



SURFACE VEHICLE INFORMATION REPORT

J2869™

AUG2016

Issued 2010-08
Reaffirmed 2016-08

Superseding J2869 AUG2010

Mechanical Systems Physics-of-Failure Analysis Experimental Validation

RATIONALE

J2869 has been reaffirmed to comply with the SAE five-year review policy.

FOREWORD

This SAE Vehicle Information Report describes, through example, a process to evaluate and reduce the experimental test data needed for a Mechanical Systems Physics-of-Failure analysis. In addition, the report describes the process used to validate the computer simulation models.

TABLE OF CONTENTS

1.	SCOPE.....	7
1.1	Purpose.....	7
1.2	Project Results	7
2.	REFERENCES.....	7
3.	BACKGROUND	7
3.1	Validation Methodology.....	8
3.2	Instrumentation and Transducers	9
3.2.1	Strain Gauge Setup.....	9
3.2.2	Accelerometer Setup	15
3.2.3	Angular Rate Gyro Setup.....	16
3.2.4	Linear Displacement Transducer Setup	16
3.2.5	Pressure Transducer Setup	16
3.3	Test Course Description	17
3.4	Test Matrix	17
3.5	Data Processing.....	18
3.5.1	Digital Filtering	18
3.5.2	Principal Strains	19
3.5.3	Decimation and Filtering	20
4.	DATA REDUCTION RESULTS	20
4.1	Speed Data	20
4.2	Test Course A	25
4.2.1	Strain Gauge Data	25
4.2.2	Accelerometer Data	32
4.2.3	Rate-gyro Data.....	43

SAE Technical Standards Board Rules provide that: "This report is published by SAE to advance the state of technical and engineering sciences. The use of this report is entirely voluntary, and its applicability and suitability for any particular use, including any patent infringement arising therefrom, is the sole responsibility of the user."

SAE reviews each technical report at least every five years at which time it may be revised, reaffirmed, stabilized, or cancelled. SAE invites your written comments and suggestions.

Copyright © 2016 SAE International

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the prior written permission of SAE.

TO PLACE A DOCUMENT ORDER: Tel: 877-606-7323 (inside USA and Canada)
Tel: +1 724-776-4970 (outside USA)
Fax: 724-776-0790
Email: CustomerService@sae.org
http://www.sae.org

SAE WEB ADDRESS:

Full document details: SAE J2869_201608

SAE values your input. To provide feedback on this Technical Report, please visit http://www.sae.org/technical/standards/J2869_201608

Documents

Document Sharing Hub

4.2.4	Linear Displacement Transducer Data	46
4.2.5	Pressure Transducer Data.....	50
4.3	Summary	54
5.	EXPERIMENTAL ANALYSIS OF SURGE BRAKE EFFECTS	54
5.1	Analysis Method	57
5.1.1	Regression Analysis	57
5.1.2	Regression with Operational Surge Brake.....	58
5.1.3	Regression with Disabled Surge Brake	59
5.1.4	Regression with Concatenated Data	59
5.1.5	Principal Component Analysis	61
5.1.6	Regression Using Principal Components	63
5.2	Experimental Analysis Conclusion.....	65
6.	DYNAMIC MODEL COMPARISON	65
6.1	Modifications to Dynamic Analysis Design System (DADS) Model.....	65
6.2	Test Course A Comparison.....	67
6.3	Test Course B Comparison.....	81
6.4	Conclusions.....	95
7.	STRAIN VALIDATION.....	96
7.1	Test Courses	96
7.2	Validation Process and Procedure	97
7.3	Data Sanity Check and Initial Reduction: Filter and Decimate Data	97
7.4	Strain Time History.....	99
7.5	Normality Check of Strain Data.....	103
7.6	Power Spectral Density (PSD) Comparison	110
7.7	Fatigue Crack Initiation Life	117
7.7.1	Fatigue Results: Test Course A at 15 mph.....	117
7.7.2	Fatigue Results: Test Course B at 20 mph.....	118
7.7.3	Fatigue Results: Test Course C at 10 mph.....	118
7.8	Prediction of Fatigue Crack Initiation Life and Factors That Affect Life.....	119
7.9	The Reasons That Cause the Fatigue Life Differences in Trailer Model.....	119
7.10	Comparison With Rigid Body Dynamic Model	126
7.11	Conclusion	140
8.	NOTES	141
8.1	Marginal Indicia	141
APPENDIX A	INSTRUMENTATION	142
APPENDIX B	MATLAB FILES.....	144
APPENDIX C	ADDITIONAL COURSE DATA	154
FIGURE 1	PHYSICS OF FAILURE PROCESS	8
FIGURE 2	LOCATION AND INSTALLATION OF THE STRAIN GAUGE ROSETTES	11
FIGURE 3	LOCATION AND INSTALLATION OF THE STRAIN GAUGE ROSETTES	11
FIGURE 4	THE LOCATION OF THE STRAIN ROSETTES ON THE FINITE ELEMENT MODEL	12
FIGURE 5	LOCATION OF FOUR OF THE STRAIN ROSETTES ON THE BOTTOM-SIDE OF THE DRAWBAR.....	13
FIGURE 6	LOCATION OF THE STRAIN ROSETTES (ENLARGEMENT).....	13
FIGURE 7	DETAILED LOCATION OF THE STRAIN ROSETTES ON UPPER AND LOWER TRIANGLE PLATES	14
FIGURE 8	DETAILED LOCATION OF THE STRAIN ROSETTES ON LEFT-SIDE ANGLE PLATES.....	14
FIGURE 9	TRIAXIAL ACCELEROMETERS AND RATE GYROS NEAR TRAILER CENTER OF GRAVITY (CG) LOCATION	15
FIGURE 10	TRIAXIAL ACCELEROMETERS AT TOP CORNERS OF TRAILER CARGO BOX.....	16
FIGURE 11	HYDRAULIC SURGE BRAKE SYSTEM LAYOUT.....	17
FIGURE 12	PSD OF SIMULATION AND EXPERIMENTAL CG ACCELERATION	19
FIGURE 13	MINIMUM, AVERAGE AND MAXIMUM TEST RUN SPEEDS	21
FIGURE 14	DIFFERENCE BETWEEN AVERAGE AND NOMINAL SPEEDS.....	23

FIGURE 15	PERCENT SPEED DIFFERENCE (EXPERIMENTAL VS. NOMINAL DATA)	23
FIGURE 16	STANDARD DEVIATION (EXPERIMENTAL VS NOMINAL SPEEDS)	24
FIGURE 17	DIFFERENCE BETWEEN RMS AND NOMINAL SPEEDS	24
FIGURE 18	AVERAGE PRINCIPAL STRAINS (TEST COURSE A, 15 MPH)	27
FIGURE 19	PRINCIPAL STRAIN STANDARD DEVIATIONS (TEST COURSE A, 15 MPH)	28
FIGURE 20	RMS VALUES OF PRINCIPAL STRAINS	29
FIGURE 21	DISTRIBUTION OF FIRST (1 ST) PRINCIPAL STRAINS	30
FIGURE 22	DISTRIBUTION OF SECOND (2 ND) PRINCIPAL STRAINS	31
FIGURE 23	AVERAGE VERTICAL ACCELERATIONS FOR SEVERAL TRAILER LOCATIONS	35
FIGURE 24	AVERAGE TRANSVERSE ACCELERATIONS FOR SEVERAL TRAILER LOCATIONS	35
FIGURE 25	AVERAGE LONGITUDINAL ACCELERATIONS FOR SEVERAL TRAILER LOCATIONS	36
FIGURE 26	VERTICAL ACCELERATION STANDARD DEVIATION FOR SEVERAL TRAILER LOCATIONS	36
FIGURE 27	TRANSVERSE ACCELERATION STANDARD DEVIATION FOR SEVERAL TRAILER LOCATIONS	37
FIGURE 28	LONGITUDINAL ACCELERATION STANDARD DEVIATION FOR SEVERAL TRAILER LOCATIONS	37
FIGURE 29	VERTICAL RMS ACCELERATIONS FOR SEVERAL TRAILER LOCATIONS	38
FIGURE 30	TRANSVERSE RMS ACCELERATIONS FOR SEVERAL TRAILER LOCATIONS	38
FIGURE 31	LONGITUDINAL RMS ACCELERATIONS FOR SEVERAL TRAILER LOCATIONS	39
FIGURE 32	VERTICAL ACCELERATION STATISTICS FOR SEVERAL TRAILER LOCATIONS	40
FIGURE 33	TRANSVERSE ACCELERATION STATISTICS FOR SEVERAL TRAILER LOCATIONS	41
FIGURE 34	LONGITUDINAL ACCELERATION STATISTICS FOR SEVERAL TRAILER LOCATIONS	42
FIGURE 35	AVERAGE RATE-GYRO ANGULAR RATES	43
FIGURE 36	RATE-GYRO ANGULAR RATE STANDARD DEVIATIONS	44
FIGURE 37	RATE GYRO RMS ANGULAR RATES	44
FIGURE 38	RATE-GYRO ANGULAR RATE DISTRIBUTIONS	45
FIGURE 39	TRAILER SUSPENSION	46
FIGURE 40	LINEAR DISPLACEMENT AVERAGE VALUE (INCHES)	47
FIGURE 41	LINEAR DISPLACEMENT STANDARD DEVIATION (INCHES)	47
FIGURE 42	LINEAR DISPLACEMENT RMS VALUE (INCHES)	48
FIGURE 43	LINEAR DISPLACEMENT DISTRIBUTIONS (INCHES)	49
FIGURE 44	AVERAGE BRAKE PRESSURE VALUES (PSI)	51
FIGURE 45	BRAKE PRESSURE STANDARD DEVIATION (PSI)	51
FIGURE 46	BRAKE PRESSURE RMS VALUES (PSI)	52
FIGURE 47	BRAKE PRESSURE VALUE DISTRIBUTIONS (PSI)	53
FIGURE 48	SURGE BRAKE PRESSURES FOR TEST COURSE B	56
FIGURE 49	PERCENT OF DATA EXPLAINED BY EACH PRINCIPAL COMPONENT (BRAKES ENABLED)	62
FIGURE 50	AVERAGE STRAIN PREDICTION ERROR	64
FIGURE 51	CORRELATION COEFFICIENTS	64
FIGURE 52	MODIFIED DADS MODEL WITH POINTS OF INTEREST	66
FIGURE 53	TEST COURSE A CG LONGITUDINAL ACCELERATION PSD COMPARISON	67
FIGURE 54	TEST COURSE A CG TRANSVERSE ACCELERATION PSD COMPARISON	68
FIGURE 55	TEST COURSE A CG VERTICAL ACCELERATION PSD COMPARISON	68
FIGURE 56	TEST COURSE A CG ACCELERATION STATISTICAL DISTRIBUTIONS	69
FIGURE 57	TEST COURSE A TRAILER ROLL RATE PSD COMPARISON	70
FIGURE 58	TRAILER PITCH RATE PSD COMPARISON	70
FIGURE 59	TEST COURSE A TRAILER YAW RATE PSD COMPARISON	71
FIGURE 60	TEST COURSE A TEST COURSE A ANGULAR RATE DISTRIBUTIONS	72
FIGURE 61	TEST COURSE A TRAILER CORNER LONGITUDINAL ACCELERATION PSD COMPARISON	73
FIGURE 62	TEST COURSE A TRAILER CORNER LONGITUDINAL ACCELERATION DISTRIBUTIONS	74
FIGURE 63	TEST COURSE A TRAILER CORNER TRANSVERSE ACCELERATION PSD COMPARISON	75
FIGURE 64	TEST COURSE ATRAILER CORNER TRANSVERSE ACCELERATION DISTRIBUTIONS	76
FIGURE 65	TEST COURSE A TRAILER CORNER VERTICAL ACCELERATION PSD COMPARISON	77
FIGURE 66	TEST COURSE A TRAILER CORNER VERTICAL ACCELERATION DISTRIBUTIONS	78
FIGURE 67	TEST COURSE A DRAWBAR ACCELERATIONS	79

FIGURE 68	TEST COURSE A DRAWBAR ACCELERATION DISTRIBUTIONS	80
FIGURE 69	TEST COURSE B CG LONGITUDINAL ACCELERATION PSD COMPARISON	81
FIGURE 70	TEST COURSE B CG TRANSVERSE ACCELERATION PSD COMPARISON.....	82
FIGURE 71	TEST COURSE B CG VERTICAL ACCELERATION PSD COMPARISON	82
FIGURE 72	TEST COURSE B CG ACCELERATION STATISTICAL DISTRIBUTIONS	83
FIGURE 73	TEST COURSE B TRAILER ROLL RATE PSD COMPARISON	84
FIGURE 74	TEST COURSE B TRAILER PITCH RATE PSD COMPARISON	84
FIGURE 75	TEST COURSE B TRAILER YAW RATE PSD COMPARISON.....	85
FIGURE 76	TEST COURSE B ANGULAR RATE DISTRIBUTIONS	86
FIGURE 77	TEST COURSE B TRAILER CORNER LONGITUDINAL ACCELERATION PSD COMPARISON.....	87
FIGURE 78	TEST COURSE B TRAILER CORNER LONGITUDINAL ACCELERATION DISTRIBUTIONS	88
FIGURE 79	TEST COURSE B TRAILER CORNER TRANSVERSE ACCELERATION PSD COMPARISON.....	89
FIGURE 80	TEST COURSE B TRAILER CORNER TRANSVERSE ACCELERATION DISTRIBUTIONS	90
FIGURE 81	TEST COURSE B TRAILER CORNER VERTICAL ACCELERATION PSD COMPARISON.....	91
FIGURE 82	TEST COURSE B TRAILER CORNER VERTICAL ACCELERATION DISTRIBUTIONS	92
FIGURE 83	TEST COURSE B TRAILER DRAWBAR ACCELERATION PSD COMPARISON.....	93
FIGURE 84	TEST COURSE B DRAWBAR ACCELERATION DISTRIBUTIONS	94
FIGURE 85	TEST MASS USED FOR TRAILER EXPERIMENTAL TESTS	96
FIGURE 86	EVALUATION PROCEDURE	98
FIGURE 87	MEAN VALUE COMPARISON OF PRINCIPAL STRAIN 1.....	99
FIGURE 88	RMS VALUE COMPARISON OF PRINCIPAL STRAIN 1	100
FIGURE 89	SKEWNESS COMPARISON OF PRINCIPAL STRAIN 1.....	100
FIGURE 90	KURTOSIS COMPARISON OF PRINCIPAL STRAIN 1.....	101
FIGURE 91	MEAN VALUE COMPARISON OF PRINCIPAL STRAIN 2.....	101
FIGURE 92	RMS VALUE COMPARISON OF PRINCIPAL STRAIN 2	102
FIGURE 93	SKEWNESS COMPARISON OF PRINCIPAL STRAIN 2.....	102
FIGURE 94	KURTOSIS COMPARISON OF PRINCIPAL STRAIN 2.....	103
FIGURE 95	TEST COURSE A HISTOGRAM FOR BOTH SIMULATION AND EXPERIMENT OF NODE 424	104
FIGURE 96	TEST COURSE A HISTOGRAM FOR BOTH SIMULATION AND EXPERIMENT OF NODE 425	105
FIGURE 97	TEST COURSE B HISTOGRAM FOR BOTH SIMULATION AND EXPERIMENT OF NODE 424	106
FIGURE 98	TEST COURSE B HISTOGRAM FOR BOTH SIMULATION AND EXPERIMENT OF NODE 425	107
FIGURE 99	TEST COURSE C HISTOGRAM FOR BOTH SIMULATION AND EXPERIMENT OF NODE 424	108
FIGURE 100	TEST COURSE C HISTOGRAM FOR BOTH SIMULATION AND EXPERIMENT OF NODE 425	109
FIGURE 101	TEST COURSE A PSD CURVES OF SIMULATION AND EXPERIMENT STRAIN DATA OF NODE 424.....	111
FIGURE 102	TEST COURSE A PSD CURVES OF SIMULATION AND EXPERIMENT STRAIN DATA OF NODE 425.....	112
FIGURE 103	TEST COURSE B PSD CURVES OF SIMULATION & EXPERIMENT STRAIN DATA OF NODE 424.....	113
FIGURE 104	TEST COURSE B PSD CURVES OF SIMULATION AND EXPERIMENT STRAIN DATA OF NODE 425.....	114
FIGURE 105	TEST COURSE C PSD CURVES OF SIMULATION AND EXPERIMENT STRAIN DATA OF NODE 424.....	115
FIGURE 106	TEST COURSE C PSD CURVES OF SIMULATION AND EXPERIMENT STRAIN DATA OF NODE 425.....	116
FIGURE 107	COMPARISON OF LIVES BETWEEN SIMULATION AND EXPERIMENT FOR TEST COURSE A AT 15 MPH.....	117
FIGURE 108	COMPARISON OF LIVES BETWEEN SIMULATION AND EXPERIMENT FOR	TEST
FIGURE 109	COMPARISON OF LIVES BETWEEN SIMULATION AND EXPERIMENT FOR TEST COURSE B AT 20 MPH.....	118
FIGURE 110	COMPARISON OF LIVES BETWEEN SIMULATION AND EXPERIMENT FOR TEST COURSE C AT 10 MPH	118
FIGURE 111	LIFE COMPARISON BETWEEN FILTERED SIMULATION STRAIN AND EXPERIMENTAL STRAIN	120
FIGURE 112	ONE OF THE JOINT REACTION FORCES AND FLEXIBLE MOTION INERTIA FORCES HISTORY	121
FIGURE 113	PARTIAL ENLARGEMENT (16 TO 22 INCHES)	121
FIGURE 114	INERTIA FORCE HISTORY INDUCED BY RIGID GROSS MOTION	123
FIGURE 115	JOINT REACTION FORCE HISTORY OF FOUR PAYLOAD JOINTS.....	123
	PARTIAL ENLARGEMENT (16 TO 22 INCHES)	124

FIGURE 116	JOINT REACTION FORCE HISTORY OF FRONT-LEFT PAYLOAD JOINTS.....	124
FIGURE 117	PARTIAL ENLARGEMENT (16 TO 22 INCHES)	125
FIGURE 118	MEAN VALUE COMPARISON OF STRAIN FOR TEST COURSE A	126
FIGURE 119	RMS COMPARISON OF STRAIN FOR TEST COURSE A	126
FIGURE 120	SKEWNESS COMPARISON OF STRAIN FOR TEST COURSE A.....	127
FIGURE 121	KURTOSIS COMPARISON OF STRAIN FOR TEST COURSE A.....	127
FIGURE 122	COMPARISON OF FLEX., RIGID, AND EXPERIMENT MEAN FOR NODES 424 AND 425	128
FIGURE 123	COMPARISON OF FLEX., RIGID, AND EXPERIMENT RMS FOR NODES 424 AND 425.....	128
FIGURE 124	COMPARISON OF FLEX., RIGID, AND EXPERIMENT SKEWNESS FOR NODES 424 AND 425	129
FIGURE 125	COMPARISON OF FLEX., RIGID, AND EXPERIMENT KURTOSIS FOR NODES 424 AND 425	129
FIGURE 126	THE HISTOGRAM FOR BOTH RIGID AND FLEXIBLE BODY SIMULATION AND EXPERIMENT OF NODE 424.....	131
FIGURE 127	HISTOGRAM FOR BOTH RIGID AND FLEXIBLE BODY SIMULATION AND EXPERIMENT OF NODE 425.....	132
FIGURE 128	HISTOGRAM FOR BOTH RIGID AND FLEXIBLE BODY SIMULATION AND EXPERIMENT OF NODE 424.....	133
FIGURE 129	HISTOGRAM FOR BOTH RIGID AND FLEXIBLE BODY SIMULATION AND EXPERIMENT OF NODE 425.....	134
FIGURE 130	NODE 425 PSD COMPARISON BETWEEN RIGID, FLEX., AND EXPERIMENT FOR TEST COURSE A	135
FIGURE 131	NODE 424 PSD COMPARISON BETWEEN RIGID, FLEX., AND EXPERIMENT FOR TEST COURSE A	136
FIGURE 132	NODE 425 PSD COMPARISON BETWEEN RIGID, FLEXIBLE, AND EXPERIMENT FOR TEST COURSE B	137
FIGURE 133	NODE 424 PSD COMPARISON BETWEEN RIGID, FLEX., AND EXPERIMENT FOR TEST COURSE B	138
FIGURE 134	LIFE COMPARISON OF FLEXIBLE, RIGID SIMULATION AND EXPERIMENT FOR TEST COURSE A	139
FIGURE 135	LIFE COMPARISON OF FLEXIBLE, RIGID SIMULATION AND EXPERIMENT FOR TEST COURSE B	140
TABLE 1	POF EXPERIMENTAL DATA FILE FORMAT	10
TABLE 2	ANALOG LOW-PASS ANTI-ALIASING CUTOFF FREQUENCIES.....	10
TABLE 3	DISTANCE BETWEEN STRAIN GAUGE LOCATION AND CORRESPONDING FE NODE LOCATION	12
TABLE 4	TEST MATRIX DATA FILE NAMES	18
TABLE 5	SPEED DATA STATISTICS FOR EXPERIMENTAL TEST RUNS IN MPH.....	22
TABLE 6	PRINCIPAL STRAIN AMPLITUDE DISTRIBUTION DATA (BRAKES DISABLED).....	25
TABLE 7	PRINCIPAL STRAIN AMPLITUDE DISTRIBUTION DATA (BRAKES ENABLED).....	26
TABLE 8	ACCELERATION AMPLITUDE DISTRIBUTION DATA (BRAKES DISABLED) IN G'S	33
TABLE 9	ACCELERATION AMPLITUDE DISTRIBUTION DATA (BRAKES ENABLED) IN G'S	34
TABLE 10	RATE-GYRO DISTRIBUTION DATA (BRAKES DISABLED) IN DEGREE/SECOND	43
TABLE 11	RATE-GYRO DISTRIBUTION DATA (BRAKES ENABLED) IN DEGREE/SECOND	43
TABLE 12	LINEAR DISPLACEMENT DISTRIBUTION DATA (BRAKES DISABLED) IN INCHES	46
TABLE 13	LINEAR DISPLACEMENT DISTRIBUTION DATA (BRAKES ENABLED) IN INCHES	46
TABLE 14	BRAKE PRESSURE DISTRIBUTION DATA (BRAKES DISABLED) IN PSI	50
TABLE 15	BRAKE PRESSURE DISTRIBUTION DATA (BRAKES ENABLED) IN PSI	50
TABLE 16	LISTING OF DATA ACQUISITION CHANNELS AND GROUPING.....	55
TABLE 17	STATISTICS FOR BRAKE SYSTEM VARIABLE (BRAKES ENABLED).....	56
TABLE 18	CORRELATION COEFFICIENT FOR TEST COURSE B BRAKE PRESSURES	56
TABLE 19	STATISTICS FOR BRAKE SYSTEM VARIABLES (BRAKES DISABLED)	56
TABLE 20	R^2 VALUES FOR STRAIN PREDICTION (BRAKES NORMALLY OPERATIONAL).....	59
TABLE 21	R^2 VALUES FOR STRAIN PREDICTION (SURGE BRAKE SYSTEM DISABLED).....	59
TABLE 22	R^2 VALUES FOR STRAIN PREDICTION (SURGE BRAKE SYSTEM DISABLED, BRAKE VARIABLES INCLUDED)	60
TABLE 23	R^2 VALUES FOR STRAIN PREDICTION (SURGE BRAKE SYSTEM DISABLED, BRAKE VARIABLES ELIMINATED)	60
TABLE 24	PRINCIPAL COMPONENT VALUES FOR THE MEASURED BRAKE SYSTEM PRESSURE.....	61
TABLE 25	INPUT MEASUREMENT CONTRIBUTION TO PRINCIPAL COMPONENTS 2, 3, AND 33.....	63

TABLE 26	ACCELEROMETER LOCATION IN DADS MODEL.....	66
TABLE 27	LIFE COMPARISON BETWEEN FLEX SIMULATION AND EXPERIMENT FOR TEST COURSE A AT 15 MPH.....	117
TABLE 28	LIFE COMPARISON BETWEEN FLEX SIMULATION TABLE AND EXPERIMENT FOR TEST COURSE B AT 20 MPH	118
TABLE 29	LIFE COMPARISON BETWEEN FLEX SIMULATION AND EXPERIMENT FOR TEST COURSE C AT 10 MPH	118
TABLE 30	LIFE COMPARISON BETWEEN SIMULATION (AFTER FILTERING) AND EXPERIMENT	120
TABLE 31	FATIGUE LIFE COMPARISON FOR TEST COURSE A	139
TABLE 32	FATIGUE LIFE COMPARISON FOR TEST COURSE B	140

1. SCOPE

This report details continuing work examining the fatigue life durability of a US Army Trailer. This report describes, through example, a process to evaluate and reduce the experimental data needed for a Mechanical Systems Physics-of-Failure analysis. In addition the report describes the process used to validate the computer simulation models.

