

Design for Manufacturing and Assembly Tips (HD Version)

Following is an expanded compilation of design & manufacturing knowledge that should help you consider how design decisions impact component costs. This document is likely the most concise, informative, and valuable material authored for this class to help with your career as a design engineer, so please give it the attention it deserves.

Part / Product Cost Reduction

Three major factors contribute to a product's expense: (1) designing costs, (2) manufacturing costs, and (3) assembly costs. **The best design engineers produce parts which achieve desired function at the lowest cost.** We reduce designing costs through experience as we become more efficient performing design, analysis, prototyping, and testing. We reduce manufacturing costs via DFM (design for manufacturing), by becoming incredibly knowledgeable about every possible manufacturing process available (which is a huge amount of learning, so don't be discouraged!). And we reduce assembly costs via DFA (design for assembly), by continuously observing and improving the processes used to assemble our designs.

Great design engineers strive to constantly improve their efficiency, in turn reducing the designing costs associated with their projects. When it comes to reducing the manufacturing and assembly costs, however, sometimes this can happen in unison (the proverbial win-win!) and sometimes it cannot. When we cannot simultaneously improve a part's ease of manufacturing and its ease of assembly, we must prioritize which is more important, and bias our design towards that goal. Regardless, it should be clear that understanding common methods of DFM and DFA is one of the most proven ways to improve your value as a designer.

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1. **Anderson's Law.** Never design a part you can buy out of a catalog unless you can clearly justify the choice (i.e. to save weight (if that's an important design goal), to reduce size for improved packaging, to use an alternate material, etc.). Off-the-shelf (OTS) parts are significantly less expensive considering the cost of design, documentation, prototyping, testing, improving and the overhead cost of purchasing all the constituent parts. Suppliers of off-the-shelf parts are more efficient at their specialty, because they are more experienced on their products, continuously improve quality, have proven reliability records, design parts better for DFM and have dedicated production facilities that can produce parts at lower cost (it's difficult to compete on the price of twenty parts with a company that manufactures the same part by the thousands). Using OTS parts helps us focus on our real mission: designing and building products.
2. **Design machined parts to take advantage of nominal raw material sizes.** As an example, a piece of 2" extruded aluminum round bar might measure between 2.005" and 1.995" in raw stock size. Since it would be necessary to turn ~ 0.010 " off the stock's OD to machine it cylindrical, the designer could not specify the OD as 2.000 ± 0.005 ", and be confident in achieving this target without buying a larger (2.5") piece of raw material. But specifying the OD as 1.980 ± 0.005 " could be easily achieved with the 2" round stock. Of course, if the OD is not important, and designer is smart, (s)he would specify it as: 2.000 ± 0.020 " and place a note on the drawing that it does NOT need to be a finished surface.
3. **Avoid designing mirror image (right or left hand) parts.**¹ When designing paired parts, design with symmetry to save manufacturing time (since parts can be stacked and machined in unison) and assembly time (because there's no right or left to track). If identical parts cannot perform both functions, add features to both right and left hand parts to make them the same. This tip also reduces design time (half as many part models and drawings to create) and manufacturing cost (making twice as many of the same part is always cheaper than making two half-size batches of different parts).
4. **Use larger feature tolerances.** ± 0.020 " is a lot easier to achieve than ± 0.005 ", so use the loosest tolerances possible and always investigate why they can't be made larger.
5. **Use fewer and/or coarser surface finish specifications.** Like finer tolerances, more stringent surface finish requirements increase manufacturing time exponentially, so make sure you can justify the magnitude of EVERY finished surface on a part or instruct the manufacturer to leave it unfinished.
6. **Use fewer dimension datums.** Each reference datum requires edge finding to locate a zero. Using fewer datums decreases setup time, reduces error (tolerance) stack up and lowers the chances for mistakes.
7. **Use nominal part dimensions.** If making the part manually, it's much easier to read nominal dimensions off a part drawing (i.e. 2.000 or 1.125 inches) than arbitrary dimension (i.e. 2.019 or 1.131 inches).
8. **Use weaker materials.** Weaker materials generally have higher machinability, so use them whenever possible. In addition, weaker materials typically have a lower cost, which can be substantial.
9. **Use thru-bolted holes.** Drilled clearance holes require less manufacturing time than threaded holes, so use thru-bolted holes whenever possible to reduce part cost. On the flip side, when using thru-bolted holes, you must be able to access the back of the part for assembly.
10. **Specify cone-bottomed holes.** Cone-bottomed holes are produced by drills; flat bottom holes are produced with end-mills. Drills are much faster for producing holes and should be used exclusively unless you have a very good reason to do otherwise.
11. **Make the part smaller.** If there's no good justification otherwise, make the part smaller; this reduces material cost, manufacturing cost and leaves more space for other components in the assembly.

