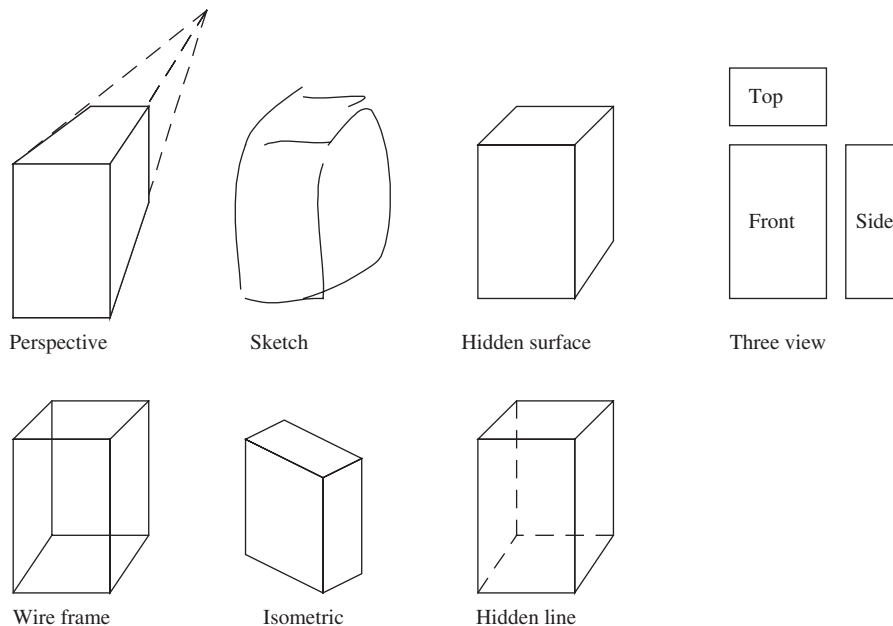


# Technical Drawing

# B

Drawings communicate geometries using centuries-old drafting standards. Examples of geometries include electronic connectors, antennae geometry, plant floor layout, bioreactor tanks, mechanical parts, bottle shapes, and tooling. The drawing creator needs to convert an idea to a detailed drawing and the details must be clear and obvious to a reader. Some of the common drawing forms are shown in [Figure B.1](#). Most projects begin with a few sketches that will be used to create a solid model in CAD (computer-aided design/drafting) software. These solid models can then be used to generate most other drawing forms. Perspective drawings are more artistic in nature and are normally used for sales and marketing. Three-view drawings are preferred for engineering work. Hidden-line, wire-frame, and isometric views are used for clarification. Some of the important motivations for creating drawings include:

- To describe the exact geometry of parts.
- To indicate other details associated with drawings (e.g., material).



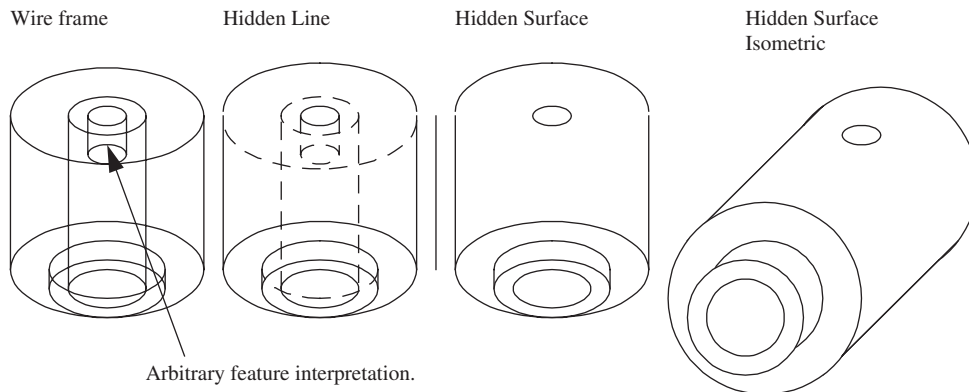
**FIGURE B.1**

Standard drawing types.

- To show how parts are assembled.
- To indicate manufacturing preferences.

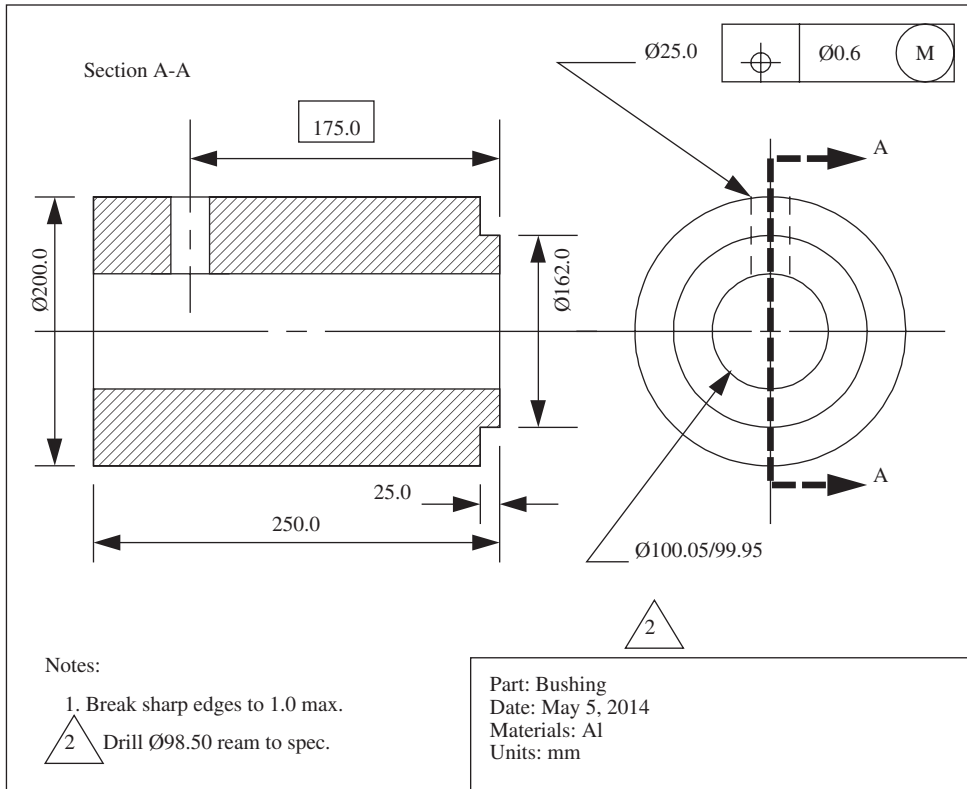
Consider the cylindrical mechanical part in Figure B.2. The outside of the part is round with a hole through the center. There is a step in the diameter on the front side and there is a radial hole on the side of the part. The four views shown are complementary. The hidden-surface drawings are easier to understand, but many details are missing. The wire-frame and hidden-line views contain all of the details but are more confusing and they are not unique. For example, the orientation of the small cylinder in the wire-frame drawing is arbitrary and could be horizontal or vertical. No drawing type is ideal, but when chosen carefully they will maximize effectiveness.

