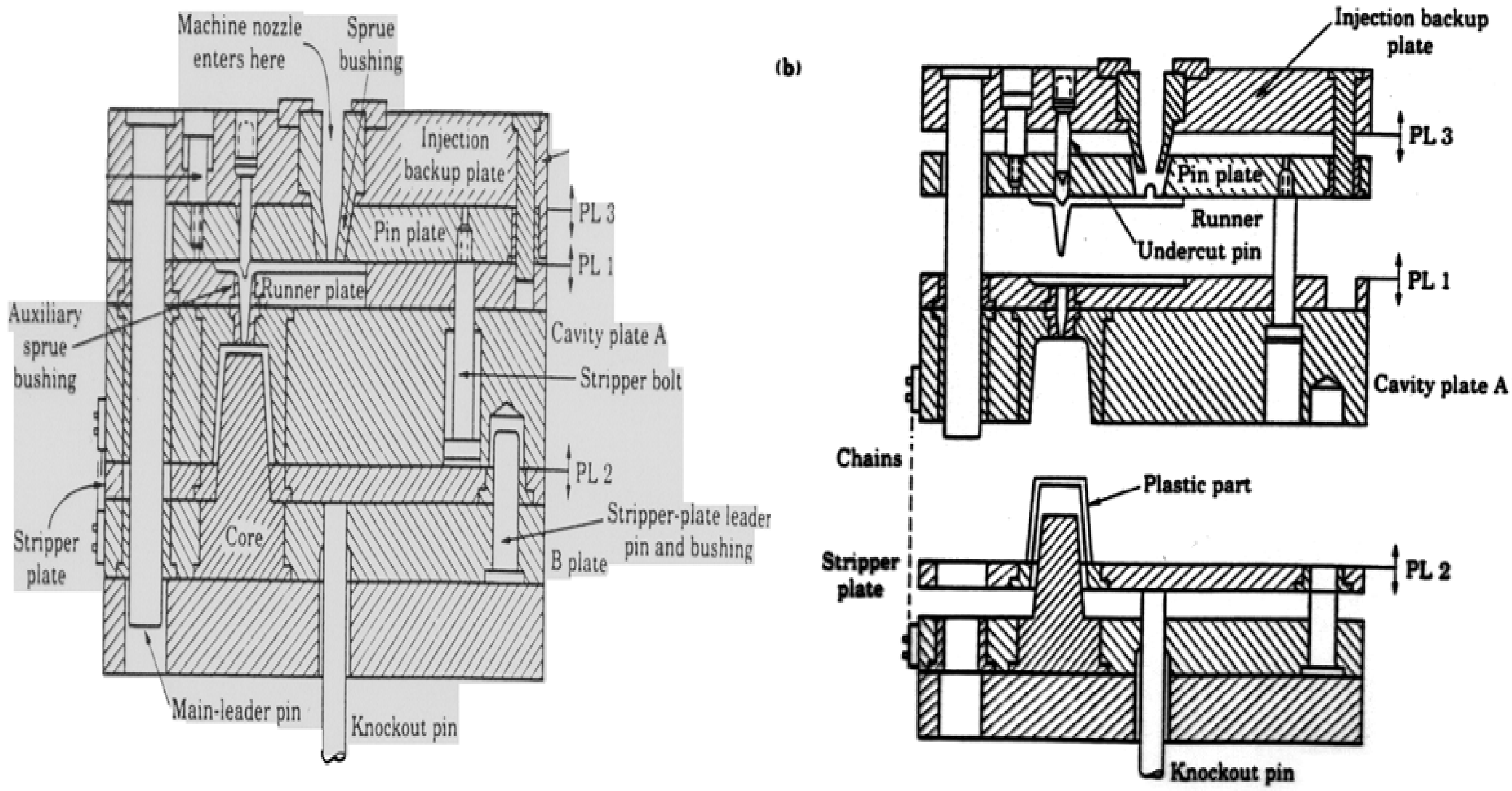
Today : Injection Molding



A three-plate injection mold in (a) closed position and (b) open position. *Source: Encyclopedia of Polymer Science and Engineering,* 2d ed. Copyright © 1985. Reprinted by permission of John Wiley & Sons, Inc.

Injection Molding Process

- Machine
- Process
- Tooling

Melting

Heating from the outside is difficult!

