What is “Packaging Dynamics”? 

- The term “dynamics” implies motion
- “Package motion” or “package movement” is generally related to:
  - manual handling (drops)
  - mechanical handling (impacts)
  - transportation (vibration)
  - stacking (compression)
History

- Pre 1950’s: Trial & Error
- Cold War & the Polaris Missile Program
- Adm. Rickover’s nuclear navy & Mil Specs
- Firestone Engineering Labs
  - Research Inc.
  - MRL
  - Mil Specs
  - MSU School of Packaging
  - MTS-Monterey
  - Lansmont
  - Damage Boundary
  - Five Step Procedure
  - 6-Step
  - Optimized Protective Packaging
History
History
History

Adm. Hyman Rickover
History
History

Mechanical Shock Test Machine
History
History

Front Cover of
The original Newton
Paper sponsored by
Monterey Research
Laboratories
History

• The “cookbook”....
• ASTM D3332 – Damage Boundary Test Method
• 5-Step Procedure for Protective Design & Testing
• 6-Step Procedure for Protective Design & Testing
Packaging Schools now at:

- Mich. State University
- Rochester Institute of Technology (RIT)
- Clemson State University
- Rutgers University
- Stout State University
- San Jose State University
- California Polytechnic University
- Florida State University
Today……

- The process for “Optimized Protective Packaging” works well
- About eight universities teaching this in the U.S.
- OPP is being incorporated into the “Supply Chain” concept to optimize the entire cost of “Quality Delivered”
- Today’s Global Economy demands this type of approach
- Those who incorporate this concept will likely succeed, those who don’t, won’t…..
- It all starts with OPP and a good knowledge of PACKAGING DYNAMICS!!
Overview

Vibration
- Frequency
- Random
- Sinusoidal
- Resonance

Shock and Drops
- Acceleration
- Equivalent Freefall Drop Height

Compression
- Peak Force
- Deflection
• **Single Degree of Freedom (SDOF) spring mass system**

  - **Mass**: Mass of spring mass system
  - **Damping**: Makes the spring mass system stop moving (desirable)
  - **Spring**: Causes the spring mass system to return to its natural position
  - **Cushion**: Damping + Spring
  - **Unyielding Surface**: Vibration table, vehicle exerting vibration, shock table, and drop impact surfaces
• We live in the time domain
• Everything we experience is with relationship to TIME
• We are used to seeing equations, graphs, and data in the time domain
  – Miles / hour
  – TIME it takes for an event
  – Shock pulse DURATION
  – Cycles per SECOND
Shock (mechanical) Terminology

- **Shock** = a sudden non-periodic excitation of a mass characterized by:
  - A sharp rise in acceleration
  - Followed by a decay (deceleration)
  - Over a discrete time period
  - Often described as a “PULSE” (defined shape)
Shock (mechanical) Terminology

Amplitude is typically in G’s

$V_{\text{peak}} = \text{Max acceleration}$

$t_r = \text{rise time}$

$t_f = \text{decay time}$

$t_d = \text{pulse duration}$

$t_d + t_{\text{sag}} = \text{period}$

Half sine  Trapezoid  Sawtooth
Shock (mechanical) Terminology

• **MASS**: A physical property indicating the acceleration resulting from a given force.
  - \( F = MA \) (Newton’s second law); Therefore \( M = F/A \)

• **STRAIN**: Deformation per unit length.

• **STRESS**: Force per unit length.

Importance: Pkg Dynamics involves the study of Spring/Mass Systems. Per the above, a “mass” involves a force in some defined acceleration environment, in our case, this is the acceleration due to gravity.

A “spring” is anything that displays a strain (deformation) when subjected to a stress.
DISPLACEMENT:
A vector quantity describing the change of position of a body and usually measured from a position of rest. Units: in, mm, m, etc. It is the integral of velocity.

VELOCITY:
A vector quantity describing the time rate of change of displacement of a body in relation to a fixed reference point. Units: in/s, m/s, etc. It is the differential of displacement with respect to time (how fast displacement changes) and the integral of acceleration.
ACCELERATION:

- A vector quantity describing the time rate of change of velocity of a body in relation to a fixed reference point.
- It is usually expressed in G's which are multiples of the gravitational constant.
- Units: in/s/s, G’s (multiples of Earth’s gravitational constant = g = 386.4 in/s²), m/s/s (m/s²)
- It is the differential of velocity with respect to time (how fast velocity changes)
Typical Shock / Drop Pulse

![Graph showing typical shock and drop pulse with axes labeled: Duration (d) on the x-axis, Deceleration (G's) on the y-axis, and Velocity Change (ΔV) as shaded area. The graph has a peak deceleration of 50 G's and shows the relationship between duration and deceleration over time.]
Vibration Terminology

The oscillation of an element of a mechanical system about a fixed reference point.
Vibration

• Unavoidable – Always occurs in the distribution environment
  – Vehicle input
  – Continuous event
  – Fatigue damage