The basic and default drawing type for engineering work is based on orthographic projections. These typically use three views from the top, side, and front of a part. The part in Figure B.2 is shown in Figure B.3 using standard engineering conventions. The part is largely symmetrical so only two views are drawn, the front and the side. The drawing has a border and a title block on the lower right side. This title block indicates that the part is called “Bushing,” it is made from aluminum, and all of the dimensions are in mm. A couple of notes are placed to the left of the title block indicating that all sharp corners need to be rounded to less than 1.0mm when removing sharp edges. The center hole feature is to be reamed (a precision operation), as indicated by note 2. Dimensions are marked on the part using arrows and extension lines. The units are not marked on each number because the default set in the title block is millimeters. The precision of the piece is set by the significant figures of each dimension. For example, a dimension of 25 could range from 24.5 to 25.5, whereas a dimension of 25.0 could range from 24.95 to 25.05. Adding a zero will add precision, and cost. Center lines are used to indicate a center of roundness; they have two small breaks separated by some distance. The dashed lines at the top of the right view are hidden lines showing the hole in the top of the part. The thick black line from A to A indicates a section view—a virtual cut through the part. The view to the left has diagonal hash lines where it has cut through the material. In this view the hole through the center and the top hole are very clear to see. This drawing also includes *geometric tolerancing and dimensioning* (GD&T) symbols. The box in the upper right side of the drawing indicates that the



**FIGURE B.2**

Multiple views of a sample part.



Note: historically the drawings were reproduced using a process that resulted in a blue color, and the term blue-print remains in common use.

**FIGURE B.3**

A two-view drawing of a symmetrical part.

center line of the side hole must be within 0.6 mm of the target location. The 175.0 mm in the square box indicates that the location of the small hole must be measured from the far face.

The glass box is the basic concept behind three-view orthographic drawings. A tetrahedral shape is converted to a three-view drawing in Figure B.4. The part is oriented so that most of the detail can be seen from the front or top of the box. Each view is then drawn as it would be seen through that face of the box. This approach ensures that the details of any feature will appear in at least one, or probably two of the views. In addition, the views do not use perspective. This means that lines farther away are still the same distance apart. In cases where parts are symmetrical, two views may be sufficient to clearly show each feature. The top view is placed at the top of the drawing sheet, the front view is placed at the bottom. The side view is normally placed on the right side for North American drawings while the European standard is to place it to the left.

