

SANDIA REPORT

SAND2007-8071

Unlimited Release

Printed December 2007

SNL Mechanical Computer Aided Design (MCAD) Guide – 2007

Jack R. Martinez, Brandon Moore, and Stephanie L. Pollice

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

Sandia is a multiprogram laboratory operated by Sandia Corporation,
a Lockheed Martin Company, for the United States Department of Energy's
National Nuclear Security Administration under Contract DE-AC04-94AL85000.

Approved for public release; further dissemination unlimited.

Issued by Sandia National Laboratories, operated for the United States Department of Energy by Sandia Corporation.

NOTICE: This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government, nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, make any warranty, express or implied, or assume any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represent that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government, any agency thereof, or any of their contractors or subcontractors. The views and opinions expressed herein do not necessarily state or reflect those of the United States Government, any agency thereof, or any of their contractors.

Printed in the United States of America. This report has been reproduced directly from the best available copy.

Available to DOE and DOE contractors from
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831

Telephone: (865) 576-8401
Facsimile: (865) 576-5728
E-Mail: reports@adonis.osti.gov
Online ordering: <http://www.osti.gov/bridge>

Available to the public from
U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Rd.
Springfield, VA 22161

Telephone: (800) 553-6847
Facsimile: (703) 605-6900
E-Mail: orders@ntis.fedworld.gov
Online order: <http://www.ntis.gov/help/ordermethods.asp?loc=7-4-0#online>



SAND2007-8071
Unlimited Release
Printed December 2007

SNL Mechanical Computer Aided Design (MCAD) Guide – 2007

Jack R. Martinez, Brandon Moore,
and Stephanie L. Pollice
WR Mechanical Design 3 Department
Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185-0648

Abstract

This document is considered a mechanical design best-practice guide to new and experienced designers alike. The contents consist of topics related to using Computer Aided Design (CAD) software, performing basic analyses, and using configuration management. The details specific to a particular topic have been leveraged against existing Product Realization Standard (PRS) and Technical Business Practice (TBP) requirements while maintaining alignment with sound engineering and design practices. This document is to be considered dynamic in that subsequent updates will be reflected in the main title, and each update will be published on an annual basis.

(Left Blank Intentionally)

TABLE OF CONTENTS

| | |
|---|----|
| INTRODUCTION | 7 |
| Models-based Philosophy | 7 |
| Getting Started | 7 |
| Naming Your Model | 7 |
| Start Parts | 8 |
| Units | 8 |
| Material Selection | 9 |
| MODELING | 9 |
| Design Intent | 9 |
| Model to Mean vs. Nominal | 9 |
| Entity Naming | 10 |
| Sketches | 10 |
| Assemblies | 11 |
| Component Placement | 11 |
| Repeat Components | 11 |
| Patterns | 11 |
| Detail Features | 12 |
| Style Feature | 12 |
| Electrical CAD Parts | 12 |
| Holes | 12 |
| Threads | 13 |
| External Threads | 13 |
| Internal Threads | 13 |
| Blind Drilled Threaded Holes | 13 |
| Taper Pipe Thread | 13 |
| Marking | 14 |
| Relations | 14 |
| Library and Commercial Parts | 14 |
| Library Part Considerations | 15 |
| Mechanical Data | 15 |
| Shared Data | 15 |
| Family Tables | 16 |
| Simplified Representations | 16 |
| Bulk Items | 16 |
| Behavioral Based Modeling | 16 |
| Geometry | 16 |
| Legacy Models | 17 |
| DRAWING | 17 |
| Drawing Format | 17 |
| Drawing Title | 17 |
| Views | 17 |
| Dimensioning | 17 |
| Notes | 18 |
| Integrated Parts List (IPL) | 18 |
| Geometric Dimensioning & Tolerancing (GD&T) | 18 |
| Drawing Release Verification Process | 18 |
| Drawing Transfer | 19 |

| | |
|--|----|
| CONFIGURATION MANagements (CM)..... | 20 |
| PDMLink Mentoring | 21 |
| The Project Tab | 21 |
| The Product Tab | 22 |
| The Library Tab..... | 22 |
| PROCESS IMPROVEMENT | 22 |
| Model Verification | 22 |
| Peer Review | 23 |
| ENGINEERING CONSIDERATIONS | 24 |
| Stress..... | 24 |
| Strain..... | 24 |
| Young’s Modulus | 24 |
| Yield Strength..... | 25 |
| Ultimate Strength..... | 25 |
| Factor of Safety | 25 |
| Linear Springs..... | 25 |
| Tension | 25 |
| Threaded Loads in Tension | 25 |
| Bolt Pattern Loading..... | 25 |
| Shear | 26 |
| Threaded Loads in Shear | 26 |
| Compression | 26 |
| Buckling | 27 |
| Pressure Vessels | 27 |
| Axial Stress | 27 |
| Hoop Stress | 27 |
| REFERENCES | 28 |
| Driving Documents..... | 28 |
| Other Documents, Texts, and Websites..... | 28 |
| APPENDIX A–Commonly Used Thread Data..... | 29 |
| APPENDIX B–Feature Tolerance Guide | 30 |
| APPENDIX C–Hole Tolerance and Surface Texture Guide | 32 |
| APPENDIX D–Accepting and Incorporating Change to this Document | 34 |

TABLE OF FIGURES

| | |
|--|----|
| Figure 1: General Stress-Strain Curve for Linear Elastic Material..... | 24 |
| Figure 2: Example Stress Calculation – Threads in Tension..... | 26 |

INTRODUCTION

This document has been compiled as a reference for seasoned design engineers and an instructional guide for new designers. It is a compilation of modeling best practices, design best practices, and proper configuration management. Following the best practices within this text will ensure that all products created by the designers are of the highest quality and comply with existing Technical Business Practice (TBP) and Product Realization Standard (PRS) requirements.

Models-based Philosophy

[*Model Building Techniques for Analysis*](#)
[*Model Building Techniques for Analysis – Quick Reference Guide*](#)
[*Model Based White Paper*](#)

There are several reasons why models are created using CAD software. These reasons include drawing creation, rapid prototyping, manufacturing directly from the model, inspection, and analysis. Therefore, care must be taken to follow proper model construction methods and recognize that your model may be used for these purposes.

Today's CAD software packages are designed in such a way that information in the model can be used by other applications. The model and drawing must be "bi-directionally associated" meaning that a change in one is propagated to the other. This does not apply to the dimensions of the model alone. Notes, symbols, Geometric Dimensioning and Tolerancing (GD&T), title block information, and material properties are examples of important attributes that must be defined within the model and then coupled to within the drawing.

It should be expected that CAD models will be used as the input to analysis studies and in generating manufacturing tool paths. Specific features such as holes, fillets, chamfers, and rounds are often suppressed or deleted prior to analysis. For this reason, these types of features should not be referenced by subsequent features, and the preferred practice is to create them as late in the model tree as possible.

Getting Started

When a new part model is created, a part number, units system, and a material must be assigned. Each new model shall be created from the latest start template. In addition, the model should contain, at a minimum, all required parameters or attributes. Design-intent-based parameters may be added as needed for relations, programming, and controlling the design.

Naming Your Model

[*PRS 12101*](#)

The model name must be unique from all other models created and stored at Sandia. Uniqueness is obtained using a model name composed of a base number and suffix followed by the appropriate file extension (.prt, .asm, .drw). For individual parts, the base number refers to the physical part. The combination of the base number and suffix indicates the particular design that will be used to build the part. Therefore, any combination of base number and suffix could represent a particular design that meets the functional requirements of the physical part. For assemblies, the base number refers to the physical end item that consists of multiple parts. The combination of base number and suffix indicates possible configurations used to define various

build options such as required parts, processes, and their associated alternates. The rules for rolling part number suffixes are not well defined, and considerable latitude is common among product engineers.

A two-digit suffix communicates forward interchangeability. Three-digit suffixes are used to create multiple independent parts using the same base number.

Current practice includes appending the classification level and category to the filename. During model release, the Product Data Management (PDM) workflow will require the Derivative Classifier (DC) information. We expect that the redundancy of filename extensions and metadata pertaining to classification will be resolved in the future.

In some cases, a single model is used to represent multiple configurations. For example, a single cable can be routed in multiple fashions within a single assembly. Adding descriptive indexes is discouraged because there is no clear and specific standard that defines this practice. The preferred approach is to utilize the flexible capability in Pro/E and multiple configuration capability of SolidWorks. The result is a single model that contains the flexibility to be used in multiple configurations at the next assembly level.

Start Parts

All non-library product models must use start parts, which contain a minimum set of required model parameters and features. There are various start part templates available. The template that you will use depends on the unit system required as well as the type of model. The start parts should include the initial base features: three perpendicular planes, a coordinate system, and the six standard views (front, back, left, right, top and bottom). The start part should be set to the Pro/E absolute default accuracy of .0001 for both English (in) and Metric (mm) models.

On the other hand, library models shall not be created using start parts. Depending on the type of library part, these models follow a different set of requirements for parameters, model tree structure, mass properties, notes, and other information necessary for searching and usability. There is a specific method for creating new library parts. As a result, contact the site librarian for the process.

Units

[PRS 31102](#)

The default template that Pro/E uses is the “in-start” template. It applies the English unit system to your model. To assign a metric unit system to a new model, uncheck the “use default template” and select the unit system you would like to apply (inches, millimeter, centimeter, etc.). A common unit system should be used throughout a design. While Pro/E allows English and metric parts in the same environment, consistent units will reduce the likelihood of conversion error.

Material Selection

[PR3 31102](#)
[Materials WISDM](#)

Ensure the correct material is assigned to the model. A database of materials is provided in Pro/E (ex. wisdom, legacy). If the material you need is not in the database, contact a member of CAD support to ensure the new material is added. Until this material is added, a user-defined material can be temporarily assigned. Common practice is to use MatWeb for density and in cases where physical parts exist, adjust the density so that the mass properties of the model correspond with the known physical properties of the part. A model must never maintain the default density of 1.00 pound per cubic inch.

Proper material assignment will allow accurate mass property analysis and FEA. In the cases where exotic materials are needed, or more detailed information is required than what is supplied by Pro/E material databases or MatWeb, the Materials WISDM website may be consulted.

