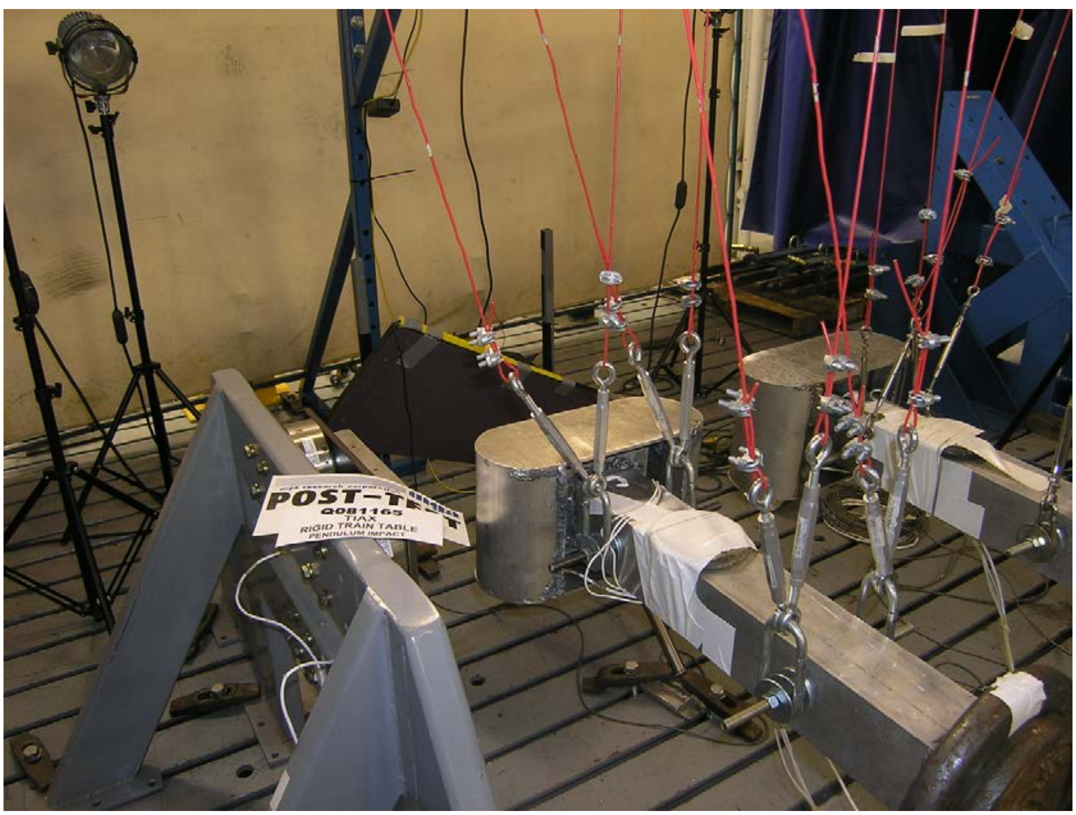
C.4.5 Photographs

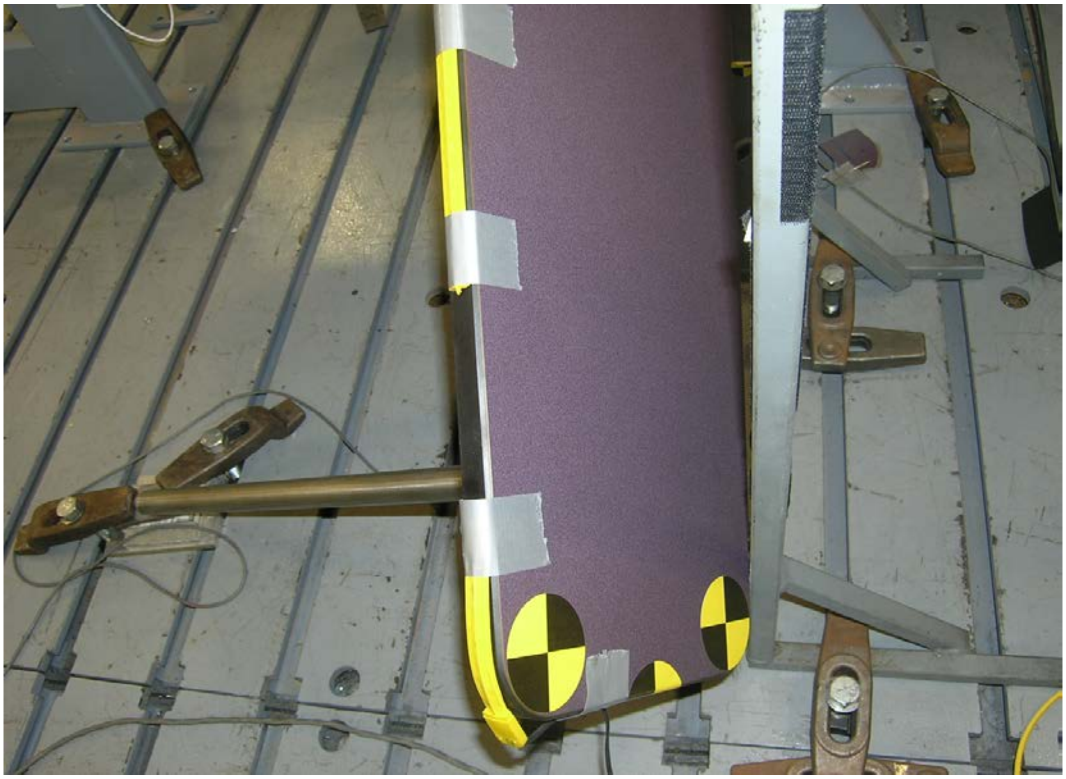



mga research corporation
PRE-TEST
Q081165
TIAX
RIGID TRAIN TABLE
PENDULUM IMPACT


POST-TEST
Q081165
TIAX
RIGID TRAIN TABLE
PENDULUM IMPACT




Q081165
TIAX
RIGID TRAIN TABLE
PENDULUM IMPACT



Appendix D
Finite Element Analyses

A finite element (FE) model of the crashworthy workstation table, developed as part of the base program, was used to predict table behavior in order to aid in the test development process. The test data was subsequently used to improve the accuracy of the model.