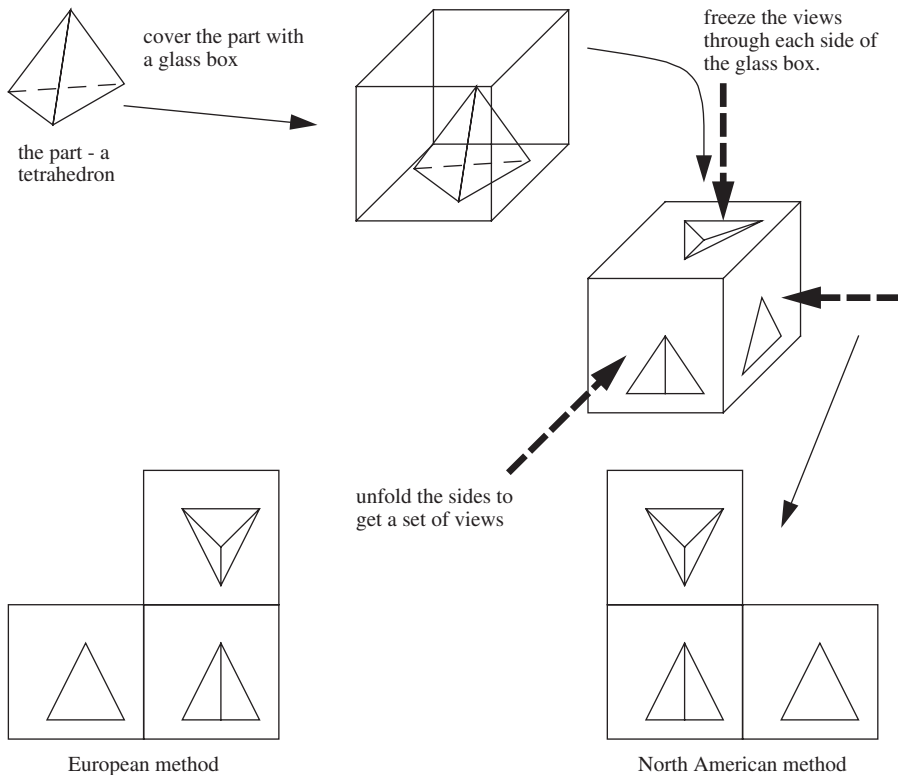


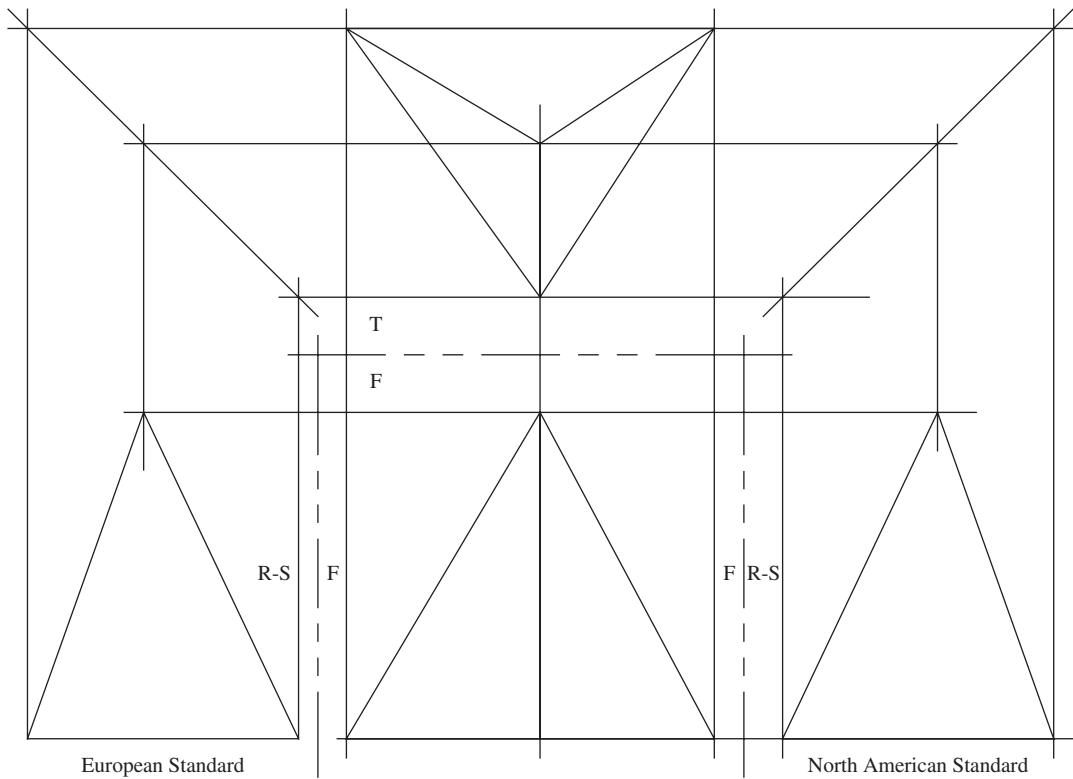
FIGURE B.4

A three-view drawing of a tetrahedron using a glass box.

The example of the tetrahedron is continued in [Figure B.5](#). The lines with two dashes are called the fold lines; these are the edges of the glass box. The  $45^\circ$  line is used to match the side-front-top views. This construction is important because it coordinates a feature across all three views. For example, the vertices, edges, and faces of the tetrahedron can be traced between the views. This can eliminate some arbitrary interpretation.

When choosing the orientation of the parts in the drawings it is important to use the front and top views to convey the most detail. The side views are then used for clarification and verification. Some of the general rules for selecting the front and top views include:

- It should be a natural front to the object.
- It should be the most important view.
- The part appears stable.
- The views minimize hidden lines in other views.
- The views contain most of the detail.

**FIGURE B.5**

Spacing multiple drawing views.

## PROBLEMS

- B.1** How does a perspective view differ from an isometric drawing?
- B.2** What does a dashed line on a drawing represent?
- B.3** Draw a wire-frame, hidden-line, and hidden-surface view of the letter A.
- B.4** Why does a round part only need two views?
- B.5** What does a center line represent?
- B.6** Why are title blocks used on drawings?
- B.7** Where would a Canadian draw a side view?
- B.8** Is an orthographic projection a perspective view?

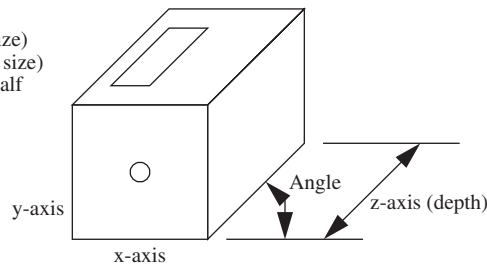
## B.1 Oblique and isometric projections

Two-dimensional views alone do not always provide a good sense of three-dimensional shapes. Effective techniques for adding three dimensions include *oblique* and *isometric projections*. Both drawing styles are shown in Figure B.6. In oblique projections the front view is as normal, but depth is set at an angle. In isometric projections the faces are all set at  $30^\circ$  or  $60^\circ$  angles. Both of these drawing styles use true-length lines so that dimensions can be measured directly. The result is that the drawings are not visually correct, but they allow measured precision. A square and a rectangle have been added on the top and front sides to illustrate face locations and feature distortion. In the oblique projection the circle faces the front and is round. In the isometric projection it is at an angle and appears as an oval. In both projections the rectangle is distorted. Isometric projections are normally done at  $30^\circ$  angles with each side drawn to scale. For oblique projections the angles and depth ratios can vary.

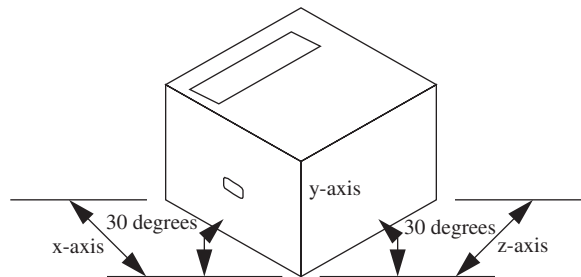
These projections are particularly helpful when doing hand sketches of designs, and the visual nature can help concept development.