MODELING

The modeling portion of this paper proposes guidance in the creation, modification, storing, and sharing of models and assemblies.

Design Intent

[PR3 31102](#)

Efficient design leads to reliable and robust models. Designs are created for a reason. Design intent is the intelligent arrangement of features, parts, and assemblies that create a solution to a design problem. If a part is intended to have four holes that are equally spaced and have the same radius, the holes should be created in a way that conveys that intent. Methods of conveying design intent include:

- Using sketch constraints and construction geometry to control cross-section geometry (parallel lines, equal radii, etc.)
- Using shared data functionality when applicable (ex. skeleton parts or imported geometry). **Caution:** doing this can create unknown implicit relationships and has the potential to cause regeneration failures.
- Proper selection of datums, for feature placement, that captures the intent of the placement (ex. use a concentric axis to place a concentric feature).

Model to Mean vs. Nominal

[PR3 31102](#)
[MDCoP](#)

All dimensions in a model, regardless of tolerance scheme, should be modeled to the mean value. This allows the manufacturer to build a part from the geometry and ensures that their cuts will be made along the mean dimension of the feature. Modeling to mean dimensions is a manufacturing recommendation that allows the machining organization to work with the maximum total tolerance available. Other considerations that are made at the manufacturing level are tool wear, machine calibration, specific tool properties, tool lubrication, and manufacturing methods. The following table provides a reference to the "As-Read" dimensions found on a drawing compared to the "As-Modeled" mean dimensions that should be found in the model.

Table 1: Dimensions & Tolerances As Read on Drawing vs. As Modeled

| Tolerance Type | As-Read | | As-Modeled |
|------------------------------|--------------|------------------|------------|
| Bilateral Symmetric | .500±.005 | | .500 |
| Limit | .750 .748 | | .749 |
| Bilateral Plus-Minus | .500 | + .020 - .010 | .505 |
| Unilateral Plus-Minus | .750 | + .020 - .000 | .760 |

Note: If the model was created to the nominal value, in the case of a unilateral plus-minus tolerance, the manufacturer's cut would be made at the upper or lower limit of the tolerance, increasing the likelihood of the part being out of specification.

In the event that a non-mean dimensioning scheme is required, consider using the DimBound capability of Pro/E. Reference the Mechanical Design Community of Practice (MDCoP) website for specific directions. The video related to the session held May 2005 shows a DimBound demonstration.

There will be situations where this practice is not practical; for example, if the model that you are creating is to be used to generate an analysis mesh, the surfaces may need to be modeled to maximum material condition (MMC), least material condition (LMC), or line-to-line. In situations such as this, consult with your project leader in determining the recommended approach.

Entity Naming

[PRS 31102](#)

Apply descriptive names to features when probable. This might allow an easier interrogation of the model for the model creator as well as subsequent users. Naming datums that may be used in drawing creation or assembly constraints should be performed when possible. It is not necessary to rename every feature within the Model Tree for the sake of renaming.

Sketches

[D2A](#)
[Best Practices](#)

Sketched features should be kept simple. Try not to include too many features in a single sketch. The model will be easier to modify and interpret if the features are created separately. Some best practices include:

- Do not include fillets/chamfers in the sketch if at all possible.
- Referencing datums where possible or surfaces, if necessary. Avoid edges and vertices.
- Whenever possible, use the default datums (front, right, and top) as your primary datums.
- Use sketch constraints to capture the design intent of the feature.

- Dimension the sketch as you would on a drawing.
- Leverage symmetry as often as possible.
- Include reference dimensions that capture design intent and are likely to be shown on the drawing.
- Ensure fully-dimensioned sketches using Strong dimensions
- Use the axis point tool within the sketcher to create an axis perpendicular to the sketching plane when needed.
- If relations are used in sketcher, ensure a description is included with the relation (/ * is used when adding a comment).
- Do not leave weak dimensions in a sketch. Ensure all dimensions are strong. This will minimize unanticipated change due to the possibility that weak dimensions automatically update upon a related feature modification.
- Do not leave 0.000 dimensions in a sketch, address these with sketcher constraints.

Assemblies

[PRS 31102](#)

At a minimum, the assembly model should contain the necessary parts and hardware that define the assembly. While contrary to current PRS standards, modeling of bulk items such as glues, solders, or alternate items is discouraged. These items should be included in product structure (EBOM or model note). There are cases where variations to the modeled assembly structure are required. For example, a manufacturing organization might need to view the structure in a way that complements the manufacturing tooling. This use case scenario will be addressed in future implementations of product structure tools.

Component Placement

Always attempt to use the functional assembly datums or mated surfaces such as an assembly axis or plane to constrain components. Avoid using edges or points to constrain components. All components in the assembly should be fully constrained, with the exception of models used for mechanism analysis. Avoid using coordinate systems to place components to allow for ease of modifications. If coordinate systems are required, be sure to give the coordinate system a descriptive name for simple recognition.

Repeat Components

Create an assembly template when placing several components in a similar fashion. This is great for quickly placing bolts in holes that were not created with a pattern feature. Leverage the copy and paste functionality of the CAD tool when possible.

Patterns

[Best Practices](#)

Patterns should be used whenever possible. Geometry considerations need not be the only area of concern when designing a part. Engineering reuse, systems design, and other downstream users will benefit from an efficient and concise part model tree. Another important aspect of using patterns is that part-level patterns can be utilized in assemblies. Relations can be used to capture the design intent of your pattern. For example, use relations to keep holes equally spaced regardless of quantity.

Detail Features

[D2A](#)

Detailed features, such as fillets and chamfers should be added as late in the model tree as possible. This technique mitigates the possibility of unintended parent/child dependencies and increases the ability to simplify the model to perform various analyses.

Style Feature

[Creating Cables Using Pro/E Style Feature](#)

The style feature can be used to create 3D curves used for cables and other features. When coupled to shared reference data (i.e., skeleton models) the curve can be dynamically updated with the referenced component (this method can create unwanted parent/child relationships). This makes for a powerful cable tool that updates the curve as the connectors change position in an assembly. The path the style feature takes can also be adjusted manually by manipulating set bend points along the curve.

Electrical CAD Parts

[Best Practices](#)

Electrical connectors and cables can be difficult to keep up to date if an assembly is frequently changing. Following the steps below will allow electrical connectors and components to be consistently assembled. These steps will also enable the use of Routed Systems Designer (RSD) for cabling between connectors, ensuring the cables are dynamically updated as the assembly changes. The steps are:

- CSYS names in sub-models should match that of the electrical component group.
- CSYS Z axis should be pointing outwards (when component is mounted, “outward” is normal to and away from the mounting surface of the board). CSYS X and Y axes must be in the same orientation as its ECAD counterpart.
- Pin 1 or centroid of the part should be included.
- For connectors, the CSYS goes on the cable side of the flange with Z positive pointing outward.

Holes

[PRS 31102](#)

The Hole Feature is a useful tool that allows the designer to create threaded, unthreaded, straight, countersunk, or counter bored holes. When creating standard holes, using the Hole Feature is the preferred method. When custom holes are required, a cut/extrusion or cut/revolve should be used. If the custom hole is tapped, use the guidance in the “Threads” section of this guide to create the hole.

When considering design for analysis, the cosmetic thread feature is treated as a separate surface during meshing. For this reason, use an individual cosmetic feature rather than the threaded Hole Feature. This will enable the analysts to suppress the cosmetic feature.

Threads

[PRS 31102](#)

External Threads

The cosmetic thread feature should be used when creating external threads in Pro/E. The shaft diameter of the threads should be modeled to the “mean” major diameter. The cosmetic thread feature should be modeled to the minor diameter of the external thread per the thread data table found in Appendix A. A model note should be created with the cosmetic feature as the parent. The note should contain the following text:

```
&MAJOR_DIAMETER:ATT-  
&THREADS_PER_INCH:ATT[ .0 ]&FORM:ATT-  
&CLASS:ATT&PLACEMENT:ATT.
```

The contents of this note result in “.125-20UNC-2B”, for example. Best practice is to store notes in the Working Directory as text and retrieved when required.

Internal Threads

Internal threaded Hole Features should be modeled to the “mean” of the minor diameter. The Pro/E hole feature should be used, when possible, to create internally threaded holes. When custom sizes are required, use the cosmetic thread feature. The Hole Diameter should be modeled to the “mean” minor diameter. The cosmetic should be modeled to the major diameter of the internal thread. When a custom thread is created, use the external thread note methodology described above.

Blind Drilled Threaded Holes

Blind holes should be modeled to a minimum depth of 3–5 times the thread pitch past the last full thread. Reference the [Threaded Loads](#) section in the Engineering Considerations section of this guide to calculate the number of threads needed for your application. The drill tip should always be modeled, unless the hole is intended to be flat bottomed. This will ensure that a typical drilling event will not cause a hole to break through to the opposite surface. Care should be taken in this respect because stress due to the drilling event will cause material movement ahead of the drill tip. This may result in no breakthrough, but it may result in a bump of stressed material on the opposite surface. In cases like this, considering a flat-bottom-tapped hole might be required.

Taper Pipe Thread

More recent versions of Pro/E allow you to apply threads to an angled surface. For older versions, tapered pipe threads can be modeled as an ordinary thread feature, using National Pipe Thread (NPT) as the thread form and the nominal size (0.250, 0.375, etc.) as the major diameter. Use the tap drill size as the minor diameter for both internal and external threads.

Reference [Appendix “A”](#) for commonly used thread data.

Marking

[PRS 31102](#)
[9919100](#)

When a part requires direct marking using a tool path, the marking should be included in the model. For parts, use a cosmetic groove feature, with the font set to “font.” This will allow the machinist to create the marking directly from the model. For now, the cosmetic groove feature is not available in assemblies, so a separate marking part should be created and placed in the assembly. Reference the marking requirements for text, size, and width.

Relations

[PRS 31102](#)

Use relations to drive design intent in a model, when applicable. Be sure to include a description of the relation in the relation window. Descriptive text must be lead with the characters /*.

Relations can also be used to drive dimensions in sketch mode. The parameter “trajpar” varies from 0 to 1 along the length of a sweep. When used in a sketch relation, “trajpar” can be used to create complicated features such as sinusoidal sweeps for wave springs or variably curved turbine blades.

