Accelerometers: One size does not fit all…

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Overview

- Identify the need for accelerometers
- Survey of accelerometer types
- Overall measurement system
  - Sensors
  - Transducers
  - Signal Conditioners
  - Output
- Accelerometer systems
- Specifications for measuring acceleration
  - Range, Resolution, and Frequency

Why use an accelerometer?

- Need drag factor for speed computations
  - Only technique capable of measuring truly representative values
  - Accounts for total vehicle/braking/tire/road system
  - Should use an exemplar vehicle on site if possible
- Measure straight line acceleration

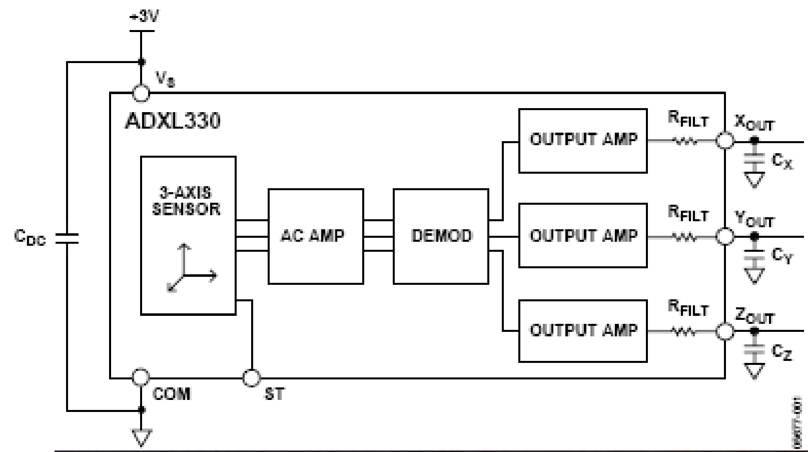
What else?

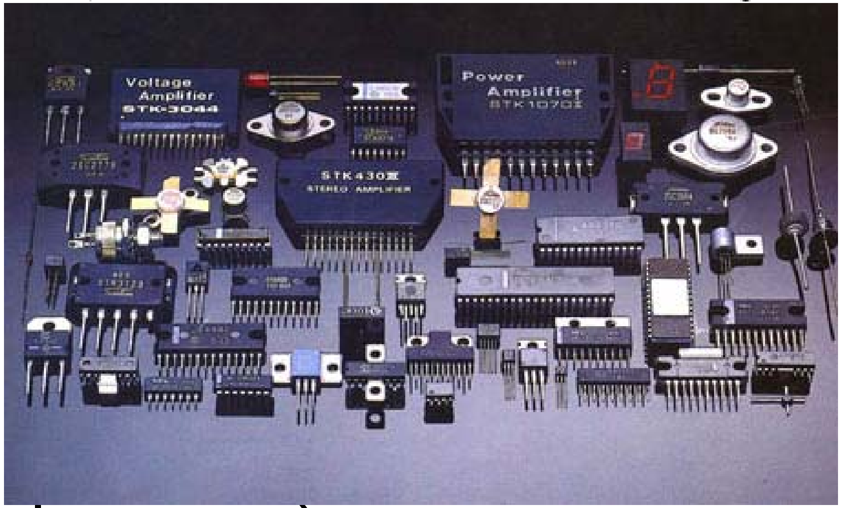
- Lateral Acceleration in Yaw testing
- Crash Testing and Sensing
  - Air bag deployment
  - NCAP, J211, Government sponsored crash testing
  - Crash test dummies
  - Determine PDOF during crash
  - Post impact trajectory

Types of Accelerometers

- Pendulum
- Recording Radar
- Time distance
  - Shot Marker
  - Video
- Electronic
  - Piezoelectric
  - Seismic Mass
  - Piezoresistive
  - MEMS

(micro electrical mechanical systems)

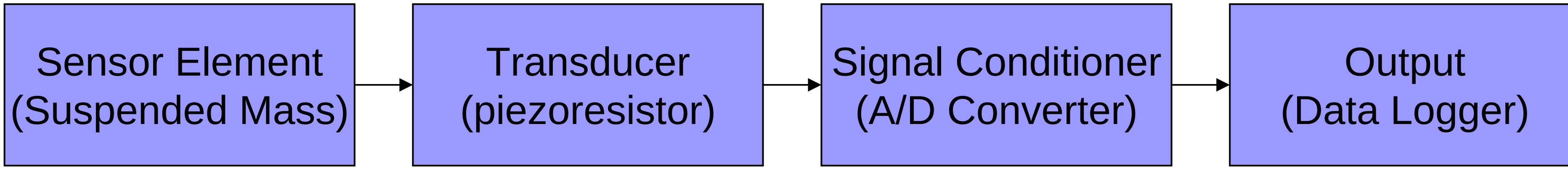




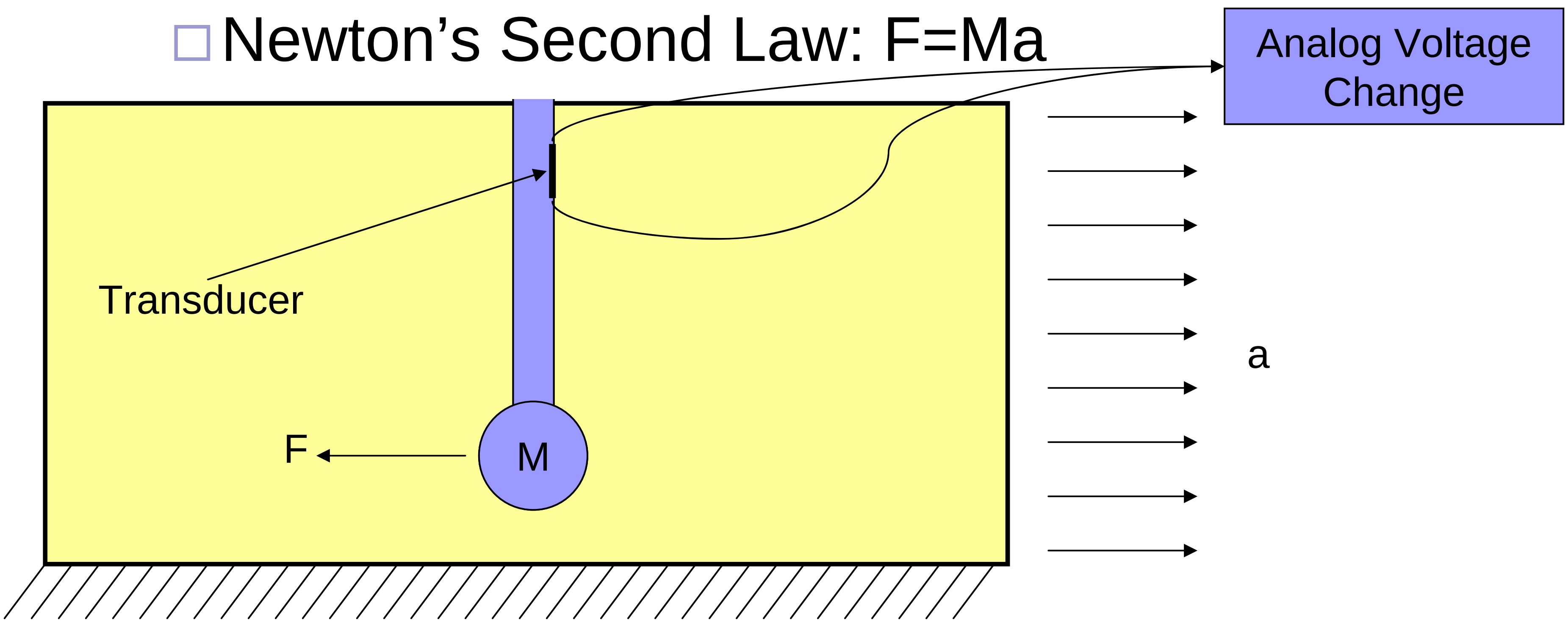
Concomitant Methods

- Measure velocity and time
  - Stalker RADAR
  - accel = DeltaV / DeltaT
  - Noisy for a(t)
  - Great for average acceleration
- Measure force with known mass
  - Most acceleration sensors
  - accel = Force / mass
  - Can be very sensitive

Overall Measurement System



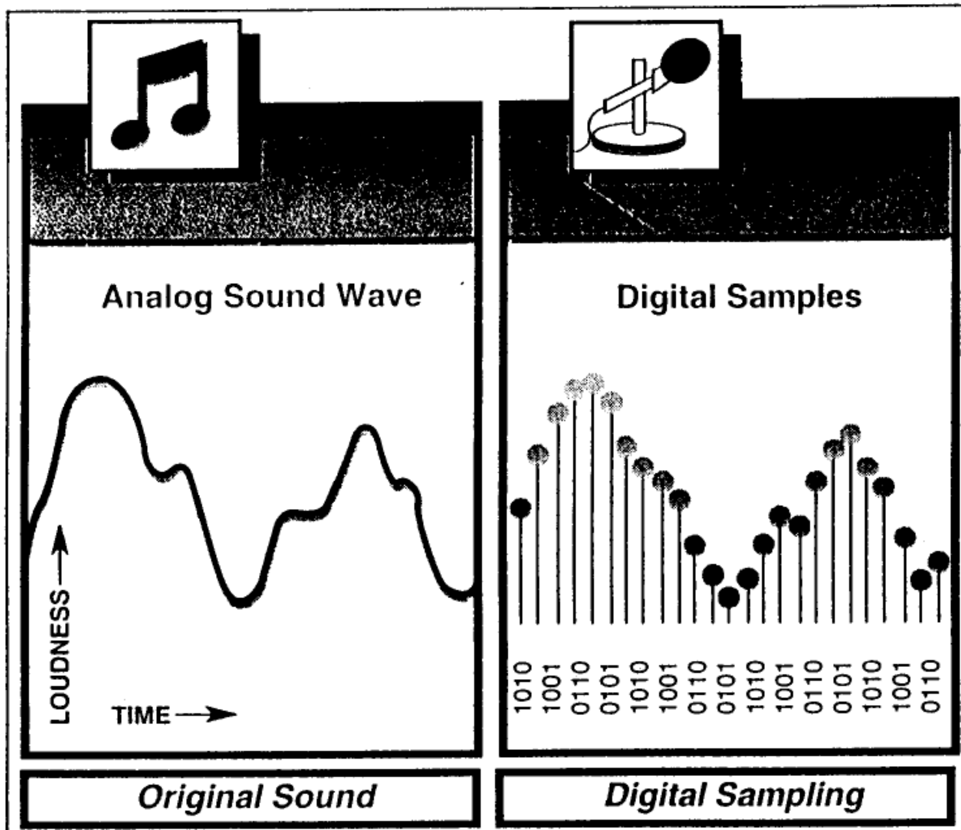
- Sense acceleration
  - Newton's Second Law: F=Ma



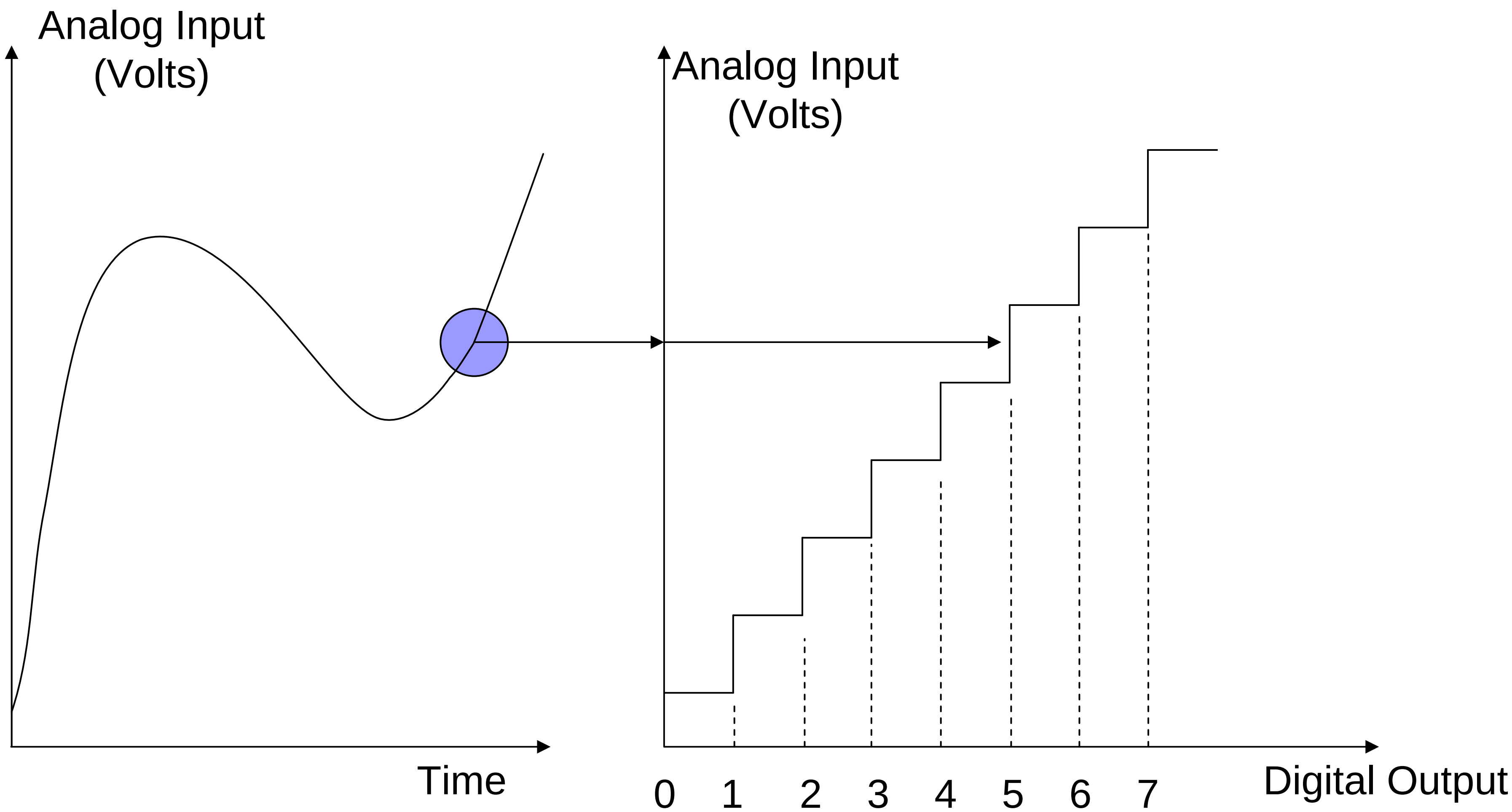
Overall Measurement System

Sensor Element (Suspended Mass) → Transducer (piezoresistor) → Signal Conditioner (A/D Converter) → Output (Data Logger)

- Convert Transducer Output
  - May need amplification (Wheatstone Bridge)
  - May need filtering
  - Convert analog signal to digital signal



Analog to Digital



5=0101

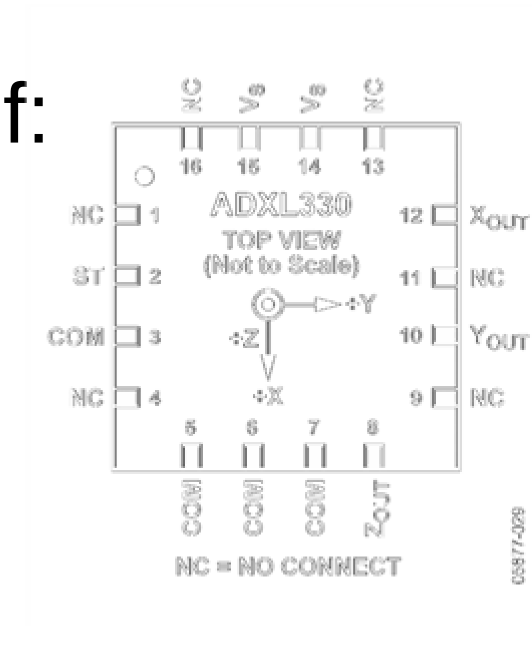
Overall Measurement System

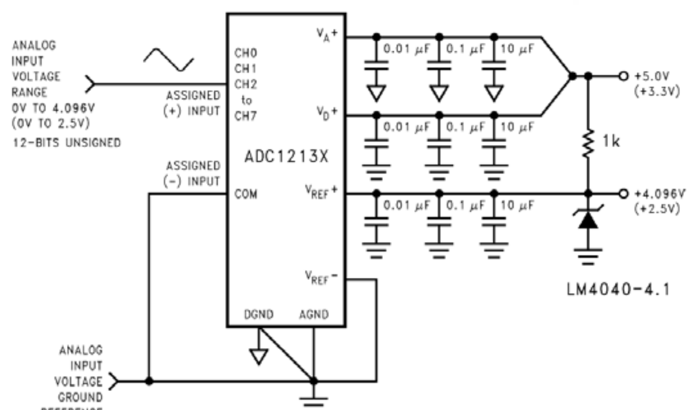
Sensor Element (Suspended Mass) → Transducer (piezoresistor) → Signal Conditioner (A/D Converter) → Output (Data Logger)

- Record / Display Data
  - Convert Binary into human readable data
  - Requires calibration

Piece-meal Accelerometer Measurement System

- Assemble everything yourself:
  - Accelerometer
  - Filtering
  - A/D Converter
  - Data Logger
  - Data Reduct





Piece-meal Accelerometer Measurement System

- Advantages:
  - May get better performance
  - Helps understanding
  - May be lower cost
  - Expandable
- Disadvantages:
  - Time consuming
  - Requires verification and calibration
  - May not work quite right the first time

Turn-Key Systems

- Requires no assembly or familiarity with electronics
- May be pricy

Comparing Accelerometer Systems

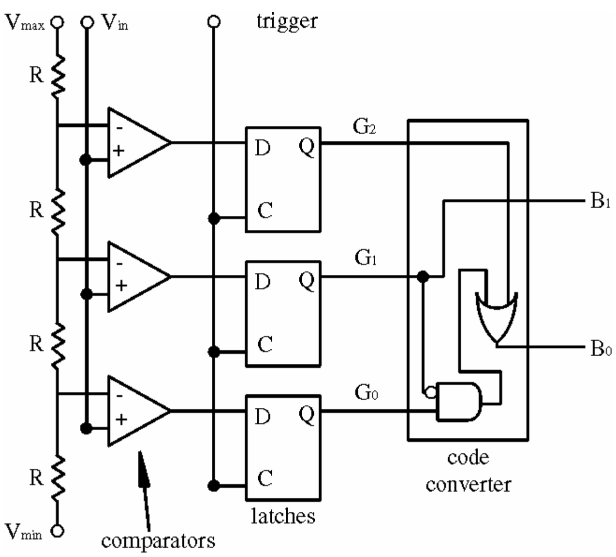
- Range
  - What is the anticipated range (Peak-Peak) of the event?
    - +/- 1.5 G for braking/acceleration
    - +/- 100G (possibly) for crash events
- Sampling Frequency
  - How long does your event last?
    - a.k.a: Period
  - Are there details within your event?
  - How much memory (cost) can you afford?
  - Are there frequency limits for the sensor?
    - DC coupled/output (good for vehicle performance)
    - High frequency capabilities (good for crash testing)

Comparing Accelerometer Systems

- Resolution
  - How many bits does your Analog to Digital Converter use?
  - Number of levels = $2^{\#\text{ of bits}}$
    - e.g. 10 bits gives $2^{10} = 1024$ possible values
    - e.g. 12 bits gives $2^{12} = 4096$ possible values
  - Resolution is the range of the instrument divided by the number of levels

$$res = \frac{range}{2^n}$$

Specifying a Dream Accel



- +/- 100g's = 200g range
- 24 Bit A/D = 16,777,216 levels
  - ~0.000012 g resolution
- 10,000 samples per second
- 30 second event
  - Required Memory:

$$2^{24}(10{,}000)(30)/8 = 629 \text{ Gigabytes}$$

- Overkill for a brake test!

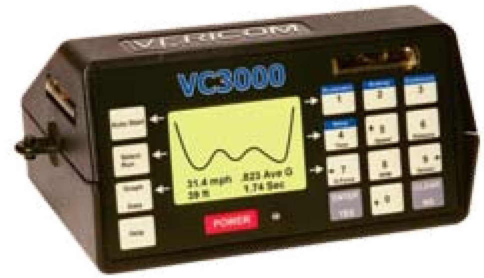
Specifying a Realistic Accel.