Oblique Projections:

- cavalier ( $45^\circ$ , with full depth size)
- cabinet ( $0-90^\circ$ , with half depth size)
- general ( $0-90^\circ$ , with between half and full depth size)



Isometric Projection



**FIGURE B.6**

Oblique and isometric projections for a unit cube.

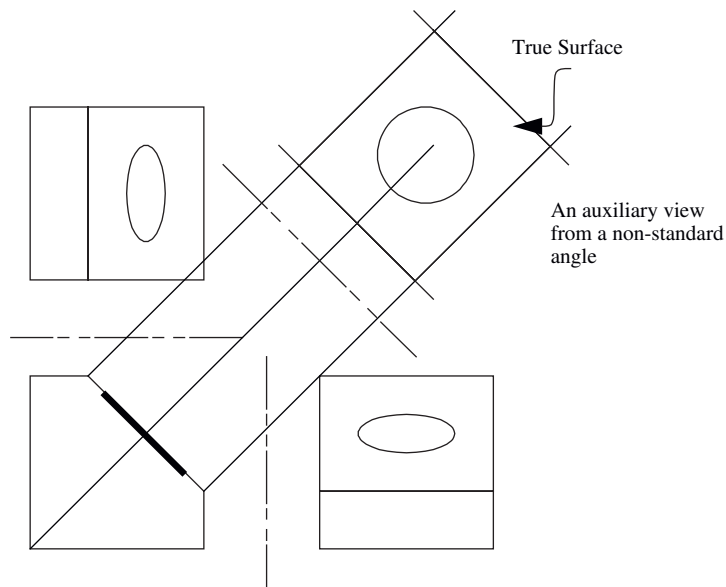
## PROBLEMS

**B.9** What angles are used for a cabinet view?

- B.10** Draw a freehand sketch of the word “fun” using (a) an isometric view and (b) an oblique view.

## B.2 Auxiliary views

Sometimes parts have faces or features that are not clear from one of the three drawing views. In these cases an additional view is drawn at an angle. An auxiliary view has been added to [Figure B.7](#) to show the diagonal face parallel to the viewing plane; this is called a *true surface*. The value of this arrangement is illustrated with the circle on the inclined face. In the normal top and side views the circle appears to be an oval, but it appears correctly in the auxiliary view. This example only shows the face of interest, but sometimes all of the details will be added.



**FIGURE B.7**

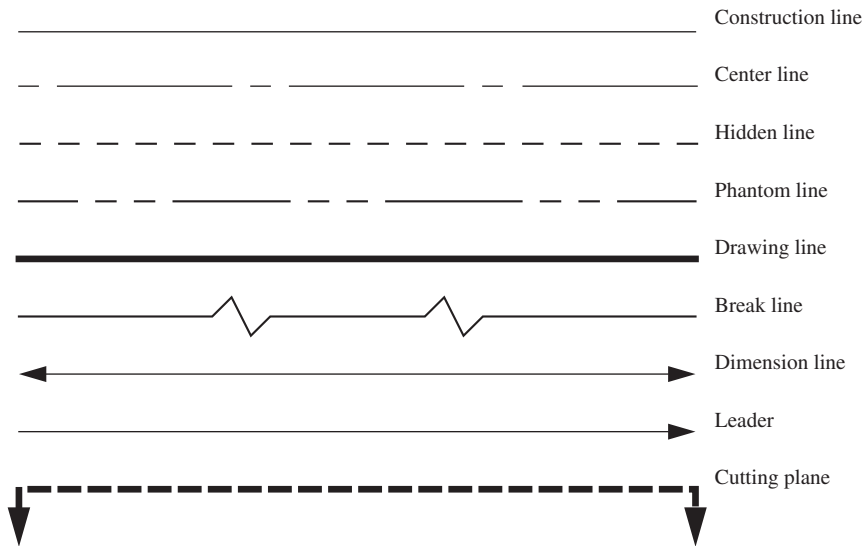
An auxiliary view.

## PROBLEMS

- B.11** Why would a drawing include an auxiliary view?

### B.3 Notations and features

There are a few drafting conventions that help professionals to read prints. Basic lines are used to indicate part edges; other lines are reference lines, as shown in [Figure B.8](#). Construction lines were used heavily when drafting was done by hand, but they remain as very useful to indicate dimension references. Center lines are used to indicate the center of round features. A drawing line is a heavier line used to represent visible edges in a drawing view. Hidden lines are used to show lines hidden behind solid faces, to aid understanding. Phantom lines are used for other types of reference lines on drawings. When part dimensions are very long, break lines are used to show where a part has been visually cut. Dimension lines have arrows on both ends to show dimensions, and leader lines have an arrow on one end for notes. Cutting plane lines are very heavy dashed lines to indicate a cutting plane through the material of a part.

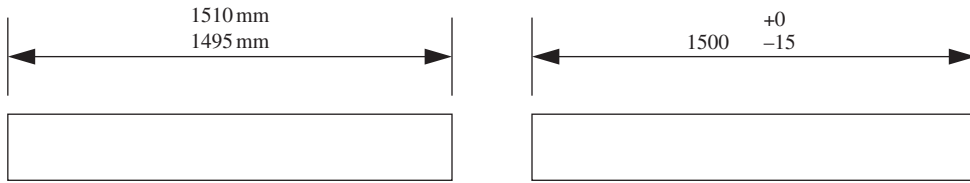


**FIGURE B.8**

Special line types.

