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PadCAD

Cushion Design Software

English-French Version



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PadCAD User Manual

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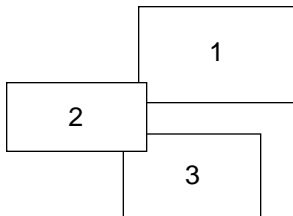
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1. Installation of *The Bard (Music)*, a work by Emanuel Hahn.
Photo: National Gallery of Canada.
2. High-density polyethylene shipping container.
Photo: CCI.
3. Experienced handlers load a truck at Exhibit Transportation Services.
Photo: CCI.

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1. Introduction

PadCAD Version 3.0 software simplifies the design of protective cushioning systems for fragile objects by eliminating the need to interpret numerous graphs and perform repetitive calculations. The software is easy to use and incorporates an extensive database of shock and vibration performance data for 20 different cushioning materials [1]. The shock isolation data have been obtained from dynamic cushioning curves and are presented in an equation form that enables users to specify performance requirements to within a few G's of acceleration [2]. The equations also preserve the static load ranges of the original curves, so the cushion material recommendations are not prone to compressive creep due to overload conditions.

PadCAD avoids the complexity of traditional three-dimensional CAD software by using pre-defined designs, with dimensions and surfaces described in common terms. Ten pre-defined cushion geometries are available, and most of them require only a single coverage parameter (linear dimension) as the basis for the entire cushion design; even the initial value for this parameter can be generated by the software using an estimate feature. Two additional geometry options provide added flexibility for specifying protective cushion coverage and layout.

PadCAD provides context-sensitive information to guide the user while entering the various design parameters, and gives warnings for unsuitable values. Should problems occur with cushion geometry, impact of surface projections against inner container surfaces, shock amplification in flexible components, or resonance effects, red text for the affected values will alert the user; printed results retain these warnings by enclosing the relevant text items inside squares.

In addition to cushion design and performance predictions, PadCAD provides a detailed cut list for the individual components of the cushioning system, and calculates the total cushioning material requirement for the design. All of this information appears on a single Results screen that can be printed, taken to the shop, or retained for future reference. The Results screen also includes all of the design parameters, total package weight, hazard predictions, and thermal half time.

PadCAD, like the cushion curves on which it is based, is a predictive design tool. Cushion data contained in PadCAD originate from industrial test methods employing rigid fixtures and flat drops onto square foam samples [3]. Because the contribution of an external container (i.e. energy lost when an external container deforms on striking a hard surface) is not accounted for in this test procedure, actual packages may perform better than predicted, especially for edge or corner drops. On the other hand, if binding of the object in the cushioning system occurs or if a design incorporates tall, narrow cushions that are prone to buckling, actual cushion

performance could be much less than predicted. Therefore, although PadCAD can assist in the development of a successful package design, it is advisable to verify the performance of the packaging system if possible. If elaborate test facilities and equipment are not available, simple tests with simulated contents and inexpensive shock indicators can help provide a basic indication of whether or not the required performance objectives have been met.

A brief overview of packaging basics and tips can be found in Appendices A and B.

2. System Requirements

The following configuration will enable PadCAD to operate with reasonable speed and good rendition of its graphic information.

- PC 486/66 or higher
- Microsoft Windows 3.1 or higher
- 3.5-in floppy disk drive
- 8 MB RAM
- 15 MB hard disk space
- 800 x 600, 24-bit colour display
- mouse or pointing device

3. Installation

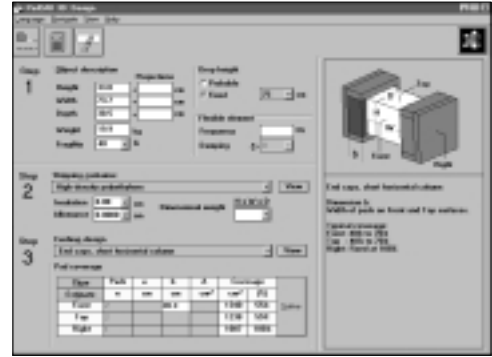
To install PadCAD on your computer:

- locate the setup disk (Disk 1) and insert it in drive A
- choose Run (from the File menu in Windows 3.1, or from the Start menu in Windows 95)
- type a:setup and press Enter
- follow on-screen instructions

4. PadCAD Design Screen

The entire cushion design procedure takes place on the Design screen. The organization of information on this screen is in keeping with the three items to consider in a protective package design: Step 1 concerns the object and shipping hazards; Step 2 concerns the shipping container; and Step 3 concerns the cushioning system geometry. As design information is entered in Steps 1 through 3, context-sensitive information is provided

in two information windows on the right-hand side of the screen. When all necessary design parameters have been entered, clicking on the Solve button displays a list of suitable cushioning materials and a minimum thickness for each one in the upper portion of the text information window (if the problem cannot be solved, diagnostic information appears in this area). Selecting a cushioning material by clicking on it and pressing the Enter key (or double-clicking on the selection) displays the Results screen.



The PadCAD Design Screen.

4.1 Menu Bar

The menu bar contains four titles: Language, Navigate, View, and Help. The items under each title are described below.

Language

Two language options are available: English and French. The language can be changed at any time without affecting data entries or any results that are displayed; all text and preliminary results (if displayed) are translated.

Navigate

Various keyboard shortcuts for moving between items on the PadCAD screens and for executing certain PadCAD functions are included under this heading; a summary of these is also provided in Appendix G.

View

Two choices are available: a graphical presentation of shipping container selections (described in Appendix C), and one of cushion designs (described in Appendix D).

Help

Several features are available under this title:

About—displays general information about PadCAD.

Abbreviations and symbols—contains a quick reference for all of the abbreviations and symbols that appear on the Design and Results screens; this information can also be found in Appendix F.

Package design—displays general design guidelines for protective cushioning systems.

Sample problem—automatically fills all of the data fields with parameters for an example featuring a double-case system, and presents an image of the double-case system in the information window; clicking on the Solve button generates a list of cushion material choices for this problem; double-clicking on one of the material choices or selecting a material and pressing the Enter key displays the Results screen, with detailed results for this example.