• Two types
  – Random
  – Sinusoidal (Sine)
Vibration Types

Sinusoidal Vibration
- Laboratory Environment
- Excites one frequency at a time
- Usually for product and reliability testing

Random Vibration
- Real World Environment
- Excites all frequencies at a time
- Usually for packaged and distribution testing
Sinusoidal Vibration Parts

- **Period (p) or Cycle**: $2d = p$
- **Duration (d)**
- **Amplitude**: $1/f = p$ & $1/p = f$

Graph showing amplitude, duration, and period with corresponding equations.
Frequency (Vibration)

• An expression of the number of times that a repeated event occurs per second. This is often described in cycles per second or “Hertz” abbreviate Hz.
  – With relationship to vibration
    • 1 cycle is 1 up and down motion
  – Examples:
    • 1 Hz means 1 cycles per second
    • 100 Hz means 100 cycles per second
      – Each cycle has a duration of 1/100 sec
Spectrum (Vibration)

• Definition
  – A frequency domain representation of a time domain event
  – Inverse of the time domain

• All lab vibration data is viewed using a spectrum for vibration
QUESTIONS??
• Single Degree of Freedom (SDOF) spring mass system with *Measured Response and Controlled Input*

- **R** Measured Response of the spring mass system.
- **I** Control input of either the shock table or vibration table
Inputs and Response Measurements

SHOCK INPUT

CUSHIONED PRODUCT RESPONSE

G's

TIME
Shock Input and Response
Shock Input and Response
Shock Input and Response
Shock Input and Response
Shock Input and Response
Vibration Amplification (Q)

• The unit-less ratio of response with relationship to input that is calculated during vibration.
  – May represent: Displacement, acceleration, velocities

\[ Q = \frac{R}{I} \]

- \( Q \) = Amplification
- \( R \) = Response
- \( I \) = Input
Resonant (Natural) Frequency

• The frequency at which a spring-mass system displays its maximum amplification (and response)
• A graph depicting the dimensionless ratio of response amplitude of a system with relationship to the input amplitude
Transmissibility Plot

1:1 Coupling
- Response = Input
- Q = 1

Amplification
- Response > Input
- Q > 1
- Damage occurs

Attenuation
- Response < Input
- Q < 1
- Vibration protection
Drop Terminology

A single *uncontrolled* collision of one mass with a second mass
Recall that:

VELOCITY CHANGE ($\Delta V$):

- The difference in system velocity magnitude and direction from the start to the end of a shock pulse.
- The magnitude may be determined from the integral of the acceleration versus time signature.
- May be “conceptualized” as the momentum dissipated during the shock event.
- The integral of the acceleration vs time waveform
- Equals $(1+e) (2gh)^{1/2}$ where:
  
  $e = V_r/V_i$, $g =$ acceleration of gravity, $h =$ freefall drop height
This means that we can determine an equivalent drop height associated with a shock pulse (waveform) IF we can estimate “e”, coef of restitution.

We know that: \( \Delta V = V_i - (-V_r) = V_i + V_r = (1+e) (2gh)^{1/2} \)

Solving for drop height: \( h = (\Delta V)^2 / (2g) (1+e)^2 \)

We also know that: \( 0 \leq e \leq 1 \) [Often (e = 0.5) is used as an estimate]

So, the effective freefall drop height (EFFDH) can be estimated from the velocity change of a shock pulse and an estimate of e.
Our Friend “Velocity Change”

**Practical Example:**

48G, 9 ms half sine pulse:

\[
\text{EFFDH} = (\Delta V) = (1+e) (2gh)^{1/2}
\]

\[
(\Delta V) = (A_p) (T_e) = (G) (g) (\text{dur}) (\text{factor}) = (48G's) (386.4 \text{ in/s}^2) (.009 \text{ s}) (2/\pi) = 106 \text{ in/s}
\]

Therefore: \[h = (\Delta V)^2 / (2g) (1+e)^2\]

\[= (106 \text{ in/s})^2 / (772 \text{ in/s}^2)(1.5)^2 = 6.5 \text{ inches}\]
Compression Terminology

The ability of a material or structure to withstand loads tending to reduce size. It is usually measured by plotting applied force against deformation in a testing machine.
Dynamic Compression (with Vibration)
Static Compression Graph Parts

- Peak Force (lbs)
- Deflection

Graph: Force (Lbs) on the y-axis and Deflection on the x-axis.
QUESTIONS??
Packaging Dynamics Webinar Series

#1: Overview and Definition of Terms – Jan 2015

#2: Defining & Quantifying the Distribution Environment Through Which All Products Must Travel – March 2015

#3: Determining the Vibration Sensitivity & Shock Fragility of Products; Test Methods, End Results, and Significant Insights – May 2015


#5: Design and Testing of the Protective Package System; How We Know When the Job Was Done Correctly– Oct 2015
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