SPECTRUM
Technologies, Inc.

Sulastic Rubber Springs

2007 Toyota Tundra Sulastic Isolator Evaluation

October 13, 2007

SPECTRUM Technologies, Inc.

Engineering Report
Michael B. Pickel

Date of Order:	10/5/07
Test Date:	10/8-9/07
Date Reported:	10/13/07
Project Number:	SULASTIC

SUBJECT: 2007 Toyota Tundra Sulastic Isolator Comparison to Baseline Suspension

REQUESTER: Sulastic Rubber Springs
Requesting Engineer – Roberto Tapia CEO (408) 239-4527

OBJECTIVE: To compare and document the improvements in ride quality of the 2007 Toyota Tundra due to Sulastic isolators.

TEST ITEMS: One 2007 Toyota Tundra CrewMax Limited VIN: TBDV58137S477888
One set Prototype Sulastic Isolators for the 2007 Tundra

PROCEDURE: Members from Sulastic Rubber traveled to Spectrum in Redford, Michigan with prototype isolators for the new Tundra. The Tundra was instrumented with 6 triaxial accelerometers to measure both the baseline condition and the same conditions with the Sulastic isolators. The accelerometer locations and components were defined as follows:

Accelerometer	Channel	Tag Description
1X	1	Right Rear Frame Rail +X
1Y	2	Right Rear Frame Rail –Y
1Z	3	Right Rear Frame Rail -Z
2X	4	Right Rear Frame @ Shock Tower +X
2Y	5	Right Rear Frame @ Shock Tower +Y
2Z	6	Right Rear Frame @ Shock Tower +Z
3X	7	Right Rear Front Spring Eye +X
3Y	8	Right Rear Front Spring Eye –Y
3Z	9	Right Rear Front Spring Eye +Z
4X	10	Top of axle Right Side +X
4Y	11	Top of axle Right Side +X
4Z	12	Top of axle Right Side +X
5X	13	Right Rear Body @ Mount -X
5Y	14	Right Rear Body @ Mount +Y
5Z	15	Right Rear Body @ Mount -Z
6X	16	Drivers Left Rear Seat Attachment –X
6Y	17	Drivers Left Rear Seat Attachment –Y
6Z	18	Drivers Left Rear Seat Attachment +Z

Triaxial accelerometers were used at each location. The global coordinate system was used was for each accelerometer. PCB triaxial accelerometers were attached at or near each component – photos were taken and presented in this report.

The PCB accelerometers were attached to a Mars Lab EBRT. Data was recorded at 256 samples per second, filtered at 128 Hz and stored to disk. There was one test recorded to disk at Spectrum. The test is titled "Tundra". The following is a list of each road surface/condition recorded for test Tundra:

Data set	**Road Surface Description**
.000	Baseline I-275 South 70 mph – "Highway Hop"
.001	Baseline Smooth Road I-96 West 75 mph
.002	Baseline Rough Road Glendale W to E 25 mph
.003	Baseline Pot hole 10 mph
.004	Baseline Railroad Crossing E to W 25 mph
.005	Baseline Railroad Crossing W to E 25 mph
.006	Sulastic Isolators Crossing E to W 25 mph
.007	Sulastic Isolators Rough Road Glendale W to E 25 mph
.008	Sulastic Isolators Pot hole 10 mph
.009	Sulastic Isolators I-275 South 70 mph – "Highway Hop"
.010	Sulastic Isolators Smooth Road I-96 West 75 mph

.

The data was sampled at 256 samples per second. The filters were set to 128 Hz. The recorded data is "flat" to 100 Hz.

After the data was collected and reviewed on the road, the equipment and computer containing the data sets were returned to Spectrum for processing. The data was processed into nCode "dac" files. The data was analyzed using time histories of acceleration and displacement. Peak-hold FFT's and linear averaged FFT's were also used.

The data will also be archived at Spectrum for future use if needed.

RESULTS:

The Sulastic Isolators made a significant difference in the overall performance of the Tundra. The Sulastic isolators significantly reduced the impact harshness over potholes, railroad crossings and broken pavement. The Sulastic isolators reduced "highway Hop" by 50 percent**.** The isolators also reduced the rigid body pitch mode by 75 percent – the vehicle with the sulastic isolators stays level under all normal driving conditions. **It is important to note that the isolators tested were the first set of prototypes and were NOT optimally tuned for the Tundra, rather just a good estimate of stiffness to begin testing and evaluating**. **The mounts must now be 'Tuned" for the Tundra application.** It was noted that the ride quality on smooth road did show signs of slight "nervousness". Spectrum believes this to be due to the mounts tested as being too soft in the fore-aft direction – a stiffer mount will work better. This fact is known due to the initial evaluation performed on 10/8 was at 93 degrees and the mounts did show signs of additional fore-aft motion on smooth road. However on this morning, 10/13, the temperature was 36 degrees and the truck road significantly better (Thermal swings of 60 degrees are common this time of year in Michigan!). The smooth road performance with the Sulastic Isolators in colder temperatures was equal to the smooth road performance of the stock system when warm.

It must also be mentioned that the Tundra has a significant frame bending mode at 7.7 Hz. The bending occurs at the rear kick-up in the frame. The frame at this section is open C channel and flexes significantly over undulating concrete surfaces. The Sulastic mounts reduced this hopping motion by 50 percent, however, the Sulastic isolators effectively reduces the vertical leaf spring rate by translating the energy in the fore-aft direction. This reduction in vertical spring stiffness tends to make the shock absorbers feel too stiff for the new effective vertical spring rate. To take full advantage of the Sulastic system, Spectrum believes adjustable rear shocks are needed. The compression rate of the rear shocks can now be reduced for better ride over SMOOTHER road surfaces. The results of the testing can be viewed in the Plots1-18 in this report. Set-up photos are in Photos 1-9.

With the Sulastic isolators installed, the energy from the front suspension is more noticeable. This is either due to the fact that the front is now harsher than the rear and is perceived more significant, or the significant reduction in the 1.6 Hz body pitch mode has applied more energy to the front of the vehicle. Further testing will tell.

RECOMMENDATIONS:

The Sulastic isolators performed well for the first prototype set, however, the spring rates of the isolator's needs to be optimized, or "tuned" for the specific Tundra application.

Spectrum would like to evaluate the following conditions:

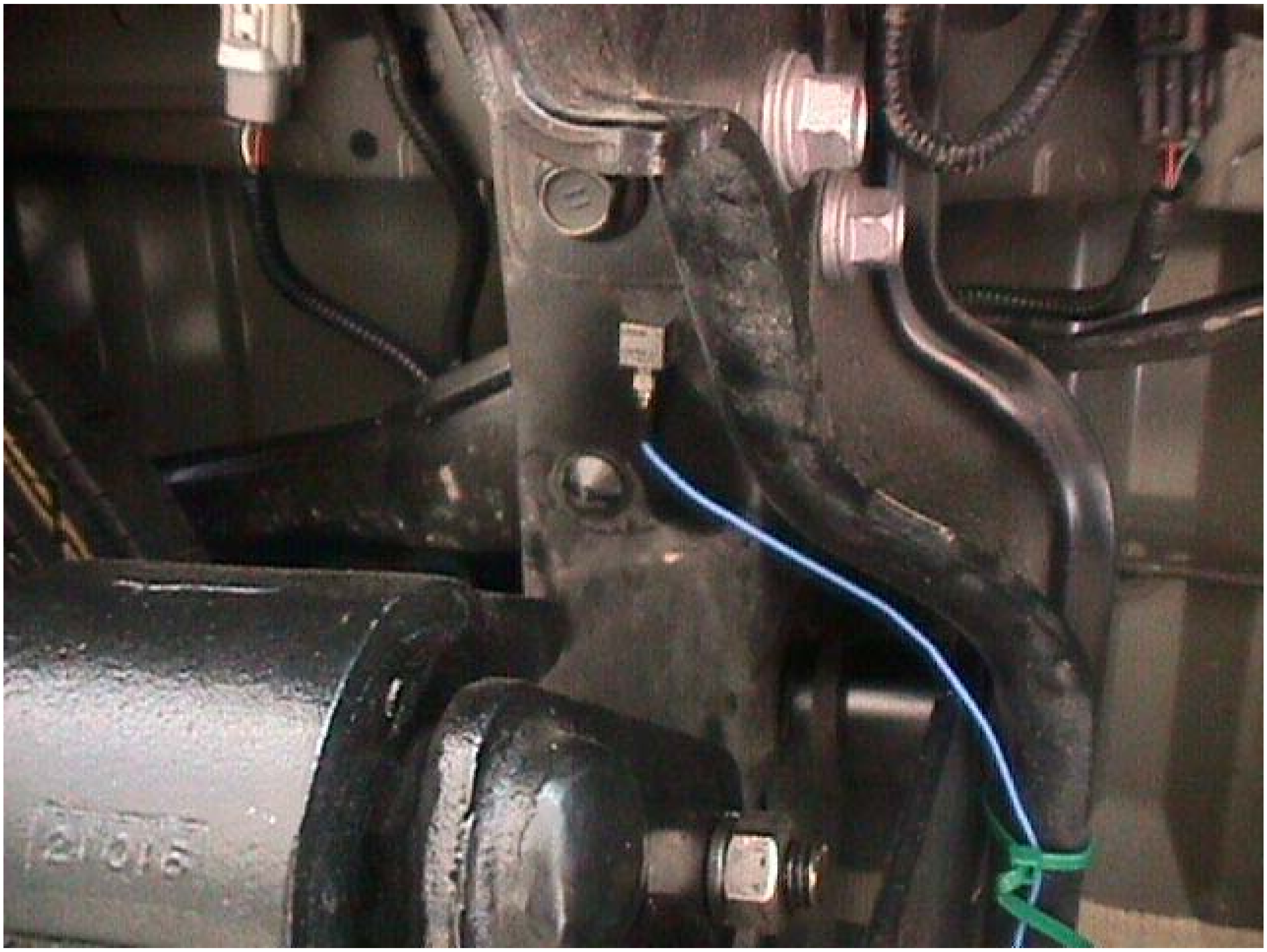
1) Stiffer Sulastic mounts with baseline system
2) Stiffer Sulastic mounts with adjustable Rancho 9000 Series Shocks in the rear
   The rear shocks are on order and will be at Spectrum Shortly.
3) Stiffer Sulastic mounts and al 4 adjustable Rancho shocks.
   The front shocks are on order and will be at Spectrum Shortly.
4) Numbers 1-3 with a 15 lb. tuned absorber on the rear of the frame
   One is currently on a Dodge megacab and will work on the Tundra!

Changing one part of a factory suspension will effect the overall tuning and performance of the rest of the factory parts. The factory system was optimized and tuned with all of the baseline components. The installation of the Sulastic isolators is an excellent starting point to improve ride quality, however, to take full advantage of the new SYSTEM the rest of the components must be tuned to work in unison.

