Chapter 1

Engineering Aid Rating

Topics

Overview

Engineering Aids (**EA**) provide vital and continuous support in a variety of ways for construction projects throughout the Naval Construction Force (**NCF**). Your contributions as an EA may be in the form of direct labor, indirect labor, or both.

Depending on your individual assignment, your duties could range from staking out a project site to keeping its time records. Regardless of the labor category, all of which are important to the full completion and close out of a project, you will be part of a project's team effort. This chapter will help prepare you by acquainting you with your duties and responsibilities as an EA.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Describe the Engineering Aid rating.
2. Understand the administrative duties of the Engineering Aid rating.
3. Understand the professional duties of the Engineering Aid rating.

Prerequisites

None

This course map shows all of the chapters in Engineering Aid Basic. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Topographic Surveying and Mapping	↑	E
ndirect Leveling/Level and Traverse Computations		N
Care and Adjustment of Survey Equipment		G
Materials Testing: Soil and Concrete		N
Direct Leveling and Basic Engineering Surveys		E
Horizontal Control		E
Direct Linear Measurements and Field Survey Safety		R
Surveying: Elements and Equipment		
Construction Drawings		N
Electrical: Systems and Plans		G
Mechanical: Systems and Plans		A D
Concrete and Masonry		
Wood and Light Frame Structures		B
Drafting: Projections and Sketching		A
Drafting: Geometric Construction		S
Drafting: Fundamentals and Techniques		
Drafting: Equipment		C
Mathematics and Units of Measurement		
Engineering Aid Rating		

Features of this Manual

This manual has several features which make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.

- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.

- Audio and video clips are included in the text, with italicized instructions telling you where to click to activate it.

- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. f the

answer is correct, you will be taken to the next section heading. f the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

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1.0.0 ENGINEERING AID RATING

Engineering Aid is one of seven Occupational Field 13 (construction) ratings in the Navy. All OF-13 ratings are general ratings.

1.1.1 Scope of Duties and Responsibilities

From concept to conclusion, Engineering Aids are involved in NCF projects.

EAs:

- Obtain field data necessary for engineering studies or for actual construction of any type of structure.

- Plan, supervise, and perform tasks required in construction drafting, construction surveying, planning and estimating; quality control.
    - Prepare, edit, and reproduce construction drawings
    - Make and control surveys: run and close traverses, run level circuits, stake out construction projects
    - Prepare progress reports, time records, construction schedules, material and labor estimates
    - Establish and operate a basic quality control system for testing soils, concrete, and other construction materials

1.2.0 Importance of the EA Rating

Each of the other six Occupational Field 13 ratings may or may not perform a function on a particular NCF project. A project may be primarily or solely vertical or horizontal in scope, with each project's design requirements determining a different combination of skill needs. However, the function of the EA is significant on every project.

EAs contribute directly or indirectly, to all construction projects in their entirety, whether vertical or horizontal. From a project's conception to its completion report, the EA contributes to the team effort. Some efforts might not be measurable in terms of work-in-place such as surveying, staking, or establishing elevations, but an EA's indirect labor could be a deciding factor in the accuracy and quality of a finished project. Accuracy in compiling man-hour expenditures and progress reports may alert the operations officer to a lagging work schedule. The operations officer could then adjust timetables and priorities to meet standing completion requirements.

An EA's breadth of contributions to NCF projects translates into civilian construction in a multitude of ways: Drafting, Surveying, Materials Testing, Timekeeping, and Recordkeeping. These are just a few examples of an EA's support to the mission of the NCF. You will learn a majority of your individual tasks through on-the-job training or informal schools. The tasks you perform will depend upon your particular duty station, your specific billet assignment, and the prevailing contingency-operational, logistical, or both, but your contributions will add to the tradition of the Seabee's "Can-Do" performance.

1.3.0 Typical EA Billets

Most EA sea duty billets are in a Naval Mobile Construction Battalion, the "Green Machine." This is where you will have the widest range of opportunities to develop and apply your skills through the varied projects of a battalion's tasking.

Most EA shore duty billets are at public works activities. However, other types of independent sea, shore, or oversea billets are also available.

 f you are a selected reservist, a Naval Construction Force Support Unit (**NCFSU**), providing augmented construction, engineering, and logistics support, is another unit with a significant number of EA billets.

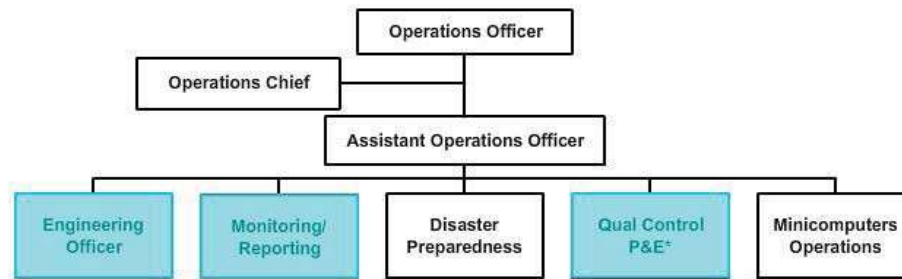### 1.3.1 Assignment to an NMCB Operations Department

Your sea duty assignment to an NMCB will usually place you in the operations department (**S-3**) of Headquarters Company.

With minor variations to suit the type of unit, its mission, and prevailing conditions, the organization of any Seabee operations department (staff, battalion, or detached unit) is similar in basic composition. To support construction, the operations department has specific functional areas:

- planning and estimating
- engineering
- monitoring/reporting
- quality control
- disaster preparedness
- minicomputer operations
- resource control

The operations officer may expand or modify the organization to suit the battalion's mission and/or the available personnel.

The *Naval Construction Force Manual,* NAVFAC P-315 provides information on the organization of the operations department, and how your duties and responsibilities relate to its functions. *Figure 1-1* shows a standard organizational chart of a Naval Mobile Construction Battalion operations department.

Figure 1-1 – Typical NMCB Operations Department Organization

1.3.1.1 Engineering Division

The operations department assigns most EAs to the engineering division, so you need to be familiar with the overall organization of the division and the duties and responsibilities of personnel within it. Your specific assignment could encompass any one or more of these responsibilities. Study the following sections and visualize how your assignment can contribute to both the division's mission and the larger mission of the operations department.

The engineering officer, normally a Civil Engineer Corps (**CEC**) officer, heads the operations department's engineering division. The engineering officer and staff are responsible for providing all design and engineering services necessary for the successful conduct of the construction program.

Their specific responsibilities include:

- Providing guidance and support to company deployment planning teams
- Reviewing all plans for sound engineering practices and practicability of planning and construction
- Resolving field problems relative to errors or design revisions
- Briefing company commanders on engineering aspects of new projects
- Providing liaison with customers concerning engineering and design
- Providing liaison with other divisions within the operations department in the interest of the successful conduct of the construction program

n addition, the engineering division is responsible for, and renders technical support by:

- Providing technical engineering construction inspection (by the engineering officer on behalf of the operations officer) to ensure projects adhere to the plans and specifications, and that quality workmanship prevails at all times
- Providing survey services, as required, for the construction companies
- Providing up-to-date drawings and specifications for projects in progress

- Providing soils and materials testing and evaluation services

- Maintaining as-built drawings and providing copies, as appropriate, to customer commands

1.3.1.2 1.2 Monitoring/Reporting Division

The assistant operations officer heads the operations department's monitoring/reporting division, sometimes referred to as the management division. The operations Yeomen and the battalion timekeeper normally staff this division but sometimes, capable EAs fill the position of timekeeper/computer. The monitoring/reporting division collects, compiles, and analyzes all information related to construction operations. The battalion uses this information to prepare construction operations reports, including the Deployment Completion Report, the Project Execution Report, the Monthly Situation Reports, and any other special reports required by higher authority. The engineering division assists the monitoring/reporting division in preparing these reports by supplying technical information concerning construction projects. Existing records may provide all the information for some reports, while others may require special investigation and research.

For example, each battalion submits a Monthly Situation Report (**SITREP**) of operations to its mmediate Superior in Command (**ISIC**) with copies to Commander, NAVFAC, and to any other administrative, military, and operational commanders concerned. This report is a concise review of the battalion's activities during the month regarding accomplishments, problems, and capabilities. t includes such information as planning, construction, welfare, morale, discipline, safety, training, and equipment. t includes the numbers of officers and enlisted personnel for the battalion headquarters site and for all its detachments, including specifying the methods of movements for personnel traveling.

Commander NCF specifies the enclosures to the Monthly S TREP, and they generally include:

- Progress and performance reports

- Progress photographs

- Labor distribution reports

- Financial reports

- Equipment status reports

- Training reports

- Summary of important events that occurred during the reporting period

There are detailed instructions covering the preparation of the Monthly S TREP and other reports, so if your assignment is to the monitoring/reporting division, your only problem will be the compilation of data for a specific report.

The monitoring/reporting division is also responsible for the following:

- Maintaining a complete status folder on each project

- Maintaining complete and accurate timekeeping records and labor analysis reports

- Maintaining and updating visual status boards required for effective construction management including:

- company personnel strength
- project status
- labor analysis
- project schedules

- Preparing project completion letters according to applicable instructions from higher authority

- Maintaining constant liaison with the material liaison officer

n addition, the monitoring/reporting division maintains constant coordination and works closely with the quality control/planning and estimating division as well as the company deployment planning team concerning the technical aspects of a project, its progress reports, and the master scheduling.

1.3.2 Assignment to a Typical Public Works Department

f you receive orders to a shore or overseas shore activity other than a Seabee staff or school command, you will normally find yourself assigned to the public works department (**PWD**) of the activity. Depending on the organization of the department and individual personnel capabilities, EAs assigned to PWDs may fill several different types of billets. Although civilians fill most PWD jobs, military billets do exist to implement the rotation of Occupational Field 13 personnel from sea to shore duty. Most public works EA billets are in the PWD engineering division, where the EA works with civil service personnel in performing drafting and/or surveying tasks.

However, senior EAs with planning and estimating or inspecting experience may work in the facilities management engineering division as planners and estimators or maintenance inspectors. Sometimes when there is a shortage of senior military personnel in the facilities management engineering division, EAs and other OF-13 petty officers may train for the planning and estimating or maintenance inspecting billets.

A unique situation exists at most public works departments. Your military duties and responsibilities will fall under military supervision, whereas a civilian engineer will directly supervise your professional work.

Adjusting to this situation may be difficult at first, but an alert EA will benefit from the wider experience of the civilian engineer. A good working relationship between you and your civilian co-worker is of the utmost importance. Once this relationship is established, duty at a public works department can be interesting and rewarding. *Figure 1-2* shows a standard organizational chart for a public works department.
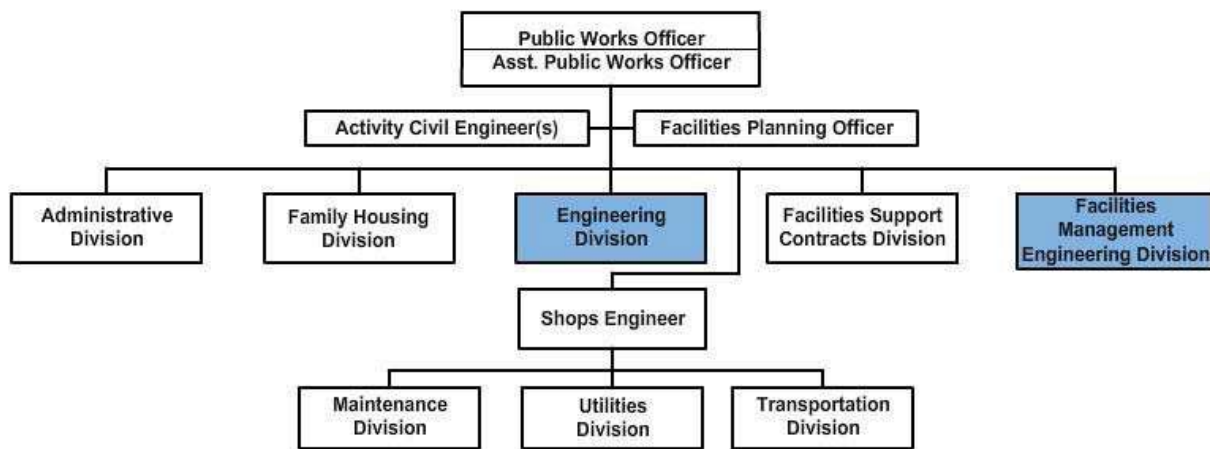
Figure 1-2 – Typical Public Works Department Organization

1.3.2.1 Engineering Division

The public works engineering division is responsible for the following:

- All matters pertaining to engineering studies and reports, including preliminary designs and estimates for special repair and improvement projects

- Engineering design, including development of plans and specifications

- Maintenance of technical plan files and records

This division is responsible for preparation of shore facilities development reports and for the submission of basic data required by the NAVFAC Engineering Field Division (**EFD**) director for preliminary engineering studies.

The PW officer establishes the engineering division to handle only routine work. He relies upon the NAVFAC regional EFD for:

- Design of major public works and public utilities

- Preparation of specifications in connection with the design

- Engineering investigations in specialized fields

Whenever the workload justifies or requires such action, the engineering division may subdivide into branches of specific engineering disciplines:

- Electrical

- Mechanical

- Architectural and structural

- Civil

- Plans and specifications

Some PW departments may combine the mechanical and electrical branches or merge the civil branch into the architectural and structural branch, but in all cases, surveying work remains a part of the civil component. PW departments with limited workload and staffing may combine the engineering and maintenance components into a single engineering division.

Regardless of the PW activity's size or workload, most EAs will work in the engineering division, and as such, your tasks, (design, reproduction, surveying, etc.) will be similar to those performed in the engineering division of the NMCB, with the exception of supervision. Often, you may be the only EA assigned to a particular public works activity; therefore, you may not have any supervisory duties.

1.3.2.2 Facilities Management Engineering Division

This PWD division's tasking is maintenance management.

 ts responsibilities include:

- ntegration of a maintenance work load program
- Screening and classifying all work requests, including emergency-service type work, before submission to shops for accomplishment
- Continuous inspection of public works and public utilities to reveal the need for maintenance work
- Preparation of manpower and material estimates for job orders
- Determining the need for engineering advice and assistance
- nitiation of requests to the public works officer for approval to perform work by contract

The facilities management engineering division may include specific branches:

- nspection
- Planning and estimating
- Work reception and control

At some public works departments, experienced BUs, CEs, UTs, SWs, and a few EAs with broad construction experience, supplement the inspection branch. PWDs staffed primarily with Seabees may have senior or master chief petty officers as supervisors for the inspection branch and/or the planning and estimating branch.

1.3.3 EA Billets

 n addition to the NMCB "Green Machine" and the Public Works Departments, as an EA, you will have a variety of billet options, as they are available. Alternatively, you may receive orders to a particular unit as a need arises. Other types of billets for EAs include assignment to Construction Battalion Maintenance Units (**CBMU**s), Naval Amphibious Construction Battalions (**ACB**s), Underwater Construction Teams (**UCT**s), Seabee teams, and various other commands.

Senior EAs may do a tour on a regimental staff, a Seabee Readiness Group (SRG), or at Seabee headquarters. They may also fill a billet as an instructor at one of the Naval Construction Training Centers (**NCTC**s), a personnel detailer at Naval Manpower Procurement Center (**NMEAB01PC**), or a writer for advancement examinations and training manuals at the Naval Education and Training Program Management Support Activity (**NETPMSA**).

2.0.0 ADMINISTRATIVE DUTIES

 f you are an EA3, you are just beginning to develop your professional skills, such as drafting, surveying, materials testing, quality control, and eventually planning and

estimating. However, from time to time, you will also need to demonstrate your supervisory abilities. nitially limited, your duties and responsibilities as a supervisor will gradually increase as you advance in your career.

Becoming a Petty Officer Third Class is a major milestone in your naval career, and the Navy now imposes special trust and confidence in you. n return, the Navy expects you to be professionally competent and capable of instructing and supervising subordinates.

As a Petty Officer, your leadership will influence others, so you must always exhibit a strong sense of personal integrity and dedication to both your work and the Navy. Sometimes you may be unaware of your own influence, but as a Petty Officer, you will always be leading by example.

Adjusting to your role as a supervisor will be one of your greater challenges, so start preparing now. Prior knowledge of both your administrative and professional duties will put you ahead. Your early training and study will prove beneficial when you need to lead others. Consider your training and studies as placing additional tools in your personal tool kit. You will be able to draw on them whenever you need them.

To help prepare you for the job ahead, this manual will acquaint you with some of the common administrative and professional duties of an EA3. t will not attempt to present material on basic leadership techniques for a PO3. That topic is already adequately covered in *Military Requirements for Petty Officer Third Class,* NAVEDTRA 10044, and *Military Requirements for Petty Officer Second Class,* NAVEDTRA 10045 (latest revisions). As a Petty Officer Third Class, you will also need to study those basic leadership techniques and apply them in your role as a supervisor when called upon.

n this section, you will also learn to recognize the scope of other general duties and responsibilities associated with an EA3 in a typical Seabee billet.

2.1.0 Assignment as Team Leader

Although EA2s normally serve as team, party, or crew leaders, in a case where you hold seniority in years over the rest of the junior personnel assigned to your team or section, the section leader may assign you to perform those duties and occupy a position of higher responsibility.

Survey party crew chief or drafting room leader are two typical supervisory assignments that may come to you as an EA3. n general, your duties as a survey party chief or crew leader will involve planning work assignments, supervising, coordinating your work with the work of other teams, initiating requisitions, and keeping time cards. The following will help you prepare for your supervisory assignment.

2.1.1 lanning Work Assignments

Proper planning saves time, effort, and money for the Navy and makes the job easier for all concerned parties. The following will help you in planning day-to-day work assignments.

2.1.1.1 Understand the Task Clearly

When you receive a tasking, either written or oral, the first thing you need to do is make sure you fully understand exactly what you need to accomplish. Do not be afraid to ask questions and find answers. Approach as information resources those in a position to supply the information you need.

Make sure you know the tasking's priority, required time of completion, and any special instructions you must follow. f the task is an oral assignment, take detailed notes. Do

not leave anything to memory; you might forget important information or instructions. A good supervisor always carries a notebook and pen/pencil.

2.1.1.2 1.2 Know the Capability of Your Crew

As you plan to accomplish your assigned tasks, always consider the capability of your crew. As you assign tasks to your crew, you can determine who is to do what and how long it should take to finish the job. dleness tends to breed boredom and discontent, so when crewmembers finish one job, always have another one ready to start.

2.1.1.3 Establish Daily Goals

Encourage your crew to work together as a team to accomplish daily goals. Your goals should keep your crew busy but make sure they are "realistic" goals.

During a contingency, people will make a tremendous effort to meet deadlines, but people are not machines. When there is no anticipated urgency, do not expect them to maintain an excessively high rate of production.

 n your planning, be sure you allow for those things that do not contribute directly to the accomplishment of the assigned task, such as in-house technical training, safety stand-down, and other administrative matters.

2.1.1.4 Select Proper Methods, Equipment, and Supplies

 n planning to accomplish an assigned task, consider every possible method. f there is more than one-way of doing a particular job, make sure you select the best method. After making your selection, analyze it to see if you can simplify it to save time and/or effort.

One of the most common mistakes new supervisors make is forgetting to bring certain equipment or supplies to the jobsite. When you are planning for surveying operations, selecting the required equipment and supplies is a vital step. Nothing is more frustrating than to arrive at the jobsite and discover that "someone" forgot to bring a tripod for the transit. The best way to minimize this embarrassing situation is to prepare an equipment and supply checklist for each job assignment and, after gathering all the items, double-check the list to make sure nothing is missing. f you are planning more than one job, include sufficient equipment and supplies to accomplish all the jobs.

The same planning steps apply to drafting assignments. As you gain experience, you will devise methods that will enable you to improvise with the equipment and supplies you have on hand, but certain drafting assignments are difficult to accomplish without proper equipment and supplies.

2.1.2 Supervision

Once you have properly planned for accomplishing a task, you need to supervise the job carefully to ensure its proper, safe, and timely completion. The following will aid you in supervising work teams.

2.1.2.1 Keep the Crew Well Informed

A crew performs much more efficiently when it is well informed. Before starting a job, make sure your crew knows what it needs to accomplish. nform them of the tasking and give instructions on any steps or methods that may be unique or necessary for this task or outside of normal procedures. Encourage questions about any points that may not be clear to them. Explain how the job relates to other jobs and to the overall

mission. Make sure all crewmembers know exactly what you expect of them and what their responsibilities are.

Be sure each crewmember knows all pertinent safety precautions and wears any required safety apparel. Check all equipment and tools before use to ensure they are in a safe condition. Do not permit the crew to use dangerously defective tools or equipment; be sure the crew turns them in for repair immediately.

While the job is under way, check from time to time to ensure that the work is progressing satisfactorily. Determine if the team is using the proper methods, tools, and equipment. f team members are doing a procedure or step incorrectly, stop them and point out the mistakes. Then explain the correct procedure and check to see that they follow it. When you check your crew's work, try to do it in such a way that the members feel the purpose of your checking is to teach, guide, and direct instead of just finding fault and criticizing.

When time permits, rotate your crewmembers to various jobs. Rotation gives them varied experience and will help ensure you have a backup member who can do the work if another is hospitalized, transferred, or on leave.

2.1.2.2 Seek Teamwork

Good supervisors get others to work together to get the job accomplished. Maintain an approachable attitude towards your crew. During the project, make them feel free to come to you and seek your advice whenever they are in doubt.

Good supervisors display emotional balance. They do not become panicky before their crewmembers or become unsure in the face of conflicting forces. Use tact and courtesy in dealing with your team. Do not show partiality to any particular member or become pliable with influence. Keep them informed on matters that affect them personally or concern their work. n addition, seek to maintain a high level of morale; low morale can have a definite effect upon a crew's work in both quality and quantity.

This is only a brief treatment of the subject of supervision. As you advance in rate, you will spend more and more of your time supervising others, so make a continuing effort to learn more about the subject. Study some of the many books on supervision, as well as those on leadership. Also, read articles that concern supervisors. They appear from time to time in trade journals and other publications on topics such as safety, training, job planning, and so forth.

The Navy always has a big need for petty officers who are skilled supervisors and team leaders. So consider the role of supervisor a challenge and endeavor to become proficient in all areas of the supervisor's job--to get the best efforts from a team.

2.1.3 2.1.3 Cooperation

For a project to run smoothly and finish on time, all crew leaders and supervisors, must coordinate their work efforts and cooperate as one big team. For example, most surveying operations guide the work done by other construction crews. Therefore, you must work closely with the other crew leaders to ensure that your surveys are timely and do not delay the overall project. Cooperation with other supervisors will eliminate many problems that could otherwise arise when you are coordinating your own team's work efforts. n effect, you are merging your ideas and efforts into the bigger picture to make the project run smoothly.

Cooperation is also essential to your success as a drafting supervisor. Consult the Builder crew supervisor on any design problems and construction methods. f the

Builders need a particular set of drawings, spending too much time on unnecessary details could delay their delivery and the job. So right from the start, get into the habit of cooperating with other supervisors and you will gain their respect as well as the respect of your superiors and crewmembers.

2.2.0 Maintaining Files

Maintaining records, or simply "filing," is one job an EA needs to learn fast and well. When you transfer to a new unit or command, chances are good that one of your assignments will be to organize and keep track of the large variety of engineering drawings normally found in the drafting and reproduction section.

Your biggest filing challenge will be to make any single drawing (sheet), as well as the record pertaining to that particular drawing, readily available.

Since most filing cabinets or protected stowage receptacles are limited in space, you may need to develop an ingenious approach to a highly organized filing system. Keep in mind that each agency (such as NAVFACENGCOM) that makes an engineering drawing identifies it with an assigned number. The first major file breakdown then, is a separate file for drawings by each of the different agencies. Within each agency's file, the most convenient way to file their drawings and prints is by the numerical sequence they assigned.

2.2.1 Original Copies

File original drawings flat-NEVER fold them. For large size originals, use shallow-drawer file cabinets of the type shown in *Figure 1-3*.

**Figure 1-3 – Typical shallow-drawer cabinet for large,
original drawings, tracings, and negatives.**

Typically, you can store smaller size drawings on edge in the standard deep-drawer-type cabinet shown in *Figure 1-4*. Stationary partitions divide each drawer into compartments, and each compartment has a "compressor spring" to keep the drawings on edge in a compressed stack.
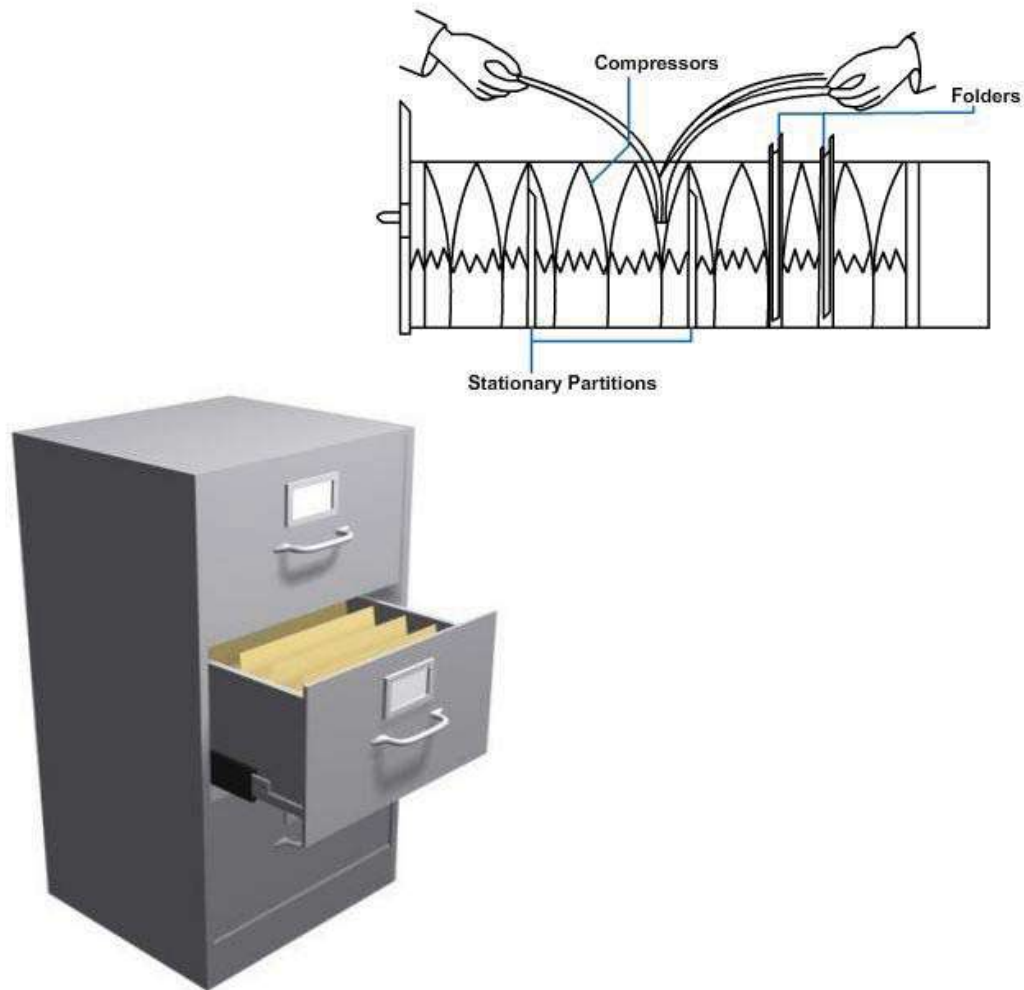

**Figure 1-4 – Typical deep-drawer
cabinet for small original drawings,
tracings, and negatives.**

2.2.2 Prints and Data

Current status determines the manner in which you maintain other prints and drawings. Usually, you will place active project prints and drawings on stick files (*Figure 1-5*) for easy access and reference. Stick files can be either manufactured metal components or locally prepared strips of wood. Sometimes you can stow extra sets of project drawings by rolling and placing them in a cylindrical plastic or cardboard tube.

Figure 1-5 – Stick File used for filing active project prints and drawings.

Depending on your unit's available configuration, you can stow inactive prints, such as those from completed projects or as-built drawings, either in the flat shallow-drawer file cabinet or in the standard deep-drawer cabinet. f you stow inactive drawings in the deep cabinet, there are specific folding instructions, see *Figure 1-6*.

For large, inactive prints, fold them in an accordion-pleat manner, ensuring that the drawing number is outside when finished. Final folded size should be 8 1/2 by 11 inches. Make or procure a plastic or plywood "folding guide" measuring 8 3/8- by 10 7/8 inches and follow these steps to prepare the drawings for stowage.

1. Lay the print face down. Using the folding guide, start by turning the edge containing the drawing number and fold the print into a 10 7/8-inch lengthwise fold. Use a small block of wood to compress the crease.

2. Turn the print over, make the next lengthwise accordion-pleat fold, and continue to turn over and fold until you have used up the width of the drawing.

3. Lay the lengthwise-folded drawing so the drawing number is face down. Using the folding guide again, begin at the end containing the drawing number and make the first 8 1/2-inch crosswise fold. Turn the print over; make the next accordion-pleat fold, and continue to turn over and fold until you have used up the length of the drawing.
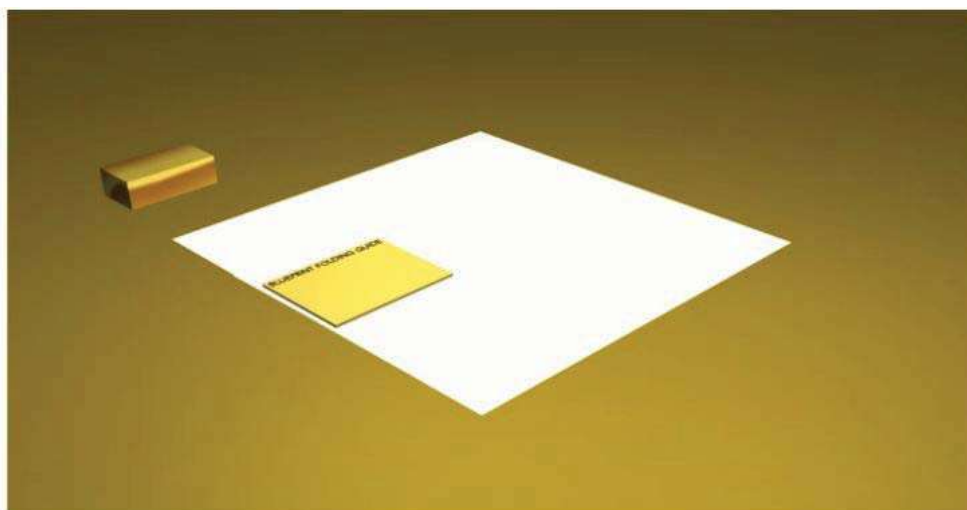
Figure 1-6 – Folding prints accordion style for storage.

File any data related to drawings, such as correspondence, according to Department of the Navy *Standard Subject Identification Codes Manual,* SECNAV NST 5210.11 series. f you maintain a separate folder or drawer file for each project, file the data in the appropriate projects folder. However, if the data or correspondence affects a limited number of drawings, you can file it in a separate drawer or cabinet according to their respective drawing numbers.

2.2.3 Recording Files

Keep a record of each drawing on an NDEX CARD in a suitable file drawer.

You can use a card similar to the sample in *figure 1-7* and enter the information in the numbered spaces as follows:

1. Standard Subject dentification Code (**SSIC**) (numerical and/or name title). The SECNAV NST 5210.11 series prescribes these classification codes. A copy of this instruction is available in your personnel office and in your technical library.

    The classification system in this manual meets the needs of the entire Department of the Navy for a single, standard, subject scheme for numbering, arranging, filing, and referencing various types of Navy and Marine Corps documents.

    Generally, large shore activities, such as public works departments, Naval Construction Battalion Centers, or regimental headquarters use the SS C system. Smaller mobile units (NMCBs, drafting room supervisors, quality control (QC) staff, EAs assigned to detachments) may devise their own indexing system for drawings according to the volume of records they handle.

2. Agency drawing number (NAVFACENGCOM DWG No.)

3. Title of the drawing, taken from the title block

4. Cross-index references to any related correspondence or data

5. Number of any agency letter forwarded with the drawing

6. Number of the A & E firm, contractor, naval shipyard, or other agency that actually made the drawings

7. Name of the A & E firm, contractor, naval shipyard, or other agency that actually made the drawings

8. Applicable unit (NMCB, Detachements, ETC.)

 f you maintain a separate folder or drawer file for each project, you must make a notation on the index card as to where to find the drawings related to that project. Project numbers will appear in the cross-index block of the index card but you can also modify your index card to accommodate any additional information your unit requires.

Figure 1-7 – Typical drawing file index card.

3.0.0 PROFESSIONAL DUTIES

 f you are an EA3 assigned to a typical Seabee battalion, you are very likely to perform your professional duties from within the engineering division of Operations (S-3). The Engineering Officer will assign you, or you may have a choice, to one of the sections within the division: drafting/print-reproduction, surveying, or materials testing. The following are some of the duties and responsibilities while assigned to these sections.

3.1.0 Assignment to Drafting/Reproduction Section

When you are first assigned to the drafting section, the drafting supervisor will usually task you with the simplest drafting or reproduction jobs so the experienced drafting crew can be free for the more complicated work. These simple tasks also serve as training for the inexperienced draftsman. n general, your assignments will probably include a variety of engineering services requests, such as reproducing prints, preparing charts, revising working drawings, preparing simple construction and fabrication drawings from sketches, and performing other EA-related office jobs. Other related tasks may include preparing overlay maps for operational, logistics, and/or contingency needs; performing operator's maintenance of the Plotter, plastic and metal engraving, maintaining a complete up-to-date technical library, and assisting other divisions and sections within the operations department as directed by the drafting supervisor.

3.1.1 Project Drawings
Often, during homeport periods, the bulk of your job in the drafting section will be to reproduce several project drawings the different construction crews and details need for project planning and material estimates. Any failure to produce the required quantity of prints on time could have an adverse effect on an entire construction project's planning and execution. To achieve maximum production, every draftsman in the section should train to perform this essential task. An experienced EA3 must be able to plan ahead, ensuring that sufficient quantities of basic reproduction materials, such as print paper and toner are on hand, and that the Plotter is in good working condition.

3.1.2 Maintaining a Technical Library

Another important responsibility of the drafting section is to establish and maintain an engineering technical library of current reference publications.

All operations department personnel, as well as anyone else in the battalion, may need to use the library to research technical information. To render service to others, one member of the drafting section must maintain the library in an orderly manner. Normally, this collateral duty assignment as librarian falls to an EA3 working in the drafting room. He is responsible for arranging the publications, indexing them, checking-out/checking-in borrowed publications, and ensuring replacement of missing publications. He is also responsible for packing the entire library for embarkation during overseas deployment.

A current COMCBPAC/LANT 5070 series instruction contains the minimum requirements for a technical library. The instruction includes all administrative, military, and technical library requirements each battalion must meet.

Appendix of this manual includes additional publications not listed in the COMCBPAC/LANT instruction. Depending on the particular mission of each deployment, the battalion may require additional publications.

The librarian must constantly monitor the technical library and know where each publication is at all times. Loss of important reference publications could cause delays in solving engineering problems. Security of frequently borrowed publications and a good check-out/check-in system will help prevent the loss of important publications.

3.2.1 Assignment to Surveying Section

One of the main units of the engineering division is the surveying or field engineering section. This section, like the drafting reproduction section, falls under the direct supervision of an EA1, depending on the number of senior EAs on board with surveying experience. The size and organization of the entire surveying section will vary with the anticipated workload.

Your job, along with the other crew members in this section, is to carry out the scope of the tasks and responsibilities required of the surveying section.

Depending on the overall mission of the battalion, typical surveying tasks may include:

- Collecting field data and sketches for design purposes
- Conducting surveys for horizontal construction (roads, airfields, aboveground and belowground utilities)
- Conducting layout surveys for vertical construction (buildings, retaining walls, waterfront structures, and so forth)
- Developing level nets and level loops to establish vertical control
- Developing triangulation networks to establish horizontal control
- Measuring structures in place to prepare as-built drawings

Versatility in the surveying section is essential to accomplish all of the assigned tasks.

Sometimes the survey crew supervisor will use all crews for one phase of the surveying task; at other times, crews will shuttle from one phase to another. For most surveying tasks, there will be two types of surveying parties: the transit party and the level party, so named for the type of surveying instrument they will use.

3.3.1 Assignment to Materials Testing Section

EAs assigned to the soils laboratory perform tests on such items as subbase materials, aggregates, and concrete and bituminous mixes to determine if these materials meet specified quality requirements. You may perform some of these tests together with a more experienced EA. As you gain experience in testing different types of materials used in construction, you may also work with the quality control (QC) section of the operations department.

EAs assigned to the material testing section work closely with the QC staff in several areas, such as:

- Testing materials to ensure that their inherent character meets minimum requirements

- nterpreting results of tests conducted on soil, concrete, and asphalt

- Preparing reports of the tests performed by the testing section

Summary

Your opportunities as an Engineering Aid will be many and varied as you transition from the probable sea duty "Green Machine" tour to a typical shore duty Public Works Activity. Each will provide experiences that can broaden your professional growth. Both your direct labor (contribution in the field) and your indirect labor (from your assigned unit's spaces) will contribute to a project's and a unit's success.

Review Questions (Select the Correct Response)

1.   The Engineering Aid rating is a ___ rating.

      A.   specialty
      B.   warfare
      C.   general
      D.   fleet

2.   **(True or False)** Engineering Aids have limited and only specific functions on projects.

      A.   True
      B.   False

3.   **(True or False)** Engineering Aids contribute only to vertical construction projects.

      A.   True
      B.   False

4.   **(True or False)** While the functions of the other Seabee ratings may relate to the whole of a construction project, the EA's functions relate only to the site preparation and layout phases.

      A.   True
      B.   False

5.   Most EA sea duty billets are in the ___.

      A.   Public Works Activities
      B.   Amphibious Seabees
      C.   Naval Mobile Construction Battalions
      D.   Engineering Field Divisions

6.   Assignment to a Seabee Battalion will usually place you in ___ .

      A.   Alfa Company
      B.   Bravo Company
      C.   Charlie Company
      D.   Headquarters Company

7.   Assignment to a Seabee Battalion will usually place you in the ___ department.

      A.   administration
      B.   training
      C.   operations
      D.   supply

8. Which of the following tasks are an NMCB engineering division's responsibilities?

   A. Providing as-built copies of drawings to customer activities
   B. Maintaining construction project status boards
   C. Both A and B

9. Which of the following tasks are an NMCB monitoring/reporting division's responsibilities?

   A. Maintaining project status records
   B. Timekeeping and labor analysis
   C. Preparing project completion letters
   D. All of the above

10. At most public works departments, your military duties will fall under ___ supervision, and your professional work will fall under ___ supervision.

    A. military; military
    B. civilian; civilian
    C. civilian; military
    D. military; civilian

11. **(True or False)** An EA assigned to a Public Works Activity may not have any supervisory duties.

    A. True
    B. False

12. **(True or False)** Engineering Aid billets are limited to Naval Mobile Construction Battalions and Public Works Activities.

    A. True
    B. False

13. ___ or ___ are two typical supervisory assignments that may come to you as an EA3.

    A. Survey party crew chief; planning and estimating supervisor
    B. Quality control supervisor; materials testing supervisor
    C. Panning and estimating supervisor; quality control supervisor
    D. Survey party crew chief; drafting room leader

14. **(True or False)** A crew leader/supervisor who asks questions relative to assigned tasking is demonstrating weak leadership.

    A. True
    B. False

15. Your survey crew is not being efficient in performing assigned tasks. Which of the following conditions may be an underlying cause of this inefficiency?

    A. Crew members were not properly briefed as to the scope of their assigned tasks
    B. Crew members did not understand their assigned responsibilities
    C. The importance of assigned tasks in relation to overall mission of the unit was not emphasized
    D. All of the above

16. Original drawings should always be ___.

    A. folded and filed in deep drawers
    B. rolled and stowed
    C. hung on stick files
    D. filed flat without folding

17. n which of the following ways should you store small prints in a standard deep-drawer cabinet?

    A. On edge
    B. Flat
    C. Rolled
    D. Folded

18. What is the final folded size of prints in accordion-pleat type of folds?

    A. 8 3/8 by 10 7/8 inches
    B. 8 1/2 by 11 inches
    C. 8 3/4 by 11 inches
    D. 9 by 11 inches

19. n which of the following ways should you store prints or drawings of active projects for easy reference?

    A. n folders
    B. n stick files
    C. n deep-drawer cabinets
    D. Rolled

20. Which of the following shore activities generally use the Standard Subject dentification Codes System for the filing of drawing records?

    A. Public Works Centers
    B. Naval Construction Battalion Centers
    C. Naval Construction Regiments
    D. All of the above

21. Which of the following information should you always record on the index card for your drawing files?

    A. Drawing title and number
    B. Cross-referenced correspondence relating to the drawing(s)
    C. Name of agency that made the drawing
    D. All of the above

22. **(True or False)** During homeport periods, there will be less need to reproduce project drawings.

    A. True
    B. False

23. Which of the following tasks are you responsible for as the Engineering Technical Library librarian?

    A. Ensuring that the publications are all in their proper location
    B. Maintaining an efficient check-out/check-in system
    C. Taking action, as necessary, to ensure that any lost or missing required publications are obtained
    D. All of the above

24. For most surveying tasks, there will be two types of surveying parties: the ___ party and the ___ party

    A. staking; measuring
    B. transit; level
    C. aligning; sighting
    D. elevation; distance

25. EAs assigned to the material testing section work closely with the ___ staff.

    A. quality control
    B. surveying
    C. planning and estimating
    D. file reproduction

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

Advancement Handbook for Petty Officers, Engineering Aid (EA), NAVEDTRA 71365, Naval Education and Training Program Management Support Activity, Pensacola, Fla., 1989.

Construction Force Manual, NAVFAC P-315, Naval Facilities Engineering Command, Alexandria, Va., 1985.

Military Requirements for Petty Officer Third Class, NAVEDTRA 14504, Naval Education and Training Program Management Support Activity, Pensacola, Fla., 2003.

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Chapter 2

Mathematics and Units of Measurement

Topics

1.0.0   Fundamentals of Mathematics

2.0.0   Geometry

3.0.0   Hints on Computing

4.0.0   Units of Measurement

To hear audio, click on the box.

Overview

Engineering Aids use mathematics as basic tool. The use of mathematics is found in every rating in the Navy, from the simple arithmetic of counting for inventory purposes to the complicated equations encountered in computer and engineering designs. Mathematics is a broad science that cannot be covered fully in formal service school training, so it is up to you to devote some of your own time to the study of this subject. This chapter covers various principles of mathematics. The instructions given will aid you in making mathematical computations in the field and the office. This chapter also covers units of measurement and the conversion from one system to the other; that is, from the English to the metric system.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Identify the fundamentals of mathematics.
2. Identify the fundamentals of geometry.
3. Describe the procedures for using a scientific calculator.
4. Understand hints of computation operations.
5. Identify the different units of measurements.

Prerequisites

None

This course map shows all of the chapters in Engineering Aid Basic. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Topographic Surveying and Mapping	↑	E
Indirect Leveling/Level and Traverse Computations		N
Care and Adjustment of Survey Equipment		G
Materials Testing: Soil and Concrete		I
Direct Leveling and Basic Engineering Surveys		N
Horizontal Control		E
Direct Linear Measurements and Field Survey Safety		E
Surveying: Elements and Equipment		R
Construction Drawings		I
Electrical: Systems and Plans		N
Mechanical: Systems and Plans		G
Concrete and Masonry		AID
Wood and Light Frame Structures		B
Drafting: Projections and Sketching		A
Drafting: Geometric Construction		S
Drafting: Fundamentals and techniques		I
Drafting: Equipment		C
Mathematics and Units of Measurement		
Engineering Aid Rating		

Features of this Manual

This manual has several features which make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.

- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.

- Audio and video clips are included in the text, with italicized instructions telling you where to click to activate it.

- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the

answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.1.1 FUNDAMENTALS of MATHEMATICS

Mathematics is, by broad definition, the science that deals with the relationships between quantities and operations and with methods by which these relationships can be applied to determine unknown quantities from given or measured data. The fundamentals of mathematics remain the same no matter to what field they are applied. It has been subdivided into a number of major branches. Those with which you will be principally concerned are:

- ARITHMETIC, the art of computation by the use of positive *real numbers*. Starting with the review of arithmetic, you will, by diligent effort, build up to a study of algebra.

- ALGEBRA, the branch of mathematics that deals with the relations and properties of numbers by means of letters, signs of operation, and other symbols. Algebra includes solution of equations, polynomials, verbal problems, graphs, and so on.

- GEOMETRY, the branch of mathematics that investigates the relations, properties, and measurement of solids, surfaces, lines, and angles; it also deals with the theory of space and of figures in space.

- TRIGONOMETRY, the branch of mathematics that deals with certain constant relationships that exist in triangles and with methods by which they are applied to compute unknown values from known values.

1.1.0 Study Guides

Mathematics is an exact science, and there are many books on the subject. These numerous books are the result of the mathematicians' efforts to solve mathematical problems with ease. Methods of arriving at solutions may differ, but the end results or answers are always the same. These different approaches to mathematical problems make the study of mathematics more interesting, either by individual study or as a group. You can supplement your study of mathematics with the following training manuals:

NAVEDTRA 14139-Mathematics, Basic Math and Algebra

NAVEDTRA 14140-Mathematics, Trigonometry

NAVEDTRA 14141-Mathematics, Pre-Calculus and Introduction to Probability

NAVEDTRA 14142-Mathematics, Introduction to Statistics, Number Systems and Boolean Algebra

1.2.0 Types of Numbers

Positive and negative numbers belong to the class called real numbers. Real numbers and imaginary numbers make up the number system in algebra. In this training manual, we will deal only with real numbers unless otherwise indicated.

A real number may be rational or irrational. The word rational comes from the word ratio. A number is rational if it can be expressed as the quotient, or ratio, of two whole numbers. **Rational numbers** include fractions like 2/7, whole numbers (integers), and radicals if the radical is removable. Any whole number is rational because it could be expressed as a quotient with 1 as its denominator. For instance, 8 equals 8/1, which is the quotient of two integers. A number like $\sqrt{16}$ is rational since it can be expressed as

the quotient of the two integers in the form 4/1. An irrational number is a real number that cannot be expressed as the ratio of two integers. The following numbers and 3.1416 are examples of **irrational numbers**.

$$\sqrt{3}, \quad 5\sqrt{2}, \quad \sqrt{7+5}, \quad \frac{3}{8}\sqrt{20}$$

An integer may be prime or composite. A number that has factors other than itself and 1 is a composite number. For example, the number 15 is a composite number. It has the factors 5 and 3. A number that has no factors except itself and 1 is a prime number. Since it is to your advantage to separate a composite number into prime factors, it is helpful to be able to recognize a few prime numbers. The following are examples of prime numbers: 1, 2, 3, 5, 7, 11, 13, 17, 19, and 23. A composite number may be a multiple of two or more numbers other than itself and 1, and it may contain two or more factors other than itself and 1. Multiples and factors of numbers are as follows: Any number that is exactly divisible by a given number is a multiple of the given number. For example, 24 is a multiple of 2, 3, 4, 6, 8, and 12 since it is divisible evenly by each of these numbers. Saying that 24 is a multiple of 3, for instance, is equivalent to saying that 3 multiplied by some whole number will give 24. Any number is a multiple of itself and also of 1.

1.3.0 Fractions, Decimals, and Percentages

The most general definition of a fraction is "an indicated division." Any division may be indicated by placing the dividend over the divisor with a line between them. By the above definition, any number, even a so-called "whole" number, may be written as a common fraction. The number 20, for example, may be written as 20/1. This or any other fraction that amounts to more than 1 is an **improper fraction**. For example, 8/3 is an improper fraction; the accepted practice is to reduce an improper fraction to a mixed fraction (a whole number plus a **proper fraction**). Perform the indicated division and write the fractional part of the quotient in its lowest term. In this case, 8/3 would be 2 2/3. A fraction that amounts to less than 1 is a proper fraction, such as the fraction 1/4. Follow these rules in the solution of fractions:

If you multiply or divide both the numerator and denominator of a fraction by the same number, the value does not change. The resulting fraction is called an **equivalent fraction**.

You can add or subtract fractions only if the denominators are alike.

To multiply fractions, simply find the products of the numerators and the products of the denominators. The resulting fractional product must be reduced to the lowest term possible.

To divide a fraction by a fraction, invert the divisor and proceed as in multiplication.

The method of canceling can be used to advantage before multiplying fractions (using the principle of rule No. 1) to avoid operations with larger numbers.

A decimal fraction is a fraction whose denominator is 10 or some power of 10, such as 100, 1,000, and so on. For example,

$$\frac{7}{10}, \frac{23}{100} \text{and} \frac{87}{1,000}$$

are decimal fractions. Accordingly, they could be written as 0.7, 0.23 and 0.087 respectively. Decimal fractions have certain characteristics that make them easier to use in computations than other fractions. A thorough understanding of decimals will be useful to the Engineering Aid in making various engineering computations. *Figure 2-1* shows decimal equivalents of fractions commonly used by Builders, Steelworkers, Utilitiesmen, and other trades.

$\frac{1}{64}$	= .015625	$\frac{17}{64}$	= .265625	$\frac{33}{64}$	= .515625	$\frac{49}{64}$	= .765625
$\frac{1}{32}$	= .03125	$\frac{9}{32}$	= .28125	$\frac{17}{32}$	= .53125	$\frac{25}{32}$	= .78125
$\frac{3}{64}$	= .046875	$\frac{19}{64}$	= .296875	$\frac{35}{64}$	= .546875	$\frac{51}{64}$	= .796875
$\frac{1}{16}$	= .0625	$\frac{5}{16}$	= .3125	$\frac{9}{16}$	= .5625	$\frac{13}{16}$	= .8125
$\frac{5}{64}$	= .078125	$\frac{21}{64}$	= .328125	$\frac{37}{64}$	= .578125	$\frac{53}{64}$	= .828125
$\frac{3}{32}$	= .09375	$\frac{11}{32}$	= .34375	$\frac{19}{32}$	= .59375	$\frac{27}{32}$	= .84375
$\frac{7}{64}$	=.109375	$\frac{23}{64}$	= .359375	$\frac{39}{64}$	= .609375	$\frac{55}{64}$	= .859375
$\frac{1}{8}$	= .125	$\frac{3}{8}$	= .375	$\frac{5}{8}$	= .625	$\frac{7}{8}$	= .875
$\frac{9}{64}$	= .140625	$\frac{25}{64}$	= .390625	$\frac{41}{64}$	= .640625	$\frac{57}{64}$	= .890625
$\frac{5}{32}$	= .15625	$\frac{13}{32}$	= .40625	$\frac{21}{32}$	= .65625	$\frac{29}{32}$	= .90625
$\frac{11}{64}$	= .171875	$\frac{27}{64}$	= .421875	$\frac{43}{64}$	= .671875	$\frac{59}{64}$	= .921875
$\frac{3}{16}$	= .1875	$\frac{7}{16}$	= .4375	$\frac{11}{16}$	= .6875	$\frac{15}{16}$	= .9375
$\frac{13}{64}$	= .203125	$\frac{29}{64}$	= .453125	$\frac{45}{64}$	= .703125	$\frac{61}{64}$	= .953125
$\frac{7}{32}$	= .21875	$\frac{15}{32}$	= .46875	$\frac{23}{32}$	= .71875	$\frac{31}{32}$	= .96875
$\frac{15}{64}$	= .234375	$\frac{31}{64}$	= .484375	$\frac{47}{64}$	= .734375	$\frac{63}{64}$	= .984375
$\frac{1}{4}$	= .25	$\frac{1}{2}$	= .5	$\frac{3}{4}$	= .75	1	= 1.00

Figure 2-1 - Decimal equivalents.

In connection with the study of decimal fractions, businessmen as early as the fifteenth century made use of certain decimal fractions so much that they gave them the special designation percent. The word percent is derived from Latin. It was originally per centum, which means "by the hundredths." In banking, interest rates are always expressed in percent; statisticians use percent; in fact, people in almost all walks of life use percent to indicate increases or decreases in production, population, cost of living, and so on. The Engineering Aid uses percent to express change in grade (slope), as shown in *Figure 2-2*.
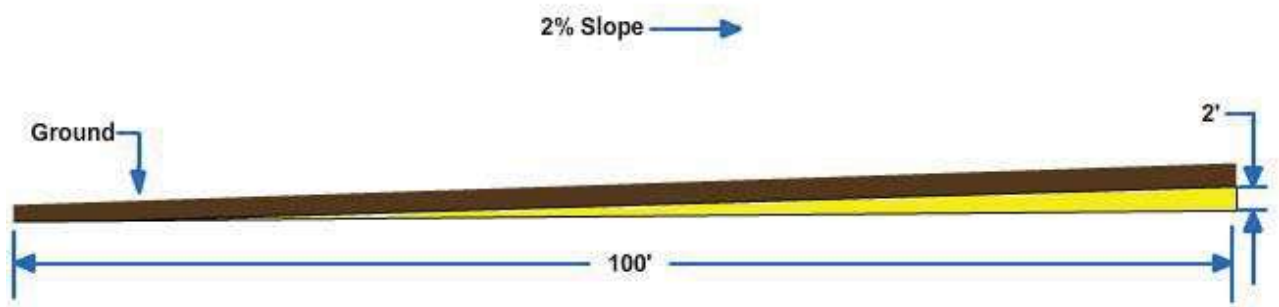
Figure 2-2 - Percent Grade.

1.4.0 Powers, Roots, Exponents and Radicals

Any number is a higher power of a given *root*. To raise a number to a power means to multiply, using the number as a factor as many times as the power indicates. A particular power is indicated by a small numeral called the exponent; for example, the small 2 on 3^2 is an exponent indicating the power.

Examples:

$3^2 = 3 \times 3 = 9$

$3^3 = 3 \times 3 \times 3 = 27$

$6^2 = 6 \times 6 = 36$

$6^3 = 6 \times 6 \times 6 = 216$

Many formulas require the power or roots of a number. When an exponent occurs, it must always be written unless its value is 1.

A particular root is indicated by the radical sign ($\sqrt{}$), together with a small number called the index of the root. The number under the radical sign is called the radicand. When the radical sign is used alone, it is generally understood to mean a square root, and $\sqrt[3]{}$, $\sqrt[5]{}$, and $\sqrt[7]{}$, indicate cube, fifth, and seventh roots, respectively. The square root of a number may be either + or -. The square root of 36 may be written thus: $\sqrt{36} = \pm 6$, since 36 could have been the product of $(+6)(+6)$ or $(-6)(-6)$. However, in practice, it is more convenient to disregard the double sign (±). This example is what we call the root of a perfect square. Sometimes it is easier to extract part of a root only after separation of the factors of the number, such as $\sqrt{27} = \sqrt{9 \times 3} = 3\sqrt{3}$. As you can see, we were able to extract only the square root of 9, and 3 remains in the radical because it is an irrational factor. This simplification of the radical makes the solution easier because you will be dealing with perfect squares and smaller numbers.

Examples:

$$\sqrt{25} = \sqrt{5 \times 5} = 5$$

$$\sqrt{24} = \sqrt{4 \times 6} \quad 2\sqrt{6} = 2 \times 2.236 = 4.472$$

$$\sqrt[3]{40} \quad \sqrt[3]{8 \times 5} \quad 2\sqrt[3]{5} = 2 \times 1.710 = 3.420$$

Radicals are multiplied or divided directly.

Examples:

$$\sqrt{3} \times \sqrt{6} \quad \sqrt{18} \quad \sqrt{9 \times 2} \quad 3\sqrt{2}$$

$$\frac{\sqrt{12}}{\sqrt{3}} \quad \frac{\sqrt{4} \times \sqrt{3}}{\sqrt{3}} \quad \sqrt{4} \quad \pm 2$$

Like fractions, radicals can be added or subtracted only if they are similar.

Examples:

$$2\sqrt{5} + \sqrt{5} \quad 3\sqrt{5}$$

$$\sqrt{2 \times 4} + \sqrt{2 \times 9} \quad \sqrt{2}(\sqrt{4}) + \sqrt{2}(\sqrt{9})$$

$$= 2\sqrt{2} + 3\sqrt{2}$$

$$= 5\sqrt{2}$$

When you encounter a fraction under the radical, you have to **rationalize** the denominator before performing the indicated operation. If you multiply the numerator and denominator by the same number, you can extract the denominator, as indicated by the following example:

$$\sqrt{\frac{2}{5}} \quad \frac{\sqrt{2}}{\sqrt{5}} \times \frac{\sqrt{5}}{\sqrt{5}} \quad \frac{\sqrt{10}}{\sqrt{25}} \quad \frac{1}{5}\sqrt{10}$$

The same is true in the division of radicals; for example,

$$\sqrt{\frac{3}{6}} \quad \frac{\sqrt{3}}{\sqrt{6}} \div \frac{\sqrt{3}}{\sqrt{3}} \quad \frac{1}{\sqrt{2}}$$

Any radical expression has a decimal equivalent, which may be exact if the radicand is a rational number. If the radicand is not rational, the root may be expressed as a decimal approximation, but it can never be exact. A procedure similar to long division may be used for calculating square root. Cube root and higher roots may be calculated by methods based on logarithms and higher mathematics. Tables of powers and roots

have been calculated for use in those scientific fields in which working with roots is frequently necessary. This method is, however, slowly being phased out and replaced by the use of hand-held scientific calculators.

1.4.1 Arithmetic Extraction of Square Roots

If you do not have an electronic calculator, you may extract square roots arithmetically as follows:

Let's say you want to extract the square root of 2,034.01. First, divide the number into two-digit groups, working away from the decimal point. Thus set off, the number appears as follows:

$$\sqrt{20\ 34.01}$$

Next, find the largest number whose square can be contained in the first group, This is the number 4, whose square is 16. The 4 is the first digit of your answer. Place the 4 above the 20, and place its square (16) under the first group, thus:

$$\begin{array}{r} 4 \\ \sqrt{20\ 34.01} \\ \underline{16} \end{array}$$

Now perform the indicated subtraction and bring down the next group to the right, thus:

$$\begin{array}{r} 4 \\ \sqrt{20\ 34.01} \\ \underline{16} \\ 434 \end{array}$$

Next, double the portion of the answer already found (4, which doubled is 8), and set the result down as the first digit of a new divisor, thus:

$$\begin{array}{r} 4 \\ \sqrt{20\ 34.01} \\ \underline{16} \\ 8\ /\ 434 \end{array}$$

The second digit of the new divisor is obtained by a trial-and-error method. Divide the single digit 8 into the first two digits of the remainder 434 (that is, into 43) until you obtain the largest number that you can (1) add as another digit to the divisor and (2) use as a multiplier which, when multiplied by the increased divisor, will produce the largest result containable in the remainder 434. In this case, the first number you try is 43 + 8, or 5. Write this 5 after the 8 and you get 85. Multiply 85 by 5 and you get 425, which is containable in 434.

The second digit of your answer is therefore 5. Place the 5 above 34. Your computation will now look like this:

$$\begin{array}{r} 4\ \ 5 \\ \sqrt{20\ 34.01} \\ \underline{16} \\ 85/434 \\ \underline{425} \end{array}$$

Proceed as before to perform the indicated subtraction and bring down the next group, thus:

$$\begin{array}{r} 4\ \ 5 \\ \sqrt{20\ 34.01} \\ \underline{16} \\ 85\ /434 \\ \underline{425} \\ 901 \end{array}$$

Again double the portion of the answer already found, and set the result (45 x 2, or 90) down as the first two digits of a new divisor thus:

$$\begin{array}{r} 4\ \ 5 \\ \sqrt{20\ 34.01} \\ \underline{16} \\ 85\ /434 \\ \underline{425} \\ 90/\ \ 901 \end{array}$$

Proceed as before to determine the largest number that can be added as a digit to the divisor 90 and used as a multiplier which, when multiplied by the increased divisor, will produce a result containable in the remainder, 901. This number is obviously 1. The increased divisor is 901, and this figure, multiplied by the 1, gives a result exactly equal to the remainder 901.

The figure 1 is therefore the third and final digit in the answer, the square root of 2,034.01 is therefore 45.1

Your completed computation appears thus:

$$\begin{array}{r} 4\ \ 5.\ \ 1 \\ \sqrt{20\ 34.01} \\ \underline{16} \\ 85\ /434 \\ \underline{425} \\ 901/\ 901 \\ \underline{901} \end{array}$$

1.4.2 Negative Exponents

In some formulas, like the velocity (V) of liquids in pipes, which you will encounter later in Engineering Aid Advanced, it is more convenient to use fractional exponents instead of radicals.

Examples:

$$\sqrt{3} = 3^{1/2} \qquad\qquad \sqrt[3]{3} = 3^{1/3}$$

$$\sqrt[3]{3} = 3^{1/3} \qquad\qquad \sqrt[3]{3}^2 = 3^{2/3}$$

As you can readily observe, the index of the root in the above examples is the denominator of the fractional exponent. When an exponent occurs in the radicand, this exponent becomes the numerator of the fractional exponent. Roots of numbers not found in tables may be easily computed by proper treatment of the radical used.

Examples:

$$\sqrt{\frac{7}{16}} \qquad \frac{\sqrt{7}}{\sqrt{16}} \qquad \frac{1}{4}\sqrt{7} \qquad \frac{2.646}{4} \qquad 0.6615$$

$$\sqrt{8\frac{3}{4}} \qquad \sqrt{\frac{35}{4}} \qquad \frac{\sqrt{35}}{\sqrt{4}} \qquad \frac{1}{2}\sqrt{35} \qquad \frac{5.916}{2} \qquad 2.958$$

In some work, negative exponents are used instead of reciprocals of numbers.

Examples:

$$3^{-1} = 1/3 \qquad\qquad 10^{-1} = 1/10$$
$$3^{-2} = 1/3^2 = 1/9 \qquad\qquad 10^{-2} = 1/100$$
$$1/5^{-1} = 5 \qquad\qquad 10^{-3} = 1/1000$$

Very small or very large numbers used in science are expressed in the form 5.832×10^{-4} or 8.143×10^6 to simplify computation. To write out any of these numbers in full, just move the decimal point to either left or right, the number of places equal to the exponent, supplying a sufficient number of zeros depending upon the sign of the exponent, as shown below:

$5.832 \times 10^{-4} = 0.0005832$ (decimal moved four places to the left)

$8.143 \times 10^6 = 8,143,000$ (decimal moved six places to the right)

1.5.0 Reciprocals

The reciprocal of a number is 1 divided by the number. The reciprocal of 2, for example, is 1/2, and the reciprocal of 2/3 is 1 divided by 2/3, which amounts to 1 x 3/2, or 3/2. The reciprocal of a whole number, then, equals 1 over the number, while the reciprocal of a fraction equals the fraction inverted.
In problems containing the power of 10, using reciprocals is generally more convenient than writing out lengthy decimals or whole numbers.

Example:

$$\frac{1}{250{,}000 \times 300 \times 0.02} = \frac{1}{2.5 \times 10^5 \times 3 \times 10^2 \times 2 \times 10^2}$$

$$= \frac{10^5}{2.5 \times 3 \times 2} = \frac{10^5}{15} = \frac{1 \times 10^5}{15}$$

$$= .0667 \times 10^5 = 6.67 \times 10^{-2} \times 10^{-5}$$

$$= 6.67 \times 10^{-7}$$

$$= 0.000000667$$

Reciprocal is also used in problems involving trigonometric functions of angles, as you will see later in this chapter, in the solutions of problems containing identities.

1.6.0 Ratio and Proportion

Almost every computation you will make as an EA that involves determining an unknown value from given or measured values will involve the solution of a proportional equation. A thorough understanding of ratio and proportion will greatly help you solve both surveying and drafting problems.

The results of observation or measurement often must be compared to some standard value in order to have any meaning. For example, if the magnifying power of your telescope is 20 diameters and you see a telescope in the market that says 50 diameter magnifying power, you can see that the latter has a greater magnifying power. How much more powerful? To find out, we will divide the second by the first number, which is

$$\frac{50}{20} = \frac{5}{2},$$

The magnifying power of the second telescope is 2 1/2 times as powerful as the first. When the relationship between two numbers is shown this way, the numbers are compared as a ratio. In mathematics, a ratio is a comparison of two quantities. Comparison by means of a ratio is limited to quantities of the same kind, For example, in order to express the ratio between

12 feet and 3 yards, both quantities must be written in terms of the same unit. Thus, the proper form of this ratio is 4 yards: 3 yards, not 12 feet: 3 yards.

When the parts of the ratio are expressed in terms of the same unit, the units cancel each other and the ratio consists simply of two numbers. In this example, the final form of the ratio is 4:3.

Since a ratio is also a fraction, all the rules that govern fractions may be used in working with ratios. Thus, the terms may be reduced, increased, simplified, and so forth, according to the rules for fractions.

Closely allied with the study of ratio is the subject of proportion. A proportion is nothing more than an equation in which the members are ratios. In other words, when two ratios are set equal to each other, a proportion is formed. The proportion may be written in three different ways, as in the following examples:

$$15:20 :: 3:4$$

$$\frac{15}{20} = \frac{3}{4}$$

$$15:20 = 3:4$$

The last two forms are the most common. All of these forms are read, "15 is to 20 as 3 is to 4." In other words, 15 has the same ratio to 20 as 3 has to 4. In addition to gaining this knowledge, you should develop the ability to recognize a computational situation as one that is available to solution by proportional equation. A very large area of surveying computations-the area that involves triangle solutions-uses the proportional equation as the principal key to the determination of unknown values on the basis of known values. Practically any problem involving the conversion of measurement expressed in one unit to the equivalent in a different unit is solvable by proportional equation. Similarly, if you know the quantity of a certain material required to produce a certain number of units of product, you can determine by proportional equation the quantity required to produce any given number of units.

In short, it is difficult to imagine any mathematical computation involving the determination of unknown values on the basis of known values that is not available to solution by proportional equation.

Your knowledge of equations need not extend beyond that required to solve linear equations; that is, equations in which the unknown appears with no exponent higher than 1. The equation

$$4x + 7 = \frac{15}{6},$$

for example, is a linear equation, because the unknown (technically known as the "variable' '), x, appears to only the first power. The equation $X^2 + 2x = -1$, however, is a quadratic, not a linear, equation because the variable appears to the second power.

1.7.0 Arithmetic

The common arithmetical operations are addition, subtraction, multiplication, and division. Arithmetical operations with common fractions are explained in chapter 4, and arithmetical operations with decimal fractions, in chapter 5 of NAVEDTRA 14139.

1.8.0 Algebraic Notations and Algebraic Operations

Algebraic fundamentals, such as the meanings of terms; systems of groupings; and the addition, subtraction, multiplication, and division of algebraic monomials and polynomials are explained in chapter 9 of NAVEDTRA 14139. The factoring of algebraic expressions is explained in chapter 10 of NAVEDTRA 14139.

2.0.0 GEOMETRY

Since geometry is the branch of mathematics that investigates the relations, properties, and measurement of solids, surfaces, lines, and angles, it follows that just about everything a surveyor does involves geometry in some way or other. Whenever you establish a point, chain a linear distance, measure a vertical distance, turn an angle, or determine an area or a volume, you are working with geometry.

To begin with, you must know how to recognize the common types of geometrical plane and solid figures and how to compute the areas of the plane figures and the volumes of the solid ones.

2.1.0 Surfaces and Figures

There is a surface on this sheet of paper. A geometrical surface has length and breadth.

It has no thickness. A surface may be either a plane surface or a curved surface. When this page is held perfectly level at every point, the surface is then a plane surface. When the page is rolled to resemble a tube, the plane surface becomes a curved surface.

A plane is a real or imaginary surface in which a straight line between any two points lies wholly on that surface. *Figure 2-3* shows two intersecting planes. Plane ABCD is shown to be a horizontal plane; plane abed is a vertical plane perpendicular to ABCD.

A plane surface is a surface on which every point lies in the same plane.

Figure 2-3 - Intersecting planes.

Plane figures are plane surfaces bounded by either straight lines or curved lines.

2.2.0 Polygons

A plane figure bounded by straight-line sides is called a polygon. The smallest possible number of sides for a polygon is three, and a three-sided polygon is called a triangle.

Some terms and definitions relating to polygons are as follows:

Sides	The boundary lines of a polygon
Perimeter	The sum of the sides
Triangle	A polygon bounded by three sides
Quadrilateral	A polygon bounded by four sides
Hexagon	A polygon bounded by six sides
Heptagon	A polygon bounded by seven sides
Octagon	A polygon bounded by eight sides
Equilateral	A polygon with sides of equal length
Regular	An equilateral polygon
Irregular	A nonequilateral polygon
Parallelogram	A quadrilateral with both pairs of opposite sides parallel
Rectangle	A parallelogram in which adjacent sides join at right angles
Square	An equilateral rectangle
Oblong	A nonequilateral rectangle
Trapezoid	A quadrilateral with only one pair of opposite sides parallel, the other being not parallel
Trapezium	A quadrilateral with no sides parallel
Rhombus	An equilateral parallelogram in which adjacent sides join at oblique (other than right) angles
Rhomboid	A nonquilateral parallelogram in which adjacent sides join at oblique angles

Figure 2-4 shows a triangle, quadrilateral, pentagon, hexagon, heptagon, and octagon. *Figure 2-5* shows a trapezoid, trapezium, rhombus, and rhomboid.
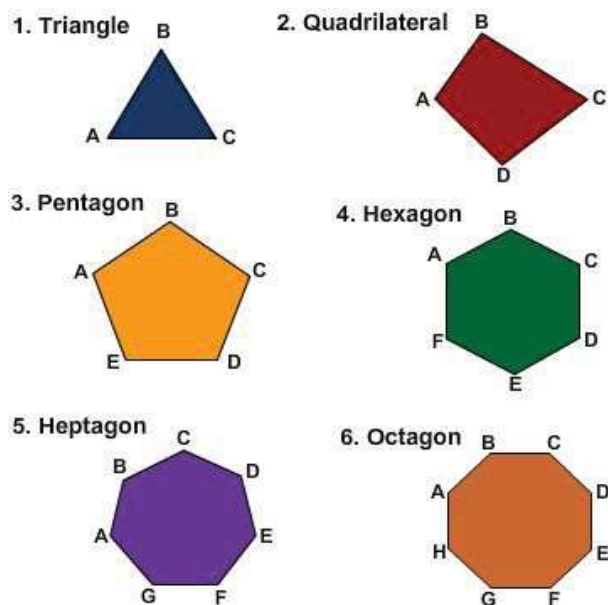
Figure 2-4 – Geometric figures of a triangle, quadrilateral, pentagon, hexagon, heptagon, and octagon.
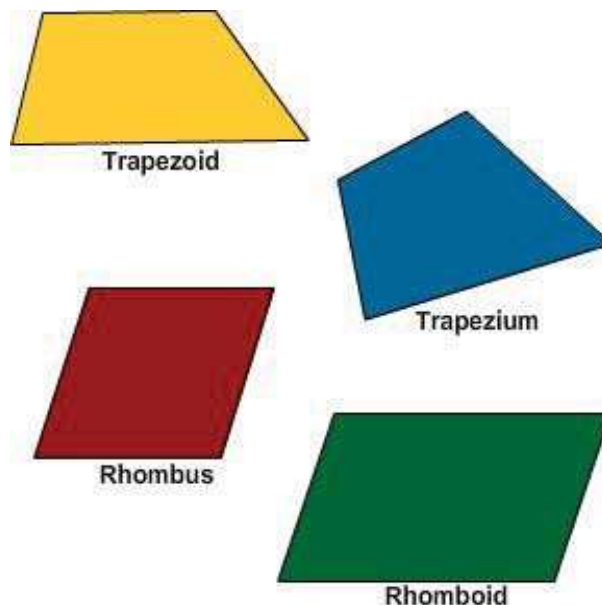
Figure 2-5 – Geometric figures of a trapezoid, trapezium, rhombus, and rhomboid.

2.3.0 Determining Areas

The area of any surface is the number of units of area measure the surface contains. A unit of area measure is a square unit. The main thing to remember when computing for areas is that the dimensions used must be of the same unit of measure-if in inches, all units must be in inches and if in feet, all must be in feet.

2.3.1 Area of a Rectangle

Figure 2-6 shows a rectangle measuring 10 feet by 8 feet, divided up into units of area measure, each consisting of 1 sq foot. If you were to count the units, one after the other, you would count a total of 80 units. However, you can see that there are 8 rows of 10 units, or 10 rows of 8 units. Therefore, the quickest way to count the units is simply to multiply 10 by 8, or 8 by 10.

You could call the 8-feet dimension the width and the 10-feet dimension the length, in which case you would say that the formula for determining the area of a rectangle is the width times the length, or A = wl. Or, you could call the 10-feet dimension the base and the 8-feet dimension the altitude (meaning height), in which case your formula for area of a
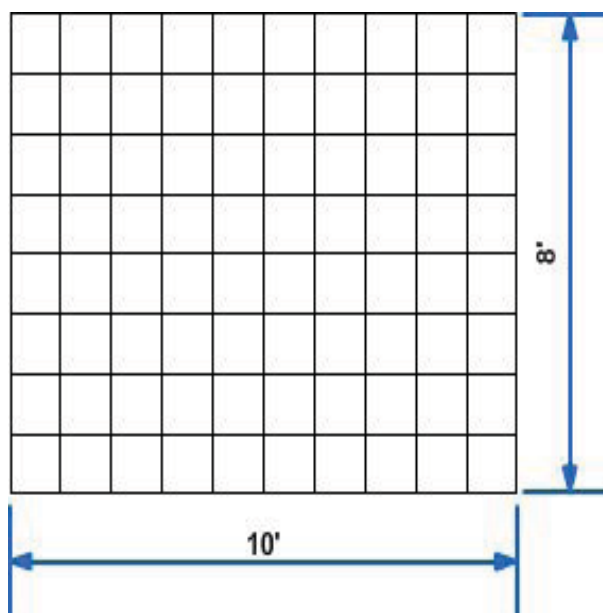
Figure 2-6 – Area of a Rectangle

rectangle would be A = bh.

2.3.2 Area of a Triangle

Figure 2-7 shows a triangle consisting of one-half of the rectangle shown in *Figure 2-6*. It is obvious that the area of this triangle must equal one-half of the area of the corresponding rectangle, and the fact that it does can be demonstrated by geometrical proof. Therefore, since the formula for the area of the rectangle is A = bh, it follows that the formula for the triangle is A = 1/2bh.

Figure 2-7 – Area of a triangle.

The triangle shown in *Figure 2-7*, because it is half of a corresponding rectangle, contains a right angle, and is therefore called a right triangle. In a right triangle the dimension h corresponds to the length of one of the sides. The triangle shown in *Figure 2-8*, however, is a scalene triangle, so-called because no two sides are equal. Classification of triangles will be discussed later in this chapter.

Now, a perpendicular CD drawn from the apex of the triangle (from angle C) divides the triangle into two right triangles, ⟩ADC and ⟩BDC. The area of the whole triangle equals the sum of the areas of ⟩ADC and ⟩BDC. The area of ⟩ADC equals 1/2 (AD)(DC), and the area of ⟩BDC equals 1/2(DB)(DC). Therefore, the area of the whole triangle equals

$$\frac{AD}{2}(DC) + \frac{DB}{2}(DC), \text{ or } DC\frac{(AD+DB}{2}$$

Figure 2-8 - Triangle.

But since AD + DB = AB, it follows that the area of the whole triangle equals

$$DC\frac{(AB}{2}.$$

The length of AB is called the base (b), and the length of DC, the altitude (h); therefore, your formula for determining the area of an oblique triangle is again A = 1/2bh.

You must remember that in a right triangle, h corresponds to the length of one of the sides, while in an oblique triangle it does not. Therefore, for a right triangle with the length of the sides given, you can determine the area by the formula A = 1/2bh. For an oblique triangle with the length of the sides given, you cannot use this formula unless you can determine the value of h. Later in this chapter you will learn trigonometric

methods of determining areas of various forms of triangles on the basis of the length of the sides alone.

2.3.3 Area of a Rhombus or Rhomboid

Figure 2-9 shows a rhomboid, ABCD. If you drop a perpendicular, CF, from Λ C to AD, and project another from Λ A to BC, you will create two right triangles, ⟩ AEB and ⟩ CFD, and the rectangle AECF. It can be shown geometrically that the right triangles are similar and equal.

You can see that the area of the rectangle AECF equals the product of AF x FC. The area of the triangle CFD equals 1 /2(FD) (FC). Because the triangle AEB is equal and similar to CFD, the area of that triangle also equals 1/2(FD) (FC). Therefore, the total area of both triangles equals (FD) (FC). The total area of the rhomboid equals the area of the rectangle AECF + the total area of both triangles.

The total area of the rhomboid equals (AF) (FC) + (FD) (FC), or (AF + FD) (FC). But AF + FD equals AD, the base. FC equals the altitude. Therefore, the formula for the area of a rhomboid is A = bh. Here again

Figure 2-9 - Rhomboid.

you must remember that h in a rectangle corresponds to the length of one of the sides, but h in a rhombus or rhomboid does not.
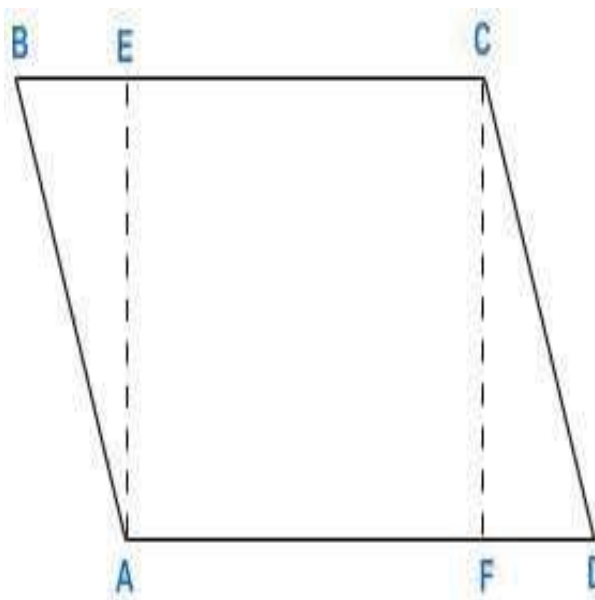
2.3.4 Area of a Trapezoid

Figure 2-10 shows a trapezoid, ABCD. If you drop perpendiculars BE and CF from points B and C, respectively, you create the right triangles AEB and DFC and the rectangle EBCF between them. The area of the trapezoid obviously equals the sum of the areas of these figures.

The area of ⟩ AEB equals 1/2(AE)(FC), the area of ⟩ DFC equals 1/2(FD)(FC), and the area of EBCF equals (EF)(FC). Therefore, the area of the trapezoid ABCD equals l/2(AE)(FC) + (EF)(FC) + 1/2(FD)(FC), or

$$\frac{(AE + FD + 2EF)(FC)}{2}.$$
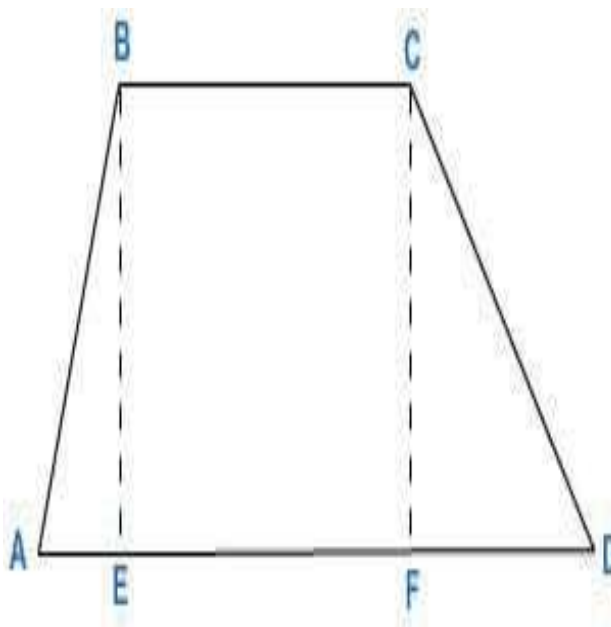
Figure 2-10 - Trapezoid.

However, 2EF = EF + BC. Therefore, the area of the trapezoid equals

$$\frac{(AE + FD + EF + BC)(FC)}{2}.$$

But AE + FD + EF = AD. Therefore, the area of the trapezoid equals

$$\frac{(AD + BC)(FC)}{2}.$$

AD and BC are the bases of the trapezoid and are usually designated as b_1 and b_2, respectively. FC is the altitude and is generally designated as h. Therefore, the formula for the area of a trapezoid is

$$A = 1/2\ (b_1 + b_2)\ h.$$

Stated in words, the area of a trapezoid is equal to one-half the sum of its bases times its altitude.

2.3.5 Area by Reducing to Triangles

Figure 2-11 shows you how to determine the area of a trapezium, or of any polygon, by reducing it to triangles. The dotted line connecting A and C divides the figure into the triangles ABC and ACD. The area of the trapezium obviously equals the sum of the areas of these triangles.
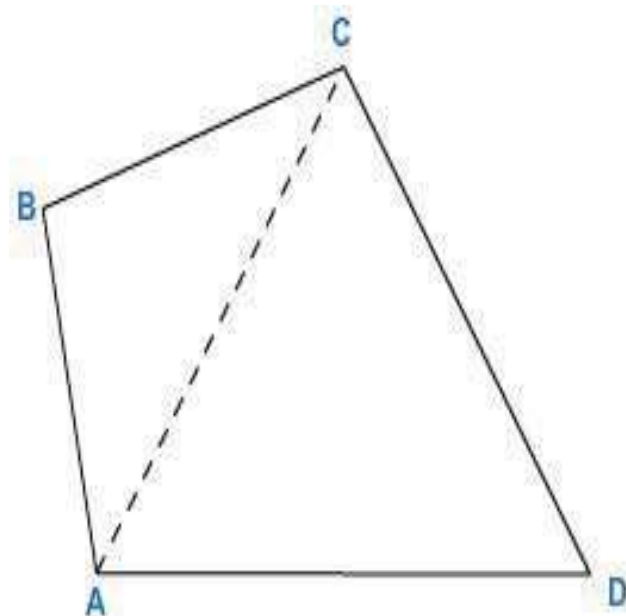
2.3.6 Area of a Circle

Figure 2-12 shows how you could cut a disk into 12 equal sectors. Each of these sectors would constitute a triangle, except for the slight curvature of the side that was originally a segment of the circumference of the disk. If this side is considered the base, then the altitude for each triangle equals the radius (r) of the original disk. The area of each triangle, then, equals

$$\frac{br}{2},$$

and the area of the original disk equals the sum of the areas of all the triangles. The sum of the areas of all the triangles, however, equals the sum of all the b's, multiplied by r and divided by 2.

But the sum of all the b's equals the

Figure 2-11 - Trapezium.
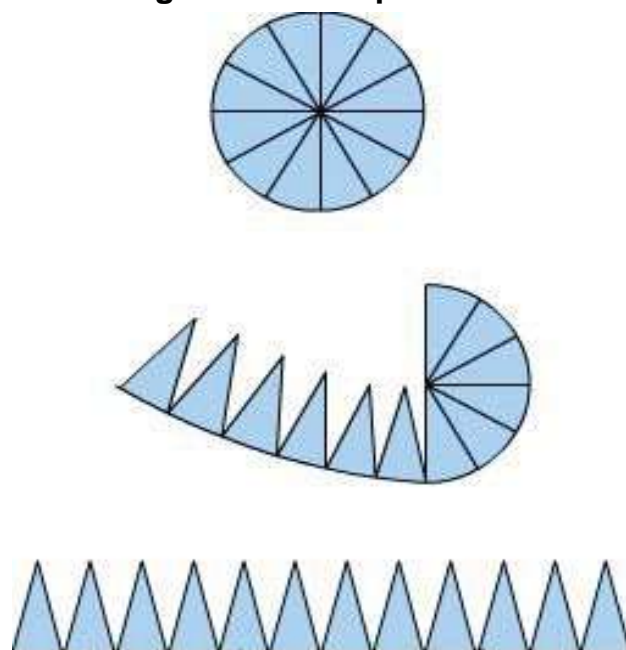
Figure 2-12 – Area of a circle.

circumference (c) of the original disk. Therefore, the formula for the area of a circle can be expressed as

$$A = \frac{cr}{2}.$$

However, the circumference of a circle equals the product of the diameter times ν (Greek letter, pronounced "pi"). ν is equal to 3.14159… The diameter equals twice the radius; therefore, the circumference equals $2\nu r$. Substituting $2\nu r$ for c in the formula

$$A = \frac{cr}{2}, \text{ we have } A = \frac{(2\nu r)(r)}{\text{or } 2}, \quad \frac{2\nu}{\dfrac{r^2}{2}}, \text{ or } \nu r^2.$$

This is the most commonly used formula for the area of a circle. If we find the area of the circle in terms of circumference,

$$A = \frac{c^2}{4\nu}.$$

2.3.7 Area of a Segment and a Sector

A segment is a part of a circle bounded by a chord and its arc, as shown in *Figure 2-13*. The formula for its area is, where r = the radius and n = the central angle in degrees,

$$A = \frac{r^2}{2} \left(\frac{\nu n}{180} - \sin n \right)$$

A sector is a part of a circle bounded by two radii and their intercepted arc. The formula for its area is

$$A = \frac{\nu U\ ^2Q}{360},$$

where r and n have the same designation as above.

2.3.8 Area of a Regular Polygons

Figure 2-14 is a regular polygon. In any regular polygon, the area is equal to one-half the perimeter of the polygon times the radius of the inscribed circle. This is expressed in formula form as follows:

$$A = \frac{SHULPHWHU \xi U}{2}$$

You can verify the above formula by
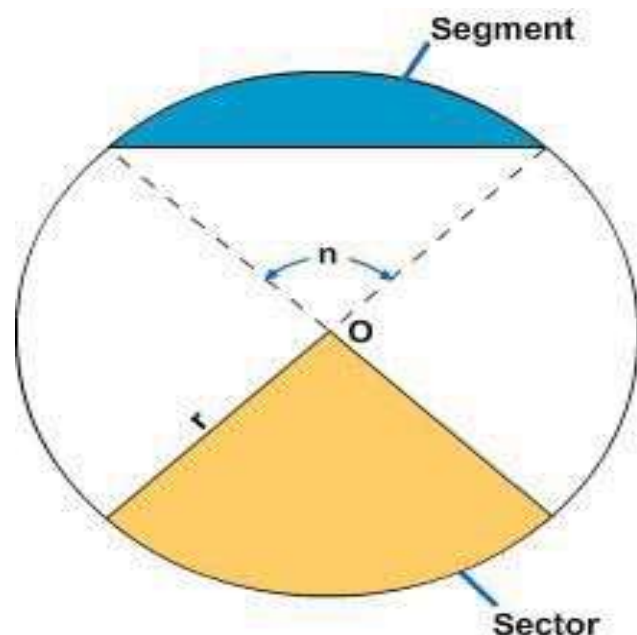
Figure 2-13 - Segment and sector of a circle.
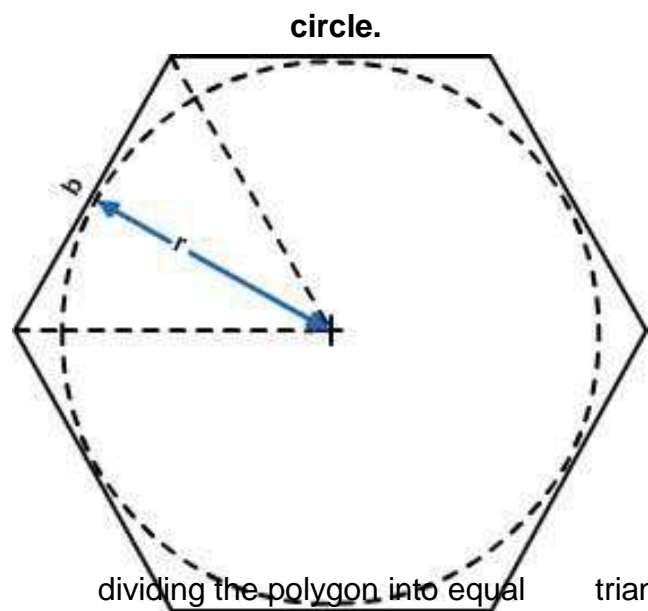
dividing the polygon into equal trian

Regular Polygon

gles with the sides as their bases and with r as their altitudes; if you multiply the areas of

Figure 2-14 - Regular polygons

the individual triangles by the number of sides in the polygon, you will arrive at the above formula.

2.3.9 Area of an Ellipse

The derivation of an ellipse from a conic section and methods of drawing ellipses are explained in chapter 3. An ellipse is shown in *Figure 2-15*.