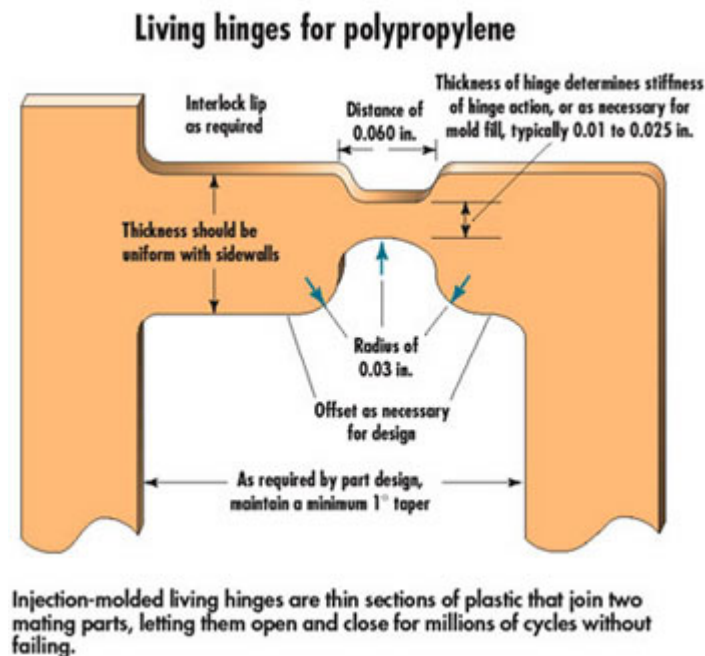
12. **Design for minimum raw-stock removal.** It takes less time to remove less material. Better designs start with material that is near net shape and minimize the amount of machining operations. When making a large number of parts from extruded raw stock, investigate having a custom extrusion die made.
13. **Avoid small cutting tools.** Larger tools are stronger and remove material faster without vibrating or breaking. Time is money when it comes to manufacturing, so try to avoid designs requiring small tools.
14. **Design for favorable tool stiffness.** Since the strength and stiffness of cutting tools limit productivity, maximize stiffness by minimizing each tool's required length (L) relative to its diameter (D). L:D ratios should be under 3:1 for milling and 8:1 for drilling whenever possible; smaller is always better.
15. **Design around standardized cutter sizes.** If you can design features to use standardized cutter sizes, you can often make parts on manual machines that otherwise would require CNCs. CNCs cost more per hour to operate, so for prototyping, parts that can be produced on manual machines are typically cheaper. In addition, custom cutters normally cost 2 -5 times as much and can take weeks to receive.
16. **Avoid unnecessary fillets.** Fillets look nice in a solid model but can add a LOT of expense in secondary operations. Make sure fillets are justified (i.e. in areas of high stress) because they can significantly increase part cost and demonstrate ignorance or apathy if specified without cause.
17. **Avoid unnecessary contours.** Simpler shapes require simpler processes and (manual) machines, so whenever possible, try to avoid designing tapers, contours, and undercuts into otherwise simple parts.
18. **Show Cartesian coordinates on detail drawings.** When dimensioning bolt circles (polar arrays), include Cartesian coordinates so hole centers can be easily located when machining or programming a CNC machine. If the manufacturer takes time to calculate the coordinates, you pay for that time; so reduce part cost by including coordinate dimensions on drawings as well as bolt circle diameters.
19. **Design for favorable part stiffness.**² The workpiece must be rigid enough to withstand the forces of clamping and machining without distortion, so try to avoid parts with thin walls or webs, or deep pockets.
20. **Design the part for convenient fixturing.** Most machined parts are held in a vise or a chuck, so try to design parts with compatible clamping surfaces to ensure rigid and secure workholding.
21. **Reduce the total number of parts.**³ The reduction of the number of parts in a product is probably the best opportunity for reducing manufacturing costs. Less parts implies less purchases, inventory and handling. A part that does not need to have relative motion with respect to other parts, does not have to be made of a different material, or that would make the assembly or service of other parts extremely difficult or impossible, is an excellent target for elimination. Some approaches to part-count reduction are based on the use of one-piece structures and selection of manufacturing processes such as injection molding, extrusion, casting, and powder metallurgy (which are beyond the scope of this course).
22. **Consider higher volume, lower cost-per-part processes.** Machining is used widely for prototyping parts, and where high precision is required in the final part. However, many mass produced parts can be designed for higher volume manufacturing processes such as casting, forging, stamping, forming, molding, and extruding. Although these processes typically have higher initial setup costs, the amortized cost-per-part is often much lower.
23. **Good designs are elegant in their simplicity.** As stated eloquently by [Dr. Kevin Craig](#), create designs that are explicitly simple. Keep complexity intrinsic, buried, and invisible. The less thought and less knowledge a device requires for production, testing and use, the simpler it is.
24. **Treat each drawing you create as a resume.** Good shops that manufacture parts for customers will always have enough work to stay busy; in other words: they don't need your business. Your drawings