A detailed model of the table structure was developed using Hypermesh based on the Pro-Engineer CAD models generated for the table design. Figure D1 shows the FE model of the workstation table. Figure D1(a) shows the steel frame of the table: the I-beam assembly is shown in blue, the table and leg supports in orange, and the top and bottom wall mounting brackets in red. In Figure D1(b), the four honeycomb blocks, shown in yellow, have been added, as have the plastic spacers, shown in dark grey. The thickness of the spacers is equivalent to the thickness of the C-channel. The spacers are necessary to fill the gap between the honeycomb and the melamine, which is mounted on top of the C-channel. Figure D1(c) shows the added melamine table top and the rigid indenters, which are intended to represent the approximate width of a human torso. Note that a rubber strip that runs along the edge of the table top was not included in the model. Also, the melamine has not been scored, as it was in the final design, to minimize the load required to initiate table crush. The model includes approximately 250,000 elements.

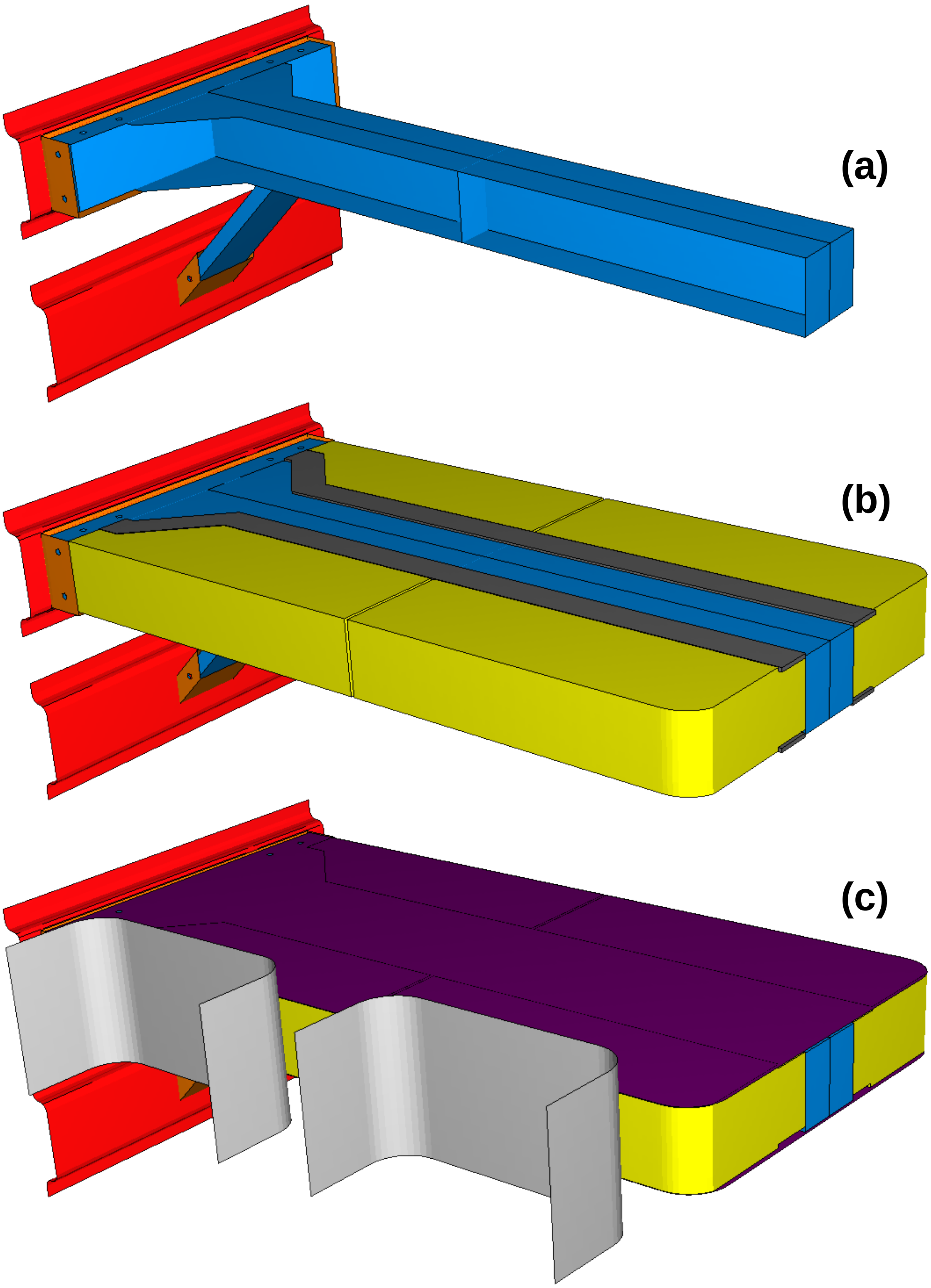


Figure D1. The Finite Element Model for the Workstation Table: (a) Table Frame Only; (b) Honeycomb Blocks and Spacers Added; (c) Melamine and Rigid Indenters Added

Not shown in Figure D1 is a series of springs that connect the nodes of the honeycomb to the nodes of the melamine and the nodes of the I-beam to the nodes of the melamine. The force-deflection characteristics of these nonlinear springs were defined to represent the strength of the contact cement and the epoxy, respectively. Based upon estimates from laboratory work, the contact cement was defined to have a very low tensile strength of approximately 0.8 psi; the epoxy was assumed to have a much greater strength of 80 psi. The strength of the contact cement was assumed to peak when the separation of the honeycomb and the melamine reached 0.1 in and decrease after the separation reached 0.2 in, as shown in Figure D2. (This strength was distributed to the nonlinear springs, with 16 springs per square inch assigned a maximum strength of 0.05 lbf each.)

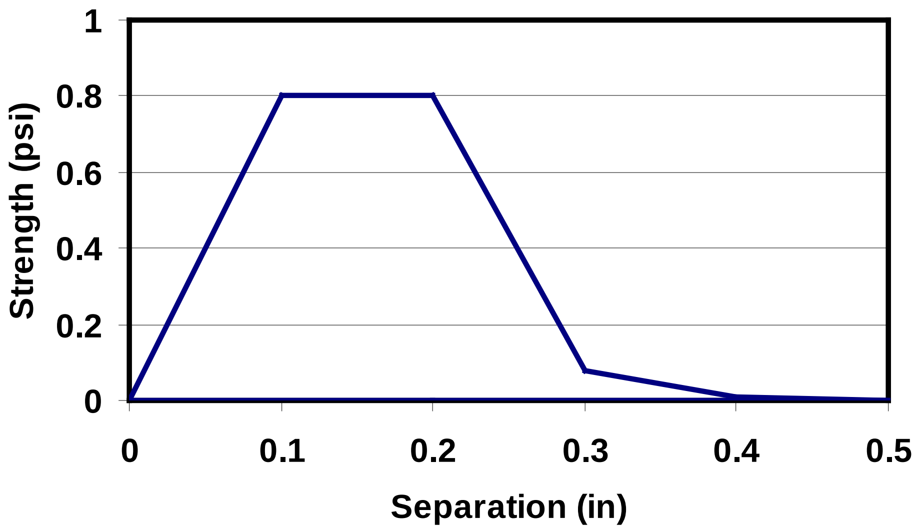


Figure D2. The Separation-Strength Curve Assumed for the Contact Cement

Loads were applied to the table by two rigid indenters, each 15 in wide with a 3-inch radius at either side. Each indenter was centered on one of the honeycomb blocks and constrained to move only in the longitudinal direction.

