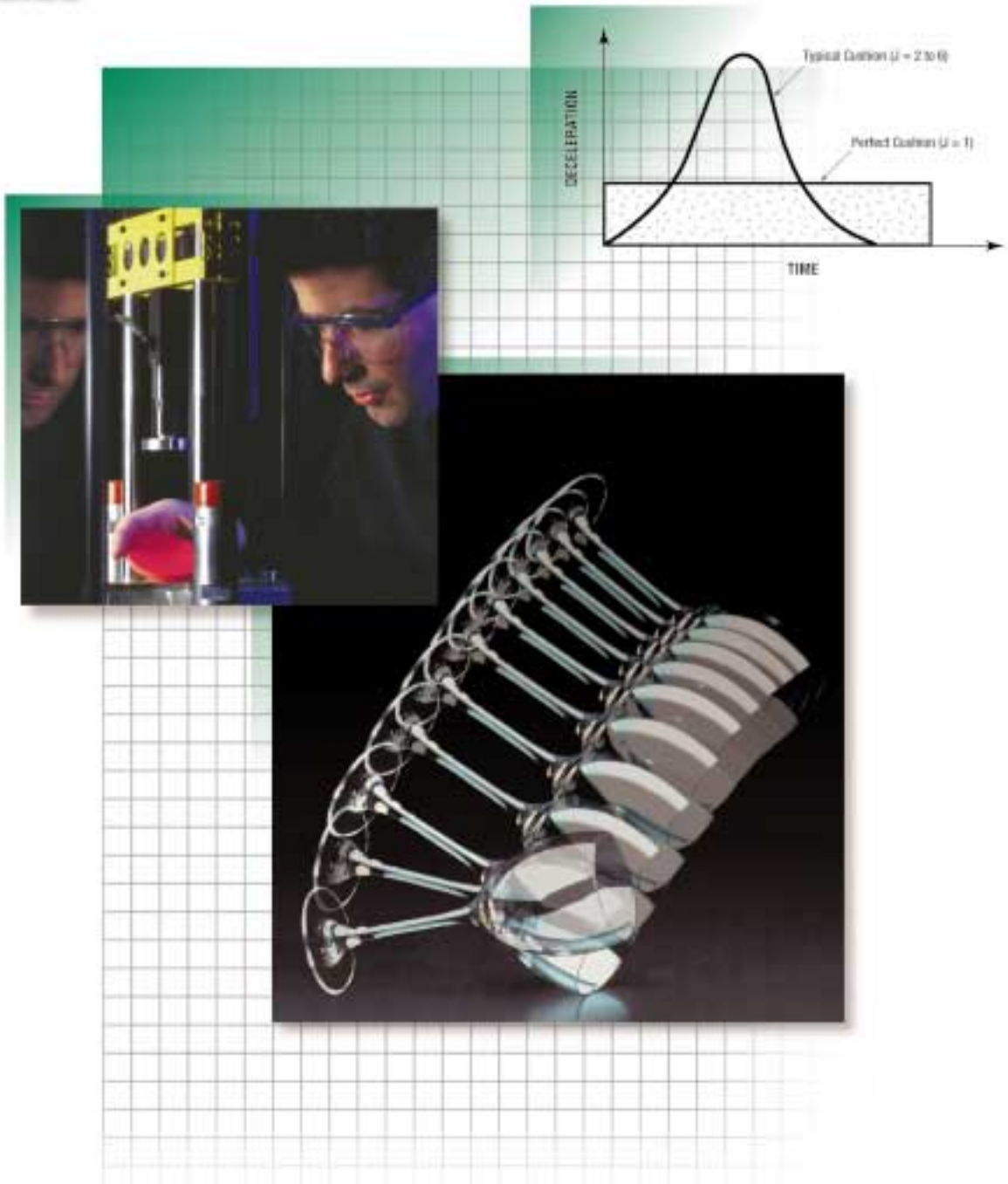




**PORON®** Urethane Foams

# Shock Control

## Design Guide



# Shock Control with PORON® Urethane Foams

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# Shock Control

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Durability is a key quality characteristic in a wide range of manufactured goods, from consumer electronics and appliances to portable computers and telecommunications devices. High quality products are often differentiated by consistent and durable performance.