Example wave spring equation:

$$dy = \sin(\text{trajpar} * 360 * \text{number_of_waves}) * \text{overall_spring_height}$$

Example of a relation driving a parameter

$$\text{density} = \text{pro_mp_density}$$

Example:

$$\text{Length} = \text{d23}$$

Library and Commercial Parts

[PRS31107](#)
[IHS](#)

When commercial parts are included in an assembly, the parts library should be queried before creating the model. Verified library parts should have the prefix VL- before the part number. Note: this is an exception to the naming convention discussed earlier. Common military parts will start with AN, MS or NAS. If you do not have a parts library available to you, or if you cannot locate a specific library or commercial part, contact your site’s librarian.

Sandia National Laboratories (Sandia) has access to Information Handling Services’ (IHS) comprehensive, Internet-based information solutions that provide accurate and reliable engineering information. These products make it easier for you to reduce research times, streamline work flows, meet deadlines, avoid unnecessary costs, and spend more time on primary job responsibilities.

[IHS](#) provides access to commercial industry standards, military and government documents, etc. It is a subscription service that is available to all employees through a contract as part of Sandia’s Technical Library.

Library Part Considerations

Library parts must be used. These types of parts range from flat washers to high-strength bolts to MDM-type connectors. Standard parts have been catalogued and used by the design and engineering communities for decades. These types of parts are captured by documents such as Military Standards (MS), National Aerospace Standards (NAS), and Air Force-Navy Aeronautical Standards (AN). When performing the unique work for which Sandia is known, there are circumstances that arise where a standard part needs to be modified to match a specific application. The preferred method for dealing with this type of circumstance is to:

- Obtain a copy of the desired standard library part.
- Assign and rename the part using a Sandia-specific part number (R12345-000, for example).
- Correctly model desired modification geometry.
- Create a drawing that:
 - Calls out the standard library part
 - Shows necessary inherited reference dimensions
 - Shows modified geometry dimensions and tolerances
 - Specifically identifies this “new part” as a modified standard library part
- Place the new part in the PDMLink system as required.
- Request that the modified part be placed in a modified parts library context within PDMLink. Ensure that future search capabilities exist. Proper library part creation, loading, and classification are required to achieve reuse of information.

To properly follow configuration management requirements, do not store design files locally or within a shared server environment. The PDM tool must be used to capture design at every phase of the process.

Mechanical Data

[SLEDS](#)

The *Sandia Laboratory Engineering Drawing System* (SLEDS) manual is a general reference for mechanical information such as gear design, welding, riveting, fasteners, cable drawings, torque guides, press fits, sheet metal data, and tolerance comparators. This manual is an excellent compilation of mechanical theory and data. Another powerful reference is the *Machinery's Handbook*. Additional online references include [MatWeb](#), [efunda](#) and [Process Associates](#).

Shared Data

Reference geometry from other features, parts, and assemblies can be utilized by sharing CAD data. Sharing data allows designers to reference existing models to ensure their designs are accurate and compatible. Shared data can be dependent upon or independent of reference geometry. Dependency ensures all updates are dynamically incorporated. Independently referenced data captures a snapshot of the current configuration. **Caution:** the use of external references can create unwanted parent/child relationships as well as relationships between classified and unclassified information.

Example: For cable creation, skeleton models can be set up independent of or dependant to the reference geometry and will ensure accurate placement with stand-alone functionality.

Family Tables

[PRS 31102](#)

Family tables can be used to define the alternative construction of a part, or an alternate representation of an assembly. When you create a family table, ensure an instance is created, with an indexed name that references the generic. Never use the “generic” instance in an assembly. In the family table, the asterisk (*) should never be used in the place of a value. Designers must fully understand how a family table generic and instances are managed within the PDM system before attempting to perform a check-in event.

Simplified Representations

[Best Practices](#)

Simplified representations can be used to display different representations of features in parts or components in an assembly. They can also be used to show different instances from a family table. These are very useful when creating complex views in drawings. Ensure descriptive names, such as “case removed,” are given to the simplified representations so that other designers can interpret their intent.

Bulk Items

[PRS 31102](#)

[PRS 12101](#)

While contrary to current PRS standards, modeling of bulk items such as glues, solders, or alternate items is discouraged. In cases where the bill of materials (BOM) is displayed on the drawing, an automated BOM should be used. To keep the automated BOM parametrically driven, bulk items may be used to drive the BOM entries.

Behavioral-based Modeling

[MDCoP](#)

Behavioral-based modeling techniques such as sensitivity analysis and design optimization are extremely powerful tools. These design study tools will ensure that the intent of the design is accurately incorporated in the model. To use this functionality, determine what you would like to optimize (i.e., volume, center of gravity, mass, and moment of inertia) and create an analysis feature for it. Select which values you would like to have varied and apply an upper and lower limit. Run the design study until the tool converges on the desired value. **Note:** multiple objectives can be set in each study but will increase the overall processing time.

Geometry

[Pro/E Tips and Techniques](#)

It is important that ModelCHECK be run on all Pro/E models and drawings prior to release. ModelCHECK functionality is explained in more detail in a later section. Models must be corrected so that they do not contain the following commonly-found oversights:

- Geometry errors
- Suppressed features or components
- Relation errors
- Circular references
- Buried features
- Incomplete features
- Weak dimensions
- Blank or missing parameters
- Regeneration errors

Legacy Models

The current strategy concerning legacy models is to update them to current standards when the necessary work required to do so is feasible. When this type of opportunity arises, discuss this option with your project leader, lead designer, or your manager for guidance.

It is important to understand that legacy practices used in the past to create models and drawings will have a direct effect upon how designers and customers interact with a Product Lifecycle Management (PLM) environment.

DRAWING

[DRM
9900000](#)

For general drawing and inspection practices, reference 9900000, General Requirements and/or the Drawing Requirements Manual (DRM).

Drawing Format

[PRS 31101](#)

It is important that the latest drawing format is used when creating drawings. The latest drawing formats should be made available to the designer through the CAD support department and automatically loaded upon drawing creation from a properly configuration managed location within the PDM tool.

Drawing Title

[D10127](#)

Drawing titles, as specified on the drawing, must provide a descriptive explanation of the part, meet naming standards, and be parametrically tied to model parameters. The title is required to be portion marked when the contents are classified. The title should include a designation when applicable (MC#, etc.), basic name (concept) and modifier (specific characteristics). Example: TC450, Switch, Inertial as a drawing title within the title block of the drawing format.

Views

[Best Practices](#)

Default views should consist of those available in the start parts. All views and features on the drawing should be driven from the model. If sketched entities, symbols, or notes are required in the drawing, relate them to the associated view or object.

Dimensioning

[PRS 31102](#)

In drawings, “driving dimensions” from the model should be displayed using the show/erase tool. “Driven dimensions,” created within the drawing, are discouraged.

Notes

[PRS 31102](#)

General notes must be driven from the model. Separate columns should be divided into separate notes (Ex: col_1_notes, col_2_notes, etc.). All symbols should be driven from the model as well. This includes surfaces finishes and geometric tolerances.

Integrated Parts List (IPL)

[PRS 31108](#)

An integrated parts list, or BOM, placed on the drawing should be driven by the model when possible. The items listed in the IPL should contain all necessary parts needed to define the specific assembly geometry.

Geometric Dimensioning & Tolerancing (GD&T)

[PRS 31102](#)

[SAND2005-5290P, Feature Tolerance Guide, Page 1](#)
[SAND2005-5290P, Feature Tolerance Guide, Page 2](#)

The current ASME GD&T standard, ASME Y-14.5M-1994, as defined in 9900000 shall be used unless otherwise specified.

All dimensions must have tolerances defined. The tolerance on a basic dimension defined with an enclosing box does not need to be modified. Basic dimensions without the enclosing box should have their tolerances set to zero.

Reference [Appendix B](#) and [Appendix C](#) for critical information found in the Feature Tolerance Guide (*SAND2005-5290P*) concerning general tolerance information and application.

Drawing Release Verification Process

[Organization 2990 Policy on Drawing Release Verification](#)

All mechanical drawings must ensure that changes per engineering authorizations are made to the proper Pro/Engineer models and drawings, modified Pro/Engineer files are stored within design definition manager (DDM) prior to IMS release of drawing images, and that IMS images are verified against previously released IMS images as a final quality check. The specific steps follow:

- Verify Pro/Engineer Files Prior to Change: Prior to making changes indicated on engineering authorizations, the proper Pro/Engineer files must be checked out of DDM.
 - Clear Pro/Engineer session memory (Mapkey: Erase Not Displayed–END) to ensure that DDM files are active following checkout from DDM. This step must be done to ensure that another version of model or drawing (currently in memory) is not maintained instead of the file being checked out of DDM.
 - Review the models and drawings and double check them against the existing IMS drawing images to ensure that these Pro/Engineer files are the appropriate files.

- Store work in DDM: Release drawing image to IMS after ensuring that Pro/Engineer files are stored in DDM.
 - Before releasing a drawing image to IMS, check Pro/Engineer files into DDM.
 - Clear session memory using the Mapkey: Erase Not Displayed–END.
 - Checkout as stored files again from DDM into empty work directory.
- Verification of Pentagon S Drawings: The 2990 designers must take special care to ensure that drawing images that contain Pentagon S features are carefully reviewed by the customer engineer prior to being released into IMS.
- Pre-IMS Verification of Drawing Image:
 - Promote Pro/Engineer drawing within DDM to “in-approval.”
 - Verify generated TIFF image (prompted via e-mail) against Pro/Engineer drawing before promoting to “released” state which loads the image into IMS.
- IMS Image Verification:
 - Use IMS or the NWie Portal tool to verify that the new drawing images stored in IMS contains intended changes compared to the previous issue of these drawing images that are stored in IMS.

Drawing Transfer

[PRS11101](#)

[PRS12002](#)

Transferring drawings and their associated models between sites requires a secure and consistent method—currently via the NWC Hub. All models and files associated with the drawing are sent together as the product definition set; this will ensure the files can be opened at the receiving site. The sender must notify the receiver prior to sending the product definition set. Information included with the product definition set contains:

- Name of sending and receiving site
- Reason for distribution and reference EA#
- Name, organization, and phone number of person to notify at receiving site
- Date and time of transfer

Prior to sending this information to the receiving site, the files that are being sent will be tagged with the receiving site’s data. For example, if the files are being sent to the Kansas City Plant (KCP), a “KCP” tag will be appended to the CAD files. This will ensure that when the files are sent back according to Memorandum of Understanding (MOU) agreements, the files can be managed within Sandia’s PDM system without naming conflicts.

