

Design Standards & Best Practices for CADD/CAM/CNC

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This document shall provide guidelines for understanding and implementing the ETSU design standards and best practices as well as file and layer naming conventions within the CADD/CAM/CNC disciplines. This standard is recommended for use within the CADD, CNC, and various design/prototype/build classes offered within the curricula of the Engineering Technology manufacturing-related programs (e.g., Industrial Technology, Manufacturing ET, & Product Development). When followed, these guidelines will facilitate communication within design teams, prevent errors and speed up troubleshooting.

CADD Standards:

- **Scale:**
 - **Design to scale (i.e., use 1:1 "Model Space").**
Generally, you can mess with scaling in "Paper Space" for generating hardcopies.

- **Layer vs. Object Properties:**
Set property features (e.g., color, line type, line weight, etc.) by layer whenever possible. Only change an object's properties "locally" when absolutely necessary for same-layer differentiation; this includes text objects. (i.e., most object properties for color, line type and line weight should be "By Layer.")

- **Color-coded Layers:**
 - **Default ("0")—(Black)**
 - **Dimensions—All types (Red)**
 - **Edges—Top (UPR) side &/or exterior (EXT) geometry (Blue, shades of);**
 - **Edges—Bottom (LWR) side &/or interior (INT) geometry (Green, shades of);**
Note: "bottom" data may need to be mirrored when machining face-up
 - **Electronic components (Gray, lighter shades of)**
 - **Origin/Important Points (Orange)**
 - **Points—Construction/Tracing (Orange/Browns, shades of)**
 - **Reference geometry (Gray, darker shades of)**
 - **Toolpaths—Centerline (Pink/Purple, shades of)**

Notes: Color coded layers are more of a quick visual check for preventing &/or catching errors. Color choices should be individually adjusted as required to make accommodation for color blindness. Recommended colors are optimized for plotting (i.e., a white drawing background, not the AutoCAD default background color of black).

- **File Naming:**
 - **Use capitalized first letter and dash and/or underline separators instead of spaces.**
 - **Use numerical designators to track major design evolution and design-level changes**
 - "Model" or "Mod" (e.g., "Mod02," "M02," or "02")
 - For pre-prototype development, use "Mod00" or "Beta00"
 - For first physical prototype, begin as "Mod01."
 - **Use alpha characters (-, A, B, C, D, etc.) designators to track minor/incremental design changes or document-level "revisions".**
 - Start with either "NoRev" or "Rev-" for first document "release."
 - Subsequent revisions sequence from A through Z (exceptions: skip "I," "O" & "Q") then continue with "AA," "AB," "AC," etc.

