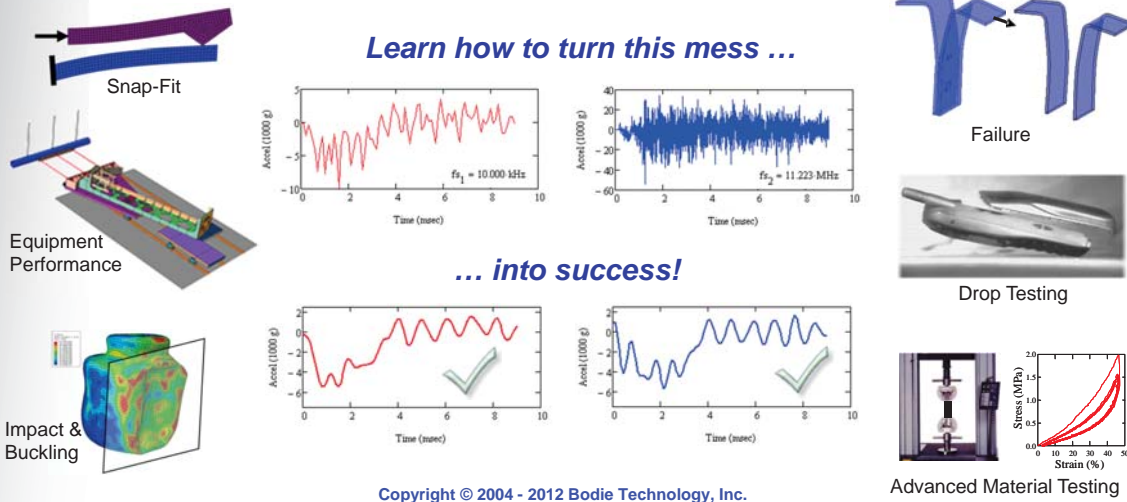


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Smart-Tools for Analyzing
Noisy & Challenging Problems™



Getting More From Abaqus by Tackling Noisy and Challenging Data

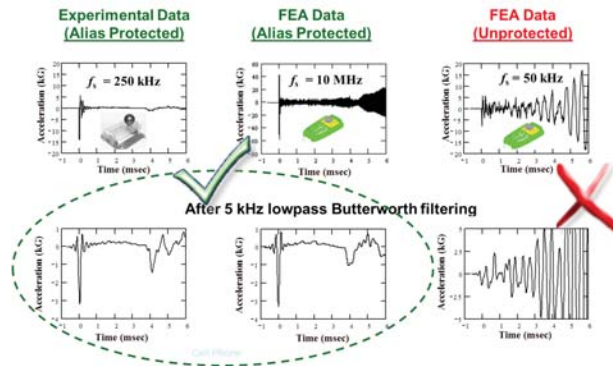
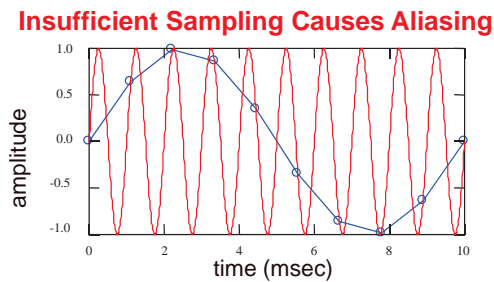
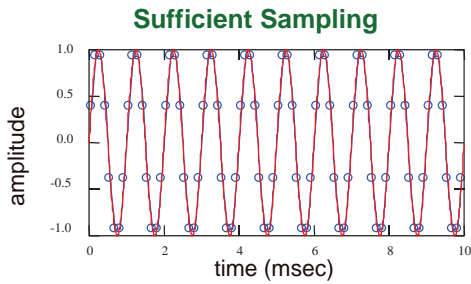


Overview

- Noisy Data – **The Disease**
- Bodie Technology Offerings – **The Cure**
 - Customizable Training, Kornucopia® Software, Expert Consulting
- Technology Demonstrations
 1. Abaqus/Standard quasi-static rolling
 2. Abaqus/Explicit quasi-static snap-fit
 3. Transient impact analyses via Abaqus/Explicit
 - Including Shock Response Spectrum (SRS) assessments
 4. Improving FEA-Test correlations of impact events via highpass filtering
 5. Preparing and cleaning physical test data for use in FEA modeling
- Bodie Technology Development Roadmap
 - Upcoming Kornucopia® V1.6 release
 - Future Kornucopia® platforms: Plug-ins for Abaqus/Viewer, Excel, and Python

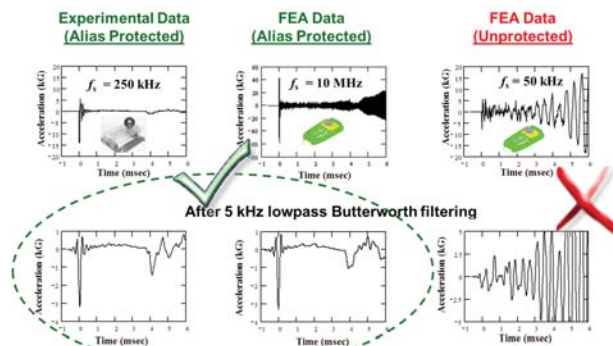
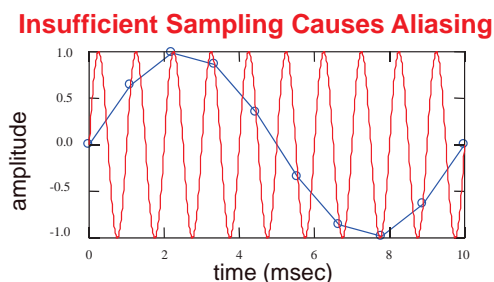
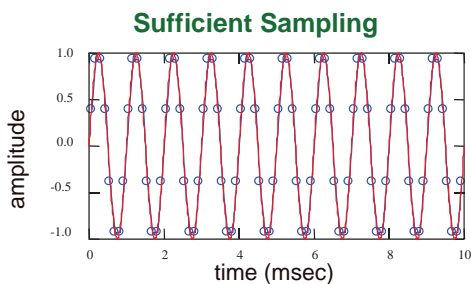
Noisy Data - The Disease

- Representing or manipulating oscillatory data with digital methods



Noisy Data - The Disease

- Representing or manipulating oscillatory data with digital methods

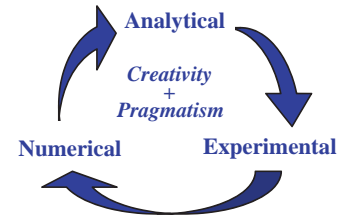


Bodie Technology, Inc.

Specializes in solving complex problems in nonlinear mechanics by employing a proven mix of computational and testing knowledge in novel ways



- Kornucopia® Software
- Customizable Training
- Expert Consulting



www.BodieTech.com
info@BodieTech.com

Smart-Tools for Analyzing Noisy and Challenging Problems™

"Bodie Technology provides engineers with excellent software, training, and consulting resources to help analyze complex nonlinear mechanics problems, especially those involving problematic or noisy datasets."

Steve Levine, Chief Strategy Officer, SIMULIA



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Technology Demonstrations

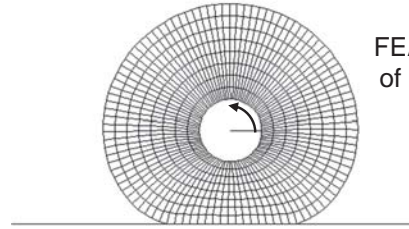
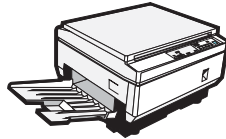
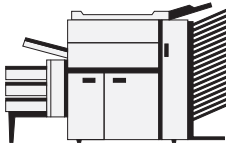
1. Abaqus/Standard quasi-static rolling
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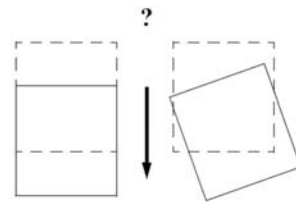
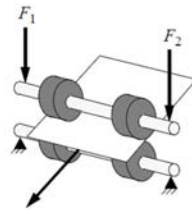
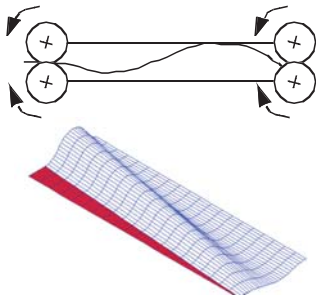
Abaqus/Standard Quasi-Static Rolling

- Analyzing Paper Motion in Copiers

- Understand media transport, influence of roller deformation, frictional effects, roller viscoelasticity ...