CONFIGURATION MANagements (CM)

[PRS12002](#)

[PRS12003](#)

[The Institute of Configuration Management](#)

Every organization is driven by requirements. Configuration management (CM), depending on context, may take on various meanings. Historically, the notion of CM has been tied to decades-old military standards that were introduced in the 1960s. Initially, these standards were imposed upon defense contractors as a method to track parts that were built and delivered. Similar to today, suppliers of the time “made last minute changes to products and yet failed to update the documentation. Documentation did not match the products delivered. Suppliers could not verify what they had shipped. As a result, the ability to operate and maintain the equipment was at risk” (*CMII for Business Process Infrastructure*, Vincent C. Guess, p. 12, 2002). The original definition of configuration management follows:

Configuration Management—A discipline applying technical and administrative direction and surveillance over the life cycle of configuration items to:

1. Identify and document the functional and physical characteristics of configuration items (CI's). (Identification)
2. Control changes to CI's and their related documentation. (Configuration Control)
3. Record and report information needed to manage CI's effectively, including the status of proposed and approved changes. (Status Accounting)
4. Audit CI's to verify conformance to documented requirements. (Reviews and Audits)

The military standards that are used as reference material for the definition above are no longer active and were limited to design definition only: “The ability to accommodate change is not emphasized” (n, p. 12).

Because traditional approaches to CM are oriented toward controlling change, the Institute of Configuration Management (ICM) has redefined configuration management so that it is oriented towards accommodating change. The scope of this new definition includes all design and process-related information that could impact safety, quality, schedule, cost, profit, or the environment. This definition, known as CMII, is as follows:

CM is the process of managing an organization's products, facilities and processes by managing their requirements, including changes, and assuring that results conform in each case. CMII expands the scope of CM to encompass all information that could impact safety, quality, schedule, cost, profit or the environment. CMII shifts the emphasis of CM to:

1. accommodating change,
2. accommodating the reuse of standards and best practices,
3. assuring that all requirements remain clear, concise, and valid,
4. communicating 1, 2, and 3 to each user promptly and precisely, and
5. assuring conformance in each case.

Process improvement, per CMII, is measured by the ability to “change faster and/or document better” (n, p. 21).

Sandia designers might find that most of their generated files fall under this definition. Since CAD files fall into the realm of design definition, one might ask why, then, do we not just follow the original CM definition that has been followed for such a long time? The quick answer to that is the fact that, even in mechanical design, designers must also follow processes for creating, managing, documenting, storing, and deleting information. As a result, designers and engineers must not only focus on the native CAD files but also all processes, requirements, instructions, specifications, and other ancillary items that lend themselves to the creation of an end item.

Windchill is a software tool that attempts to manage an enterprise’s information following CMII principals. There are two parts of this tool’s environment that manages CAD files–PDMLink and ProjectLink. While working within Windchill, designers must be aware that CAD models, drawings and other files must be stored and managed within PDMLink or ProjectLink in order to align the management of these files with CMII principles.

This document covers Windchill functionality at a high level. For specific guidance in using the tool to perform daily tasks, refer to the PDMLink Mentoring materials or your PDMLink mentor for guidance.

PDMLink Mentoring

In providing a strategy for training designers and engineers on how to use PDMLink, the PDMLink functional team has developed training materials derived from Sandia’s configuration of Windchill. A mentor will be assigned to each designer, and it will be the responsibility of the mentor to ensure that his or her assigned designer learns how the tool works and how it has been configured for use at Sandia. When the mentoring period is complete, the newly trained designer will become a mentor.

The Project Tab

[SNL PDMLink 8.0 Configuration Requirements](#)

ProjectLink is used mainly in the development phase of design. This is where much of the collaboration, sharing of data, teamwork, and project management tasks are conducted. ProjectLink is an environment that maintains its own configuration management of design development, but it allows renaming, duplicating, and sharing of CAD files across projects. The system tracks “renamed and saved-as” history as well as the version/iteration of the source item.

There are out-of-the-box (OOTB) roles defined for work performed within Projects. Roles are used to apply access controls, and in many cases the lead designer/engineer will play multiple roles for a particular development project. A few roles will be common between Projects and Products.

The Product Tab

[SNL PDMLink 8.0 Configuration Requirements](#)

PDMLink manages files around the notion of Projects, Products, and Libraries. Projects are mentioned above. Products are used to apply rigid access controls and CMII principals in controlling iterations, configurations, and processes. A release process is defined through a PDMLink workflow that allows a collection of files to be peer reviewed and approved for release. The tasks that are assigned by the workflow are assigned to roles, not individuals, due to an effort to minimize administrative burden.

Workspace usage is required by the Windchill tool when performing work. You can think of a workspace as your working directory. Like a working directory, you must be fully aware of what workspace is active because this is where your CAD information will be saved and retrieved by default. Unlike a working directory, each workspace is directly tied to a specific Project, Product, or Library.

The Library Tab

[SNL PDMLink 8.0 Configuration Requirements](#)

The library section of PDMLink is used to manage commonly used information. Information such as CAD formats, material specifications, fastener models, and templates are managed within this area. The access controls controlling who has access to modify this information may be different than those in Products or Projects—usually more restrictive.

PROCESS IMPROVEMENT

In an effort to improve quality of design, it is important to have a well-established and balanced review process. Currently, 2990 has defined a peer review process that is used when reviewing technical work. PDMLink contains built-in workflow capability that automates this process. Future implementations of PDMLink will address the validity and effectiveness of required review steps within a particular workflow.

Model Verification

When checking out a model or drawing for revision, the integrity of the model should be checked to ensure that it meets current standards. A good way to ensure integrity is to walk through a systematic process when revising a model or drawing. Below are some of the items that should be interrogated when checking out a model or drawing:

- Reference the message log for any errors; correct any that exist.
- Utilize ModelCHECK to discover errors and warnings.
- Ensure all files are correctly named.
- Check for correct material assignment.
- Compare the model tree to an AML or BOM, ensuring the correct models are present. It is understood that the version being referenced in the AML or BOM is the latest release version.
- Check all parameters, and ensure they are present and filled in correctly.

- Check notes for special modeling considerations (MBE_NOTES).
- Make sure all markings in the model are correctly applied. Mechanical markings such as grooves should be represented in the Pro/E model as a cosmetic groove. Ensure that the marking is applied at the correct level. For example, if the marking is to be applied to an assembly, the cosmetic feature should be modeled within that particular assembly, not the part to which the feature is applied.
- Ensure all models are properly constrained.
- Verify a consistent unit system, either Metric or English.
- Check that no driven dimensions exist in piece part drawings.
- Verify that notes and dimensions in the drawing are driven by the model.
- If modification originated in an EA, ensure that simply opening and regenerating a model/drawing in the current CAD tool version does not change the as-stored configuration (See Drawing Release Verification Process section above).

Adhering to a standard, systematic process when revising drawings and models will encourage quality in the files.

Peer Review

[Peer Review Policy](#)
[PDMLink Mentoring Materials](#)

Designs will always benefit from a second opinion. Your work, including drawings, models, and documents, must be reviewed by one of your mentors or peers. Doing this will increase the quality of your work, strengthen your knowledge base, increase the level of design professionalism, and increase customer confidence.

PDMLink has a built-in capability to define formal workflows that manage the processes used to perform design work—from conception to retirement. Depending on life cycle, access controls, roles, and the type of object that you are working on, the specific workflow used to review and release the object will be applied by the PDM tool. The PDMLink Mentoring Materials cover this topic in detail and should be followed during the review and release process.

ENGINEERING CONSIDERATIONS

[SLEDS](#)

When performing calculations based on the information within this section, consult with a mechanical engineer to validate the method used and applicability. For safety critical situations such as pressure vessel design, validate the design with pressure experts.

Stress

Stress (σ) is defined as a force (F) applied over an area (A). Typical units are pounds per square inch (psi) in English and Pascal (Pa) in the metric unit system.

$$\sigma = \frac{F}{A} \quad (1)$$

Strain

Strain (ϵ) is a ratio of the change in length (Δl) of a part, due to deformation, to the original (l_o) length of a part.

$$\epsilon = \frac{\Delta l}{l_o} \quad (2)$$

Young's Modulus

Young's modulus (E) is a measurement of the linear elastic characteristics of a material and quantified as the ratio of stress (σ) to strain (ϵ).

$$E = \frac{\sigma}{\epsilon} \quad (3)$$

This is illustrated, as shown in Figure 1, on a stress strain diagram as the slope of the elastic section of the curve (the linear section of the curve).

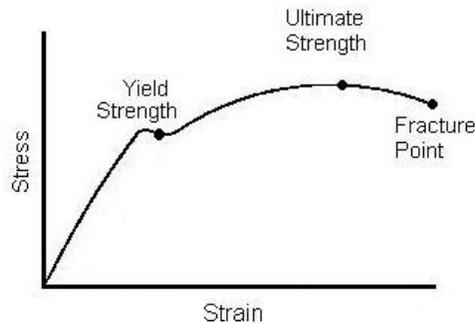


Figure 1: General Stress-Strain Curve for Linear Elastic Material

Yield Strength

The maximum stress a material can withstand without permanent deformation is the yield strength. Designers typically use the yield strength as the maximum allowable stress.

Ultimate Strength

The maximum stress level a material can withstand is known as the ultimate strength. At this stress level, the material will fail.

Factor of Safety

The ratio of the yield strength of a material divided by the peak stress experienced is known as the Factor of Safety (FOS). If a stainless steel part with yield strength of 300MPa experiences a peak stress of 150MPa, then the factor of safety for the part is 2.

Linear Springs

Known as Hooke's Law, the force of a spring is determined by the spring constant (k) and the displacement of the spring (x) from its "at rest" position.

$$F = k \cdot x \quad (4)$$

Tension

Tension is a stress load that acts on the surface perpendicular to the force applied. Tension tends to stretch the body it acts on.

