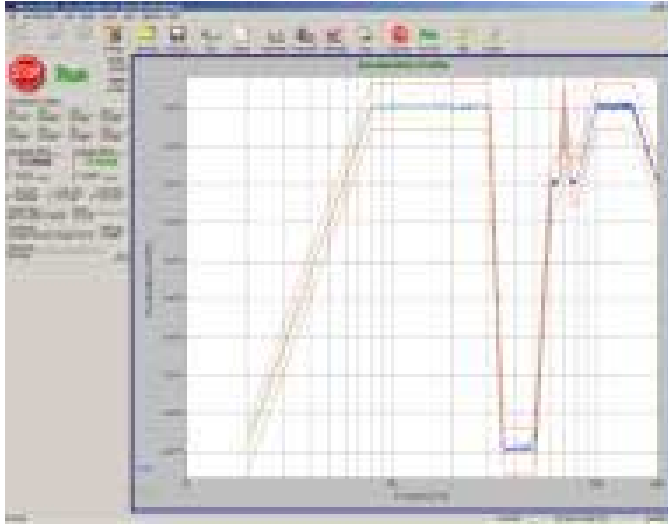


# Random Vibration Kurtosis Control



# Kurtosis Summary

- ◆ What is kurtosis?
- ◆ Why are we interested in kurtosis?
- ◆ How can we use kurtosis?
- ◆ What does kurtosis do for you?
- ◆ How does this relate to the real world?
- ◆ Determining spectrum and kurtosis
- ◆ Kurtosis Demonstrations



# The Problem

## *Definition of the Problem*

- ◆ Traditional random testing does not always find failures that occur during the life of a product.
- ◆ This is likely because the product experiences high G forces in actual use that are higher than traditional random testing generates



# Kurtosis

- ◆ Show of hands: Who has heard of the term “Kurtosis” before today?
- ◆ Definition in terms of statistical moments
  - Mean is the 1<sup>st</sup> moment
  - Variance is the 2<sup>nd</sup> moment
  - Skewness is normalized 3<sup>rd</sup> central moment
  - Kurtosis is normalized 4<sup>th</sup> central moment



# Calculating Kurtosis

- ◆ The basic function for calculating kurtosis for zero-mean data is:

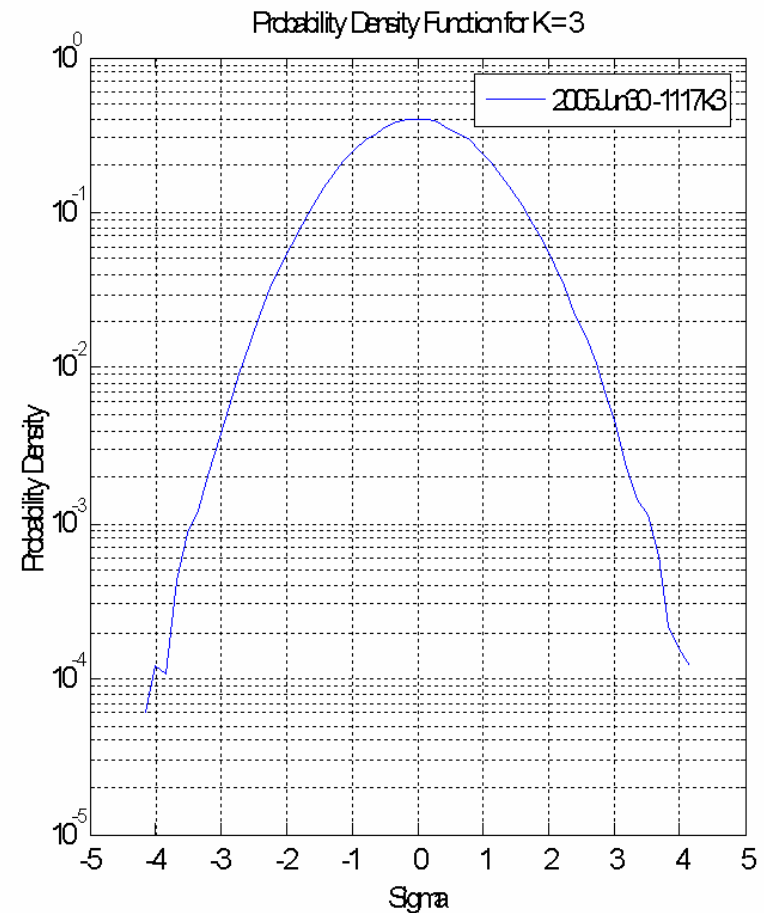
$$\frac{\text{average}(\text{data}^4)}{\text{average}(\text{data}^2)^2}$$

- ◆ Different people normalize this value in different ways
  - As commonly used, Gaussian kurtosis = 3
  - Microsoft Excel subtracts 3, so Gaussian kurtosis = 0
  - Others divide by 3, so Gaussian kurtosis = 1
- ◆ When using Excel, add 3 to their kurtosis number to get the values used in VibrationVIEW™



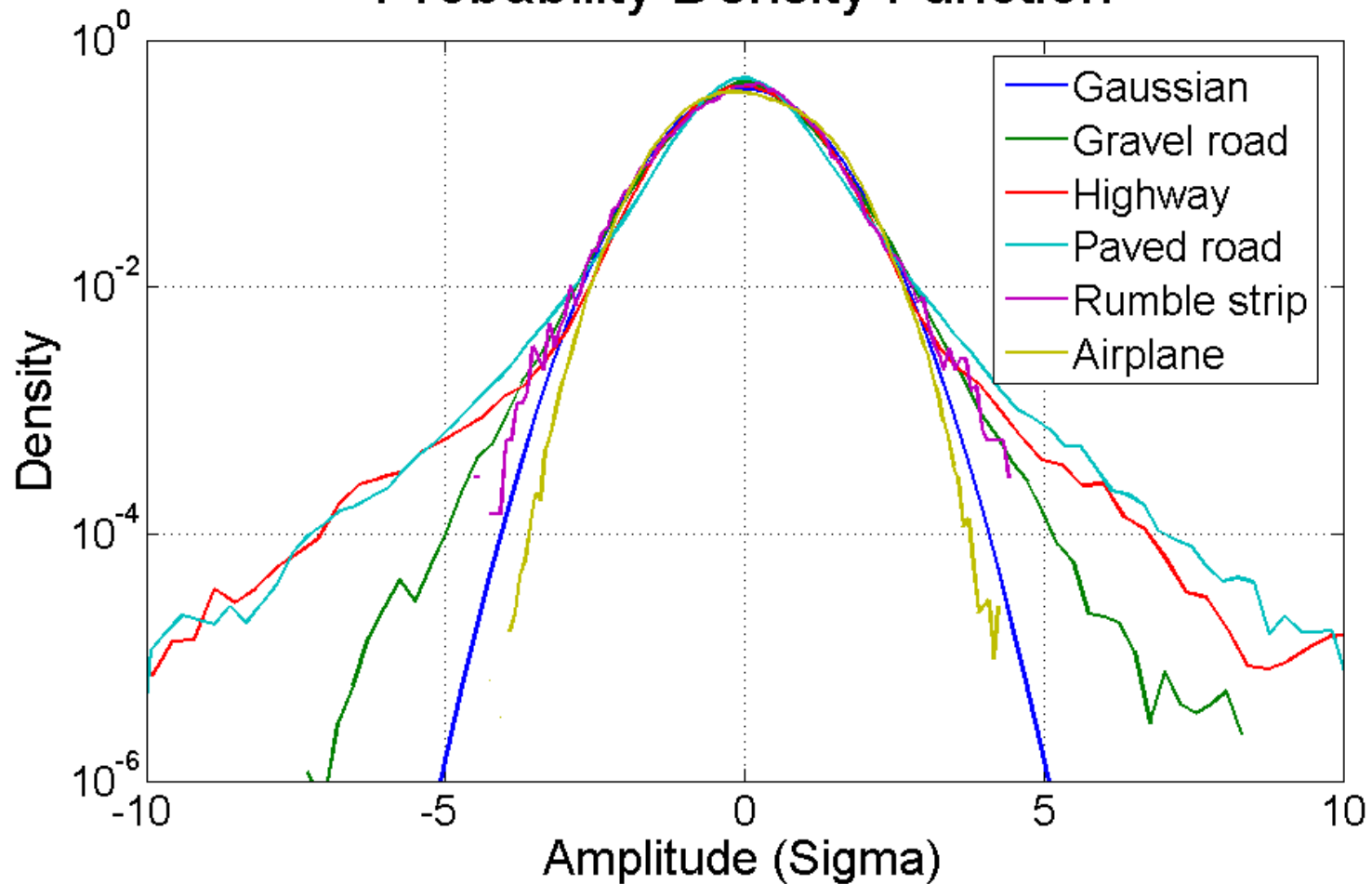
# Traditional Random Testing

- ◆ Current random testing seeks to achieve a Gaussian distribution
  - “Normal” distribution
  - Concentrated around mean
  - Low probability of extreme values
  - Kurtosis = 3