1.1 Purpose

Evaluate and reduce the experimental data obtained during testing of an instrumented trailer.

1.2 Project Results

The results of the project can be split into three areas; experimental data evaluation, dynamic model comparison, and fatigue life validation.

In the experimental data evaluation, it was hypothesized that the hydraulic surge brakes contributed to the fatigue-related failures of the trailer drawbar. Using principal component statistical analysis, it is shown that the surge brakes have little effect on the fatigue damage. Additionally, the principal component analysis reveals that the vertical accelerations and the yaw rate of the trailer were the primary contributors to the strain, which was measured close to the point of failure.

The multi-body dynamic simulation model was compared to measured accelerations and angular rates. The longitudinal and vertical accelerations were the best matches, using both Power Spectral Density (PSD) and statistical distribution comparisons. The worst comparison data was the transverse acceleration and yaw rate. Reasons for the poor matches for these signal components are both the tire model, which does not generate lateral forces based on terrain geometry, and the profilometry data used in the simulations, since it represents only the terrain elevation along the longitudinal path of the vehicle and not the spatial geometry of the terrain under the tire contact patch.

Finally, the fatigue life predictions were calculated using both rigid- and flexible-body simulations and experimental results. The fatigue life predictions show that using a CAE procedure for durability analysis is feasible provided that care is taken in the development of the CAD and dynamics models. The flexible body is necessary for obtaining accurate life predictions, however, using the flexible body simulation requires careful selection of the static correction mode shapes. High frequency modes should not be included since the trailer frame is a low frequency structure.

2. REFERENCES

1. Hurty, W.C. "Dynamic Analysis of Structural Systems Using Component Modes," AIAA Journal, Vol. 3, No. 4, 1965.
2. Craig, R.R. and C.C. Bampton, "Coupling of Substructures for Dynamic Analysis," AIAA Journal, Vol. 6, No. 7, 1968.
3. Meirovitch, L. Principles and Techniques of Vibrations, Prentice Hall, 1997.
4. DRAW Concept Manual, Center for Computer-Aided Design, The University of Iowa, 1999.
5. Murphy, N.R. Jr. "A Method for Determining Terrain Surface Roughness," U.S. Army Engineer Waterways Experiment Station, Geotechnical Laboratory, Vicksburg, MS, September 1984.

3. BACKGROUND

The US Army trailer evaluated in this continuing study was instrumented and tested at Aberdeen Test Center (ATC) during the months of June and July, 2001. The objective of this test was to validate the Physics-of-Failure (PoF) simulation results, including the dynamic response and the critical point strain and fatigue life. Therefore, the comparison of the simulation results with the measured results (time domain data) from the Army Trailer is carried out to determine whether the process of simulation is acceptable, find factors that may affect the simulation results, determine whether the flexible body is required for this analysis, and examine the rivet hole sensitivities.

The PoF process used to identify the fatigue life of the trailer is shown in Figure 1. The process began with the development of a Computer Aided Design (CAD) model of the trailer using Pro/Engineer software. From the CAD model, both a rigid-body multi-body dynamic model and a finite element model were developed using DADS and NASTRAN, respectively. These models were validated in a previous report, using both physical measurements and modal (vibration) test results.

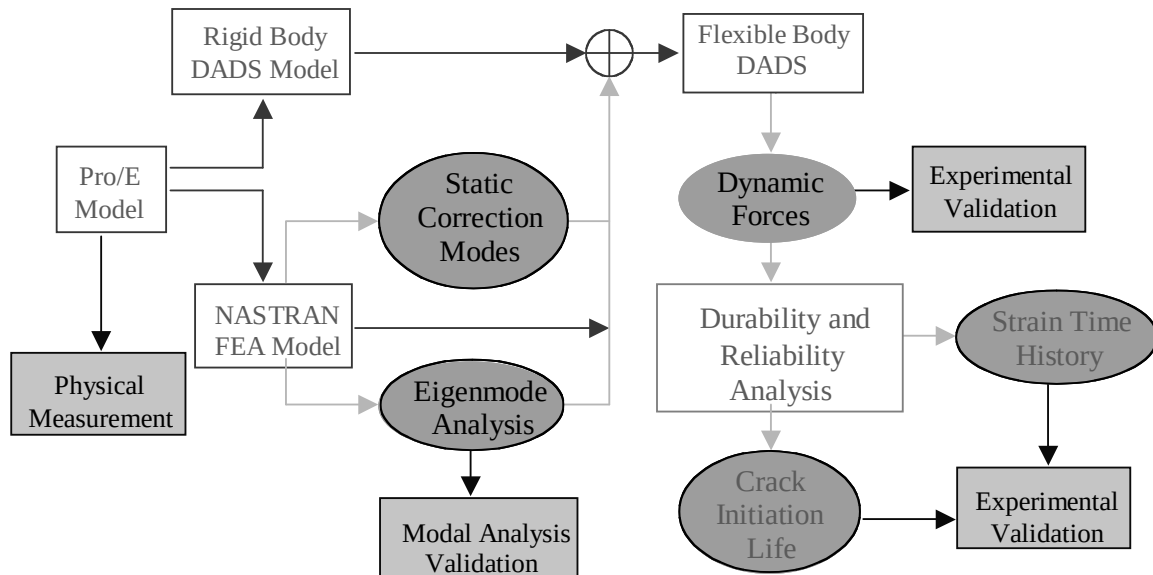


FIGURE 1 - PHYSICS OF FAILURE PROCESS

A flexible-body multi-body dynamic model of the trailer was developed using component-mode synthesis. In particular, the Craig-Bampton [1-3] mode set was analyzed using the NASTRAN FEA model, and then combined with the rigid-body dynamic model. In the simulation-based PoF process, the flexible-body dynamic model was used to generate load histories based on assumed operational usage and measured terrain profiles. The Durability and Reliability Analysis Workspace software (DRAW) [4], developed at the University of Iowa's Center for Computer-Aided Design, used the load histories to create a strain time history, and also to estimate the fatigue durability of the trailer. The fatigue durability criteria used was the formation of a 2 mm crack in any of the model's components. Neither the flexible-body dynamic model, nor the DRAW analysis of the trailer had been previously validated.

In order to verify the simulation results, critical point strain and fatigue life of the trailer, strain gauges were used in the testing. By using the strain gauge data and corresponding FE nodal strain simulation results, validation based on the strain can be performed. The measured strain can also be used as an input of the simulation to predict fatigue life based on experimental strain. The comparison between experimental and simulation-based fatigue life is also carried out.

3.1 Validation Methodology

It is generally acknowledged that mathematical models cannot perfectly simulate real system behavior. One of the reasons for this is that there are always uncertainties in the values of mathematical model parameters and experimental measurement results. Because of this, we require objective, well-found mathematical techniques for model validation. It is desirable to establish a technique for comparing mathematical model behavior to experimental uncertainty. In our validation, the surface roughness of the section of the test course is known to some level of fidelity, but not to the degree of accuracy required for a point-by-point comparison of the mathematical model data and measured data. Therefore, the validation will be done using statistical techniques rather than on a point-by-point basis.

It is important that the data "match" in both the time and frequency domains. In the time domain, histograms of the measured and modeled data should be statistically similar. The first four statistical moments; mean, variance (or standard deviation), skewness and kurtosis for each data channel will be calculated and compared. Additionally, the root mean square (RMS) will be calculated for the time domain data.

In the frequency domain, the PSD will be computed for model and measured data for all the data that are selected. The PSD curves, predicted by the model, will be compared with the measured PSD curves.

The spectral resolution and number of statistical degrees of freedom should be approximately the same for the modeled and measured cases.

3.2 Instrumentation and Transducers

The trailer was instrumented by ATC with a number of strain gauges, accelerometers, rate gyros, linear displacement transducers and pressure transducers. A total of 59 channels were sampled, in the order specified in Table 1. The original sample rate was 1262.626 Hz (7.92E-4 second period).

Analog low-pass anti-aliasing filters were used on every channel, however the cutoff frequency of the filters varied by the type of transducer being measured. Table 2 lists the filter cutoff frequencies and transducer types.

The following subsections provide details of how the test trailer was instrumented and the relationship of the instrumentation locations to the simulation model.

3.2.1 Strain Gauge Setup

The trailer was instrumented with 8 strain gauge rosettes. Based on simulation results, which showed that the critical region is located at the bottom of the straight drawbar, the strain gauges were arranged around the critical region and some complicated structural locations. Four of the strain gauge rosettes were located on the bottom-side of the straight drawbar, and the other four rosettes were placed near complicated structural locations on the upper and lower triangle plates and the angle plate. The instrumented locations are shown in Figures 2 and 3.

Strain gauge locations are shown relative to the FEA mesh in Figure 4, which also indicates the corresponding FE node numbers. The finite element model is created based on the mid surface of the component and does not consider the small joint attached parts and hole, while the strain gauges are attached on the surface of the component. It is difficult to position the strain gauges at exactly the same location as the FE model nodes, especially near the joints and holes. Therefore, the strain gauges are located as close as possible to the corresponding FE node. Table 3 indicates the coordinates of each strain gauge rosette location and their differences from the closest FE node locations, in which the differences are the comparison between their distances from origin of the reference frame.

TABLE 1 - POF EXPERIMENTAL DATA FILE FORMAT

Col #	Description	Units	Col. #	Description	Units
1	Time	seconds	31	Lunette Accel (T)	g's
2	Btm Drwbr Cntr (T) strain	μ inch	32	Lunette Accel (L)	g's
3	Btm Drwbr Cntr (45) strain	μ inch	33	Tongue Accel (V)	g's
4	Btm Drwbr Cntr (L) strain	μ inch	34	Tongue Accel (T)	g's
5	Btm Drwbr Cntr Aft (T) strain	μ inch	35	Tongue Accel (L)	g's
6	Btm Drwbr Cntr Aft (45) strain	μ inch	36	Trailer CG Accel (V)	g's
7	Btm Drwbr Cntr Aft (L) strain	μ inch	37	Trailer CG Accel (T)	g's
8	Btm Drwbr CS Edge (T) strain	μ inch	38	Trailer CG Accel (L)	g's
9	Btm Drwbr CS Edge (45) strain	μ inch	39	CS Forward Accel (V)	g's
10	Btm Drwbr CS Edge (L) strain	μ inch	40	CS Forward Accel (T)	g's
11	Btm Drwbr CS Edge Aft (T) strain	μ inch	41	CS Forward Accel (L)	g's
12	Btm Drwbr CS Edge Aft (45) strain	μ inch	42	CS Aft Accel (V)	g's
13	Btm Drwbr CS Edge Aft (L) strain	μ inch	43	CS Aft Accel (T)	g's
14	Top Triang Plate Corner (T) strain	μ inch	44	CS Aft Accel (L)	g's
15	Top Triang Plate Corner (45) strain	μ inch	45	RS Forward Accel (V)	g's
16	Top Triang Plate Corner (L) strain	μ inch	46	RS Forward Accel (T)	g's
17	Btm Triang Plate Corner (T) strain	μ inch	47	RS Forward Accel (L)	g's
18	Btm Triang Plate Corner (45) strain	μ inch	48	RS Aft Accel (V)	g's
19	Btm Triang Plate Corner (L) strain	μ inch	49	RS Aft Accel (T)	g's
20	Left Angle Plate Lower (V) strain	μ inch	50	RS Aft Accel (L)	g's
21	Left Angle Plate Lower (45) strain	μ inch	51	Trailer CG Pitch Rate	deg/sec
22	Left Angle Plate Lower (L) strain	μ inch	52	Trailer CG Roll Rate	deg/sec
23	Left Angle Plate Upper (V) strain	μ inch	53	Trailer CG Yaw Rate	deg/sec
24	Left Angle Plate Upper (45) strain	μ inch	54	CS Shock Absorber Disp	Inches
25	Left Angle Plate Upper (L) strain	μ inch	55	RS Shock Absorber Disp	inches
26	CS Axle Accel (V)	g's	56	Surge Brake Pressure	psi
27	CS Frame Accel (V)	g's	57	CS Wheel Brake Pressure	psi
28	RS Axle Accel (V)	g's	58	RS Wheel Brake Pressure	psi
29	RS Frame Accel (V)	g's	59	Long. Ground Speed	mph
30	Lunette Accel (V)	g's			

TABLE 2 - ANALOG LOW-PASS ANTI-ALIASING CUTOFF FREQUENCIES

Transducer Type	Filter Cutoff Frequency
Strain gauge	100 Hz
Accelerometer	200 Hz
Rate gyro	20 Hz
Linear position	20 Hz
Pressure	100 Hz



FIGURE 2 - LOCATION AND INSTALLATION OF THE STRAIN GAUGE ROSETTES

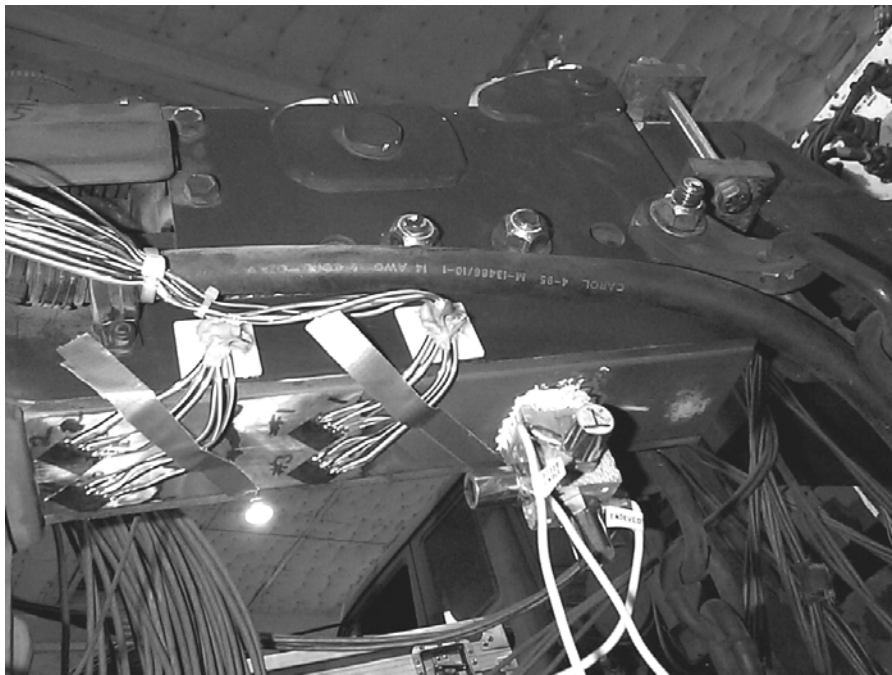


FIGURE 3 - LOCATION AND INSTALLATION OF THE STRAIN GAUGE ROSETTES

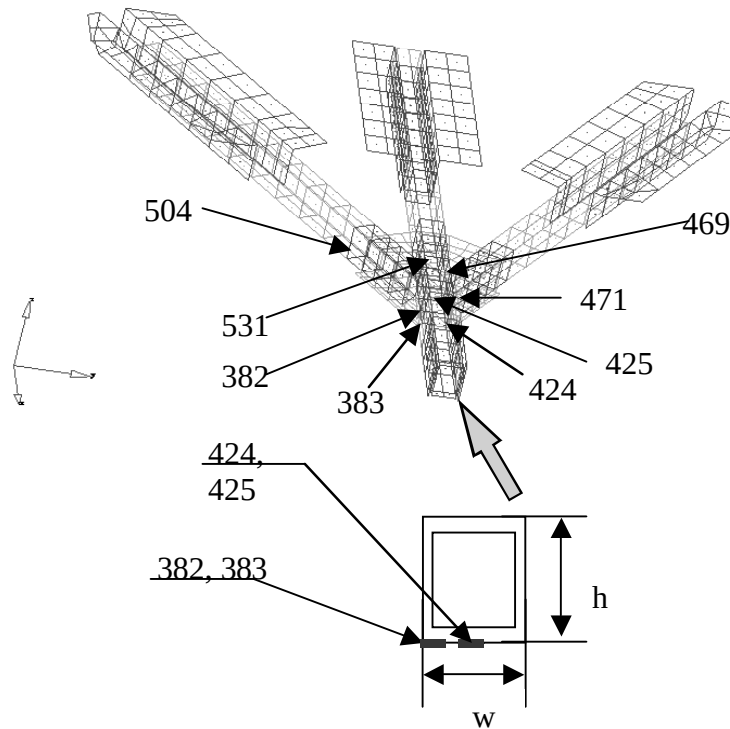


FIGURE 4 - THE LOCATION OF THE STRAIN ROSETTES ON THE FINITE ELEMENT MODEL

TABLE 3 - DISTANCE BETWEEN STRAIN GAUGE LOCATION AND CORRESPONDING FE NODE LOCATION

Distance Between FE Node and Gauge Location					
Node	Model	x	y	z	Distance (in)
382	FE Model	21.23076	-1	-3.25	0.29
	Gauge	21.375	-1	-3.5	
383	FE Model	25.15384	-1	-3.25	0.25
	Gauge	25.15	0	-3.5	
424	FE Model	25.15384	0	-3.25	0.25
	Gauge	25.15	0	-3.5	
425	FE Model	21.23076	0	-3.25	0.29
	Gauge	21.375	0	-3.5	
469	FE Model	21.12	1.25	-0.06	0.33
	Gauge	21.37	1.35	-0.25	
471	FE Model	21.12	1.25	-3.44	0.33
	Gauge	21.37	1.35	-3.25	
504	FE Model	14.26999	-5.94999	-3.5	0.47
	Gauge	14.34	-5.5	-3.6	
531	FE Model	21.12	-1.5	0	0.52
	Gauge	20.62	-1.38	0.1	

Figure 5 indicates the detailed location of all eight strain gauges on the FE model, while Figure 6 shows the detailed locations of four of strain gauges along the bottom of the straight drawbar.