The longer axis, AB, is called the major axis, and the shorter axis, CD, the minor axis. Call the length of the major axis a and that of the minor axis b. The area equals the product of half the major axis times half the minor axis times ν . In formula form, it is stated as

$$\$ \quad \nu \left(\frac{D}{2}\right)_A \left[\frac{E}{2}\right]_{\therefore}$$

$$= \nu \left(\frac{DE}{4}\right)_{A\;\therefore}$$

= 0.7854ab
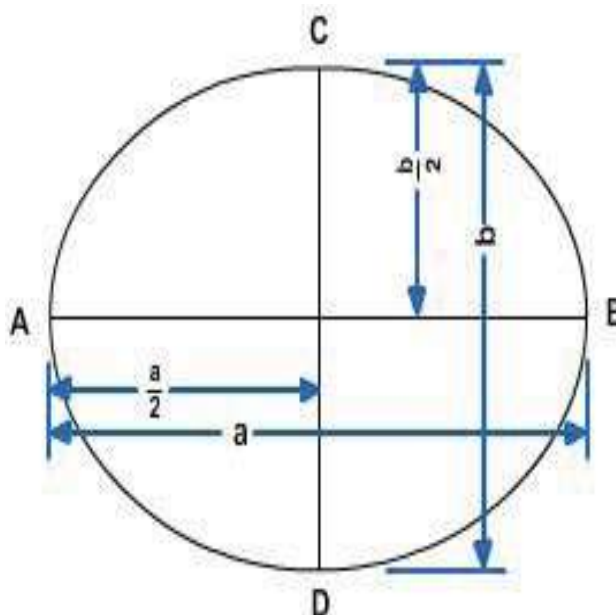
Figure 2-15 - Ellipse.

2.3.10 Irregular Areas

Irregular areas are those areas that do not fall within a definite standard shape. As you already have learned, there are formulas for computing the area of a circle, a rectangle, a triangle, and so on. However, we do not have a standard formula for computing the area of an irregular shaped plane, unless we use higher mathematics (calculus), and integrate incremental areas using lower and upper limits that define the boundaries.

As an EA, however, most areas you will be concerned with are those you will meet in plane surveying. In most surveys, the computed area is the horizontal projection of the area rather than the actual surface of the land. The fieldwork in finding areas consists of a series of angular and linear measurements defining the outline of whatever the shape is of the area concerned and forming a closed traverse. The following office computation methods, which you will learn as you advance in rate, are:

1. Plotting the closed traverse to scale and measuring the enclosed area directly with a polar planimeter (used only where approximate results are required, or for checking purposes).

2. Subdividing the area into a series of triangles, and taking the summation of all the areas of these triangles.

3. Computing the area using the coordinates of the individual points of the traverse (called the coordinate method).

4. Computing the area by means of the balanced latitude and departure, and calculated double meridian distances of each course (called the DMD method).

5. Computing the area by counting squares; this method is nothing but superimposing small squares plotted on a transparent paper having the same scale as the plotted traverse (or of known graphical ratio) and counting the number of squares within the traverse. The smaller the squares, the closer to the approximate area you will get.

6. Computing an irregular area bounded by a curve and perpendicular lines, as shown in *Figure 2-16*. Here, you can use the **trapezoidal rule**. The figure is considered as being made up of a series of trapezoids, all of them having the same base and having common distances between offsets.
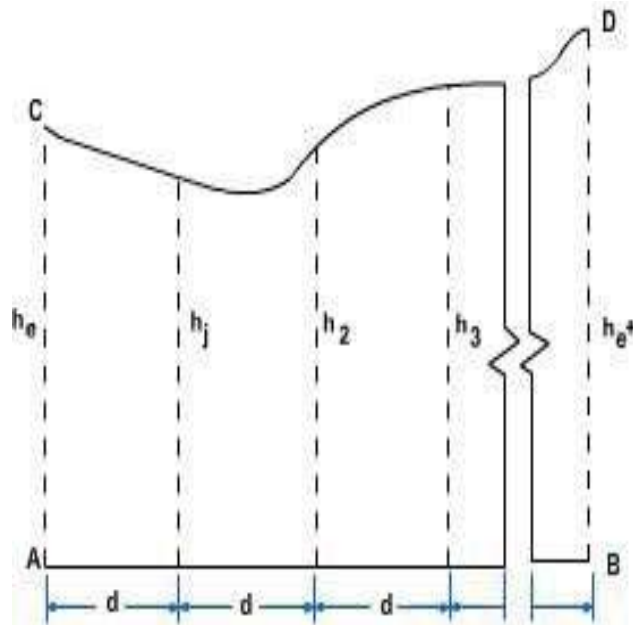
Figure 2-16 - Irregular area by trapezoidal rule.

The formula in computing the total area is as follows:

$$ A = d \left(\frac{K_H}{2} + \Sigma K + K_H^+ \right) $$

Where h_e and h_e^+ = the end offsets of the series of trapezoids

Σh = the sum of the intermediate offsets ($h_1 + h_2 + h_3 + \ldots$)

and d = the common distance between the offsets

For the present, try to find the areas of irregular figures by subdividing the area to series of triangles and by the method of counting the squares.

There are also areas of spherical surfaces and areas of portions of a sphere. For other figures not covered in this training manual, consult any text on plane and solid geometry.

2.4.0 Determining Volumes

From the preceding section you learned the formulas for computing the areas of various plane figures. These plane areas are important in the computation of volumes, as you will see later in this section.

When plane figures are combined to form a three-dimensional object, the resulting figure is a solid. For example, three rectangles and two triangles may be combined as shown in *Figure 2-17*. The flat surfaces of the solid figure are its faces, the top and bottom faces are the bases, and the faces forming the sides are the lateral faces or surfaces.

Some solid figures do not have any flat faces, and some have a combination of curved and flat surfaces. Examples of solids with curved surfaces include cylinders, cones, and

spheres. Those solids having no flat faces include a great majority of natural objects, such as rocks, living matter, and many other objects with irregular surfaces.

A solid figure whose bases or ends are similar, equal, and parallel polygons, and whose faces are parallelograms, is known geometrically as a PRISM. The name of a prism depends upon its base polygons. If the bases are triangles, as in *Figure 2-17*, the figure is a **triangular prism**. A rectangular prism has bases that are rectangles, as shown in *Figure 2-18*. If the bases of a prism are perpendicular to the planes forming its lateral faces, the prism is a right prism.

A parallelepiped is a prism with parallelograms for bases. Since the bases are parallel to each other, this means that they cut the lateral faces to form parallelograms. If a parallelepiped is a right prism and if its bases are rectangles, it is a rectangular solid. A cube is a rectangular solid in which all of the six rectangular faces are squares.

In determining the volume of most solids, you should use the following general formula:

$$V = B h$$

Where V = the volume
B = the area of the base or end area
h = the height of the solid (the perpendicular height from its base)
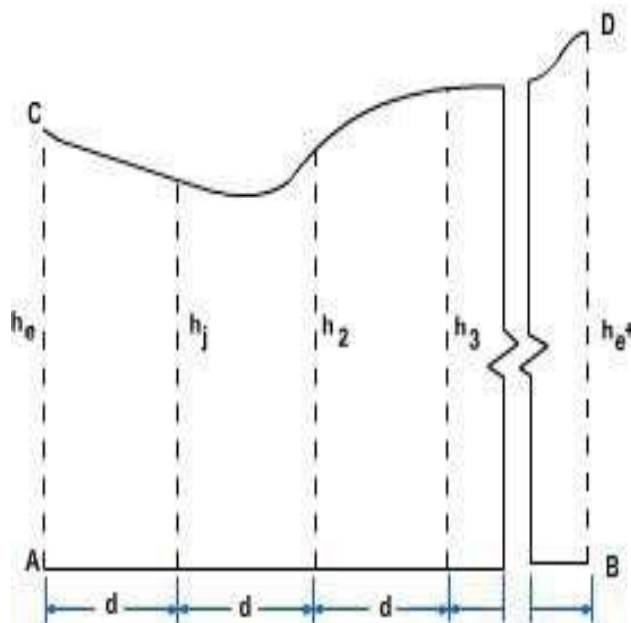
Figure 2-17 – Parts of a prism (triangular)
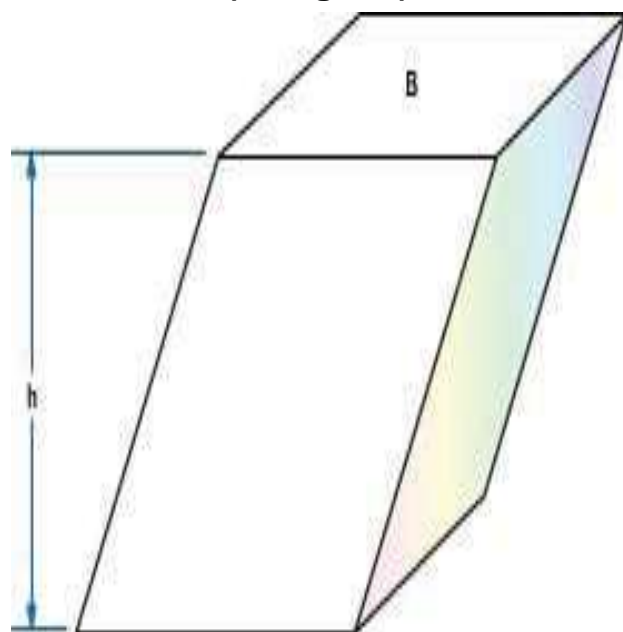
Figure 2-18 - Rectangular prism, showing its height

2.4.1 Volume of a Prism

For the volume of any prism, then, you simply determine the end area or the base area by the appropriate method and multiply the end area by the length or the base area by the height.

2.4.2 Volume of a Cylinder

From the standpoint of volume calculation, the only difference between a cylinder and a prism lies in the fact that the end or base of a cylinder is a circle rather than a polygon. Therefore, the volume of a cylinder is equal to its end area times its length. But you determine its end area from the formula v which is the formula used for computing r^2

the area of a circular plane. Therefore, the volume of a cylinder is $v r^2$ L.

2.4.3 me of a Cone or Pyramid

The best way to approach the problem of determining the volume of a cone or pyramid is on the basis of the fundamental fact that the volume of a cone equals one-third of the volume of the corresponding cylinder, while the volume of a pyramid equals one-third of the volume of the corresponding prism. For any of these solids, volume equals base times height divided by 3. Therefore, the formula for computing the volume of a cone is

$9 \quad \frac{1}{\_} \mathbf{v} U^2 K$, and that for a pyramid $9 \quad \frac{1}{\_}\%K.$

is $\frac{3}{3}$

A pyramid may have either a rectangular or a triangular base.

2.4.4 me of Other Geometric Figures

There will be no attempt to illustrate the derivation of formulas presented in this section. The formulas for the computations of volumes and surface areas of the following geometric figures are presented here only for additional information.

A frustum is that portion of a cone or pyramid that remains after the upper part is cut off by a plane parallel to the base.

1. SPHERE

    Volume of a sphere = $\dfrac{4}{3} \mathbf{v} r^3$

    Surface area = $4 \mathbf{v} r^2$

    Where r = the radius of the sphere

2. FRUSTUM OF A CONE

    Volume of frustum = volume of large cone- volume of small cone

    $= \dfrac{1}{U_1 3} \mathbf{v} K(\ ^2 + U_1 U_2 + U_2^2)$ cubic units

    Lateral area = $\mathbf{v}(r_1 + r_2$ square units $)s$

    Where h = the altitude of the frustum

    r_1 = the radius of the base

    r_2 = the radius of the top

    s = the slant height

3. FRUSTUM OF A PYRAMID

    Volume of a frustum = volume of large pyramid – volume of a small pyramid

    $= \dfrac{1}{3} K(\ \%_1 + \sqrt{\%_1 \%_2} + \%_2)$

    Where h = the altitude of frustum

    B_1 = the area of lower base

    B_2 = the area of upper base

2.5.0 Trigonometry

This section will focus primarily on the study of plane trigonometry. It is intended only as a review of the relationships among the sides and angles of plane triangles and their ratios, called the trigonometric functions.

Spherical trigonometry will be covered as you advance in rate. It is a prerequisite to the study of navigation, geodesy, and astronomy. Hence, the subject of spherical trigonometry will be introduced in the Engineering Aid class C1 school curriculum.

2.5.1 Measuring Angles

When two straight lines intersect, an angle is formed. You can also generate an angle by rotating a line having a set direction, *Figure 2-19* depicts the generation of an angle. The terminal line OB is generated from the initial point OA and forms Λ AOB, which we will call ε (Greek letter, pronounced "theta"). Angle ε is generally expressed in degrees. The following paragraphs will discuss the degree and the radian systems that are generally used by Engineering Aids.

The degree system is the most common system used in angular measurement. Angular measurement by **revolution** is perhaps the unit with which you are most familiar.
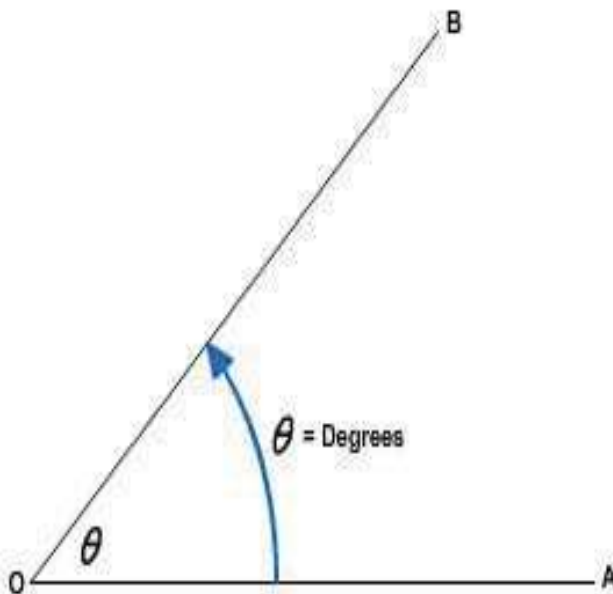
Figure 2-19 - Generation of an angle, resulting angle measured in degrees.

In the degree system, a complete revolution is divided into 360 equal parts called degrees (360°). Each degree is divided into 60 minutes (60'), and each minute into 60 seconds (60"). For convenience in trigonometric computations, the 360° is divided into four parts of 90° each.

The 90° sectors, called quadrants, are numbered counterclockwise starting at the upper right-hand sector.

When the unit radius r (the line generating the angle) has traveled less than 90° from its starting point in a counterclockwise direction (or, as conventionally stated, in a positive direction), the angle is in the first quadrant (I).

When the unit radius lies between 90° and 180°, the angle is in the second quadrant (II). Angles between 180° and 270° are said to lie in the third quadrant (III) and angles greater than 270° and less than 360° are in the fourth quadrant (IV).

When the line generating the angle passes through more than 360°, the quadrant in which the angle lies is found by subtracting from the angle the largest multiple of 360 that the angle contains and determining the quadrant in which the remainder falls.

The radian system of measuring angles is even more fundamental than the degree system. It has certain advantages over the degree system, for it relates the length of arc generated to the size of the angle and the radius. The radian measure is shown in *Figure 2-20*. If the length of the arc(s) described by the extremity of the line segment generating the angle is equal to the length of the line (r), then the angle described is exactly equal to one radian in size; that is, for one radian, s = r.

The circumference of a circle is related to the radius by the formula, $C = 2\nu r$.

This says that the circumference is 2ν times the length of the radius. From the relationship of arc length, radius, and radians in the preceding paragraph, this could be extended to say that a circle contains 2ν radians, and the circumference encompasses 3600 of rotation. It follows that

Figure 2-20 - Radian measure.

$$2\nu \text{ radians} = 3600$$

$$\nu \text{ radians} = 1800$$

By dividing both sides of the above equation by ν, we find that

$$\text{radian} = \frac{1800}{\nu} \quad 57.29590, RU 57.30 \quad \text{(approximately)}$$

As in any other formula, you can always convert radians to degrees or vice versa by using the above relationship.

2.5.2 Angles

The functions of angles can best be illustrated by means of a "circle of unit radius" like the one shown in *Figure 2-21*. A so-called "Cartesian axis" is inscribed within the circle. Coordinates measured from 0 along the x axis to the right are positive; coordinates measured from 0 along the x axis to the left are negative. Coordinates measured along the y axis from 0 upward are positive; coordinates measured along the y axis from 0 downward are negative.

Fig

**ure 2-21 – Circle of unit radius
with quadrants shown.**

Angles are generated by the motion of a point P counterclockwise along the circumference of the circle. The initial leg of any angle is the positive leg of the x axis. The other leg is the radius r, at the end of which the point P is located; this radius always has a value of 1. The unit radius (r = OC) is subdivided into 10 equal parts, so the value of each of the 10 subdivisions shown is 0.1.

For any angle, the point P has three coordinates: the x coordinate, the y coordinate, and the r coordinate (which always has a value of 1 in this case). The functions of any angle are, collectively, various ratios that prevail between these coordinates.

The ratio between y and r (that is, y/r) is called the sine of an angle. In *Figure 2-21*, AP seems to measure about 0.7 of y; therefore, the sine which is equal to 45° in this case, would seem to be 0.7/1, or about 0.7. Actually, the sine ε of 45° is 0.70711. Graphically, the sine is indicated in *Figure 2-21* by the line AP, which measures 0.7 to the scale of the drawing.

The ratio between x and r (that is, x/r) is called the cosine of the angle. You can see that for 45°, x and y are equal, and the fact that they are can be proven geometrically. Therefore, the cosine of 45° is the same as the sine of 45°, or 0.70711. Graphically, the length of line OA represents the cosine of angleε when the radius (r) is equal to 1.

The ratio between y and x (that is, y/x) is known as the tangent of an angle. Since y and x for an angle of 45° are equal, it follows that the tangent of an angle of 45° equals 1. The tangent is also indicated graphically by the line BC-drawn tangent to the circle at C and intersecting the extended r at B and DB-which is also drawn tangent at D. As you examine *Figure 2-21*, you can deduce that BC is equal to OC. OC is equal to the unit radius, r.

The three functions shown in *Figure 2-21* are called the "direct" functions. For each direct function there is a corresponding "reciprocal" function-meaning a function that results when you divide 1 by the direct function. You know that the reciprocal of any fraction is simply the fraction inverted. Therefore, for the direct function sine, which is y/r, the reciprocal function (called the cosecant) is divided by y/r, which is r/y.

Since y at sine 45° equals about 0.7, the cosecant for 45° is r/y, which is equal to 1/0.7, or about 1.4. The cosecant is indicated graphically by the line OB in *Figure 2-21*. If you measure this line, you will find that it measures just about 1.4 units to the scale of the drawing.

For the direct function cosine, which is x/r, the reciprocal function (called the secant) is r/x. Since x for cosine 45° also measures about 0.7, the secant for 45°, r/x, is the same as the cosecant, or also about 1.4. The secant is also indicated graphically in *Figure 2-21* by the line OB.

For the direct function tangent, which is y/x the reciprocal function (called the cotangent) is x/y. Since x and y at tangent 45° are equal, the value for cotangent 45° is the same as that for the tangent, or 1. The cotangent is shown graphically in *Figure 2-21* by the line DB, drawn tangent to the circle at D.

2.5.3 and Cofunctions

The functions cosine, cosecant, and cotangent are cofunctions of the functions sine, secant, and tangent, respectively. A cofunction of an angle A has the same value as the corresponding function of (90° – A); that is, the same value as the corresponding function of the complement of the angle. The sine of 30°, for example, is 0.50000. The cosine of 60° (the complement of 30°) is likewise 0.50000. The tangent of 30° is 0.57735. The cotangent of 60° (the complement of 30°) is likewise 0.57735.

Commonly used functions and cofunctions are as follows:

$$\sin A = \cos (900 - A)$$

$$\sec A = \csc (900 - A)$$

$$\tan A = \cot (900 - A)$$

2.5.4 Functions of Obtuse Angles

In *Figure 2-22*, the point P has generated an obtuse (larger than 90°) angle of 135°. This angle is the supplement of 45° (two angles are supplementary when they total 180°). We have left a dotted image of the reference angle A, which is equal to the supplementary angle of 135°. You can see that the values of x, y, and r are the same for 135° as they are for 45°, except that the value of x is negative. From this it follows that the functions of any obtuse angle are the same as the functions of its supplement, except that any function in which x appears has the opposite sign.

The sine of an angle is y/r. Since x does not appear in this function, it follows that sin A = sin (180° – A).

The cosine of an angle is x/r. Since x appears in this function, it follows that cos A = - cos (180° – A).

Figure 2-22 - Function of an obtuse angle.

The tangent of an angle is y/x. Since x appears in this function, it follows that tan A = - tan (180°- A).

The importance of knowing this lies in the fact that many tables of trigonometric functions list the functions only for angles to a maximum of 90°. Many oblique triangles, however, contain angles larger than 90°. To determine a function of an angle larger than 90° from a table that stops at 90°, you lookup the function of the supplement of the angle. If the function is a sine, you use it as is. If it is a cosine or tangent, you give it a negative sign.

The relationships of the function of obtuse angles are as follows:

$$\sin A = \sin (180° - A)$$

$$\cos A = - \cos (180° - A)$$

$$\tan A = - \tan (180° - A)$$

$$\cot A = - \cot (180° - A)$$

$$\sec A = -\sec(180° - A)$$

$$\csc A = \csc(180° - A)$$

The above relationships apply only when angle A is greater than 90° and less than 180°

2.5.5 Angles in a Right Triangle

For an acute angle in a right triangle, the length of the side opposite the angle corresponds to y and the length of the side adjacent to the angle corresponds to x, while the length of the hypotenuse corresponds to r. Therefore, the functions of an acute angle in a right triangle can be stated as follows:

Sine = side opposite / hypotenuse

Cosecant = hypotenuse / side opposite

Cosine = side adjacent / hypotenuse

Secant = hypotenuse / side adjacent

Tangent = side opposite / side adjacent

Cotangent = side adjacent / side opposite

If you consider a 90° angle with respect to the "circle of unit radius" diagram, you will realize that for a 90° angle, x = 0, y = 1, and r (as always) equals 1. Since sine = y/r, it follows that the sine of 90° = 1. Since cosine = X/r, it follows that the cosine of 90° = 0/1, or 0. Since tangent= y/x, it follows that tan 90° = 1/0, or infinity (00). From one standpoint, division by 0 is a mathematical impossibility, since it is impossible to state how many zeros there are in anything. From this standpoint, tan 90° is simply impossible. From another standpoint, there are an "infinite" number of zeros in 1. From that standpoint, tan 90° is infinity.

In real life, the sides of a right triangle y, x, and r, or side opposite, side adjacent, and hypotenuse, are given other names according to the circumferences. In connection with a pitched roof rafter, for instance, y or side opposite is "total rise," x or side adjacent is "total run," and r or hypotenuse is "rafter length." In connection with a ground slope, y or side opposite is "vertical rise," x or side adjacent is "horizontal distance," and r or hypotenuse is "slope distance."

2.5.6 ving Triangles

To "solve" a triangle means to determine one or more unknown values (such as the length of a side or the size of an angle) from given or known values. Here are some of the methods used.

2.5.6.1 Pythagorean Theorem

When you know the lengths of two sides of a right triangle, or its hypotenuse and one side, you can determine the length of the remaining side, or the length of the hypotenuse, by applying the Pythagorean Theorem. The Pythagorean Theorem states that the square of the length of the hypotenuse of any right triangle equals the sum of the squares of the lengths of the other two sides.

Figure 2-23 shows a right triangle with acute angles A and B and right angle C. Sides opposite A and B are designated as a and b; the hypotenuse (opposite C) is designated as c. Side a measures 3.00 feet, side b measures 4.00 feet, and the hypotenuse measures 5.00 feet. Any triangle with sides and hypotenuse in the ratio of 3:4:5 is a right triangle.

If $c^2=a^2+b^2$, it follows that $c = \sqrt{D^2 \ E^2}$.

The formulas for solving for either side, given the other side and the hypotenuse; or for the hypotenuse, given the two sides, are

$$a = \sqrt{F^2 \ E^2}$$

$$b = \sqrt{F^2 \ D^2}$$

$$c = \sqrt{D^2 + E^2}$$

Figure 2-23 - A right triangle

In *Figure 2-23*, $a^2 = 9$, $b^2 = 16$, and $c^2 = 25$.
Therefore, a = the square root of (25 - 16), or 3;
b = the square root of (25 - 9), or 4; and c = the square root of (9 + 16), or 5.

2.5.6.2 Acute Angle of Right Triangle by Tangent

One of the angles in a right triangle always measures 90°. Because the sum of the three angles in any triangle is always 180°, each of the other two angles in a right triangle must be an acute (less than 90°) angle. Also, if you know the size of one of the acute angles, you can determine the size of the other from the formulas A = (90° - B) and B = (90° - A).

In any right triangle in which you know the lengths of the sides, you can determine the size of either of the acute angles by applying the tangent of the angle.

Take angle A in *Figure 1-23*, for example. You know that

$$\tan A = \frac{D}{E}, RU\frac{3.00}{4.00}, RU\ 0.75\ .$$

Reference to a table of natural tangents shows that an angle with tangent 0.75 measures to the nearest minute, 36°52'.

2.5.6.3 Side of Right Triangle by Tangent

If you know the length of one of the sides of a right triangle and the size of one of the acute angles, you can determine the length of the other side by applying the tangent. Suppose that for the triangle shown in *Figure 2-23* you know that angle A measures 36°52' and that side b measures 4.00 feet. You want to determine the length of side a. Since

$$\tan A = \frac{D}{E},$$

it follows that a = b (tan A). From a table of natural tangents you find that tan 36052' = 0.74991. Therefore,

a = 4.00(0.74991), or 3.00 feet.

2.5.6.5 Side of Right Triangle Cotangent

Suppose that for the triangle shown in *Figure 2-23*, you know that angle B measures 53°08' and that side a measures 3.00 feet. You want to determine the length of side b. You could do this as previously described by applying

$$\tan B = \frac{E}{D}$$

However, the fact that side b is larger than side a means that tan B is larger than 1 (you recall that any angle larger than 45° has a tangent larger than 1).

You know that the cotangent is the reciprocal function of the tangent. Therefore, if

$$\tan B = \frac{E}{D}, \quad \cot B = \frac{D}{E}, \text{ it follows that } b = \frac{D}{FRW\%}.$$

A table of natural functions tells you that cot 53°08' = 0.74991. Therefore,

$$b = \frac{3}{0.74991}, RU\ 4.00.$$

2.5.6.5 Acute Angle of Right Triangle by Sine or Cosine

If you know the length of the hypotenuse and length of a side of a right triangle, you can determine the size of one of the acute angles by applying the sine or the cosine of the angle. Suppose that for the triangle shown in *Figure 2-23*, you know that the hypotenuse, c, is 5.00 feet long and that the length of side a is 3.00 feet long. You want to determine the size of angle A. Side a is opposite angle A; therefore,

$$\sin A = \frac{D}{F}, RU \frac{3}{5}, RU\ 0.6.$$

A table of natural functions tells you that an angle with sine 0.6 measures (to the nearest minute) 36°52'.

Suppose that, instead of knowing the length of a, you know the length of b (4.00 feet). Side b is the side adjacent to angle A. You know that

$$\cos A = \frac{E}{F}, RU \frac{4}{5}, RU\ 0.8.$$

A table of natural functions tells you that an angle with cosine 0.8 measures 36°52'.

If you know the size of one of the acute angles in a right triangle and the length of the side opposite, you can determine the length of the hypotenuse from the sine of the angle. Suppose that for the triangle shown in *Figure 2-23*, you know that angle A = 36°52' and side a = 3.00 feet.

$$Sin A = \frac{D}{F}; \text{ therefore, } c = \frac{D}{VLQ\$}, RU \frac{3}{0.6}, RU\ 5.00IHHW$$

If you know the size of one of the acute angles in a right triangle and the length of the side adjacent, you can determine the length of the hypotenuse from the cosine of the

angle. Suppose that for the triangle in *Figure 2-23*, you know that angle A = 36°52' and side b = 4.00 feet.

$$\text{Cos A} = \frac{E}{F}; \text{ therefore, } c = \frac{E}{FRV\$}$$

Tables show that cos 36°52' = 0.80003. Therefore,

$$c = \frac{4.00}{0.80003}, \text{ or 5.00 feet}$$

2.5.6.6 Solution by Law of Sines

For any triangle (right or oblique), when you know the lengths of two sides and the size of the angle opposite one of them, or the sizes of two angles and the length of the side opposite one of them, you can solve the triangle by applying the law of sines. The law of sines (which is explained and proved in NAVPERS 10071-B, chapter 5) states that the lengths of the sides of any triangle are proportional to the sines of their opposite angles. It is expressed in formula form as follows:

$$\frac{D}{VLQ\$} \quad \frac{E}{VLQ\%} \quad \frac{F}{VLQ\&}$$

In the triangle shown in *Figure 2-24*, ⋀A = 41°24', a = 8.00 feet, and b = 12.00 feet. If

$$\frac{E}{VLQ\%} \quad \frac{D}{VLQ\$}\, '$$

It follows that

$$\sin B = \frac{E\,VLQ\$}{D}.$$
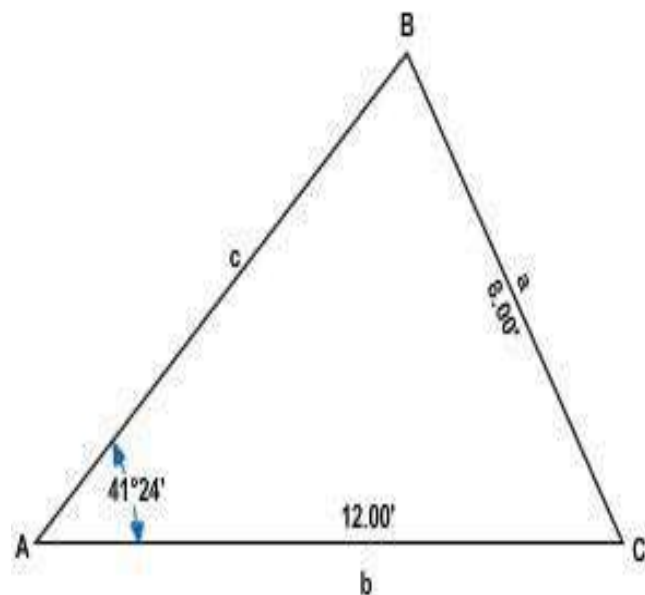
Figure 2-24 - Oblique triangle (law of sines).

The sine of 41°24' is 0.66131; therefore,

$$\text{Sin B} = \frac{12(\ 0.66131)}{8}, RU\ 0.99196.$$

Tables show that the angle with sine 0.99196 measures 82°44'. Therefore, ⋀B =82°44'. ⋀C = 180° - (A + B), or 180° - (41°24' - 82°44') or 180° -124°08, RU 55°52'.

$$\text{If } \frac{F}{VLQ\&} \quad \frac{D}{VLQ\$}, \text{ then } c = \frac{D\,VLQ\&}{VLQ\$}.$$

The sine of 55°52' is 0.82773. Therefore, $c = \frac{8(\ 0.82773)}{9.66131}$, or 10.01 feet.

2.5.6.7 Solution by Law of Cosines

Suppose you know two sides of a triangle and the angle between the two sides. You cannot solve this triangle by the law of sines, since you do not know the length of the side opposite the known angle or the size of an angle opposite one of the known sides.

In a case of this kind you must begin by solving for the third side by applying the law of cosines. If you are solving for a side on the basis of two known sides and the known included angle, the law of cosines states that in any triangle the square of one side is equal to the sum of the squares of the other two sides minus twice the product of these two sides multiplied by the cosine of the angle between them. This statement may be expressed in formula form as follows:

$$a^2 = b^2 + c^2 - 2bc \cos A$$

$$b^2 = a^2 + c^2 - 2ac \cos B$$

$$c^2 = a^2 + b^2 - 2ab \cos C$$

For the triangle shown in *Figure 2-25,* you know that side c measures 10.01 feet; side b, 12.00 feet; and angle A (included between them), 41°24'. The cosine of 41°24' is 0.75011. The solution for side a is as follows:

$$a = \sqrt{E^2 + F^2 \ 2EF\ FRV\ \$}$$

$$a = \sqrt{144 + 100.20 \ 2(12)(10.01)(0.75011)}$$

$$a = \sqrt{244.20\ 180.20}$$

$$a = \sqrt{64}$$

a = 8.00 feet

Figure 2-25 - Oblique triangle (law of cosines)

Knowing the length of this side, you can now solve for the remaining values by applying the law of sines.

If you know all three sides of a triangle, but none of the angles, you can determine the size of any angle by the law of cosines, using the following formulas:

$$\cos A = \frac{E^2 + F^2 - D^2}{2EF}$$

$$\cos B = \frac{D^2 + F^2 - E^2}{2DF}$$

$$\cos C = \frac{D^2 + E^2\ F^2}{2DE}$$

For the triangle shown in *Figure 2-26,* you know all three sides but none of the angles. The solution for angle A is as follows:

$$\cos A = \frac{E^2 + F^2\ D^2}{2EF}$$

$$\cos A = \frac{144 + 100.20\ \ 64}{2(\ 12)\ (\ 10.0\ 1)}$$

$$\cos A = \frac{180.20}{240.24}$$

$\cos A = 0.75008$
The angle with cosine 0.75008 measures (to the nearest minute) 41°24'.

2.5.6.8 Solution by Law of Tangents

The law of tangents is expressed in words as follows: In any triangle the difference between two sides is to their sum as the tangent of half the difference of the opposite angles is to the tangent of half their sum.

Figure 2-26 - Any triangle, given three sides

For any pair of sides-as side a and side b-the law may be expressed as follows:

$$\frac{D\ E}{D+E}\quad \frac{WDQ\,1/2(\ \$\ \%)}{WDQ\,1/2(\ \$+\%)}$$

For the triangle shown in *Figure 2-27,* you know the lengths of two sides and the size of the angle between them. You can determine the sizes of the other two angles by applying the law of tangents as follows.

First note that you can determine the value of angles (B + C), because (B + C) obviously equals 180° - A, or 180° - 34°, or 146°. Now, if you know the sum of two values and the difference between the same two, you can determine each of the values as follows:

Figure 2-27 - Oblique triangle (law of tangents)

$$
\begin{aligned}
x + y &= 5 \\
\underline{x - y} &= \underline{1} \\
\text{(add) } 2x\quad &= 6 \\
x &= 3 \\
y &= 5 - x \\
y &= 2
\end{aligned}
$$

Now, you know the sum of (B + C). Therefore, if you could determine the difference, or (B - C), you could determine the sizes of B and C You can determine 12(B - C) from the law of tangents, written as follows:

$$\tan \frac{1}{2}(B - C) = \frac{(B - C)\tan\frac{1}{2}(B + C)}{B + C}$$

One-half of (B + C) means one-half of 146°, or 73°. The tangent of 73° is 3.27085. The solution for 12(B - C) is therefore as follows:

$$\tan\frac{1}{2}(B - C) = \frac{(10 - 8)(3.27085)}{10 + 8}$$

$$\tan\frac{1}{2}(B - C) = \frac{6.54170}{18} = 0.36342$$

(from table of natural tangents) 1/2 (B - C) = 19°58' (B - C) = 2(19058') = 39°56'

Knowing both the sum (B + C) and the difference (B - C), you can now determine the sizes of B and C as follows:

B + C = 146°00'

B - C = 39°56'

2B   = 185°56'

B   = 92°58'

C   = (146° - 92°58') + 53°02'

2.5.6.9 The Ambiguous Case

When the given data for a triangle consists of two sides and the angle opposite one of them, there may be two triangles that conform to the data. A situation in which there can be two triangles is called the ambiguous case. *Figure 2-28* shows two possible triangles that might satisfy this situation. Both triangles shown are with given angle A = 30°00', given side a = 4.00 feet, and given side c = 6.00 feet.

The best way to determine whether or not the given data for a triangle involves an ambiguous case is to lay out a figure to scale on the basis of the data, as shown in *Figure 2-29*. Suppose, for example, that the data describes a triangle with angle A = 22°00'; side opposite, 5.40 feet; and other side, 14.00 feet. Lay off a line, AB, 14.00 feet long (to scale, of course), as shown in the upper triangle of *Figure 2-29*. Use a protractor to lay off a line from A at 22°00'. Set a compass to the graphical distance of 5.40 feet (length of side opposite A) and with B as a center, strike an arc. You observe that this arc intersects the line from A at two places. Therefore, the triangle ACB and the triangle ADB both satisfy the data, and you have an ambiguous case.
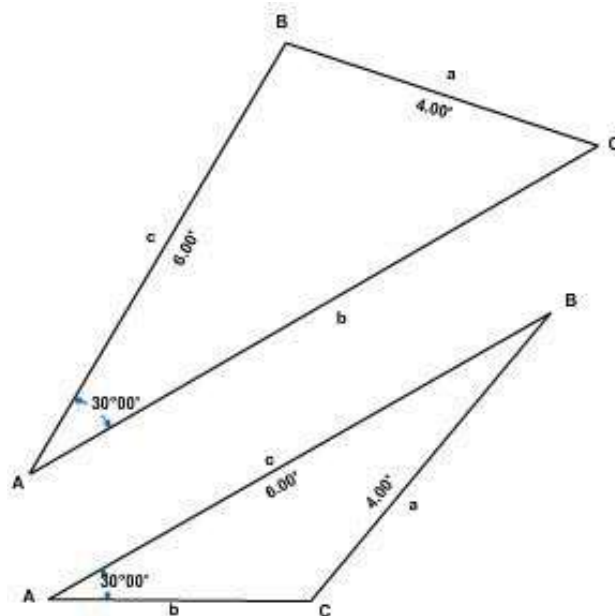
Figure 2-28 -Two ambiguous case triangles (solution of one will satisfy the other).

Suppose now that the data describes a triangle with angle A = 35°00'; side opposite, 10.00 feet; and other side, 8.00 feet. Lay off the line AB 8.00 feet long as shown in the lower triangle of *Figure 2-29*, and lay off a line from A at 35°00', Set a compass to 10.00 feet (length of side opposite A) and with B as a center, strike an arc. This arc will intersect the line from A at only one point. Therefore, only one triangle satisfies the data.

2.5.6.10 Determining the Angle from Three known Sides

There are several formulas for determining the size of an angle in a triangle from three known sides. The most convenient involves the versed sine of the angle, which means (1 -cos) of the angle.

Figure 2-29 -Comparison of an ambiguous case.

The formula goes as follows:

$$1 - \cos A = \frac{2(\text{V} - \text{E})\ (\text{V} - \text{F})}{EF}$$

$$1 - \cos B = \frac{2(\text{V} - \text{D})\ (\text{V} - \text{F})}{DF}$$

$$1 - \cos C = \frac{2(\text{V} - \text{E})\ (\text{V} - \text{E})}{DE}$$

The value s means one-half the sum of sides a, b, and c or

$$s = \frac{D + E + F}{2}$$

For the triangle shown in *Figure 2-30*, you would determine the size of angle A as follows:

$$s = \frac{10.00 + 12.00 + 15.00}{2}\quad \frac{37.00}{2}\quad 18.50$$

$$1 - \cos A = \frac{2(\ 18.50 \quad 15)\ (\ 18.50 \quad 10)}{(\ 15)\ (\ 10)}$$

$$= \frac{2(\ 3.50)\ (\ 8.50)}{150}$$

$$1 - \cos A = \frac{59.50}{150}\quad 0.39667$$

$$\cos A = 1 - 0.39667 = 0.60333$$
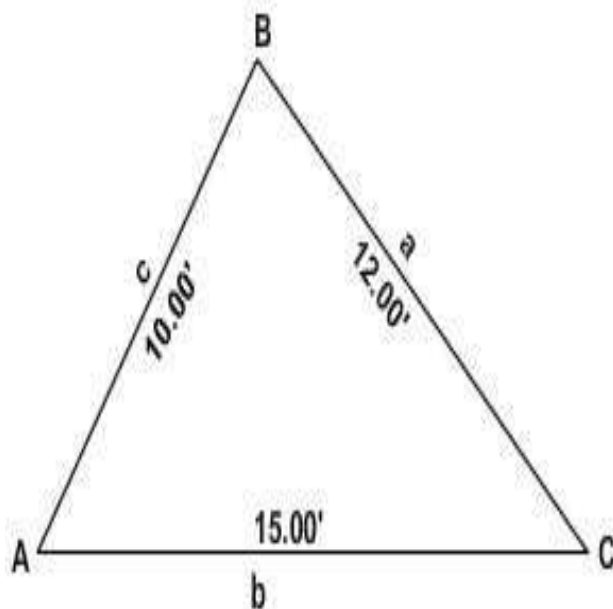
Figure 2-30 – Oblique triangle with three sides given and solved by versed sine formula.

The angle with cosine 0.60333 measures (to the nearest minute) 52°53'.

3.0.0 HINTS on COMPUTING

As a general rule, when you express dimensions, you express all dimensions with the same precision. Suppose, for example, you have a triangle with sides 15.75, 19.30, and 11.20 feet long. It would be incorrect to express these as 15.75, 19.3, and 11.2 feet, even though the numerical values of 19.3 and 11.2 are the same as those of 19.30 and 11.20.

Another general rule is that it is useless to work computations to a precision higher than that of the values applied in the computations. Suppose, for example, you are solving a right triangle for the length of side a, using the Pythagorean Theorem. Side b is given as 16.5 feet, and side c, as 20.5 feet. By the theorem you know that side a equals the square root of (20.52 – 16.52), or the square root of 148.0. You could carry the square root of 148.0 to a large number of decimal places. However, any number beyond two decimal places to the right would be useless, and the second number would be determined only for the purpose of rounding off the first.

The square root of 148.0, to two decimal places, is 12.16. As the 0.16 represents more than one-half of the difference between 0.10 and 0.20, you round off at 0.2, and call the length of side less than one-half of the difference between 0.10 and 0.20, you would have rounded off at the lower tenth digit, and called the length of side a 12.1 feet.

Suppose that the hundredth digit had represented one-half of the difference between 0.10 and 0.20, as in 12.15. Some computers in a case of this kind always round off at the lower Figure, as, 12.1. Others round off at the higher Figure, as 12.2. Better balanced results are usually obtained by rounding off at the nearest even Figure. By this rule, 12.25 would round off at 12.2, but 12.35 would round off at 12.4.

4.0.0 UNITS of MEASUREMENT

Engineering science would not be as precise as it is today if it did not make use of systems of measurement. In fieldwork, drafting, office computation, scheduling, and quality control, it is important to be able to measure accurately the magnitudes of the various variables necessary for engineering computations, such as directions, distances, materials, work, passage of time, and many other things.

The art of measuring is fundamental in all fields of engineering and even in our daily lives. We are familiar, for instance, with "gallons," which determines the amount of gasoline we put in our car and with "miles," which tells us the distance we have to drive to and from work. It is also interesting to note that the development of most of these standard units of measure parallels the development of civilization itself, for there has always been a need for measurement. In the early days, people used night and day and the cycle of the four seasons as their measure of time. The units of linear measure were initially adopted as comparison to the dimensions of various parts of a man's body. For example, a "digit" was at that time the width of a man's middle finger, and a "palm" was the breadth of an open hand. The same applies to most other units of linear measure that we know today-like the "foot," the "pace," and the "fathom." The only difference between today's units of measure and those of olden days is that those of today are standardized. It is with the standard types of measurements that we are concerned in this training manual.

At present, two units of measurement are used throughout the world. They are the English system and the metric system. Many nations use the metric system.

The metric system is the most practical method of measurement, for it is based on the decimal system; in which units differ in size by multiples of tens, like the U.S. monetary system in which 10 mills equal 1 cent; 100 mills or 10 cents equal
1 dime; and 1,000 mills, 100 cents, or 10 dimes equal one dollar. When we perform computations with multiples of 10, it is convenient to use an exponential method of expression as you may recall from your study of mathematics.

Table 2-1 - Linear conversion factors.

	Inches	Feet	Yards	Statute miles	Centimeters	Meters	Kilometers
Inch	1	.083333	.0277	- - - -	2.540005	.0254	- - - - - -
Foot	12	1	.333		30.48006	0.304801	- - - - - -
Yard	36	3	1	.000568	.914402	.914402	.000914
Statute mile	63,360	5280	1760	1	1609.347	1609.347	1.609347
International nautical mile	- - -	6076.10	2025.36	1.15077	- - - - - -	- - - - -	- - - - - -
United States nautical mile	- - -	6080.20	2026.73	1.151553	- - - - - -	- - - - -	- - - - - -
Centimeter	.3937	- - - -	- - - -	- - - -	1	.01	- - - - - -
Meter	39.37	3.280833	1.093611	0.62137	100	1	.001
Kilometer	- - -	- - - -	- - - -	- - - -	- - - -	1000	1
Decimeter	3.937	.328	- - - -	- - - -	- - - -	.1	- - - - - -
Decameter	393.7	32.8	- - - -	- - - -	- - - -	10	- - - - - -
Hectometer	- - -	328'1"	- - - -	- - - -	- - - -	- - - -	.1
Myriameter	- - -	- - - -	- - - -	6.213712	- - - -	- - - -	10

A unit of measurement is simply an arbitrary length, area, or volume, generally adopted and agreed upon as a standard unit of measurement. The basic standard for linear measurement, for example, is the meter, and the actual length of a meter is, in the last analysis, equal to the length of a bar of metal called the International Meter Bar, one replica of which is kept in the National Bureau of Standards, Washington, D.C.

As an EA, you will not necessarily be working with all the units described in this chapter, and therefore need not attempt to memorize them all. Many are included simply to show that units are arbitrary and that there are many different kinds of units.

4.1.0 Linear Measurement

Linear measure is used to express distances and indicate differences in their elevations. The standard units of linear measure are the foot and the meter. In surveying operations, both of these standard units are frequently divided into tenths, hundredths, and thousandths for measurements. When longer distances are involved, the foot is expanded into a statute or a nautical mile and the meter into a kilometer. Table 2-1 shows the conversion factors for the common linear measurements.

4.1.1 ish Units

In the English system, the most commonly used basic unit of linear measurement is the foot, a unit that amounts to slightly more than three-tenths of the international meter. In what is called engineer's measurement, the foot is subdivided decimally; that is, into tenths, hundredths, or thousandths of a foot. In what is called carpenter's measurement, or English units, the foot is subdivided into twelfths called inches, and the inch is further subdivided into even-denominator fractional parts, as 1/2 inch, % inch, 1/8 inch, and so on.

Fractions or multiples of the basic 1-foot unit are used to form larger units of linear measure as follows:

1 link	=	0.66 feet
1 yard	=	3.00 feet
1 rod, pole, or perch	=	16.50 feet
1 Gunter's chain	=	66.00 feet
1 engineer's chain	=	100.00 feet
1 statute mile U.S.	=	5280.00 feet
1 nautical mile (international)	=	6076.10 feet

A unit of linear measurement called VARA, of Spanish and Portuguese origin, was formerly used to measure land boundaries in those areas of the United States that were at one time under Spanish control. In those areas, old deeds and other land instruments still contain property descriptions in varas, which vary from state to state and country to country from 32 to 43 inches.

4.1.2 Metric Units

In many of the non-English-speaking countries of the world, the most commonly used basic unit of linear measure is the meter. The length of a meter was originally designed to equal (and does equal very nearly) one ten-millionth part of the distance, measured along a meridian, between the earth's equator and one of the poles. A meter equals slightly more than 1.09 yards.

The big advantage of the metric system is that it is a decimal system throughout; that is, that the basic unit can be both subdivided into smaller units decimally and converted to larger units decimally by simply moving the decimal point in the appropriate direction. Names of units smaller than the meter are indicated by the Latin prefixes deci- (one-tenth), centi- (one-hundredth), mini- (one-thousandth), and micro- (one-millionth), as follows:

1 decameter	$= 0.1$ meter (1×10^{-1})
1 centimeter	$= 0.01$ meter (1×10^{-2})
1 millimeter	$= 0.001$ meter (1×10^{-3})
1 micrometer	$= 0.000001$ meter (1×10^{-6})

Names of units larger than the meter are indicated by the Greek prefixes deca- (ten), hecto- (one hundred), kilo- (one thousand), myria- (ten thousand), and mega- (one million), as follows:

1 decimeter	$= 10.00$ meters (1×10)
1 hectometer	$= 100.00$ meters (1×10^{2})
1 kilometer	$= 1,000.00$ meters (1×10^{3})
1 myriameter	$= 10,000.00$ meters (1×10^{4})
1 megameter	$= 1,000,000.00$ meters (1×10^{6})

4.2.0 Units of Area Measurement

In the English and metric system, area is most frequently designated in squares of linear units, such as square inches, feet, yards, or miles; or square centimeters, meters, or kilometers. In the English system, the land-area measurements most commonly used are the square foot and the acre. Formerly the square rod (1 rod = 16.5 feet) and the

square Gunter's chain (1 Gunter's chain = 66 feet) were used. One of the area measurements, with its equivalents, is as follows:

$$1 \text{ acre} = 10 \text{ square Gunter's chains}$$

$$= 160 \text{ square rods}$$

$$= 43,560 \text{ square feet}$$

An equilateral rectangular (square) acre measures 208.71 feet on a side. There are 640 acres in a square mile.

Other area equivalents that may be of value to you are as follows:

1 square inch (sq in.) = 6.4516 + square centimeters (sq cm)

1 square foot (sq feet) = 144 square inch

$$= 0.0929 + \text{ square meter (sq m)}$$

1 square yard (sq yd) = 9 square feet

$$= 0.8361 - \text{square m}$$

1 square meter (sq m) = 10.7639 square feet

$$= 1.1960 + \text{ square yd}$$

Actually, more attention should be given to linear equivalents. If you know the linear conversion factor from one unit to the other, you can always compute for any equivalent area or even volume. Just remember, area is expressed in square units and volume is expressed in cubic units.

Example: Find the area of a rectangle 2 feet by 3 feet in square inches.

Area = 2 feet x 3 feet = (2 x12) (3 x 12) = 864 sq inch

4.3.0 Units of Volume Measurement

From your study of mathematics, you learned that volume is the measure of the amount of space that matter occupies. It is expressed in certain cubic units, depending upon the linear measurements or dimensions of the object.

As an EA, you will be interested in unit volume of measurements from the standpoint of earthwork, construction materials, material testing, rainfall runoff, and capacities of structures, such as, for example, a reservoir. The accuracy of your computations will depend upon your knowledge of the correct conversion factors and the units used. Remember that your dimensions must always be expressed in one kind of unit of measure; for instance, if you are using the meter, all dimensions must be in meters. The basic units of volume that you might be using are as follows:

1 cubic inch (cu inch)	=	16.3872 cubic centimeters (cc)
1 cubic foot (cu feet)	=	1,728 cubic inch = 0.0283 cubic meters (cu m)
1 cubic yard (cu yd)	=	27 cubic feet = 0.7646 cubic meter
1 cubic meter (cu m)	=	1,000,000 cc = 35.3145 cubic feet = 1.3079 cubic yards
1 U.S gallon	=	231 cubic inch

1 cubic feet	=	7.4805 gallons
1 acre feet	=	43,560 cubic feet
	=	1,233.49 cubic meters

4.4.0 Units of Weight

The units of weight most frequently used in the United States for weighing all commodities except precious stones, precious metals, and drugs are the units of the so-called avoirdupois system. Avoirdupois units of weight are as follows:

437 � grains (gr)	=	1 ounce (oz)
16 ounces (oz)	=	1 pound (lb)
100 pounds (lb)	=	1 hundred-weight (cwt)
1,000 pounds (lb)	=	1 kip (K)
2,000 pounds (or 20 cwt)	=	1 short ton (T)
2,200 pounds	=	1 long ton

Precious stones and precious metals are usually weighed in the United States by the system of try weight, in which there are 12, rather than 16, oz in the pound. Drugs are weighed by apothecaries' weight, in which there are also 12 oz in the pound.

The basic unit of the metric system of weight is the gram, which contains 15.432 grains. The grain was originally supposed to be equal to the weight of a single grain of wheat; The gram of 15.432 grains is also used in the avoirdupois, troy, and apothecaries' system of weights.

Multiples and subdivisions of the basic unit of metric weight (the gram) are named according to the usual metric system of nomenclature, as follows:

0.000001 g	=	1 microgram
0.001 g	=	1 milligram
0.01 g	=	1 centigram
0.10g	=	1 decigram
10.00 g	=	1 decagram
100.00 g	=	1 hectogram
1,000.00 g	=	1 kilogram

A metric ton equals 1,000 kilograms, which equals 1.1 short tons.

The Engineering Aid is interested in the weight of his instruments and the pull to be applied to the ends of the tape to give correct linear measurements. The common units of weight in surveying are the ounce, the pound, the gram, and the kilogram. The following tabulation gives the relationship between these units:

1 ounce (oz)	=	28.3495 grams (g)
1 pound (lb)	=	453.5924 g = 0.4536 kg
1 kilogram (kg)	=	2.2045 lb = 35.27 oz

4.5.0 Units of Angular Measurement

Angular or circular measure is used for designating the value of horizontal and vertical angles. For general use in the measurement of angles, the circumference of the circle is divided into some even number of equal parts. The unit of angular measure is the angle at the center of the circle subtended by one of the small subdivisions of the circumference. The various units of angular measure are known as units of arcs. In practice these units of arcs may be further expressed in decimal or fractional parts.

The Engineering Aid may encounter three systems of angular measure in the use of surveying instruments. They are the sexagesimal, the centisimal or metric, and the mil system.

4.5.1 Sexagesimal or North American System

In the sexagesimal or North American system, the circle is divided into 360 equal parts known as degrees of arc, each degree into 60 equal parts known as minutes of arc, and each minute into 60 equal parts known as seconds of arc. As an example, angles in this system are written as 263°47'16".48 which is read as "two hundred sixty-three degrees, forty-seven minutes, and sixteen point four eight seconds of arc." In the United States, this is the most commonly used system of angular measurement.

4.5.2 Centisimal or Metric System

In the centisimal or metric system, the full circle is divided into four quadrants, and each quadrant is divided into 100 equal parts known as grads or grades. Each grad is further divided into decimal parts. As an example, angles in this system are written as 376g.7289, or 376g72'89" which is read as "three hundred seventy-six point seven two eight nine grads," or as "three hundred seventy-six grads, seventy-two centisimal minutes, and eighty-nine centesimal seconds. "

4.5.3 Mil System

In the mil system, the circle is divided into 6,400 equal parts known as MILS. The mil is divided into decimal parts. As an example, angles in this system are written as 1728.49 roils, which is read as "one thousand seven hundred twenty-eight point four nine mils." This system is used principally by artillery people. The significance of this unit of angular measure is the fact that 1 mil is the angle that will subtend 1 yd at a range of 1,000 yds.

The relationships among values in the three systems of angular measure are as follows:

$$1 \text{ circle} = 360 \text{ degrees} = 400 \text{ grads} = 6{,}400 \text{ mils}$$

$$1 \text{ degree} = 1.1111 \text{ grads} = 17.7778 \text{ mils}$$

$$1 \text{ minute} = 0.2963 \text{ mils}$$

$$1 \text{ grad} = 0.9 \text{ degree} = 0^\circ 54' 00''$$

$$1 \text{ mil} = 0.0562 \text{ degree} = 0^\circ 03' 22''.5 \text{ or } 3.3750 \text{ minutes}$$

$$= 0.0625 \text{ grad}$$

4.6.0 More Units of Measurement

Aside from the units of measurement discussed above, EAs must also deal with other units of measurement, such as time, temperature, pressure, and so forth. They must use exact time in computing problems in astronomy and some laboratory works, apply temperature corrections to tape readings, evaluate the effect of atmospheric pressure at different elevations, and get involved in some other types of measure that will be discussed in the following paragraphs.

4.6.1 Time Measurement

For practical purposes in everyday affairs and in surveying, the measurement of time intervals is of great concern. The time used in everyday life is known as standard time and is based on the mean apparent revolution of the sun around the earth because of the earth's rotation on its axis. Standard time is used in surveying to regulate the normal day's operations. But, when it is necessary to observe the sun or the stars to determine the azimuth of a line or the position of a point on the earth's surface, the surveyor uses three other kinds of time. They are apparent (true) solar time, civil (mean solar) time, and sidereal (star) time. You will learn more about these different times when you study the chapter on "Geodesy and Field Astronomy" in *Engineering Aid Advanced.*

In the practice of surveying, it is customary to say, or write, the time of day as the number of hours, minutes, and seconds since midnight. Then the recorded time would appear, for example, as $16^h 37^m 52^s.71$ which is read as "sixteen hours, thirty-seven minutes, and fifty-two point seven one seconds of time."

Units of time measure are sometimes used to designate the sizes of angles. The longitude of a point on the earth's surface is often expressed in this manner. The relationship between the units of time measure and the units of angular measure in the sexagesimal system are as follows:

$$1 \text{ hour} = 15 \text{ degrees} (1^h = 15^\circ)$$

$$1 \text{ minute of time} = 15 \text{ minutes of arc} (1^m = 15')$$

$$1 \text{ second of time} = 15 \text{ seconds of arc} (1^s = 15'')$$

$$1 \text{ degree} = 4 \text{ minutes of time} (1^\circ = 4^m)$$

$$1 \text{ minute of arc} = 4 \text{ seconds of time} (1' = 4^s)$$

$$1 \text{ second of arc} = 0.0667 \text{ second of time} (1'' = 0.0667^s)$$

4.6.2 Temperature Measurement

In certain types of measurement, when the existing temperature differs from a standard temperature, the measured values will be in error and must be corrected, In each of the several temperature-measurement scales, the unit of measure is called a degree, which varies for the different temperature scales, When the scale extends below zero, values below zero are identified by a minus sign. Temperatures are written, for example, as 23°F or – 5°C, the letter designating the particular temperature scale. To avoid confusion when writing or talking about temperature, we should always be sure to indicate the type of scale used, Two of the most commonly used temperature scales are the centigrade scale and the Fahrenheit scale.

On the Centigrade scale (also known internationally as "Celsius Scale" after Anders Celsius, a Swedish astronomer who first devised it), zero is the freezing point of water, and plus 100 is its boiling point.

On the Fahrenheit scale, the temperature of the freezing point of water is plus 32°, and its boiling point is plus 212°.

Now let us compare these scales. A Fahrenheit degree represents five-ninths of the change in heat intensity indicated by a degree on the Centigrade scale. Temperatures on either of the two scales can be converted to the other by the following formulas:

$$\text{Degrees C} = 5/9 \ (\text{degrees F} - 32°),$$

$$\text{Degrees F} = (9/5 \ \text{degrees C}) + 32°$$

Note that, when converting Fahrenheit to Centigrade, you should first subtract the 32°, then multiply by 5/9. When converting Centigrade to Fahrenheit, you should first multiply by 9/5, then add the 32°.

4.6.3 Pressure Measurement

Measurements of atmospheric pressure are used in surveying to determine approximate differences in elevation between points on the earth's surface and to determine the best approximate correction for the effect of atmospheric refraction. The units of measure for atmospheric pressure and their relationships are as follows:

1 atmosphere = 29.9212 inches of mercury

= 760 millimeters of mercury

= 14.6960 pounds per square inch

= 1,03323 kilograms per square centimeter

= 33.899 feet of water

= 1.01325 bars, or 1013.25 millibars

4.6.4 Dry Measure

Dry measure is a system of measure of volume used in the United States for dry commodities, such as grains, fruits, and certain vegetables. The basic unit in dry measure is the bushel. The standard U.S. bushel contains about 77.6 lb of water. Since there are about 62.4 lb of water in a cu foot, a U.S. bushel has a volume of $\dfrac{77.6}{62.442}$, or about 1 % cu feet.

Units of dry measure are as follows:

$$1 \text{ bushel} = 4 \text{ pecks}$$

$$1 \text{ peck} = 8 \text{ quarts}$$

$$1 \text{ quart} = 2 \text{ pints}$$

4.6.5 Board Measure

Board measure is a method of measuring lumber in which the basic unit is a board foot (bf). A board foot is an abstract volume 1 foot long by 1 foot wide by 1 inch thick. The chief practical use of board measure is in cost calculations; lumber is sold by the board foot just as sugar is sold by the pound.

There are several formulas for calculating the number of board feet in any given length of lumber with given section dimensions. Because lumber dimensions are most frequently given by length in feet and width and thickness in inches, the following formula is probably the most practical:

$$Bf \; \frac{thickness\, in\, inches\, x\, width\, in\, inches\, x\, length\, in\, feet}{12}$$

Board measure is calculated on the basis of the nominal, not the actual, section dimensions. The actual section dimensions of (for example) 2 by 4 stock, which is surfaced on all four surfaces (S4S), are about 1 5/8 inch thick by 3 5/8 inch wide. Nevertheless, the computation for the number of (for example) 300 linear feet of 2 by 4 stock would be as follows:

$$Bf \; \frac{2\, x\, 4\, x\, 300}{12} \; 200 Bf$$

4.6.6 Measure

In the United States the basic unit of liquid measure is the gallon, which has a volume of 231 cu inch or 0.13 cu feet. The gallon is subdivided into smaller units as follows:

$$1 \text{ gallon} = 4 \text{ quarts}$$

$$1 \text{ quart} = 2 \text{ pints}$$

$$1 \text{ pint} = 4 \text{ gills}$$

Units larger than the gallon in liquid measure are as follows:

$$1 \text{ barrel} = 31.5 \text{ gallons}$$

$$1 \text{ hogshead} = 63 \text{ gallons or 2 barrels}$$

For petroleum products the standard barrel contains 42 gallons.

In the metric system, the basic unit of liquid measure is the liter, equal in volume to a cubic decimeter, or about 61 cubic inch. There are 3.785 liters in a U.S. gallon.

Following the usual metric system of nomenclature, subdivisions and multiples of the liter are as follows:

$$0.000001 \text{ liter} = 1 \text{ microliter}$$

$$0.001 \text{ liter} = 1 \text{ milliliter}$$

0.01 liter = 1 centiliter

0.10 liter = 1 deciliter

10.00 liter = 1 decaliter

100.00 liter = 1 hectoliter

1,000.00 liter = 1 kiloliter

4.6.7 Electrical Measure

In an electrical circuit there is a flow of electrons, roughly similar to the flow of water in a water pipe. The flow is occasioned by the production, at a generating station, battery, or other source, of an electromotive force (E), roughly similar to the "head" of water in a water system. The size of the electromotive force is measured in units called volts.

The rate of flow of the electrons through the circuit is called the current (I). Current is measured in units called amperes.

The usual conductor for transporting a flow of electrons through a circuit is wire. Generally speaking, the smaller the diameter of the wire, the more resistance (R) to the flow, and the larger the diameter, the less resistance.

Resistance is measured in units called ohms.

The definitions of the unit's volt, ampere, and ohm are as follows:

1 volt   Electromotive force required to send a current of 1 ampere through a system in which the resistance measures 1 ohm.

1 ampere   Rate of flow of electrons in a system in which the electromotive force is 1 volt and the resistance 1 ohm.

1 ohm   Resistance offered by a system in which the electromotive force is 1 volt and the current 1 ampere.

The ohm is named for Georg Simon Ohm, a German scientist and early electrical pioneer, who discovered that there is a constant relationship between the electromotive force (E), the current (I), and the resistance (R) in any electrical circuit. This relationship is expressed in "Ohm's law" as follows: $I \quad \dfrac{E}{R}$

From the basic law it follows that

$$E = IR$$
$$R = \frac{E}{I}$$

From Ohm's law you can (1) determine any one of the three values when you know the other two and (2) determine what happens in the circuit when a value is varied.

Suppose, for example, that the resistance (R) is increased, while the electromotive force (E) remains the same. Obviously the current (I) must drop proportionately. To avoid a drop in the current, it would be necessary to increase the electromotive force proportionately.

When an electrical circuit is open (that is, when there is a break in the circuit, such as an open switch), there is no flow of electrons through the circuit. When the circuit is closed, however, the current will begin to flow. With a constant electromotive force (E), the rate at which the current (1) flows will depend on the size of the resistance (R). The size of the resistance will increase with the number of electrical devices (such as lights, motors, and the like) that are placed on the circuit, and the amount of power each of these consumes.

Power may be defined as "electrical work per unit of time." James Watt, another early pioneer in the electrical field, discovered that there is a constant relationship between the electromotive force (E), the current (I), and the power consumption (P) in a circuit. This relationship is expressed in the formula P = IE, from which it follows that

$$I = \frac{P}{E} \ and \ E = \frac{P}{I}$$

Power is measured in units called WATTS, a watt being defined as the work done in 1 second when 1 ampere flows under an electromotive force of 1 volt.

Suppose you have a 110-volt circuit in your home. The constant E of this circuit, then, is 110 volts. In the circuit there is probably a 15-ampere fuse. A fuse is a device that will open the circuit by "burning out" if the current in the circuit exceeds 15 amperes. The reason for the existence of the fuse is that the wiring in the circuit is designed to stand safely a maximum current of 15 amperes. A current in excess of this amount would cause the wiring to become red hot, eventually to "burn out," and perhaps to start an electrical fire.

Suppose you light a 60-watt bulb on this circuit. Your E is 110 volts. By the formula

$$I = \frac{P}{E}$$

you know that the current in the circuit with the 60-watt bulb on is

$$\frac{60}{110}$$

or about 0.54 amperes, which is well within the margin of safety of 15 amperes. Dividing 15 amperes by 0.54 amperes you find that this fuse will protect a 27-lamp circuit.

But suppose now that you place on the same one-lamp circuit an electric toaster taking about 1,500 watts (electrical devices are usually marked with the number of watts they

consume) and an electrical clothes dryer taking about 1,200 watts. The total P is now 60 + 1,500 + 1,200, or 2,760 watts. The current will now be

$$\frac{2,760}{110}$$

or 25 amperes. Theoretically, before it reaches this point, the 15-ampere fuse will burn out and open the circuit.

4.6.8 Mechanical Power Measure

Mechanical power (such as that supplied by a bulldozer) is measured in units called foot-pounds per second (feet-lb/sec) or foot-pound per minute (feet-lb/min). A foot-pound is the amount of energy required to raise 1 lb a distance of 1 foot against the force of gravity.

One horsepower equals 33,000 feet-lb/sec or 550 feet-lb/min. One horsepower equals about 746 watts.

4.7.1 Conversion of Units

To convert a measure expressed in terms of one unit to the equivalent in terms of a different unit is, when you know the ratio between the units, a simple proportional equation problem.

Suppose, for example, that you want to convert a linear distance in engineer's measure (feet and decimals of feet) to the equivalent in carpenter's measure (feet and twelfths of feet) to the nearest one-eighth in. Suppose that the original distance is 12.65 feet. This means "12 feet and 65 hundredths of a foot." You want to determine first, then, how many twelfths of a foot there are in 65 hundredths of a foot. The original ratio is 12/100. The proportional equation solution is as follows:

$$\frac{x}{65} \quad \frac{12}{100}$$

$$x \quad \frac{12 \times 65}{100} \quad \frac{780}{100} \quad 7.8$$

Therefore, there are 7.8 inches. (twelfths of a foot) in 0.65 feet. The next step is to determine how many eighths of an inch there are in 0.8 inch; that is, in eight-tenths of an inch the initial ratio is 8/10, and the proportional equation solution is as follows:

$$\frac{x}{8} \quad \frac{8}{10}$$

$$x \quad \frac{8 \times 8}{10} \quad \frac{64}{10} \quad 6.4$$

Therefore, there are (rounded off) 6/8 inch, or 3/4 inch, in 0.8 inches In 12.65 feet, then, there are 12 feet 7 3/4 inch to the nearest 1/8 inch

Actually, the proportional method used above can be simplified by using the following solution:

Convert 12.65 feet to the nearest 1/8 inch in carpenter's measure.

12.65 feet = 12 feet + (0.65 x 12 = 7.8 inches,)

= 12 feet 7.8 inches

= 12 feet 7.0 inches + (0.8 x 8 = 6.4

eighths)

= 12 feet 7.0 inches + 6/8 inches or 3/4 inches

to the nearest eighth inch

= 12 feet 7 3/4 inch

In converting from engineer's to carpenter's linear measure, or vice versa, surveyors working with values to only the nearest 0.01 feet frequently use the following conversions to decimal equivalents of the common carpenter's measure subdivisions of the inch.

1 inches	=	0.08 feet
2 inches	=	0.17 feet
3 inches	=	0.25 feet
4 inches	=	0.33 feet
5 inches	=	0.42 feet
6 inches	=	0.50 feet
7 inches	=	0.58 feet
8 inches	=	0.67 feet
9 inches	=	0.75 feet
10 inches	=	0.83 feet
11 inches	=	0.92 feet
$\frac{1}{8}$ inches	=	0.01 feet
$\frac{1}{4}$ inches	=	0.02 feet
$\frac{1}{2}$ inches	=	0.04 feet
$\frac{3}{4}$ inches	=	0.06 feet

Using these values, you can convert decimals of a foot to inches carpenter's measure, or inches carpenter's measure to decimals of a foot, very easily. To convert (for example) 0.37 feet to inches carpenter's measure, you have the following:

$$0.33 \text{ feet} = 4 \text{ inches}$$

$$0.04 \text{ feet} = \frac{1}{2} \text{ inch}$$

$$0.37 \text{ feet} = 4\frac{1}{2} \text{ inches}$$

To convert (for example) 7 3/8 in. carpenter's measure to engineer's measure, you have the following:

$$7 \text{ inches} = \qquad 0.58 \text{ feet.}$$

$$\frac{3}{8} \text{inch} = \qquad (3 \times 0.01) = 0.03 \text{ feet.}$$

$$7\frac{3}{8} \text{inches} = \qquad 0.61 \text{ feet.}$$

For a great many types of conversions there are tables in which you can find the desired values by inspection. Various publications contain tables for making the following conversions:

Meters to feet

Feet to meters

Degrees Centigrade to degrees Fahrenheit

Degrees Fahrenheit to degrees Centigrade

Inches and sixteenths to decimals of a foot

Sixteenths of an inch to decimals of a foot

Minutes to decimals of a degree

Degrees to roils and roils to degrees

Grads to degrees, minutes, and seconds

A conversion factor is a number that, if multiplied by a value expressed in terms of one unit, will produce the equivalent value expressed in terms of a different unit. The factor for converting linear feet to miles, for instance, is 0.00019. If you multiply 5,280 feet by 0.00019, you get 1.0032 miles, which is close enough to a mile to satisfy most practical purposes.

When you know the ratio between two different units, you can easily work out your conversion factor. For example, you know that the ratio of degrees to roils is

$$\frac{9}{160},$$

The conversion factor for converting degrees to roils is the number of roils in 1 degree which is

$$\frac{160}{9}, \text{or } 17.8.$$

The conversion factor for converting roils to degrees is the number of degrees in a roil, which is

$$\frac{9}{160}, \text{or } 0.0562.$$

Some of the common conversion factors are as follows:

Linear feet x 0.00019 = miles

Square yards x 0.0002067 = acres

Linear yards x 0.0006 = miles

Acres x 4840.0 = square yards

Square inches x 0.007 = square feet

Cubic inches x 0.00058 = cubic feet

Square feet x 0.111 = square yards

Cubic feet x 0.03704 = cubic yards

Summary

As an Engineering Aid, the use of mathematics is found in a variety of your day to day duties. Knowing how to compute easily, quickly, systematically and accurately, you will contribute to a project's and a unit's success.

Review Questions (Select the Correct Response)

A calculator and pencil and paper may be needed to solve some of these problems.

1. **(True or False)** Positive and negative numbers are not real numbers.

    A.   True
    B.   False

2. Which one of the following is not a rational number?

    A.   Fractions
    B.   Whole numbers
    C.   Percentage
    D.   Radicals

3. Which of the following is not a prime number?

    A.   25
    B.   7
    C.   3
    D.   17

4. Which of the following is not an improper fraction?

    A.   8/3
    B.   24/4
    C.   1/4
    D.   12/5

5. **(True or False)** You can add or subtract fractions only if the numerators are alike.

    A.   True
    B.   False

6. To raise a number to a power means to_____, using the number as a factor as many times as the power indicates.

    A.   subtract
    B.   multiply
    C.   add
    D.   divide

7. $3^2 =$

    A.   6
    B.   8
    C.   9
    D.   10

8. $7^3 =$

    A. 21
    B. 49
    C. 342
    D. 343

9. **(True or False)** The square root must always be +.

    A. True
    B. False

10. $\sqrt{24} =$

    A. 2.236
    B. 22.36
    C. 4.472
    D. 44.72

11. $\dfrac{\sqrt{21}}{\sqrt{3}} =$

    A. 2.432
    B. 2.345
    C. 2.2
    D. 2.645

12. If you have a fraction under a radical, you have to rationalize the _____ before performing the indicated operation. $\sqrt{2+4} + \sqrt{2+9} =$

    A. exponent
    B. denominator
    C. numerator
    D. square root

13. If you multiply the_____ and_____ by the same number, you can extract the denominator.

    A. exponent, square root
    B. denominator, exponent
    C. numerator, denominator
    D. square root, numerator

14. $\sqrt{4} =$

    A. 4
    B. 2
    C. $4^{1/2}$
    D. 0

15. $\sqrt[3]{5}$ =

A. $5^{1/3}$
B. 15
C. 5^3
D. 5/3

16. $\sqrt[2]{6}$ =

A. 12
B. $6^{1/2}$
C. 6
D. 6.2

17. $\sqrt[3]{5}\,^2$ =

A. 17
B. $5^{3/2}$
C. $5^{2/3}$
D. 15

18. **(True or False)** When an exponent occurs in the radicand, this exponent becomes the numerator of the fractional exponent.

A. True
B. False

19. $\sqrt{\dfrac{7}{9}}$ =

A. .8
B. .882
C. .9
D. .093

20. 4^1 =

A. 4/1
B. -1/4
C. 1/4
D. -1/4

21. 6^2 =

A. $1/6^2$
B. 12
C. 1/36
D. 36

22. $10^3 =$

    A. $1/10^3$
    B.   1000
    C.   1/1000
    D.   -1/10

23. $6.259 \times 10^{-4} =$

    A.   6.2590000
    B.   0000.6259
    C. $.6259^{-4}$
    D.   0.0006259

24. $\dfrac{1}{250,000 \lceil 300 \lceil 0.02} =$

    A.   0.000667
    B.   6.67 x 10-7
    C.   0.000000667
    D.   .667

25. A ratio is a comparison of how many quantities?

    A.   one
    B.   two
    C.   three
    D.   four

26. 24 feet and 3 yards written in comparison is equal to_____.

    A.   24:3
    B.   12:3
    C.   11
    D.   8:3

27. **(True or False)** A plane is a real or imaginary surface in which a straight line between any two points lies wholly on that surface.

    A.   True
    B.   False

28. A quadrilateral is a polygon bounded by_____sides.

    A.   three
    B.   four
    C.   five
    D.   six

29. Find the area of a right triangle with a base of 6 centimeters and a height of 9 centimeters

    A. 27cm
    B. 27cm^2
    C. 28cm
    D. 28cm^2

30. The formula for a rhomboid is

    A. A = 1/2bh
    B. A = lwh
    C. A = wl
    D. A = bh

31. Find the area of a trapezoid with a base of 2.5 cm, 6 cm and a height of 5 cm.

    A. 21.25
    B. 2.125
    C. .2125
    D. 212.5

32. Find the area of a circle with a circumference of 4.

    A. 127
    B. 1.27
    C. 12.7
    D. .127

33. Find the area of a segment with r = 4, n = 12 (using 3.14 for ν)

    A. 16.7
    B. 167
    C. .167
    D. 1.67

34. $A = \dfrac{\text{perimeter } \xi \text{ r}}{2}$ is used to solve what type of problem?

    A. Regular Polygon
    B. Ellipse
    C. Irregular Trapezoid
    D. Triangle

35. Solve the following formula $A = \left(\dfrac{a}{A\,4} \times \dfrac{b}{3}\right)$

    A. 0.262ab
    B. 37.68ab
    C. 2.62ab
    D. 262ab

36.   A solid figure whose base or ends are similar, equal, and parallel polygons and whose faces are parallelograms, is known geometrically as a_____.

       A.   Parallelogram
       B.   Prism
       C.   Cone
       D.   Cylinder

37.   A cone has a circular base of radius 14 cm, a height of 48 cm and a slant height of 50 cm. Calculate the volume of the cone. (using 22/7 for ν)

       A.   9856cm
       B.   9856cm^2
       C.   9856cm^3
       D.   9856cm^4

38.   The_____is the most common system used in angular measurement.

       A.   Trigonometric function
       B.   Revolution
       C.   Quadrant
       D.   Degree System

For questions 39-42 determine the quadrant in which each of the following angles lies.

39.   260$\circ$

       A.   First
       B.   Second
       C.   Third
       D.   Fourth

40.   290$\circ$

       A.   First
       B.   Second
       C.   Third
       D.   Fourth

41.   800$\circ$

       A.   First
       B.   Second
       C.   Third
       D.   Fourth

42.   1,930

     A.   First
     B.   Second
     C.   Third
     D.   Fourth

43.   **(True or False)** The radian system of measuring angles is even more fundamental than the degree system.

     A.   True
     B.   False

44.   Express $160°$ in radians, using ν in the answer.

     A. $160/180\,\nu$
     B. $180/160\,\nu$
     C. $8\,\nu/9$
     D. $9/8\,\nu$

45.   Express $\nu/20$ in degrees

     A.   8 degrees
     B.   9 degrees
     C.   10 degrees
     D.   11 degrees

46.   The ratio between y and r (y/r) is called the _____ of an angle.

     A.   sine
     B.   cosine
     C.   tangent
     D.   cotangent

47.   The ratio between x and r (x/r) is called the _____ of an angle.

     A.   sine
     B.   cosine
     C.   tangent
     D.   cotangent

48.   The ratio between y and x (y/x) is called the _____ of an angle.

     A.   sine
     B.   cosine
     C.   tangent
     D.   cotangent

49.   Secant is the reciprocal function for_____.

       A.   sine
       B.   cotangent
       C.   cosecant
       D.   cosine

50.   Cotangent is the reciprocal function for_____.

       A.   sine
       B.   tangent
       C.   cosecant
       D.   cosine

51.   **(True or False)** When solving an obtuse angle, if you see the cosine function,
       you give it a negative sign.

       A.   True
       B.   False

Use the given triangles to solve questions 52-57, round to the nearest decimal.

52.   sin ε =

       A.   6
       B.   0.6
       C.   60
       D.   6.0

53.   cos ε =

       A.   0.8
       B.   9
       C.   0.9
       D.   10

54.   tab ε =
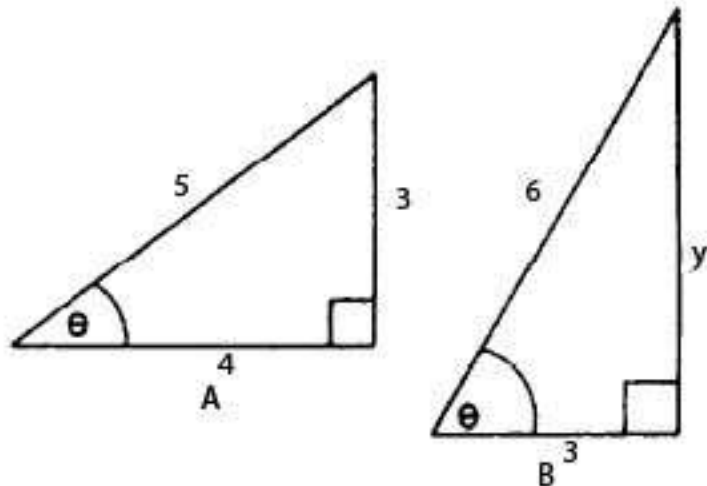
       A.   0.34
       B.   75
       C.   34
       D.   0.75

55. $\sin \varepsilon = \dfrac{[}{\backslash}$

   A. 13
   B. 1.33
   C. 0.13
   D. 13.01

56. $\sec \varepsilon = \dfrac{\text{⊬}}{[}$

   A. 1.14
   B. 1.25
   C. 125
   D. 0.124

57. $\csc \varepsilon = \dfrac{U}{\backslash}$ (round to the nearest hundredth)

   A. 1.67
   B. 1.6
   C. 0.16
   D. 16

58. What is the length of the hypotenuse of the right triangle if the lengths of the other two sides are 3 and 4?

   A.5
   B. 0.5
   C. 25
   D. 0.25
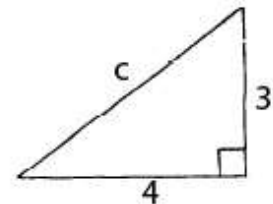
59. The right triangle shown has a hypotenuse equal to 40 and one of the other sides equal to 10.
    What is the length of the remaining side?

   A. 3.87
   B. 38.7
   C. .387
   D. 387
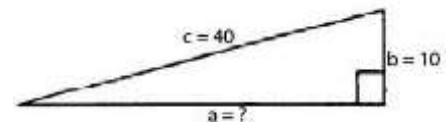
60. Solve this problem for the triangle given. You know that angle *A* measures 36052' and that side b measures 12 feet. You want to determine the length of side a.

A. 12.00 feet
B. 3.00 feet
C. 9.1 feet
D. 5.00 feet
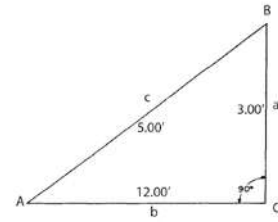
61. Solve this problem for the triangle given Angle *B* = 53008' and a = 3.00 feet. Find the length of b.

A. 12.00 feet
B. 3.00 feet
C. 9.00 feet
D. 4.00 feet
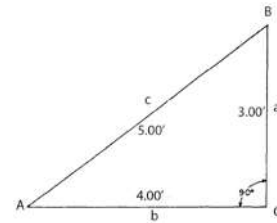
62. Solve this problem for the triangle given. Angle   = 36052' and b = 23.00 feet. Find the length of a.

A. 28.00 feet
B. 28.72 feet
C. 28.74 feet
D. 28.75 feet
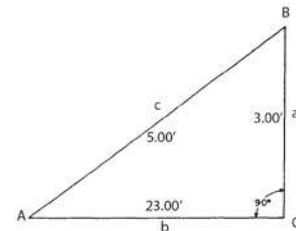
63. Solve for side b in triangle *ABC*, given c = 5, *B* = 300 , and *C* = 97030'. Give side accuracy to one decimal place.

A. 2.0
B. 2.5
C. 3.0
D. 3.5
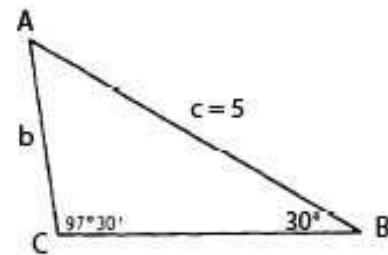
64. Solve for side a in triangle *ABC*, given b = 7, c = 5, *A* =190. Give side accuracy to one decimal place.

    A. 2.7
    B. 2.8
    C. 2.9
    D. 3.0
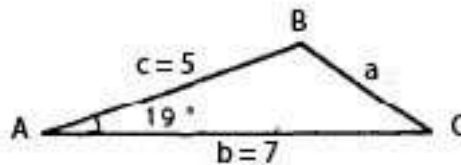
65. Use the triangle given to determine the size of *A*.

    A. 14583
    B. .14583
    C. 1.4583
    D. 14.8535
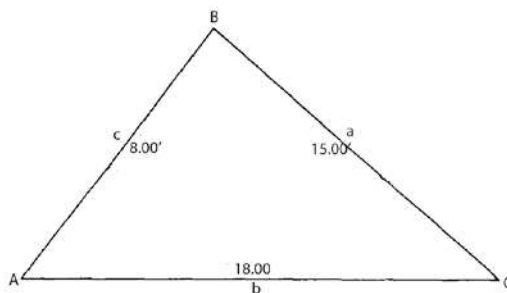
66. **(True or False)** The two units of measurement used throughout the world are the French system and the metric system.

    A. True
    B. False

67. 1 statute mile =

    A. 52.80 feet
    B. 5.280 feet
    C. 5280.00 feet
    D. .5280 feet

68. 1 millimeter =

    A. 0.01
    B. 0.001
    C. 0.0001
    D. 0.000001

69. How many acres are in 3 square miles?

    A. 640
    B. 643
    C. 1920
    D. 1922

70. How many grains does a gram contain?

    A. 1.5432
    B. 15.432
    C. .1532
    D. 154.32

71.   _____is used for designating the value of horizontal and vertical angles.

    A.   Circular measure
    B.   Area measurement
    C.   Volume measurement
    D.   Units of weight

72.   1 minute is equal to how many mils?

    A.   2963
    B.   29.63
    C.   2.963
    D.   0.2963

73. $14^h 19^m 57^s.32$ is read as

    A.   14:19:57.32
    B.   14 hours, 19 minutes, 57.32 seconds
    C.   2:19:57.32
    D.   fourteen hours, nineteen minutes, and fifty-seven point three-two seconds of time

74.   **(True or False)** On the Fahrenheit scale, the temp of the freezing point of water is plus 310.

    A.   True
    B.   False

75.   Solve this equation, when degrees F = 121. C = 5/9(121-320)

    A.   48.0
    B.   48.4
    C.   49.0
    D.   49.4

76.   **(True or False)** Measurements of atmospheric pressure are used in surveying to determine approximate differences in elevation between points on the earth's surface and to determine the best approximate correction for the effect of atmospheric refraction.

    A.   True
    B.   False

77.   The basic unit in dry measurement is the_____.

    A.   kilogram
    B.   pound
    C.   bushel
    D.   gram

78.   Solve the equation: 500 linear feet of 2 by 6 stock =___Board feet (Bf).

        A.   100 Bf
        B.   200 Bf
        C.   500 Bf
        D.   600 Bf

79.   12 gallons equals_____quarts.

        A.   40
        B.   42
        C.   46
        D.   48

80.   _____is used to measure the size of the electromotive force.

        A.   Gallon
        B.   Volts
        C.   Current
        D.   Amperes

81.   Use the following to solve this problem.
        P=2,000, E = 110
        Can a 15 amperes handle this load?

        A.   Yes
        B.   No

Trade Terms Introduced in this Chapter

Real Numbers a rational number or the limit of a sequence of rational numbers, as opposed to a complex number

Rational Numbers a number that can be expressed exactly by a ratio of two integers

Irrational Numbers a number that cannot be exactly expressed as a ratio of two integers

Improper fraction a fraction having the numerator greater than the denominator

Proper fraction a fraction having the numerator less, or lower in degree, than the denominator

Equivalent fraction fractions that have the same value

Root quantity that, when multiplied by itself a certain number of times, produces a given quantity

Rationalize to eliminate radicals from (an equation or expression)

Trapezoidal Rule a numerical method for evaluating the area between a curve and an axis by approximating the area with the areas of trapezoids

Triangular Prism a prism whose bases are triangles

Revolution a turning round or rotating, as on an axis

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

CliffsNotes.com. *Angles.* 19 Feb 2009 <http://www.cliffsnotes.com/WileyCDA/CliffsReviewTopic/topicArticleId-11658,articleId-11558.html>.

CliffsNotes.com. *Solving Right Triangles*. 19 Feb 2009 <http://www.cliffsnotes.com/WileyCDA/CliffsReviewTopic/topicArticleId-11658,articleId-11571.html>.

CliffsNotes.com. *Tables of Trigonometric Functions*. 19 Feb 2009 <http://www.cliffsnotes.com/WileyCDA/CliffsReviewTopic/topicArticleId-11658,articleId-11565.html>.

Mathematics, Vol. 2-A, NAVEDTRA 10062

Mathematics, Vol. 2-B, NAVEDTRA 10063

Mathematics, Vol. 3, NAVEDTRA 10073-A1

Surveying Tables and Graphs, Army TM5-236

NAVPERS 10071-B

General Tables of Units of Measurements. 19 Apr 2006 <http://ts.nist.gov/WeightsAndMeasures/Publications/appxc.cfm>

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Chapter 3

Drafting Equipment

Topics

To hear audio, click on the box. 🔊

Overview

If "a picture can paint a thousand words," then drafting is the universal language. Drafting is a specialized drawing style engineers and designers use to convey and record ideas or information necessary for the construction of structures and machines. Drafting follows clearly defined usage rules to ensure that it conveys the same meaning at all times. Those who learn the rules can interpret exactly what a drawing presents.

In contrast to pictorial drawings, such as landscapes and portraits, engineering drawings use a graphical language to describe every integral part of an object. As an Engineering Aid, you will specialize in engineering drawings. The Illustrator Draftsman will specialize in pictorial drawings.

In this chapter, you will learn that drafting divides into the following classifications: technical and illustrative, mechanical and freehand, and engineering. You will also learn about charts, graphs, drafting guidelines, and a variety of instruments and materials designed to help you perform your drafting duties. This chapter also contains helpful hints about operating, adjusting, and maintaining your drafting instruments.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Understand the types of drafting done by the Engineering Aid rating.