- **DWG & 3DM Native Format—Use an appropriately readable “Long File Name” to provide authorship, project description, design precedence and revision status:**
 - Project_Name-Model_No-Rev_Letter
(e.g., Dynamo15_Mod01_RevC.dwg)
 - Creator_Name-Project_Name-Model_No-Rev_Letter
(e.g., Smith_JB-FireX_M03_NoRev.dwg)
- **DXF-R12:**
 - DXF-designated files are used for data transfer among CADD applications and/or denote special-purpose types of CADD files with limited and/or specially formatted data, often machine specific.
 - There are numerous versions of the DXF file format. The most popular with equipment manufacturers and other CADD systems is the DXF-R12 format found at the very bottom of the drop down list in AutoCAD list.
 - Keep layer names that will be exported to DXF-R12 format limited to no more than twenty-six (26) characters. Any/all characters past the 26 limit are simply truncated and tossed into in the bit bucket. Name things accordingly.
 - Mixed case named layers exported and saved in DXF-R12 format by AutoCAD are converted to all upper case.
- **Best Practices (Device-specific Rules & Recommendations)**
 - **AXYZ CNC Router**
 - Export only desired tool paths; no edges or reference geometry.
 - Use the “COPYBASE” command & select appropriate (locked) origin;
 - Begin “New” drawing; select “Open with no template — Imperial;”
 - Paste at “0,0”
 - File -> “Save As” in “AutoCAD R12/LT2 DXF (*.dxf)” format.
 - After exporting, change the named layers to an appropriate group name:
 - Use ALL CAPS for the group (color) names
 - Choose the appropriate matching layer color from the short primary list
 - Objects on the “GRAY” layer/group will import in the GREEN group.
 - Using MS-DOS-style 8.3 “filename.ext” type of file name provides notable benefits:
 - Differentiates toolpath-only file from the project’s other design data file(s);
 - The AXYZ Toolpath program saves Ready (RDY) files only in the 8.3 DOS format; pre-naming the DXF file to 8-3 filename sets the default file name.
 - **ULS Laser engraver/cutter:**
 - For most CADD-based laser engraving/cutting/marking applications, there are basically only three (3) effective “shades of gray:” White [untouched], very light gray [low (18 to 25%) power burn] and black [high power burn]. For images with desired multiple shades of gray, it is suggested using some sort of raster etched “halftone” image (Hint: Use the ULS “One Touch Photo” application.).
 - Most CADD-based laser projects need only one or more of the following layers with the following layer (or object) properties:
 - Raster_Etch: Color: **Black** (or light (18 – 25%) gray); line weight: default
 - Vector_Etch: Color: **Blue**; line weight; 0 mm and
 - Vector_Cut: Color: **Red**; line weight; 0 mm.
 - If your drawing has any type of solid fill (i.e., Hatch Pattern = “Solid”), always save only in the native DWG format. **NEVER EVER** save file(s) with solid fills (or solid hatch patterns) in DXF-R12 format; the file size will increase an order of magnitude or two.
 - **OMAX abrasive water jet:**
 - During development, export desired edge data only; save file in R12 DXF format.
 - In the R12 DXF file, rename the layer edge to the desired number of quality of cut (typically “3”) and set the default color of the layer to “black” (or “white” if using the default black background).
 - Highlight all edge geometry and change the object color properties to “3” (green).

- **Best Practices (CNC General—Rules & Recommendations)**
 - **Work from the “0” or “Default” Layer Then Push Your Design to the Proper Layer(s)**
 - To reduce the likelihood of accidentally changing “good” data (e.g., developed edges when creating tool paths), move active geometry to a neutral “working” layer (e.g., “0” or “Default” layer). When applicable, new geometric data can be moved to or joined with data on the appropriate layer.
 - Once finalized, layer lock designed edges. When manually creating toolpaths from edge data:
 - a) unlock the edge data;
 - b) offset the edge(s) appropriately;
 - c) change the new, offset data to the neutral working layer (e.g., “0”);
 - d) re-lock the edge data layer; and then
 - e) go do the voodoo you need to do.
 - As edges are progressively optimized, segments can be joined with or added to the appropriate layer. (i.e., select geometry and use the “Join” (or “PEDIT” command in AutoCAD) to incorporate new segments into polyline(s) on the appropriate layer.)
 - Use the layer color and line weight properties to make things easier and reduce confusion as to what’s been done and what still needs work.
 - **Create Beautifully Smooth Ogee Curves**
 - Smooth, tangent transitions from line-to-arc or arc-to-arc are not just visually appealing but, in the CNC realm, also prevent unwanted “seams” due to momentary cutter dwelling as the cutter has to stop and change direction.
 - Object Snaps are your best friends. It is quite easy to use the 3-point circle command snapping to two existing arcs and a point (node) then trimming to create Ogee curves. Likewise the Tan-Tan-Tan circle command can be useful.
 - Extending the existing arcs prior may take a bit of time but you’ll reap rewards in fewer errors and missed tiny “untrimmed” stubs.
 - **Edges/Toolpaths Using Lines & Arcs vs. Splines & NURBS**
 - “Traditional” or legacy CNC controllers were created for 2D and 3D contouring using lines (G01) and arcs (G02 and G03)
 - Avoid NURBS, splines, ellipses, etc. if there is any chance that the CADD data may be exported one day to a CNC device with an older controller or proprietary CAM application that wants to see only linear and/or circular interpolation data (i.e. the basic directional G-Codes: G01, G02, & G03).
 - When using “Raster-to-Vector” applications to automate the generation of edges, further simplifying the resulting myriad “near tangent” minuscule straight line arc segments into actual Ogee curves will often enhance machine performance, part appearance and scalability. It’s OK to spend time making things better.
 - **Pay Attention To Minimum Internal Radii**
 - Ensure that cutter(s) will actually fit into the desired internal cavities (i.e., the cutter radius cannot be larger than the internal edge radius). Adjust as required.
 - This holds true for operations down the line from the CNC mill or router. For example, as the bearing follower on round-over style router bits are typically ½” DIA, the internal radius for any post-CNC routed edge should be 0.250” or greater.
 - To avoid unwanted pauses and visible blemishes in the final edges, in addition to the required radius offset (R), add a minimum of 5-6% of the diameter (no final roughing pass) or 10-12% of the diameter (if including a final roughing pass). As an example, for a ½” DIA cutter on the AXYZ CNC router, use a minimum 0.313” internal radius. The extra offset ensures smooth, blemish-free cutter movement.
 - **Tool Path Direction Is Important.**
 - Given the rotation of the tool (CW from the perspective of the motor);
 - Internal pockets are to be machined with tool paths that travel clockwise (CW).
 - External machining tool paths are to travel counterclockwise (CCW).