Threaded Loads in Tension

For threaded loads in tension, the equivalent thread tensile area must be calculated for use in the stress equation. The equation for the equivalent thread tensile area is:

$$A_s = 0.7854 \left(D - \frac{0.9743}{n} \right)^2 \quad (5)$$

Where n is the number of threads per inch and D is the basic major diameter. The axial stress in the bolt can now be calculated:

$$\sigma = \frac{F}{A_s} \quad (6)$$

Bolt Pattern Loading

Determining how many bolts are required to support or withstand a load is a common problem faced by designers. Reference the following example:

Example: How many ¼-20 stainless steel bolts are required to support a 500 lb mass in tension?

The yield strength (σ_y) of annealed stainless steel is roughly 30,000 psi

Remember, stress can be calculated as: $\sigma_t = \frac{F}{A_t}$

The stress a 500 lb mass would exert on one ¼-20 bolt would be:

$$\sigma_t = \frac{500 * 32.2}{\frac{\pi (.25)^2}{4}} = 327,986 \text{ psi}$$

Dividing this calculated stress by the yield strength of the bolt gives,

$$\text{bolts} = \frac{\sigma_t}{\sigma_y} = \frac{327986}{30000} = 10.93, \text{ or } 11 \text{ bolts.}$$

With a factor of safety of 1.5, the 500 lb mass would require a minimum of 17 bolts.

Note: For a threaded load, the equivalent surface area would be used for A_t .

Figure 2: Example Stress Calculation – Threads in Tension

Shear

Shear is a stress load that acts on the surface parallel to the force applied. The same mechanics apply to a shear load as a tensile or compressive load.

Threaded Loads in Shear

For threaded loads in shear, the equivalent thread shear area must be calculated for use in the stress equation. The equation for the equivalent thread shear area is:

$$AS_s = \pi n L_e K_n \max \left[\frac{1}{2n} + 0.57735(E_s \text{ min} - K_n \text{ max}) \right] \quad (7)$$

Where n is the number of threads, L_e is the length of engagement, $K_n \text{ max}$ is the maximum minor diameter of the internal threads and $E_s \text{ min}$ is the minimum pitch diameter of the external thread.

Compression

Compression is also a perpendicular load, but it tends to compress or squeeze the body it acts on.

Buckling

When a column is placed under a compressive load, it has the potential to buckle. For an ideal column (long, slender, and perfectly cylindrical) the stress required to buckle is driven by Euler's formula for columns:

$$\sigma = \frac{F}{A} = \frac{\pi^2 \cdot E}{\left(\frac{l}{r}\right)^2} \quad (8)$$

The force required to buckle the column is driven by the formula:

$$F = \frac{(K\pi^2 EI)}{l^2} \quad (9)$$

Where,

F = Maximum force

E = Modulus of Elasticity (Young's modulus)

I = Area moment of inertia

l = Unsupported length of column

K = A constant based on the constraints placed on the column. For both ends free to turn $K = 1$; for both ends fixed $K = 4$; for one end free to turn and the other end fixed $K = 2$ approximately; and for one end fixed and the other end free to move laterally $K = 1/4$.

Pressure Vessels

Axial Stress

Stress perpendicular to the circumference of the pressure vessel is called axial stress. In a spherical pressure vessel, this is the only stress experienced. The stress is a function of the internal or external pressure (P), the radius of the vessel (r) and the wall thickness (t).

$$\sigma_a = \frac{P \cdot r}{2 \cdot t} \quad (10)$$

Hoop Stress

Stress perpendicular to the radius of the pressure vessel is called Hoop Stress. Note that the Hoop Stress is twice that of the axial stress. Because a spherical tank only experiences axial stress, it is a more efficient pressure vessel, but a sphere is not always the most manageable geometry. For situations when a sphere is not acceptable, hoop stress must be accounted for in any cylindrical portions of the tank. The stress is a function of the internal or external pressure (P), the radius of the vessel (r), and the wall thickness (t).

$$\sigma_h = \frac{P \cdot r}{t} \quad (11)$$

REFERENCES

Driving Documents

1. [PR5 Link](#) Sandia National Laboratories Official PR5 Website
2. [9900000](#) “General Requirements”
3. [9919100](#) “Marking, General Methods”
4. [D10127](#) “Part Names and Drawing Titles”
5. [TBP-DEF](#) “Nuclear Weapons Complex Abbreviations”
6. [TBP-PRP](#) “Product Realization Process”
7. [TBP-307](#) Use of Mechanical Models in the Product Realization Process

Other Documents, Texts, and Websites

- a. [Drawing Requirements Manual](#)
- b. [Model Building Techniques for Analysis \(D2A\)](#)
- c. [Information Handling Services \(IHS\)](#)
- d. [Sandia Laboratory Engineering Drawing System \(SLEDS\)](#)
- e. [Creating Cables Using Pro/E Style Feature](#)
- f. [New Hire Design Resources](#)
- g. [Mechanical Design Community of Practice \(MDCoP\)](#)
- h. [Peer Review Policy](#)
- i. [SAND2005-5290P, Feature Tolerance Guide, Page 1](#)
- j. [SAND2005-5290P, Feature Tolerance Guide, Page 2](#)
- k. *CMII for Business Process Infrastructure*, Vincent C. Guess, Holly Publishing, 2002.
- l. [DA PDMLink 8.0 Configuration Requirements](#)
- m. [Materials WISDM](#)
- n. PDMLink Training:
 1. [Windchill PDMLink 8.0 – Application Orientation](#)
 2. [Windchill PDMLink 8.0 – CAD Data Management](#)
 3. [Windchill PDMLink 8.0 – Communication and Collaboration](#)
 4. [Windchill PDMLink 8.0 – Document Management](#)
 5. [Windchill PDMLink 8.0 – Environment Management](#)
- o. ProjectLink Training:
 1. [Windchill ProjectLink 8.0 – Application Orientation](#)
 2. [Windchill ProjectLink 8.0 – Communication and Collaboration](#)
 3. [Windchill ProjectLink 8.0 – Creating and Managing the Project Environment](#)
 4. [Windchill ProjectLink 8.0 – Project Process Participation](#)
- p. [Windchill PDMLink 8.0 and ProjectLink 8.0 Collaboration](#)
- q. ProductView Training:
 1. [ProductView 8.0 – Application Orientation](#)
 2. [ProductView 8.0 – Annotation and Sectioning](#)

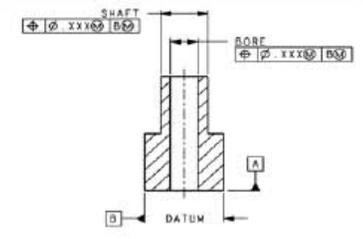
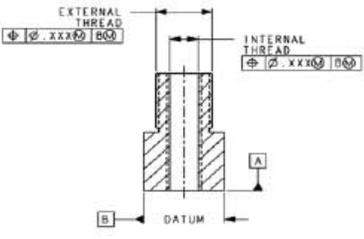
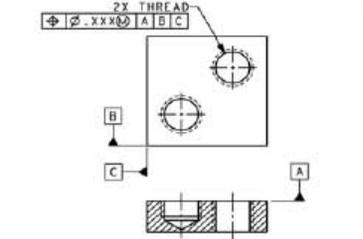
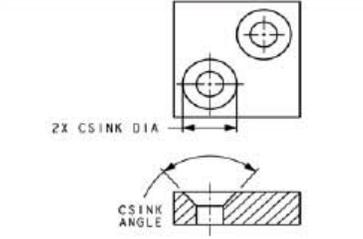
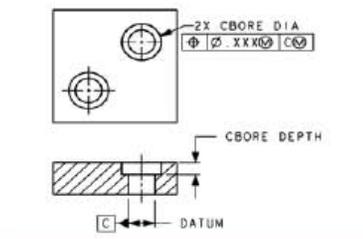
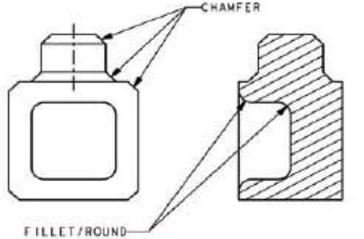
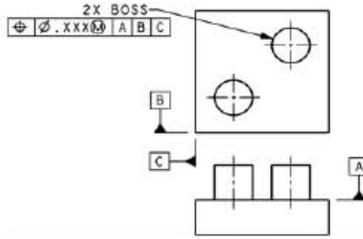
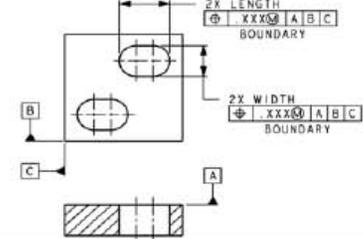
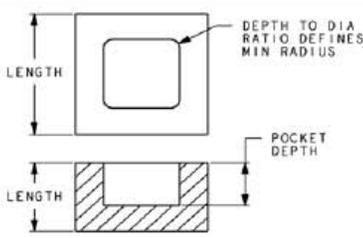
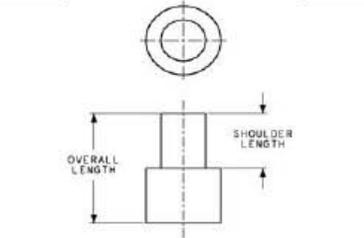
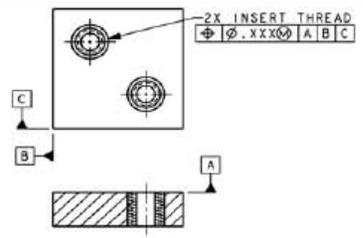
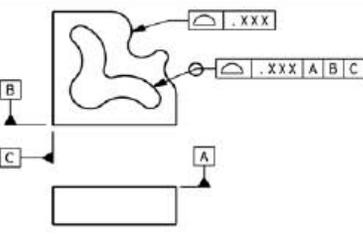
APPENDIX A–Commonly Used Thread Data