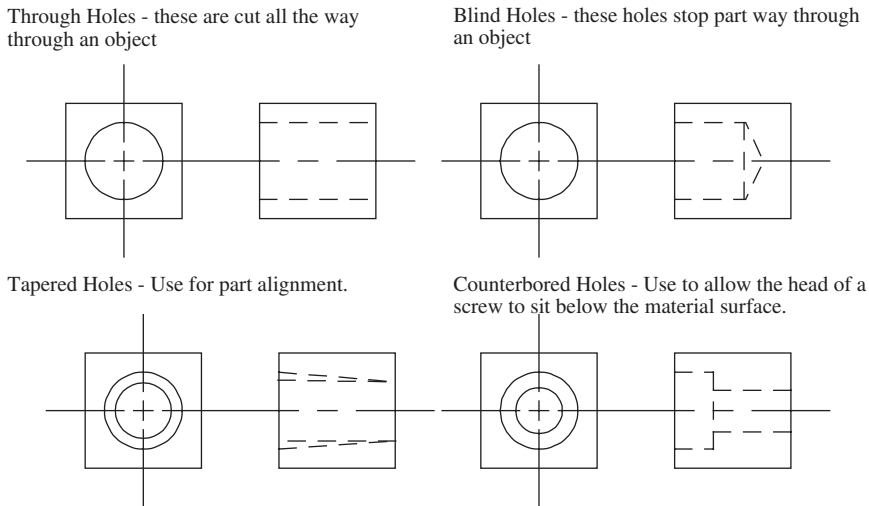
Part dimensions and tolerances are indicated in a drawing with arrows that show the significant dimension. The example on the left in [Figure B.9](#) ranges in size from 1494.5 mm to 1510.5 mm. The example on the right should have a nominal width of 1500 but can be up to 1500.5, or down to 1484.5. The unitless dimensions on the right side would require a note in the title block that says “Units: mm.” When a tolerance is on both sides of a dimension it is called a bilateral tolerance; in this example it would be  $1500 \pm 10$ . A tolerance on a single side of a dimension is called a unilateral tolerance, as shown in the right example in the figure. These are also called minimum and maximum metal conditions. Consider a part to fit in a gap of 1501 mm. The maximum metal condition cannot be over 1500 mm, but the minimum metal condition could be as small as 1490. The number of significant





**FIGURE B.9**

Dimensions and tolerances.



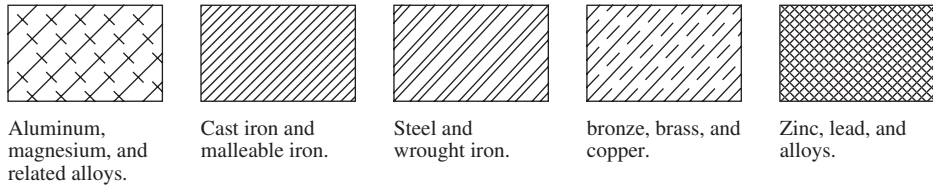
**FIGURE B.10**

Holes.

figures in a tolerance also dictates the precision of the parts, in this case up to 0.5 mm. Individual tolerances can be adjusted by adding or removing significant figures. Of course, larger tolerances decrease the cost of manufacturing.

Conventions for part holes are illustrated in [Figure B.10](#). Through holes are cut so that they pass completely through the part, whereas blind holes do not. Blind holes are made with drills that leave a conical shape at the hole bottom; it should be drawn for accuracy. A tapered hole will be used to help align a shaft as it enters the hole. The counter-bored hole has an extra pocket cut so that the head of the bolt or screw will be beneath the surface of the material. There are many more hole types that can be found on tool manufacturers' websites.

When doing cross-section drawings the materials are sometimes represented with a cross hatch pattern, as shown in [Figure B.11](#). These notations are particularly useful when dealing with assemblies of dissimilar materials. The figure also contains a number of abbreviations for part features. For example, if an iron piece is to be case hardened on one face (carbon infused), a leader line would point to the face and indicate "HDN."

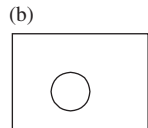
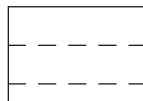
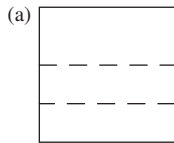


Abbreviation	Description
CBORE	counter bore
CSK	countersink
DIA	diameter
HDN	case harden
L	lead
LH	left hand
NC	national course
NF	national fine
P	pitch
R	radius
Rc	Rockwell C hardness
RH	right hand
THD	thread(s)
TIR	total indicated runout
TPI	threads per inch
UNC	unified national course
UNF	unified national fine

**FIGURE B.11**  
Material and feature indicators.

## PROBLEMS

- B.12** Why would a dimension include two or three numbers?
- B.13** How can a blind hole be changed to a through hole?
- B.14** Where are phantom lines normally used?
- B.15** What does “LH” normally mean on a threaded hole?
- B.16** Add the necessary dimensions and lines to the three-view drawing shown here. Use a ruler/ scale to determine the dimensions.



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## B.4 Professional drawing practices

A simple drawing may be a single page in a manual, or data sheet. More extensive drawings will come in a package with multiple pages. Larger drawing packets are like any document, they have a variety of content and features for explanation and organization. Drawing packets often include the following:

Higher level:

- A bill of materials (BOM) that lists all of the drawings and purchased parts
- Assembly and subassembly drawings
- Assembled views of subassembly and the final assembly
- Surveyor plots

Specific details:

- A detailed drawing (on a separate sheet with a separate title block) for each part
- Supplier drawings including purchased parts
- Modified purchased parts
- Electronic media with solid model files

The BOM lists the various components in the design. Each part that has a drawing should appear in the BOM by name. The BOM will also include purchased parts. The group responsible for manufacturing, fabrication, or construction will use the BOM to order materials and plan for building the design. For assemblies the BOM may appear on the same page and use numbers to show part position and assembly order. BOMs normally include details such as:

- All part numbers
- All part names
- The quantity of each part required
- Raw materials such as metal stock
- Supplier sources and part numbers

Each drawing must have a title block or equivalent. A title block clearly describes the drawing with enough information to identify the part, identify the designer, and identify other important details. The block often appears in the bottom right side of the drawing in a large, easy-to-read font. In more formal design control systems, these may also include tracking details. Common contents of the title block includes:

- Company name, and division, if applicable
- Machine or department name
- Part name
- Drawing number
- Part number
- Number of parts required
- Scale (e.g., 1:2 if 5 cm on the drawing is 10 cm on the part)
- Drafter name and date
- Drawing checker name and date
- Material
- Default tolerances

- Finishing details such as coatings
- Default units for all dimensions

Completed drawings will normally be checked by another engineer or an experienced fabricator. Sometimes the review occurs in a design review meeting where others look at the design details and suggest corrections and additions. Typical problems found in the process are listed.