- Top vs. Bottom Surfaces
 - If machining both the top and bottom surfaces of a product, it is necessary to **reverse the direction of the tools paths for the bottom data** in AutoCAD. To machine the bottom of the product, both the .DXF data and the product will be flipped; i.e. data will be mirrored and product will be physically turned over to machine the bottom side.
- **Curl On / Curl off**
 - To avoid a visible tooling mark where the cutter is introduced to the edge, tooling paths should be designed so that they “curl on”, with the tool approaching the product at a tangent to the edge, and likewise, “curl off” tangent to the edge.
 - Locate curl-on/curl-off transitions where they are most “invisible” to the end user (e.g., bottom inside corner of a leg or support).
 - Hint #1: a transition from an arc (to another arc, line, etc.) can be a good opportunity to extend the arc, and create the desired curl.
 - Hint #2: It is a best practice to conclude a finish pass along a long arc or straight line in a direction that is traveling away from the operator.
- **Internal “Islands”**
 - “Islands”—small, isolated columns of unrouted/unmilled material—are formed within pockets when centerline tool path step-overs do not sufficiently overlap.
 - When using the nominal 70% DIA step-over rule of thumb, islands will be generally found in tool paths containing acute angles (i.e., less than 90°).
 - Dropping circles equal to the cutter diameter along the centerline tool paths in question will expose uncut regions.
 - When a few islands are encountered, alter the centerline tools paths to extend slightly beyond the natural intersection an appropriate distance to eliminate the island and then tie the entry and exit lines together with a small (but not too small) fillet in a sort of loopy-loop.
 - For a large number of islands, begin the pocket entry with one clearing pass of a line, arc or ogeed arcs cutting through the island set.
- **Stepovers (Routing Internal Pockets):**
 - 2-½D Pocketing (i.e., flat bottom):
 - **Design from edges.** Create and finalize your desired edges prior to creating and optimizing your finishing and roughing centerline toolpaths. Ultimately, your finished part is a collection of desired edges; everything else is simply the path towards that goal (no pun intended).
 - For the best (i.e., most accurate and straightest) edges, especially in deep cuts, minimize tool deflection by including a “final roughing pass” offset nominally 5 to 10% of the tool diameter from the finish pass (i.e., the radius offset) [See table below].
 - As a general rule, when creating centerline toolpaths for clearing out the interior of a flat-bottomed pocket, choose a stepover offset that is either 70% (gross) or 30% (fine) of the cutter diameter. For “bull nose” or “bowl cutting” tools with radiused corners, calculate clearing offsets based upon the “flat” diameter.