always compete against others as job shops decide which to take on. Many shops will refuse to quote parts that appear to be drawn by someone who is inexperienced, ignorant or apathetic; OR they will add a nuisance cost multiplier of 150% - 300% realizing you don't know what you're doing and you're going to require hand-holding to get the parts your project needs. So realize the impression drawings make on others and invest time to present yourself as intelligent, competent and organized.

The following tips can help reduce the assembly costs associated with a design. As with most of the tips summarized in this document, every tip cannot apply to every design. In addition, some tips may result in higher manufacturing costs, so you must decide what is more important or which gives the lowest overall final part cost.

The best design for assembly is usually the one that has the fewest parts and the least costly type of fastening (consistent with the functional requirements of the product).

1. **Reduce / minimize the number of parts.** Handling fewer parts typically results in lower assembly times, and reduced supplier and inventory management. You're almost an engineer, you can do it ☺!
2. **Make a major product redesign.** This occurs when an assembly is redesigned so that the function supplied by one of its components is achieved by another method. One example would be the replacement of a threaded fluid system with a system that uses quicker push-lock fittings.
3. **Use a different technology altogether.** Sometimes great benefits can be achieved when a drastic design change enables a product function to be performed in a completely different manner. This often occurs, for example, when a mechanical device is replaced with electronics.
4. **Incorporate hinges.** Hinges (or flexures) can be incorporated into many plastic parts if the material is thin and flexible, thereby eliminating the need for multi-part hinges, fasteners, and time required to attach them to two other parts. Many product storage containers are made with [integral / living hinges](#).



5. **Incorporate integral springs.** Springs can be incorporated into a variety of parts, resulting in a simpler, faster assembly. Separate springs are often difficult to handle and insert into the assembly. Integral springs can therefore provide significant assembly advantages.