The nodes along the top and bottom rims of the mounting brackets were fixed. In addition, the groups of nodes on either side of the bolts connecting the I-beam assembly to the table and leg supports were constrained to move together using ABAQUS MPCs (multiple-point constraints).

D.1. Quasi-Static Analysis

For the pre-test simulation of the quasi-static test, a total of 7 in of rigid indenter motion was imposed at an effectively uniform rate of 50 in/sec (2.8 mph or 1.3 m/sec). Using ABAQUS/Explicit, quasi-static simulations require a significant amount of computation time because CPU time is proportional to simulated time. The imposed indenter velocity of 50 in/sec was selected so as to complete the analysis as quickly as possible while minimizing the effects of inertia on the outcome of the analysis.

A comparison of predicted load-crush characteristics with measured results was shown in Figure 7 of the main body of this report and is repeated here as Figure D3. As noted, the predicted crush strength is about 15 percent greater than that measured. In the model, the crush strength is primarily driven by the strength parameters used in the foam plasticity material model to describe the honeycomb crush strength. The initial model used a crush strength of 26.3 psi that hardened linearly to 36.8 psi at a strain level of 1. To adjust the model so that it better captured the measured crush behavior, the initial strength was increased to 23 psi and the strength at a strain level of 1 was increased to 30.6 psi. The model was rerun using these values and produced the agreement shown in Figure 8 of the main body of the report and in Figure D4.

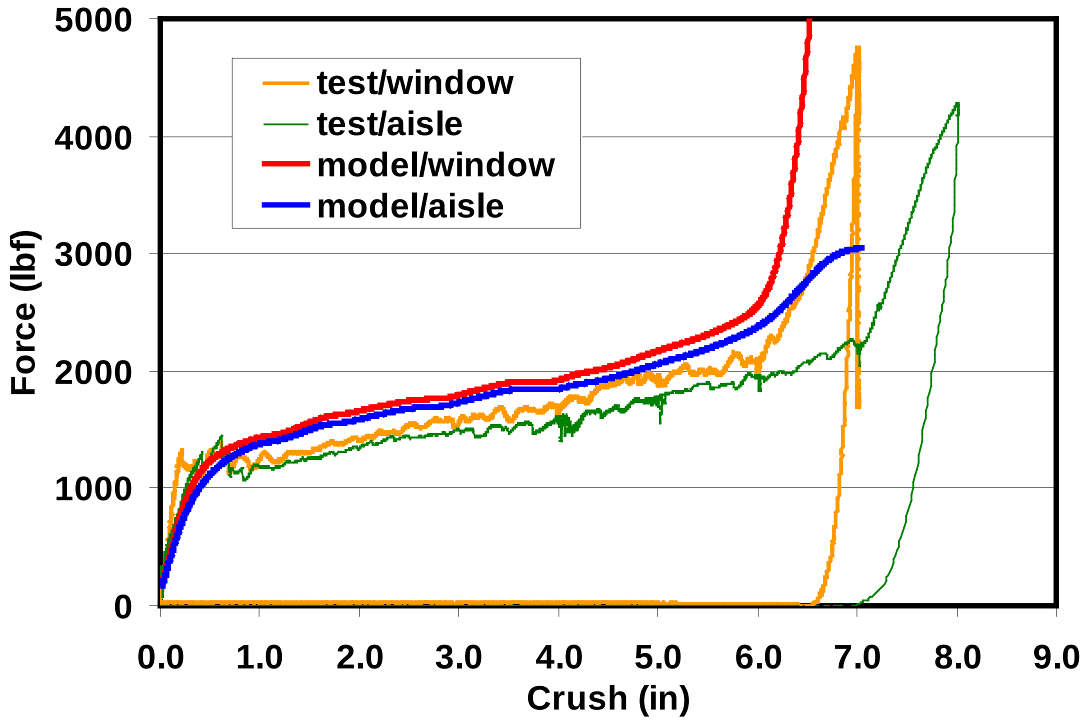


Figure D3. Comparison of Pre-Test Model Prediction of Load-Crush Response with Test Results

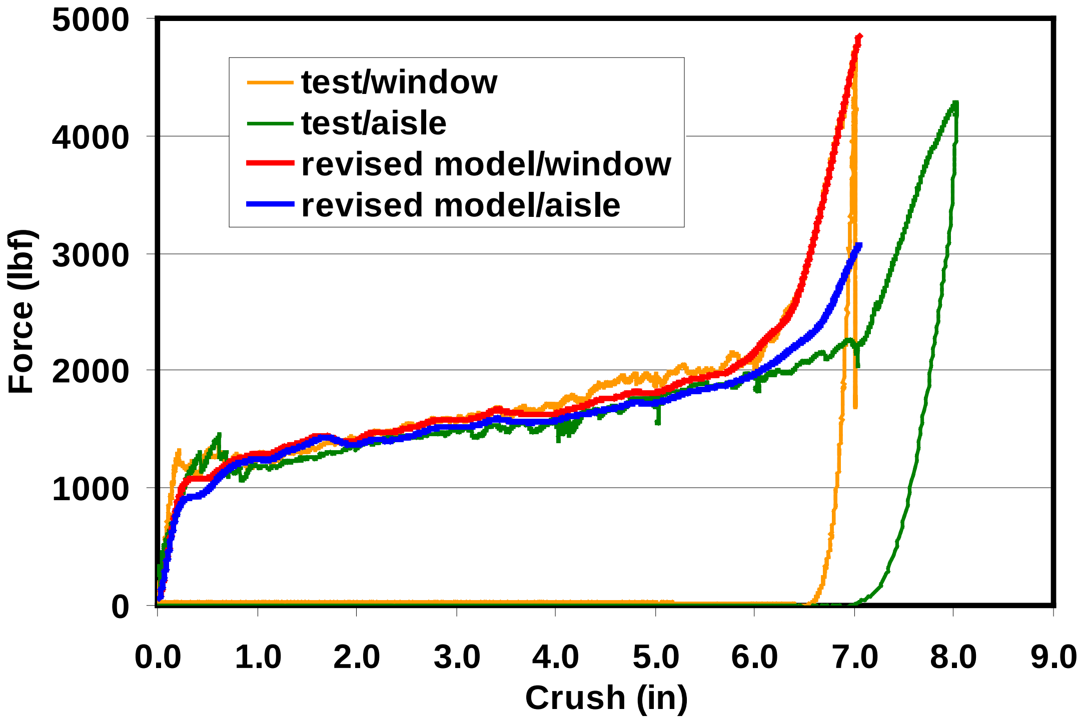


Figure D4. Comparison of Revised Model Prediction of Load-Crush Response with Test Results