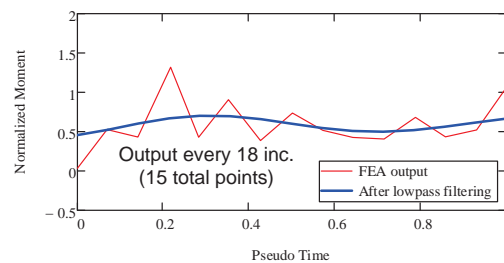
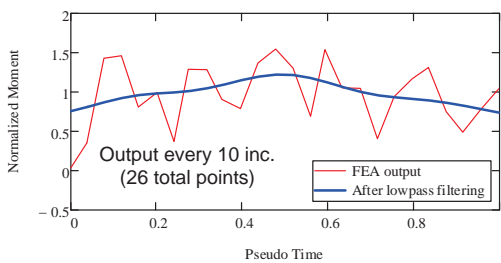
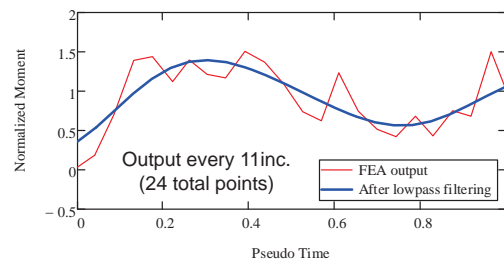
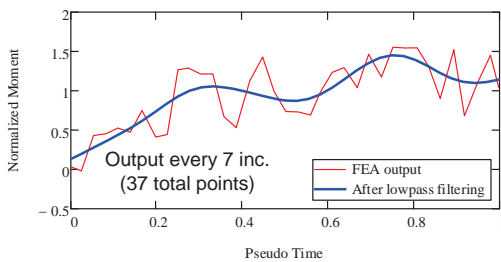
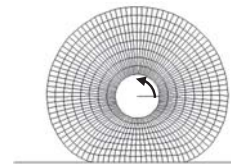
FEA model
of rotating
roller



Abaqus/Standard Quasi-Static Rolling

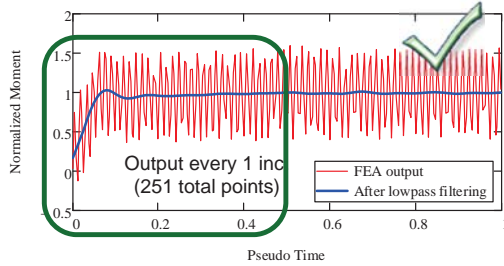
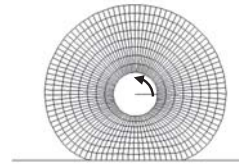
- Nonlinear quasi-static model predicts the torque (moment) required to rotate foam roller.

- Results from same model, just 4 different output requests.



Abaqus/Standard Quasi-Static Rolling

- Nonlinear quasi-static model predicts the torque (moment) required to rotate foam roller.
 - Correct model results using proper DSP techniques.



Solution noise caused by mesh discretization interacting with contact during rolling.

Using proper DSP approach, steady state answer achievable with 1/2 the run-time!

Abaqus/Standard Quasi-Static Rolling

- Nonlinear quasi-static model predicts the torque (moment) required to rotate foam roller.
 - Results from **same model**, just 4 different output requests.

Aliasing errors!

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Quasi-Static Snap-Fit Via Explicit Dynamics FEA

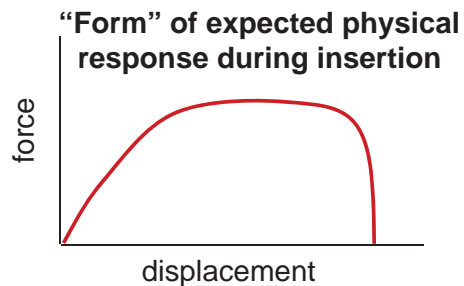
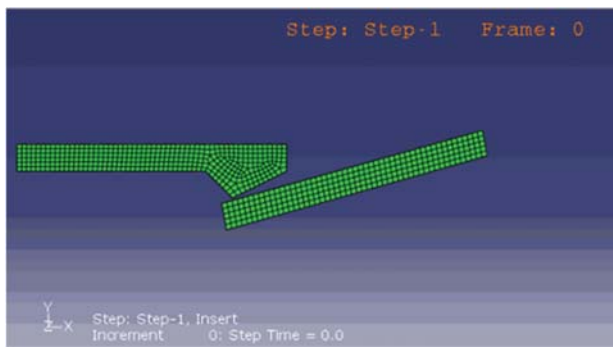
Preliminary scouting analysis of a Snap-Fit design

- Understand sensitivity to lower arm angle and influence of friction.
- Simulate both insertion and retraction
 - Implicit FEA will have difficulty with “snap” and retraction, so simulate with Explicit FEA.

FEA via Abaqus/Explicit, Filtering via Kornucopia®



3 angles: θ_0 , θ_0+5° , θ_0-5°



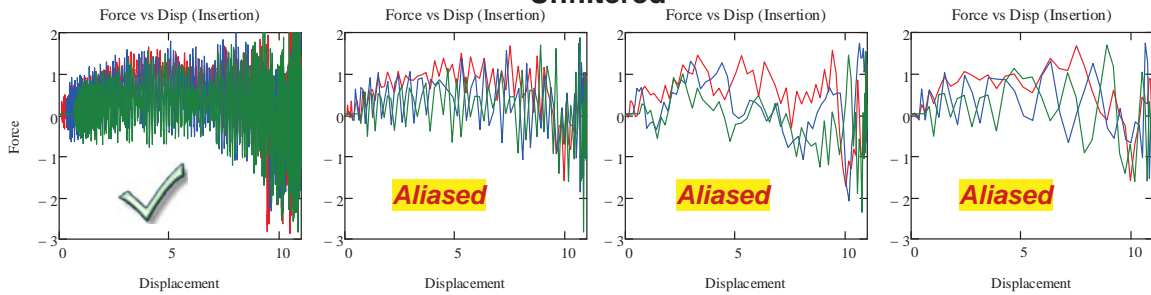
Quasi-Static Snap-Fit Via Explicit Dynamics FEA

Insertion Results Using Different Output Requests

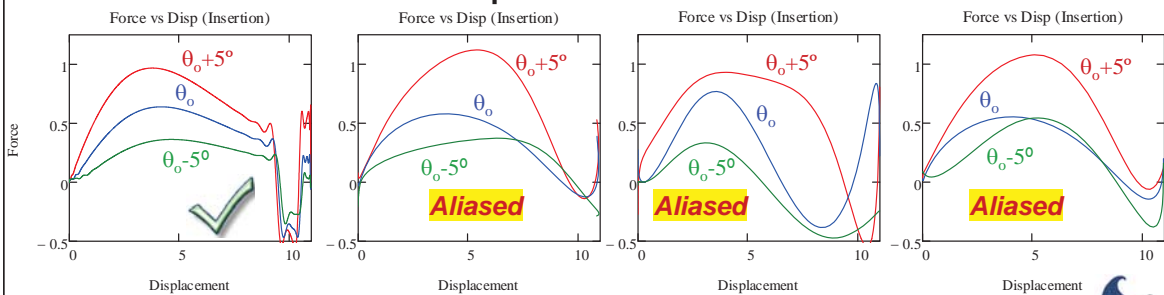


Every increment (~35,000 incs) 100 increments 80 increments 50 increments

Unfiltered



Lowpass filtered until smooth



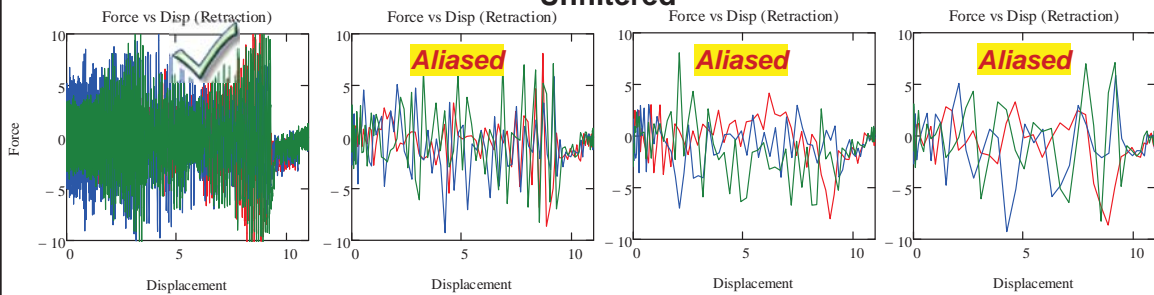
Quasi-Static Snap-Fit Via Explicit Dynamics FEA