4.2 Button Bar

The button bar contains controls that provide quick access to some common PadCAD functions.

Units

Clicking this button converts imperial units of measure to metric, or vice versa; unit conversions can be made at any time without affecting the displayed design parameters or solution list.

Calculator

Clicking this button activates a small pop-up calculator that can be used to perform basic math operations.

Erase all

Clicking this button clears all results and numeric data fields, resets drop-down lists and default values, and positions the cursor in the Height input field in Step 1.

About PadCAD

Clicking this button provides general information about PadCAD (the same information that is available under About in the Help menu).

4.3 Conventions

The following conventions apply to the data input areas and certain text labels on the Design screen.

White data entry fields

These data fields accept only numeric values that fall within pre-defined ranges. Notification is provided if the numeric entries are outside of acceptable ranges, and invalid entries (e.g. text) are filtered. Editing options for these fields can be displayed by clicking the right mouse button while the cursor is in the field.

White drop-down lists

These data fields (Fragility, Allowance, Insulation, Dimensional weight) accept choices from the listed alternatives or any user-specified values within an acceptable range. Notification is provided for numeric entries outside of this range.

Grey drop-down lists

These data fields (Fixed drop height, Damping, Shipping container, Cushion design) accept only choices from the listed alternatives.

Red text

Items that display in red text are a warning of possible problems with the pad design geometry (e.g. pads that are too large for the available surface area) or an indication of possible undesirable dynamic effects in the package design (e.g. deflection constraints, shock amplification in flexible elements, and resonance). Additional information on the significance of these warnings is provided in sections that follow.

Displayed results

Results are usually cleared when design parameter fields are entered or changed, but remain displayed for some (e.g. Projection values and Frequency values) changes so that the effect of modifying these parameters can be evaluated (context-sensitive information for these parameters is suppressed while preliminary results are displayed).

Terms

A complete glossary of PadCAD's terminology can be found in Appendix E.

4.4 Step 1

Height, Width, and Depth

These are the external dimensions of the item that will be supported on the cushioning system. This item can be the fragile object itself, an object supported in a transit framework, or one or more fragile objects firmly supported inside a container (i.e. double-case system).

***Note:** It is important that object dimensions for Height, Width, and Depth are correctly assigned as these define the Front, Right, and Top surfaces, which in turn affect the reporting of final results on case dimensions and pad components. It is easy to make the correct dimension assignments by using the following conventions:*

Height = vertical measurement when the object is in its upright (shipping) position

Width = longer horizontal dimension

Depth = shorter horizontal measurement

Projections

Enter the height of the tallest projection along the Height axis (i.e. projections on the Top or Bottom surfaces), Width (Right or Left surfaces), and Depth (Front or Back surfaces). PadCAD provides a warning (in the form of red text labels under the heading dm on the Results screen) if there is a risk of impact between the projections and the inner surfaces of the shipping container when the package is dropped from the design drop height.

Weight

This refers to the total weight supported by the cushioning system. If support braces or inner containers are used, then the weight of these items should also be included.

Fragility

The fragility value (in units of G) can be selected from the drop-down list or can be entered directly into the data field box if this information is known precisely.

Drop height

Two drop height options are available: Probable drop height and Fixed drop height.

Probable drop height

If this option is selected, PadCAD calculates the total package weight and uses this estimate to assign a drop height according to the probable drop height table below.

1-5 kg = 120 cm	1-10 lb = 48 in
5-10 kg = 105 cm	10-20 lb = 42 in
10-25 kg = 90 cm	20-50 lb = 36 in
20-45 kg = 75 cm	50-100 lb = 30 in
45-115 kg = 60 cm	100-250 lb = 24 in
115-225 kg = 45 cm	250-500 lb = 18 in
>225 kg = 30 cm	>500 lb = 12 in

Fixed drop height

As an alternative to the probable drop height option, a fixed drop height hazard that is independent of package weight can be assigned. One of six different drop height values ranging from 30 to 120 cm (12 to 48 in) can be selected from the drop-down list.

Flexible element

This is an advanced feature of PadCAD that can be used when flexible element frequencies are either known or can be measured experimentally. If this information is not available and the field is left blank, PadCAD considers the object to be rigid and to behave accordingly. In such cases, the packaged object and its parts should be made as stiff as reasonably possible; for flexible elements that are accessible, stiffening can be achieved indirectly by disassembly, or by bracing and/or wrapping.

Frequency

This refers to the frequency at which a flexible element oscillates freely. If a value is entered in this field, PadCAD calculates the shock amplification factor and performs a check for resonance effects. Shock amplification is a theoretical prediction with a maximum value of approximately 1.8 [4]. Resonance effect predictions involve comparing the flexible element frequency to experimentally derived transmissibility data for cushioning materials under various loadings [1].

Damping

If the fraction of critical damping for the flexible element is known, it should be entered in this data field by selecting the closest value from the drop-down list. If damping information is unavailable, entering a value of zero provides an assessment of the maximum dynamic response.

4.5 Step 2

Shipping container

From the drop-down list, select the shipping container that most closely matches the one that you plan to use. PadCAD uses this information to calculate total package weight (and assign a probable drop height if that option has been specified).

View

Clicking on the View button displays images of the container types that can be selected (these are the same images available under the View menu at the top of the screen). Choose a wall thickness for the container using the drop-down list below the image (where choices are available) and click on the container image to select it.