- A “bowl cutting”-style router bit with a roundover feature impart a fillet between the “floor” and the side walls of a pocket. This fillet not only provides a more finished appearance but reduces stress concentrations in the corners making the product less prone to cracks and/or breakage.
 - Consider the geometry of the cutter, and identify how much (if any) of the cutter is flat. The overall radius of the cutter is the radius of the flat arear plus the fillet radius.
 - Although additional math and time are required, the benefits of increased strength and appearance outweigh the costs of increased design and run time and adding an additional tool path.

CNC Routing (Wood & Polymers) Finish, Final Roughing, & Stepoover Offsets for Common Router Bit Diameters (inches)				
Tool Bit DIA (inches)	Required	Suggested Stepoovers		
	Finish Pass Offset (Radius)	Final Roughing (6%) Offset	Rough Clearing 70% DIA	Fine Clearing 30% DIA
1/16 (0.0625)	0.03125	0.005	0.044	0.019
1/8 (0.125)	.0625	0.010	0.088	0.038
3/16 (0.1875)	.09375	0.013	0.131	0.056
1/4 (0.250)	0.125	0.015	0.175	0.075
3/8 (0.375)	0.1875	0.020	0.245	0.113
1/2 (0.500)	0.250	0.030	0.350	0.150
5/8 (0.625)	0.3125	0.038	0.438	0.188
3/4 (0.750)	0.375	0.045	0.525	0.225
1 (1.000)	0.500	0.060	0.700	0.300
1-1/8 (1.250)	0.5625	0.068	0.788	0.338
1-1/4 (1.250)	0.625	0.075	0.875	0.375
1-1/2 (1.250)	0.750	0.090	1.050	0.450
2 (2.000)	1.000	0.120	1.400	0.600
“Bowl Cutting” Router Bits—1/4 Radius				
3/4 (Bowl)	0.375	.030	0.175	0.075
1-1/4 (Bowl)	0.625	.030	0.525	0.225

- **Centerline Toolpath Creation Workflow for Pockets and Cut-outs**
 - CAM software will generate centerline tool paths based upon the boundary geometry (i.e., edges) and specified parameters including but not limited to cutter diameter, nominal step over value(s), finish pass, etc. The quality, completeness, efficiency of CAM-generate toolpaths is, of course, based upon the quality of the underlying algorithms. When a machine-generated toolpath is deemed sub-optimal, a knowledgeable CADD/CNC designer can typically create a single, polyline toolpath that is more efficient (i.e., faster running) &/or optimized than a first or second generation, computer-generated path.