2. Describe the drafting equipment used by the Engineering Aid rating.

Prerequisites

None

This course map shows all of the chapters in Engineering Aid Basic. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

		E
Topographic Surveying and Mapping		N
Indirect Leveling/Level and Traverse Computations		G
Care and Adjustment of Survey Equipment		I
Materials Testing: Soil and Concrete		N
Direct Leveling and Basic Engineering Surveys		E
Horizontal Control		E
Direct Linear Measurements and Field Survey Safety	↑	R
Surveying: Elements and Equipment		I
Construction Drawings		N
Electrical: Systems and Plans		G
Mechanical: Systems and Plans		AID
Concrete and Masonry		
Wood and Light Frame Structures		B
Drafting: Projections and Sketching		A
Drafting: Geometric Construction		S
Drafting: Fundamentals and Techniques		I
Drafting: Equipment		C
Mathematics and Units of Measurement		
Engineering Aid Rating		

Features of this Manual

This manual has several features that make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.

- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.

- Audio and video clips are included in the text, with italicized instructions telling you where to click to activate it.

- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is

for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.0.0 TYPES of DRAFTING

Drafting is classified into categories according to its purpose or how it is accomplished: technical or Illustrative, mechanical or freehand, and engineering.

1.1.0 Technical and Illustrative

Drafting may be technical or illustrative. **Technical drafting** presents technical information in a graphic form. For example, a technical drawing may show the type and proper placement of structural members in a building. **Illustrative drafting** presents a pictorial image only; an example is a perspective drawing of a proposed structure. The term illustrative drafting is not commonly used in construction drafting.
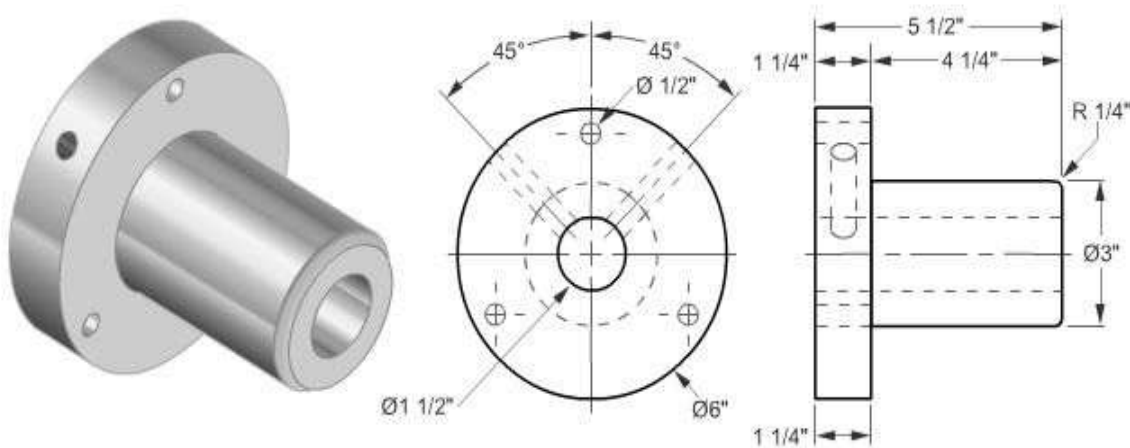
Figure 3-1 - Illustrative versus technical drafting.

Figure 3-1 shows the same item as an illustrative drawing and a technical drawing.

1.2.0 Mechanical and Freehand

Mechanical drafting is any drawing in which the pencil or pen is guided by mechanical devices, such as compasses, straightedges, and french curves. In contrast, **freehand drafting** is any drawing in which the pencil or pen is guided solely by the draftsman's hand. Sketches are the result of freehand drafting. With the exception of lettering, most technical drafting is mechanical.

The term mechanical can also describe certain types of industrial or engineering drawings, regardless of whether the drawings are done mechanically or freehand. Some authorities confine the term, used in this sense, to the drawing of machinery details and parts. Others confine it to the drawing of plumbing, heating, air conditioning, and ventilating systems in structures. In the Seabees, mechanical drawing refers to the arrangements of machinery, utility systems, heating, air conditioning, and ventilating systems.

1.3.0 Engineering Drafting

As an Engineering Aid, you will be concerned primarily with three broad types of engineering drafting:

- *Topographic drafting*, or drafting done in connection with topographic and civil engineering surveys. It may include drawings not directly related to topographic maps, such as plotted profiles and cross sections.

- *Construction drafting*, or drafting of architectural, structural, electrical, and mechanical drawings related to structures.

- *Administrative drafting*, or drafting done in support of your unit's administrative and operational functions, such as technical and display charts, safety and embarkation signs, project completions, and unit readiness graphics.

In performing drafting duties, you will be working from sketches, field notes, or direct instructions from your drafting supervisor. *Figure 3-2* shows examples of each type of drafting.
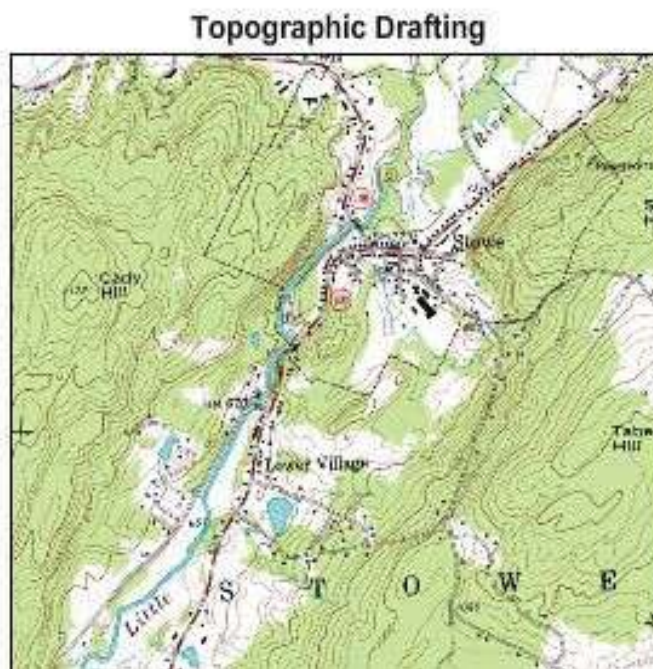
Figure 3-2 – Examples of topographic, construction, and administrative drafting.

1.3.1 harts and Graphs

Graphic presentation of engineering data means using *charts* and *graphs*, rather than numerical tables or word descriptions, to present statistical engineering information. A properly constructed chart or graph offers a sharp, clear, visual statement about a particular aspect or series of related facts, emphasizing the numerical value of the facts or showing the way these facts are related.

A chart or graph that emphasizes numerical value is called *quantitative*; one that emphasizes relationships is called *qualitative*. The trend of an activity over a period of time, such as the mishaps summary report of a deployed unit rendered over a 6-month deployment period, is more memorable from the shape of a curve describing the trend than from numerical statistics. Successful graphic presentation of engineering data requires as much drafting ability as the graphic representation of engineering objects. Lines must be sharp, opaque, well contrasted, and of uniform weight. Drafters normally execute letters and figures with the standard lettering set according to accepted conventions.

Charts and graphs can be technical or display charts.

1.3.1.1 Technical Engineering Charts

Technical engineering charts are usually based on a series of measurements of laboratory experiments or work activities. Such measurements examine the quantitative relationship between a set of two factors or variables. Of the two variables, one has either a controlled or regular variation and is called the independent variable. The other is called the dependent variable because its values are related to those of the independent variable. The line connecting plotted points is called a curve, although it may be broken, straight, or curved. The curve demonstrates the relationship between the variables and permits reading approximate values between plotted points.

1.3.1.2 Display Charts

The purpose of *display charts* is to convey data to nontechnical audiences. The message presents a general picture of a situation, usually comparative. There are many varieties of display charts, including bar charts, status charts, and training aids. A Seabee battalion frequently uses display charts in operations and training departments. When so used, they must conform to minimum standards the command prescribes.

Any construction job involves quantities of people, materials, and equipment. Good planning, organization, and supervision lead to efficient job operation and completion. Statistics based on the results of past jobs with similar working conditions provide a basis for predicting the amount of time that a proposed job will take. Graphic presentation of past and current statistical data allows for easy comparison.

These statistics offer the best possibilities for study when presented graphically, usually in the form of a curve. The prediction of expected achievement is usually presented as a bar chart called a time-and-work schedule. When the scheduled work progress is compared with the actual progress (work in place), the chart is called a progress chart.

1.4.0 Drafting Guidelines

As stated earlier, definite guidelines in drafting provide uniform interpretation of all engineering drawings. Any drawing prepared by or for the Navy must be prepared following the latest military standard (*MIL-STD*), Department of Defense Standard (*DOD-STD*), and applicable *NAVFACENGCOM* design manuals. For subjects these references do not cover, refer to civilian publications, such as the Architectural Graphic Standards. In exceptional cases, you may devise your own symbols as long as you adequately explain with notes or a legend any nonstandard features in your drawing.
Many drawings continue in use for years; occasionally, you will have to work with drawings containing obsolete symbols. Look for a legend on the drawings; it should help you identify unfamiliar symbols. If there is no legend, studying the drawing carefully should enable you to interpret the meaning of unfamiliar symbols and abbreviations.

The Assistant Secretary of Defense (Supply and Logistics), Office of Standardization publishes and constantly updates the DoD drawing standards. Any Navy activity can obtain copies of these standards by writing to the following:

Naval Publications and Forms Center

5801 Tabor Avenue

Philadelphia, PA 19120

All requests should state the desired title and identifying number and be submitted on DD Form 1425. To ensure that you have the latest edition of a standard, check the Department of Defense Index of Specifications and Standards, which is issued 31 July of each year. Also, check the supplements to the Index.

Current editions of the following military standards should be available to the EA:

MIL-HDBK-1006/1	Policy and Procedures for Project Drawings and Specifications Preparation
MIL-STD-12D	Abbreviations for Use on Drawings and in Technical Type Publications
MIL-STD-14A	Architectural Symbols
MIL-STD-17B	Mechanical Symbols
MIL-STD-18	Structural Symbols
DOD-STD-100C	Engineering Drawing Practices

In addition, the following civilian industry standards should be on hand in the drafting room:

ANSI Y14.1	Drawing Sheet Size and Format
ANSI Y14.2	Line Conventions and Lettering
ANSI Y14.3	Multi and Sectional View Drawings
ANSI Y14.5-82	Dimensioning and Tolerancing for Engineering Drawings
AWS A3.0-85	Welding Terms and Definitions Standards
ASTM E380	Standard for Metric Use

2.0.0 DRAFTING EQUIPMENT

To be a proficient draftsman, you must be familiar with the tools of your trade and the proper techniques of using them. You should carefully choose your drafting equipment and accessories. Owning a few good pieces of equipment is much better than having a large selection of undependable and shoddy equipment.

2.1.0 NMCB Standard Draftsman Kit

To ensure that every Naval Mobile Construction Battalion's (NMCB's) drafting section is properly outfitted with adequate drafting equipment and accessories, standard draftsman kits are provided in each NMCB's allowance. The drafting equipment and supplies contained in the draftsman kit #0011 are listed in the NMCB's TABLE OF ALLOWANCE (Assembly 80011). For this reason, this chapter will make no attempt to list all equipment and supplies currently carried in the standard draftsman kit.

One complete NMCB's draftsman kit is designed for use by three draftsmen. Normally, two complete draftsman kits will be carried in a battalion allowance, available for checkout to the drafting section supervisor or engineering chief. It is each crewleader's responsibility to make sure that the kits assigned to him are complete. The crewleader continuously reviews and updates the kits according to current battalion requirements.

The battalion supply department stocks most of the consumable items contained in the kit, such as pencils, pencil leads, lead holders, masking tape, and ink, for kit replenishment. It also stocks additional drafting equipment and supplies, such as

pointers and dust brushes, in most battalion drafting rooms to supplement the drafting kits.

To avoid losing any equipment and supplies not included in the draftsman kit, do not pack them with the kit when you turn in the kit to the supply department at the end of a deployment or homeport period.

The following sections will acquaint you with general drafting equipment and supplies, placing emphasis on items used by Seabee draftsmen.

2.2.0 Drafting Media

Materials on which draftsmen draw are called *drafting media*. There are three basic types: paper, cloth, and film. As a Seabee draftsman, you will commonly use tracing paper, profile paper, plan/profile paper, and cross-section paper. Although it is not in the draftsman kit, illustration board is used for preparing signs and charts. Seabee draftsmen rarely use tracing cloth and film, hence this chapter will not describe it.
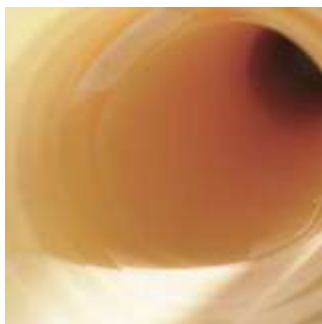
Tracing paper (also called *tracing vellum*) is a high-grade white (or slightly tinted) transparent paper that takes pencil well and erases cleanly. You can make reproductions directly from pencil drawings on tracing paper; however, for better results in reproduction, you will usually ink over a pencil drawing on tracing paper. See *Figure 3-3*.

Figure 3-3 – Tracing paper.

Profile, *plan/profile*, and cross-section paper are called *gridded media*. Each type of gridded media is designed for a specific purpose. Most gridded media EAs use are suitable for reproduction.

Profile paper is normally available in two grid patterns: 4 by 20 lines (4 lines vertical and 20 lines horizontal) per inch and 4 by 30 lines per inch with the vertical lines accented every 10th line. Horizontal lines on the 4 by 20 are accented medium-weight every 5th line and heavyweight every 50th line. Horizontal lines on the 4 by 30 have heavyweight accent lines every 25th line. Profile paper is generally used for road design profiles.

Plan/profile paper has rulings and grid accents similar to those of 4 by 20 and 4 by 30 profile paper, except that the grid patterns occupy only the lower half of the paper. The upper half is plain paper, used to draw the plan view in relation to the profile or to add explanatory notes to the profile. Plan/profile paper is also used for road design.
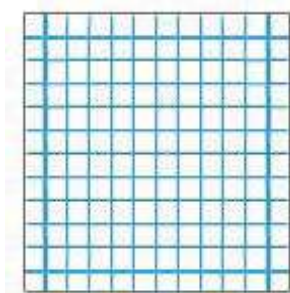
Figure 3-4 – Cross-section paper.

Cross-section paper, also known as graph paper, is available in a variety of grid patterns. Generally, the EA uses graph paper with a grid scale of 10 by 10 lines per square inch for drawing road cross sections, rough design sketching, preparing schedules, plotting graphs, and many other uses. See *Figure 3-4*.

Most drafting media are available in three styles: plain sheets or rolls, preprinted sheets with borders and title blocks, and sheets with non-reproducible grids. For further information on the many varieties of drafting media available, refer to suppliers' catalogs.

Figure 3-5 – Illustration board.

Illustration board is drawing paper with a high rag content mounted on cardboard backing. See *Figure 3-5*.The type normally found in a Seabee drafting section has a smooth white drawing surface that takes ink readily. Normally, the board is 30 inches by 40 inches and comes in 50-sheet packages. EAs use illustration board for making signs and for large unmounted charts and for mounting maps, photos, and drawings that require a strong backing. They also use a thinner board, called **bristol board**, for making small signs and charts. The thickness of bristol board is about the same as an ordinary index card. Unlike illustration board, bristol board has two white smooth sides that take ink very well. Bristol board is less expensive than illustration board and you can easily cut, to size with a paper trimmer. It is available in many sizes; the most popular size is 20 inches by 30 inches in 50- or 100-sheet packages.

2.3.0 Drafting Pencils

Two types of pencils are used in drafting: wooden and mechanical. The latter is actually a lead holder and may be used with leads of different hardness or softness.

Drafting pencils are graded according to the relative hardness of their graphite lead. A soft pencil is designated by the letter B, a hard pencil by the letter H. *Figure 3-6* shows 17 common grades of drafting pencils from 6B (the softest and the one that produces the thickest line) to 9H (the hardest and one that produces a thin, gray line).

You will notice that the diameters of the lead vary. This feature adds strength to the softer grades. As a result, softer grades are thicker and produce broader lines, while harder grades are smaller and produce thinner lines. Unfortunately, manufacturers of pencils have not established uniformity in grades. Hence, a 3H may vary in hardness from company to company. With experience and preference, you may select the trade name and grade of pencil that suits your needs.
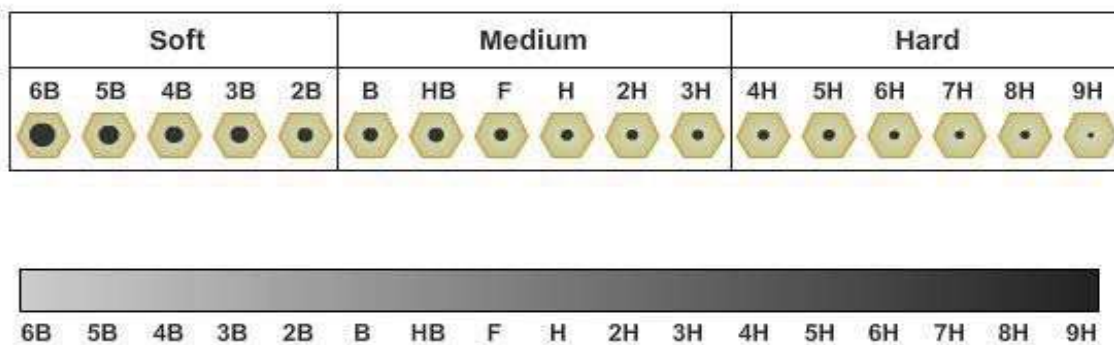
Figure 3-6 - Grades of drafting pencils.

2.4.0 Erasers and Erasing Accessories

You must be very careful in selecting an eraser to select one that will remove pencil or ink lines without damaging the surface of the drawing sheet.

Pearl Pink Vinyl Eraser

Figure 3-7 - Common types of erasers

A vinyl eraser is ideal for erasing lines drawn on tracing cloth and films. An ordinary double-beveled pencil eraser generally comes in red or pink color (sometimes called a *pink pearl*). A harder eraser (sometimes called a *ruby red*) is designed for erasing lines in ink. The *art gum* eraser, made of soft pliable gum, will not mar or scratch surfaces. It is ideally suited for removing pencil or finger marks and smudges.

You can also use a kneaded eraser-the type used by artists. It is a rubber dough, kneadable in your hand, and has the advantage of leaving very little debris on the drawing sheet.

Slide 5 of *Figure 3-7* shows an *electric eraser*. The control switch is directly under the fingertip; the body of the machine fits comfortably in the palm of the hand, and the rotating eraser can be directed as accurately as a pencil point. Refills for either ink or pencil erasing are available.

⚠️ **CAUTION** ⚠️

Do not hold the electric eraser steadily in one spot, or you may wear a hole in, or otherwise damage, the surface of the material you are erasing. When there are many lines close together only one of which needs removing or changing, you can protect the desired lines with an erasing shield, as shown in *Figure 3-8*.

Finely pulverized gum eraser particles are available in squeeze bottles or in *dry clean pads* for keeping a drawing clean while you work on it. If you sprinkle a drawing or tracing occasionally with gum eraser particles, then triangles, T squares, scales, french curves, and other equipment not only tend to stay clean themselves, but tend to clean the drawing or tracing as they move over the surface.

Figure 3-8 – Eraser shield.

Before inking a drawing, you usually prepared it by sprinkling on *pounce* (a very fine bone dust) and then rubbing in the pounce with a felt pad on the container. Pounce helps to prevent a freshly inked line from spreading.

Use a draftsman's *dust brush* for brushing dust and erasure particles off a drawing.

2.5.0 Drafting Tables with Boards

Most EA shops are furnished with standard drafting tables with drafting boards, as shown in *Figure 3-9*. The majority of this furniture is easily adjustable to the users' needs. The table should be high enough for you to work in a standing position without stooping or holding your arms in a raised position. The drawing board has hinged attachments for adjusting the incline; your line of sight should be approximately perpendicular to the drafting surface. Your drafting stool should be high enough in

relation to the table for you to see the whole drafting board but not so high that you are seated uncomfortably.

The drafting boards contained in the draftsman kit are constructed of joined strips of softwood, usually clear white pine or basswood. They are equipped with hinged attachments for securing the board to a table or fabricated base.

If suitable bases are not available, table bases may be constructed at the unit carpenter shop.

You should consider only the left-hand vertical edge as a working edge for the T square if you are right-handed (the right-hand edge if you are left-handed). You should never use the T square with the head set against the upper or lower edge of the board, as the drafting board may not be perfectly square.

The drafting board should be covered. A variety of good drafting board cover materials is available. Available cover materials are cellulose acetate-coated paper, vinyl, and mylar film. Vinyl drafting board covers have the added advantage of being able to close up small holes or cuts, such as those made by drafting compasses or dividers. In general, drafting board covers protect the drafting board surface by preventing the drafting pencil from following the wood grain, by reducing lighting glare, and by providing an excellent drafting surface.

The L-Shaped desk features a drafting table and computer desk combination. The drawing board is adjustable to any angle.

Figure 3-9 - Drafting tables with boards.

Since you will be constantly using your eyes, your working area must be well lighted. Natural light is best, if available and ample; although in the majority of cases acceptable natural light will be the exception rather than the rule. Drafting rooms are usually lighted with overhead fluorescent fixtures.

Ordinarily, these fixtures are inadequate in quality and intensity of light. Adjustable lamps will improve the lighting conditions. The most popular type of adjustable lamp is the floating-arm fluorescent fixture that clamps onto the table. Arrange your lighting to come from the front-left, if you are right-handed; from the front right, if you are left-handed. This minimizes shadows cast by drawing instruments and your hands.

Never place your drafting board so that you will be subject to the glare of direct sunlight. North windows are best for admitting daylight in the Northern Hemisphere. Conservation of vision is of the utmost importance. You must make every possible effort to eliminate eyestrain.

2.6.0 T Squares

The T square gets its name from its shape. It consists of a long, straight strip, called the blade, which is mounted at right angles on a short strip called the head. The head is

mounted under the blade so that it will fit against the edge of the drawing board while the blade rests on the surface. T squares vary in size from 15 to 72 inches in length, with 36 inches the most common.

The T square shown in *Figure 3-10* is typical of the ones used by an EA. The head is made of hardwood, the blade usually of maple with a natural or mahogany finish. The edges of the blade are normally transparent plastic strips glued into grooves on both edges of the blade, as shown in the cross section in *Figure 3-10*. This allows the edge of the T square to ride above the drawing as the blade is moved up or down the board. This arrangement is a great advantage when you are drawing with ink. Since the tip of the ruling pen does not come in contact with the blade, but is below it, ink cannot be drawn under the blade to blot the drawing. The T square is used for drawing horizontal lines only. Always draw lines along the upper edge of the blade. The T square also serves as a base for drawing the vertical and inclined lines of a triangle. Some T squares have adjustable heads to allow angular adjustments of the blade.

Figure 3-10 - Drafting board with T square and drafting paper in place

Handle your T square carefully. If dropped, it may be knocked out of true and become useless. Additionally, to prevent warping, hang the T square by the hole in the end of the blade or lay it on a flat surface so that the blade rests flat. Before beginning a new job, test the top edge of your T square for warp or nicks by drawing a sharp line along the top of the blade.

Turn the T square over and redraw the line with the same edge. If the blade is warped, the lines will not coincide. If the blade swings when the head is held firmly against the edge of the drawing board, the blade may be loose where it is joined to the head, or the edge of the T square head may be warped. You can usually tighten a loose blade by adjusting the screws that connect it to the head, but if it is out of square, warped, or in bad condition, select a new T square.

2.7.0 Parallel Straightedge

Many draftsmen prefer to use a **parallel straightedge** (*Figure. 3-11*) rather than a T square. The primary purpose of the parallel straightedge is the same as the T square. The parallel straightedge is a laminated maple blade with transparent plastic edges similar to those on the T square. The parallel straightedge uses a system of cords and pulleys so that it is supported at both ends by a cord tacked to the drawing board. You can move the straightedge up or down the board with pressure at any point along its length and maintain parallel motion automatically. It comes complete with cord, tacks, cord tension adjuster, and mounting instructions. Some straightedges, like the one shown in *Figure 3-11*, are equipped with a cord lock on one end of the blade. The straightedge is locked into place by turning the cord lock clockwise. This permits use of the straightedge on an inclined board. It also prevents accidental movement when you are inking or using mechanical lettering devices. The advantages of the parallel straightedge become particularly significant when you are working on large drawings. While the T square works well for small work, it becomes unwieldy and inaccurate when you are working on the far right-hand side of large drawings

Figure 3-11 - Parallel straightedge.

2.8.0 Steel Straightedge

When drawing long, straight lines, use a **steel straightedge** (*Figure 3-12*) because its heavy weight helps keep the straightedge exactly in position. The steel straightedge is also excellent for trimming blueprints and cutting heavy illustration board. Steel straightedges are usually made of stainless steel and are available in lengths of 15 inches to 72 inches The one included in the draftsman kit is 42 inches long. Some have a beveled edge.

Figure 3-12 - Steel straightedge.

2.9.0 Triangles

Triangles are used in combination with the T square or straightedge to draw vertical and inclined lines. They are usually made of transparent plastic, which allows you to see your work underneath the triangles. Triangles are referred to by the size of their acute angles. *Figure 3-13* shows two basic drafting triangles: the 45° (each acute angle

measures 45°, and the 30°/60° (one acute angle measures 30°; the other, 60°). The size of a 45° triangle is designated by the length of the sides that form the right angle (the sides are equal). The size of a 30°/60° triangle is designated by the length of the longest side that forms the right angle. Sizes of both types of triangles range from 4 inches through 18 inches in 2-inch increments.

Figure 3-13 - 45° and 30°/60° drafting triangles.

Like all other drafting equipment, triangles must be kept in good condition. If you drop a plastic triangle, you may damage its tip. Also, triangles may warp so that they do not lie flat on the drawing surface, or the edge may deviate from true straightness. To prevent warping or chipping, always lay them flat or hang them up when you are not using them. Since there is seldom enough drawer space available to permit laying triangles flat, develop the habit of hanging them up. If the tips are bent, use a sharp knife to cut off the damaged part. If the triangle is warped, you may be able to bend it back by hand. If this does not straighten it, leave the triangle lying on a flat surface with weights on it or hold the triangle to the opposite curvature with weights. If the triangle becomes permanently warped so that the drawing edges are curved or the angles are no longer true, throw it away and get another. To test the straightness of a triangle, place it against the T square and draw a vertical line, as shown in *Figure 3-14*. Then reverse the triangle and draw another line along the same edge. If the triangle is straight, the two lines will coincide; if they do not, the error is half the resulting space.
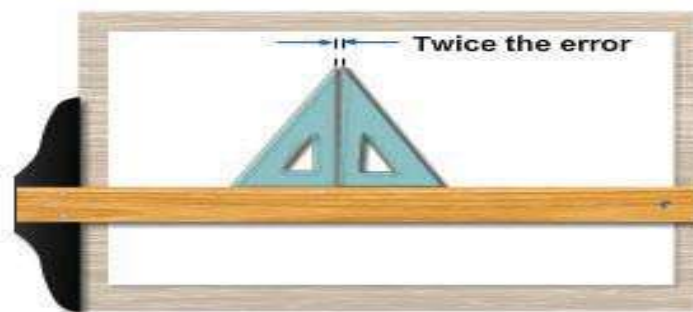
Figure 3-14 - Testing a triangle for straightness.

2.10.0 Protractors

Protractors are used for measuring and laying off angles other than those drawn with the triangle or a combination of triangles. Most of the work you will do with a protractor will involve plotting information obtained from field surveys. Like the triangle, most protractors are made of transparent plastic. They are available in 6-, 8-, and 10-inch sizes and are either circular or semicircular in shape, as shown in *Figure 3-15*.
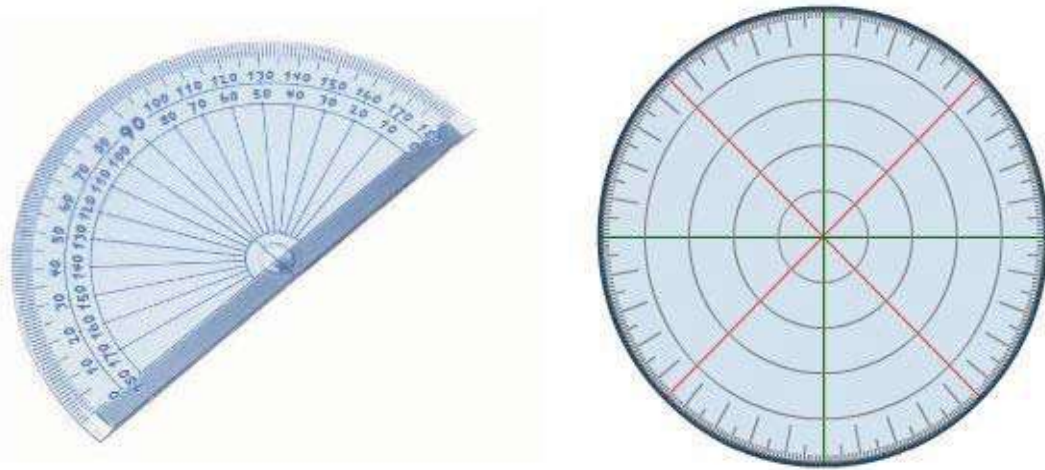
Figure 3-15 - Types of protractors.

Protractors EAs use are usually graduated in increments of 1/2°. By careful estimation, you may obtain angles of 1/4°. Protractor numbering arrangement varies. Semicircular protractors are generally labeled from 0° to 180° in both directions. Circular protractors may be labeled from 0° to 360° (both clockwise and counterclockwise), or they may be labeled from 0° to 90° in four quadrants. Stow and care for protractors in the same manner as triangles.

2.11.0 Adjustable Triangles

The *adjustable triangle*, shown in *Figure 3-16*, combines the functions of the triangle and the protractor. When it is used as a right triangle, you can set and lock the hypotenuse at any desired angle to one of the bases. The transparent protractor portion is equivalent to a protractor graduated in 1/2° increments. The upper row of numbers indicates angles from 0° to 45° to the longer base; the lower row indicates angles from 45° to 90° to the shorter base. By holding either base against a T square or straightedge, you can measure or draw any angle between 0° and 90°.

The adjustable triangle is especially helpful in drawing
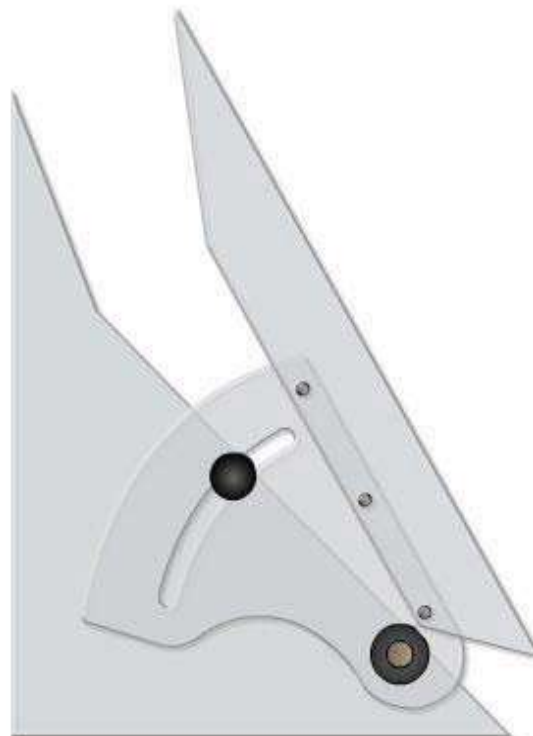
Figure 3-16 - Adjustable triangle.

building roof pitches. It also allows you to transfer parallel inclined lines by sliding the base along the T square or straightedge.

2.12.0 French Curves

Use irregular curves (called **french curves**) for drawing smooth curved lines other than arcs or circles, lines such as ellipses, parabolas, and spirals. Transparent plastic french curves come in a variety of shapes and sizes.

Figure 3-17 shows an assortment of french curves. In such an assortment, you can find edge segments you can fit to any curved line you need to draw.

Stow and care for french curves in the same manner as triangles.
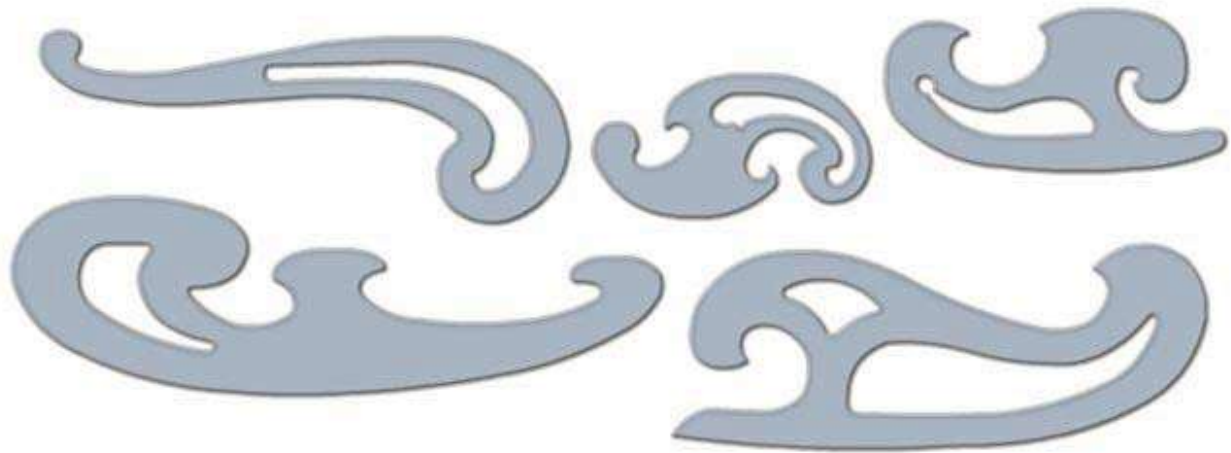
Figure 3-17 - French curves.

2.13.0 Drawing Instrument Sets

So far we have discussed only those instruments and materials you will need for drawing straight lines (with the exception of french curves). Many drawings you prepare will require circles and circular arcs. Use instruments contained in a drawing instrument set for this purpose. Many types of drawing instrument sets are available; however, it is sometimes difficult to judge the quality of drafting instruments by appearance alone. Often their characteristics become evident only after use.

The drawing instrument set shown in *Figure 3-18* is typical of sets in the standard draftsman kit. The following sections describe these instruments as well as some special-purpose instruments not found in the set. These special-purpose instruments may be purchased separately or found in other instrument sets.
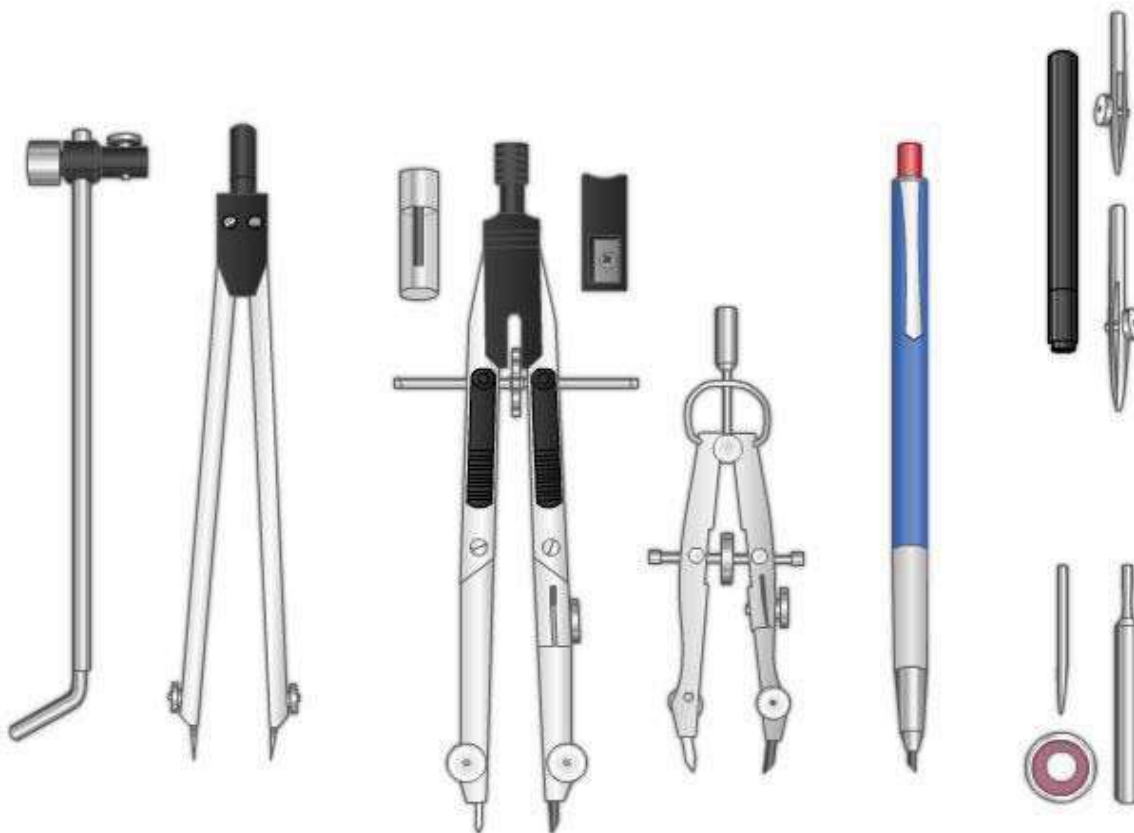
Figure 3-18 - Drawing instrument set.

2.13.1 Compasses

Circles and circular curves of relatively short radius are drawn with compasses. The large pivot joint compass is satisfactory for drawing circles of 1 inch to about 12 inch diameter without an extension bar. The pivot joint provides enough friction to hold the legs of the compass in a set position. One of the legs has a setscrew for mounting a pen or pencil attachment on the compass. You can insert an extension bar to increase the radius of the circle drawn. The other type of compass in the drawing instrument set is the bow compass. Many experienced draftsmen prefer the bow compass over the pivot joint compass. The bow compass is much sturdier and is capable of taking the heavy pressure necessary to produce opaque pencil lines without losing the radius setting.

There are two types of bow compasses. The location of the adjustment screw determines the type. The bow pen/pencil in *Figure 3-18* is the center adjustment type, whereas the bow drop pen in *Figure 3-19* is the side adjustment type. Each type comes in two sizes: large and small. Large bow compasses are usually of the center adjustment type, although the side adjustment type is available. The large bow compasses are usually about 6 inches long, the small compasses approximately 4 inches long. Extension bars are available for large bow compasses. Bow compasses are available as separate instruments, or as combination instruments with pen and pencil attachments.

Most compasses have interchangeable needlepoints. Use the conical or plain needlepoint when you use the compass as dividers. Use the shoulder-end needlepoint with pen or pencil attachments. When you draw many circles using the same center, the compass needle may bore an oversized hole in the drawing. To prevent these holes, use a device called a horn center or center disk. Place this disk over the center point. Then place the point of the compass needle into the hole in its center.

Figure 3-19 – Bow instruments: bow pen/pencil; bow divider, bow drop pen drawing instrument set

2.13.2 Dividers

Dividers are similar to compasses, except that both legs have needlepoints. The instrument set (*Figure 3-18*) contains two different types and sizes of dividers: large 6-inch hairspring dividers and small center adjustment bow dividers (*Figure 3-19*). You can also use the large pivot joint compass *(Figure 3-19)* as dividers. As with compasses, dividers are available in large and small sizes, and in pivot joint, center adjustment bow, and side adjustment bow types. *Figure 3-20* shows a small side adjustment bow divider. Use pivot joint dividers for measurements of approximately 1 inch or more. For measurements of less than 1 inch, use bow dividers. You can also use dividers to transfer measurements, step off a series of equal distances, and divide lines into a number of equal parts.

Figure 3-20 - Bow divider.

2.13.3 Drop Bow Pen

The ***drop bow pen*** (*Figure 3-21*) is not one of the standard instruments, but it is essential for some jobs. Use it to ink small circles with diameters of less than 1/4 inch. As the name indicates, the pen assembly is free to move up and down and to rotate around the main shaft. When using this instrument, hold the pen in the raised position, adjust the setscrew to give the desired radius, and then gently lower the pen to the paper surface and draw the circle by rotating the pen around the shaft.
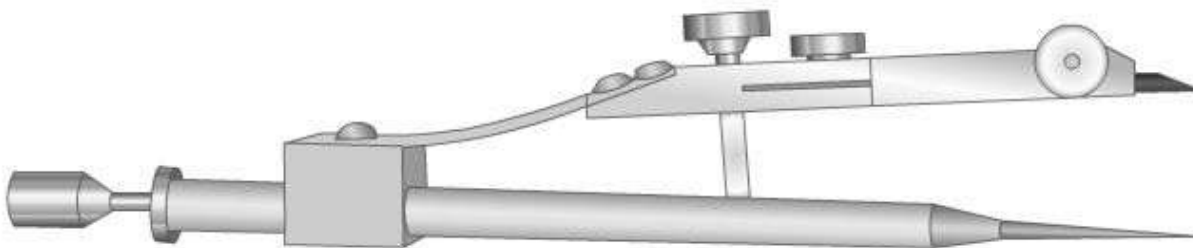
Figure 3-21 – Drop bow pen

2.13.4 Maintenance of Compasses and Dividers

Figure 3-22 shows the three shapes in which compasses and dividers are made: round, flat, and bevel. Figure 3-23 shows two most common types of pivot joints on compasses and dividers. When you select compasses and dividers, test them for alignment by bending the joints and bringing the points together. New instruments are factory adjusted for correct friction setting. They rarely require adjustment. Use a small jeweler's screwdriver or the screwdriver found in some instrument sets for adjusting most pivot joint instruments. Skilled instrument repairmen should adjust instruments that require a special tool.

Adjust pivot joint compasses and dividers so that they can be set without undue friction. They should not be so rigid that their manipulation is difficult, nor so loose that they will not retain their setting.

Figure 3-22 – Shapes of compasses and dividers.
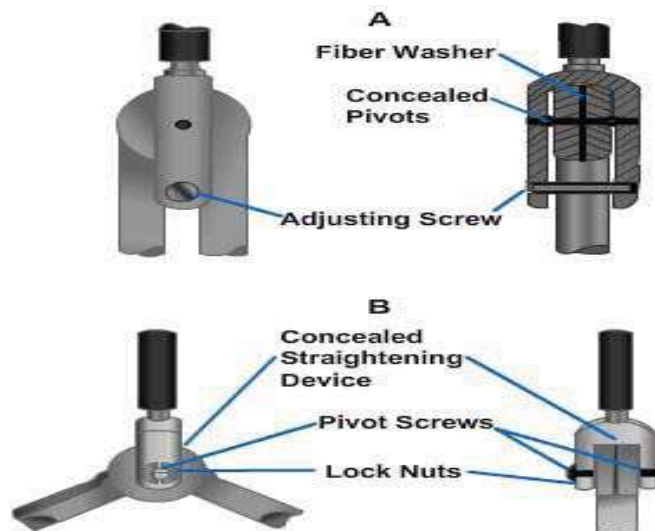
Figure 3-23 - Sections of pivot joints.

Divider points should be straight and free from burrs. When the dividers are not in use, protect the points by sticking them into a small piece of soft rubber eraser or cork. When points become dull or minutely uneven in length, make them even by holding the dividers vertically, placing the legs together, and grinding them lightly back and forth against a whetstone. (See *Figure 3-24*, view A.) Then hold the dividers horizontally and sharpen each point by whetting the outside of it back and forth on the stone, while rolling it from side to side with your fingers (*Figure 3-24*, view B). The inside of the leg should remain flat and not be ground on the stone. Do not grind the outside of the point so that a flat surface results. In shaping the point, be careful to avoid shortening the leg.

Keep needles on compasses and dividers sharpened to a fine taper. When pushed into the drawing, they should leave a small, round hole in the paper no larger than a pinhole. Since the same center is often used for both the compasses and dividers, it is best that

needles on both be the same size. If the compass needle is noticeably larger, grind it until it is the correct size.
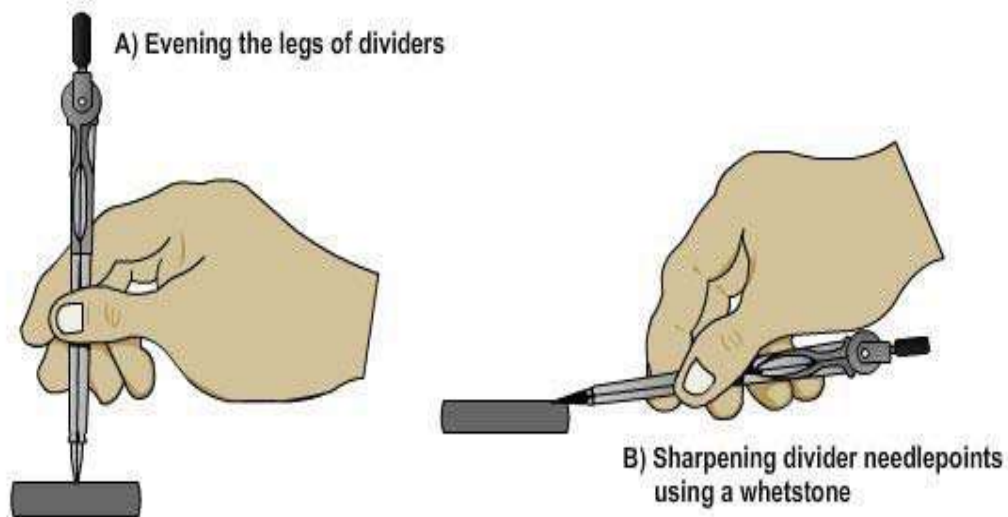
Figure 3-24 – Divider maintenance (A) Evening the legs of dividers; (B) Sharpening divider needlepoints.

To make a compass needle smaller, wet one side of the whetstone and place the needle with its shoulder against this edge. Then grind it against the whetstone, twirling it between your thumb and forefinger (*Figure 3-25*). Test it for size by inserting it in a hole made by another needle of the correct size. When pushed as far as the shoulder, it should not enlarge the hole. The screw threads on bow instruments are delicate. Because of this, take care never to force the adjusting nut. Threads must be kept free from rust or dirt. If possible, keep drawing instruments in a case, since the case protects them from damage by falls or unnecessary pressures. Also, the lining of the case is usually treated with a chemical that helps prevent the instruments from tarnishing or corroding.
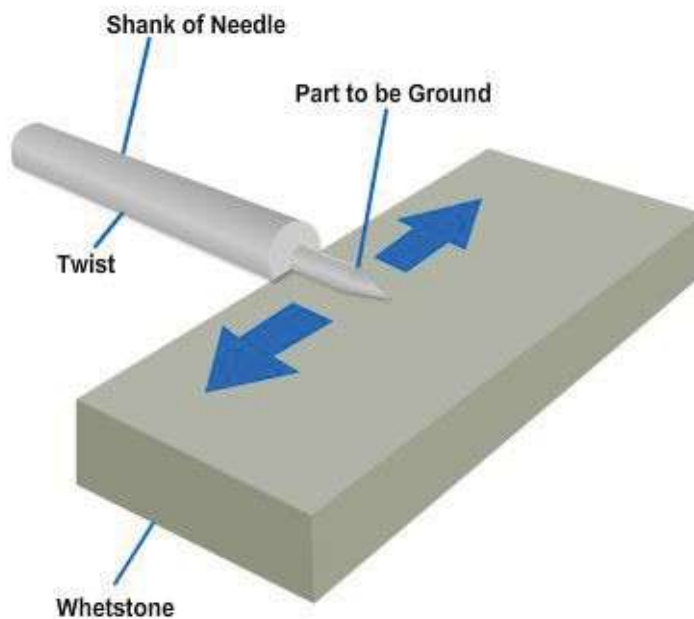
Figure 3-25 - Shaping a compass needle.

To protect instruments from rusting when they are not in use, clean them frequently with a soft cloth and apply a light film of oil to their surface with a rag. Do not oil joints on compasses and dividers. When the surface finish of instruments becomes worn or scarred, it is subject to corrosion; therefore, never use a knife edge or an abrasive to clean drafting instruments.

2.13.5 Beam Compass

The ***beam compass*** (*Figure 3-26*) is used for drawing circles with radii larger than can be set on a pivot joint or bow compass. Both the needlepoint attachment and the pen or pencil attachment on a beam compass are slide-mounted on a metal bar called a beam. You can lock the slide-mounted attachments in any desired position on the beam. Thus, a beam compass can draw circles of any radius up to the length of the beam. With one or more beam extensions, the length of the radius of a beam compass ranges from about 18 inches to 70 inches.
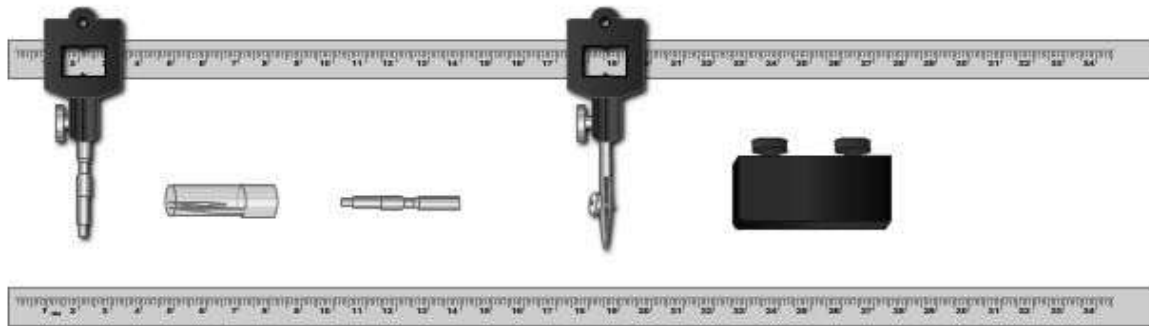
Figure 3-26 - Beam Compass.

2.14.0 Proportional Dividers

Proportional Dividers (*Figure 3-27*) are used for transferring measurements from one scale to another. This capability is necessary to make drawings to a larger or smaller scale. Proportional dividers can divide lines or circles into equal parts.

Proportional dividers consist of two legs of equal length, pointed at each end, and held together by a movable pivot. By varying the position of the pivot, you can adjust the lengths of the legs on opposite sides of the pivot so that the ratio between them is equal to the ratio between two scales. Therefore, a distance spanned by the points of one set of legs has the same relation to the distance spanned by the points of the other set as one scale has to the other. On the proportional dividers, a thumb nut moves the pivot in a rack-and-gear arrangement. When you reach the desired setting, a thumb-nut clamp on the opposite side of the instrument locks the pivot in place. A scale and vernier on one leg facilitate accurate setting.

Figure 3-27 - Proportional dividers.

On less expensive models, the movable pivot is not on a rack and gear, and there is no vernier. Set the dividers by reference to the table of settings that comes with each pair;

they will accommodate varying ranges of scales from 1:1 to 1:10. However, do not depend entirely on the table of settings. You can check the adjustment by drawing lines representing the desired proportionate lengths, and then applying the points of the instrument to each of them in turn until, by trial and error, you reach the correct adjustment.

To divide a line into equal parts, set the divider to a ratio of 1 to the number of parts desired on the scale marked Lines. For instance, to divide a line into three parts, set the scale at 3. Measure off the length with points of the longer end. The span of the points at the opposite ends will be equal to one-third the measured length. To use proportional dividers to transfer measurements from feet to meters, draw a line 1 unit long and another line 3.28 units long and set the dividers by trial and error accordingly.

Some proportional dividers have an extra scale for use in getting circular proportions. The scale marked Circle indicates the setting for dividing the circumference into equal parts. The points of the dividers are of hardened steel, and if you handle them carefully, these points will retain their sharpness during long use. If they are damaged, you may sharpen them and the table of settings will still be usable, but the scale on the instrument will no longer be accurate.

2.15.0 Scales

In one sense, the term scale means the succession of graduations on any graduated standard of linear measurement, such as the graduations on a steel tape or a thermometer. In another sense, when we refer to the "scale of a drawing," the term means the ratio between the dimensions of the graphic representation of an object and the corresponding dimensions of the object itself.

Figure 3-28 – Types of scales in cross section.

Suppose, for example, that the top of a rectangular box measures 6 inches by 12 inches, if you draw a 6-inch by 12-inch rectangle on the paper, the dimensions of the drawing would be the same as those of the object. The drawing would, therefore, be a full-scale drawing. This scale could be expressed fractionally as 1/1, or it could be given as 1 inch = 1 inch.

Suppose that instead of making a full-scale drawing, you decided to make a half-scale drawing. You should then draw a 3-inch by 6-inch rectangle on the paper. This scale could be expressed fractionally as 1/2, or it could be given as 1 inch = 2 inches, or as 6 inches = 1 foot. In this case, you made the drawing on a smaller scale than the scale of the original object, the scale of an original object being always 1/1, or unity. The relative size of a scale is indicated by the fractional representation of the scale. A scale whose fractional representation equals less than unity is a less-than-full scale. One whose fractional representation is greater than unity (such as a scale of 200/1) is a larger-than-full scale. A scale of 1/10,000 is, of course, smaller than a scale of 1/100.

A scale expressed as an equation can always be expressed as a fraction. For example, the scale of 1 inch = 100 feet, expressed fractionally, comes to 1 over (100 x 12), or 1/1,200. Obviously, any object larger than the drawing paper on which it is to be represented must be "scaled down" (that is, reduced to less than- full scale) for graphic representation.

Conversely, it is often desirable to represent a very small object on a scale larger than full scale for clarity and to show small details. Because the drawings an EA prepares frequently require scaling down, the following discussion refers mostly to that procedure. However, scaling up rather than down simply means selecting a larger-than-full scale rather than a smaller-than-full scale for your drawing. You could, if necessary, determine the dimensions of your drawing by arithmetical calculation; for example, on a half-scale drawing, you divide each of the actual dimensions of the object by 2. However, this might be a time consuming process if you were drawing a map of a certain area to a scale of 1 inch = 1,000 miles, or 1/6,335,000 feet. Consequently, you will usually scale a drawing up or down by the use of one or another of a variety of scales. This sense of the term scales refers to a graduated, ruler-like instrument on which you can determine scale dimensions for a drawing by inspection.

Scales vary in types of material, shapes, style of division, and scale graduations. Good quality scales are made of high-grade boxwood or plastic, while inexpensive scales are sometimes made of yellow hardwood. The boxwood scales have white plastic scale faces permanently bonded to the boxwood. The graduation lines on the boxwood scales are cut by a highly accurate machine. Plastic scales, less expensive than boxwood scales, have clear graduations and are reasonably accurate.

Scales are generally available in four different shapes, as shown in *Figure 3-28*. The numbers in the figure indicate the location of the scale face. The triangular scale provides six scale faces on one rule. The two-bevel flat scale provides two scale faces on one side of the rule only. The opposite-bevel flat scale provides two scale faces, one on each side of the rule. And the four-bevel flat scale provides four scale faces, two on each side of the rule. The most common types of scales are the architect's, the engineer's, the mechanical engineer's, and the metric. All of these scales are found in the EA's draftsman kit with the exception of the mechanical engineer's scale, which is primarily used by machine draftsmen.

To gain a better understanding of the architect and engineer's scale, both of which the following sections will describe, having the actual scales at hand as you study may be helpful.

2.15.1 Architect's Scale

Architect's scales are usually triangular and are used wherever dimensions are measured in feet and inches. Major divisions on the scale represent feet; those divisions are subdivided into 12ths or 16ths, depending on the individual scale.

Figure 3-29 shows the triangular architect's scale and segments of each of the eleven scales found on this particular type of scale. Notice that all scales except the 16th scale are actually two scales read either from left to right or right to left. When reading a scale numbered from left to right, notice that the numerals are closer to the outside edge. On scales numbered from right to left, notice that the numerals are closer to the inside edge.

Architect's scales are "open" divided (only the main divisions are marked throughout the length), with the only subdivided interval an extra interval below the 0-foot mark. These extra intervals are divided into 12ths. To make a scale measurement in feet and inches,

lay off the number of feet on the main scale and add the inches on the subdivided extra interval. However, notice that the 16th scale is fully divided with its divisions divided into 16ths.

Now let us measure off a distance of 1 foot 3 inches to see how to read each scale and how the scales compare to one another. (Refer to *Figure 3-29.*) Since the graduations on the 16th scale are subdivided into 16ths, we will have to figure out that 3 inches actually is 3/12 or 1/4 of a foot. Changing this to 16ths, we now see we must measure off 4/16ths to equal the 3-inch measurement. Note carefully the value of the graduations on the extra interval, which varies with different scales. On the 3 inches = 1 foot scale, for example, the space between adjacent graduations represents one-eighth inch. On the 3/32 inches = 1 foot scale, however, each space between adjacent graduations represents 2 inches

The scale 3/32 inches = 1 foot, expressed fractionally, comes to 3/32 = 12, or 1/128. This is the smallest scale provided on an architect's scale. The scales on the architect's scale, with their fractional equivalents, are as follows:

3 inches = 1 foot	% scale
1 Y inches = 1 foot	1/8 scale
1 inch = 1 foot	1/12 scale
% inch = 1 foot	1/16 scale
Y inch = 1 foot	1/24 scale
3/8 inch = 1 foot	1/32 scale
% inch = 1 foot	1/48 scale
1/16 inch = 1 foot	1/64 scale
1/8 inch = 1 foot	1/96 scale
3/32 inch = 1 foot	1/128 scale
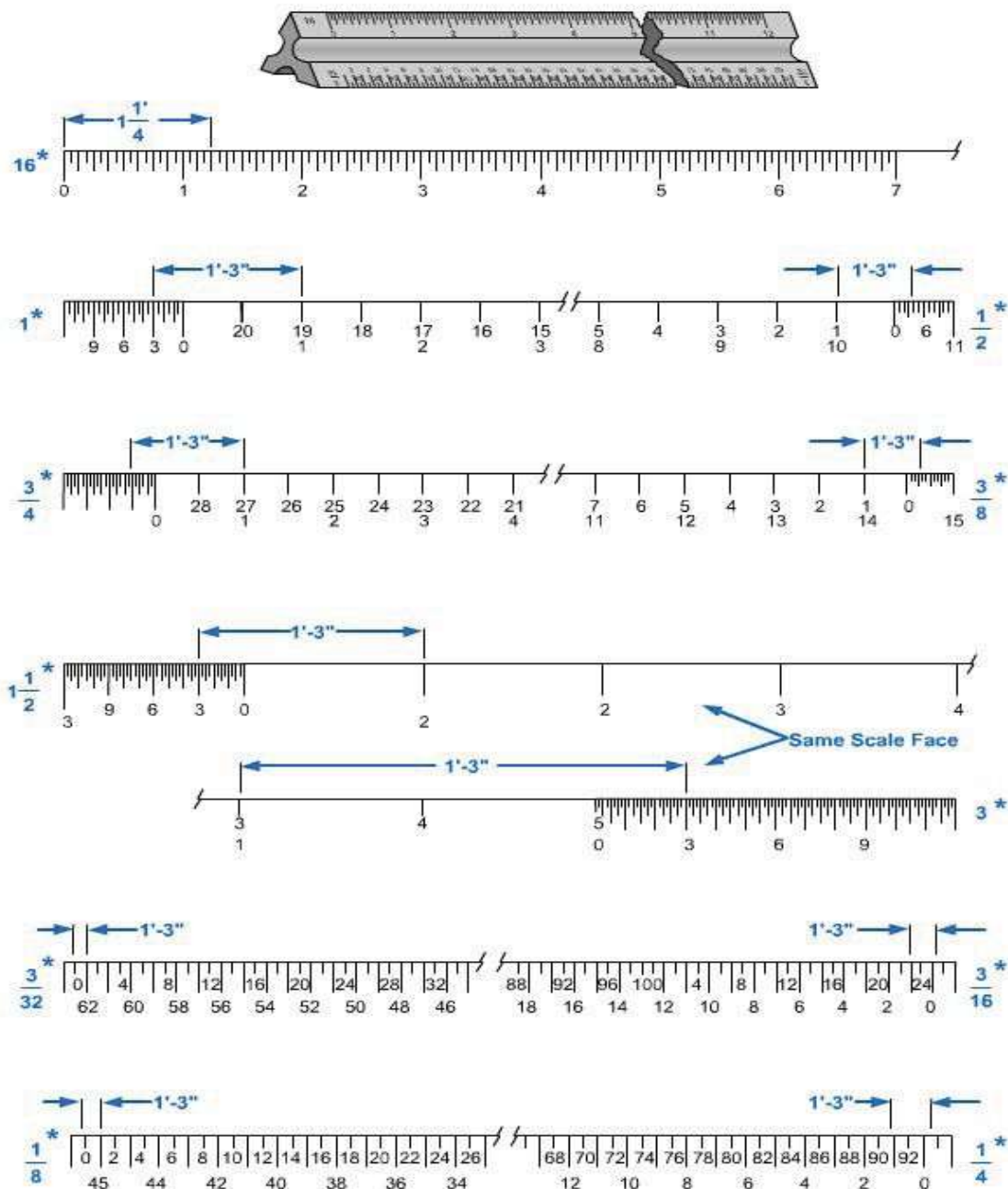
Figure 3-29 - Architect's scale.

Note:
16 scale is subdivided into sixteenths.
All others are subdivided into twelfths.
* scale designation numbers.

2.15.2 Engineer's Scale

The chain or civil engineer's, scale, commonly called the ***engineer's scale***, is usually a triangular scale, containing six fully divided scales subdivided decimally, each major interval on a scale being subdivided into 10ths. *Figure 3-30* shows the engineer's scale and segments of each of the six scales. Each of the six scales is designated by a

number representing the number of graduations that particular scale has to the linear inch. On the 10 scale, for example, there are 10 graduations to the inch; on the 50 scale, there are 50. You can see that the 50 scale has 50 graduations in the same space occupied by 10 on the 10 scale. This space is 1 linear inch.

To determine the actual number of graduations represented by a numeral on the engineer's scale, multiply the numeral by 10. On the 50 scale, for instance, the numeral 2 indicates 2 x 10, or 20 graduations from the 0. On the 10 scale, the numeral 11 indicates 11 x 10, or 110 graduations from the 0. Note that the 10 scale is numbered every major graduation, while the 50 scale is numbered every other graduation. Other scales on the engineer's scale are the 20, 30, 40, and 60.

Because it is decimally divided, the engineer's scale can be used to scale dimensions down to any scale in which the first figure in the ratio is 1 inch and the other is 10 or a multiple of 10.

Suppose, for example, that you wanted to scale a dimension of 150 mi down to a scale of 1 inch = 60 miles. You would use the 60 scale, allowing the interval between adjacent graduations to represent 1 mile. To measure off 150 miles to scale on the 60 scale, you would measure off 2.5 inches, which falls on the 15th major graduation.

Suppose now that you want to scale a dimension of 6,500 feet down to a scale of 1 inch = 1,000 feet. The second figure in the ratio is a multiple of 10 times a multiple of 10. You would therefore use the 10 scale, allowing the interval between adjacent graduations on the scale to represent 100 feet, in which case the interval between adjacent numerals on the scale would indicate 1,000 feet. To measure off 6,500 feet, you would simply lay off from 0 to 6.5 on the scale.

To use the engineer's scale for scaling to scales expressed fractionally, you must be able to determine the fractional equivalent of each of the scales. For any scale, this equivalent is simply 1 over the total number of graduations on the scale, or 1 over the product of the scale number times 12, which is the same thing. Applying this rule, the fractional expressions of each of the scales is as follows:

10 scale = 1/120

20 scale = 1/240

30 scale = 1/360

40 scale = 1/480

50 scale = 1/600

60 scale = 1/720

Suppose you want to scale 50 feet down to a scale of 1/120. The 10 scale gives you this scale; therefore, use the 10 scale, allowing the space between graduations to represent 1 foot, and measuring off 5 (for 50 feet). The line on your paper would be 5 inches long, representing a line on the object itself that is 120 inches x 5 inches, or 600 inches, or 50 feet long.

Similarly, if you want to scale 50 feet down to a scale of 1/600, use the 50 scale and measure off 5 for 50 feet. In this case, the line on your paper would be 1 inch long, representing a line on the object itself that is 1 x 600, or 600 inches, or 50 ft long.

When the drawing does not need to be made to a specified scale-that is, when the dimensions of lines on the drawing are not required to bear a specified ratio to the dimensions of lines on the object itself-use the most convenient scale on the engineer's scale.

Suppose, for example, that you want to draw the outline of a 360-foot by 800-foot rectangular field on an 8-inch, by 10 1/2-inch sheet of paper with no specific scale prescribed. All you want to do is reduce the representation of the object to one that will fit the dimensions of the paper. You could use the 10 scale, allowing the interval between adjacent graduations to represent 10 feet. In this case, the numerals on the scale, instead of representing 10, 20, and so on, will represent 100, 200, and so on. To measure off 360 feet to scale, measure from 0 to the 6th graduation beyond the numeral 3. For 800 feet, measure from 0 to the numeral 8. Because you allowed the interval between adjacent graduations to represent 10 feet, and because the 10 scale has 10 graduations to the inch, the scale of your drawing would be 1 inch = 100 feet, or 1/1,200.

2000.0 MI (Scale: 1" = 1000.0 MI)
(Scale: 1" = 1 inch)
1.0"
10*

2000.0 MI (Scale: 1" = 2000.0 MI)
20*

5 MI (Scale: 1" = 3 MI)
30*

5 MI (Scale: 1" = 4 MI)
40*

120 MI (Scale: 1" = 50 MI)
50*

120 MI (Scale: 1" = 60 MI)
60*
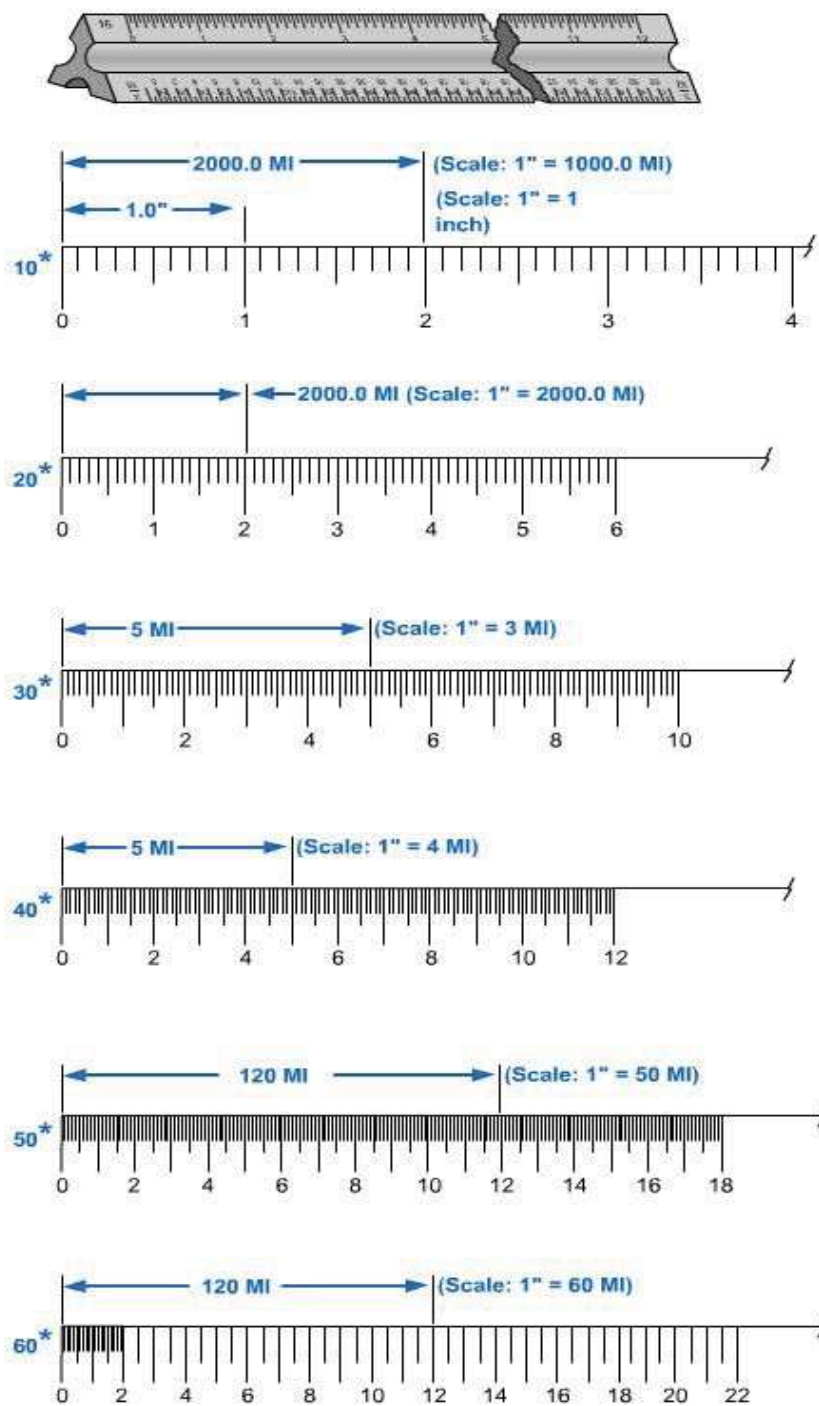
Note:
   Each scale is a multiple of ten.
   * scale designation numbers.

Figure 3-30 - Engineer's scale.

2.15.3 Metric Scale

Use the *metric scale* in place of the architect's and engineer's scale when measurements and dimensions are in meters and centimeters. Metric scales are available in flat and triangular shapes. The flat 30-cm metric scale is shown in *Figure 3-31*. The top scale is calibrated in millimeters and the bottom scale in half millimeters.

Figure 3-31 - Metric scale.

The triangular metric scale has six fully divided scales, which are 1:20, 1:33 1/3, 1:40, 1:50, 1:80, and 1:100. When using scales on a drawing, do not confuse the engineer's scale with the metric scale. They are very similar in appearance. Whenever conversions are made between the metric and English system, remember that 2.54 centimeters equals 1 inch.

2.15.4 Triangular Scale Clip

For use with a triangular scale, a scale clip or scale guard, such as the one shown in *Figure 3-32*, is very helpful. The clip makes it easy for you to identify what scale you are using. Large spring type paper clips will serve the same purpose when scale clips are not available.

2.16.0 Map Measures and Scale Indicators

Map measures are precision instruments for measuring the lengths of roads, pipelines, and other irregular outlines on maps and drawings. Measure distances by first setting the instrument to zero, then tracing the line you are measuring with the small, projecting tracing wheel, like that on the map measures shown in *Figure 3-33*.

Figure 3-32 – Triangular scale clip.

In using map measures, do not depend entirely on the indicated numerical scale. Always check it against the graphical scale on the map or drawing. Verify if, for example, 1 inch traversed on the graphical scale really registers 1 inch on the dial; if not, make the proper correction to the distance measured. Actually, a map measure is just another odometer. Odometers are used to measure actual distances, while the map measures are used to measure scaled distances.

There are many ways of indicating the scale on a drawing. Among these are the fractional method, the equation method, and the graphic method.

Figure 3-33 - Types of map measures.

In the fractional method, the scale is indicated as a fraction or a ratio. A full-size scale is indicated as 1/1; enlarged scale, as 10/1, 4/1, 2/1, etc.; and reduced scale, as 1/2, 1/4, 1/10, etc. Notice that the drawing unit is always given as the numerator of the fraction and the object unit as the denominator. On maps, the reduced scale fraction may be very large (for example, 1/50,000), compared to the typical scales on machine drawings. On maps, the scale is frequently expressed as a ratio, such as 1:50,000. In the equation method, a certain number of inches on the drawing is set equal to a certain length on the object. Symbols are used for feet (') and inches ("). On architectural drawings, a certain number of inches on the drawing is set to equal to 1 foot on the object. A full-size scale is entered as 12" = 1' - 0"; an enlarged scale, as 24" = 1'-0"; and a reduced scale, as 1/8" = 1' - 0". On civil engineering drawings, 1 inch on the drawing is set to equal to a certain measurement on the object: 1" = 5', 1" = 100', 1" = 1 mile.

In the graphic method, an actual measuring scale is shown on the drawing. Typical graphic scales are shown in *Figure 3-34*. Note that in each case, the primary scale lies to the right of the 0; a subdivided primary scale unit lies to the left of the 0.
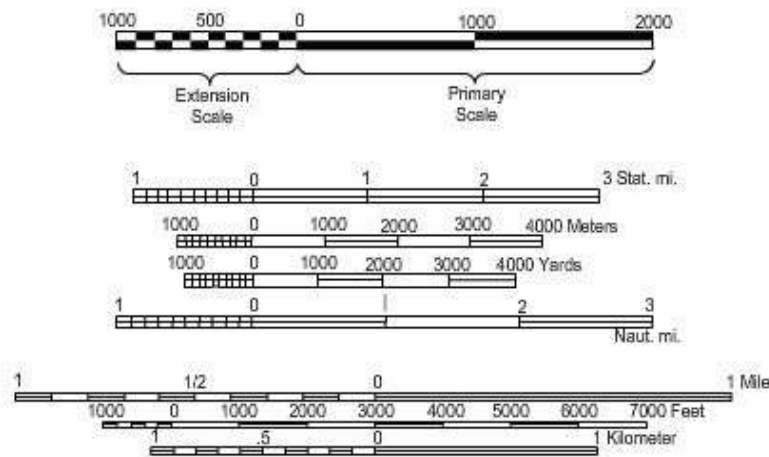
Figure 3-34 - Typical graphic scales.

2.17.0 Drafting Templates

Drafting templates are timesaving devices used for drawing various shapes and standard symbols. They are especially useful when shapes and symbols must appear on the drawing a number of times. Templates are usually made of transparent green or

clear plastic. They are available in a wide variety of shapes, including circles, ellipses, hexagons, triangles, rectangles, and arcs. Special templates are available for symbols used on architectural drawings, mechanical drawings, and maps. Templates for almost every purpose are available from the well-known drafting supply companies. *Figure 3-35* shows only a few of the more common types of drafting templates.

Figure 3-35 - Drafting Templates.

2.18.0 Freehand Letter Pens

Frequently, you will prepare inked drawings, maps, or charts that require freehand lines and lettering. Many types of freehand pens are available. But here we will be concerned only with those pens the EA uses. Included in the draftsman kit is a reservoir pen set, which you may use either with a penholder, as a freehand pen, or fitted into a mechanical lettering device for template lettering.

Use the technical fountain pen (sometimes called a Rapidograph pen or reservoir pen) for ruling straight lines of uniform width with the aid of a T square, triangle, or other straightedge. You may also use it for freehand lettering and drawing and with various drawing and lettering templates. One of the best features of the technical fountain pen is its ink reservoir. The reservoir, depending on the style of pen, is either built into the barrel of the pen or is a translucent plastic ink cartridge

Figure 3-36 - Technical fountain pens.

attached to the body of the pen. The large ink capacity of the reservoir saves time because you do not have to replenish the ink supply constantly. Therefore, many EAs prefer the technical fountain pen to the ruling pen.

A typical technical fountain pen is shown in *Figure 3-36*. Various manufacturers offer variations in pen style and line size. Some pens are labeled by the metric system

according to the line weight they make. Other pens are labeled with a code that indicates line width measured in inches. For instance, a No. 2 pen draws a line .026 inches in width. Most technical fountain pens are color-coded for easy identification of pen size. These pens are available either as individual fountain pen units, resembling a typical fountain pen, or as a set, having a common handle and interchangeable pen units. The pen shown in Figure 3-36 is a part of a set of technical fountain pens.

Some reservoir pens for lettering are made so the point section will fit in a **Leroy scriber**, a system using templates and special scribing tools to create machine-perfect lettering. These pens may also be used for any work that a regular technical fountain pen is used for.

2.18.1 Using the Technical Fountain Pen

You must hold the technical fountain pen so that it is perpendicular to the drawing surface at all times. If you do not hold the pen in the correct manner, the point will bevel or wear unevenly and eventually form an elliptical point. With the point in this condition, the pen will produce lines of inconsistent widths.

To fill the reservoir of a fountain pen, use the knob on the barrel opposite the point. When you turn the knob counterclockwise, a plunger is forced down into the barrel forcing out any ink remaining in the reservoir. Place the point end of the pen into the ink and turn the knob clockwise to pull the plunger up. As the knob pulls the plunger up, the plunger draws ink through the point, filling the reservoir.

To fill the ink cartridge type of pen shown in *Figure 3-37*, remove the cartridge from the body and insert the ink bottle dropper all the way into the reservoir cartridge. Place the dropper in contact with the bottom of the reservoir cartridge to prevent the ink from forming air bubbles. Fill the cartridge to approximately three-eighths of an inch from the top, then replace the cartridge and clamp ring.

Figure 3-37 - Technical fountain pen.

2.18.2 Care and Cleaning of the Technical Fountain Pen

The feed tube of the pen point is threaded (*Figure 3-37*). Along this threaded portion is an inclined channel that allows air to enter the ink reservoir. This channel must be free of dried ink or foreign particles to ensure correct ink flow. When cleaning the pen, scrub the threads and channel with a brush, such as a toothbrush, wetted with a cleaning solution of soap and water. A cleaning pin (a tiny weighted needle) is made to fit into the feed tube and point (*Figure 3-37*). This cleaning pin assures a clear passage of ink from

the reservoir to the point. Usually, a light shake of the pen will set the cleaning pin in motion, removing any particles that settle in the tube when the pen is not in use. (Do not shake the pen over your drawing board.)

If you do not use the pen frequently, the ink will dry, clogging the point and feed tube. When the pen becomes clogged, soak it in pen cleaner or ammonia water until it unscrews with little or no resistance. A better practice is to clean the pen before you put it away if you know in advance that you will not be using it for several days.

You must handle the cleaning pin with care, especially the smaller sizes. A bent or damaged cleaning pin will never fit properly into the feed tube and point.

2.19.0 Drawing Ink

A draftsman's drawing ink is commonly called *india ink* (*Figure 3-38*). Drawing ink consists of a pigment (usually powdered carbon) suspended in an ammonia-water solution. Ink thickened by age or evaporation maybe thinned slightly by adding a few drops of a solution of four parts aqua ammonia to one part distilled water. After the ink dries on paper, it is waterproof. Drawing ink is available in many different colors, but for construction and engineering drawings, black ink is preferred for reproduction and clarity. Small 3/4- or 1-oz bottles of black, red, and green ink are found in the standard draftsman kit. Larger bottles are available for refilling the small bottles. The stopper for a small ink bottle is equipped with either a squeeze dropper or a curved pipette for filling pens.

Figure 3-38 – Drawing Ink.

When you are working with ink, always keep the stopper on the ink bottle when you are not filling the pen, and keep the bottle far away from your drawing. Nothing is more frustrating for a draftsman than spilling a bottle of ink on a finished drawing. Special bottle holders are available to minimize this hazard. If you do not have a bottle holder, it would be to your advantage to devise your own.

2.20.0 Other Tools
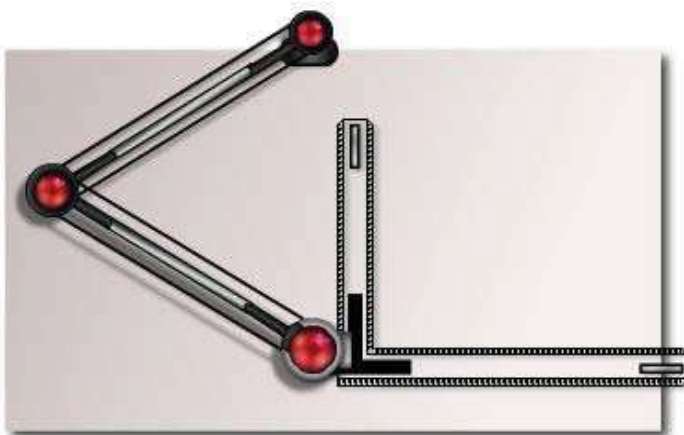
Figure 3-39 - Drafting machine.

Many tools other than the ones already presented in this chapter are currently used to create technical drawings. A variety of drafting machines (not in the draftsman kit) are available at several shore-based support activities.

Depending on the requirements of a particular activity, an EA assigned to staff or independent duty may also be exposed to a more advanced and sophisticated computer-assisted drafting method. The standard drafting machine combines the functions of a parallel ruler, protractor, scales, and triangles. Various drafting operations requiring straight and parallel lines may be performed

advantageously with a drafting machine.

The majority of drafting machines are constructed so that you can move the protractor head over the surface of a drafting table without change in orientation by means of a parallel motion linkage consisting of two sets of double bars. *Figure 3-39* shows a rigid metal connecting link or arms, commonly called pin-joint linkage.

Another type of drafting machine has two steel bands enclosed in tubes working against one another (Figure 3-39) (although this type may also have the bands without the tubes). If these bands become loose through wear, their tension can be increased. This type of drafting machine is superior to that with pin-point linkage because there is less lost motion.

To learn more about other tools and their uses, become loose through wear or expansion, the refer to Chapter 1 of the field manual FM 5-553, tension can be increased on them. This type of General Drafting, published by the Headquarters, drafting machine is superior to that with pin-point Department of the Army, and other civilian linkage because there is less lost motion publications.

Summary

As an Engineering Aid, you will use a variety of equipment in your day to day duties. Knowing how to use and care for the equipment available to you will contribute to a project's and a unit's success.

Review Questions (Select the Correct Response)

1. _____ drafting is used to show the type and proper placement of structural members in a building.

   A. Illustrative
   B. Technical
   C. Graphical
   D. Freehand

2. In the Seabees, _____ drafting specifically refers to the arrangements of machinery, utility systems, heating, air conditioning, and ventilating systems.

   A. Illustrative
   B. Technical
   C. Freehand
   D. Mechanical

3. Types of administrative drafting you may be called to perform include creating _____.

   A. Technical and display charts, safety and embarkation signs, project completions, and unit readiness graphics
   B. Architectural, structural, electrical, and mechanical drawings
   C. Topographical maps, plotted profiles, and cross sections
   D. Portraits and landscapes

4. Charts and graphs that emphasize numerical values are called _____, while those that emphasize relations are called _____.

   A. Mechanical, freehand
   B. Qualitative, quantitative
   C. Quantitative, qualitative
   D. Mechanical, qualitative

5. Any drafting done for or by the Navy must be prepared using the _____.

   A. Latest military standard
   B. Department of Defense standard
   C. NAVFACENGCOM design manuals
   D. All of the above

6. _____ is a high-grade white (or slightly tinted) transparent paper that takes pencil well and erases cleanly.

   A. Tracing paper
   B. Profile paper
   C. Cross-section paper
   D. Illustration board

7.   Cross-section paper is more commonly known as_____.

   A.   Profile paper
   B.   Profile/plan paper
   C.   Graph paper
   D.   Illustration board

8.   A_____grade drafting pencil produces a darker, thicker line, while a _____grade drafting pencil produces a lighter, thinner line.

   A.   Wooden, mechanical
   B.   Hard, soft
   C.   Soft, hard
   D.   Mechanical, wooden

9.   An_____eraser is soft and pliable and used for removing pencil or finger marks and smudges.

   A.   Vinyl
   B.   Art gum
   C.   Electric
   D.   Ruby red

10.   **(True or False)** You use a T square with the head set against the upper or lower edge of the drafting board.

   A.   True
   B.   False

11.   A_____consists of a long, straight strip, called the blade, which is mounted at right angles on a short strip, called the head.

   A.   Parallel straightedge
   B.   Steel straightedge
   C.   Map measure
   D.   T square

12.   A_____consists of a laminated blade with transparent plastic edges and uses a series of cords and pulleys to move up and down the drawing board.

   A.   Parallel straightedge
   B.   Steel straightedge
   C.   Map measure
   D.   T square

13.   A _____ is used for drawing long, straight lines because its heavy weight helps keep it in position; it is also excellent for trimming blueprints and cutting heavy illustration board.

        A.   Parallel straightedge
        B.   Steel straightedge
        C.   Map measure
        D.   T square

14.   _____ are used in combination with a T square or straightedge to draw vertical and inclined lines.

        A.   Triangles
        B.   Map measures
        C.   Dividers
        D.   Compasses

15.   _____ are used for measuring and laying off angles other than those that may be drawn with a triangle or combination of triangles; they are either circular or semicircular in shape.

        A.   Dividers
        B.   Compasses
        C.   Protractors
        D.   Map measures

16.   With a T square or a straightedge, you can use this drafting instrument to measure or draw any angle between 0 and 90 degrees and transfer parallel inclined lines.

        A.   Adjustable triangle
        B.   French curve
        C.   Protractor
        D.   Compass

17.   _____ are used for drawing smooth curved lines that are not arcs or circles, such as ellipses, parabolas, and spirals.

        A.   Protractors
        B.   Compasses
        C.   Triangles
        D.   French curves

18.   Circles and circular curves of relatively short radius are drawn with _____ .

        A.   French curves
        B.   Compasses
        C.   Triangles
        D.   T squares

19. A_____is similar to a_____, except that both legs end in needlepoints.

    A. Protractor, compass
    B. Compass, divider
    C. Compass, protractor
    D. Divider, compass

20. _____are used for transferring measurements from one scale to another.

    A. French curves
    B. Map measures
    C. Compasses
    D. Proportional dividers

21. The_____of a drawing refers to the ratio between the dimensions of the graphic representation of an object and the corresponding dimensions of the object itself.

    A. Scale
    B. Topography
    C. Construction
    D. Qualitative relationship

22. _____scales are used wherever dimensions are measured in feet and inches.

    A. Engineer's
    B. Architect's
    C. Metric
    D. Mechanical

23. _____scales are used wherever dimensions are measured in 10ths.

    A. Engineer's
    B. Architect's
    C. Metric
    D. Mechanical

24. _____scales are used wherever dimensions are measured in meters and centimeters.

    A. Engineer's
    B. Architect's
    C. Metric
    D. Mechanical

25. _____are precision instruments for measuring the lengths of roads, pipelines, and other irregular outlines on maps and drawings.

   A.   Scales
   B.   Map measures
   C.   Protractors
   D.   Dividers

26. _____are time saving devices that are used for drawing common shapes and standard symbols and come in a wide variety of shapes.

   A.   Protractors
   B.   Dividers
   C.   French curves
   D.   Drafting templates

27. **(True or False)** You should hold a technical fountain pen so that it is perpendicular to the drawing surface at all times to avoid uneven point wear.

   A.   True
   B.   False

Trade Terms Introduced in this Chapter

Adjustable triangle	A drawing device that combines the functions of a triangle and a protractor.
Administrative drafting	Drafting done in support of the administrative and operational functions of your unit.
Architect's scales	Triangular rulers used wherever dimensions are measured in feet and inches; major divisions on the scales represent feet, which in turn are subdivided into 12ths or 16ths, depending on the individual scale.
Art gum	Eraser made of soft, pliable gum that does not mar or scratch the paper.
Beam compass	Drawing device used for drawing circles with radii larger than can be set on a pivot joint or bow compass
Bristol board	Thin board with two smooth sides that take ink well, used for making small signs and charts
Charts	A presentation of information in the form of graphs or tables
Compasses	Drawing device used to create circles and circular curves of relatively short radius.
Construction drafting	Drafting of architectural, structural, electrical, and mechanical drawings related to structures.
Cross-section paper	Also referred to as graph paper, used for drawing road cross sections, rough design sketching preparing schedules, plotting graph, and much more.
Display charts	Drawings designed primarily to convey information to nontechnical audiences, usually depicting a comparative general picture of a situation.
Dividers	Drawing device similar to compasses, except that both legs are provided with needlepoints.
DOD-STD	Department of Defense standard.
Drafting media	Materials on which drawings are made, e.g., vellum, graph paper, illustration board.
Drafting templates	Usually transparent or clear plastic guides used for drawing various shapes and standard symbols.
Drop bow pen	Drawing device used to ink small circles with diameters of less than a quarter of an inch.
Dust brush	Used to remove dust and erasure particles off a drawing.
Dry clean pads	Used to keep a drawing clean while you are working on it.