- +/- 2g's = 4 g range
- 10 bit A/D = 1024
  - 0.004g resolution
- 100 samples per second
- 30 second event
  - Required Memory:

$$2^{10}(100)(30)/8 = 384 \text{ Kb}$$

- Sufficient for Vehicle Dynamics but not Crash Recording

Resolution for a Brake Test

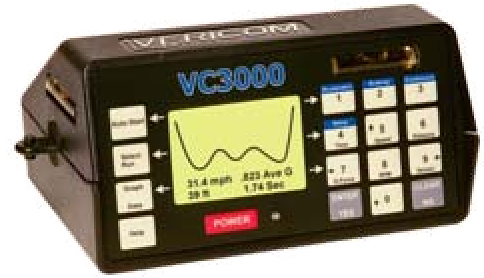


- 200g range (for example)
- 10 bit A/D
- 3200 Hz Sampling
- Resolution:
  - 200g /1024 = 0.19g
- Electronic or mechanical noise will have steps of 0.19g
- Automatic 30% error if measuring f=0.7
- Not so good for brake/dynamics test

- 4g range
- 10 bit A/D for externals
- 16 bit for Accel. Output
- 100 Hz Sampling
- Resolution:
  - 4g /65,336 = 0.00006g
- Electronic or mechanical noise will have steps of 0.0005g realistically.
- Automatic 0.07% error if measuring f=0.7
- Good for brake/dynamics test

Sampling Rate for a Crash

- 200g range (for example)
  - Can resolve peak amplitudes in crashes
- 3200 Hz Sampling
  - 320 samples in a 100 mSec crash event.
  - Can resolve frequencies up to 1600 Hz (vibration of the vehicle)
- Good instrument for crash testing



- 4g range
  - Peak accelerations are cut-off
- 100 Hz Sampling
  - 10 samples in a 100 mSec crash event.
  - Can resolve frequencies up to 50 Hz
- Little useful information for crash testing

Common Mistakes

- Reporting only peak values
  - Common in popular literature
- Be wary of “misapplying” accelerometer results
  - Crown Vic with Eagle RS-A may not represent a Geo Metro
  - New F-150 may not represent old Chevy ¾ ton.

Summary

- Why use an accelerometer in Crash Reconstruction?
- Overall Measurement System
  - Sensors (seismic mass)
  - Transducers (piezoelectric effect)
  - Signal Conditioners (filtering and A/D conversion)
  - Output (recording and interpretation)
- Accelerometer systems
- Specifications for measuring acceleration
  - Range, Resolution, and Frequency

Using Accelerometer Data

What do we do with the information?

What are we going to do?

- First of all, we will examine various ways of starting the VC3000DAQ accelerometer.
- Next, we will look at the data generated during the accelerometer runs.
- We will look at how to read and interpret the accelerometer graphs.
- We will summarize the results.

VC3000 DAQ Installed

Start Modes

- Auto-Start is used for braking runs. The accelerometer is started when a default value is set for the deceleration (0.20g is the default value).
- The accelerometer then measures the deceleration until the vehicle comes to a stop.

Start Modes

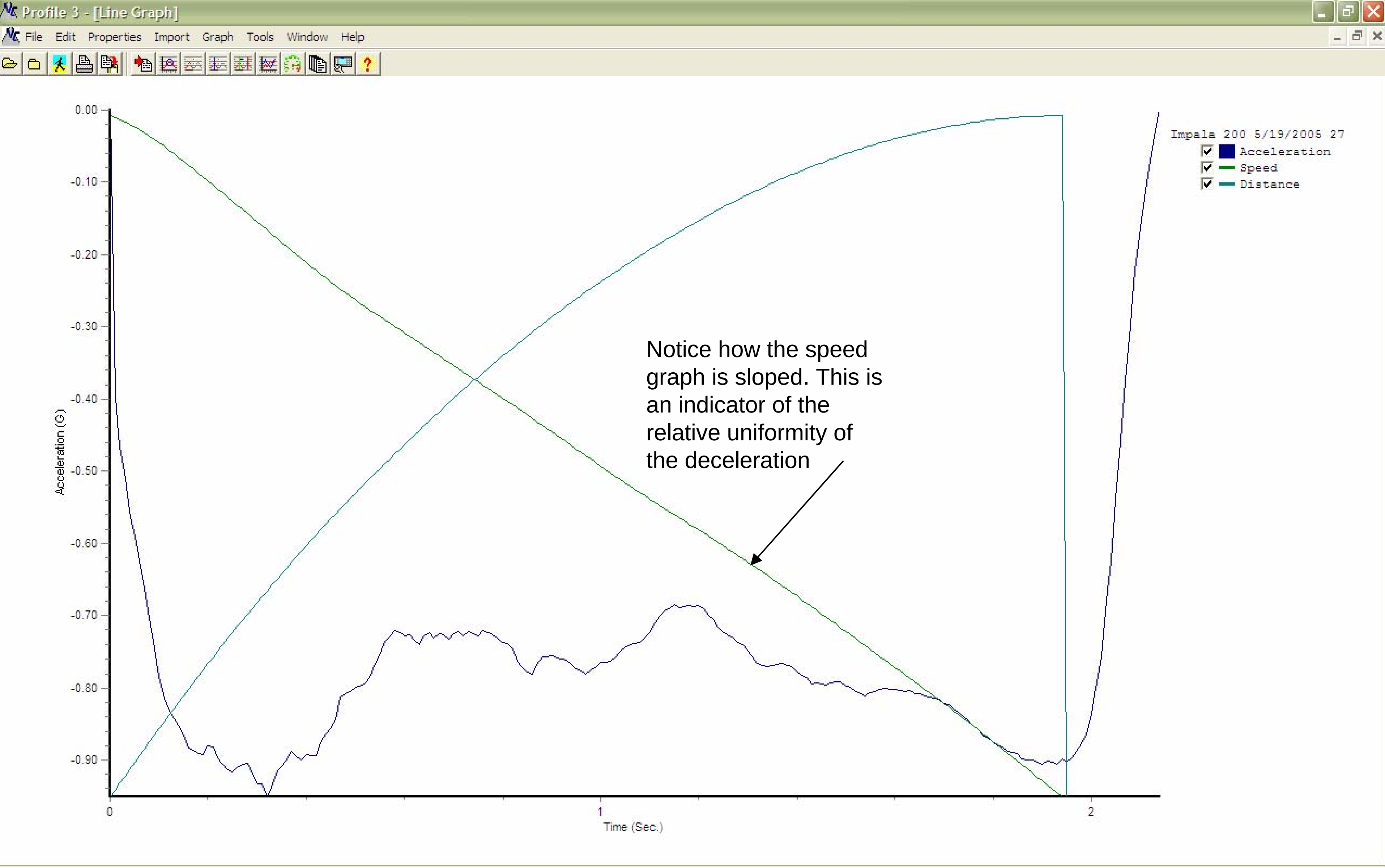
- The accelerometer may be set up to start with an external switch or signal.
- Examples would be a tape switch on the brake pedal or a hook-up to the brake light switch.
- This mode may be used when determining timing of some action relative to when the driver hits the brakes.
- The accelerometer then measures the deceleration until the vehicle comes to a stop.

Start Modes

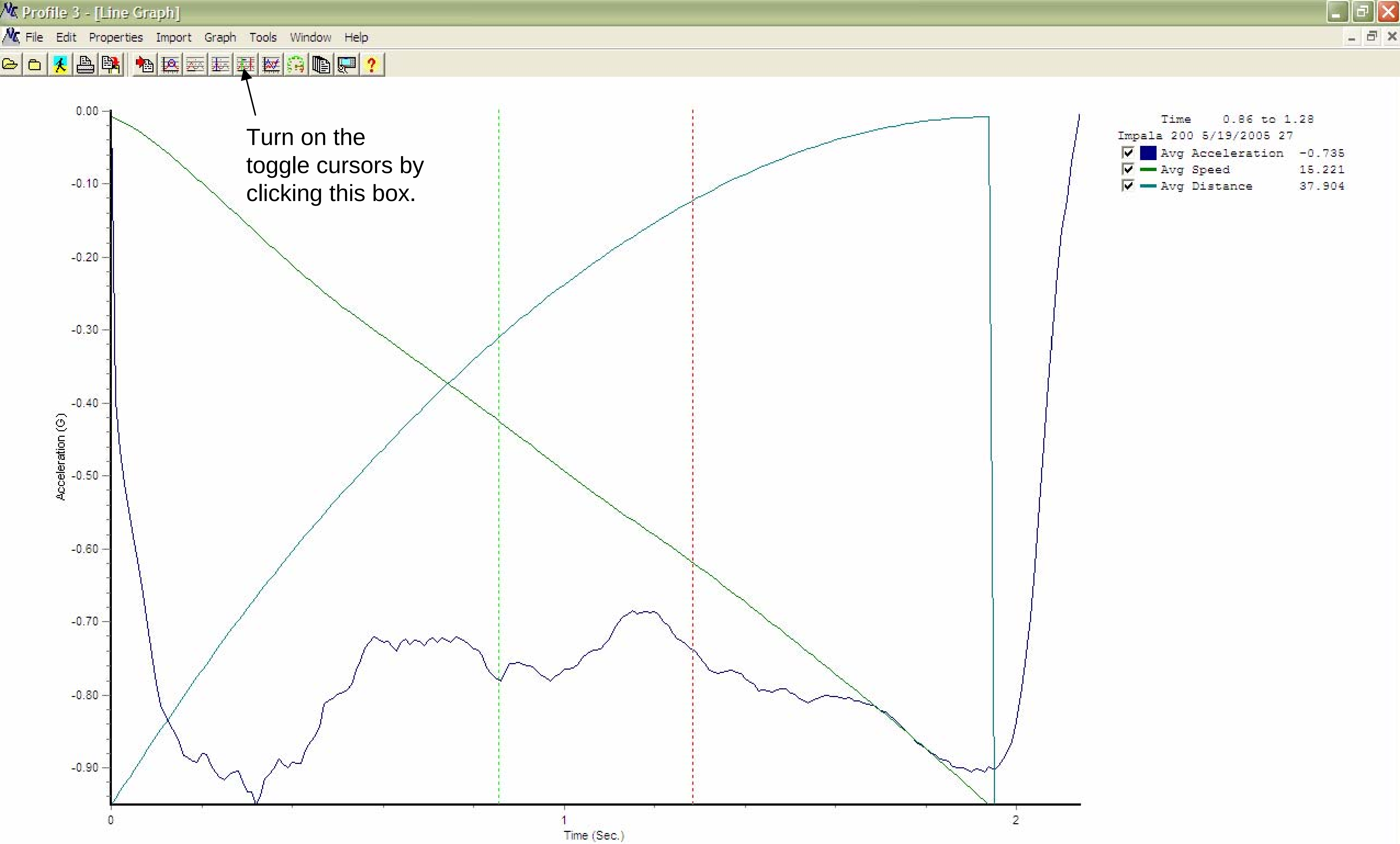
- The accelerometer may be used in continuous mode. This may be quite useful as several tests may be carried out during the same run.
- The accelerometer is manually started and stopped by the operator.
- During the time it is on, it measures all variables continuously.

Auto-Start Braking Run

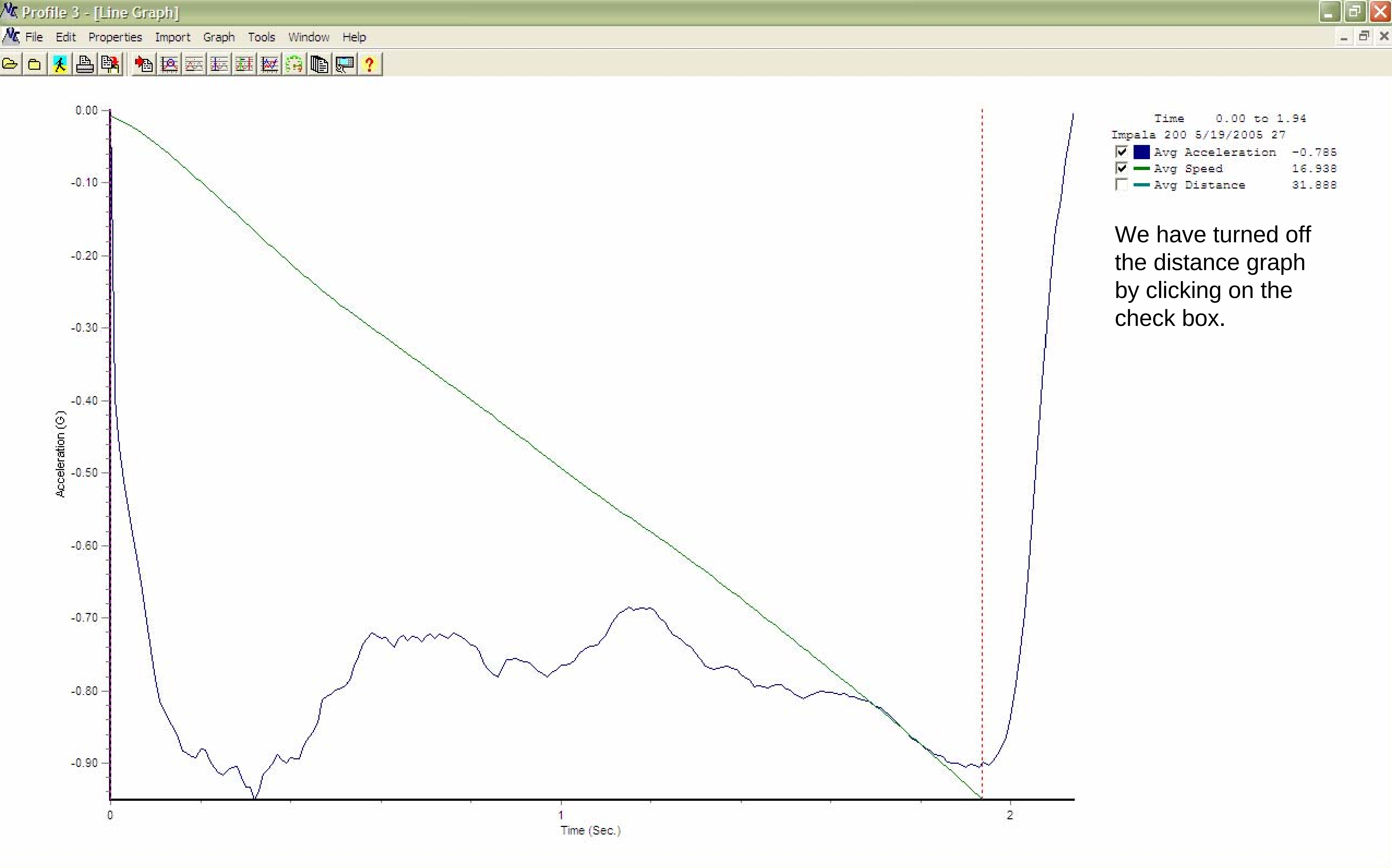
- The next several slides will show graphs generated by the VC3000DAQ when in the braking mode.
- We measure the stopping deceleration.
- The instrument then calculates speed and distance from this information.
- We will look at how to use some of the features of the Profile® program to interpret the generated data.



This is a braking run from the VC3000DAQ. Initiation was at a pre-set 0.20g. We have graphs of distance, speed, and acceleration. Notice the graphs are labeled as discreet values.

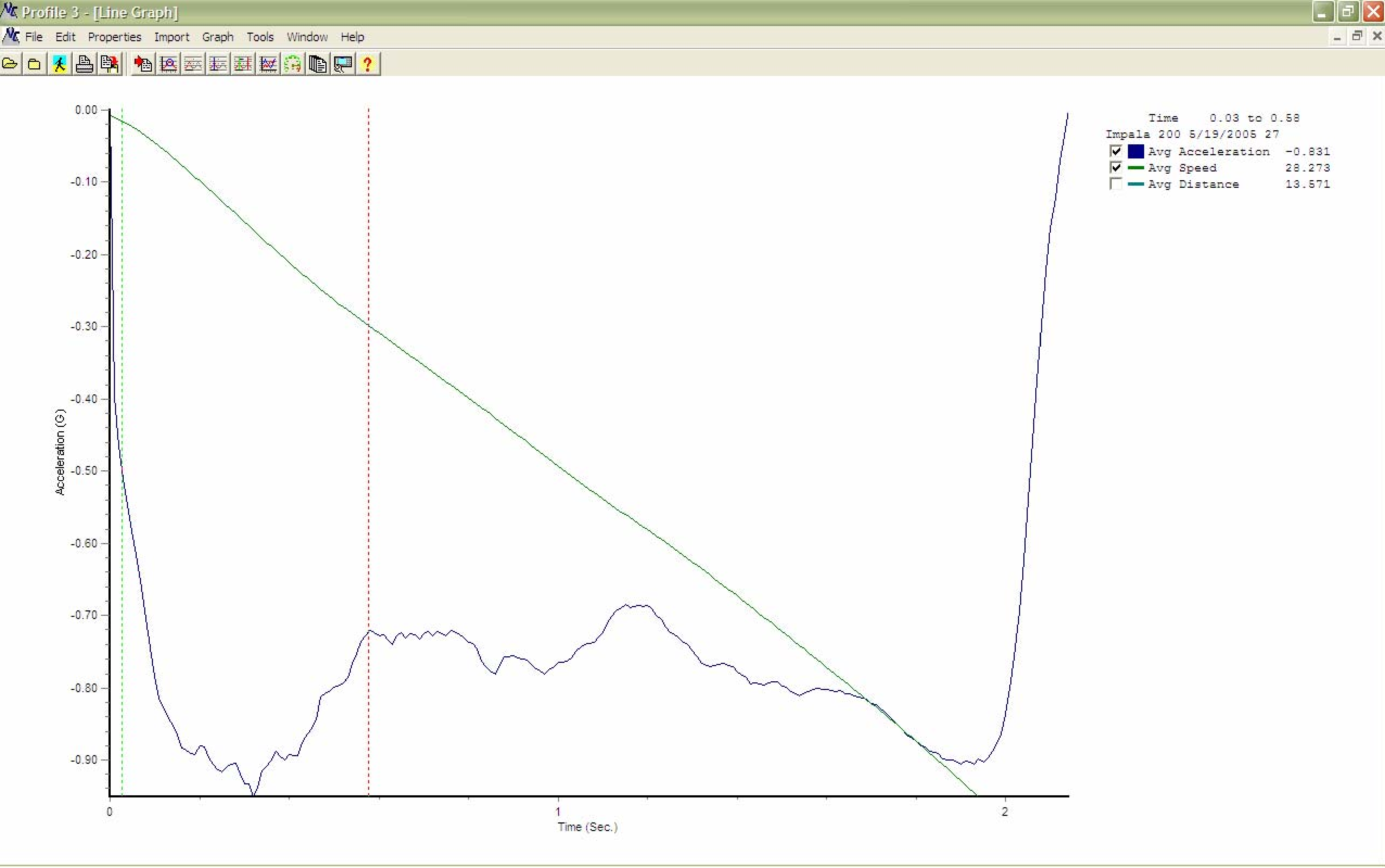


Notice the green and red vertical dotted lines. These are the *toggle* cursors. They enable us to chose a range over which we may find average values for the measured variables. The graphs are labeled as average values.

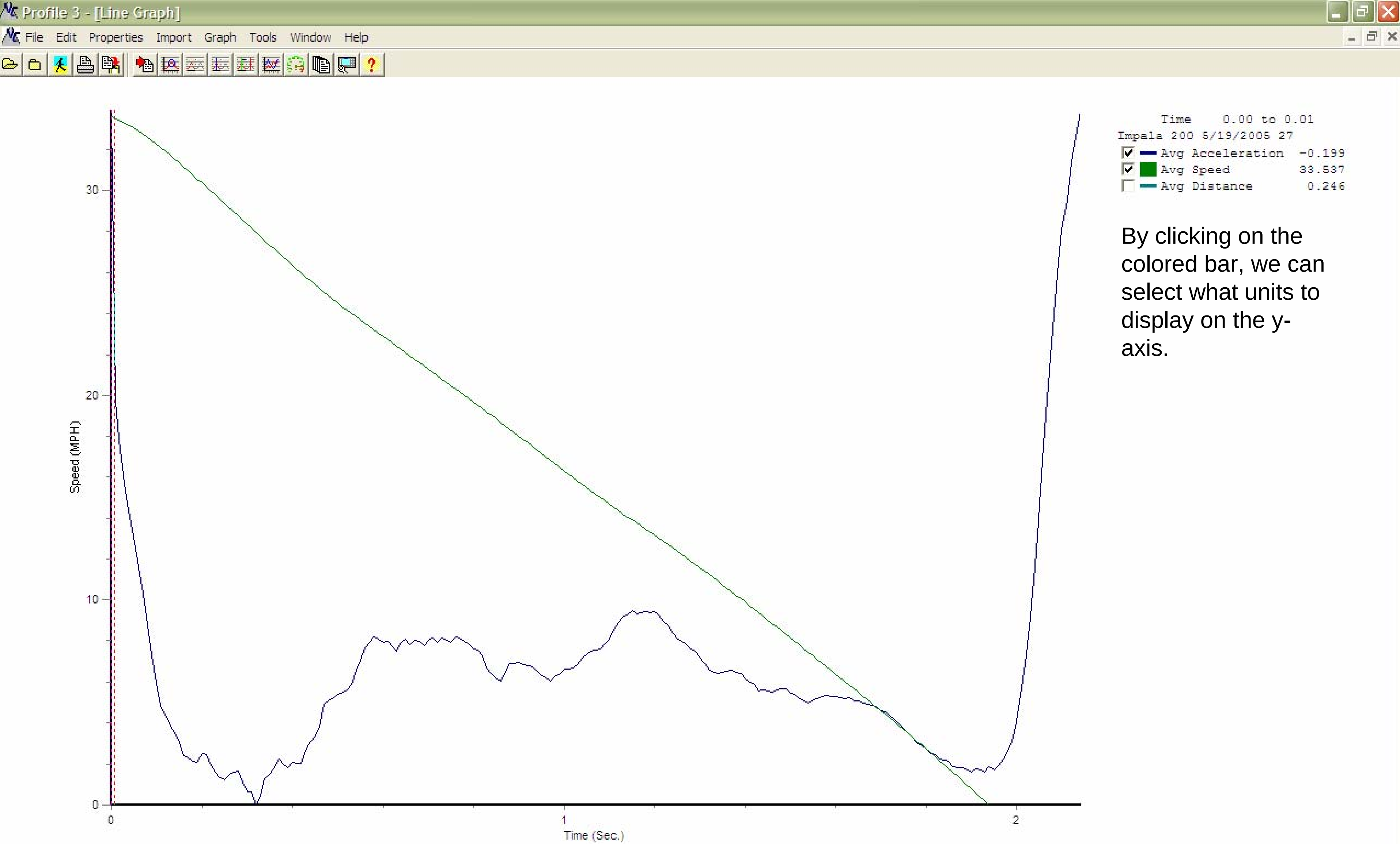


We have turned off the distance graph by clicking on the check box.