Michael B. Pickel
Development Engineer

Vehicle used for evaluation

Photo 1

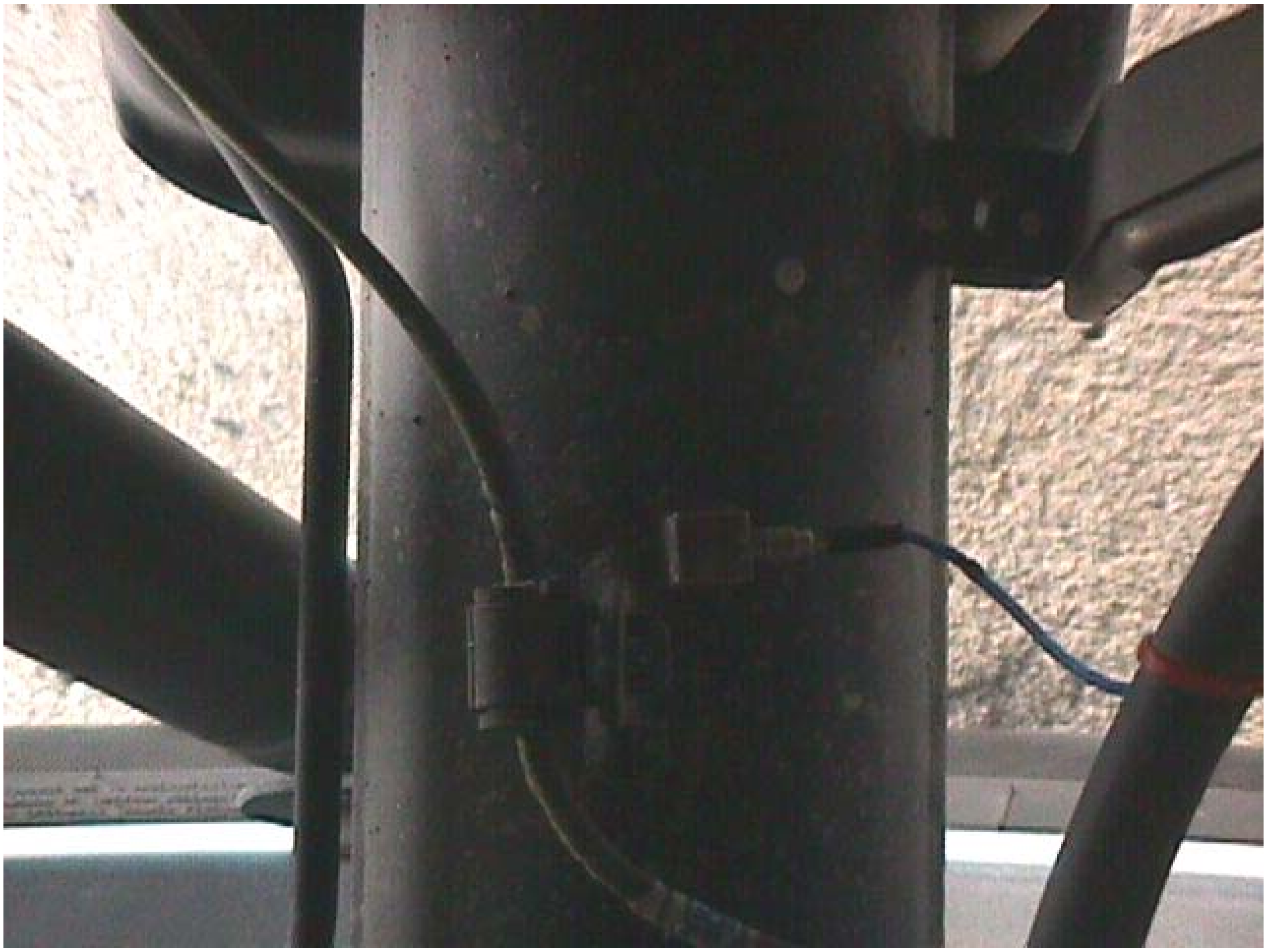


Triaxial accelerometer #1 at right rear of frame.
The right side was chosen due to the fact that is does not have the fuel tank, this allows the right side to have more energy over impacts than the left side.

Triaxial Accelerometer #2 at right shock tower

Triaxial Accelerometer #3 at front spring eye

Photo 4



Triaxial Accelerometer #4 on top of axle

Photo 5

Triaxial Accelerometer #5 on right rear body at mount

Photo 6

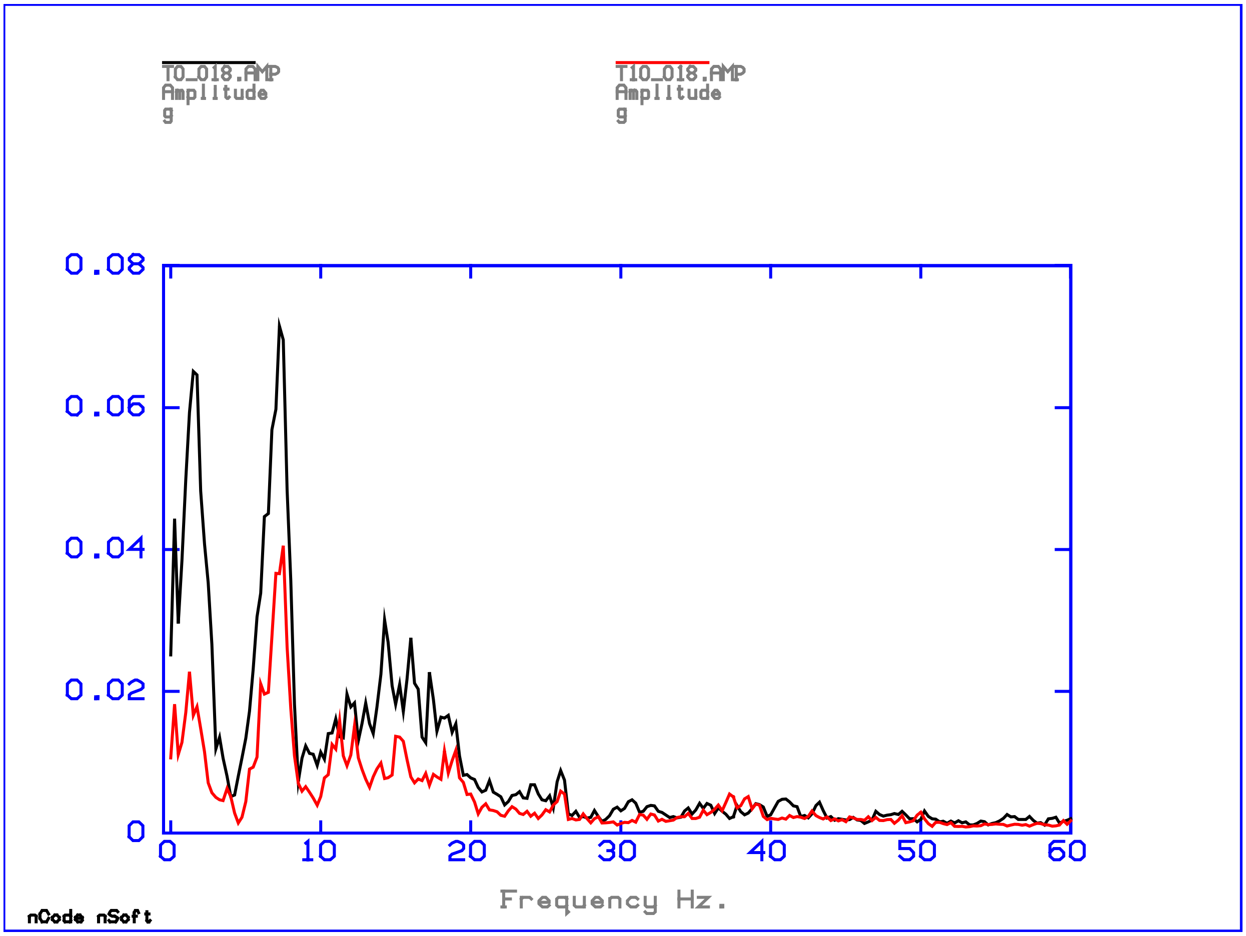
Triaxial Accelerometer #6 on drivers right rear seat pedestal

Photo 7

Mars Labs EBRT data Acquisition system used to collect data

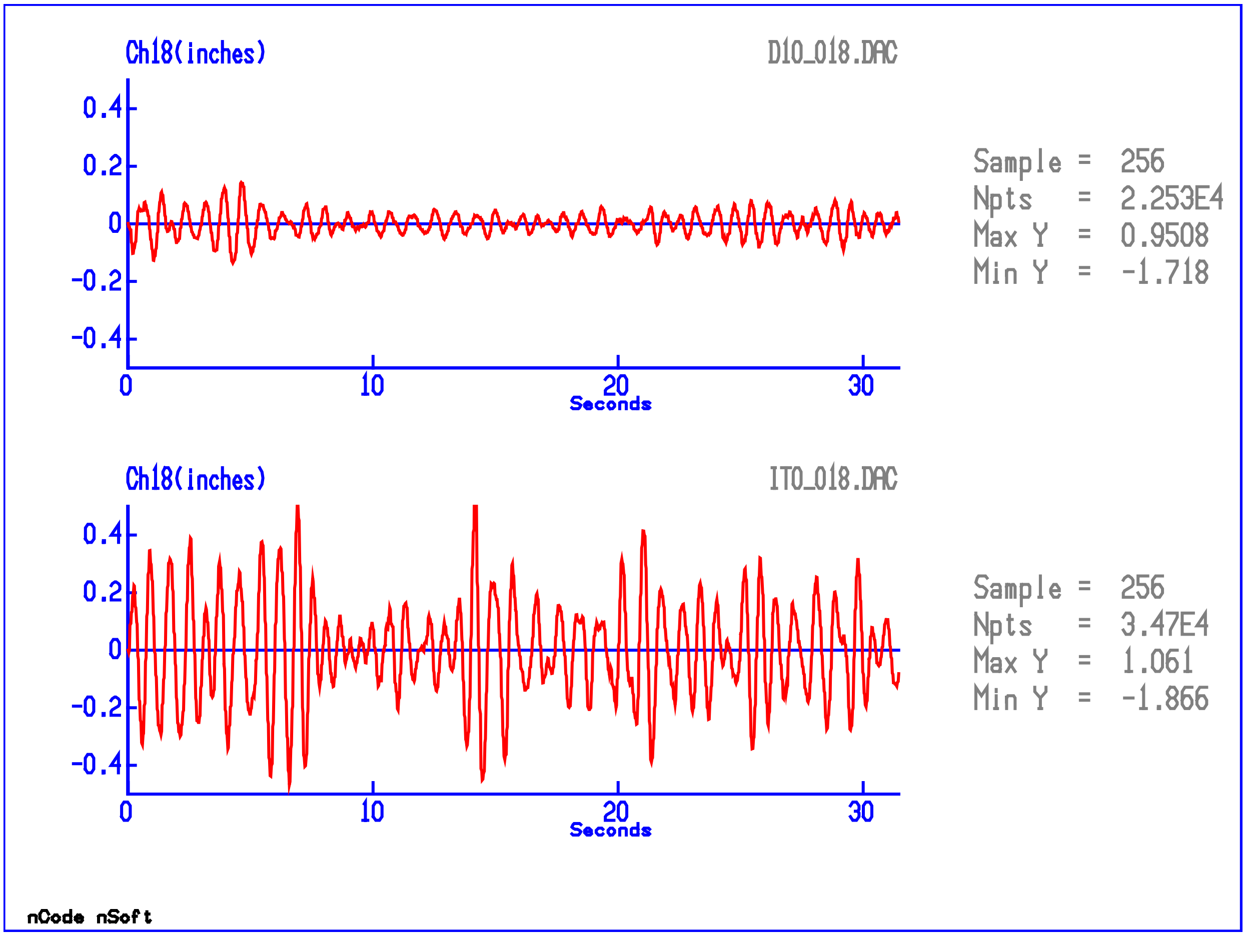
Photo 8

Installed Sulastic Isolator – right side



Seat Track Vertical Acceleration– Peak hold g's
Black = Baseline suspension
Red= Sulastic suspension