Electric eraser	Powered eraser with hand grip and rotating eraser head.
Engineer's scale	Triangular rulers used wherever dimensions are measured in 10ths.
Freehand drafting	Drawing in which the pencil or pen is guided solely by the draftsman's hand.
French curves	Drawing device used to create irregular, smooth, curved lines that are not arcs or circles, such as ellipses, parabolas, and spirals; come in a variety of shapes and sizes.
Graphs	Diagram that exhibits a relationship, often functional, between two sets of numbers as a set of points having coordinates determined by the relationship.
Gridded media	Profile, plan/profile, and cross-section paper.
Illustration board	Drawing paper with a high rag content mounted on cardboard backing.
Illustrative drafting	Type of drawing that presents a pictorial image only.
India ink	Draftsman's drawing ink consisting of a pigment suspended in an ammonia-water solution; dries waterproof.
Leroy scriber	A system using templates and special scribing tools to create machine-perfect lettering.
Map measures	Precision instruments for measuring the lengths of roads, pipelines, and other irregular outlines on maps and drawings.
Mechanical drafting	Mechanical drafting is any drawing in which the pencil or pen is guided by mechanical devices, such as compasses, straightedges, and french curves. Also refers to the arrangements of machinery, utility systems, heating, air conditioning, and ventilating systems.
Metric scale	Triangular rulers used wherever dimensions are measured in meters and centimeters.
MIL-STD	Abbreviation for military standard.
NAVFACENGCOM	Abbreviation for Naval Facility and Engineering Command.
NMCB	Abbreviation for Naval Mobile Construction Battalion.
Parallel straightedge	Drafting device which is used to draw long straight lines, uses a system of cords and pulleys so that it is supported at both ends by a cord; can be adjusted up and down the board and maintain parallel motion
Pink pearl	Ordinary double-beveled pencil eraser
Plan/profile paper	Type of graph paper similar to profile paper with the grid only covering the lower half of the paper; the upper half is

plain, used to draw the plan view in relation to the profile, or to add explanatory notes

Pounce	Very fine bone dust used to prevent a freshly inked line from spreading.
Profile paper	Type of graph paper, usually 4 lines vertical and 20 or 30 lines horizontal per inch, with every 10th vertical line accented, generally used for road design profiles.
Proportional dividers	Drafting instrument used to transfer measurements from one scale to another; consists of two legs of equal length, pointed at each end, and held together by a movable pivot.
Protractors	Semi-circular or circular drawing device used for measuring and laying off angles other than those that may be drawn with the triangle or a combination of triangles.
Qualitative	Emphasizing relationships.
Quantitative	Emphasizing numerical values
Ruby red	A vinyl eraser of moderate hardness designed for erasing lines in ink.
Steel straightedge	A stainless steel blade used as a guide to draw lines or trim drafting media.
Technical drafting	A type of drawing that presents technical information in a graphic form.
Technical engineering charts	Drawings that examine the quantitative relationship between a set of two factors or variables, usually based on a series of measurements from laboratory experiments or work activities.
Topographic drafting	Drafting done in connection with topographic and civil engineering surveys
Tracing paper (tracing vellum)	High-grade white (or slightly tinted) transparent paper that takes pencil well, and from which pencil lines can be easily erased.
Triangles	Drawing device, usually made of transparent or translucent plastic, used in combination with a t square or straightedge to draw vertical and inclined lines.

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

Advancement Handbook for Petty Officers, Engineering Aid (EA), NAVEDTRA 71365, Naval Education and Training Program Management Support Activity, Pensacola, Fla., 1989.

Construction Force Manual, NAVFAC P-315, Naval Facilities Engineering Command, Alexandria, Va., 1985.

Military Requirements for Petty Officer Third Class, NAVEDTRA 10044-A, Naval Education and Training Program Management Support Activity, Pensacola, Fla., 1987.

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Chapter 4

Drafting: Fundamentals and Techniques

Topics

To hear audio, click on the box.

Overview

As an Engineering Aid, you will often be asked to prepare drawings and charts. To perform that task successfully, you must be familiar with the fundamental techniques for using various types of drafting equipment and accessories. You will also need to familiarize yourself with the standards and conventions that apply to your project.

You will follow the standard drawing format, line conventions, and lettering described in detail in the following publications: DoD-STD-100C, *Engineering Drawing Practices* and MIL-HDBK-1006/1, *Policy and Procedures for Project Drawing and Specification Preparation*. You are responsible for keeping up to date on the latest revisions of these publications and other applicable reference materials.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Describe how you should prepare your work area.
2. Identify basic drafting techniques.
3. Identify basic drawing formats.
4. Describe line conventions
5. Identify the proper order of penciling lines.
6. Identify the proper order of inking lines.

7. Describe the proper method of lettering.

8. Describe the proper method of creating inclined lettering.

9. Describe the proper method of composing lettering.

10. Describe the proper method of using mechanical lettering systems.

Prerequisites

None

This course map shows all of the chapters in Engineering Aid Basic. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Topographic Surveying and Mapping		E
Indirect Leveling/Level and Traverse Computations		N
Care and Adjustment of Survey Equipment		G
Materials Testing: Soil and Concrete		I
Direct Leveling and Basic Engineering Surveys		N
Horizontal Control		E
Direct Linear Measurements and Field Survey Safety		E
Surveying: Elements and Equipment		R
Construction Drawings		I
Electrical: Systems and Plans		N
Mechanical: Systems and Plans		G
Concrete and Masonry		AID
Wood and Light Frame Structures		B
Drafting: Projections and Sketching		A
Drafting: Geometric Construction		S
Drafting: Fundamentals and Techniques		I
Drafting: Equipment		C
Mathematics and Units of Measurement		
Engineering Aid Rating		

Features of this Manual

This manual has several features which make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.

- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.

- Audio and video clips are included in the text, with italicized instructions telling you where to click to activate it.

- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.0.0 WORK PREPARATION

Before you begin to work, devote some time and thought to organize your working area. Arrange your drafting furniture so you can work comfortably without fatigue or eyestrain. Be sure to check the lighting before you set up your drafting table. Devise a system of stowing your equipment and supplies so they are handy and in order.

1.1.0 Work Area

Your immediate work area should be large enough to allow sufficient freedom of movement but not so large that you waste time reaching for equipment, supplies, and reference publications. An ideal working area allows each draftsman approximately 90 sq ft of space, although you may actually have more or less depending on the total area of the drafting room and the number of draftsmen who will work there. If you are easily distracted, do not butt your drafting table up against and facing another draftsman's table. Ensure that you have adequate lighting. The best light for drafting is natural light coming over the left shoulder and from the front left to avoid shadows cast by your hands, T square or parallel ruling straightedge, and triangles. Avoid glaring light as it will cause eyestrain. Use a drafting lamp if necessary.

Your drafting table height should be from 36 to 40 inches above floor level. Your drafting chair or stool should be high enough that you can see the whole drawing board, but not so high that you have to lean over uncomfortably to draw. You may adjust your board at an incline or leave it flat according to your preference. A slope of 1 to 8 works well for the inclined position. By shifting your body or head slightly, you should be able to look directly at any point on an average-sized drawing sheet; that is, your line of sight should be approximately **perpendicular** to the drawing surface.

Before you begin to draw, arrange your equipment in an orderly manner. Place each article so that you can reach it easily, and keep it in place when you are not using it. A systematic arrangement is timesaving and efficient. Keeping your tools in order decreases the likelihood of accidentally dropping them or pushing them off the table. You will find it very convenient to have a small worktable adjacent to your drafting board. Placing your drafting tools and reference publications on the worktable leaves you with an uncluttered drawing board surface. When you use the drafting board in the inclined position, a separate worktable becomes a necessity. You will select the drafting equipment and materials according to the needs of each of your drafting assignments. Let your good judgment and common sense guide you in their selection. After some experience, you will automatically select proper equipment and materials as they are required. Until you become proficient, don't hesitate to seek the advice of your drafting supervisor or an experienced draftsman. You will be exposed to modern drafting equipment, materials, and software as you are assigned to staff and support billets within the Naval Construction Force (NCF).

1.1.1 Drafting Board

As a Seabee draftsman, you will probably not be able to select your drafting board. Unless the board is new, it will probably be marred and full of small pinholes. To obtain a smooth drawing surface, cover the board with a vinyl material or heavy manila paper. Laminated vinyl covering minimizes pencil scoring, reduces glare, and is easily kept clean by wiping with a damp cloth. Heavy manila paper will serve the same purpose, but must be replaced when it becomes soiled or marked with use.

1.1.2 Drafting Paper

You will prepare most of your drawings on tracing paper. You will use tracing paper to copy or trace drawings either in pencil or in ink. You will also prepare most of your original pencil drawings on tracing paper. This type of paper is especially suited for reproduction of blueprints; however, it tears easily and becomes soiled after repeated handling.

When making a drawing directly on tracing paper, place a smooth sheet of white paper below it (detail paper works well). The whiteness of this sheet (called a platen sheet) gives better line visibility, and its hard surface enables you to draw good pencil lines without grooving the tracing paper. Do not use gritty erasers on tracing paper, especially if you are going to apply ink later. If you must make erasures, use a green or red ruby eraser, which is only slightly abrasive. Abrasive erasers wear away the surface. Erase carefully so you don't tear the drawing. A light back-and-forth motion works best. If the surface of the drawing becomes scratched by erasing, it can be partially smoothed by burnishing the damaged area with a hard, smooth object or your thumbnail. Avoid using the electric eraser on tracing paper, as it will quickly "burn" a hole through the paper. To clean up smudges and dust, use a soft art gum eraser or sprinkle pounce on the drawing and rub lightly with your hand or a triangle. Water, perspiration, or graphite from your pencil will ruin drawing paper. In order to keep moist hands or arms from marring the drawing, use a clean sheet of paper as a mask to protect the drawing surface next to the work area. Between drawing sessions, protect unfinished drawings by covering them.

Do not fold tracing paper. The crease marks will damage the lines on the drawing and cause blurred prints when the drawing is reproduced. For that matter, you should never fold any drawing. Drawings and tracings should be either stored flat or rolled and placed in cylindrical containers. The exception to this rule is that prints or drawings larger than 8 % inches by 11 inches may be folded so that they can be filed in standard filing cabinets.

Besides tracing paper, you will select other types of paper for special uses. You will mainly be concerned with the gridded papers. You will use gridded paper of a quality similar to that of tracing paper and should handle it in the same way. As you gain experience, you will learn which type of paper to use for each drafting assignment. Of course, you will be limited by the types of paper available and the guidelines given to you by your drafting supervisor.

1.1.3 Drafting Pencils

For the average drafting assignment, you will use three or four pencils. You should use a hard pencil, 4H or 5H, to lay out the drawing in light construction and projection lines. You will then use a medium pencil, H or F, to darken the required lines and to make arrowheads and lettering. Base your pencil choice on the grade of drawing paper you use. A soft, rough-textured paper usually requires a softer pencil for layout work, since a hard pencil would leave indentations in the paper and thus spoil the appearance of the drawing.

One way to find out if you are using the proper pencils on a drawing is to make a blueprint (reproduction) of the drawing. If the reproduced lines do not appear, or appear too light, use a softer pencil. If, on the other hand, lines appear too dark in relation to other lines, use a harder pencil. You may be able to vary the weight of lines by the amount of pressure exerted on the pencil, but do not attempt this without experience. Bearing down on a hard pencil to produce darker lines may cause grooves in the paper.

Another way to find out if you are using the proper pencil is to hold your drawing up to a light and view it from the back side. Pencil adjustment is the same as in the previous method. Of course, both methods apply only when transparent drawing paper is used.

To sharpen a pencil, cut the wood away from the unlettered end (*Figure 4-1, View A*) with a draftsman's pencil sharpener or a penknife. The lettered end should be left intact so that the grade of pencil can always be identified. The cut should be started about 1 1/2 inch from the end, leaving half an inch of lead exposed. To produce a conical or needlepoint (*Figure 4-1, View B*), which is best for general use, rotate the pencil between the fingers at the same time as the exposed lead is rubbed back and forth across the full length of the sandpaper pad (*Figure 4-1, View C*). Many draftsmen prefer to use a mechanical lead pointer instead of the sandpaper pad. The mechanical pointer quickly produces a uniform conical or needlepoint. However, other types of points still require the sandpaper pad. The resulting needlepoint should be dulled slightly by drawing it lightly across a piece of scrap paper several times. Avoid sharpening pencils near your drawing. Graphite particles will cause smudges that are difficult to erase. Use a cloth or tissue to wipe away graphite particles that cling to the pencil after it is sharpened. A wedge point (*Figure 4-1, View D*) will aid an experienced draftsman in the extensive drawing of straight lines. This point is produced by sharpening a pencil to the conical point just described, then flattening both sides on the sandpaper pad. For an elliptical point, hold the pencil firmly with thumb and fingers and cut the lead on the sandpaper pad by a back-and-forth motion, keeping the pencil at an angle of about 25 degrees to the pad. Continue until a flat ellipse is formed, as shown in *Figure 4-1, View E*. A good draftsman never uses a dull pencil.

Figure 4-1 - Sharpening pencil points.

Some draftsmen prefer to use mechanical drafting pencils instead of wooden pencils. The lead of a mechanical pencil is sharpened in the same manner as the lead of a wooden pencil. However, the length of the mechanical pencil is not depleted as the lead is sharpened. This is an advantage over wooden pencils that become difficult to use when they are less than 3 inches long. When changing leads for the mechanical pencil, ensure that the changeable lead grade designator on the mechanical pencil corresponds to that of the lead used.

2.0.0 BASIC DRAFTING TECHNIQUES

Always practice handling and using drafting instruments before attempting complex drawing problems. You will continue to make improvements in the quality of your drawings by developing correct drawing habits. The main purpose of making your first

drawings is to learn to use instruments. Each drawing will offer an opportunity for practice. Later on, good form in the use of instruments will become a natural habit.

Accurate pencil drawings are of the first importance since all inked drawings and tracings are made from finished pencil drawings. You cannot correct a poor pencil drawing when you make the ink tracing. Any drawing important enough to be inked or traced in ink must be accurate, legible, and neat. Because you will prepare most military and commercial blueprints from pencil drawings, you should work to hone your pencil drawing technique. Good technique and skillful pencil drawing are basic to proficiency in drafting.

The following sections will guide you in attaching your drawing paper to the board and in drawing basic lines with the T square, triangles, and pencil.

2.1.0 Attachment of Paper to the Board

Once you are relatively familiar with your equipment and materials, get started by attaching your drafting paper to the board. Place the sheet close to the left edge of the drafting board. Working in this area makes the T square easier to handle and reduces the likelihood of error because of T square "swing." The drafting sheet should be far enough from the bottom of the board (about 3 inches) to ensure firm support for the head of the T square when you are drawing on the lower part of the sheet. *Figure 4-2* shows a drawing sheet properly attached to the board on which a T square is used.

Figure 4-2 – Attaching drafting paper to the board.

After aligning the drawing sheet, smooth out any wrinkles and fasten the four corners with short strips of drafting tape. If you are attaching large sheets, place additional strips of tape at the top and bottom edges of the sheet. Drafting tape has a lighter coating of adhesive than does masking tape and will hold the drawing firmly, yet it can be removed without tearing or marring the drawing. If you use masking tape or transparent tape, leave a large margin in the event you tear the paper when removing the tape. When placed diagonally across the corners of the sheet, as shown in *Figure 4-2*, drafting tape offers little obstruction to movement of the T square and triangles. Avoid the use of thumbtacks; they will eventually ruin the drafting board. If you are using a parallel straightedge or drafting machine instead of a T square, the procedure just described is the same with one exception. Instead of placing the paper close to the left edge of the board, place it approximately at the midpoint of the length of the parallel straightedge or in the center of the drawing board surface when you are using a drafting machine.

2.2.0 Horizontal Lines

As a draftsman, you will construct a horizontal line by drawing from left to right along the working edge of a T square, as shown in *Figure 4-3*. This working edge, when true, is perpendicular to the working edge of the drafting board. When you draw horizontal lines, keep the working edge of the T square head in firm contact with the working edge of the drafting board. Incline your pencil to the right at an angle of about 60 degrees with the point close to the junction of the working edge and the paper. Hold the pencil lightly and, if it was sharpened with a conical point, rotate it slowly while drawing the line to achieve a uniform line width and preserve the shape of the point. Normally, when you are drawing a series of horizontal lines, start from the top and work your way down
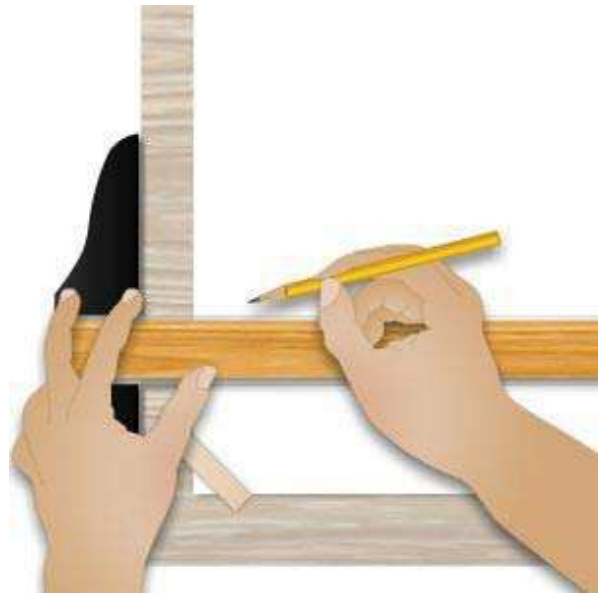
Figure 4-3 – Construction of a horizontal line.

2.3.0 Vertical Lines

You will create vertical lines **parallel** to the working edge of the drafting board by using triangles in combination with a T square. Place one leg of a triangle against the working edge of the blade so that the other leg faces the working edge of the board to prevent casting a shadow over your work. Draw lines from the bottom up, as shown in *Figure 4-4*. Incline your pencil toward the top of the working sheet at an angle of approximately 60 degrees, with the point as close as possible to the junction of the triangle and the drafting paper. When drawing a series of vertical lines, start from the left and work your way to the right. Never use the lower edge of the T square blade as a base for triangles.
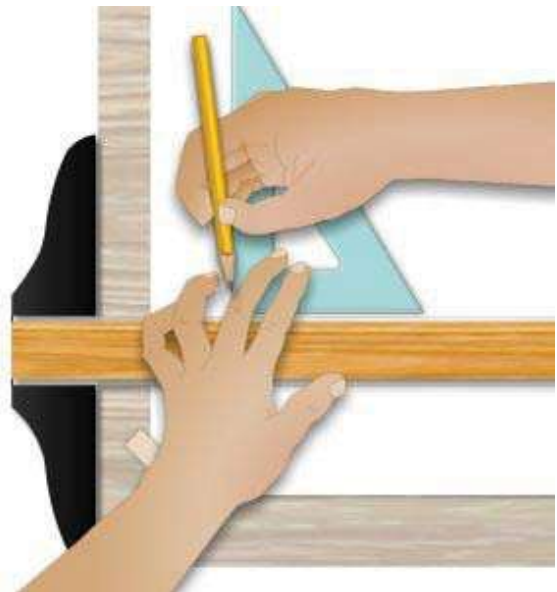
Figure 4-4 – Construction of a vertical line.

2.4.0 Inclined Lines

Measure the direction or angle of inclination of an inclined line on a drafting sheet in reference to the base line from which it is drawn. Inclined lines at standard angles are constructed with the T square as a base for triangles used either singly, as shown in *Figure 4-5 Views A and B*, or in combination, as shown in *Figure 4-3 View C*.
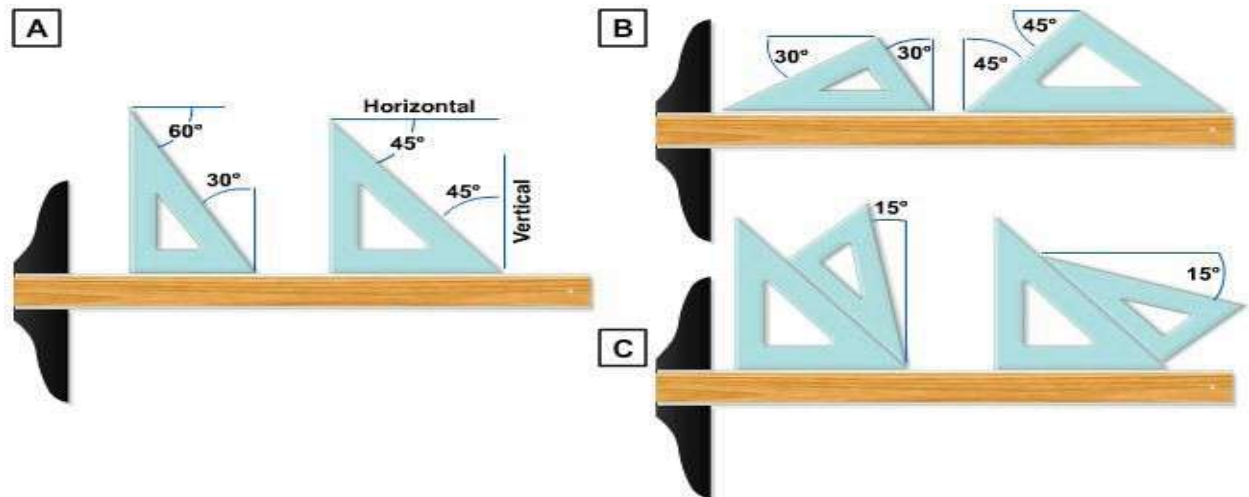
Figure 4-5 – Construction of an inclined line.

In combination with the T square as a base, use the triangles as guides for producing lines at intervals of 15 degrees, as shown in *Figure 4-6*. You can use the 45-degree triangle to divide a circle into 8 equal parts; you can use the 30°/60° triangle to divide a circle into 12 equal parts. For drawing lines at angles other than those described above, use a protractor.
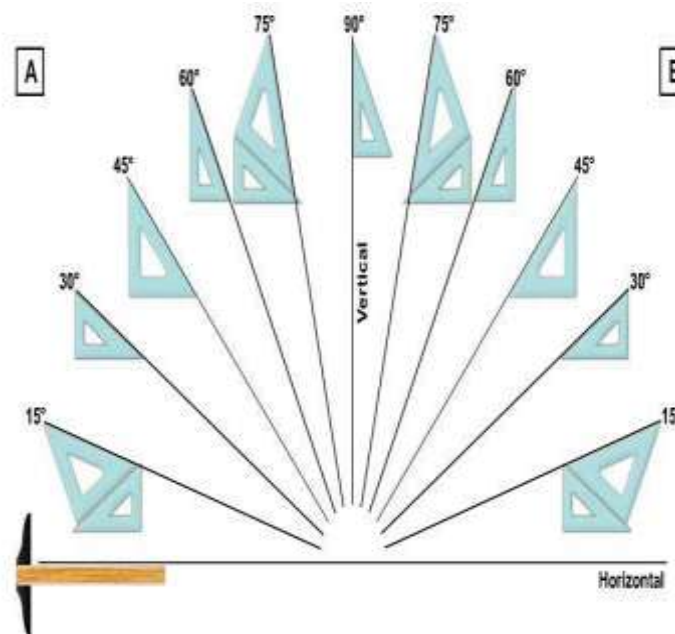
Figure 4-6 – Using a T square (or parallel straightedge) and triangles to draw lines at different angles to the horizontal. Arrows indicate the direction in which the lines should be drawn.

2.5.0 Protraction of Angles

To measure an angle, place the center mark of the protractor at the vertex of the angle, with the 0-degree line along one side, then note the degree mark that falls on the side. To lay off an angle, position the protractor as above and use a needlepoint or a sharp-pointed pencil to mark the desired values, then project lines from the vertex to these marks.

Using only the three points on the protractor, as described above, may result in considerable inaccuracy, particularly if you need to extend the lines of an angle for some distance beyond the protractor. *Figure 4-7* illustrates a refinement of the procedure. Suppose you need to measure angle BOA. Extend line AO on to C; extend line BO on to D. When you set the center of the protractor at O, make sure that both points c and a are on line AC. Take your reading at point d as well as at point b when you measure the angle.
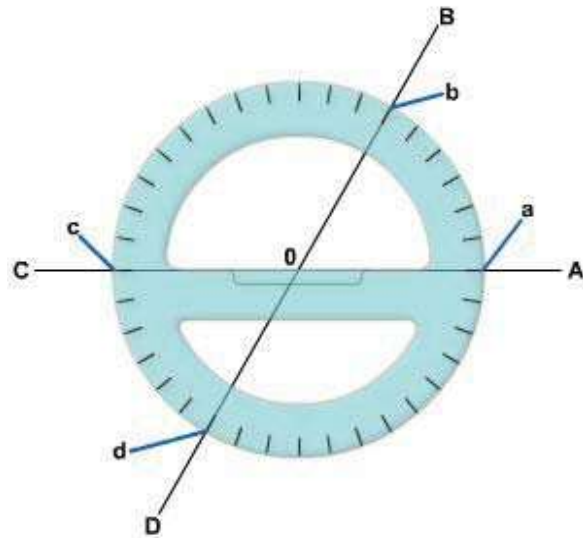
Figure 4-7 - Protracting an angle.

If you are laying off the angle BOA, protract and mark point d as well as point b; this gives you three points (d, O, and b) for establishing line DB. If you are using a semicircular protractor, you can't, of course, locate point d; but your accuracy will be improved by lining up c, O, and a before you measure or lay off the single angle BOA.

2.6.0 Parallel and Perpendicular Lines

To draw a line parallel to a given line (*Figure 4-8*), adjust the hypotenuse of a triangle in combination with a straightedge (T square or triangle) to the given line; then, holding the straightedge firmly in position, slip the triangle to the desired position and draw the parallel line along the hypotenuse.
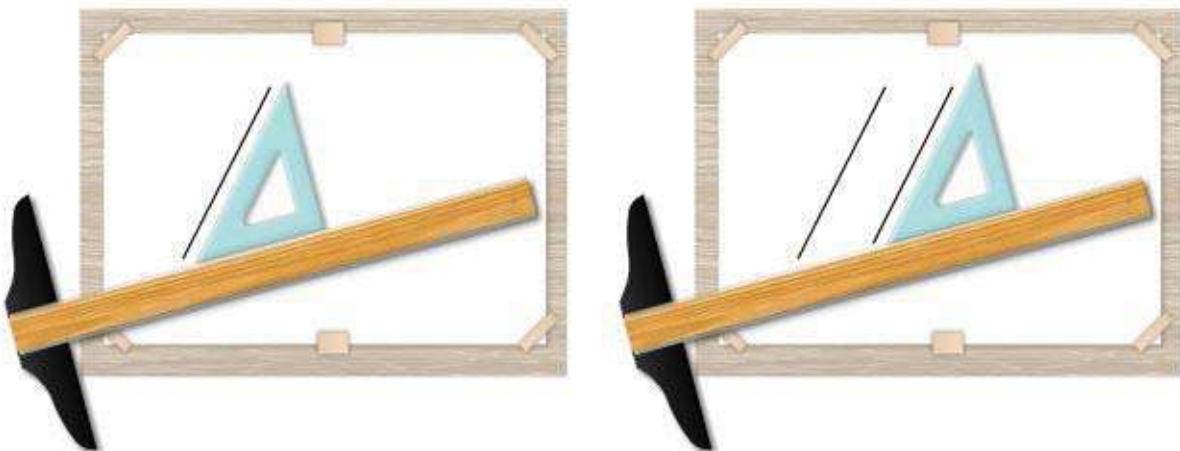
Figure 4-8 - Drawing parallel lines.
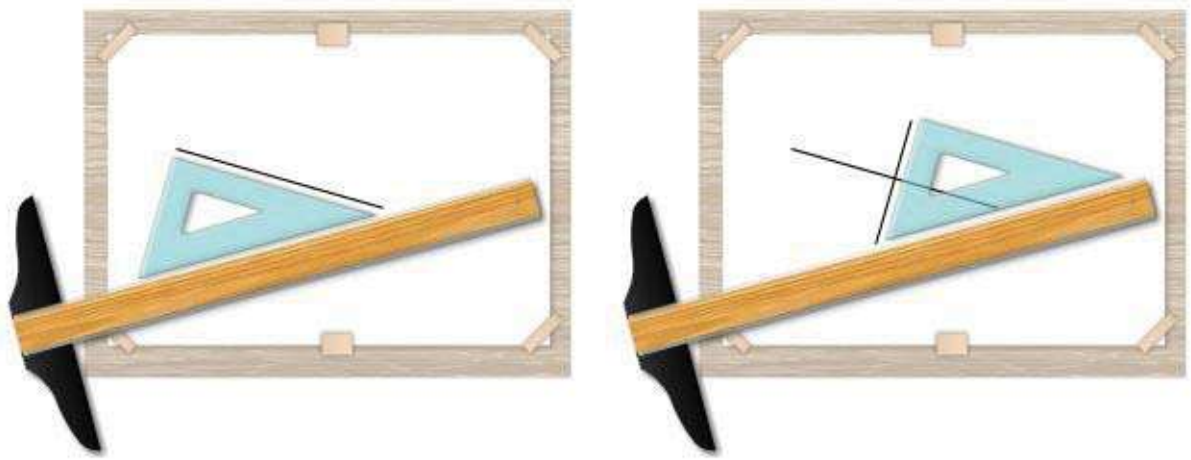
Figure 4-9 - Drawing perpendicular lines.

To construct a line perpendicular to an existing line, use the triangle and straightedge in combination, with the hypotenuse of the triangle resting against the upper edge of the straightedge (*Figure 4-9*). Adjust one leg of the triangle to a given line. Slide the triangle along the supporting straightedge to the desired position and draw the line along the leg, perpendicular to the leg that was adjusted to the given line. In the same manner, angles with multiples of 15 degrees may be drawn, using the triangle combinations shown in *Figure 4-6*.

2.7.0 Curved Lines

You will prepare many drawings that require the construction of various curved lines. Basically you will draw types of curved lines: circles and segments of circles, called **arcs**, which are drawn with a compass; and noncircular curves, which are usually drawn with french curves. We will discuss only techniques for using the compass and the french curve. We will discuss the application of compass techniques in geometric construction later.

2.7.1 Use of the Compass

When you draw circles and arcs, it is important that the lines you produce with the compass are the same weight as corresponding pencil lines. Since you cannot exert as much pressure on the compass as you can with pencils, use a compass lead about one grade softer than the pencil used for corresponding line work. For dim construction lines, use 4H to 6H leads. Avoid using leads that are too short.

Sharpen the compass lead with a single elliptical face, as shown in *Figure 4-10, View A*. A sandpaper pad works best for sharpening compass leads. You will normally place the elliptical face of the lead in the compass so that it faces outward from the other compass leg. Adjust the shoulder-end needlepoint so that the point extends slightly farther than the lead, as shown in *Figure 4-10, View B*. Pressing the needlepoint lightly in the paper, center the compass vertically when the legs are brought together.

Sharpening the Compass Lead

Adjusting the Compass Point
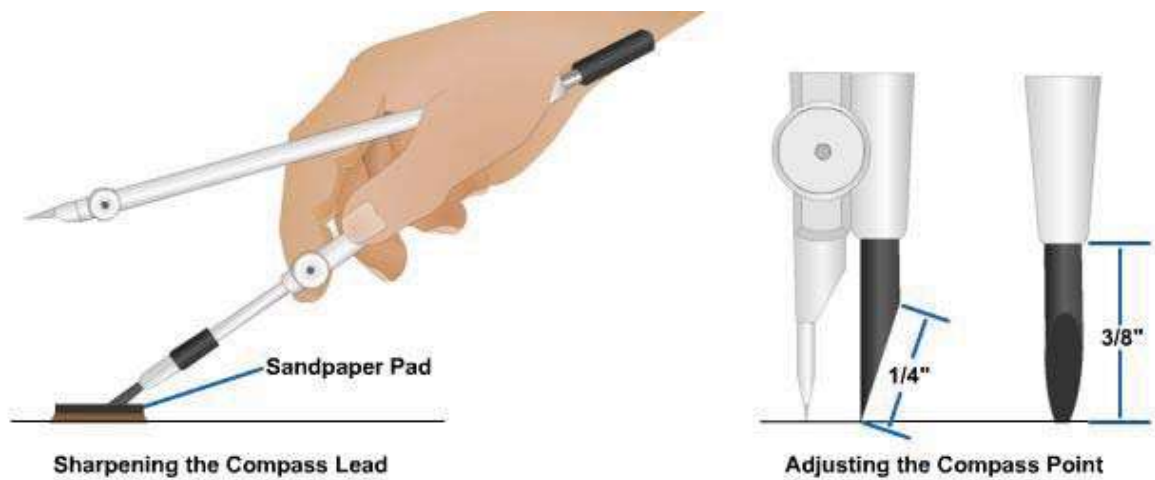
Figure 4-10 – Sharpening the compass lead and adjusting the point.

Use bow compasses and pivot joint compasses in the same manner. To draw a circle with a compass, lightly press the needlepoint into the drawing paper and rotate the marking leg around it. Always rotate the compass clockwise. As you rotate, lean the compass slightly forward. With a little practice, you will find that you can easily draw smooth circles using only the thumb and forefinger of one hand. It is important to use an even pressure as you rotate the compass.

You may find it necessary to rotate the compass several times to produce a circle with a uniform dense black line.

When you wish to set the compass to draw a circle of a given diameter, use a piece of scratch paper and follow the steps listed below, referring to *Figure 4-11*.

1. Draw a horizontal line with a straightedge.

2. With the straightedge as a base, use a triangle and draw a vertical line intersecting the horizontal line (*Figure 4-11, view A*).

3. Measure the radius of the circle with a scale, as shown in *Figure 4-11, View B*, and draw a second vertical line from this point.

4. Set the needlepoint at the intersection of the first vertical line and the horizontal line (*Figure 4-11, View C*). This is the center of the circle.

5. Set the marking leg to fall on the intersection of the second vertical line and the horizontal line (*Figure 4-11, View D*).

6. Draw a half circle with the compass (*Figure 4-11, View E*).

7. Check your work by measuring the diameter established by this half circle with a scale (*Figure 4-11, View F*).

Once you have set the compass to the exact radius of the circle, handle it very carefully so that you don't disturb the setting. Set the needlepoint at the center of the circle and carefully rotate the compass to draw a line describing the circumference of the circle. Do not apply too much pressure on the needlepoint or it will bore a hole in the paper and you will lose the accurate center mark. To minimize the diameter of the hole, set the needlepoint of the compass on a small strip of paper or thin cardboard over the drafting sheet at the center of the circle.
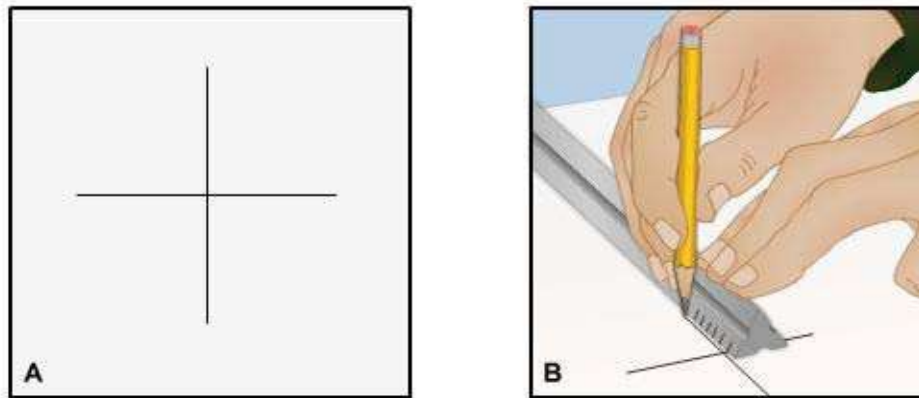
Figure 4-11- Drawing a circle of a given radius.

When you are using the pencil leg to draw circles smaller than 1 inch in radius, keep the adjustable pencil and needle legs straight. For larger circles, both legs should be adjusted so that they are perpendicular to the paper. On the other hand, when you are using the compass with the pen leg, you MUST adjust it at the hinge joint to keep it perpendicular to the paper for all size circles. (See *Figure 4-12, View A*.) If the pen is not perpendicular to the paper, ink will not flow properly. To draw large circles, insert the extension bar in the pen or pencil leg, as shown in *Figure 4-12, View B*. When the extension bar is used to draw large circles, the process of using the compass with only one hand becomes awkward. You should use both hands, as shown in *Figure 4-12, View B*.
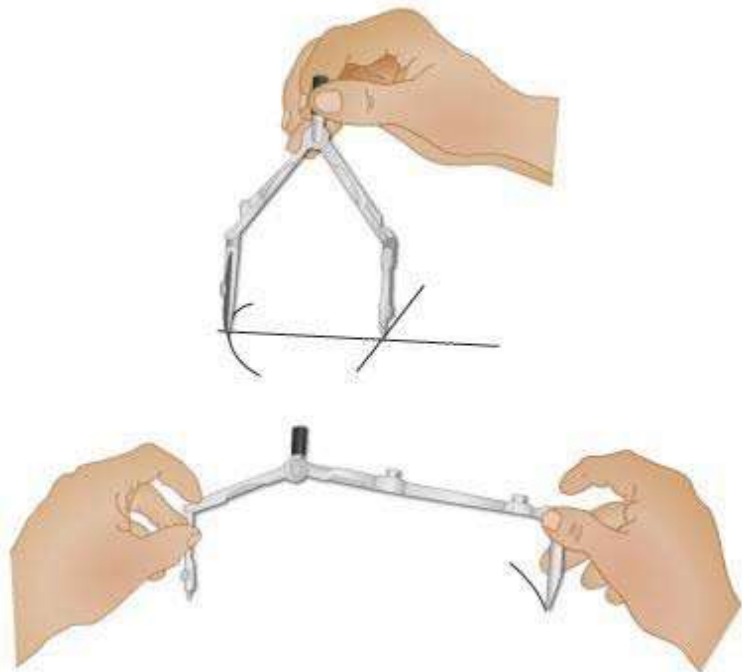
Figure 4-12 – Drawing a circle in ink.

2.7.2 Use of the French Curve

Use the french curve to draw a smooth line through predetermined points. After plotting the points, sketch a light pencil line to connect the points in a smooth flowing line. To draw the finished line over the freehand line, match the various parts of the french curve to various segments of the freehand curve. Avoid abrupt changes in curvature by placing the short radius of the french curve toward the short radius portion of the line being drawn. Change your position around the drawing board when necessary so that you can work on the side of the french curve that is away from you. Avoid working on the "under" side of the French curve. Place the french curve so that it intersects at least two points of the line.

When drawing the line along the edge of the french curve, stop short of the last point intersected. Then move the french curve along to intersect two or three more points and make sure that the edge of the curve connects smoothly with the line already drawn. When using the irregular curve, you can draw a perfectly smooth curved line by plotting enough points (the sharper the curve, the more points you need) and by drawing in shorts steps.

Figure 4-13 shows how a smooth line is drawn through a series of plotted points. The french curve in *Figure 4-13 Slide A* matches points 1, 2, 3, and 4. Draw a line from 1 to 3 only (not to 4).

At *Figure 4-13, Slide B*, the curve matches points 3 to beyond 4. Draw a line from 3 to 4 only (not to 5).

At *Figure 4-13, Slide C*, the curve matches points 4, 5, and 6. Draw a line from 4 to just short of 6.

At *Figure 4-13, Slide D*, the curve matches a point short of 6 to beyond 7. Draw a line from 6 to 7.

At *Figure 4-13, Slide E*, the curve matches a point short of 7 to beyond 9. Draw a line from 7 to 9.

At *Figure 4-13, Slide F*, the curve matches a point short of 9 to beyond 11. Draw a line from 9 to 11.

You will probably notice how the curve is turned over and reversed to find portions that fit the points on the line with increasing or decreasing changes in curvature.

When you are drawing a curved line that extends into a straight line, draw the curve first, and join the straight line to it.

2.8.0 Use of Drafting Templates

Use drafting templates only when accuracy can be sacrificed for speed. For example, you can draw circles or arcs more quickly with a template than with a compass. Templates must be used properly to be effective. To draw a circle with the circle template (*Figure 4-14*), lay
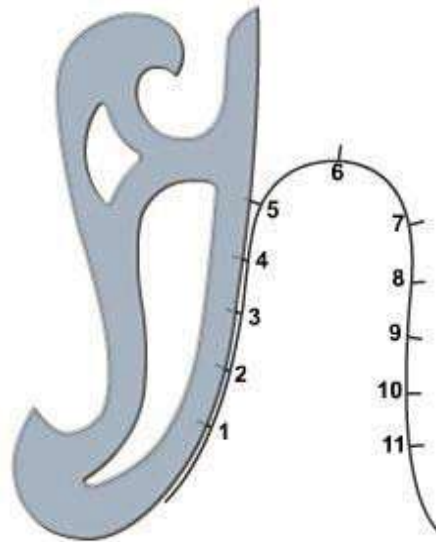
Figure 4-13 – Use of the french curve.
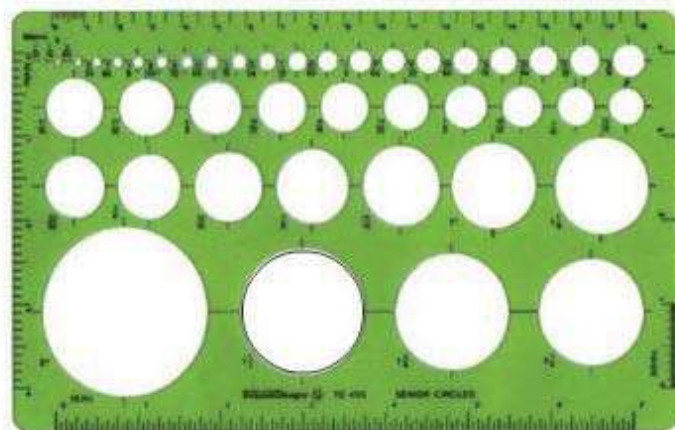
Figure 4-14 – Use of the circle template.

out center lines on the drawing where the circle is to be drawn. Then place the correct circle opening over the center line so that the quadrant lines on the template coincide with the center lines on the paper. Draw the circle, using a sharp, conical point on the pencil. Allowance must always be made for the width of the pencil line in placing the template opening in the right position on the drawing.

To draw an arc, lay out tangent lines on the drawing. Place the correct size circle of the template on the paper so that the template quadrant lines coincide with the tangent lines, and draw the arc.

When using a template, you must hold it down firmly to keep it from slipping out of position. Be sure to draw figures or circles from the template with the correct line weight on the first setting, as it is difficult to reset the template in the exact position.

2.9.0 Use of the Dividers

Use dividers to transfer measurements, to step off a series of equal distances, and to divide lines into a number of equal parts. Manipulate dividers with one hand. In setting dividers (*Figure 4-15*), hold one leg between the thumb and the first and second fingers, and hold the other leg between the third and fourth fingers. Place the second and third fingers on the inside of the legs; the dividers are opened by spreading these fingers apart. Close the dividers by squeezing the thumb and first finger toward the fourth finger while gradually slipping out the other two fingers.

To transfer measurements on a drawing, set the dividers to the correct distance, then transfer the measurements to the drawing by pricking the drawing surface very lightly with the points of the dividers.

Figure 4-15 - Holding a divider.

To measure off a series of equal distances on the line, set the dividers to the given distance. Step off this distance as many times as desired by swinging the dividers from one leg to the other along the line, first swinging clockwise 180 degrees, then counterclockwise 180 degrees, and so on.

In dividing either a straight line (*Figure 4-16, View A*) or a curved line (*Figure 4-16, View B*) into a given number of equal parts (for example, four) by trial, open the dividers to a rough approximation of the first division (in this case, one quarter of the line length) and step off the distance lightly, holding the dividers by the handle and pivoting the instrument on alternate sides of the line at each step. If the dividers fall short of the end of the line after the fourth step, hold the back leg in place and advance the forward leg, by guess, one quarter of the remaining distance. Repeat the procedure until the last step falls at the end of the line. Be careful during this process not to punch holes in the paper, but just barely mark the surface for future reference. To identify prick marks made with small dividers for future reference, circle the marks lightly with a pencil.
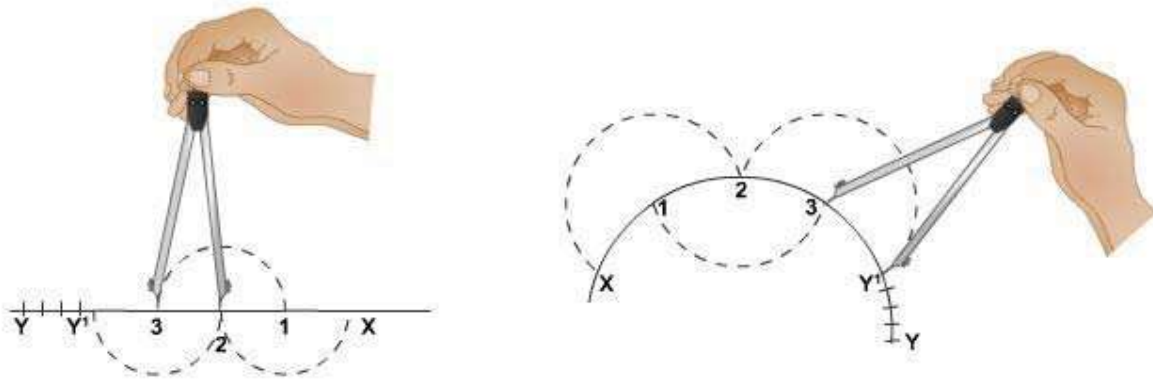
Figure 4-16 – Dividing a straight line and a curved line.

2.10.0 Use of the Drafting Scale

Your drawing accuracy depends to a great extent upon correct use of the scale in marking off distances. Place the edge of the scale parallel to the line being measured (*Figure 4-17*). To eliminate shadows cast by your body or hands, point the desired scale face away from you for horizontal measurements and toward your left for vertical measurements. With a sharp pencil, mark off short dashes at right angles to the scale at the correct distances, aligning the mark carefully with the scale graduation. Have your eye approximately over the point being measured and make light marks to denote the point of measurement.
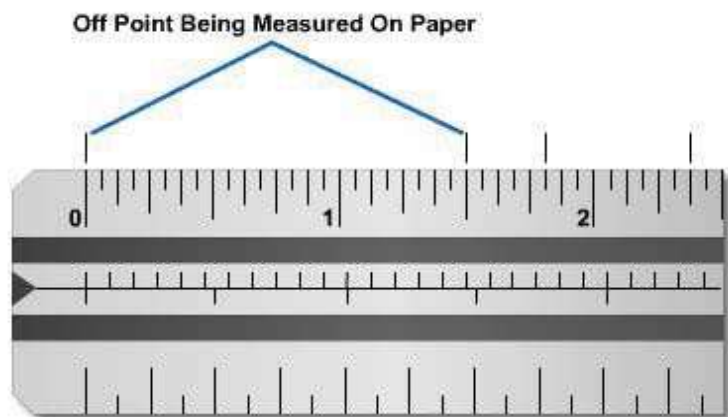
Figure 4-17 – Use of the drafting scale.

When setting the compass to a given radius or when setting divider points, never place the sharp points of these instruments on the scale. Lay out the desired radius or distance on a straight pencil line by using the scale in the manner described above. Adjust the compass or dividers to the indicated length by using the measured line. A scale surface marred by pinpricks is difficult to read and unsuitable for accurate work.

In making successive measurements along the same line, make as many measurements as possible without moving the scale. If a number of distances are to be laid out end to end, hold the scale in one position and add each successive measurement to the preceding one. Moving the scale to a new position each time, may cause slight errors to accumulate. For example, four successive measurements of 1 5/8

inch each should give an overall length of 6 1/2 inches, not 6 9/16 inches. Therefore, make as many measurements as you can without changing the reference point. This will avoid cumulative errors in the use of the scale.

Note that your pencil touches the scale only for the purpose of marking a point on the paper. Never use a scale as a straightedge for drawing lines. A typical office ruler has a metal edge; it is a scale and straightedge combined. But a draftsman's measuring scale is for measuring only; it is not a ruler. A scale properly used will last for decades, but a scale used as a straightedge will soon have the graduations worn away.

3.0.0 DRAWING FORMATS

Drawing format refers to the systematic space arrangement of required information within the drafting sheet. This information is used to identify, process, and file drawings methodically.

DoD-STD-100C, *Engineering Drawing Practices*, and MIL-HDBK-1006/1, *Policy and Procedures for Project Drawing and Specification Preparation* detail the *s*tandard sizes and formats for military drawings. With the exception of specific local command requirements, you will use DoD-STD-100C and MIL-HDBK-1006/1 as your guidelines for preparing SEABEE drawings. Most of the documents applicable to these standards have recently been revised and updated in order to gain like information and to share uniformity of form and language within the Naval Construction Force and among DoD organizations. The current widespread use of conventional and computer-generated, reduced-size copies of drawings and the exchange of microfilm and other media are other influencing factors for standard updates.

3.1.0 Sheet Sizes

Standard drawing sheet sizes facilitate readability, reproduction, handling, and uniform filing. Blueprints produced from standard size drawing sheets are easily assembled in sets for project stick files and can readily be folded for mailing and neatly filed in project letter size or legal size folders. (Filing drawings and folding blueprints will be covered later in this training manual.)

Figure 4-18 shows finished format sizes for drawings that are, according to **ANSI** Y14.1(1980), approved and adopted for use under DoD-STD-100C.

Drawings that are relatively small and should be stored or filed flat are referred to as **flat size**. Drawings that are long in length are filed in rolls and referred to as **roll size**. Finished format sizes for a drawing refer to the dimensions between trim lines (X and Y in *Figure 4-18*). The **trim line** is the outside line of either the vertical or horizontal margin. The inside lines of the margins are called **borderlines**. Width (X) is always parallel to the working edge of the drawing board; length (Y) is always perpendicular to the working edge of the drawing board.

FLAT SIZES				
SIZE DESIGNATION LETTER	X (WIDTH)	Y (LENGTH)	MARGIN	
			H (HORIZ)	V (VERT)
A (HORIZ)	8.5	11.0	0.38	0.25
A (VERT)	11.0	8.5	0.25	0.38
B	11.0	17.0	0.38	0.62
C	17.0	22.0	0.75	0.50
D	22.0	34.0	0.50	1.00
E	34.0	44.0	1.00	0.50
F	28.0	40.0	0.50	0.50

NOTES:

1. ALL DIMENSIONS ARE IN INCHES

Figure 4-18 – Guide for preparing horizontal and vertical margins, sizes, and finished drawing format for flat drawings.

Notice, in *Figure 4-19*, that you should add 2 inches to the left margin and to the right margin for protection of roll-size drawings. The edge of a drawing prepared on tracing paper will tear easily after it is rolled and unrolled several times.

ROLL SIZES					
SIZE DESIGNATION LETTER	X (WIDTH)	Y (LENGTH)		MARGIN	
		MIN	MAX	H (HORIZ)	V (VERT)
G	11.0	22.5	90.0	0.38	0.50
H	28.0	44.0	145.0	0.50	0.50
J	34.0	55.0	176.0	0.50	0.50
K	40.0	55.0	143.0	0.50	0.50

NOTES:

1. ADDITIONAL PROTECTION MARGINS FOR ROLL SIZE DRAWINGS ARE NOT INCLUDED IN ABOVE DIMENSIONS

2. ALL DIMENSIONS ARE IN INCHES

Figure 4-19 – Guide for preparing horizontal and vertical margins, sizes, and finished drawing format for roll drawings.

3.2.0 Sheet Layout

Sheets of drafting or tracing paper are cut slightly larger than their required finished sizes and are fastened to the drafting board as previously described. Using a hard (4H to 6H) pencil and a T square (or parallel straightedge), draw a horizontal trim line near the lower edge of the paper. Draw a vertical trim line near the left edge of the paper with a T square (or parallel straightedge), pencil, and triangle, as previously described. On the horizontal trim lines, mark off dimensions establishing the finished length of the sheet (distance between vertical trim lines) and the location of the vertical. Use a full-size scale when you are laying off a series of measurements along a line. On the vertical trim lines, mark off the dimensions establishing the finished width of the sheet (distance between horizontal trim lines) and the location of the horizontal borderlines. Scale the dimensions along the borderlines.

After the drawing is completed, give the borderlines the required weight. After removing the completed drawing from the board, cut it to its finished size along the trim line. If blueprints are to be made on paper that is not precut to the standard drawing size, you may find it necessary to leave an extra margin outside the trim lines. By leaving an extra margin, you can darken the trim lines. The darkened trim lines, when reproduced, will provide a visible line for trimming the blueprints to size. The extra margin will also help protect the drawing when it is repeatedly handled or attached to the drawing board later for revisions.

3.3.0 Basic Format

The following discussion deals with the basic drafting format. By basic format, we mean the title block, revision block, list of materials, and other information that must be placed on applicable size drafting sheets. Although you may find slight variations on local-command-prepared drawings, the basic format specified in MIL-HDBK-1006/1 is required on all **_NAVFACENGCOM_** drawings.

3.3.1 Title Block

The primary purpose of a drawing title block is to identify a drawing. Title blocks must be uniform in size and easy to read. You may mechanically letter or freehand letter a title block or use commercially available standard size drafting sheets with preprinted title blocks.

Generally, place the title block in the lower right-hand corner of the drawing sheet, regardless of the size of the drawing (except for vertical title block). You will use three sizes of title blocks: a block for A-, B-, C-, and G-size drawings (*Figure 4-20*), a slightly larger block for D-, E-, F-, H-, J-, and K-size drawings (*Figure 4-21*), and a vertical title block (*Figure 4-22*). The vertical title block format must be used for all 22-inch by 34-inch (D-size) drawings and is optional for 28-inch by 40-inch (F-size) drawings.

Note: All dimensions are in inches. 1 inch = 25.4 mm.

Figure 4-20 – Preparing title block for A-, B-, C-, and G-size drawings.

Note: All dimensions are in inches. 1 inch = 25.4 mm.

Figure 4-21 – Preparing title block for D-, E-, F-, H-, J-, and K-size drawings.

Figure 4-22 – Example of vertical title block prepared by NAVFACENGCOM.

In a multiple-sheet drawing, use either the basic title block or a "continuation sheet title block" format (*Figure 4-23*) for second and subsequent sheets provided all sheets are the same size. Certain information common to all drawings in the basic title block is optional in the continuation sheet title block.
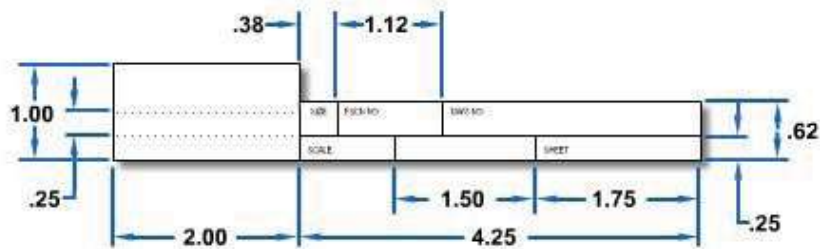
A. Continuation Sheet Title Block For A-, B-, C-, and G- Size Drawings
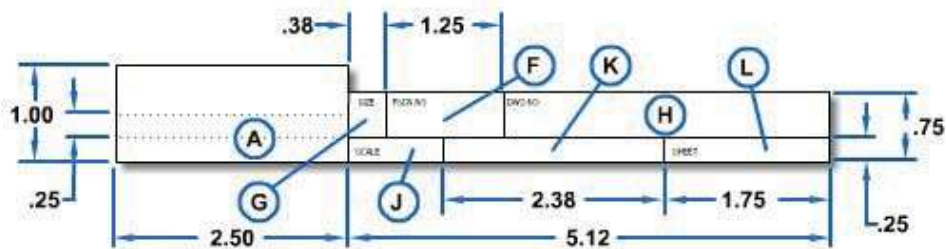
B. Continuation Sheet Title Block For D-, E-, F-, H-, J-, and K-, Size Drawings

C. Example of Multiple Sheet Numbering

Figure 4-23 – Use of continuation sheet title block and multiple sheet numbering.

Figure 4-20 shows the letter designations used to locate the following title block information.

(A) Record of preparation: This information will vary with each command or activity, but will normally include the dates and the surnames of the persons concerned with the preparation of the drawing. You may also place the applicable work request number or locally assigned drawing number in the upper portion of this space. This block is optional for continuation sheets.

(B) Drawing title: In the space provided for the drawing title, you will include the general project and the specific features shown on the drawing.

Example 1:

```
+----------------------------------------------------+
|                RESTROOM FACILITIES                 |
|                   SEABEE PARK                      |
|                                                    |
|                  ARCHITECTURAL                     |
|                                                    |
|       PLANS, ELEVATIONS, SECTIONS, DETAILS         |
+----------------------------------------------------+
```

Example 2:

```
+----------------------------------------------------+
|                 DEFINITIVE DRAWING                 |
|                                                    |
|                  BERTHING PIER                     |
+----------------------------------------------------+
```

Once you enter the general project (such as RESTROOM FACILITIES, SEABEE PARK, in example 1) in the title block of sheet 1, do not repeat it on each sheet of a set of multiple-project drawings. Example 2 is the title taken from the title block of a drawing contained in NAVFAC P-272, Definitive Designs for Naval Shore Facilities. In this example the general project or common title, DEFINITIVE DRAWING, appears as the top line title on all drawings in NAVFAC P-272. This block is optional for continuation sheets.

(C) <u>Preparing activity</u>: Reserve this space for the name and location of the activity preparing the drawing. In addition, place the words DEPARTMENT OF THE NAVY in this space. This block is optional for continuation sheets.

The information you place in spaces (D) and (E) (*Figure 4-21*) varies with each command and with the purpose of the drawing (*Figure 4-24*). You will usually reserve one space for the signature of (APPROVED BY) your commanding officer or officer in charge and the other space for the signature of the commander of the activity or command requiring the drawing (SATISFACTORY TO). As *Figure 4-24* shows in the examples, these two spaces may be used interchangeably. This is acceptable as long as you maintain consistency. It is also acceptable to use only space (E) when a SATISFACTORY TO space is not required for the drawing as shown on the NAVFAC title blocks in *Figures 4-25* and *4-26*. In this case, you will either extend the (F) space upward or the (A) space downward if you require additional space. If you do not require these blocks, you can combine them into block (A) for continuation sheets or use them for other purposes.

Figure 4-24 – Examples of title blocks used on drawings prepared by Naval Construction Battalion and Naval Construction Regiment.

Figure 4-25 Example of a title block prepared by an activity not requiring NAVFACENGCOM

Figure 4-26 – Example of a title block used on drawing prepared by NAVFACENGCOM.

(F) <u>Code identification number</u>: The federal supply code for manufacturers (**FSCM**) is a five-digit number used to identify the government design activity; that is, the activity having responsibility for the design of an item. For most of your drawings, NAVFAC has the ultimate design responsibility, therefore, you will use the identification number "80091" in the title block of all NAVFACENGCOM drawings. You may choose to use either "FSCM" or "Code 10" (the terms are interchangeable) in the title block.

(G) <u>Drawing size</u>: Reserve this space for the letter designating the drawing format size.

(H) <u>Drawing number</u>: If the drawing is prepared for or by NAVFACENGCOM, you will use a NAVFAC drawing number. MIL-HDBK 1006/1, *Policy and Procedures for Project Drawing and Specification Preparation* covers the assignment of NAVFAC drawing numbers. If the drawing does not require a NAVFAC drawing number, leave this space blank and use a local command drawing number in space (A). Occasionally, local title blocks require the drawing number to be in space (H). (*Figure 4-24.*)

(J) <u>Scale</u>: Record the scale used to prepare the drawing in this space. When you use more than one scale in the drawing, use the words AS SHOWN or AS NOTED after the word SCALE in space (J). If the drawing is not to scale, enter the word NONE in this space.

(K) <u>Specification number</u>: If you prepared the drawing for NAVFACENGCOM, use this space for the project specification or contract number. If the drawing does not pertain to a particular project specification or contract, you will normally leave this space blank.

(L) <u>Sheet number</u>: On a single construction drawing, you will enter SHEET 1 of 1 in this space. For numbering of second and subsequent sheets in a multiple-sheet drawing (*Figure 4-23, View C*), similar drawing numbers appear in both basic and continuation sheet title blocks; however, you will enter the total sheet number on sheet 1 and the specific sheet number on each subsequent sheet.

3.3.2 Satisfactory To Block

In addition to spaces (D) and (E) on the title block, which are provided for approval signatures, you may require a second SATISFACTORY TO block when an outside activity requests a drawing. The extra SATISFACTORY TO block is identical to the SATISFACTORY TO space in the title block but is located adjacent to title block space (F).

3.3.3 Revision Block

A REVISION block contains a list of all revisions made to the drawing. On construction drawings, you will place the revision block in the upper right-hand corner. Basically, all revision blocks provide the same information; only the sizes of the blocks differ (*Figure 4-27, Slide 1*). Enter revision information chronologically starting at the top of the revision block.

Use revision letters to identify a change or revision to a drawing. Use uppercase letters in alphabetical sequence, omitting the letters I, O, Q, S, X, and Z. Assign the letter A to the first revision to a drawing. Identify all changes that are incorporated in a drawing at one time by the same revision letter. You may number the changes sequentially to permit ready identification of a specific change. In this case, the appropriate serial number will appear as a suffix to the revision letter (for example, A1, A2, A3, etc.). Whenever possible, place the revision letter near the actual change on the drawing, positioning it so it will not be confused with other symbols on the drawing. Usually, you will place the revision letter inside of a circle or triangle. If you use a circle or triangle on the drawing, you should also use it in the revision block.

Make a brief description of each change in the description column, adjacent to its revision letter, in the revision block. Also add the approval signature and date of revision in the appropriate columns. If you are preparing the drawing for Architect/Engineer (A/E) firms, your revision block should include a separate PREPARED BY column (*Figure 4-27, Slide 2*).
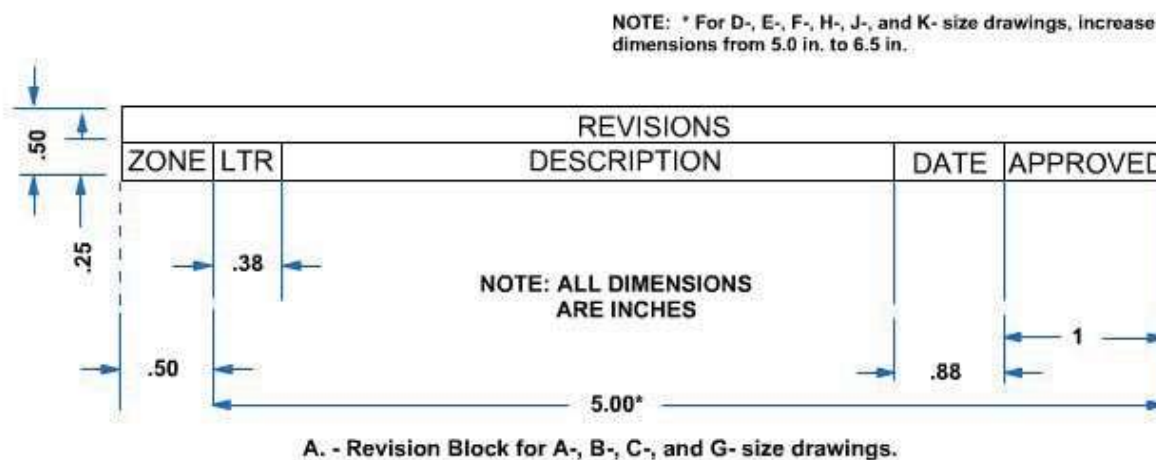
Figure 4-27 – Format used in preparing revision blocks.

You will normally omit the zone column on the standard revision block on construction drawings but you may use it in reviewing maps. Indicate zones by alphabetical or numerical entries and space them evenly in the margin for locating an object on the drawing or map. DoD-STD-100C describes the use of zoning. Like title blocks, revision blocks may vary with each command, and you will be required to follow command guidelines. DoD-STD-100C covers the procedure for making revisions to drawings.

3.3.4 Bill of Materials

When you use a BILL OF MATERIALS block on a construction drawing, place it directly above the title block against the right-hand margin. A bill of materials is a tabulated list of material requirements for a given project. The size of the BILL OF MATERIALS block will depend on the size of the drawing and the number of material items listed. On most

construction projects, it is impossible to list all items in a single BILL OF MATERIALS block; therefore, omit it from the drawings; an estimator will prepare a separate list of materials.

4.0.0 LINE CONVENTIONS

When you are preparing drawings, you will use different types of lines to convey information. Line characteristics, such as widths, breaks in the line, and zigzags, have definite meanings. *Figure 4-28*, taken from DoD-STD-100C, shows the different types of lines you should use on your drawings.

The widths of the various lines on a drawing are very important in interpreting the drawing. DoD-STD-100C specifies that three widths of line should be used: thin, medium, and thick. As a general rule, on ink drawings, these three line widths are proportioned 1:2:4, respectively. However, the actual width of each type of line should be governed by the size and type of drawing.

The width of lines in format features (that is, title blocks and revision blocks) should be a minimum of 0.015 inches (thin lines) and 0.030 inches (thick lines). To provide contrasting divisions between elements of the format, use thick lines for borderlines, outline of principal blocks, and main divisions of blocks. Use thin lines for minor divisions of title and revision blocks and bill of materials. Use medium line widths for letters and numbers.

You cannot control the width of lines drawn with a pencil as well as the width of lines drawn with pen and ink. However, pencil lines should be opaque and of uniform width throughout their length. Cutting plane and viewing plane lines should be the thickest lines on the drawing. Lines used for outlines and other visible lines should be differentiated from hidden, extension, dimension, or center lines.

LINE STANDARDS			
Name	Convention	Description and Application	Example
Center Lines		Thin lines made up of long and short dashes alternately spaced and consistent in length. Used to indicate symmetry about an axis and location of centers.	
Visible Lines		Heavy unbroken lines. Used to indicate visible edges of an object	
Hidden Lines		Medium lines with short evenly spaced dashes. Used to indicate concealed edges	
Extension Lines		Thin unbroken lines. Used to indicate extent of dimensions	
Dimension Lines		Thin lines terminated with arrow heads at each end. Used to indicate distance measured	
Leader		Thin line terminated with arrowhead or dot at one end. Used to indicate a part, dimension or other reference	
Break (Long)		Thin, solid ruled lines with freehand zigzags. Used to reduce size of drawing required to delineate object and reduce detail	
Break (Short)		Thick, solid free hand lines. Used to indicate a short break	
Phantom or Datum Line		Medium series of one long dash and two short dases evenly spaced ending with long dash. Used to indicate alternate position of parts, repeated detail or to indicate a datum plane	
Stitch Line		Medium line of short dases evenly spaced and labeled. Used to indicate stitching or sewing	
Cutting or Viewing Plane / Viewing Plane Optional		Thick solid lines with arrowhead to indicate direction in which section or plane is viewed or taken	
Cutting Plane for Complex or Offset Views		Thick short dashes. Used to show offset with arrowheads to show direction viewed	

Figure 4-28 – Use of line characteristics and conventions.

4.1.0 Construction Lines

Usually the first lines that you will draw are construction lines. Use these same lines to lay out your drafting sheet; you will also use them to lay out the rest of your drawing. Line weight for construction lines is not important since they will not appear on your finished drawing. Construction lines should be heavy enough to see, but light enough to erase easily; use a 4H to 6H pencil with a sharp, conical point. With the exception of light lettering guidelines, you must erase or darken all construction lines before a drawing is reproduced.
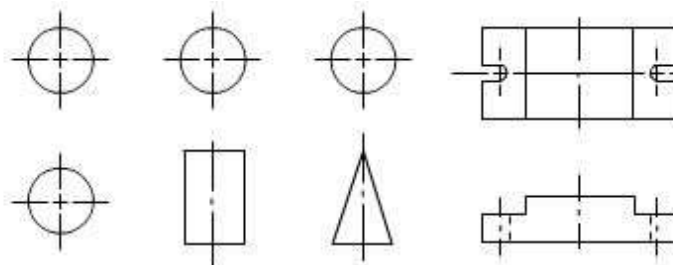
4.2.0 Center Lines

Use center lines to indicate the center of a circle, arc, or any symmetrical object. (See *Figure 4-29.*) Compose center lines with long and short dashes, alternately and evenly spaced, with a long dash at each end. Extend center lines at least % inch outside the object. At intersecting points, draw center lines as short dashes.

You may draw a very short center line as a single dash if there is no possibility of confusing it with other lines. You can also use center lines to indicate the travel of a moving center, as shown in *Figure 4-29*.
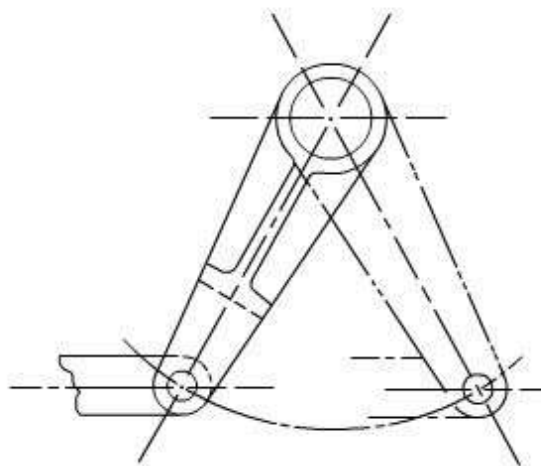
Figure 4-29 – Use of center lines.

4.3.0 Visible Lines

Draw the visible edge lines of the view as solid, thick lines. The visible edge lines include not only the outlines of the view, but lines defining edges that are visible within the view. (See *Figure 4-30.*)
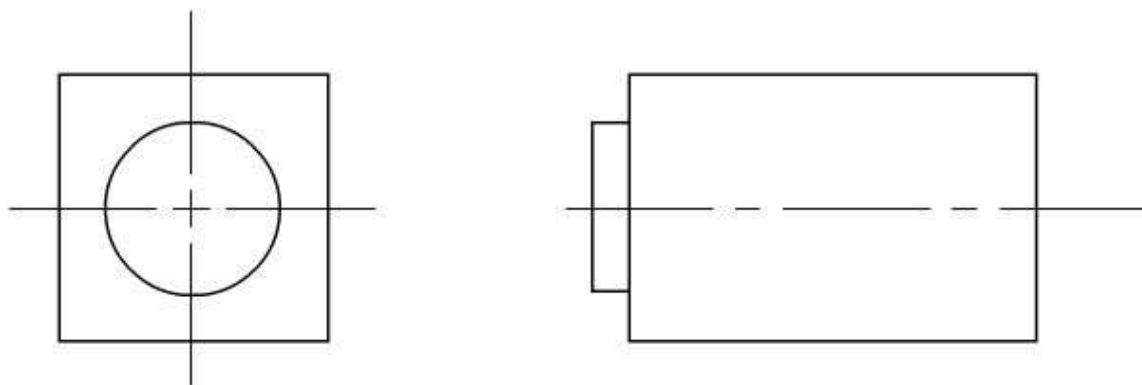
Figure 4-30 – Use of visible edge lines.

4.4.0 Hidden Lines

Draw hidden edge lines with short dashes and use them to show hidden features of an object. Begin a hidden line with a dash in contact with the line from which it starts, except when it is the continuation of an unbroken line. (See *Figure 4-31*.)
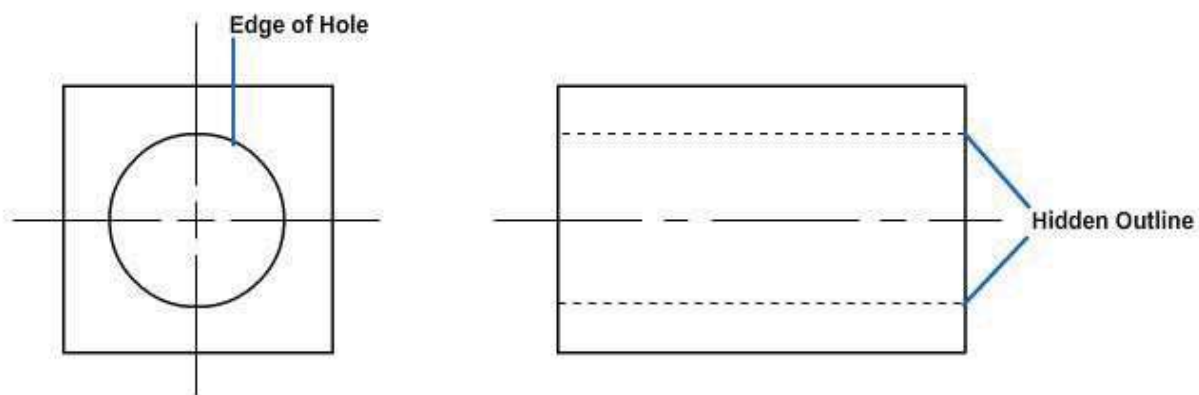
Figure 4-31 – Use of hidden edge lines.

To prevent confusion in the interpretation of hidden edge lines, you must apply certain standard techniques in drawing these lines. A hidden edge line that is supposed to join a visible or another hidden line must actually contact the line, as shown in the upper views of *Figure 4-32*; the lower views show the incorrect procedure.
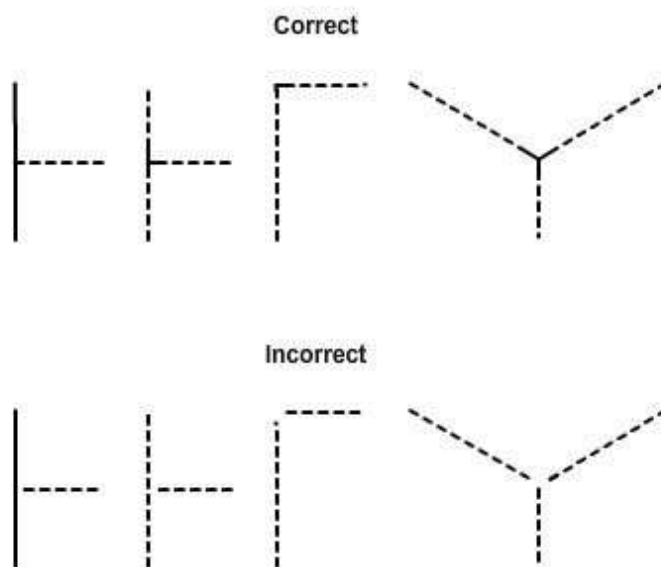
Figure 4-32 – Correct and incorrect procedures for drawing adjoining hidden lines.

Figure 4-33 shows an intersection between a hidden edge line and a visible edge line. Obviously, on the object itself the hidden edge line must be below the visible edge line. Indicate this face by drawing the hidden edge line as shown in the upper view of *Figure 4-33*. If you drew it as indicated in the lower view, the hidden edge line would appear to be above, rather than beneath, the visible edge line.

Correct   Incorrect

Figure 4-33 – Correct and incorrect procedures for drawing a hidden edge line that intersects a visible edge line.

Figure 4-34 shows an intersection between two hidden edge lines, one of which is beneath the other on the object itself. Indicate this fact by drawing the lines as indicated in the upper view of *Figure 4-34*. If you drew them as indicated in the lower view, the wrong line would appear to be uppermost.

Correct   Incorrect

Upper Line

Lower Line
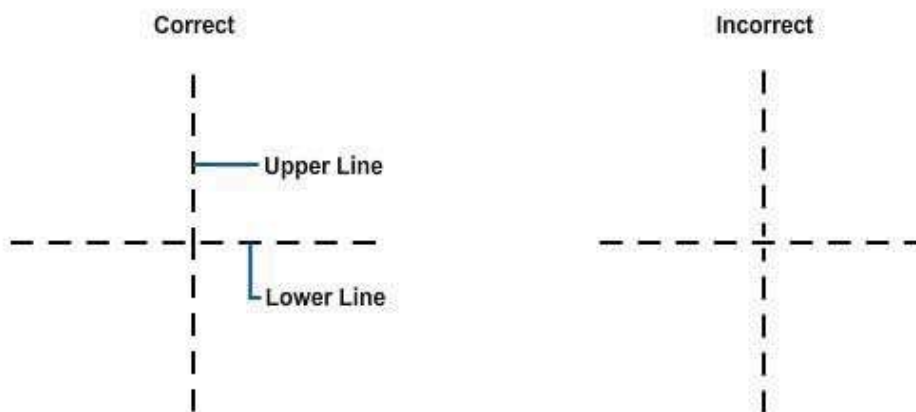
Figure 4-34 – Correct and incorrect procedures for drawing intersecting hidden edge lines that are on different levels.

4.5.0 Extension Lines

Use extension lines to extend dimensions beyond the outline of a view so that they can be read easily. Start these thin, unbroken lines about one sixteenth of an inch from the outline of the object and extend them about one-eight of an inch beyond the outermost dimension line. Draw extension lines parallel to each other and perpendicular to the distance you are showing. (*Figure 4-35*) In unusual cases, you may draw the extension lines at other angles as long as their meaning is clear.
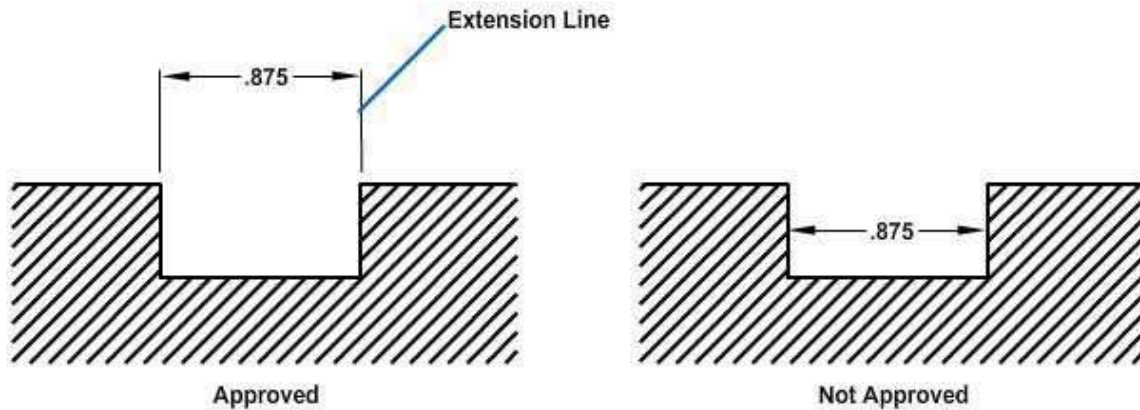
Figure 4-35 - Use of extension lines.

As far as practical, avoid drawing extension lines directly to the outline of an object. When extension lines must cross each other, break them as shown in *Figure 4-36*.
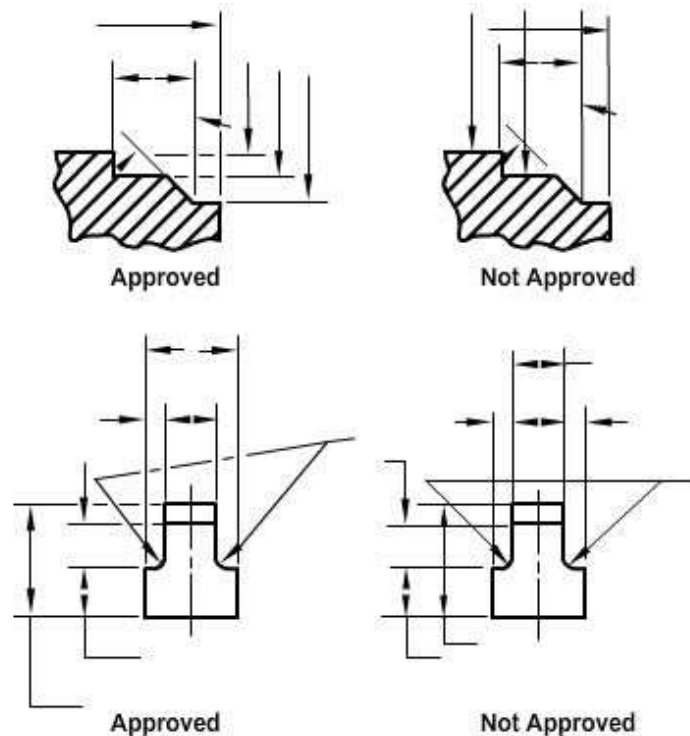
Figure 4-36 – Breaking extension lines and leaders at points of intersection.

4.6.0 Dimension Lines

Insert a dimension line, terminating at either end in a long, pointed arrowhead, between each pair of extension lines. You will draw a dimension line as a thin line with a break to provide a space for the dimension numerals (except in architectural and structural drafting). Occasionally, when you need to indicate the radius of an arc, you will draw an arrow only the end of the line that touches the arc. The other end, without an arrow, terminates at the point used as the center in drawing the arc. The arrowhead on a dimension or leader line is an important detail of a drawing. If you draw these arrowheads sloppily and varied in size, your drawing will not look finished and

professional. The size of the arrowhead used on a drawing may vary with the size of the drawing, but all arrowheads on a single drawing should be the same size, except occasionally when space is very restricted. The arrowheads you will use on Navy drawings are usually solid, or filled in, and are between one eighth and one fourth of an inch long, with the length about three times the spread. (See *Figure 4-37*.)

With a little practice, you can learn to make good arrowheads freehand. Referring to *Figure 4-37*, first define the length of the arrowhead with a short stroke as shown at A. Then draw the sides of the arrowhead as indicated at B and C. Finally, fill in the area enclosed by the lines, as shown at D.

Figure 4-37 – Method of drawing an arrowhead

4.7.0 Leaders

Use leaders to connect numbers, references, or notes to the appropriate surfaces or lines on the drawing. From any suitable portion of the reference, note, or number, draw a short line parallel to the lettering. From this line, draw the remainder of the leader at an angle (dog leg) to an arrowhead or dot. In this way, the leader will not be confused with other lines of the drawing. If the reference is to a line, always terminate the leader at this line with an arrowhead, as shown in *Figure 4-38*. However, a reference to a surface terminates with a dot within the outline of that surface.
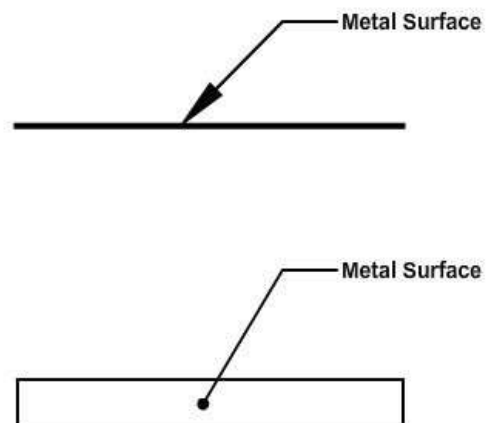
Figure 4-38 – Use of a leader.

4.8.0 Break Lines

You may reduce the size of an object's graphic representation (usually for the purpose of economizing on paper space) by using a device called a break. Suppose, for example, you wanted to make a drawing of a rectangle 1 ft wide by 100 ft long to the scale of 1/12, or 1 inch = 1 foot. If you drew the full length of the rectangle, you would need a sheet of paper 100 inches long. By using a break, you can reduce the length of the figure to a feasible length, as shown in *Figure 4-39*.

On the original object, the ratio of width to length is 1:100. You can see that on the drawing, the ratio is much larger (roughly 1:8). However, the break tells you that a considerable amount of the central part of the figure is presumed to be removed.

Use thick, wavy lines for a short break, as shown in *Figure 4-39, View A.* You will usually indicate a short break for rectangular sections with solid, freehand lines. For wooden rectangular sections, you will make the breaks sharper, with a serrated appearance, rather than wavy.

For long breaks, you will use full, ruled lines with freehand zigzags, as shown in *Figure 4-39, View* B. For wider objects, a long break might have more than one pair of zigzag lines.
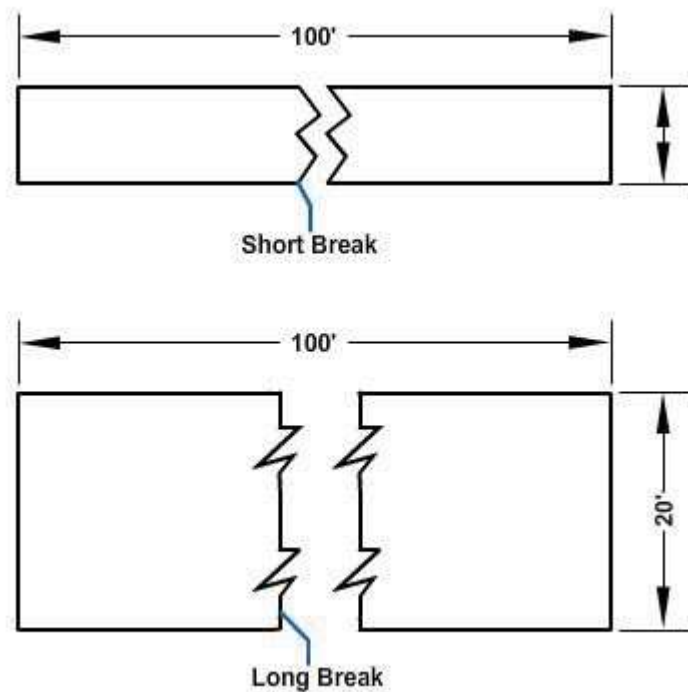
Figure 4-39 – Use of proper line conventions for (A) short break, and (B) long break.

For drawings made to a large scale, use special conventions that apply to drawing breaks in such things as metal rods, tubes, or bars. *Figure 4-40* shows the methods of drawing these breaks.
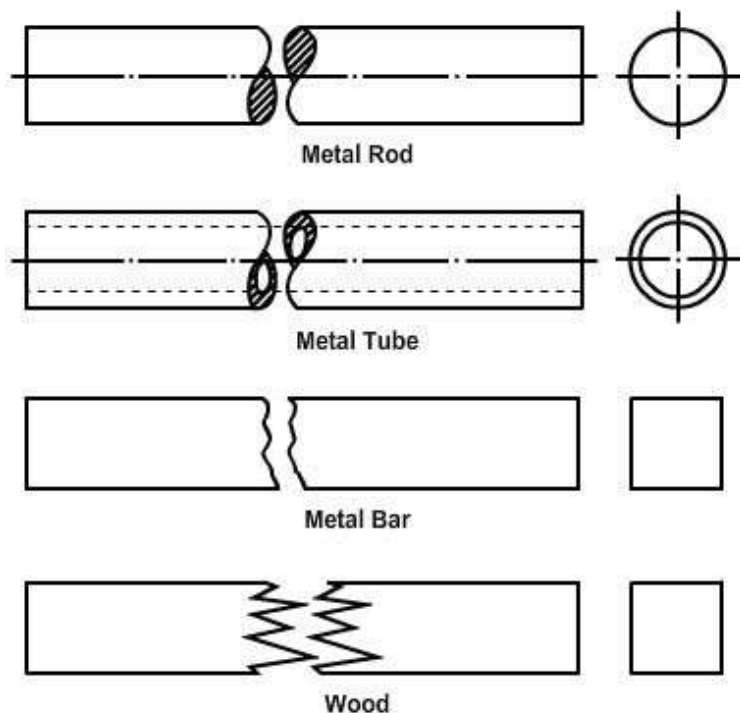
Figure 4-40 - Use of special breaks.

4.9.0 Phantom Lines
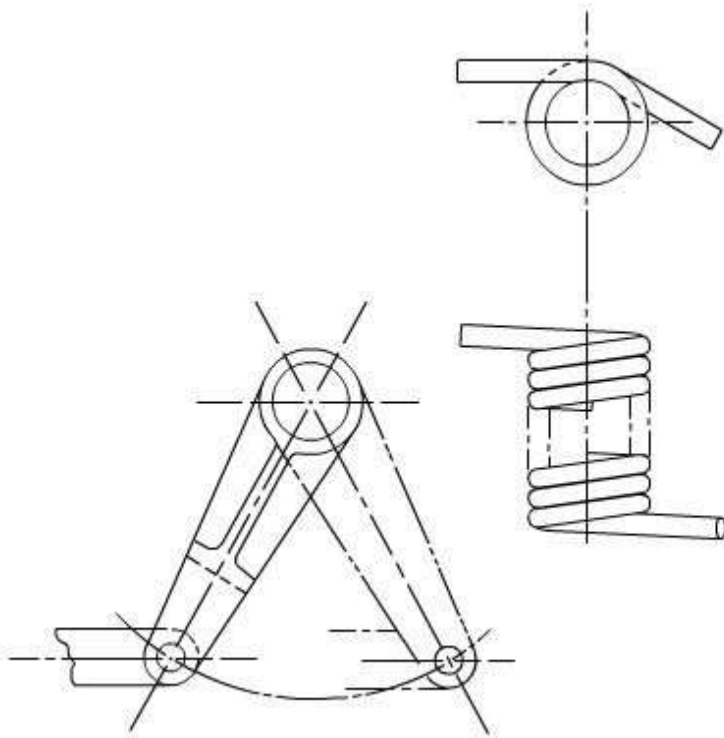
Figure 4-41 - Use of phantom lines.

You will use phantom lines most frequently to indicate a moving part's alternate position, as shown in the left-hand view of *Figure 4-41*. Draw the part in one position in full lines and in the alternate position in phantom lines.

You will also use phantom lines to indicate a break when the nature of the object makes the use of the conventional type of break unfeasible. The right hand view of *Figure 4-41* shows an example of this use of phantom lines.

4.10.0 Section Lines

Sometimes you can best convey the technical information in a drawing by a view that represents the object as it would look if part of it were cut away. A view of this kind is called a section.

The upper view of *Figure 4-42* shows a plan view of a pipe sleeve. The lower view is a section, showing the pipe sleeve as it would look, viewed from one side, if you cut it exactly in half vertically. The surface of the imaginary cut is crosshatched with lines called section lines.