- Design Tool Paths from Edges:
 - The product edges dictate the necessary tool path. Working from the product edge, the necessary step over distance can be calculated so that the tool will have the proper depth of cut. (See “Stepovers (Routing Internal Pockets)” above.)
 - **Step 1: Design the Product Edges**
 - Once the product edges have been designed (and the appropriate layers locked), edges can be offset, to create lines parallel to the product edge, at a calculated distance away from the edge.
 - **Step 2: Offset/Create the Finish Pass**
 - Machining/routing operations will require at least one pass or circuit offset by the cutter radius.
 - Where surface finish is particularly important, a “finish pass” will yield the best edges, and can help to eliminate visible tooling marks. Accordingly, a “final roughing pass” offset from the final, finish pass can help achieve better edges, especially in deep cuts. See Step 3 below for details.
 - The finish pass should have an appropriately located and sized “curl on” and “curl off” (see above).
 - For the best side-wall appearance, the finish pass should also occur at the full desired depth of cut (compared to any multi-pass (increasing depth) roughing passes). This often entails separate finishing and roughing passes.
 - **Step 3: Offset/Create the Final Roughing Pass (Optional)**
 - The final roughing pass should be offset 5 to 10% of the tool diameter from the finish pass.
 - The final roughing pass typically ends near but not at the full depth of cut (compared to the roughing passes, which may occur in several passes to achieve the desired depth. Thus, (with a bottom cutting router bit), both the final edge dimension and depth can be improved.
 - **Step 4: Offset/Create Design the Roughing &/or Pocket Clearing Pass(es)**
 - Consider the depth of material to be cleared. To avoid overloading the machine/tool, it is often necessary to multi-pass (i.e. repeating the same tooling paths at increasing depths to achieve the final depth desired).
 - The roughing pass should typically be offset either 70% (gross) or 30% (fine) of the cutter diameter, depending on how much material is to be removed.
 - **Step 5: Create Transitions & Join the Various Toolpath Elements into One Polyline**
 - Create smooth (Ogee) transitions between the passes. This includes curl-offs and/or curl-on geometry as necessary.
 - While working on complex pockets, some designers find it less confusing to work backwards (i.e., begin with curl-off of the final/finish pass then work your way into the pocket interior.
 - Use the “Join” or “PEDIT” command periodically to tie the various ranks of concentric toolpaths and transitions together.
 - **Best Practice:** Assigning the joined toolpath to a layer with a contrasting color (e.g., the appropriate centerline toolpath layer with pink/purple color assignment) and thicker line weight (e.g., 0.030 mm) while working from the Zero/Default layer (default color “white” and line thickness will provide an obvious demarcation between what has been completed and what needs to be completed.

Self-Organizing Named Layers for CADD/CAM/CNC:

The following layer naming convention was first inspired by Charles Simonyi's "Hungarian Notation," a computer science convention for naming variables to indicate data type &/or intended use. For an historical, general overview is available at the following URL: [https://msdn.microsoft.com/en-us/library/aa260976\(VS.60\).aspx](https://msdn.microsoft.com/en-us/library/aa260976(VS.60).aspx). While ISO 13567 (Technical product documentation – Organization and naming of layers for CAD) (URL: <https://www.iso.org/standard/70181.html>), the United States National CAD Standard® (NCS) (URL: <https://www.nationalcadstandard.org/ncs6/>)—including the American Institute of Architect's CAD Layer Guidelines—and the federal government's GSA/Public Buildings Service (PBS) CAD Standards (URL: <https://www.gsa.gov/real-estate/design-construction/cad-standards>) have all been developed by the construction industry for architectural/engineering (A/E) drawings and BIM-based modeling, there is no single recognized equivalent for mechanical &/or manufacturing industries. From years of experience incorporating evolving variants of the following layer naming convention in CAD/CAM/CNC projects, we have discovered that the use of logically named layers with appropriately embedded information speeds development reduces programming errors and aids in troubleshooting.

The basic configuration of the Self-Organizing Named Layers for CADD/CAM/CNC is as follows:

[Type ID{Orientation/Sequencing}_{DIA}]-[Descriptor_Major{-Descriptor_Minor}]

wherein:

- Strings within brackets—"[" & "]"—are required; strings within braces—"{" & "}"—are optional;
- the [Type_ID{Orientation}_{DIA_or_other}] string is the feature/function prefix;
- a single underline ("_") separates the Type_ID{Orientation} and DIA/other strings
- a single dash/hyphen ("-") separates the Type_ID and descriptor strings;
- the [Descriptor_Major{-Descriptor_Minor}] string is a descriptor for design information;
- (See **Descriptors for Design Information** section (below) for best practices)
- Items within braces are primarily informational for segregation of data and understanding; and
- dash/hyphen ("-") and underline ("_") characters are typically used as hierarchical separators (i.e., no spaces).