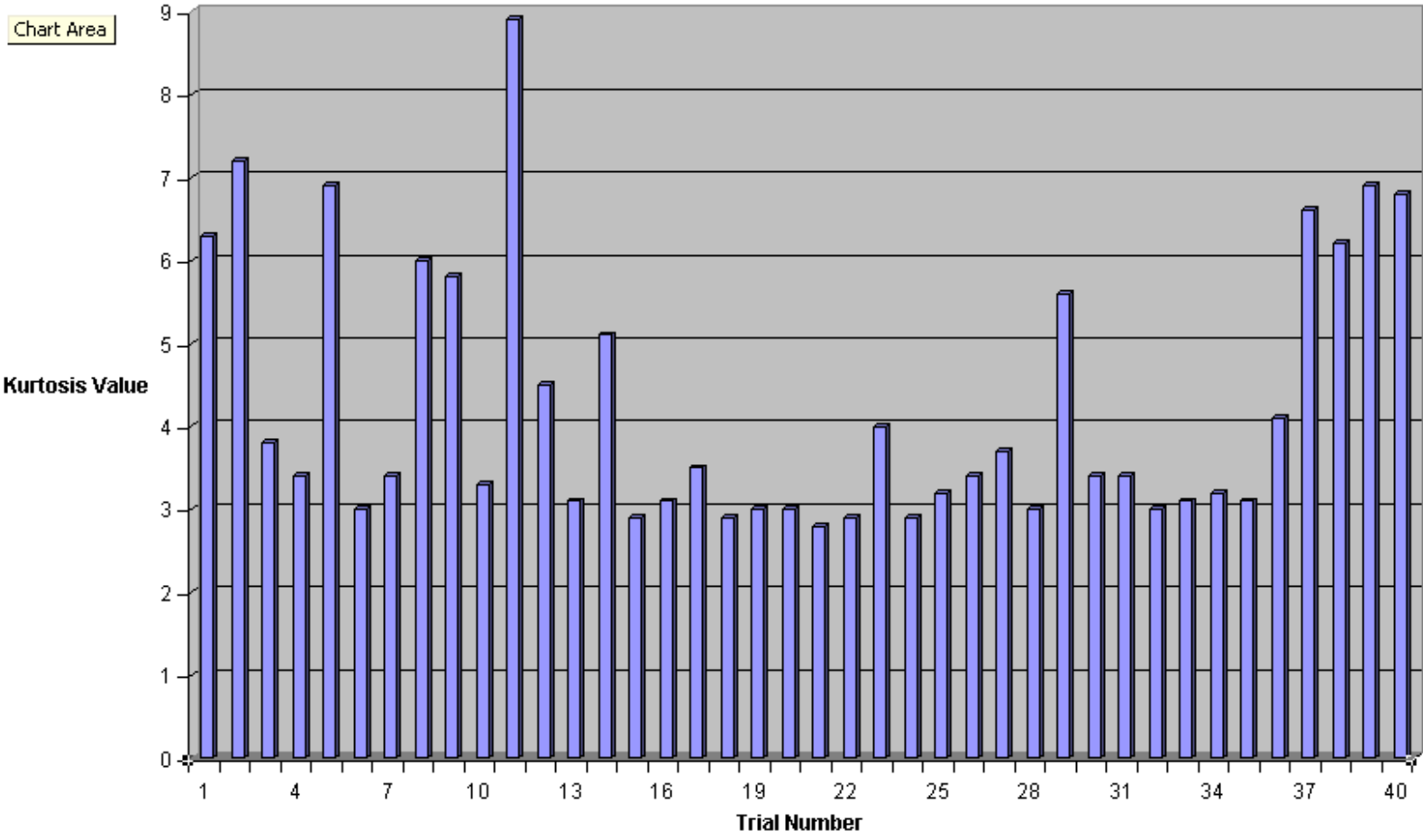


# Field Measurements

## Probability Density Function



# Kurtosis values of all tests



# Alternatives to Random

---

- ◆ Time history replication
- ◆ HALT/HASS
- ◆ 6DOF systems
- ◆ Sine-on-Random
- ◆ Random-on-Random
- ◆ Sine-on-Random-on-Random
- ◆ Shock-on-Random
- ◆ Multi-axis Random



# Time History Replication

## ◆ Technique

- Measure the waveform in the field
- Reproduce the *same waveform* in the lab.

## ◆ Advantages

- Spectrum is the same as in the field.
- Waveform has same amplitude distribution
- Waveform has same peak acceleration levels

## ◆ Disadvantages

- Difficult to find a representative waveform
- May only be representative of a particular situation
- No standard to measure acceptable test



# HALT and HASS

## ◆ Technique

- Repetitive shock: pound on table with many hammers
- Random firing of the hammers results in a random vibration
- Control the RMS acceleration levels
- Used extensively in the automotive world

## ◆ Advantages

- Gives high peak acceleration levels
- Equipment is smaller the ED equivalent
- Good at rapidly producing failures

## ◆ Disadvantages

- Spectrum is not controlled, is variable
- Generally not representative of the field environment



# Mixed-mode Random

- ◆ Sine-on-Random
  - Overlay sine tones on a random background
- ◆ Random-on-Random
  - Apply a time-varying random spectrum
- ◆ Sine-on-Random-on-Random
  - Attempt to reproduce field measurements better
- ◆ Shock-on-Random
  - Suggested to overlay transient events on random
  - Desire is to increase peak acceleration levels

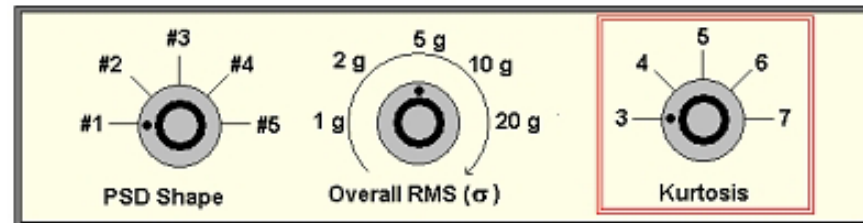


# What is missing on shaker controllers?

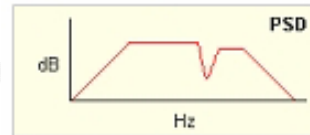
- ◆ Random vibration controllers have 2 basic “knobs”:
  - Frequency content - Power Spectral Density (PSD)
  - Amplitude level - RMS
- ◆ Need a third ‘knob’ to adjust the Kurtosis
  - Allows adjustment of the PDF (probability density function)
  - Increasing kurtosis = increasing peak levels
  - Allows the damage-producing potential of the test to be adjusted independent of the other two controls.



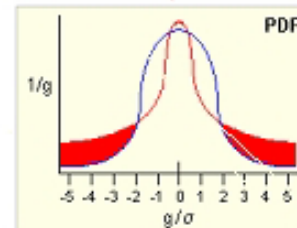
# The Missing Knob



Describes *Relative Shape* of Power Spectral Density



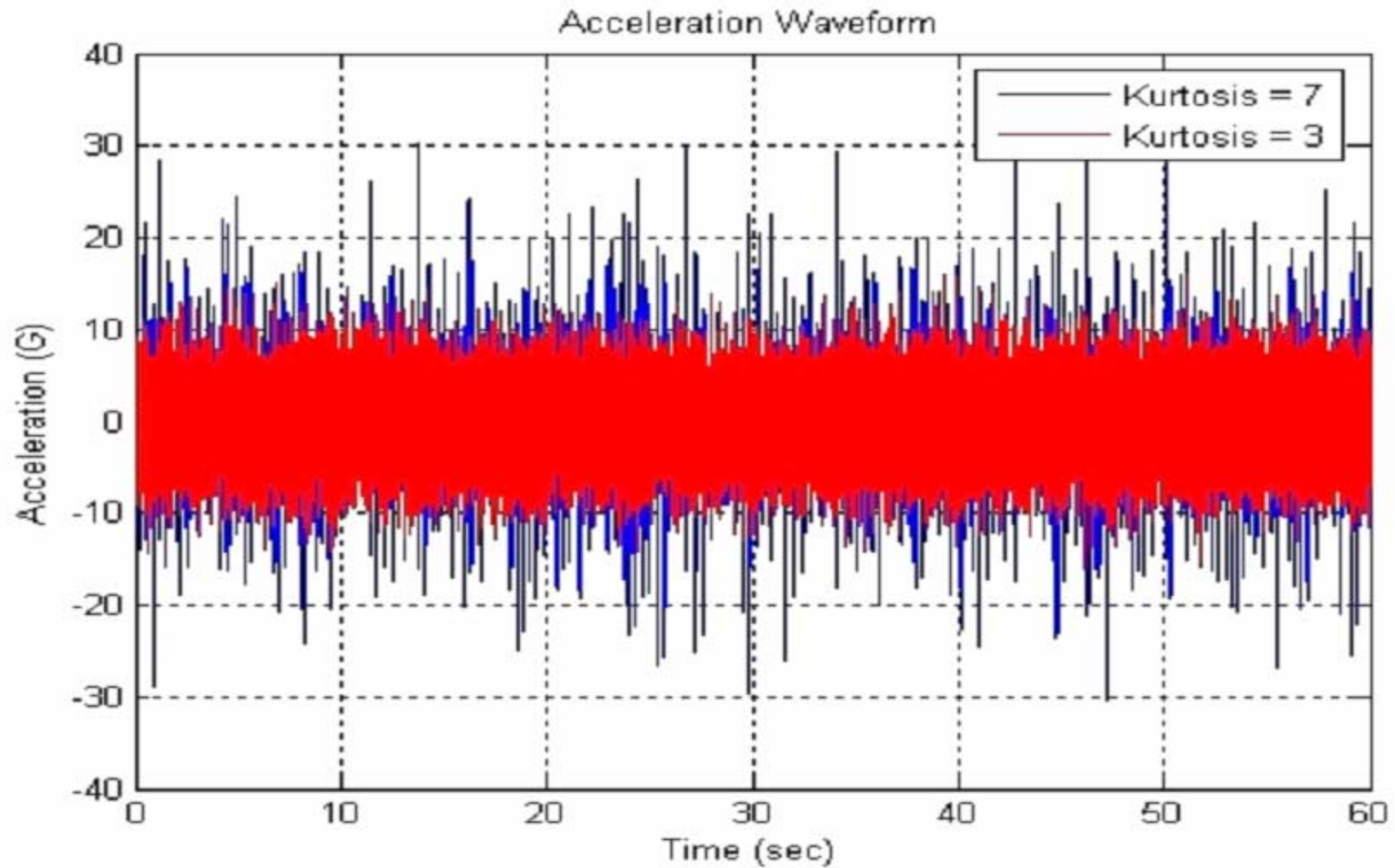
Determines *Time Spent* Above the  $\pm 2\sigma$  Level