- Conduction
- Radiation
- Convection

- Internal shearing for internal heat generation!

Some numbers and facts:

- Clamp actuation can be hydraulic or electro-mechanical.
- Molds specified by shot capacity and clamping force.

  Eg, 75 Ton, 6.5 ounces.
- Typical Clamping forces: 50-1,000 Tons.
- Typical Pressures: 5,000 - 40,000 psi.
- Typical temperatures: a few 200-400 ^{o}C
- Typical injection rates: 10-100 cc/sec.
- Metals (in a matrix) and thermosets can also be injection molded.

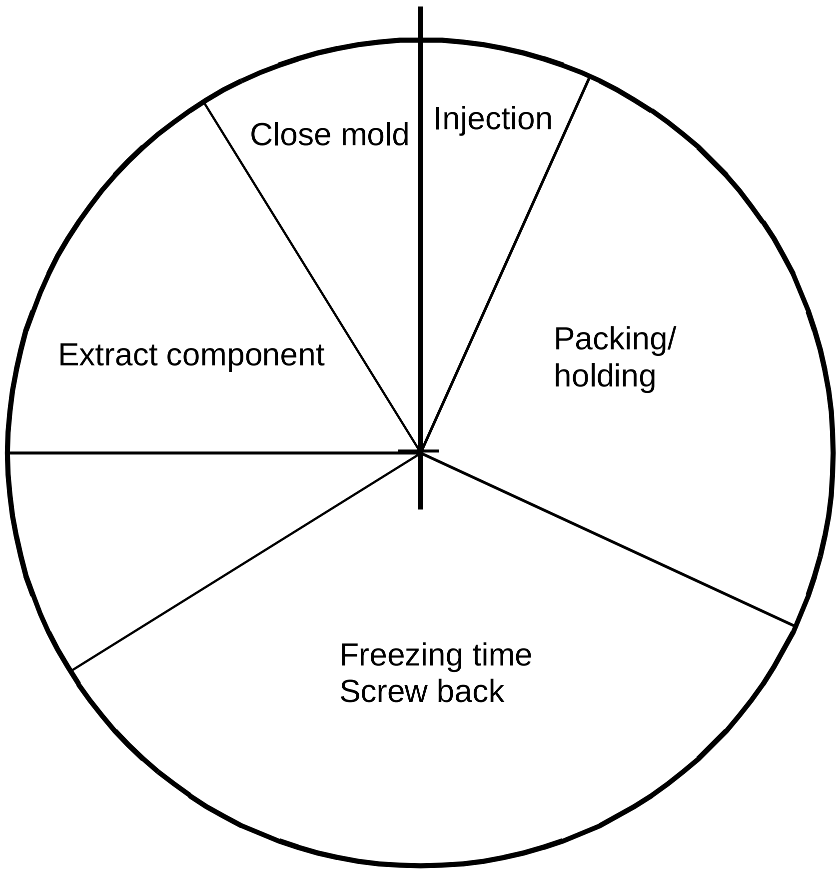
Mold design

- Hardened steel, very high finish, abrasive resistant, chemically inert.
- Can be actuated to rotate (for threaded parts), for composite molds, for stripping and ejection.
- Must account for shrinkage, can have cooling channels.
- Use taper so that part can be extracted.
- Can have inserts.
- Tooling is very expensive. Long manufacturing lead time and usually the critical bottleneck. Sometimes molds can be huge (think rubbermaid 30 gallon), so difficult to change. i.e., Mass production!