We have placed the toggle cursors at the beginning of the graph and then at the point where the speed is zero at the end of the skid. The overall average of the skid is 0.785g.

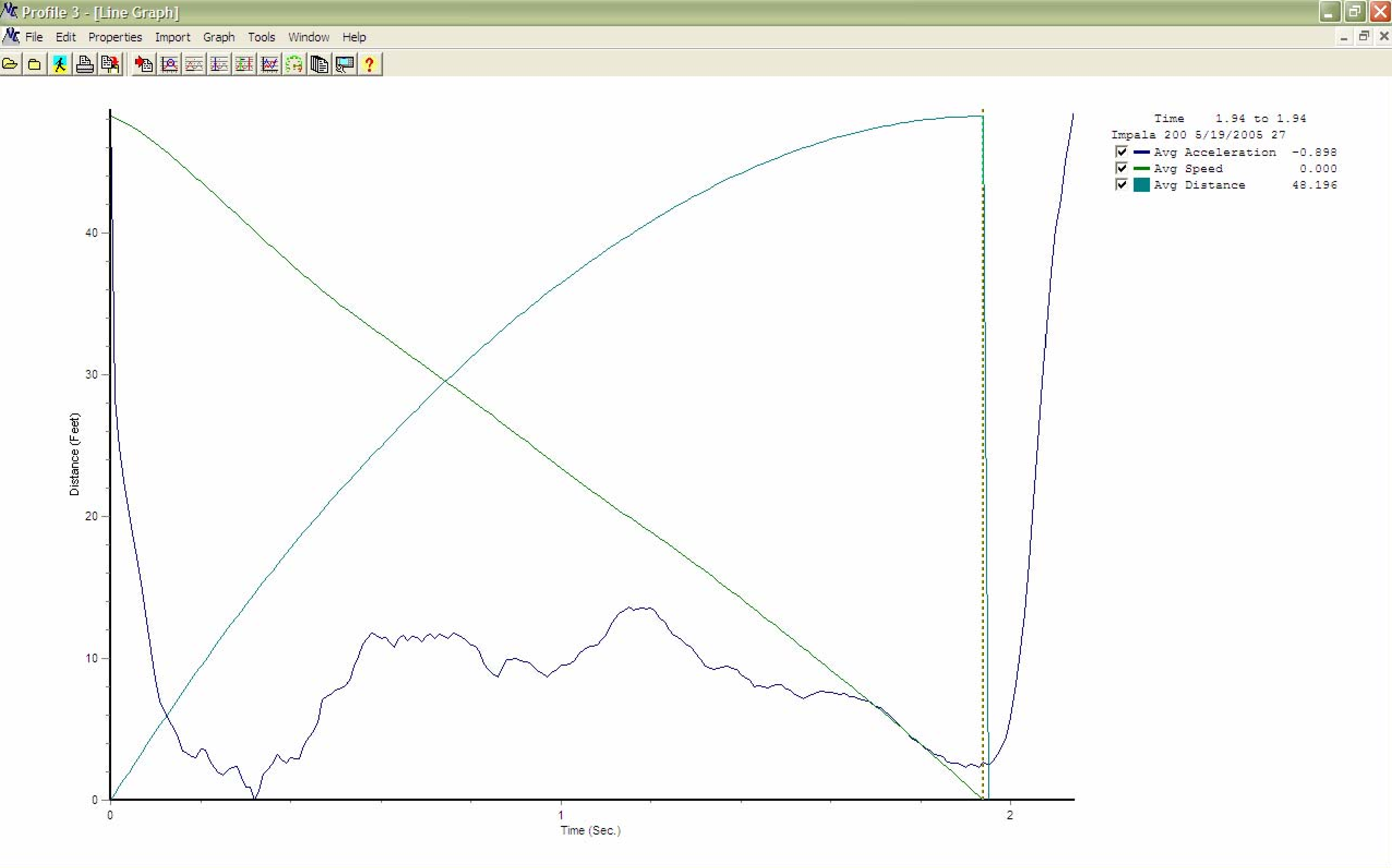


Here we have placed the green toggle at a point on the graph indicating a deceleration of about 0.50g. This would be about where we begin to see shadow marks on the road. The red toggle is about where we would see locked wheel skids. The average value for this range is 0.831g, which is higher than the overall average of 0.785.



By clicking on the colored bar, we can select what units to display on the y-axis.

By bringing the two cursors together at the start of the skid, we can see how fast we were going at the start of the skid. In this case, it is about 33.5 mph.



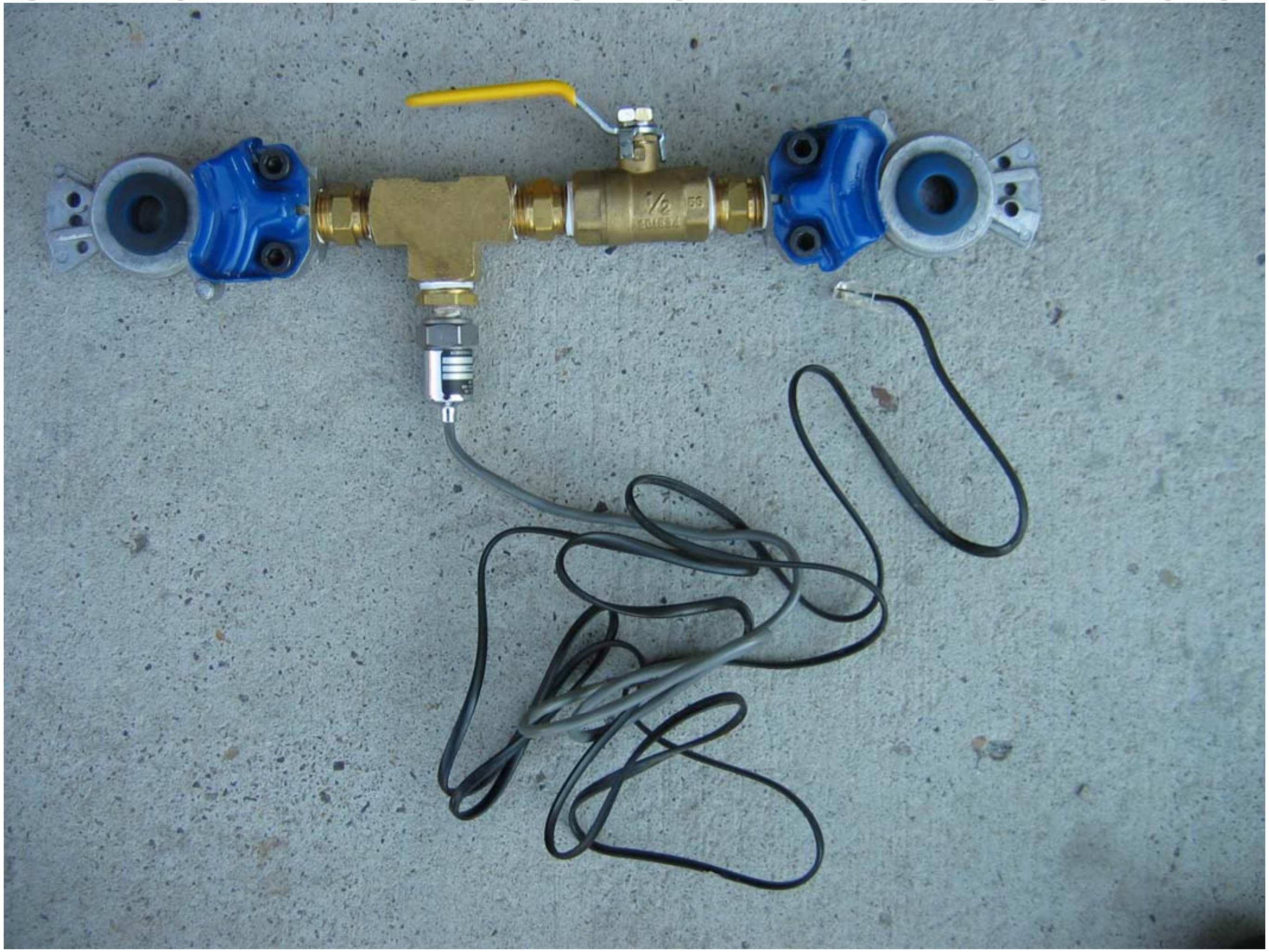
We have turned the distance graph back on and have made the y-axis read in feet. By bringing the toggle cursors together at the point where the speed is zero, we can see the skid distance is a bit over 48 feet. We also see the time to skid is about 1.94 seconds.

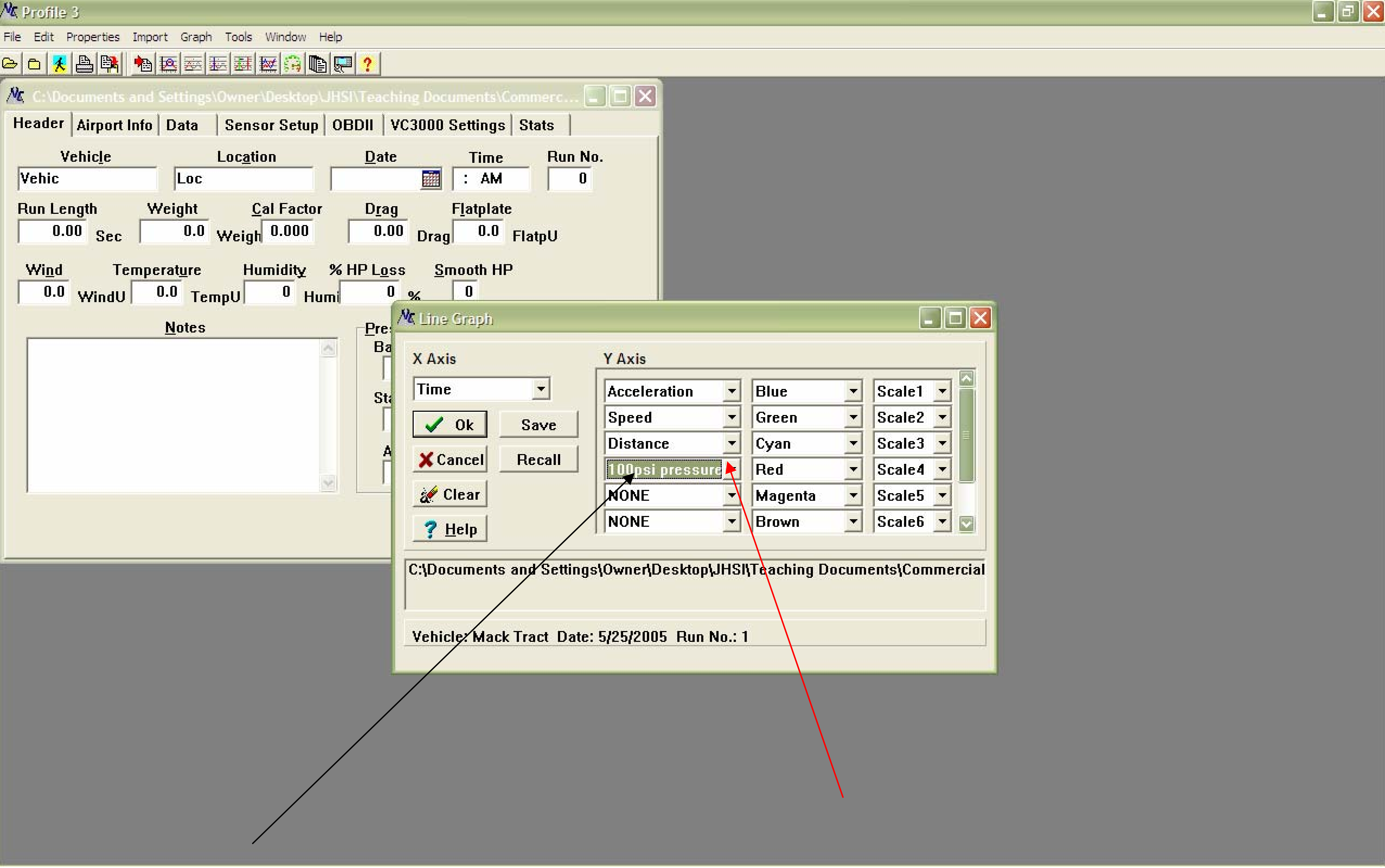
Discreet Start (Tape Switch)

- This next set of slides will help us explore graphs generated by a discreet start.
- In this case, a tape switch on the brake pedal will be used to start the instrument.
- In addition, an external pressure sensor will be plugged into the VC3000DAQ in order to measure the air pressure at the glad hands on a TT unit.