Insulation

If insulation will be added to the shipping container, insert the actual (measured) thickness of insulation that will be used, either by entering it directly or selecting it from the drop-down list. PadCAD predicts the thermal half time based on a simple steady-state heat transfer model, which assumes that an insulating material such as polystyrene will be used to line the case interior and that this material has a resistance rating of approximately $32 \frac{\text{m}^2 \cdot \text{°C}}{\text{W}}$ $\left(4 \frac{\text{h} \cdot \text{ft}^2 \cdot \text{°F}}{\text{BTU} \cdot \text{in}} \right)$

***Note:** The thermal model in PadCAD accounts for portions of the object that are covered by the cushioning material, and the insulating effect this provides. Therefore, it is advisable to first evaluate the thermal properties of the basic package without added insulation (i.e. set the Insulation parameter field to zero). If the calculated thermal half time is within acceptable limits, then additional insulation is not necessary (which will reduce package size and cost).*

Allowance

A case fit allowance between the case interior and cushioning material can be specified or chosen from the drop-down list. The allowance is commonly used when the cushions are adhered directly to an inner container or object support framework.

Dimensional weight

Several values for the denominator in the dimensional weight equation are included in the drop-down list. The field may be left blank to bypass the calculation of dimensional weight without affecting the cushion design procedure.

4.6 Step 3**Cushion design**

Select a design from the drop-down list; this configures the Pad coverage work area for that design.

View

Clicking the View button displays images of the twelve different cushion design options that are available (these are the same images available under the View menu at the top of the screen). Select the one that is most appropriate for the shape of the object to be cushioned by clicking on the image.

Pad coverage

This work area allows the user to specify the shape and coverage of the protective cushions. Design parameters must be entered in all white fields. [There are no white fields in the Pad coverage work area if the chosen design option is Encapsulation, because this option is based on 100% material coverage on all sides of the object.] If a heading label in the work area changes to red when a parameter is entered, it is a warning that the cushion coverage exceeds the available surface area of the object. However, in some situations it may be desirable to project the area of a dense object onto a larger surface area, so PadCAD solves problems even if red labels are displayed.

Clear

Clicking on this button erases all entries in the Pad coverage work area.

Estimate

Clicking on this button provides initial values for the design parameter(s) for the selected pad design based on the original object dimensions.

Solve

Clicking on the Solve button initiates a search of the material database for the minimum thickness of any material that is capable of meeting (or exceeding) the fragility requirements on all sides of the object (see Pre-screen Results, below). If any design parameters are missing, this is indicated in the text information window. In some cases all of the required information is present but no solutions can be found; this can be caused by inappropriate cushion geometry (usually one or two sides cannot be solved) or a request for an unattainable level of shock isolation (either by specifying a fragility that is too low or a drop height that is too high).

4.7 Pre-screen Results

Possible solutions to the specified design parameters appear as a list of suitable cushioning materials (with their minimum thickness) inside the text information window. When one of these items is selected by clicking on it, performance specifications for this choice (Go, dm, T, F.eq., Am, Ge, and Q) are provided in the lower portion of the text information window. These terms are identified below, and further information is available in Appendix E.

***Note 1:** Am and Ge will not appear if the Frequency parameter field in Step 1 has been left blank.*

***Note 2:** The appearance of red text labels in the Pad coverage work area is a warning that the cushion design may be prone to buckling. To avoid buckling, reduce the material thickness or increase the pad area.*

Shock information

Am: shock amplification factor (dynamic response)
dm: maximum deflection of the item into the cushioning system
F.eq.: equivalent shock frequency
Ge: peak acceleration of flexible elements
Go: peak acceleration of the cushioned object
T: shock pulse duration

Vibration information

Q = 1.2, Max., 1.0, 0.8, 0.6, 0.4, 0.2 are vibration transmissibility values of the object on the cushion system, and the numbers below these headings are the frequencies at which these Q values occur. (Transmissibility data originate from experimental tests using a continuous vibration source of 0.5 G [1].) If a flexible component frequency lies in the resonant frequency range of the cushion system, the Max. heading is red, indicating the possibility of undesirable resonance effects in the flexible component. Zeroes appear

during the pre-screening process if the cushion design involves a load condition for which there are currently no transmissibility data.

Probable drop height

The probable drop height for the package can be compared with the fixed drop height (if a fixed drop height has been specified).

Thermal half time

The thermal half time of the complete package is reported in hours.

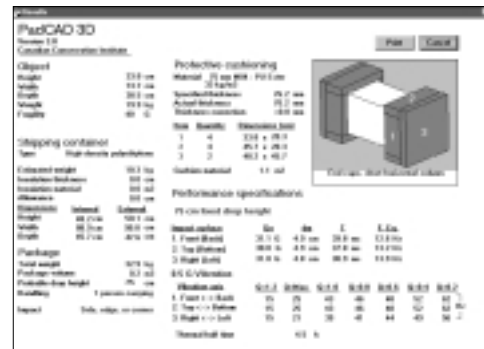
Final results

After pre-screening the results for various materials and making a final selection, the PadCAD Results screen can be displayed using either of these methods:

1. Select a cushion material and thickness from the list (with a single click, or Up/Down arrow key) and then press the Enter key, or double-click on the chosen material.
2. Select a material from the cushion material list, and then place the cursor inside the Actual thickness data field. If the foam material is different from the displayed value, adjustments can be made in this field to maintain proper allowances and accurate fitting of the various package components. Once the correct thickness value is entered, press the Enter key.

5. PadCAD Results Screen

The Results screen provides a summary of all of the design parameters that have been entered on the Design screen, along with information specific to the cushioning material that has been chosen. The screen can be printed by clicking on Print, or the user can return to the Design screen (without losing the current design parameters and results) by clicking on Cancel.



The PadCAD Results Screen.

5.1 Object

All of the object information that was entered on the Design screen is reproduced. Flexible component information appears if a non-zero Frequency value was entered in Step 1.

5.2 Shipping Container

Information about the shipping container that was entered in Step 2 on the Design screen is repeated under this heading. Both internal and external dimensions of the shipping container are reported. The external dimensions extend to the outer surface of framing members if they are present.

5.3 Package

A summary of the characteristics of the complete package, including the object, appears under this heading. A prediction of typical handling methods and the probable impact surfaces in the event of an accidental drop is also provided. If a denominator value was entered into the Dimensional weight formula in Step 2 on the Design screen, information on the dimensional weight of the package is provided under this heading.