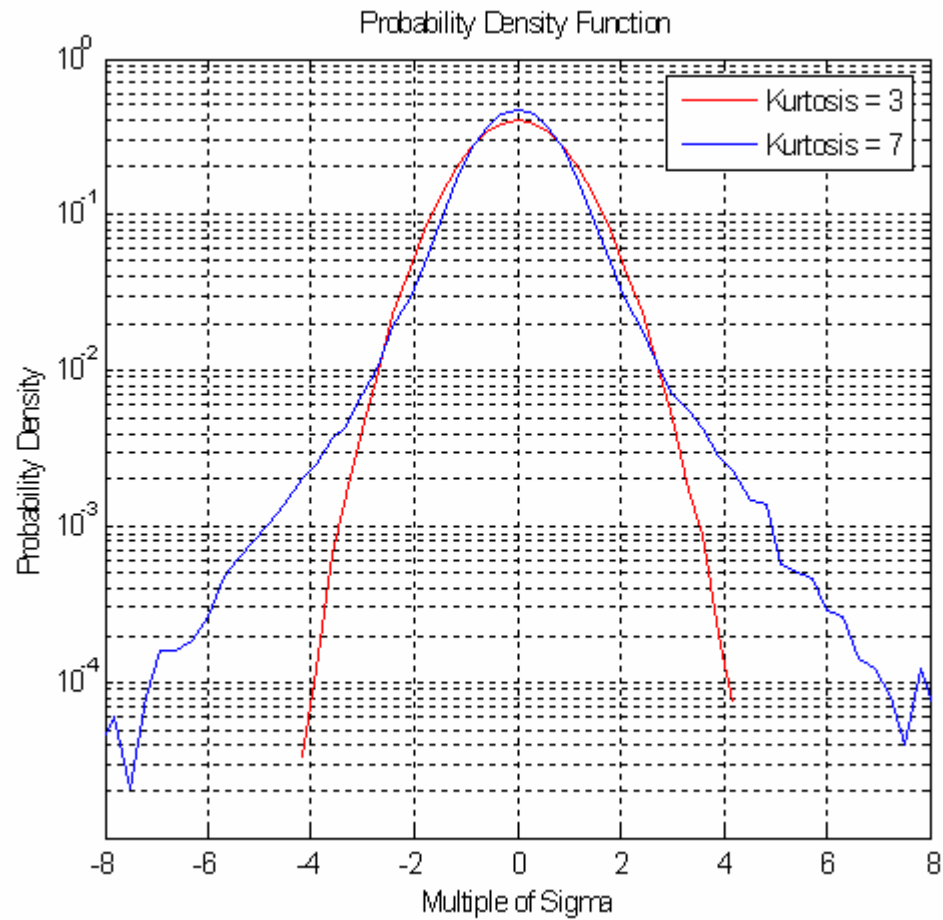
Defines Spectrum Amplitude by Setting Area Under Curve



# Waveform Comparison



# PDF Comparison

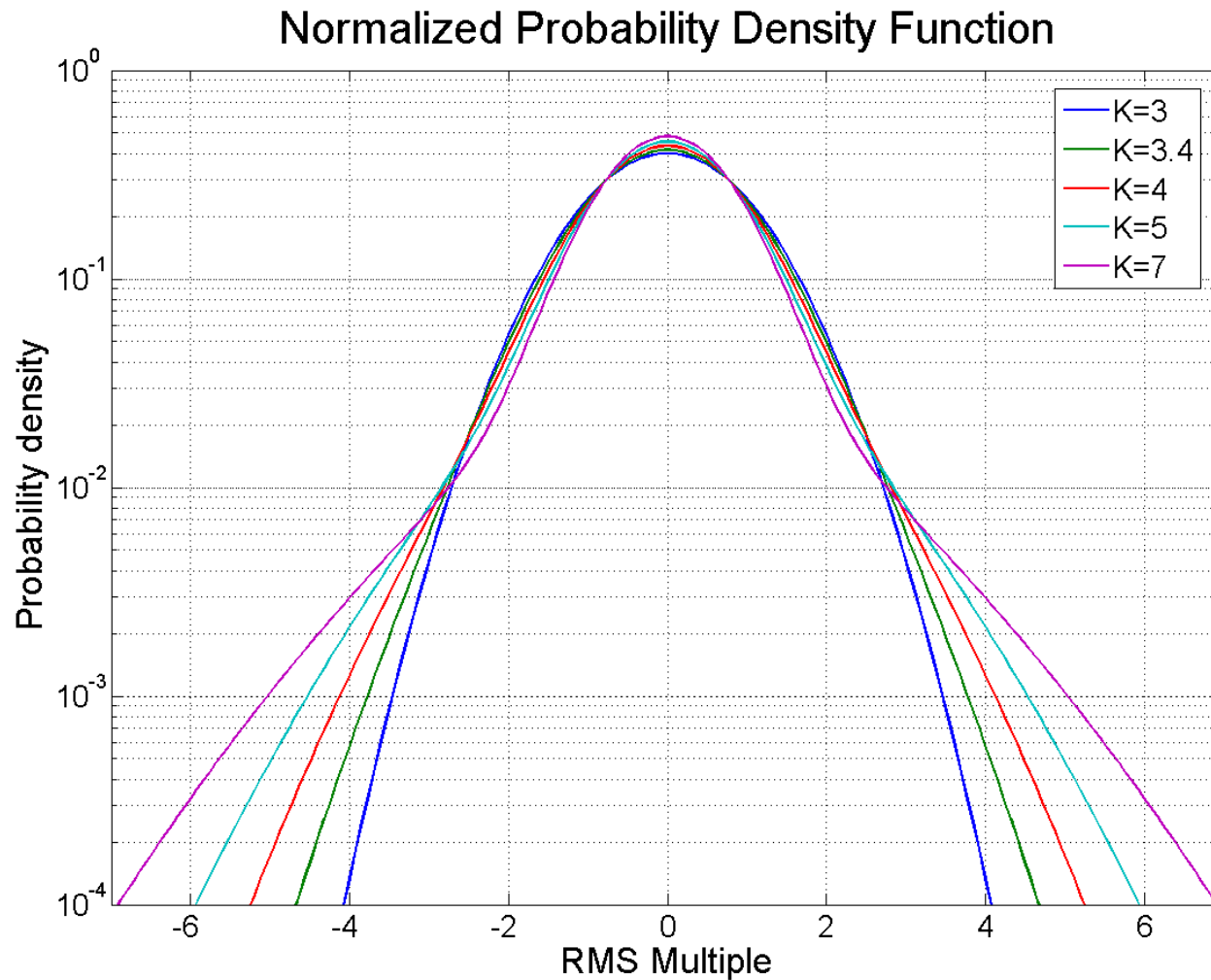


# Kurtosis Control

- ◆ Objective is to control the amplitude distribution to achieve the higher peaks seen in field data
  - Spectrum is a measure of the frequency content
  - RMS is a measure of the amplitude
  - Kurtosis is a measure of the “peakiness”
- ◆ Solution is use a non-Gaussian vibration and control the Kurtosis
- ◆ This is what we call Kurtosion™
  - Method to simultaneously control Spectrum, RMS, *and Kurtosis*
  - Patent-pending