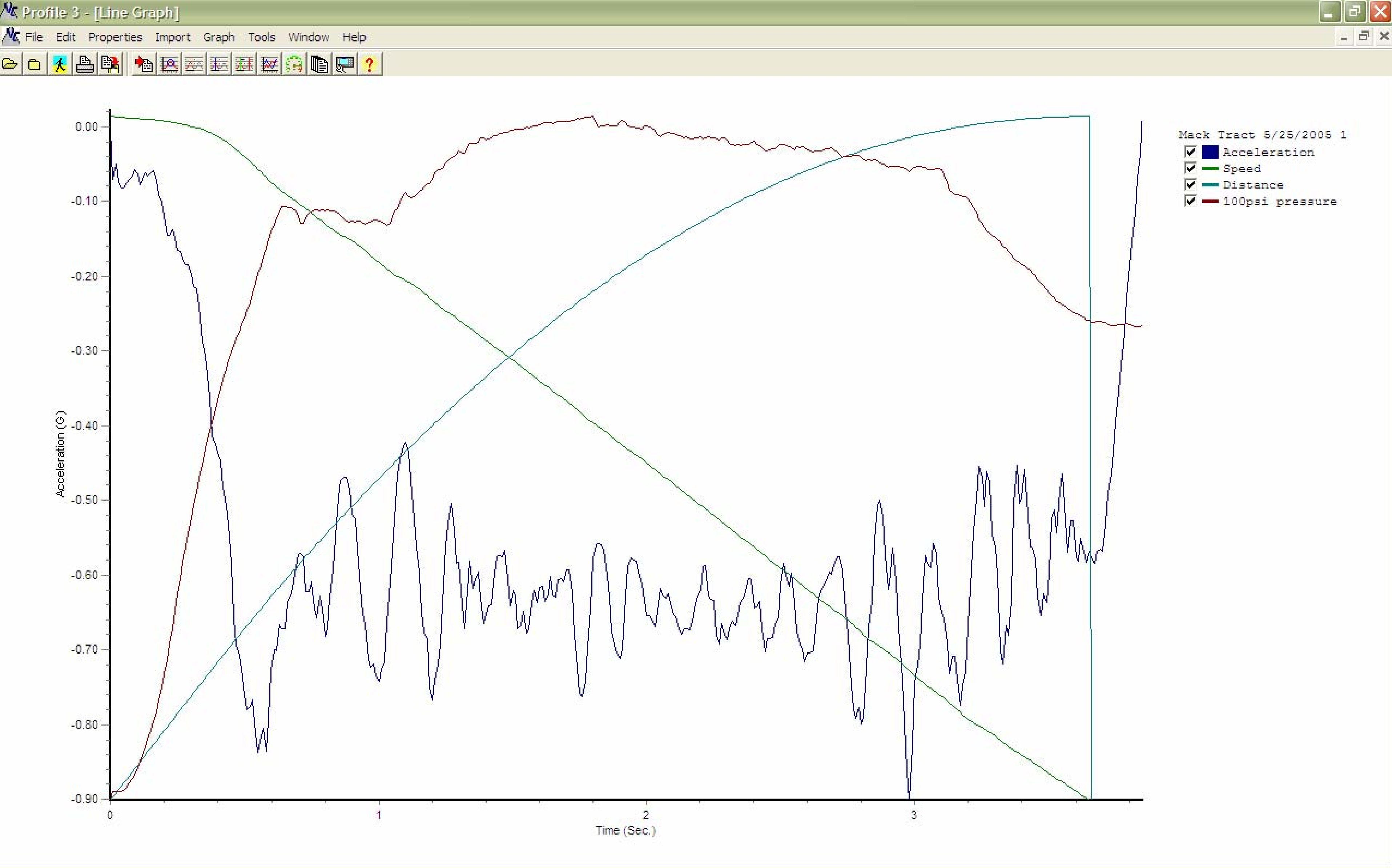
Tape Switch

External Pressure Transducer

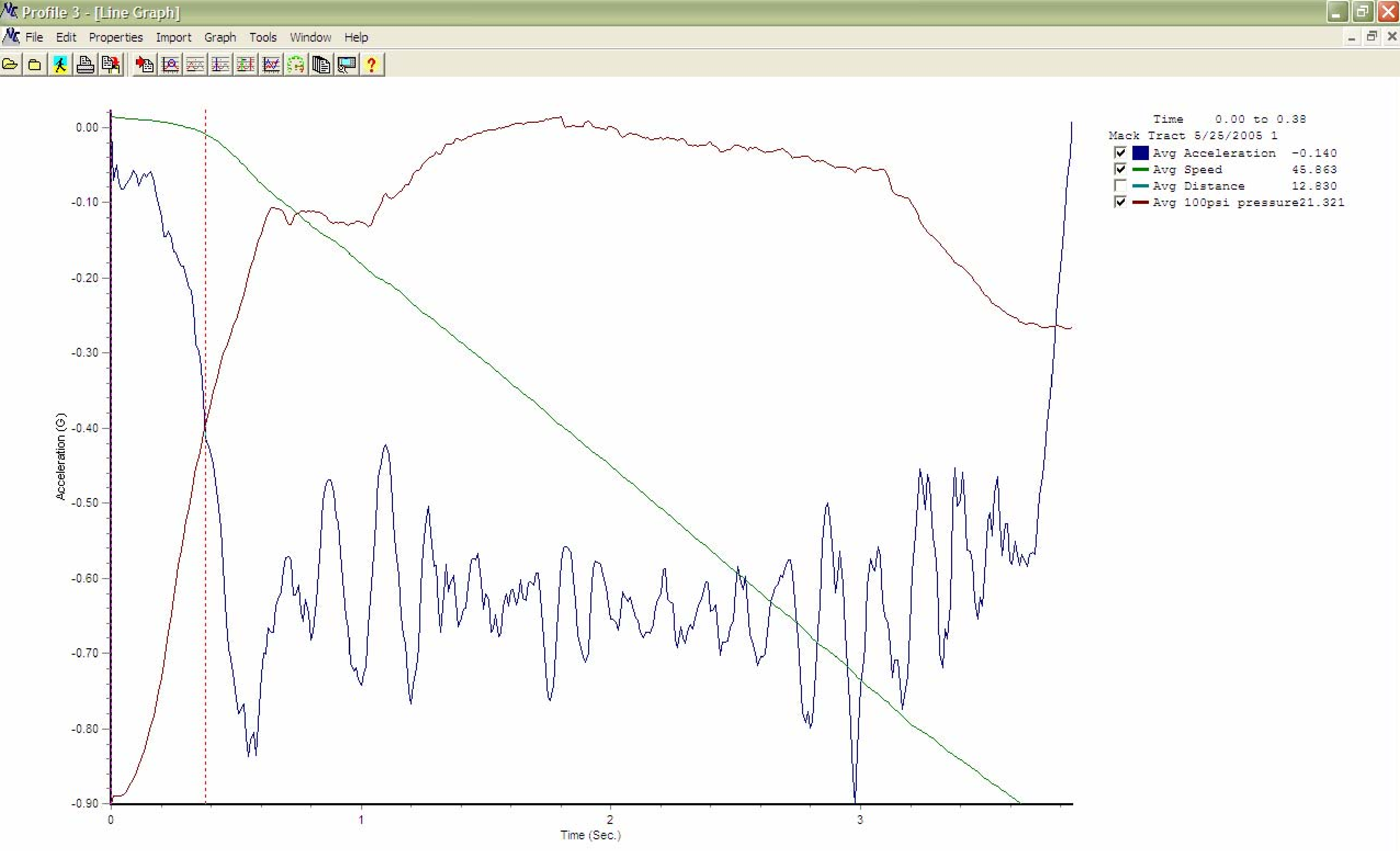




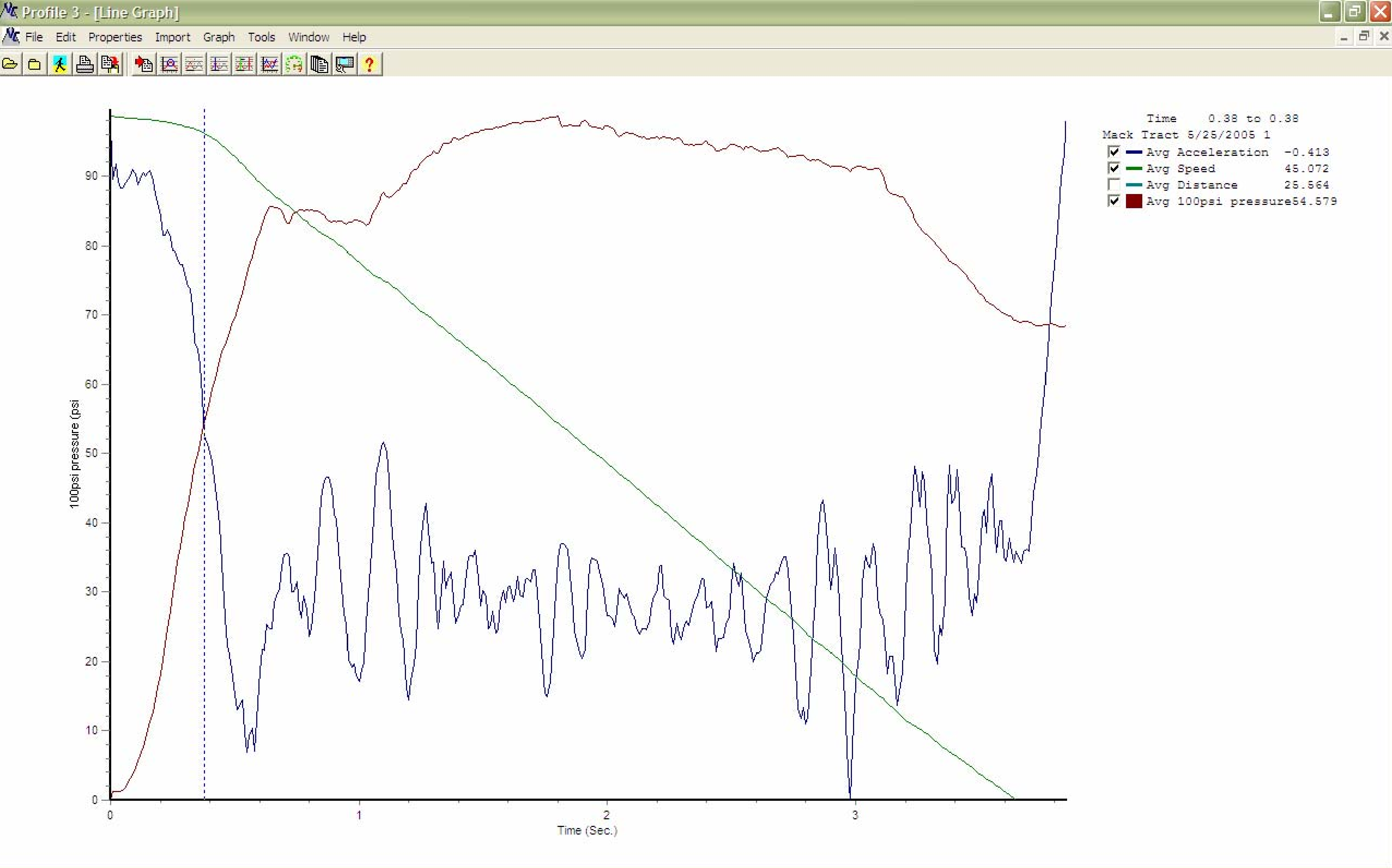
We are setting the graph to also show the pressure rise in an air brake system (black arrow). This is done by clicking the arrow box next to the variable and selecting the appropriate name (red arrow).



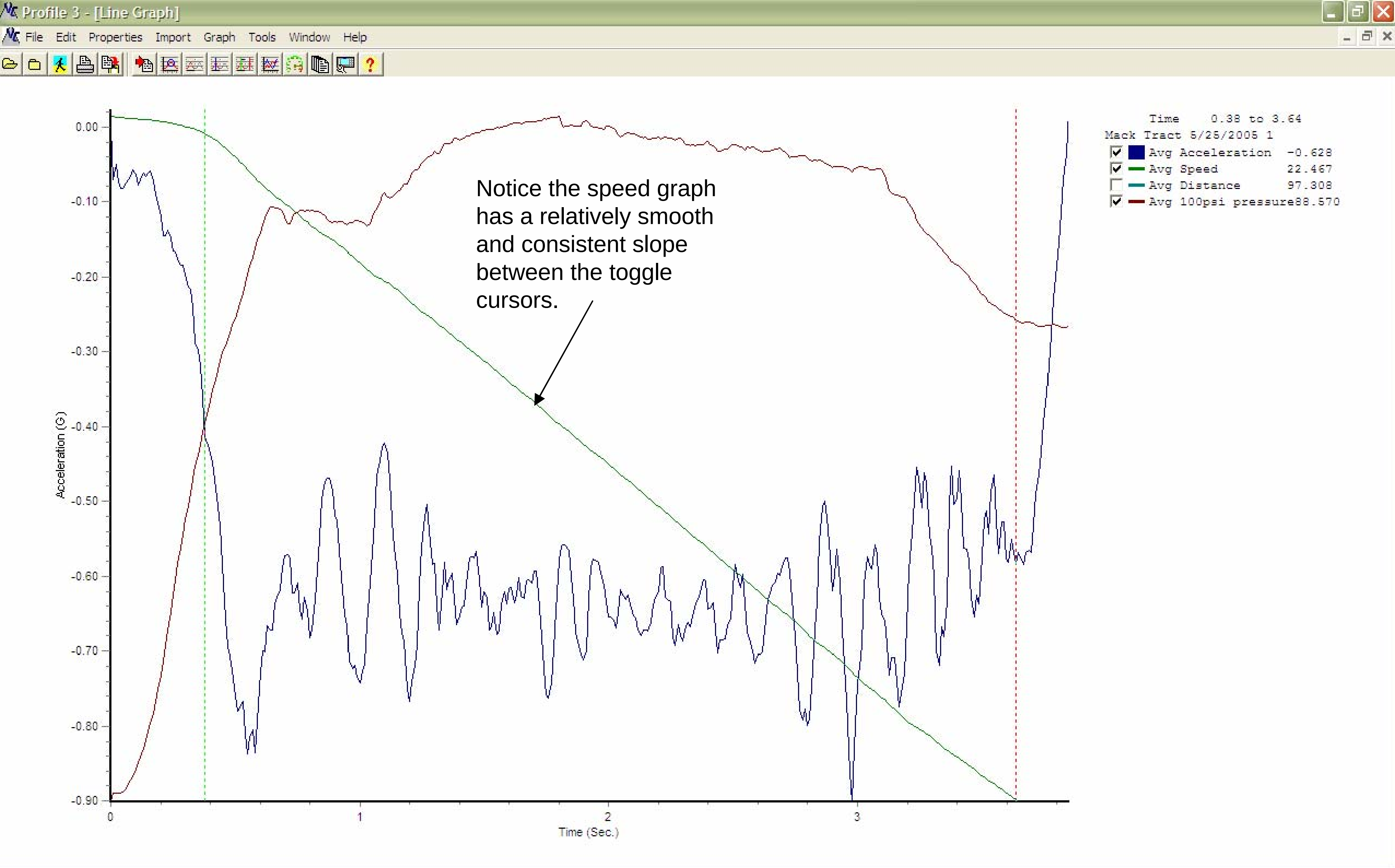
This graph looks a bit complicated, so we will look at it a piece at a time. We will turn off the distance graph and turn on the toggle cursors.



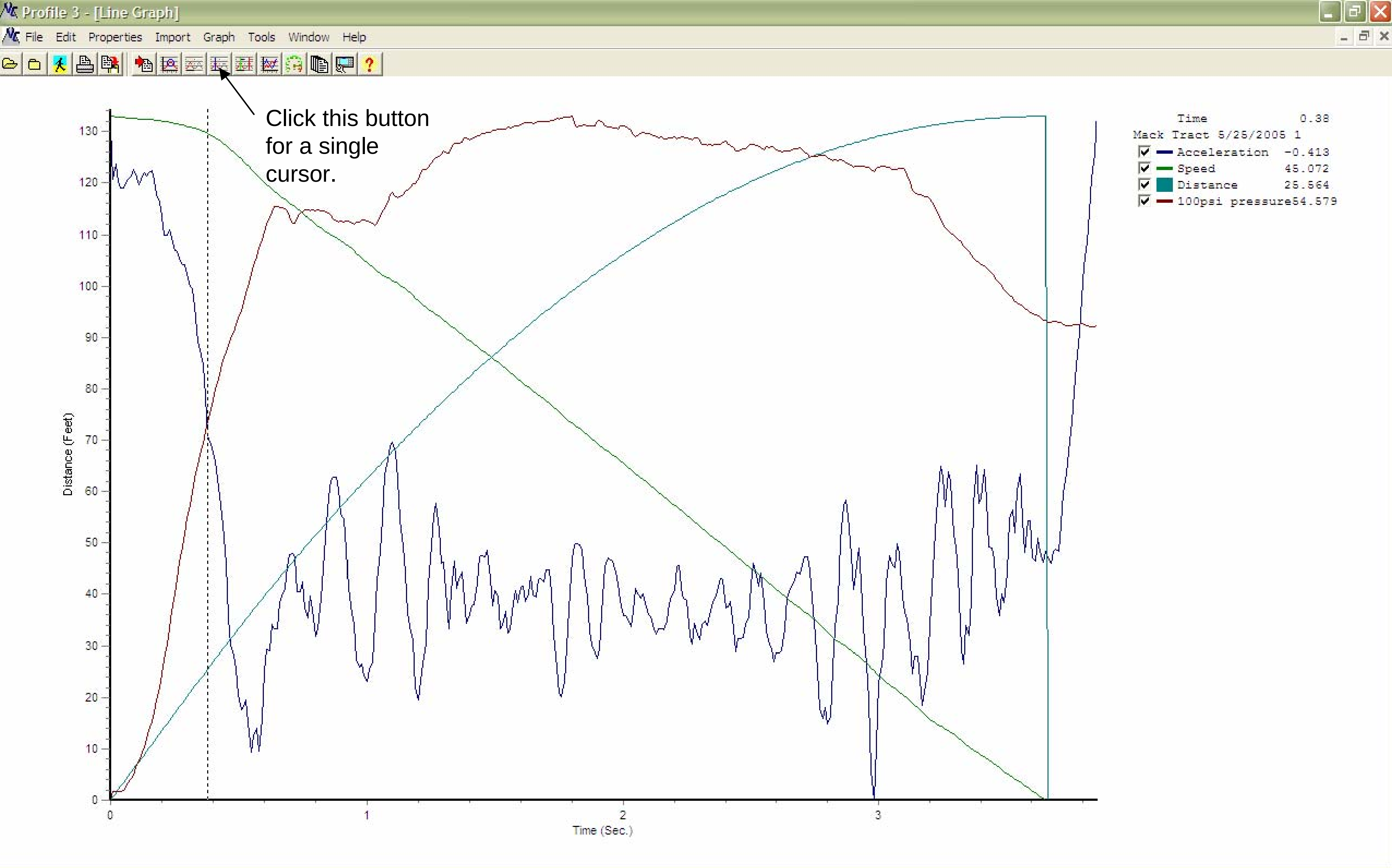
Our goal here is to determine brake lag time for this TT unit. The green cursor is at time 0.00, which is when the driver's foot hit the brake. The red line is placed at a deceleration of about 0.40g. We can see the lag time is then 0.38 seconds.



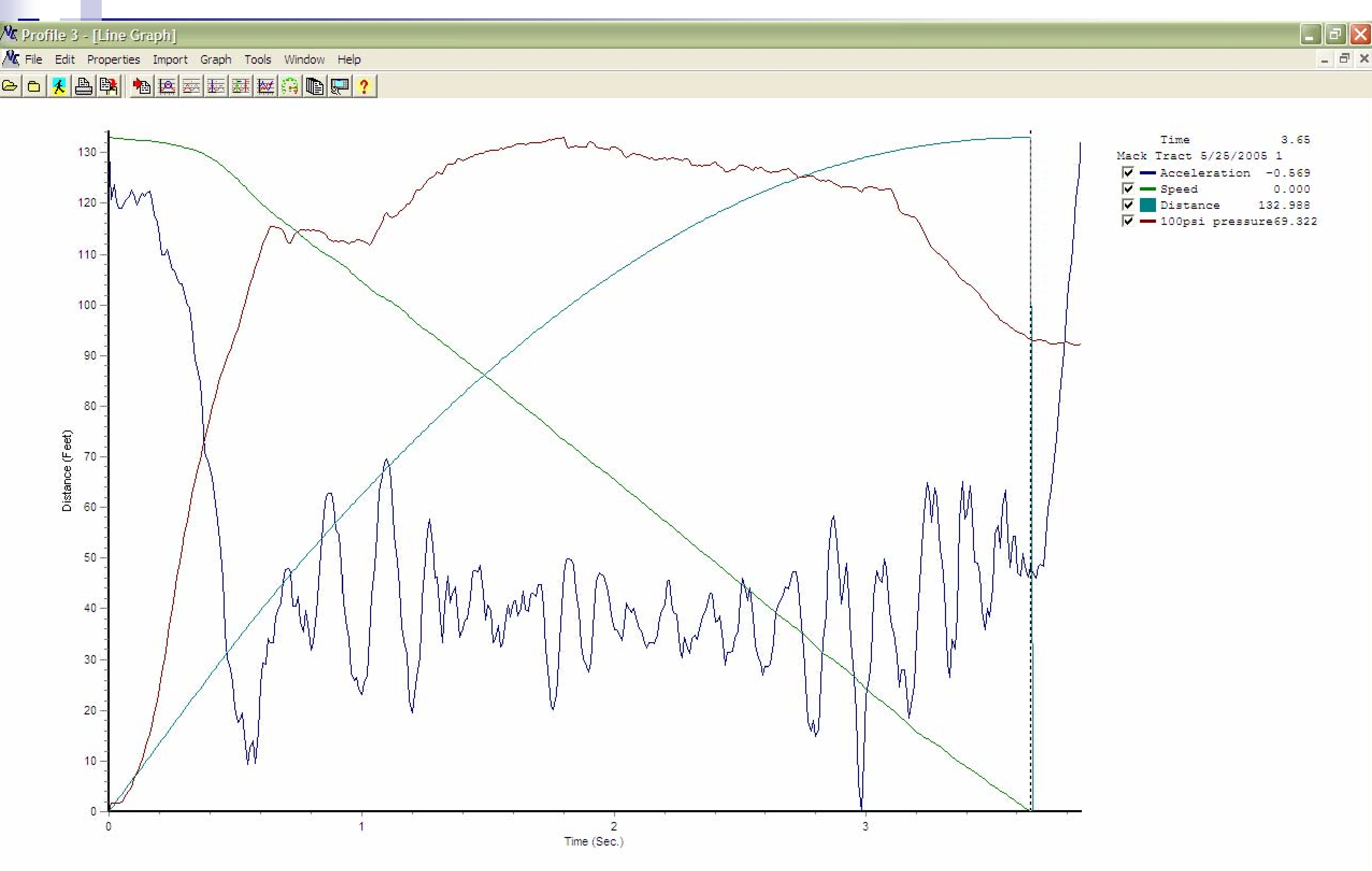
By bringing the cursors together at time 0.38 seconds and by changing the y-axis to read pressure in psi, we can see the air pressure at the glad hands was a bit over 54 psi.



We have changed the y-axis to g's and have placed the toggles between the 0.40g mark and the point where the speed graph goes to zero. We can see the average deceleration for this unladen TT unit is 0.628g. The acceleration graph is noisy because of the wheel hop of the trailer.



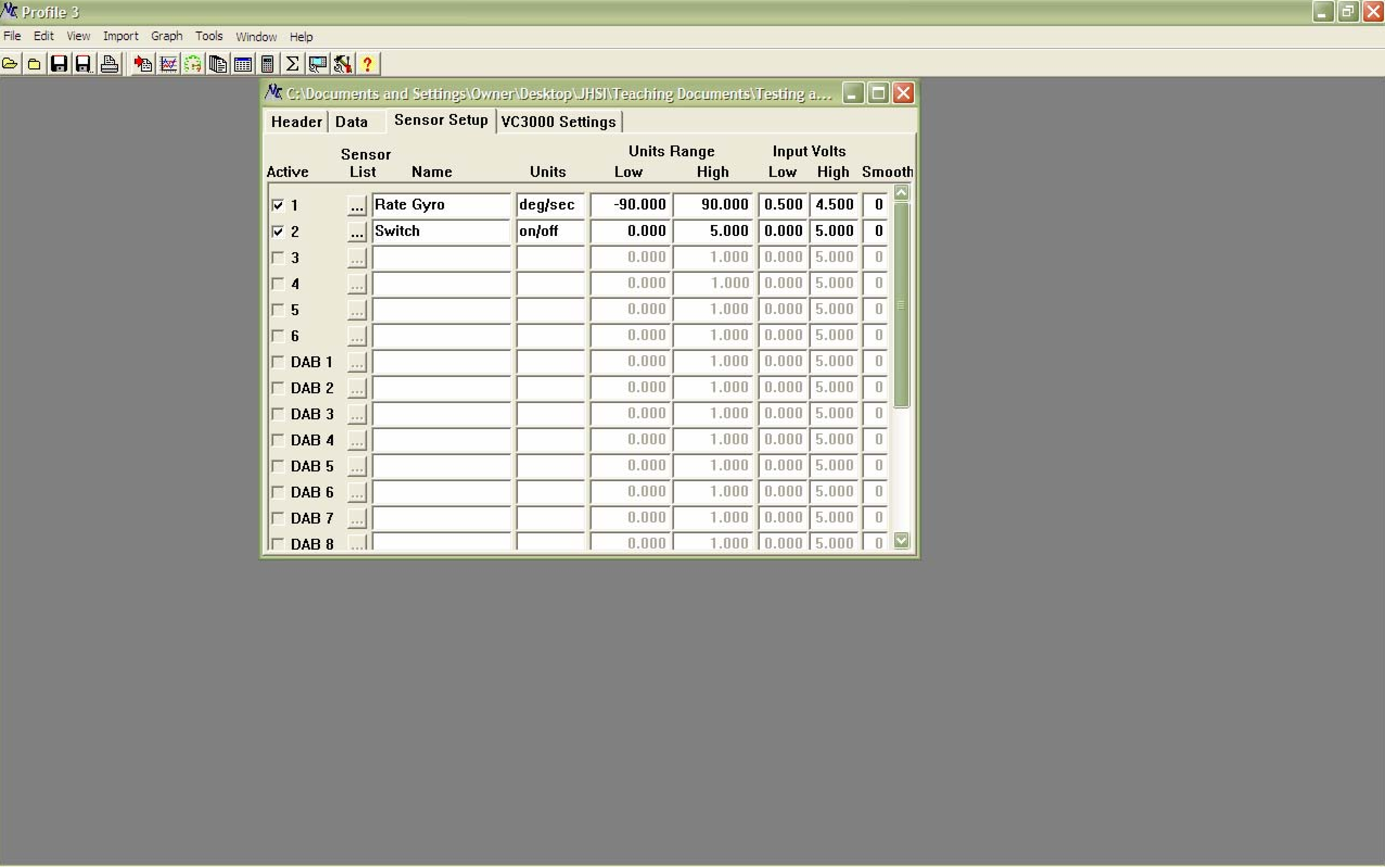
Sometimes it is useful to use a single cursor. A single cursor will give us discreet values at any point on the graphs. The cursor is placed at 0.38 seconds, which shows us a speed of 45 mph and a travel distance of 25.6 feet from time zero. The deceleration at this point is about 0.41g.



