ANALYSIS OF FIELD SHOCK/DROP DATA and CREATION OF LABORATORY TESTS

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FIELD DATA WORKSHOP II

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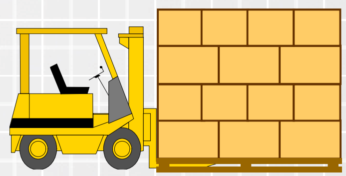
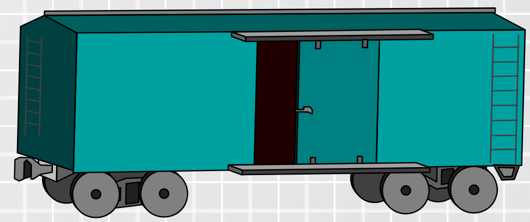
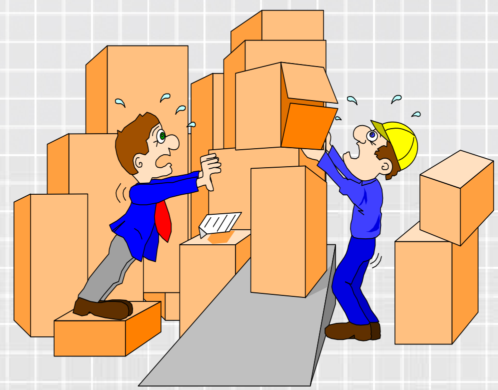
INTRODUCTION

- How to translate properly recorded information into meaningful laboratory tests
- Shock/impact
  - Pallet marshalling
  - Rail switching



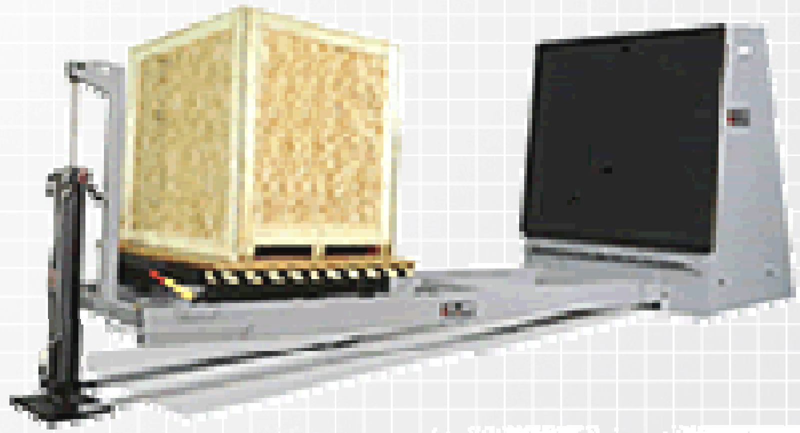


- Drop
  - Handling, sorting, etc.



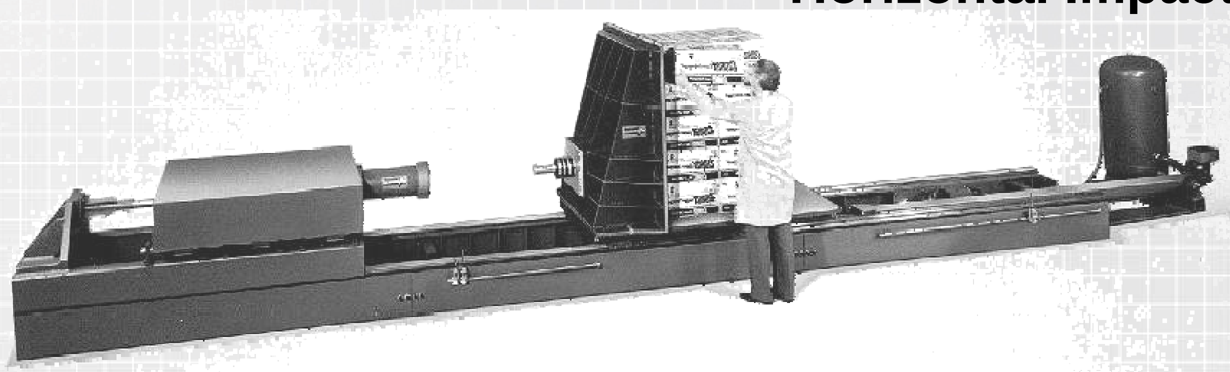
SHOCK/IMPACT

- Today's reality is that we test for pallet marshalling and rail switching with



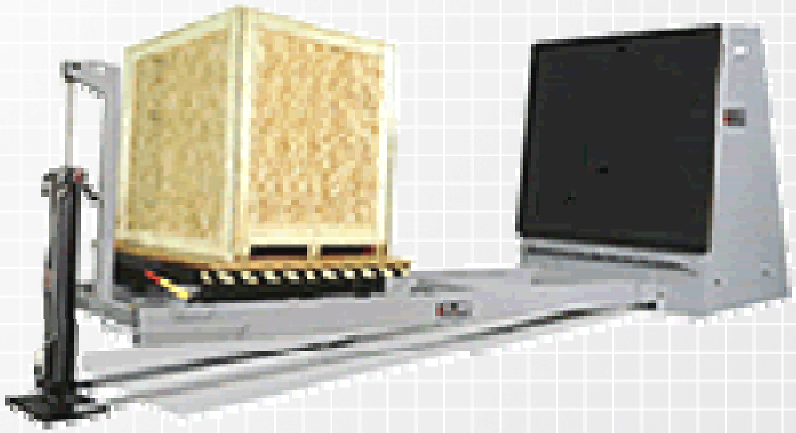
Inclined-Impacter

Horizontal Impacter



SHOCK/IMPACT

- For inclined-impacters, the only parameter we can control is velocity



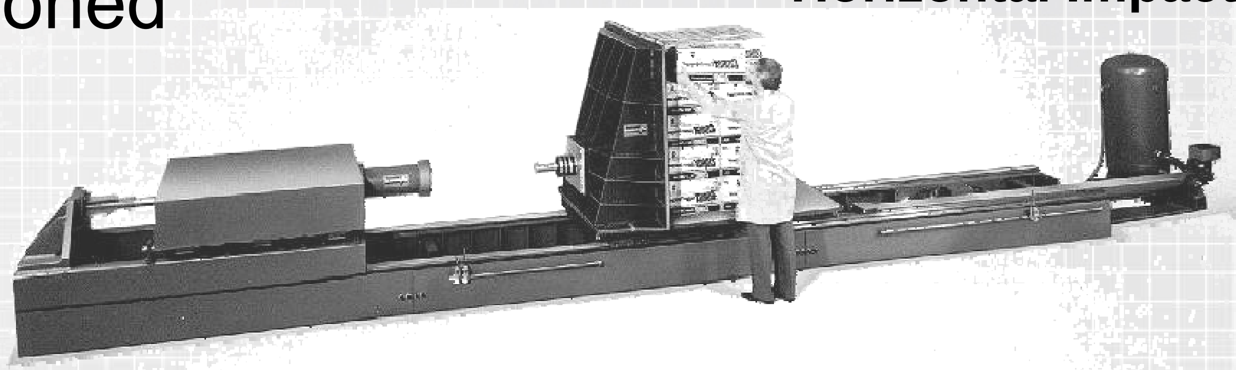
Inclined-Impacter

  - So for pallet marshalling lab tests there's little point in doing more than measuring or estimating field impact velocities