[Scan and insert Figure 7.1.1]

6. **Incorporate snap fits.** Screw-type and other fasteners can often be replaced with integral snap-fit elements, tabs, or catches using a variety of materials, dramatically reducing assembly times.

[Scan and insert Figure 7.1.3]

7. **Incorporate guides, bearings, and covers.** With some manufacturing processes, these elements can be incorporated into the basic part with a tremendous reduction in the number of components. Many plastic materials have natural lubricity that make them suitable for applications involving bearing surfaces, particularly if the velocity and pressure involved are low. For more demanding applications, porous metals like bronze or powder-metal parts can be used so that lubricating oil is retained in the part itself.
8. **Consolidate electrical components.** For example, one combination PCB is preferable to multiple PCBs in separate locations; a light switch and fan switch in the same mounting plate is preferable to locating them separately, each with their own mounting hardware.
9. **Standardize designs to use OTS fasteners and other parts.** Use as few sizes and styles as possible and reduce the total number.
10. **Use subassemblies, particularly modular subassemblies, which can provide quality, reliability, and serviceability advantages.** Finally assembly is also simplified if it involves only the placement and attachment of major modules. In addition, in many cases a particular module can be applicable to a number of different assemblies, and thereby gain the benefit of economies of scale of production.
11. **At the same time, avoid too many levels of subassembly,** since extra subassemblies add overhead in the form of mfg. specs, floor space, and inventory, and can actually increase mfg. throughput time.
12. **Design parts so they cannot be inserted incorrectly.**
13. **Design parts to be self-aligning during assembly.**
14. **Eliminate adjustments as much as possible during assembly.**
15. **Use funnel-shaped openings of holes and slots when possible to simplify mating part insertion.**
16. **When mating parts have multiple through holes for fasteners, shafts, etc., use slots or oversized clearance holes to allow for possible misalignment and quicker assembly.**
17. **Design parts so they are easier to handle.**
18. **As much as possible, avoid designs that require parts to be manually held in place until other parts are inserted.**
19. **Use the loosest fit possible between mating parts, consistent with product function,** unless the purpose of the tight fit is to hold the parts together.
20. **Keep internal mechanism accessible, or use a design that permits a housing cover to be installed after all other assembly and adjustment operations are complete.**
21. **Design small parts so they can be inserted in as many ways as possible,** from both ends, if possible, with the least amount of angular orientation.
22. **Avoid mirror image (L & R) parts and subassemblies to speed assembly and reduce part overhead.**

23. **Try to avoid the use of components that can tangle when in mass prior to assembly** (i.e. parts with hook-like projections, and unnecessary holes and slots).
24. **Use snap rings as an inexpensive way to fasten parts allowing freedom of movement**, such as a rotating shaft, as a separate retaining ring is often more economical than the use of a headed pin due because of reduced machining cost.
25. **Occasionally it pays to add parts to an assembly if doing so allows looser tolerances in the component parts**. An example is a gear train with an idler gear whose position is adjustable, thus obviating the need for extreme tolerances on the location of the gear-shaft holes.
26. **Use cast or molded-in identification instead of attached labels** because it eliminates the costs involved in purchasing, stocking, and affixing separate labels, and cannot fall off in use.