- Within standards: Legal and corporate
- Clarity: All descriptions, dimensions, etc., should be well understood
- Completeness: Sufficient dimensions, etc., should be present for production
- Redundancy: Redundant information should be eliminated unless essential
- Manufacturability: The cost and feasibility of production should be considered; e.g., are tolerances sufficient/excessive? Are other steps adequate for product life?
- Are surface finishes, coatings, and supplemental operations suitable for the design?

Many industries have strict controls concerning designs, including medical, aerospace, defense, and automotive. Such controls require that the drawings are always current, and this is achieved with formal systems of document control. In such environments, each drawing is given a revision number that is used to track the current design. Any drawing with a previous revision number is removed from circulation. These updated drawings are normally accompanied by an *engineering change notice* (ECN) which indicates those features that have been changed. Systems that deal with public safety will often carry these requirements.

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## PROBLEMS

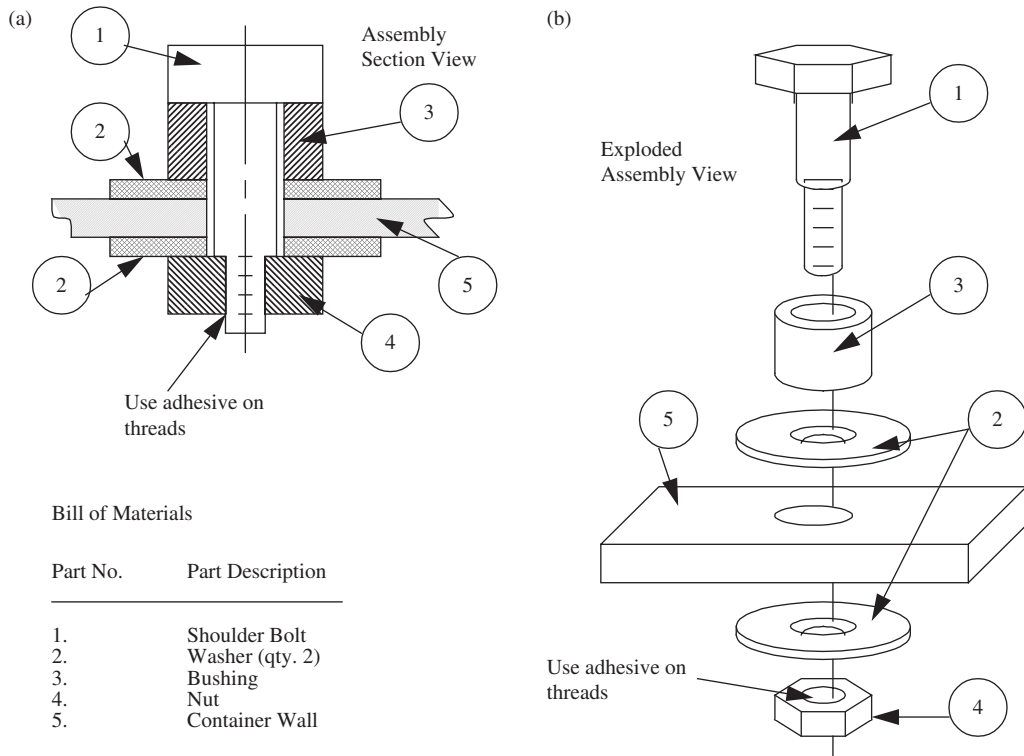
- B.17** Why should drawings be numbered?
- B.18** How would a coating of pink paint be indicated on a drawing?
- B.19** Could a BOM be included with a design package?
- B.20** List six items that could be found in a drawing title block.

---

## B.5 Assembly drawings

Examples of exploded and section assembly views are shown in [Figure B.12](#). The purpose of these drawings is to show how all of the parts in a design are combined. The examples show a shoulder bolt, bushing, two washers, a nut, and a base piece (the container wall). The section view ([Figure B.12\(a\)](#)) shows where the parts should be after assembly. The exploded view ([Figure B.12\(b\)](#)) shows how the parts are assembled using a line from the bolt, through the parts, into the nut. A design package may contain either of these drawings, or something similar, based on the needs. A BOM is provided to list all of the parts and numbers, which in turn are labeled on the drawings.

Hidden lines, dimensions, tolerances, and fine details are normally omitted from these diagrams. However, notes will be added if they are important for assembly or fabrication of the parts. The example drawings in the figure both indicate that an adhesive is to be applied to the nut/bolt thread, a common practice to prevent unwanted loosening.



**FIGURE B.12**

Assembly drawing examples showing (a) section view and (b) exploded view.

In more extensive designs there may be assembly drawings for various subassemblies, and then a higher level assembly drawing for the subassemblies. Designs with small details within large dimensions may also use an inset bubble with a finer level of detail for critical sections. These drawings can be time consuming to create manually, but CAD software provides many tools for creating these quickly. Designers will also use the assembly capability to verify that assembly is possible.

## PROBLEMS

- B.21** Why would a set of drawings come with an assembly view?
- B.22** What type of assembly view shows the final component locations and contact points.
- B.23** Sketch an assembly view for a disposable coffee cup.