5.4 Protective Cushioning

The material selection appears along with its specified thickness. Actual thickness refers to the measured thickness of the cushioning material; Thickness correction is the difference between the Specified and Actual thickness values if a correction was made.

A list of all the individual pad components necessary to fabricate the cushioning system also appears in this section. The quantity and dimensions of each component are tabulated; for most cushion designs, the components are labelled 1, 2, and 3, and an image is provided for reference purposes (a cut list is not provided for the Variable coverage by area option, as the coverage is defined in terms of area alone). A total material requirement is posted for all design options.

Note 1: *This is the calculated material requirement based on the pad dimensions (or cushion coverage) and some waste allowance may be necessary in practice.*

5.5 Performance Specifications

Performance specifications that appeared in the Pre-screen results are also posted on the Results screen. The probable drop height appears below the shock performance specifications. A notification label appears if any corrections have been made to the material thickness because the cushion data set applies to the specified material thickness. Minor corrections should not have a major influence on these results.

Appendix A. Packaging Basics

Shipping hazards

Fragile items can be damaged by routine handling operations, by the failure of a carrier to restrain cargo properly inside vehicles during transit, or by the rough ride of poorly maintained transport vehicles. Damage can also occur during handling operations at transportation transfer points (where packages are loaded, transferred, and unloaded from vehicles) and during movement in storage facilities.

Distribution systems each have their own risk profile, and significant savings in packaging can be realized if these risks are known. Commercial equipment manufacturers recognize this, and monitor their distribution networks with instrumented packages containing simulated contents, or with actual shipments that include data recorders and shock indicators.

For distribution networks with well-maintained vehicles and carriers who exercise care in the proper blocking and bracing of items during transit, the most likely risk factors are accidental drops or mishandling at transfer points. Observations and long experience in the packaging field have led to a method of assessing these hazards on the basis of total package weight. This information is summarized in probable drop height tables (see p. 6), which have been widely used by package designers and can provide reasonable risk assessments for many applications.

Selecting drop heights that are higher or lower than the probable drop height for a given package based on weight can incorporate more or less performance into a cushion system, e.g. specifying a higher than probable drop height for items of high value will result in more cushioning and added protection, and specifying a lower than probable drop height for items of lower value will reduce packaging costs by providing minimal packaging with less cushioning.

Cushioning

Protective cushioning reduces the peak force an item experiences on impact, but increases the time this force is sustained, e.g. if an unprotected item subjected to a particular impact experienced a force of hundreds to thousands of G's applied for several milliseconds, a cushioned item subjected to the same impact would experience a reduced force of only hundreds to tens of G's that lasted for 10–50 ms. This would reduce the likelihood of damage because most objects are more sensitive to the peak force than to the duration over which the force is applied.

Cushioning materials must be of sufficient density and thickness if they are to provide protection for fragile items. Factors that influence the choice of appropriate cushioning material include the probable drop height, object damage threshold (peak force limit),

object weight, and cushion geometry (the amount of cushioning material in contact with the object's surface, which affects the load per unit area of cushion material). In general, the appropriate material density for a given fragility and application will be dictated by the object weight and the cushion geometry; material thickness requirements will then increase with increasing drop height.

The intensity of a shock and the sensitivity of fragile items to shock are quantified by the unit G, which is the ratio of the force during the shock to the force resulting from gravity. Therefore, if a cushioned object is subjected to a force that is equal to 25 times its own weight for a brief interval of time, it experiences a shock of 25 G on impact. The main objective of protective packaging is to ensure that if the package is dropped from a given height, the peak shock experienced by the cushioned object will not exceed its fragility rating.

Object sensitivity to shock

Standard test methods to evaluate an object's fragility account for the combined effects of peak force and duration. The result of these test procedures is a maximum G value that is applicable over the range of shock pulse durations that may be encountered in a cushioned condition. In cases where fragility data for an object are unavailable, estimates can be made by comparing the object with others of known fragility.

Inferred estimates usually result in an overdesigned cushion system (protection that is more than adequate). The exception to this is if the object or any of its parts reacts unfavourably to the increased shock pulse duration created by the cushioning; should this occur, an alternate cushioning system can be chosen or the object's response can be altered by disassembly, gentle restraint, protective wrapping, or the incorporation of damping treatments.

Vibration

The vibration susceptibility of an object is expressed as the frequency at which it vibrates (natural frequency). For a protective package design to be effective for a particular object, the cushioning system must not transmit or amplify any externally applied vibration that matches the natural frequency of the object or any of its parts.

Vibration levels in moving vehicles have been studied extensively, and test data on the vibration properties of cushioning materials under various load conditions subjected to continuous transit level vibration are also available (transmissibility data) [1].

To protect items from vibration damage during shipment, either ensure that the natural frequency of all vibration-prone items does not fall within the resonance region of the cushioning material (i.e. Q is not between 1.2 and 1.0) or alter the response of the vibration-prone items by disassembly, restraint, wrapping, or damping.

Appendix B. Packaging Tips

General tips

Before packaging an object, identify and gently restrain any components that may rattle. If multiple objects are to be placed inside an inner box which will then be supported on a cushioning system, gently restrain the objects relative to each other and to the box. The cushioning system should be the most flexible component of your protective packaging system.

Many different cushion designs are possible, and a number of alternatives may be equally effective. As a general rule, symmetrical pad layouts and even weight distribution of the item supported on the cushioning system allow the protective cushions to deflect evenly in response to impact and vibration.

If an item is sensitive to bending, choose a cushion design that supports the entire bearing area. Alternatively, place the object inside a reasonably strong container or transit framework, which can then be supported on individual pads without subjecting the object to load concentrations.

For objects with even weight distribution and low sensitivity to bending, pad-type solutions (as opposed to full encapsulations) provide effective cushioning and reduce cushion material use. Pads can also be used in conjunction with support braces or frames (e.g. a travelling frame can transform a painting in a decorative frame with an irregular surface into a flat square area for which it is easy to design protective padding).

Cushion designs based on individual pads provide effective shock and vibration isolation, and are less restrictive to object movement than encapsulations; the openings that are incorporated in the sway space of pad designs make manual packing and unpacking of the package contents easier.