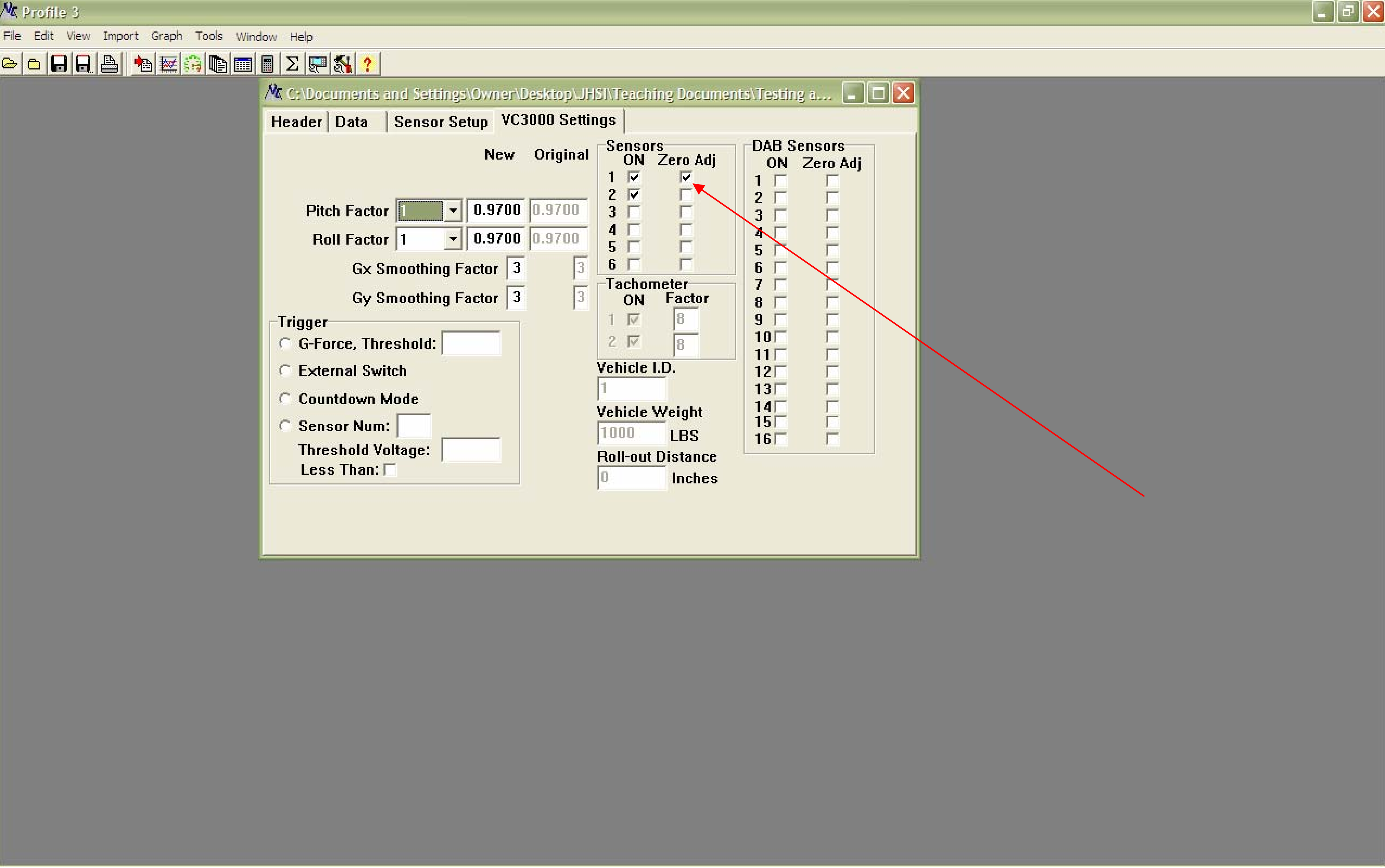
The single cursor has been placed at the point where the speed is zero. The distance from start is 132.988 feet. The difference in distance between the 25.564 feet from the last slide is about 107. feet. This represents the braking distance of the TT from about 0.41g. The calculated deceleration from these data is 0.630, which compares to the average of 0.628 computed by the instrument.

Continuous Mode

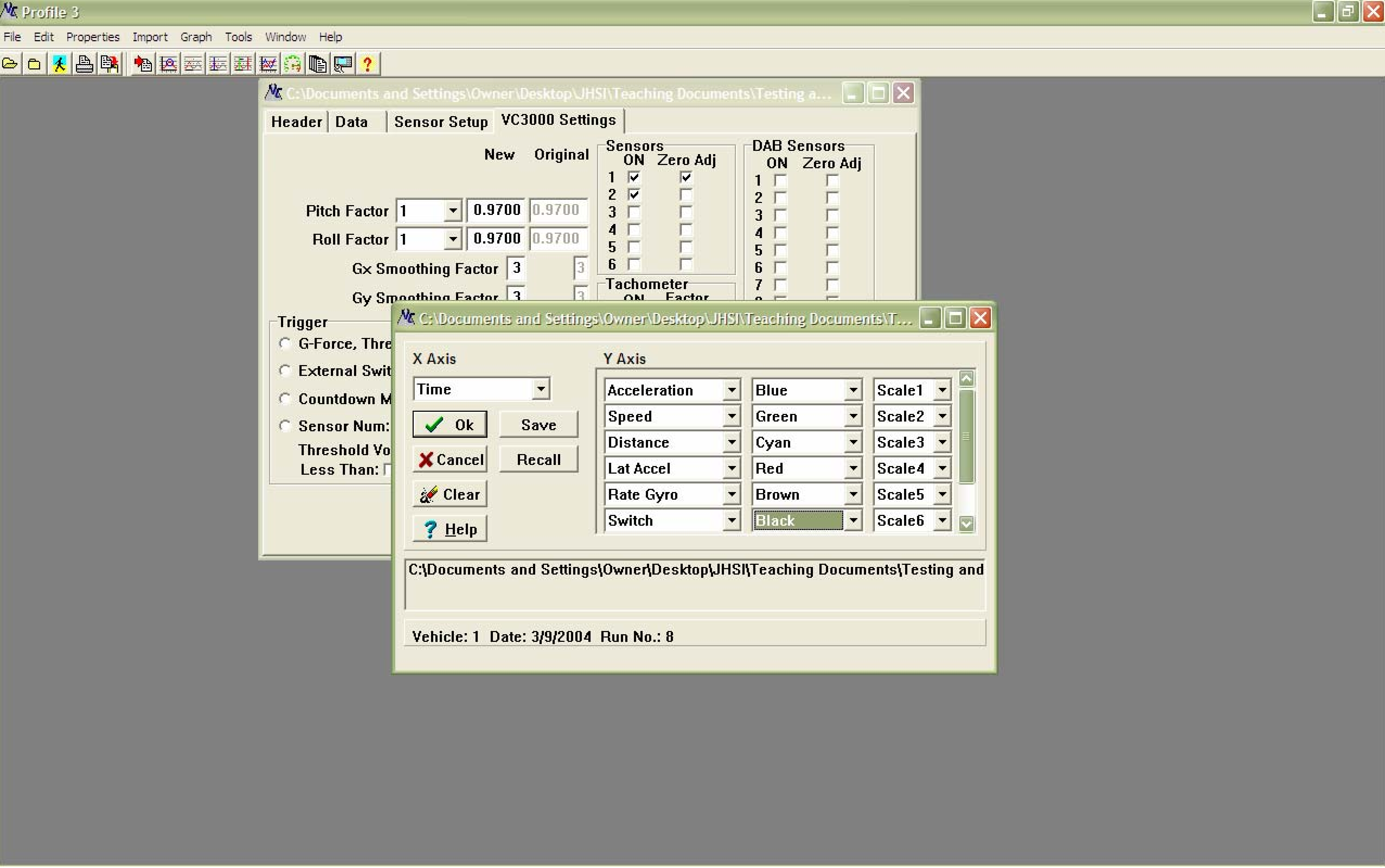
- The continuous mode configuration allows measurement from the time the operator turns on the instrument until the instrument is turned off by the operator.
- This allows several performance variables to be measured in the same test, such as acceleration and braking.
- Lateral and longitudinal accelerations are measured simultaneously.
- Simultaneous data from other sensors may be gathered at the same time.



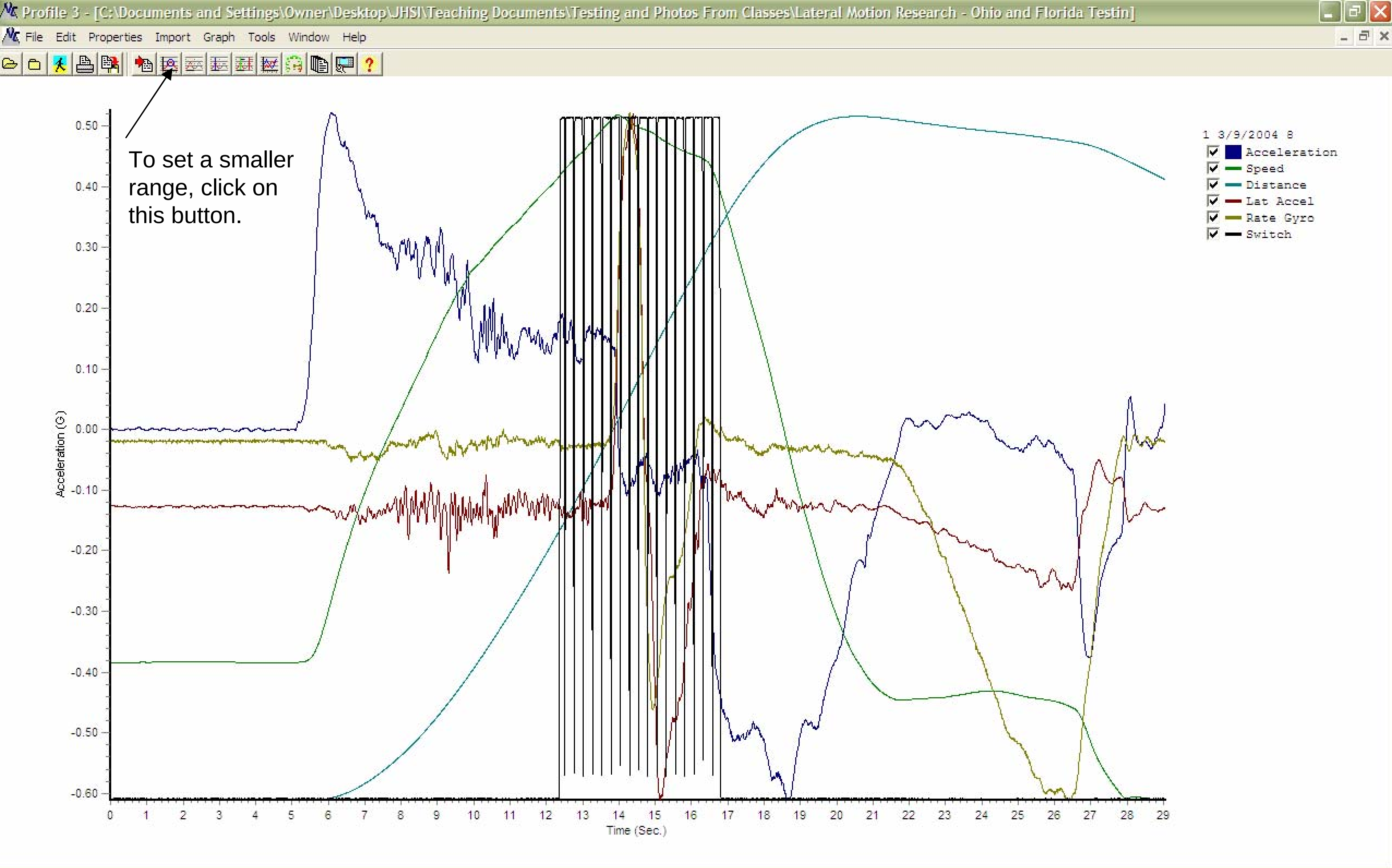
When using external sensors, the VC3000 must be configured. Click on the “Sensor Setup” tab for this.



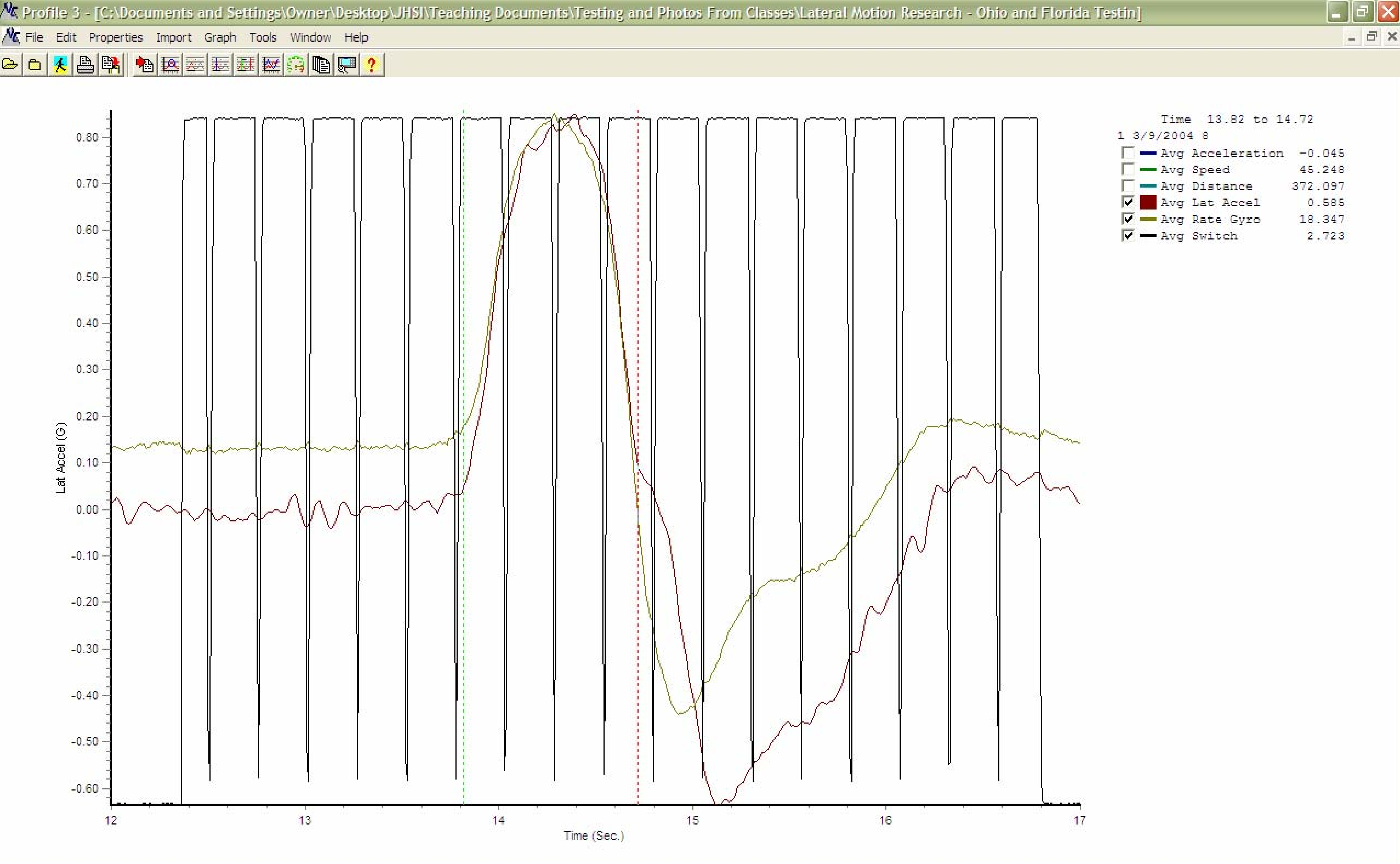
The “VC3000 Settings” tab should also be clicked. Turn on the sensors to be used. The rate gyro must have the “zero adjust” box checked. (Red Arrow) The switch does not need a zero adjust.



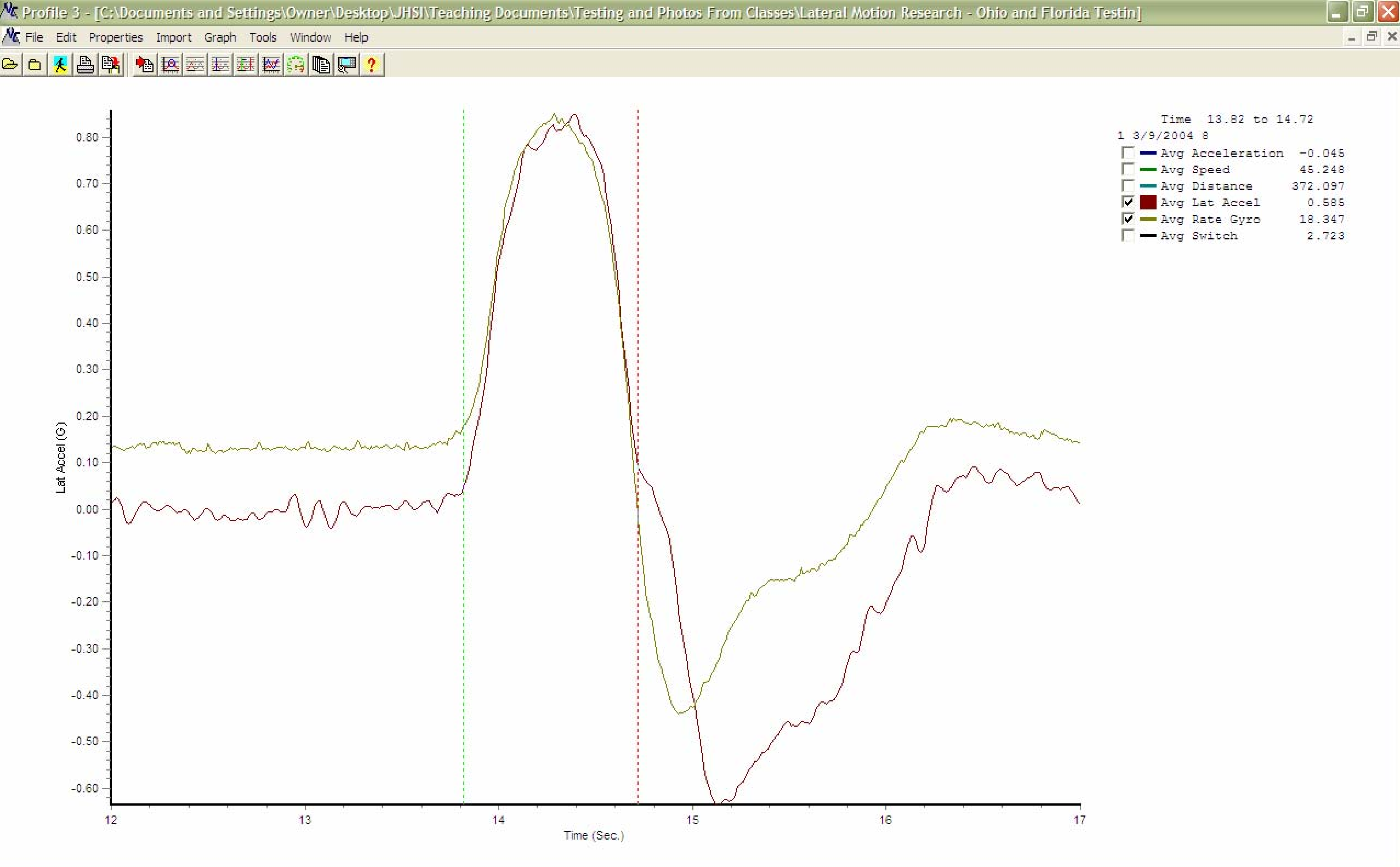
Next we configure the display. We will have six separate graphs displayed, all coupled by time.