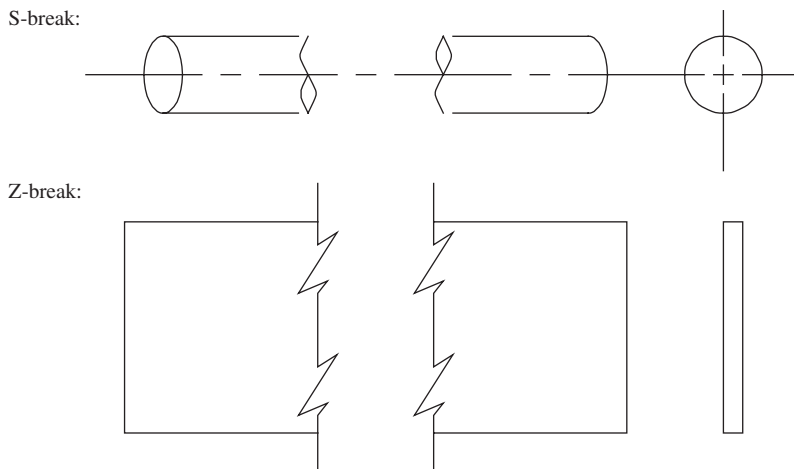
## B.6 Special part views

In any drawing or graph, we want to use as much of the paper as possible to show the details. [Figure B.13](#) shows two methods for shortening long parts so that the remaining portion can be drawn larger with more detail. The S-break is commonly used for round objects while the Z-break is used for flat and rectangular pieces. Other break lines can be identified by the rough, nonstraight shapes.

Section views are used to see internal features of a part to help visualize inner features or when the internal features cannot be shown with hidden lines. An example of a section drawing is shown in [Figure B.14](#). The line/plane for the section is indicated with the heavy dashed line. The arrows indicate which direction the view will look; features in the other direction will not be seen. The section name is indicated with the letters “A” at the ends of the section line. In this example the section is not essential but it helps illustrate the internal geometry. The section view is an extra drawing, in addition to the three view drawings.

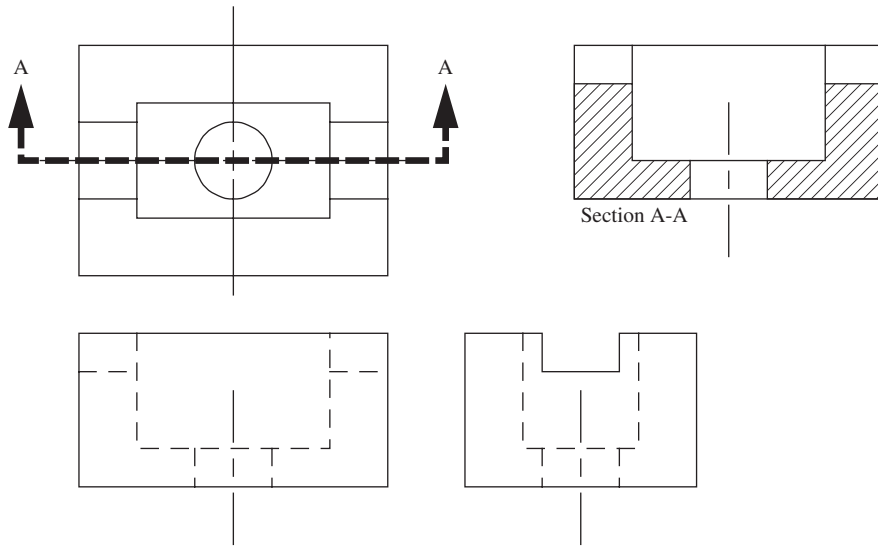
Section lines do not need to be straight. The example in [Figure B.15](#) shows a section line that only exposes the top half of the round part. Without the section view this part would be much harder to understand. Unlike the previous example where the section view was separate, this one has been incorporated into one of the normal views. In the top half, the section details are shown with diagonal and visible lines. The bottom half of the right view shows external edge lines and internal hidden lines.

[Figure B.16](#) shows another section view for a large round part, possibly an induction motor stator. Internal features of the stator are shown by removing part of the surface. The section is indicated by a nonstraight cut line. This approach does not require the addition of another section view. Without the exposed section the drawing would not be sufficient for geometrical understanding.