A cushioning system can operate effectively only if the object is able to move freely and deflect into the cushions without binding or excessive friction. To help ensure such free movement, provide an allowance of about 0.3 cm ($\frac{1}{8}$ in) between the cushioning and adjacent elements of the package (such as the object or container). Wrapping the object firmly in polyethylene will also help it to slide freely on the protective cushions. [Additional benefits of wrapping in polyethylene include protection against abrasion (with firm wrapping, slippage takes place between the pad surface and the outer surface of the polyethylene film) and effective moisture control for hygroscopic materials (but ensure that they are conditioned to the correct humidity before wrapping).]

Trimming the pad edges improves the ability of the cushioning system to absorb minor impacts (the majority of impacts encountered during shipment are far lower than the design drop height) and makes it easier to assemble the package components. The angle is not critical; pads in the sample problem have been trimmed to about 60°.

Common problems

Under correct load conditions, a 10–15% loss in cushion thickness can be expected over time; this is normal and is often accounted for in cushion designs. Under excessive loads, however, cushion materials suffer continued deformation (known as compressive creep), which results in reduced cushioning efficiency as objects become loose inside a package. To avoid compressive creep, ensure that the load applied to a cushion material is within its correct working load range. PadCAD solutions are not prone to serious compressive creep problems because results are provided only within the recommended load range of cushioning materials. It is still important, however, to ensure that thermo-plastic materials such as polyethylene are not exposed to high temperatures, which can lead to excessive compression even under normal loading.

When a pad does not have a large enough cross-sectional area in relation to its height, buckling can occur. To avoid buckling, the minimum pad area should be at least $(1.33 \times \text{material thickness})^2$. PadCAD warns of possible buckling problems during pre-screening and in the final results.

Appendix C. Shipping Containers

Container selection depends on the risks likely to be encountered in a particular distribution network, e.g. less rugged containers are acceptable (and economical) for shipments using specialized carriers, but more sturdy containers are necessary for transport by common carriers.

PadCAD offers (and illustrates) a number of container options; these are described in some detail below. Choose the option that most closely matches the container you plan to use, and PadCAD accounts for this selection when estimating hazards and the weight of the complete package.

Cardboard box

This is a simple construction regular slotted container (RSC), and can be made using either single-wall cardboard that is 0.5 cm ($\frac{3}{16}$ in) thick or double-wall cardboard that is 1 cm ($\frac{3}{8}$ in) thick.

Triwall cardboard

This case is built of triple-wall cardboard that is 1.6 cm ($\frac{5}{8}$ in) thick with wood reinforcing members. It is strong, inexpensive, and easy to fabricate. For detailed instructions on how to construct this type of container, see CCI Notes 1/4 [5].

Cleated panel box

Based on a description by Hanlan [6], this is simple, strong, lightweight, and makes very efficient use of wood framing members. A key element of its strength is the three-way corner, in which each of the three framing members is fastened to the side grain of the adjacent one. Three material thickness options are available.

General purpose wood

Generic cases such as this one can be made of sheet material that is either 1 cm ($\frac{3}{8}$ in) or 1.25 cm ($\frac{1}{2}$ in) thick, using various construction techniques; framing is typically 1 x 3 or 1 x 4.

Limited military case

This type of case is used for large or bulky items not exceeding 900 kg (2000 lb). Outer dimension limits are as follows: length, 6 m (20 ft); width, 3.5 m (12 ft); height, 3.5 m (12 ft). Sheathing for the top, sides, and floorboard is 1 cm ($\frac{3}{8}$ in) plywood. For loads up to 225 kg (500 lb) the base construction consists of 2 x 3 skids spaced 91 cm (36 in) apart and 2 x 3 cross stringers spaced 61 cm (24 in) apart. For loads over 225 kg (500 lb) up to a maximum of 900 kg (2000 lb), 2 x 4 members are used. The sides are made of 1 cm ($\frac{3}{8}$ in) plywood with 1 x 4 framing spaced 61 cm (24 in) apart. Lower frame members are 1 x 6 [7].

Road case (vinyl and aluminum varieties are illustrated)

Road cases are strong, lightweight cases made of plywood laminates, and assembled using aluminum extrusions and rivets. They are available from local manufactures in almost every major city and can be easily manufactured to specific size requirements, with a wide variety of hardware options. These cases can be re-used many times.

Aluminum case

Extruded or welded aluminum cases are very strong and extremely lightweight. The illustrated case is a Bolex camera case with a wall thickness of 0.5 cm ($3/16$ in). It has been shipped extensively and has proven very durable.

High-density polyethylene

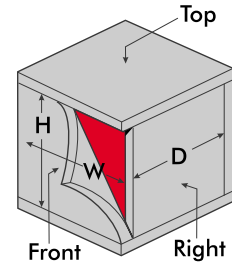
The illustrated case is made of moulded high-density polyethylene with a wall thickness of 1 cm ($3/8$ in). This case has been used by CCI to transport seminar materials to international venues, and it is the case that is used in the sample problem.

Appendix D. Cushion Designs

The following information applies to the cushion design options available in PadCAD. Note that in some cases, it may be possible to “stretch” one or more dimensions of the displayed shape and apply the pad design to a different-shaped object, e.g. the “End caps, short horizontal column” solution could be applied to a plate form object such as a painting by increasing the Height and decreasing the Depth.

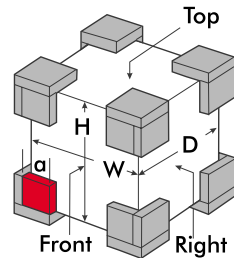
Encapsulation

Encapsulation refers to complete cushion coverage on all sides of the object. Complete cushion coverage requires the use of a lot of material, but labour requirements are low; it can also double as thermal insulation. For optimum cushioning, ensure that the object can slide freely inside the cushioning system without binding or excessive friction when the package is closed. This design option requires no design parameters in Step 3 of the Design screen because it is based on the original object dimensions and coverage of all sides is 100%. Final pad dimensions include overlaps for void filling.