Shock resistance is an important aspect of durability for any portable product that might

be dropped, or for any product that might otherwise receive an impact during shipping or in end use. Shock resistance is imparted by strong, lightweight materials, rugged mechanical joints and electrical connections, and well-designed cushions. Effective methods for selecting and sizing cushions from PORON® cellular urethanes are outlined in this design guide.

# FRAGILITY

**Properly engineered cushions enable a product to survive a drop from a specified height.**

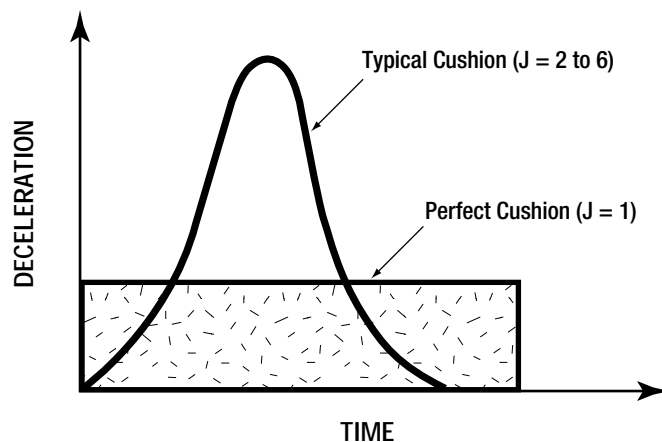
While an object falls, it accelerates under the influence of gravity. The earth's gravitational pull exerts a force which we call its weight, causing the object's downward velocity to accelerate at  $386 \text{ in/sec}^2$ , or 1 g. When the object strikes the ground, it abruptly decelerates. Instrumented drop weight impact testing is widely used to measure deceleration versus time during impact; a typical result is shown in **Figure 1**. A 1 lb portable radio transceiver, for example, may experience a peak force of 100 lb, corresponding to a peak deceleration of 100 g.

Fragility is a measure of the maximum deceleration a product can withstand without failing. Failure can result from breakage or excessive plastic deformation in highly stressed solder joints and fastening points. Fragilities of 50-200 g are common in consumer electronics and telecommunications products, but product fragilities vary widely. Fragility is measured by techniques including ASTM D-3331 impact testing and ASTM D-3332 shock machine testing.

**Product fragility determines the cushion thickness required to protect it from a given impact load.**

To understand why, consider a hypothetical "perfect shock absorber". In free fall from a height H, an object will land with an impact velocity v of  $(2gH)^{1/2}$ . An object dropped from a height H onto a "perfect shock absorber" of thickness T would come to rest after traveling the distance T decelerating uniformly at  $H/T$  g.

**Figure 1. Impact Testing and the "Perfect Shock Absorber"**



**The area under a deceleration-time curve equals the impact velocity.**

Thus, the “perfect shock absorber” minimizes peak deceleration by providing a constant deceleration over the maximum possible time, as shown in **Figure 1**. When fragility  $F$  is known and drop height  $H$  is specified, the minimum theoretical cushion thickness is provided by a “perfect shock absorber” of thickness

$T_{\min} = Hg/F$ . The actual cushion thickness required will always be greater than  $T_{\min}$ , typically by a factor of 2 to 6. **A cushion thickness of  $4Hg/F$  is often recommended as a starting point in design.** When impact velocity is specified rather than drop height, the equivalent free fall drop height ( $H = v^2/2g$ ) is used, and an initial cushion thickness of  $2v^2/F$  is often recommended.

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## SHOCK ENERGY

While product fragility  $F$  controls cushion thickness, shock energy  $E$  is the key to material selection. When the anticipated shock results from a free fall onto a rigid surface, shock energy is simply the product of weight  $W$  and drop height  $H$ :  $E = WH$ . When the anticipated shock is not from a free fall, impact energy is calculated from other methods. For example, a moving projectile of mass  $m$  and

velocity  $v$  has kinetic energy  $E = mv^2/2$ , and a rotating mechanism has kinetic energy  $E = I\omega^2/2$ , where  $I$  is its mass moment of inertia and  $\omega$  its angular velocity.