According to DoD-STD-100C, "section lining shall be composed of uniformly spaced lines at an angle of 45 degrees to the baseline of the section. On adjacent parts, the lines shall be drawn in opposite directions. On a third part, adjacent to two other parts, the section lining shall be drawn at an angle of 30 to 60 degrees."

You can use the cross-hatching shown in *Figure 4-42* on any drawing of parts made of only one material (like machine parts, for example, which are generally made of metal). The cross-hatching

Figure 4-42 – Drawing of a plan view and a full section.

is the symbol for metals and may be used for a section drawing of any type of material.

A section like the one shown in *Figure 4-42*, which goes all the way through and divides the object into halves, is called a full section. If the section showed the sleeve as it would look if cut vertically into unequal parts, or cut only part way through, it would be a partial section. If the cut followed one vertical line part of the way down and then was offset to a different line, it would be an offset section.

4.11.0 Viewing or Cutting Plane Lines

Use *viewing plane lines* to indicate the plane or planes from which a surface or several surfaces are viewed.

Use *cutting plane lines* to indicate a plane or planes in which a sectional view is taken.

Use section views to give a clearer view of interior or hidden features of an object that cannot be clearly observed in conventional outside views.

Obtain a section view by cutting away part of an object to show the shape and construction at the cutting plane.

Notice the CUTTING PLANE LINE AA in *Figure 4-43, View A*; it shows where the imaginary cut has been made. The single view in *Figure 4-43*, V*iew B*, helps you to visualize the cutting plane. The arrows point in the direction in which you are to look at the sectional view.

Figure 4-43, View C is a front view showing how the object looks when cut it in half.

The orthographic section view of *Figure 4-43, View D* should be used on the drawing instead of the confusing front view in *Figure 4-43, View A*. Notice how much easier it is to read and understand.

Note that hidden lines behind the plane of projection are omitted in the sectional view. These lines are omitted by general custom, because the elimination of hidden lines is the basic reason for making a sectional view. However, lines that would be visible behind the plane projection must be included in the section view.

Figure 4-43 – Action of a cutting plane.

Cutting plane lines, together with arrows and letters, make up the cutting plane indications. Placing arrows at the end of the cutting plane lines indicates the direction to view the sections. The cutting plane may be a single continuous plane, or it may be offset if the detail can be shown to better advantage. On simple views, indicate the

cutting plane as shown in *Figure 4-43, View A*. On large, complex views or when the cutting planes are offset, indicate them as shown as in *Figure 4-44*

Identify all cutting plane indications with reference letters placed at the arrowhead points. When a change in direction of the cutting plane is not clear, place reference letters at each change of direction. When more than one sectional view appears on a drawing, letter the cutting plane indications alphabetically.

Include the letters that are part of the cutting plane indication as part of the title; for example, SECTION A-A, SECTION B-B, if the single alphabet is exhausted, multiples of letters may be used. You may abbreviate the word *SECTION*, if desired. Place the title directly under the section drawing.

Sect A-A
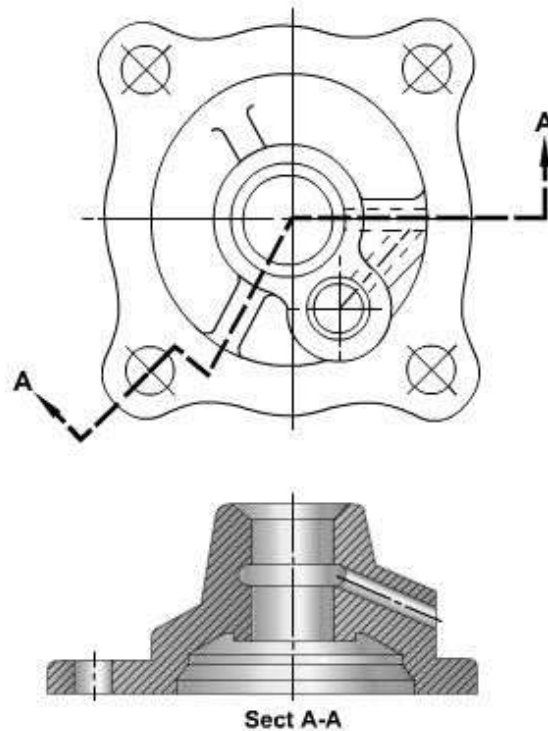
Figure 4-44 – Use of an offset section.

4.12.0 Datum Lines

Use a ***datum line*** to indicate a line or plane of reference, such as the plane from which an elevation is measured. Datum lines consist of one long dash and two short dashes equally spaced. Datum lines differ from phantom lines only in the way they are used.

4.13.0 Stitch Lines

Use ***stitch lines*** to indicate the stitching or sewing lines on an article. Stitch lines consist of a series of very short dashes (medium thickness), approximately half the length of the dash of hidden lines, evenly spaced. You can indicate long lines of stitching by a series of stitch lines connected by phantom lines.

4.14.0 Match Lines

Use ***match lines*** when an object is too large to fit on a single drawing sheet and must be continued on another sheet. Identify the points where the object stops on one sheet and continues on the next sheet with corresponding match lines.

Match lines are medium weight lines labeled with the words *MATCH LINE* and referenced to the sheet that has the corresponding match line. Examples of construction drawings that may require match lines are maps and road plans where the length is much greater than the width and reducing the size of the drawing to fit a single sheet is impractical.

5.1.1 ORDER of PENCILING

With experience, you will find that a drawing can be made far more efficiently and rapidly if all the lines in a particular category are drawn at the same time and if the various categories of lines are drawn in a specific order or succession.

Figure 4-45 shows the order in which the lines of the completed drawing (shown in the last view) were drawn. This order followed the recommended step-by-step procedures:

1. Draw all center lines.

2. Draw the principal circles, arcs, fillets, rounds, and other compass-drawn lines. A fillet is a small arc that indicates a rounded concave joint between two surfaces. A round is a small arc that indicates a rounded convex joint between two surfaces.

Figure 4-45 – Order of penciling a drawing.

3. Draw the horizontal and vertical outlines, visible lines, and hidden lines.

4. Draw the non-horizontal and non-vertical outlines, visible lines, and hidden lines.

5. Clean up the drawing, erasing all excess lines and construction lines. A construction line is a light line used only as a drawing guide.

6. Draw extension lines, dimension lines, section lines, and any other lines required.

7. Inscribe the dimensions and lettering.

To a limited extent you can vary the thickness of a pencil line by varying the extent to which you bear down on the pencil, but because you can't bear down very hard without troughing the paper, you can't get much variety in line weight with a pencil. If you will be inking over a drawing, this doesn't make any difference. However, if you will not be reproducing a drawing or will be reproducing it directly from the pencil original, you must follow the line conventions as closely as possible.

6.1.1 ORDER of INKING

As a novice, you may be intimidated by the prospect of inking a drawing without spoiling it. You can greatly reduce the danger of spoiling a drawing by learning how to use drawing instruments properly and following a definite order of inking. Nowadays, draftsmen prefer the reservoir pen or rapidograph to the ruling pen for inking straight and curved lines and even for lettering. On the other hand, you should NEVER use a ruling pen to ink freehand lines.

One good way to avoid smeared ink lines is by using *space blocks*. These strips of tape or thin pieces of plastic, when fastened to both faces of the triangles, french curves, or templates (*Figure 4-46*), raise their edges from the surface of the drafting paper and prevent ink from running under the edge.
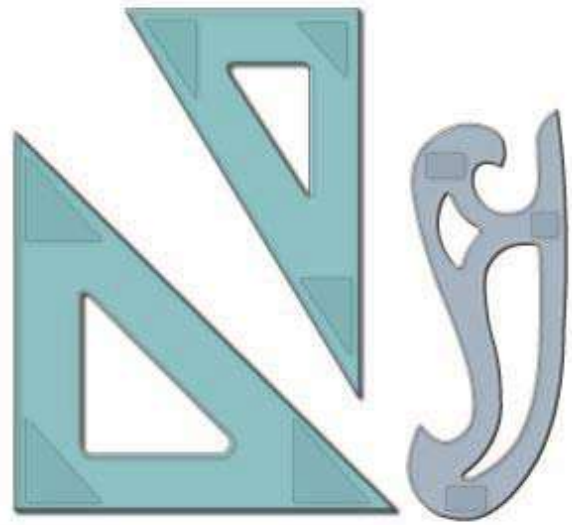
Figure 4-46 - Use of space blocks.

When you use a rapidograph or reservoir pen with a T square or parallel straightedge, make long lines with a whole arm movement and short lines with a finger movement.

Draw horizontal lines from left to right, starting at the top of the drawing and working down. (If you are left-handed, you will, of course, draw these lines from right to left, and similarly reverse many of the directions given in this training manual.)

Vertical lines are usually drawn in an upward direction, moving from left to right across the drawing. However, when you have to draw a number of vertical lines or lines slanted in the same direction, the way you draw them will be governed by the source of your light and the way you have found that you can draw vertical lines with greatest control.

Let the first lines dry before starting to draw any intersecting lines. Watch carefully when you draw one line across another line. You vary the thickness of ink lines by selecting a pen unit that matches your desired application and/or line convention.

The order generally recommended for inking is as follows:

1. Start inking from the top of the paper and progress toward the bottom.
2. Start inking all arcs of circles, fillets, rounds, small circles, large circles, and other compass-drawn lines.
3. Ink all irregular curves, using a French curve or a spline as a guide.
4. Ink all thick horizontal lines, then all medium and thin lines.
5. Start at the left edge and ink the thick first, the medium next, and finally the thin vertical lines from left to right.
6. Follow the same procedure described in (4) and (5) for slanting lines.
7. Ink section lines, dimensions, and arrowheads.
8. Ink notes and title, meridian symbol, and graphic scales.
9. Ink borders and check inked drawing for completeness.

10. Use an art gum or a kneaded eraser to erase pencil marks or for final cleanup of the drawing.

7.0.0 LETTERING

You cannot convey all of the information presented in a drawing by graphic shapes and lines alone. To make a drawing informative and complete, you must include lettering in the form of dimensions, notes, legends, and titles.

Lettering can either enhance your drawing by making it simple to interpret and pleasant to look at, or it can ruin your drawing by making it difficult to read and unsightly in appearance. Mastering the techniques and skills required for neat, legible lettering is essential.

7.1.0 Freehand Lettering

As you work with experienced draftsmen, you will notice their freehand lettering adds style and individuality to their work. They take great pride in their freehand lettering ability. By learning basic letter forms and practicing constantly, you will soon be able to do a creditable job of lettering and acquire your own style and individuality. Anyone who can write can learn to letter. As you practice, you will steadily improve both your style and the speed with which you can letter neatly. Don't give up if your first attempts do not produce neat lettering. Don't be afraid to ask your supervisor for a few pointers. You will gain an understanding of the letter shapes and the ability to visualize them by drawing them until the muscles of your hand are accustomed to the pattern of the strokes that make up the letters. You should be able to draw good letters without consciously thinking of this pattern.

Your position and how you hold your pencil will greatly affect your lettering. You should sit up straight and rest your forearm on the drawing board or table. Hold the pencil between the thumb, forefinger, and second finger; the third and fourth fingers and the ball of the palm rest on the drawing sheet. Do not grip the pencil tightly. A tight grip will cramp the muscles in your fingers, causing you to lose control. If you get "writer's cramp" easily, you are probably holding your pencil too tightly. The pencil should be kept sharpened to produce uniform line weights. A conical-shaped pencil point works best for most lettering. Usually, an F or H pencil is used for lettering. A pencil that is too hard may cut into the paper, or it may produce lettering that will not reproduce easily. A pencil that is too soft will require frequent sharpening, and it will produce lettering that may smear easily on a drawing.

7.2.0 Guidelines

Figure 4-47 shows the use of light pencil lines called guidelines. Guidelines ensure consistency in the size of the letter characters. If your lettering consists of capitals, draw only the cap line and base line. If lowercase letters are included as well, draw the waist line and drop line.

Figure 4-47 – Example of laying off guidelines use.

The waist line indicates the upper limit of the lowercase letters. The **ascender** is the part of the lowercase letter that extends above the body of the letter; for example, the dot portion of the character *i* in *Figure 4-47*. All ascenders are as high as the caps. The drop line indicates the lower limit of the lowercase letters. The **descender** is the part of the lowercase letter that extends below the body of the letter, an example being the tail of the character *g* in *Figure 4-47*. The vertical distance from the drop line to the base line is the same as the vertical distance from the waist line to the cap line. It is about one third of the vertical distance between the base line and the cap line, or about one half of the vertical distance between the base line and the waist line.

Figure 4-48 shows an easy way to lay out guidelines for caps and lowercase. Let the height of a capital be 1 1/2 times the distance "a." Set a compass or dividers to distance "a," and lay off distance "a" above and below the midline selected for the guidelines. This method locates the cap line and the drop line. Then set the compass or dividers to one half of "a," and lay off this distance above and below the midline. This method locates the waist line and the base line.

Figure 4-48 - Laying off guidelines.

To help you keep your lettering vertical, construct vertical guidelines, spaced at random along the horizontal guidelines. For inclined lettering, lay off lines inclined at the angle you wish your lettering to be slanted. (*See Figure 4-49*) Inclined lines are known as direction lines and are normally slanted at a maximum of 68 degrees.
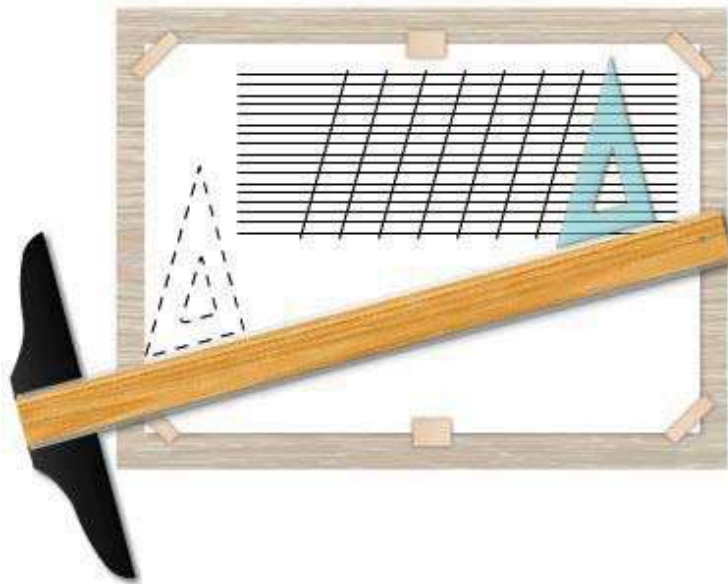
Figure 4-49 – Laying off lines for lettering.

7.2.1 Ames Lettering Instrument

If you have many lines of lettering to do, you will find a lettering instrument, such as the Ames lettering instrument, shown in *Figure 4-50,* quite useful and timesaving. The top-left section of *Figure 4-50*, shows how to use this instrument in conjunction with a T square to draw properly spaced horizontal guidelines. Insert the point of your pencil through one of the holes, and the instrument slides along the T square as you move the pencil across the page. The enlarged drawing of the instrument in the lower part of the figure shows the details of how the instrument is used. Notice the three rows of holes in the circular disc of the instrument. The holes in the center row are equally spaced guidelines.
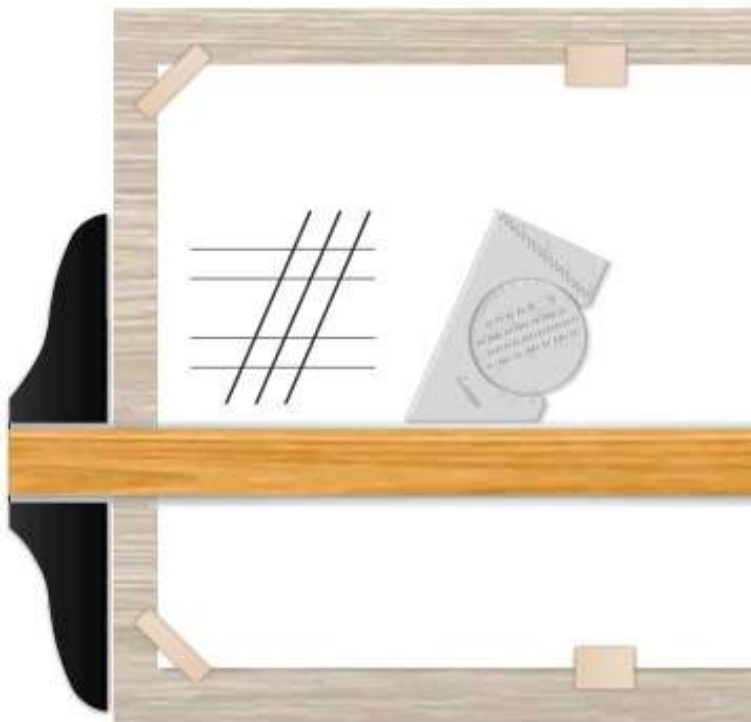
Figure 4-50 – Using the Ames lettering instrument.

Use the two outside rows for drawing both capital and lowercase guidelines. Use the left row to get a proportion of 3 to 5 for lowercase and capital letters, and the right row for a proportion of 2 to 3.

You can use the Ames lettering instrument to create lettering ranging in height from 1/16 to 5/16 inches. You can attain different letter heights by rotating the circular disc within the outer section of the instrument. Use the numbers along the bottom edge of the disc to set the instrument for a particular letter height. A number aligned with the index line on the outer section of the instrument indicates the height of the lettering in 32nds of an inch. In *Figure 4-50*, the number 8 is aligned with the index; therefore, the distance between the capital letter guides produced by this setting is 8/32 inch or % inch.

By standing the Ames lettering instrument on its greater sloping side, you can use it for drawing guidelines for inclined lettering that slope at an angle of 67 1/2 degrees with the horizontal. (See the upper-right portion of *Figure 4-50*.)

7.2.2 tween Guidelines

The spacing between two lines of capitals may vary from one half of the height to the full height of a capital. Two thirds of the height is customarily used.

The spacing commonly used between lines of lowercase letters is shown in *Figure 4-51*. The space indicated by the letter *S* equals the vertical distance between the waist line and the cap line.
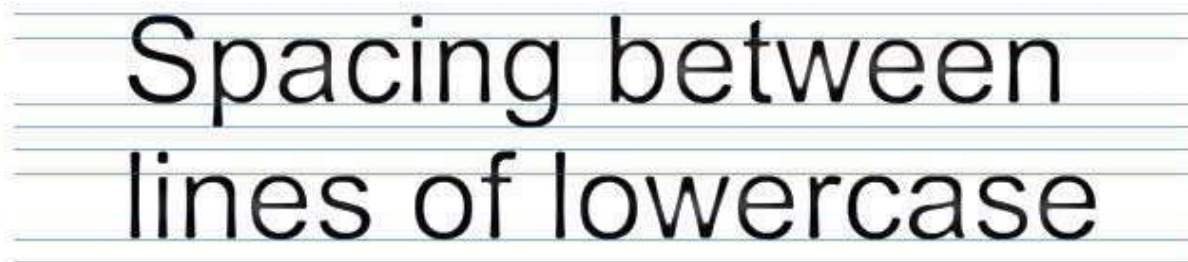
Figure 4-51 – Spacing between lines of lowercase letters.

7.3.0 Vertical Single-Stroke Gothic Lettering

The generally accepted style of lettering for SEABEE drawings is the single-stroke Gothic vertical (*Figure 4-52*) or inclined lettering. The term *Gothic* refers to the style of letters. Gothic lettering is the simplest style to make and the easiest to read on a drawing. Single-stroke means that each stroke of the letter is made by one stroke of the pencil. *Figure 4-53* shows the basic strokes required for single-stroke lettering. Draw vertical strokes from the top down with an even finger movement. (You draw Inclined

A B C D E F G H I J K L M
N O P Q R S T U V W X Y Z

a b c d e f g h i j k l m
n o p q r s t u v w x y z

1 2 3 4 5 6 7 8 9 0

$1\frac{1}{2}$ $\frac{3}{4}$ $\frac{5}{16}$ $\frac{7}{8}$
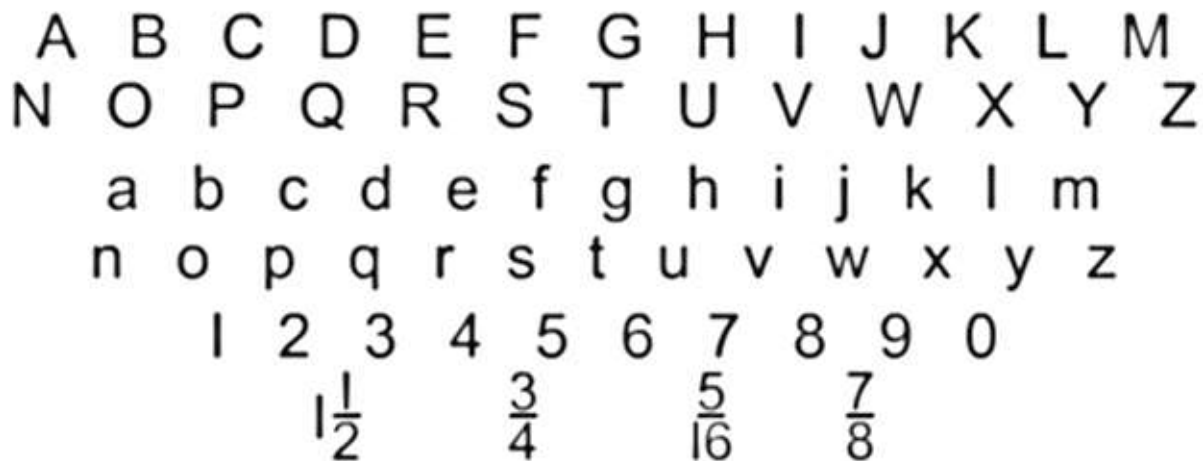
Figure 4-52 – Vertical single-stroke Gothic capitals and numerals.
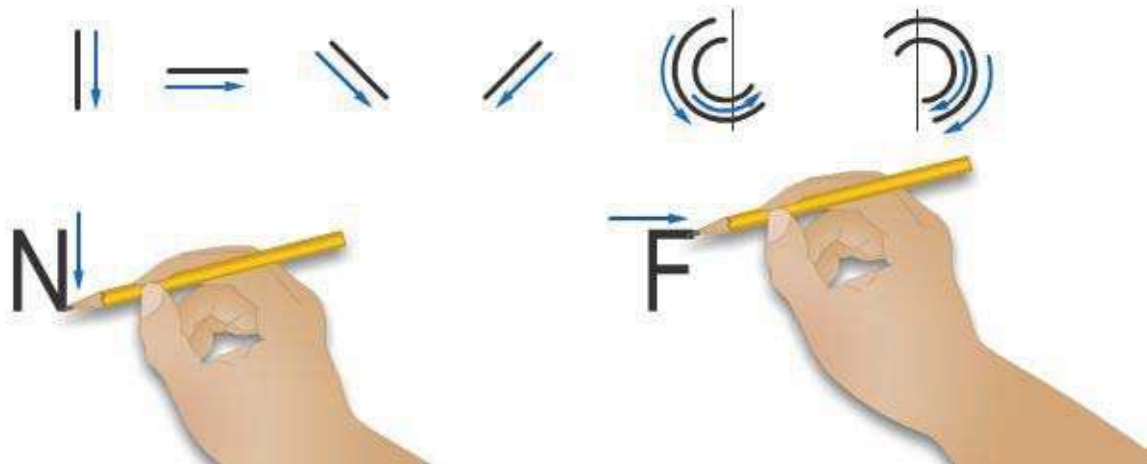
Figure 4-53 - Basic lettering strokes.

strokes in the same manner.) Draw horizontal strokes from left to right with a complete hand movement, pivoting at the wrist. Draw curved strokes proceeding from above downward, using a combined finger and wrist motion.

Draw lettering strokes; do not sketch them. It is important to use the correct direction and sequence of strokes recommended for each letter. We will discuss and show the required shapes of vertical single-stroke Gothic letters and numerals in the next several figures and paragraphs. To emphasize the proportions of the letters and numerals, each character is shown in a grid, six units high. The grid serves as a reference for comparing the height of the various characters in proportion to their width as well as locating the individual strokes that compose the characters. For learning purposes, the characters are grouped by the type of strokes required to form each character.

7.3.1 Straight-Line Capitals

The capital letters shown in *Figure 4-54* are formed with only straight-line strokes.

Z, X, Y, K. Stroke 2 of the *Z* is longer than stroke 1. The inclined strokes of the *X* are closer together at their starting than at their finishing points. The three strokes of the *Y* intersect slightly below the center of the square. Stroke 2 of the *K* intersects stroke 1 at a point one third of the distance up from the base line. Stroke 3, if extended, would intersect stroke 1 at the top. See *Figure 4-54.*
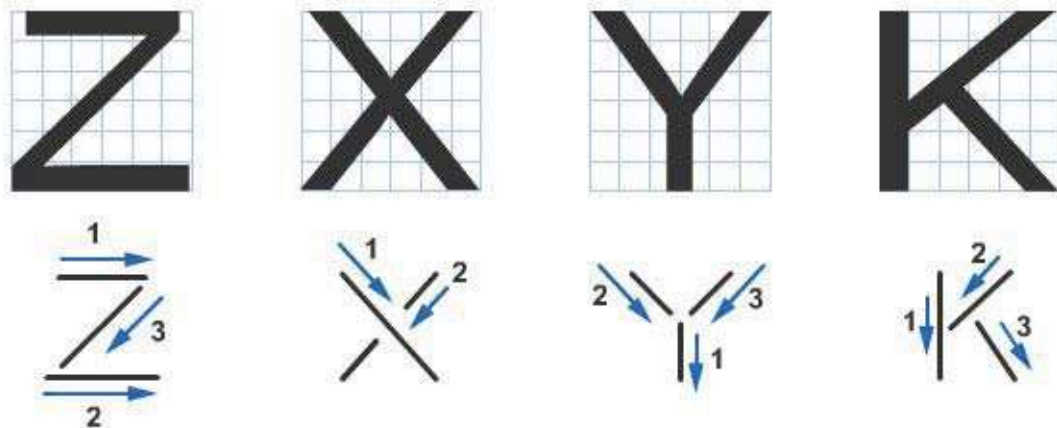
Figure 4-54 – Basic lettering strokes for *Z, X, Y,* and *K.*

I, A, L, T. The letter *I* is the basic vertical stroke. Inclined strokes 1 and 2 of the *A* intersect just above the cap line; stroke 3 is located one third of the distance up from the base line. Draw the horizontal stroke of the *T* first; then draw the vertical stroke or stem from the center. With both *L* and *T,* the horizontal stroke may be lengthened or shortened to balance the letters in a word. If, for example, *L* precedes *A,* reduce its horizontal stroke slightly; if *T* precedes *A,* extend its horizontal stroke slightly. See *Figure 4-55.*
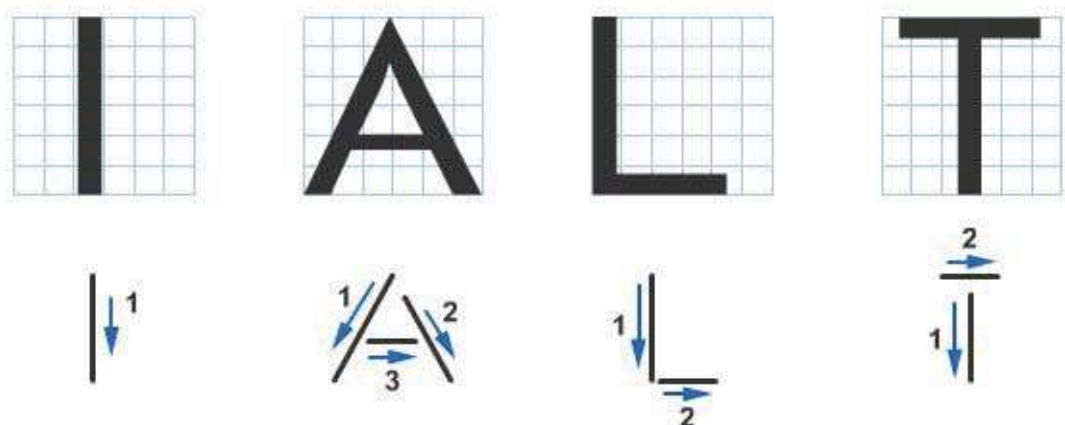
Figure 4-55 – Basic lettering strokes for *I, A, L,* and *T.*

E, H, F. In *E, H,* and F, the central horizontal bar is placed slightly above the center for stability. In both *E* and *F,* the cap line stroke is four units long and the central stroke is three fifths of this length. The base line of *E* is one-half unit longer than its cap line. See *Figure 4-56.*
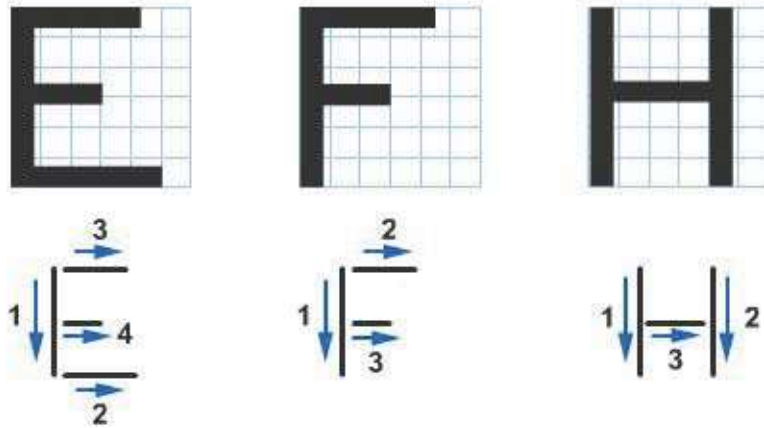
Figure 4-56 – Basic lettering strokes for *E, F,* and *H.*

M, N, W, V. The two inclined strokes of the *V* intersect just below the base line. The *W* is 1 1/3 times the width of a normal letter; note that it is wider than *M.* Strokes 1, 2, 3, and 4 of the *W* intersect below the base line. Strokes 3 and 4 of the *M* and 2 and 3 of the *N* intersect on the base line. Note that the outside strokes of the *M* and *N* are drawn first. See *Figure 4-57.*
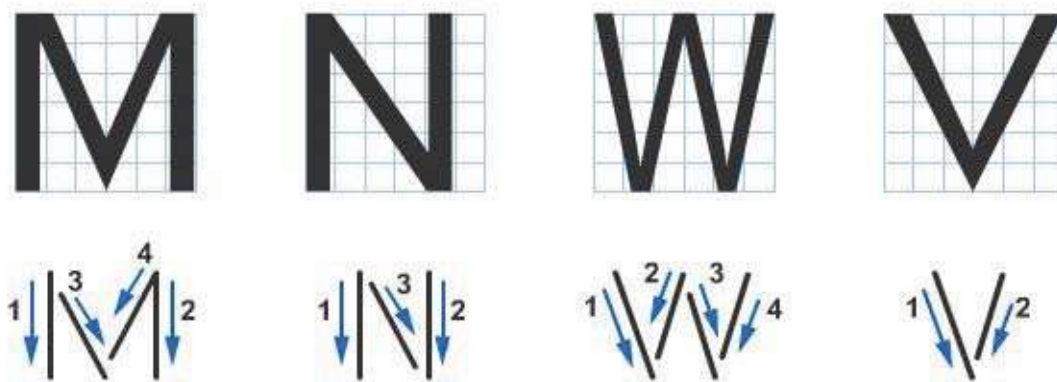
Figure 4-57 – Basic lettering strokes for M, N, W, and V*.*

7.3.2 Curved and Straight-Line Combinations

Figures 4-58 through *4-61* show capital letters formed by either curved line strokes or by a combination of curved- and straight-line strokes.

O, Q, C, G. The *O* and *Q* are complete circles; *C* and *G* are not the full width of the square because they are not full circles. The tail of *Q,* if extended, would intersect center of the circle. Stroke 4 of *G* begins at the center of the circle. See *Figure 4-58.*

U, J, D. Stroke 3 of *U* is elliptical and connects two parallel vertical lines a third of the distance above the base line. Stroke 2 of *J* is similar but not so broad. Stroke 4 of *D* is circular, joining two horizontal segments. See *Figure 4-59.*

P, R, B. The horizontal midstrokes of *P* and *R* lie just below the midpoint, and the horizontal midstroke of *B* lies just above the midpoint. Horizontal stroke 4 in *B* is slightly longer than strokes 2 and 3, which are the same length. See *Figure 4-60.*

S and &. The upper and lower portions of *S* are ellipses, the upper slightly smaller than the lower. The ampersand *(&)* is basically similar despite a greater difference in the sizes of the ellipses. See *Figure 4-61.*
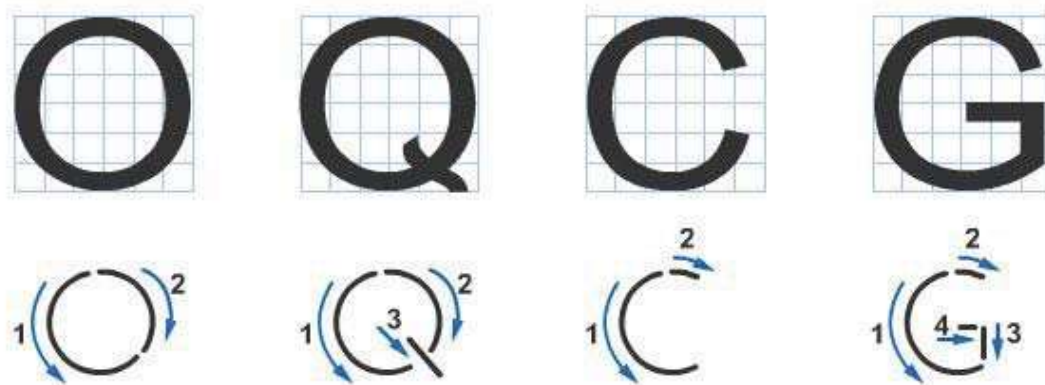
Figure 4-58 – Basic lettering strokes for *O, Q, C,* and *G.*
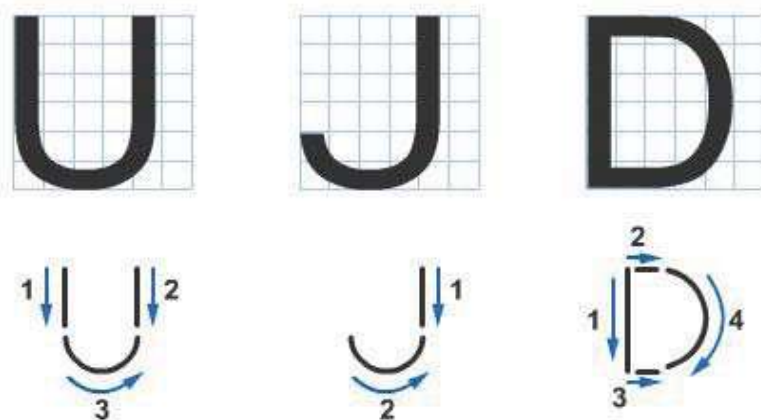
Figure- 4-59 – Basic lettering strokes for *U, J,* and *D.*
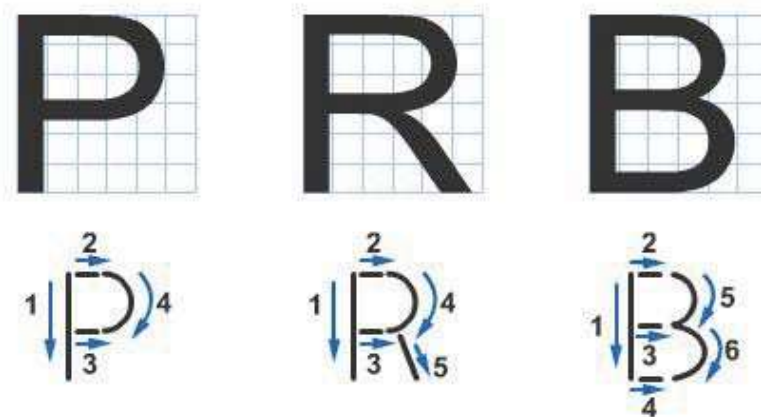
Figure 4-60 – Basic lettering strokes for *P, R,* and *B.*

7.3.3 Numerals and Fractions

It is vitally important for you to take extreme care in drawing numerals, particularly in the preparation of construction drawings. A poorly drawn numeral can cause costly errors and delays.

Draw numerals using the same size guidelines as the capital letters on a drawing. Place vertical guidelines at random. Do not make numerals too small or crowded, since this can impair their legibility.

Figure 4-62 shows that the vertical stroke of the numeral 4 is placed two units from the right side. The horizontal bar is one quarter the height of the number above the base line. Note that the closed curves of *0, 6,* and *9* are elliptical, not circular. The *6* is an inverted *9.* The *8* is composed of two ellipses tangent slightly above the center point. The top ellipse also is narrower. The *3* is the same as the *8* with the left portions of the loops cut off. The curved lines of *2* follow the elliptical contours of *8.* The top portion of the *5* is slightly narrower than the bottom. The bottom ellipse is two thirds of the height of the figure from the base line.
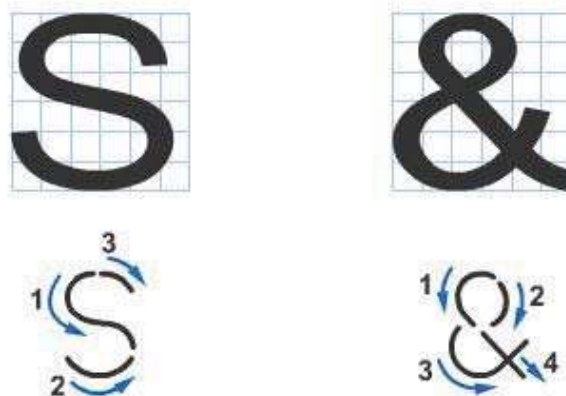
Figure 4-61 – Basic lettering strokes for *S* and *&.*
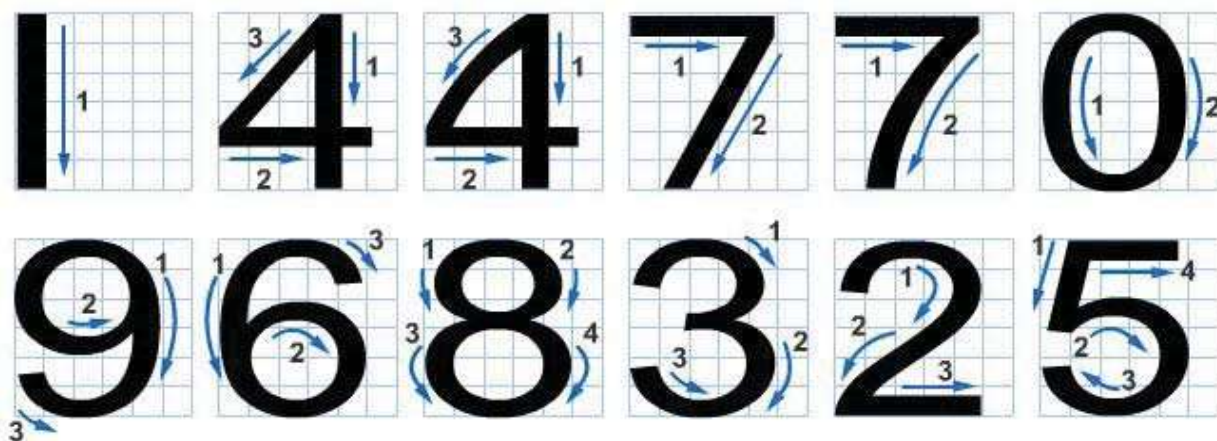
Figure 4-62 - Lettering vertical numerals.

Always draw the division bar between the numerator and denominator of the fractions as parallel to the guidelines, as shown in *Figure 4-63*. The complete height of a fraction is twice that of a whole number. Center the division bar midway between the base line and cap line. Space the top guideline of the numerator and the bottom guideline of the denominator a full number height from the division bar. The numbers composing a fraction are three quarters of the height of a full number. The clear space on either side of the division bar is one quarter of a full number. Center the numbers in a fraction about a vertical guideline that cuts the fraction bar in half.
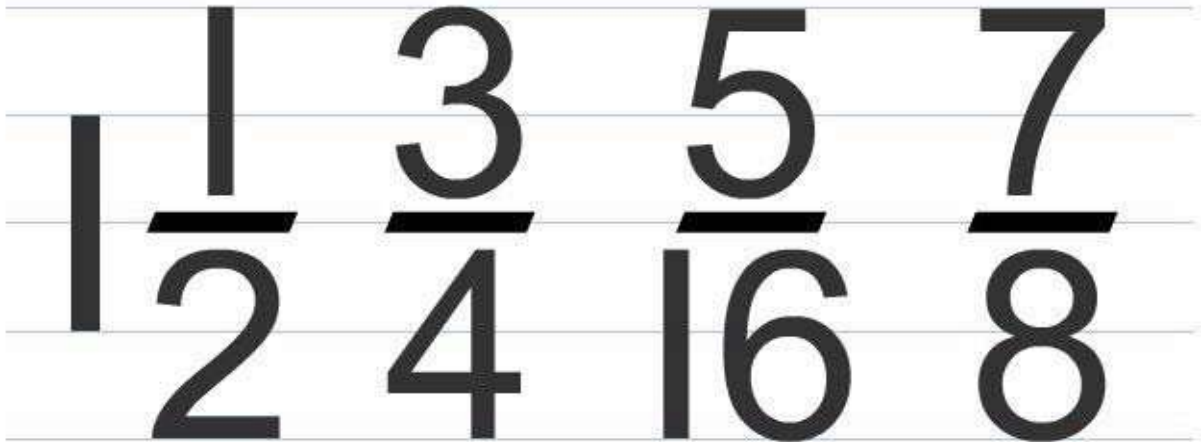
Figure 4-63 - Vertical fractions.

7.3.4 Lower Case Letters

Never use lowercase letters on construction drawings, although it is acceptable to use them for notes on maps or similar drawings. NEVER use lowercase letters on drawing title blocks. *Figure 4-64* shows lowercase letters along with guidelines and strokes used to form each letter.

The crosses of *f* and *t* are on the waist line and extend the same distance on either side of stroke 1. The horizontal stroke of e is just above mid height. The bodies of *a, b, g, p,* and *q* are circular and vertical strokes of these letters do not increase their width at the points of tangency. The vertical strokes of *p* and *q* terminate at the drop line. The vertical strokes of *g, j,* and *y* terminate in curves that are tangent to the drop line.
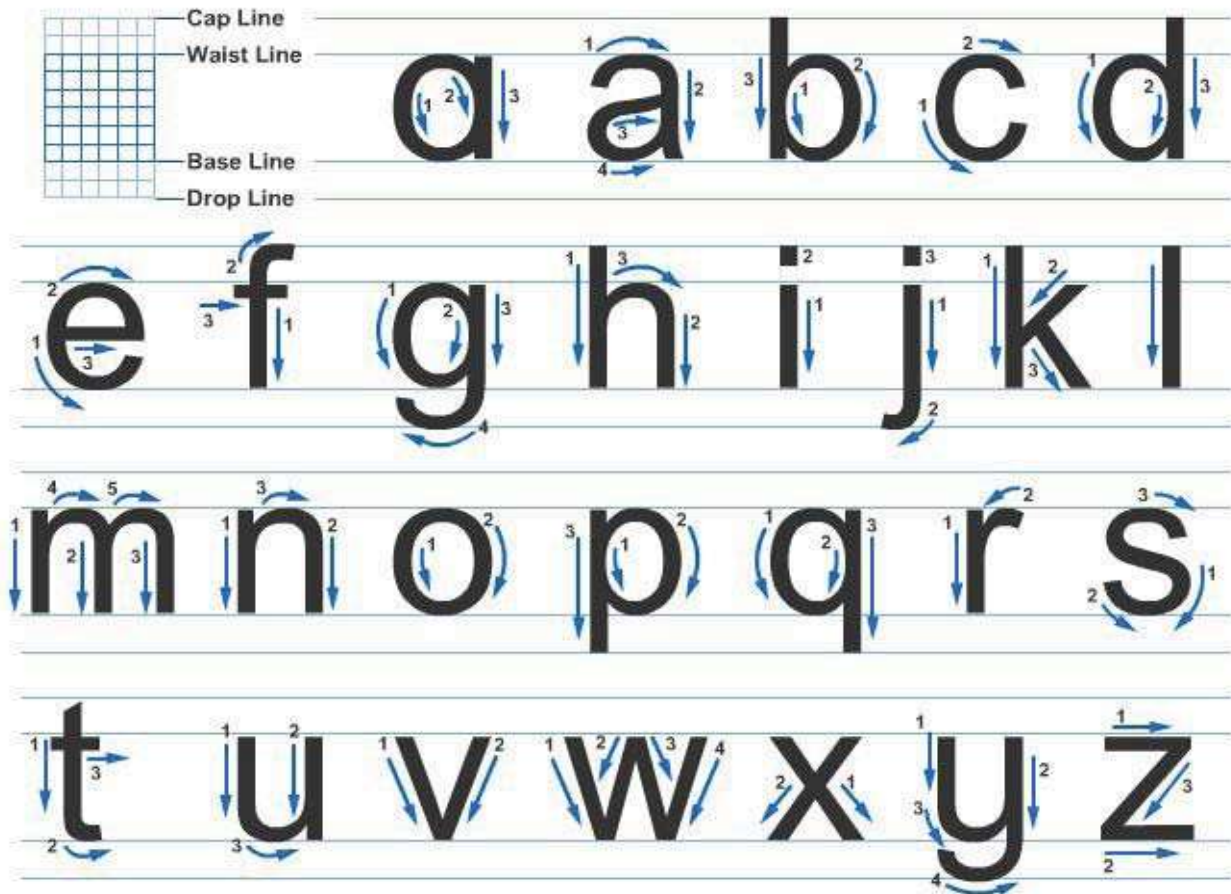
Figure 4-64 - Lettering vertical lowercase letters.

8.0.0 INCLINED LETTERING

Inclined single-stroke Gothic lettering is also acceptable on SEABEE drawings, although it is not recommended for the beginner and should not be attempted until you have mastered vertical lettering techniques. Inclined and vertical lettering should never appear on the same drawing. The lettering style used must always be consistent.

Figures 4-65 and 4-66 show the required formation of inclined letters. The angle of inclination is 67 1/2 degrees from the horizontal. Inclined guidelines may be drawn with the lettering triangle as described, or a line at the proper angle may be laid off with the protractor and parallel lines constructed from it. Horizontal guidelines and sequence of strokes are the same as for vertical letters. Rules of stability, proportion, and balance are similar. The circles and circular arcs used in vertical letters become elliptical in inclined letters, their major axes making angles of 45 degrees with the horizontal. Letters such as *A, M, V,* and *Y* should be made symmetrically about a guideline. Inclined lowercase letters follow the same principles as inclined capitals.
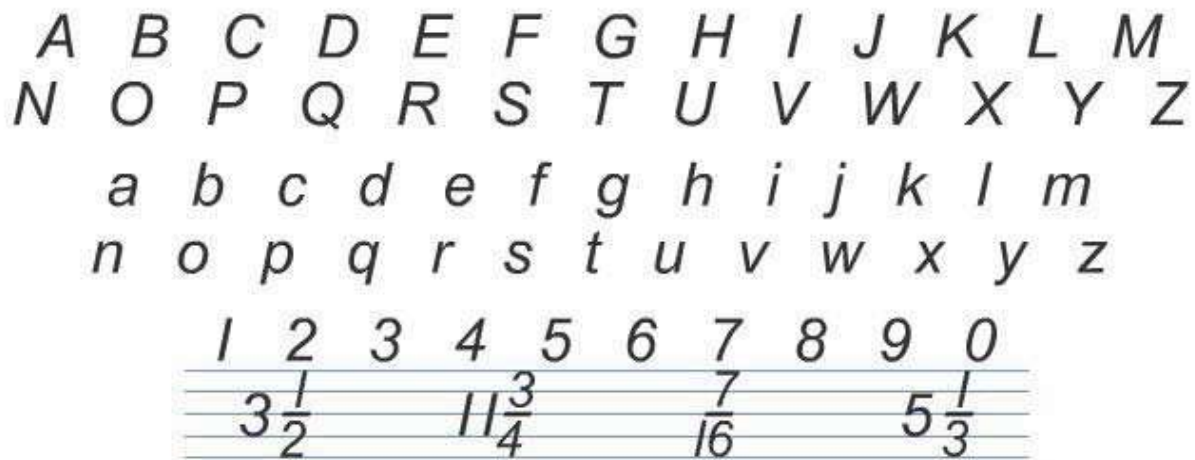
Figure 4-65 - Inclined single-stroke Gothic.

Figure 4-66 - Inclined letter formation.

9.0.0 COMPOSITION of LETTERING

Once you have learned the proper shapes and strokes required to form each letter and numeral, concentrate on practicing the composition of words and sentences. Proper spacing of letters and words does more for the appearance of a block of lettering than the forms of the letters themselves. This does not mean, however, that you should discontinue further practice of correctly forming each letter.

9.1.1 Letter Spacing

In straight-line lettering, determine the spacing between letters by eye after making the first letter and before making each succeeding letter. To give a word the appearance of having uniformly spaced letters, make the areas between the letters nearly equal, as shown in *Figure 4-67*. The areas between adjacent letters in a word vary with respect to whether the letters have straight sides (*H, I, M, N*) or slanted sides (*A, V, W*) and whether the letters are round (*O, Q, C, G*) or open (*L, J*). You will draw adjacent straight-sided letters farther apart than adjacent round letters. You will draw adjacent slant-sided and open letters nearer together than adjacent round letters. Where letters *L* and *T, L* and *V, A* and *V,* and other pairs of like shape come together in a word, you may have to draw the top of one above the bottom of the other to avoid having the word

appear as two or more words. In letter spacing, the six problems listed below are the hardest to solve. You will solve the first five problems by moving the letters closer together, the sixth by moving the letters farther apart.

POOR SPACING

GOOD SPACING
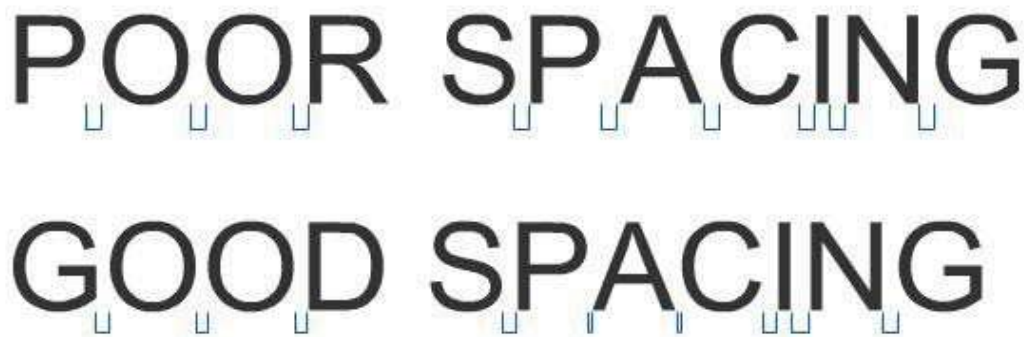
Figure 4-67 - Letter spacing.

1. Round next to round. (Increase the area at top and bottom where letters curve away from each other, as in *Figure 4-68A*.)

2. Round next to slant. (Increase the area at top or bottom where letters move away from each other, as in *Figure 4-68B*.)

3. Vertical next to slant. (Increase the area at top or bottom where one letter slants away from the other, as in *Figure 4-68C*.)

4. Slant next to slant. (Increase the area at top or bottom where letters slant in opposite directions, as in *Figure 4-68D*.)

5. Round next to vertical. (Increase the area at top and bottom where round letter curves away, as in *Figure 4-68E*.)

6. Vertical next to vertical. (Decrease the area at top and bottom where stems move together, as in *Figure 4-68F*.)

A GOOD good
Round to Round

B ACE vote
Round Next to Slant

C HAND live
Vertical Next to Slant

D WAVE wavy
Slant Next to Slant

E ONC hope
Round Next to Vertical

F LIME limp
Vertical Next to Vertical

Figure 4-68 - Common spacing problems.

A good way to evaluate the spacing of letters is to hold the lettering away from you and squint your eyes, observing the gray tone throughout the lettering. If the tone appears spotty or varies too much, the letters are poorly spaced.

9.2.0 Word Spacing

Proper spacing between words is an important factor in making them easy to read. Allow enough space between words and sentences to keep them from running together, but not so much as to cause words to be read one at a time. A good practice to follow is making spaces between words equal to the space that the letter *O* occupies as shown in *Figure 4-69*. If you prefer, you can use the letter *N* or a correctly spaced letter *I* instead. Naturally, the design of the last letter of a word and of the first letter of the following word must be considered in determining the amount of space you leave between words. You should leave a space equal to a capital *O* between two full-height straight-stemmed letters, such as *H* and *E* or *D* and *B*. Of course, if one or both of the letters are curved, the space should be appropriately reduced. If the two letters involved are lowercase, use the lowercase *o* to determine the width of the space. If one letter is full height and the other is lowercase height, such as the words *bid now or on him,* the space is equal to half a capital *O* and half a lowercase *o.*

Figure 4-69 – Spacing between words and lines.

9.3.0 Line Spacing

In addition to the spacing between letters and words, the spacing between lines of lettering adds to the readability of the lettering. Again your eye and your artistic ability must be your guide. Except when you are trying for a special effect, you should have enough space between the lines to make it easy for the reader to see what he is reading.

The distance you leave between lines may vary from 1/2 to 1 1/2 times the height of the letter. For the sake of appearance, do not use the same distance as the letter height. As a general rule, two-thirds of the letter height is a good distance between lines. This spacing allows room for descenders of lowercase letters and still maintains a clear space of one third of the letter height between the descenders and capital letters, or ascenders of lowercase letters of the following line. *Figure 4-69* shows proper word and line spacing.

9.4.0 Centering

Since the letters of the alphabet vary in width, you may find it difficult to center a line of lettering. *Figure 4-70* shows one way of solving this problem. First, take a piece of scratch paper and letter in the required line. Then, place this lettering above the area in which your lettering is to go and center it. Finally, use the sample as a guide to lettering the desired line.
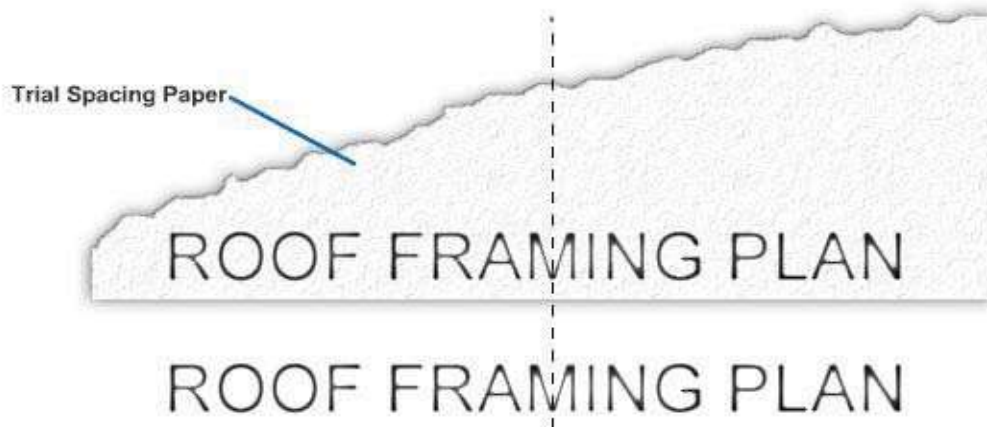
Figure 4-70 – Centering with trial spacing paper.

Ending a line of lettering at a given point is equally difficult. As in centering, first, letter the line on a piece of scratch paper in order to achieve the proper line length.

To make lines of lettering come out to a specified length, you must adjust the word and/or letter spacing. This adjustment in spacing is called ***justifying***. A good example of justifying is found in the columns of this manual. Notice how all full lines start and stop on the right- and left-hand margins. Usually, you will only find justified lettering typeset or typewritten by mechanical means. However, if you do have an occasion to justify your lettering, you should try to keep the spacing between the words as uniform as possible. Uneven spacing detracts from the appearance of the job. When it is impossible to divide the spacing evenly, insert wider spacing at points where one word ends and the next begins with tall letters, like *d, b,* and *l.*

If you use too much space between the words, the paragraph will tend to fall apart because it is filled with rivers of white space that will disturb the eye.

When a line is so short that it calls for an undue amount of space between words to lengthen the line, allow more space between the letters in each word. This is known as letterspacing. When words are letterspaced, always allow extra space between words so that they will not seem to run together when they are read.

Letter spacing makes short words in titles or headings appear longer. Though it frequently improves the appearance of words in caps, letterspacing reduces the legibility of words in lowercase. Use this process with caution.

10.0.0 MECHANICAL LETTERING

At times you will be tasked with preparing drawings, charts, maps, or signs that require the use of mechanical lettering. When we refer to mechanical lettering, we mean standard uniform characters that are executed with a special pen held in a scriber and guided by a template. Mechanical lettering does not normally require the use of lettering guidelines. You will use mechanical lettering principally for title blocks and notes on drawings, marginal data for special maps, briefing charts, display charts, graphs, titles on photographs, signs, and any other time that clear, legible, standardized lettering is required. Note that freehand lettering is the required lettering on most of your drawings; reserve mechanical lettering for special uses similar to those described above. The availability of mechanical lettering devices should not deter you from the daily practice required to execute freehand lettering. With continuous practice, you will become proficient in both mechanical and freehand lettering.

Figure 4-71 - Leroy lettering set.

One of the most popular types of mechanical lettering sets is the LEROY lettering set. A standard Leroy lettering set consists of a set of templates, a scriber, and a set of pens. (See *Figure 4-71*.)

10.1.0 Templates

Templates are made of laminated plastic with the characters engraved in the face so that the lines serve as guide grooves for the scriber. The height of the characters, in thousandths of an inch, is given by a number on the upper right-hand side of the template. For example, 3240-500CL indicates a No. 500 template. The entire number and letter designation identifies the template in the manufacturer's catalog. A standard set of templates offers character heights from 80 (0.08 inch or 5/64 inch) to 500 (0.5 inch or 1/2 inch). The scale at the bottom of each template has the zero in the center and is arranged for proper spacing in relation to character heights. The distance between each scale division represents the center-to-center distance of normal-width letters.

10.2.0 Pens

A standard set of pens for producing various line weights consists of 11 sizes ranging from 000, the finest, to 8. Each pen is composed of two parts: the ink reservoir and the cleaning pin. The reservoir is a series of connected tubes of decreasing diameters, the smallest establishing line thickness. The cleaning pin acts as a valve, protruding beyond the edge of the bottom tube when the pen is not touching the drawing surface. In this position, no ink flows. When the pen is resting on a drawing surface, the cleaning pin is pushed up, allowing the ink to flow. The action of the pin in the tube minimizes ink clogging.

As stated earlier, some reservoir pens are made so the point section will fit in a Leroy scriber. They are popular with the SEABEEs (and widely used over the standard pens contained in the Leroy, especially for long hours of lettering.

A SCRIBER holds the pen in alignment and controls its motion as the tracing pin is guided through the character grooves of the template. Two types of scribes are available: adjustable and fixed. An adjustable scriber produces letters with any slant from vertical to 22 1/2 degrees forward from a single template; a fixed scriber produces only vertical letters. Both scribers consist of a tracing pin, pen socket, socket screw, and tail pin. *Figure 4-72* shows a fixed scriber. The tracing pin on most Leroy scribers is reversible. One point is used with fine groove templates (Nos. 060, 080, and 100), and the other point is for wider groove templates (No. 120 to No. 500).
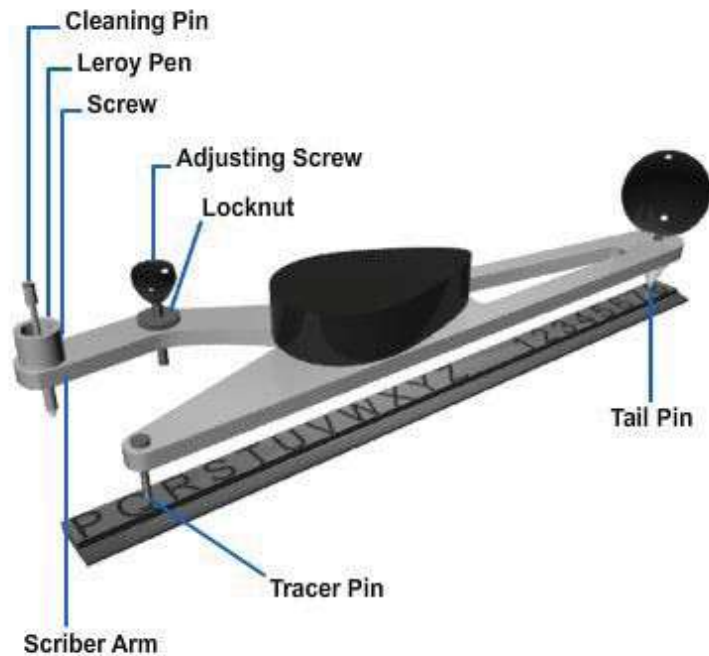
Figure 4-72 - Leroy scriber and template.

10.3.0 Line Weights

The table below shows the recommended combinations of template and pen for the best proportion between line thickness and letter size.

Template No.	Pen No.
060	000
080	000 or 00
100	00
120	0
140	1
175	2
200	3
240	3
290	4
350	4
425	5
500	6

This list is also found inside the lid of the Leroy lettering set case.

10.4.1 Operating Procedures

You will require a certain technique to manipulate the Leroy scriber with the template and, at the same time, hold the template against the working edge of the T square or straightedge without slipping.

Hold the T square or straightedge in position with the ball of your left hand resting on the blade while using the fingers of your left hand to hold the template against the working edge and changing the position of the template when necessary. Hold the scriber between your thumb and first three fingers of your right hand. The little finger of the right hand presses the right side of the template against the working edge, preventing the tracing pin from slipping out of the character grooves of the template. Take care to keep the tail pin in the straight-guide groove at the bottom of each template. When you are making long lines of large lettering, you may find it helpful to secure the T square or straightedge at both ends of the drawing board with drafting tape.

Using the above techniques to manipulate the scriber and template, follow the steps listed below to form uniform letters, words, and sentences. As you follow the steps, refer to *Figure 4-72*.

1. Select the template with letters of the desired height. The distance between each graduation at the bottom of the template is equal to the height of the letter that can be made with the template. The numbers in a fraction are made by using a template one size smaller than that used for whole numbers.

2. Lay the template along the top edge of a T square or straightedge.

3. Using the table of recommended template and pen sizes previously mentioned, select the proper pen to give a well-proportioned letter.

NOTE

On drawings with a great deal of lettering, the recommended combinations may be altered by one pen size, either under or over the recommended size, for variation and appearance. Never use a pen size more than two over the recommended size.

4. Insert the selected pen into the socket of the scriber arm until the shoulder of the pen rests on the scriber arm.

5. Tighten the screw on the side of the scriber arm.

6. Loosen the locknut on the adjusting screw in the scriber arm.

7. Set the tail pin of the scriber in the straight-guide groove of the template.

8. Set the tracer pin of the scriber in the groove of a character.

9. Lower the pen gently to the drawing surface.

10. Raise or lower the scriber arm by turning the adjusting screw until the tip of the cleaning pin within the pen just touches the drawing surface. Tighten the locknut when the desired height is reached. To prevent blotting, make this rough adjustment before putting ink into the pen.

11. Remove the scriber from the template.

12. Remove the cleaning pin from the pen.

NOTE

To prevent the ink from flowing straight through the pen, you should not remove the cleaning pin of a Leroy pen No. 4 or larger from the pen.

13. Fill the reservoir of the pen with drawing ink. You should fill the Leroy pen with ink in the same manner as any common drafting inking instrument. Keep the reservoir from one-fourth to three-fourths full; too low an ink level results in irregular lines.

14. If you removed the cleaning pin, reinsert it into the pen.

15. Wipe the lower tip of the pen with a cloth to remove any excess ink that may have been pushed through by the cleaning pin.

16. Draw a test line on a piece of scratch paper to ensure that the ink will flow smoothly.

17. Gently lower the pen to the drawing surface after inserting the tail and tracer pins in their proper grooves.

18. Proceed with the lettering by moving the tracer pin in the grooves of the characters, keeping the tail pin in the straight-guide groove.

If the ink does not flow properly, turn the cleaning pin inside the pen and wipe the tip with a cloth; also, make any necessary minor adjustments to the adjusting screw to allow the ink to flow properly. Tighten the locknut. When you will not be lettering for short periods of time, place the tip of the pen, still in the socket of the scriber arm, on a piece of moist cotton. This will prevent the ink from drying around the opening of the pen and will help the ink to flow properly when you begin lettering again.

10.5.1 Spacing and Centering

The rules for freehand letterspacing and word spacing also apply to mechanical lettering. Guidelines are not necessary for mechanical lettering; however, when you are making more than one line of lettering, you may draw horizontal base lines at intervals to help you maintain the proper spacing between the lines. Spacing between lines of mechanical lettering is the same as for freehand lettering. When centering lettering above a certain part of a drawing, or within a certain space, use the scales along the bottom edges of the templates. Each space on the scale represents the center-to-center distance of normal-width letters. For example, to center the words *LEROY LETTERING* about a certain line, proceed as follows:

1. Count the letters in each word and the spaces between words. Result: 15.

2. Considering the letter *I* and the space between the words as half value for each, reduce the total by one. Result: 14.

3. Divide the result of No. 2 above by two. Result: 7.

NOTE

If there had been an odd number of half values, you would use the next lower number and allow more space between words than normally required.

4. Set the zero of the scale at the vertical line about which the lettering is to be centered and mark off seven spaces to the left and right of zero.

5. Start the *L* of the word *LEROY* in the title at the left mark and continue to the end. The right edge of the *G* should fall on the mark to the right.

10.6.0 Maintenance of Mechanical Lettering Equipment

Thoroughly clean your pens with water after each use and store them properly in the lettering set case. Never wash your pens under running water in a sink; you may accidently lose the pens and cleaning pins down the drain. If you cannot clean a pen satisfactorily with water, use a diluted solution of ammonia or available commercial pen cleaning solutions and pen cleaning kits. You can remove caked or dried ink by soaking the pens overnight in a cleaning solution. Be aware, however, the pens may corrode if soaked excessively. Handle cleaning pins with care because they are fragile and easily bent, especially the smaller ones.

Avoid excessively tightening the screw that holds the pen in the scriber because the fine threads tend to strip very easily.

Clean your templates after every use, because dirt and dried-on ink are very easily transferred onto an otherwise clean drawing. Ensure that the template grooves are kept free from all foreign matter and that the tracer pin does not cut into the sides of the grooves. In order to form perfect letters every time, you must make sure that the tracer pin slides along the grooves smoothly. When you use small templates, insert a small sharp tracing pin in the scriber. If you are using a larger template, avoid using a sharp tracing pin because it can damage the grooves of the template.

Summary

As an Engineering Aid, you will use a variety of drafting equipment and accessories in performing your day to day duties. Familiarity with fundamental techniques and standards will help you perform your tasks successfully.

Review Questions (Select the Correct Response)

1. **(True or False)** The best light for drafting is natural light coming over the left shoulder and from the front left to avoid shadows cast by your hands.

    A. True
    B. False

2. To obtain a smooth drawing surface, cover your drafting board with_____.

    A. Vinyl or heavy manila paper
    B. Tracing paper or gridded paper
    C. Cloth
    D. Nothing

3. **(True or False)** To clean up smudges on a tracing paper drawing, use an electric eraser.

    A. True
    B. False

4. Use a_____pencil to lay out the drawing in light construction and projection lines and a_____pencil to darken the required lines and to make arrowheads and lettering.

    A. Soft, hard
    B. Hard, soft
    C. Medium, soft
    D. Hard, medium

5. **(True or False)** You can correct a poor pencil drawing when you trace it in ink.

    A. True
    B. False

6. When using a T square with a drawing board, align your paper to the _____of the board.

    A. Top
    B. Bottom
    C. Left
    D. Right

7. **(True or False)** You should draw horizontal lines from right to left.

    A. True
    B. False

8.   **(True or False)** You should draw vertical lines from the bottom up.

   A.   True
   B.   False

9.   How is the direction or angle of inclination of an incline line measured?

   A.   In reference to the left side of the drawing board
   B.   In reference to the right side of the drawing board
   C.   In reference to the base line from which it is drawn
   D.   In reference to the triangle used

10.   **(True or False)** Using three points on the protractor to draw an angle will result in extremely accurate measurements.

   A.   True
   B.   False

11.   **(True or False)** Parallel and perpendicular lines are drawn with a combination of straightedges and triangles.

   A.   True
   B.   False

12.   Noncircular curves are usually drawn_____.

   A.   With protractors
   B.   With curves
   C.   With compasses
   D.   Freehand

13.   Always rotate the compass_____.

   A.   Counterclockwise
   B.   Clockwise and then counterclockwise
   C.   Counterclockwise and then clockwise
   D.   Clockwise

14.   **(True or False)** When you are drawing a curved line that extends into a straight line, draw the straight line first, and join the curve line to it.

   A.   True
   B.   False

15.   Use drafting templates_____.

   A.   Whenever you're in a hurry
   B.   When speed can be sacrificed for accuracy
   C.   When accuracy can be sacrificed for speed
   D.   When you can't find a compass

16. _____are used to transfer measurements, to step off a series of equal distances, and to divide lines into a number of equal parts.

    A.   Protractors
    B.   Scales
    C.   Dividers
    D.   Straightedges

17. **(True or False)** Scales are suitable for drawing lines.

    A.   True
    B.   False

18. _____refers to the systematic space arrangement of required information within the drafting sheet used to identify, process, and file drawings methodically.

    A.   Drawing format
    B.   Sheet size
    C.   Roll size
    D.   Title block

19. The_____is the outside line of either the vertical or horizontal margin.

    A.   Borderline
    B.   Trim line
    C.   Hidden line
    D.   Extension line

20. The inside lines of the margins are called_____.

    A.   Borderlines
    B.   Trim lines
    C.   Hidden lines
    D.   Extension lines

21. Sheets of drafting or tracing paper are cut_____their required finished size and fastened to the drafting board.

    A.   Exactly to
    B.   Slightly smaller than
    C.   Slightly larger than
    D.   Double the size of

22. The title block, revision block, and list of materials are part of the_____.

    A.   Drawing number
    B.   Record of preparation
    C.   Sheet size
    D.   Basic format

23. The primary purpose of the_____is to identify a drawing.

    A.   Bill of Materials
    B.   Satisfactory To
    C.   Revision block
    D.   Title block

24. The_____is an additional approval signature block provided when an outside activity requests a drawing.

    A.   Bill of Materials
    B.   Satisfactory To
    C.   Revision block
    D.   Title block

25. The_____contains a list of all changes made to the drawing.

    A.   Bill of Materials
    B.   Satisfactory To
    C.   Revision block
    D.   Title block

26. The_____is a tabulated list of material requirements for a given project.

    A.   Bill of Materials
    B.   Satisfactory To
    C.   Revision block
    D.   Title block

27. DoD-STD-100C specifies that_____widths of line should be used in drafting drawings.

    A.   2
    B.   3
    C.   4
    D.   5

28. The first lines you will draw are_____, and they are used to lay out the rest of your drawing.

    A.   Hidden lines
    B.   Visible lines
    C.   Center lines
    D.   Construction lines

29. Use_____to indicate the center line of a circle, arc, or any symmetrical object.

    A.   A solid, thick line
    B.   A thin unbroken line
    C.   Long and short dashes, alternately and evenly spaced, with a long dash at each end
    D.   Short dashes

30. Visible lines are drawn as_____.

    A.   A solid, thick line
    B.   A thin unbroken line
    C.   Long and short dashes, alternately and evenly spaced, with a long dash at each end
    D.   Short dashes

31. Hidden edge lines are drawn with_____.

    A.   A solid, thick line
    B.   A thin unbroken line
    C.   Long and short dashes, alternately and evenly spaced, with a long dash at each end
    D.   Short dashes

32. Extension lines are drawn with_____.

    A.   A solid, thick line
    B.   A thin unbroken line
    C.   Long and short dashes, alternately and evenly spaced, with a long dash at each end
    D.   Short dashes

33. _____lines are terminated at each end with arrows and inserted between each pair of extension lines.

    A.   Center
    B.   Visible
    C.   Hidden edge
    D.   Dimension

34. _____are used to connect numbers, references, or notes to the appropriate surfaces or lines on the drawing.

    A.   Phantom lines
    B.   Dimension lines
    C.   Leaders
    D.   Break lines

35. This device is used to reduce the size of an object's graphic representation (usually for the purpose of economizing on paper space).

   A. Phantom lines
   B. Dimension lines
   C. Leaders
   D. Break lines

36. _____are used frequently to indicate a moving part's alternate position.

   A. Phantom lines
   B. Dimension lines
   C. Leaders
   D. Break lines

37. Cutaway views are called_____.

   A. Leaders
   B. Sections
   C. Dimensions
   D. Crosshatching

38. _____lines indicate the plane or planes from which a surface or several surfaces are viewed.

   A. Cutting plane
   B. Viewing plane
   C. Dimension
   D. Crosshatching

39. A_____line consists of one long dash and two short dashes equally spaced.

   A. Phantom
   B. Dimension
   C. Datum
   D. Break

40. Stitch lines consist of_____.

   A. A series of very short dashes of medium thickness, approximately have the length of the dash of hidden lines, evenly spaced
   B. A solid, thick line
   C. A thin unbroken line
   D. Long and short dashes, alternately and evenly spaced, with a long dash at each end

41.   _____ lines are used when an object is too large to fit on a single drawing sheet and must be continued on another sheet.

   A.   Break
   B.   Dimension
   C.   Datum
   D.   Match

42.   When penciling a drawing, _____ lines should be drawn first.

   A.   Horizontal and vertical outlines
   B.   Circles and arcs
   C.   Center
   D.   Nonhorizontal and nonvertical outlines

43.   _____ are strips of tape or thin pieces of plastic which are fastened to faces of triangles, curves and templates to raise their edges from the surface of the drafting paper and prevent ink from running under the edge.

   A.   Space blocks
   B.   Drafting tape
   C.   Masking tape
   D.   Duct tape

44.   **(True or False)** When freehand lettering, you should grip the pencil tightly.

   A.   True
   B.   False

45.   _____ ensure consistency in the size of the letter characters.

   A.   Trim lines
   B.   Guidelines
   C.   Phantom lines
   D.   Center lines

46.   The generally accepted style of lettering for Seabee drawings in the _____.

   A.   Arial Bold
   B.   Single-stroke Gothic vertical or inclined
   C.   Times Roman
   D.   Comic Sans

47.   Z, X, Y, K are formed with only _____.

   A.   Horizontal strokes
   B.   Curved and straight-line combinations
   C.   Curved strokes
   D.   Straight-line strokes

48. O, Q, C, G are formed with only_____.

    A.   Horizontal strokes
    B.   Curved and straight-line combinations
    C.   Curved strokes
    D.   Straight-line strokes

49. **(True or False)** Drawing numerals requires a different set of guidelines than capital letters.

    A.   True
    B.   False

50. **(True or False)** It is acceptable to use lowercase letters on construction drawings.

    A.   True
    B.   False

51. **(True or False)** Inclined lettering uses the same horizontal guidelines and sequence of strokes as vertical lettering.

    A.   True
    B.   False

52. **(True or False)** The spacing between adjacent letters in a word is always the same.

    A.   True
    B.   False

53. A good practice is to make the spaces between words equal to the space that the letter_____occupies.

    A.   I
    B.   j
    C.   O
    D.   i

54. The recommended distance you leave between lines is_____the height of the letter.

    A.   Triple
    B.   Double
    C.   Equal
    D.   Varies from 1/2 to 1 1/2 times

55.   _____is adjusting word and/or letter spacing to make lines of lettering come out to a specified length.

   A.   Composition
   B.   Centering
   C.   Justifying
   D.   Formation

56.   _____refers to standard uniform characters that are executed with a special pen held in a scriber and guided by a template.

   A.   Freehand lettering
   B.   Mechanical lettering
   C.   Drafting templates
   D.   Cursive lettering

57.   _____are made of laminated plastic with the characters engraved in the face so that the lines serve as guide grooves for a scriber.

   A.   Templates
   B.   Protractors
   C.   Compasses
   D.   Straightedges

58.   A standard set of pens for producing various line weights consists of 11 sizes ranging from 000, the_____, to 8.

   A.   Finest
   B.   Widest
   C.   Thickest
   D.   Darkest

59.   **(True or False)** When using a Leroy scriber to draw long lines of large lettering, you may find it helpful to secure the T square or straightedge at both ends of the drawing board with drafting tape.

   A.   True
   B.   False

60.   **(True or False)** Spacing between lines of mechanical lettering is different than freehand lettering.

   A.   True
   B.   False

61.   **(True or False)** You should wash your pens under running water in a sink.

   A.   True
   B.   False

Trade Terms Introduced in this Chapter

ANSI Acronym for American National Standards Institute.

Arcs Segments of circles.

Ascender The part of the lowercase letter that extends above the body of the letter.

Borderlines The inside lines of the margins.

Cutting plane lines Lines used to indicate a plane or planes in which a sectional view is taken.

Datum line Used to indicate a line or plane of reference, such as the plane from which an elevation is measured.

Descender The part of the lowercase letter that extends below the body of the letter.

Flat size Relatively small drawings that should be stored or filed flat.

FSCM Acronym for Federal Supply Code for Manufacturers.

Match lines Lines used when an object is too large to fit on a single drawing sheet and must be continued on another sheet.

NAVFACENGCOM Abbreviation for Naval Facility and Engineering Command

Parallel Extending in the same direction, equidistant at all points, and never converging or diverging.

Perpendicular Meeting a given line or plane at right angles.

Roll size Relatively long drawings that should be stored in rolls

Space blocks Strips of tape or thin pieces of plastic used to raise drafting instruments from the surface of the paper and prevent ink from running under the edge.

Stitch lines Lines used to indicate the stitching or sewing lines on an article.

Trim line Outside line of either the vertical or horizontal margin.

Viewing plane lines Indicates the plane or planes from which a surface or several surfaces are viewed

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

Advancement Handbook for Petty Officers, Engineering Aid (EA), NAVEDTRA 71365, Naval Education and Training Program Management Support Activity, Pensacola, Fla., 1989.

Construction Force Manual, NAVFAC P-315, Naval Facilities Engineering Command, Alexandria, Va., 1985.

Military Requirements for Petty Officer Third Class, NAVEDTRA 10044-A, Naval Education and Training Program Management Support Activity, Pensacola, Fla., 1987.

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Chapter 5

Drafting: Geometric Construction

Topics

To hear audio, click on the box.

Overview

As an Engineering Aid, you will find it essential to know the principles and application of geometric construction. You must be able to draw many types of lines. In a line drawing, a line may be straight line, a circle, an arc of a circle or a fillet, a circular curve, a noncircular curve, or a combination of these basic line types.

You must also be able to construct line drawings at specified angles to each other, various plane figures, and other graphic representations consisting exclusively of lines. This chapter provides information that will aid you in drawing different types of geometric constructions.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Describe different methods of drawing straight lines.
2. Describe how to transfer and bisect an angle.
3. Describe how to construct plane figures.
4. Describe how to construct circular curves.
5. Describe how to construct an ellipse.

Prerequisites

None

This course map shows all of the chapters in Engineering Aid Basic. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Topographic Surveying and Mapping	↑	E
Indirect Leveling/Level and Traverse Computations		N
Care and Adjustment of Survey Equipment		G
Materials Testing: Soil and Concrete		I
Direct Leveling and Basic Engineering Surveys		N
Horizontal Control		E
Direct Linear Measurements and Field Survey Safety		E
Surveying: Elements and Equipment		R
Construction Drawings		I
Electrical: Systems and Plans		N
Mechanical: Systems and Plans		G
Concrete and Masonry		AID
Wood and Light Frame Structures		
Drafting: Projections and Sketching		B
Drafting: Geometric Construction		A
Drafting: Fundamentals and Techniques		S
Drafting: Equipment		I
Mathematics and Units of Measurement		C
Engineering Aid Rating		

Features of this Manual

This manual has several features which make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.

- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.

- Audio and video clips are included in the text, with an italicized instruction telling you where to click to activate it.

- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is

for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.0.0 STRAIGHT LINES

You can draw horizontal and vertical lines, perpendicular and parallel lines, and inclined lines by either using a straightedge (or a T square) with a triangle or by employing a drafting compass. In this section, we will describe how to use a drafting compass to draw straight lines.
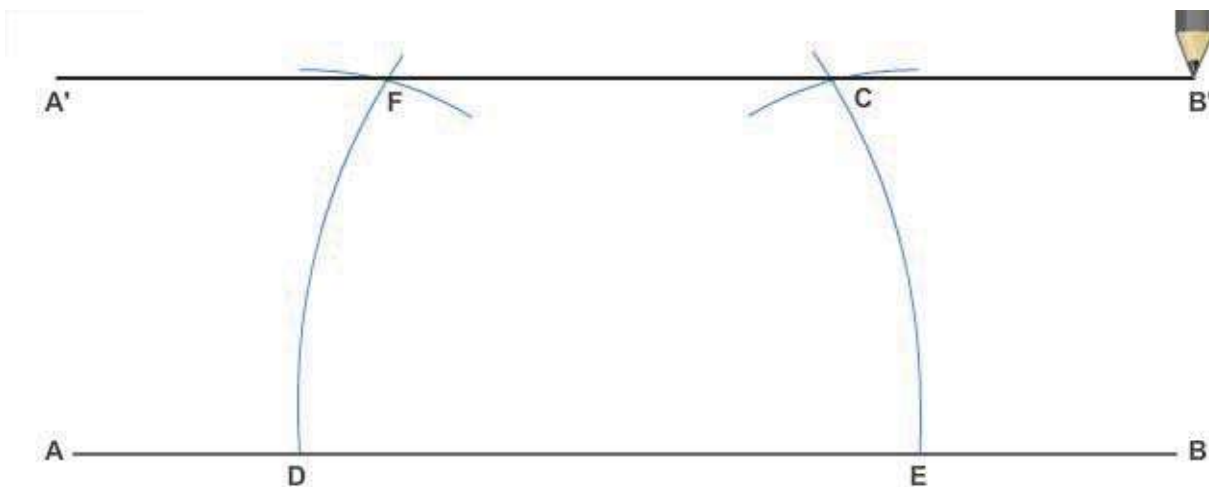
Figure 5-1 – Drawing a line through a given point, parallel to another line.

Figure 5-1 shows how to draw a line parallel to another line. Here, the line is to be drawn through given point C. To draw a line through C parallel to AB, place the needlepoint of the compass on any point D on AB and strike arc CE. Shift the needlepoint to E, maintaining the same radius, and strike arc DF. Set a compass to a chord of arc CE and lay off the chord DF from D, thus locating point F. The line running through F and C is parallel to AB.
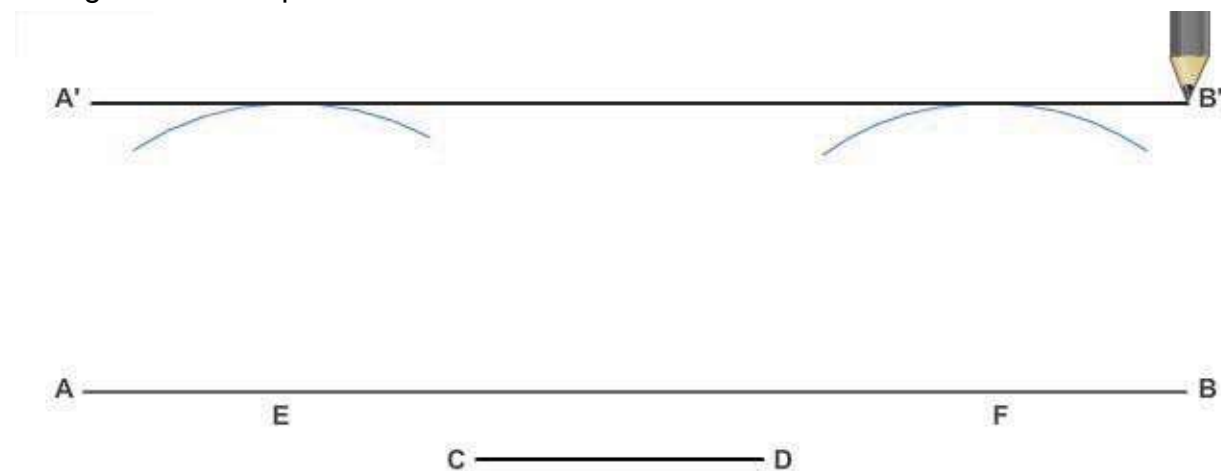
Figure 5-2 – Drawing a line through a given point, parallel to another line.

Figure 5-2 shows another method of drawing one line parallel to another. Use this method when you need to draw the second line at a given distance from the first. To draw a line parallel to AB at a distance from AB equal to CD, set a compass to the length of CD, and, from any points E and F on AB, strike two arcs. A line A'B' drawn tangent to (barely touching) the arcs is parallel to AB, and located CD distance from AB.

In the preceding chapter, you learned how to draw a line perpendicular to another by using a straightedge and a triangle. Two other methods of solving this problem are explained below.
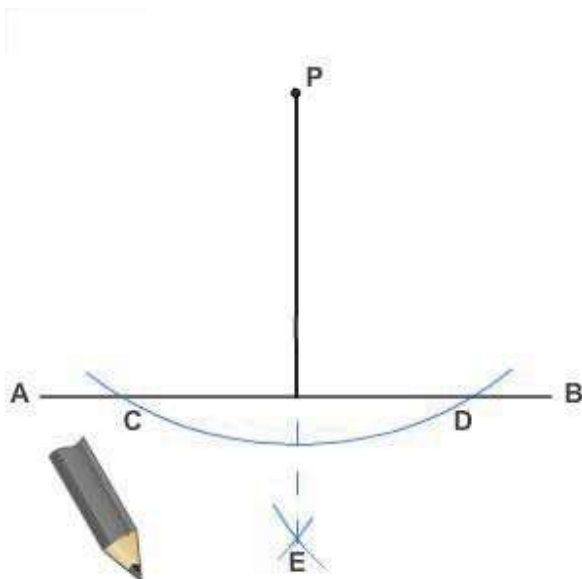
Figure 5-3 – Dropping a perpendicular from a given point to a line.

Figure 5-3 shows a method of dropping a perpendicular from a given point to a line, using a compass. To drop a perpendicular from point P to AB, set the needlepoint of the compass at P and strike an arc intersecting AB at C and D. With C and D as centers and any radius larger than one-half of CD, strike arcs intersecting at E. A line from P through E is perpendicular to AB.

Figure 5-4 shows a method of erecting a perpendicular from a given point on a line. To erect a perpendicular from point P on AB, set a compass to any convenient radius, and, with P as a center, strike arcs intersecting AB at C and D. With C and D as centers and any radius larger than one-half of CD, strike arcs intersecting at E. A line from P through E is perpendicular to AB.
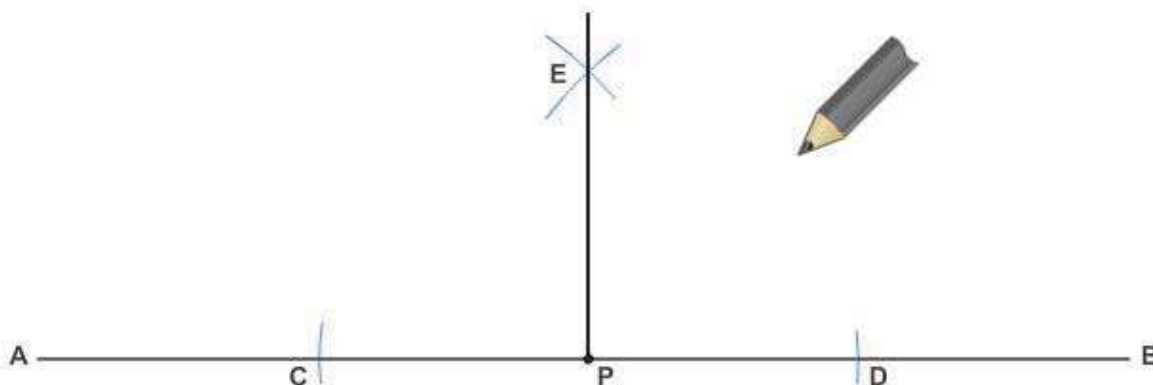
Figure 5-4 – Erecting a perpendicular from a given point on a line.

1.1.0 Bisection of a Line

You can bisect a line by trial and error with dividers; that is, by setting the dividers to various spreads until you find one that correctly measures one-half the length of the line.