# PDF varies with Kurtosis



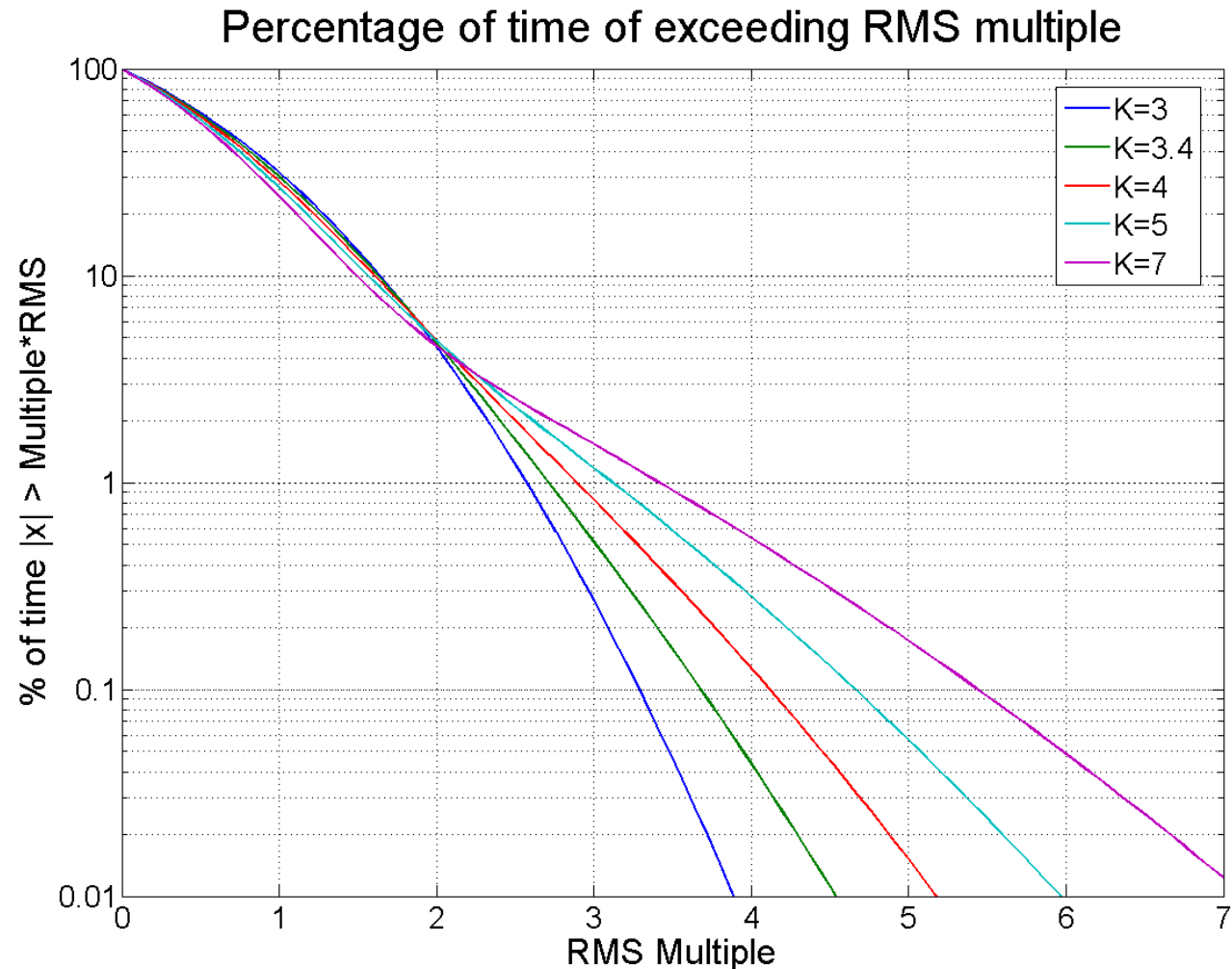
# Increased kurtosis = More time at peaks

Kurtosis = 3 is  $> 3\sigma$   
0.27% of time

Kurtosis = 4 is  $> 3\sigma$   
0.83% of time

Kurtosis = 7 is  $> 3\sigma$   
1.5% of time

Note: 1.5% of a 1 hour  
test is nearly a full  
minute above  $3\sigma$

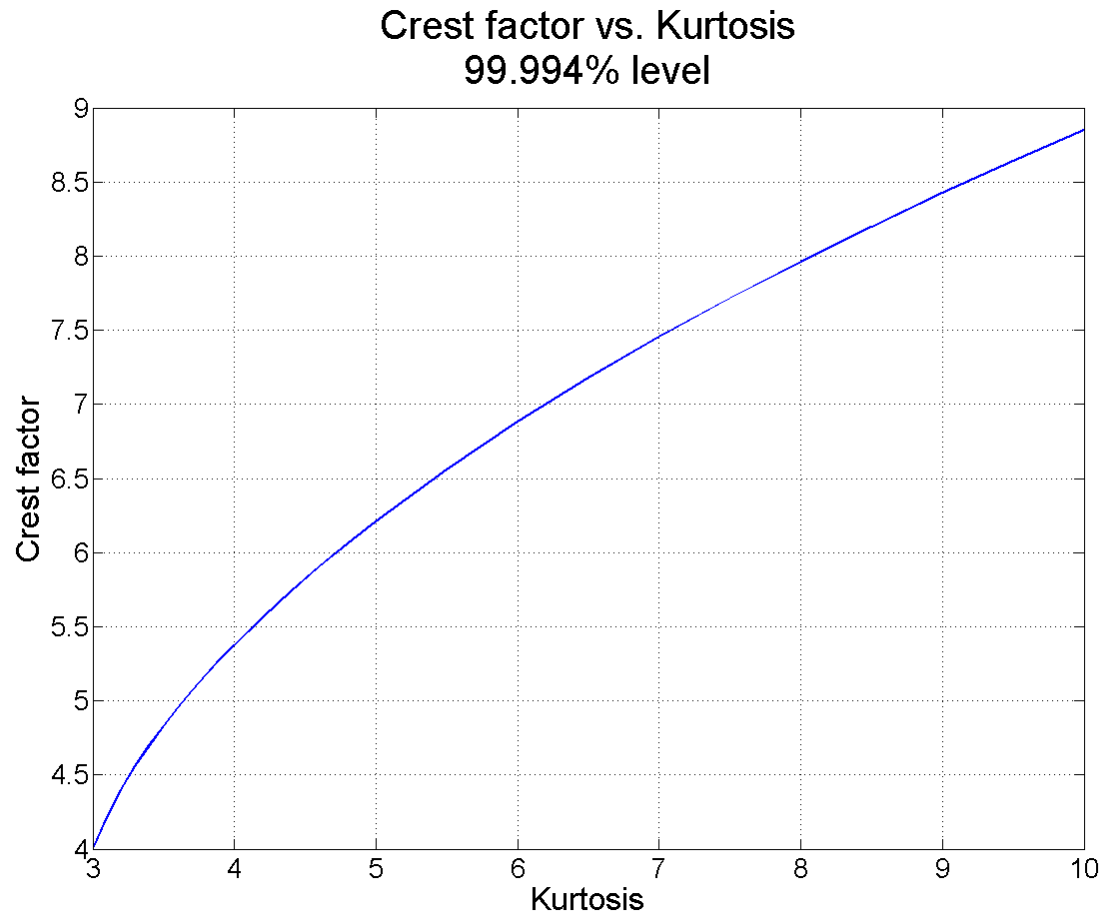


# Increased kurtosis = Higher peaks

Crest Factor:  
The ratio of  
peak to  
rms

Note:

Crest factor of the 99.994% probability level is plotted, as this is the 4 times rms (4 sigma) level for a kurtosis=3 random test. Also, this is the typical maximum peak seen on a kurtosis=3 random test.



# Useful properties for kurtosis control

- ◆ Set kurtosis independent of RMS
- ◆ Set kurtosis without affecting PSD
- ◆ Increase kurtosis over the full spectrum
- ◆ Dynamic range of the controller is maintained



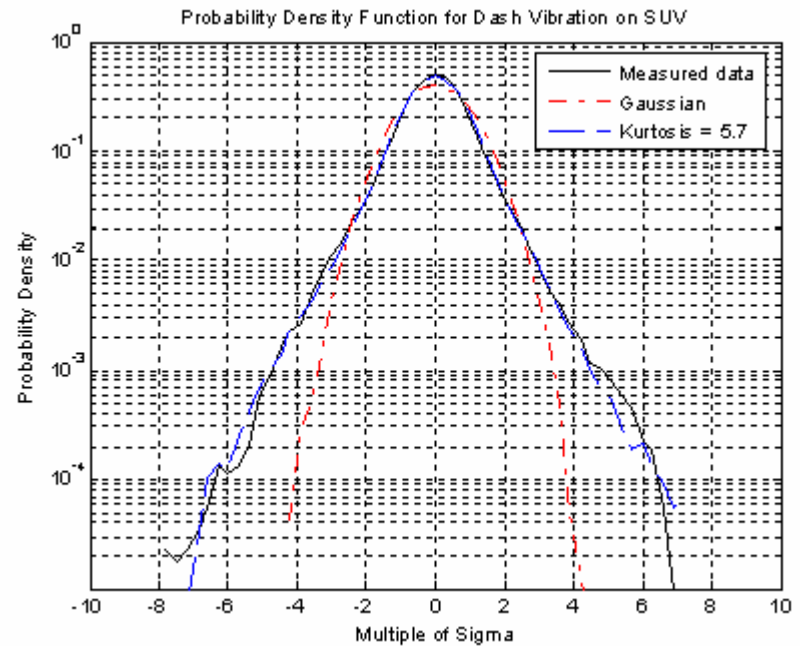
- 
- ◆ What does this have to do with the Real World?