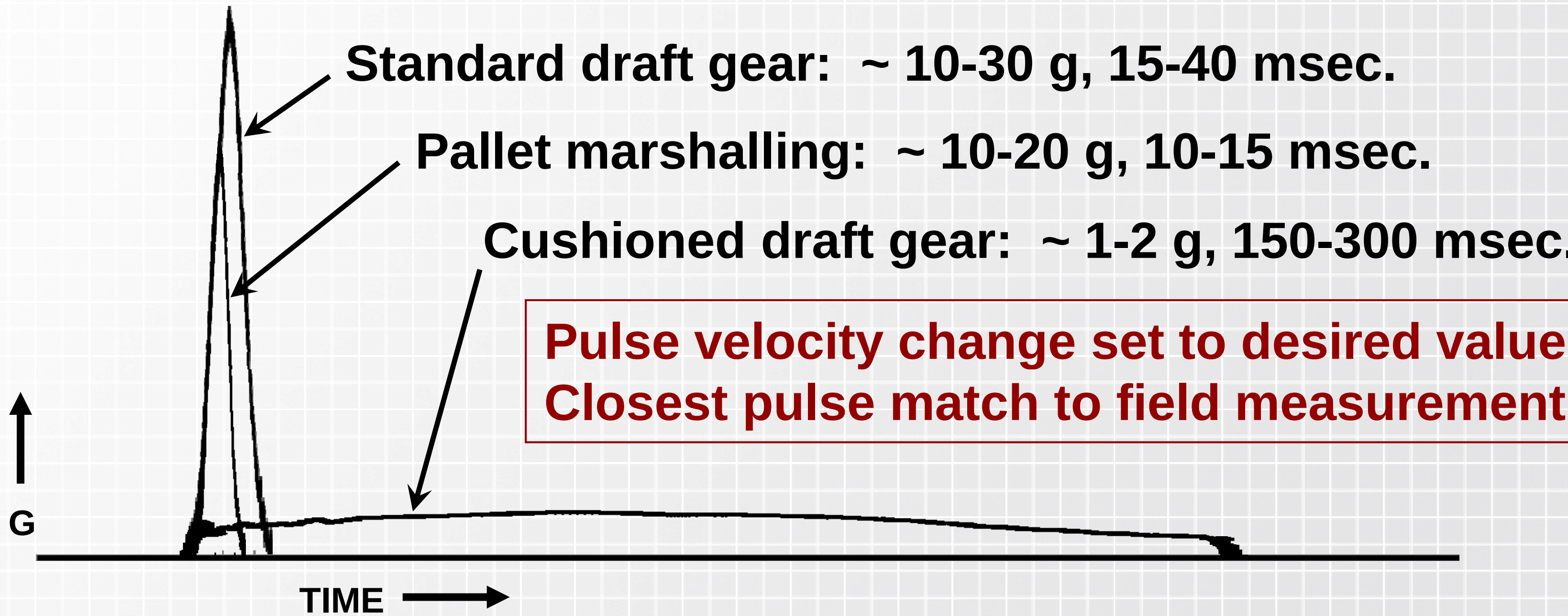
SHOCK/IMPACT

- For horizontal impact machines, we can typically only produce relatively short-duration, high g half sines and relatively long-duration, low g rectangular pulses
  - Half sines for pallet marshalling and standard draft gear railcar impacts
  - Rectangular pulses for cushioned draft gear

Horizontal Impacter

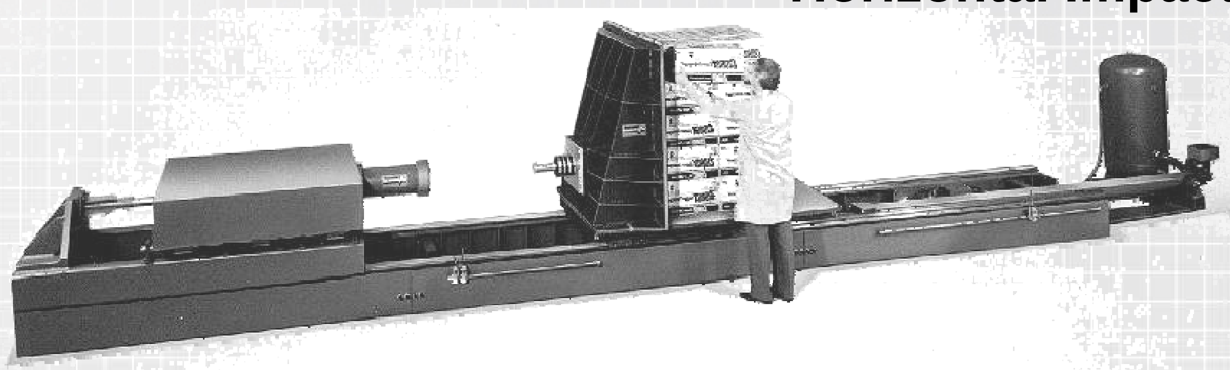


SHOCK/IMPACT



Pulse velocity change set to desired value
Closest pulse match to field measurement

Horizontal Impacter

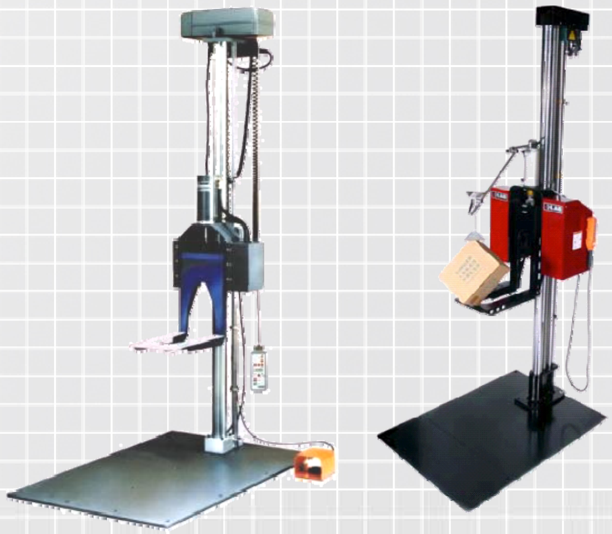


SHOCK/IMPACT – IMPROVEMENT?