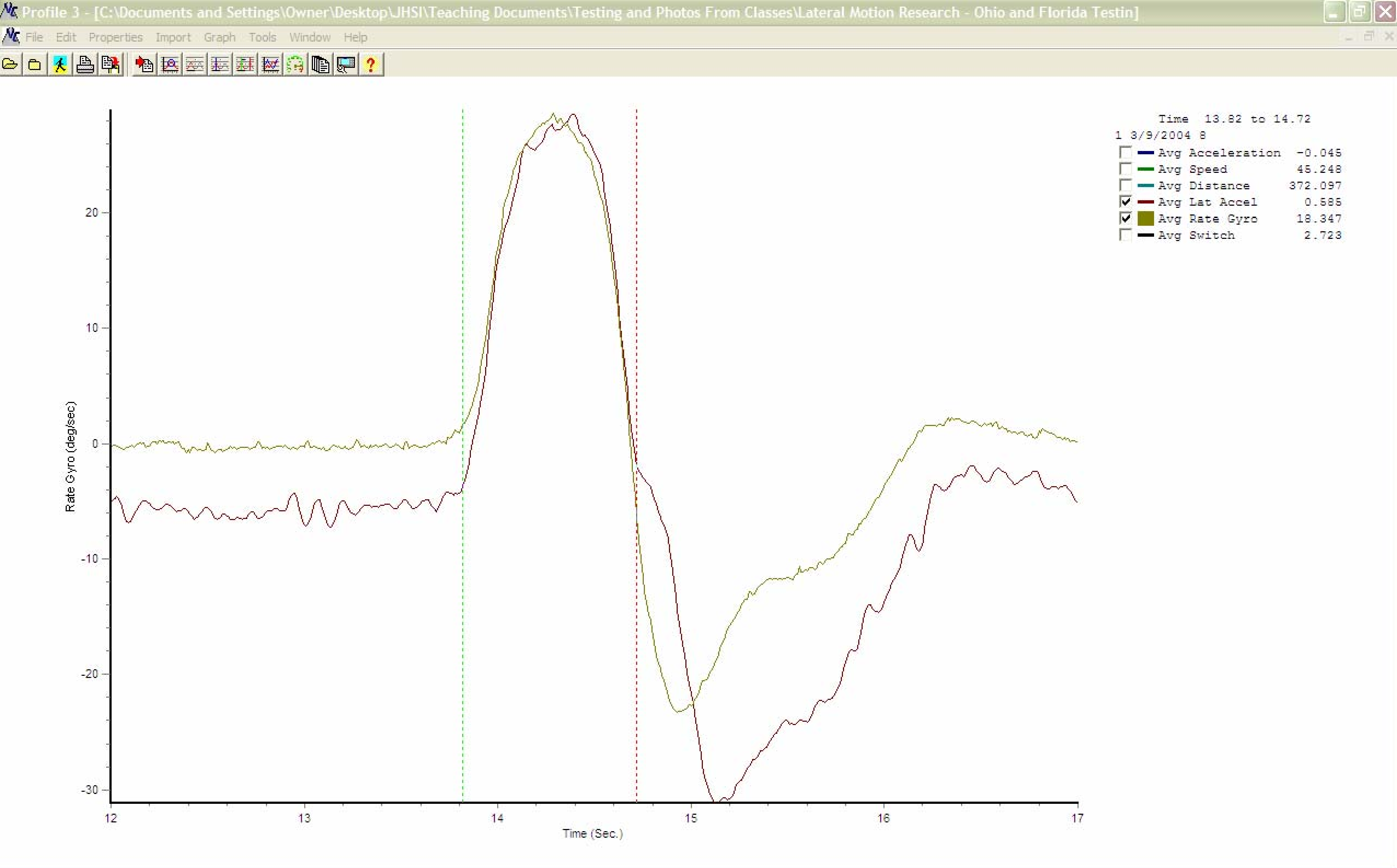
Oh, boy! This looks pretty complicated! We should probably start simplifying some things. Since this test was for lateral acceleration, we can turn off acceleration, speed, and distance. We will also set the range between 12 and 17 seconds.



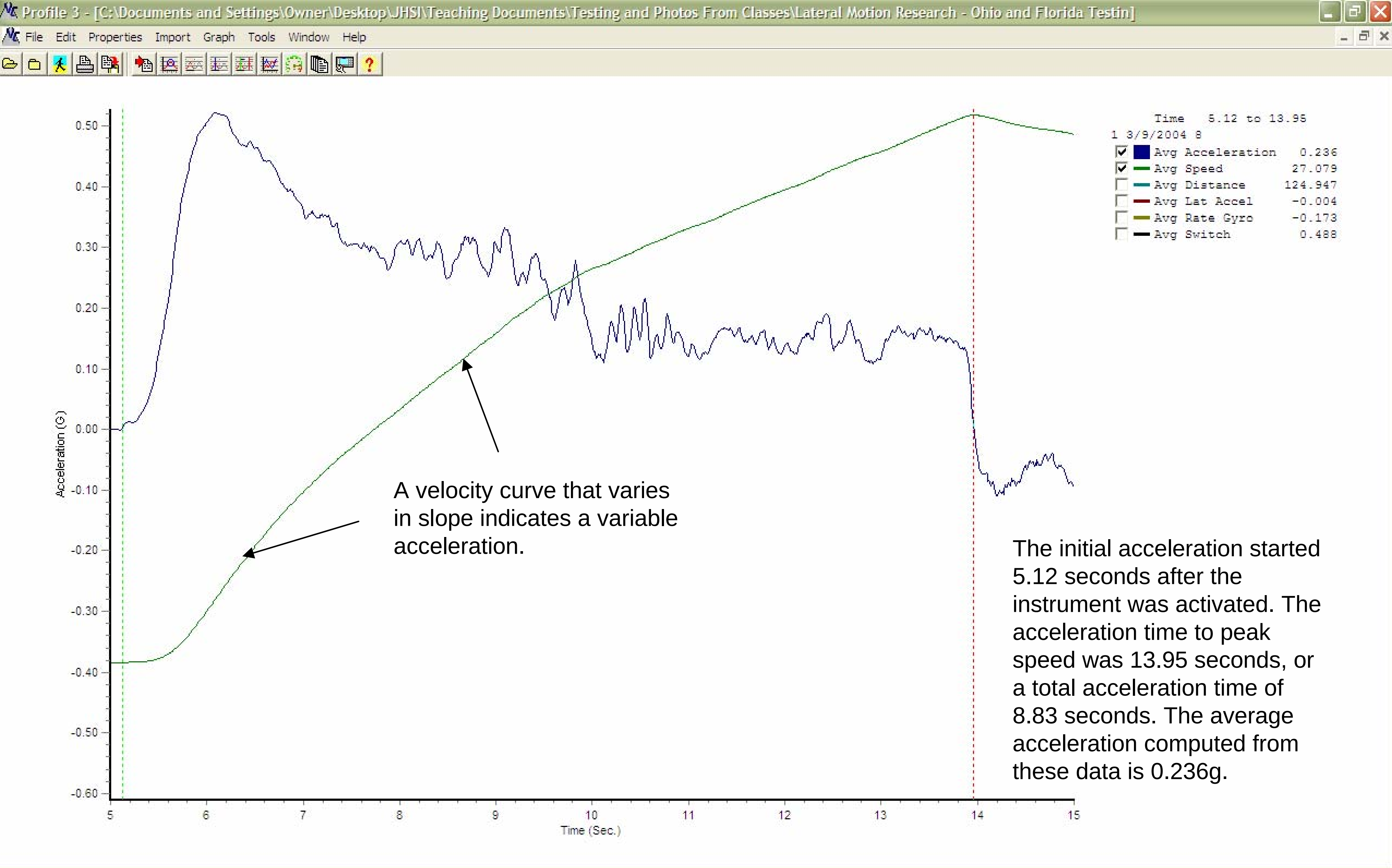
This is better. We have lateral g, the rate gyro, and the switch showing on the graph. The switch shows a +5 volt input every time the DRMS marking system fires. We put in the toggle cursors before we adjusted the range, which is now 12 to 17 seconds.



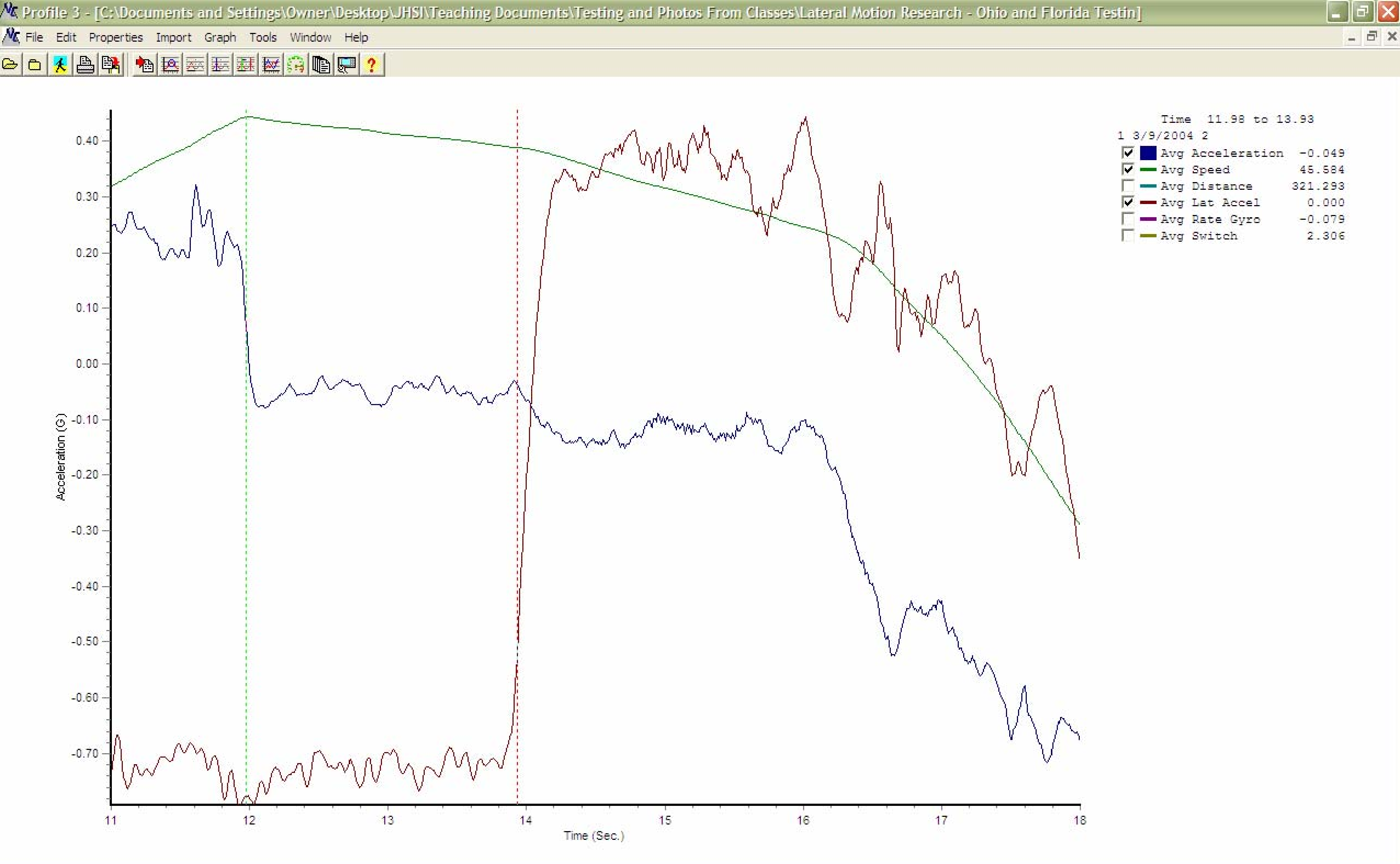
We have turned off the switch to make the graphs of interest more clear. The chart toggles show the average lateral acceleration for the initial left steer on a lane change maneuver. Notice this average of 0.585 is considerably below the peak, which is above 0.80. This is an example of *transient* behavior.



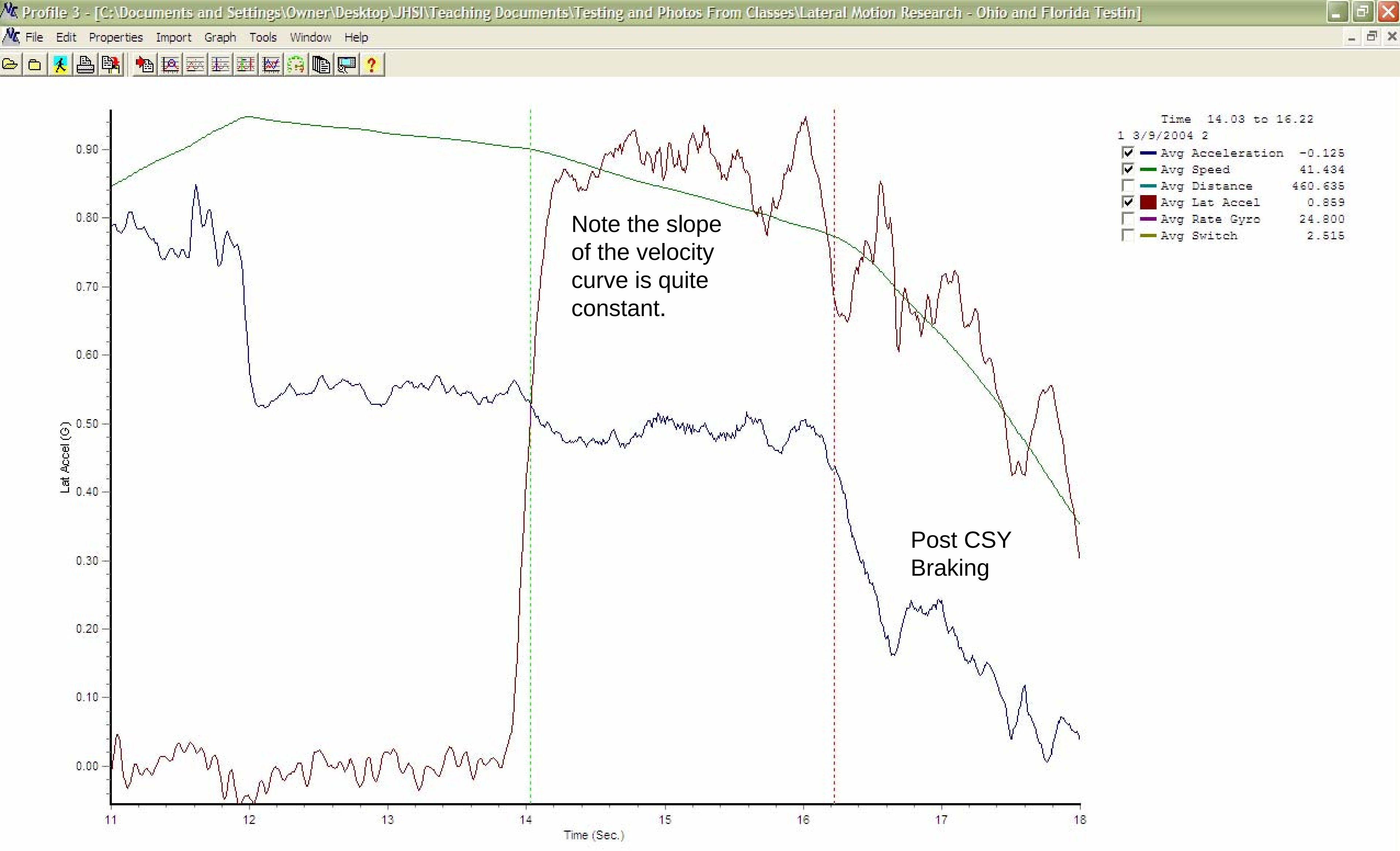
This is the same graph as the previous slide. We have set the y-axis to show the rate gyro in degrees per second. This is the average rate of heading change of the vehicle as it goes into the first half of a lane change. The average is a little over 18 degrees per second, which is below the peak, which is just under 30 degrees per second.



This is from the same data set as the last slide. We have changed the range to 5-15 seconds. We are now just looking at acceleration and speed. The speed at the initial left turn was 45.811 mph and the average acceleration was 0.236g from a stop.



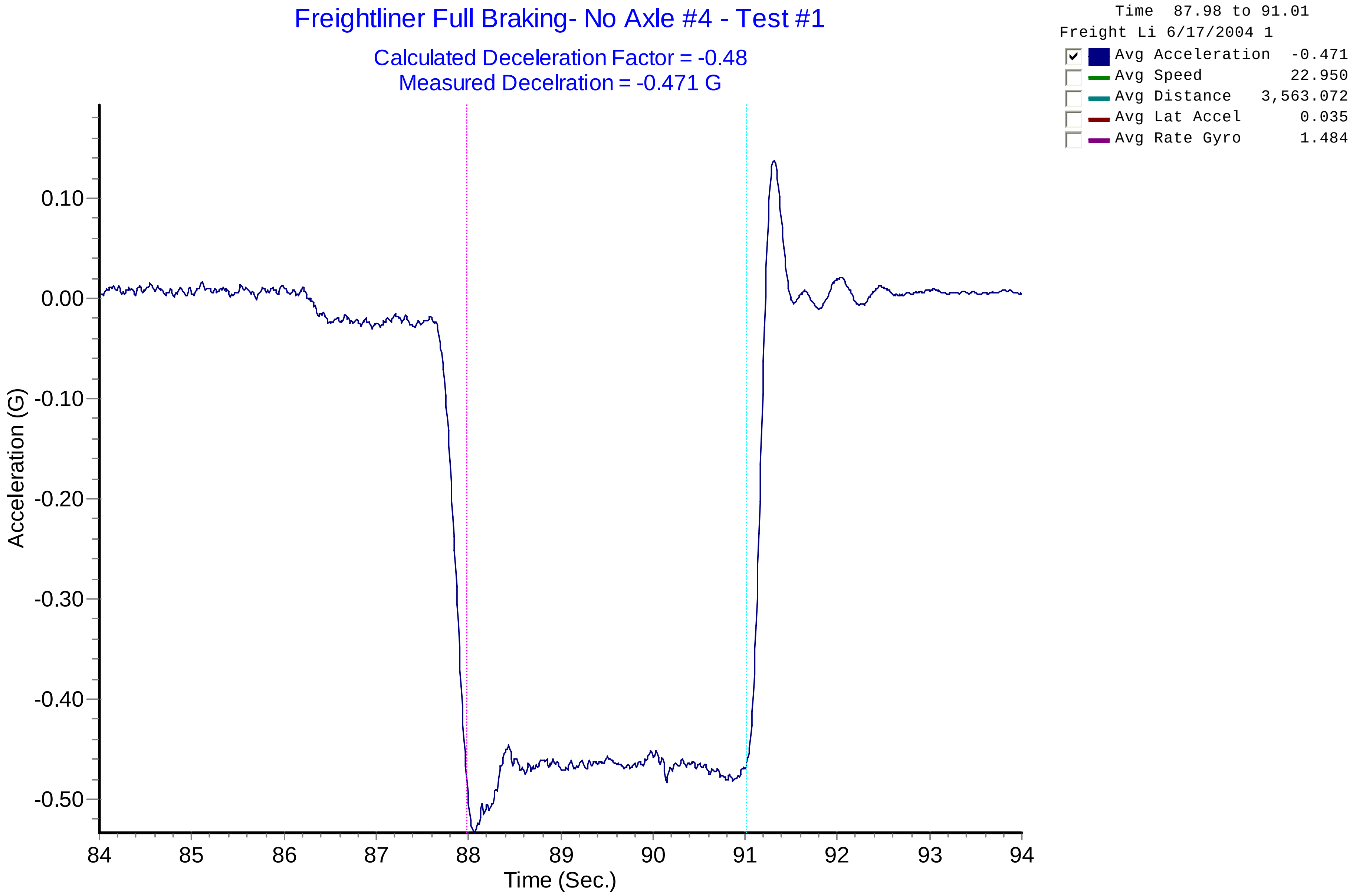
This is a continuous mode graph of a vehicle in a CSY situation. The peak speed was 46.649 mph. The toggle cursors show the deceleration of the vehicle from the time the driver took his foot off the gas until the turn was initiated. The value is 0.049g.