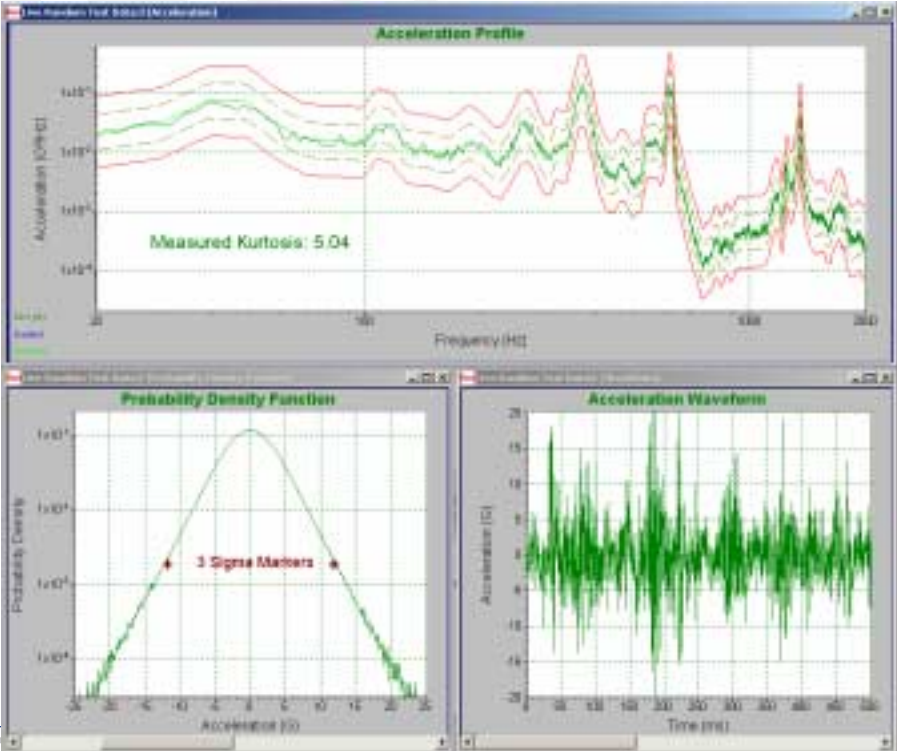
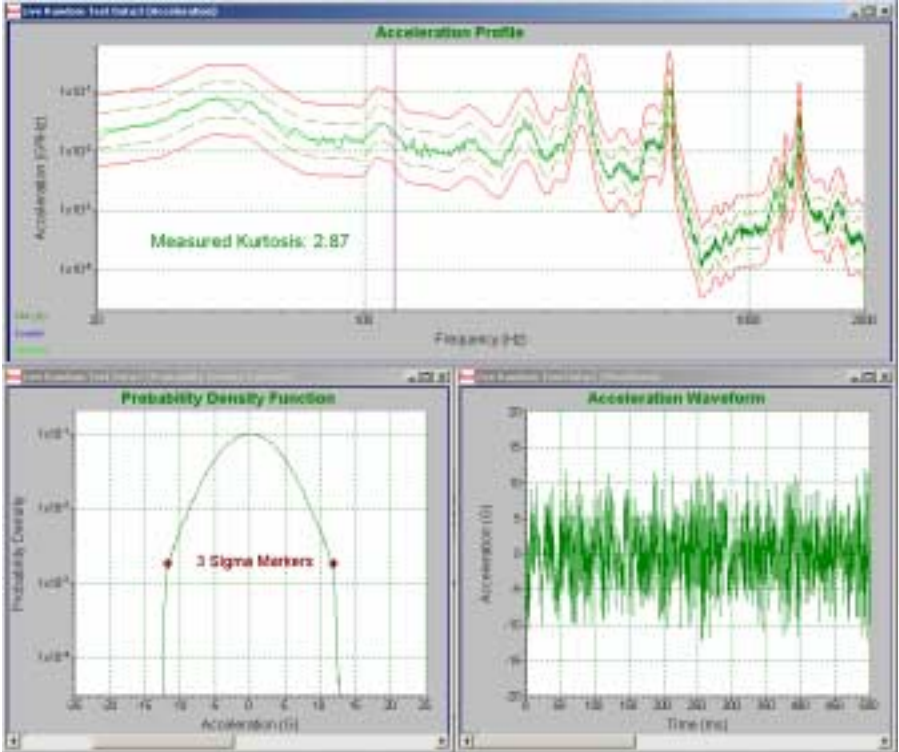


*Oldsmobile Bravada, dashboard vibration  
As vehicle travels down I-196.*

*PDF for Gaussian, and actual,  
and controlled kurtosis*



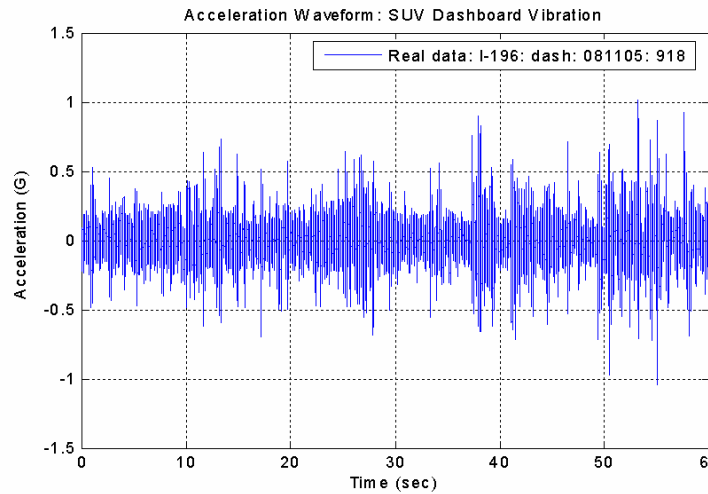
*Spectrum defined by field measured data  
Traditional random test with 3 sigma clipping*



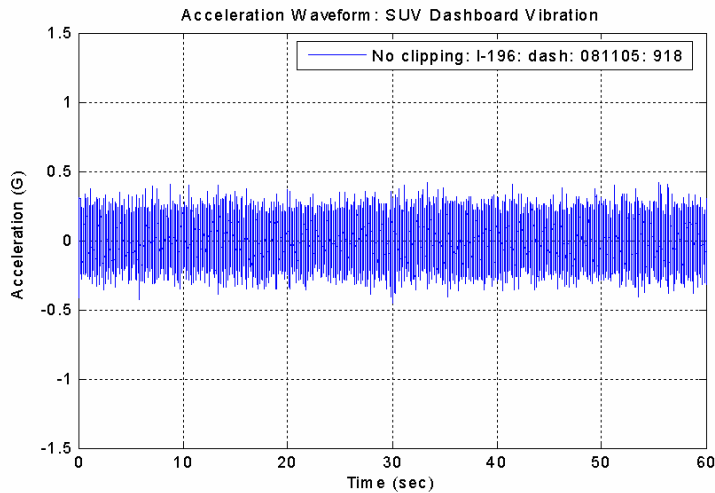
*Same spectrum defined by field measured data  
Now with Kurtosis Control set to 5*



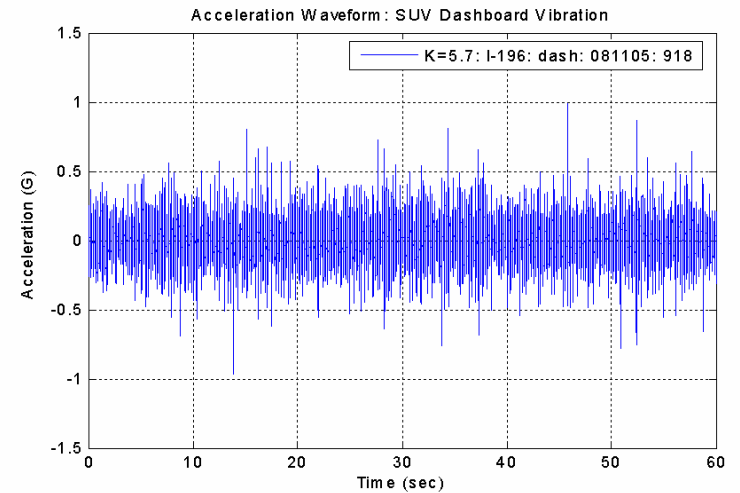
60 seconds of some actual field data  $K=5.7$



60 seconds of some Traditional random  $K=3$



60 seconds of  $K=5.7$  "Kurtosis" random



# Light Bulb Failure Test

- ◆ Demonstrates that for a Random test,
  - given a spectrum
  - given an RMS level
  - then increasing kurtosis significantly shortens the time to failure.



# Test procedure

## Procedure:

- ◆ Vibration Research Corporation tested the functionality of a new kurtosis control method of random testing, called sigma stretching. The procedure involved the following:
- ◆ Tests were performed on 66 (qty) standard 75 Watt light bulbs, “Do-it” brand, purchased at Gemmen’s hardware store in Hudsonville, Michigan. A fixture with 2 light bulb sockets was mounted to the top of an electro-dynamic shaker.