Once the anticipated shock energy is known, material firmness and bearing area can be chosen for optimal cushion performance, based on the method given below.

# MATERIAL PROPERTY DATA

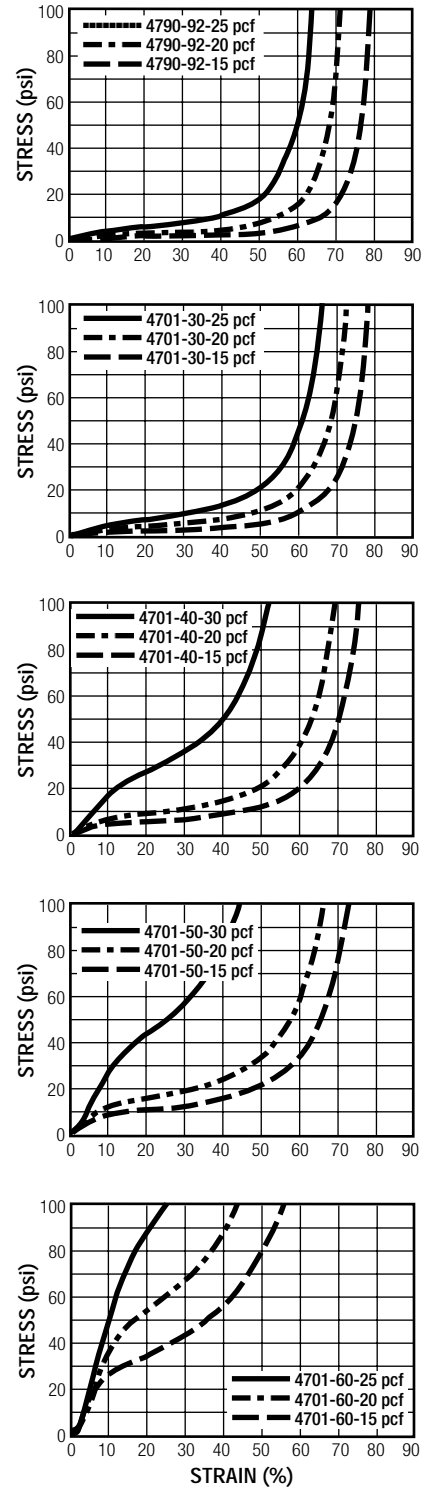
**Cushion materials are selected by matching the firmness of the material to the size of the shock.**

Small shocks are absorbed most gently by soft cushions, while high energy shocks require firm cushions.

Several measures of material firmness are available, including compressive stress-strain ( $\sigma$ - $\epsilon$ ) and indentation hardness data. Typical  $\sigma$ - $\epsilon$  curves, also called compression force deflection (CFD) curves, are given for the Industrial PORON materials in **Figure 2**. A single point from each of these curves, the compression force at 25 percent deflection, is typically cited in PORON material specifications. Indentation hardness is related to CFD; the correlation between these two measures of cushion material firmness is shown in **Figure 3**.

**Figure 2. Typical Compression Force Deflection Curves for PORON® Urethanes**

PORON cellular urethanes are available in a range of densities (15, 20, 25, and 30 lb/ft<sup>3</sup>) and a range of firmnesses.



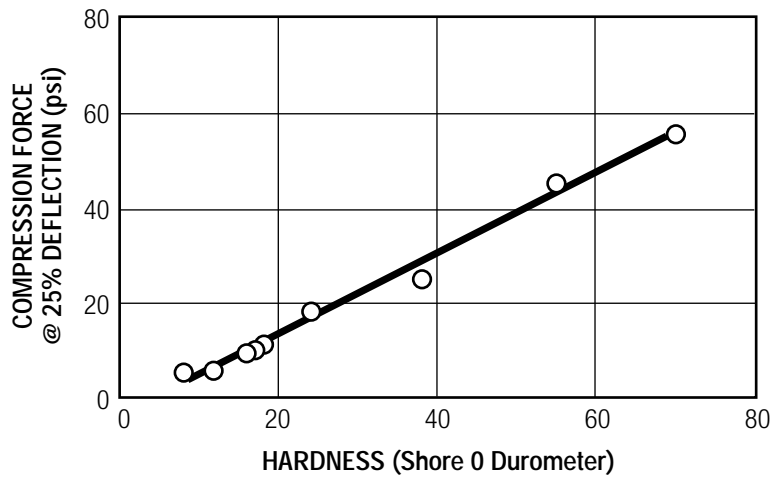
Note: CFD strain rate is 1in/min.