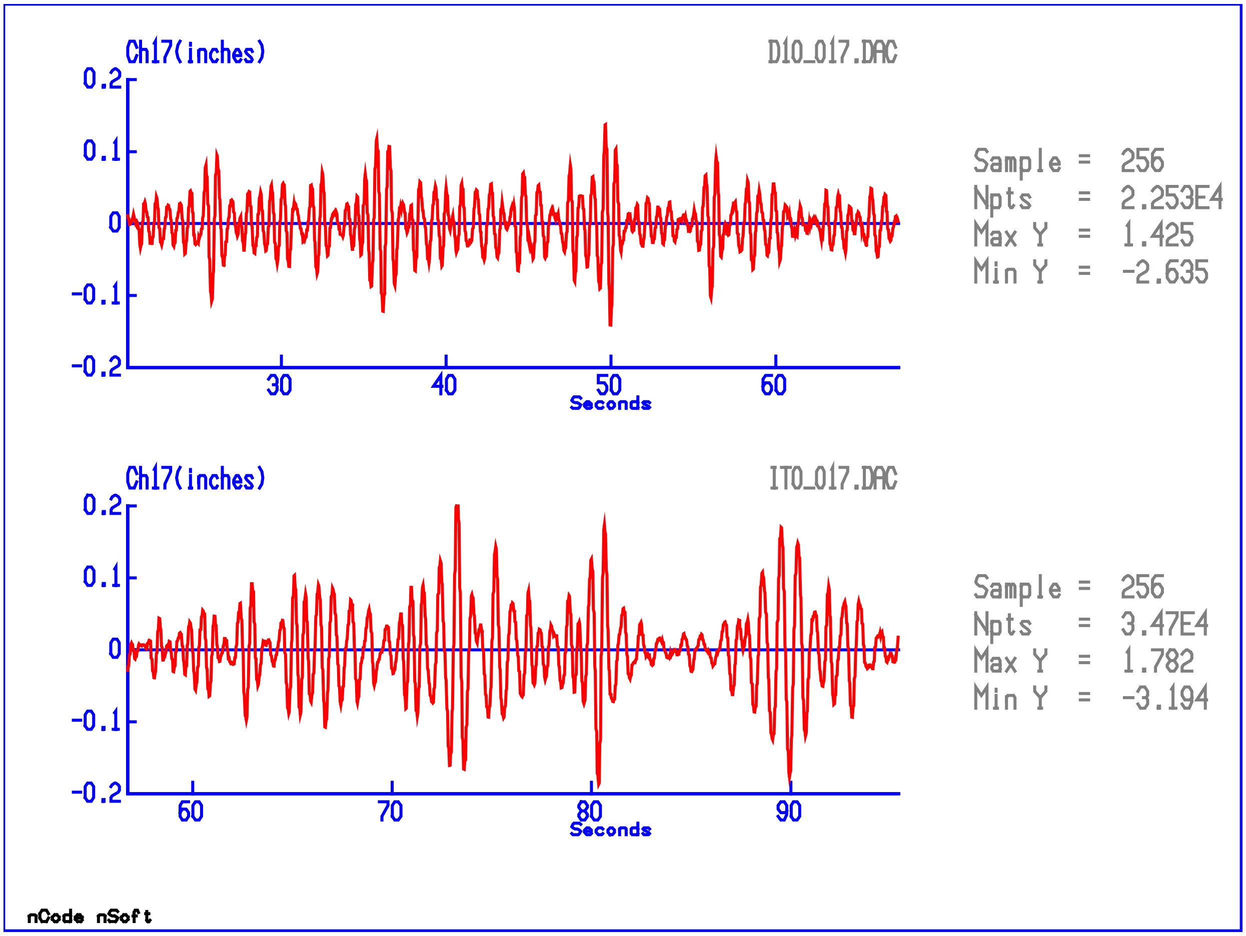
This plot is of the "Highway Hop" condition. It is created by undulating concrete road surfaces. As you can see there are 2 peaks in this data, one at 1.6 Hz and the other at 7.7 Hz. The 1.6 Hz is the vehicle pitch mode. The pitch is excited by the concrete "waves" in the road. The second peak is the frame first vertical bending mode, or resonance. The 7.7 Hz vertical frame bending is sometimes called "Bed Bounce".
The concrete has peaks every 20 feet; this excites the frame bending mode at 70 mph. The sulastic isolators do a great job in reducing this vertical energy. The higher the impact energy, the better the sulastic isolators work. We must be careful not to lose the great factory smooth road ride.



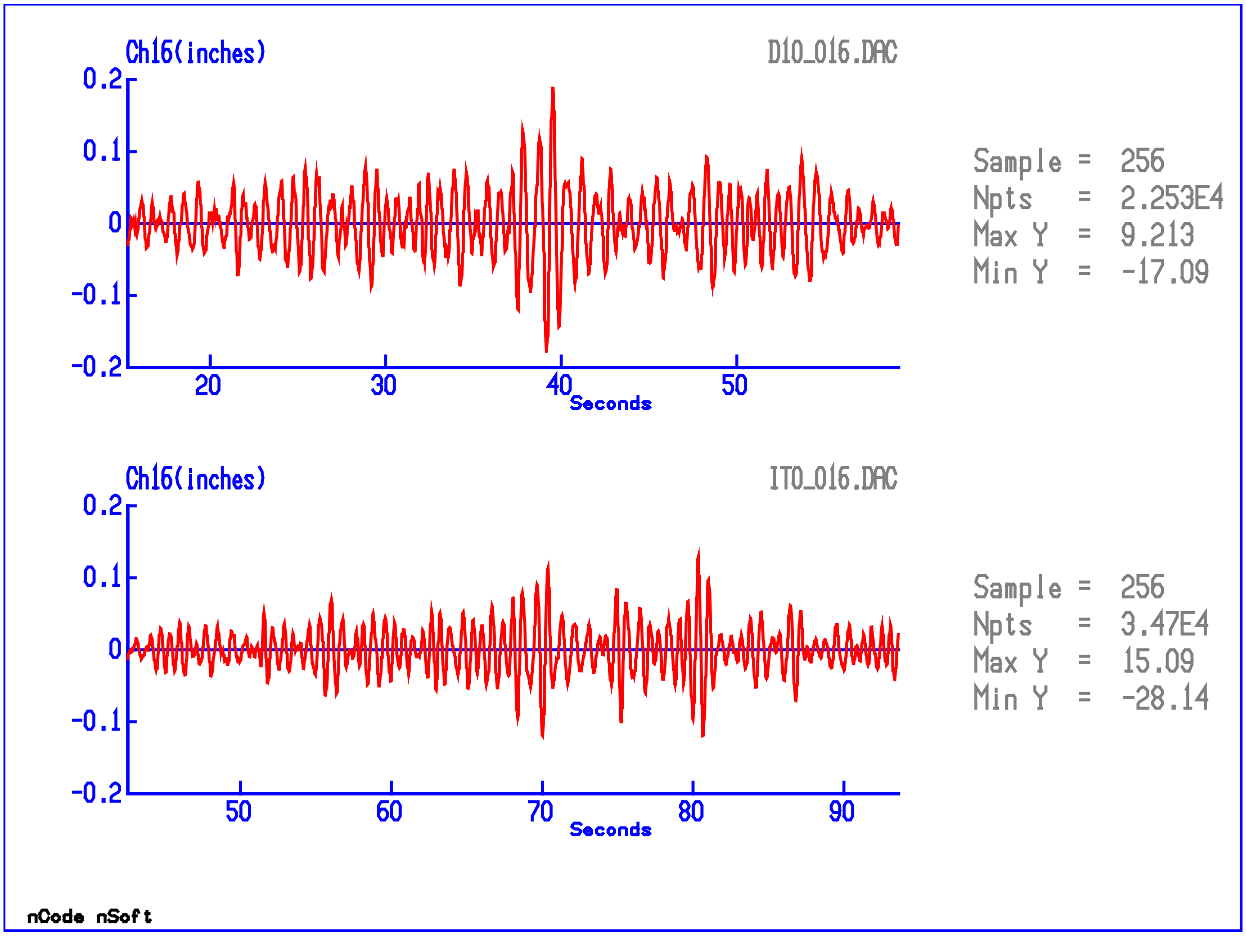
Seat Track Vertical Displacement in Time – Inches
Top= Sulastic suspension
Bottom = Baseline suspension

This is Plot 1 in time – this is what you feel for Highway hop, or Bed Bounce, we'll call it frame vertical bending. This plot is a summation of all frequencies to 128 Hz, however 1.6 and 7.7 dominate the displacement. The sulastic is much improved.

Plot 2



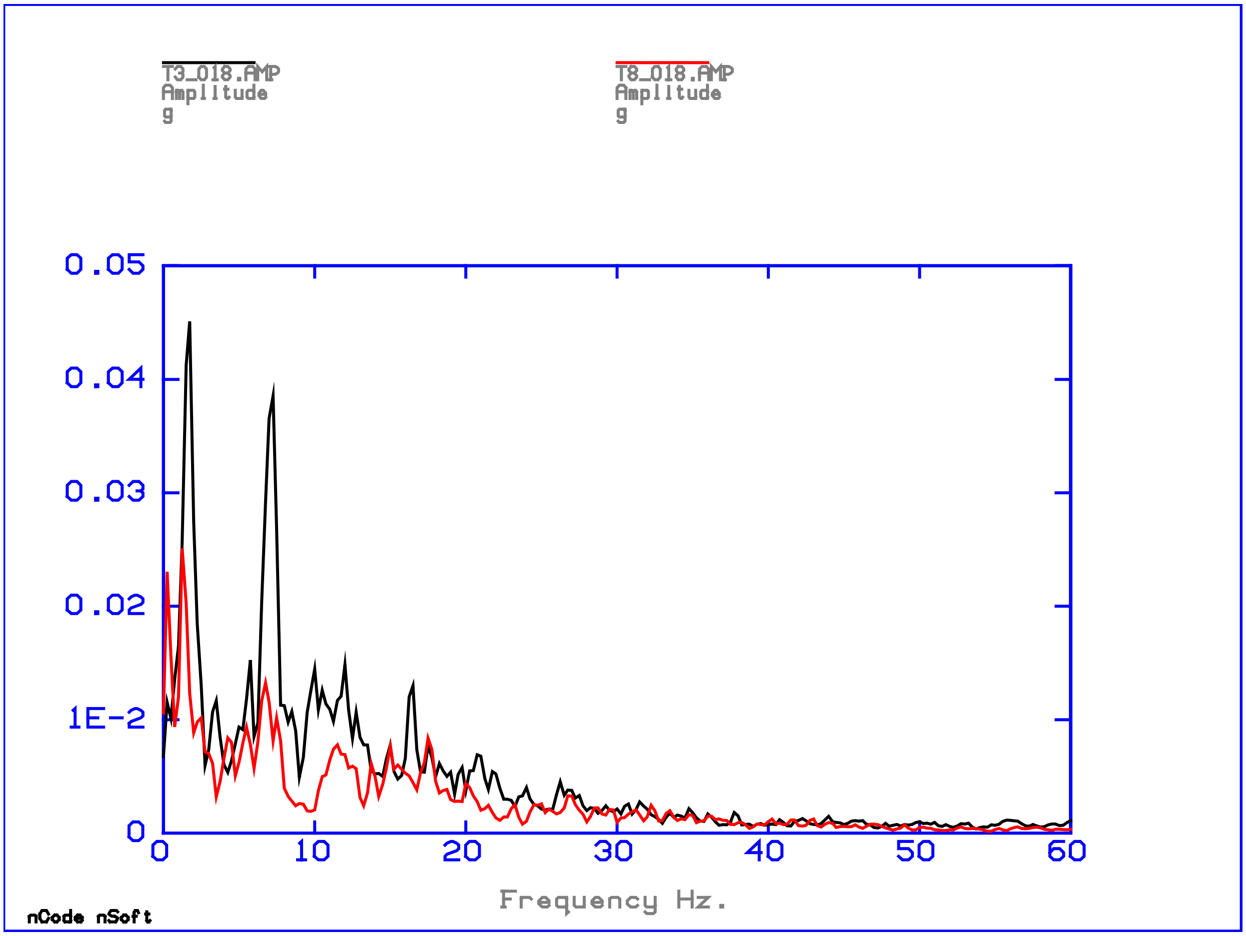
Seat Track Lateral Displacement in Time – Inches
Top= Sulastic suspension
Bottom = Baseline suspension
Sulastic is fine in the lateral direction during frame bending



Seat Track Fore-aft Displacement in Time – Inches
Top= Sulastic suspension
Bottom = Baseline suspension

This is where the sulastic isolators translate the vertical energy into for-aft. It is believed that the rate of the mount tested is too soft and allows higher fore-aft motion. This can be corrected by stiffening the mount and reducing the compression of the shock. This should give the best of both worlds. When the components arrive, a third data set will be collected.

Remember – This first round of mount stiffness was a "best effort estimation"