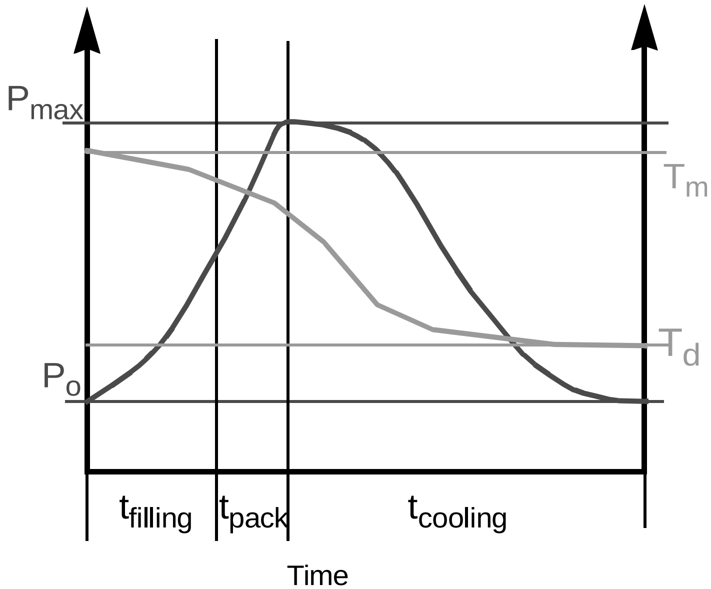
Rate issues and parameter selection

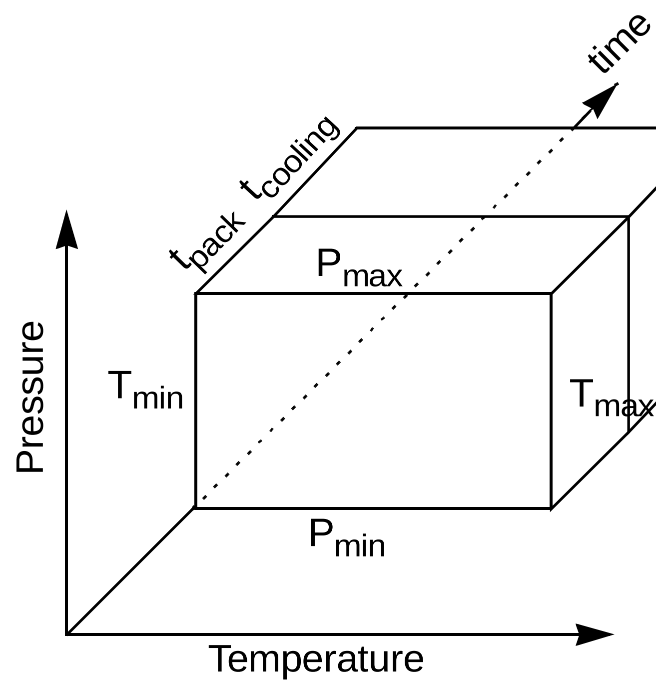
- Mold filling time
- Packing time
- Cooling time
- Opening/Removal/Closing time