Retraction Results Using Different Output Requests

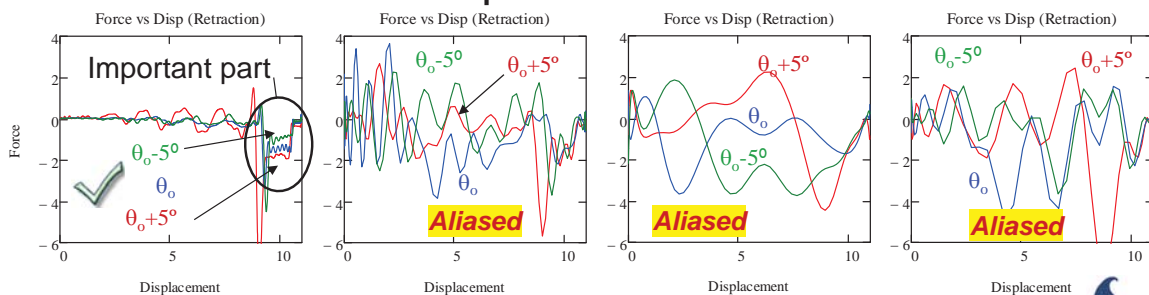


Every increment (~35,000 incs) 100 increments 80 increments 50 increments

Unfiltered



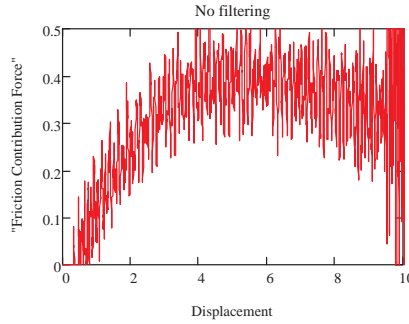
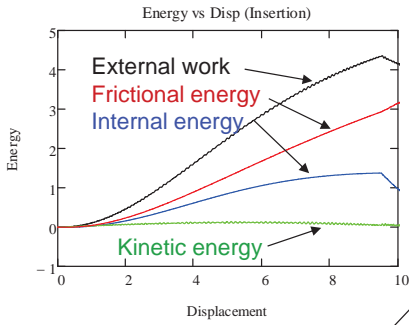
Lowpass filtered until smooth



Quasi-Static Snap-Fit Via Explicit Dynamics FEA Energy Methods, Derivatives, and DSP to Improve Analysis



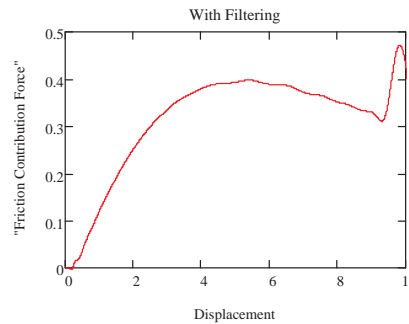
Estimating Frictional Influence



Case: θ_0

$$F_{fric} = \frac{\partial(U_{friction})}{\partial(u)}$$

Similar computations for other cases of θ_0+5° and θ_0-5°



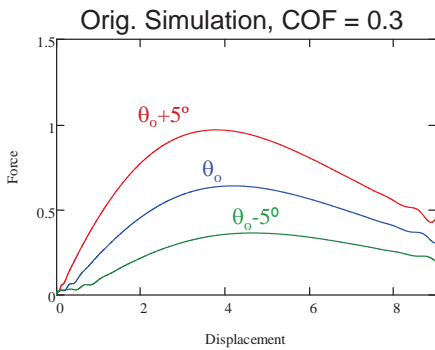
Filtered via bi-directional lowpass 6th order butterworth, $f_c=0.005 \cdot f_s$



Quasi-Static Snap-Fit Via Explicit Dynamics FEA Energy Methods, Derivatives, and DSP to Improve Analysis



Estimating Frictional Influence



Prediction equation

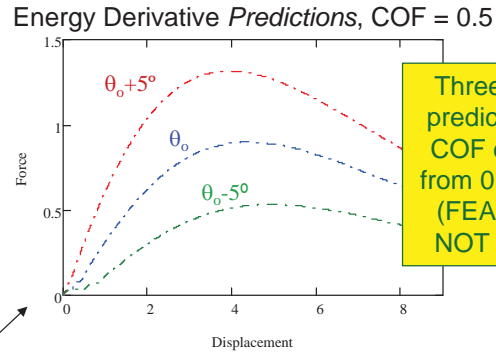
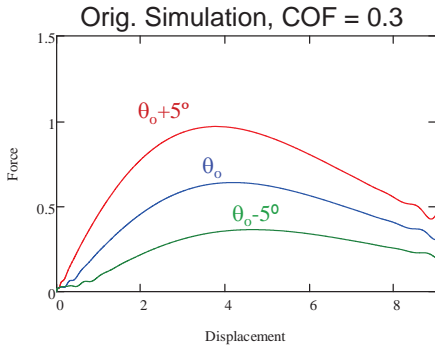
$$F_{total|COF=new} = F_{total|COF=0.3} + F_{fric|COF=0.3} \cdot \left(\frac{COF_{new}}{COF=0.3} - 1 \right)$$



Quasi-Static Snap-Fit Via Explicit Dynamics FEA Energy Methods, Derivatives, and DSP to Improve Analysis



Estimating Frictional Influence

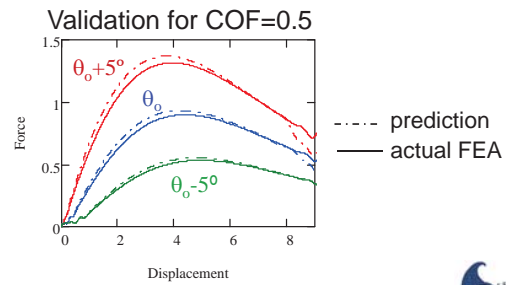


Three FAST predictions of COF change from 0.3 to 0.5 (FEA model NOT re-run)

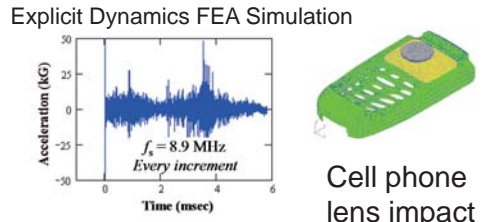
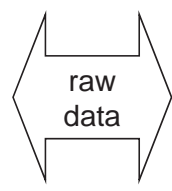
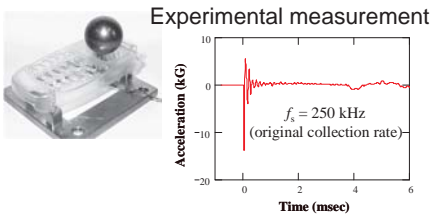
Prediction equation

$$F_{total|COF=new} = F_{total|COF=0.3} + F_{fric|COF=0.3} \cdot \left(\frac{COF_{new}}{COF=0.3} - 1 \right)$$

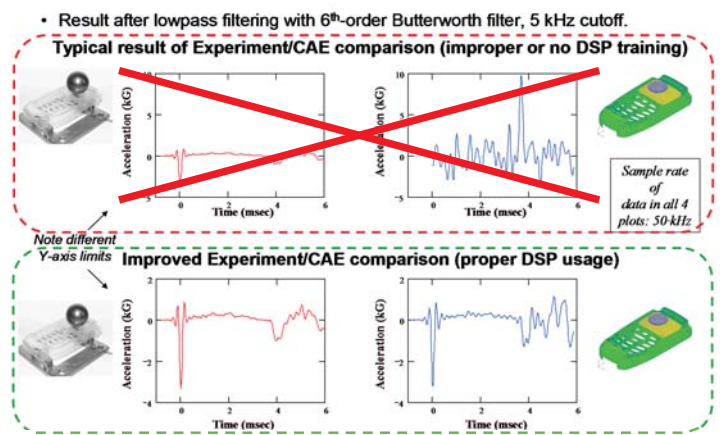
Validating predictions by running actual full FEA models for all three angle cases with COF = 0.5



Severe Impact of Plastic Housing



Why do 2 engineers find completely different results starting with same data?