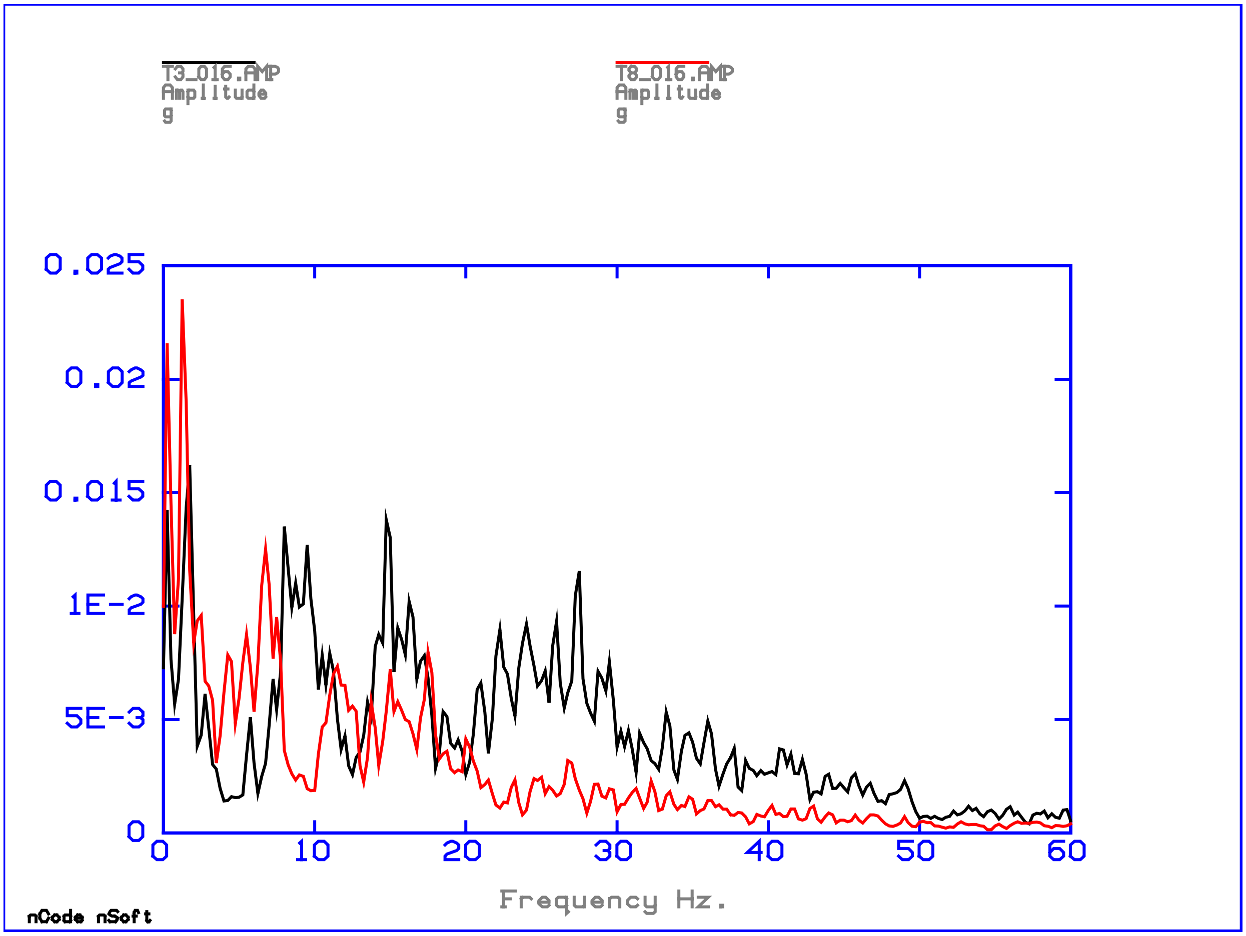


Seat Track Vertical Acceleration – Peak hold g's
Black = Baseline suspension
Red= Sulastic suspension

This is the seat track vertical going over a pot-hole. This plot looks just like Plot 1 frame bending because the vehicle dynamics don't change with inputs, the same 2 modes dominate the response. Again, vehicle pitch and frame vertical bending are significantly reduced. This is with a stock shock also. Less shock compression will only make this better.

Remember, car makers tune the best selling truck to be the best, all others are a compromises. The double cab 6.5' box version, we believe was the optimally tuned Tundra. The Crew Max and other Trucks with the short 5.5' bed have unique frame issues to deal with.

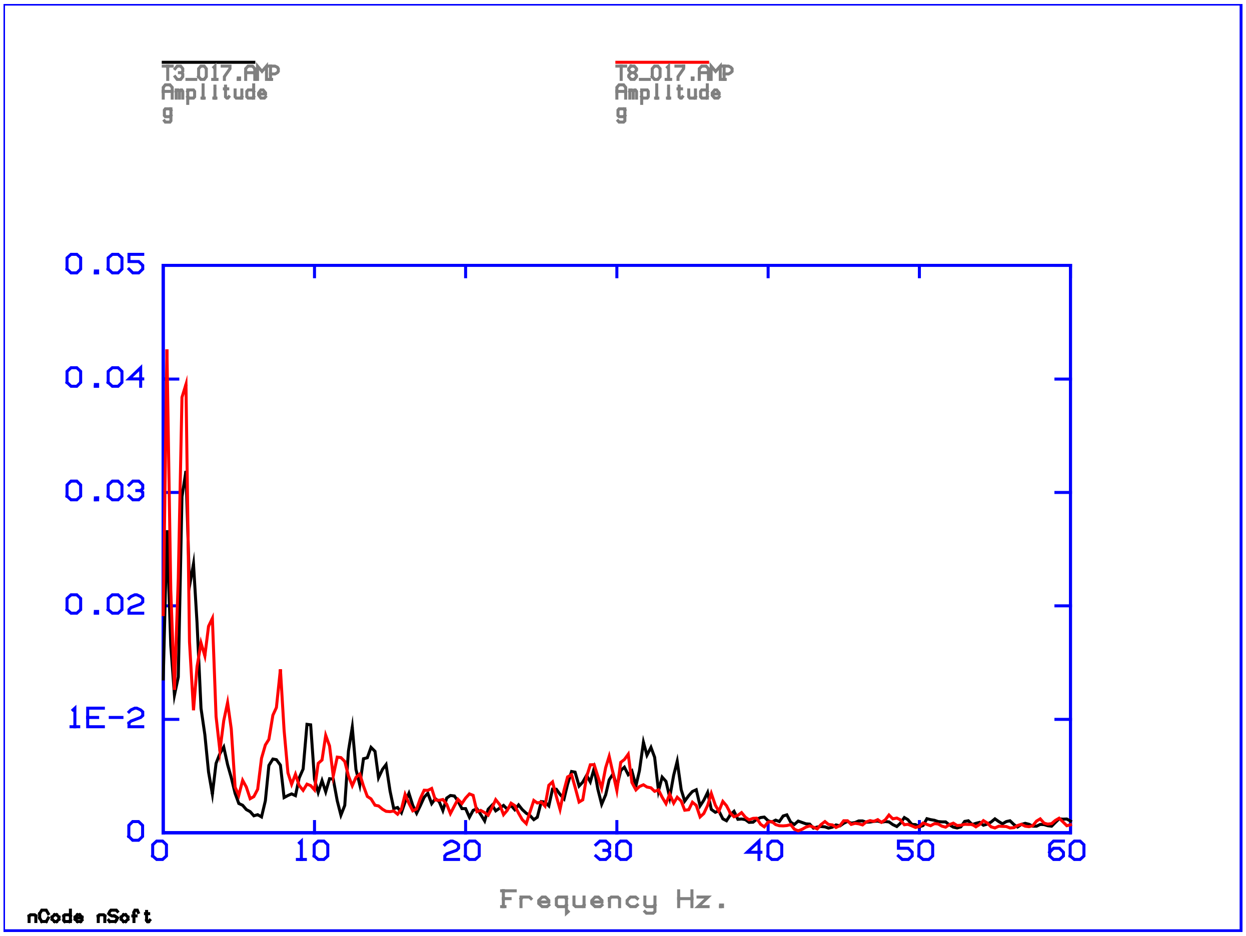
Plot 4



Seat Track Fore-Aft Acceleration – Peak hold g's
Black = Baseline suspension
Red= Sulastic suspension

Again, the sulastic has more fore-aft during a pot hole, but his was at 93 degrees. The cold weather made the feel over potholes fell exceptional. Finer tuning should not be able to eliminate, or balance out for excellent road feel under smooth and rough roads.

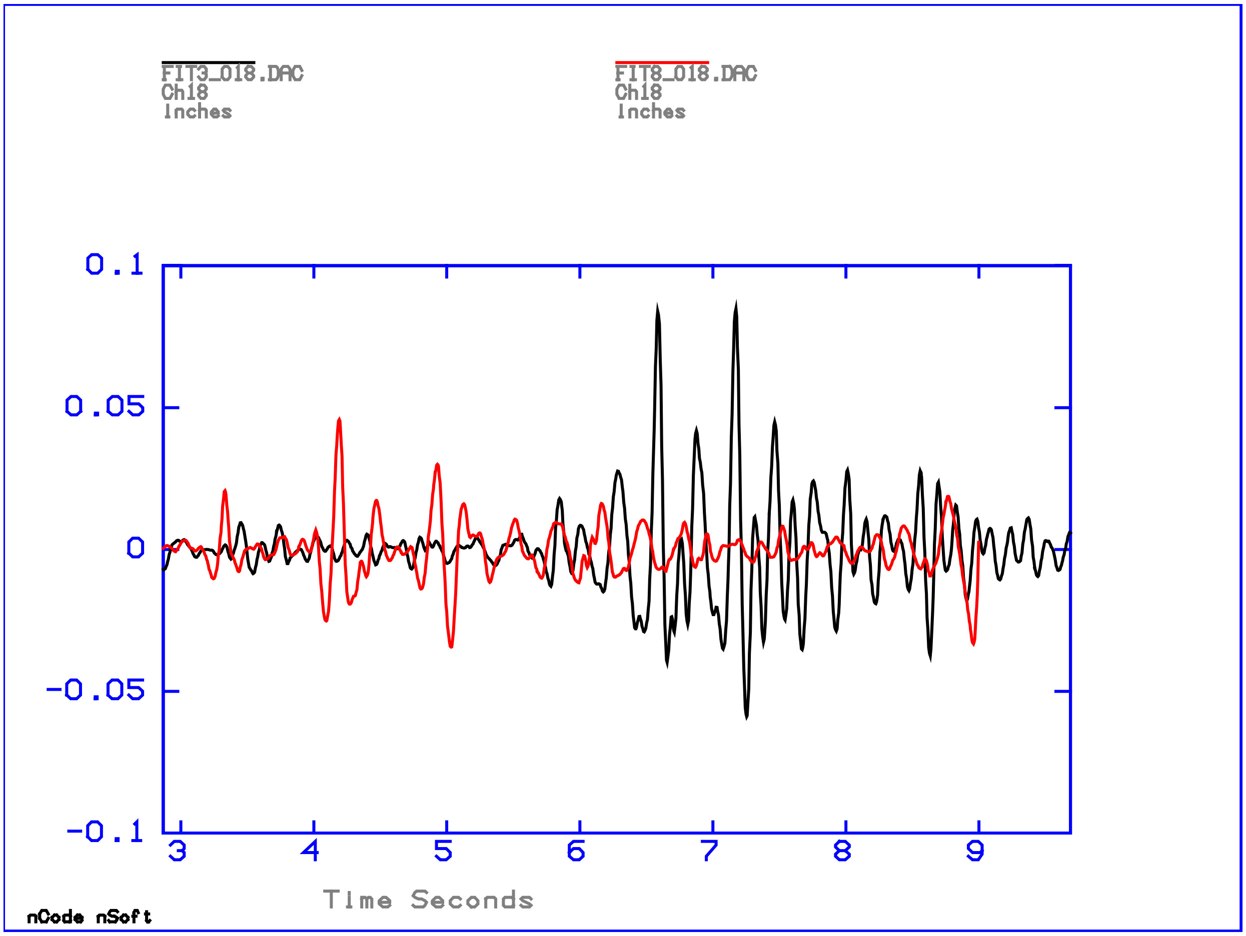
Plot 5



Seat Track Lateral Acceleration – Peak hold g's
Black = Baseline suspension
Red= Sulastic suspension

Lateral acceleration during a pot hole event. Again the soft Sulastic mount moves more than stock under this impact condition. Stiffer mounts and softer shocks should balance this.