**The area under the CFD curve is a measure of the energy per unit volume stored during compression.**

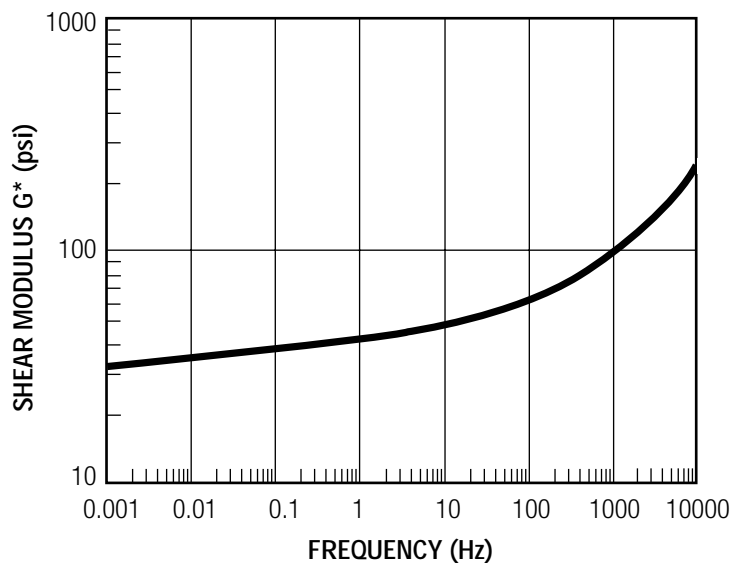
In one traditional design method, this area is matched to the impact energy to be absorbed. This method is suitable for designing a shock absorber based on a steel spring, whose force deflection

curve is linear and elastic (insensitive to strain rate). PORON cellular urethanes exhibit nonlinear  $\sigma$ - $\epsilon$  curves which depend on strain rate. The variation of firmness with strain rate depends on the chemical structure of each elastomer. A typical example is given in **Figure 4**, which shows the shear modulus  $G^*$  as a function of frequency for PORON 4701-40-20.

**Figure 3. PORON® Cellular Urethane - Compression Force Deflection vs. Indentation Hardness**



**Figure 4. Typical Rate - Dependence of Firmness**  
 PORON® 4701-40-20  
 at 23°C



# IMPACT PERFORMANCE DATA

**Cushion materials are selected by matching the firmness of the material to the size of the shock.**

Because PORON materials are both nonlinear and viscoelastic, accurate theoretical design calculations from CFD data are difficult to obtain. Empirical design curves have proven very useful for matching material firmness to shock size.

Empirical design curves have been developed based on laboratory drop weight impact testing. In this testing, a weight  $W$  is dropped from a height  $H$  onto a cushion of thickness  $T$ . The falling weight typically has a flat face which impacts the cushion over a known area  $A$ . During impact, deceleration is recorded versus time, from which the peak deceleration  $P$  is reported. Impact performance can thus be characterized as a function of four design variables:

$$P = f(W, H, A, T) \quad (1)$$

Material characterization is simplified by the fact that these four variables are not independent. It is widely recognized that drop weight and impact area affect impact performance only through the ratio  $W/A$ , commonly called static stress:

$$P = f(W/A, H, T) \quad (2)$$

Cushion material characterization is further simplified to two independent variables, thanks to an insight published over thirty years ago<sup>1</sup>:

$$PT/H = f(WH/AT, \sqrt{H/T}) \quad (3)$$

Remember that the ratio  $H/T$  is the minimum possible peak deceleration provided by a theoretical "perfect shock absorber". Thus, the dependent variable  $PT/H$  is a normalized peak deceleration. The dimensionless ratio  $PT/H$  is often abbreviated as  $J$ <sup>1</sup>. When  $J = 1$ ,  $P = H/T$ ;  $J = 1$  describes the performance of the theoretical "perfect shock absorber".