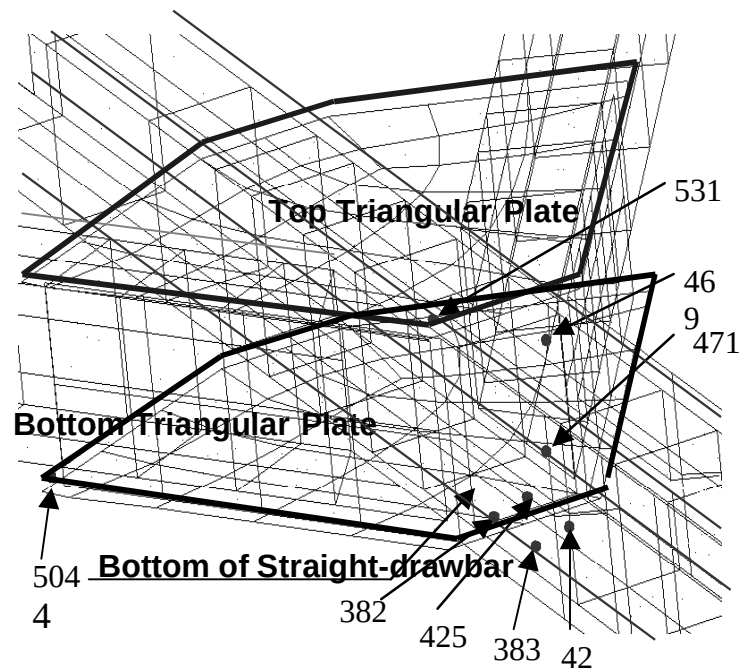


FIGURE 5 - LOCATION OF FOUR OF THE STRAIN ROSETTES ON THE BOTTOM-SIDE OF THE DRAWBAR

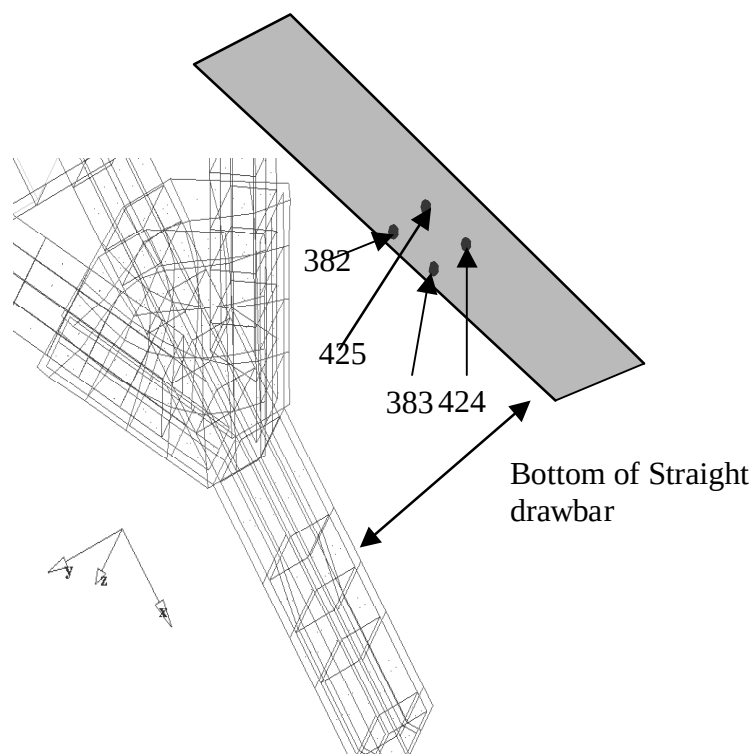


FIGURE 6 - LOCATION OF THE STRAIN ROSETTES (ENLARGEMENT)

Two of the strain gauge rosettes were located on the upper and lower triangle plates, and the remaining two were located on the angle plate, as shown in Figures 7 and 8 respectively.

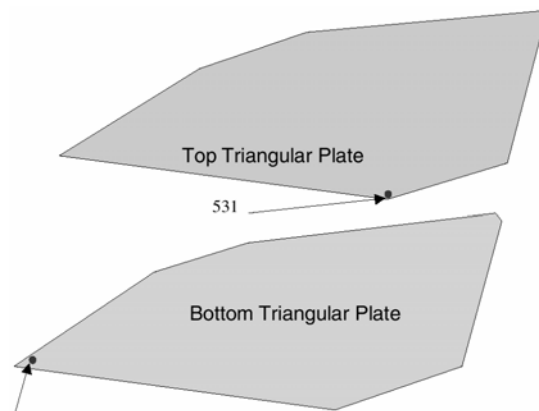


FIGURE 7 - DETAILED LOCATION OF THE STRAIN ROSETTES ON UPPER AND LOWER TRIANGLE PLATES

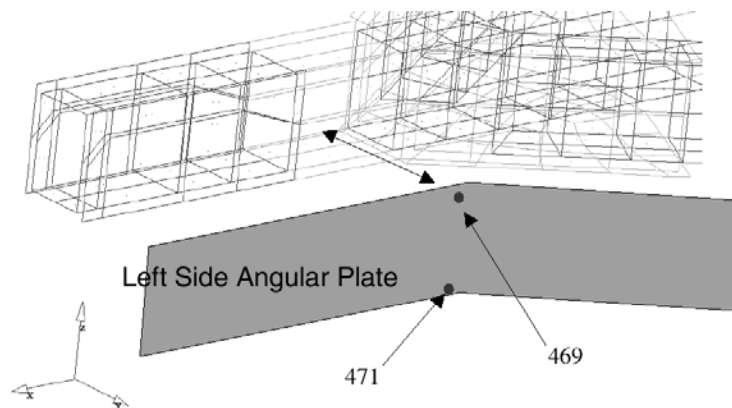


FIGURE 8 - DETAILED LOCATION OF THE STRAIN ROSETTES ON LEFT-SIDE ANGLE PLATES

3.2.2 Accelerometer Setup

A total of seven tri-axial and four single axis accelerometers were used during the trailer testing. One of the tri-axial accelerometers was located on the lunette, and another on the trailer tongue. Significant differences between these two sets of transducers should only exist for experimental runs where the surge brake was active. Another tri-axial accelerometer was located near the trailer CG, as shown in Figure 9. The remaining four tri-axial accelerometers were located at the corners of the cargo box, as shown in Figure 10. The four single axis accelerometers were either located at the frame attachment point for both the curbside and roadside suspension road arms or close to the axle location on the road arms. The axis of the axle accelerometers changes due to jounce/rebound of the suspension.



FIGURE 9 - TRIAXIAL ACCELEROMETERS AND RATE GYROS NEAR TRAILER CENTER OF GRAVITY (CG) LOCATION



FIGURE 10 - TRIAXIAL ACCELEROMETERS AT TOP CORNERS OF TRAILER CARGO BOX

3.2.3 Angular Rate Gyro Setup

A tri-axial angular rate gyro was used to measure the roll, pitch and yaw rates of the trailer. The transducer was mounted as close to the trailer CG as possible. This is shown in Figure 9. The tri-axial angular rate gyro is packaged with the accelerometer located at the trailer CG.

3.2.4 Linear Displacement Transducer Setup

Linear displacement transducers were used to measure the shock absorber displacements during the trailer testing.

3.2.5 Pressure Transducer Setup

A total of three pressure transducers were used in the trailer instrumentation package. One of the transducers measured the pressure as close to the surge brake master cylinder as possible. The master cylinder is located in the hitch assembly. The other two transducers were used to measure pressures close to the left and right drum brakes. The hydraulic surge brake system layout is shown in Figure 11.

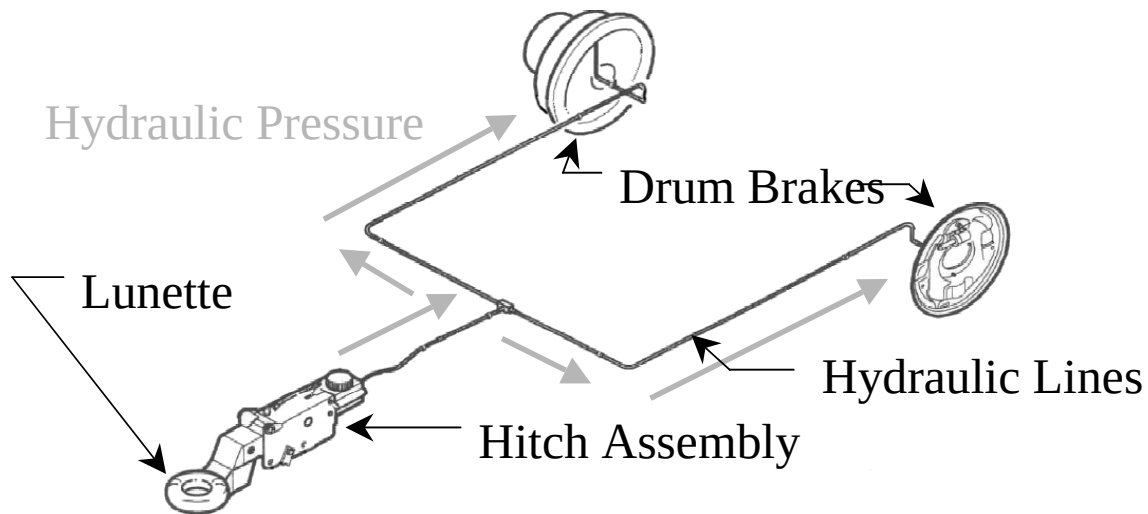


FIGURE 11 - HYDRAULIC SURGE BRAKE SYSTEM LAYOUT

3.3 Test Course Description

Six test courses at the Aberdeen Test Center were utilized for the PoF validation effort. All testing was done when the courses were dry. These test courses are:

1. Test Course A: This is a rough course composed of native soil. When the course is dry, dust is severe. Much of the course is rough due to many years of testing tank-type vehicles.
2. Test Course B: This course is paved with unevenly laid granite blocks forming a surface. It duplicates the rough cobblestone road found in many parts of the world. The course is useful as a standard rough road for accelerated testing of wheeled vehicles, and is generally included in cycles of courses used for vibration studies. The course irregularities vary both along the length of the course and across the width. The motion imparted by the granite paving blocks to a vehicle is a random combination of roll, pitch and high-frequency vibrations.
3. Test Course C: This test course consists of a single 4-inch radius bump. The road surface is concrete. The bump extends across both vehicle wheel tracks, and does not excite the roll degree-of-freedom of the vehicle.
4. Test Course D: This test course is a typical paved primary road segment. The road surface is asphalt.
5. Test Course E: This is a moderate course with a substantial roadbed, composed primarily of quarry spall and bank gravel. The loop includes sharp and sweeping curves, and the surface ranges from smooth to rough, with the roughness due to potholes, wash boarding and rutting.
6. Test Course F: This course is laid out in a loop of moderately irregular terrain. Surfaces range from smooth to rough, and there are sweeping turns. Under dry conditions, the course is extremely dusty.

Measured terrain profiles for the Test Courses A and B as well as Test Courses E and F were used in the simulations.

3.4 Test Matrix

Table 4 lists the data file names associated with the experimental testing. All of the data files were identically formatted comma-separated columns of numbers. The table lists the names of the particular test course, whether the surge brake system was enabled or disabled, and the speed of the test. File names in boldface represent tests that were determined to be good, while file names not in boldface represent data that was determined inconsistent due to a number of possible reasons. All validation work uses the boldfaced experimental test files. The column order, transducer type and units of measurement were previously specified in Tables 1 and 2.

TABLE 4 - TEST MATRIX DATA FILE NAMES

Course/Speed	Brakes	5 mph	10 mph	12 mph	15 mph	20 mph	25 mph	35 mph	50 mph
Test Course A	No		run032	run038	run039				
			run037		run055				
	Yes		run027	run028	run031				
			run042	run030	run044				
				run043	run049				
					run050				
Test Course B	No				run002	run003	run004		
					run010	run011	run012		
	Yes				run005	run006	run007		
					run013	run014	run015		
							run017		
Test Course C	No	run021	run022	run023					
	Yes	run018	run019	run020					
Test Course D	No								run025
	Yes								run026
Test Course E	No							run040	
	Yes							run041	
Test Course F	No				run034	run035	run036		
	Yes				run045	run046	run047 run054		

3.5 Data Processing

One of the major lessons learned as a result of this PoF validation project is that all the data, both experimentally measured and simulation generated needed to be processed the same way. Primarily this concerned filtering and decimation of the data, but it also applied to the frequency content required at each stage of the simulation process.

3.5.1 Digital Filtering

The simulation models contain data with varying frequency content. For example, the rigid-body DADS model has a natural frequency for each rigid-body motion, and it has a forced-response frequency spectrum due to the motion of the prime-mover and the irregularity of the terrain profile. The flexible-body DADS model adds the frequencies for the three eigenmodes used in the simulation model. A PSD plot of the center of gravity (CG) vertical (local) acceleration is shown in Figure 12 for both simulation and measured data. Although the output frequency of the simulation was the same as the experimental sample rate, the response spectrum is limited by the model representation.

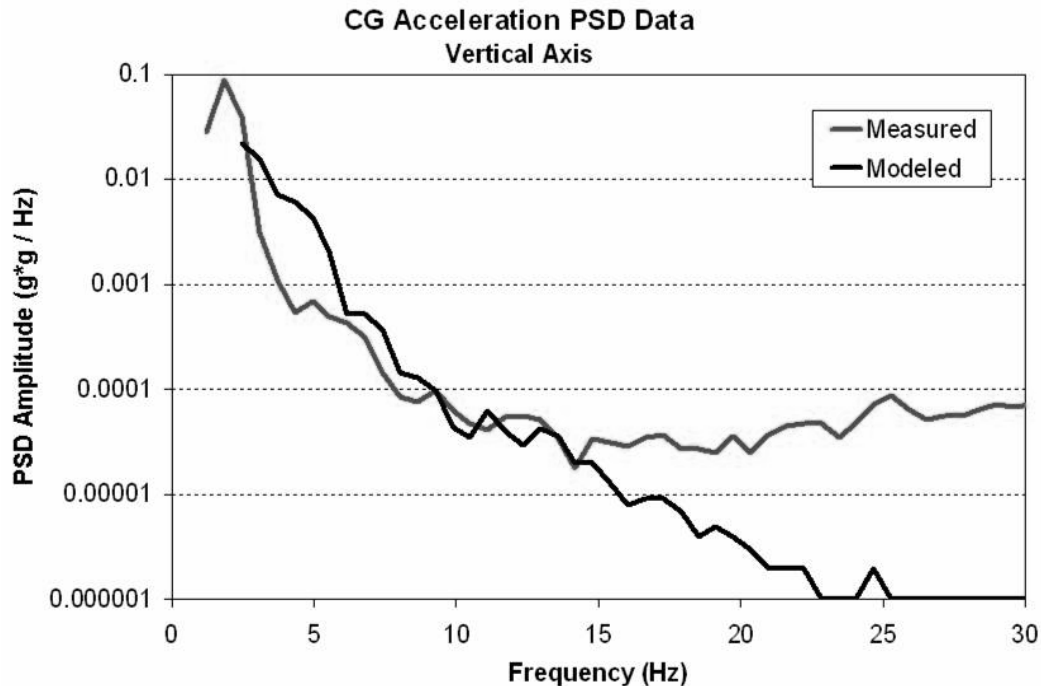


FIGURE 12 - PSD OF SIMULATION AND EXPERIMENTAL CG ACCELERATION

In order to properly compare the simulation and experimental data, the experimental data must be filtered to reduce the effect of any frequency content that is higher than that present in the simulation data. Since the experimental data is being post-processed, the filter can be applied phaselessly (both forward and backward in time).

3.5.2 Principal Strains

For a general loading on a body, the normal strain at a surface point can be determined using a strain rosette, and once readings on the three gauges of the rosette are made, the data can then be used to specify the state of strain at the point. This strain is normally expressed as two principal strains.

Strain deformation was measured using 0-45-90 degree strain gauge rosettes. These can be expressed as principal strains, using the following formulas

$$\varepsilon_{1,2} = \frac{\varepsilon_0 + \varepsilon_{90}}{2} \pm \sqrt{\frac{(\varepsilon_0 - \varepsilon_{45})^2 + (\varepsilon_{90} - \varepsilon_{45})^2}{2}} \quad (\text{Eq. 1})$$

and

$$\tan(2\alpha) = \frac{\varepsilon_0 - 2\varepsilon_{45} + \varepsilon_{90}}{\varepsilon_0 - \varepsilon_{90}} \quad (\text{Eq. 2})$$

where ε_0 , ε_{45} and ε_{90} , are the measured strains, and α is the angle between the reference gauge and the largest principal strain, ε_1 . The shear strain, γ , is given by

$$\gamma = 2\sqrt{\frac{(\varepsilon_0 - \varepsilon_{45})^2 + (\varepsilon_{90} - \varepsilon_{45})^2}{2}} \quad (\text{Eq. 3})$$

Matlab code for reducing the strain data to principal strains is provided in Appendix B.

3.5.3 Decimation and Filtering

The data connection between the multi-body dynamic simulation (DADS) and the finite element analysis was performed at 100 Hz. The decision to use the 100 Hz rates was primarily due to the flexible-body vibration mode frequencies, which were all less than 30 Hz and the computational time required by DRAW to solve the finite element model. This computational time is directly proportional to the frequency (i.e., 200 Hz takes twice the time as 100 Hz). Thus, a requirement exists to decimate the experimental data for comparison to the DRAW results.

Decimation involves both filtering and re-sampling the data. Matlab includes a function 'decimate' as part of the Signal Processing Toolkit. This function employs an eighth-order phaseless Chebyshev type-1 low pass filter whose cutoff frequency is set to the Nyquist-rate of the re-sampled data. The filter is applied to the data before it is re-sampled.

For example, in this case the data is originally sampled at 1262.626 Hz and we want to decimate it by a factor of 12, so the re-sampled frequency is 105.22 Hz, which is close to the 100 Hz simulation data. The 'decimate' function will first filter the original data at 31.57 Hz, and then resample, using every 12th point.

4. DATA REDUCTION RESULTS

Data reduction was initially performed for all test runs, and then focused specifically on the Test Course A runs, since these were known to cause the failures seen in the field testing of the trailer.

4.1 Speed Data

The foremost variable when validating vehicle models is the experimental test speeds. These speeds must conform with the simulation test speeds in order to make comparisons of the vehicle response.

Table 5 lists the various different test runs, the nominal speed of the run, the average of the actual speed of the run, and some comparisons of the nominal and experimental data. The last two lines of this table are highlighted, since these runs are detailed in further analysis.

The data is easier to understand when presented graphically. Figure 13 shows the minimum, average, and maximum speeds using a stacked bar chart. From this figure, it can be seen that some problems exist with cases 25 and 29. These correspond to two runs on Test Course A (run #32 at 10 mph and run #30 at 12 mph, respectively). Further investigation of the data from these runs shows failures of the vehicle speed sensor.

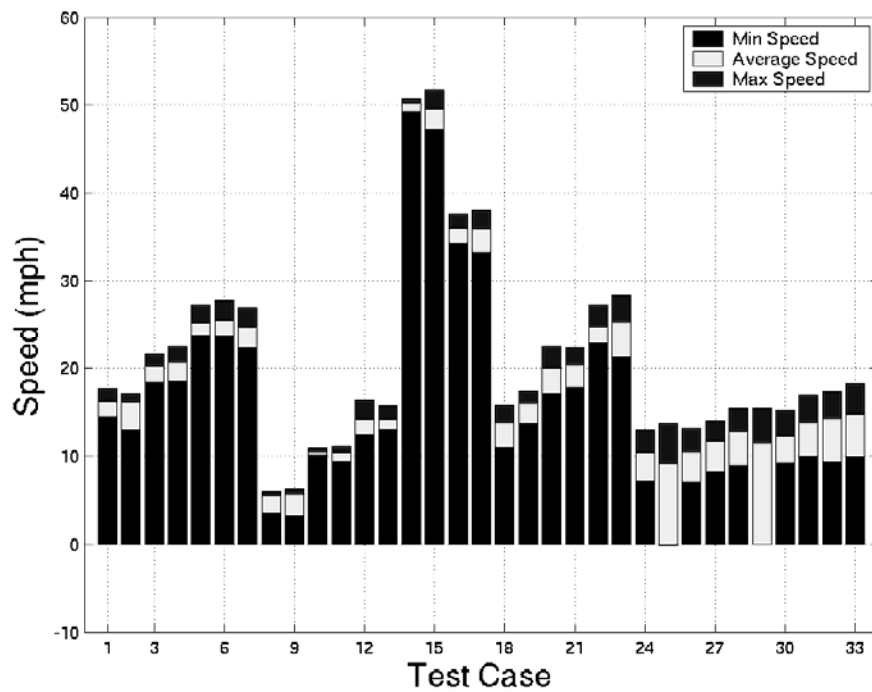


FIGURE 13 - MINIMUM, AVERAGE AND MAXIMUM TEST RUN SPEEDS

TABLE 5 - SPEED DATA STATISTICS FOR EXPERIMENTAL TEST RUNS IN MPH

Course	Case #	Run #	Nominal Speed	Average Speed	Speed Difference	% Speed Difference	Std. Dev.	RMS	-Peak	+Peak
Test Course A	24	27	10	10.32	0.32	3.21	1.28	10.40	7.12	12.97
	25	32	10	9.21	-0.79	-7.91	3.11	9.72	-0.10	13.66
	26	37	10	10.43	0.43	4.26	1.31	10.51	7.05	13.11
	27	42	10	11.66	1.66	16.59	1.05	11.71	8.27	14.01
	28	28	12	12.74	0.74	6.15	1.50	12.83	8.94	15.43
	29	30	12	11.60	-0.40	-3.36	2.48	11.86	-0.05	15.41
	30	38	12	12.26	0.26	2.13	1.17	12.31	9.21	15.25
	31	43	12	13.77	1.77	14.71	1.23	13.82	10.01	16.95
	32	52	15	14.25	-0.75	-5.02	0.97	14.28	9.32	17.30
	33	55	15	14.75	-0.25	-1.64	0.86	14.78	9.85	18.24
Test Course B	1	10	15	16.16	1.16	7.70	0.61	16.17	14.49	17.71
	2	13	15	16.06	1.06	7.06	0.57	16.07	12.96	17.17
	3	11	20	20.17	0.17	0.83	0.58	20.17	18.34	21.60
	4	14	20	20.62	0.62	3.11	1.06	20.65	18.51	22.51
	5	12	25	25.28	0.28	1.12	0.73	25.29	23.81	27.20
	6	15	25	25.48	0.48	1.91	0.85	25.49	23.72	27.77
	7	17	25	24.65	-0.35	-1.41	1.07	24.67	22.37	26.92
Test Course C	8	18	5	5.47	0.47	9.43	0.37	5.48	3.49	5.99
	9	21	5	5.67	0.67	13.41	0.55	5.70	3.17	6.29
	10	19	10	10.43	0.43	4.34	0.20	10.44	10.12	10.97
	11	22	10	10.33	0.33	3.31	0.48	10.34	9.42	11.09
	12	20	12	14.16	2.16	18.02	1.27	14.22	12.49	16.37
	13	23	12	14.21	2.21	18.45	0.81	14.24	13.02	15.73
Test Course D	14	25	50	50.22	0.22	0.44	0.38	50.22	49.28	50.81
	15	26	50	49.56	-0.44	-0.87	1.20	49.58	47.25	51.70
Test Course E	16	40	35	36.04	1.04	2.97	0.98	36.05	34.26	37.66
	17	41	35	35.96	0.96	2.75	0.98	35.98	33.27	38.08
Test Course F	18	34	15	13.76	-1.24	-8.27	0.90	13.79	11.04	15.80
	19	45	15	16.02	1.02	6.83	0.93	16.05	13.66	17.42
	20	35	20	19.99	-0.01	-0.06	1.41	20.04	17.18	22.47
	21	46	20	20.41	0.41	2.06	0.83	20.43	17.77	22.36
	22	36	25	24.76	-0.24	-0.97	0.93	24.77	22.82	27.24
	23	54	25	25.36	0.36	1.44	1.24	25.39	21.26	28.38

Figure 14 shows the difference between the average and nominal speeds for each test run. Since the nominal speeds vary from 5 to 50 mph, it is better to compare the quality of the test using the relative speed difference, shown as a percentage in Figure 15.