| | External Threads | External Threads | | Internal Threads | Internal Threads | Pitch |
|--------------------|---|--|--|---|--|--|
| | Model Shaft Geometry to This Mean of the Major Diameter | Model Cosmetic Thread feature to This Minor Diameter | | May use the nominal shown (same and Major diameter) for Cosmetic Thread | Model Hole Geometry to this Mean of the Minor Diameter | Use to calculate hole depth beyond thread depth (example: 0.012 x 3) |
| .060(#0)-80UNF-2A | 0.058 | 0.044 | | .060(#0)-80UNF-2B | 0.049 | 0.012 |
| .086(#2)-56UNC-2A | 0.083 | 0.064 | | .086(#2)-56UNC-2B | 0.070 | 0.018 |
| .086(#2)-64UNF-2A | 0.084 | 0.066 | | .086(#2)-64UNF-2B | 0.072 | 0.016 |
| .112(#4)-40UNC-2A | 0.109 | 0.081 | | .112(#4)-40UNC-2B | 0.089 | 0.025 |
| .112(#4)-48UNF-2A | 0.109 | 0.086 | | .112(#4)-48UNF-2B | 0.093 | 0.021 |
| .138(#6)-32UNC-2A | 0.134 | 0.099 | | .138(#6)-32UNC-2B | 0.109 | 0.031 |
| .138(#6)-40UNF-2A | 0.135 | 0.107 | | .138(#6)-40UNF-2B | 0.115 | 0.025 |
| .164(#8)-32UNC-2A | 0.160 | 0.125 | | .164(#8)-32UNC-2B | 0.135 | 0.031 |
| .164(#8)-36UNF-2A | 0.160 | 0.129 | | .164(#8)-36UNF-2B | 0.138 | 0.028 |
| .190(#10)-24UNC-2A | 0.185 | 0.138 | | .190(#10)-24UNC-2B | 0.151 | 0.042 |
| .190(#10)-32UNF-2A | 0.186 | 0.151 | | .190(#10)-32UNF-2B | 0.160 | 0.031 |
| .216(#12)-24UNC-2A | 0.211 | 0.164 | | .216(#12)-24UNC-2B | 0.176 | 0.042 |
| .216(#12)-28UNF-2A | 0.212 | 0.171 | | .216(#12)-28UNF-2B | 0.182 | 0.036 |
| .250-20UNC-2A | 0.245 | 0.188 | | .250-20UNC-2B | 0.202 | 0.05 |
| .250-28UNF-2A | 0.246 | 0.205 | | .250-28UNF-2B | 0.216 | 0.036 |
| .312-18UNC-2A | 0.307 | 0.243 | | .312-18UNC-2B | 0.259 | 0.056 |
| .312-24UNF-2A | 0.308 | 0.260 | | .312-24UNF-2B | 0.272 | 0.042 |
| .375-16UNC-2A | 0.369 | 0.297 | | .375-16UNC-2B | 0.314 | 0.063 |
| .375-24UNF-2A | 0.370 | 0.323 | | .375-24UNF-2B | 0.335 | 0.042 |
| .438-14UNC-2A | 0.431 | 0.349 | | .438-14UNC-2B | 0.368 | 0.071 |
| .438-20UNF-2A | 0.432 | 0.375 | | .438-20UNF-2B | 0.389 | 0.05 |
| .500-13UNC-2A | 0.493 | 0.404 | | .500-13UNC-2B | 0.426 | 0.077 |
| .500-20UNF-2A | 0.495 | 0.437 | | .500-20UNF-2B | 0.452 | 0.05 |
| .562-12UNC-2A | 0.555 | 0.459 | | .562-12UNC-2B | 0.481 | 0.083 |
| .562-18UNF-2A | 0.557 | 0.493 | | .562-18UNF-2B | 0.509 | 0.056 |
| .625-11UNC-2A | 0.617 | 0.512 | | .625-11UNC-2B | 0.537 | 0.091 |
| .562-12UNC-2A | 0.555 | 0.459 | | .562-12UNC-2B | 0.481 | 0.083 |
| .562-18UNF-2A | 0.557 | 0.493 | | .562-18UNF-2B | 0.509 | 0.056 |
| .625-11UNC-2A | 0.617 | 0.512 | | .625-11UNC-2B | 0.537 | 0.091 |
| .625-18UNF-2A | 0.619 | 0.555 | | .625-18UNF-2B | 0.572 | 0.056 |
| .750-10UNC-2A | 0.742 | 0.626 | | .750-10UNC-2B | 0.653 | 0.1 |
| .750-16UNF-2A | 0.744 | 0.672 | | .750-16UNF-2B | 0.689 | 0.063 |
| .875-9UNC-2A | 0.866 | 0.737 | | .875-9UNC-2B | 0.767 | 0.11 |
| .875-14UNF-2A | 0.868 | 0.786 | | .875-14UNF-2B | 0.806 | 0.071 |
| 1.000-8UNC-2A | 0.990 | 0.845 | | 1.000-8UNC-2B | 0.878 | 0.125 |
| 1.000-12UNF-2A | 0.992 | 0.896 | | 1.000-12UNF-2B | 0.919 | 0.083 |

APPENDIX B—Feature Tolerance Guide

Feature Tolerance Guide

This guide provides general feature tolerance information. GD&T notation per ASME Y14.5M-1994, is shown for reference only. Actual dimensioning schemes and GD&T callouts may vary based on design intent. In some cases, General Requirements Specification 9900000 may be used to control coaxiality and/or perpendicularity in lieu of GD&T callouts.

| Turned Cylinder | Turned Threaded Cylinder | Threaded Block | Countersink |
|---|---|--|--|
|  <p>SHAFT $\Phi .XXX \text{ (B)}$ BORE $\Phi .XXX \text{ (B)}$ DATUM A B</p> |  <p>EXTERNAL THREAD $\Phi .XXX \text{ (B)}$ INTERNAL THREAD $\Phi .XXX \text{ (B)}$ DATUM A B</p> |  <p>2X THREAD $\Phi .XXX \text{ (A B C)}$ A B C</p> |  <p>2X CSINK DIA CSINK ANGLE</p> |
| Counterbore | Chamfer or Round | Round Boss | Straight Slot |
|  <p>2X CBORE DIA $\Phi .XXX \text{ (C)}$ CBORE DEPTH DATUM C</p> |  <p>CHAMFER FILLET/ROUND</p> |  <p>2X BOSS $\Phi .XXX \text{ (A B C)}$ A B C</p> |  <p>2X LENGTH $\Phi .XXX \text{ (A B C)}$ BOUNDARY 2X WIDTH $\Phi .XXX \text{ (A B C)}$ BOUNDARY A B C</p> |
| Block with Pocket | Turned Length | Threaded Insert | Irregular Shape |
|  <p>LENGTH POCKET DEPTH DEPTH TO DIA RATIO DEFINES MIN RADIUS</p> |  <p>OVERALL LENGTH SHOULDER LENGTH</p> |  <p>2X INSERT THREAD $\Phi .XXX \text{ (A B C)}$ A B C</p> |  <p>$\Phi .XXX$ $\Phi .XXX \text{ (A B C)}$ A B C</p> |

Appendix B, Cont'd—Feature Tolerance Guide

| Feature Description | | Depth to Diameter Ratio or Size | Size Tolerance (+/-) | | | Position \oplus | | | Perpendicularity \blacklozenge | | |
|--------------------------|---------------------------------|---------------------------------------|--|---------------|---------------|-------------------|--------------|--------------|---|--------------|---------------|
| | | | Low \$ | Med \$ | High \$ | Low \$ | Med \$ | High \$ | Low \$ | Med \$ | High \$ |
| Turned Cylinder | Shaft | Less than or equal to 4:1 \clubsuit | 0.005 | 0.003 | 0.0005 | 0.014 | 0.003 | 0.001 | 0.002 | 0.001 | 0.0005 |
| | | | <i>0.001</i> | <i>0.0002</i> | <i>0.0001</i> | <i>0.003</i> | <i>0.002</i> | <i>0.001</i> | 0.005 | 0.003 | 0.001 |
| | Bore \blacksquare | Less than 3:1 \clubsuit | 0.005 | 0.003 | 0.0005 | 0.014 | 0.005 | 0.002 | 0.005 | 0.003 | 0.001 |
| | | | <i>0.001</i> | <i>0.0002</i> | <i>0.0001</i> | <i>0.003</i> | <i>0.002</i> | <i>0.001</i> | <i>0.002</i> | <i>0.001</i> | <i>0.0005</i> |
| Turned Threaded Cylinder | External Thread | Less than or equal to 4:1 \clubsuit | Class 1A | Class 2A | Class 3A | 0.010 | 0.007 | 0.003 | 0.014 | 0.005 | 0.0005 |
| | Internal Thread | Less than or equal to 2:1 \clubsuit | Class 1B | Class 2B | Class 3B | 0.014 | 0.007 | 0.003 | 0.010 | 0.005 | 0.001 |
| Threaded Block | Thread | Less than or equal to 2:1 \clubsuit | Class 1B | Class 2B | Class 3B | 0.014 | 0.007 | 0.003 | 0.010 | 0.005 | 0.001 |
| Countersink | Csink Angle | n/a | 3.0° | 2.0° | 1.0° | n/a | n/a | n/a | n/a | n/a | n/a |
| | Csink Diameter \blacksquare | n/a | 0.015 | 0.010 | 0.005 | n/a | n/a | n/a | n/a | n/a | n/a |
| Counterbore | Cbore Diameter | Less than or equal to 4:1 \clubsuit | For tolerance information, see hole tolerance guide on reverse | | | 0.014 | 0.007 | 0.003 | n/a | n/a | n/a |
| | Cbore Depth | Less than or equal to 4:1 \clubsuit | 0.008 | 0.004 | 0.001 | n/a | n/a | n/a | n/a | n/a | n/a |
| Chamfer or Round | Chamfer Edge | 1 inch max size | 0.015 | 0.010 | 0.002 | n/a | n/a | n/a | n/a | n/a | n/a |
| | Round Edge \blacksquare | 1 inch max size | 0.015 | 0.010 | 0.002 | n/a | n/a | n/a | n/a | n/a | n/a |
| Round Boss | Round Boss \blacklozenge | Less than 1:1 \clubsuit | 0.005 | 0.003 | 0.0005 | 0.010 | 0.005 | 0.002 | 0.005 | 0.003 | 0.001 |
| | | 1:1 to 2:1 \clubsuit | 0.007 | 0.005 | 0.001 | 0.014 | 0.007 | 0.003 | 0.005 | 0.003 | 0.001 |
| Straight Slot | Length and Width \blacksquare | Less than 2:1 \clubsuit | 0.015 | 0.003 | 0.001 | 0.020 | 0.010 | 0.005 | 0.005 | 0.002 | 0.001 |
| | | 2:1 to 4:1 \clubsuit | 0.005 | 0.002 | 0.0005 | 0.020 | 0.006 | 0.002 | 0.003 | 0.001 | 0.0005 |
| | | | 0.020 | 0.005 | 0.002 | 0.020 | 0.010 | 0.005 | 0.010 | 0.004 | 0.002 |
| Block with Pocket | Pocket Depth | Less than or equal to 4:1 \clubsuit | 0.008 | 0.004 | 0.002 | n/a | n/a | n/a | n/a | n/a | n/a |
| | Length | n/a | 0.010 | 0.005 | 0.002 | n/a | n/a | n/a | n/a | n/a | n/a |
| Turned Length | Overall Length | n/a | 0.010 | 0.005 | 0.001 | n/a | n/a | n/a | n/a | n/a | n/a |
| | Shoulder Length | n/a | 0.005 | 0.002 | 0.0005 | n/a | n/a | n/a | n/a | n/a | n/a |
| Threaded Insert | Helicoils | n/a | n/a | n/a | n/a | 0.014 | 0.007 | 0.003 | 0.010 | 0.005 | 0.001 |
| | Inserts | n/a | n/a | n/a | n/a | 0.022 | 0.015 | 0.011 | 0.018 | 0.013 | 0.009 |
| Feature Description | | Feature Size Envelope | Profile | | | Profile to Itself | | | | | |
| Irregular Shape | Profile \heartsuit | Less than 1 X 1 | 0.020 | 0.010 | 0.004 | 0.010 | 0.006 | 0.002 |  | | |
| | | 1 X 1 to 4 X 4 | 0.020 | 0.014 | 0.006 | 0.015 | 0.010 | 0.003 | | | |
| | | 4 X 4 to 12 X 12 | 0.030 | 0.018 | 0.012 | 0.030 | 0.014 | 0.004 | | | |