- The best approach could be the simulation of typical field shock pulses for the various situations
  - Large pulse variations, but…
  - Perhaps the approach could be to measure pulses, calculate shock response spectra (SRS), compile SRSs, and then determine representative pulses
  - A research project?

DROP

- In the real world of distribution, there are few “pure” free-fall drops
- But in the lab, we do free-fall drops onto a hard surface using a drop tester



- Therefore, it is useful to analyze the data in terms of Equivalent Free-Fall Drop Height (EFFDH) or Equivalent Damage Potential

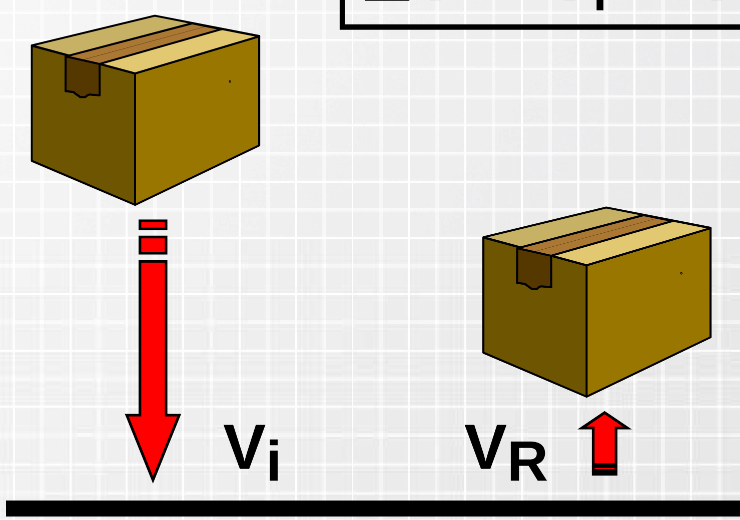
DROP

- Recorders do not measure drop height or damage potential directly, they measure 3-axis shock pulses
- Calculation of equivalent drop height or equivalent damage potential is not trivial
- Two approaches:
  - The “standard” – calculation of EFFDH from pulse velocity change and a calibrated estimate of package coefficient of restitution, perhaps combined with a “zero-g” reading”
  - Use of SRS analysis to determine Equivalent Damage Potential

DROP – CoR Approach

- When a package is dropped, it may rebound
- There is a quantity called "velocity change" (ΔV) which is equal to the sum of the impact and rebound velocities

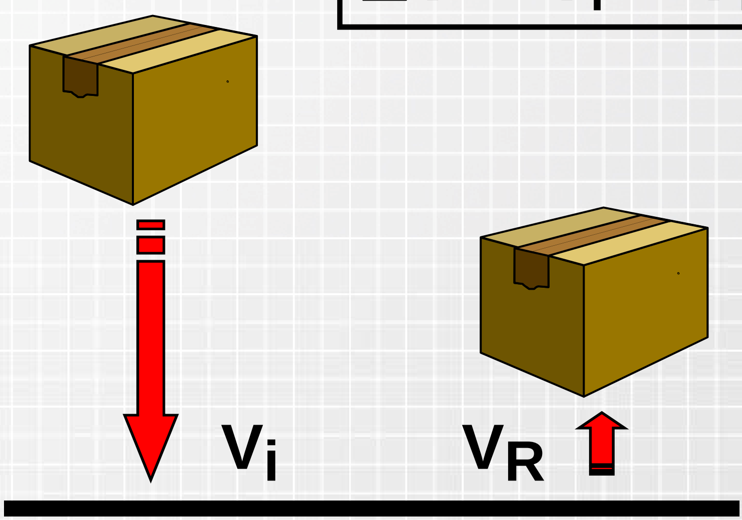
$$\Delta V = V_i + V_R$$



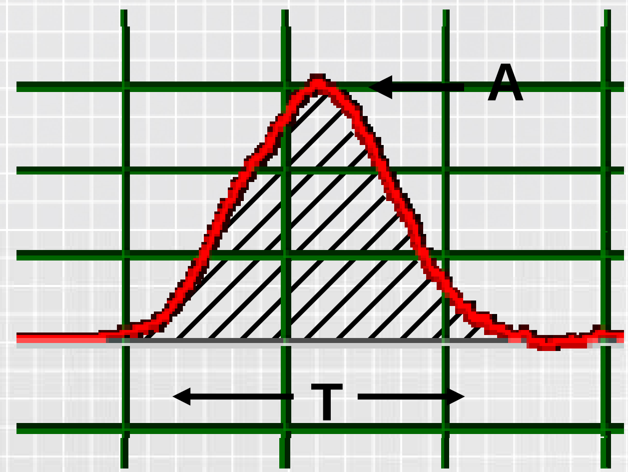
DROP – CoR Approach

- Recorders measure shock pulses, from which can be calculated velocity change
- But drop height is related to impact velocity only

$$\Delta V = V_i + V_R$$



ΔV IS PROPORTIONAL TO AREA UNDER THE PULSE



DROP – CoR Approach

- How to determine and subtract V_R?
- Rebound velocity V_R is a fraction of the impact velocity V_i depending upon how "elastic" the package is
- "Elasticity" ***e*** is called the ***coefficient of restitution***, and is equal to V_R / V_i
- Combining and re-arranging, we get

$$\Delta V = V_i (1 + e)$$

- ***e*** can be determined from lab calibration using a drop tester and the dummy pkg.

DROP – CoR Approach

- Complications – ***e*** can vary with impact orientation, drop height, and other factors
- So in general there are <u>*many*</u> ***e***'s, each applicable for only a specific situation or limited range
  - Package design to reduce variability of ***e***
  - Simplifying assumptions
  - Software to create a "package profile"
- Impact surface can also affect ***e***
  - Modify ***e*** based on peak pulse accelerations?
- Cushion properties can change

EFFDH from SHOCK PULSES and *e*

- Determine the shock pulse velocity change (ΔV) for each of the axes of measurement
  - Subjective judgment will likely be required
- Square the ΔV for each axis, and add these squared values together to get the "resultant" or total squared velocity change for the event, ΔV_t^2
- Using an appropriate value for **e**, calculate EFFDH
  - More subjectivity?