Figure 16 shows the standard deviation of the experimental speed data. The large deviations associated with cases 25 and 29 confirm that there are problems with the speed data for those test runs.

Figure 17 shows the difference between the RMS speed values and the nominal values. This plot mirrors the same information as the relative difference plot, Figure 15.

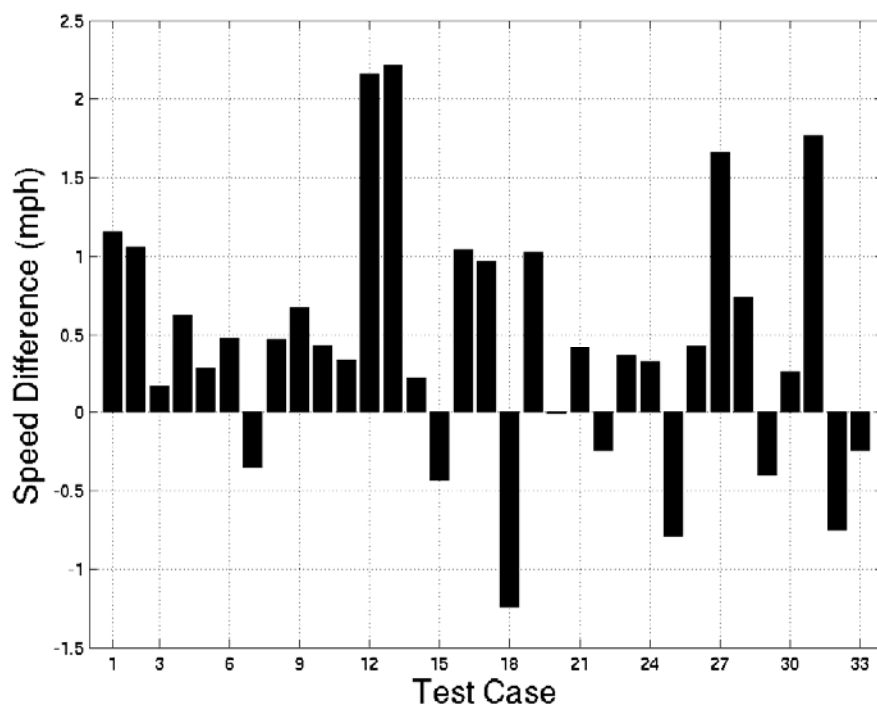


FIGURE 14 - DIFFERENCE BETWEEN AVERAGE AND NOMINAL SPEEDS

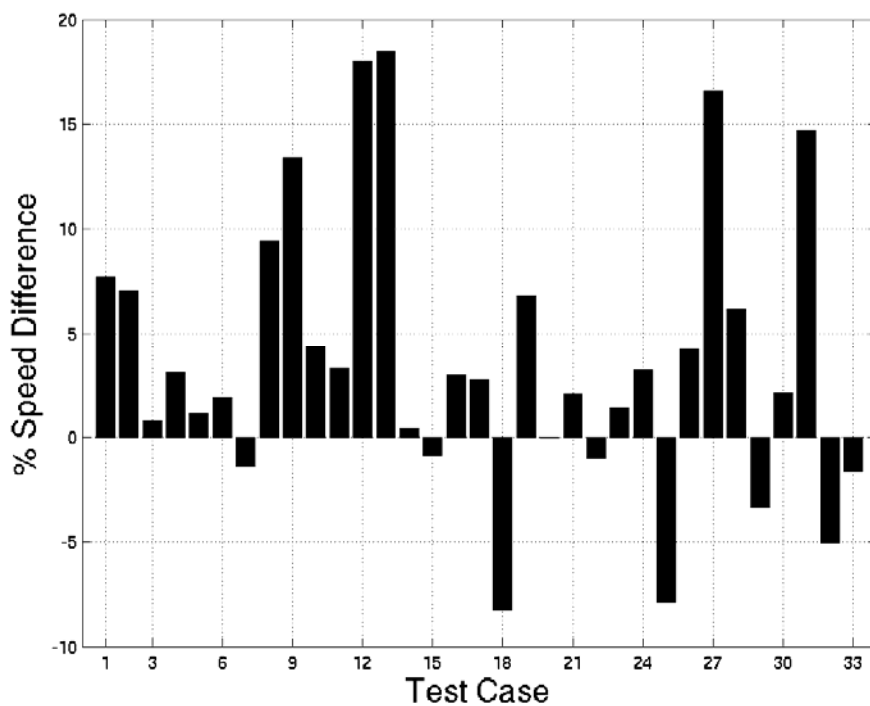


FIGURE 15 - PERCENT SPEED DIFFERENCE (EXPERIMENTAL VS. NOMINAL DATA)

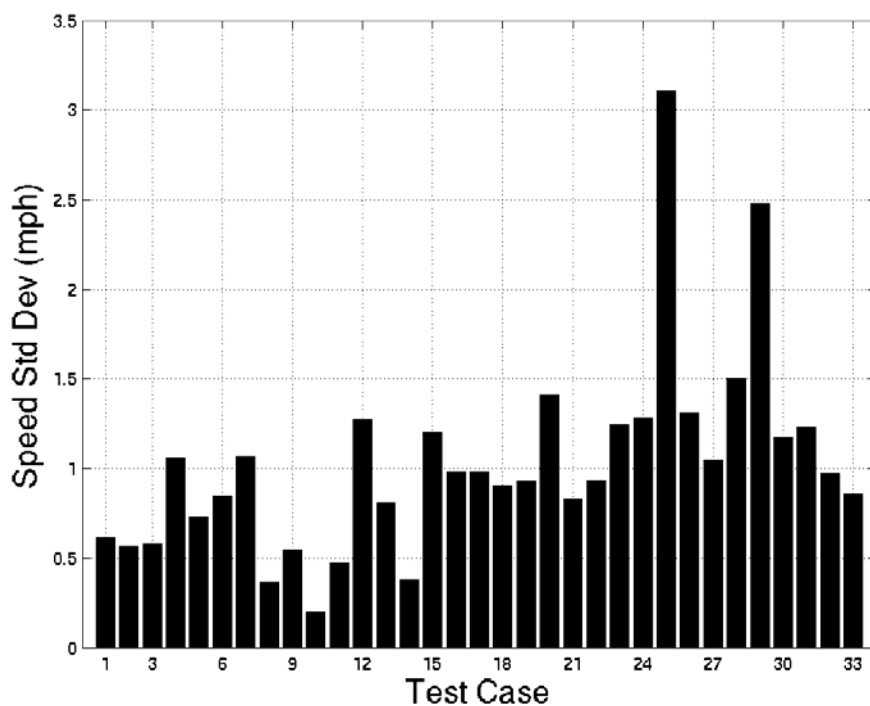


FIGURE 16 - STANDARD DEVIATION (EXPERIMENTAL VS NOMINAL SPEEDS)

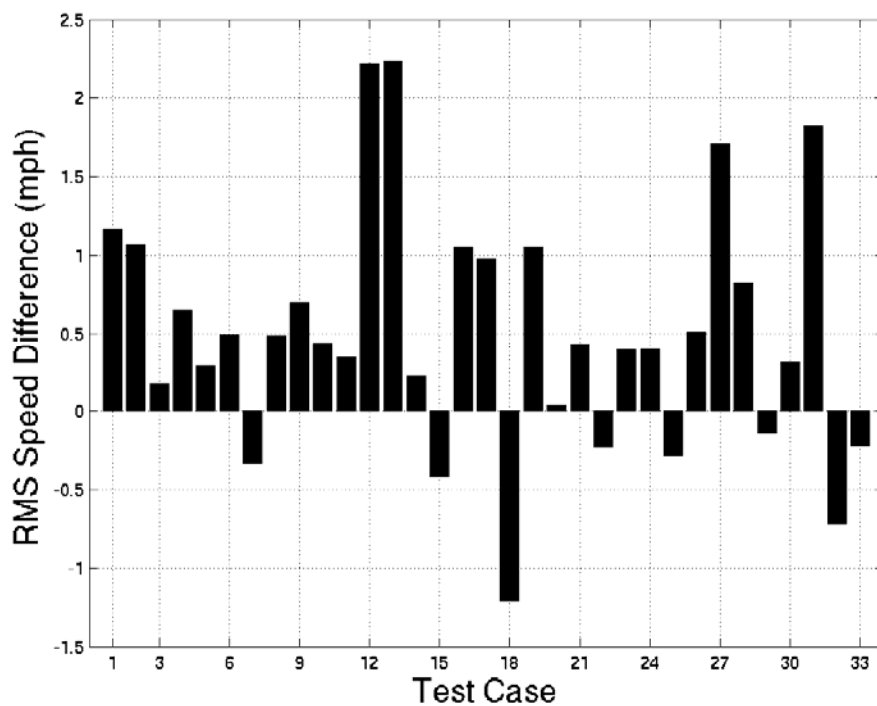


FIGURE 17 - DIFFERENCE BETWEEN RMS AND NOMINAL SPEEDS

The bias in the speed measurements can be accounted for by using the measured average, rather than the nominal speed value, for the dynamic simulations. However, there is no good way to handle the variance unless the position of the vehicle, relative to the terrain, is known. In this case, the measured velocity profile can be integrated with respect to time, and used as a kinematic position driver in the DADS software. Unfortunately, the position of the vehicle was not measured, so the average speed was used for all the dynamic simulations.

4.2 Test Course A

Data reduction results are presented for experimental test runs numbered 52 and 55 (shown in Table 5 as cases #32 and #33), which were collected on Test Course A at a nominal speed of 15 mph with the surge brakes enabled and disabled, respectively. Comparative data for other runs on Test Course A are presented Appendix C.

Amplitude distributions (average, standard deviation, RMS, +peak, -peak, +99.9%, -99.9%, +99%, -99%, +90%, -90%) were performed on all data. Strain gauge data were resolved as principal strains before computing the distributions. All other channels were directly used.

4.2.1 Strain Gauge Data

The principal strains and rotation angle were calculated from the measured gauge data. This is presented in Table 6 for the case with the brakes disabled, and Table 7 for the case with the brakes enabled. In each table, the description identifies both the location of the strain gauge, and the nearest finite element node number.

TABLE 6 - PRINCIPAL STRAIN AMPLITUDE DISTRIBUTION DATA (BRAKES DISABLED)

Description	Ave	Std Dev	Rms	+Peak	-Peak	+99.9	-99.9	+99	-99	+90	-90
Btm Cntr (ϵ_1)	242.938	150.225	285.632	880.486	-20.345	857.991	-5.944	690.530	2.054	443.680	50.013
#424 (ϵ_2)	-87.290	46.750	99.021	-3.956	-430.34	-9.427	395.83	-14.877	230.13	-36.162	145.30
(α)	-0.179	6.433	6.435	44.782	-44.869	42.740	42.631	22.807	22.438	3.785	-4.173
Btm Cntr Aft (ϵ_1)	284.480	167.241	329.996	1006.189	-40.338	982.870	-18.012	789.999	22.046	511.970	82.419
#425 (ϵ_2)	-90.984	59.190	108.542	-4.963	-514.44	-8.766	489.89	15.835	276.98	-30.056	166.05
(α)	5.114	11.245	12.353	44.937	-44.980	44.564	44.591	39.708	39.772	14.548	-0.450
Btm Edge (ϵ_1)	191.440	112.308	221.951	651.319	-8.258	642.308	-3.616	525.357	12.180	341.845	52.941
#383 (ϵ_2)	-77.209	47.480	90.640	20.508	-339.27	13.857	295.91	1.502	222.97	-20.362	139.56
(α)	2.759	8.292	8.739	44.961	-44.997	42.995	43.436	31.042	30.220	9.272	-2.585
Btm Edge Aft (ϵ_1)	219.534	138.438	259.537	791.191	-55.423	786.361	30.984	635.930	3.046	406.053	48.416
#382 (ϵ_2)	-83.040	53.540	98.803	65.274	-463.15	44.050	408.03	7.074	245.79	-23.520	151.44
(α)	1.477	7.692	7.832	44.990	-44.968	43.040	42.504	31.691	28.343	6.428	-1.432
Top Plate (ϵ_1)	24.597	15.111	28.868	128.575	-0.091	124.926	3.273	86.042	5.985	38.804	11.275
#531 (ϵ_2)	-13.730	17.111	21.939	0.274	158.78	-1.615	152.29	-3.206	95.468	-5.233	23.928
(α)	15.840	15.060	21.856	44.044	-44.823	43.855	44.749	41.608	43.478	0.225	31.164
Btm Plate (ϵ_1)	14.077	5.182	15.000	37.045	1.226	34.522	3.566	29.426	4.842	21.222	8.149
#504 (ϵ_2)	-7.231	4.648	8.596	5.722	-42.737	3.310	38.794	0.415	26.830	-2.801	11.847
(α)	-14.723	11.936	18.953	44.423	-44.810	19.567	44.736	15.121	40.992	2.144	28.961
Ang. Lower (ϵ_1)	264.853	171.321	315.432	828.211	-17.173	758.451	-10.943	671.887	0.038	499.069	27.221
#471 (ϵ_2)	-54.740	63.711	83.997	14.447	-743.11	10.987	695.70	-0.738	365.79	-12.850	96.577
(α)	-4.025	9.135	9.982	44.905	-44.930	43.646	43.765	31.655	34.105	2.969	12.086
Ang Upper (ϵ_1)	50.794	47.988	69.877	506.827	-10.53	475.728	-6.896	261.520	-3.088	86.524	9.189
#469 (ϵ_2)	-168.67	136.302	216.854	-3.282	-670.82	-7.397	657.97	-12.480	575.06	-32.209	375.37
(α)	9.590	12.555	15.798	44.995	-45.00	44.220	-44.55	39.664	-39.79	21.127	-2.490

TABLE 7 - PRINCIPAL STRAIN AMPLITUDE DISTRIBUTION DATA (BRAKES ENABLED)

Description		Ave	Std Dev	RMS	+Peak	-Peak	+99.9	-99.9	+99	-99	+90	-90
Btm Cntr #424	(ϵ_1)	218.164	127.738	252.808	666.656	-2.979	658.671	5.521	610.086	30.535	382.589	53.824
	(ϵ_2)	-75.143	36.514	83.545	-14.713	-313.36	-17.453	-296.56	-24.222	-191.40	-36.896	-122.76
	(α)	-8.938	12.900	15.693	44.918	-44.794	44.480	-44.411	39.686	-40.831	-0.919	-22.333
Btm Cntr Aft #425	(ϵ_1)	243.083	154.273	287.90	774.404	-41.626	764.828	-24.706	710.929	6.357	441.772	49.657
	(ϵ_2)	-95.015	53.499	109.04	-12.480	-394.90	-18.492	-374.27	-24.186	-260.29	-34.963	-164.73
	(α)	4.773	11.075	12.059	44.910	-44.711	44.298	-43.934	38.246	-37.029	15.801	-3.505
Btm Edge #383	(ϵ_1)	157.614	99.048	186.15	490.097	-9.280	485.771	-4.573	449.787	1.657	285.090	34.692
	(ϵ_2)	-68.377	41.352	79.91	5.359	-246.95	2.077	-237.15	-1.611	-194.16	-17.108	-124.59
	(α)	1.593	9.906	10.033	44.996	-44.859	44.374	-44.438	38.555	-37.611	8.869	-4.791
Btm Edge Aft #382	(ϵ_1)	174.121	117.657	210.14	598.355	-48.786	588.660	-35.979	523.232	-1.912	325.854	28.977
	(ϵ_2)	-69.101	47.985	84.128	57.870	-432.52	47.495	-342.00	20.270	-202.51	-18.452	-133.44
	(α)	-0.265	7.556	7.561	44.755	-44.895	41.944	-43.349	24.192	-30.904	4.464	-5.253
Top Plate #531	(ϵ_1)	26.852	11.623	29.260	84.748	4.055	81.603	7.042	73.976	10.065	41.080	16.229
	(ϵ_2)	-11.878	10.379	15.774	0.719	-87.387	-1.608	-81.635	-3.544	-73.601	-6.221	-18.739
	(α)	-21.364	16.114	26.760	44.898	-44.179	44.852	-44.052	40.305	-42.180	1.044	-35.563
Btm Plate #504	(ϵ_1)	28.892	3.540	29.108	40.115	16.989	38.222	18.944	36.610	20.862	33.519	24.288
	(ϵ_2)	-10.250	5.855	11.804	6.054	-38.049	4.421	-35.321	2.934	-30.411	-3.515	-16.355
	(α)	17.418	5.458	18.253	32.763	-9.396	27.982	-4.497	26.113	-0.146	23.617	10.136
Ang. Lower #471	(ϵ_1)	193.147	139.823	238.44	631.754	-5.869	610.917	-1.459	533.269	4.910	389.554	23.859
	(ϵ_2)	-49.027	70.741	86.069	11.629	-731.14	9.168	-602.25	2.865	-352.88	-4.924	-117.93
	(α)	-1.082	12.251	12.298	44.790	-44.918	44.161	-44.429	39.315	-39.108	10.552	-13.261
Ang Upper #469	(ϵ_1)	56.142	33.830	65.547	268.708	-2.140	247.43	0.377	190.161	5.556	91.777	17.142
	(ϵ_2)	-171.31	135.234	218.25	3.524	-588.83	-0.439	-574.30	-9.340	-547.18	-25.818	-371.99
	(α)	9.196	13.287	16.159	44.929	-44.922	44.814	-44.234	40.255	-40.243	22.129	-2.786

Much of this information is easier to understand graphically. Figure 18 shows the average principal strain for each of the eight rosette positions. In general, it shows that the average strains, along the bottom of the drawbar, were larger for the case #33 (run055) where the surge brake was disabled. However, the average vehicle speed for this run was 3.4% faster than case #32 (run052), with the brake enabled.

The standard deviations of the principal strains for each of the strain gauge locations are shown in Figure 19. In this figure, nearly all of the principal strain standard deviations are larger when the brakes are disabled.

The RMS values of the principal strains for each of the strain gauge locations are shown in Figure 20. As expected, the graphs are qualitatively similar to the standard deviation plots.

Finally, Figures 21 and 22 portray the data range statistics as stacked bar charts. Although the test case with the brakes disabled shows higher peak values of principal strains, the charts look similar. Figure 21 also shows that the largest values of the 1st principal strain occurred at the bottom center aft strain gauge (BCA). The BCA strain gauge was placed closest to the point of failure.