Figure 5-5 shows the geometric construction for bisecting a line. To bisect the line AB, use the ends of the line, A and B, as centers; set a compass to a radius greater than one-half the length of AB, and strike arcs intersecting at C and D. A line drawn from C through D bisects AB.
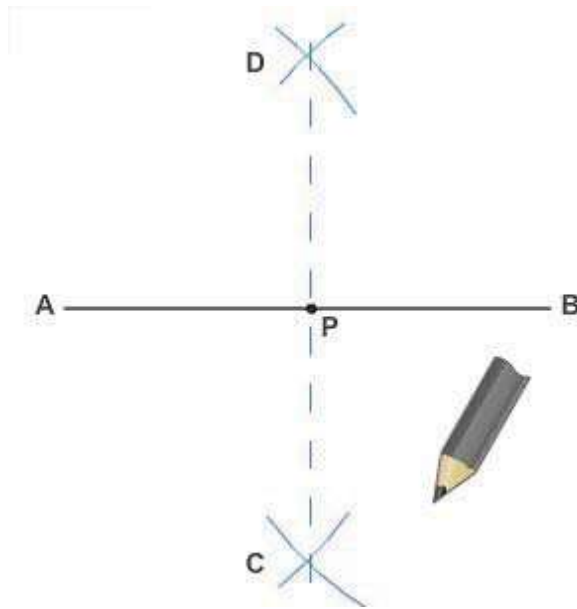
Figure 5-5 – Bisecting a line.

1.2.0 Division into Any Number of Parts

You can divide a line into more than two equal parts by trial and error with the divider. *Figure 5-6* shows the geometric construction for dividing a line into any number of equal parts. To divide AB into 10 equal parts, draw a ray line CB from B at a convenient acute angle to AB. Set a compass to spread less than one-tenth of the length of CB, and lay off this interval 10 times from B on CB. Draw a line from the 10th interval to A, and project the other points of intersection from CB to AB by lines parallel to the first one. The projected points of intersection divide AB into 10 equal parts.
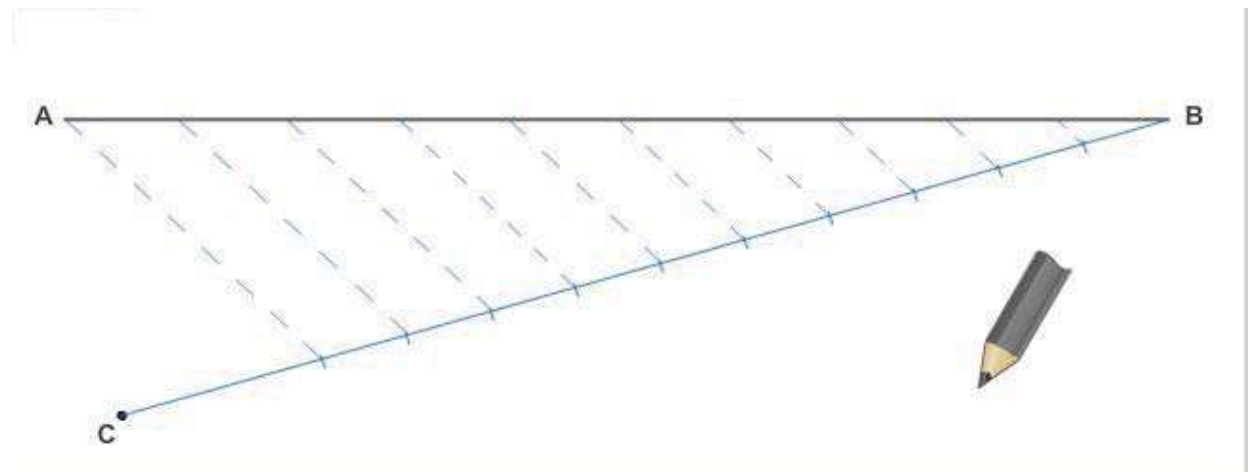
Figure 5-6 – Dividing a line into any number of equal parts.

Figure 5-7 shows how you can use a scale to lay off equal intervals on the ray line.
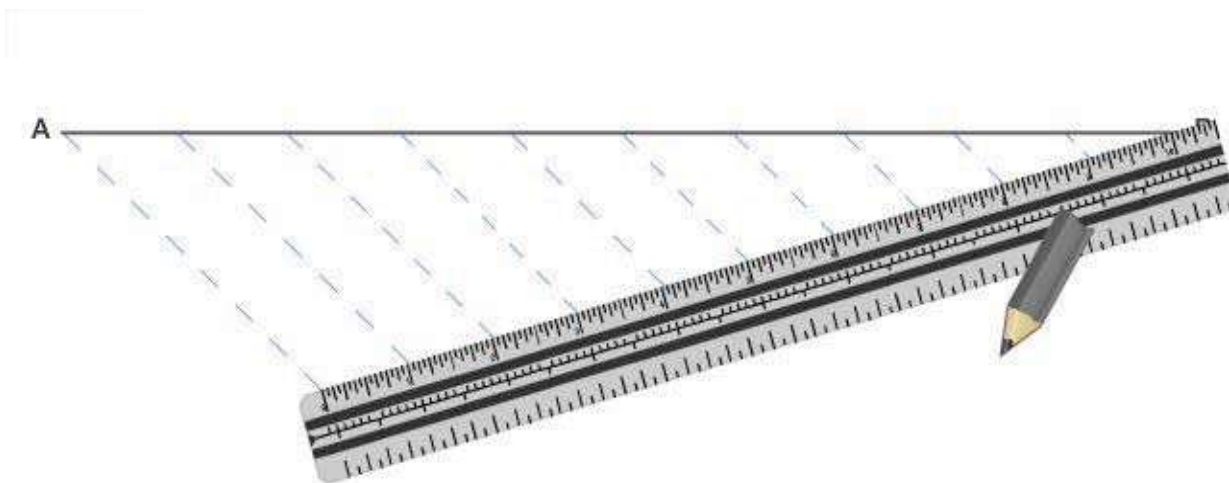
Figure 5-7 – Using a scale to lay off equal intervals on a random line.

1.3.0 Division Into Proportional Parts

Figure 5-8 shows a method of dividing a line into given proportional parts. The problem here is to divide the line AB into parts that have proportions of 2:3:4. Lay off ray line CB from B at a convenient acute angle to AB. Set a compass to a convenient spread, and lay off this interval from B on CB the number of times that is equal to the sum of the figures in the proportion (2 + 3 + 4 = 9). Draw a line from the point of intersection of the last interval to A, and use a straightedge and triangle to project the second and fifth intercepts on CB to AB by lines parallel to the first one. The projected intercepts divide AB into segments that have proportions of 2:3:4.

Here again, you could use a scale to lay off nine equal intervals on CB.
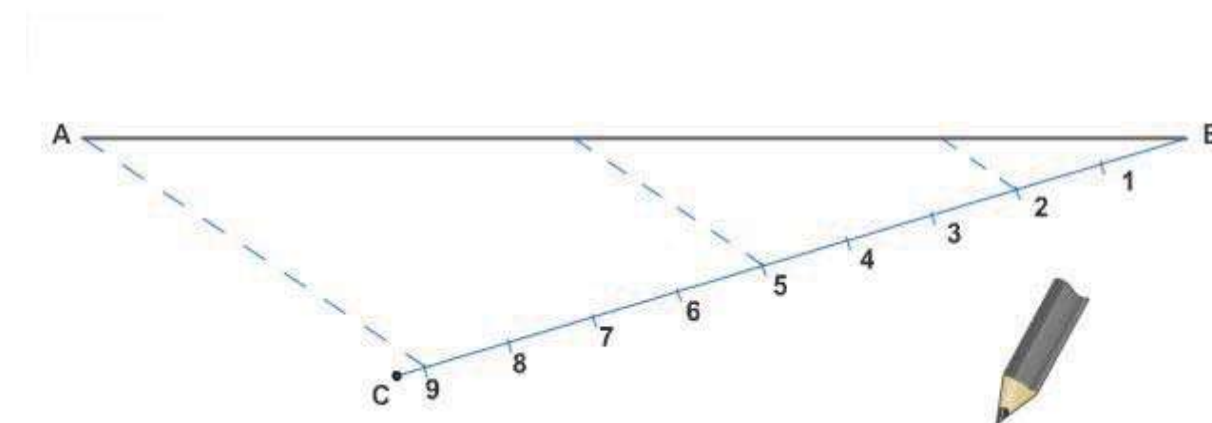
Figure 5-8 – Dividing a line into proportional parts.

1.4.0 Division According to a Given Ratio

You may be required to divide a line into parts so that the ratio between the whole line and one of the parts is the same as that between two other lines. Figure 5-9 shows one method of doing this. In this case, you divide AB so that the ratio between AB and a part of AB is the same as the ratio between CD and EF. From A, draw a ray line AG at a

convenient acute angle from AB. On AG, lay off AH equal to EF and AI equal to CD. Draw a line from I to B, and use a straightedge and triangle to project H to J on a line parallel to IB. The ratio of AB to AJ is the same as that of CD to EF.

2.0.0 ANGLES

You already know how to lay off an angle of given size with a protractor, or trigonometrically by the use of the tangent or the chord method.

2.1.0 Transfer of an Angle

Using geometric construction, you can lay off an angle equal in size to one that is already drawn on another part of the same drawing or on a different drawing. *Figure 5-10* shows this procedure, called transferring an angle. Here, the draftsman desired to lay off from O' a line that would make an angle with B'O' equal to angle BOA. *Figure 5-10, View A*

Figure 5-9 – Dividing a line into parts according to a given ratio.

shows the first step, drawing an arc through OB and OA, with O as a center. *Figure 5-10, View B* shows the second step, drawing an arc of the same radius from B'O', with O' as a center. Next, *Figure 5-10, View C* shows measuring the length of the chord of the arc between OB and OA and laying off the same length on the arc from B'O'. *Figure 5-10, View D* shows a line drawn from O' through A', making an angle with B'O' equal to angle BOA.

2.2.0 Bisection of an Angle

Figure 5-10 – Transferring an angle.

To *bisect* an angle means to divide it in half. If you know the size of the angle, you can bisect it by simply dividing the size by 2 and laying off the result with a protractor.

Geometric construction for bisecting an angle is shown in *Figure 5-11*. To bisect the angle AOB, first lay off equal intervals from O on OA and OB. With the ends of these intervals as centers, strike intersecting arcs of equal radius at P. Draw a line from O through the point of intersection of the arcs, P. The line OP bisects angle AOB.
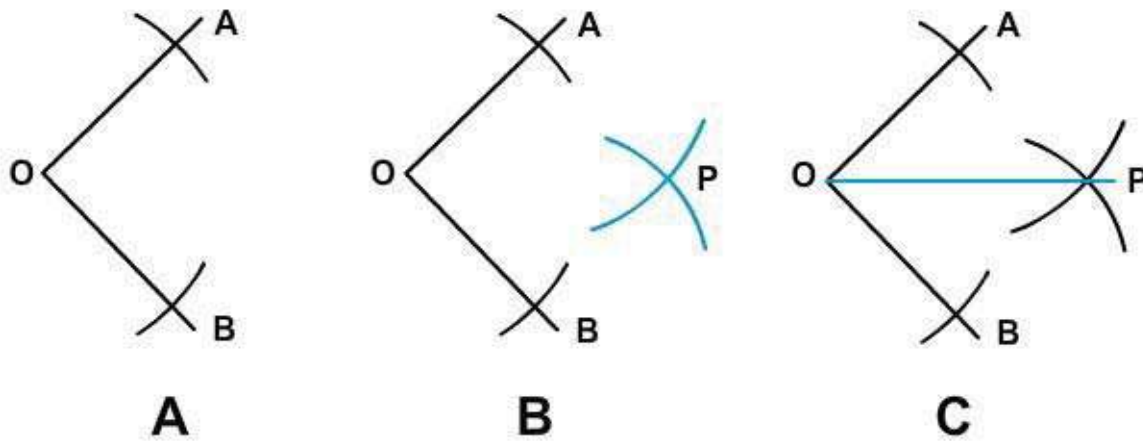
Figure 5-11 – Bisecting an angle.

3.0.0 PLANE FIGURES

This section explains how to construct certain plane figures, such as the triangle, rectangle, square, and regular polygon. You must understand the geometrical construction of plane figures because they appear in engineering drawings.

3.1.0 Triangle: Three Sides Given

To draw a triangle with three sides given, first draw a straight line AB, equal in length to one of the given sides (*Figure 5-12*). With A as a center, strike an arc with a radius equal to the given length of the second side. With B as a center, strike an intersecting arc with a radius equal to the length of the third side. Draw lines from A and B to the point of intersection of the arcs.
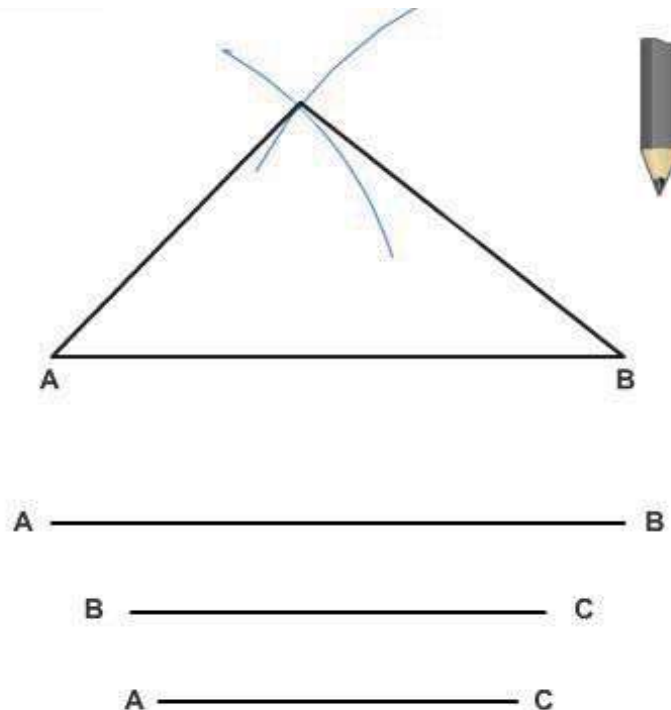
Figure 5-12 – Constructing a triangle with three sides given.

3.2.0 Right Triangle: Hypotenuse and One Side Given

Figure 5-13 shows a method of drawing a right triangle when the hypotenuse and one side are given. The line H is the given hypotenuse; the line S is the given side. Draw AB equal to H. Locate the center of AB (by bisection), and, with the midpoint as a center and a radius equal to one half of AB, draw the semicircle from A to B as shown. Set a compass or dividers to the length of S, and, with A as a center, strike an arc intersecting the semicircle at C. Draw AC and BC.

Figure 5-13 – Constructing a triangle with hypotenuse and one side given.

3.3.0 Equilateral Triangle: Length of Side Given

To construct an equilateral triangle when the length of a side is given, follow the method previously described for constructing a triangle when the length of each side is given. The sides of an equilateral triangle are equal in length.

Each angle in an equilateral triangle measures 60°. You can apply this fact in constructing an equilateral triangle with given length of side, such as the one shown in *Figure 5-14*. Simply use a 30°/60° triangle and a T square or straightedge to erect lines from A and B at 60° to AB.

Figure 5-14 – Equilateral triangle with a given length of side AB.

3.4.0 Equilateral Triangle in a Given Circumscribed Circle

A circumscribed plane figure is one that encloses another figure, the circumscribed figure being tangent to the extremities of the enclosed figure. An *inscribed* plane figure is one that is enclosed by a circumscribed figure.

Figure 5-15 shows you how to inscribe an equilateral triangle within a given circumscribed circle. Draw a vertical center line intersecting the given circle at A and B. With B as a center and a radius equal to the radius of the circle, strike arcs intersecting the circle at C and D. Lines connecting A, C, and D form an equilateral triangle.
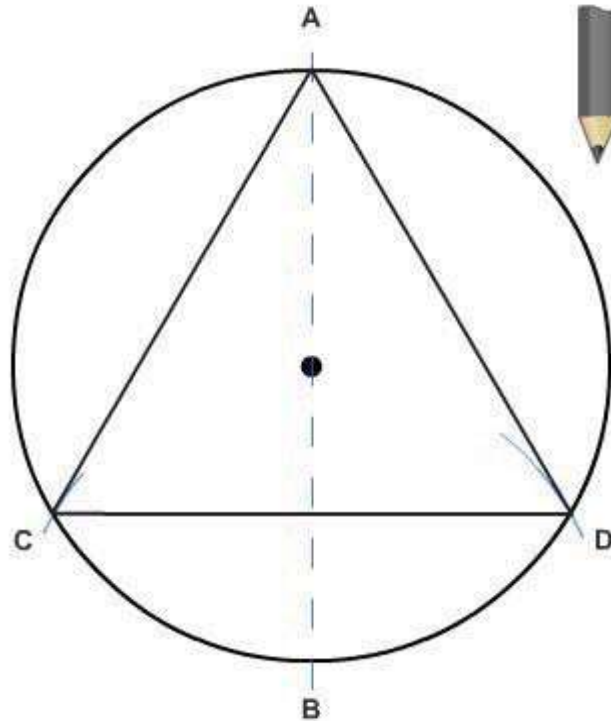
Figure 5-15 – Equilateral triangle in a given circumscribed circle.

3.5.0 Equilateral Triangle on a Given Inscribed Circle

Figure 5-16 shows one method of circumscribing an equilateral triangle on a given inscribed circle. Draw AB parallel to the horizontal center line of the circle and tangent to the circumference. Then use a 30°/60° triangle to draw AC and BC at 60° to AB and tangent to the circle.
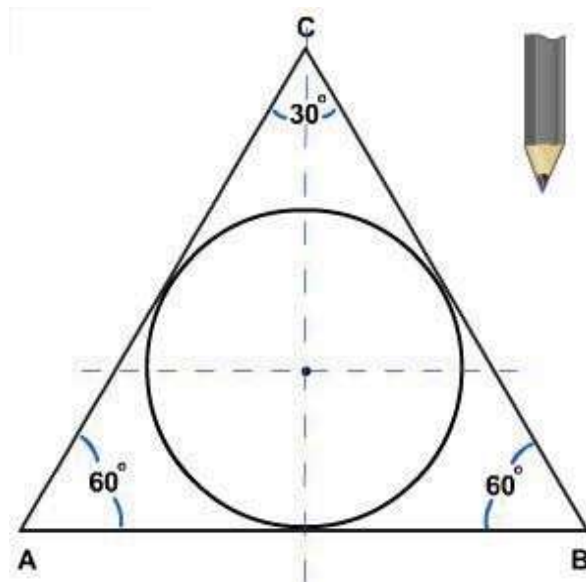
Figure 5-16 – One method: Equilateral triangle on a given inscribed circle.
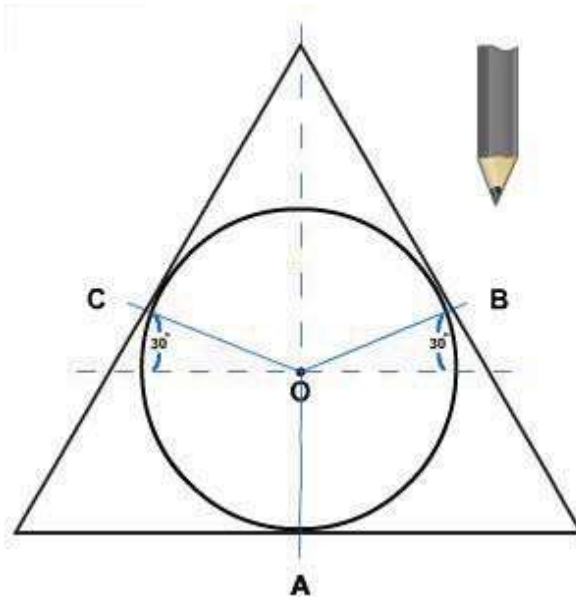
**Figure 5-17 – Another method:
Equilateral triangle on a given
inscribed circle.**

Figure 5-17 shows another method of accomplishing this construction. Draw radii at 30°
to the horizontal center line of the circle, intersecting the circumference at C and B.
There is a third point of intersection at A, so you now have three radii: OA, OB, and OC.
Draw the sides of the triangle at A, B, and C, tangent to the circle and perpendicular to
the relevant radius.

3.6.0 Rectangle: Given length and Width

To construct a rectangle with a given length and width, draw a horizontal line AB, equal
to the given length. With a straightedge and triangle, erect perpendiculars from A and B,
each equal to the given width. Connect the ends of the perpendiculars.

3.7.0 Square: Given Length of Side

You can construct a square with a given
length of side by the method described for
constructing a rectangle. Another method is
shown in *Figure 5-18*. With a T square,
draw horizontal line AB equal to the given
length of side. With a T square and a 45°
triangle, draw diagonals from A and B at
45° to AB. Erect perpendiculars from A and
B, intersecting the diagonals, then connect
the points of intersection.
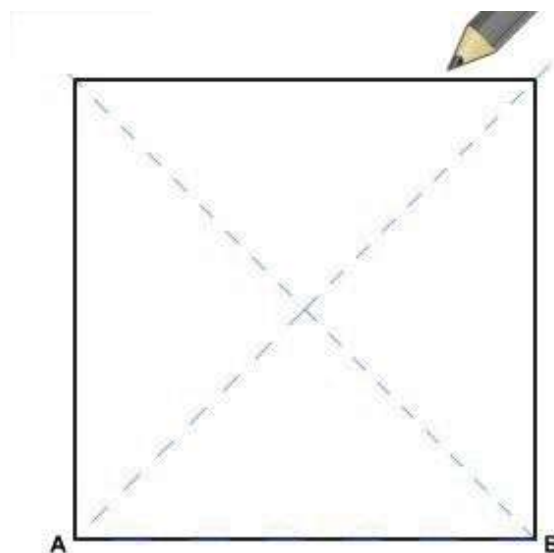
**Figure 5-18 – Square with a given
length of side.**

3.8.0 Square: Given Length of Diagonal

Figure 5-19 shows a method of constructing a square with a given length of diagonal. Draw horizontal line AB, equal to the given length of the diagonal. Locate O at the center of AB, and lay off CD through O, perpendicular to and slightly longer than AB. Use a T square and a 45° triangle to draw AF and EB at 45° to AB and CD, then connect AE and FB.

3.9.0 Square in a Given Circumscribed Circle

Figure 5-20 shows a method of drawing a square in a given circumscribed circle. Draw the diameters AB and CD at right angles to each other and connect the points where the diameters intersect the circumference of the circle.
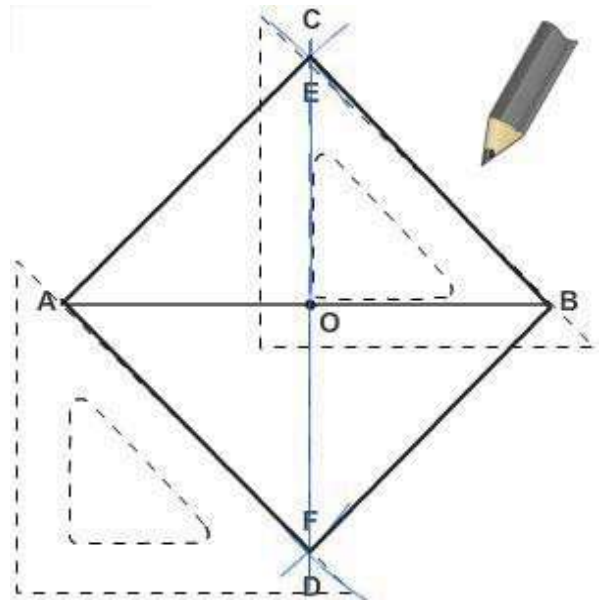
Figure 5-19 – Square with a given length of diagonal.
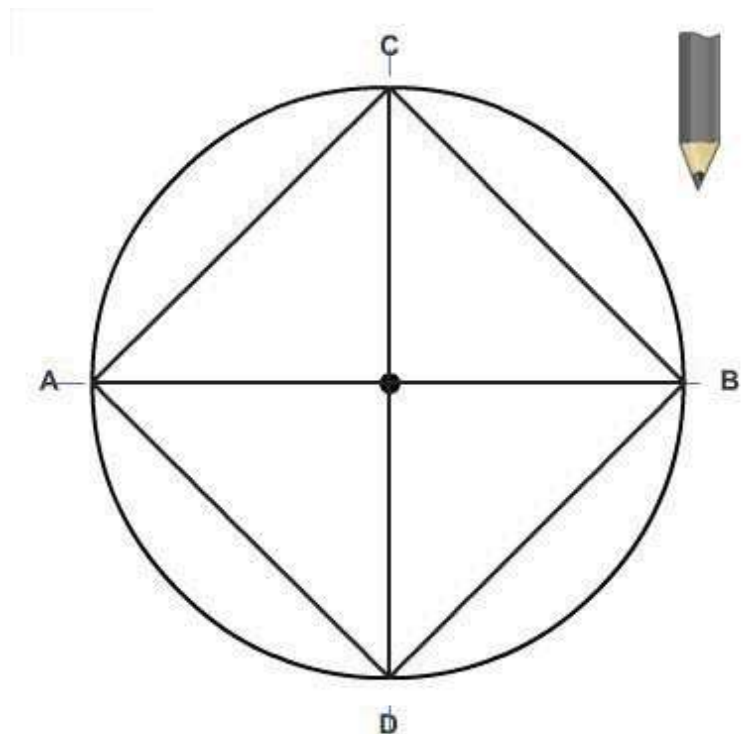
Figure 5-20 – Square in a given circumscribed circle.

3.10.0 Square Circumscribed on a Given Inscribed Circle

Figure 5-21 shows a method of circumscribing a square on a given inscribed circle. Draw diameters AB and CD at right angles to each other. Then draw each side of the square tangent to the point where a diameter intersects the circumference of the circle and perpendicular to the diameter.
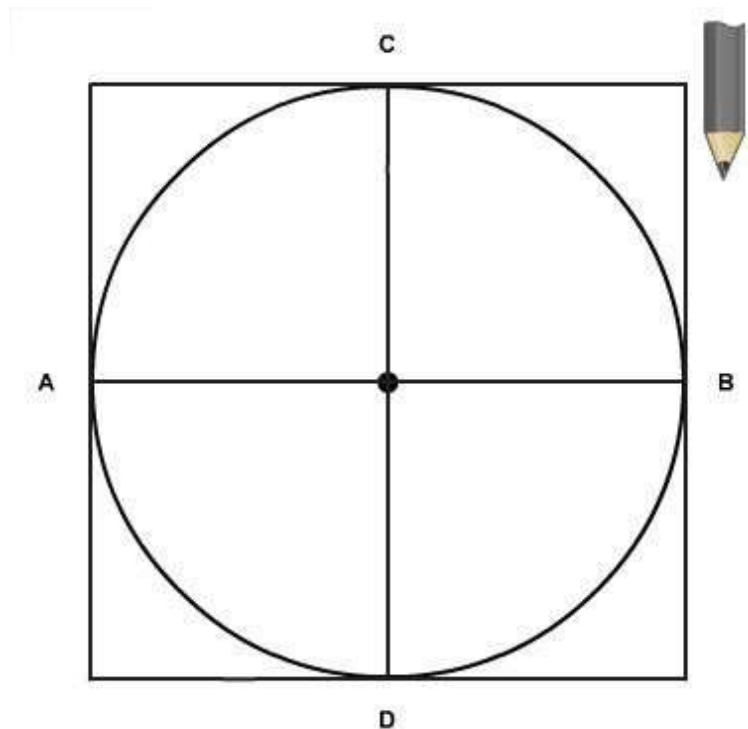
Figure 5-21 – Square on a given inscribed circle.

3.11.0 Any Regular Polygon in a Given Circumscribed Circle

You can construct any regular polygon in a given circumscribed circle by trial and error with a drafting compass or dividers as shown in *Figure 5-22*. To draw a nine-sided regular polygon in the circle shown, divide the circumference by trial and error with a compass or dividers into nine equal segments and connect the points of intersection. To get a trial spread for a compass or dividers, divide the central angle subtended by the entire circle (360) by the number of sides of the polygon, in this case, by nine. Then, lay off the central angle
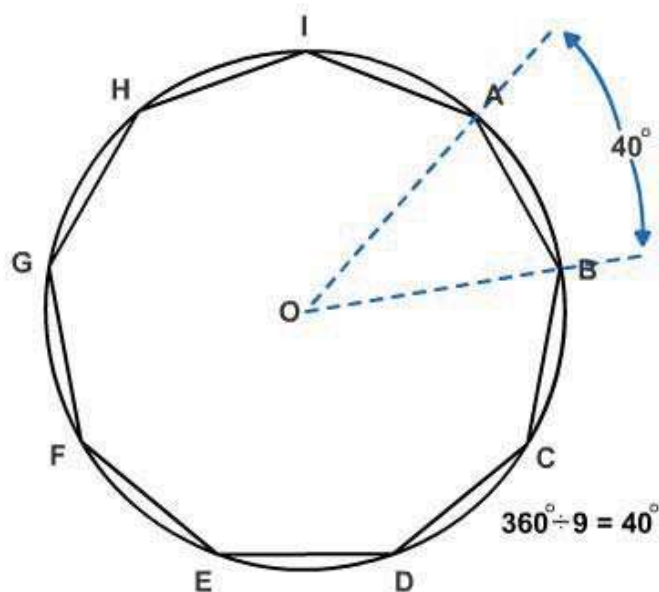
Figure 5-22 – Regular polygon in a given circumscribed circle.

quotient from the center of the circle to the circumference with a protractor.

3.12.0 Any Regular Polygon on a Given Inscribed Circle

The same method (dividing the circumference into equal segments) can be used to construct a regular polygon on a given inscribed circle. In this case, however, instead of connecting the points of intersection on the circumference, draw each side tangent to the circumference and perpendicular to the radius at each point of intersection, as shown in *Figure 5-23*.

3.13.0 Any Regular Polygon with a Given Length of Side
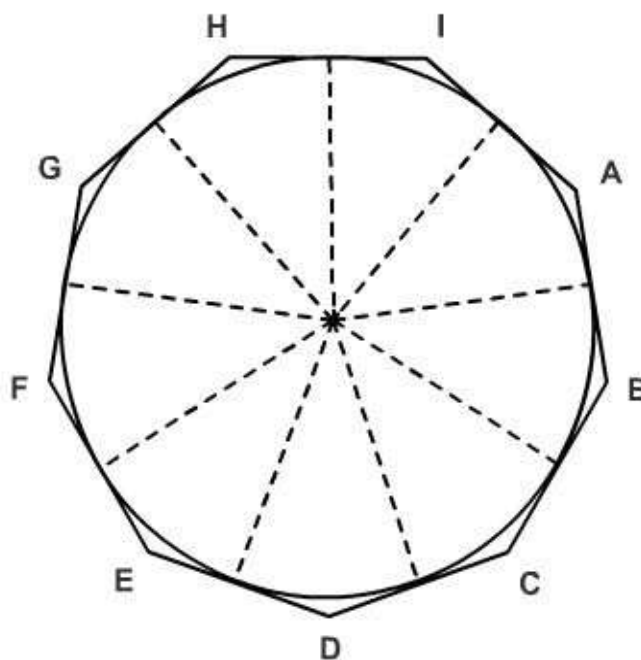
Figure 5-23 – Regular polygon on a given inscribed circle.

Figure 5-24 shows a method of drawing any regular polygon with a given length of side. To draw a nine-sided regular polygon with length of side equal to AB, first extend AB to C, making CA equal to AB. With A as a center and AB (or CA) as a radius, draw a semicircle as shown. Divide the semicircle into nine equal segments from C to B, and draw radii from A to the points of intersection. The radius A2 is always the second side of the polygon.

Draw a circle through points A, B, and D. To do this, first erect perpendicular bisectors from DA and AB. The point of intersection of the bisectors is the center of the circle. The circle is the circumscribed circle of the polygon. To draw the remaining sides, extend the radii from the semicircle as shown, and connect the points where they intersect the circumscribed circle.

Besides the methods described for constructing any regular
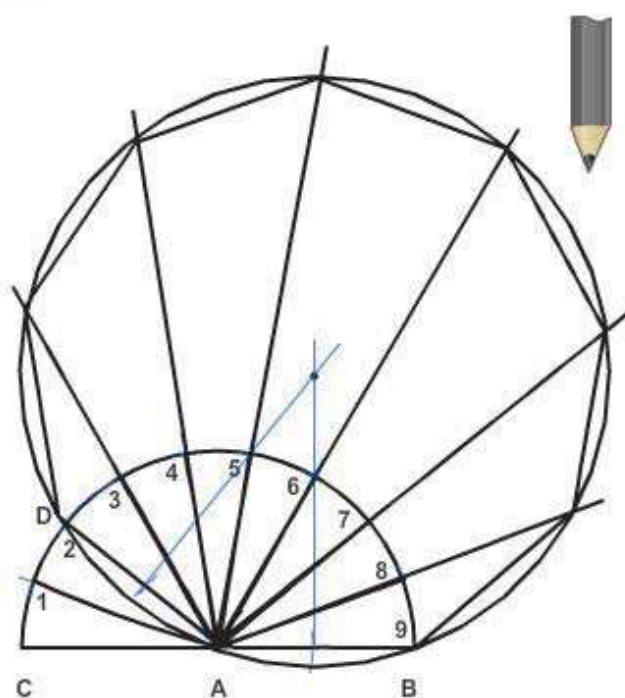
Figure 5-24 – Any regular polygon with a given length of side.

polygon, there are particular methods for constructing a regular pentagon, hexagon, or octagon.

3.14.0 Regular Pentagon in a Given Circumscribed Circle

Figure 5-25 shows a method of constructing a regular pentagon in a given circumscribed circle. Draw a horizontal diameter AB and a vertical diameter CD. Locate E, the midpoint of the radius OB. Set a compass to the spread between E and C, and, with E as a center, strike the arc CF. Set a compass to the spread between C and F, and, with C as a center, strike the arc GF. A line from G to C forms one side of the pentagon. Set a compass to GC and lay off this interval from C around the circle. Connect the points of intersection.
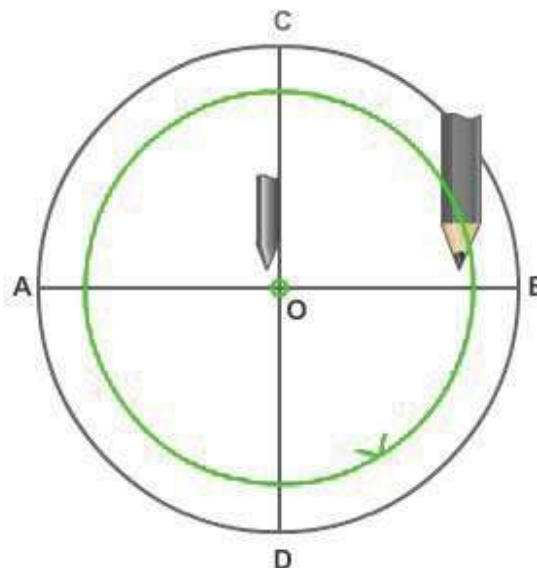
Figure 5-25 – Regular pentagon in a given circumscribed circle.

3.15.0 Regular Pentagon on a Given Inscribed Circle

To construct a regular pentagon on a given inscribed circle, determine the five equal intervals on the circle in the same manner. However, instead of connecting these points, draw each side of the figure tangent to the circle at a point of intersection.

3.16.0 Regular Hexagon in a Given Circumscribed Circle

Many bolt heads and nuts are hexagonal (six-sided) in shape. *Figure 5-26* shows a method of constructing a regular hexagon in a given circumscribed circle. The diameter of the circumscribed circle has the same length as the long diameter of the hexagon. The radius of the circumscribed circle (which equals one-half the long diameter of the hexagon) is equal in length to the length of a side. Lay off the horizontal diameter AB and vertical diameter CD. OB is the radius of the circle. From C, draw a line CE equal to OB; then lay off this interval around the circle, and connect the points of intersection.

Figure 5-27 shows another method of constructing a regular hexagon in a given circumscribed circle. Draw vertical diameter AB, and use a T square and a
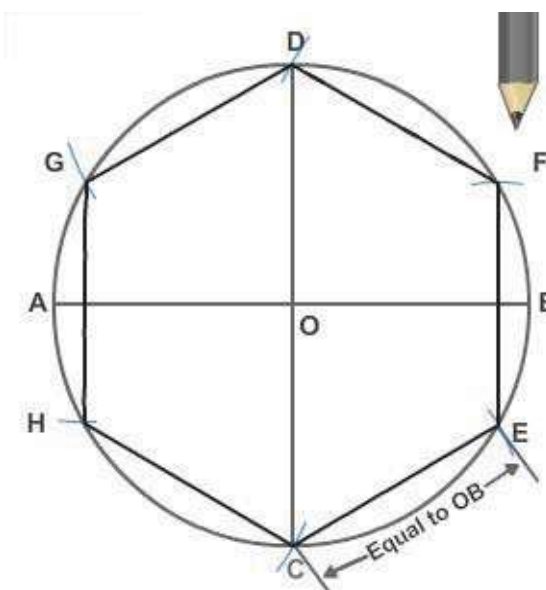
Figure 5-26 – One method: Regular hexagon in a given circumscribed circle.

30°/60° triangle to draw BC from B at 30° to the horizontal. Set a compass to BC, lay off this interval around the circumference, and connect the points of intersection.
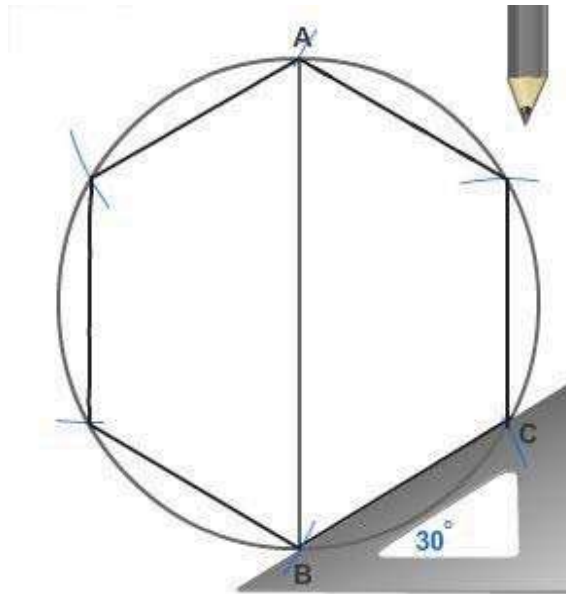
Figure 5-27 – Another method: Regular hexagon in a given circumscribed circle.

3.17.0 Regular Hexagon on a Given Inscribed Circle

Figure 5-28 shows a method of constructing a regular hexagon on a given inscribed circle. Draw horizontal diameter AB and vertical center line. Draw lines tangent to the circle and perpendicular to AB at A and B. Use a T square and a 30°/60° triangle to draw the remaining sides of the figure tangent to the circle and at 30° to the horizontal.
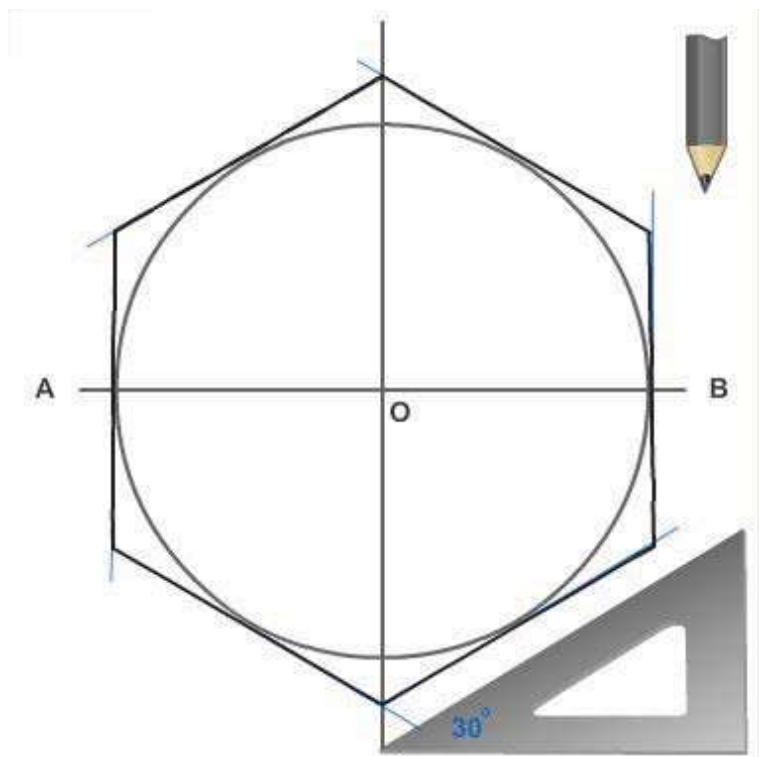
Figure 5-28 – Regular hexagon on a given inscribed circle.

3.18.0 Regular Octagon in a Given Circumscribed Circle

Figure 5-29 shows a method of constructing a regular octagon in a given circumscribed circle. Draw horizontal diameter AB and vertical diameter CD. Use a T square and a 45° triangle to draw additional diameters EF and GH at 45° to the horizontal. Connect the points where the diameters intersect the circle.

3.19.0 Regular Octagon Around a Given Inscribed Circle

Figure 5-30 shows a method of constructing a regular octagon around a given inscribed circle. Draw horizontal diameter AB and vertical diameter CD. Draw tangents at A, B, C, and D perpendicular to the diameters. Draw the remaining sides of the figure tangent to the circle at 45° to the horizontal.
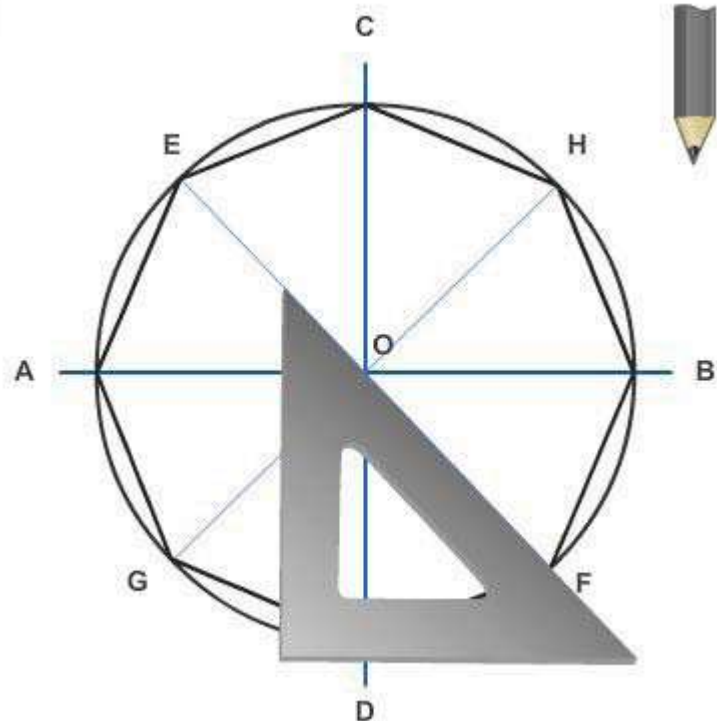
Figure 5-29 – Regular octagon in a given circumscribed circle.

4.0.0 CIRCULAR CURVES

Many of the common geometrical constructions occurring in the drafting room are those involving circular curves. This section explains how to construct circular curves that may be required to satisfy varying conditions.
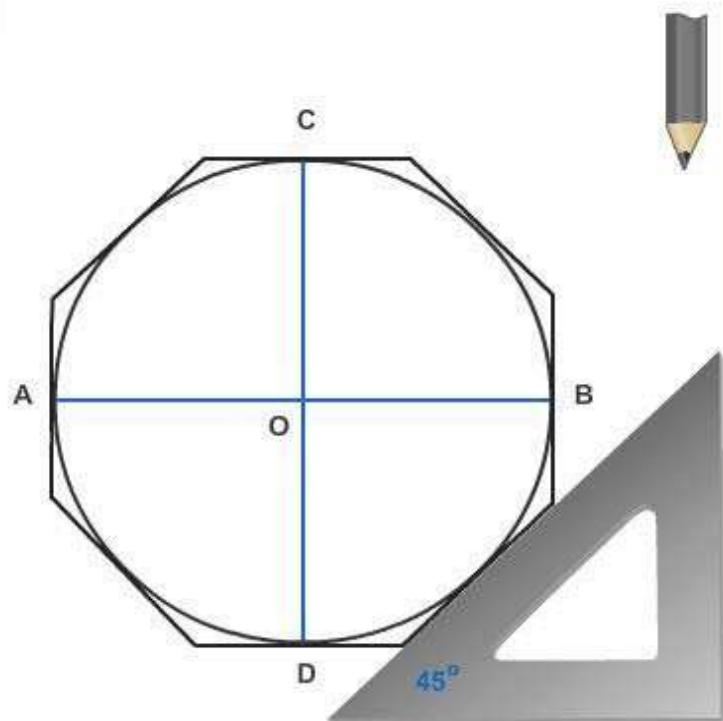
Figure 5-30 – Regular octagon around a given inscribed circle.

4.1.0 Circle Through Three Points

In *Figure 5-31* the problem is to draw a circle (or a circular arc) that passes through points A, B, and C. Connect the points by lines and erect perpendicular bisectors as shown. The point of intersection of the perpendicular bisectors (O) is the center of the circle or arc passing through all three points.

4.2.0 Line Tangent to a Circle at a Given Point

A line that is tangent to a circle at a given point is perpendicular to the radius that intersects the point. It follows that one method of drawing a line tangent to a circle at a given point is to draw the radius that intersects the point and then draw the line tangent at the point of intersection and perpendicular to the radius.

Figure 5-31 – Circle or arc through three points.
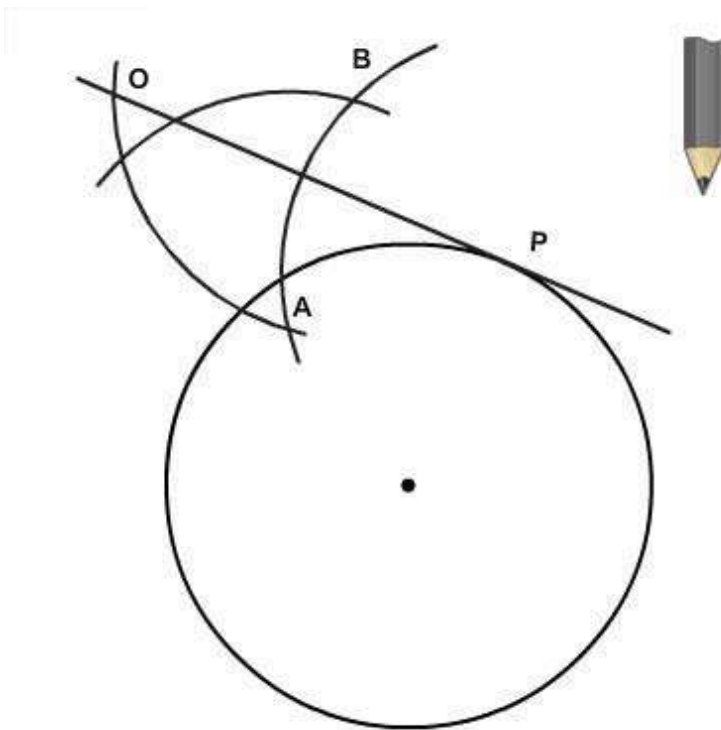
Another method is shown in *Figure 5-32*. To draw a line tangent to the circle at P, set a compass to the radius of the circle, and, with P as a center, strike an arc that intersects the circle at A. With the compass still set to the radius of the circle, use A as a center and strike an arc that intersects the first arc at B. With B as a center and the compass still set to the radius of the circle, strike another arc. A line through the point of intersection (0) of the last drawn arc and through P is tangent to the circle at P.

Figure 5-32 – Line tangent to a given point on a circle.

4.3.0 Circular Arc of a Given Radius Tangent to Two Straight Lines

Drawing a fillet or round presents the problem of drawing a circular arc of a given radius tangent to two nonparallel lines.

Figure 5-33 shows a method that can be used when the two nonparallel lines form a right angle. AB is the given radius of the arc. Set a compass to this radius, and, with the point of intersection of the lines as a center, strike an arc intersecting the lines at C and D. With C and D as centers and the same radius, strike intersecting arcs as shown. The point of intersection of these arcs (0) is the center of the circle of which an arc of the given radius is tangent to the lines.

Figure 5-34 shows a method that can be used regardless of the size of the angle formed by the lines. Again AB equals the given radius of the arc, and the problem is to draw an arc with radius equal to AB, tangent to CD and EF. Draw GH parallel to CD and at a distance from CD equal to the given radius of the arc. Draw IJ parallel to EF and also at a distance equal to the given radius of the arc. The point of intersection between GH and IJ (P) is the center of the circle of which an arc of the given radius is tangent to CD and EF.

Figure 5-33 – Circular arc tangent to two lines that form a right angle.
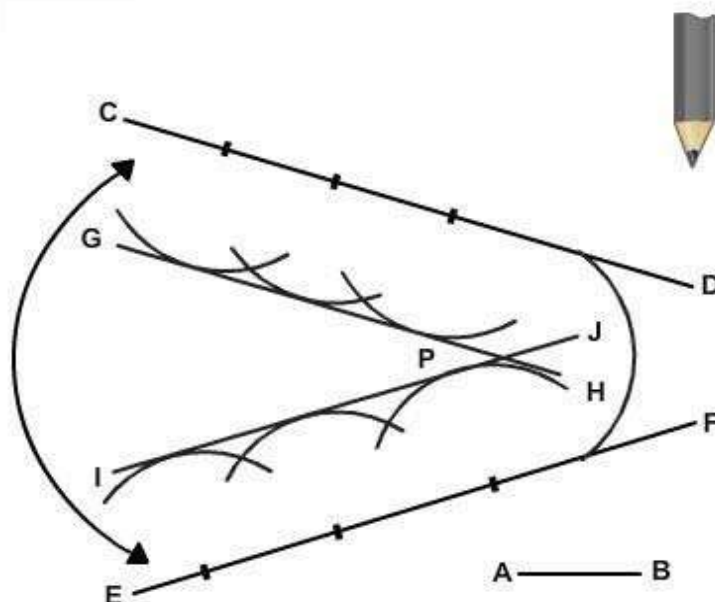
Figure 5-34 – Circular arc tangent to two lines that form any angle.

4.4.0 Circular Arc of a Given Radius Tangent to a Straight Line and to Another Circular Arc

The problem in *Figure 5-35* is to draw a circular arc with a radius equal to AB, tangent to the circular arc CD and to the straight line EF. Set a compass to a radius equal to the radius of the circular arc CD plus the given radius AB (which is indicated by the dashed line shown), and, with O as a center, strike the arc GH. Draw a line IJ parallel to EF at a distance from EF equal to AB. The point of intersection (P) between GH and IJ is the center of the circle of which an arc of the given radius is tangent to CD and EF.
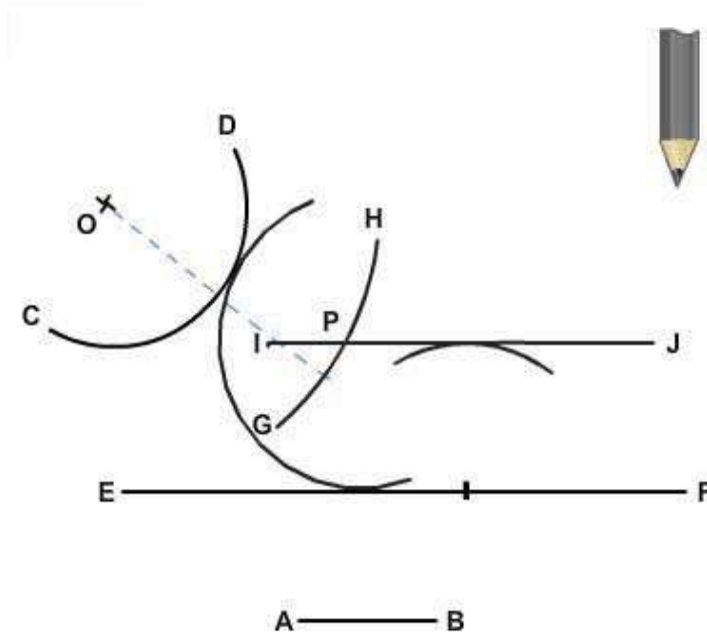
Figure 5-35 – Circular arc tangent to a straight line and another circular arc.

4.5.0 Circular Arc of a Given Radius Tangent to Two Other Circular Arcs

The problem in *Figure 5-36* is to draw an arc with a radius equal to AB, tangent to the circular arcs CD and EF. Set a compass to a spread equal to the radius of arc CD plus AB (indicated by the left-hand dashed line), and, with O as a center, strike an arc. Set the compass to a spread equal to the radius of arc EF plus AB (indicated by the right-hand dashed line), and, with O' as a center, strike an intersecting arc. The point of intersection between the two arcs (P) is the center of the circle of which an arc of given radius is tangent to arcs CD and EF.

In *Figure 5-36* the circular arcs CD and EF curve in opposite directions. In *Figure 5-37* the problem is to draw an arc with radius equal to AB, tangent to two circular arcs, CD and EF, that curve in the same direction.

Set a compass to a radius equal to the radius of EF less AB, and, with O' as a center, strike an arc. Then, set a compass to a radius equal to the radius of arc CD plus line AB, and, with O as center, strike an intersecting arc at P. The point of intersection of these two arcs is the center of the circle of which an arc of the given radius is tangent to CD and EF.

When one circular arc is tangent to another, the two arcs usually curve in opposite directions. However, an arc may be drawn tangent to another with both curving in the same direction. In a case of this kind, the tangent arc is said to enclose the other.

An arc tangent to two others may enclose both, or it may enclose only one and not the other. In *Figure 5-38* the problem

Figure 5-36 – Circular arc tangent to two other circular arcs.
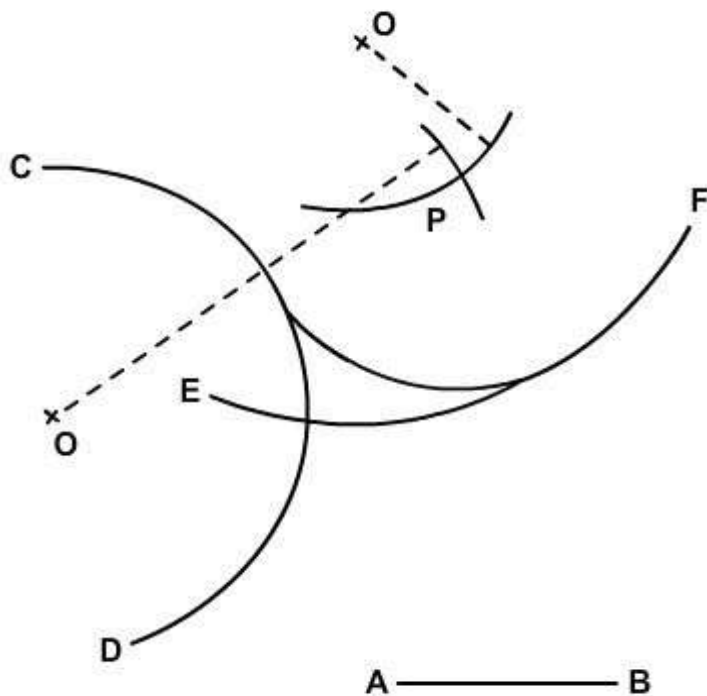
Figure 5-37 – Circular arc tangent to arcs that curve in the same direction.

is to draw a circular arc with a radius equal to AB, tangent to and enclosing both arcs CD and EF. Set a compass to a radius equal to AB less the radius of CD (indicated by the dashed line from O), and, with O as a center, strike an arc. Set the compass to a radius equal to AB less the radius of EF (indicated by the dashed line from O'), and, with O' as a center, strike an intersecting arc at P. The point of intersection of these two arcs is the center of a circle of which an arc of given radius is tangent to, and encloses, both arcs CD and EF.

In *Figure 5-39* the problem is to draw a circular arc with a radius equal to AB, tangent to, and enclosing, CD, and tangent to, but NOT enclosing, EF. Set a compass to a radius equal to AB less the radius of arc CD (indicated by the dashed line from 0), and, with O as a center, strike an arc, Set the compass to AB plus the radius of EF (as indicated by the dashed line from O'), and, with O' as a center, strike an intersecting arc at P. The point of intersection of the two arcs is the center of a circle of which an arc of the given radius is tangent to and encloses arc CD and also is tangent to, but does not enclose, arc EF.

Figure 5-38 – Circular arc tangent to and enclosing two other circular arcs.
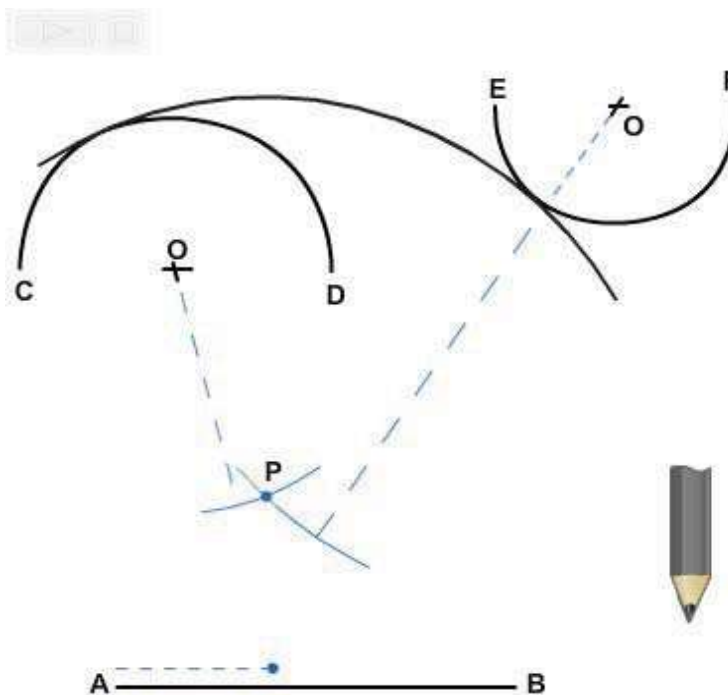
Figure 5-39 – Circular arc tangent to and enclosing one arc and tangent to, but not enclosing, another arc.

4.6.0 Compound Curves
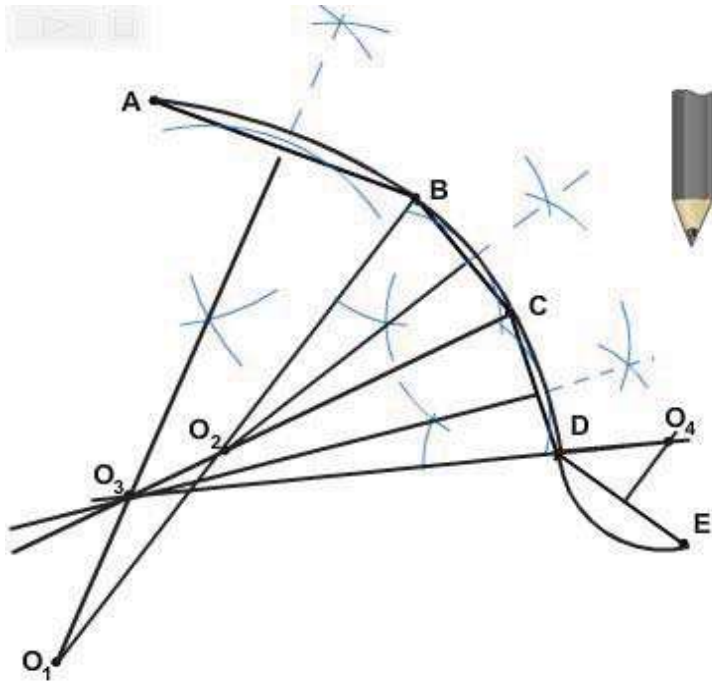
Figure 5-40 – Curve composed of a series of consecutive tangent circular arcs.

A ***compound curve*** is a curve that is made up of a series of successive tangent circular arcs. In *Figure 5-40* the problem is to construct a compound curve passing through given points A, B, C, D, and E. First, connect the points by straight lines. The straight line between each pair of points constitutes the chord of the arc through the points.

Erect a perpendicular bisector from AB. Select an appropriate point O_1 on the bisector as a center, and draw the arc AB. From O_1, draw the radius O_1B. From BC, erect a perpendicular bisector. The point of intersection O_2 between this bisector and the radius O_1B is the center for the arc BC. Draw the radius O_2C, and erect a perpendicular bisector from CD. The point of intersection O_3 of this bisector and the extension of O_2C is the center for the arc CD.

To continue the curve from D to E, you must reverse the direction of curvature. Draw the radius O_3D, and erect a perpendicular bisector from DE on the opposite side of the curve from those previously erected. The point of intersection of this bisector and the extension of O_3D is the center of the arc DE.

4.7.0 Reverse, or Ogee, Curve

A reverse, or ogee, curve is composed of two consecutive tangent circular arcs that curve in opposite directions.

Figure 5-41 shows a method of connecting two parallel lines by a reverse curve tangent to the lines. The problem is to construct a reverse curve tangent to the upper line at A and to the lower line at B.
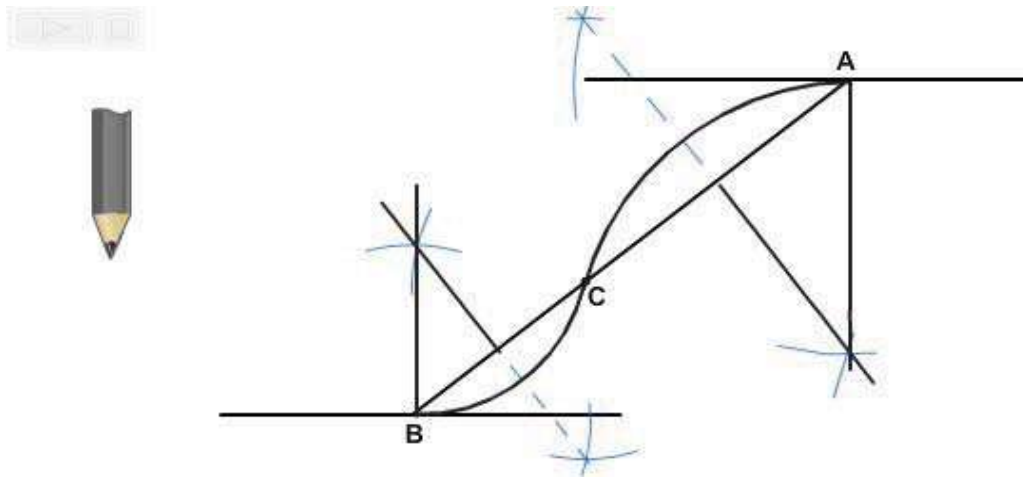
Figure 5-41 – Reverse curve connecting and tangent to two parallel lines.

Connect A and B by a straight line AB. Select point C on AB where you want to have the reverse curve change direction. Erect perpendicular bisectors from BC and CA, and erect perpendiculars from B and A. The points of intersection between the perpendiculars and are the centers for the arcs BC and CA.

Figure 5-42 shows a method of constructing a reverse curve tangent to three
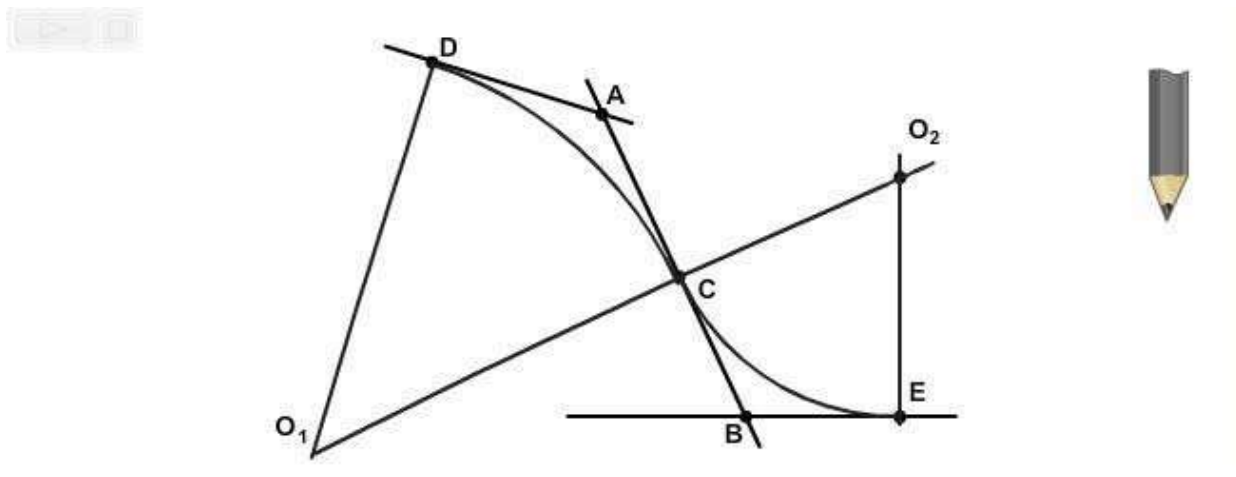
Figure 5-42 – Reverse curve tangent to three intersecting straight lines.

intersecting straight lines. The problem is to draw a reverse curve tangent to the three lines that intersect at points A and B. Select point C on AB where you want the reverse curve to change direction. Lay off from A a distance equal to AC to establish point D. Erect a perpendicular from D and another from C. The point of intersection of these perpendiculars is the center of the arc DC.

Lay off from B a distance equal to CB to establish point E. Erect a perpendicular from E, and extend to intersect it. The point of intersection is the center of the arc CE.

5.0.0 NONCIRCULAR CURVES

The basic uniform noncircular curves are the ellipse, the parabola, and the hyperbola. These curves are derived from conic sections as shown in *Figure 5-43*. The circle itself (not shown, but a curve formed by a plane passed through a cone perpendicular to the vertical axis) is also derived from a conic section.
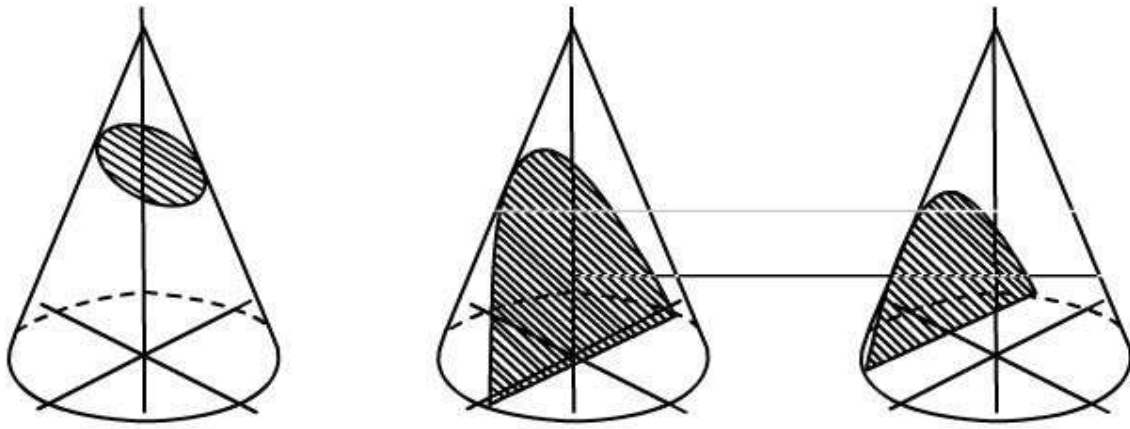
Figure 5-43 – Conic sections: ellipse, parabola, and hyperbola (left to right).

This section describes methods of constructing the ellipse only. Methods of constructing the hyperbola are given in *Engineering Drawing* by French and Vierck and in *Architectural Graphic Standards.*

Of the many different ways to construct an ellipse, the three most common are the pin-and-string method, the fourcenter method, and the concentric-circle method. The method you should use will depend on the size of the ellipse and where you will use it.

5.1.0 Ellipse by Pin-And-String Method

The dimensions of an ellipse are given in terms of the lengths of the major (longer) and minor (shorter) axes. *Figure 5-44* shows a method called the pin-and-string method of constructing an ellipse. The problem is to construct an ellipse with a major axis, AB, and a minor axis, CD. Set a compass to one-half the length of AB, and, with C as a center, strike arcs intersecting AB at F and F'. The points F and F' are called the foci of ellipse. Set a pin at point C, another at F, and a third at F'. Tie the end of a piece of string to the pin at F, pass the string around the pin at C, draw it taut, and fasten it to the pin at F'. Remove the pin at C, place the pencil point in the bight of the string, and draw the ellipse as shown in view C, keeping the string taut all the way around.
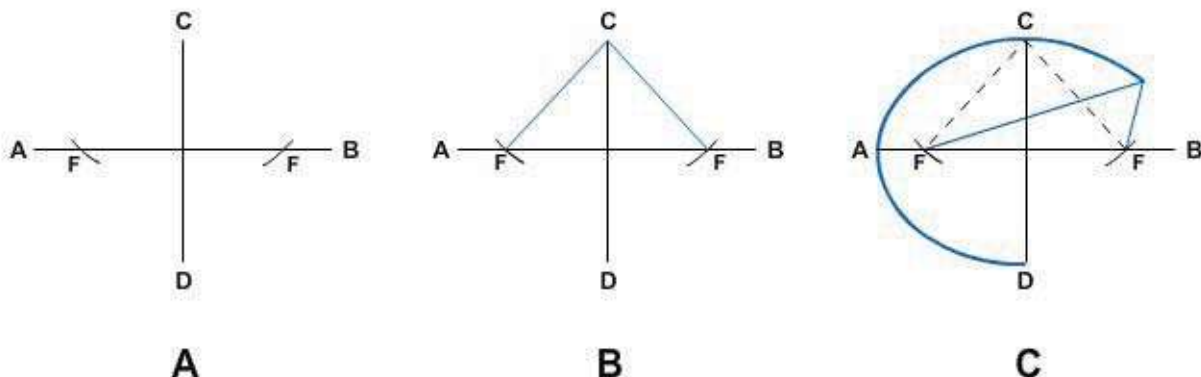
Figure 5-44 – Ellipse by pin-and-string method.

5.2.0 Ellipse by Four-Center Method

The four-center method is used for small ellipses. Given major axis, AB, and minor axis, CD, mutually perpendicular at their midpoint, O, as shown in *Figure 5-45*, draw AD, connecting the end points of the two axes. With the dividers set to DO, measure DO along AO and reset the dividers on the remaining distance to O. With the difference of semiaxes thus set on the dividers, mark off DE equal to AO minus DO. Draw perpendicular bisector AE, and extend it to intersect the major axis at K and the minor axis extended at H. With the dividers, mark off OM equal to OK, and OL equal to OH. With H as a center and radius R1 equal to HD, draw the bottom arc. With L as a center and the same radius as R1, draw the top arc. With M as a center and the radius R2 equal to MB draw the end arc. With K as a center and the same radius, R2, draw the end arc. The four circular arcs thus drawn meet, in common points of tangency, P, at the ends of their radii in their lines of centers.

DE = AO-DO

R₁ = HD = LC
R₂ = KA = MB
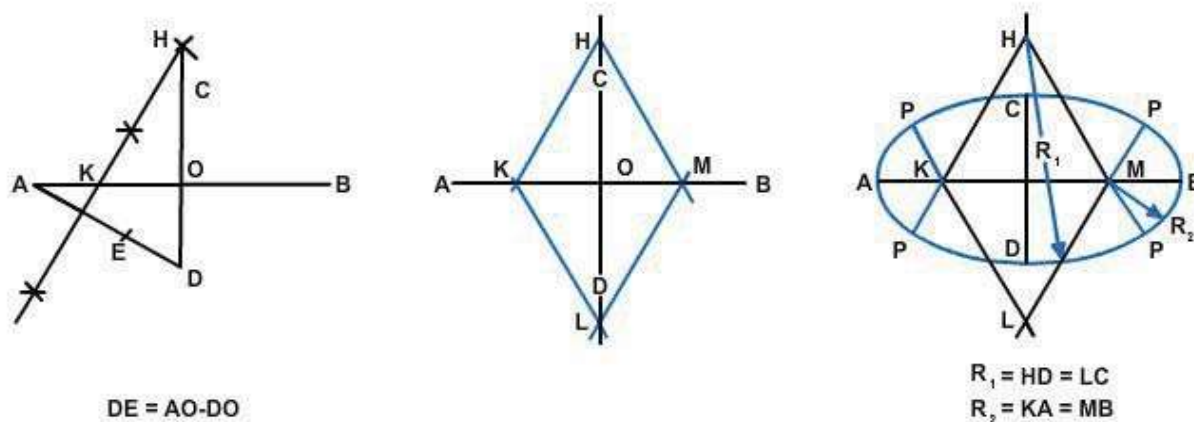
Figure 5-45 – Ellipse by four-center method.

5.3.0 Ellipse by Concentric-Circle Method

Figure 5-46 shows the concentric-circle method of drawing an ellipse. With the point of intersection between the axes as a center, draw two concentric circles (circles with a common center), one with a diameter equal to the major axis and the other with a diameter equal to the minor axis, as shown in *Figure 5-46, View A*. Draw a number of diameters as shown in *Figure 5-46, View B*. From the point of intersection of each diameter with the larger circle, draw a vertical line; and from the

A
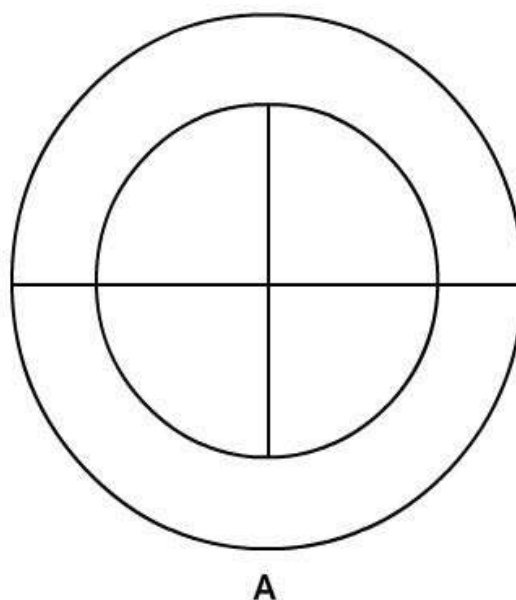
Figure 5-46 – Ellipse by Concentric-Circle Method.

point of intersection of each diameter with the smaller circle, draw an intersecting horizontal line, as shown in *Figure 5-46, View C.* Use a French curve to draw the ellipse through the points of intersection, as shown in *Figure 5-46, View D.*

Summary

As an Engineering Aid in the field, you may not have access to a computer and drafting software. You should know basic geometric construction principles and how to apply them to create accurate drawings by hand.

Review Questions (Select the Correct Response)

1.   To_____line AB, use the ends of the line, A and B, as centers; set a
      compass to a radius greater than one-half the length of AB; and strike arcs above
      and below line AB, intersecting at C and D. Draw a line from C to D.

      A.   create a line parallel to
      B.   bisect
      C.   create a line tangent to
      D.   create a line skewed to

2.   You can divide a line into more than two equal parts by trial and error with a
      _____.

      A.   triangle
      B.   protractor
      C.   divider
      D.   piece of string
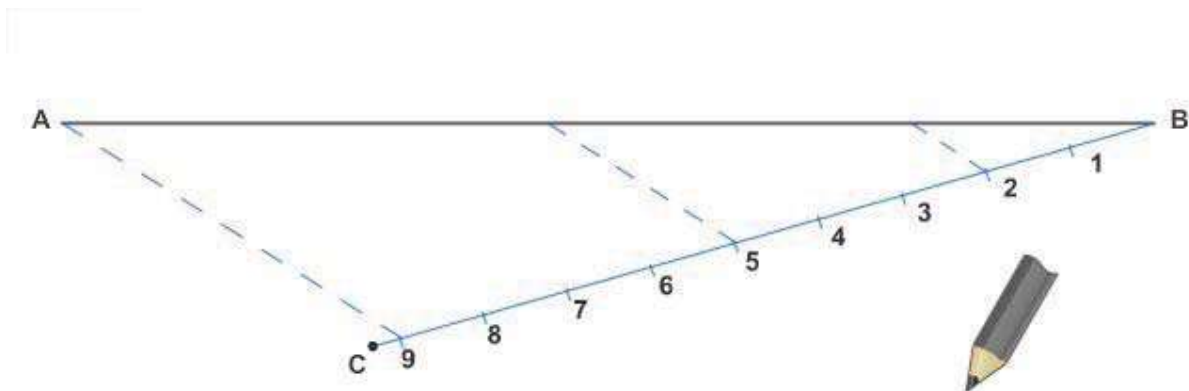
3.   The figure above shows_____.

      A.   dividing a line into proportional parts
      B.   bisecting a line
      C.   creating a line perpendicular to another line
      D.   creating a line parallel to another line

4. The figure to the right shows _____.

    A. dividing a line into parts so that the ratio between the whole line and one of the parts is the same as that between two other lines.
    B. dividing a line into proportional parts
    C. creating a line perpendicular to another line
    D. creating a line parallel to another line
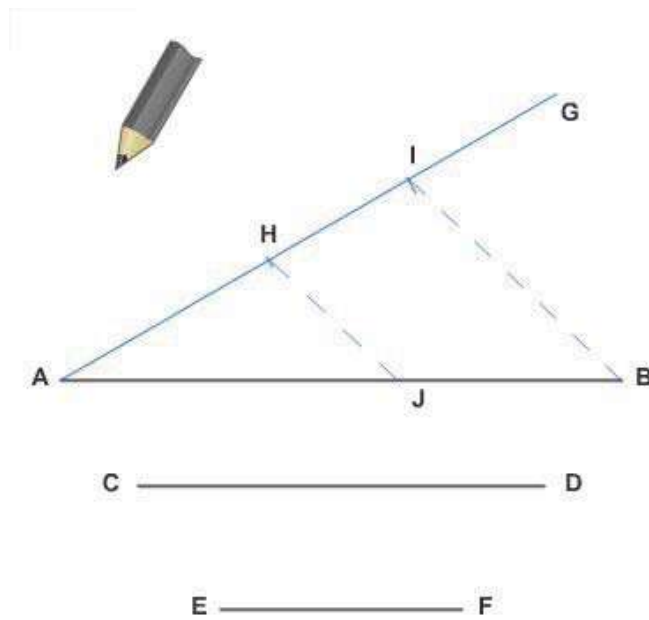
5. Using geometric construction, you can lay off an angle equal in size to one that is already drawn on another part of the same drawing or on a different drawing; this is called _____.

    A. division according to a given ratio
    B. bisecting an angle
    C. bisecting a line
    D. transferring an angle.

6. If you know the size of an angle, you can _____ it simply by dividing the size by 2 and laying off the result with a protractor.

    A. bisect
    B. transfer
    C. circumscribe
    D. inscribe

7.   The figure to the right shows_____.

    A.   constructing an
          equilateral triangle
          with a given length of
          side AB
    B.   constructing a
          triangle with
          hypotenuse and one
          side given
    C.   constructing a
          triangle with three
          sides given
    D.   constructing
          equilateral triangle in
          a given
          circumscribed circle
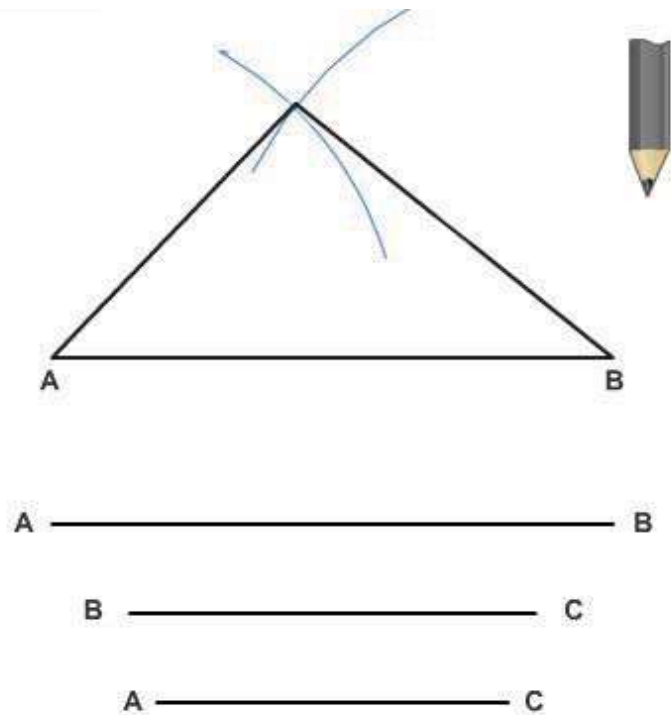
8.   The figure below shows_____.

    A.   constructing an equilateral triangle with a given length of side AB
    B.   constructing a triangle with hypotenuse and one side given
    C.   constructing a triangle with three sides given
    D.   constructing equilateral triangle in a given circumscribed circle
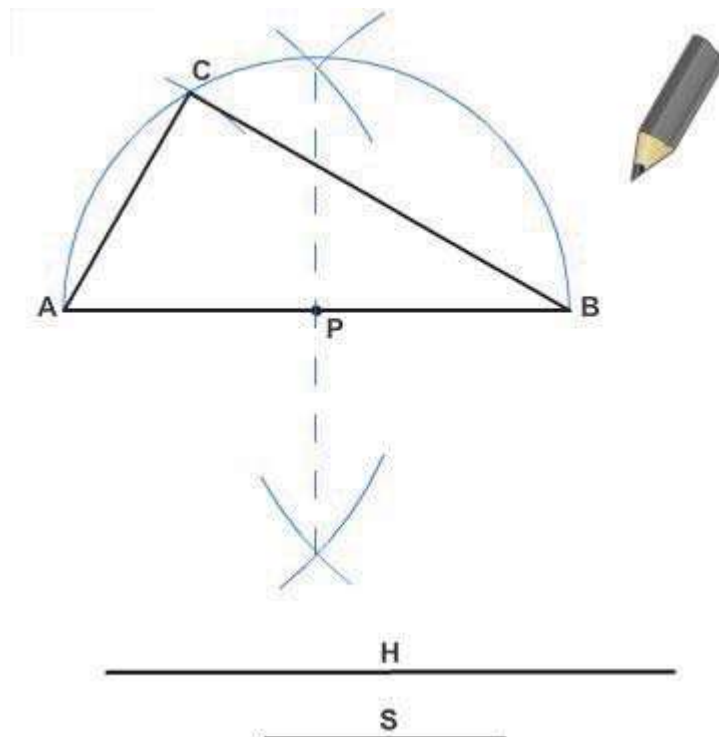
9.   Each angle in an equilateral triangle measures_____degrees.

        A.   180
        B.   45
        C.   90
        D.   60

10.   A(n)_____plane figure is one that encloses another figure and is tangent
        to the extremities of the enclosed figure.

        A.   inscribed
        B.   circumscribed
        C.   ogee
        D.   compound

11.   A(n)_____plane figure is one that is enclosed by a circumscribed figure.

        A.   inscribed
        B.   circumscribed
        C.   ogee
        D.   compound

12.   The figure below shows_____.

        A.   constructing an equilateral triangle with a given length of side AB
        B.   constructing a triangle with hypotenuse and one side given
        C.   constructing an equilateral triangle on a given inscribed triangle
        D.   constructing equilateral triangle in a given circumscribed circle
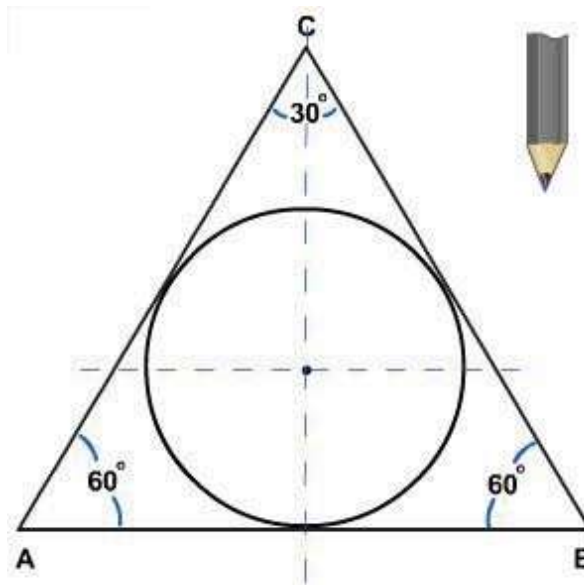
13.   To construct a_____with a given length and width, draw a horizontal line AB, equal to the given length. With a straightedge and triangle, erect perpendiculars from A and B, each equal to the given width. Connect the ends of the perpendiculars.

A.   octagon
B.   pentagon
C.   rectangle
D.   hexagon

14.   The figure to the right shows_____.

A.   drawing a square with a given length of side
B.   drawing a octagon with a given length of side
C.   drawing a regular pentagon with a given length of side
D.   drawing a regular hexagon with a given length of side
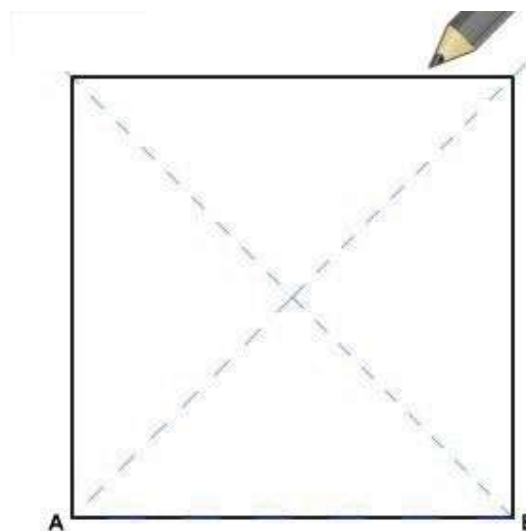
15.   The figure to the right shows_____.

A.   drawing a square with a given length of side
B.   drawing a octagon with a given length of side
C.   drawing a square with a given length of diagonal
D.   drawing a regular hexagon with a given length of side
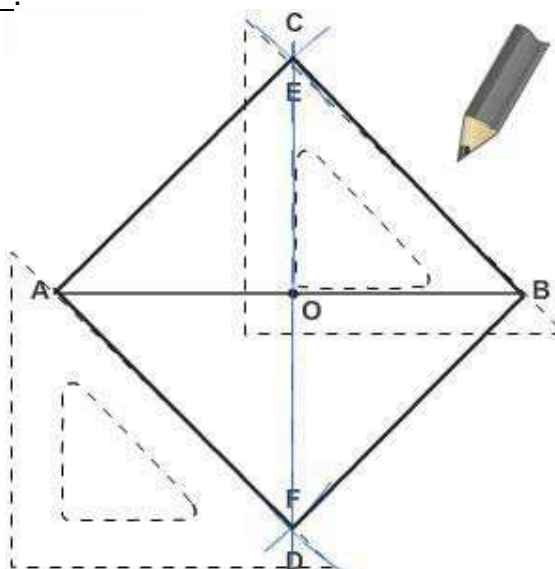
16. The figure to the right shows_____.