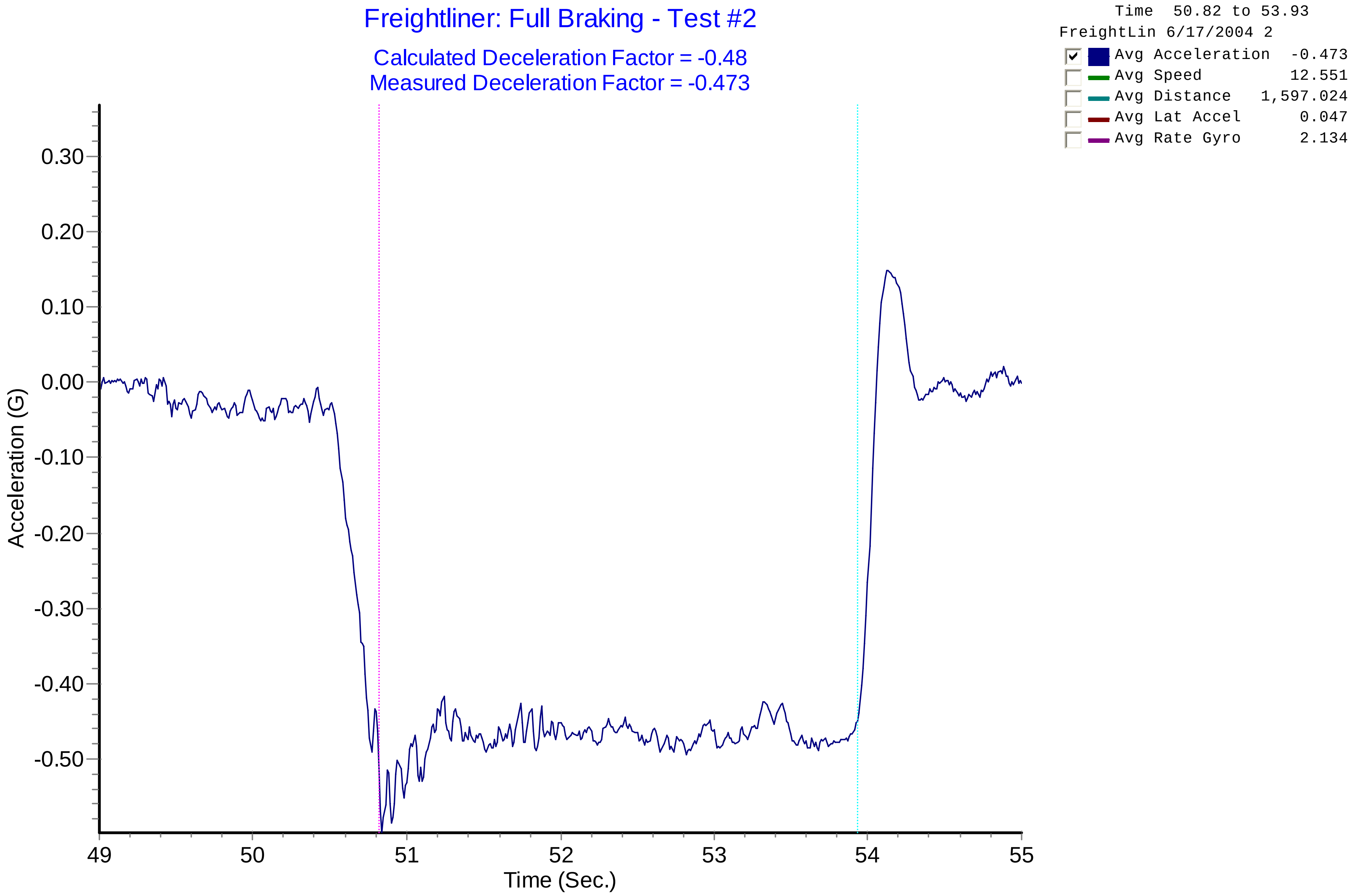
This is the same graph as the previous slide. We are showing lateral g on the y-axis and have toggled over the CSY portion of the graph. The average lateral g is 0.859 and the deceleration is 0.125g. This is *steady state* behavior.

Further Examples

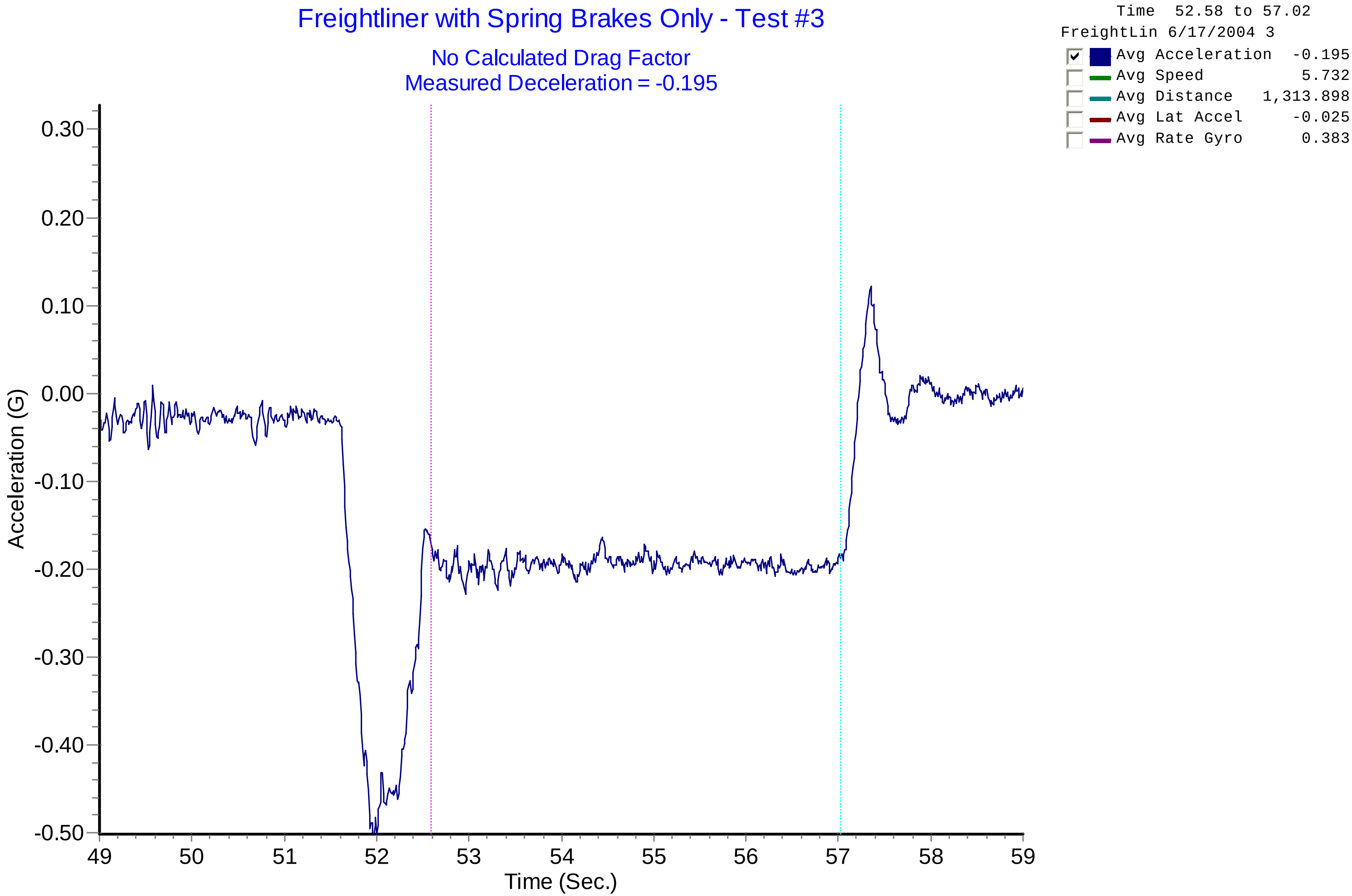
- The next several slides show the results of other testing.
- The accelerometer was in continuous mode, and the data extracted in the manner we have just discussed.



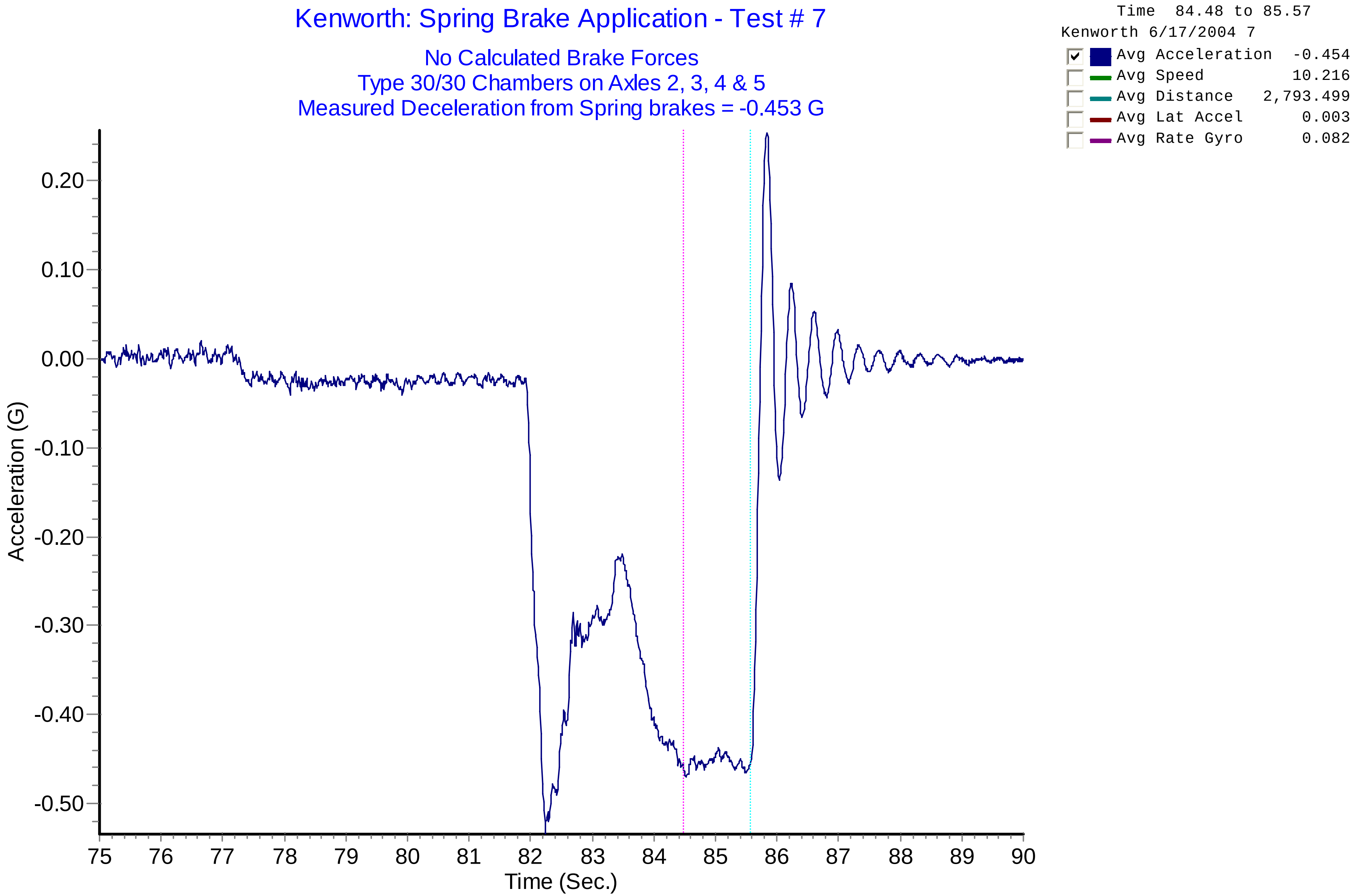
Freightliner Full Braking- No Axle #4 - Test #1
Calculated Deceleration Factor = -0.48
Measured Decelration = -0.471 G
Time 87.98 to 91.01
Freight Li 6/17/2004 1
Avg Acceleration -0.471
Avg Speed 22.950
Avg Distance 3,563.072
Avg Lat Accel 0.035
Avg Rate Gyro 1.484
Acceleration (G)
0.10
0.00
-0.10
-0.20
-0.30
-0.40
-0.50
84
85
86
87
88
89
90
91
92
93
94
Time (Sec.)



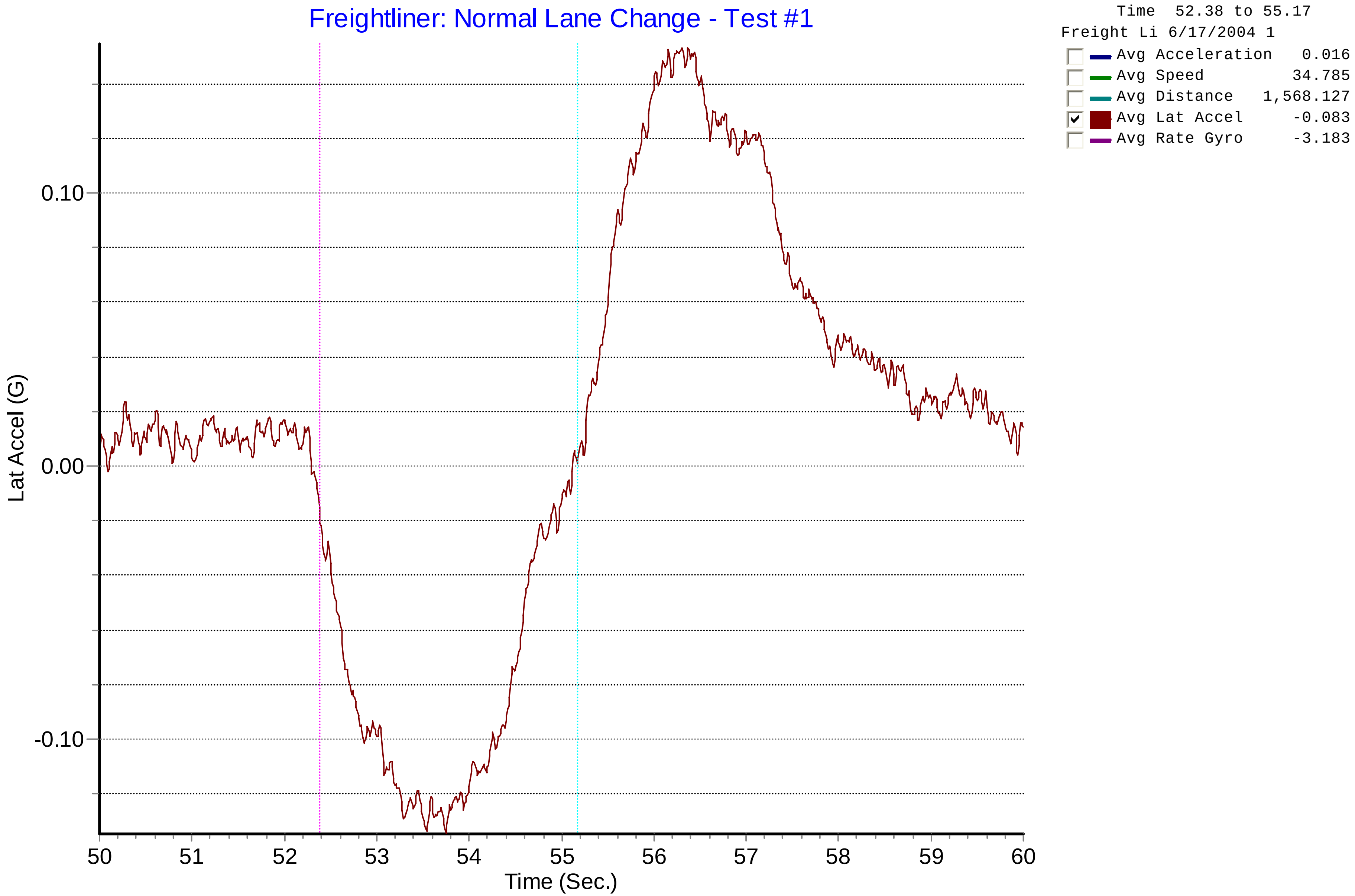
Freightliner: Full Braking - Test #2
Calculated Deceleration Factor = -0.48
Measured Deceleration Factor = -0.473
Time 50.82 to 53.93
FreightLin 6/17/2004 2
Avg Acceleration -0.473
Avg Speed 12.551
Avg Distance 1,597.024
Avg Lat Accel 0.047
Avg Rate Gyro 2.134
Acceleration (G)
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
-0.50
49
50
51
52
53
54
55
Time (Sec.)



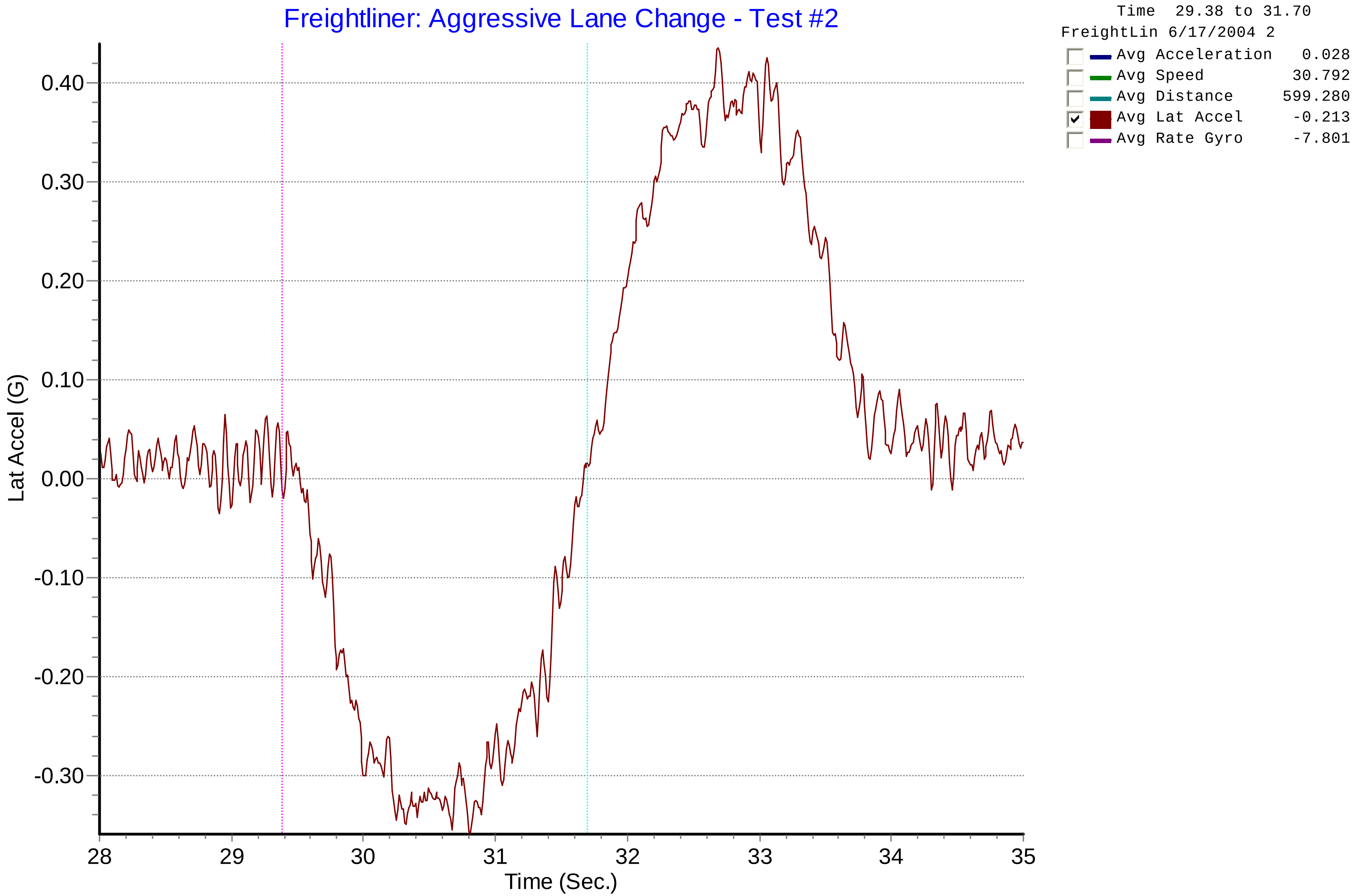
Freightliner with Spring Brakes Only - Test #3
No Calculated Drag Factor
Measured Deceleration = -0.195
Time 52.58 to 57.02
FreightLin 6/17/2004 3
Avg Acceleration -0.195
Avg Speed 5.732
Avg Distance 1,313.898
Avg Lat Accel -0.025
Avg Rate Gyro 0.383
Acceleration (G)
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
-0.50
49
50
51
52
53
54
55
56
57
58
59
Time (Sec.)