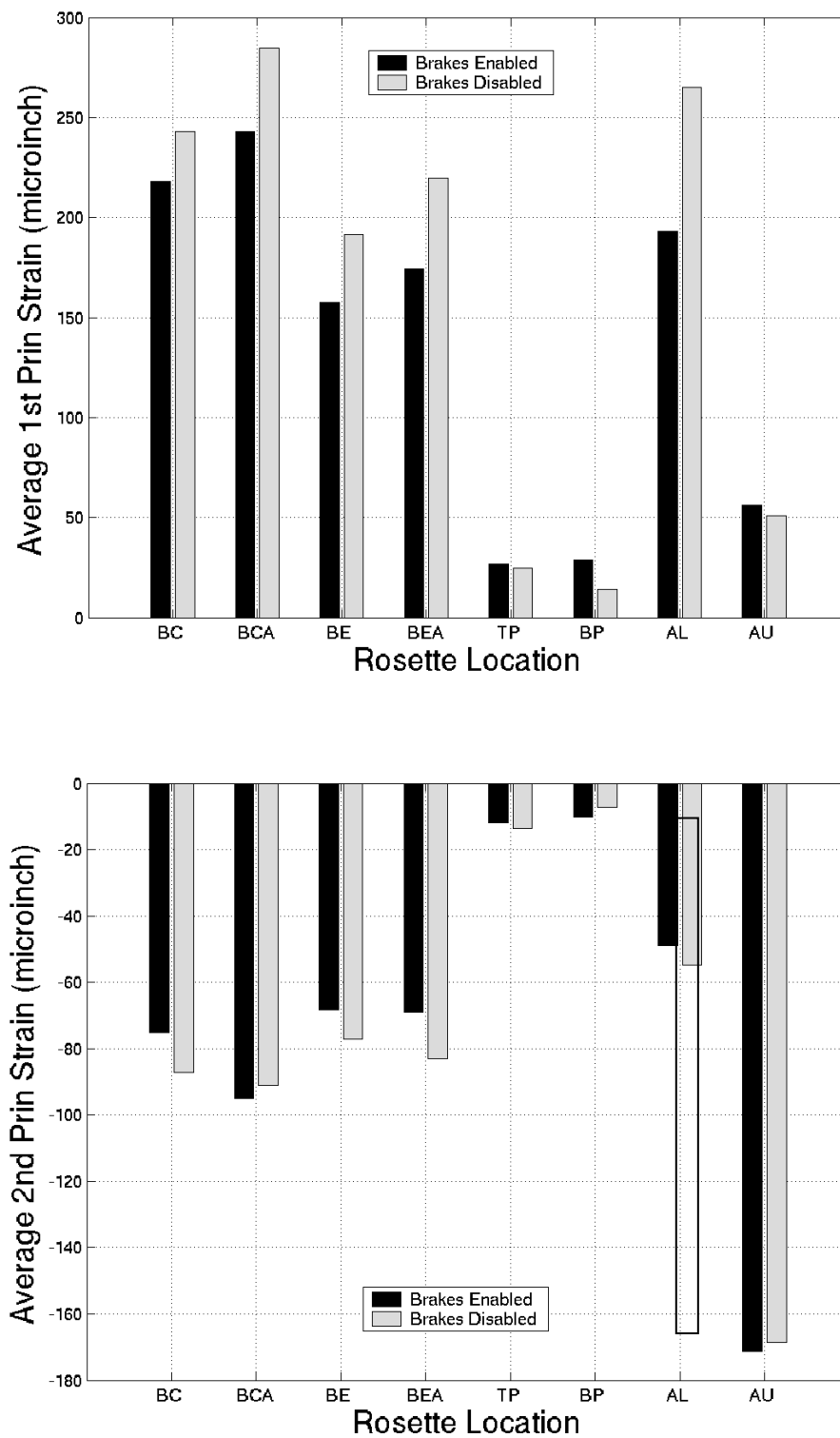


FIGURE 18 - AVERAGE PRINCIPAL STRAINS (TEST COURSE A, 15 MPH)

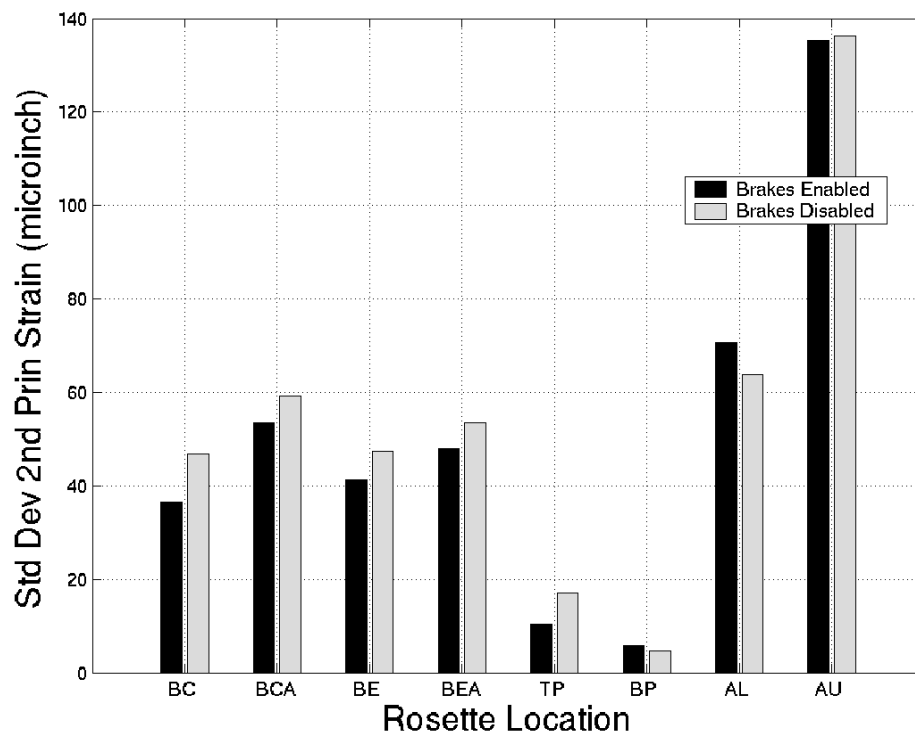
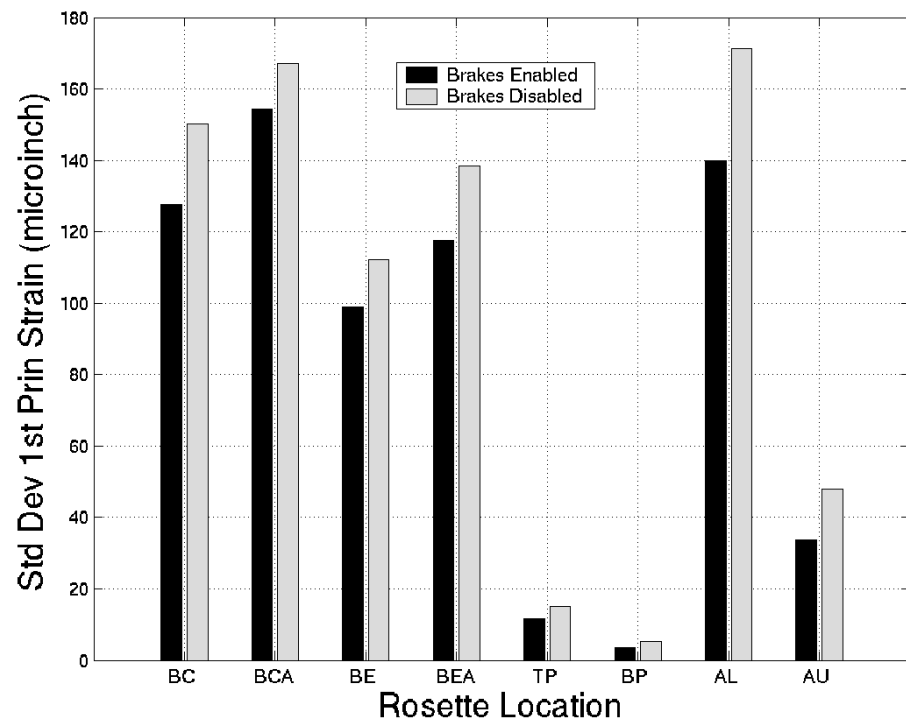


FIGURE 19 - PRINCIPAL STRAIN STANDARD DEVIATIONS (TEST COURSE A, 15 MPH)

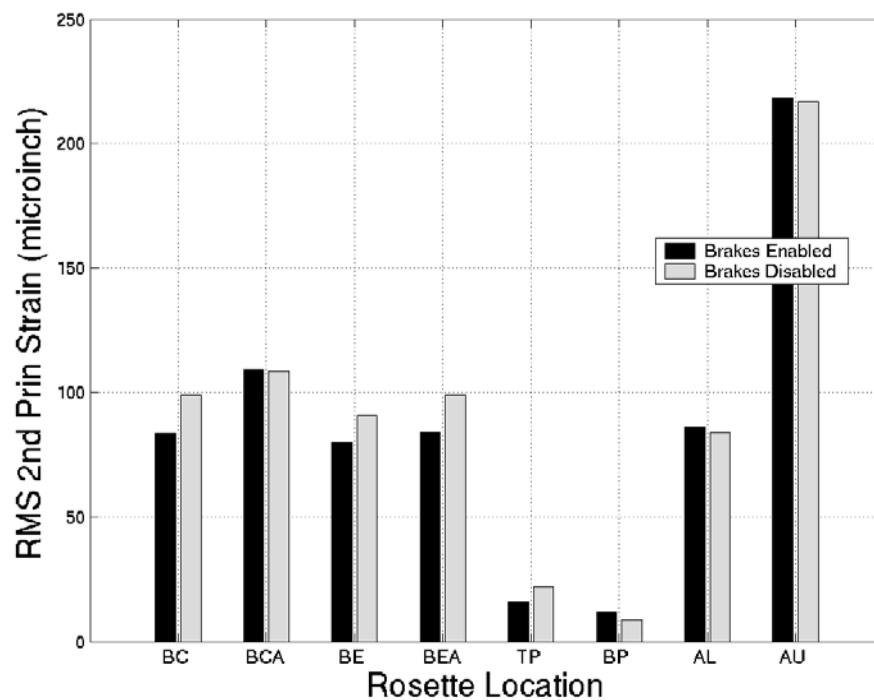
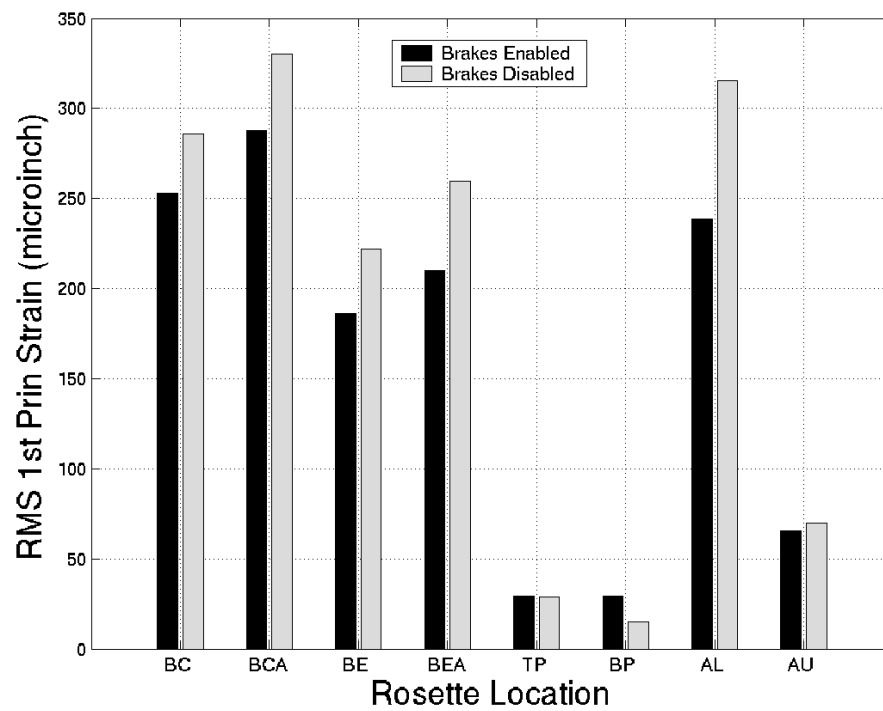
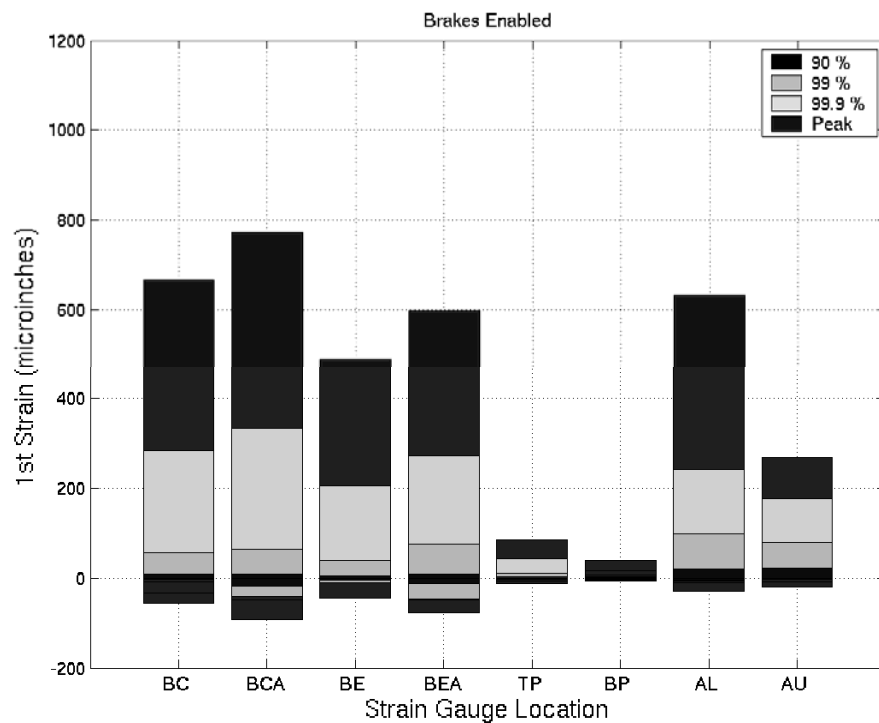
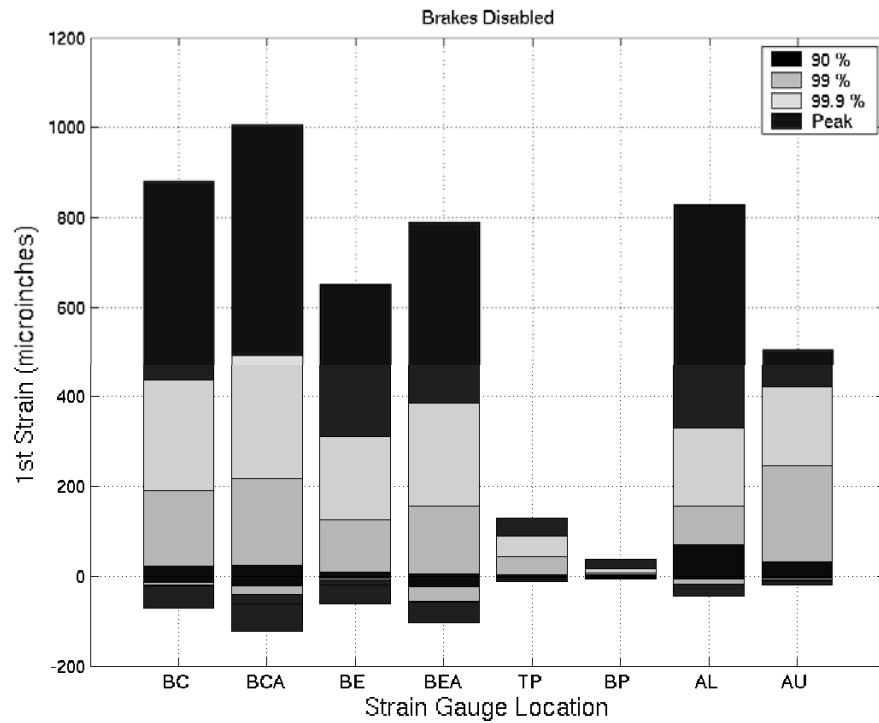
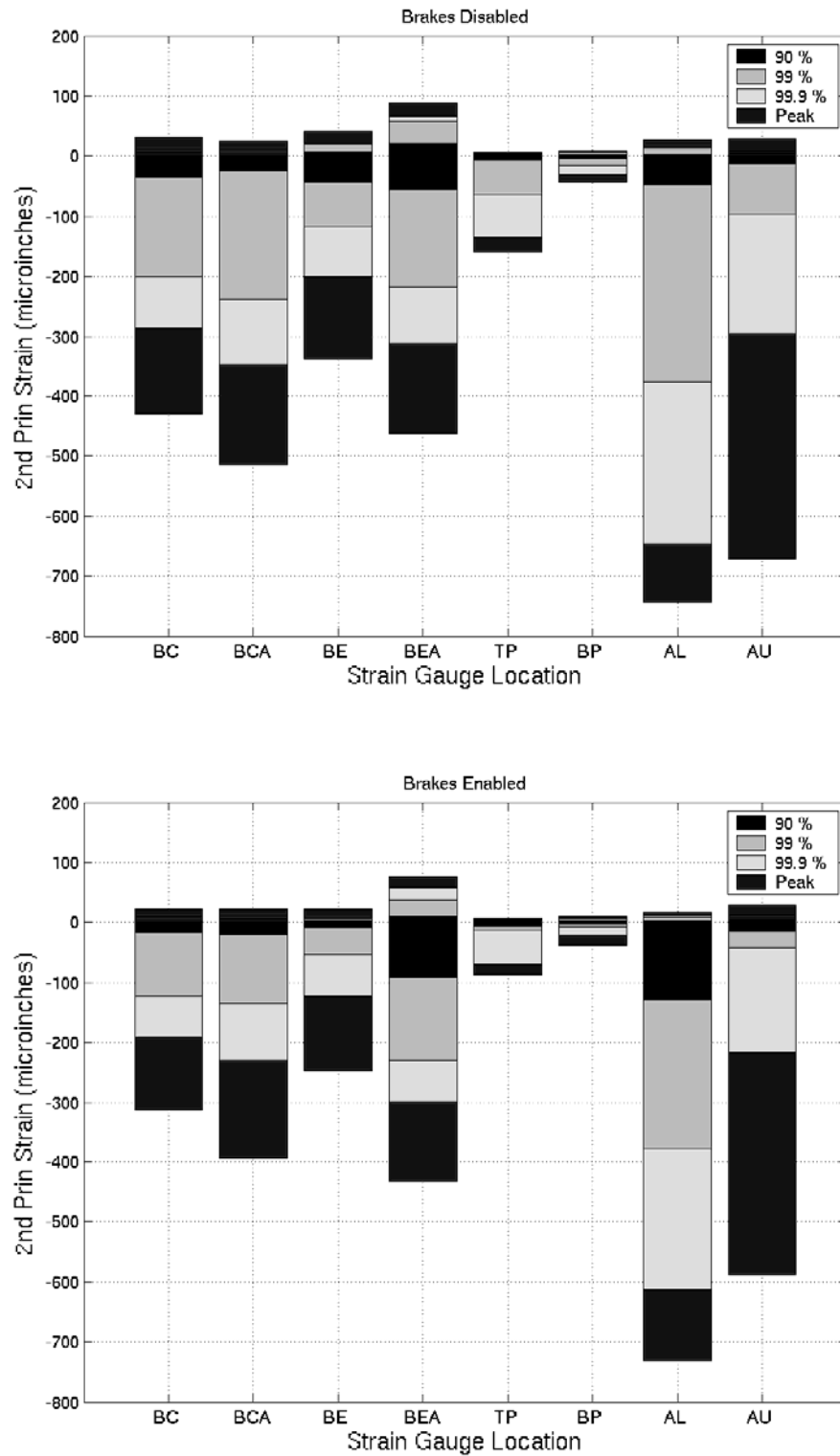


FIGURE 20 - RMS VALUES OF PRINCIPAL STRAINS

FIGURE 21 - DISTRIBUTION OF FIRST (1ST) PRINCIPAL STRAINS

FIGURE 22 - DISTRIBUTION OF SECOND (2ND) PRINCIPAL STRAINS

4.2.2 Accelerometer Data

Statistics about the accelerometer data amplitude distribution are given in Table 8 for the case with the brakes disabled and in Table 9 for the case with the brakes enabled.

Figures 23 through 25 show the average accelerations (vertical, transverse, and longitudinal) for several locations on the trailer. In addition to the lunette, drawbar (tongue) and CG location, the four triaxial accelerometers at the top corners of the trailer box on both the roadside (RS) and curbside (CS) are displayed.

For this type of experimental testing, and the types of accelerometers used, it would be expected that the average accelerations would tend toward zero. As seen in the figures, all of the averages are less than 0.25 g. Since a fairly long sample signal was used, these average values can be assumed to be representative of the instrumentation bias values. For some accelerometers, particularly vertical accelerometers at the CG, curbside forward, and roadside aft locations, the transverse accelerometer on the drawbar (tongue), and the longitudinal accelerometer on the lunette, questions can be raised about the data, instrumentation and/or test procedures, because of the sign reversal (positive/negative) of the average on the brakes disabled and brakes enabled testing.

The standard deviations of the accelerations are graphed in Figures 26 through 28, and the similar appearing RMS accelerations in Figures 29 through 31. These figures show a higher signal variance for the aft mounted accelerometers (both roadside and curbside) in the vertical and transverse directions. This means that the trailer is experiencing significant movement relative to the pintle/lunette, as these accelerometers were the most distant.

Also showing some significance is the longitudinal acceleration of the lunette in Figures 28 and 31. In the case where the brakes are enabled, both the standard deviation and RMS longitudinal accelerations are approximately twice that seen when the brakes are disabled.

Figures 32 through 34 show the statistical distributions of the acceleration data. With the surge brakes enabled, only the peak positive vertical acceleration of the drawbar was greater than the corresponding acceleration with the surge brakes disabled. In some cases, particularly longitudinal accelerations, the difference in the peak accelerations is quite pronounced.