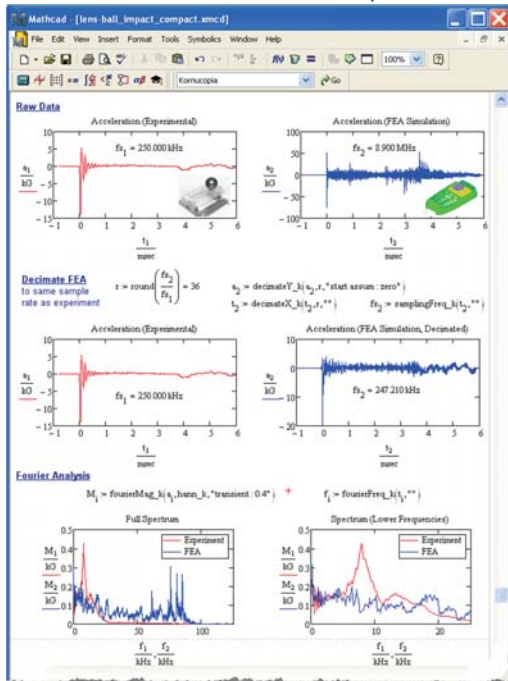


Engineer A
"NO correlation"
Aliasing distorted analysis

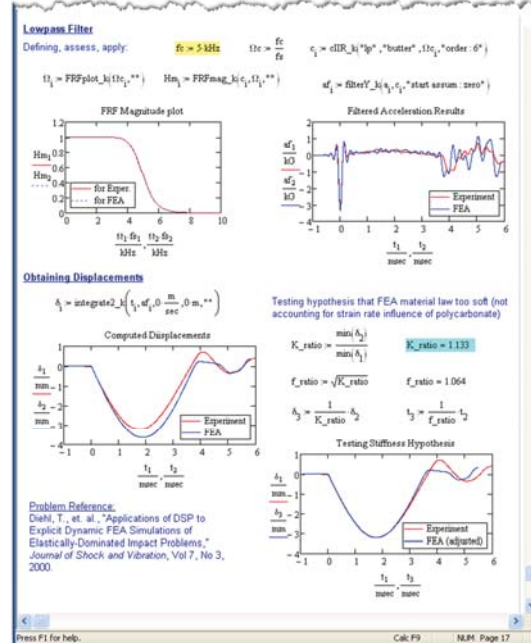
Engineer B
"Good Match"

Successful Analysis of Challenging Data: Accelerations and Displacements

Reusable, well
documented Kornucopia®
analysis worksheet



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Shock Response Spectrum (SRS and PVSS)

- Methodology to assess impact severity from acceleration data. Applicable to
 - FEA
 - Physical tests
- Methodology based on assessing how a spectrum of Spring/Mass/Damper systems respond to transient acceleration input
- Useful to answer questions such as
 - “Will a sensor or other component survive the impact event?” Examples include:
 - Cameras
 - Motion-sensing electronics
 - IC chips
 - Applicable to cell phones, smart-bombs, ...



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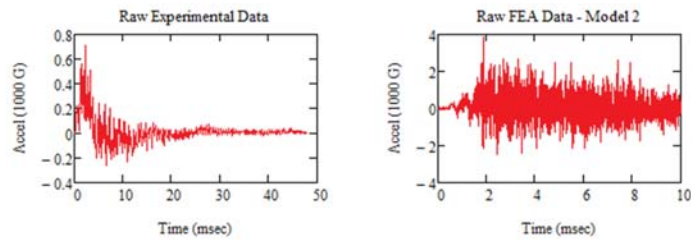
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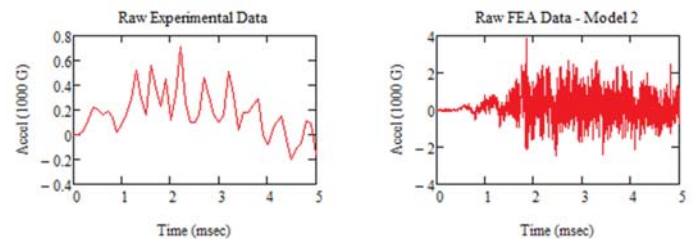
SRS and PVSS Penetrator Example

Given

- Acceleration data from:
 - Experiment
 - Explicit Dynamics model
- Spec on absolute max shock for device to be placed near nose cone:
(as stated by customer)
 - 6,000·G for 0.1·msec
 - 2,000·G for 0.5·msec



Zoom from 0 to 5·msec



How to compare the following data to the specs?

- Experiment and FEA Peak Accel = 700·G and 4,000·G
- Experiment and FEA data look totally different!

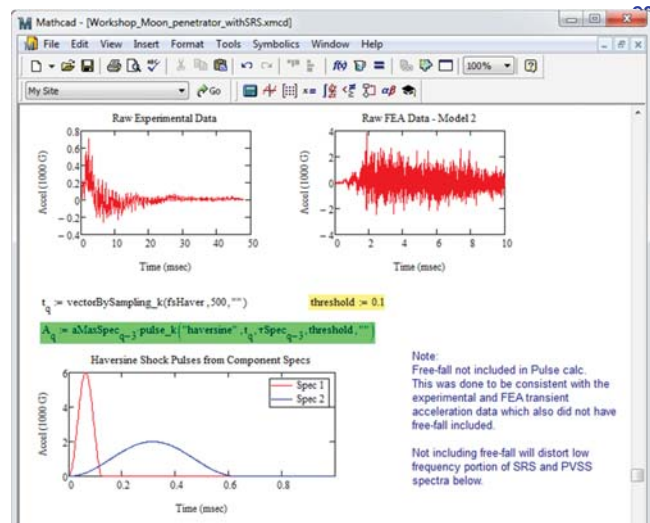
How to relate 0.1 and 0.5·msec from spec to Test and FEA data?



SRS and PVSS Penetrator Example

Given

- Acceleration data from:
 - Experiment
 - Explicit Dynamics model
- Spec on absolute max shock for device to be placed near nose cone:
(as stated by customer)
 - 6,000·G for 0.1·msec
 - 2,000·G for 0.5·msec



First convert specs to Haversine shock pulses

- Easily done with Kornucopia® functions



SRS and PVSS Penetrator Example

Given

- Acceleration data from:
 - Experiment
 - Explicit Dynamics model
- Spec on absolute max shock for device to be placed near nose cone:

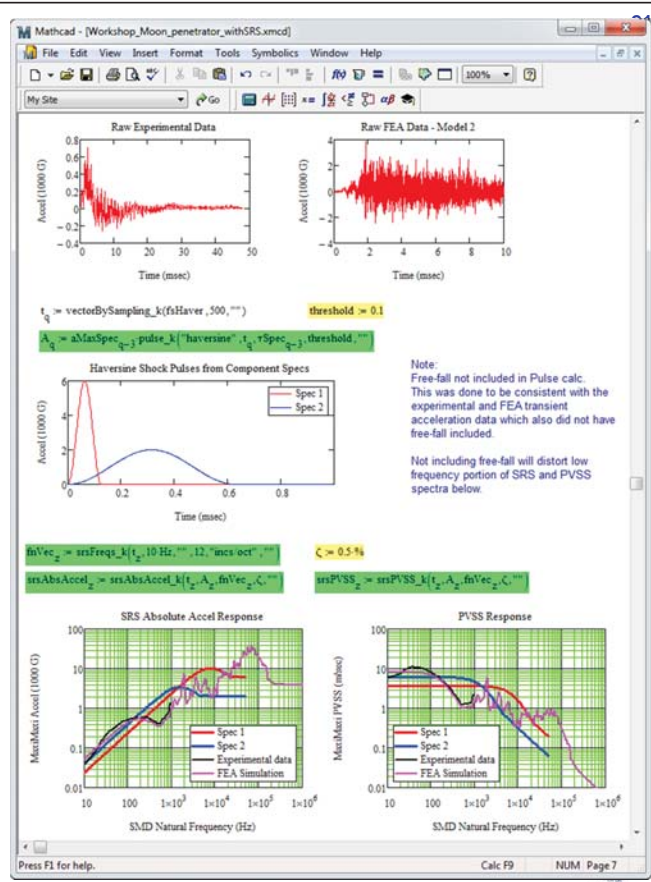
(as stated by customer)