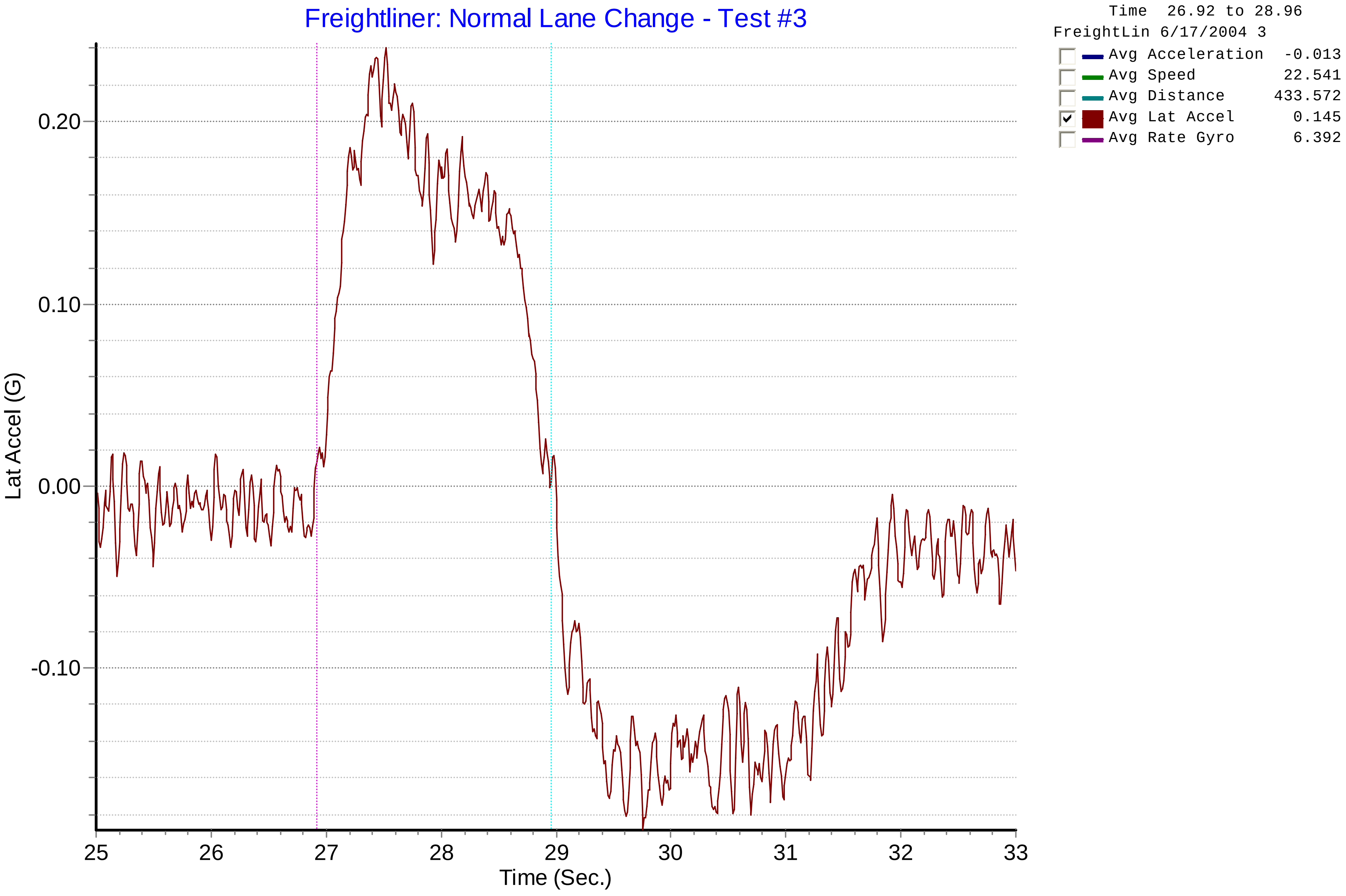


Kenworth: Spring Brake Application - Test # 7
No Calculated Brake Forces
Type 30/30 Chambers on Axles 2, 3, 4 & 5
Measured Deceleration from Spring brakes = -0.453 G
Time 84.48 to 85.57
Kenworth 6/17/2004 7
Avg Acceleration -0.454
Avg Speed 10.216
Avg Distance 2,793.499
Avg Lat Accel 0.003
Avg Rate Gyro 0.082
Acceleration (G)
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
-0.50
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
Time (Sec.)



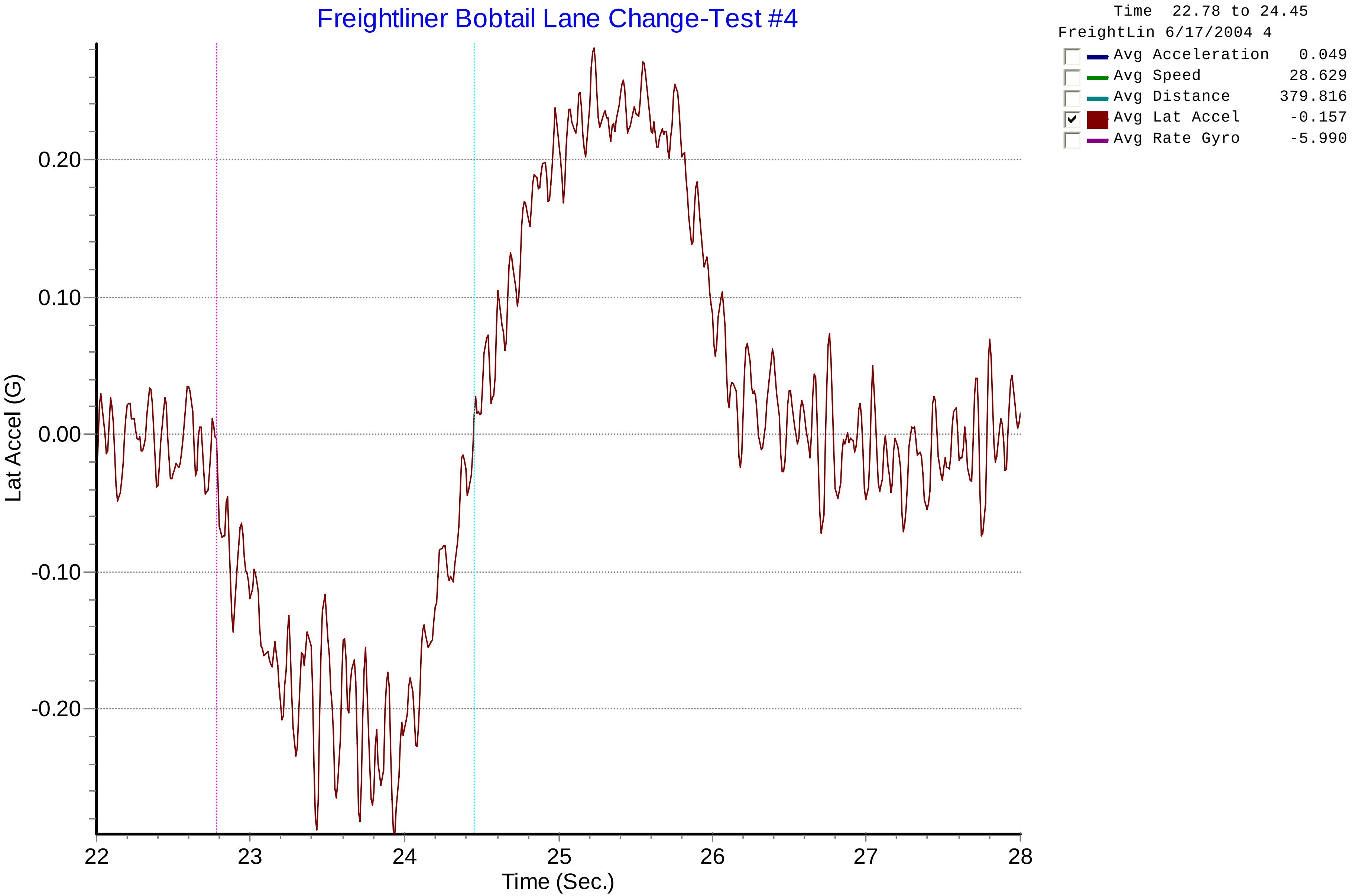
Freightliner: Normal Lane Change - Test #1
Time 52.38 to 55.17
Freight Li 6/17/2004 1
Avg Acceleration 0.016
Avg Speed 34.785
Avg Distance 1,568.127
Avg Lat Accel -0.083
Avg Rate Gyro -3.183
Lat Accel (G)
0.10
0.00
-0.10
50
51
52
53
54
55
56
57
58
59
60
Time (Sec.)

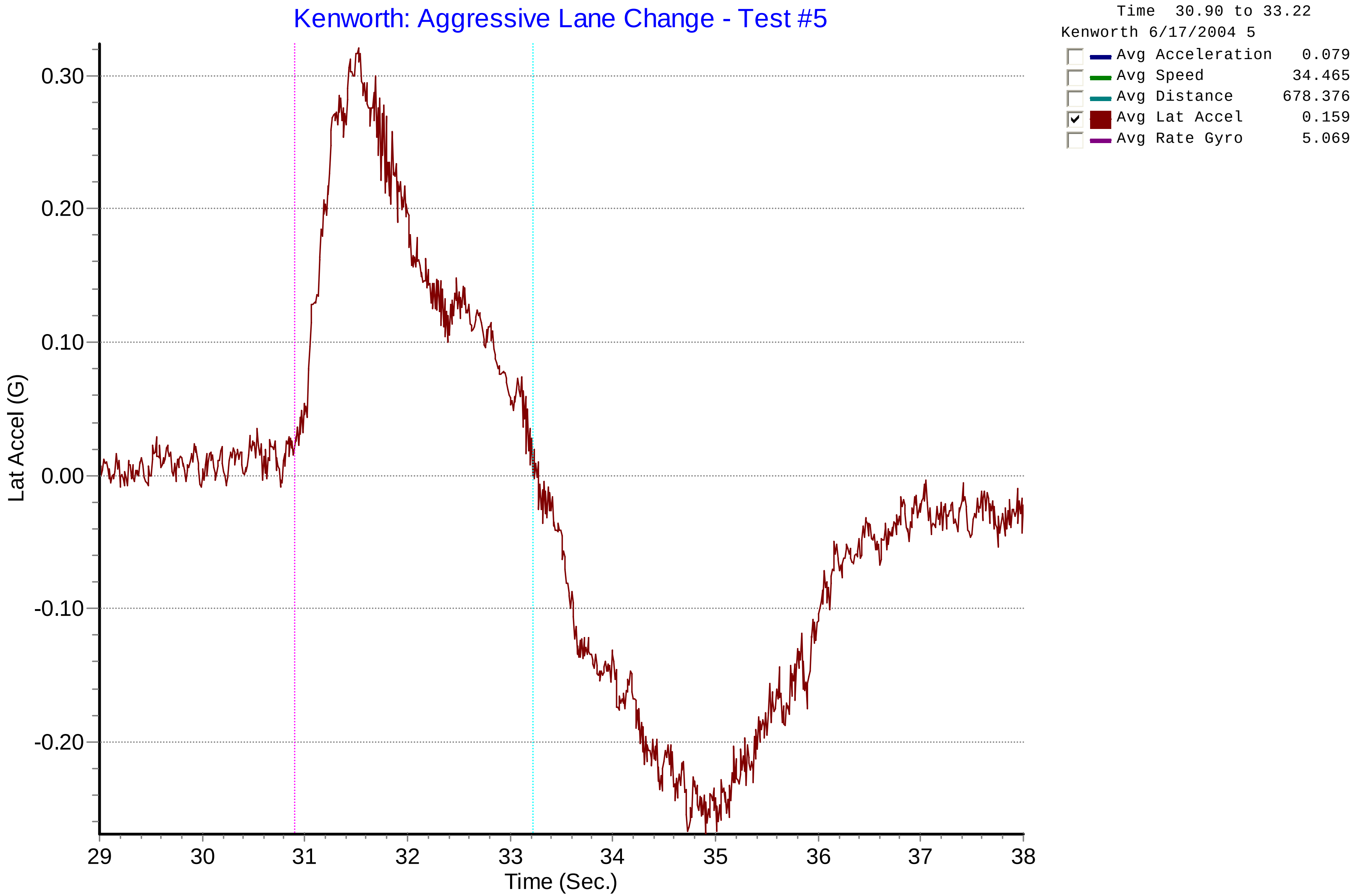

Freightliner: Aggressive Lane Change - Test #2
Time 29.38 to 31.70
FreightLin 6/17/2004 2
Avg Acceleration 0.028
Avg Speed 30.792
Avg Distance 599.280
Avg Lat Accel -0.213
Avg Rate Gyro -7.801
Lat Accel (G)
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
28
29
30
31
32
33
34
35
Time (Sec.)

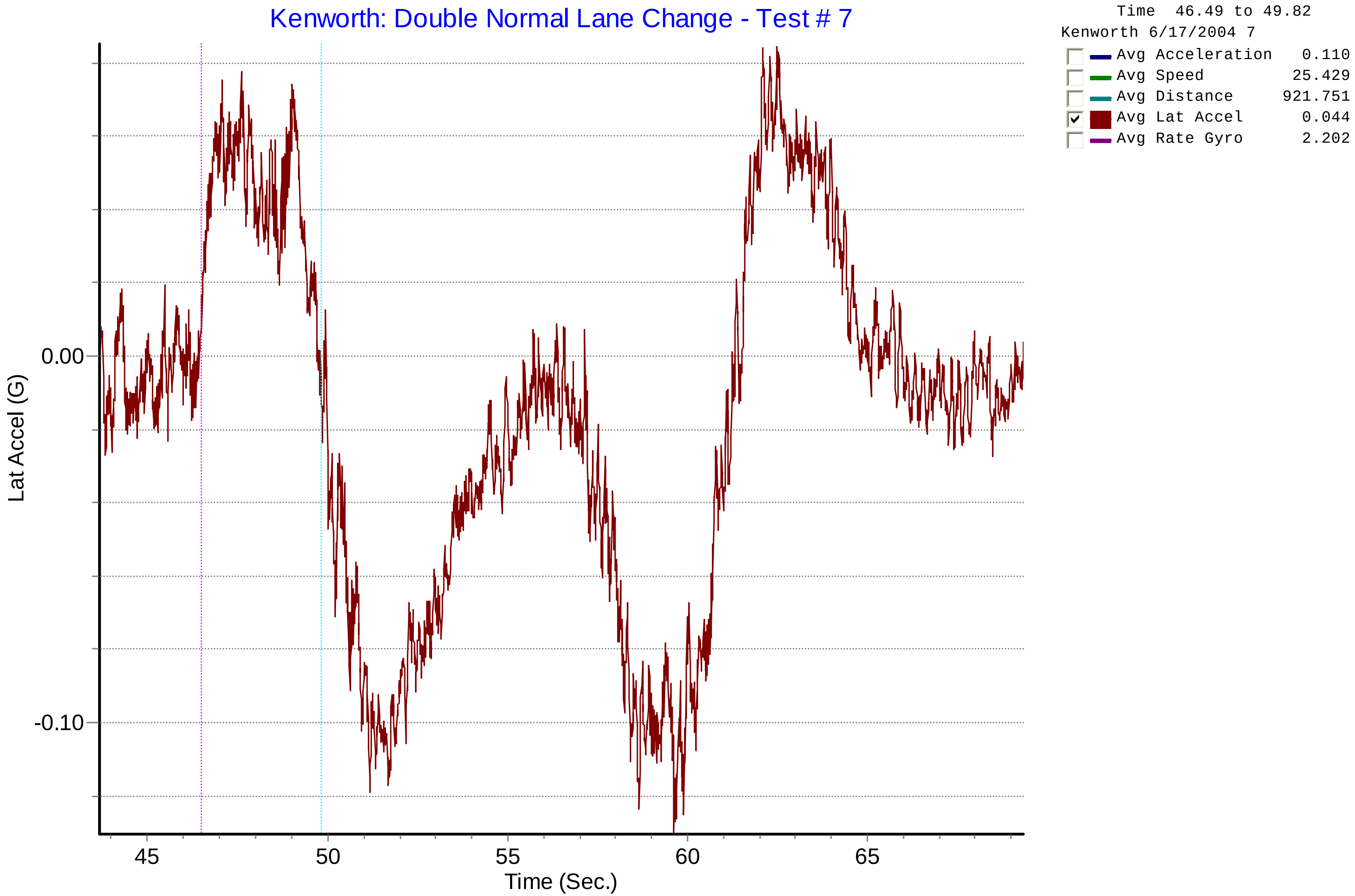


Freightliner: Normal Lane Change - Test #3
Time 26.92 to 28.96
FreightLin 6/17/2004 3
Avg Acceleration -0.013
Avg Speed 22.541
Avg Distance 433.572
Avg Lat Accel 0.145
Avg Rate Gyro 6.392
Lat Accel (G)
0.20
0.10
0.00
-0.10
25
26
27
28
29
30
31
32
33
Time (Sec.)

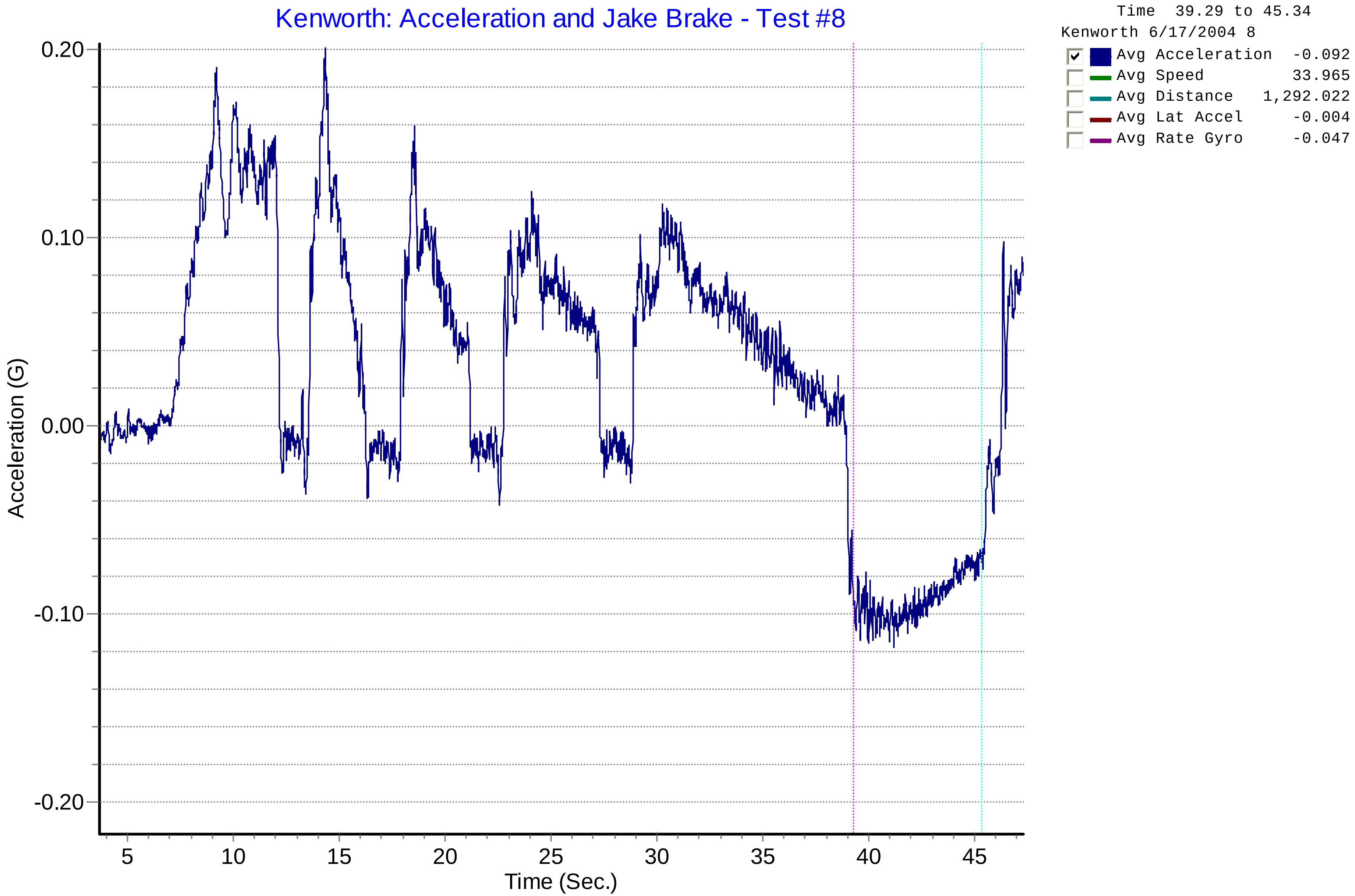
Freightliner Bobtail Lane Change-Test #4




Kenworth: Aggressive Lane Change - Test #5
Time 30.90 to 33.22
Kenworth 6/17/2004 5
Avg Acceleration 0.079
Avg Speed 34.465
Avg Distance 678.376
Avg Lat Accel 0.159
Avg Rate Gyro 5.069
Lat Accel (G)
0.30
0.20
0.10
0.00
-0.10
-0.20
29
30
31
32
33
34
35
36
37
38
Time (Sec.)



Kenworth: Double Normal Lane Change - Test # 7
Time 46.49 to 49.82
Kenworth 6/17/2004 7
Avg Acceleration 0.110
Avg Speed 25.429
Avg Distance 921.751
Avg Lat Accel 0.044
Avg Rate Gyro 2.202
0.00
-0.10
Lat Accel (G)
45
50
55
60
65
Time (Sec.)



Kenworth: Acceleration and Jake Brake - Test #8
Time 39.29 to 45.34
Kenworth 6/17/2004 8
Avg Acceleration -0.092
Avg Speed 33.965
Avg Distance 1,292.022
Avg Lat Accel -0.004
Avg Rate Gyro -0.047
0.20
0.10
0.00
-0.10
-0.20
Acceleration (G)
5
10
15
20
25
30
35
40
45
Time (Sec.)

Summary

- In this presentation, we have examined how we may chose an accelerometer system.
  - The system we would use for brake testing is not the same system we would use for crash testing.
- We have seen examples of how to set up and use the accelerometer to help us both measure and understand vehicle dynamics.
- This understanding assists us in becoming more informed and competent crash reconstructionists.