Molding cycle

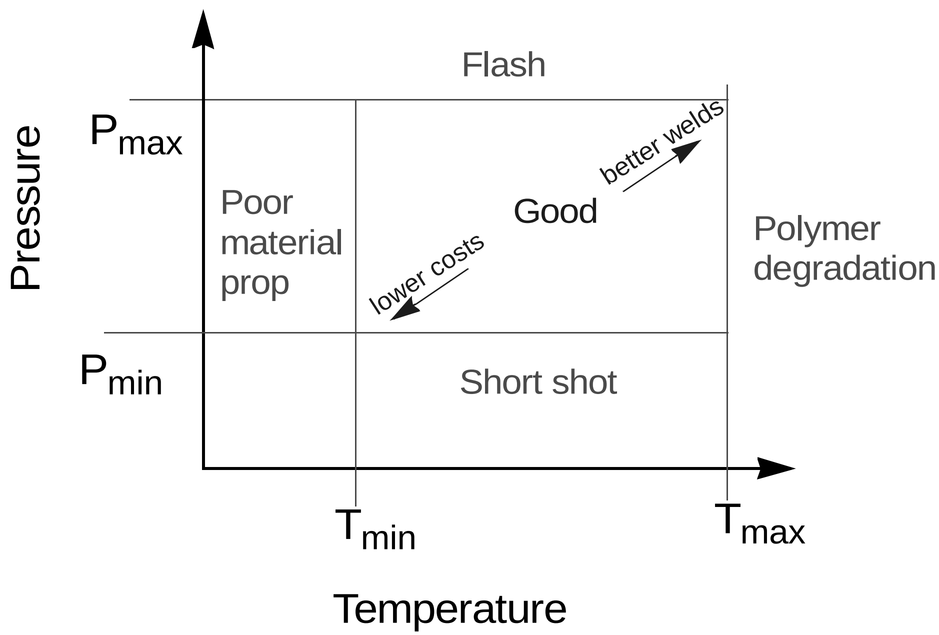


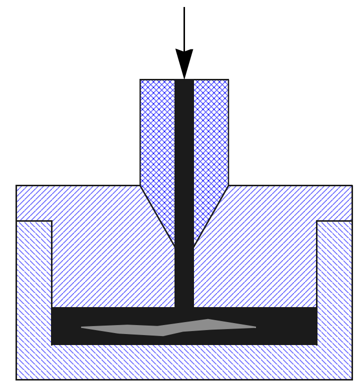
The processing window



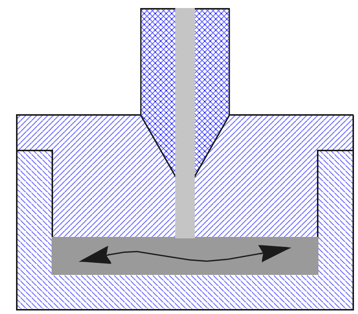


Optimizing process parameters





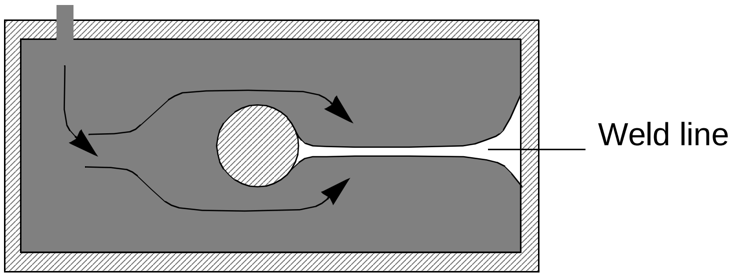
Increased packing time compensates for shrinkage during solidification

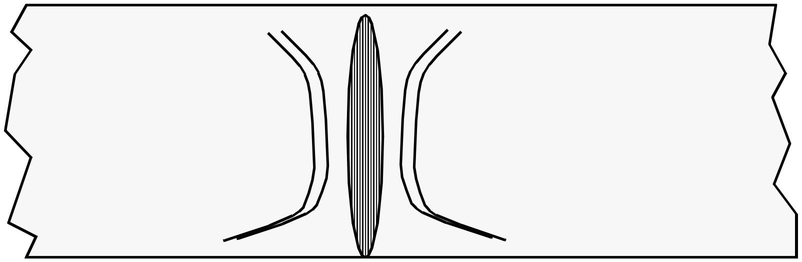


Increased cooling time reduced residual stresses

BUT CYCLE TIME **IS** IMPORTANT

Weld lines





A weld is formed where the two melt zones meet, creating a v notch. The weld is weaker than the rest of the component.

The weld problem is usually alleviated by increased temperature and higher pressure. Unfortunately, this increases cycle time.

Cooling and shrinking

- Solidification rate of a section is proportional to (thickness)^2. In fact,

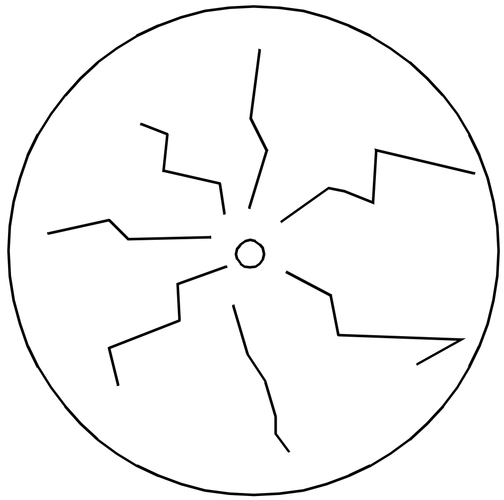
$$t \propto \frac{(\text{thickness})^2}{\alpha}$$