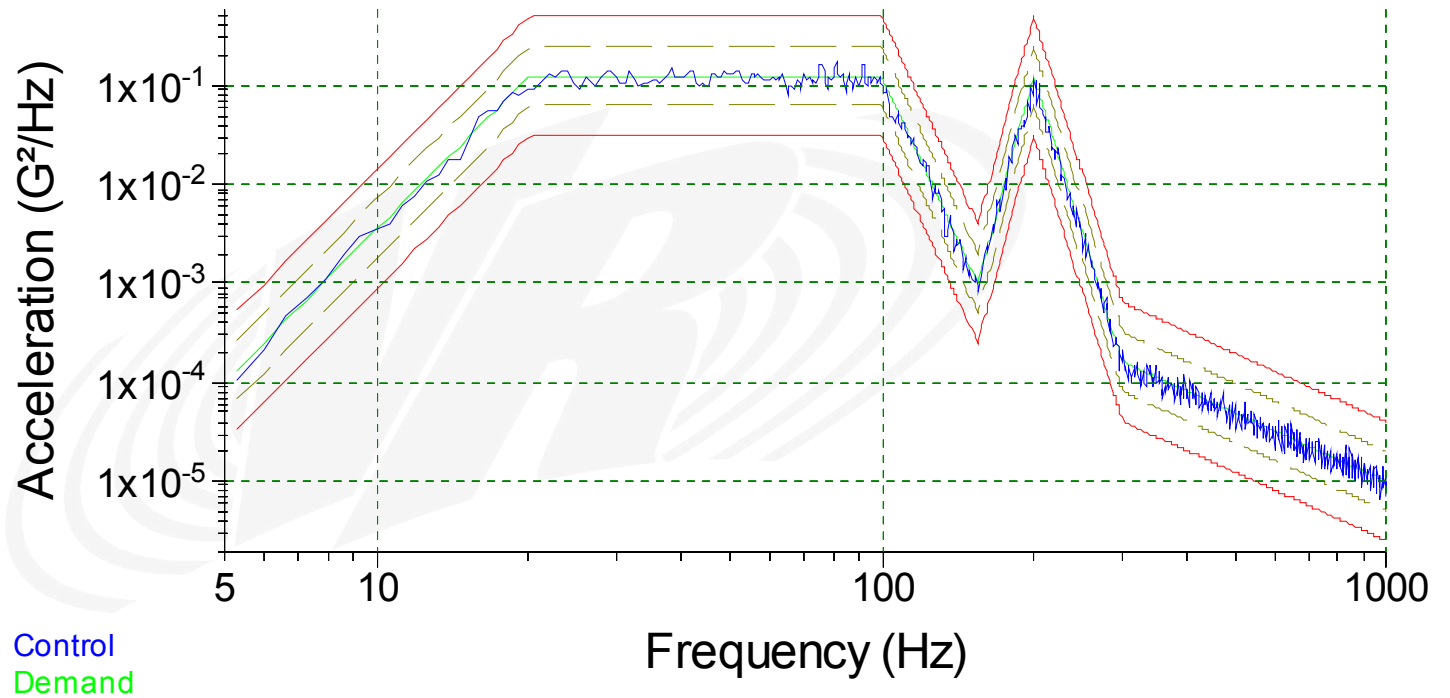
## Kurtosis Testing Set-up:

- ◆ *Light bulbs were chosen to demonstrate kurtosis control because of the simplicity of the test set-up and the minimal cost factor in bringing them to failure. Although it is possible for light bulbs to experience this profile, particularly in transportation, the 75 Watt light bulbs were chosen primarily as an instrument to demonstrate the effects of kurtosis control.*
- ◆ This fixture, with 2 unused bulbs, was subjected to random vibration with a slightly modified “Body and IP” test profile. This profile was chosen because it is a standard random profile used in the automotive industry for items mounted to the body and instrument panel of a car. The standard, as we know it, was modified by pushing the break-point, defining the flat broad-band energy, to 100 Hz. This encompassed the resonances observed in the light bulb around 90 Hz. See the profile and break-points used in the next slide.



# Test spectrum

## Acceleration Profile



Frequency	G <sup>2</sup> /Hz	dB/Octave
5 Hz	0.0001	15.47
20 Hz	0.1242	0
100 Hz	0.1242	-33.12
155 Hz	0.001	56.95
200 Hz	0.1242	-49.4
300 Hz	0.00016	-6.932
1000 Hz	1e-005	



# Test parameters

- ◆ Same PSD and RMS levels
- ◆ Varied only the kurtosis
- ◆ Eleven trials (22 bulbs) were tested to failure at each of these settings
  - kurtosis = 3 (Gaussian)
  - kurtosis = 5
  - kurtosis = 7