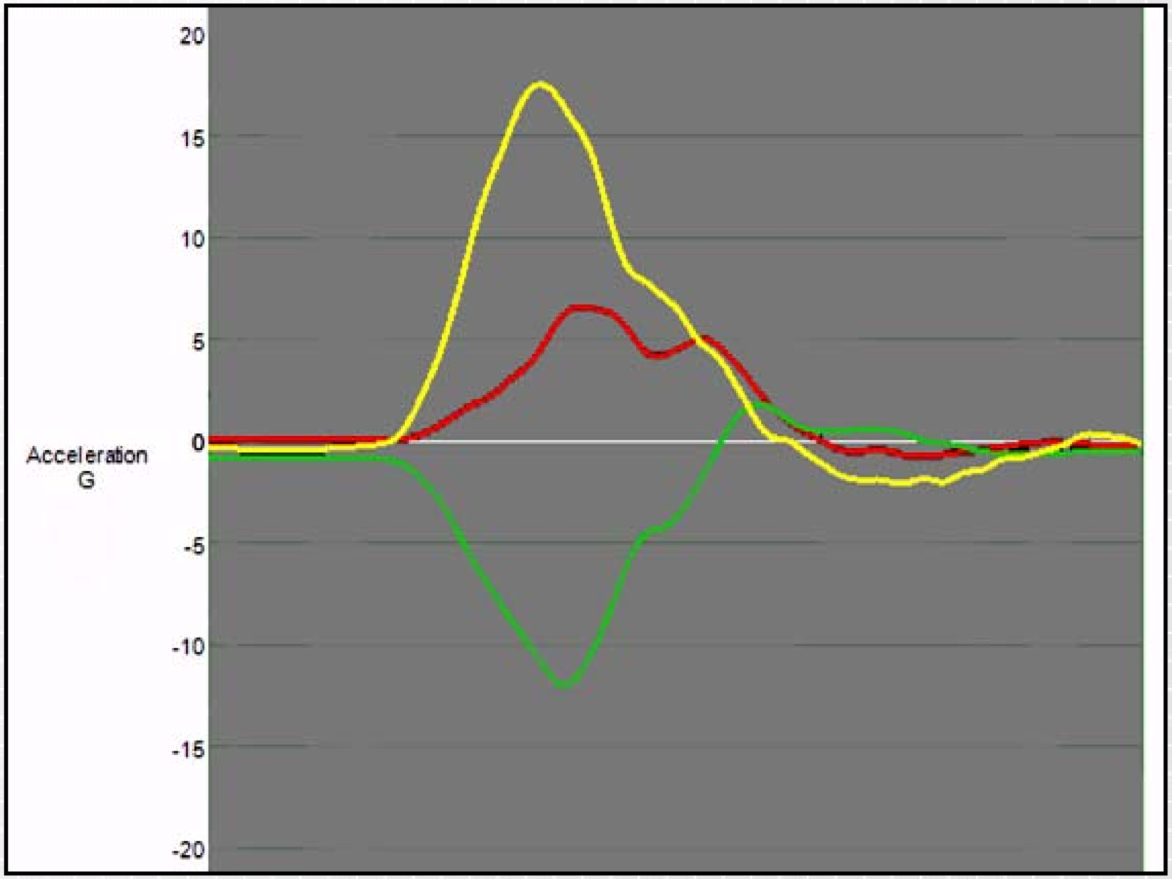
EFFDH from SHOCK PULSES and *e*

$$\text{EFFDH} = \frac{\Delta V_t^2}{(1 + e)^2 \; x \; 2g}$$

If the analysis software includes other features for determining drop height (such as a"zero-g" function, etc.), use as appropriate – either independently or in conjunction with the above

SUBJECTIVE ASPECTS

- Determining the ΔV for each axis



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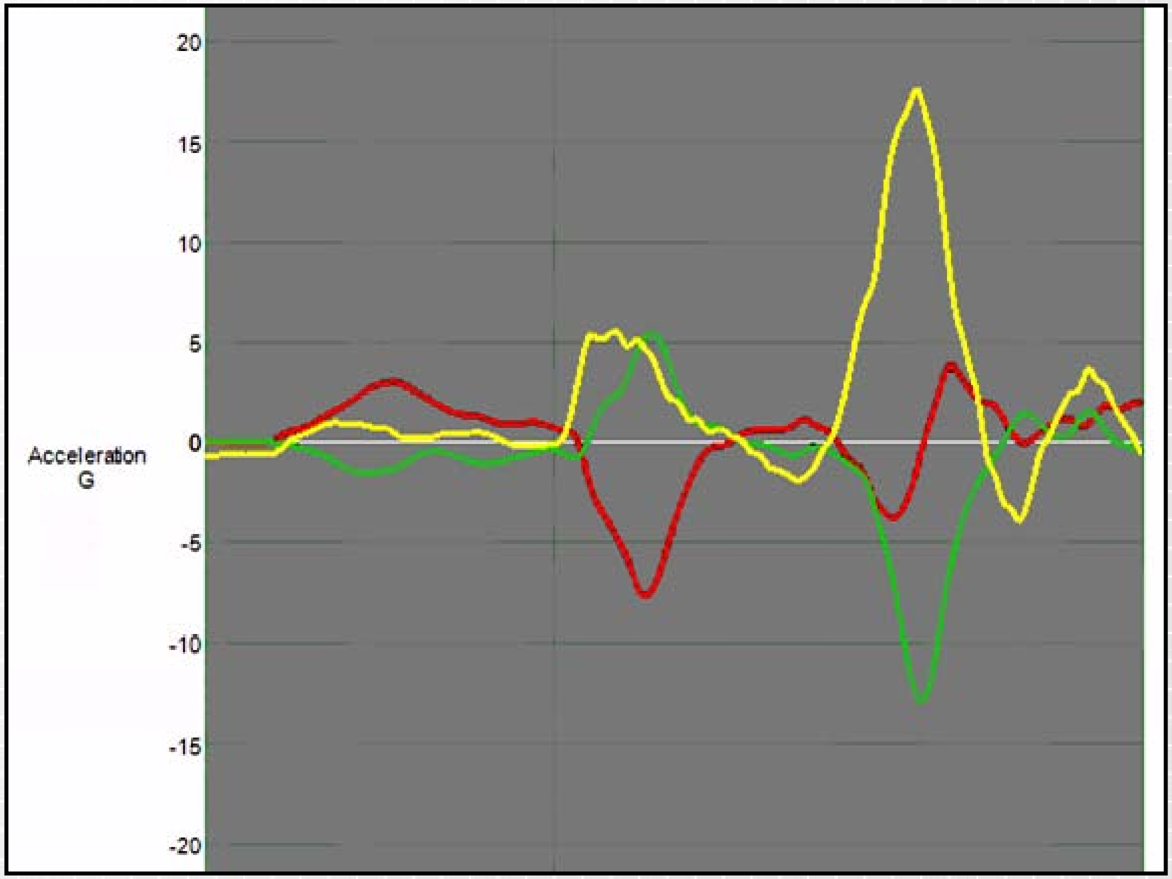