Designing for Fastening (DFF)²

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1. **Allow for access to screw fasteners by efficient driving and tightening tools**. Powered screwdrivers should have access whenever possible. If not, the design should permit the use of hand-powered socket wrenches. Regular wrenches should only be used for holding a bolt head while the nut is tightened.
2. **If hand tools (i.e. wrenches or ratchets) must be used for tightening fasteners, permit at least 60-deg of lever swing** so sufficient tightening per stroke can take place.
3. **When possible, use fewer larger fasteners vs. more smaller fasteners**.
4. If mating parts are subject to misalignment, **use screws that provide a piloting action and avoid cross threading**, such as dog and cone points.
5. **Consider self-tapping screws instead of nuts or threaded holes in mating parts**. Threading is one of the most time consuming (i.e. expensive) mfg. processes, so reduce or eliminate it for mass production.
6. **Consider rivets instead of screws for a lower-cost method of fastening parts together**. Reference standardized design rules for rivets (i.e. grip length, hole clearance, installation tool clearance, minimum edge (tear-out) distance, backup washers, etc.), or you will look dumb.
7. **Consider drivescrews when strong holding forces aren't required to reduce hole-making and assembly costs**.
8. **Use push-on fasteners if snap-fits aren't feasible** instead of threaded fasteners.
9. **Select fastener head types for ease of driving / torqueing**. Hex, Phillips, and Torx heads are the best. Socket (Allen) head are higher in cost due to the required progressive heading die operation. Slotted head are the cheapest, but most difficult to reliably drive, so avoid if trying to reduce assembly time.
10. **Use combined fasteners (i.e. those with integral washers) to expedite assembly, procurement, and stock handling**.
11. **Consider the use of spring nuts when torque requirements are not high**, because this type of nut is inexpensive and easier to assemble.
12. **If a locknut must be used, avoid the use of slotted nuts and cotter pins**, as these are much more labor intensive than plastic or deformed-thread type locking nuts.

13. **Use bent tabs or crimped sections instead of separate fasteners to hold several parts together.**
14. **Use integral locators, hooks, or lips to replace some of the fasteners holding one part to another.**
15. **Press fits or integral tabs can sometimes replace more complex fasteners.** Press fits with flexible or grooved components are normally less expensive and as effective as precision machined parts.

Designing for Drilling²

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1. Drill entry and exit surfaces should be perpendicular to the drill bit to avoid starting and exiting problems, and help ensure the hole is placed in the proper location.
2. If holding straightness is important, avoid interrupted cuts caused by intersecting holes unless a guide bushing can be placed at each reentry surface.
3. Use standardized drill sizes whenever possible to avoid the cost of custom drills and drill grinding.
4. Through holes are preferable to blind holes because of improved chip evacuation.
5. Avoid blind holes with flat bottoms.
6. Avoid deep holes $> 3xD$ because of chip-clearance and hole straightness problems.
7. Deep holes can be made using more expensive processes like gun drilling and reaming.
8. Avoid very small holes ($< 1/8"$) whenever possible because small drills are quite fragile.
9. If large finished holes are required, it is desirable to place cored (cast-in) holes in the workpiece prior to the drilling operation.
10. If the part requires multiple holes, try to dimension them from the same datum to simplify fixturing.
11. Insofar as possible, design parts so all holes can be drilled from one side or from the fewest number of sides to simplify tooling and minimize handling time.
12. Standardize the size of holes, fasteners, and screw threads as much as possible so the number of drill changes can be minimized.
13. Use Cartesian or ordinate rather than angular dimensions to layout holes because they are easier for the machinist to interpret and less prone to error.

Recommended Tolerances for Diameters of Drilled Holes

<i>Hole Diameter, in (mm)</i>	<i>Recommended Tolerance, in (mm)</i>
0 – 1/8 (0 – 3)	+0.003 to -0.001 (+0.08 to -0.025)
1/8 – 1/4 (3 – 6)	+0.004 to -0.001 (+0.1 to -0.025)
1/4 – 1/2 (6 – 13)	+0.006 to -0.001 (+0.15 to -0.025)

1/2 – 1 (13 – 25)	+0.008 to -0.002 (+0.2 to -0.05)
1 – 2 (25 – 50)	+0.010 to -0.003 (+0.25 to -0.08)
2 – 4 (50 – 100)	+0.012 to -0.004 (+0.3 to -0.1)

Design for Reaming²

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1. Never rely on reaming to correction location or alignment discrepancies (use a boring bar or endmill instead).
2. Avoid intersecting drilled and reamed holes if possible to avoid tool breakage.
3. If a blind hole required reaming, drill extra depth to provide room for chips.