 - 6,000·G for 0.1·msec
 - 2,000·G for 0.5·msec

Then compute SRS Abs Accel and PVSS Spectra on

- Haversine shock pulses
- Experimental data
- FEA data

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SRS and PVSS Penetrator

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- Acceleration data from:
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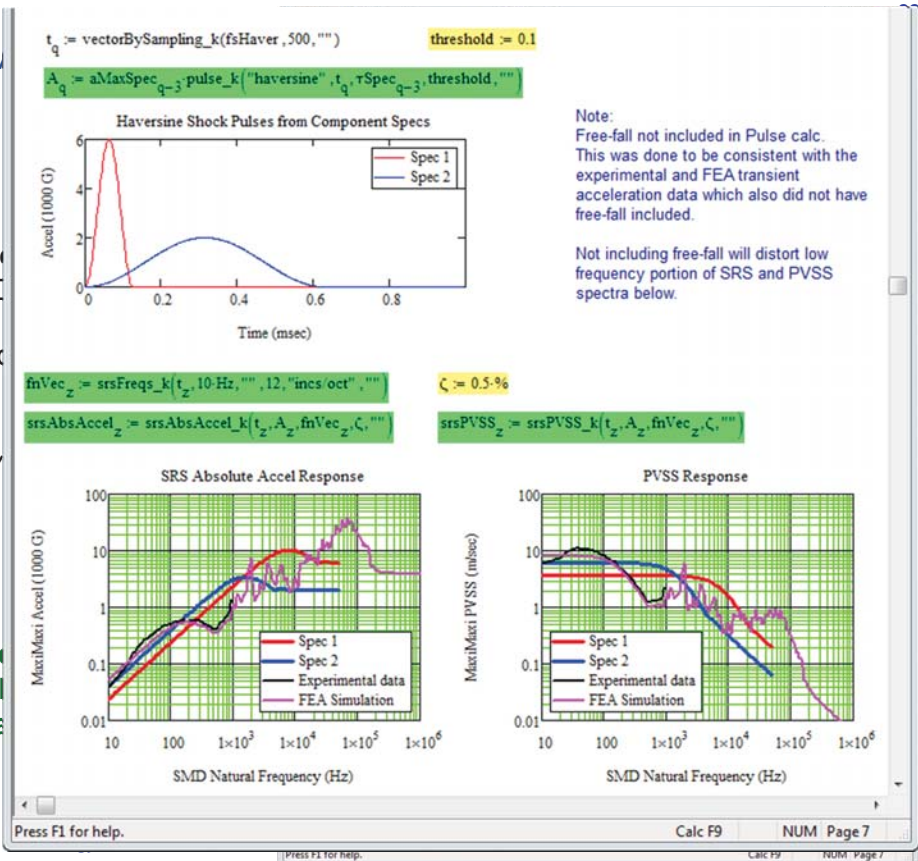
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SRS and PVSS Penetrator Example

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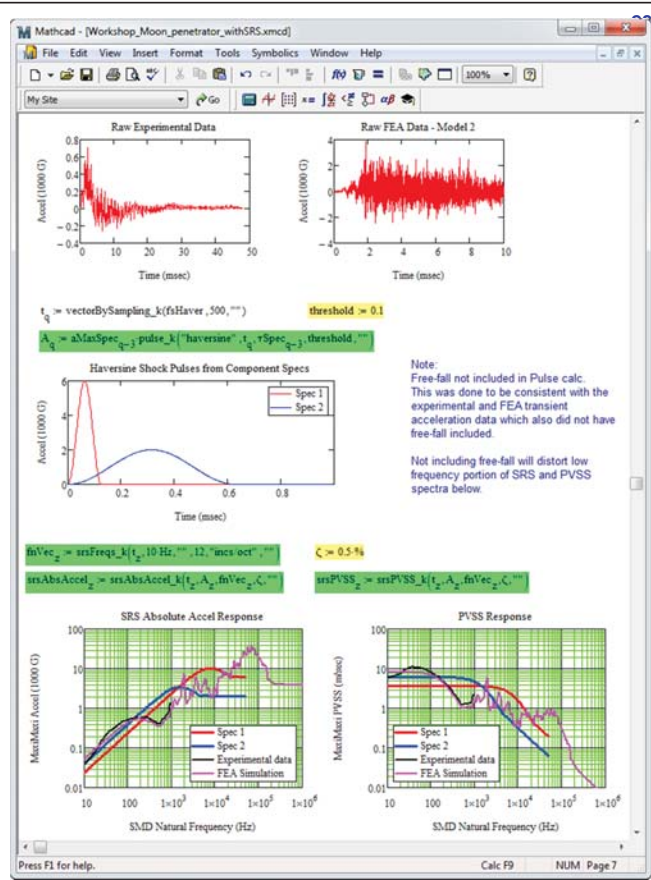
(as stated by customer)

 - 6,000·G for 0.1·msec
 - 2,000·G for 0.5·msec

Then compute SRS Abs Accel and PVSS Spectra on

- Haversine shock pulses
- Experimental data
- FEA data
- Need estimate of natural frequencies of device

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SRS and PVSS Penetrator Example

Given

- Acceleration data from:
 - Experiment
 - Explicit Dynamics model
- Spec on absolute max shock for device to be placed near nose cone:

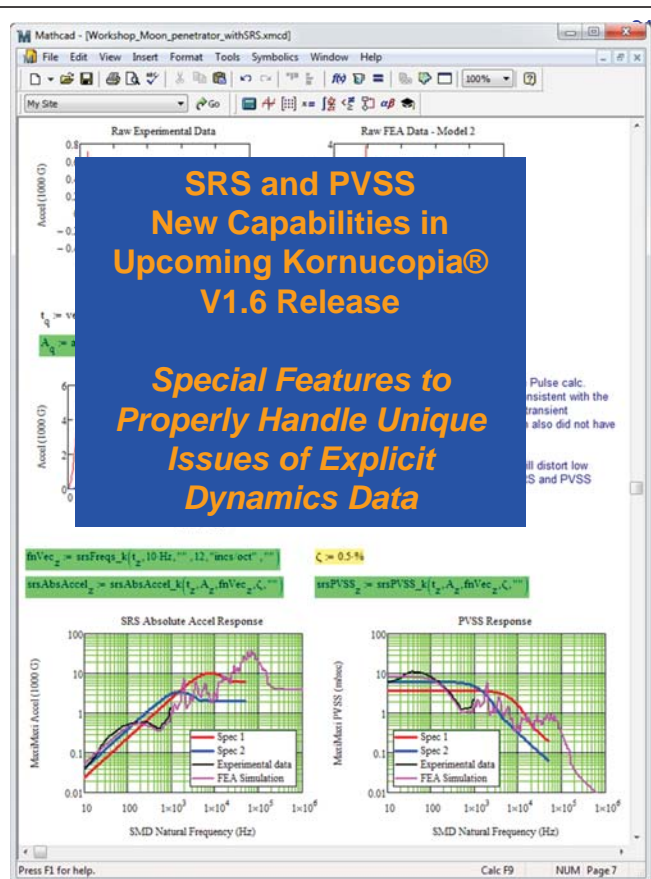
(as stated by customer)

 - 6,000·G for 0.1·msec
 - 2,000·G for 0.5·msec

Then compute SRS Abs Accel and PVSS Spectra on

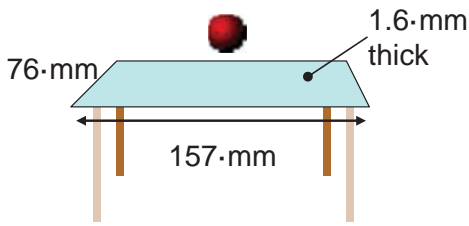
- Haversine shock pulses
- Experimental data
- FEA data
- Need estimate of natural frequencies of device

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Integrating Acceleration Data – Another Big Challenge!

Why does this measured acceleration produce a ridiculous displacement?

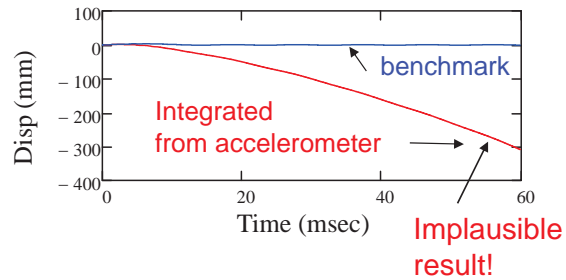
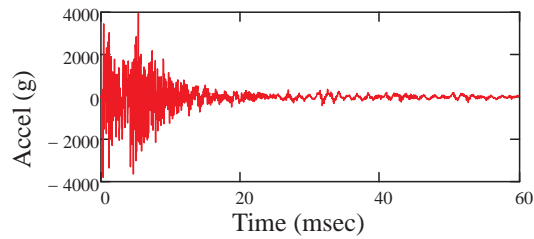


Steel ball impacting aluminum plate

Answer:

Low frequency distortion in accelerometer data

- Very common with measured data



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Example Templates in Library Help Meet the Challenge!