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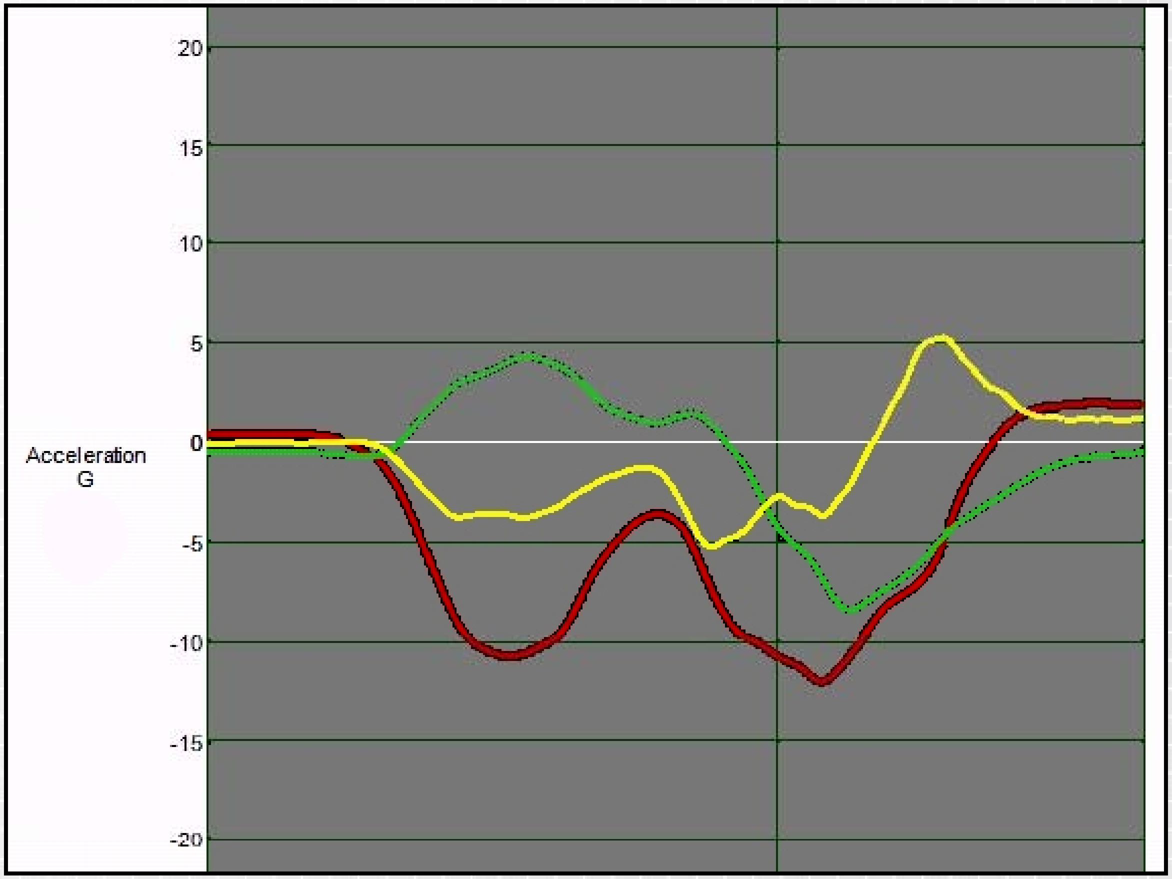

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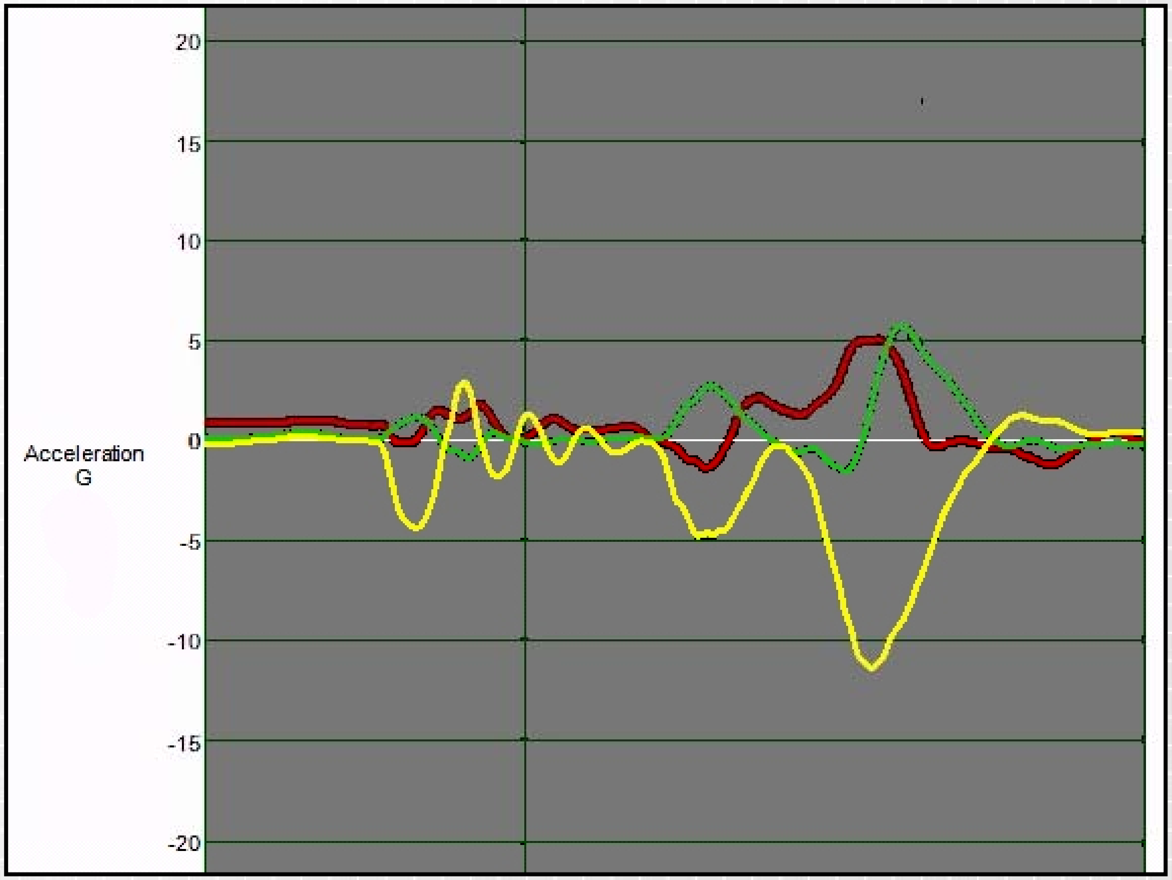