Legend:

| |
|---|
| Low Precision; low cost |
| Tolerances are easily met using conventional machining methods. Inspection can be performed in a simple, open setup environment. APPROXIMATE EXPECTED YIELD RATE OF 99% |
| Precision; medium cost |
| Tolerances may require newer, modern types of machining equipment or technology and may represent the upper limit of production capability. Inspection may require the use of an optical comparator or CMM equipment. APPROXIMATE EXPECTED YIELD RATE OF 87% |
| High Precision; high cost |
| Tolerances can be achieved using unique, specialized or slower, more precise machining methods or technology. Additional machining operations are often necessary. Inspection is difficult, requiring the industry's best available equipment. APPROXIMATE EXPECTED YIELD RATE OF 50% |

General Notes:

- Tolerances shown define the tolerance limits within each precision range. When possible, use low precision tolerances or less while maintaining design intent.
- Tolerances apply to:
 - A 12 inch cube maximum size envelope. Tolerances shown in *blue italics* may be used for sizes less than a 1 inch cube.
 - Aluminum and steel (common alloys and stainless) with Rockwell hardness of 40 or less.
- All units are in inches unless otherwise specified.
- Thread tolerances apply to the pitch diameter.
- Consult with manufacturing and inspection for tolerance information on the following:
 - Rework, modified parts, or non-machined stock surfaces
 - Thin walls, sheets, and limited access features
 - Features machined into curved surfaces
 - Features and inserts with a projected tolerance zone

Symbol Notes:

- \clubsuit Cutting tool engagement with respect to cutting tool diameter.
- \clubsuit Overall feature length with respect to feature diameter or size.
- \blacklozenge Optional orientation refinement relative to datum A.
- \blacksquare Tolerances apply to standard size features (increments of 1/64; 1/16 for csink). Non-standard sizes may result in additional cost.
- \blacklozenge As a general rule, the minimum gap between bosses or between a boss and another feature is 1/4 the boss height. This condition as well as the depth to diameter ratio must be satisfied.
- \heartsuit Profile tolerances apply to 2D applications. Consult manufacturing for 3D applications. Ratio of cutting tool engagement with respect to cutting tool diameter is less than or equal to 1:1.



Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under Contract DE-AC04-94AL85000.

Guide Developed By
Sandia National Laboratories
Albuquerque, New Mexico 87185
SAND2005-5290P, Issue B, April 2006

APPENDIX C–Hole Tolerance and Surface Texture Guide

Hole Tolerance Guide

This guide provides general hole tolerance information. GD&T notation per ASME Y14.5M-1994, is shown for reference only. Actual dimensioning schemes and GD&T callouts may vary based on design intent.

| Holes | | | | Feature Description | | | Size Tolerance | | | Position \oplus | | | Perpendicularity \perp | | | | | | | | | | | |
|--------------------|---------------------|---------------|-----------------------|---|------------|--------------------|---------------------|---------------|-----------------------|--------------------------|------------|--------------------|--------------------------|---------------|-----------------------|---------------------|------------|--|---------------|--|--|-----------------------|--|--|
| | | | | Hole Diameter | | | Hole Depth | | | Drill Depth \heartsuit | | | Hole Size Range | | | Standard Drill Size | | | Deoimal Equiv | | | Tolerance \clubsuit | | |
| | | | | See Below depth to diameter ratio less than or equal to 4:1 \bullet | | | 0.010 0.005 0.001 | | | 0.010 0.005 0.003 | | | 0.014 0.007 0.003 | | | 0.003 0.002 0.0005 | | | | | | | | |
| | | | | 0.003 0.007 0.0005 | | | n/a n/a n/a | | | n/a n/a n/a | | | n/a n/a n/a | | | | | | | | | | | |
| | | | | 0.010 0.005 0.003 | | | n/a n/a n/a | | | n/a n/a n/a | | | n/a n/a n/a | | | | | | | | | | | |
| | | | | 0.010 0.005 0.003 | | | n/a n/a n/a | | | n/a n/a n/a | | | n/a n/a n/a | | | | | | | | | | | |
| | | | | 0.010 0.005 0.003 | | | n/a n/a n/a | | | n/a n/a n/a | | | n/a n/a n/a | | | | | | | | | | | |
| Hole Size Range | Standard Drill Size | Deoimal Equiv | Tolerance \clubsuit | | | Hole Size Range | Standard Drill Size | Deoimal Equiv | Tolerance \clubsuit | | | Hole Size Range | Standard Drill Size | Deoimal Equiv | Tolerance \clubsuit | | | | | | | | | |
| | | | Low $\$$ | Med $\$$ | High $\$$ | | | | Low $\$$ | Med $\$$ | High $\$$ | | | | Low $\$$ | Med $\$$ | High $\$$ | | | | | | | |
| 0 thru 0.0465 | 80 | 0.0138 | + 0.003 - 0.001 | +/- 0.0015 | +/- 0.0002 | 0.0996 thru 0.1495 | 38 | 0.1015 | + 0.005 - 0.001 | +/- 0.0025 | +/- 0.0002 | 0.2970 thru 0.5312 | N | 0.3020 | + 0.010 - 0.002 | +/- 0.003 | +/- 0.0003 | | | | | | | |
| | 79 | 0.0145 | | | | | 37 | 0.1045 | | | | | 5/16 | 0.3125 | | | | | | | | | | |
| | 1/64 | 0.0156 | | | | | 36 | 0.1065 | | | | | O | 0.3160 | | | | | | | | | | |
| | 78 | 0.0160 | | | | | 7/64 | 0.1094 | | | | | P | 0.3230 | | | | | | | | | | |
| | 77 | 0.0180 | | | | | 35 | 0.1100 | | | | | 21/64 | 0.3281 | | | | | | | | | | |
| | 76 | 0.0200 | | | | | 34 | 0.1110 | | | | | Q | 0.3320 | | | | | | | | | | |
| | 75 | 0.0210 | | | | | 33 | 0.1130 | | | | | R | 0.3390 | | | | | | | | | | |
| | 74 | 0.0225 | | | | | 32 | 0.1160 | | | | | 11/32 | 0.3438 | | | | | | | | | | |
| | 73 | 0.0240 | | | | | 31 | 0.1200 | | | | | S | 0.3480 | | | | | | | | | | |
| | 72 | 0.0250 | | | | | 1/8 | 0.1250 | | | | | T | 0.3580 | | | | | | | | | | |
| | 71 | 0.0260 | | | | | 30 | 0.1285 | | | | | 23/64 | 0.3594 | | | | | | | | | | |
| | 70 | 0.0280 | | | | | 29 | 0.1360 | | | | | U | 0.3680 | | | | | | | | | | |
| | 69 | 0.0292 | | | | | 28 | 0.1405 | | | | | 3/8 | 0.3750 | | | | | | | | | | |
| | 68 | 0.0310 | | | | | 9/64 | 0.1405 | | | | | V | 0.3770 | | | | | | | | | | |
| | 67 | 0.0320 | | | | | 27 | 0.1440 | | | | | W | 0.3860 | | | | | | | | | | |
| | 66 | 0.0330 | | | | | 26 | 0.1470 | | | | | 25/64 | 0.3906 | | | | | | | | | | |
| | 65 | 0.0350 | | | | | 25 | 0.1495 | | | | | X | 0.3970 | | | | | | | | | | |
| | 64 | 0.0360 | | | | | 24 | 0.1520 | | | | | Y | 0.4040 | | | | | | | | | | |
| | 63 | 0.0370 | | | | | 23 | 0.1540 | | | | | 13/32 | 0.4062 | | | | | | | | | | |
| | 62 | 0.0380 | | | | | 5/32 | 0.1562 | | | | | Z | 0.4130 | | | | | | | | | | |
| 61 | 0.0390 | 22 | 0.1570 | 27/64 | 0.4219 | | | | | | | | | | | | | | | | | | | |
| 60 | 0.0400 | 21 | 0.1590 | 7/16 | 0.4375 | | | | | | | | | | | | | | | | | | | |
| 59 | 0.0410 | 20 | 0.1610 | 29/64 | 0.4531 | | | | | | | | | | | | | | | | | | | |
| 58 | 0.0420 | 19 | 0.1660 | 15/32 | 0.4688 | | | | | | | | | | | | | | | | | | | |
| 57 | 0.0430 | 18 | 0.1695 | 31/64 | 0.4844 | | | | | | | | | | | | | | | | | | | |
| 56 | 0.0465 | 17 | 0.1730 | 1/2 | 0.5000 | | | | | | | | | | | | | | | | | | | |
| 0.0466 thru 0.0995 | 3/64 | 0.0469 | + 0.004 - 0.001 | +/- 0.002 | +/- 0.0002 | 0.1496 thru 0.1990 | 11/64 | 0.1719 | + 0.006 - 0.001 | +/- 0.0025 | +/- 0.0003 | 0.5313 thru 0.9375 | 33/64 | 0.5156 | + 0.012 - 0.003 | +/- 0.003 | +/- 0.0003 | | | | | | | |
| | 55 | 0.0520 | | | | | 16 | 0.1770 | | | | | 17/32 | 0.5312 | | | | | | | | | | |
| | 54 | 0.0550 | | | | | 15 | 0.1800 | | | | | 35/64 | 0.5469 | | | | | | | | | | |
| | 53 | 0.0595 | | | | | 14 | 0.1820 | | | | | 9/16 | 0.5625 | | | | | | | | | | |
| | 1/16 | 0.0625 | | | | | 13 | 0.1850 | | | | | 37/64 | 0.5781 | | | | | | | | | | |
| | 52 | 0.0635 | | | | | 3/16 | 0.1875 | | | | | 19/32 | 0.5938 | | | | | | | | | | |
| | 51 | 0.0670 | | | | | 12 | 0.1890 | | | | | 39/64 | 0.6094 | | | | | | | | | | |
| | 50 | 0.0700 | | | | | 11 | 0.1910 | | | | | 5/8 | 0.6250 | | | | | | | | | | |
| | 49 | 0.0730 | | | | | 10 | 0.1935 | | | | | 41/64 | 0.6406 | | | | | | | | | | |
| | 48 | 0.0760 | | | | | 9 | 0.1960 | | | | | 21/32 | 0.6562 | | | | | | | | | | |
| | 47 | 0.0785 | | | | | 8 | 0.1990 | | | | | 43/64 | 0.6719 | | | | | | | | | | |
| | 46 | 0.0810 | | | | | 7 | 0.2010 | | | | | 11/16 | 0.6875 | | | | | | | | | | |
| | 45 | 0.0820 | | | | | 13/64 | 0.2031 | | | | | 45/64 | 0.7031 | | | | | | | | | | |
| | 44 | 0.0860 | | | | | 6 | 0.2040 | | | | | 23/32 | 0.7188 | | | | | | | | | | |
| | 43 | 0.0890 | | | | | 5 | 0.2055 | | | | | 47/64 | 0.7344 | | | | | | | | | | |
| | 42 | 0.0935 | | | | | 4 | 0.2090 | | | | | 3/4 | 0.7500 | | | | | | | | | | |
| | 3/32 | 0.0938 | | | | | 3 | 0.2130 | | | | | 49/64 | 0.7656 | | | | | | | | | | |
| | 41 | 0.0960 | | | | | 7/32 | 0.2188 | | | | | 25/32 | 0.7812 | | | | | | | | | | |
| | 40 | 0.0980 | | | | | 2 | 0.2210 | | | | | 51/64 | 0.7969 | | | | | | | | | | |
| | 39 | 0.0995 | | | | | 1 | 0.2290 | | | | | 13/16 | 0.8125 | | | | | | | | | | |
| 0.1991 thru 0.2969 | A | 0.2340 | + 0.007 - 0.002 | +/- 0.0025 | +/- 0.0003 | 0.1991 thru 0.2969 | 15/64 | 0.2344 | + 0.007 - 0.002 | +/- 0.0025 | +/- 0.0003 | 0.9376 thru 1.000 | 53/64 | 0.8281 | + 0.015 - 0.003 | +/- 0.003 | +/- 0.0003 | | | | | | | |
| | 1 | 0.2390 | | | | | 27/32 | 0.8438 | | | | | | | | | | | | | | | | |
| | 15/64 | 0.2344 | | | | | B | 0.2380 | | | | | 55/64 | 0.8594 | | | | | | | | | | |
| | 1 | 0.2420 | | | | | C | 0.2420 | | | | | 7/8 | 0.8750 | | | | | | | | | | |
| | 1/4 (E) | 0.2500 | | | | | D | 0.2460 | | | | | 57/64 | 0.8906 | | | | | | | | | | |
| | F | 0.2570 | | | | | 1 | 0.2610 | | | | | 29/32 | 0.9062 | | | | | | | | | | |
| | G | 0.2610 | | | | | 17/64 | 0.2656 | | | | | 59/64 | 0.9219 | | | | | | | | | | |
| | H | 0.2650 | | | | | 1 | 0.2720 | | | | | 15/16 | 0.9375 | | | | | | | | | | |
| | I | 0.2720 | | | | | 1 | 0.2770 | | | | | 61/64 | 0.9531 | | | | | | | | | | |
| | J | 0.2770 | | | | | 1 | 0.2810 | | | | | 31/32 | 0.9688 | | | | | | | | | | |
| | K | 0.2810 | | | | | 9/32 | 0.2812 | | | | | 63/64 | 0.9844 | | | | | | | | | | |
| | L | 0.2900 | | | | | 1 | 0.2950 | | | | | 1 | 1 | | | | | | | | | | |
| M | 0.2950 | 19/64 | 0.2965 | | | | | | | | | | | | | | | | | | | | | |