   A. drawing a square around a given inscribed circle
   B. drawing a square in a given circumscribed circle
   C. drawing a regular pentagon on a given inscribed circle
   D. drawing a regular pentagon in a given circumscribed circle
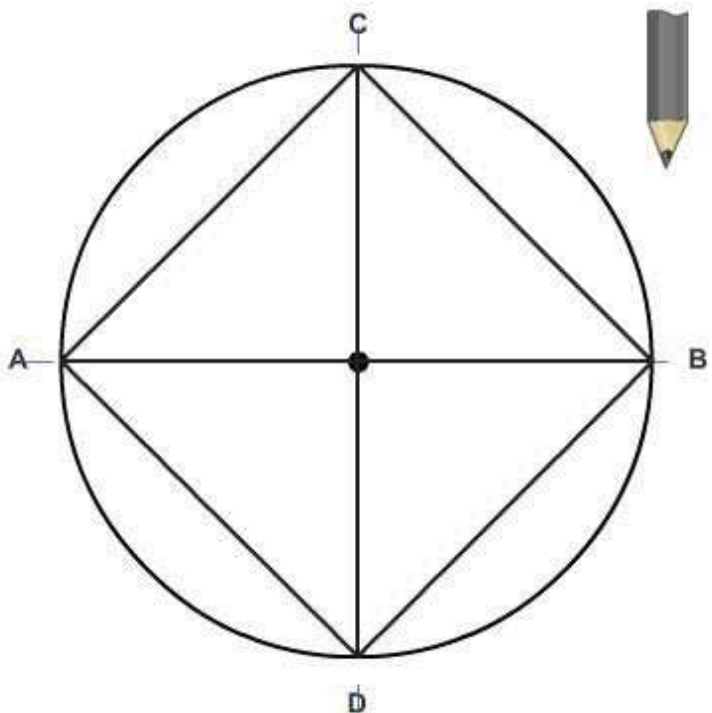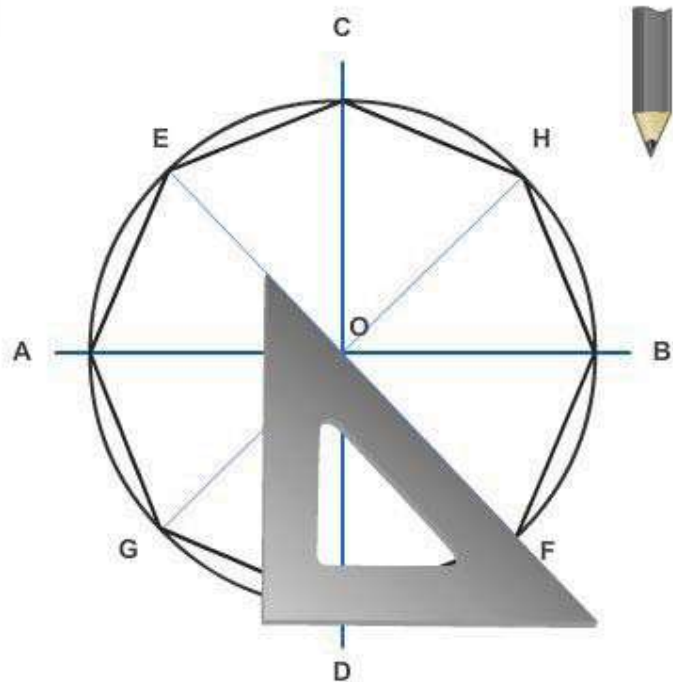

17. The figure above shows_____.

   A. drawing a square around a given inscribed circle
   B. drawing a square in a given circumscribed circle
   C. drawing a regular pentagon on a given inscribed circle
   D. drawing a regular pentagon in a given circumscribed circle
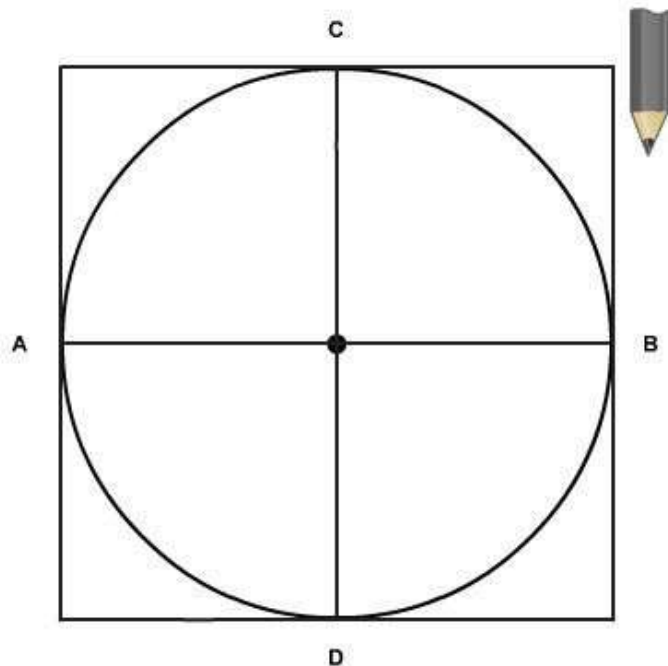
18. The figure to the right shows_____.

A. drawing a square with a given length of side
B. drawing a octagon with a given length of side
C. drawing a regular polygon on a given inscribed circle
D. drawing a regular polygon in a given circumscribed circle

$360° \div 9 = 40°$
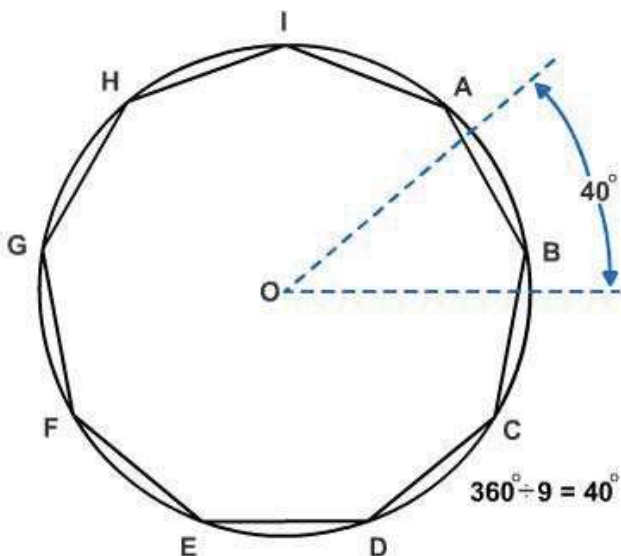
19. The figure to the right shows_____.

A. drawing a square with a given length of side
B. drawing a octagon with a given length of side
C. drawing a regular polygon on a given inscribed circle
D. drawing a regular polygon in a given circumscribed circle
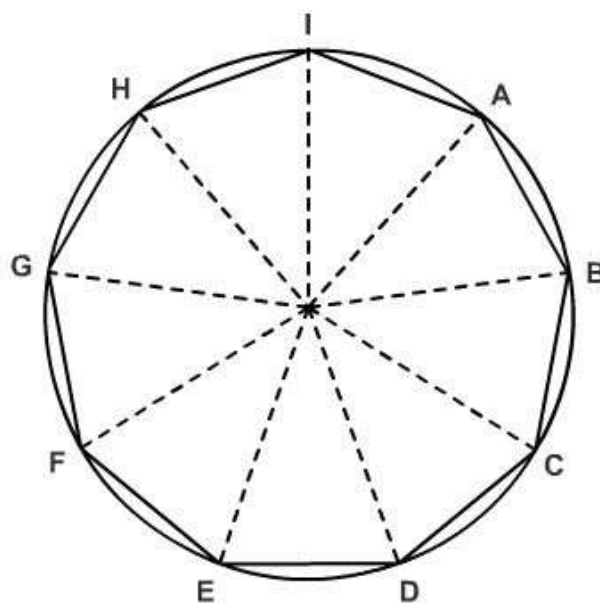
20. The figure to the right shows_____.

A. drawing a square with a given length of side

B. drawing any regular polygon with a given length of side

C. drawing a regular polygon on a given inscribed circle

D. drawing a regular polygon in a given circumscribed circle
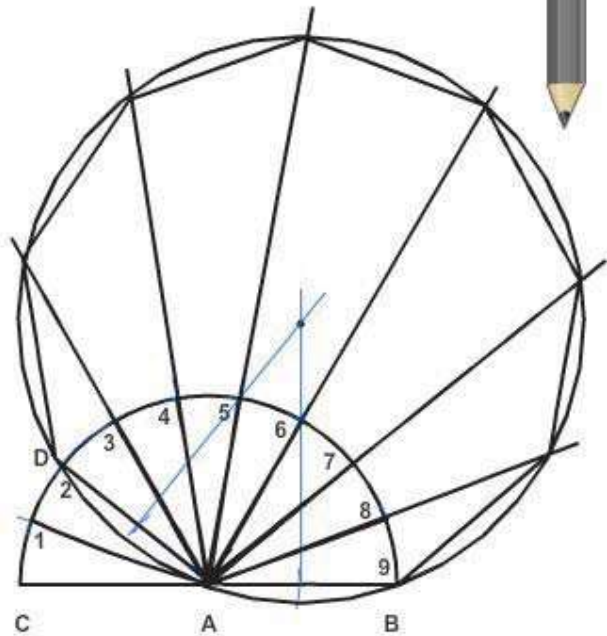
21. The figure to the right shows _____

A. drawing a regular octagon around a given inscribed circle

B. drawing a regular octagon in a given circumscribed circle

C. drawing a regular pentagon on a given inscribed circle

D. drawing a regular pentagon in a given circumscribed circle
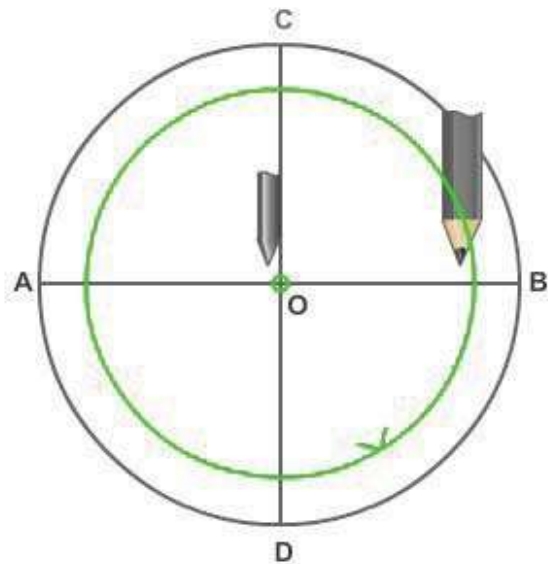
22.   The figure to the right shows_____.

    A.   drawing a regular octagon around a given inscribed circle
    B.   drawing a regular octagon in a given circumscribed circle
    C.   drawing a regular hexagon on a given inscribed circle
    D.   drawing a regular hexagon in a given circumscribed circle
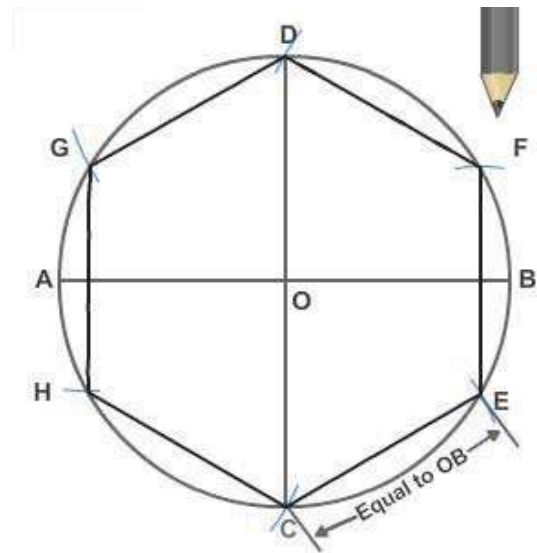
23.   The figure to the right shows_____.

    A.   drawing a regular octagon around a given inscribed circle
    B.   drawing a regular octagon in a given circumscribed circle
    C.   drawing a regular hexagon on a given inscribed circle
    D.   drawing a regular hexagon in a given circumscribed circle
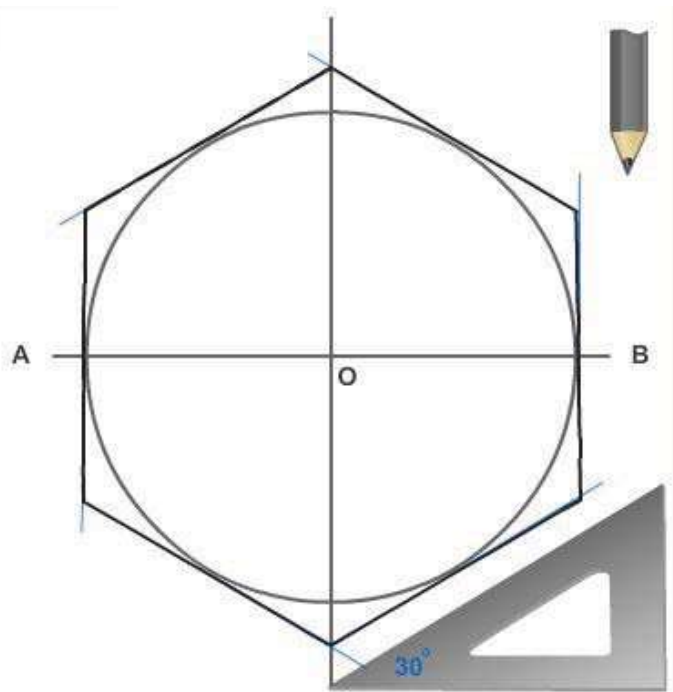
24. The figure to the right shows_____.

    A.   drawing a regular
          octagon around a
          given inscribed circle
    B.   drawing a regular
          octagon in a given
          circumscribed circle
    C.   drawing a regular
          hexagon on a given
          inscribed circle
    D.   drawing a regular
          hexagon in a given
          circumscribed circle

25. The figure to the right shows_____.

    A.   drawing a regular
          octagon around a
          given inscribed circle
    B.   drawing a regular
          octagon in a given
          circumscribed circle
    C.   drawing a regular
          hexagon on a given
          inscribed circle
    D.   drawing a regular
          hexagon in a given
          circumscribed circle
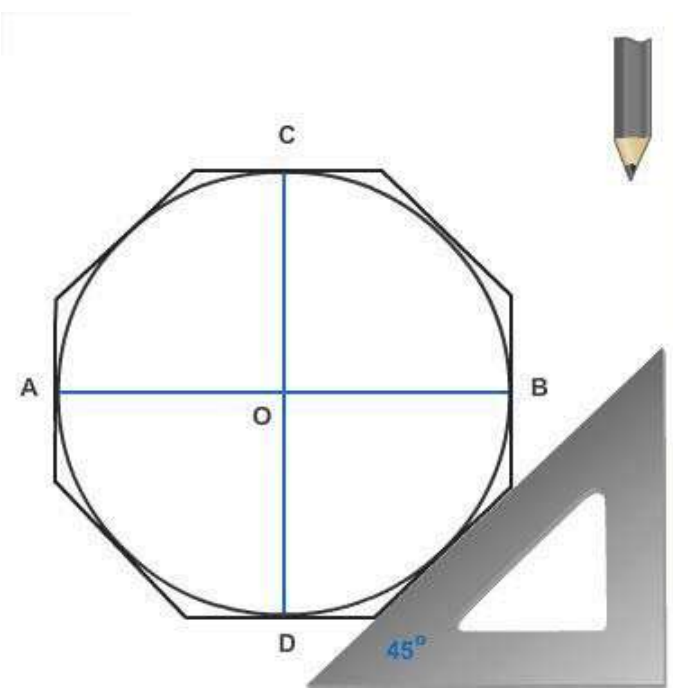
26. The figure to the right shows_____.

    A. drawing a circular arc tangent to a straight line and another circular arc

    B. drawing a circle or arc through three points

    C. drawing a line tangent to a given point on a circle

    D. drawing a curve composed of a series of consecutive tangent circular arcs
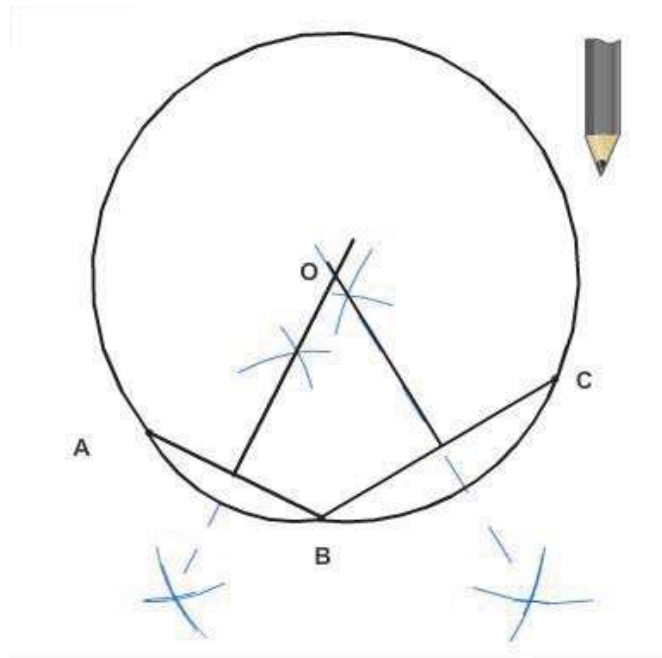
27. A line that is tangent to a circle at a given point is_____to the radius that intersects the point.

    A. skewed

    B. curved

    C. parallel

    D. perpendicular

28. The figure to the right shows_____.

    A. drawing a circular arc tangent to a straight line and another circular arc

    B. drawing a circular arc tangent to and enclosing two other circular arcs

    C. drawing a circular arc tangent to two lines that form a right angle

    D. drawing a curve composed of a series of consecutive tangent circular arcs
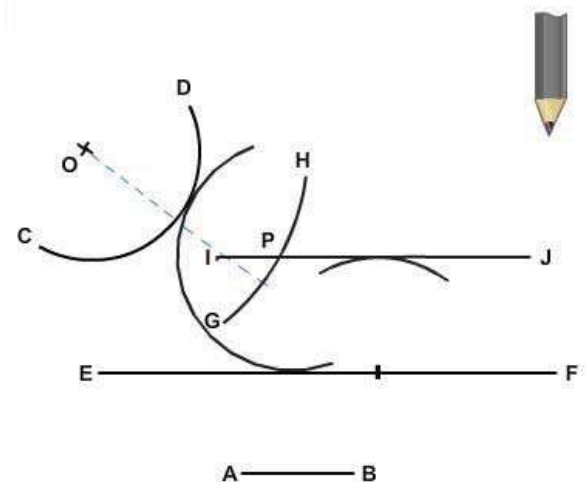
29. The figure to the right shows_____.

    A.   drawing a circular arc tangent to a straight line and another circular arc

    B.   drawing a circular arc tangent to and enclosing two other circular arcs

    C.   drawing a circular arc tangent to and enclosing one arc and tangent to, but enclosing, another arc

    D.   drawing a curve composed of a series of consecutive tangent circular arcs
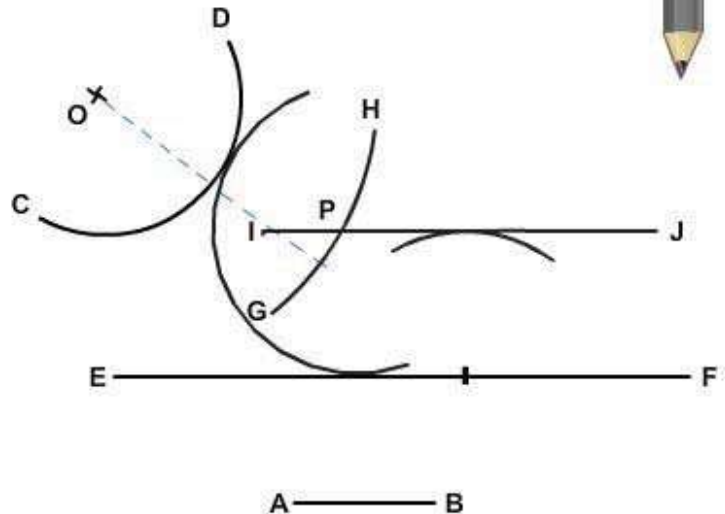
30. The figure to the right shows_____.

    A.   drawing a reverse curve connecting and tangent to two parallel lines

    B.   drawing a circular arc tangent to and enclosing two other circular arcs

    C.   drawing a circular arc tangent to and enclosing one arc and tangent to, but not enclosing another arc

    D.   drawing a curve composed of a series of consecutive tangent circular arcs
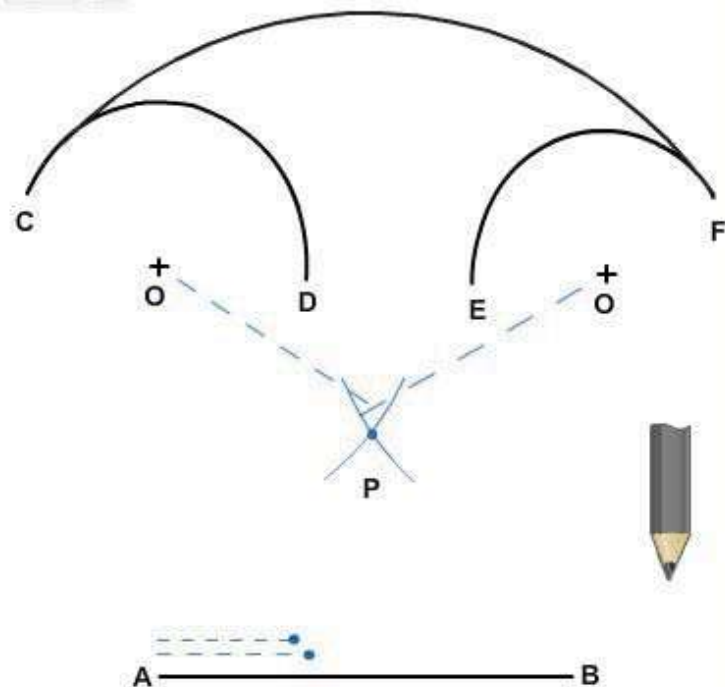
31. A curve that is made up of a series of successive tangent circular arcs is called a(n)_____curve.

 A. ogee
 B. elliptical
 C. circumscribed
 D. compound

32. A(n)_____curve is composed to two consecutive tangent circular arcs that curve in opposite directions.

 A. ogee
 B. elliptical
 C. circumscribed
 D. compound

33. The basic uniform_____are the ellipse, the parabola, and the hyperbola.

 A. lines
 B. polygons
 C. noncircular curves
 D. circular curves
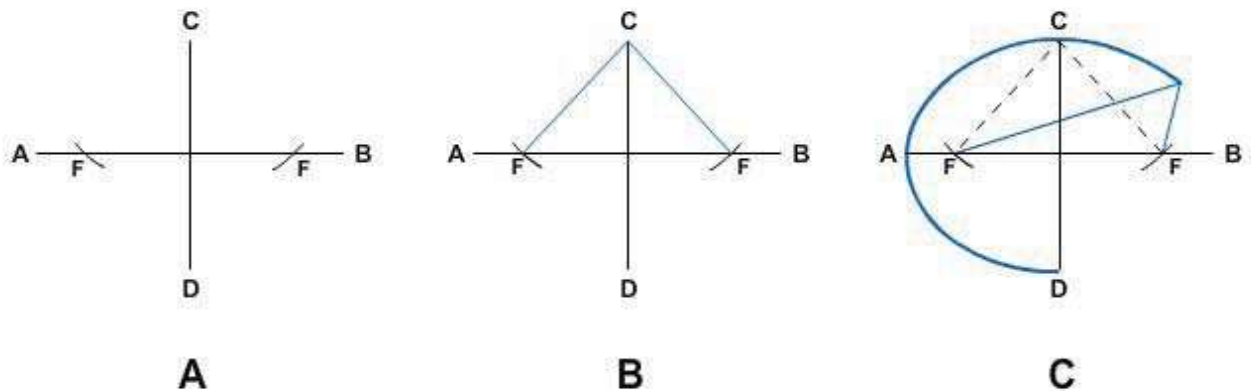
34. The figure above shows_____.

 A. drawing an ellipse freehand
 B. drawing an ellipse by pin-and-string method
 C. drawing an ellipse by four-center method
 D. drawing an ellipse by concentric-circle method

35. The four-center method is used to draw_____.

 A. concentric circles
 B. small ellipses
 C. parallel lines
 D. perpendicular lines

36.   The figure to the right shows_____.

    A.   drawing an ellipse freehand
    B.   drawing an ellipse by pin-and-string method
    C.   drawing an ellipse by four-center method
    D.   drawing an ellipse by concentric-circle method

A

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

Blueprint Reading and Sketching, NAVEDTRA 14040, Naval Education and Training Program Management Support Activity*, Pensacola, FL, 2003.

Graphic Symbols for Electrical and Electronics Diagrams, American National Standard, ANSI 2.2-1975, The Institute of Electrical and Electronics Engineers, NY, 1986.

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Chapter 6

Drafting: Projections and Sketching

Topics

To hear audio, click on the box.

Overview

This chapter deals with projection theory and methods of preparing projection drawings. You should be able to clearly represent any given object or structure on paper by applying basic geometric construction to the various projection methods. Although the methods discussed here are basic to all drawings, you can easily adapt them for construction drawings. This chapter also covers various techniques of freehand sketching. You will learn how to prepare quick sketches to convey or develop your ideas.

Every object or structure you draw has length, width, and depth, regardless of its size. Your goal, however, is to draw the object or structure on paper, which is a flat two-dimensional plane. To show the three dimensions by lines alone, you must use either a system of related views or a single pictorial projection. You must be able to show clearly the shape of the object, give the exact size of each part, and provide necessary information for constructing the object.

In theory, projection is done by extending lines of sight (called projection lines) from the eye of the observer, through lines and points of an object being viewed, to the plane of projection.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Describe the different types of parallel projection.
2. Describe the different types of perspective projection and perspective drawing.
3. Describe the different techniques used in sketching.

Prerequisites

None

This course map shows all of the chapters in Engineering Aid Basic. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

		E
Topographic Surveying and Mapping	↑	N
Indirect Leveling/Level and Traverse Computations		G
Care and Adjustment of Survey Equipment		I
Materials Testing: Soil and Concrete		N
Direct Leveling and Basic Engineering Surveys		E
Horizontal Control		E
Direct Linear Measurements and Field Survey Safety		R
Surveying: Elements and Equipment		I
Construction Drawings		N
Electrical: Systems and Plans		G
Mechanical: Systems and Plans		
Concrete and Masonry		AID
Wood and Light Frame Structures		
Drafting: Projections and Sketching		B
Drafting: Geometric Construction		A
Drafting: Fundamentals and techniques		S
Drafting: Equipment		I
Mathematics and Units of Measurement		C
Engineering Aid Rating		

Features of this Manual

This manual has several features which make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.

- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.

- Audio and video clips are included in the text, with an italicized instruction telling you where to click to activate it.

- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.0.0 PARALLEL PROJECTION

To satisfy requirements for preparing single or multi-view drawings, there are two main types of projection: parallel and perspective (*Figure 6-1*). Parallel projection (*Figure 6-2*) is further classified into subtypes according to the direction of its projection lines relative to the plane of projection. If the projection lines are not only parallel to each other but are also perpendicular (normal) to the plane of projection, the result is an orthographic projection. If they are parallel to each other but oblique to the plane of projection, the result is an **oblique projection**.
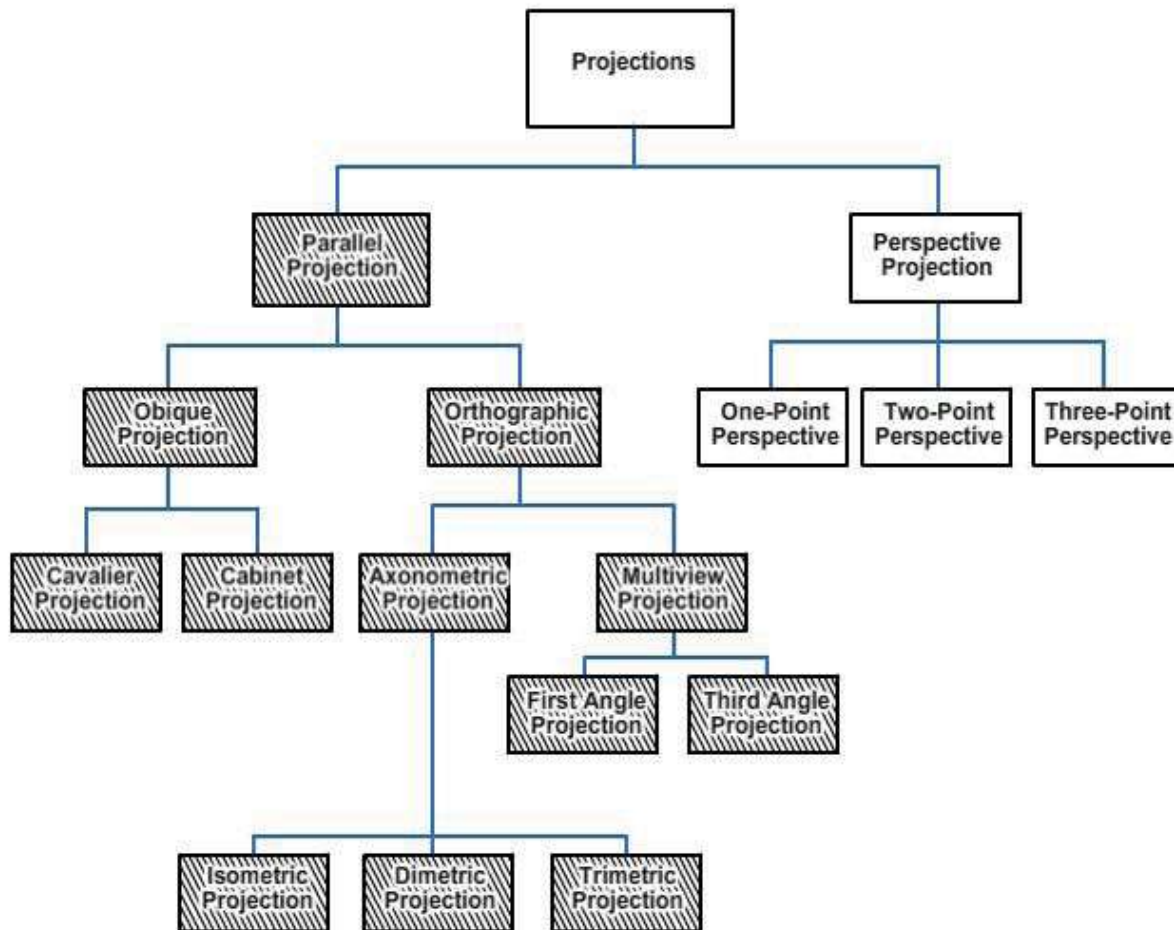
Figure 6-1 - Classification of major projections.

To better understand the theory of projection, you must become familiar with certain elements common to each type of projection. Some of these elements are defined below.

The point of sight (or station point) is the position of the observer in relation to the object and the plane of projection (*Figure 6-2*). It is from this observation point that the view of the object is taken. Since changing the point of view gives different views of the same object, there must be a different point of sight for each view. Imagine yourself looking first at the front of an object, then down at the top, and then at the right or left side, as the case may be. Each additional view requires a new point of sight.
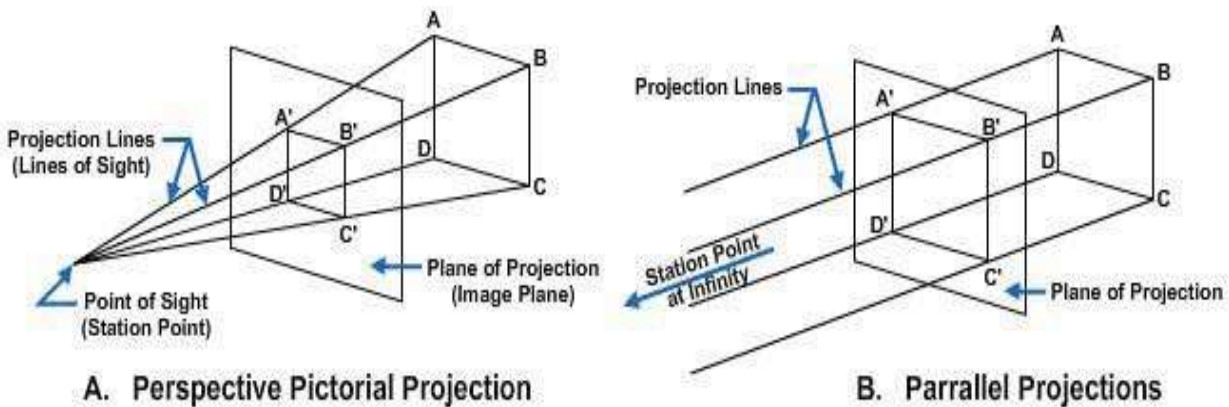
Figure 6-2 - Types of projections.

The observer views the features of the object through an imaginary ***plane of projection*** (or ***image plane***). In parallel projection, you place this theoretical transparent plane between the point of sight and the object, as shown in *Figure 6-2*. For perspective pictorials, you normally place the image plane between the point of sight and the object. For the purpose of studying any type of projection, assume the planes of projection are in fixed positions. Once you place the object in a definite imagined position, never change it. If you want a different view of the object, change the location of the point of sight.

The projection lines (or lines of sight) are the imaginary lines from the eye of the viewer (point of sight) to points on the object (*Figure 6-2*). By the use of projection lines, points on the object are projected on the image plane. These points are the points at which the projection lines appear to pierce the image plane. By the projection of the prominent points, lines, and surfaces of an object, a complete view of that object can be projected on the plane of projection.

The following sections will discuss the relationship between the point of sight (station point), the plane of projection (image plane), the projection lines (lines of sight), and the manner in which to use them for each individual type of projection.

1.1.0 Orthographic Projection

When called upon to draw a three-dimensional object or figure, you are expected to represent the parts and forms on the flat plane of the drafting paper so that all features are shown in their true dimensions and in their true relationship with other features on that part of the object. To do this, you must draw a number of views of the object from different angles. Orthographic projection consists of projecting these essential views into a single plane. The term orthographic is derived from the word *orthos* meaning perpendicular or right-angular.

1.1.1 Multi-View Projection

When you view an object through a plane of projection from a point at infinity, you obtain an accurate outline of the visible face of the object (*Figure 6-3*). However, the projection of one face usually will not provide an overall description of the object; you must use other planes of projection. Establishing an object's true height, width, and depth requires front, top, and side views, which are called the **principal planes of projection**. *Figure 6-4* shows the three principal (or primary) planes of projection, known as the vertical, horizontal, and profile planes. The angles formed between the horizontal and the vertical planes are called the first, second, third, and fourth angles, as indicated in the figure. Currently, however, for technical reasons, only the use of first- and third-angle projection is practical.
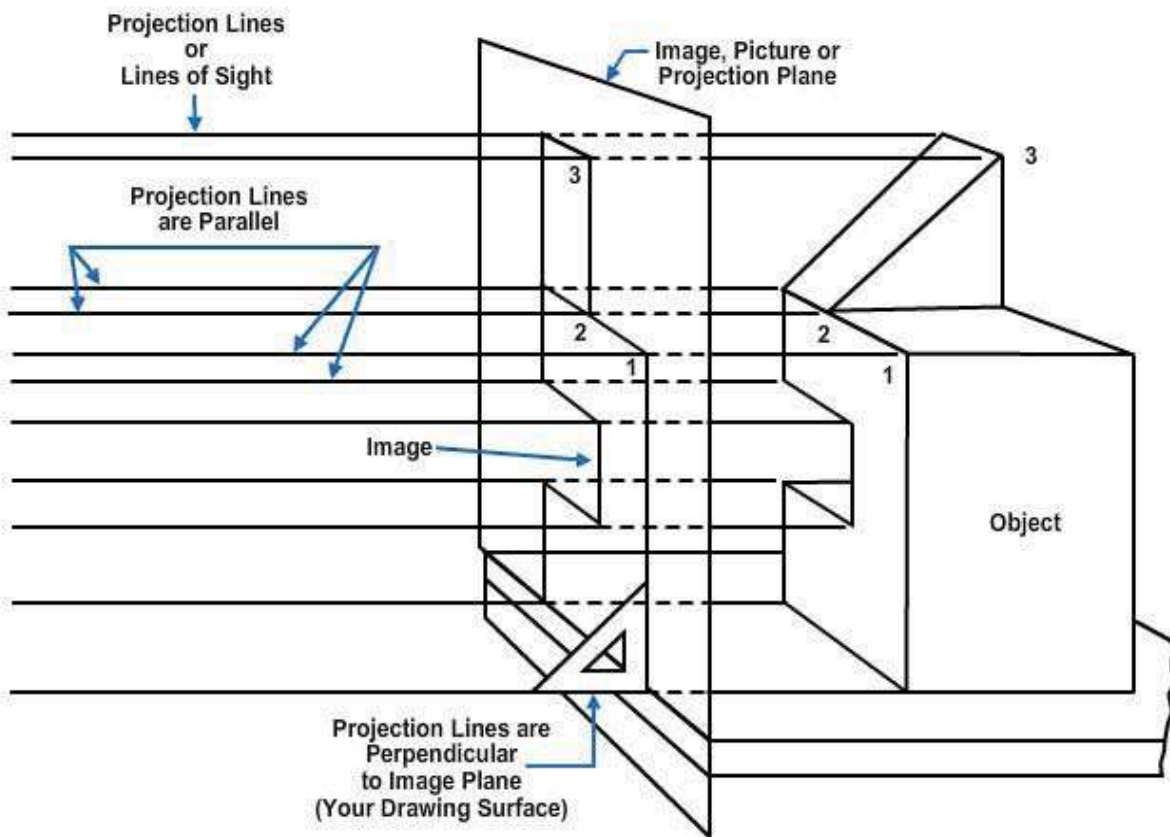
Figure 6-3 - Basic orthographic projection.
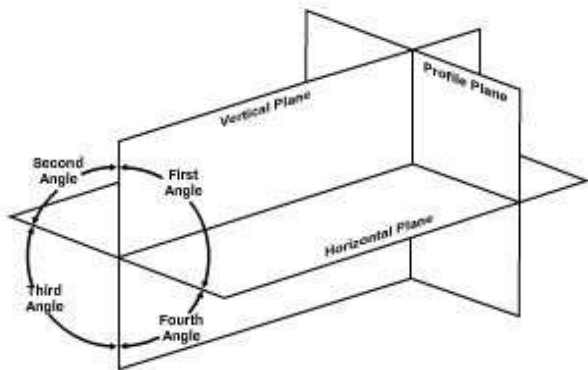
Figure 6-4 - Primary (principal) planes of projections.

1.1.1.1 First-Angle Projection

Figure 6-5 is a fine example of first-angle projection using a cube. The front of the cube is facing toward the vertical plane of projection. As you can see, you get a front view on the vertical plane, a left side view on the profile plane, and a top view on the horizontal plane.

Now, to put these views on a sheet of drafting paper, put them all into the same plane. Presume that the vertical plane of projection is already in the plane of the paper. To get the other two views into the same plane, rotate the profile plane counterclockwise and the horizontal plane clockwise. The projection now appears as shown in *Figure 6-6*.
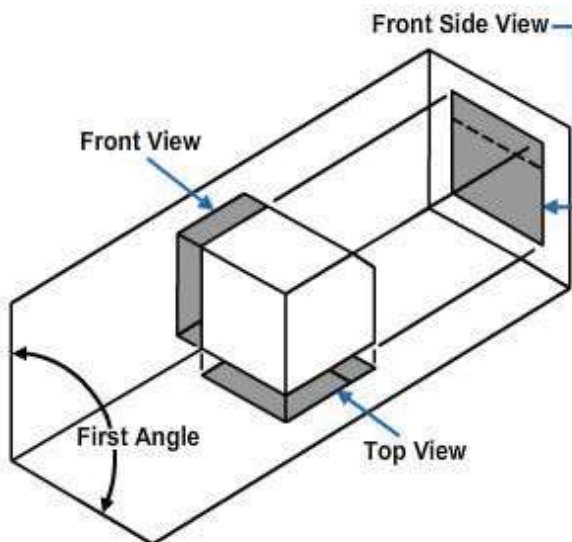
Figure 6-5 – Example of a first-angle projection.
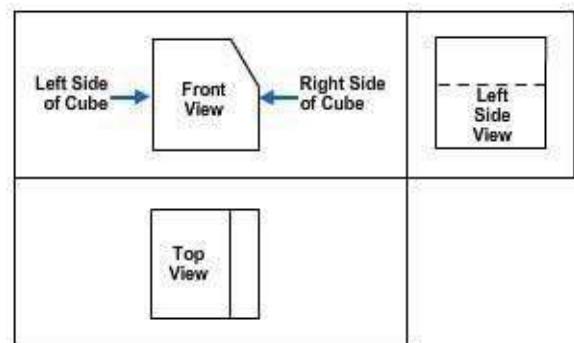
Figure 6-6 – First-angle projection brought into a single plane.

In common European drafting practice, this first-angle projection arrangement of views is considered satisfactory. In the United States, it is considered illogical because the top view is below the front view; because the right side of the object, as shown in the front view, is toward the left side view of the object; and because the bottom of the object, as shown in the front view, is toward the top view of the object. For these and other reasons, first-angle projection is not commonly used in the United States.

1.1.1.2 Third-Angle Projection

Figure 6-7 shows a third-angle projection of a cube. As you can see, you get a front view on the vertical plane, a top view on the horizontal plane, and a right side view on the profile plane.
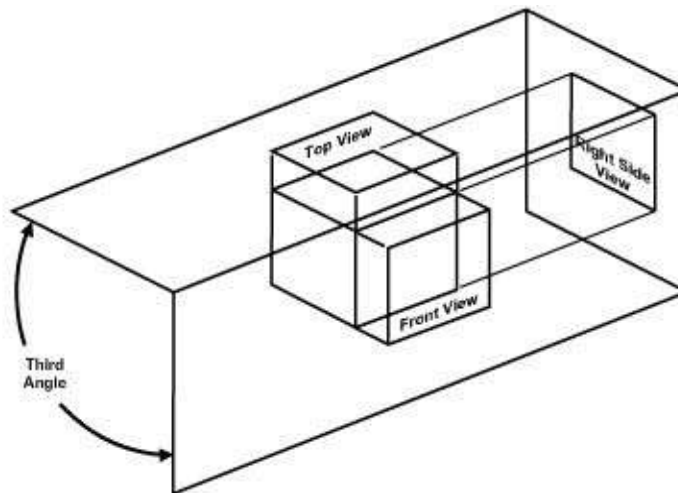
Figure 6-7 - Example of a third-angle projection.

Assume that the vertical plane is already in the plane of your drawing paper. To get the other two views onto the same plane, rotate them both clockwise. *Figure 6-8* shows a third-angle projection of an object brought into a single plane. The top view is above the front view; the right side of the object, as shown in the front view, is toward the right side view; and the top, as shown in the front view, is toward the top view.

Figure 6-9 shows the basic principles of the method used to make the projection shown in *Figure 6-8*. Draw a horizontal line AB and a vertical line CD, intersecting at O. AB represents the joint between the horizontal and the vertical plane; CD represents the joint between these two and the profile plane. You could draw any of the three views first and the other two projected from it. Assume that the front view is drawn first on the basis of given dimensions of the front face. Draw the front view, and project it upward with vertical projection lines to draw the top view. Project the top view to CD with horizontal projection lines. With O as a center, use a compass to extend these projection lines to AB. Draw the right side view by extending the projection lines from AB vertically downward and by projecting the right side of the front view horizontally to the right.
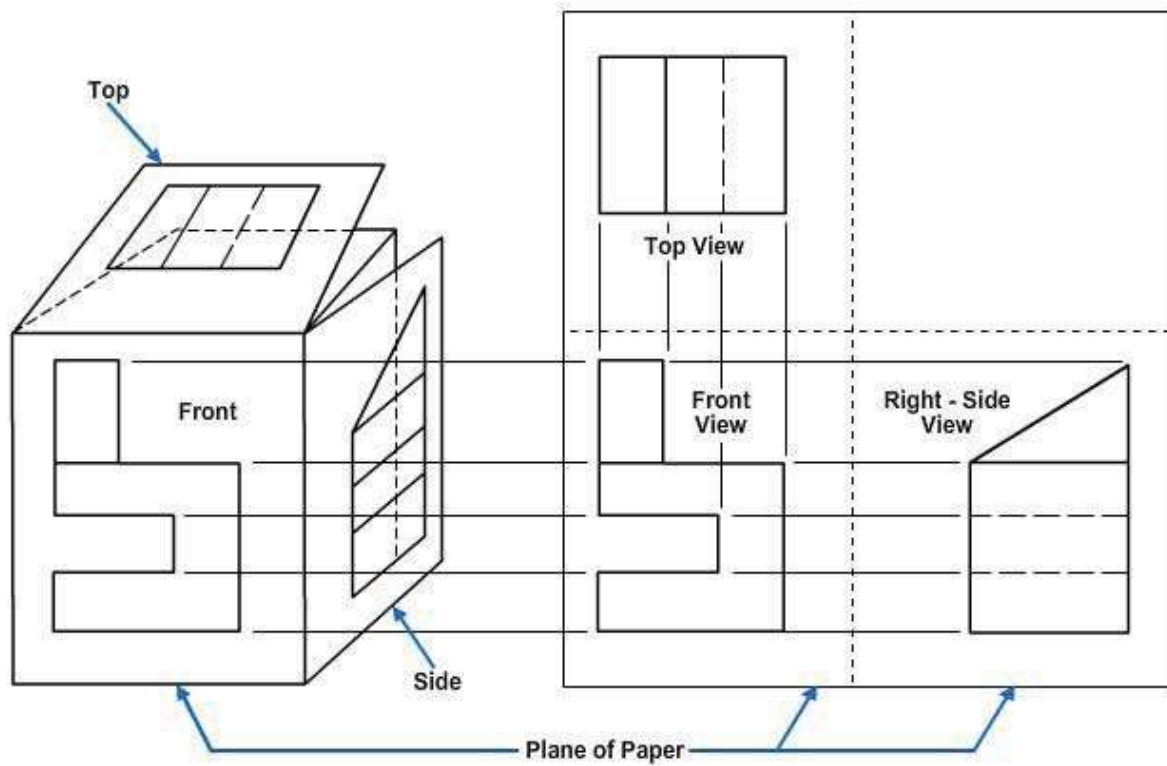
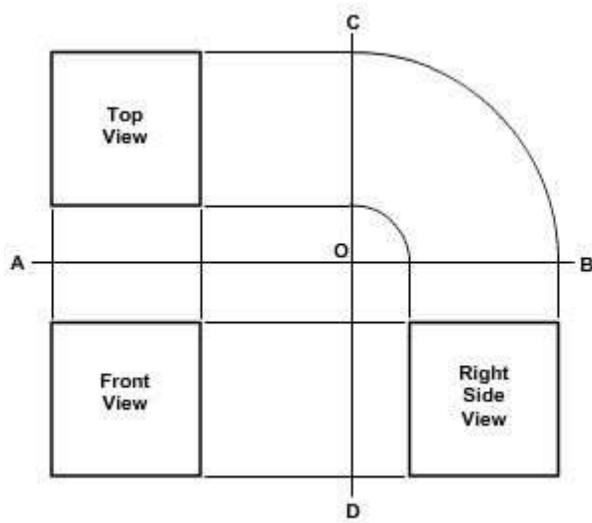**Figure 6-8 – A third-angle projection brought into a single plane.**

Figure 6- 9 – Method of making a third-angle projection.

1.1.1.3 Use of a Miter Line

Using a miter line (*Figure 6-10*), you can lay out a third view while you are in the process of drawing two other views. Place the miter line (*Figure 6-10, View B*) to the right of the top view at a convenient distance, keeping the appearance of a balanced drawing. Draw light projection lines from the top view to the miter line (*Figure 6-10, View C*), then vertically downward (*Figure 6-10, View D*). Using the front view, draw horizontal projection lines (*Figure 6-10, View E*) to the right, intersecting the vertical projection lines. This process results in the outline and placement of the right side view (*Figure 6-10, View F*).

Some EAs prefer to extend the top view projection lines to the right side view.
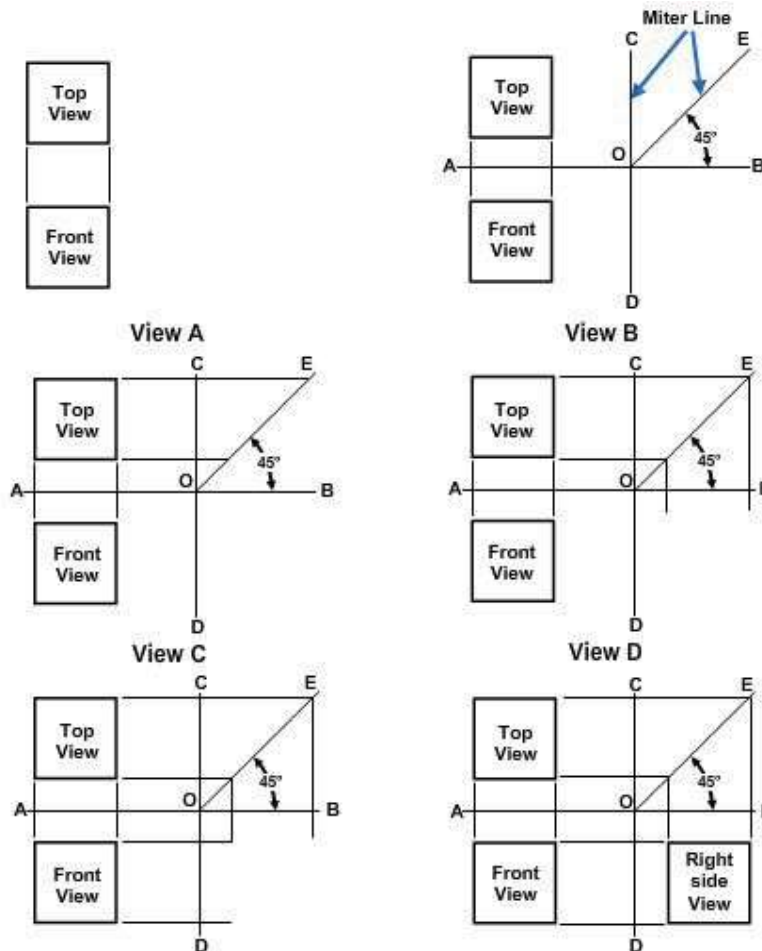
Figure 6-10 – A third-angle projection brought into a single plane.

1.1.1.4 Arrangement of Views

You should arrange the six principal views of an object drawn in a third-angle projection in accordance with the American standard arrangement of views. This arrangement (practiced since the late 1800s) depicts the relative position of the six principal views and their relationship to each other on a drafting plane.

As shown in *Figure 6-11*, all views (except the front view) are rotated toward the observer as though they are hinged. **REMEMBER**, the front view always lies in the plane of the drafting surface and does not require any rotation. Notice that the front, right side, left side, and rear views line up in direct horizontal projection.

Use the minimum number of views necessary to show an item. The three principal views are top, front, and right-side. Project and draw the top view (also called a "plan" in architectural drawings) on an image plane above the front view of the object. The front view (elevation) should show the most characteristic shape of the object or its most natural appearance when observed in its permanent or fixed position. Place the right-side view (elevation) at a right angle to the front and top views, making all the views mutually perpendicular.
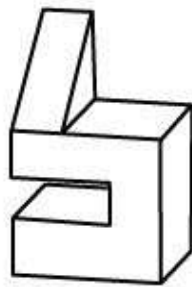
Figure 6-11 – A third-angle projection brought into a single plane.

1.1.1.5 Spacing of Views

Space the views as necessary on the paper to give the appearance of a balanced drawing.

Figure 6-12 - Proper spacing of views.

Figure 6-12, View A shows an easy way to locate horizontally aligned views on a standard size drawing sheet. With a compass or scale, lay off the length plus the width of the object (A + B) from one end of the horizontal margin. Divide the remaining distance, C, into three equal parts (C/3). The result will be the approximate distance from either view to the vertical margin. The two views should be equidistant from the vertical margin. Adjust the spacing between views so that the apparent area is close to the apparent area between either view and the vertical margin. Basically, the shape of the object will determine the space between views. Generally, the distance from the views to the vertical margins and the distance between views (X) will be approximately equal. To locate the views vertically on the paper, lay off the depth of the object (D) on the vertical margin. Divide the remaining distance (E) into two equal parts (E/2). This will be the approximate distance from the top or bottom of the view to the horizontal margins.

Figure 6-12, View B shows how the same method also applies to vertically aligned views on a standard size drawing sheet.

Figure 6-13 shows the proper spacing of a three-view drawing. As you can see, the same principle is applied as in spacing a two-view drawing. Distances are again equal as indicated, with distance B equal to, or slightly less than, distance A, and distance D equal to, or slightly less than, distance C.

Figure 6-13 - Proper spacing of views on a three-view projection.
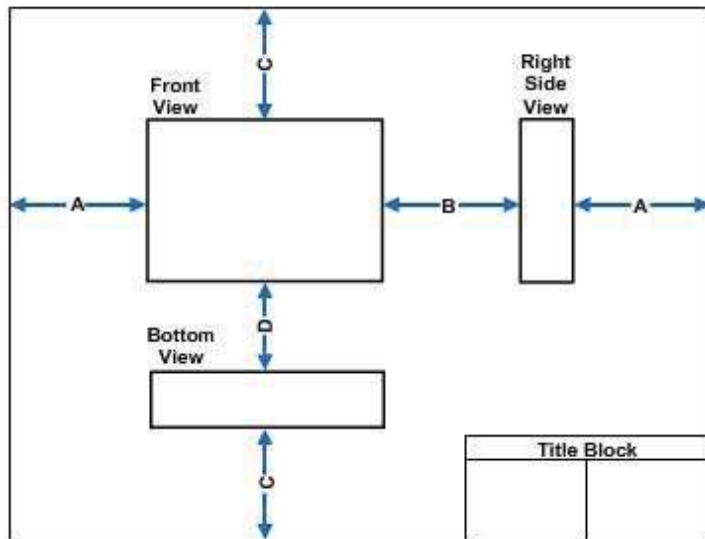
Figure 6-14 – Improved spacing for three-view projection of object shown in Figure 6-

While the spacing of views in *Figure 6-13* is technically correct, the drawing appears unbalanced because of the large empty space in the upper right corner and the right side view crowding the title block. If the drawing will contain a sizeable bill of materials in the upper right corner, this spacing will be satisfactory. If not, it should be improved, if possible.

If the object allows an arbitrary choice in designating the surfaces as top, front, and so on, you can improve the spacing by changing the designation shown in *Figure 6-13* and projecting the object as shown in *Figure 6-14*. The surface appearing as the top in *Figure 6-13* is now called the front; it follows that the surface which appears as the front in *Figure 6-13* appears as the bottom in *Figure 6-14*. Again the right side view appears, but it now appears in the upper, rather than the lower, right corner and vertically rather than horizontally.

Spacing views in a drawing of a circular object is like spacing letters; try to equalize the areas of the spaces around and between the views. *Figure 6-15* shows properly spaced two-view drawings of a perforated disk. For the views that are horizontally in line, locate the horizontal center line midway between the horizontal margins; for the views that are vertically in line, locate it midway between the vertical margins. The other spacing is as indicated. To determine the lengths of distances A and 2/3 A, set a compass to the diameter plus the thickness of the disk, and lay off this distance on the margin. Then divide the remaining segment of the margin into three intervals, two of them being equal, and the third one being 1 1/2 times as long as each of the others.
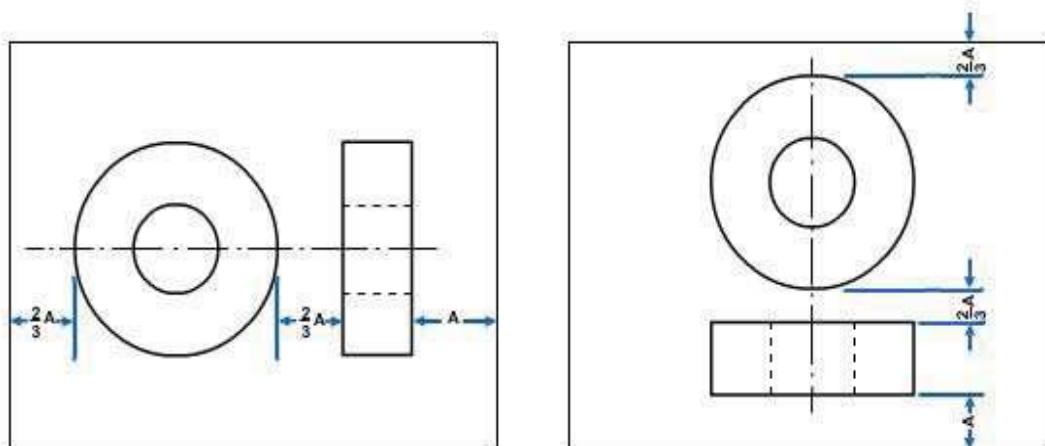
Figure 6-15 – Spacing of views of a circular object.

1.1.1.6 View Analysis

In order to analyze a multi-view projection, you must be able to determine what each line in a particular view represents. Remember, in a third-angle projection, always presume the plane of projection is between the object and the observer, regardless of which view you are considering. In a third-angle projection, each view of an object's surface is depicted as it would appear to an observer looking directly at it.

Figure 6-16 shows a six-view, multi-view, third-angle projection of the block shown in a single-view projection in the upper left corner of the figure. You should not have any trouble analyzing the front view; you know that the top is up, the bottom is down, the left side is to the left, and the right side is to the right.

In the top and bottom views, it's easy to see that the right-hand vertical line represents the right side and the left-hand vertical line, the left side. But you might have to think a minute to realize that the upper horizontal line in the top view represents the back face of the block, while the upper horizontal line in the bottom view represents the front face of the block. Note, also, that a line appears as a visible line in the top view and as a hidden line in the bottom view.
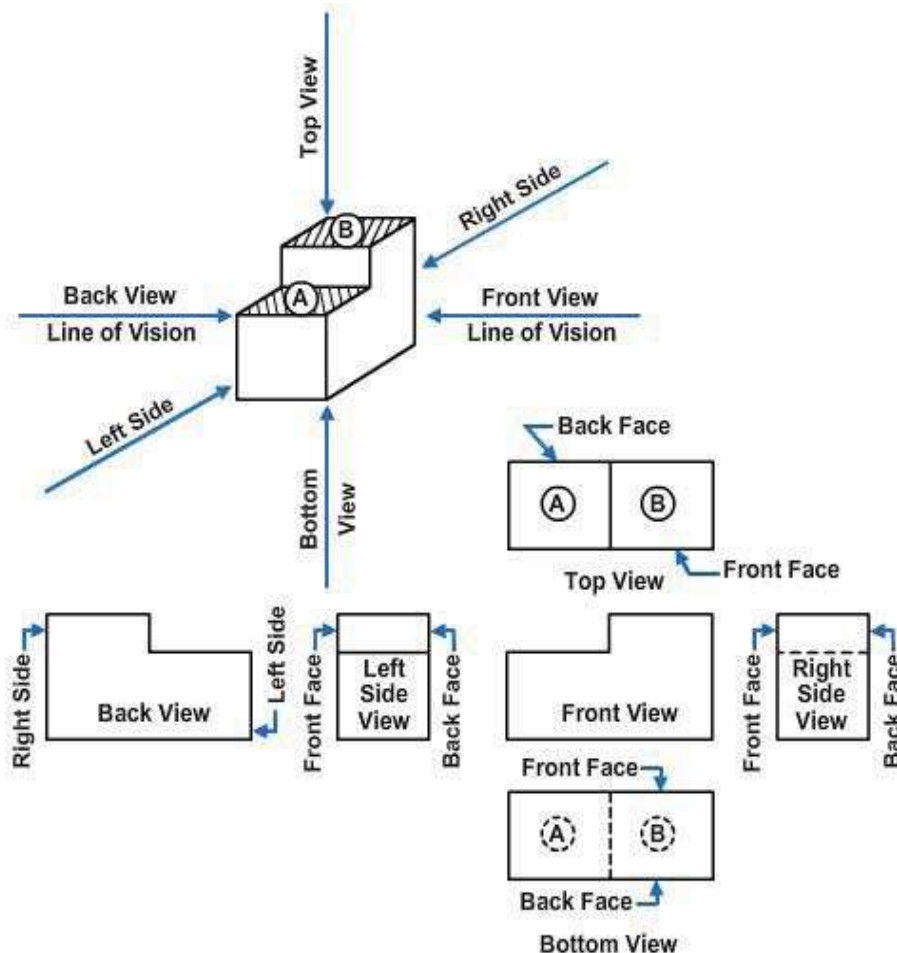
Figure 6-16 – Multi-view analysis of a third-angle orthographic projection.

In the right side and left side views, you can readily see that the upper horizontal line represents the top of the block and the lower horizontal line, the bottom. But you may have to think a minute to realize that the left-hand vertical line in the right side view represents the front face of the block, while the left-hand vertical line in the left side view represents the back face. Again, there is a line that appears as a visible line in the right side view and as a hidden line in the left side view.

The back view shows the block reversed, so that the cutaway part, which appears to the right in the front view, appears to the left in the back view. Similarly, the right-hand vertical line in the front view represents the right side of the block, while the right-hand vertical line in the back view represents the left side.

Note that in the top, bottom, and side views, the line that represents the front face of the block faces toward the front view of the block. Similarly, in the back view, the line that represents the left side faces toward the left side view of the block. This applies to third-angle projection only.

A point that constitutes a corner on an object is sometimes numbered for purposes of identification in various views of the object. *Figure 6-17* shows how a corner point number may be visible or hidden in a particular view of an object. In the upper left corner of the figure, an oblique projection of a block has a corner numbered 2. You can see that this corner is visible in top, back, and left side views, but hidden in bottom, front, and right side views.
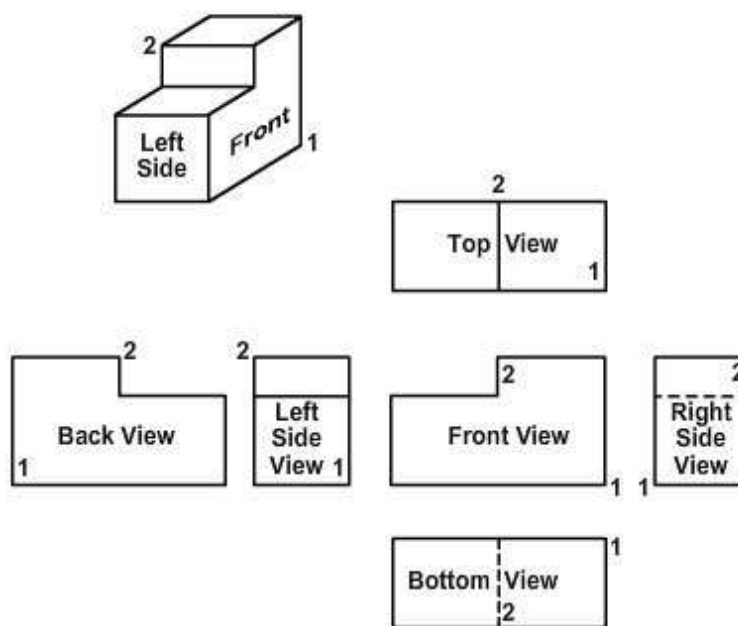
The rule for numbering is that for a hidden corner point, place the number within the outline, and for a visible corner point, outside the outline. You can see how the rule has been followed in *Figure 6-17*.

Figure 6-17 - Procedure for numbering hidden and visible corner points.

A multi-view projection should contain only as many views as required to describe the object fully. If you refer back to *Figure 6-16*, you can see at once that the back view does not convey any information that is not available in the front view; the back view is therefore superfluous and should be omitted. The same applies to the bottom view; the top view already conveys the same information. Likewise, the left side view does not convey any information not available in the right side view.
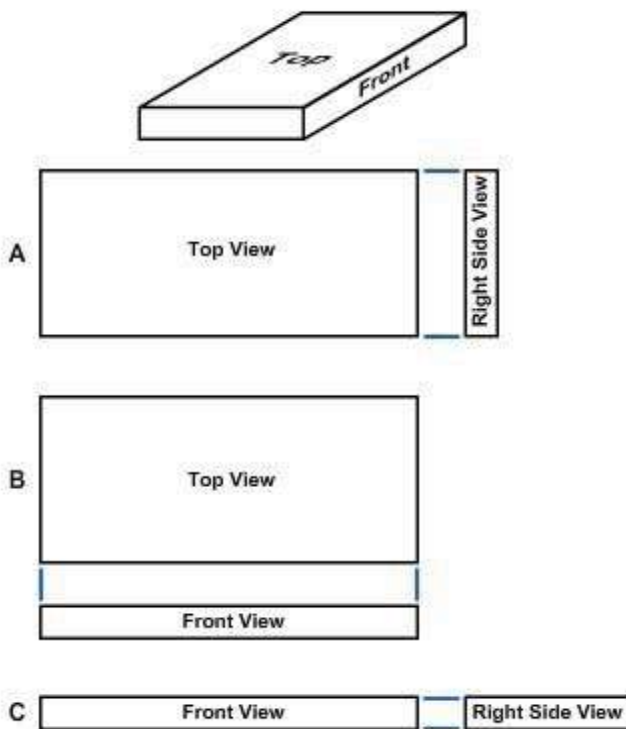
Figure 6-18 - Two-view multi-view projections.

You have the choice of omitting either the top or bottom view and either the right side or left side view. Some general rules to consider: a top view is preferable to a bottom view and a right side view, to a left side view. Also, a view with a visible line is preferable to a view with the same line shown as a hidden line. Both rules apply here to eliminate the bottom and the left side views. All you need here is a three-view projection showing the top, front, and right side views.

Sometimes you only require a two-view projection. The view at the top of *Figure 6-18* shows a single-view projection of an object. A top view of this object tells you everything you need to know except the thickness; a right side view tells you everything you need to know except the length, and a front view tells you everything you need to know except the width. Select a particular view and couple it with another view that gives you the dimension missing in the first view.

The object shown in A, B, and C has three possible two-dimensional projections. In selecting one of these three, everything else being equal, the balance of the drawing would be the deciding factor. Either A or B appears better balanced than C, and between A and B, A would look better on a long oblong sheet of paper, and B, better on a shorter oblong sheet.

The object shown in *Figure 6-18* has a definitely designated top and front; it follows that the right and left sides are also definitely designated. This is the case with many objects; you have no choice, for example, with regard to the top, bottom, front, and back of a house. Many objects, however, have no definite top, bottom, front, or back as many types of machine parts, for example. With an object of this kind, you can select a surface and call it the front, and select another and call it the top, according to convenience. As a general rule, you should show an object in the position it customarily occupies.

You can use one-view drawings for objects which can be completely defined with one view and dimensions or notes of features, such as thickness or length.

1.1.1.7 Normal and Non-Normal Lines

In a multi-view orthographic projection, a normal line is parallel to two of the planes of projection and perpendicular to the third. A line that is parallel to a plane of projection will appear on that plane in its true length (to the scale of the drawing). A line that is perpendicular to a plane of projection will appear on that plane as a point.

A line that is perpendicular to one plane of projection must of necessity be parallel to the other two. But a line that is parallel to one plane of projection may be oblique (neither parallel nor perpendicular) to one or both of the others. A line that is oblique to one or more of the planes of projection is called a non-normal line.

If a non-normal line is parallel to a plane of projection, it will appear on that plane in its true length. However, it will appear foreshortened in a view on a plane to which it is oblique. A non-normal line may, of course, be oblique to all three planes of projection, in which case it will appear foreshortened in all regular views of the object. A regular view is a view on one of the three regular planes of projection (horizontal, vertical, or profile). Views on planes other than the regular planes are called auxiliary views. Auxiliary views will be discussed later in this chapter.

Figure 6-19 – Foreshortening of a line in a multi-view projection.

The upper left corner of *Figure 6-19*A shows a single-view projection of a block. This block is placed for multi-view projection with the front parallel to the vertical plane, the bottom parallel to the horizontal plane, and the right side parallel to the profile plane. The line AB, then, is parallel to the vertical plane, but oblique to both the horizontal and the profile planes.

In the multi-view projections, you can see that it is only in the views on the vertical plane (the front and back views) that the line AB appears in its true length. In the views on the horizontal plane (top and bottom views) and in the views on the profile plane (right and left side views), the line appears foreshortened. Note, however, that you don't need to calculate the amount of the foreshortening, since it works itself out as you project the various views.

1.1.1.8 1.8 Circles in Multi-View Orthographic Projection

A circle on a surface parallel to the plane of projection will project as a circle. *Figure 6-20* shows that a circle on a surface oblique to the plane of projection will project as an ellipse. The upper view in this figure is a top view of a wedge; the wedge has a hole bored through it perpendicular to the inclined face. The outline of this hole on the front face of the wedge projects as an ellipse in the front view. You get the minor axis of the ellipse by projecting downward as shown. The length of the major axis is equal to the diameter of the hole.

The front view shows another ellipse. This is the partly hidden and partly visible outline of the hole as it emerges through the back of the wedge. The back of the wedge is parallel to the front view plane of projection; therefore, this ellipse is the true outline of the hole on the back of the wedge. The outline is elliptical because the hole, though it is circular, is bored obliquely to the back face of the wedge.

Figure 6-20 – A circle on a surface oblique to the plan of projection projected as an ellipse.

To draw these ellipses, use any of the methods of drawing an accurate ellipse covered in the previous chapter or use an ellipse template.

1.1.1.9 Auxiliary Views

In theory, there are only three regular planes of projection: the vertical, the horizontal, and the profile. Actually, presume that each of these views are doubled; there is, for example, one vertical plane for a front view and another for a back view.

Assume, then, a total of six regular planes of projection. A projection on any one of the six is a regular view. A projection NOT on one of the regular six is an auxiliary view.

The basic rule of dimensioning requires that you dimension a line only in the view in which its true length is projected and that you dimension a plane with its details only in the view in which its true shape is represented. To satisfy this rule, create an imaginary plane that is parallel with the line or surface we want to project in its true shape. A plane of this kind that is not one of the regular planes is called an auxiliary plane.
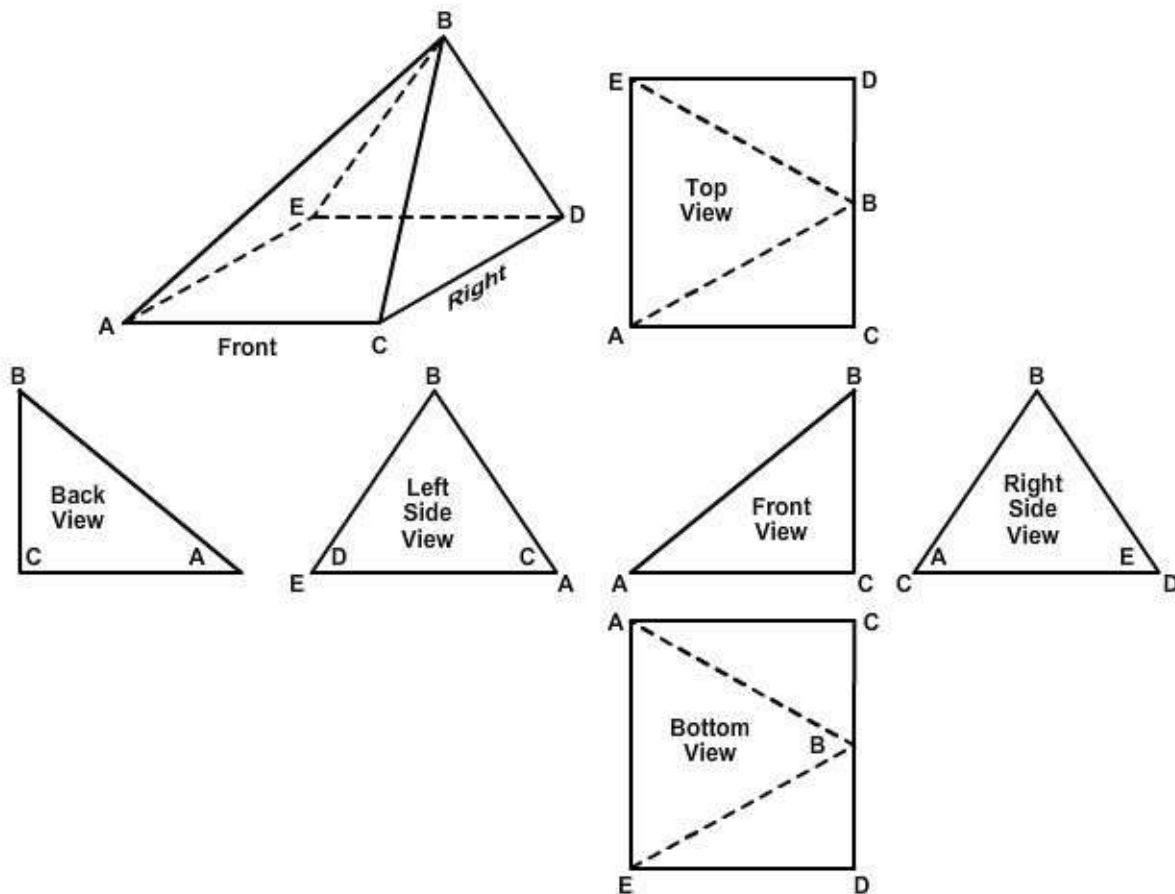
Figure 6-21 – A line oblique to all planes of projection is foreshortened in all views.

In the upper left of *Figure 6-21*, the base of the single-view projection of a triangular block is a rectangle. Presume this block is placed for multi-view projection with the right side parallel to the profile plane. Draw the block using all six views of multi-view projection.

Carefully examine *Figure 6-21*; the lines AB, AE, BD and BC and the surfaces ABC, ABE, and BDE are oblique to three regular planes of projection. The lines are foreshortened and the surfaces are not shown in their true shape in any of the six normal views.

The first step in drawing any auxiliary view is to draw the object in normal multi-view projection, as shown in *Figure 6-22*. A minimum of two orthographic views is necessary. The space between these views is generally greater than normal. The reason for this will become apparent. Notice in the front view of *Figure 6-22*, that A is the end point of line AE (top view) and C is the end point of CD.

The second step is to decide which line or surface to show in an auxiliary view and which orthographic view it will be projected from. Consider the following facts when making this decision:

1. Always project front or rear auxiliary views from a side view.

Figure 6-22 - Normal multi-view projection.

2. Always project right or left auxiliary views from a front view.

3. Always project an elevation auxiliary view from the top view.

The third step is to select the auxiliary and reference planes. The auxiliary plane is simply a plane parallel to the desired line or lines representing an edge view of the desired surface.

In *Figure 6-23*, the goal is to depict the true length of line AB and the true shape of surface ABE. You need a left side auxiliary view. Draw the auxiliary plane parallel to line AB in the front view. Line AB actually represents an edge view of surface ABE. The reference plane (top view) represents an edge view of the orthographic view (front view) from which the auxiliary view will be projected. Therefore, when you want the front, rear, or side auxiliary views, the reference plane will always be in the top view. When you draw elevation auxiliary views, the reference plane may be in any view in which the top view is represented by a straight line. The reference plane in *Figure 6-23* is the edge of the top view that represents the front view. Remember that although these planes are represented by lines, they are actually planes running perpendicular to the views.

Step four is to project and locate the points describing the desired line or surface. Draw the projection lines from the orthographic view perpendicular to the auxiliary plane. By scaling or with a compass, take the distances from the reference plane. The distances are the perpendicular distances from the reference plane to the desired point. *Figure 6-23* shows the projection lines drawn from points A, B, and C in the front view, perpendicular to the auxiliary plane. The projection line from point A indicates the line on which point E will also be located. The projection line from point C designates the line of both C and D, and that from B locates B only. To transfer the appropriate distances, first look for any points lying on the reference plane. These points will also lie on the auxiliary plane where their projection lines intersect it (points A and C). To locate points B, D, and E, measure their perpendicular distances from the reference plane in the top view and transfer these distances along their respective projection lines in the
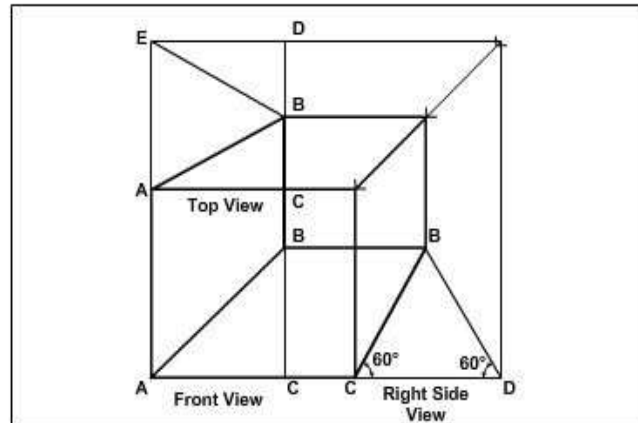
auxiliary view. The points are equidistant from both the reference and auxiliary planes. Therefore, any line parallel to the reference plane is also parallel to the auxiliary plane and equidistant from it.

The fifth step is to connect these points. When the total auxiliary view is drawn, it is sometimes hard to discern which lines should be indicated as hidden lines. A rule to remember is as follows:

Those points and lines lying furthest away from the auxiliary plane in the orthographic view being projected are always beneath any point or line that is closer. In *Figure 6-23*, point C (representing line CD) in the front view is further from the auxiliary plane than any line or surface it will cross in the auxiliary view. Therefore, it will appear as a hidden line.

The final step is to label and dimension the auxiliary view. The labeling must include an adequate description. The term AUXILIARY must be included along with the location of the view in relation to the normal orthographic views (LEFT SIDE AUXILIARY VIEW, REAR ELEVATION AUXILIARY VIEW, and so forth). Dimensions are given only to those lines appearing in their true length. In *Figure 6-23*, only lines AB, AE, and BE on the auxiliary view should be dimensioned.

Using the procedures previously described, follow the steps taken to project and draw the rear auxiliary view in *Figure 6-24*.
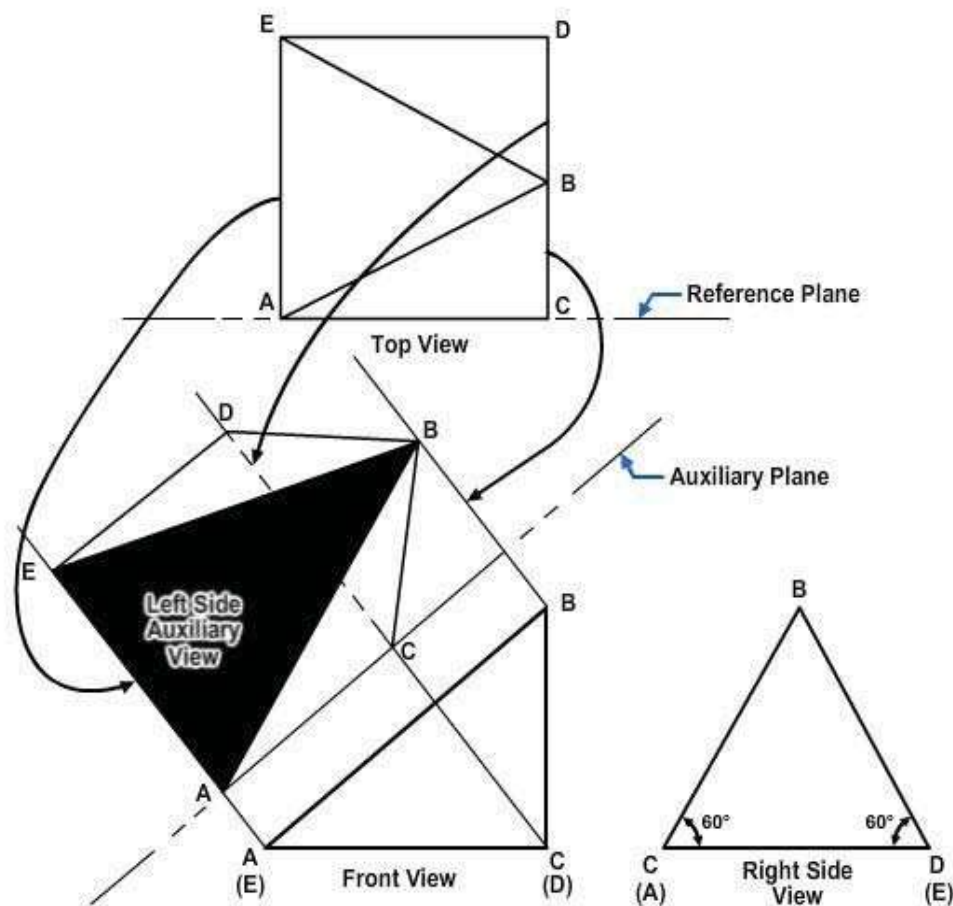
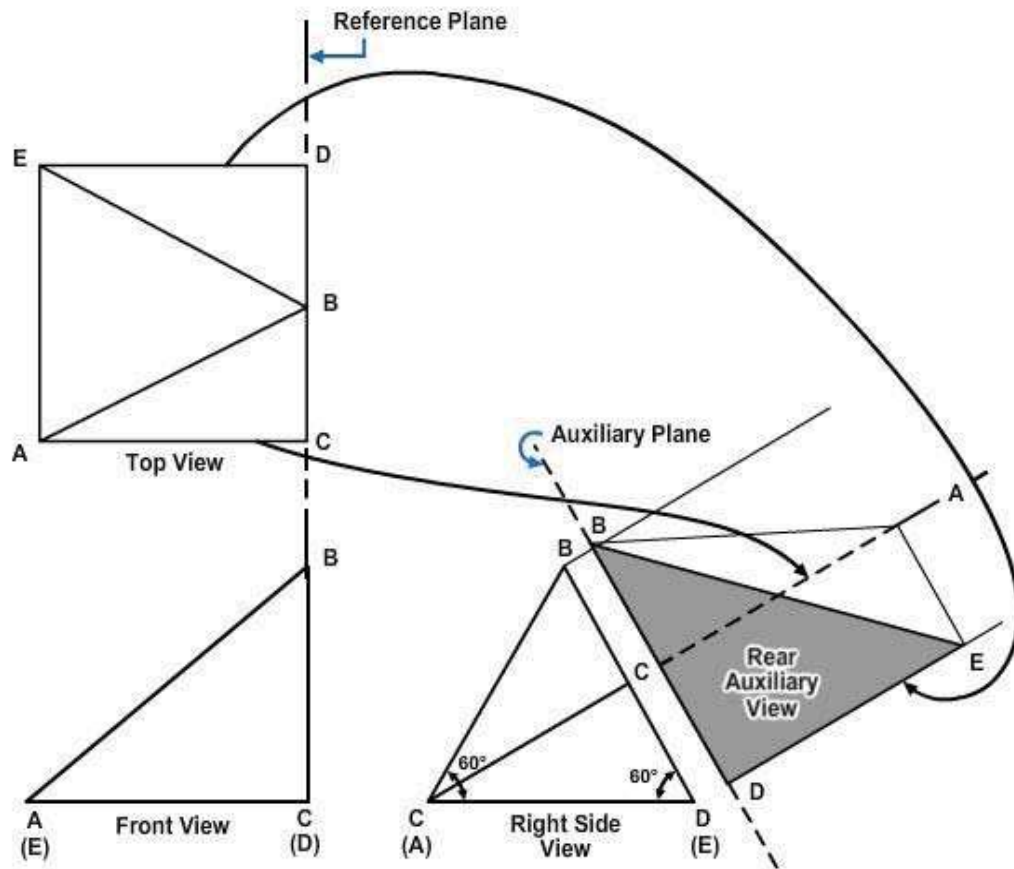**Figure 6-23 – Projection of left side auxiliary view.**

Figure 6-24 - Projection of rear auxiliary view.

Sometimes you will not need the total auxiliary view. Such a view could possibly even make the drawing confusing. In this case, use a ***partial auxiliary view***. Use only the points or lines needed to project the line or surface desired. This reduces the number of projection lines and greatly enhances the clarity of the view. If you use a partial auxiliary view, label it PARTIAL to avoid confusion. In *Figure 6-23*, if you desire only the true length of line AB, project and connect the points A and B. The view would be complete after being labeled and dimensioned.

In some cases the shape of an object will be such that neither the normal orthographic view nor the auxiliary views will show the true size and shape of a surface. When this occurs, a ***secondary auxiliary view*** is necessary to describe the surface. The procedures for projecting and drawing a secondary auxiliary view are the same as those for a normal (or primary) auxiliary view. The reference plane for a secondary auxiliary view is located in the orthographic view from which the primary auxiliary view is projected. Usually, the primary auxiliary plane becomes the secondary reference plane. The secondary auxiliary plane is in the primary auxiliary view, and its location is determined in the same manner as the primary auxiliary plane.

1.1.1.10 Auxiliary Section

An auxiliary view may be a sectional rather than a surface view. In the upper left part of *Figure 6-25*, there is a single-view projection of a block. The goal is to show the right side of the block as it would appear if the block were cut away on the plane indicated by the dotted line, the angle of observation to be perpendicular to this plane. The desired view of the right side is shown in the auxiliary section, which is projected from a front view as shown. Because the auxiliary plane of projection is parallel to the cutaway surfaces, these surfaces appear in true dimensions in the auxiliary section.
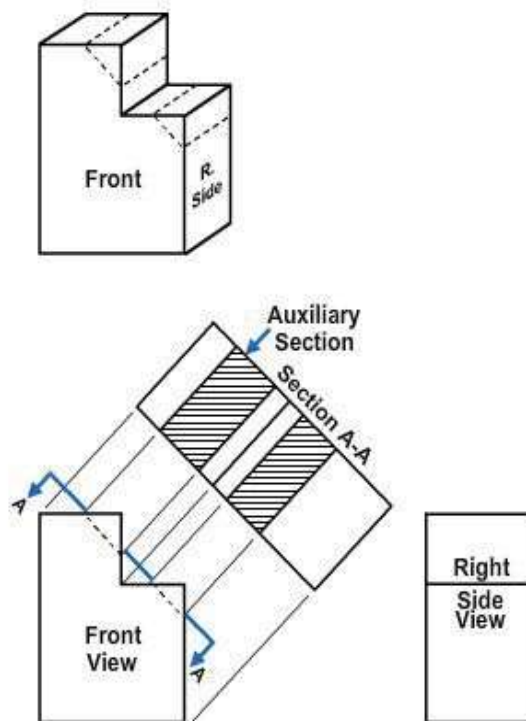
Figure 6-25 - Use of an auxiliary section.

A regular multi-view of an orthographic drawing is a view projected on one of the regular planes of projection. An auxiliary view is a view projected on a plane other than one of the regular planes.

A   B
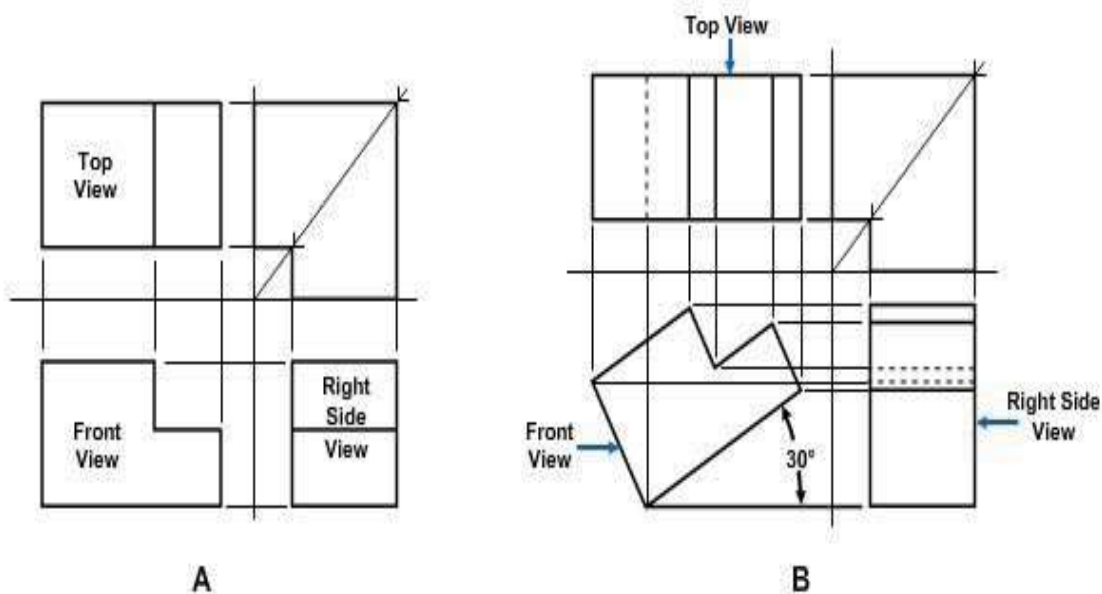
Figure 6-26 – (A) Multi-view view of block in normal position (B) Multi-view view of block revolved 30 degrees on axis perpendicular to vertical plane.

A rectangular object is in normal position for regular multi-view orthographic projection when each of its faces is parallel to one regular plane of projection and perpendicular to the other two. This is the case with the object shown in *Figure 6-26, View A*.

1.1.1.11 Use of Revolutions

In a **revolution**, you project the object on one or more of the regular planes of projection. However, instead of placing the object in a normal position, rotate it on an axis perpendicular to one of the regular planes.

Figure 6-26, View B, depicts a three-view multi-view projection showing the block in *Figure 6-26, View A*, as it appears when revolved 30 degrees on an axis perpendicular to the profile plane of projection. *Figure 6-27, View A*, shows how the block looks when it is revolved 30 degrees on an axis perpendicular to the horizontal plane. *Figure 6-27, view B*, shows the block as it appears when revolved 30 degrees on an axis perpendicular to the vertical plane.
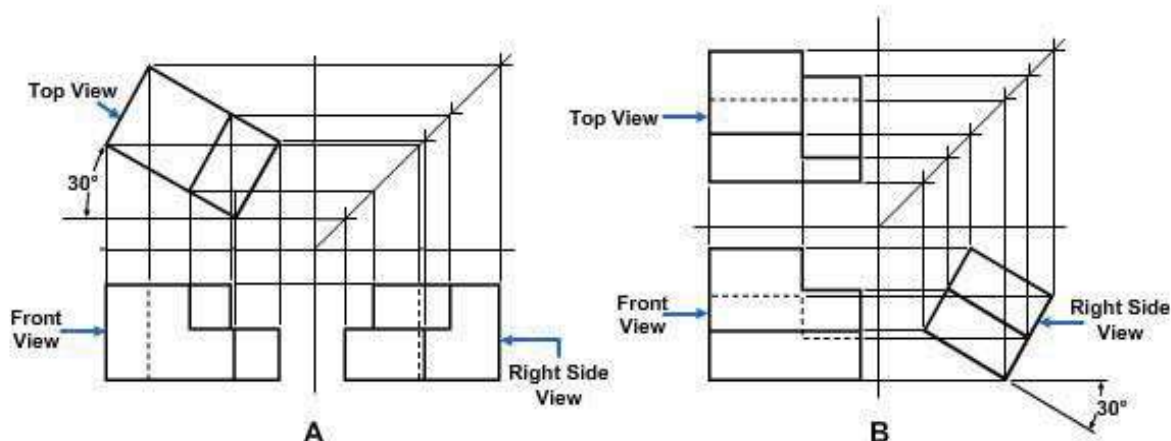
Figure 6-27 – Use of revolution on axis perpendicular to (A) horizontal plane and (B) vertical plane.