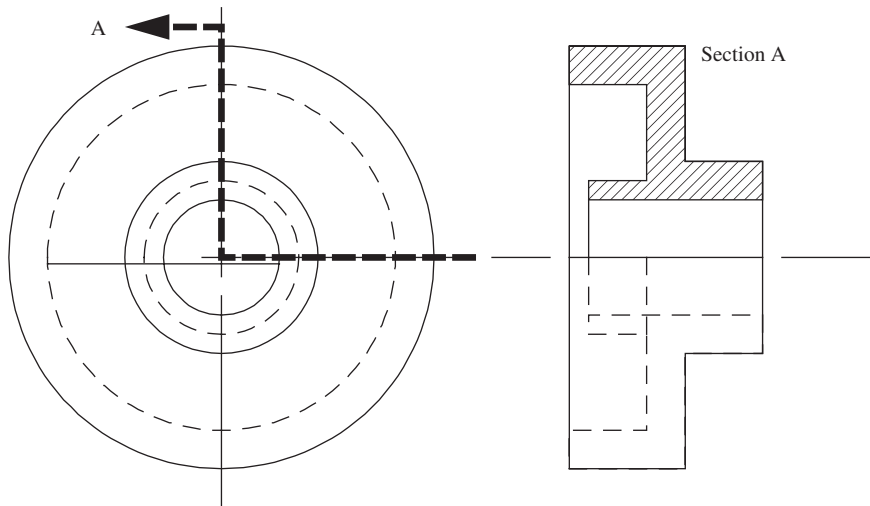


**FIGURE B.13**

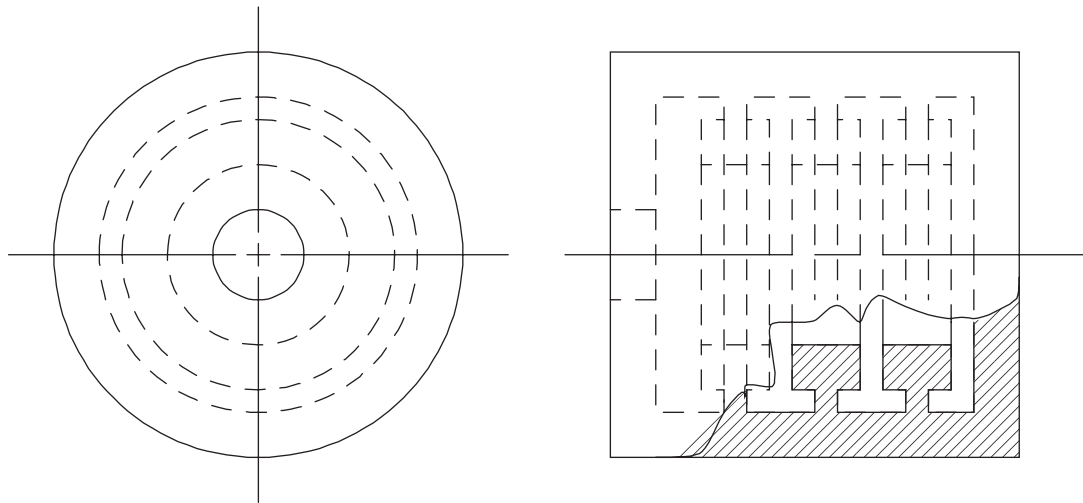
Breaking parts in drawings.



**FIGURE B.14**  
Section views.



**FIGURE B.15**  
Partial section views.

**FIGURE B.16**

Partial section views to clarify confusing features.

A similar issue can arise with complex and sweeping geometries including aircraft wings, electromagnetic waveguides, and stormwater runoff systems. Figure B.17 shows removed sections for a part with tapered ribs that do not have a square cross section. The sections A to A and B to B are used to show the shape at different points.

Sheet metals and similar materials are documented with drawings of unbent and bent geometries, as shown in Figure B.18. The bottom flat part indicates the size and hole placements for the straight sheet metal part. The upper piece shows the shape after bending. In the case of sheet metal the bend radii and angle are important, and during bending the overall length of the part will change. The after-bending view is used to verify the bends and feature locations.

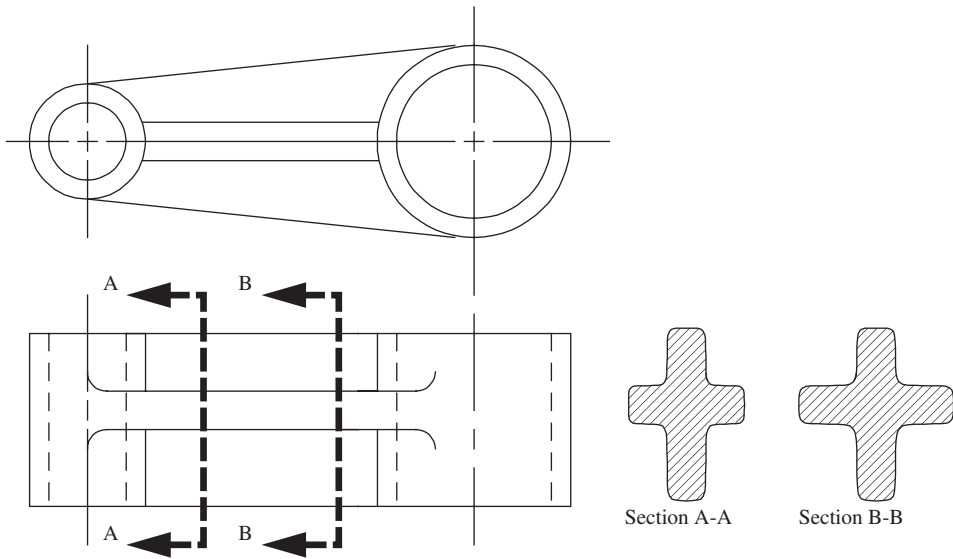
## PROBLEMS

- B.24** Why are break lines used?
- B.25** How would section views be used for a toothbrush handle?
- B.26** Why do section lines show a direction?
- B.27** Does a section line need to be straight?
- B.28** Draw a section view of a washer (that might be used with a bolt).

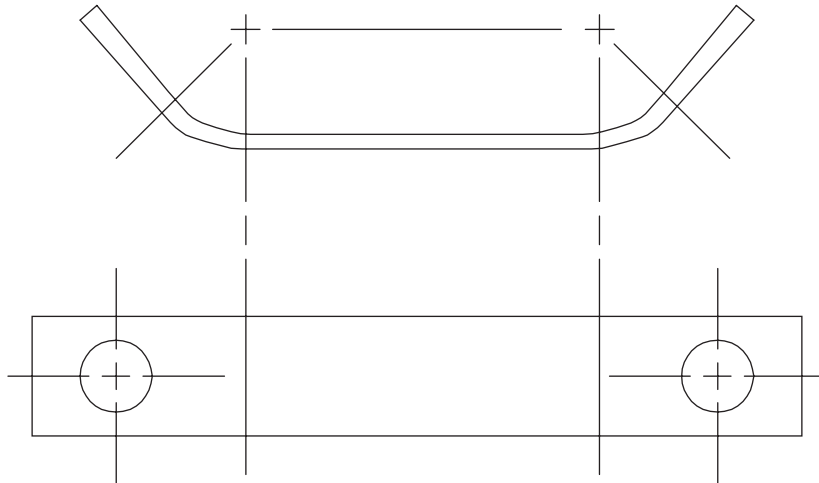
## INSTRUCTOR PROBLEM

- B.29** Create a drawing packet for a standard ball-point pen.





**FIGURE B.17**  
Cross-section views.



**FIGURE B.18**  
Bend drawings.

### Further Reading

- Dhillon, B.S., 1996. *Engineering Design; A Modern Approach*. Irwin.  
 Ullman, D.G., 1997. *The Mechanical Design Process*. McGraw-Hill.

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