Appendix C, Cont'd–Hole Tolerance and Surface Texture Guide

Legend:

| Low Precision; low cost |
|---|
| Tolerances are easily met using conventional machining methods. Inspection can be performed in a simple, open setup environment. APPROXIMATE EXPECTED YIELD RATE OF 99%. |

| Precision; medium cost |
|--|
| Tolerances may require newer, modern types of machining equipment or technology and may represent the upper limit of production capability. Inspection may require the use of an optical comparator or CMM equipment. APPROXIMATE EXPECTED YIELD RATE OF 87%. |

| High Precision; high cost |
|---|
| Tolerances can be achieved using unique, specialized or slower, more precise machining methods or technology. Additional machining operations are often necessary. Inspection is difficult, requiring the industry's best available equipment. APPROXIMATE EXPECTED YIELD RATE OF 50%. |

General Notes:

- Tolerances shown define the tolerance limits within each precision range. When possible, use low precision tolerances or less while maintaining design intent.
- Tolerances apply to:
 - A 12 inch cube maximum size envelope. Tolerances shown in *blue italics* may be used for sizes less than a 1 inch cube and to hole sizes with a .150 maximum diameter.
 - Aluminum and steel (common alloys and stainless) with Rockwell hardness of 40 or less.
- All units are in inches unless otherwise specified.
- Consult with manufacturing and inspection for tolerance information on the following:
 - Holes that require modification
 - Holes with limited access
 - Holes machined into curved surfaces
 - Holes with a projected tolerance zone

Symbol Notes:

- Cutting tool engagement with respect to cutting tool diameter.
- ▲ Optional orientation refinement relative to datum A.
- ♣ Low precision tolerances apply to conventional drilling operations using standard drill sizes. Medium and high precision tolerances may require secondary machining operations and/or additional in-process controls.
- Drill sizes shown as reference information only.
- ♥ Specify MIN, MAX, "DO NOT BREAK THRU" or "MIN WALL THICKNESS" when design intent allows.

Surface Texture Tolerance Guide

| Units | Operation | Low \$ | Med \$ | High \$ |
|-------------|-----------|-------------|-------------|------------|
| Microinches | Turned | 63/ and up | 63/ to 32/ | 32/ to 8/ |
| | Milled | 125/ and up | 125/ to 63/ | 63/ to 32/ |

| Units | Operation | Low \$ | Med \$ | High \$ |
|-------------|-----------|-------------|--------------|--------------|
| Micrometers | Turned | 1.6/ and up | 1.6/ to 0.8/ | 0.8/ to 0.2/ |
| | Milled | 3.2/ and up | 3.2/ to 1.6/ | 1.6/ to 0.8/ |

General Note:

- Consult with manufacturing and inspection when the lay or direction of tool marks is critical.



Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under Contract DE-AC04-94AL85000.

Guide Developed By
Sandia National Laboratories
Albuquerque, New Mexico 87185
SAND2005-5290P, Issue B, April 2006

APPENDIX D–Accepting and Incorporating Change to this Document

Following is the process an MCAD user shall use to ensure that comments, questions, feedback, and requests that may affect the annual update of this document:

1. Access the TeamTrack utility via the following link:
 - a. <https://teamtrack.sandia.gov/tmtrack/tmtrack.dll>
2. Select the *Submit* link
3. Select the *MCAD Guide* type in the *Request Type* dropdown menu
4. Enter the requested change in the *Description:* field
 - a. Refer to specific page numbers and paragraphs
5. Select *OK* located at the top of the page.

Your input will be issued an identification number and marked as Open. This mechanism will capture designer feedback during the fiscal year. Upon a predetermined schedule, the feedback will be output to a spreadsheet, considered for inclusion in this document, and the respective feedback requests will be closed in TeamTrack.

After editing this document with respect to new developments in technology, updated or new PRS and TBP requirements, system architecture, and designer feedback, an updated MCAD Guide will be released as a separate SAND report and published with the title tagged to match the upcoming fiscal year.

New installments of this document will be available at the beginning of each fiscal year.

DISTRIBUTION

| | | |
|---|--------|---|
| 1 | MS0639 | Mark Terhune, 2900 |
| 1 | MS0648 | Rick Harris, 2990 |
| 1 | MS0374 | Howard Walther, 2991 |
| 1 | MS0648 | Jack Martinez, 2992 |
| 1 | MS0628 | Sharon Trauth, 2993 |
| 1 | MS0624 | Tim Meeks, 2994 |
| 1 | MS0625 | Rich Graham, 2995 |
| 1 | MS0464 | Tony Hernandez, 2996 |
| 1 | MS0648 | Nick DeReu, 2997 |
| 1 | MS0464 | Fran Current, 2998 |
| 1 | MS4536 | Technical Library, 9536 (electronic copy) |