$WH$  is the kinetic energy of the shock, and  $AT$  is the volume of cushion material absorbing the shock. Thus, *the independent variable  $WH/AT$  is the energy per unit volume the cushion must absorb*. This impact energy density is often abbreviated as  $U$ .

<sup>1</sup> This method is cited by W.G. Soper and R.C. Dove in "Similitude in Package Cushioning", *Journal of Applied Mechanics*, June, 1962, pp 263-266.

Since  $\sqrt{H}$  is proportional to impact velocity, the second independent variable in equation 3 is proportional to a compressive strain rate  $d\varepsilon/dt$ . Equation (3) can thus be simplified to:

$$J = f(U, d\varepsilon/dt) \quad (4)$$

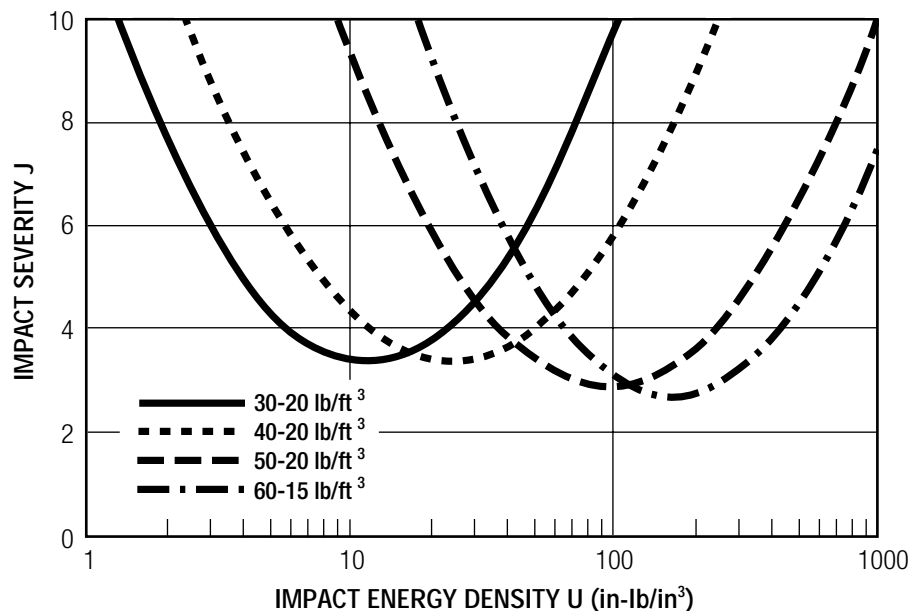
The impact performance of PORON materials does depend on strain rate, but this dependence is relatively weak, and can be overlooked for many practical design calculations. The rate-dependence of PORON 4701-40 is illustrated in **Figure 4** over seven orders of magnitude in test frequency. The majority of impact tests and cushion applications involve strain rates

within one order of magnitude:  $100 < d\varepsilon/dt < 1000/\text{sec}$ . By neglecting the effect of strain rate, a cushion material can be completely characterized by a single "J curve":

$$J = f(U) \quad (5)$$

J curves, also called cushioning efficiency curves, are given for a range of PORON materials in **Figure 5**. These curves are well suited to material selection because they clearly show each material's effective energy density range.

**Figure 5. PORON® Urethane - Impact Performance J-Curves**



# DESIGN METHOD

The concepts and data summarized in this design guide are used to design a wide range of protective cushions. A step-by-step method is outlined below:

**STEP 1.**  
Determine product fragility  $F$

**STEP 2.**  
Select cushion thickness  $T$

- If free fall drop height  $H$  is known:  $T = 4Hg/F$
- If impact velocity  $v$  is known:  $T = 2v^2/F$

**STEP 3.**  
Estimate shock energy  $E$

- In free fall:  $E = WH$
- For a moving object:  $E = mv^2/2$
- For a rotating object:  $E = I\omega^2/2$

**STEP 4.**  
Select material based on  $U$

- $U = E/V = WH/AT$   
Choose a material whose  $J$  curve has a minimum near this energy density  $U$ .