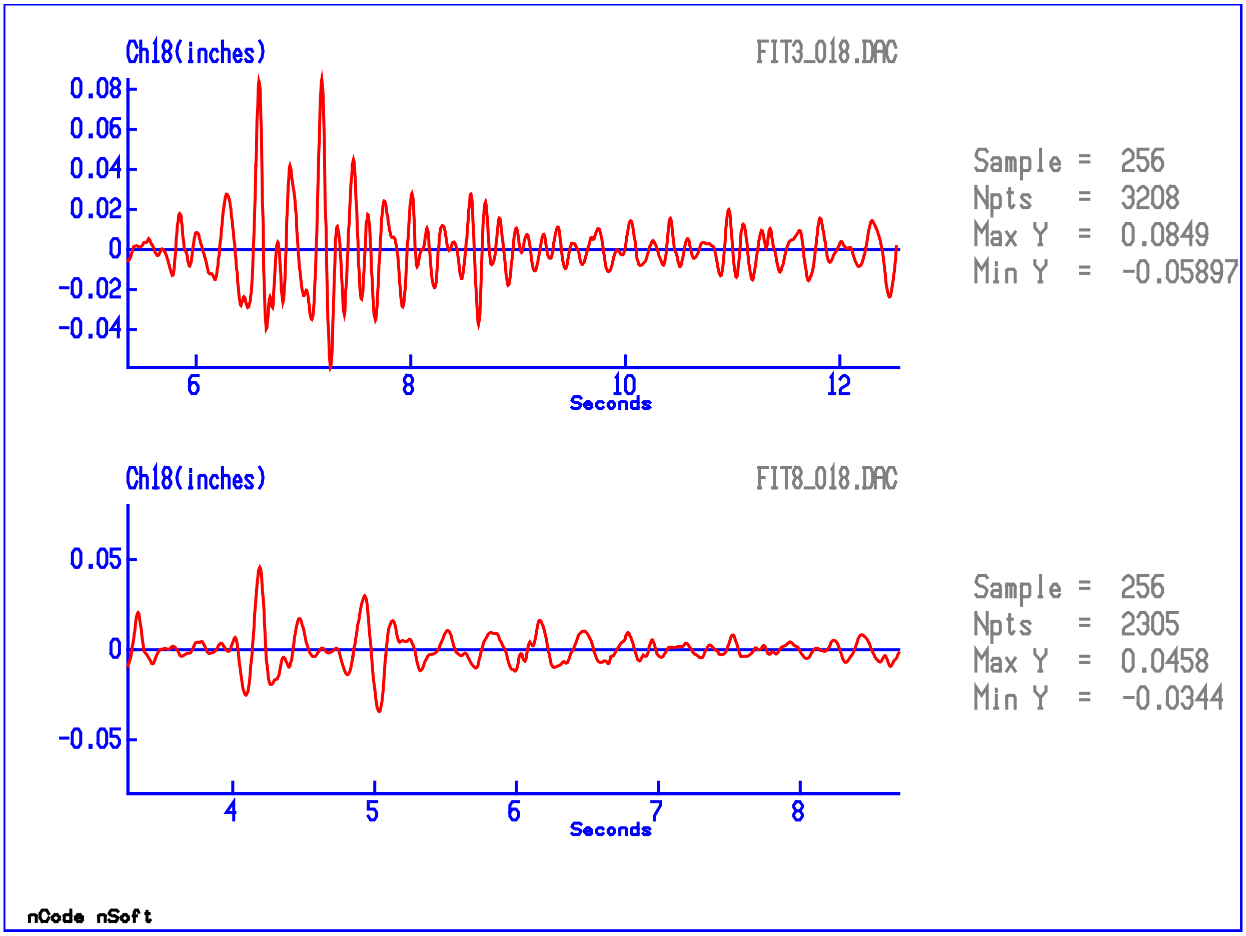
Plot 6



Seat Track Vertical Displacement – Inches from 3-10 Hz Only
Black = Baseline suspension
Red= Sulastic suspension

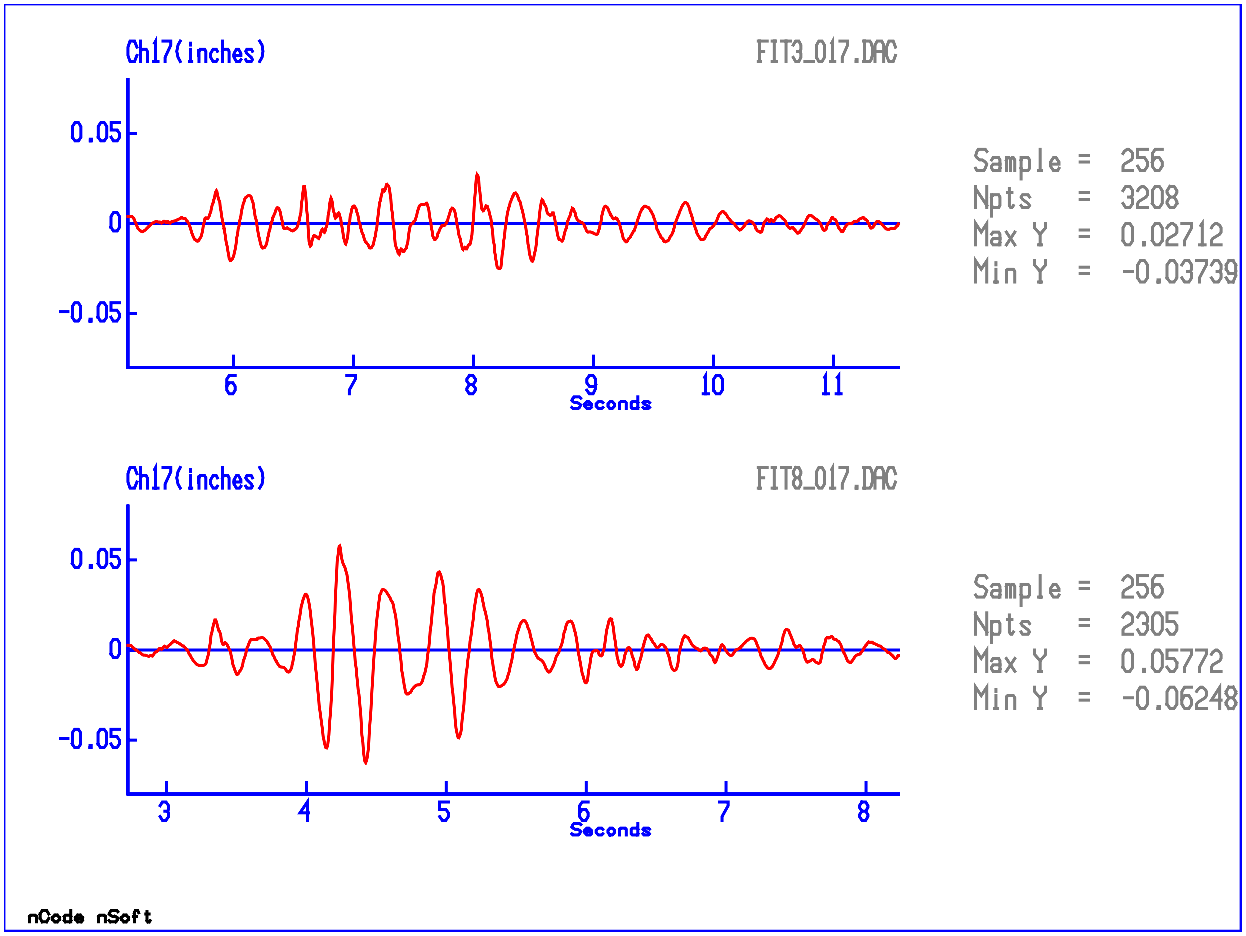
This time history shows the energy and displacement reduction on the seat track going over a pothole. This frequency range 3-10 Hz is comprised of frame vertical bending only! This demonstrates the sulastic ability to help reduce frame bending which is the number one complaint on the 2007 Tundra ride performance.

Plot 7



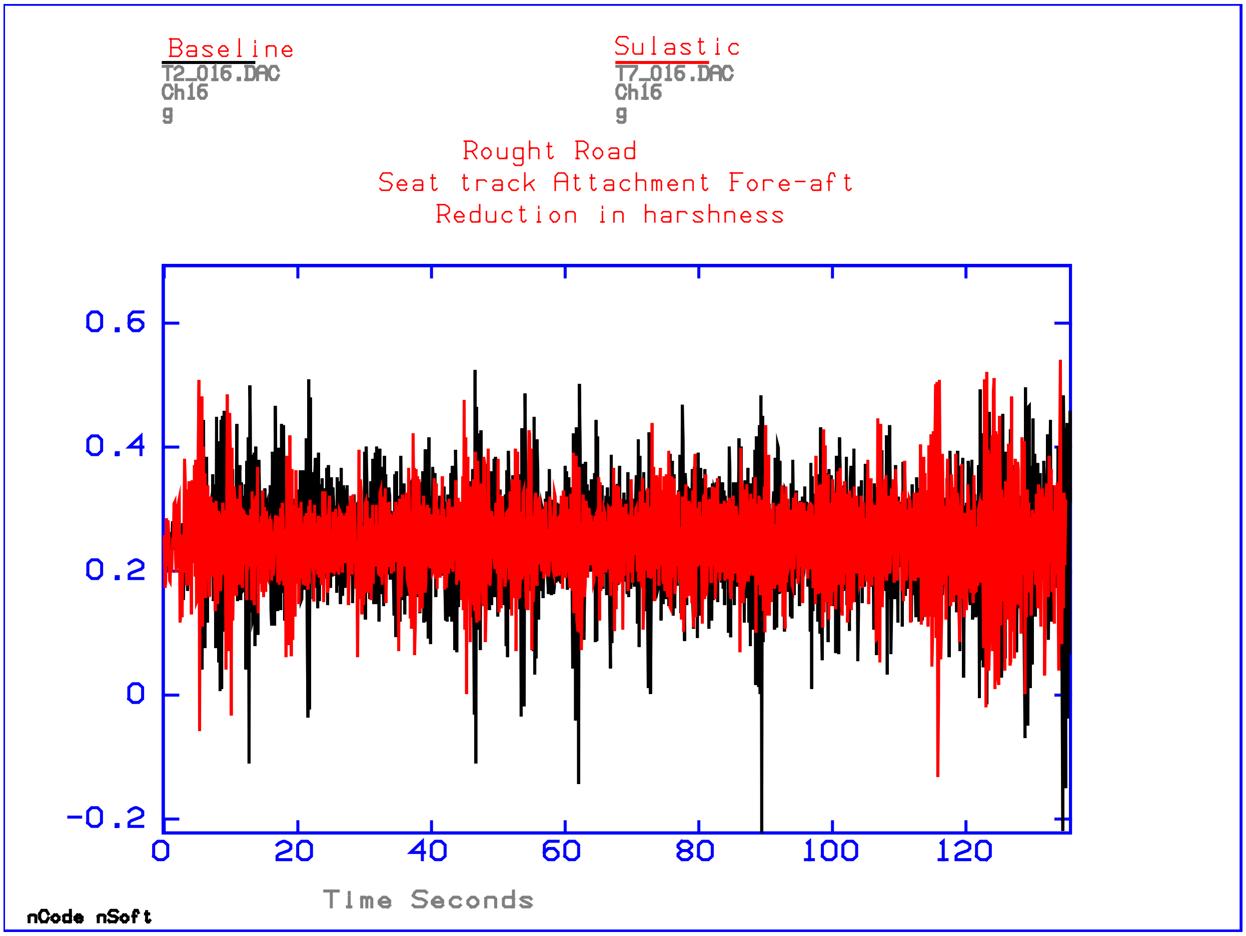
Seat Track Fore-aft Displacement – Inches from 3-10 Hz Only
Top = Baseline suspension
Bottom= Sulastic suspension

This time history shows the energy and displacement reduction on the seat track going over a pothole. This frequency range 3-10 Hz is comprised of frame vertical bending only!



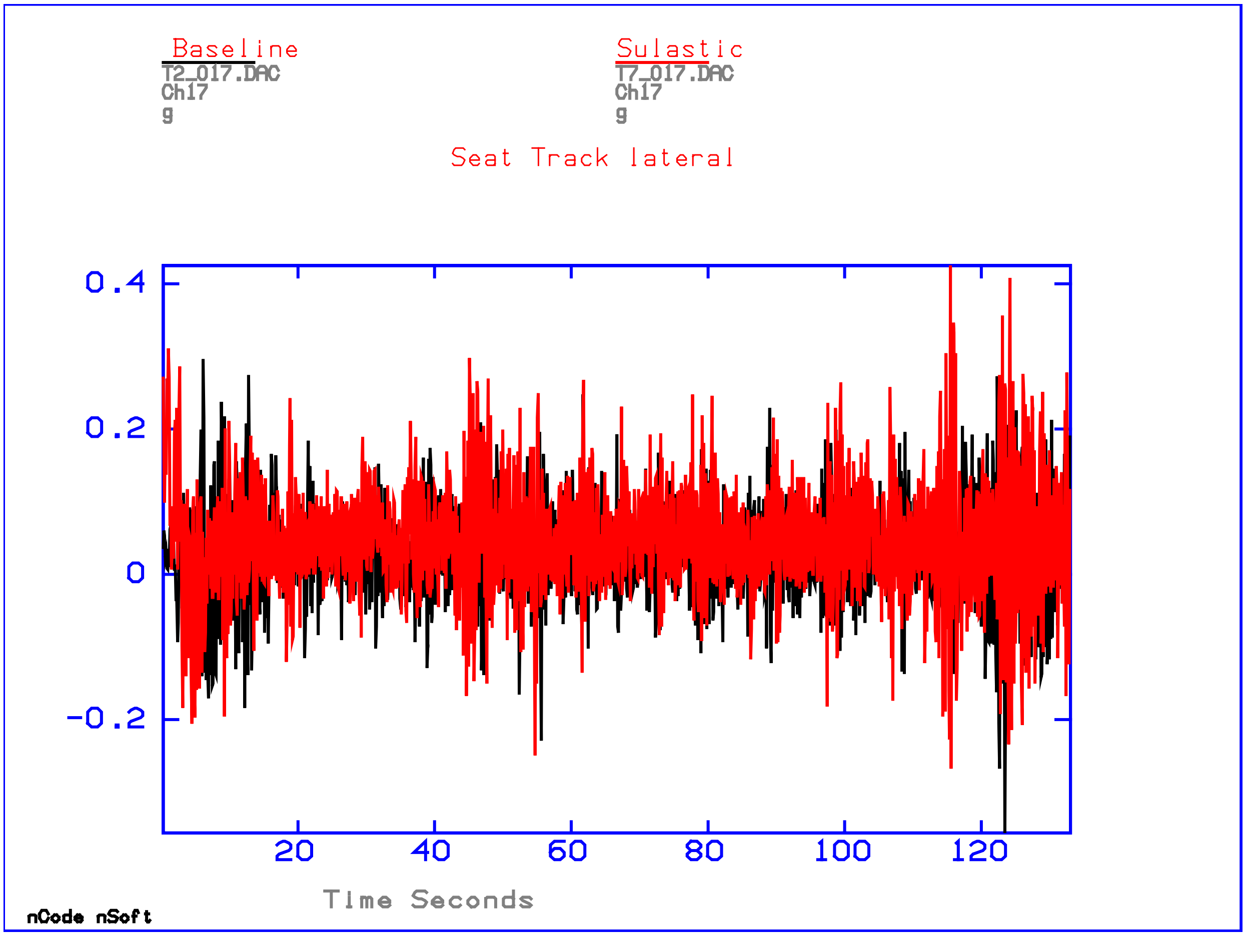
Seat Track Lateral Displacement – Inches from 3-10 Hz Only
Top = Baseline suspension
Bottom= Sulastic suspension
Pot Hole

Laterally the Sulastic has more displacement but at a lower frequency. Stiffness in the lateral direction should help. Harshness with the Sulastic over a pot hole is excellent!