where α is the thermal diffusivity of the material, given by

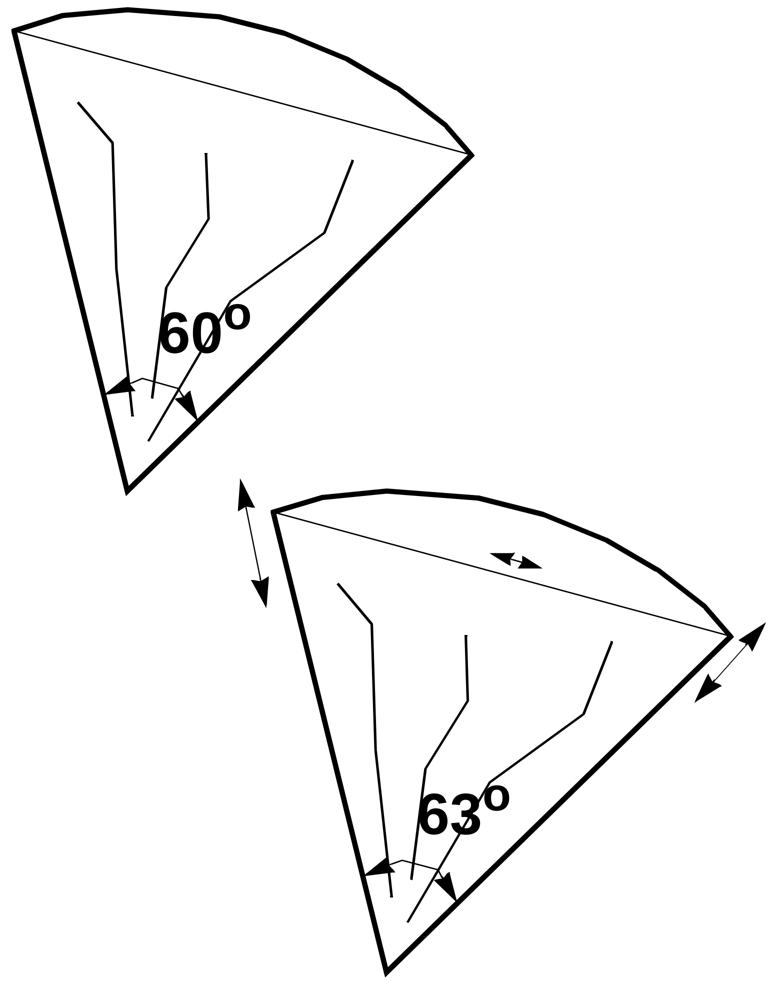
$$\alpha = \frac{k}{\rho C_p}.$$

- Shrinkage occurs during solification and during cooling.
  - Solidification shrinkage can be reduced by increased packing time
  - Temperature shrinkage controlled by larger mold size.