Lateral reaction forces predicted by the revised model are compared with measured values in Figure D5. The agreement is good overall and shows that the longitudinal applied forces create a force couple at the two upper connections to carry the load. The force at the lower support is very small. Because the predicted longitudinal forces are essentially equal to the measured values over the 1–6-inch displacement range, the approximately10 percent over-prediction in lateral reaction forces is likely due to differences between the estimated and actual effective moment arm at the wall, i.e., half of the longitudinal distance between the upper load cells. Perhaps the forces do not act through the exact center of the bolts, as the model predicts.

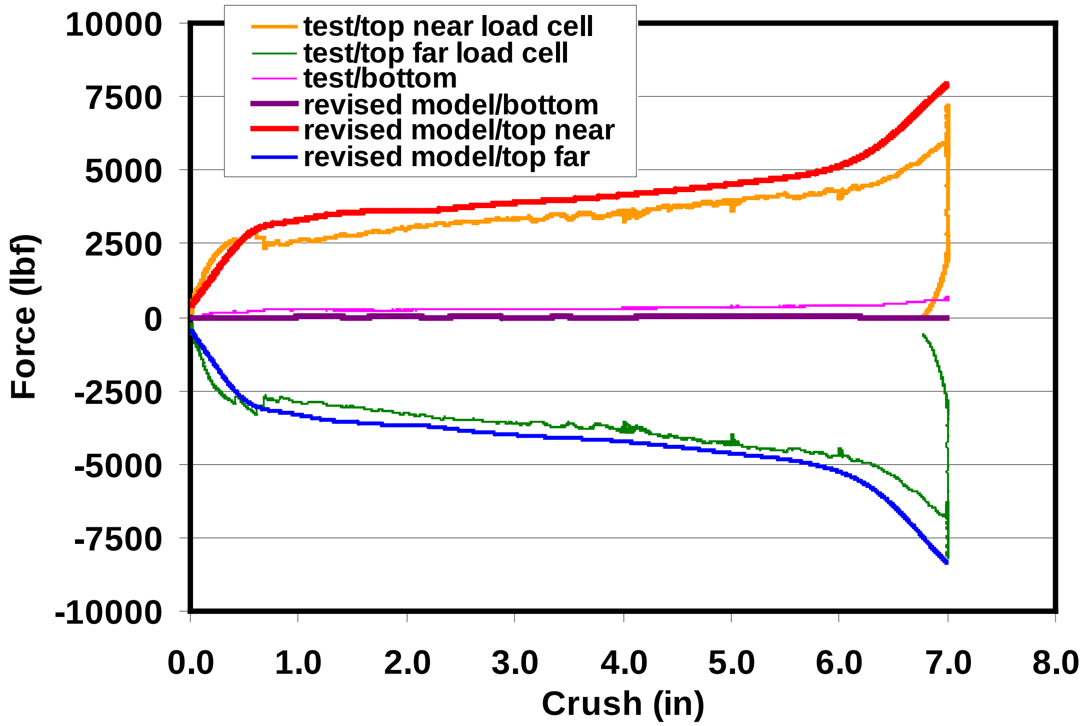


Figure D5. Comparison of Revised Model Prediction of Lateral Reaction Forces with Test Results

D.2. Dynamic Analysis

With the material model for the honeycomb modified to match the behavior observed in the quasi-static test, the model was used to simulate the two pendulum impact tests of the crashworthy workstation table. In each analysis, the impact was simulated by imparting an initial horizontal velocity on the two rigid bodies representing the impactors. The rigid impactors were free to rotate about a vertical axis. The rotational moment of inertia was defined as 100 lbm-in^2. (There was very little predicted rotation.) All other translational and rotational degrees of freedom were fixed. For the first test, the pendulum was assigned a weight of 170 lbm and an initial velocity of 12.2 mph, resulting in approximately 10,000 in-lbf of kinetic energy to represent the collision conditions from the full-scale CEM train-to-train test. For the second test, the weight was set at 75 lbm (to better represent the effective mass of a 50th percentile ATD) and the initial velocity was set at 14.1 mph, resulting in approximately 6,000 in-lbf of kinetic energy to represent the collision conditions associated with an 8 G, 250 ms triangular crash pulse. Note the third dynamic test, the test of the conventional workstation table, was not modeled.

D.1.1 Analysis of First Pendulum Test

The results of the simulation of the first pendulum test are summarized in Figures D6 through D10. Figure D6 through D8 show predicted and measured time histories of deceleration, velocity, and displacement. Clearly, the measured deceleration curve is much noisier than the predicted curve. As noted in the main body of this report, this is partly attributable to the excitation of elastic vibrational modes in the table structure that were not reproduced in the model because of the more idealized definition of the connection. The velocity and displacement results smooth out the effects of vibration and generally show excellent agreement between predicted and measured values. The reaction force data shown in Figures D9 and D10 also show excellent agreement between model and test and illustrate the very high lateral loads that arise at the connections to the wall.