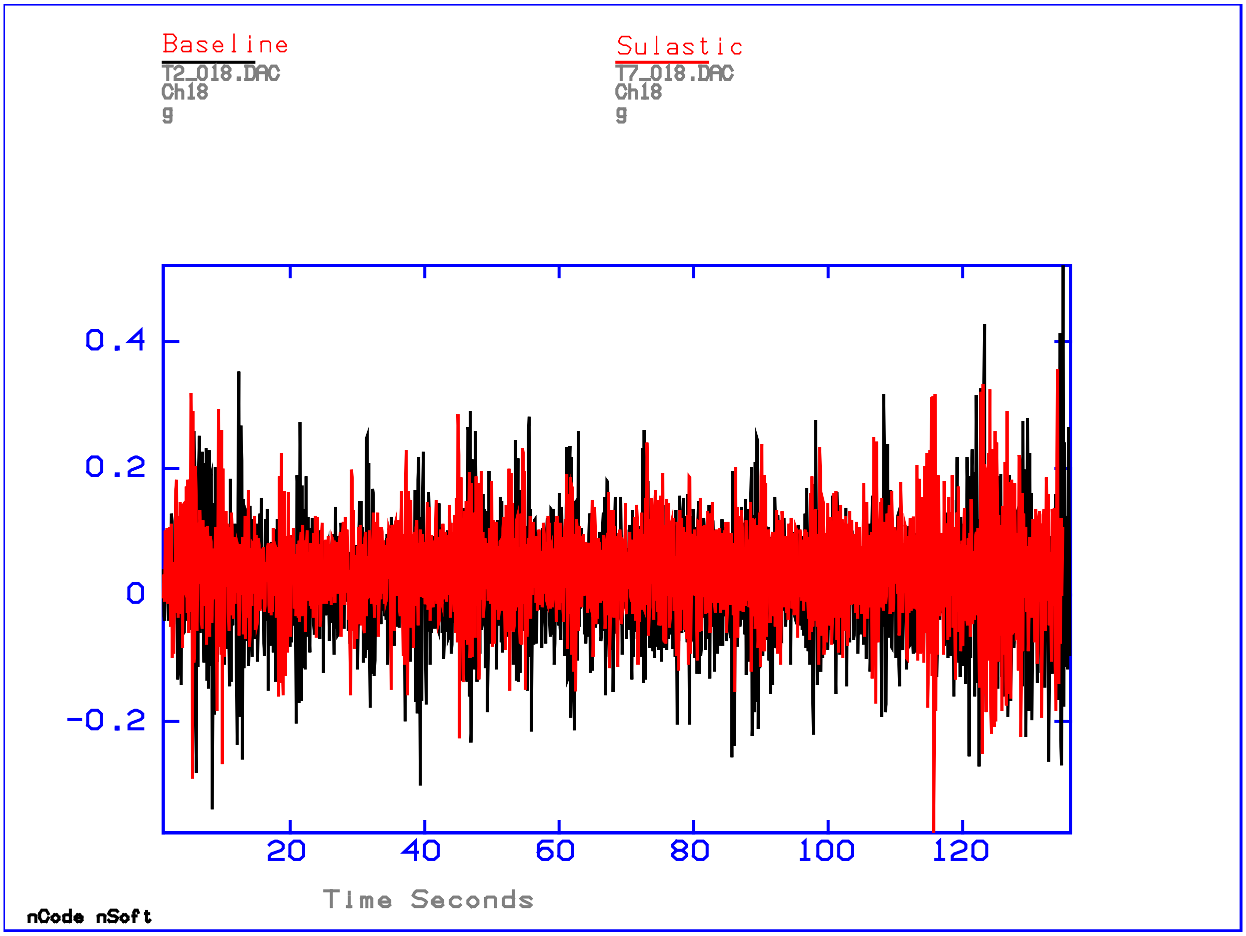


This is acceleration on the seat track over rough road. The sulastic mounts helps eliminate harshness due to broken pavement.

Plot 10

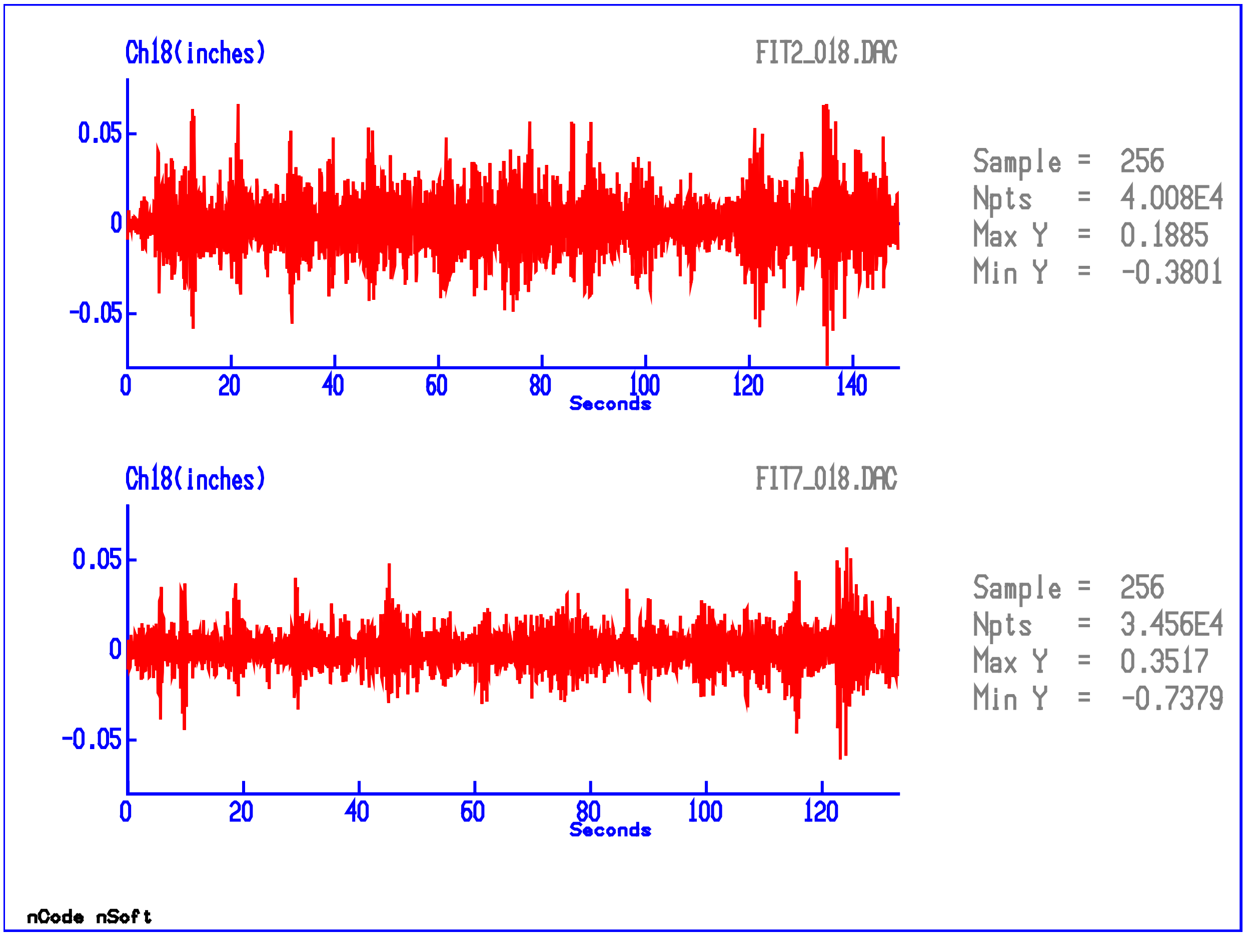


Lateral harshness over a rough road does not change much



Vertical harshness reduction is significant

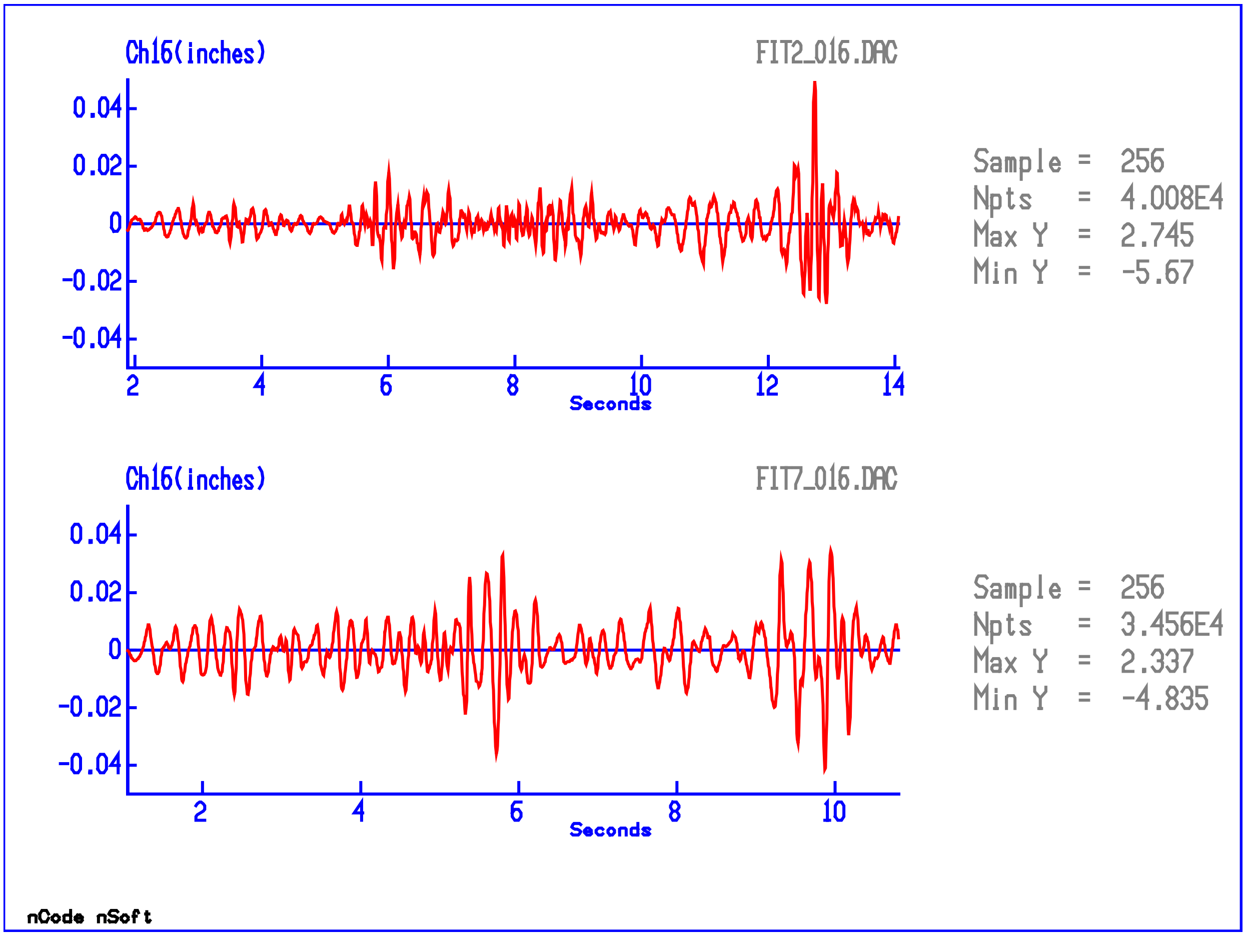
Plot 12



Rough Road – 25 mph

Seat Track Vertical Displacement – Inches at frame bending frequency 3-10 Hz
Black = Baseline suspension
Red= Sulastic suspension