TABLE 8 - ACCELERATION AMPLITUDE DISTRIBUTION DATA (BRAKES DISABLED) IN G'S

Description	Ave	Std Dev	RMS	+Peak	-Peak	+99.9	-99.9	+99	-99	+90	-90
Lunette (V)	0.12168	0.4581	0.4582	0.4583	0.4584	0.4585	0.4586	0.4587	0.4588	0.4589	0.4590
(T)	-0.075	0.3101	0.319	12.632	-8.3959	2.4542	-2.9747	0.5986	-0.7352	0.0754	-0.2314
(L)	-0.0889	0.1779	0.1989	4.0817	-4.6148	1.0331	-1.1936	0.3298	-0.5483	0.0693	-0.2562
Tongue (V)	-0.0525	0.4156	0.4189	13.57	-6.9543	1.996	-3.1291	0.7836	-1.1986	0.3574	-0.4531
(T)	-0.185	0.1688	0.2504	2.5198	-2.6362	1.1419	-1.1759	0.2237	-0.6285	-0.0321	-0.3397
(L)	-0.0053	0.1311	0.1312	1.9064	-1.0406	0.6609	-0.5848	0.3064	-0.3517	0.1384	-0.1608
CG (V)	0.1415	0.3706	0.3967	2.2667	-2.2081	1.6796	-0.8874	1.2249	-0.6657	0.6607	-0.2953
(T)	-0.0683	0.118	0.1363	0.7149	-0.594	0.4068	-0.467	0.2534	-0.3519	0.0749	-0.2094
(L)	0.0299	0.121	0.1266	1.6047	-0.4785	0.636	-0.3985	0.3406	-0.2693	0.1781	-0.1178
CS For. (V)	0.0317	0.3561	0.3575	4.3396	-3.1448	1.88	-1.6149	0.961	-0.8145	0.4544	-0.3714
(T)	0.0499	0.1613	0.1689	1.5647	-1.2575	0.9982	-0.7279	0.4733	-0.3657	0.2247	-0.1282
(L)	0.0808	0.2411	0.2543	1.8408	-1.0989	1.3538	-0.7164	0.7839	-0.5122	0.3503	-0.1999
CS Aft (V)	-0.0208	0.662	0.6623	4.1594	-2.3021	3.2007	-1.7933	2.1049	-1.4319	0.7118	-0.779
(T)	0.1244	0.3633	0.3834	5.6734	-4.6933	2.0413	-1.7544	1.1053	-0.7988	0.515	-0.2643
(L)	-0.1234	0.2317	0.2625	1.5709	-1.2324	1.0813	-0.9077	0.5811	-0.6385	0.1405	-0.3902
RS For (V)	0.0553	0.4088	0.4125	6.2374	-3.5506	2.0098	-2.0374	1.0706	-0.9092	0.544	-0.4075
(T)	-0.0394	0.1727	0.1171	1.5752	-1.3812	0.9449	-0.84	0.4047	-0.4783	0.15	-0.2343
(L)	-0.0745	0.2486	0.2596	1.975	-1.9357	1.1045	-0.8627	0.6167	-0.6569	0.2317	-0.3646
RS Aft (V)	0.0075	0.6042	0.6042	3.1227	-2.2267	2.3379	-1.5632	1.7719	-1.3449	0.7346	-0.6992
(T)	0.1265	0.3075	0.3325	4.2607	-3.6938	1.864	-1.4085	0.9809	-0.6421	0.4597	-0.2044
(L)	0.0394	0.2106	0.21421	1.3207	-0.7322	1.0818	-0.5791	0.65451	-0.4319	0.3096	-0.194
CS Axle (V)	0.0852	0.4934	0.5007	4.3174	-3.36	2.7369	-1.9719	1.5695	-1.0699	0.6409	-0.4585
CS Frame (V)	-0.0525	0.4021	0.4055	1.8081	-1.2716	1.6858	-1.0935	1.2094	-0.9464	0.4166	-0.523
RS Axle (V)	-0.0301	0.3931	0.3943	2.2952	-2.0173	1.7752	-1.4556	1.1079	-0.9078	0.4299	-0.4972
RS Frame (V)	-0.0261	0.3909	0.3917	1.6563	-1.1276	1.4053	-1.0349	1.1184	-0.9349	0.4417	-0.4812

TABLE 9 - ACCELERATION AMPLITUDE DISTRIBUTION DATA (BRAKES ENABLED) IN G'S

Description	Ave	Std Dev	RMS	+Peak	-Peak	+99.9	-99.9	+99	-99	+90	-90
Lunette (V)	0.2202	0.6183	0.6521	21.071	-13.441	4.802	-5.7613	1.5933	-1.4499	0.6616	-0.2016
(T)	-0.1545	0.5104	0.5332	15.779	-20.018	4.5127	-4.4471	1.0028	-1.3463	0.0511	-0.3657
(L)	0.0399	0.6974	0.6985	19.735	-29.825	5.7253	-7.9237	1.5271	-1.6708	0.2877	-0.217
Tongue (V)	0.13324	0.6087	0.6231	10.218	-12.366	4.929	-4.9009	1.5916	-1.559	0.5915	-0.3057
(T)	0.14123	0.2694	0.3041	6.8436	-7.2149	2.2118	-1.8035	0.8591	-0.5756	0.3469	-0.0689
(L)	0.13663	0.2205	0.2594	3.4864	-3.9984	1.9519	-1.5489	0.7293	-0.4116	0.3091	-0.0497
CG (V)	-0.1242	0.4284	0.446	4.5005	-7.6431	2.5262	-1.9716	1.1257	-1.112	0.3346	-0.5775
(T)	-0.0395	0.1547	0.1597	0.9022	-1.7508	0.5993	-0.9303	0.3599	-0.442	0.1384	-0.2067
(L)	0.1465	0.1861	0.2368	3.447	-3.808	1.7097	-1.0958	0.6771	-0.2548	0.311	-0.0186
CS For. (V)	-0.1274	0.4411	0.4591	4.3337	-7.9789	2.3179	-2.6774	1.0904	-1.2897	0.3406	-0.5656
(T)	0.021	0.2111	0.2121	3.1715	-2.8352	1.1754	-1.1853	0.6102	-0.5559	0.2416	-0.1919
(L)	0.1736	0.3394	0.3812	5.0471	-6.0943	2.6709	-2.0454	1.1309	-0.6452	0.4848	-0.1481
CS Aft (V)	0.0349	0.7652	0.766	8.4154	-6.3583	5.4353	-3.0088	2.3397	-1.7089	0.834	-0.7713
(T)	-0.0232	0.5302	0.5307	6.2574	-8.5646	3.6121	-3.5446	1.3968	-1.5638	0.4568	-0.484
(L)	-0.0918	0.3226	0.3354	4.8301	-4.9436	2.3277	-2.0992	0.8744	-0.8165	0.2134	-0.3956
RS For (V)	-0.0498	0.5111	0.5135	8.202	-9.5838	2.807	-2.972	1.3539	-1.406	0.4688	-0.56
(T)	0.1679	0.224	0.2799	3.7841	-4.5178	1.3926	-1.0656	0.7736	-0.4446	0.4001	-0.0569
(L)	-0.1321	0.3325	0.3485	4.3677	-7.5798	2.2229	-2.075	0.7561	-0.9025	0.1827	-0.439
RS Aft (V)	-0.1377	0.6953	0.7088	10.413	-3.8751	5.4252	-2.6428	1.8761	-1.6617	0.6125	-0.8755
(T)	0.139	0.4711	0.4912	9.1632	-8.374	3.4472	-3.4478	1.4288	-1.771	0.531	-0.2463
(L)	0.1491	0.2769	0.3144	4.6166	-3.0698	2.1879	-1.4118	0.9581	-0.446	0.434	-0.1111
CS Axle (V)	-0.0911	0.5322	0.534	4.1965	-2.9852	2.9817	-2.3028	1.5491	-1.3428	0.4993	-0.669
CS Frame (V)	-0.0405	0.4357	0.4376	3.5915	-2.6474	2.5291	-1.4417	1.2945	-1.0205	0.4558	-0.5216
RS Axle (V)	-0.024	0.423	0.4236	4.7063	-3.5782	3.0029	-1.6431	1.2476	-0.9086	0.4925	-0.4463
RS Frame (V)	0.0528	0.4271	0.4303	3.6333	-2.0387	2.6487	-1.2556	1.3515	-0.8782	0.5483	-0.4367