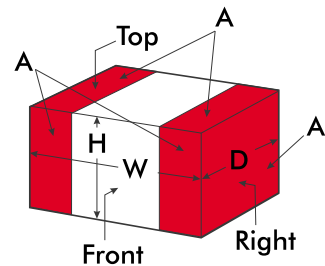
Square corner pads

Square corner pads require only a small amount of cushion material but numerous pad components that must be well bonded to ensure they do not fall apart and dislodge from their locations during shipment. Dimension “a” is the basis for the entire design, and the contact area of all pads on each object surface is $4 \times (a \times a)$. An estimate of “a” can be obtained by leaving the “a” parameter field blank and then clicking on the Estimate button (click on Clear to erase the “a” parameter).



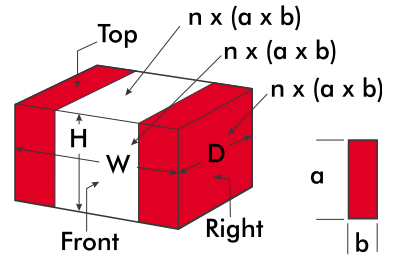
Variable coverage defined by area

This design option allows complete flexibility in the choice of cushioning layout. Solutions are provided on the basis of material coverage area (“A”) alone. As such, no individual pad component dimensions are reported because they are chosen by the user. The total material requirement displayed in the final Results screen is based on surface coverage requirements alone, and does not include any material used for void filling. Initial estimates can be obtained by clicking on the Estimate button if all Pad coverage fields are blank (click on Clear to erase).



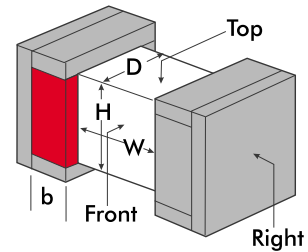
Variable coverage defined by dimension

This option provides some flexibility in the pad design but not as much as the preceding option. Pad layouts are based on a user-specified number of individual foam strips having dimensions $a \times b$. By convention, “a” is considered to be the long dimension of the strip and “b” the narrow one. The dimensions of these strips and total material requirements are provided in the final Results screen. As in the case above, the material requirements are based on surface coverage requirements alone, and do not include allowances for void filling.



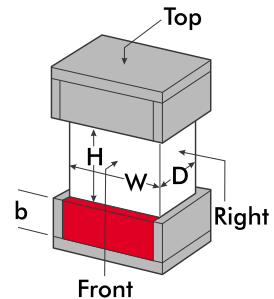
End caps, short horizontal column

This cushion design is suitable for short column forms that must travel in a horizontal orientation. The example that appears in the Help menu is an application of this design, with end caps that can slide off of an inner container. This design is based on dimension “b”, which can be specified by the user or estimated by clearing the “b” parameter field and then clicking on the Estimate button. Coverage at the column ends is fixed at 100%.



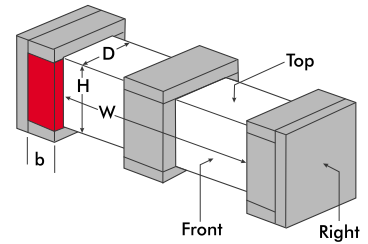
End caps, short vertical column

This design is the same as the preceding one, except it is tailored for short columns that must travel in a vertical orientation.



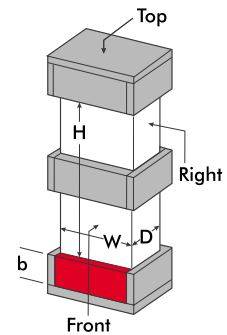
End caps, long column

This is similar to the short column solution, but includes additional pads for increased support of long columns. An estimate based on three foam strips on the Front (or Back) and Top (or Bottom) surfaces (as illustrated in the reference figure) can be obtained by clearing all Pad coverage fields; estimates for other numbers of strips can be obtained by clearing the “b” parameter, entering the desired number of strips under “Pads n,” and then clicking on the Estimate button.



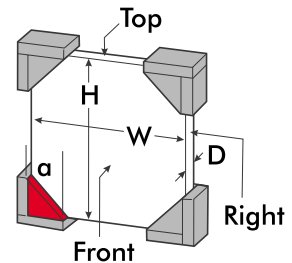
End caps, tall column

This design is the same as the preceding one, except the design is intended for tall columns that must travel in a vertical orientation.



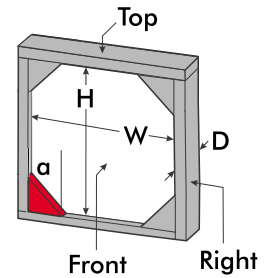
Corner pads, plate

This design is intended for objects with a plate form, such as paintings. The entire design is based on the linear dimension “a” displayed in the figure. The cut list reports pairs of triangular pads as square items, which are to be cut diagonally (one square pad yielding two triangular pad components).



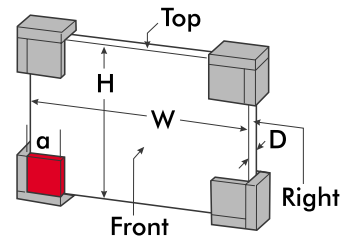
Corner/perimeter pads, plate

This design for plate forms is less labour-intensive to fabricate than the previous option, and may be preferable for heavier items. The design is based on dimension “a,” which can be estimated by clearing the “a” parameter field and then clicking on the Estimate button. As in the above design, triangular pad components are reported as square items in the cut list.



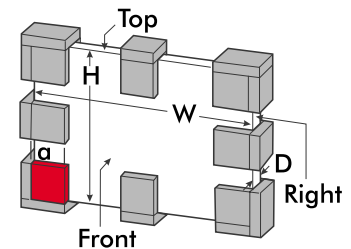
Square corner pads, plate

This design can be used for plate forms such as paintings, and consists of four corner pads. The square pads offer additional surface area that may be a better choice than triangular pads for heavier objects. This design is also based on dimension “a,” which can be estimated in the same manner as previously.