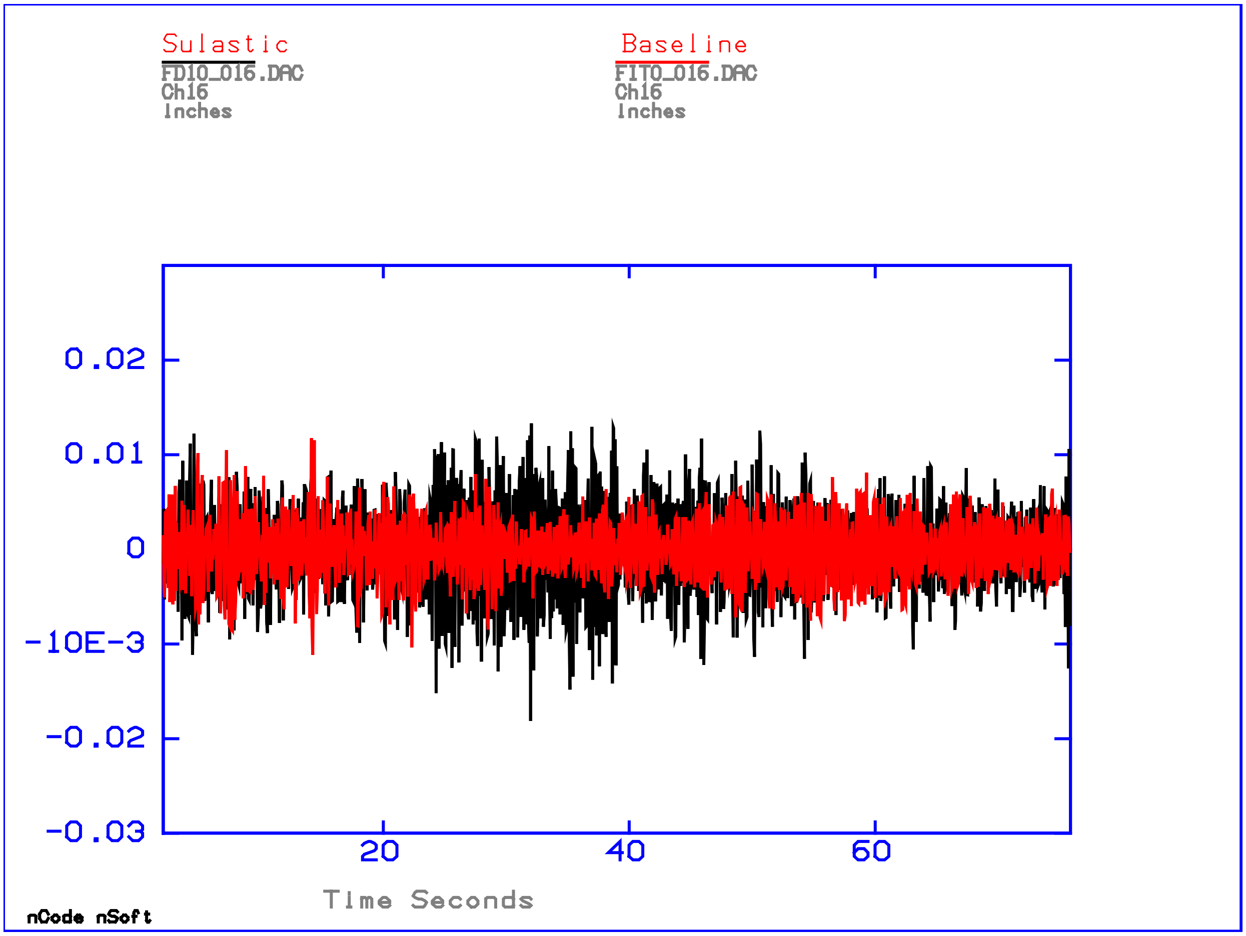
This plot correlates with the video recorded. Watch the back of the bumper hitch in the video and compare displacement on the frame!



Rough Road 25 mph

Seat Track Lateral Displacement – Inches from 3-10 Hz Only
Top = Baseline suspension
Bottom= Sulastic suspension

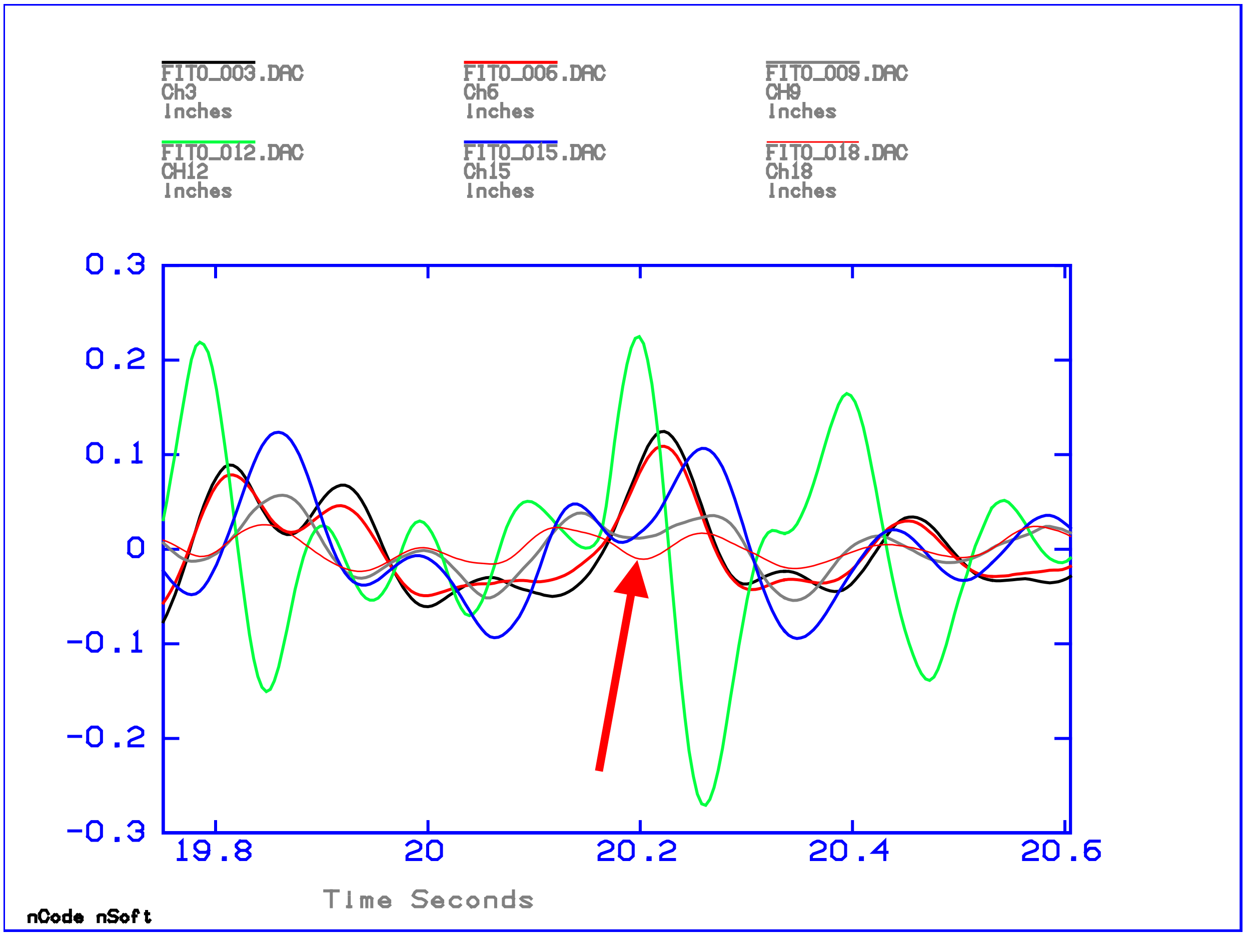
Very similar in amplitude, but sulastic isolators have more frequent high amplitudes. This is not very noticeable on the road.



Rough Road 25 mph

Seat Track Fore-aft Displacement – Inches from 3-10 Hz Only
Top = Baseline suspension
Bottom= Sulastic suspension

Here is where the Sulastic has a lower frequency but higher displacements. The peaks are again similar in amplitude of the base suspension but it happens more often. Stiffer fore-aft tuning will help this, and a softer shock will not increase the vertical – the best of both worlds!

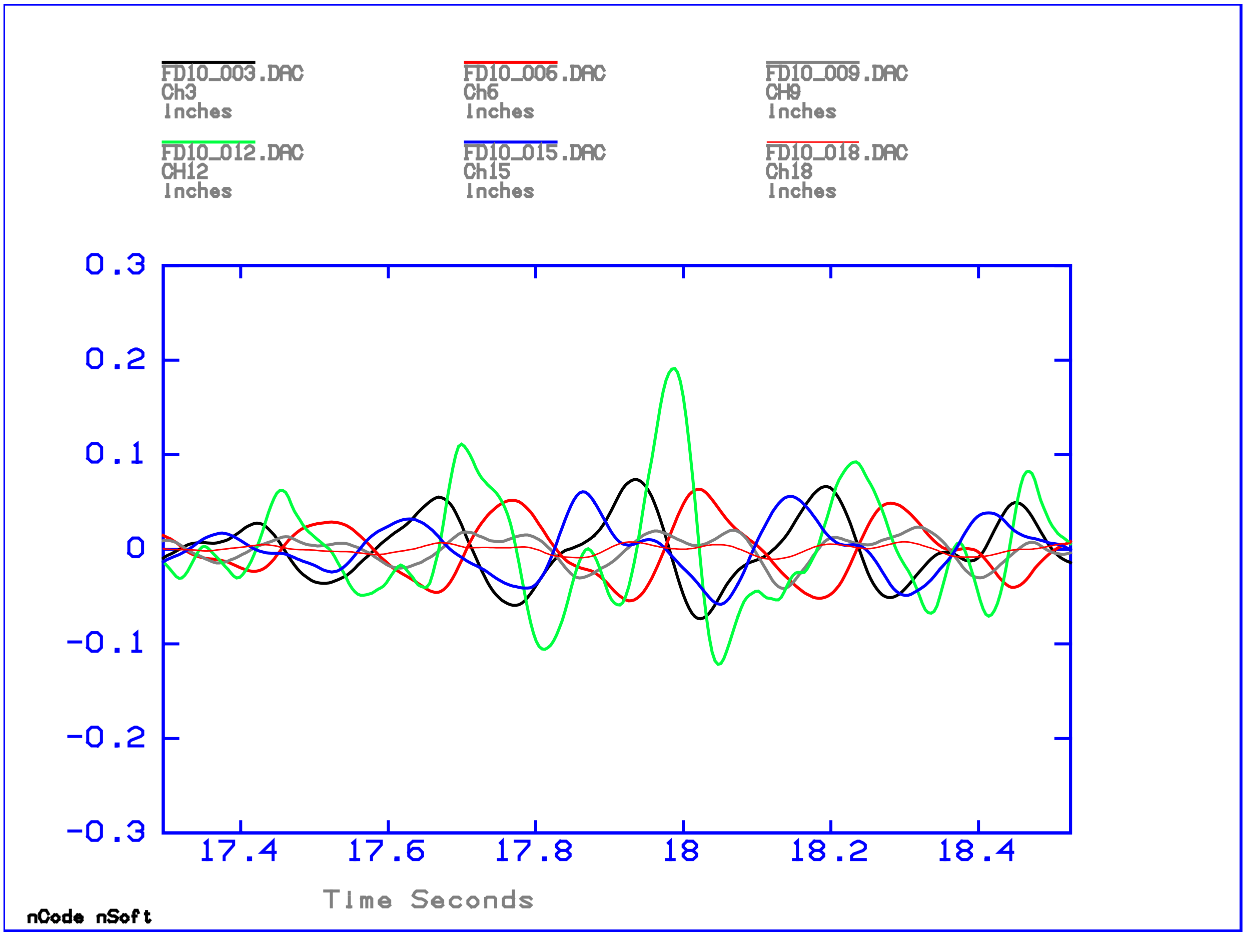


This is a baseline suspension acceleration of the frame vertical bending at 7.7 Hz on undulating concrete. This is all 6 channels vertical overlaid. This demonstrates the issue the CrewMax Frame system has.