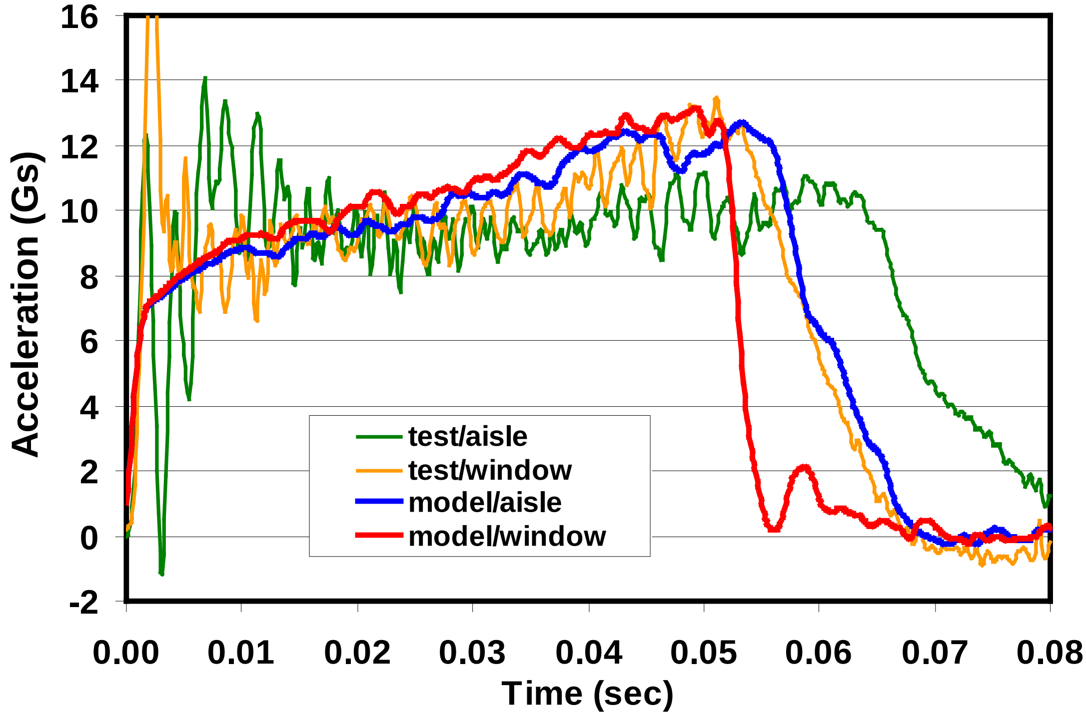


Figure D6. First Pendulum Test: Comparison of Measured and Predicted Impactor Mass Longitudinal Deceleration

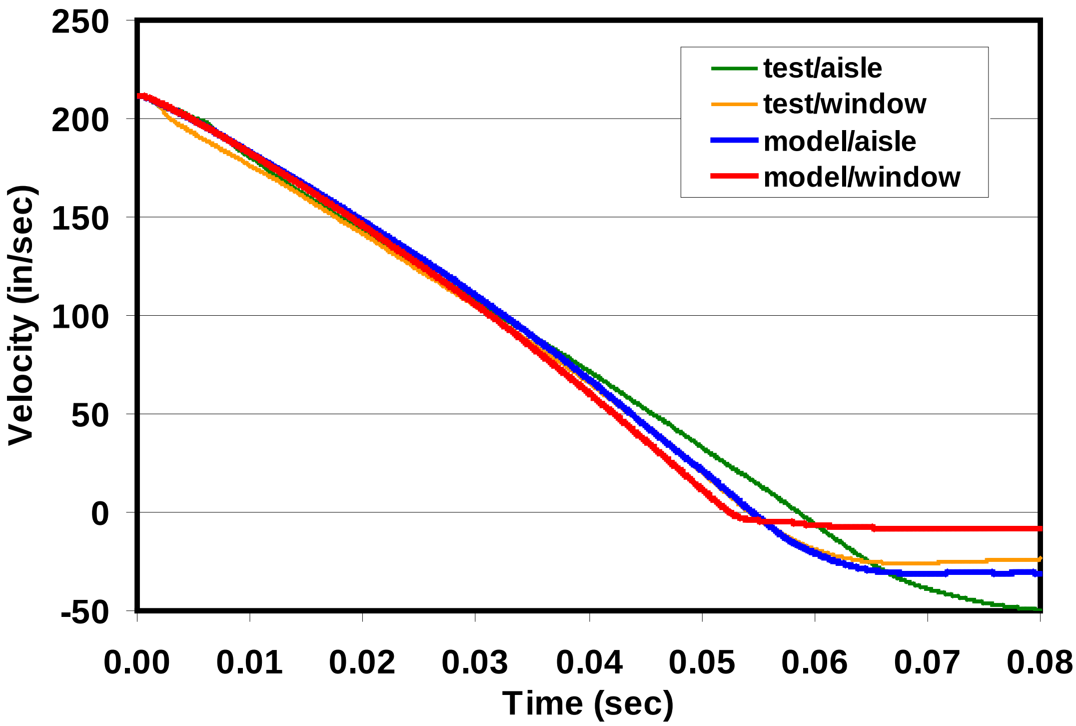


Figure D7. First Pendulum Test: Comparison of Measured and Predicted Impactor Mass Longitudinal Velocity

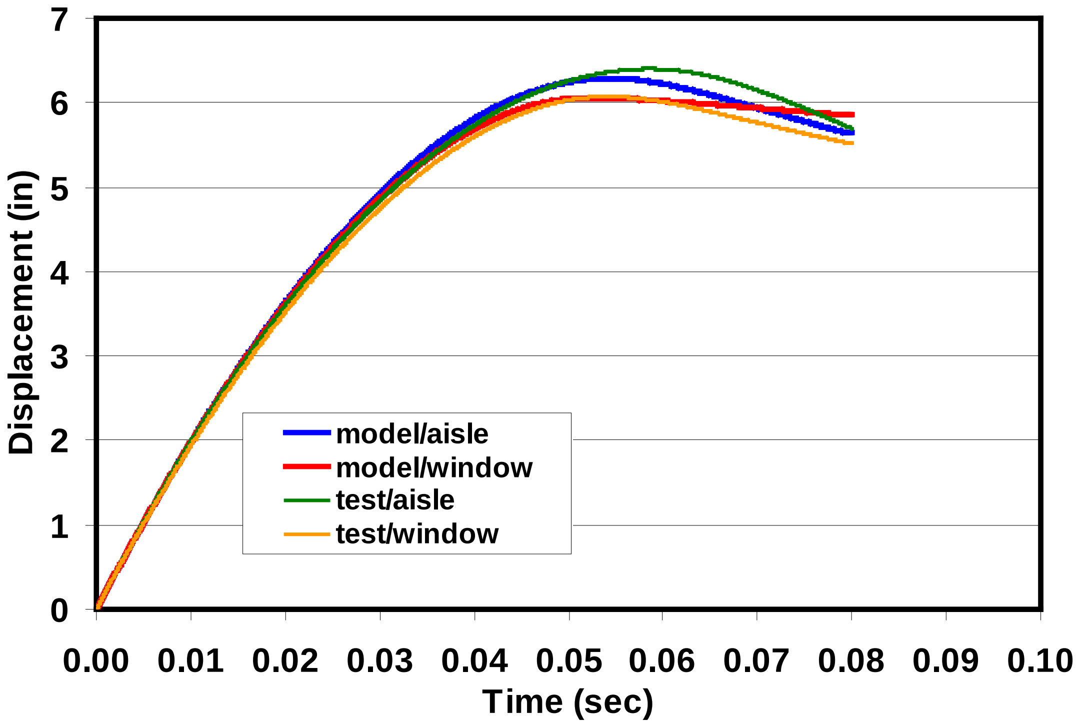


Figure D8. First Pendulum Test: Comparison of Measured and Predicted Impactor Mass Longitudinal Displacement