Kornucopia Help

Hide Locate Back Forward Stop Refresh Home Print Options

Contents | Index | Search

- TOC
- Release Notes
- Introduction and Overview
- Method Tips
- Functions
- Extra Units
- Examples
 - Tips on Using Examples Effectively
 - Tutorials
 - Simple Usage
 - Elaborate Examples
 - Cantilever Beam Analysis
 - Catenary Analysis
 - Cleaning, Averaging, and Tweakin
 - Creating Elastic/Plastic Material Dr
 - DCB Failure
 - Decimating Data
 - Derivatives and Integrals of Discre
 - General Interpolation via Paramete
 - Highpass Filter of Plate Shock
 - Hysteretic and Cyclic Data Proces
 - Improving User-Friendliness of Wic
 - Learning DSP
 - Lens-Ball Impact
 - Moon Penetrator
 - Processing Multiple Files Efficiently
 - Processing a Packed File Efficiently
 - Protective Barrier
 - Salvaging PE Shock
 - SalvagePEshock_Compact
 - SalvagePEshock_Detailed
 - Sliding Contact
 - T-bracket Failure
 - Tricks for Plotting Multiple Curves
 - Print & Troubleshooting

Salvaging PE Shock Data Using Highpass Filtering (Compact version)

Measured Accel vs Time 1 Direct Integration

Double Integration

NOT Plausible (Huge Drift)

ALL Template Example Files

- Can Open LIVE in Mathcad®
- Modify as desired by user

Salvaged Displacement via Highpass Filtering

Plausible Result

This example worksheet demonstrates how the use of highpass filtering as a method to potentially salvage severe drifting in integrated displacement data.

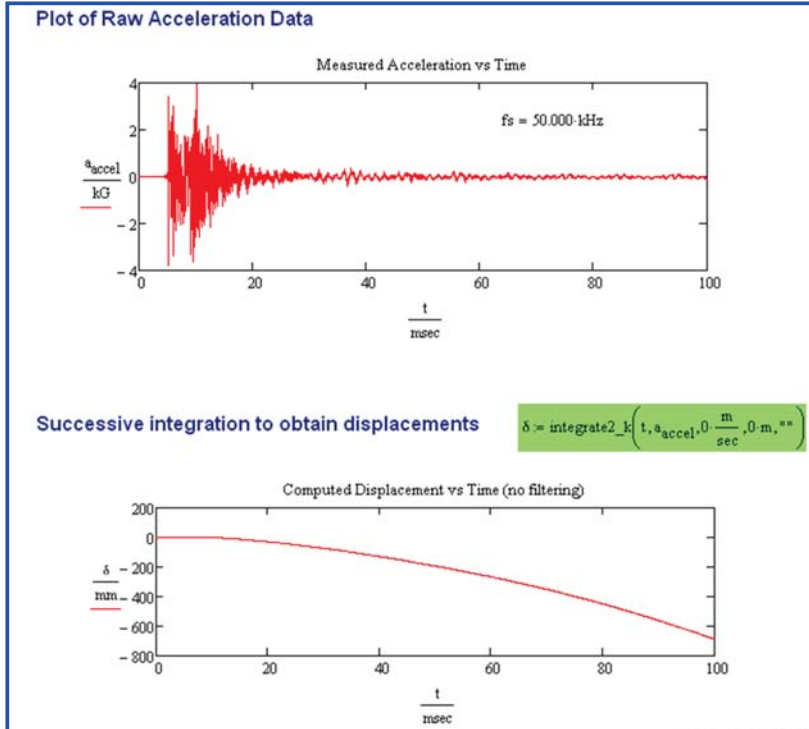
This is an HTML version of the worksheet. It is intended to be used for fast browsing. [Click here to work interactively in Mathcad® with this worksheet.](#)

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Salvaging Data via Highpass Filtering

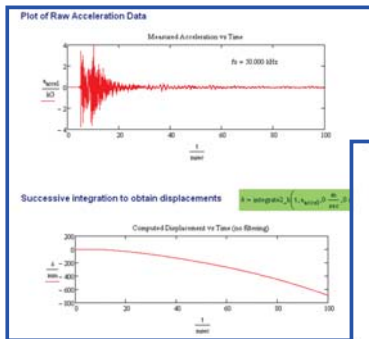


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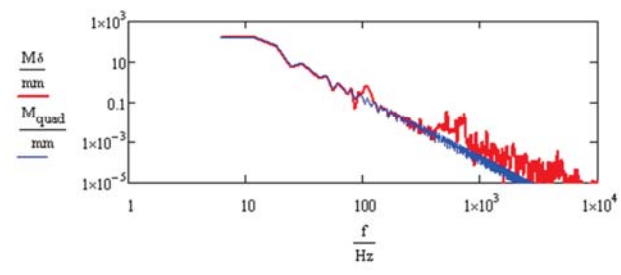
Salvaging Data via Highpass Filtering



Fourier Analysis

Fourier of the actual data $M\delta := \text{fourierMag_k}(\delta, \text{hann_k}, "")$ $f := \text{fourierFreq_k}(t, "")$
 To help interpret the Fourier Signature, we compute the Fourier Signature of a simple Quadratic curve.

$$\delta_{\text{quad}} := -700 \cdot \text{mm} \cdot \left(\frac{t}{100 \cdot \text{msec}}\right)^2 \quad M_{\text{quad}} := \text{fourierMag_k}(\delta_{\text{quad}}, \text{hann_k}, "")$$

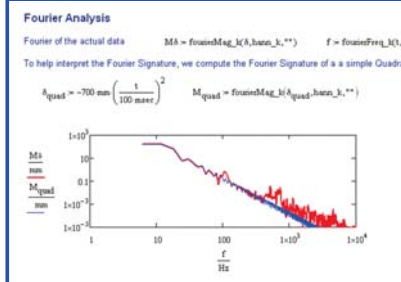
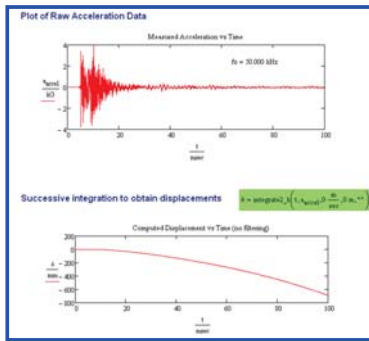


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Salvaging Data via Highpass Filtering



Highpass Filtering to Remove Drift

Guided by the Fourier analysis above, it looks like we should start filtering around 100 Hz.

- Try the following filter cutoffs: 100 Hz, 50 Hz, 25 Hz, 10 Hz, 25 Hz, 30 Hz, 28 Hz.
- Your goal when removing drift is to use as low a cutoff as possible so that the low frequency portion causing the drift is removed but the higher frequency, physical components are not removed.

Define filter cutoff $f_c = 28 \text{ Hz}$ $\omega_c = \frac{f_c}{f_s}$

Define filter coefficients $c = \text{clIR}_k(\text{'hp'}, \text{'butter'}, \omega_c, **)$

Apply filter to data $\&R = \text{filterY}_k(\delta, c, **)$

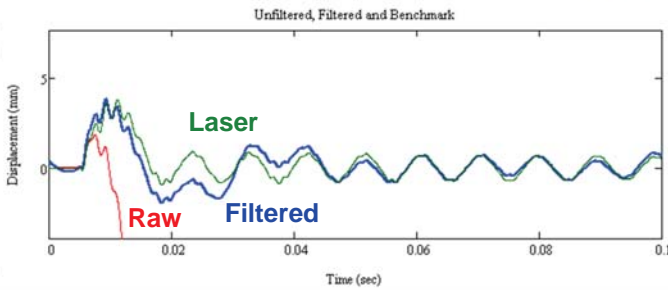
Select the curves you desire to appear in the plot.