Feature/Function Prefix:

Type_ID:

2D	—	(3D) two dimensional geometric data
3D	—	(3D) three dimensional geometric data
BL	—	Object-free layer "package" for imported data (typically locked)
CP	—	(CNC) Centerline tool path
ED	—	Design or manufactured edge or contour (Alt: Edge)
EL	—	Electrical or electronic component (Alt: Elect or Electronics)
HY	—	Hydraulic/liquid component (Alt: Hydra or Hydraulic)
LO	—	(3D) 2D Lofting geometry
NT	—	Note (Alt: Note)
OP	—	Optional (Alt: OPT)
OR	—	Origin (world/machine, tooling, &/or local run)
PN	—	Pneumatic/gas component (Alt: Pneu)
PO	—	Point or node (Alt: Point)
RE	—	Reference item, low design priority or background data (Alt: REF)
SO	—	(3D) Solid or closed, watertight polysurface object (Alt: Solid)
SU	—	(3D) Surface object (Alt: Surf or Surface)
VC	—	Vacuum component (Alt: Vac or Vacuum)

Orientation/Sequencing:

B	—	Bottom side (typically requires mirroring of CNC data)
C	—	Centerline, center, central
Clr	—	Clearance
D	—	Dorsal side
EX	—	Exterior, outer
F	—	Finish (Alt: Fin, Finish)
IN	—	Interior, inner
LH	—	Left hand, port side
LW	—	Lower (Alt: LWR)
M	—	Middle, midline, medial
R	—	Roughing Cut/Pass (Alt: Ruf, Rough)
RH	—	Right hand, starboard side
T	—	Top side (Default if missing)
UP	—	Upper (Alt: UPR)
V	—	Ventral
W	—	Waterjet (specific)
Z	—	Laser (specific)

DIA_or_other:

9999	—	(CNC) tool bit diameter formatted as inch (implied decimal) to 3rd decimal For tool &/or reference measurements between 10.000" & 99.999" use "99999" Likewise for measurements between 100.000" & 999.999" use "999999"
9999mm	—	(CNC) metric tool bit DIA formatted as 99 mm (implied decimal) to 2nd decimal
9	—	(Waterjet) Quality of cut
TL	—	Tooling data

Descriptors for Design Information (i.e., Descriptors, Major &/or Minor):

- Limit total number of alpha-numeric characters to twenty-six (26) or less

Major Descriptors:

Best Practices:

- Use "sparse" names, acronyms, initials, &/or abbreviations (e.g., BRKT for bracket, MTG for mounting, LH for left-hand, UPR, for upper, etc.);
- Use "reverse" order (i.e., from general to specific)
(e.g., "BRKT, MTG, Camera, UPR LH" = upper left-hand camera mounting bracket);

Minor Descriptors:

Best Practices:

- When on an "exportable" layer (i.e., a layer that will be saved into a R12 DXF-formatted file subject to the 26 character name limit), use abbreviations & avoid unnecessary verbiage and/or modifiers (e.g., use "-F", "-FIN", or "-Finish" instead of "Finishing Pass" and "-R" or "-Rough" instead of "-Roughing Cut").

Examples:

CPB_0500-Cavity_Deep	.....	Centerline (tool) Path , Bottom side , ½" DIA cutter for the deep cavity pocket
CPB_TL_0500-T_Nut_Flush_Rough	.....	Centerline (tool) Path , Bottom side , TooLing ½" DIA cutter for the T-Nut rim (Flush mount pocket) ; Roughing pass
CPT_0188-Hole_Vol_Tone_Pot	.....	Centerline (tool) Path , Top side , 3/16" DIA cutter for THRU holes for the Volume & Tone Pots
CPZ-Cover-Lucy_4-Vector_Cut	.....	Centerline Path , Laser ; Cover for a model 4 Lucy (semi-hollow electric guitar), Vector Cut data
EDB-Cavity-Deep	.....	EDge , Bottom side of the Deep Cavity pocket
EL-Humbucker_Generic	.....	ELectronics , Generic Humbucker
EL-Switch-6_Position_Rotary-StewMac	.....	ELectronics , 6-Position Rotary Switch , (Stewart MacDonald , vendor)
REF-Fret_21_of 25500 String_Length	.....	REFerence data: Location of 21st Fret of 25-½" String Length