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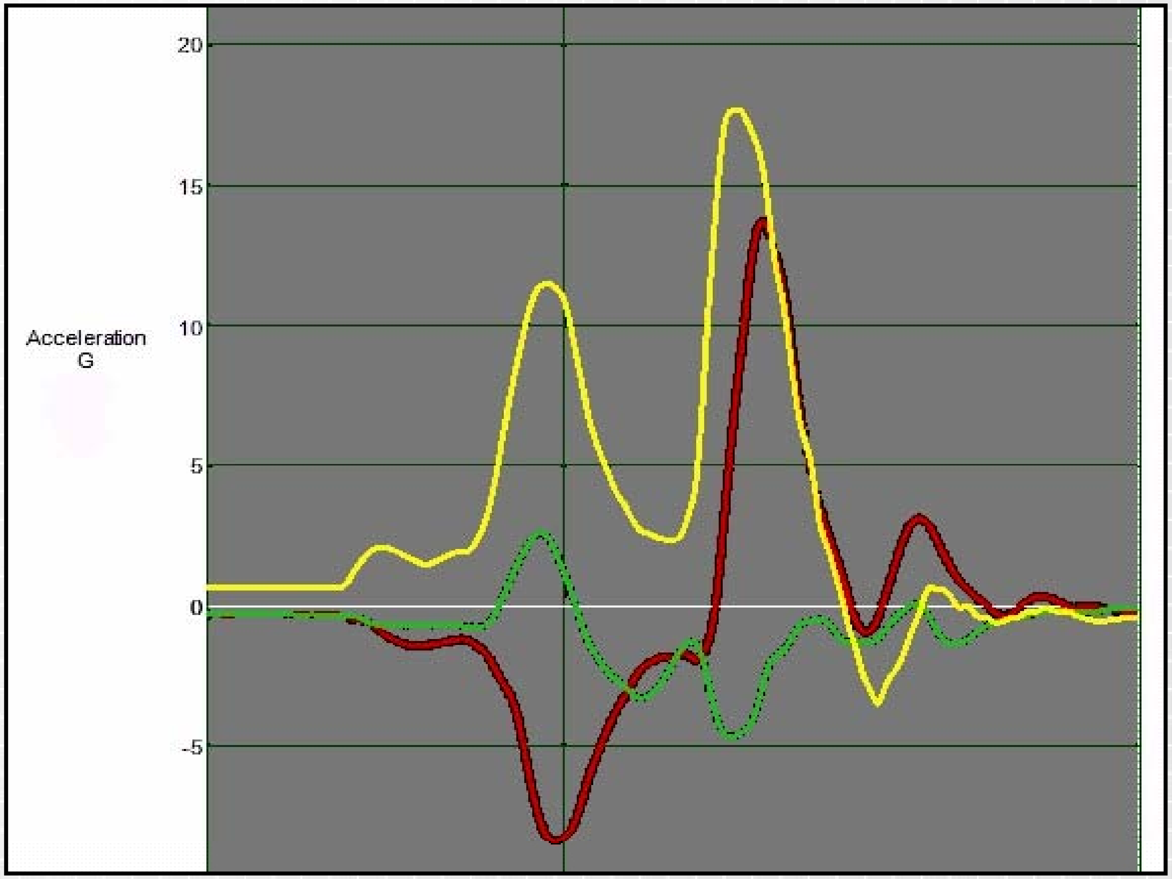


SUBJECTIVE ASPECTS

- Also…
  - Use or override automatic analyses?
  - When/if to use other analysis approaches
  - Combine strategies?
  - Modify ***e*** value based on pulse parameters?
- It sure would be nice to remove all that subjectivity…

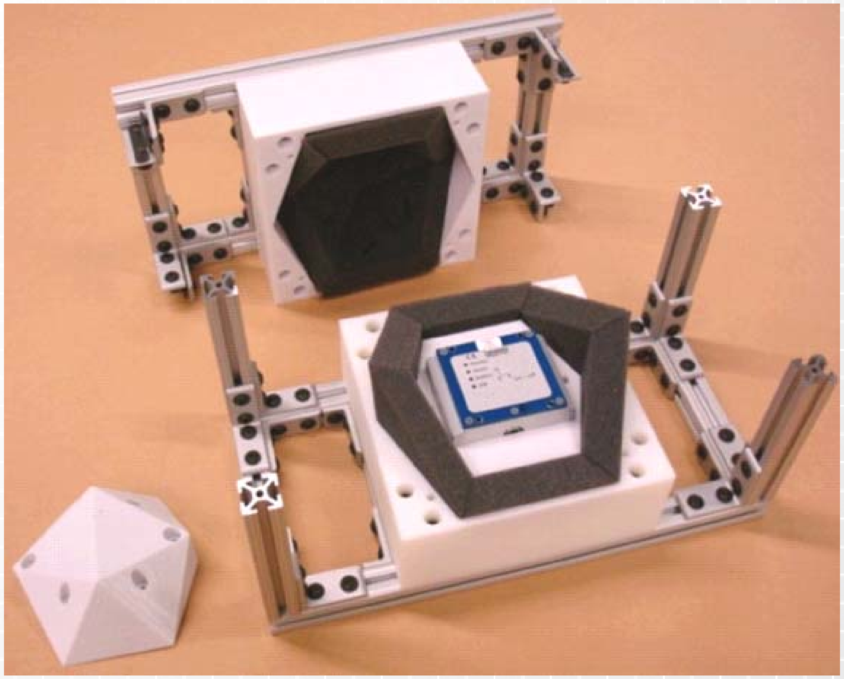
DROP – SRS APPROACH

- This methodology developed by David Leinberger and colleagues at Xerox
  - They are the only practitioners at this point
  - Potential for increased accuracy
  - Potential for removing all subjectivity
- Two parts to the approach
  - Special fixture to control the effects of impact orientation
  - Use of SRS analysis
- Reference Dave's TPF09 paper