**STEP 5.**  
Optimize bearing area  $A$  to minimize  $J$

- Once material and thickness have been chosen, optimize  $A$  to minimize  $J$ . An example is given in **Figure 6**.

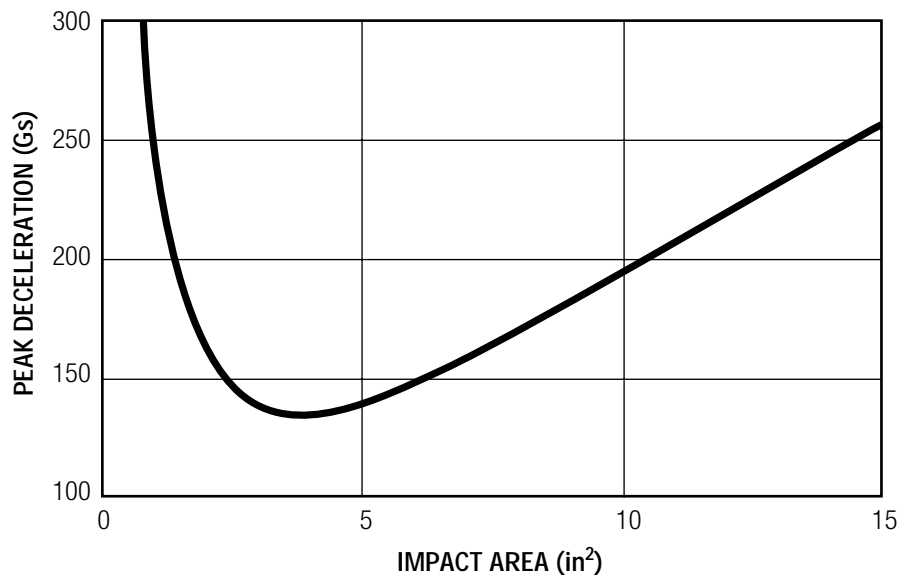
**STEP 6.**  
Estimate peak deceleration  $P$

- Read the expected  $J$  value from the  $J$  curve
- If free fall drop height  $H$  is known:  $P = JHg/T$
- If impact velocity  $v$  is known:  $P = Jv^2/2T$

The impact absorption performance of a gasket material depends on design factors and the application environment. PORON urethane foams have been used successfully in a wide range of impact protection applications.

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**Figure 6. Example of Optimizing Impact Area**



Note: Material = PORON 4701-50-15,  $W = 5$  lb,  $H = 60$  in,  $T = 1.0$  in

# NOMENCLATURE

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| <b>SYMBOL</b> | <b>DEFINITION</b>             | <b>UNITS</b>            |
|---------------|-------------------------------|-------------------------|
| A .....       | Impact Area .....             | in <sup>2</sup>         |
| E .....       | Impact Energy .....           | in-lb                   |
| f .....       | Frequency .....               | Hz                      |
| g .....       | Acceleration of Gravity ..... | 386 in/sec <sup>2</sup> |
| G* .....      | Shear Modulus .....           | psi                     |
| H .....       | Free Fall Drop Height .....   | in                      |
| I .....       | Mass Moment of Inertia .....  | in-lb-sec <sup>2</sup>  |
| J .....       | Cushioning Efficiency .....   | dimensionless           |
| m .....       | Mass .....                    | lb/g                    |
| P .....       | Peak Deceleration .....       | g's                     |
| T .....       | Cushion Thickness .....       | in                      |
| U .....       | Impact Energy Density .....   | in-lb/in <sup>3</sup>   |
| v .....       | Impact Velocity .....         | in/sec                  |
| V .....       | Cushion Volume .....          | in <sup>3</sup>         |
| W .....       | Weight .....                  | lb                      |
| σ .....       | Stress .....                  | psi                     |
| ε .....       | Strain .....                  | dimensionless           |
| dε/dt .....   | Strain Rate .....             | /sec                    |
| ω .....       | Angular Velocity .....        | rad/sec                 |



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