Recommended Tolerances for Diameters of Reamed Holes

<i>Hole Diameter, in (mm)</i>	<i>Recommended Tolerance, in (mm)</i>
0 – 1/4 (0 – 6)	±0.0005 (±0.013)
1/4 – 1/2 (6 – 13)	±0.001 (±0.025)
1/2 – 1 (13 – 25)	±0.001 (±0.025)
1 – 2 (25 – 50)	±0.002 (±0.05)
2 – 4 (50 – 100)	±0.003 (±0.08)

Design for Boring²

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1. Avoid designing holes with interrupted surfaces, as interrupted cuts tend to throw holes out of round and cause vibration and tool wear.
2. Avoid designing holed with L:D ratios of over 5:1; otherwise, accuracy may be compromised due to tool deflection. If deep holes are unavoidable, consider the use of stepped diameters to limit the depth of the bored surface.
3. If a hole must be blind, allow the rough drilled hole to be deeper than the bored portion by an amount equal to at least one-fourth the hold diameter.
4. Boring is more expensive than drilling or reaming, so avoid it whenever possible.
5. When boring as with other precision machine operations, the part must be rigid so that deflection or vibration as a result of the cutting forces is avoided. Care must also be taken in the workpiece and fixture design to avoid deflection of the part when it is clamped in the fixture, for if this occurs, machined surfaces will be off location when the part springs back from its clamped position.

Design for Welding²

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1. Welded assemblies should be made up of as few parts as possible. Bending and forming operations are often less costly than welding, so investigate (i.e. substitute or mix) accordingly.
2. Weld joints should be placed so there is room for easy access of the welding gun/nozzle, especially when designing for GMAW, GTAW, or plasma cutting.
3. The design requiring the least weld metal and the least arc time is usually the cheapest welded assembly.
4. Whenever possible, the assembly should be designed so the welded joint is horizontal, with the electrode pointing downward during welding, as this is the most productive and convenient position for all welding.
5. Good fit-up of parts at the weld joint is essential for welding speed and minimizing joint distortion of the finished weldment. The larger the gap filled with weld, the greater the possible weld distortion. The extra operation to provide a close fitting straight edge will typically be less costly than the extra welding labor required when the fit is not correct.
6. Excessive buildup of weld fillets should be kept to a minimum, as it does not add significantly to the strength of the joint.
7. It is preferable to locate welds out of sight rather than in locations where special finishing operations are required for the sake of appearance.
8. The joint should be designed so it requires minimal edge prep. It is often advisable to use slip or lap joints in welding assemblies to avoid the cost of close edge prep and to simplify fit-up problems.
9. In many cases, it is possible to use the curved edges or sides of parts comprising the assembly to provide the equivalent of a grooved edge for the welded joint. Since little, or no edge prep is therefore needed, the total operation time is reduced.
10. If post-weld machining is required, welds should be placed away from the material to be machined.
11. It is often advisable to use a number of welding subassemblies in the fabrication of a large, complex final assembly.
12. Heavier and stiffer sections are generally less prone to distortion from welding, so designers should use their mechanics of materials knowledge to help reduce post-weld distortion.
13. Long sections of thinner material (e.g. sheetmetal), when welded together, are apt to distort and buckle unless there is good rigid support for the joint.
14. Whenever possible, place welds opposite one another to reduce distortion by balancing shrinkage forces in the weld fillets.
15. The butt joint is the most efficient type of weld. If stock thickness is low, or deep-penetration welding is used, the square-edge butt joint can be employed and edge-prep time therefore saved. Thicker stock or less penetrating methods may require grooved edges.
16. Always attempt to minimize the stress the joint must carry. This can be achieved by locating weld joints away from areas of stress or designing the assembly so the parts themselves rather than the weld joints bear the load.
17. Groove welds should be designed in either compression or tension; fillet welds should be in shear only.