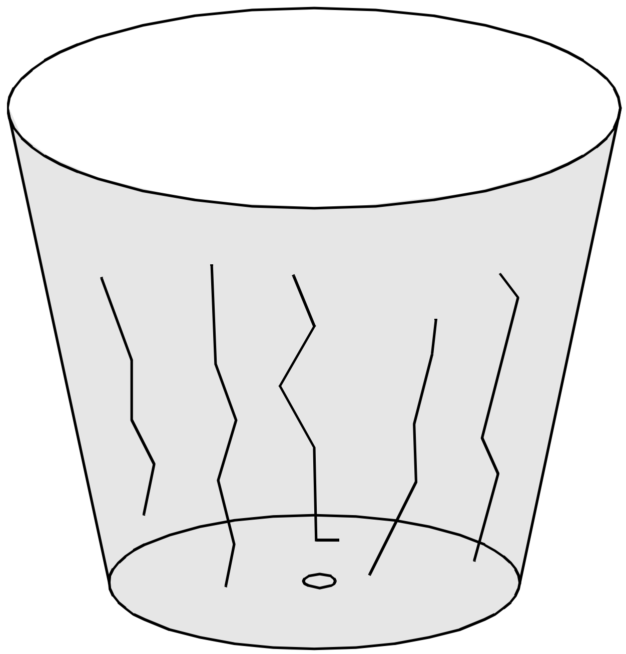
Shrinkage issues

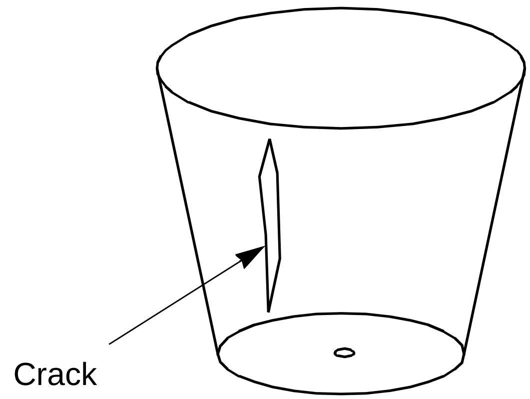


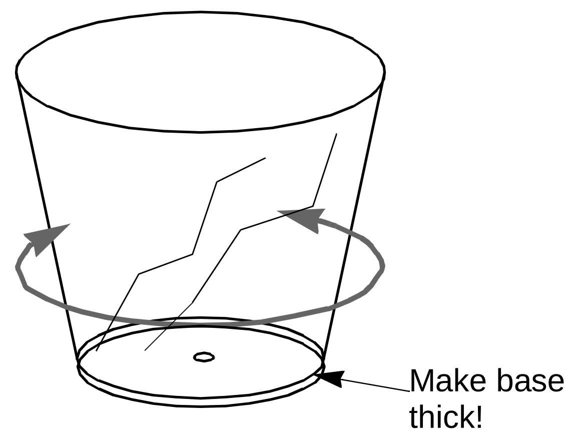
Flow based alignment



Strength issues





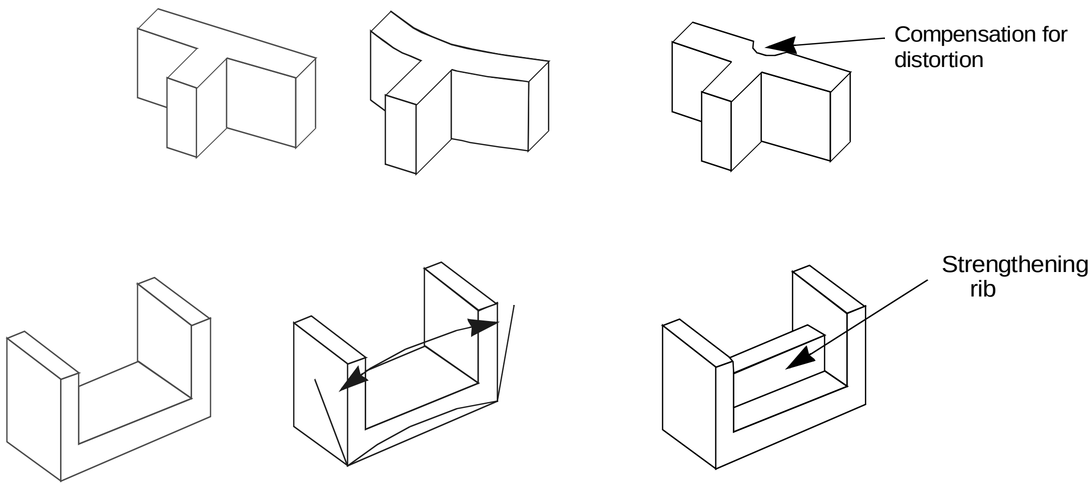


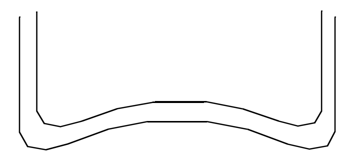
The molecules align in the major direction of flow, and hence there is greater strength.

DFM

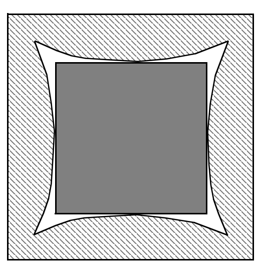
- Ribs to avoid warpage and to strengthen flat sections.
- Gate location(s) must:
  - minimize polymer travel
  - increase symmetry
  - Prevetn air entrapment
- Line up flow lines with maximum strength requirements (eg. handle in lunch box)
- Avoid welds in critical areas.
- Account for shrinkage, part removal.

Examples of DFM

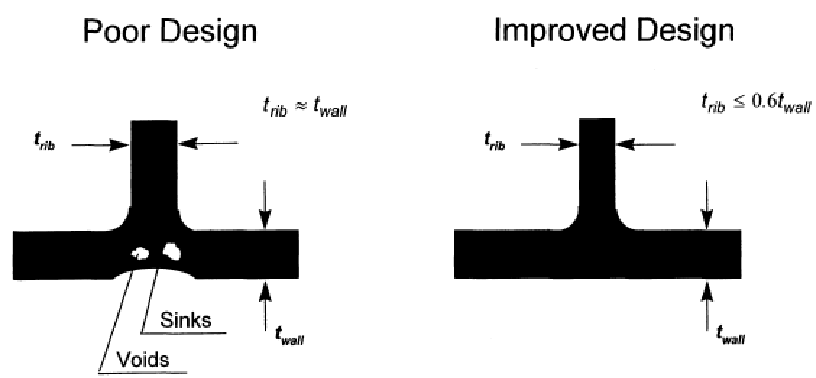




Stiffen the bottom by doming
(Like beverage cans)