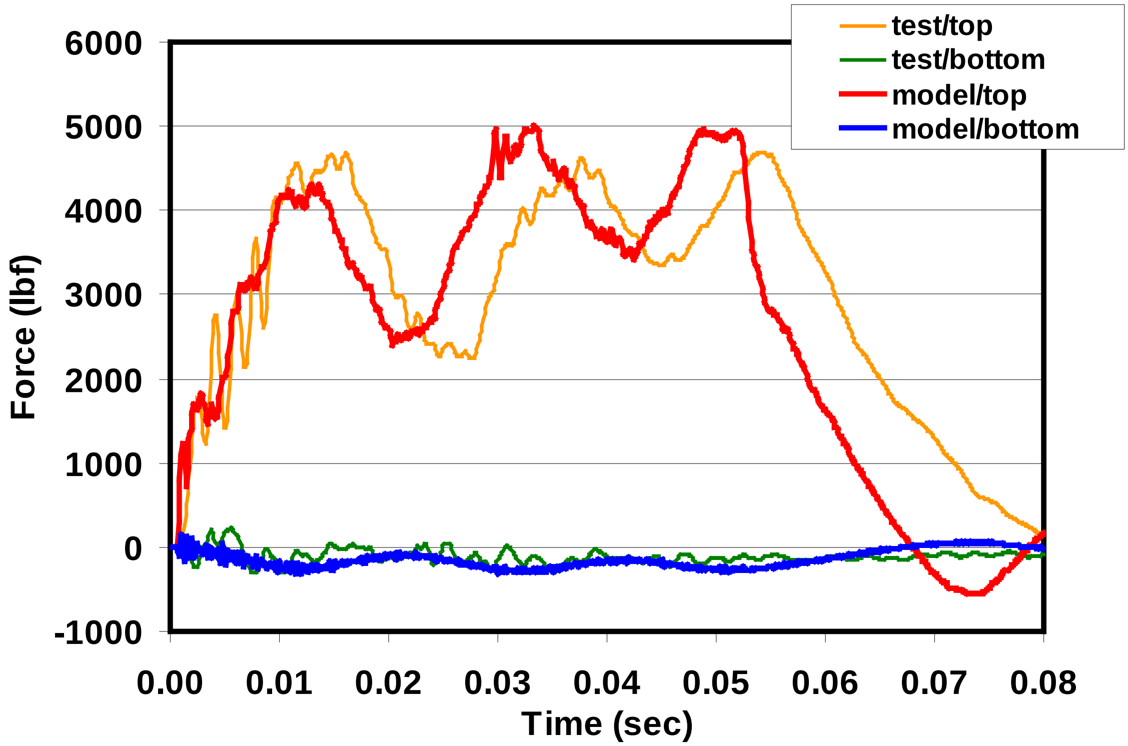


Figure D9. First Pendulum Test: Comparison of Measured and Predicted Longitudinal Reaction Forces

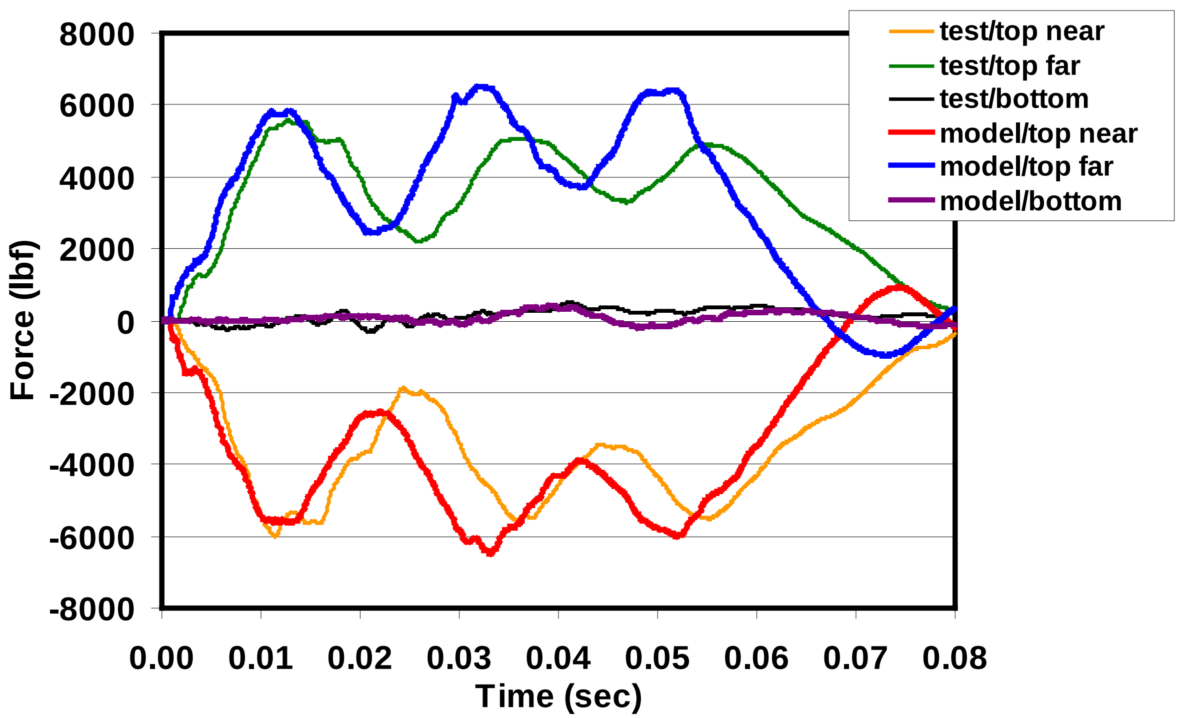


Figure D10. First Pendulum Test: Comparison of Measured and Predicted Lateral Reaction Forces

D.1.2 Analysis of Second Pendulum Test

The results of the simulation of the second pendulum test are summarized in Figures D11 through D15. Figure D11 through D13 show predicted and measured time histories of deceleration, velocity, and displacement. For the reasons noted in Section 4.2, the agreement is not as good for this test. First of all, the measured decelerations have much more high-frequency content than did the deceleration curve for the first test. But, as Figure D13 illustrates, even when the effects of the vibration are smoothed out, the agreement between the velocities is reasonably good only for the first 0.01 seconds. Once the window-side impactor hits the support, the measured window-side velocity decreases dramatically, which of course is not replicated in the model, and the level of agreement degrades rapidly. The reaction force data shown in Figures D14 and D15 also reflect the divergence in the curves that occurs due to this unexpected outcome.