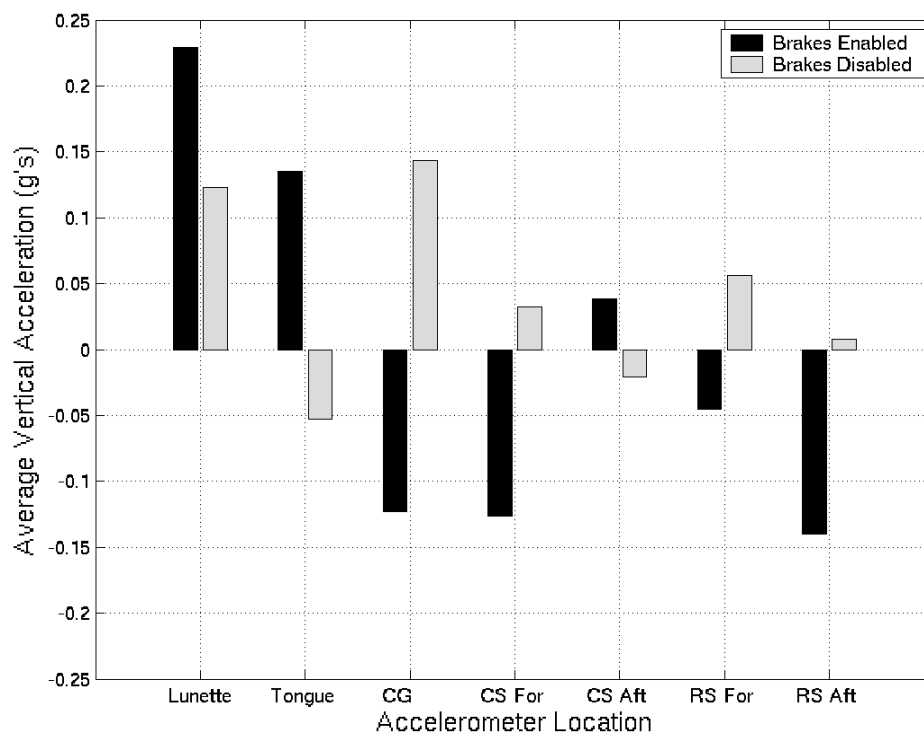


FIGURE 23 - AVERAGE VERTICAL ACCELERATIONS FOR SEVERAL TRAILER LOCATIONS

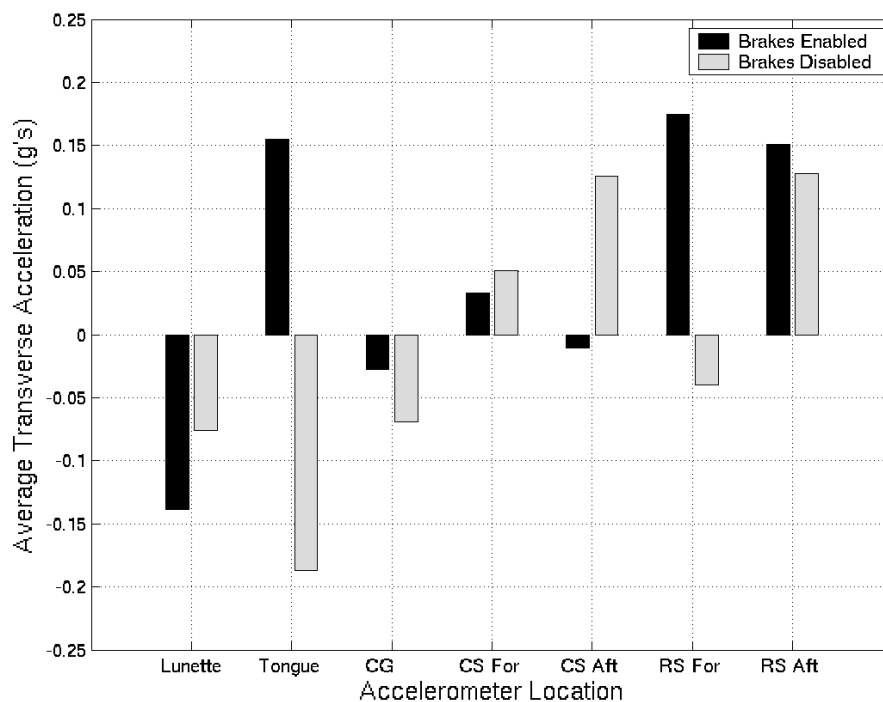


FIGURE 24 - AVERAGE TRANSVERSE ACCELERATIONS FOR SEVERAL TRAILER LOCATIONS

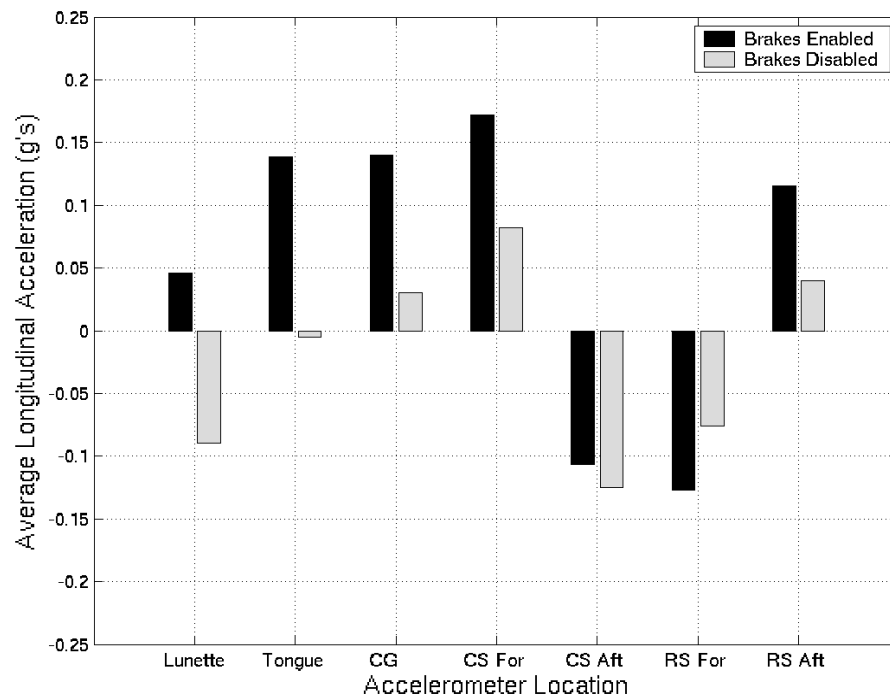


FIGURE 25 - AVERAGE LONGITUDINAL ACCELERATIONS FOR SEVERAL TRAILER LOCATIONS

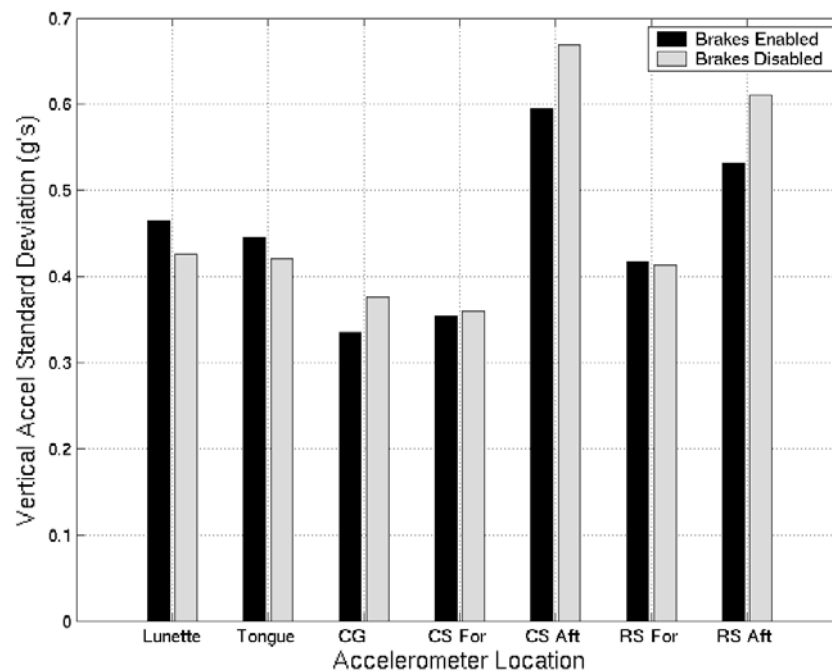


FIGURE 26 - VERTICAL ACCELERATION STANDARD DEVIATION FOR SEVERAL TRAILER LOCATIONS

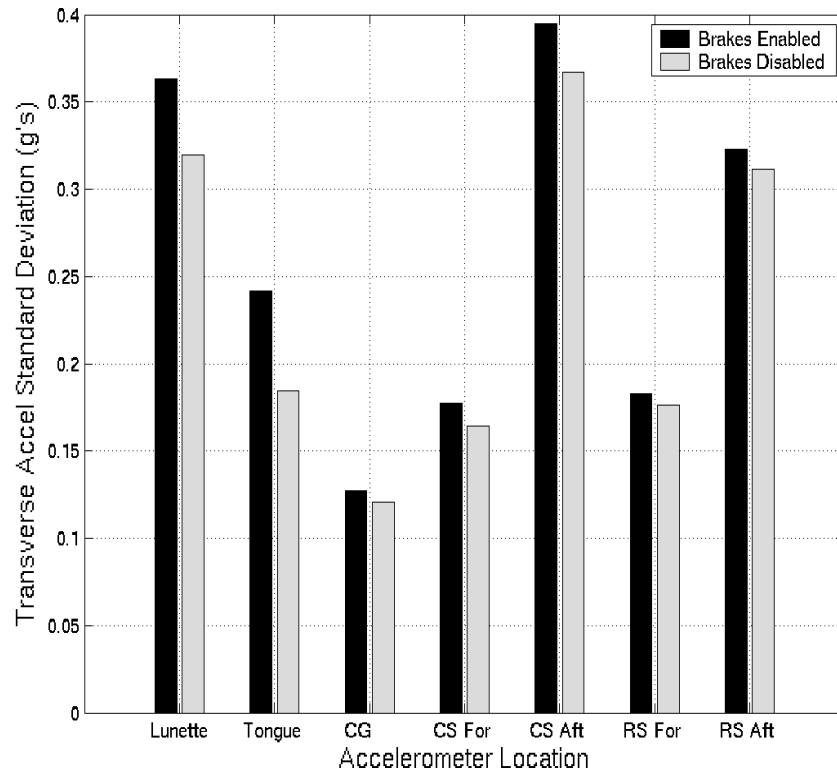


FIGURE 27 - TRANSVERSE ACCELERATION STANDARD DEVIATION FOR SEVERAL TRAILER LOCATIONS

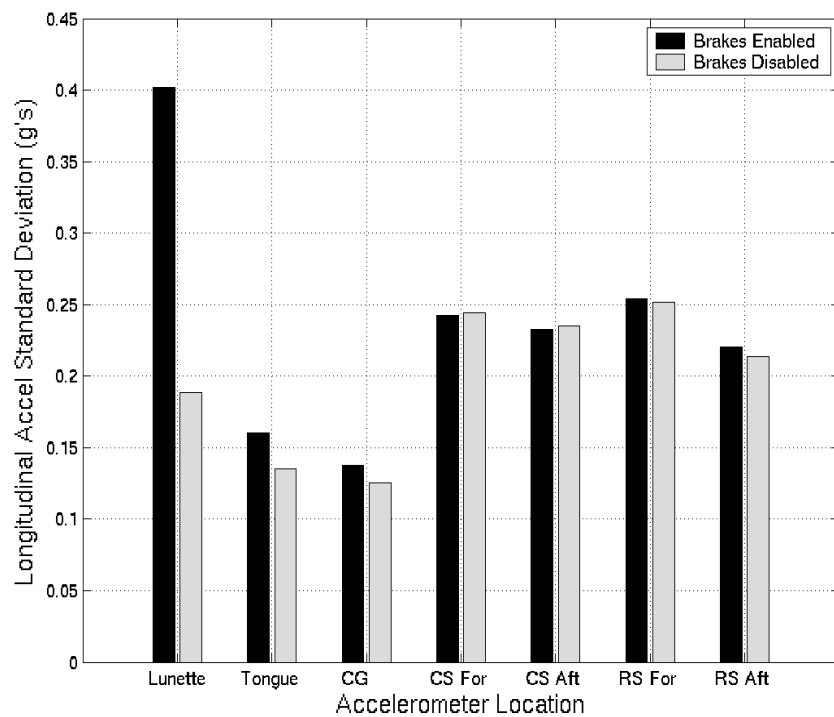


FIGURE 28 - LONGITUDINAL ACCELERATION STANDARD DEVIATION FOR SEVERAL TRAILER LOCATIONS

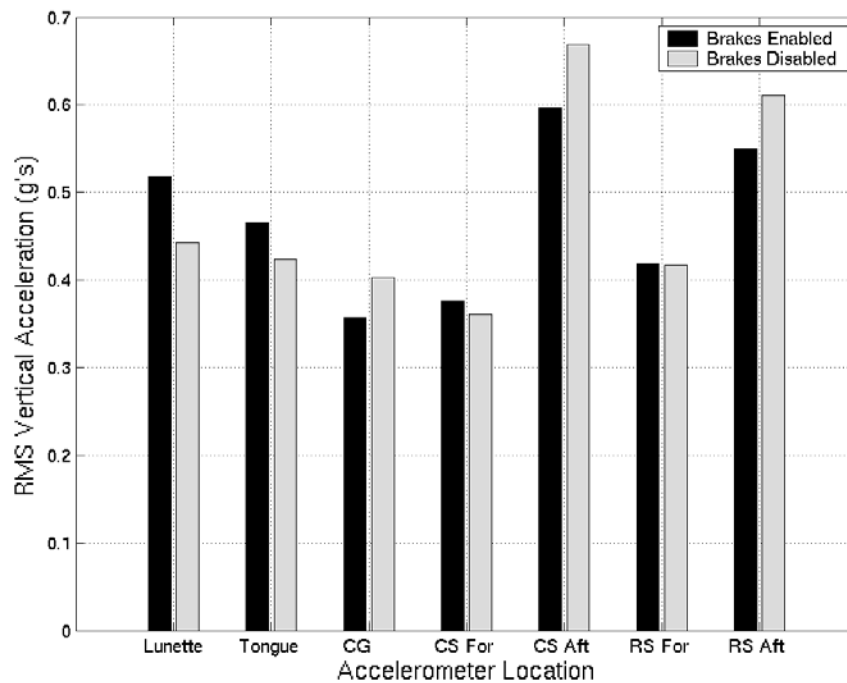


FIGURE 29 - VERTICAL RMS ACCELERATIONS FOR SEVERAL TRAILER LOCATIONS

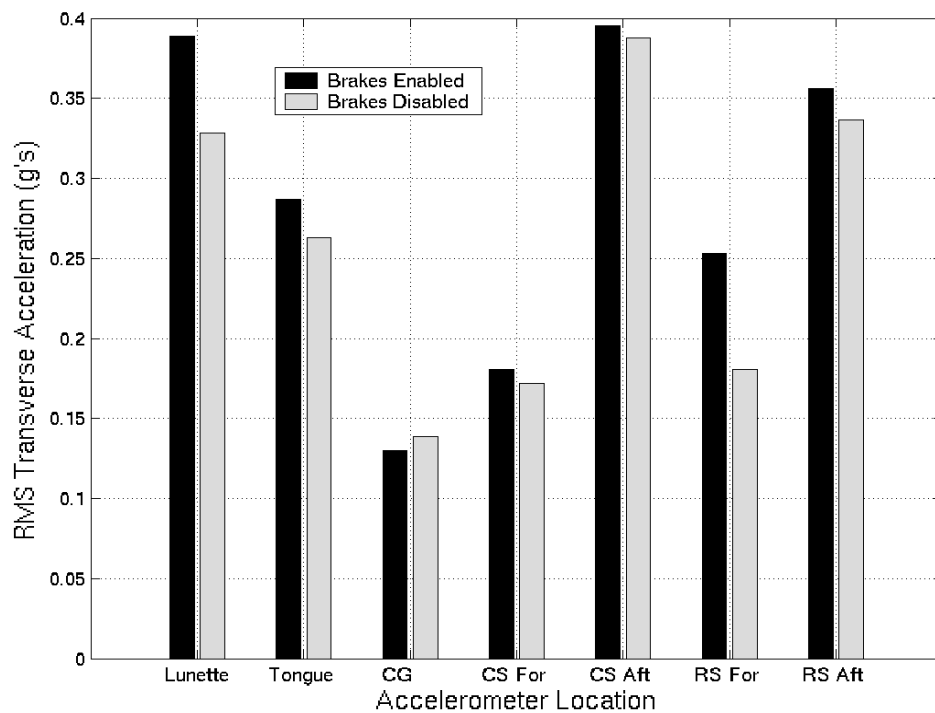


FIGURE 30 - TRANSVERSE RMS ACCELERATIONS FOR SEVERAL TRAILER LOCATIONS

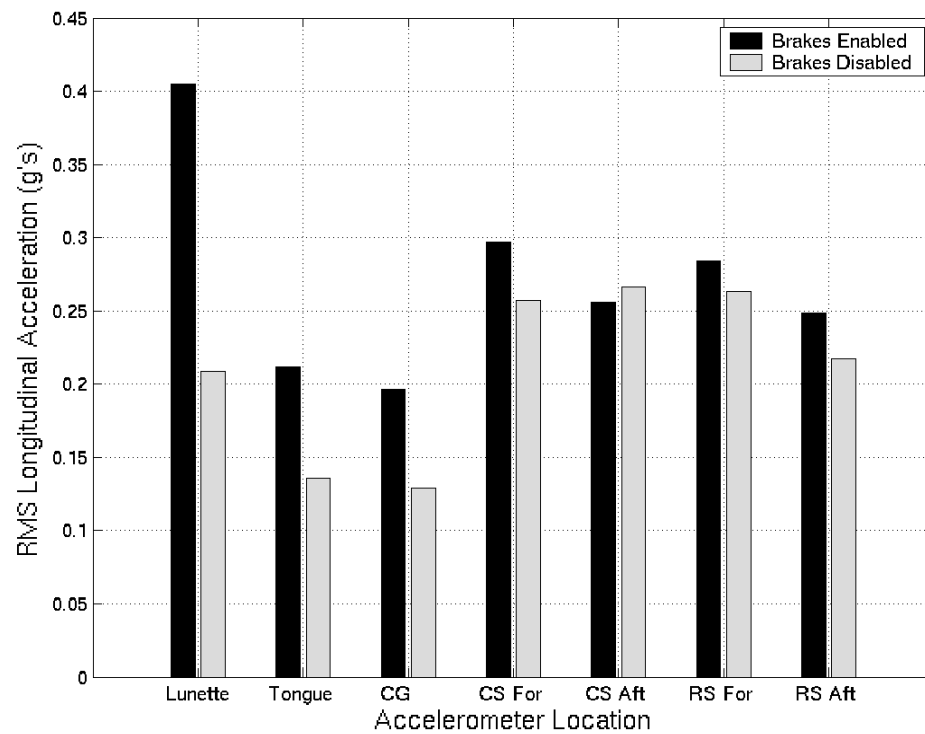


FIGURE 31 - LONGITUDINAL RMS ACCELERATIONS FOR SEVERAL TRAILER LOCATIONS

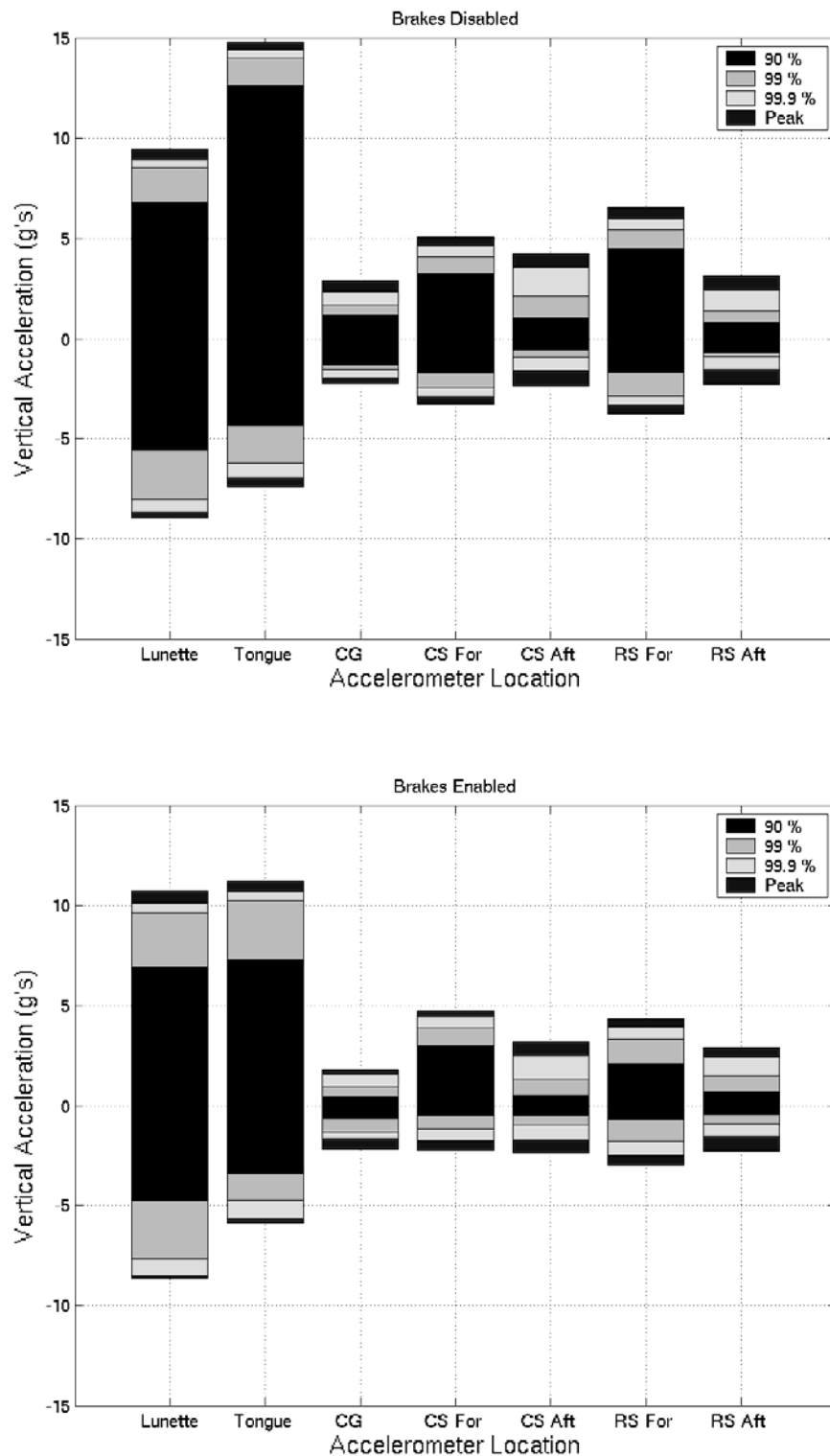


FIGURE 32 - VERTICAL ACCELERATION STATISTICS FOR SEVERAL TRAILER LOCATIONS

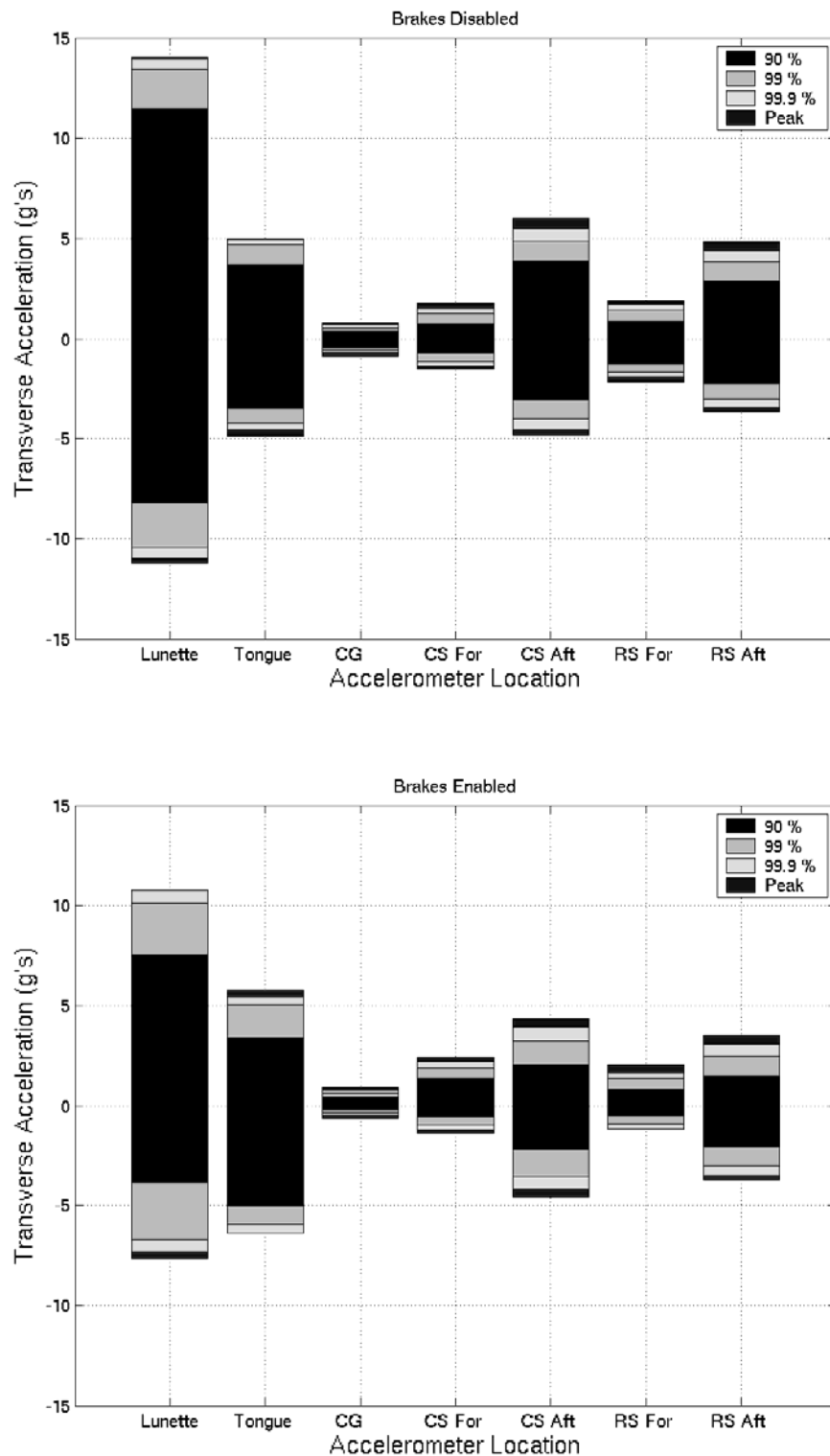


FIGURE 33 - TRANSVERSE ACCELERATION STATISTICS FOR SEVERAL TRAILER LOCATIONS

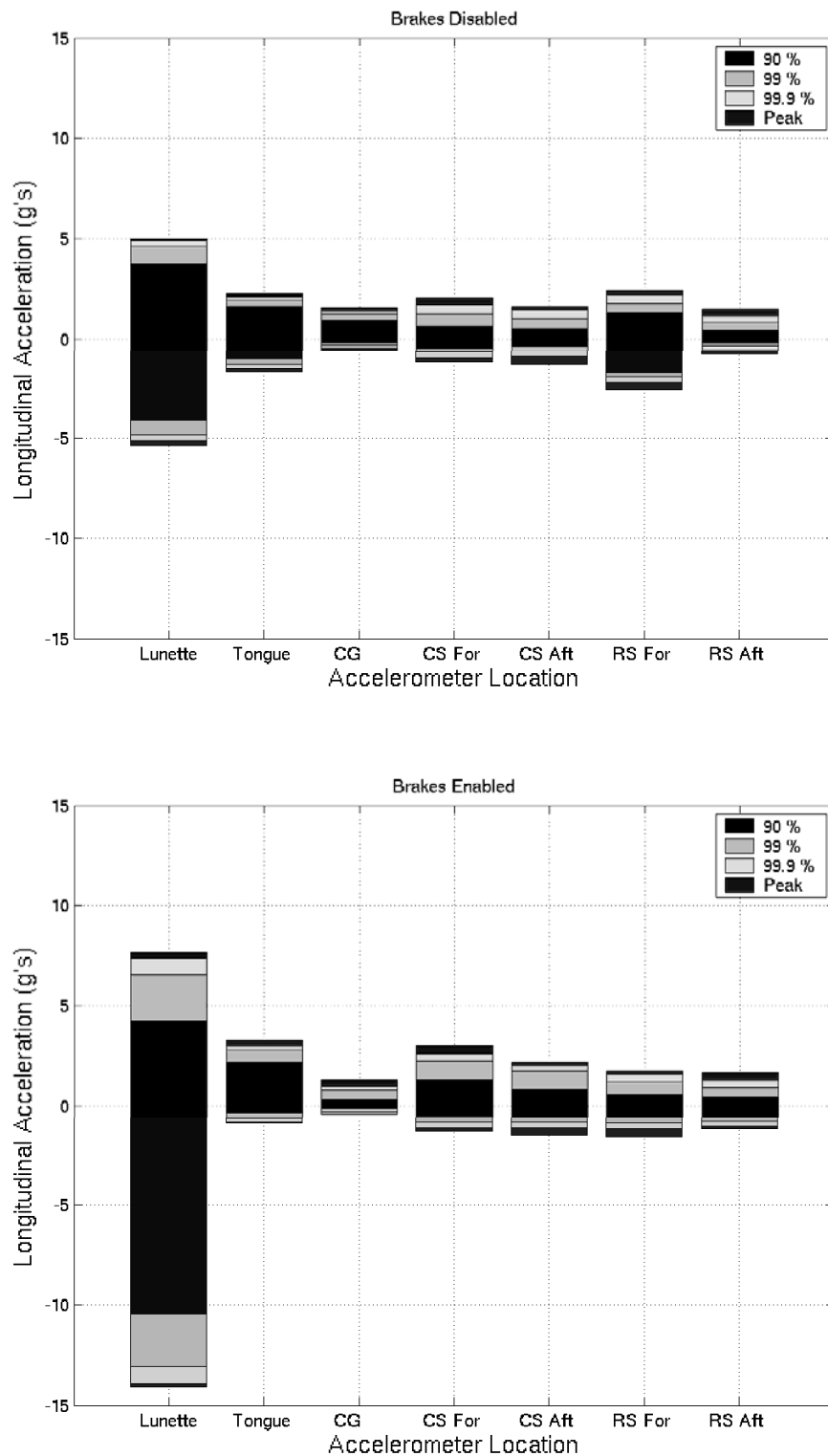


FIGURE 34 - LONGITUDINAL ACCELERATION STATISTICS FOR SEVERAL TRAILER LOCATIONS

4.2.3 Rate-gyro Data

The statistical data for the rate-gyros is provided in Tables 10 and 11 and in Figures 35 through 38. Similar to the accelerometer data, the signal average is expected to be zero; however rate-gyros are notorious for bias drift. In this case, only the pitch rate data average exceeded 0.3 degree/second.

TABLE 10 - RATE-GYRO DISTRIBUTION DATA (BRAKES DISABLED) IN DEGREE/SECOND

Description	Ave	Std Dev	RMS	+Peak	-Peak	+99.9	-99.9	+99	-99	+90	-90
CG Pitch Rate	0.5062	21.129	21.13	86.102	-86.514	82.994	-83.458	65.056	-55.193	24.919	-22.348
CG Roll Rate	0.1854	6.816	6.817	26.256	-28.468	25.406	-26.223	16.541	-16.635	8.6564	-8.4134
CG Yaw Rate	-0.0332	4.5215	4.5206	16.61	-13.423	15.613	-11.701	11.204	-9.9055	6.0071	-5.5888

TABLE 11 - RATE-GYRO DISTRIBUTION DATA (BRAKES ENABLED) IN DEGREE/SECOND

Description	Ave	Std Dev	RMS	+Peak	-Peak	+99.9	-99.9	+99	-99	+90	-90
CG Pitch Rate	0.5062	21.129	21.13	86.102	-86.514	82.994	-83.458	65.056	-55.193	24.919	-22.348
CG Roll Rate	0.1854	6.816	6.817	26.256	-28.468	25.406	-26.223	16.541	-16.635	8.6564	-8.4134
CG Yaw Rate	-0.0332	4.5215	4.5206	16.61	-13.423	15.613	-11.701	11.204	-9.9055	6.0071	-5.5888