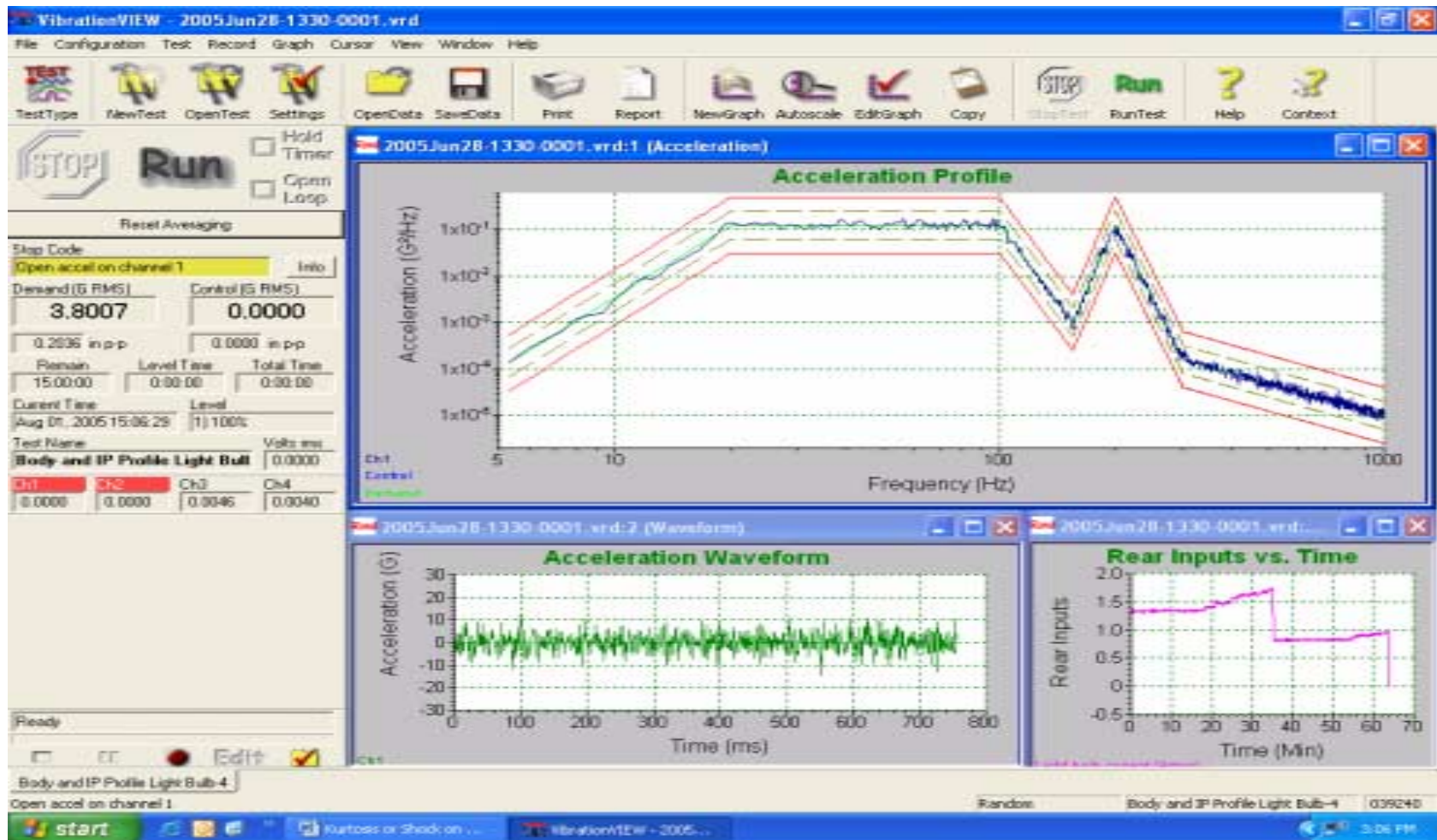


# Failure evaluation

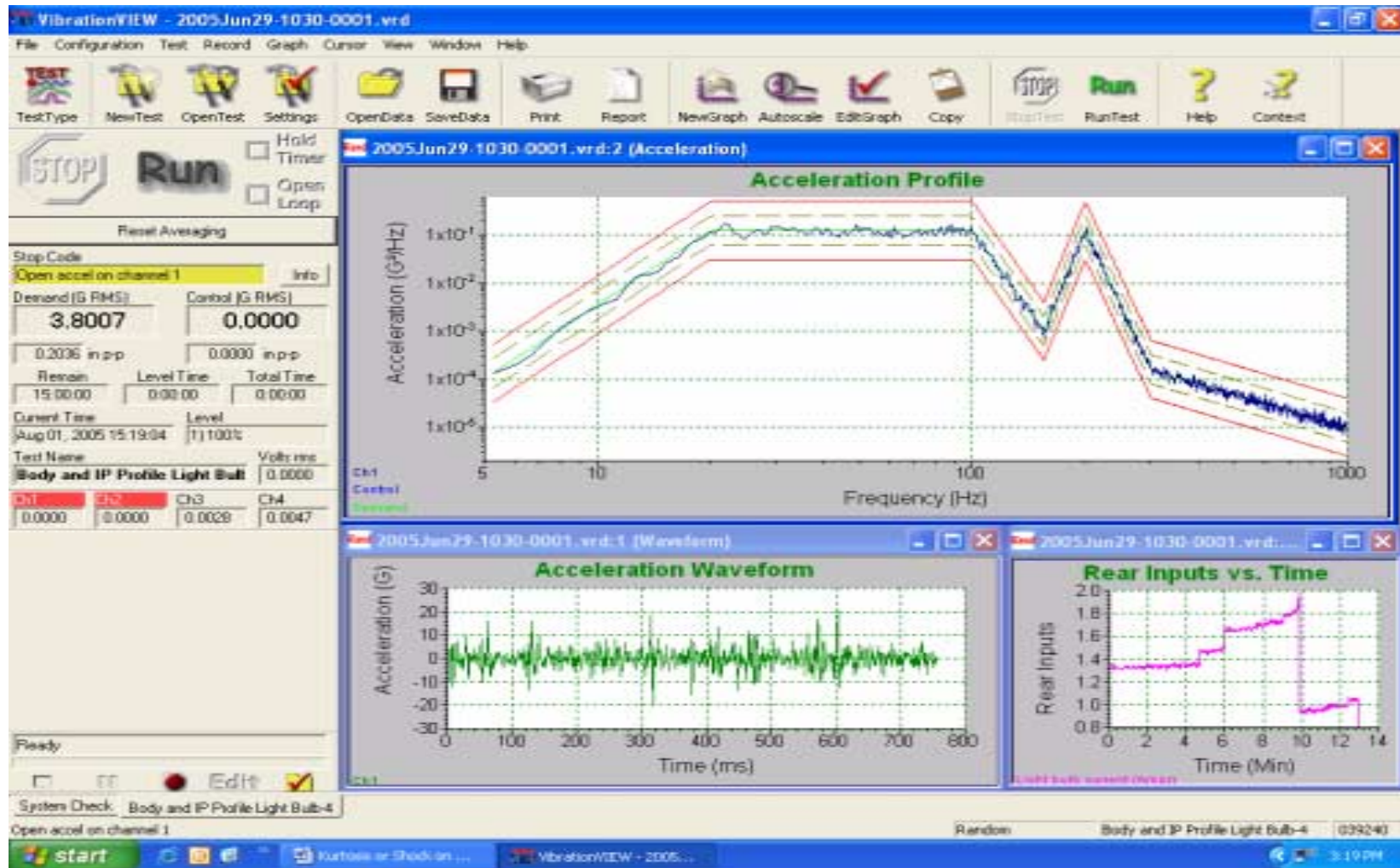
- ◆ Monitored current flowing through the two light bulbs
- ◆ Failure time determined by the time of the sudden drops in current
- ◆ Test continued until both bulbs failed (the current dropped to 0)



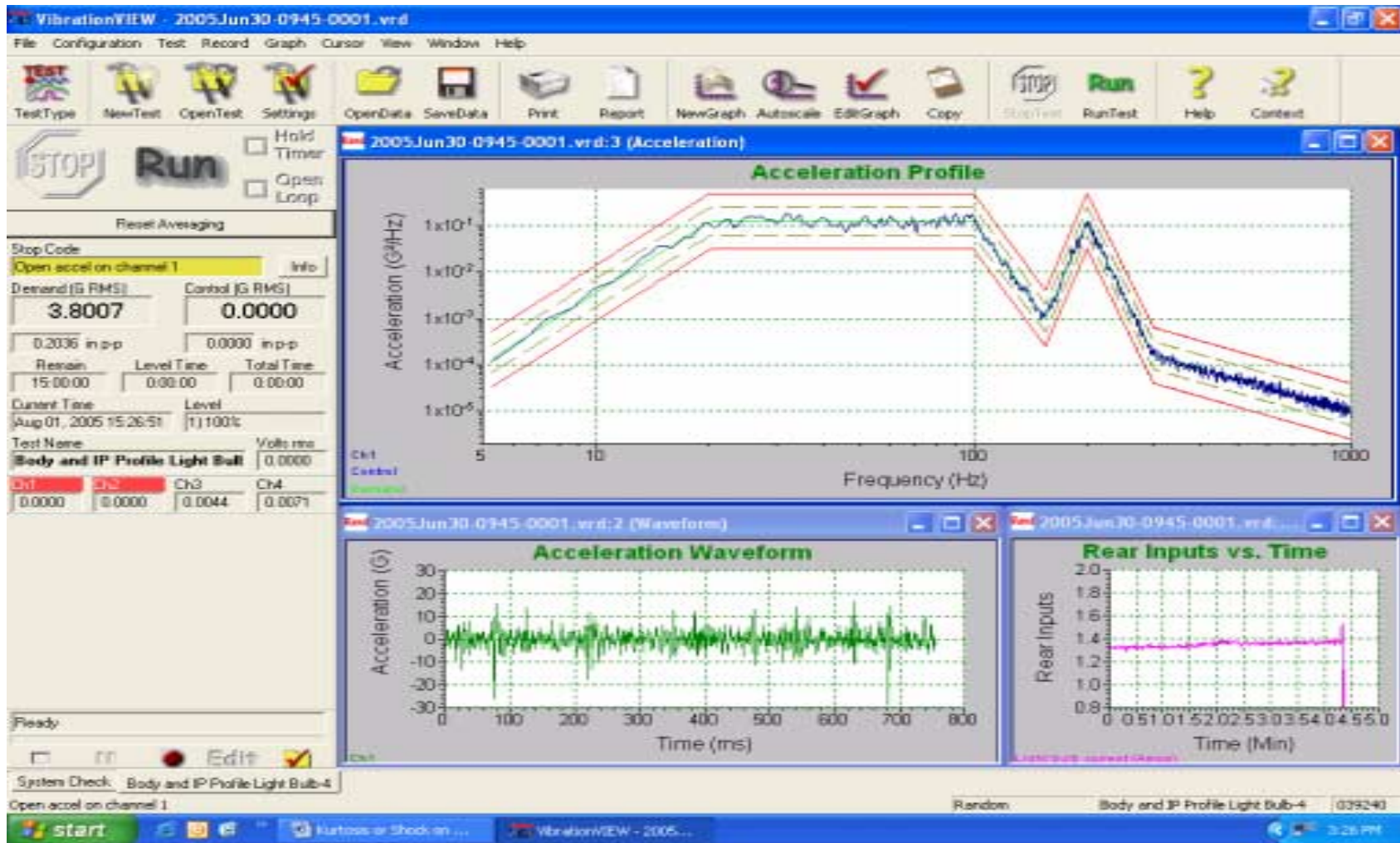
# Kurtosis = 3



# Kurtosis = 5



# Kurtosis = 7



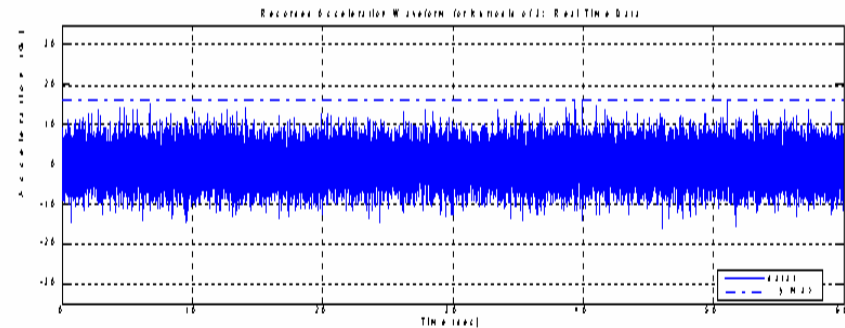
# Waveform comparison

Waveforms recorded with  
VibrationVIEW™ during the  
random light bulb tests

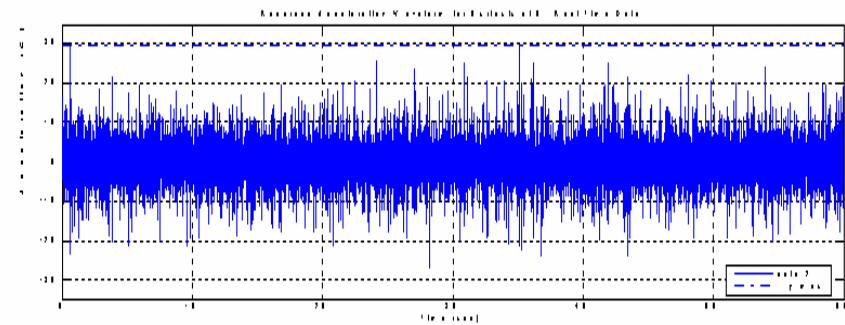
**Larger kurtosis value  
gives higher peak acceleration**

This will ultimately be responsible  
for failure of the product.