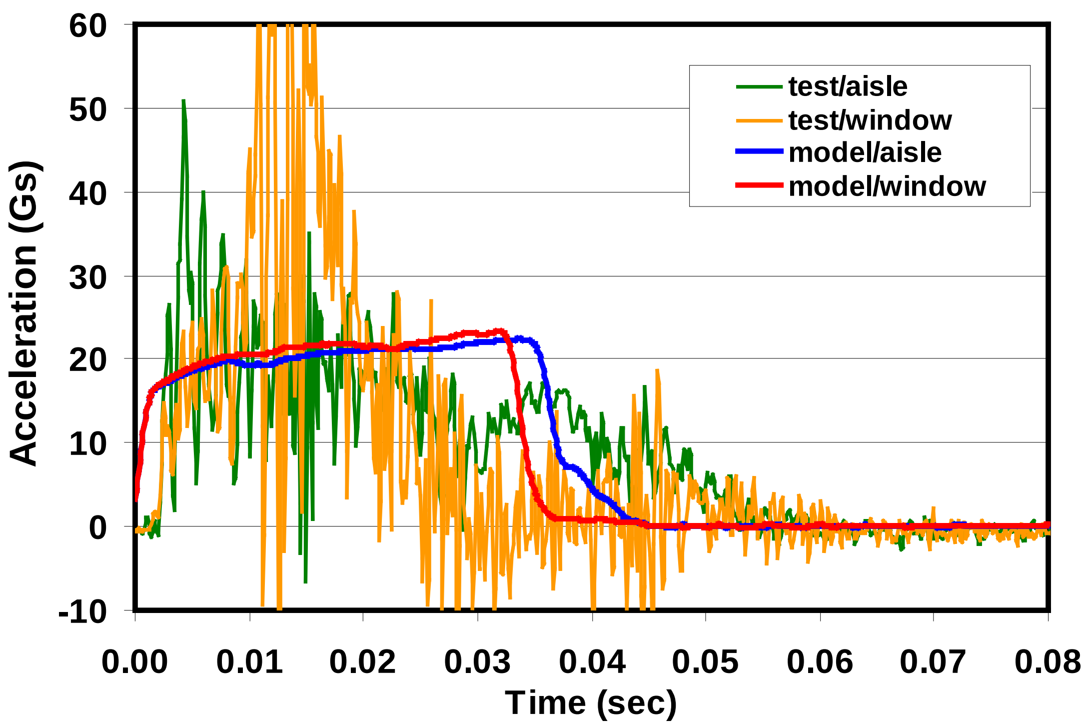


Figure D11. Second Pendulum Test: Comparison of Measured and Predicted Impactor Mass Longitudinal Deceleration

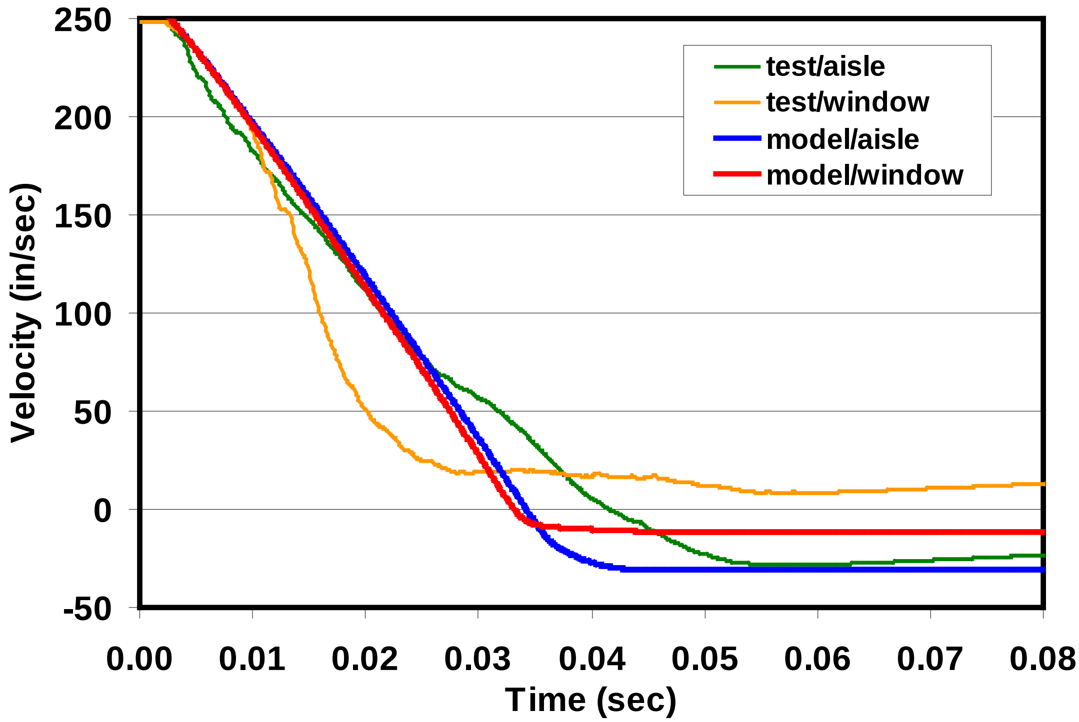


Figure D12. Second Pendulum Test: Comparison of Measured and Predicted Impactor Mass Longitudinal Velocity