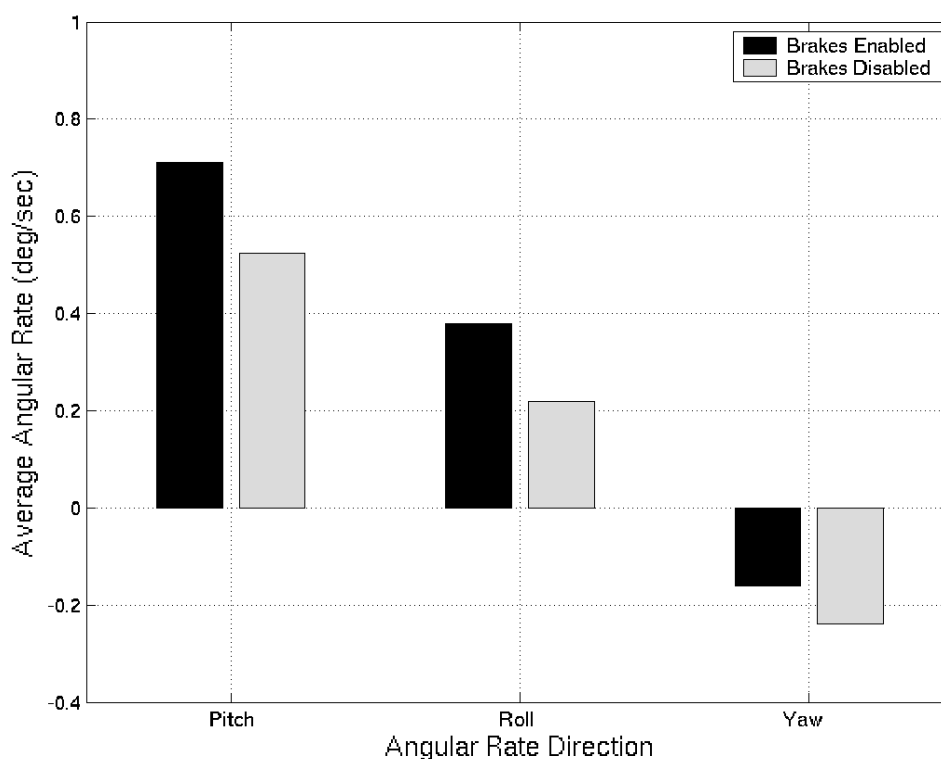


FIGURE 35 - AVERAGE RATE-GYRO ANGULAR RATES

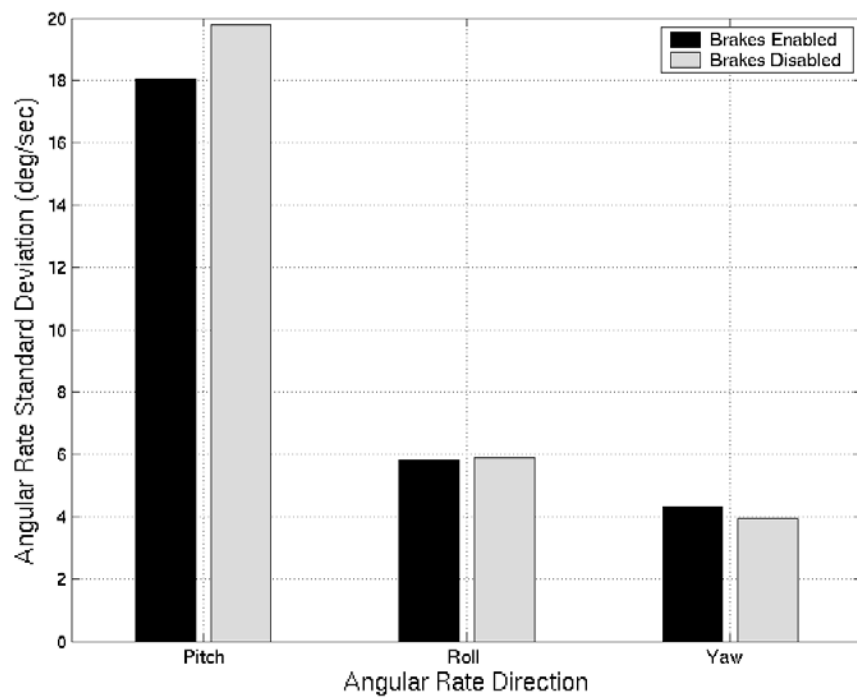


FIGURE 36 - RATE-GYRO ANGULAR RATE STANDARD DEVIATIONS

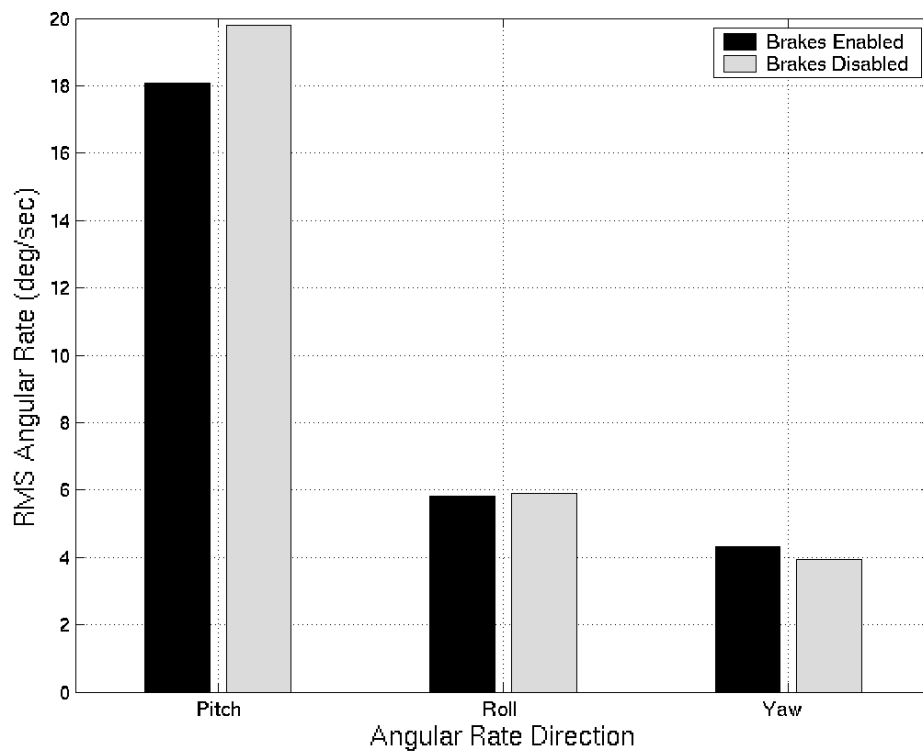


FIGURE 37 - RATE GYRO RMS ANGULAR RATES

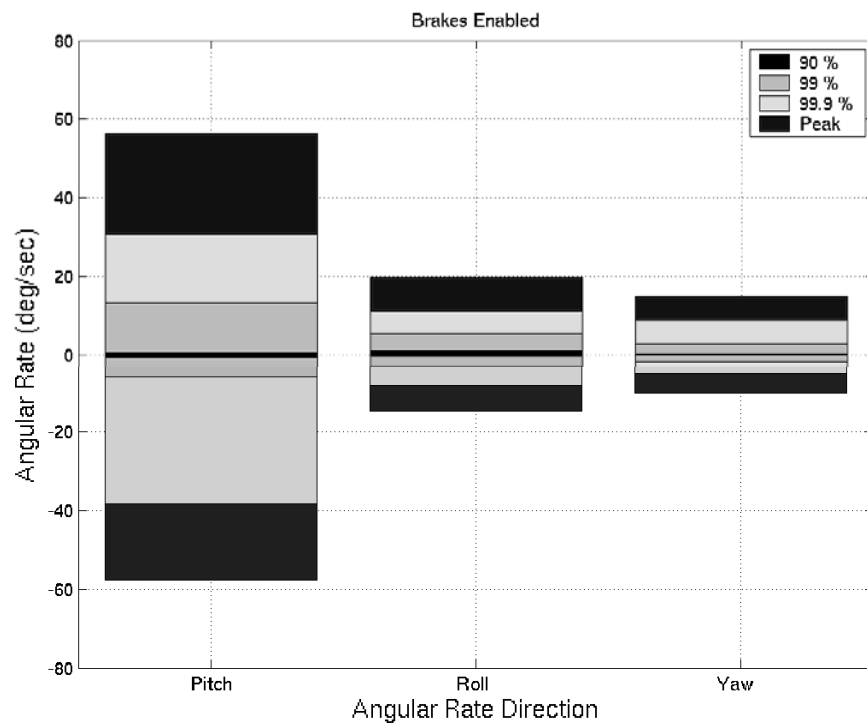
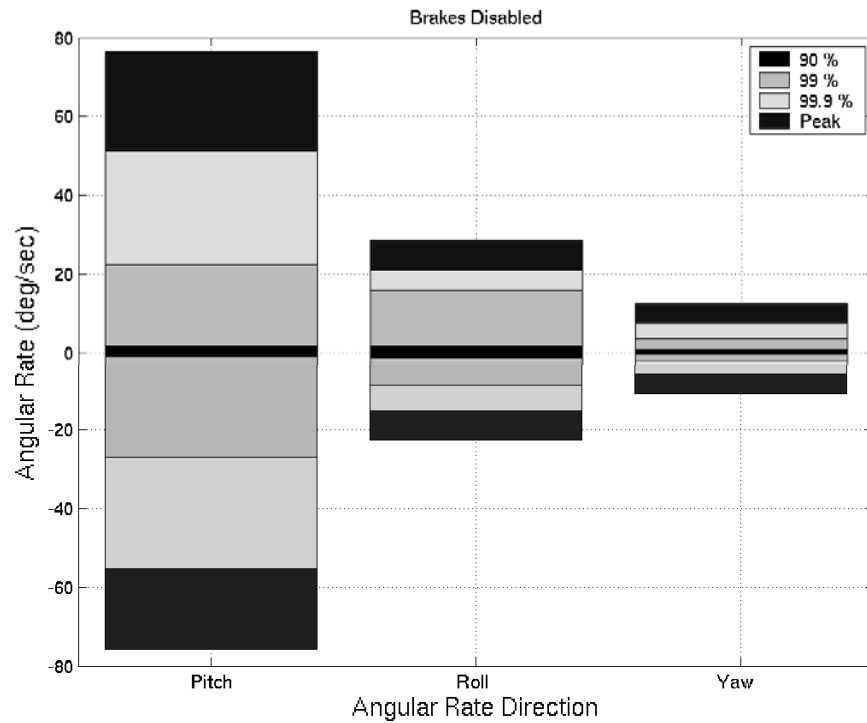


FIGURE 38 - RATE-GYRO ANGULAR RATE DISTRIBUTIONS



FIGURE 39 - TRAILER SUSPENSION

4.2.4 Linear Displacement Transducer Data

The trailer has a trailing arm suspension, shown in Figure 39. The shock absorber is oriented approximately 90 degrees from the axis of the trailing arm, and the transducer (not shown) was co-linear with the shock. Tables 14 and 15 detail the statistics of the axle displacement with the surge brakes disabled and enabled, respectively.

The average displacements are shown in Figure 40, while the standard deviations and RMS values are shown in Figures 41 and 42. Finally, the statistical distributions are shown in Figure 43.

TABLE 12 - LINEAR DISPLACEMENT DISTRIBUTION DATA (BRAKES DISABLED) IN INCHES

Description	Ave	Std Dev	RMS	+Peak	-Peak	+99.9	-99.9	+99	-99	+90	-90
CS Shock Displacement	0.0305	0.24631	0.2481	0.8698	-0.7029	0.86805	-0.692	0.82091	-0.6177	0.3067	-0.2535
RS Shock Displacement	0.0132	0.0133	0.0134	0.0135	0.0136	0.0137	0.0138	0.0139	0.0140	0.0141	0.0142

TABLE 13 - LINEAR DISPLACEMENT DISTRIBUTION DATA (BRAKES ENABLED) IN INCHES

Description	Ave	Std Dev	RMS	+Peak	-Peak	+99.9	-99.9	+99	-99	+90	-90
CS Shock Displacement	0.0538	0.2594	0.2649	1.1323	-0.6997	1.0674	-0.6905	0.845	-0.5695	0.35244	-0.2458
RS Shock Displacement	0.0258	0.2417	0.243	1.0241	-0.5707	0.9407	-0.5581	0.7497	-0.5421	0.33093	-0.2517

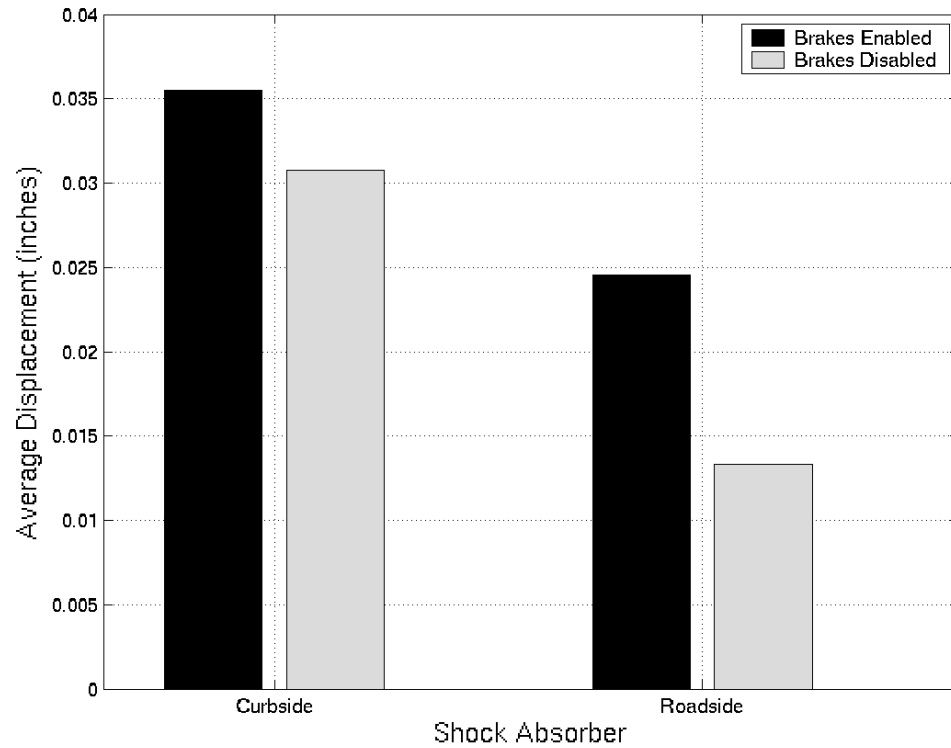


FIGURE 40 - LINEAR DISPLACEMENT AVERAGE VALUE (INCHES)

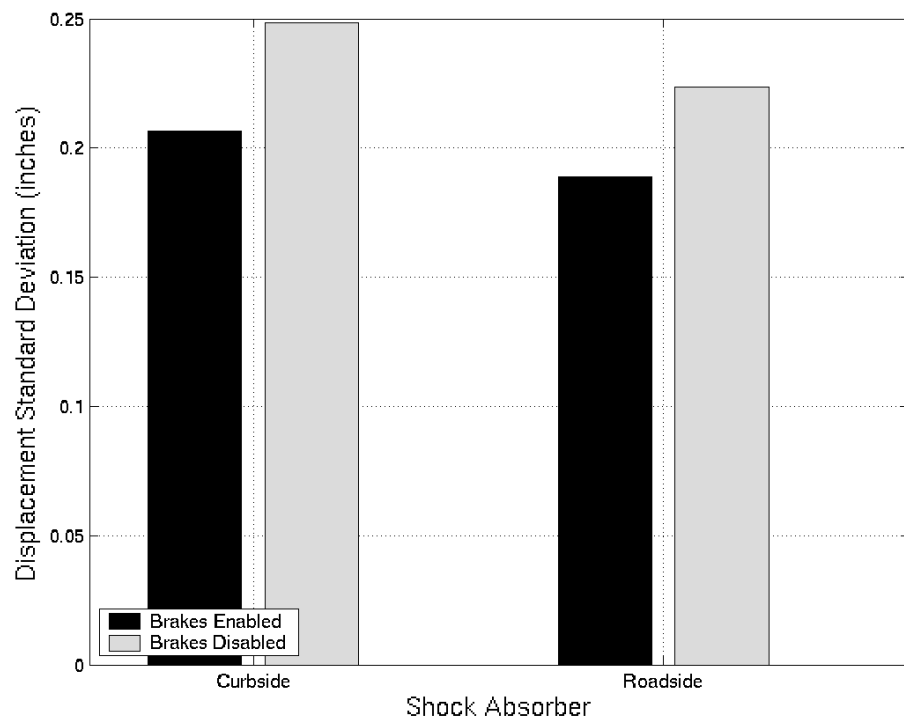


FIGURE 41 - LINEAR DISPLACEMENT STANDARD DEVIATION (INCHES)

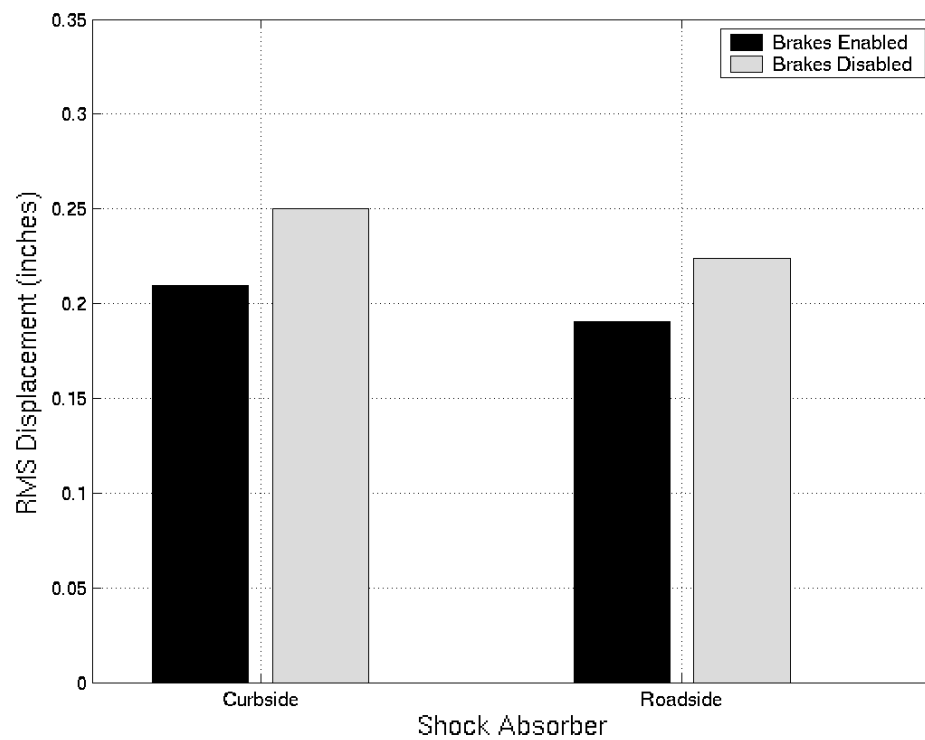


FIGURE 42 - LINEAR DISPLACEMENT RMS VALUE (INCHES)

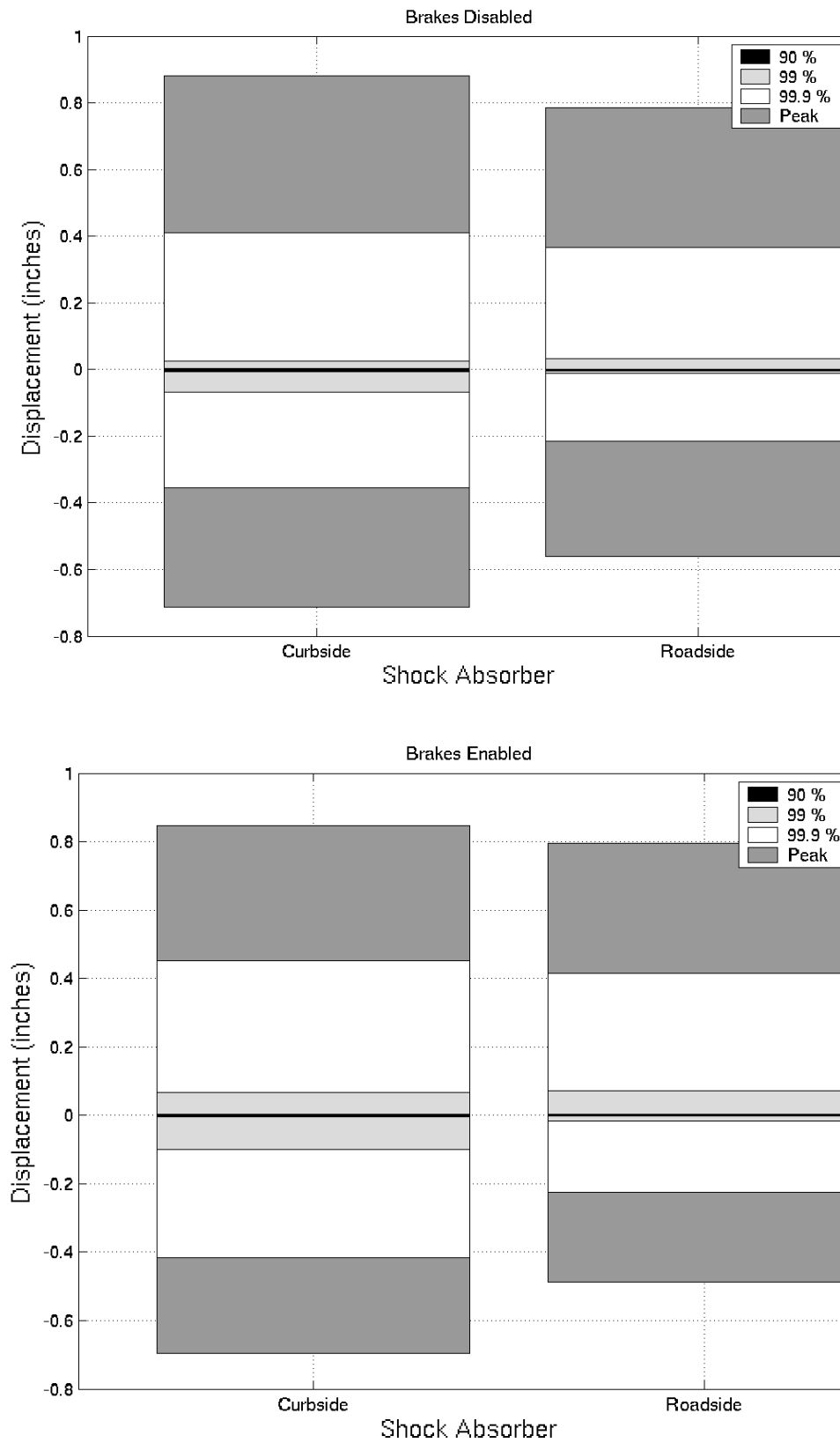


FIGURE 43 - LINEAR DISPLACEMENT DISTRIBUTIONS (INCHES)

4.2.5 Pressure Transducer Data

Analysis of the brake pressure transducer data is given in Tables 14 and 15 for the disabled and enabled brake system, respectively. It was expected that the brake system pressure would be zero when the system was disabled, but this was not true. Figures 44 through 47 provide graphical representations of the statistics to make the data more readable.

TABLE 14 - BRAKE PRESSURE DISTRIBUTION DATA (BRAKES DISABLED) IN PSI

Description	Ave	Std Dev	RMS	+Peak	-Peak	+99.9	-99.9	+99	-99	+90	-90
Master Cylinder Pressure	9.5460	0.6018	9.5650	12.1460	6.6650	11.6480	8.1600	11.1500	8.1600	10.1530	8.6580
CS Wheel Brake Pressure	-1.5119	0.6273	1.6369	4.1900	-2.6010	3.2200	-2.1160	1.7640	-1.6310	-1.6310	-1.6310
RS Wheel Brake Pressure	1.1531	0.4883	1.2522	6.1650	0.0550	5.1470	0.5640	4.1280	1.0740	1.0740	1.0740

TABLE 15 - BRAKE PRESSURE DISTRIBUTION DATA (BRAKES ENABLED) IN PSI

Description	Ave	Std Dev	RMS	+Peak	-Peak	+99.9	-99.9	+99	-99	+90	-90
Master Cylinder Pressure	-13.168	18.8242	22.9726	86.8900	-23.232	85.395	-22.236	77.422	-21.738	2.6790	-21.239
CS Wheel Brake Pressure	-16.225	16.4085	23.0752	67.7330	-24.914	66.277	-24.914	60.457	-24.429	-1.6310	-23.944
RS Wheel Brake Pressure	-16.001	16.9422	23.3035	73.3690	-25.401	71.283	-25.401	62.677	-24.382	1.0740	-23.873