Select which signals to turn on in the plot below

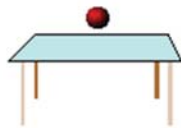
Unfiltered Filtered Laser

Select which signals to use to drive Y-axis scaling

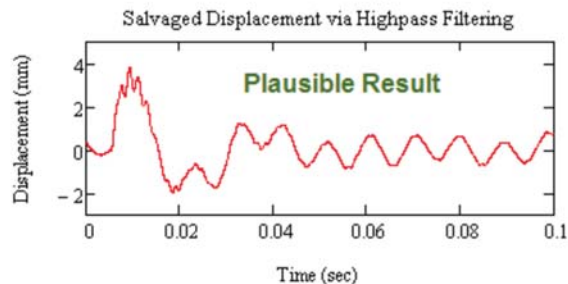
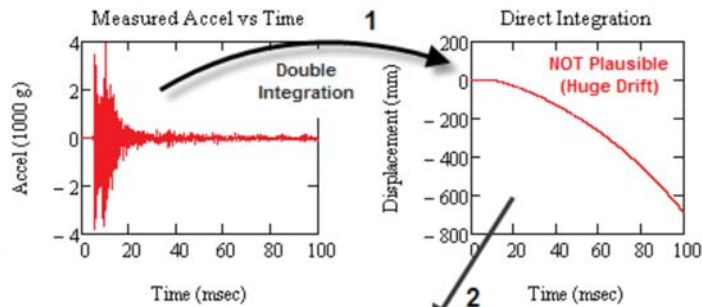
All
 2x Laser
 2x Filtered & laser
 5x Filtered & laser



Salvaging Data via Highpass Filtering



Steel ball impacting an aluminum plate with dimensions 157*mm x 76*mm x 1.57*mm



Preparing & Cleaning Challenging Data via Kornucopia®

Processing Experimental Data

File with beginning and ending markers for each dataset

Challenging data to process (multiple datasets, header issues)

Reusable, well documented Kornucopia® analysis worksheet

Read data file

```

BeginSample
SampleName: "Project\Fish\fish.nse"
MethodName: "JTF method JTF.nse"
Tool1: "011" "011" "014" "015" "016"
SampleID: "fish" "ID-1"
SampleDate: "2012-01-10"
BeginSpecimen
A10Spec: 0.253 "a"
Area: 0.939 "cm^2"
BeginData
Time Load Extension
1.88000 13752.352 0.141
0.13600 2.318 0.000 -0.000
0.14000 2.299 0.000 -0.000
0.14400 2.476 0.000 -0.000
...
EndData
EndSpecimens
A bunch more specimens
EndS
    
```

Unpack and separate datasets

```

dataA = unpack_k(fileA, (1), ("BeginData"), (3), **)
summary_k(dataA, **)
    
```

Plot raw datasets

Average datasets and plot final results

```

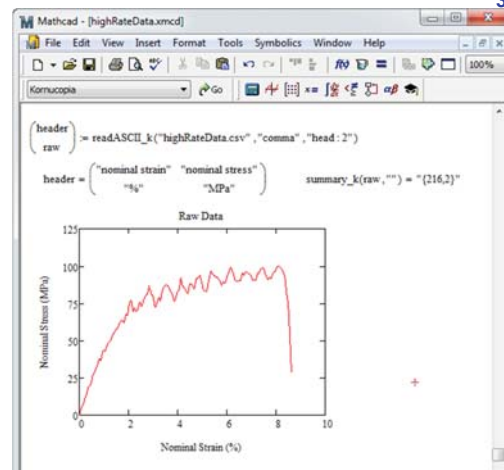
Clean data and convert to Stress vs. Strain
head_1 = trim_j(dataA, (dataA_1)^2, 1000, "max", **)
tmp_1 = tweekXY_k("start", tmp, 2, 0, 0.05, ("excess": 3))
shiftData_k(tmp, "start", 0, **)

T = ** T_1 = (head_1^2) LOAD / A_0_1
epsilon = ** epsilon_1 = (head_1^4) DISP / L_0_1
epsilonT = ** epsilonT_1 = segment(epsilon_1, T_1 / MPa)
ave = averageXY_k(epsilonT, "x", "norm": yes)
plot = nestPlot_k(epsilonT, **)
    
```



Cleaning High-Rate Data

- With high-rate measurements, there is a greater likelihood that noise and oscillations appear in your data
 - Often caused by excitation of mounting fixtures or testing frames.
- **In many cases, the FEA analyst must deal with the data “as is”**



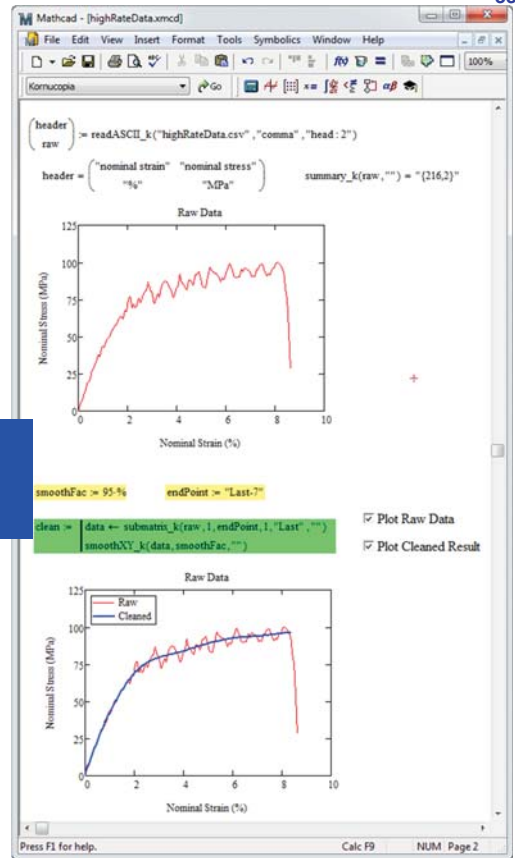
Cleaning High-Rate Data

- With high-rate measurements, there is a greater likelihood that noise and oscillations appear in your data
 - Often caused by excitation of mounting fixtures or testing frames.
- **In many cases, the FEA analyst must deal with the data "as is"**



- Interactive
- Self-documenting
- Reusable

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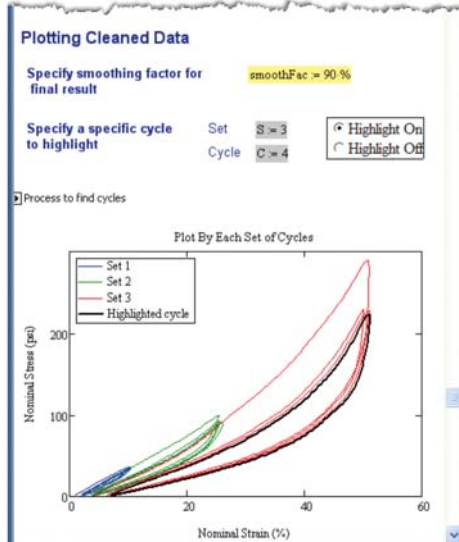
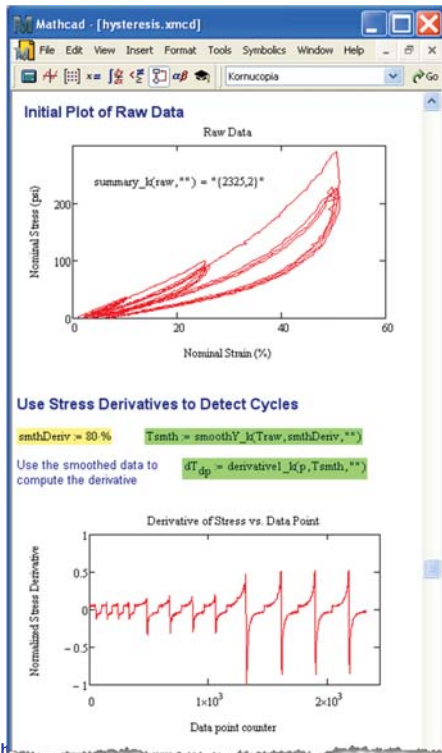


Enhancing Material Characterization from Raw Data

- Basic Steps for Elastic/Plastic Data**
- Clean and average raw data
 - Convert nominal stress/strain to true stress/strain
 - Determine modulus
 - Obtain yield stress vs plastic strain curve
 - Output to ASCII file for FEA or other use

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Cleaning Hysteresis Data via Kornucopia®



- Key Benefits:**
- Clear documentation of analysis
 - Reusable & automated
 - Saves times, Reduces errors
 - Deployable to others

Copyright



Free, Self-paced Kornucopia® Training on BodieTech.com

The screenshot shows a web browser window displaying the BodieTech.com website. The page features the Bodie Technology, Inc. logo and the tagline 'Smart-Tools for Analyzing Noisy & Challenging Problems™'. There are buttons for 'About Us' and 'Contact Us'. A navigation menu includes 'Home', 'Kornucopia', 'Training', 'Consulting', 'Resources & Videos', and 'News & Events'. The main content area is titled 'Training - Jump-Start into Kornucopia® and Mathcad®' and features a diagram showing the integration of Mathcad and Kornucopia. The diagram includes the Mathcad logo, the Kornucopia logo, and a circular flow with the text 'Analytical', 'Creativity + Pragmatism', 'Numerical', and 'Experimental'. To the right of the diagram are two small plots labeled 'raw data' and 'clean', with the word 'average' written below them. Below the diagram, the text reads: 'Mathcad and Kornucopia® can help make all sorts of calculations and data analysis faster, easier, and more accurate. If you work with any of the following this free, web-based training is for you!'