Compensating for swell



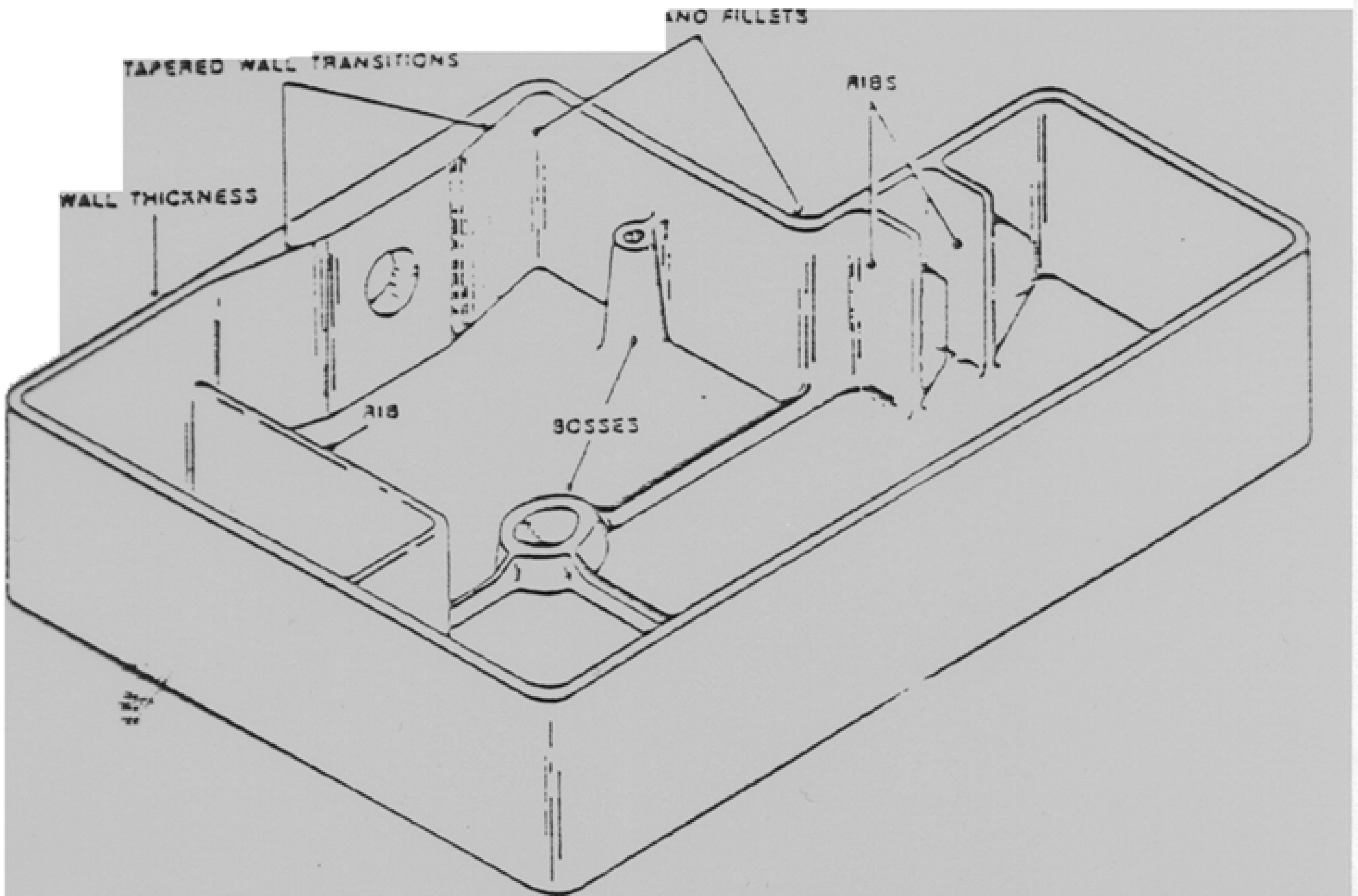


Fig. 9-15. This sketch illustrates many features of a well-designed part and points out problem areas. (*Courtesy Marbon Div Borg Warner Corp., Washington, W. Va.*)