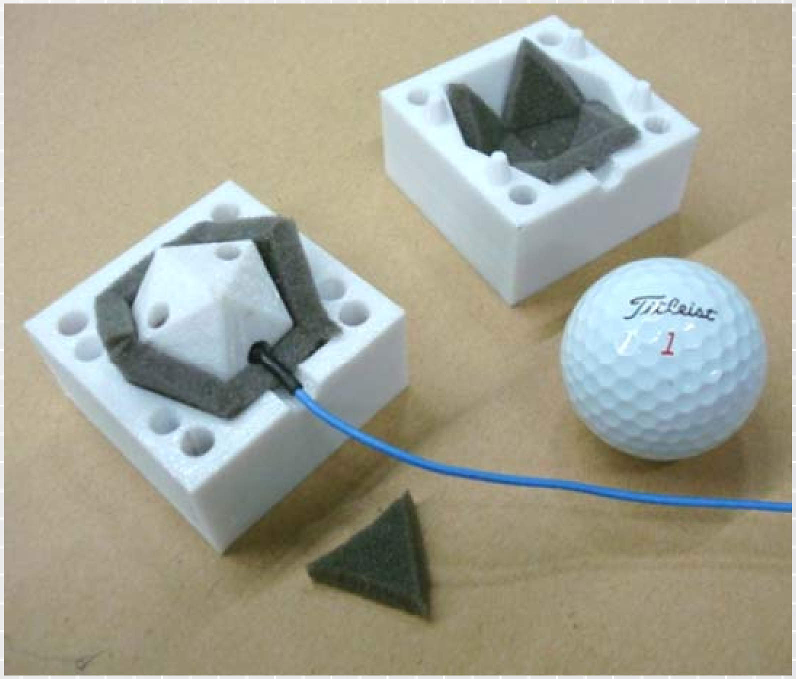
THE SPECIAL FIXTURE

- If the dummy package were a ball, impact orientation would not be an issue
- How can a ball be made into a box?
  - Rigid internal fixture with a ball inside
  - Tri-axial accelerometer in the ball
- A ball isn't practical, but the spherical shape can be adequately approximated
  - Icosahedron fixture
  - 20 equilateral triangles

THE SPECIAL FIXTURE



Icosahedron mount for recorder



Icosahedron mount for tri-axial accelerometer

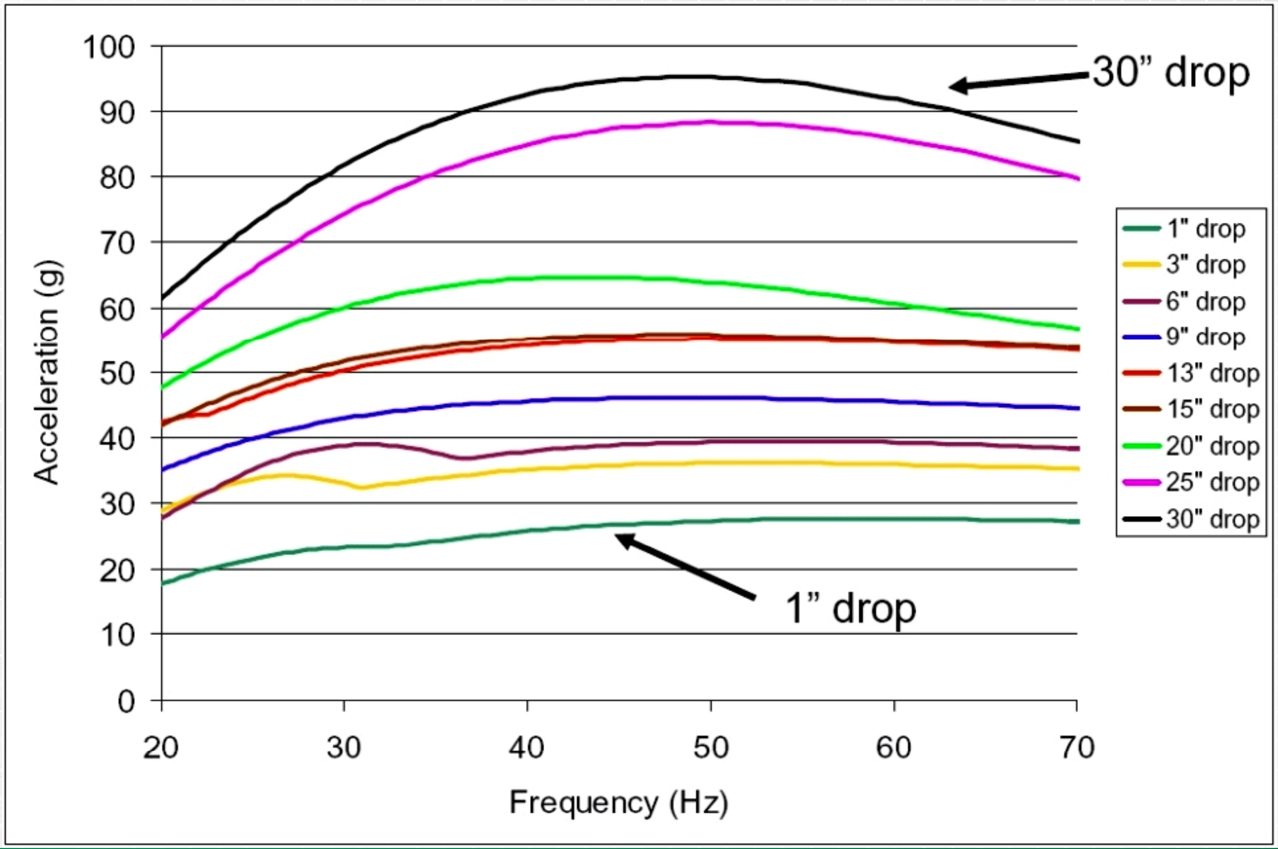
Responds like a ball within about 5%

SRS in 75 WORDS or LESS

SRS analysis calculates the responses of a large number of theoretical, single-degree-of-freedom spring-mass systems to a given shock pulse. An SRS plot is a graph of the absolute value of the peak response accelerations of each spring-mass system, plotted at their various natural frequencies. Thus SRS provides an estimate of the response of an idealized item and its components to a given input shock pulse.