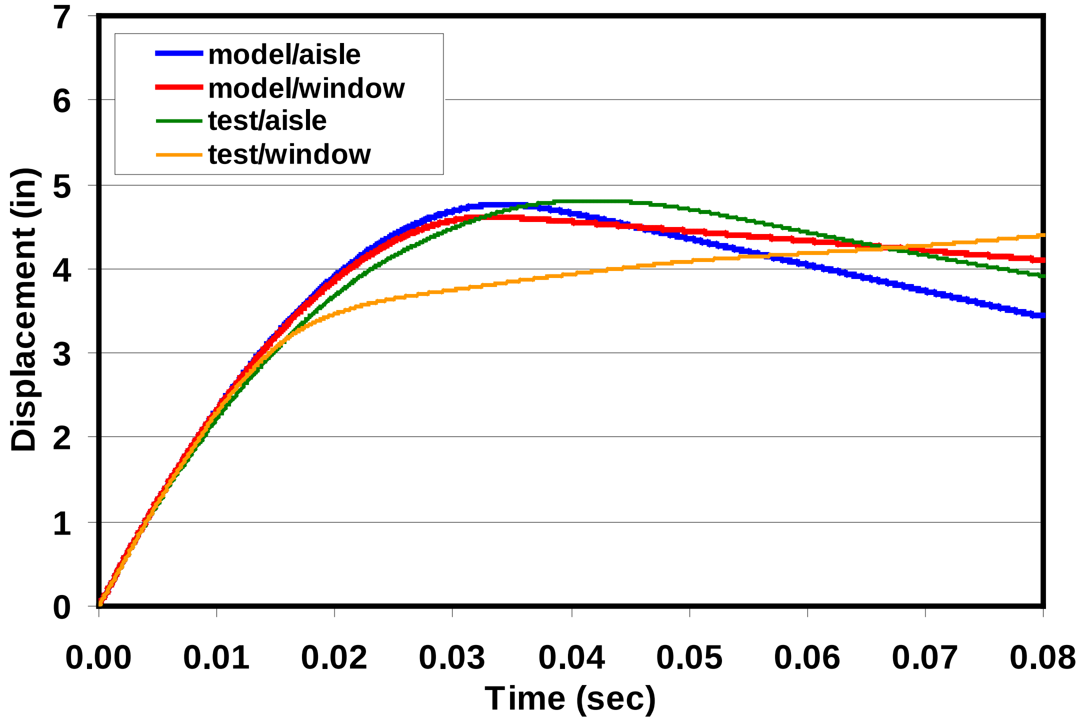


Figure D13. Second Pendulum Test: Comparison of Measured and Predicted Impactor Mass Longitudinal Displacement

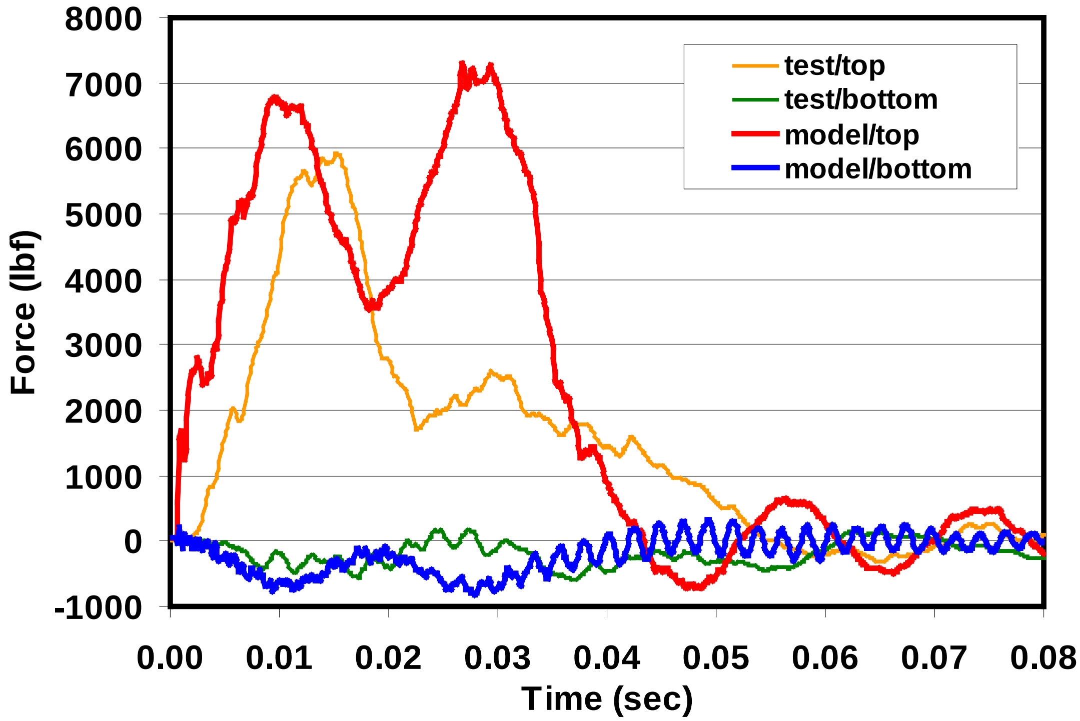


Figure D14. Second Pendulum Test: Comparison of Measured and Predicted Longitudinal Reaction Forces

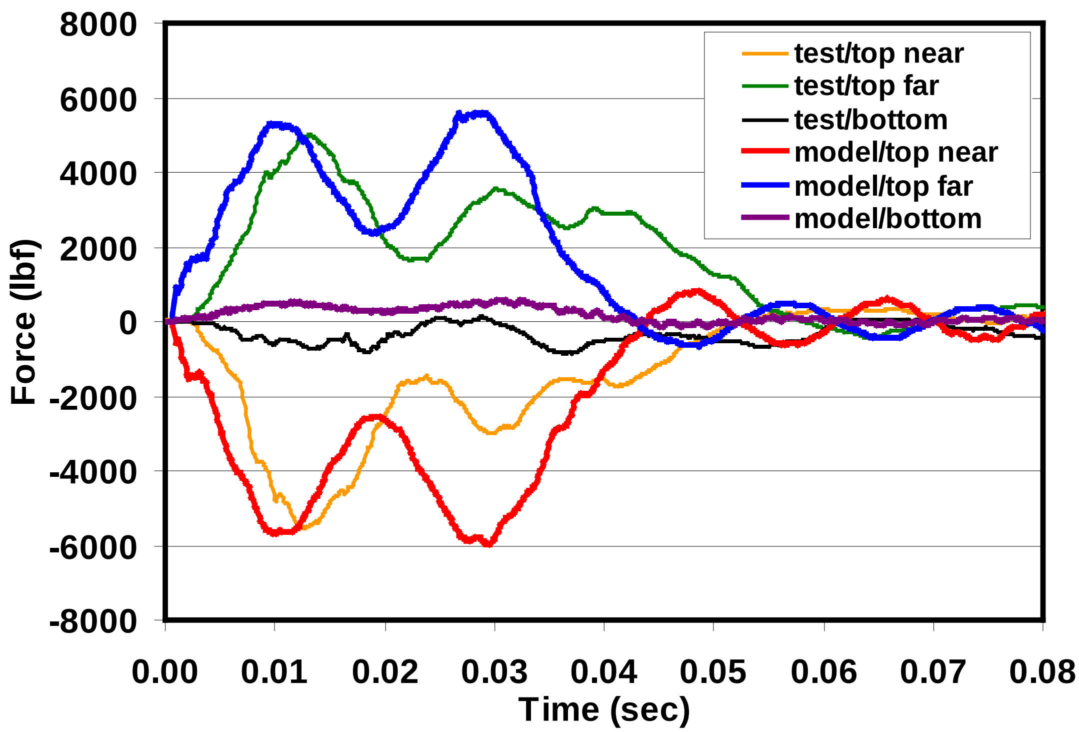


Figure D15. Second Pendulum Test: Comparison of Measured and Predicted Lateral Reaction Forces