Multiple pads, plate

This design option is similar to the one above, but permits the inclusion of additional support pads. This option is useful for large plate forms that require additional support.



Appendix E. Glossary

Acceleration

A vector quantity (having magnitude and direction) that specifies the rate of change of velocity.

Allowance

A space between the cushioning material and the object or container that enables the package components to be easily assembled and promotes effective cushion performance by avoiding binding or excessive friction.

Bubble pack

Two layers of polyethylene film, one of which is embossed with circular cells forming an air-encapsulated cushioning material.

Buckling

Uneven compression or falling over of a pad of insufficient bearing area. [The minimum bearing area of a pad is $(1.33 \times \text{material thickness})^2$.]

CAD

Acronym for Computer Assisted Design.

Cellulose wadding

A wood fibre product, generally most effective as a wrapping material but can also be used for cushioning; it is not recommended for highly fragile items.

Convuluted

Convuluted foam has a surface with cone-shaped projections that provide high loading of the material under static conditions and a progressive increase in the area of foam in contact with the protected item on impact. It is mainly used for lightweight, fragile items. Convolutions are described in terms of the overall thickness, pitch, and valley of a sectional view of the material. For example, convuluted foam materials M9 and M11 have the following form: overall thickness, 5.3 cm (2.1 in); pitch, 3.5 cm (1.38 in); valley, 2.2 cm (0.88 in); and materials M8 and M10 have the form: overall thickness, 2.5 cm (1 in); pitch, 3.5 cm (1.38 in); valley, 1.0 cm (0.42 in).

Creep

The progressive loss of material thickness over time. [A permanent “set” of 10–15% can be expected when most foam cushioning materials are loaded within their normal load range; if a material is overloaded, excessive loss in thickness will result, leading to looseness inside a package and a loss of cushioning effectiveness.]

Damping

A general term for all the forces that can dissipate shock or vibration energy; two examples of damping forces are friction and air resistance.

Depth

The shorter horizontal dimension of an object when in its preferred transit orientation.

Design drop height

The drop height that has been used by PadCAD for the design of a given cushioning system, and the drop height for which the reported shock performance specifications are valid.

Design screen

PadCAD's main data input screen on which all of the parameters of a cushioning problem are entered.

Dimensional weight

A quantity used by shippers to measure package density when estimating shipping costs; the dimensional weight is calculated by multiplying the object's height, width, and depth, and dividing this product by some denominator value specific to the shipper.

Drop height

The height above a hard floor surface from which a package might be dropped during the handling phases of shipment (when most shipping damage occurs); drops can be accidental in nature or the result of mishandling.

Dynamic cushioning curve

A graph of peak acceleration versus static load that summarizes the shock isolation performance of a cushioning material; a separate graph is produced for each different drop height, and each curve on the graph corresponds to a different cushioning material thickness.

Equivalent shock frequency (E.eq.)

The natural frequency of an object on a protective cushioning system.

Fixed drop height

A worst-case hazard [e.g. a drop of approximately 75 cm (30 in) from a truck tailgate] that can be assigned to packages containing fragile items. [A high fixed drop height will normally be assigned to items of high value; a low fixed drop height can be specified for packages that contain items of low value, or for packages that contain items of moderate value that are shipped through distribution networks that have lower risk levels (e.g. works of art or commercial items transported by specialized handlers).]

Flexible element

A vibration-prone component of an object. [Flexible elements may attenuate or amplify externally applied shocks and vibration depending on their frequency and the properties of the cushioning system; the two key items that describe the vulnerability of a flexible item are natural frequency and the fraction of critical damping.]

Fraction of critical damping

The amount of damping that is present in an object relative to a critical value that causes the object to return to its equilibrium position without oscillation when it is displaced from its equilibrium position and released.

Fragility

A measure of the sensitivity of an item to shock which is expressed in units of G (multiples of the force due to gravity); the lower the G rating, the more sensitive an item will be to shock.

Frequency

The number of complete oscillation cycles that take place in a given time period (usually 1 s).

G

Ratio of the force of impact to the force due to gravity; used to express shock severity and object fragility.

Height

The vertical dimension of an object when in its preferred transit orientation.

Insulation

Material added to the interior surfaces of a shipping container to increase the time it takes for the package to respond to external changes in temperature during shipment.

Maximum deflection (dm)

The maximum distance that an object will deflect into the protective cushioning system along an axis perpendicular to the indicated surface (Front, Right, Top) when the package is dropped flat onto that surface from the design drop height.

Pad coverage

The amount of cushioning material that covers the available surface area of the object to be packed.

Peak acceleration of the cushioned object (Go)

The maximum shock (in units of G) experienced by a cushioned object (as a rigid item) when the package is dropped flat on the Front (or Back), Right (or Left), and Top (or Bottom) surfaces from the design drop height.

Peak acceleration of flexible elements (Ge)

The product of the peak acceleration of the cushioned object (Go) and the shock amplification factor (Am) of a flexible element.

Polyethylene (PE)

An inert thermoplastic cushioning material with a closed cell structure.

Polystyrene (PS)

Non-elastic cushioning (or insulating) material that deforms permanently on impact.

Polyurethane (PU)

A soft open-celled material that is available as either an ester type or ether type (the ester formulation is more chemically stable than the ether type); this material must never come in direct contact with metals.

Probable drop height

A drop height assigned to a range of package weights that is used to estimate the handling hazards of loading, unloading, and cargo transfer during shipment. Probable drop heights are summarized in tables and have evolved from observations, experience, and monitored shipments in the packaging industry.

Projections

Items that extend from the surfaces of an object (e.g. control knobs on electronic equipment) into the sway space (space between the external object surface and the inner container surface).

Resonance

The frequency of an externally applied source of vibration corresponds to the natural frequency of a flexible object; the resulting amplitude of vibration can sometimes reach levels that exceed the externally applied vibration source, and result in damage to the object. [The amount of vibration amplification that takes place depends on the external vibration frequency and the amount of damping that is present in the vibrating object to dissipate vibration energy; the greater the amount of damping, the lower the degree of vibration amplification.]