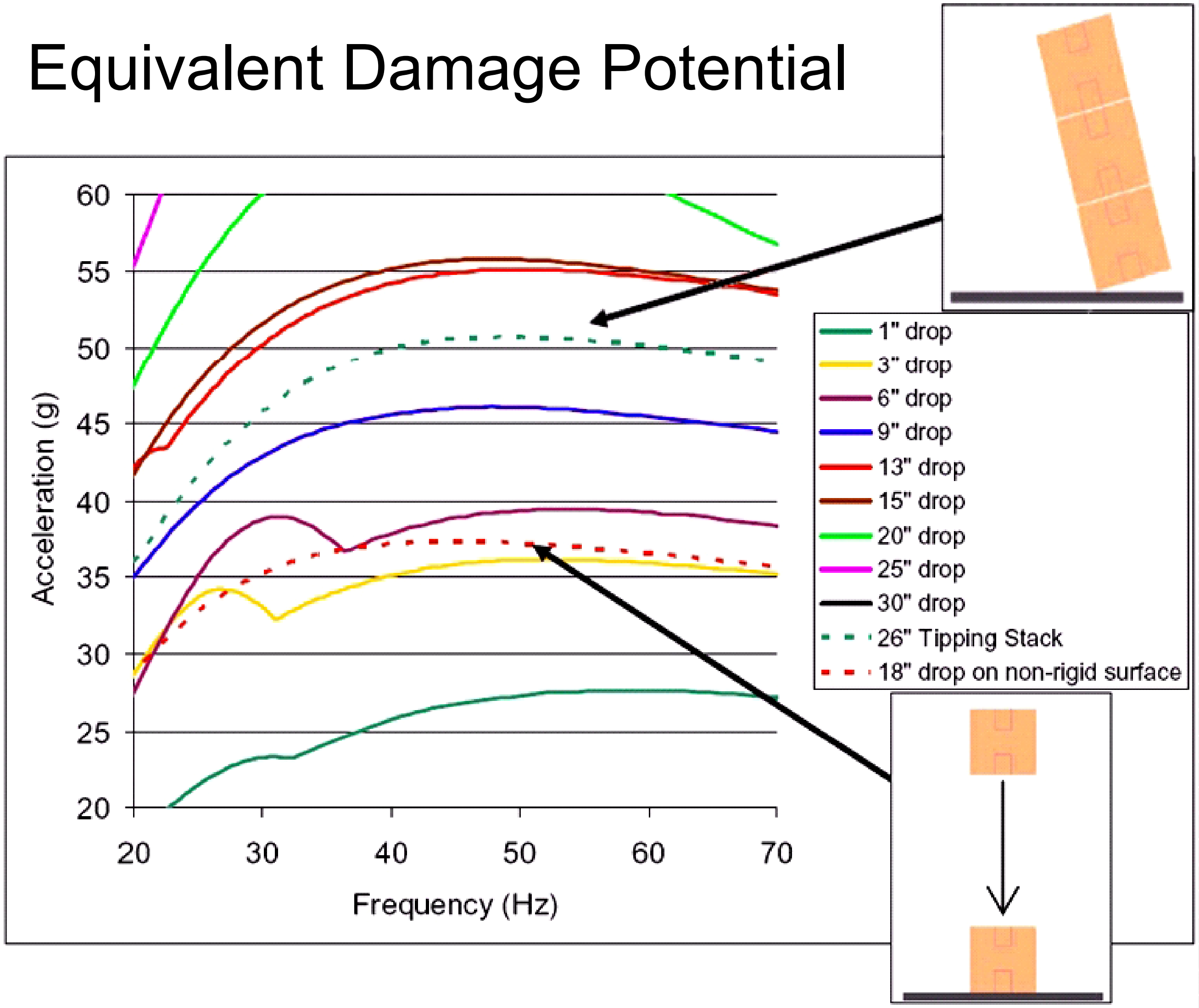
CREATION OF AN SRS LIBRARY

- Laboratory free-fall drops of the dummy package
- Convert data to SRS



FIELD SHOCKS COMPARED TO SRS

- Equivalent Damage Potential



PRACTICAL IMPLEMENTATION

- The SRSs to be compared must be from an "axis of impact resultant" calculation
  - As if there were a *single* accelerometer, accurately aligned with the axis of impact
  - Not "vector resultant" (square root of the sum of the squares)
  - Currently not a standard software feature
- But once an "axis of impact" shock pulse is obtained, (almost) all subjectivity is removed from the analysis
  - Compute the SRS, compare to library

STATISTICAL ANALYSIS

- How to create a meaningful laboratory drop test sequence from EFFDH or Equivalent Damage Potential data?
  - Must have a sufficient quantity of data
  - Analyze *one-way* shipments
- Quantify all significant events for each trip
  - Number per trip
  - Identify few highest (typically 3-5 highest)

THE "SHEEHAN METHOD"

- First postulated by Dick Sheehan of 3M in 2001
- Consists of fitting all the Nth-highest drops from each trip to statistical distributions
  - Highest drops
  - Second-highest drops
  - Third-highest drops
  - Etc.
- Then analyze the *distributions*, not the individual data points
  - This resolves issues with individual data points and outliers

THE "SHEEHAN METHOD"

- Best-fit distributions are most often log-normal or Weibull (skewed distributions)
  - Distribution type is not critical as long as there is a good fit
- Statistical software experience
  - XLStat
  - EasyFit
  - Minitab (Sheehan's choice)
- Use the 95th-percentile levels
  - Sheehan's recommendation

THE “SHEEHAN METHOD”

- Apply the same approach to determine the number of drops per trip
- The result is a simple tabulation of number of drops and drop heights

95th Percentile Statistics	
Number of Drops per trip	18
Highest EFFDH per trip	34 inches
2nd Highest EFFDH per trip	26 inches
3rd Highest EFFDH per trip	22.5 inches
4th Highest EFFDH per trip	20 inches

From Ref. 3

IMPACT ORIENTATIONS

- Calculate impact orientation percentages
  - Faces, edges, corners
  - On and around the bottom and top, vertical faces, and vertical edges

Impact Orientations	
Faces	21%
Edges	49%
Corners	30%
o/a Bottom	60%
o/a Top	19%
Vertical Faces	9%
Vertical Edges	12%

From Ref. 3

ILLUSTRATION of DROP TEST SEQUENCE

From Ref. 3

Drop Ht.	Drop Numbers and Orientations
34 inches	1 Flat Base
	2 Base Edges
23 inches	3 Base Edges
	3 Base Corners
	2 Top Corners
	2 Top Edges
	1 Flat Top
	2 Flat Vertical Faces
	2 Vertical Edges