18. When intermittent welds are used in place of continuous welds for cost and distortion reduction, the length of each fillet should be at least 4 times the fillet thickness and not less than 1-1/2". If the joint is in compression, the spacing of the welds should not exceed 16 times the thickness. If the joint is in tension, the spacing may be as much as 32 times the thickness, but not over 12".

Soldering and brazing are closely related processes in which metal components are joined by means of a filler metal. The filler metal, which has a melting point lower than that of the base metal(s), is introduced to the heated joint, wherein it melts, wets the surfaces to be joined, and is distributed in the joint by capillary action.

Soldered and brazed assemblies represent configurations that are impractical or uneconomical to make from a single piece. This may occur when:

- A. Dissimilar metals are involved, e.g. a carbide tool bit is brazed to a steel-alloy shank for a cutting tool.
- B. Light weight is important, but the shape is intricate, e.g. for an assembly of bent tubing and fittings.
- C. The part is too intricate to machine from one piece, especially because of thin sections, and when high strength and accuracy are important.
- D. Hollow shapes such as tanks, floats, or evaporators are involved. Leak-tight joints often dictate the use of soldering or brazing.

Below are a few design considerations and tips for soldering and brazing:

1. **Brazing and soldering are suitable for a broad range of production quantities,** ranging from one to tens of thousands.
2. **Brazing is applicable to a wide variety of base metals**—low carbon steels, high carbon and alloy steels, stainless steels, copper, brass, and nickel alloys.
3. **Design joints which provide the opportunity for filler metal to flow into the joint by capillary attraction, which requires a close gap (0.003 - 0.008") between surfaces of the joint.** In some instances, knurling permits concentricity of the assembly to be maintained while still allowing room for filler metal to flow by capillary action.
4. **Lap joints should be used whenever possible because they provide an easy means for controlling the joint area and gap, and usually do not present assembly or fixturing problems.** A rule of thumb for lap joints is to provide an overlap of at least three times the thickness of the thinner member joined.
5. **Butt joints and scarf joints are not recommended unless strength requirements are very low and there is no need for a pressure seal at the joint.**
6. **The higher temperature of brazing can cause distortion of the parts, so large, unsupported flat areas should be replaced by curved or ribbed areas if possible, since the latter are more self-supporting.**

SOLDERED AND BRAZED ASSEMBLIES

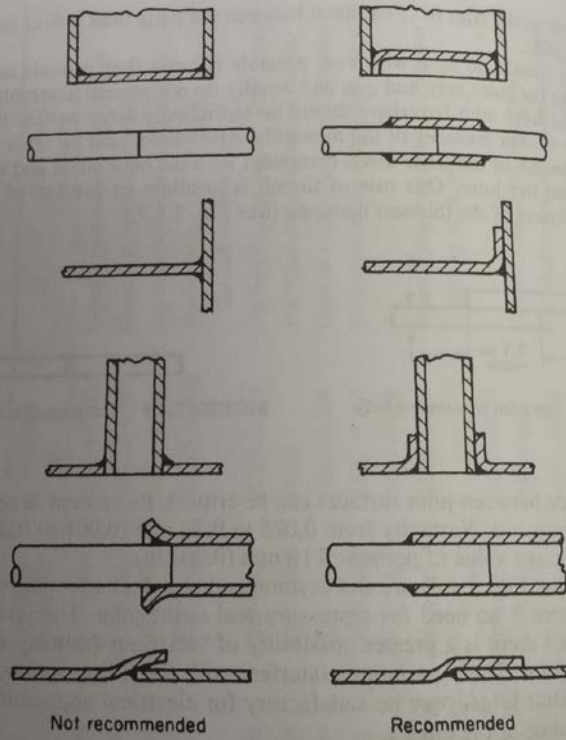


FIGURE 7.4.6 Joint configurations for soldering and brazing.

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