Road case

A general term for custom-made cases fabricated with plywood composite panels (e.g. aluminum or vinyl laminates) and held together with special aluminum extrusions and pop rivets.

Shock

A sudden, severe disturbance of a mechanical system that causes it to respond with large relative displacement of its components.

Shock amplification factor (A_m)

A dynamic effect in a flexible component that is a function of the ratio of the component frequency and equivalent shock frequency; the applied shock may be attenuated or magnified to a maximum level of 1.8 times greater than the applied shock (the amount of magnification depends on the natural frequency of the flexible component and its fraction of critical damping). PadCAD evaluates the shock amplification factor using a theoretical model based on a half sinusoidal shock motion for five different fractions of critical damping values: 0, 0.05, 0.20, 0.50, and 1.00 [4].

Shock pulse

A shock pulse is characterized by its duration, intensity, and shape (appearance on a graph of intensity versus time).

Shock pulse duration (T)

The time during which the acceleration is above a pre-defined fraction of the maximum shock pulse amplitude; shock pulse duration is independent of drop height.

Static load

The load per unit area applied to a cushioning material under static conditions; static load is normally expressed in kilograms per square centimetre or pounds per square inch.

Sway space

The clearance between the outer surface of a packaged object and the inner surface of the shipping container in which the packaged item will move in order to dissipate shock and vibration energy; the sway space may either be filled with cushion material or be partially open (as in the case of pad solutions).

Thermal half time

The time it takes for a package to reach a new temperature that is halfway between its current equilibrium temperature and the temperature of a new environment to which it is suddenly exposed.

Transmissibility

A non-dimensional ratio of the vibration response of a system to the amplitude that causes the motion under steady-state conditions.

Triwall

Triple-wall corrugated cardboard, 1.6 cm ($\frac{5}{8}$ in) thick.

Void fill

Foam that extends beyond the surface of an object to fill in voids, such as corners, inside the sway space of the package.

Weight

The total weight supported by a cushioning system, including the weight of the fragile object plus the weight of any support frames or inner containers that are used.

Width

The longer horizontal dimension of an object when in its preferred transit orientation.

Appendix F. Abbreviations and Symbols

a:	length of a cushion system component (cushion design parameter)
A:	pad area
Am:	shock amplification factor in a critical element
b:	width of a cushion system component (cushion design parameter)
cm:	centimetre
Con.:	convoluted
dm:	maximum object deflection
Fe:	flexible element frequency
F.eq.:	equivalent shock frequency
ft:	foot
Fv:	vibration frequency
G:	force of impact expressed as a multiple of the force due to gravity
Ge:	peak acceleration experienced by a flexible element ($G_e = G_o \times A_m$)
Go:	peak acceleration of the cushioned object
h:	hour
Hz:	hertz (cycles per second)
in:	inch
kg:	kilogram
lb:	pound
m:	metre
MAX:	maximum Q, resonance region of the cushion system
ms:	millisecond
PE:	polyethylene
PS:	polystyrene
PU:	polyurethane
Q:	vibration transmissibility
T:	shock pulse duration
XLPE:	cross-linked polyethylene
ζ :	fraction of critical damping

Appendix G. Keyboard Shortcuts

Actual thickness (shortcut: Ctrl+D)

Places the cursor in the Actual thickness input field if a material has been selected from the list in the Pre-screen results window.

Calculator (shortcut: Ctrl+A)

Displays a pop-up calculator that can be used to perform basic math functions.

Clear (shortcut: Ctrl+E)

Clears all numeric entries in the Pad coverage work area.

Erase all (shortcut: Ctrl+R)

Resets all PadCAD variables, clears all input fields in the Design and Results screens, and places the cursor in the Height data field of Step 1.

Estimate (shortcut: Ctrl+I)

Activates the Estimate button in the Pad coverage work area of Step 3.

Material list (shortcut: Ctrl+M)

Moves the cursor to the first item in the Materials list in the Pre-screen results window (if the list is visible).

Object description (shortcut: Ctrl+O)

Moves to Step 1. Places the cursor in the Height data field of Step 1.

Pad design (shortcut: Ctrl+N)

Moves to Step 3. Places the cursor inside the Cushion design list box.

Quit (shortcut: Ctrl+Q)

Exits PadCAD.

Shipping container (shortcut: Ctrl+C)

Moves to Step 2. Places the cursor inside the Shipping container list box.

Solve (shortcut: Ctrl+S)

Activates the Solve button in the Pad coverage work area.

Unit (shortcut: Ctrl+U)

Toggles between metric and imperial units.

Notes

1. U.S. Department of Defense. *Military Standardization Handbook*. MIL-HDBK-304B, October 1978.
2. The graphical data were converted by a TCL/TK script written by T. Strang which reads cushioning curve image files, converts data points taken from the graph into a 10th order polynomial, and confirms the fit in graphical form on the original cushioning curve. Unix shell scripts assembled the resulting data sets into Visual Basic code modules.
3. American Society for Testing Materials. "D-1596. Test Method for Shock Absorbing Characteristics of Package Cushioning Materials." *Annual Book of ASTM Standards*. Vol. 15.09. Philadelphia, PA: ASTM, 1987.
4. Harris, C.M. (ed.). *The Shock and Vibration Handbook*, 3rd ed. Chapter 42, p. 13. New York, NY: McGraw-Hill Book Company, 1988.
5. Canadian Conservation Institute. *Making Triwall Containers*. CCI Notes, No. 1/4. Ottawa: Canadian Conservation Institute, 1997.
6. Hanlon, J.F. *Handbook of Package Engineering*, 2nd ed. Section 15, p. 6. Lancaster, PA: Technomic Publishing Company Inc., 1992.
7. U.S. Department of Agriculture. *Wood Crate Design Manual*. Agriculture Handbook, No. 252, p. 445. Washington, DC: U.S. Department of Agriculture, 1964.