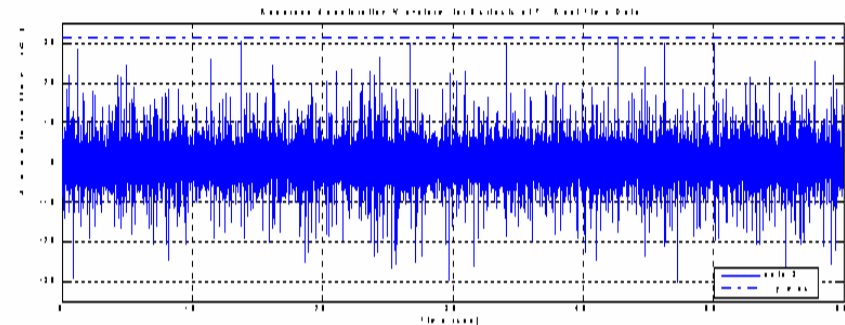
K = 3



K = 5



K = 7



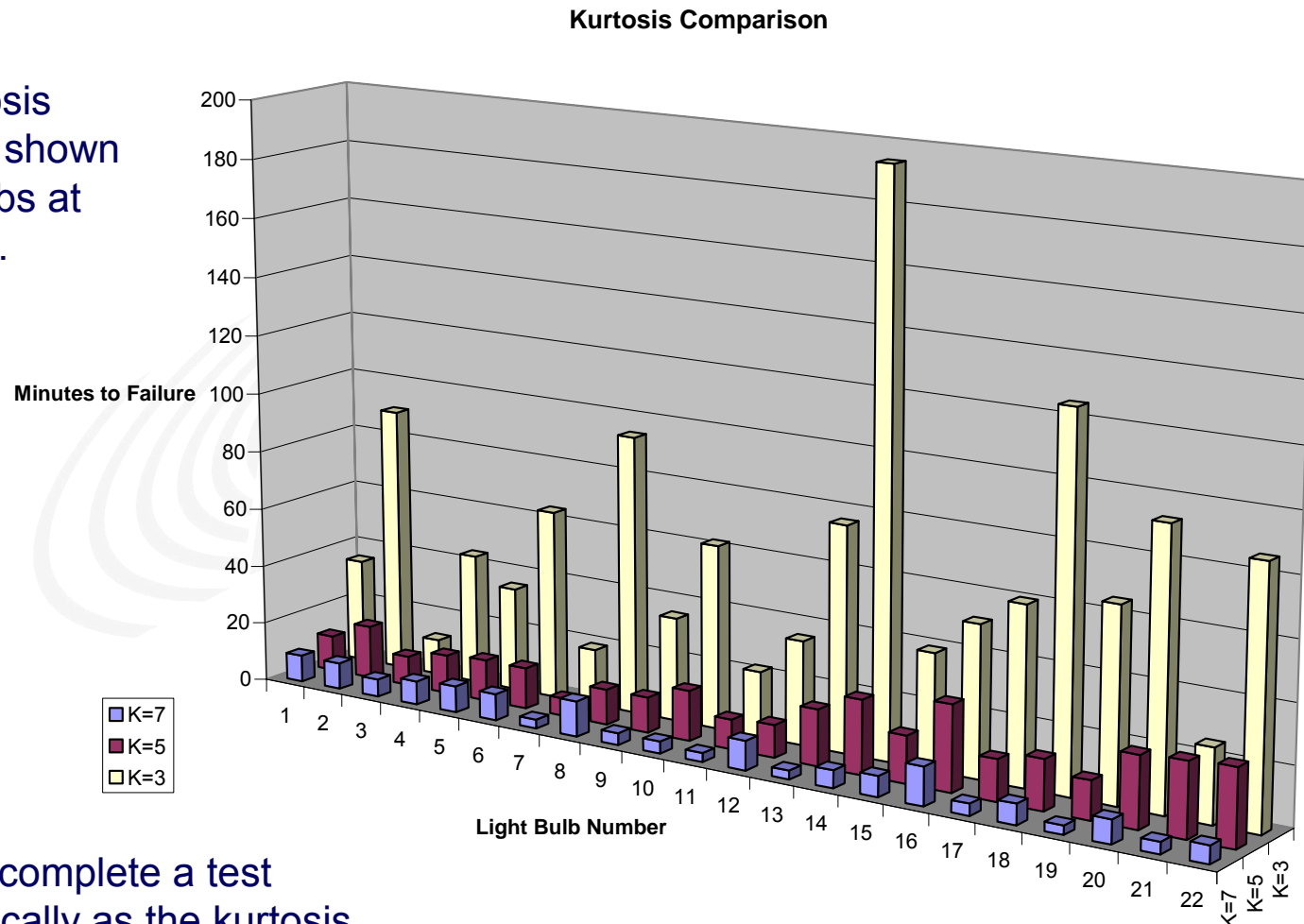
# Test results

- ◆ Note that the spectrum is the same, independent of kurtosis
  - Looking only at the spectrum and RMS, you cannot see the difference between the tests
  - Need to look at the time waveform, kurtosis calculation, and/or the PDF
- ◆ The kurtosis levels affects the **failure rate** of a product



# Kurtosis results compared

Consider the Kurtosis Comparison Chart shown here for the 22 bulbs at each kurtosis level.

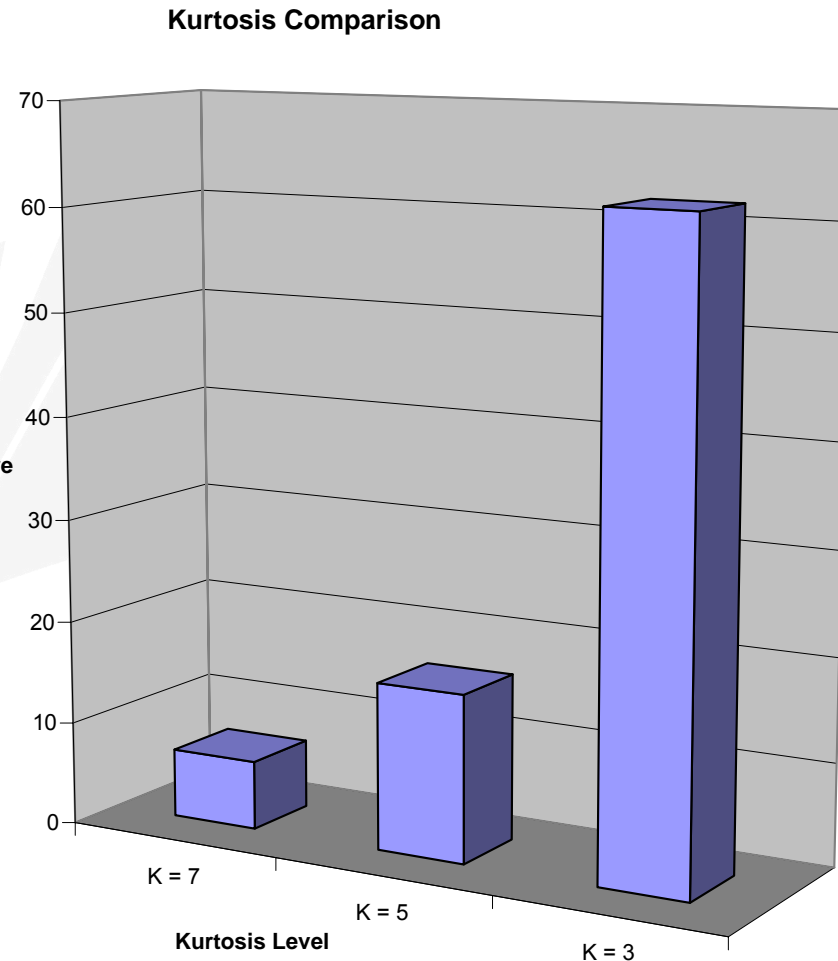


The time it took to complete a test decreased dramatically as the kurtosis level increased.



# Kurtosis results compared (cont)

Consider the graph of the Mean Minutes to Failure vs. Kurtosis Level as shown here



The increased kurtosis level dramatically decreased the mean time it took for the light bulbs to fail.



# Your Product?

- ◆ Do you have a product which:
  - Passes current random tests
  - But experience indicates vibration-related failures are indeed happening in the field
  - Then Kurtosion™ may be the tool you need to bring your product to vibration levels seen in the real world.



# Shaker Size Considerations

- ◆ Sine Rating
- ◆ Random Rating
- ◆ Shock Rating
- ◆ FDR “Rating”–Use Random and Shock
- ◆ Kurtosis “Rating”–Use Random and Shock
- ◆ Shaker Force Limits
- ◆ Shaker Current Limits (perhaps not specified)
- ◆ Shaker Displacement Limits



# Demonstrations

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- ◆ Field Data Replication
- ◆ Imported to Random
- ◆ Imported to Kurtosis



# Conclusion

- ◆ To significantly increase the reliability of your random test, you should correlate your kurtosis to real-world measured events.
- ◆ To significantly accelerate the failure of your product during testing, you should increase the kurtosis past the standard of  $k = 3$  that is used today.



# References

- ◆ [www.vibrationresearch.com/kurtosion](http://www.vibrationresearch.com/kurtosion) user kurtosion p/w control
- ◆ Van Baren, John “Kurtosis: The Missing Dashboard Knob,” *TEST Engineering & Management*, October/November 2005, pp 14-16.
- ◆ Van Baren, Philip “The Missing Knob on Your Random Vibration Controller,” *Sound and Vibration*, October 2005, pp 10-17.
- ◆ Smallwood, David O.: “Generating Non-Gaussian Vibration for Testing Purposes,” *Sound and Vibration*, October 2005, pp 18-23.
- ◆ [www.sandv.com](http://www.sandv.com) has a PDFs of all articles.
- ◆ Connon, W.H., “Comments on Kurtosis of Military Vehicle Vibration Data,” *Journal of the Institute of Environmental Sciences*, September/October 1991, pp 38-41.
- ◆ Steinwolf, A. , “Shaker simulation of random vibration with a high kurtosis value,” *Journal of the Institute of Environmental Sciences*, May/Jun 1997, pp 33-43.
- ◆ Steinwolf, A. and Connon W.H., "Limitations on the use of Fourier transform approach to describe test course profiles," *Sound and Vibration*, Feb. 2005, pp. 12-17.



# October 2005 Sound and Vibration Magazine



# Oct/Nov 2005 Test Magazine



# Oct/Nov 2005 Test Magazine reprints



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# Thank you