Black = rear frame vertical
Red= Frame at shock vertical
Grey= Front spring eye vertical
Green = Axle vertical
Blue = Rear of Body vertical
Orange = driver seat vertical

Notice the red and black trace follow each other – this is the flat section of the rear frame behind the kick-up. Notice the Grey trace – it does not follow the red and black – it actually goes negative while the red and black are positive (RED ARROW). This tells us that the frame is bending between the front spring eye and the shock tower. The frame is bending at the kick-up. This is what gives the CrewMax its high amplitude frame mode exhibited by excessive box movement at the rear of the truck at 7.7 Hz. This is what we are trying to control and engineer around for better ride. All trucks have a vertical frame mode – just none others with this amplitude at the rear. This topic is for another report – Understanding the Dynamics of the 2007 Toyota Tundra.

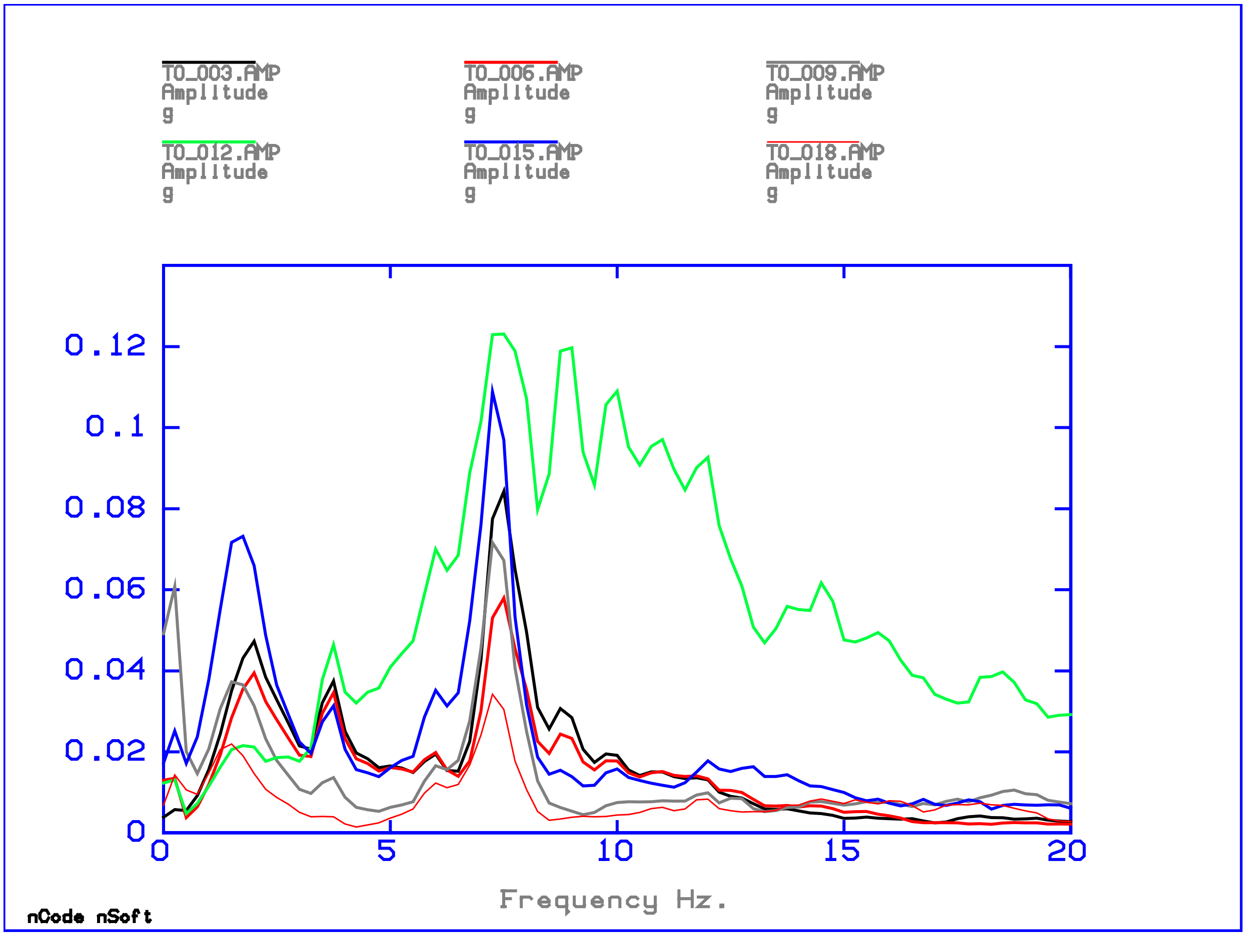
Plot 16



This is the same plot as the baseline data in Plot 16 but with the Sulastic isolators.

Black = rear frame vertical
Red= Frame at shock vertical – please invert red trace, forgot to multiply by –1 for correct phase.
Grey= Front spring eye vertical
Green = Axle vertical
Blue = Rear of Body vertical
Orange = driver seat vertical

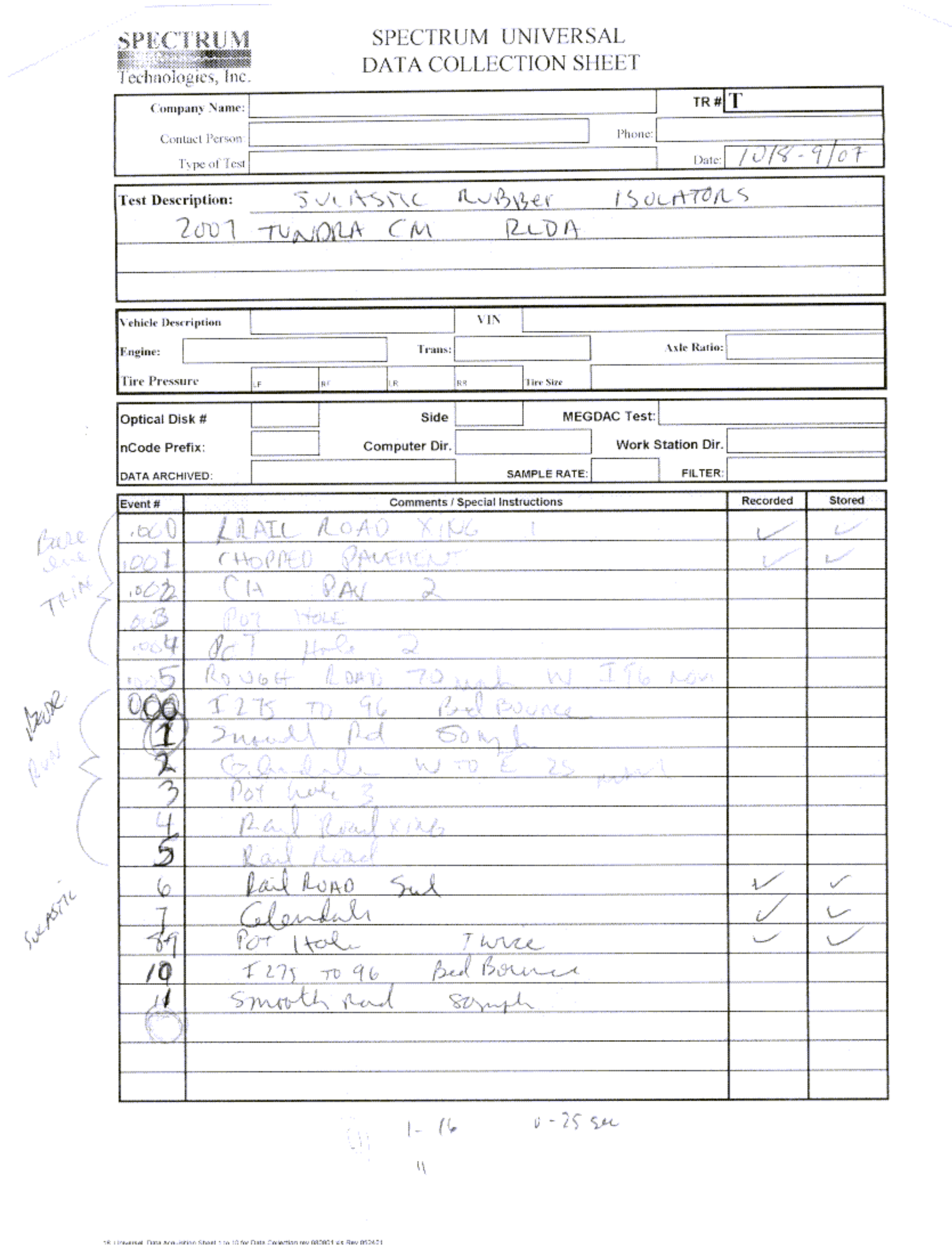
Notice all amplitudes are reduced – especially the orange trace which is the seat track!



This is the data in Plot 16 but in a Frequency Domain

Black = rear frame vertical
Red= Frame at shock vertical
Grey= Front spring eye vertical
Green = Axle vertical
Blue = Rear of Body vertical
Orange = driver seat vertical

Major structural mode at 7.7 Hz.


SPECTRUM Technologies, Inc.

SPECTRUM UNIVERSAL DATA COLLECTION SHEET

Company Name:		TR #	T
Contact Person:		Phone:	
Type of Test:		Date:	1018-9/07

Test Description: SULASTIC RUBBER ISOLATORS
2007 TUNDRA CM RLDA

Vehicle Description		VIN			
Engine:		Trans:		Axle Ratio:	
Tire Pressure	LF / RF / LR / RR	Tire Size			

Optical Disk #		Side		MEGDAC Test:	
nCode Prefix:		Computer Dir.		Work Station Dir.	
DATA ARCHIVED:		SAMPLE RATE:		FILTER:	

Event #	Comments / Special Instructions	Recorded	Stored
.000	RAIL ROAD XING 1	✓	✓
.001	CHOPPED PAVEMENT	✓	✓
.002	CA PAV 2		
.003	POT HOLE		
.004	POT Hole 2		
.005	ROUGH ROAD 70 mph W I96 NOVI		
000	I275 TO 96 Bad Bounce		
1	Smooth Rd 80 mph		
2	Glendale W TO E 25 mph		
3	Pot hole 3		
4	Rail Road XING		
5	Rail Road		
6	Rail ROAD Sul	✓	✓
7	Glendale	✓	✓
8/9	POT Hole Twice	✓	✓
10	I275 TO 96 Bad Bounce		
11	Smooth Road 80mph		

Base line TRIM (events .000–.005)

BEAR RUN (events 000–5)

SULASTIC (events 6–11)

1- 16 0-25 sec

11

Universal Data Acquisition Sheet 1 to 10 for Data Collection rev 082801 as Rev 052621

Data Collection Sheet

Diagram 1

SPECTRUM RLDA SETUP SHEET

Date ________

Test Request Number T ________

Test Description

NCODE PREFIX

Input Into Front Panel | Input into Tags and Channels

NO	Point No.	SENSOR SERIAL ID	CABLE NO.	Sensor CAL	MEGADAC CHANNEL NUMBER	Sensor Location/Name	FINAL DIR.	NCODE CHANNEL NUMBER	ME SCOPE CHANNEL NUMBER
A 1		A21/9047	7	X		REAR RIGHT FRAME	+X		
A 2		A21/9047		Y			-Y		
A 3		"		Z			-Z	—	
A 4		A21/9045	6	X		SHOCK TOWER RIGHT FRAME	+X		
A 5				Y			+Y		
A 6				Z			+Z	+	
A 7		A24/58245	I	X		FRONT SPRING EYE	+ X		
A 8				Z			- Y		
A 9				Y			+ Z	+	
A 10		A21/9049	O	X		TOP OF AXLE	+X		
A 11			O	Y			+Y		
A 12			O	Z			+Z	[illegible]	
A 13		A24/40291	5	X		Right rear Body	- X		
A 14				Y			+ Y		
A 15				Z			- Z	—	
A 16		A24/55215	3	X		Driver Rear INBOARD	- X		
A 17				Y			- Y		
A 18				Z			+ Z	+	
A 19									
A 20									
A 21						FITO_003 Ø05			
A 22									
A 23									
A 24									
A 25									
A 26									
A 27									
A 28									
A 29		(6)	(10)						
A 30									

COMPUTER DIR ________ MEGADAC TEST ________ OPTICAL DISK ________

6455
47
13

01 RLDA Sensor Location 1-30 rev 110702.xls

Accelerometer Sheet

Diagram 2