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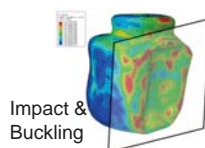
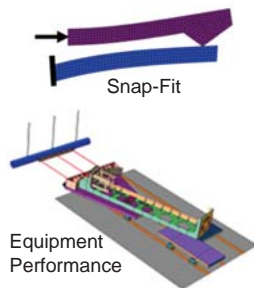


Analyzing Noisy Data via Filtering and DSP

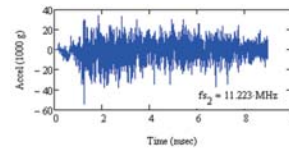
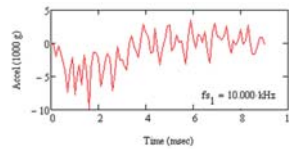
3 or 4 Day Customizable Training Seminar

Instructor: Ted Diehl, PhD

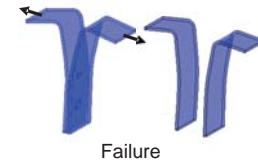
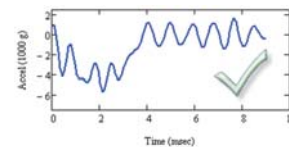
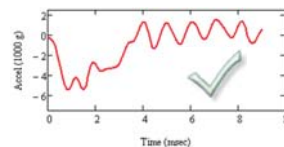
**Training specially designed for
FEA Users & Experimentalists**



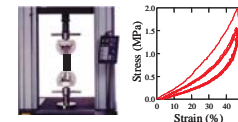
Learn how to turn this mess ...



... into success!



Drop Testing



Advanced Material Testing

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Smart-Tools for Analysis™



Course Content

Lectures

1. Motivation for Using DSP with Simulations and Experiments
2. DSP Fundamentals
3. DSP Using Various Software
4. Developing a DSP Strategy for a Given Problem
5. Using Energy to Enhance Analysis
6. Working with Experimental Data and Validating Simulations/Experiments
7. Working with Transient-Dynamic Models
8. Shock Spectrum Analysis (SRS, PVSS)
9. Working with Quasi-Static Models from Explicit FEA
10. Improving the Modeling of Failure
11. Creating Viable FEA Material Data from Noisy and Challenging Material Measurement Data

Workshops

1. Experiencing Common DSP-related Mistakes
2. Learning DSP Using Simple Signals
3. Transient Impact of a Structure
4. Transient Penetration - Comparing Models and an Experiment
5. Salvaging Shock Data via Highpass Filtering
6. Quasi-Static Cam Mechanism
7. Analyzing Failure and Crack Propagation
8. Computing Derivatives and Integrals From Noisy Data
9. Creating Elastic/Plastic Material Law From Slightly Noisy Experimental Data
10. Cleaning Problematic Hysteresis Data

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Smart-Tools for Analyzing Noisy & Challenging Problems™



“Without Kornucopia® I really doubt the quality and quantity of work would have been what it was. The 1 on 1 instruction was invaluable”

**Lt. Col. Kelly Laughlin, PhD
US Army, Picatinny Arsenal**

*Analyzing large-caliber ballistics from
both Explicit FEA and tests*



“Your DSP course taught techniques that helped me create a standardized approach for processing noisy Explicit Dynamics simulations. This has improved my analysis and helped me deliver more useful FEA results on recent projects - **your course is the best I have taken in a long time.”**

**Michael J. Iacchei, Mech. Eng.
U.S. Army, AMSAA**



Smart-Tools for Analyzing Noisy & Challenging Problems™



Helping all people
live healthy lives



“We congratulate the Kornucopia® development team for creating such an effective and simple-to-use toolkit for engineers worldwide.”

**Arun Nair, Ph.D.
Becton Dickinson & Co.**

“Kornucopia® has helped greatly in breaking down difficult data sets from experiments, in an easier, automatic, and understandable way. This has helped us setup, scrutinize and understand the experiments faster, which is priceless... It helps make the organization move faster...”

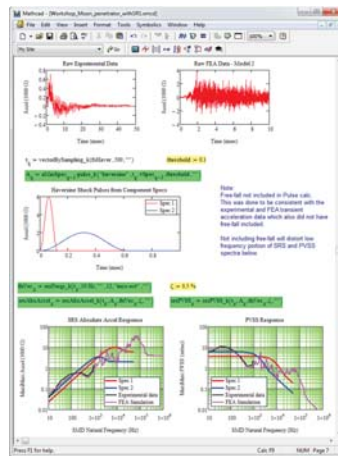
**David McCalib, Mfg. Engineer
- Blount International**



Bodie Technology Roadmap Upcoming Kornucopia® V1.6 Release

• Shock Response Spectrum

- SRS Absolute Acceleration, PVSS, and more
- Easy-to-use Pulse Generation functions
 - Convert component shock specs to SRS for direct comparison to SRS of FEA or physical accelerometer data
- *Specifically designed to handle Explicit Dynamics simulation data as well as experimental data*
- Example templates demonstrating SRS technology usage



• Other Enhancements

- Run/Loop other Mathcad worksheets from a Kornucopia® worksheet
- Enhancements to file reading, averaging, integration, & derivatives
- New example templates
 - SRS data analysis, Slice/Dice data, and more



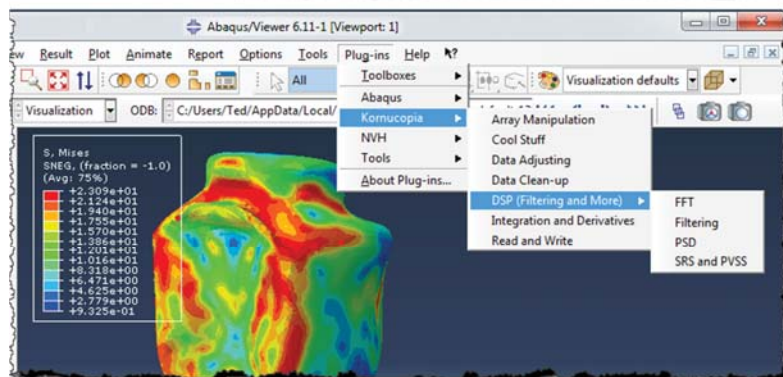
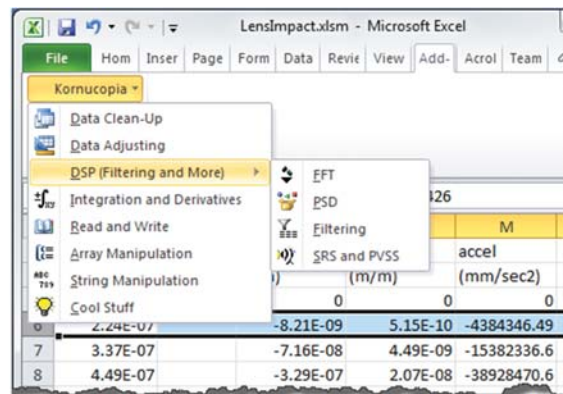
Bodie Technology Roadmap Future Kornucopia® Platforms

Independent Kornucopia® Engine

- Allows Kornucopia® technology to be connected to a variety of software packages

Initial Platform Targets

- **Abaqus/Viewer**
- **Microsoft Excel**
- **Python**
- **Mathcad**

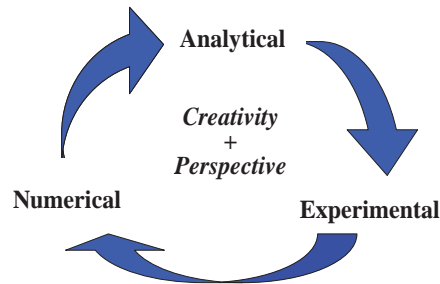


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Instructor's Profile – Ted Diehl, Ph.D.



- **Expert in Nonlinear Mechanics with 20+ Years Experience**
 - Experimental, computational, and theoretical approaches
 - Led nonlinear mechanics efforts at Kodak, Motorola, and DuPont
- **Engineering Tools**
 - Mathcad & Kornucopia®, Abaqus nonlinear FEA, and experimental methods
- **Engineering Success in Industry**
 - NASA spacecraft
 - Cell-phone impact
 - Peeling mechanics
 - Paper motion in copiers
 - Simulating fabrics
 - Flexible structures
 - Nonlinear nip mechanics
 - Ballistic protection
 - Nonlinear materials
- **Created unique DSP algorithms**
 - Enhance analysis of noisy data from experiments & Explicit Dynamics FEA
- **Developer of Kornucopia® and President of Bodie Technology Inc.**
 - *Smart-Tools for Analyzing Noisy & Challenging Problems™*