1.1.1.11 Revolved Sections

A common use of the revolution is the revolved section, shown in Figure 6-28. At the top of this figure is a single projection of a triangular block. You can show all the required information about this block in a two-view projection by including a revolved section in the front view as shown. First, assume that the block is cut by a plane perpendicular to the longitudinal axis. Then revolve the resulting section 90 degrees on axis perpendicular to the horizontal plane of projection.

Figure 6-28 – Use of revolved section (A-A). 6-24
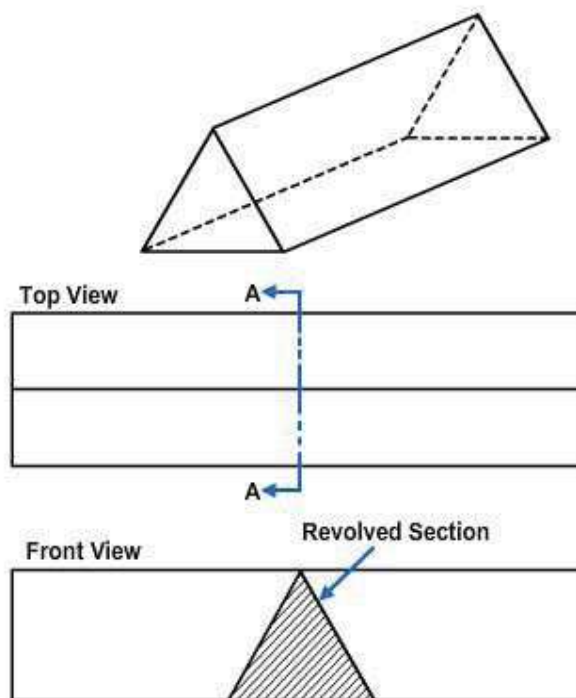
1.1.1.13 Sectioning Techniques

Use a sectional view when it will better show the object's internal structure than using hidden lines. The upper part of *Figure 6-29* shows a single-view projection of a pulley. The lower part of *Figure 6-29* shows the same object in a two-view multi-view projection. The hidden lines in the top view show the internal structure of the pulley.

The sectional view In *Figure 6-30* shows the internal structure of the pulley more clearly. Note that the sectional view omits the hidden lines behind the plane of projection of the section. Customarily, you should omit these lines because eliminating hidden lines is the fundamental reason for making a sectional view. However, in the sectional view include any lines that would be visible behind the sectional plane of projection.

The section shown in *Figure 6-30* is called a **full section.** Also, the object shown in *Figure 6-30* is a symmetrical object, meaning, in general, that the shape of one half is identical to the shape of the other. This being the case, you could have used a **half section** like the one shown in *Figure 6-31*. This half section constitutes one half of the full section. Because the other half of the full section would be identical with the half shown, it need not be drawn.

Note that a center line, rather than a visible line, is used to indicate the division between the sectioned and the unsectioned part of the sectional view. A visible line would imply a line that is
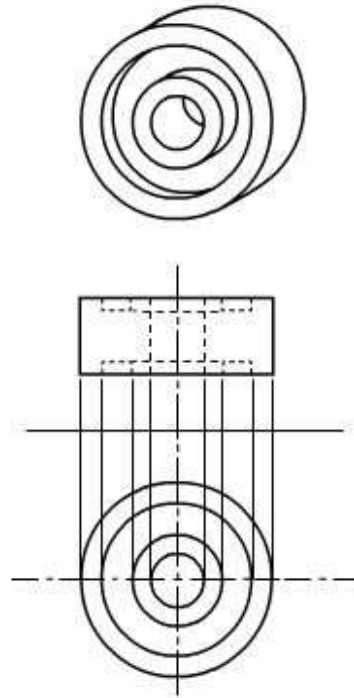
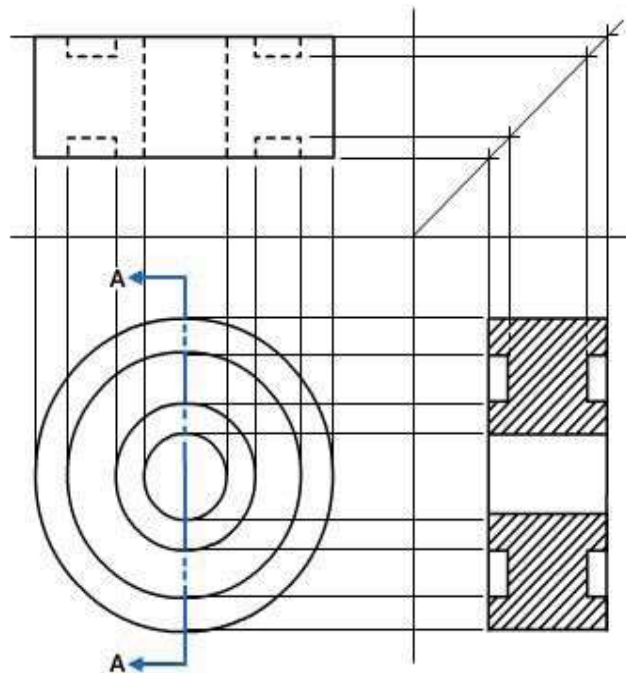**Figure 6-29 – Internal structure of an object shown by hidden lines.**

Figure 6-30 – Internal structure of an object more clearly shown by sectional view.

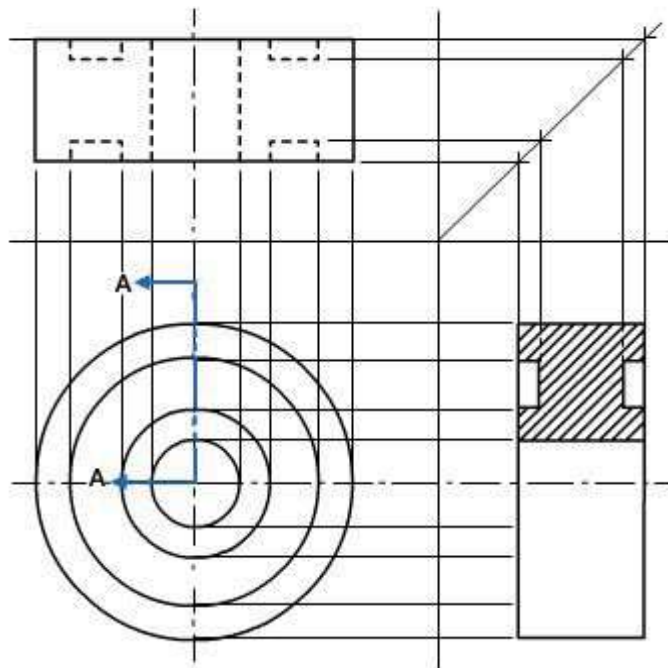actually nonexistent on the object. Another term used in place of center line is *line of symmetry*.

Figure 6-31 – Use of half section.

A section consisting of less than half a section is called a *partial section*. (See *Figure 6-32*.) Note that here you use a break line to indicate the division between the sectioned and unsectioned part. For this reason, a partial section is often called a *broken section*.

The section lines drawn on a sectional surface always serve the basic purpose of indicating the limits of the sectional or cutaway surface. They may also indicate the type of material of which the sectioned surface consists. For example, *Figure 6-33*, *View A*, shows section lining for an object made of cast iron. *View B* shows two matching parts made of steel, and *View C* shows three adjacent parts made of brass, bronze, or copper. For other symbolic section lining symbols, refer to ANSI Standard Y14.2.
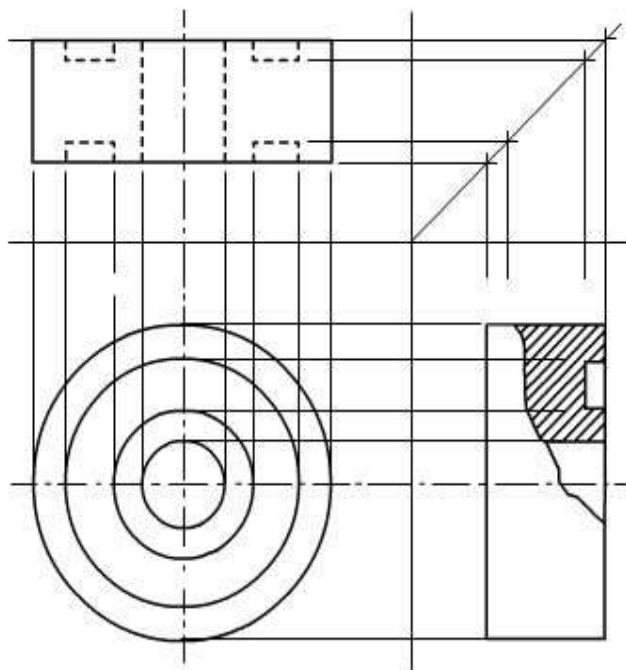

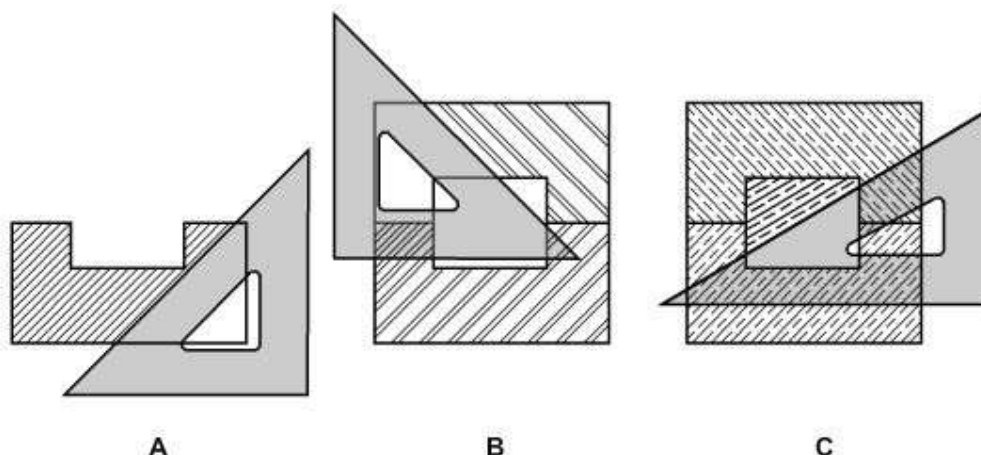**Figure 6-32 – Use of partial or broken section.**

Figure 6-33 – Diagonal hatching on separate sectional surfaces shown in normal positions.

Drawings must always identify materials by lettered form, such as notes. In view of the vast number of different materials, it is desirable (and common practice), to use a general purpose symbol for section lining. The general purpose symbol is the cast iron symbol shown in *Figure 6-33, View A*. The use of other symbols should be limited to those situations when it is truly desirable, or conventional, to graphically differentiate between materials. For example, in an assembly drawing (a drawing showing different parts fitted together), it is often desirable to differentiate materials.

On a regular multi-view section, draw **section lining** (sometimes called diagonal hatching or crosshatching) at 45° to the horizontal, as shown in *Figure 6-33, View A*. However, if section liners drawn at 45° to the horizontal would be parallel or perpendicular (or nearly so) to a prominent visible outline, change the angle to 30°, 60°, or some other angle. If two adjacent sectioned surfaces are shown, draw the hatching in opposite directions, as shown in *Figure 6-33, View B*. If you include a third surface, hatch it at another suitable angle to make the surface clearly stand out separately from the other surfaces (*Figure 6-33, View C*). Note that the hatching lines on one surface are not permitted to meet those on an adjacent surface.

In drawing section lining, use a sharp, medium-grade pencil (H or 2H). Space the lines as uniformly as possible by eye. As a rule, space your lines as generously as possible, yet close enough to distinguish the sectioned surface clearly. For average drawings, space the lines about 3/32 in. or more
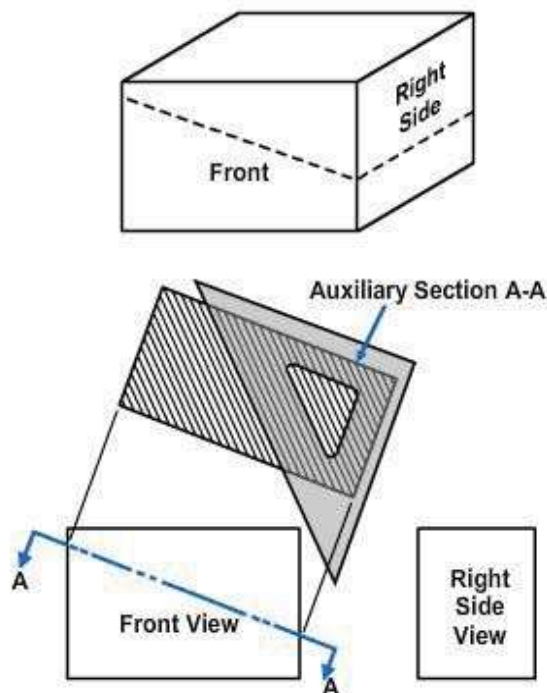

Figure 6-34 - Diagonal hatching on an auxiliary section.

apart.

Draw diagonal hatching on an auxiliary section at 45 degrees to the horizontal with respect to the section. *Figure 6-34* shows this rule.

In a revolution or other view of an object in other than the normal position, draw the diagonal hatching on a section at 45 degrees to the horizontal or vertical axis of the object as it appears in the revolution. *Figure 6-35* shows this rule.

1.1.2 Axonometric Projection

Axonometric single-plane projection is another way of showing an object in all three dimensions in a single view. Theoretically, axonometric projection is orthographic projection in that only one plane is used and the projection lines are perpendicular to the plane of projections. It is the object itself, rather than the projection lines, that is inclined to the plane of projection.
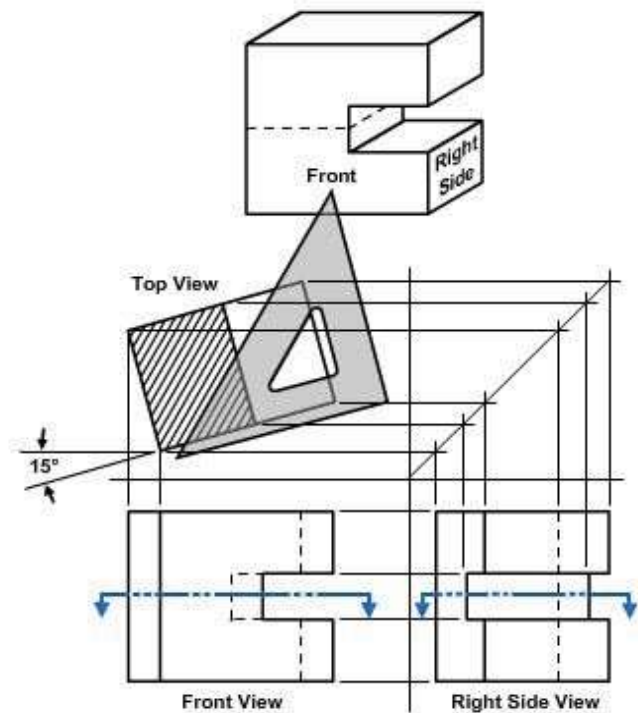
Figure 6-35 - Diagonal hatching on revolution.

1.1.2.1 Isometric Projection and Isometric Drawing

Figure 6-36 shows a cube projected by isometric projection, the most frequently used type of axonometric projection. The cube is inclined so that all of its surfaces make the same angle (35°16') with the plane of projection. As a result of this inclination, the length of each of the edges shown in the projection is somewhat shorter than the actual length of the edge on the object itself. This reduction is called **foreshortening**. The degree of reduction amounts to the ratio of 1 to the cosine of 35°16', or 1/0.8165. This means that if an edge on the cube is 1 in, long, the projected edge will be 0.8165 in.
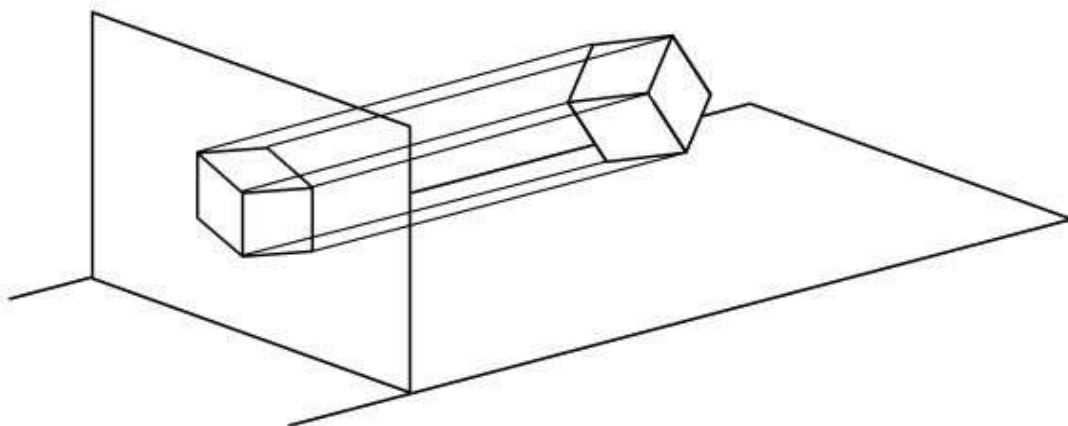
Figure 6-36 - Isometric projection of a cube.

long. As all of the surfaces make the same angle with the plane of projection, the edges all foreshorten in the same ratio. Therefore, one scale can be used for the entire layout; hence the term *isometric*, which literally means "one-scale."
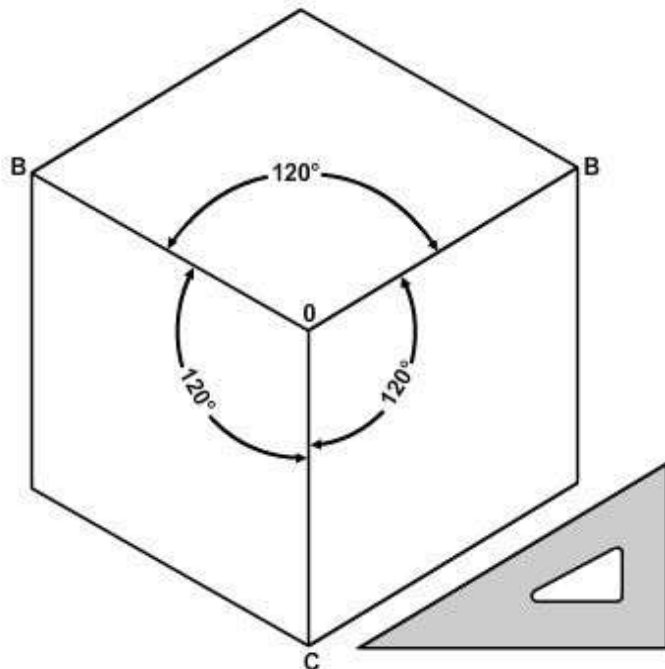

Figure 6-37 – Use of an isometric axis.

Figure 6-37 shows how an isometric projection would look to an observer whose line of sight was perpendicular to the plane of projection. Note that the figure has a central axis, formed by the lines OA, OB, and OC; this property is the origin of the term axonometric projection. In an isometric projection, each line in the axis forms a 120° angle with the adjacent line, as shown. A quick way to draw the axis is to draw the perpendicular OC, then use a T square and a 30°/60° triangle to draw OA and OB at 30 degrees to the horizontal. Since the projections of parallel lines are parallel, the projections of the other edges of the cube will be, respectively, parallel to these axes.

You can easily draw a rectangular object in isometric by the procedure known as box construction. The upper part of *Figure 6-38* shows a two-view normal multi-view projection of a rectangular block; the lower part shows an isometric drawing of the block. You can see how you build the figure on the isometric axis and how you lay out the dimensions of the object on the isometric drawing. Because you lay out the identical dimensions, it is an isometric drawing rather than an isometric projection.
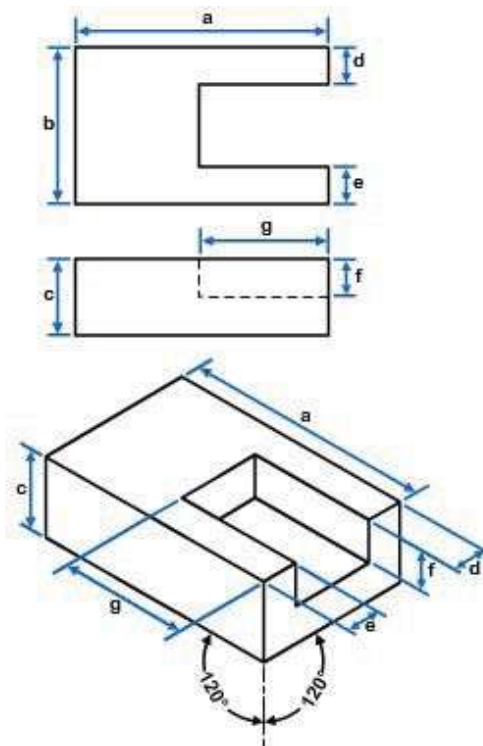

Figure 6-38 – Use of "box construction" in isometric drawing.

1.1.2.2 Non-Isometric Lines

Examining the isometric drawing shown in *Figure 6-38*, you will note that each line in the drawing is parallel to one or another of the legs of the isometric axis. You will also notice that each line is a normal line in the multi-view projection. Recall that a normal line, in a normal multi-view projection, is parallel to two of the planes of projection and perpendicular to the third. Thus, a non-isometric lines is not parallel to any one of the three legs of the isometric axis. It is not a normal line in a normal multi-view projection of the object.

The upper part of *Figure 6-39* shows a two-view normal multi-view projection of a block.

Though the line AB is parallel to the horizontal plane of projection, it is oblique to both the vertical and the profile planes. It is therefore not a normal, but an oblique, line in the multi-view projection, and it will be a non-isometric line in an isometric projection or drawing of the same object.

The line AB appears in its true length in the top multi-view view because it is parallel to the plane of the view (the horizontal plane), but it will appear as a non-isometric line, and therefore not in its true length, in an isometric drawing, as shown in the bottom part of *Figure 6-39*. It

Figure 6-39 – A non-isometric line (AB) in an isometric projection.

follows that you cannot transfer AB directly from the multi-view projection to the isometric drawing. You can, however, transfer directly all the normal lines in the multi-view projection, which will be isometric lines appearing in their true lengths in the isometric drawing. When you have done this, you will have constructed the entire isometric drawing, exclusive of line AB and of its counterpart on the bottom face of the block. The end points of AB and of its counterpart will be located, however, and it will only be necessary to connect them by straight lines.
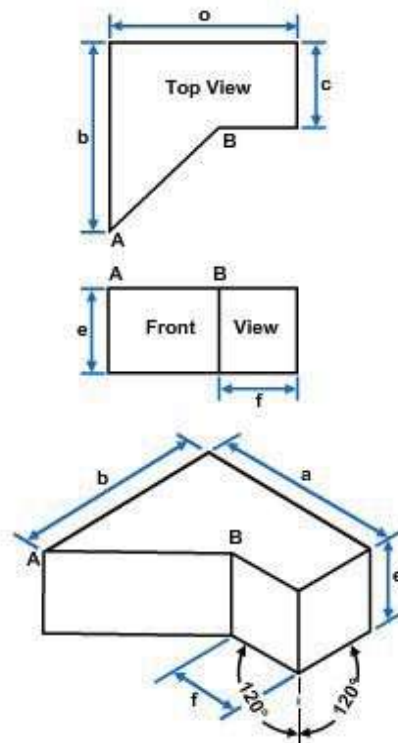
1.1.2.3 Angles in Isometric

In a normal multi-view view of an object, an angle will appear in its true size. In an isometric projection or drawing, an angle never appears in its true size, Even an angle formed by normal lines, such as each of the 90-degree corner angles of the block shown in the bottom part of *Figure 6-40*, appears distorted in isometric.

The same principle used in transferring a non-isometric line is used to transfer an angle in isometric. The upper part of *Figure 6-40* shows a two-view multi-view projection of a block. On the top face of the block, the line AB makes a 40-degree angle with the front edge. The line AB is an oblique (that is, not normal) line, which will appear as a non-isometric line in the isometric drawing. Locate the end points of AB on the isometric drawing by measuring distances along normal lines on the multi-view projection and laying them off along the corresponding isometric lines on the isometric drawing. The angle that measures 40 degrees on the top multi-view view measures only about 32 degrees on the isometric drawing. Note, however, that it is labeled 40 degrees on the isometric drawing. This is because it actually is a 40-degree angle as it would look on a surface plane at the isometric angle of inclination.
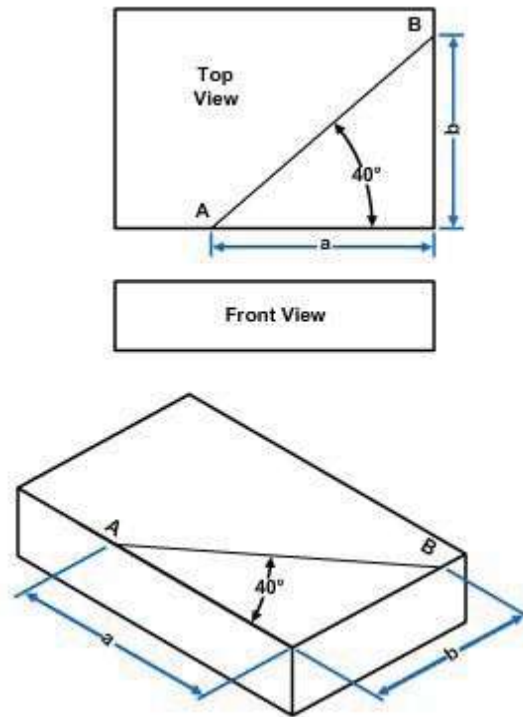
Figure 6-40 - Drawing an angle in isometric.

1.1.2.4 Circles in Isometric

A circle in a normal multiview view will appear as an ellipse in an isometric drawing. This is shown in *Figure 6-41, View A*.
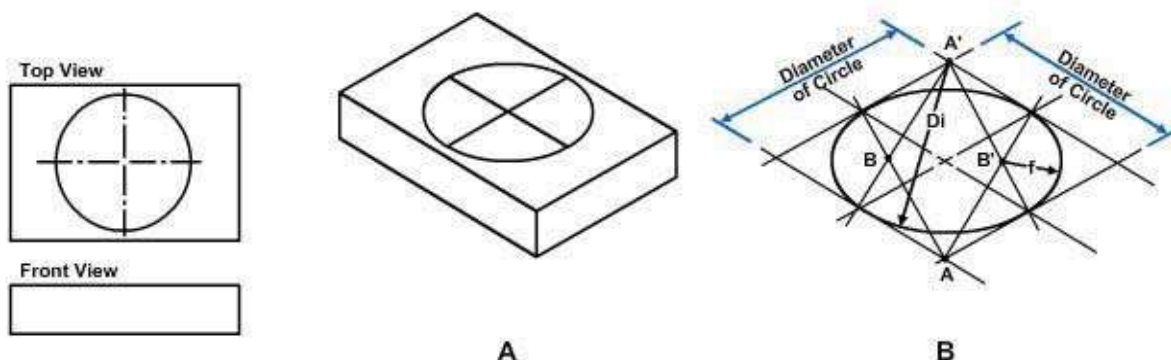
Figure 6-41 – A circle on a normal multi-view view appears as an ellipse in an isometric drawing.

A procedure that maybe used to construct an isometric circle is shown in *Figure 6-41, View B*. The steps of that procedure are as follows:

1. Draw the isometric center lines of the circle. Then, using those center lines, lay off an isometric square with sides equal to the diameter of the circle.

2. From the near corners of the box, draw bisectors to the opposite intersections of the center lines and the box. The bisectors will intersect at four points (A, A', B, B'), which will be the centers of four circular arcs.

3. Draw two large arcs with radius R, using Points A and A' as centers. Draw the two smaller arcs with radius r, using Points B and B' as centers.

The above discussion should seem familiar, since it is simply an approximation of the fourpoint method you studied in the previous chapter. However, you can use it only when drawing isometric circles on an isometric drawing.

1.1.2.5 Non-Circular Curves in Isometric

A line that appears as a noncircular curve in a normal multi-view view of an object appears as a non-isometric line in an isometric drawing. To transfer such a line to an isometric drawing, plot a series of points by measuring along normal lines in the multi-view view and transferring these measurements to corresponding isometric lines in the isometric drawing.

The upper part of *Figure 6-42* shows a two-view multi-view projection of a block with an elliptical edge. To make an isometric drawing of this block, draw the circumscribing rectangle on the top multi-view view; lay off equal intervals as shown, and draw perpendiculars at these intervals from the upper horizontal edge of the rectangle to the ellipse. Then draw the rectangle in isometric, as shown below, and plot a series of points along the elliptical edge by laying off the same perpendiculars shown in the top multi-view view. Draw the line of the ellipse through these points with a french curve.
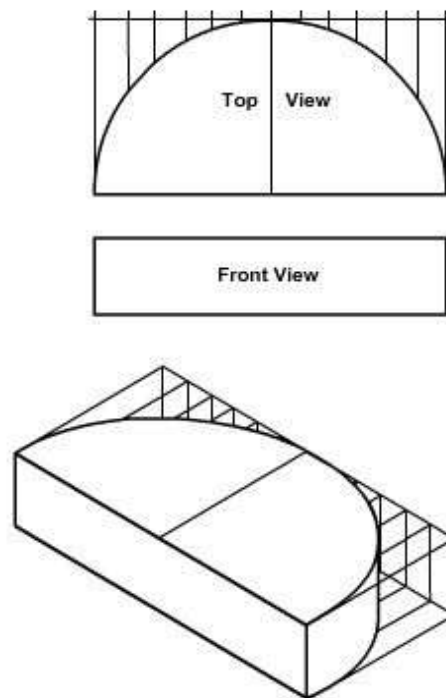

Figure 6-42 – Method of drawing a noncircular curve in isometric.

1.1.2.6 Alternate Positions of Isometric Axis

Up to this point, the isometric axis has been used with the lower leg vertical. The axis may, however, be used in any position, provided the angle between adjacent legs is always 120 degrees. *Figure 6-43* shows how varying the position of the axis varies the view of the object.

1.1.2.7 2.7 Diagonal Hatching in Isometric

Diagonal hatching on a sectional surface shown in isometric should have the appearance of making a 45-degree angle with the horizontal or vertical axis of the surface. If the surface is an isometric surface (one that makes an angle of 35°16' with the plane of projection), lines drawn at an angle of 60 degrees to the horizontal margin of the paper, as shown in *Figure 6-44*, present the required appearance. To show diagonal hatching on a non-isometric surface, you must experiment to determine the angle that presents the required appearance.
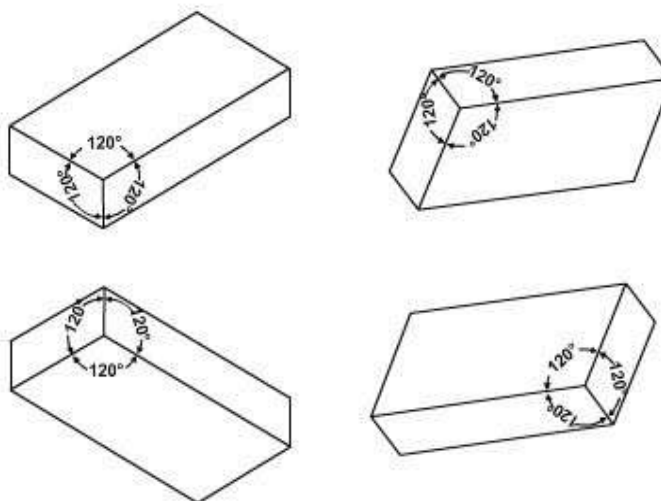
1.1.2.8 Dimetric and Trimetric Projections

Two other subclassifications of the axonometric projection category are dimetric and trimetric projections; however, these types are used less frequently than isometric projections and will not be discussed further in this training manual.

1.2.0 Oblique Single-Plane Projection

We have seen that you can draw an object showing length and width on a single plane. You can also show depth on this single plane by constructing the receding projection lines of the object at an angle other than perpendicular to the plane of projection.
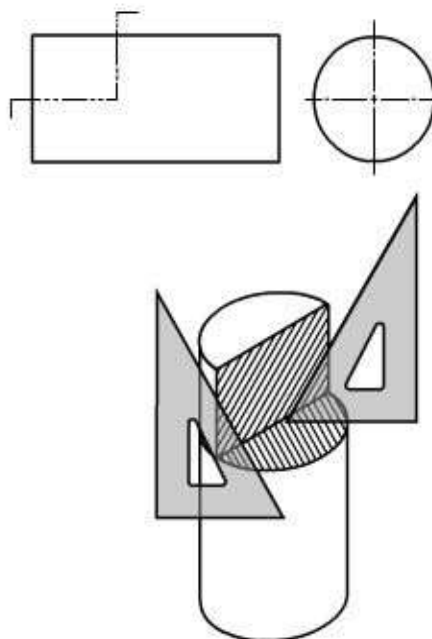
Figure 6-43 - Various positions of isometric

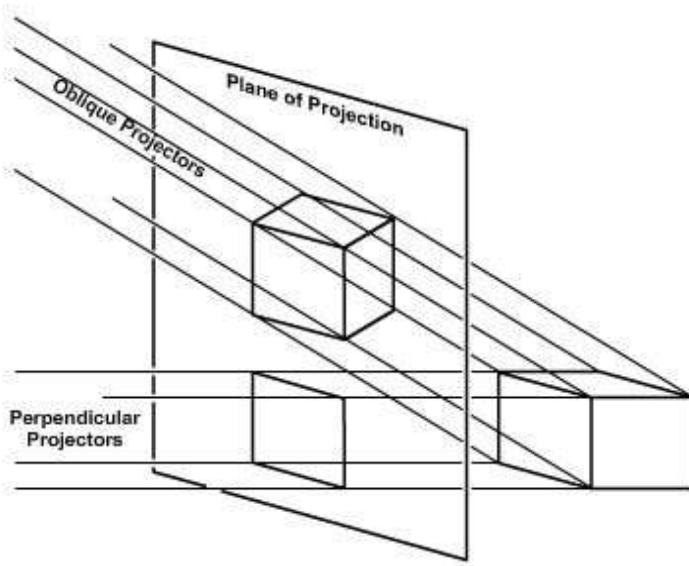**Figure 6-44 – An example of diagonal hatching in isometric.**

Figure 6-45 Oblique and orthographic projections of the same object

Figure 6-45 shows the same object by both orthographic and oblique projection. The block is placed so that its front surface (the surface toward the plane of projection) is parallel to the plane of projection. The orthographic projection shows only this surface of the block. The oblique projection, on the other hand, shows the front surface and the top and side surfaces. The orthographic projection shows only two dimensions: length and width. The oblique projection shows three: length, width, and thickness. Oblique projection, then, is one method by which an object can be shown, in a single view, in all three dimensions.

There are two types of oblique single-plane projections: cavalier and cabinet.

1.2.1 Cavalier Projection

Cavalier projection is a form of oblique projection in which the projection lines are presumed to make a 45-degree vertical and a 45-degree horizontal angle with the plane of projection. Assume that in *Figure 6-46* the line XX' represents a side-edge view of the plane of projection, and that the square ABCD represents a side of a cube placed with its front face parallel to, and its top face perpendicular to, the plane of projection. The projected lengths of AB and AD are the same as the actual lengths.

Now assume that the line XX' in *Figure 6-46* represents a top-edge view of the plane of projection, and that the square ABCD represents the top of the cube. You can see again that the projected lengths of AB and AD are the same as the actual
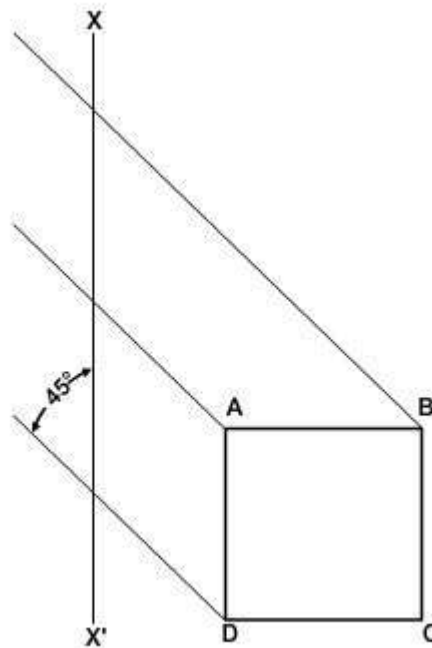

Figure 6-46 – Angle of projection lines in a cavalier projection.

lengths of AB and AD.

In a cavalier projection, any line parallel or perpendicular to the plane of projection is projected in its true length. *Figure 6-47* shows a cavalier projection of the cube shown in *Figure 6-46*. Start by drawing the axis, which consists of the front axes OA and OB and the receding axis OC. The front axes are always perpendicular to each other; the receding axis may be drawn from O at any convenient angle. All three are equal in length, the length being the length of an edge of the original cube (which may be scaled down or up if the drawing is made other than full scale). After you draw the axis, complete the projection by drawing the required parallel lines. All the edges shown in the projection are, like the edges on the original cube, equal in length.

1.2.2 Cabinet Projection

The first thing you notice about the cube shown in *Figure 6-47* is the that it doesn't look like a cube because the depth dimension appears to be longer than the height and width dimensions. The reason is that a cavalier projection corrects a human optical illusion--the one that causes an object to appear to become smaller as its distance from the eye increases. This illusion, in turn, causes receding parallel lines to appear to the eye to be shorter than they really are, and to be converging toward a point in the distance. But receding parallel lines on a cavalier projection appear in their true lengths, and they remain constantly parallel. Also, the far edges of the cube shown in *Figure 6-47* are equal in length to the near edges.

The distortion in *Figure 6-47* is only apparent. It is sometimes desirable to reduce this appearance of distortion. This can be done by reducing the length of the receding axis (OC in *Figure 6-38*). This axis can be reduced by any desired amount, but it is customary to reduce it by one half. When the receding axis is reduced by one half, the projection is called a ***cabinet projection***. *Figure 6-48* shows a cabinet projection of a cube. The length of the receding axis OC has been reduced by one half. As you can see, this representation looks more like a cube.
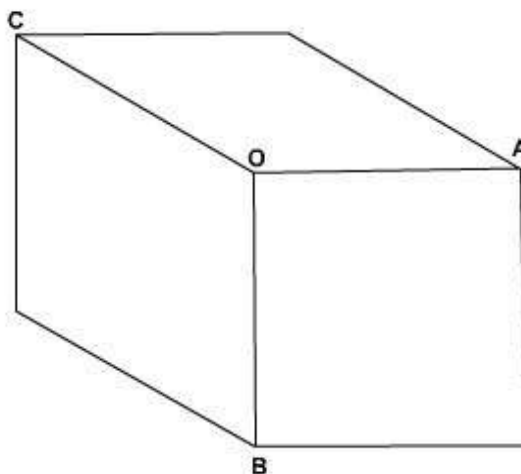
Cavalier and cabinet projections are compared in *Figures 6-49* and *6-50*.

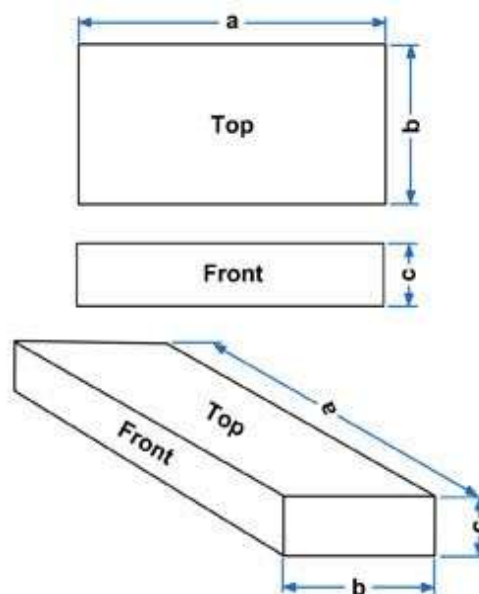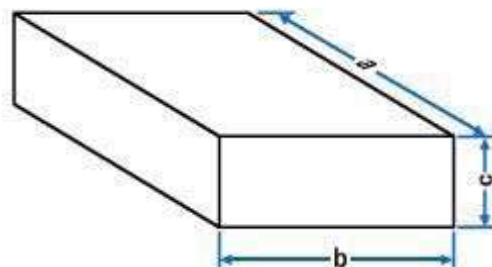**Figure 6-47 - Cavalier projection of a cube.**

Figure 6-48 - Cabinet projection of a cube.
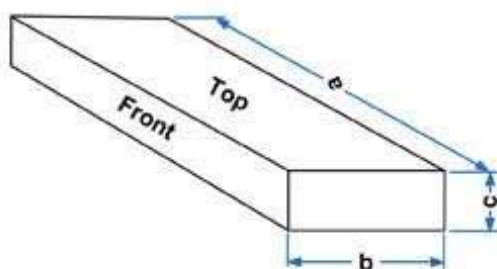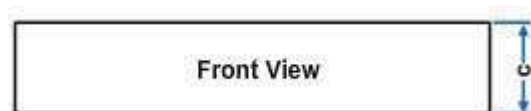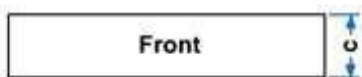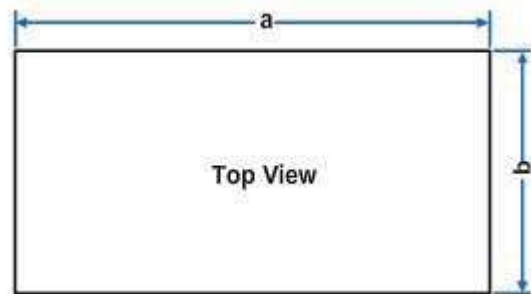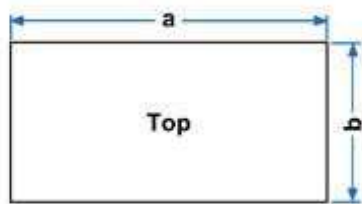
Figure 6-49 – Cavalier projection; Distances along front axis and along receding axis are all true.

Figure 6-50 – Cabinet projection: Distances along front axis are true; distances along receding axis are reduced by one half.

1.2.3 Oblique Drawing Techniques

In an oblique projection drawing of a rectangular object, one face (usually the most prominent or most important) is parallel to the plane of projection. All features appearing on this plane, such as circles or oblique lines, are in their true dimension. However, in the side or top views, these same features are somewhat distorted because of the receding axis angle. When drawing these features, you can use various techniques to aid you in their construction.

For convenience, the angle chosen for the receding axis is 30 degrees, 45 degrees, or 60 degrees because those angles are easily constructed with triangles (*Figure 6-51*).
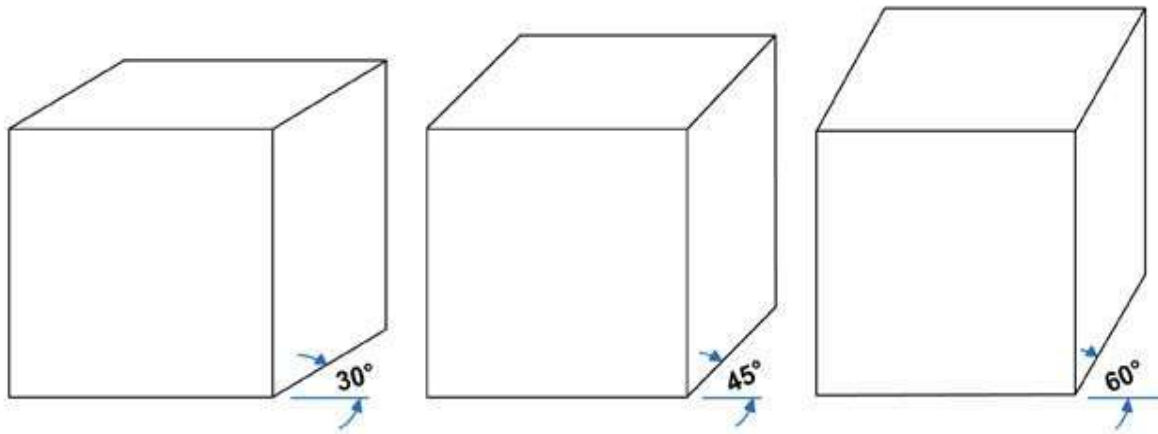
Figure 6-51 – Angles of 30 degrees, 45 degrees, and 60 degrees are normally chosen for the receding access in oblique projection because they are easily drawn with triangles.

1.2.3.1 Irregular Lines

An irregular line in an oblique drawing is a line that would be an oblique line in a normal multi-view projection. In the upper part of *Figure 6-52*, is a two-view multi-view projection of a block; the line AB is an irregular line and will not appear in its true length in an oblique projection. To transfer the line, draw the projection by transferring measurements taken along regular lines; these measurements locate the end points of the irregular line. *Figure 6-52* shows the cavalier projection of an irregular line. The procedure for cabinet projection is the same except that all measurements along the receding axis are reduced by one half.
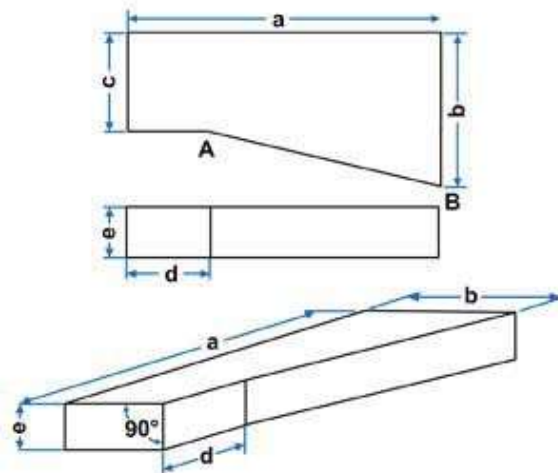
Figure 6-52 – Cavalier projection of an object with irregular lines.

1.2.3.2 Angles in Oblique

In an oblique projection, an angle on the surface that is parallel to the plane of projection will appear in its true size; an angle on any other surface will not. The upper part of *Figure 6-53* shows a two-view multi-view projection of a block. It has a 30-degree angle on the top face and another on the front face. In the cavalier projection below, the angle on the front face still measures 30 degrees; that on the top face measures only about 9 degrees. Transfer the top face angle by locating the end points of the line by measurements along regular lines.

1.2.3.3 Circles in Oblique

In an oblique projection, a circle on the surface parallel to the plane of projection will appear as a circle. A circle on any other surface will appear as an ellipse, as shown in *Figure 6-54.* The upper part of this figure shows a two-view multi-view projection of a block with a circle on its upper face. The lower part of this figure shows a cavalier projection in which the circle appears as an ellipse. Each of the conjugate (joined together) diameters of the ellipse is equal to the diameter of the circle.

Figure 6-53 – Transferring an angle in oblique projection.

Figure 6-54 – Cavalier projection of a circle on a receding surface.

2.0.0 PERSPECTIVE PROJECTION and PERSPECTIVE DRAWING

Perspective projection is achieved when the projection lines converge to a point that is at a finite distance from the plane of projection. Each projection line forms a different angle with the plane of projection, giving the viewer a three-dimensional picture of the object. This type of projection, however, cannot accurately convey the structural features of a building; hence, it is not adequate for working drawings.

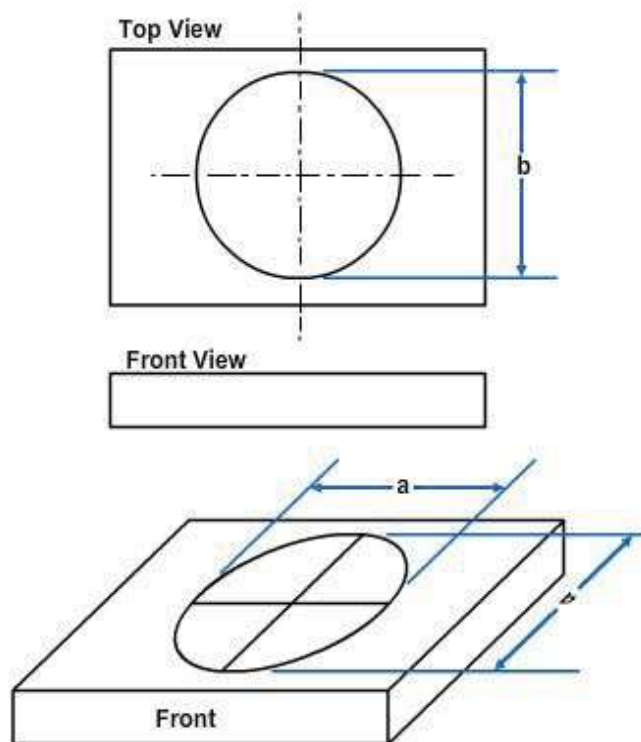On the other hand, of all the three-dimensional single-plane drawings, *perspective drawings* are the ones that look the most natural. At the same time, they are also the ones that contain the most errors. Lines that have the same length on the object have different lengths on the drawing. No single line or angle on the drawing has a length or size that has any known relationship to its true length or size when projected through perspective projections.

Perspective drawing is used only in drawings of an illustrative nature, in which an object is deliberately made to appear the way it looks to the human eye. Most of the drawings you prepare will be drawings in which accuracy, rather than eye appearance, is the chief consideration. Consequently, you will not be concerned much with perspective drawing.

If you are required to prepare perspective drawings, refer to **Illustrator Draftsman, NAVEDTRA 10472**, or civilian publications, such as **Architectural Drawing and Light Construction and Architectural Graphic Standards**.

3.0.0 SKETCHING

The ability to make quick, accurate sketches is a valuable asset in conveying technical information or ideas. Without this ability, you are handicapped in many of your day-to-day situations. Almost every drawing or graphic problem originates with a sketch. The sketch becomes an important thinking instrument, as well as a means of conversing effectively with technically trained people. Sketching is not just another trick of the trade; it is an essential skill and an important part of your training. Sketch at every opportunity to develop your skills; your skills will improve with experience.

A sketch is usually thought of as being made freehand, although in practice you may use graph paper or a small triangle for a straightedge. A sketch may be of an object or an idea or a combination of both. Sketches are used to solve graphic problems before an object or structure is put in final form on a drawing. Preliminary sketches are used to plan and organize intelligently the sheet layout of a complete set of drawings for a construction project, which often includes many views and details. There are no set standards for technical freehand sketching; however, you should use standard line conventions for clarity.

A sketch may be drawn pictorially so that it actually looks like the object, or it can be an orthographic sketch of the object showing different views. The degree of perfection required for any sketch will depend upon its intended use.

3.1.0 Sketching Materials

Sketching requires few materials; basically, you only need pencil and paper. The type of sketch prepared and your personal preferences determine the materials used.

Use a soft pencil in the grade range from F to 3H, H being a good grade for most sketching. The pencil should be long enough to permit a relaxed but stable grip. As you gain experience, you may even prefer to use fine tip felt pens. (Dark- or bright-colored pens should be used.) Felt tip pens work very well on overlay sketches (discussed later).
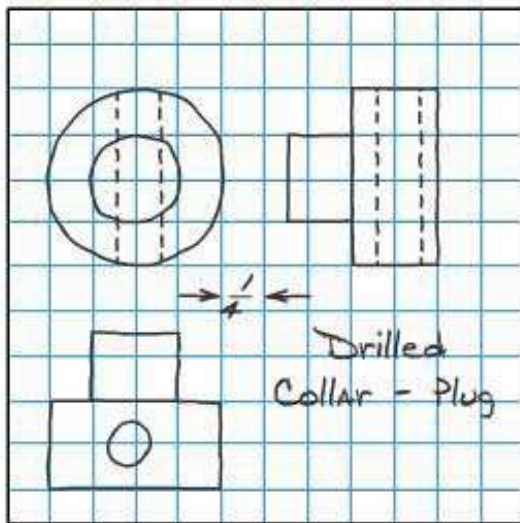
Figure 6-55 – Use of cross-sectional paper in technical sketching.
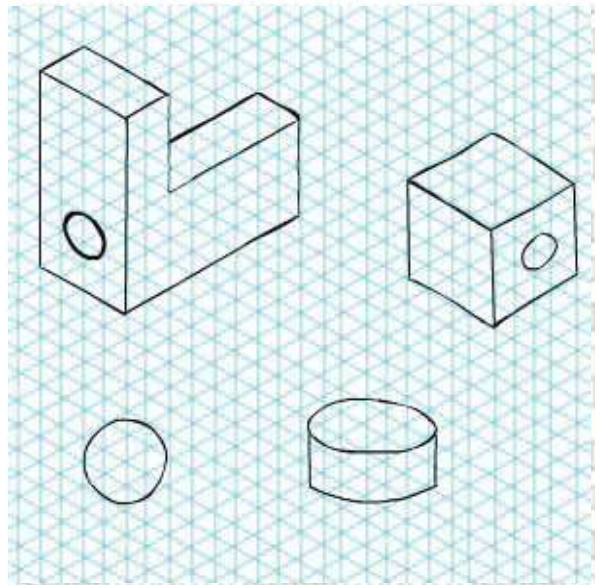
Figure 6-56 – Use of specially ruled isometric paper in technical sketching.

Most of your sketches will be done on scratch paper, which can be any type or size of paper. An experienced draftsman will keep a pad of 3 in. by 5 in. or 5 in. by 8 in. scratch paper handy at all times. Tracing paper is convenient for planning the layout of a drawing. The advantage of sketching on tracing paper is the ease with which sketches can be modified or redeveloped simply by placing transparent paper over previous sketches or existing drawings. Sketches prepared in this manner are referred to as *overlay sketches*. You can use cross-section or graph paper to save time when you are required to draw sketches to scale. (See *Figure 6-55*.) You can easily draw isometric sketches on specially ruled isometric paper. (See *Figure 6-56*.)

While you may use an eraser, you will probably do very little erasing. Sketches usually can be redrawn more quickly than mistakes can be erased.

For making dimensioned sketches in the field, you will need some sort of measuring tape--either a pocket rule or a surveyor's tape, depending on the extent of the measurements taken. If you are required to collect extensive field data, maintain a sketch notebook. A surveyor's field notebook works well for this purpose.

3.2.0 Techniques of Sketching

Your sketches should conform to one of the standard types of projection discussed in this chapter. Apply correct proportion whenever possible. When you use cross-section paper, its grid will provide a ready scale that will aid you in sketching proportionally. Do this by counting the squares within the object to be drawn. The size of your sketch depends upon the complexity of the object and the size of paper you are using.

3.2.1 Sketching Straight Lines

In sketching lines, place a dot where you want a line to begin and one where you want it to end. In sketching long lines, place one or more dots between the end dots. Swing your hand in the direction your line should go, and back again a couple of times before you touch your pencil to the paper in order to get the feel of the line. When ready, use the dots to guide your eye and your hand as you draw the line. Draw each line with a series of short strokes instead of with one stroke. Using short strokes, you can better control the direction of your line and the pressure of your pencil on the paper. Hold the pencil about three quarters of an inch to an inch from the point so that you can see what you are doing. Strive for a free and easy movement rather than a cramped finger and wrist movement.
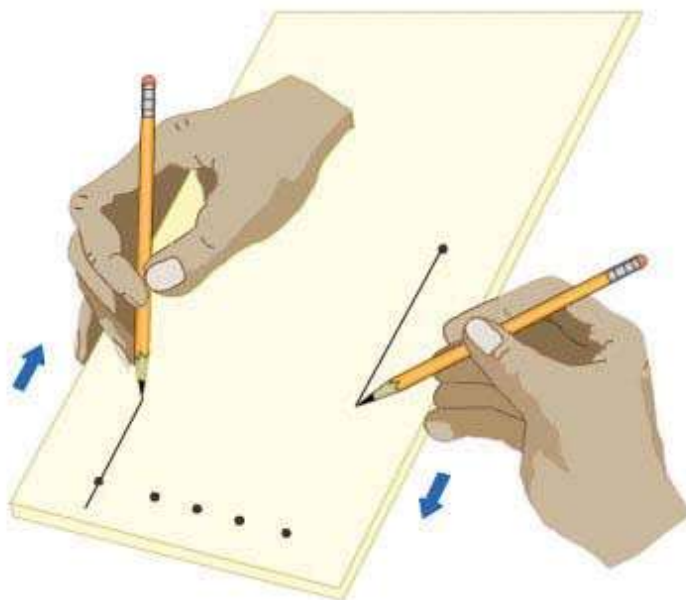
Figure 6-57 – Use of paper, pad, or table as a guide when drawing straight lines.

Another useful technique in drawing straight lines is to use the side of the paper, pad, or table as a guide for your hand. Hold the pencil at the desired starting point of the line and place the heel of your hand and one finger on the guide, as shown in *Figure 6-57*. Move the pencil, in this case, with one uniform stroke to complete the line. Try drawing several light horizontal lines and, after each one is drawn, examine it for straightness, weight, and neatness. If it is too light, use either a softer pencil or a little more pressure.

Vertical lines are usually sketched downward on the paper. The same suggestions for using locator dots, free movement of the entire arm, and guides apply to vertical lines as to horizontal lines.

Slanting lines may be drawn from either end toward the other. For better control, you might find it helpful to rotate the paper, thus placing the desired slanting line in either the horizontal or vertical position.

To keep your sketch neat, first sketch your lines lightly. Lines not essential to the drawing can be sketched so lightly that you need not erase them. Darken essential lines by running your pencil over them with more pressure. *Figure 6-58* shows line conventions drawn with various types of pencil points.

3.2.2 Dividing Lines and Areas Equally

Your ability to divide lines and areas into equal parts is necessary to arrive at many of the common geometric forms required in sketching. The simplest method of bisecting lines is by visual comparison, as shown in *Figure 6-59*. First, observe the entire line and weigh it optically to determine its fulcrum or point of balance. Compare each half visually before placing the bisecting point. This procedure can be repeated any number of times to divide a line into any number of equal divisions, merely by dividing and re-dividing its line segments.

Figure 6-58 – Line conventions drawn with various types of pencil points.
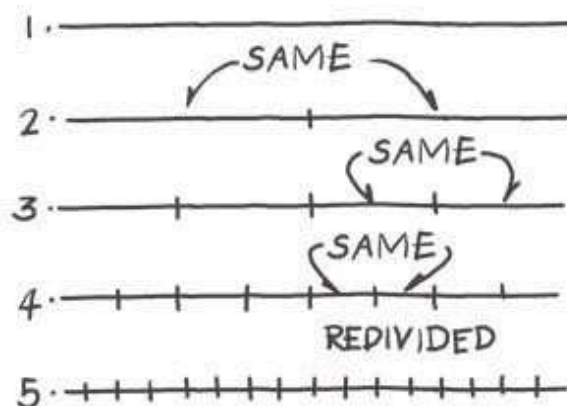
Figure 6-59 – Bisecting a line by visual comparison.

You can easily determine centers of rectangular areas drawing their diagonals. If necessary divide the halves with diagonals for smaller divisions, as shown in *Figure 6-60*.

3.2.3 ketching Angles

You will be sketching 90-degree angles in the majority of your sketches. Learn to sketch right angles accurately, even if you have to check them with a triangle occasionally. You can frequently use the perpendicular edges of your paper as a visual guide for comparison. Try turning your sketch upside down; non-perpendicular tendencies of horizontal and vertical lines will become evident. Shaping right angles correctly will give your sketch visual stability and increase its effectiveness.
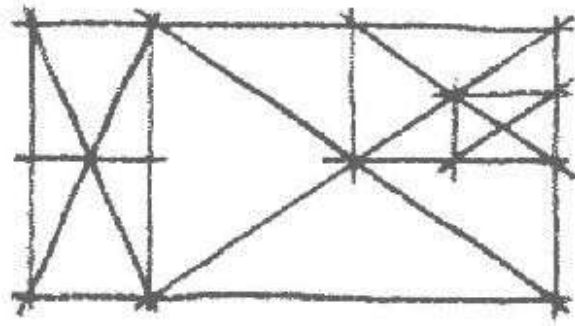
Figure 5-60 - Locating centers by sketching diagonals.

Make a 45-degree angle by dividing a right angle by visual comparison and a 30-degree or 60-degree angle by dividing the right angle into three equal parts. The 30-degree or 45-degree angle may be divided into equal parts in the same manner. (See *Figure 6-61.*) Always start with the right angle for the most accurate estimation of angle shape.
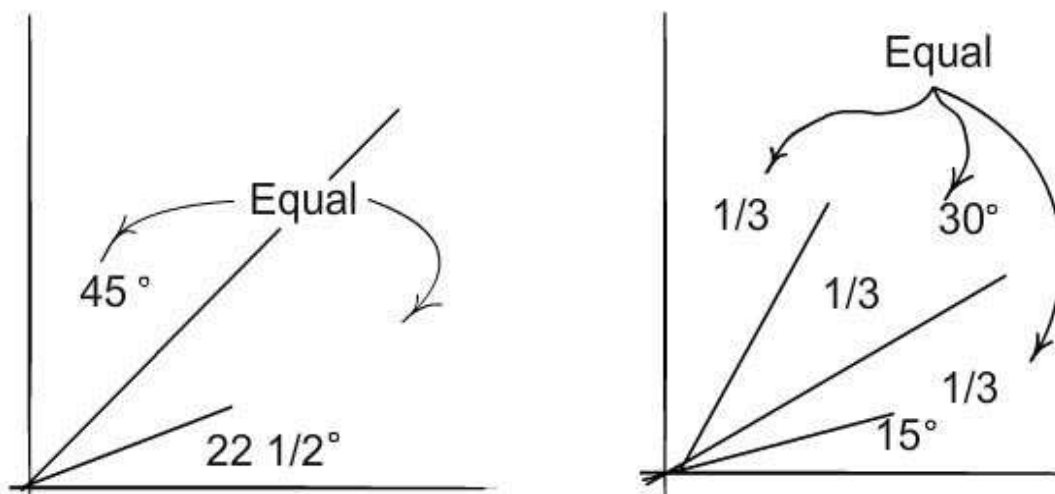
Figure 6-61 - Sketching angles by visual comparison.

3.2.4 Sketching Circles and Arcs

Perfectly round circles are the most difficult to draw freehand. *Figure 6-62* shows methods of drawing circles and curves using straight lines as construction lines. First, draw two straight lines crossing each other at right angles, as in *Figure 6-62, View A*. The point at which they cross will serve as the center of the circle. The four lines radiating from this center will serve as the radii of the circle. You can use a piece of marked scrap paper to measure an equal distance on each radius from the center. Sketch a square, with the center of each side passing through the mark defining a radius. (See *Figure 6-62, View B.*) Now sketch in your circle, using the angles of the

square as a guide for each arc. When larger circles are required, you can add 45-degree angles to the square to form an octagon. This will provide four additional points of tangency for the inscribed circle.

In *Figure 6-62*, *View C and View D*, four lines, instead of two, are sketched crossing each other. The radii are measured as in constructing the other circle, but a square is not drawn. For this method, you will find it helpful to rotate the paper and sketch the circle in one direction.

For drawing large circles, you can make a substitute for a compass with a pencil, a piece of string, and a thumbtack. Tie one end of the string to your pencil near the tip. Measure the radius of the circle you are drawing on the string, and insert your tack at this point. Now swing your pencil in a circle, taking care to keep it vertical to the paper.
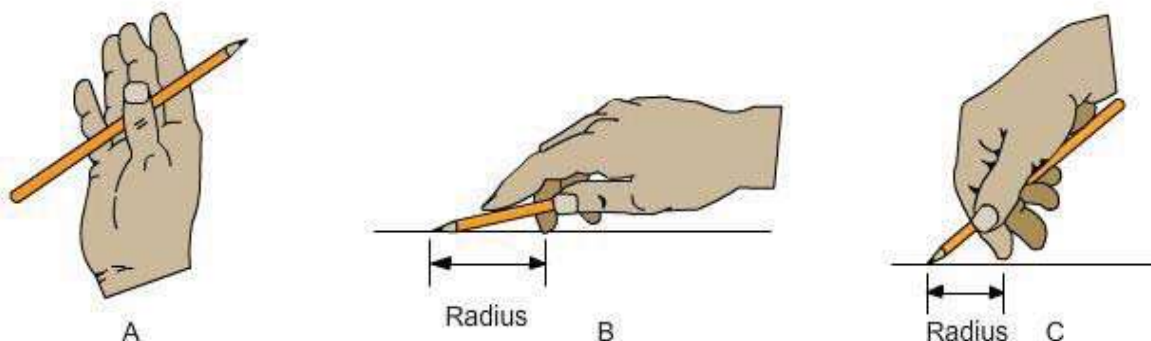
Figure 6-62 - Methods of sketching circles.
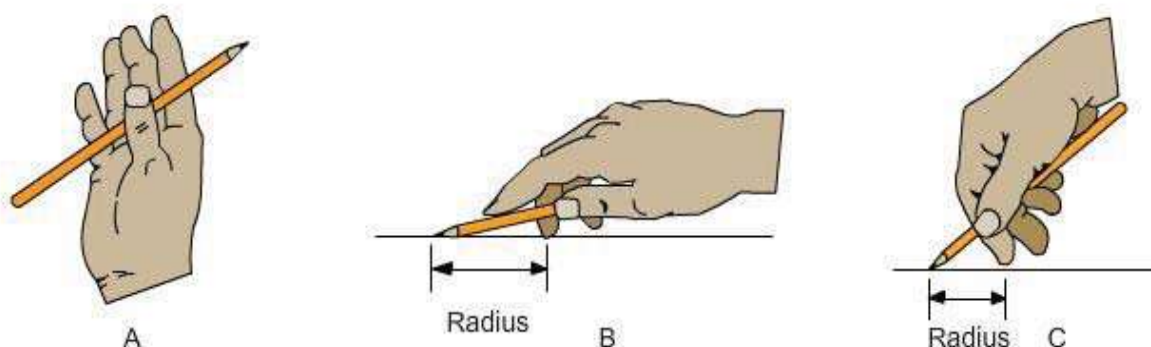
Figure 6-63 – Proper pencil grip in sketching circles and arcs.

Another technique for drawing circles is shown in *Figure 6-63*. In *Figure 6-63, View A*, observe how the pencil is held beneath the four fingers with the thumb. This grip tends to produce a soft or easy motion for sketching large circles or curves and also makes it possible to sketch small circles, as shown in *Figure 6-63, Views B and C*. Notice in *Figure 6-63, View B*, that the second finger rests at the center of the circle and forms the pivot about which the pencil lead can swing. The distance from the fingertip to the pencil lead determines the radius of the circle. To draw smaller circles, you need to

assume a somewhat different grip on the pencil, as shown in *Figure 6-63, View C*, but the principle is the same.

As shown in *Figure 6-64, View A*, the first step in sketching either large or small circles with the grips shown in the previous figure is placing the second finger on the paper at the center of the proposed circle. Then, with the pencil lightly touching the paper, use the other hand to rotate the paper to give you a circle that may look like the one in *Figure 6-64, View B*. To correct the slight error of closure shown in *View C*, erase a substantial section of the circle and correct it by eye, as shown at the right. You now have a complete and round circle, but with only a very light line, which must be made heavier. Do this as shown in *View B*. Notice that you DO NOT PIVOT on the second finger during this step. Rest your hand on its side and, keeping it within the circle, trace over the light line with your hand pivoting naturally at the wrist. As you work around the circle in this way, rotate the paper counterclockwise so that your hand can work in its most natural and easy position. Of course with smaller circles you cannot work with your hand within the circle, but you can successfully use the same general approach.

Probably one of the best methods to sketch curves connected to straight lines is the six-step method illustrated and explained below.

Figure 6-64 - Steps in sketching a circle.
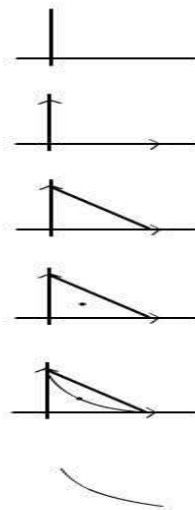
Figure 6-65 – Steps in sketching a curved line.

1. Intersect a vertical and horizontal line, lightly.

2. Mark off on the horizontal and vertical lines the same distance from the intersection.

3. Draw a light diagonal line through the two points marked.

4. Place an x or a dot in the exact center of the triangle formed.

5. Start your curve from one point of the triangle (preferably on the vertical line) touching the x or dot and ending at the other point of the triangle.

6. Erase all unnecessary guidelines and darken the curve and necessary adjoining straight lines.

With a little practice of this method, your ability to sketch curves properly should improve.

Figure 6-66 shows a convenient way to sketch arcs and curves by lightly drawing construction boxes (or blocks).
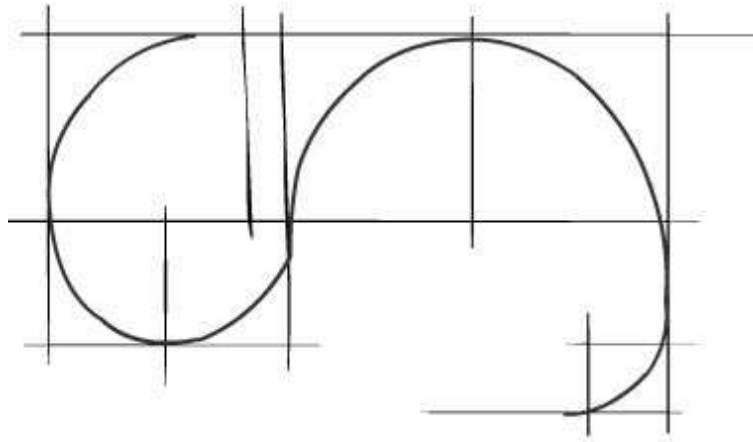
Figure 6-66 - Sketching curves using construction boxes.

3.2.5 3.2.5 Construction Lines

When you are sketching an object, such as that shown in *Figure 6-67*, don't start at one corner and draw it detail by detail and expect it come out with the various elements in correct proportion. It is better to block in the overall size of the object first, (See *Figure 6-67, View A*.) Then draw light guidelines at the correct angles for the various outlines of the object. (See *Figure 6-67, Views B and C*.)

Finish the sketch by first making an outline of the object and then drawing in the details, as shown in *Figure 6-67, View D*.
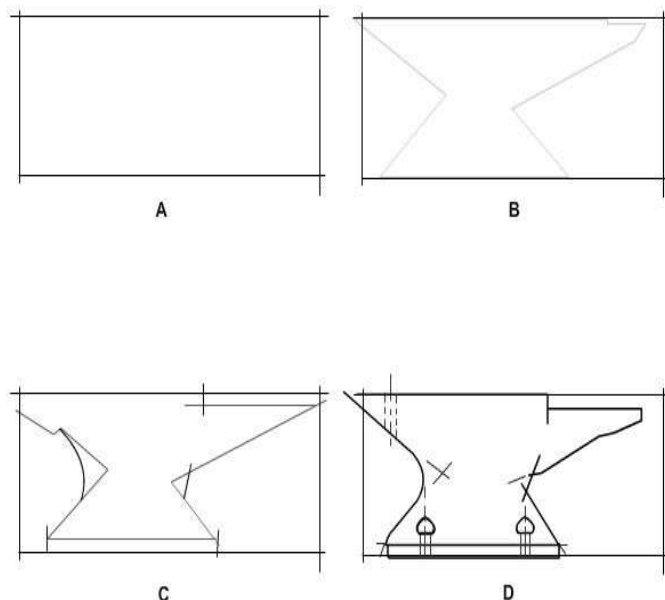
Figure 6-67 – The use of construction lines in sketching an object.

3.2.6 Order of Sketching

To make a working sketch, first choose a clean sheet of paper, either plain or ruled. Estimate the size the sketch should be, and select the views that will give the best picture of the object. Then draw the orthographic projections of these views, leaving adequate space between them for dimensions. (Refer to the working sketch in *Figure 6-68*.) In sketching, progress as follows:
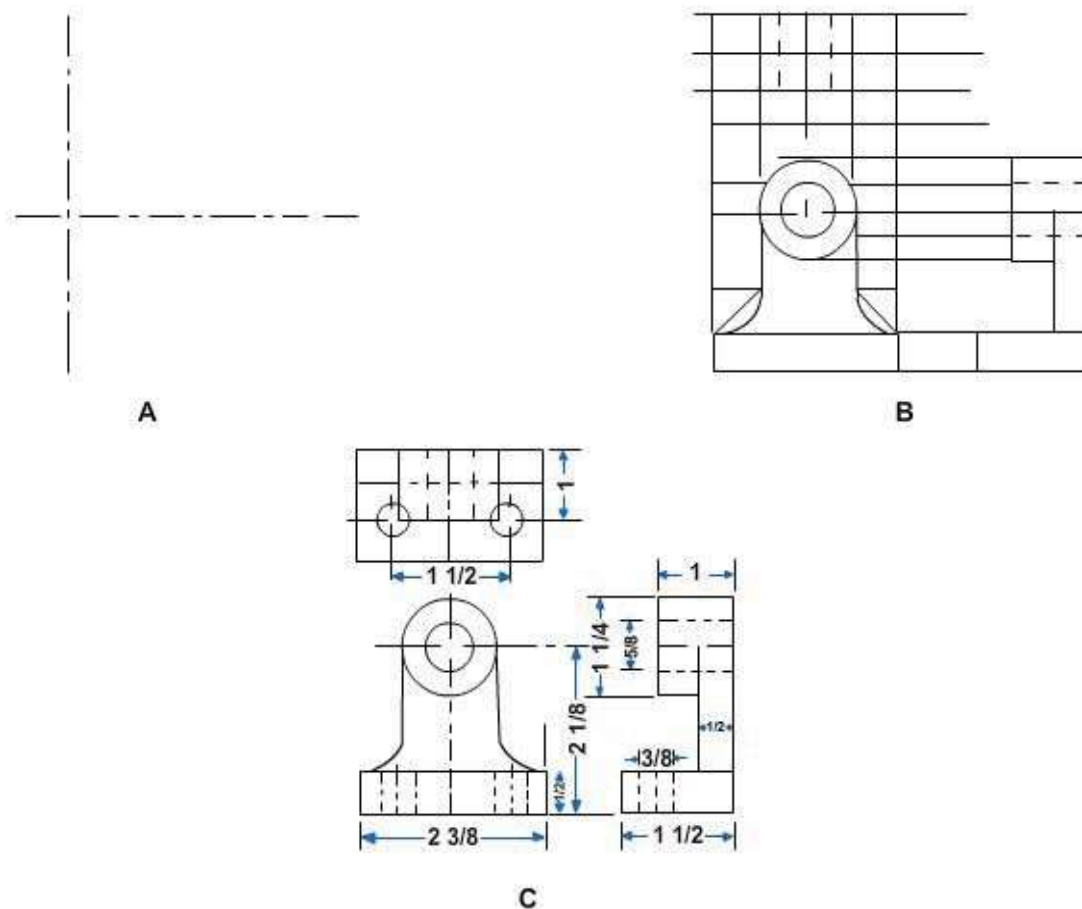
Figure 6-68 - Progress of a working sketch.

1. Draw the center lines, as shown in *Figure 6-68*, View A.

2. Block the views.

3. Draw the outlines, aligning them as in *Figure 6-68, View A*.

4. Add the details on the surface of the views

5. Darken the lines of the finished sketch.

6. Use an art gum or a kneaded eraser to erase the construction lines, which are no longer needed. If necessary, touch up the lines you may have inadvertently erased.

7. Draw all necessary extension and dimension lines.

8. Letter in the dimensions. (See *Figure 6-68, View C*)

You can see that a working sketch such as the one shown in *Figure 6-68* could easily be followed in preparing a finished drawing of the object. The sketch provides you with all the necessary information needed on the finished drawing.

3.2.7 Pictorial Sketches

Often it will be more convenient, or even necessary, to prepare isometric or oblique *pictorial sketches* instead of multi-view orthographic sketches. Pictorial sketches provide a quick method of examining tentative construction details. A quick pictorial sketch will also help you in the layout of isometric and oblique drawings.

The principles of pictorial and orthographic sketching are similar, except that in pictorial sketching you will be dealing with volumes rather than flat planes. Pictorial sketches and pictorial drawings are practically the same except for the drawing materials used in their development and the fact that pictorial sketches are not normally drawn to scale. By following a few simple steps, based on pictorial drawing construction principles, you should be able to prepare meaningful pictorial sketches.

3.2.7.1 Isometric Sketches

Select a position (view) that will show the object to the best advantage. You will know what you want included in your sketch, so move either the object or yourself until you can actually see everything you want to show. If the object is something you have in mind or if you intend to sketch an isometric view from an orthographic drawing, you will have to visualize the object and assume a viewing position. In making your isometric sketch, remember that you start by sketching three isometric axes 120 degrees apart, using two angles of 30 degrees and a vertical axis of 90 degrees. *Figure 6-69, View A*, shows a step-by-step procedure you can use to make an isometric sketch of a wooden rectangular block measuring 1 1/2 inch. by 2 inches by 4 inches.

The first step is to sketch the three isometric axes, as mentioned earlier. The second step is to mark off the 1 Ii inch for height on the vertical axis, the 2 inch width along the left axis, and the 4 inch length along the right axis. The thrid step is to draw two vertical lines 1 Ii inches high(starting with the marks on the right and left axis), then sketch parallel lines from each of the marks on the sketch. Not that the lines that are parallel on the object are parallel on the sketch. The fourth step is to dimension the sketch. The dimensions on an isometric sketch are placed parallel to the ends or edges. The final step is to check the sketch for completeness and accuracy.

3.2.7.2 Oblique Sketches

Draw the front face or view of an *oblique sketch* in the same way as an orthographic front view. Using the same wooden block that was sketched isometrically for a model, draw an oblique sketch following the basic steps shown in *Figure 6-69, View B*.

First, draw a rectangle of the front view (using light lines). Second, draw an oblique base line at a 45-degree angle starting at the corner (intersection) of the horizontal and vertical base lines. Third, sketch the remaining horizontal and vertical lines parallel to the other base lines. Fourth, erase any unnecessary lines, and, fifth, dimension and darken the completed drawing for easier reading. Remember, place the dimensions so they are parallel to the axis lines. The final step is to check the sketch for completeness and accuracy.
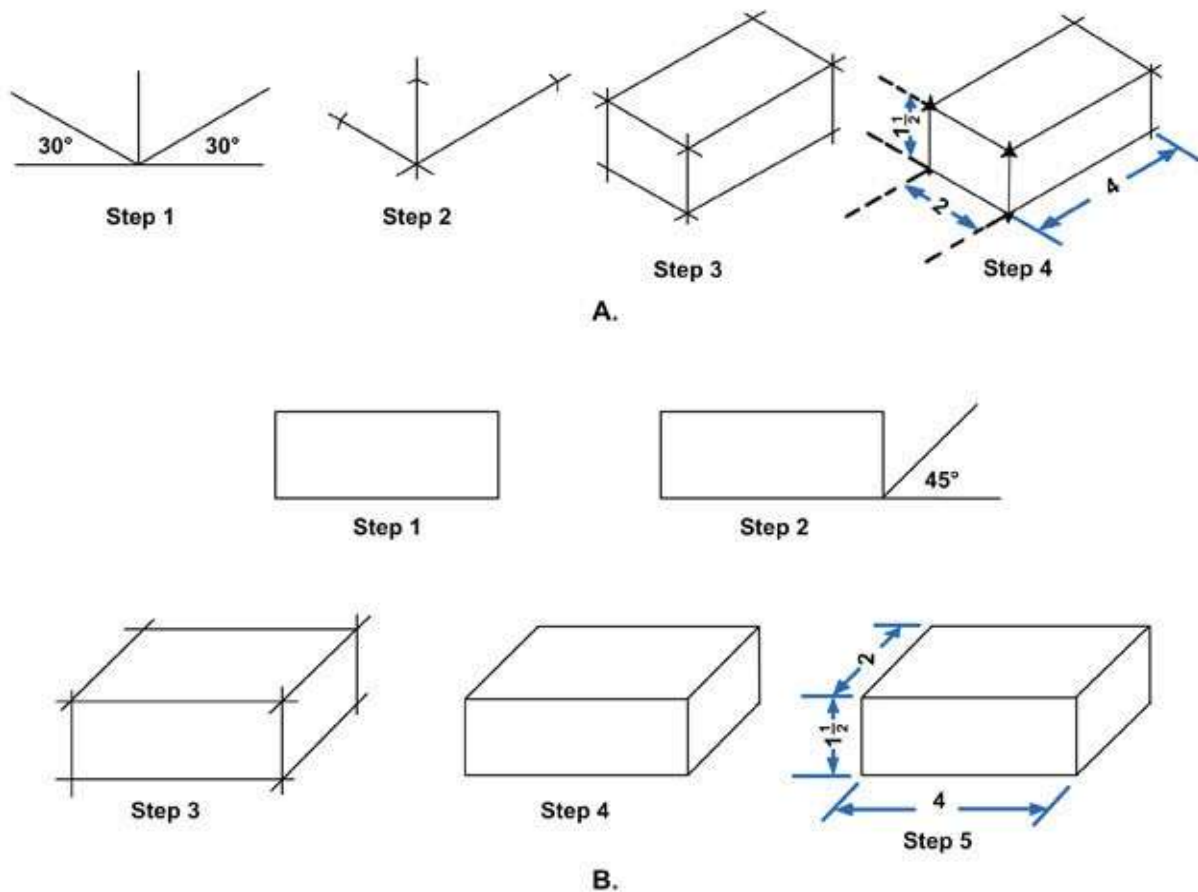
Figure 6-69 -Sketching a regular block: (A) Isometric; (B) Oblique.

In the above procedures for development of pictorial sketches, a simple rectangular form was used. All objects may be simplified to their basic geometric forms. These forms are the first consideration in the pictorial sketch. Basic volumetric forms are shown in *Figure 6-70*. By carefully analyzing any object you sketch, you will see one or more of the forms shown in *Figure 6-70*. However, at times only a part of a form is present.

Before attempting detailed sketches, practice sketching the basic forms. Then look for these forms in the object you are about to sketch and concentrate on the basic form representation. Enclose the object in a basic form, or build it up with a series of different forms, depending on the nature of the object. Details are added or "carved" from these forms after shape and proportion have been determined.
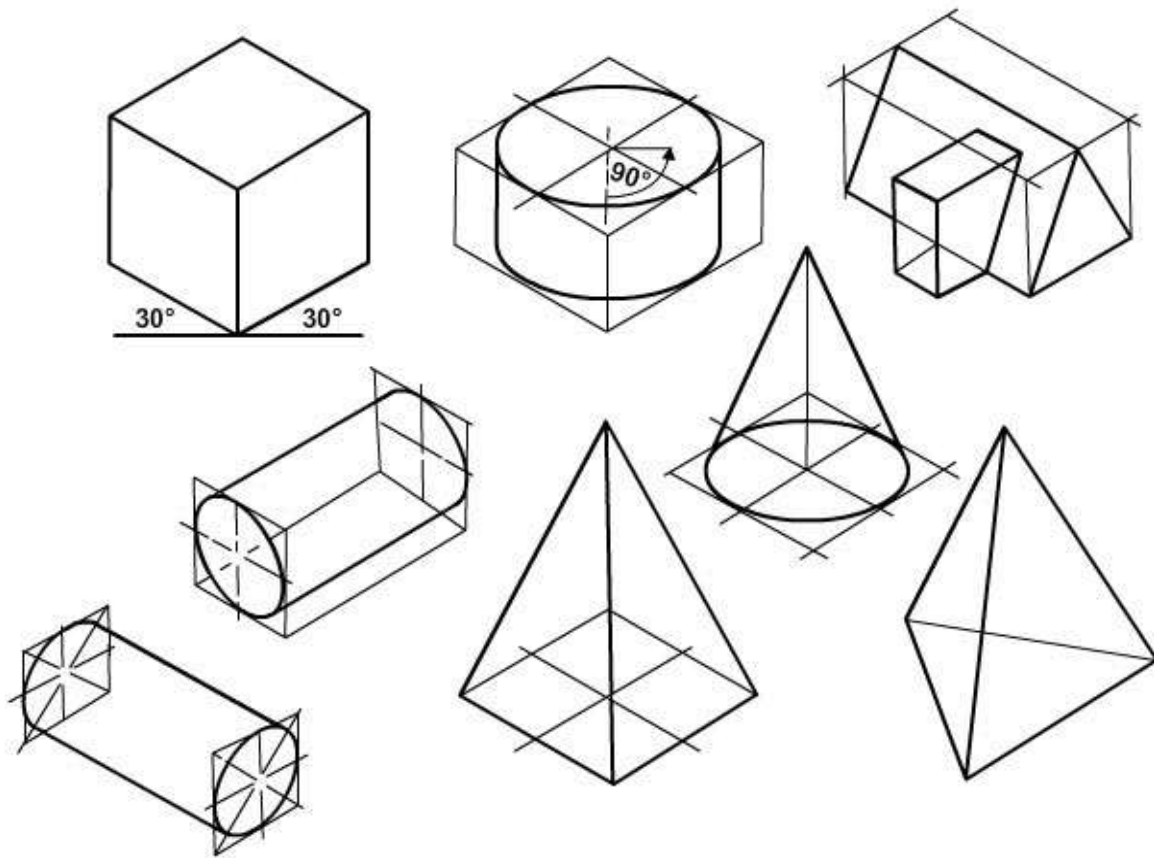
Figure 6-70 - Basic isometric forms.

3.2.8 Overlay Sketches

To make overlay sketches, sketch freehand on transparent paper placed over existing drawings or other sketches. Sometimes when you make overlay sketches, you merely trace, freehand, objects or lines from another drawing or sketch. But more often you will prepare overlay sketches by tracing and then adding supplementary sketched lines or objects.

Usually, when this type of sketch is prepared, only the prominent or desired features are traced. Overlay sketches are primarily used for planning purposes.

A suggested procedure for using overlay sketches as a tool for planning is explained in the following example:

The drafting room is being relocated. You are tasked with developing a proposed furniture and equipment layout. You have the latest prints of the floor plan and an electrical plan, and you know what furniture and equipment will be moved to the new area. The steps you take to develop the proposed layout are as follows:

1. Check the floor plan and electrical plan against the actual room layout. If necessary, check the dimensions. Correct any discrepancies with a dark-colored fine tip felt pen or colored pencil.

2. Place a piece of tracing paper over the floor plan on the print and secure it with small strips of drafting tape.

3. Trace the outline of the walls with single freehand lines (preferably with a dark colored felt tip pen). Terminate the lines, where applicable, to indicate windows and door openings.

4. Remove the tracing paper from the floor plan and place it over the electrical plan, lining the traced wall outlines up with the corresponding walls on the electrical plan. Using appropriate symbols, locate, on the traced floor plan, all electrical outlet locations.

5. You now have a clear overlay sketch of the existing floor plan without the unnecessary dimensions and information on the original print of the floor plan. This is your basic planning overlay. Check your overlay with the original prints to make sure you did not omit relevant lines.

6. Place another sheet of tracing paper over the basic planning overlay. This becomes your second overlay. On this second overlay, sketch in your desired location of all the furniture and equipment. Use simple shapes for each and estimate sizes. Use letters or symbols for identification. Repeating the outline of the walls is not necessary because you can still see the outline from the basic planning overlay.

7. If this first location sketch on the second overlay does not suit you or does not provide an adequate layout, lay another piece of tracing paper over the second layout and sketch another one. Repeat this procedure with additional overlays until you have developed a good layout.

8. Once you have a good layout, trace the wall outlines from the basic planning overlay. This final overlay sketch is your proposed furniture and equipment layout for the new location of the drafting room.

Summary

As an EA, you should be able to clearly represent any given object or structure on paper by applying basic geometric construction to the various projection methods. To show an object's three dimensions by lines alone, you must use either a system of related views or a single pictorial projection. You must be able to show clearly the shape of the object, give the exact size of each part, and provide necessary information for constructing the object. In the field, freehand sketching is an invaluable tool in preparing quick sketches to convey or develop your ideas.

Review Questions (Select the Correct Response)

1.   Parallel projection is divided into two main types of projection:_____and
      _____.

      A.   orthographic, oblique
      B   perspective, orthographic
      C.   perspective, oblique
      D.   perspective, first angle

2.   A parallel projection in which the lines of projection are perpendicular to the plane
      of projection is called a(n)_____projection.

      A.   perspective
      B.   orthographic
      C.   oblique
      D.   first angle

3.   The position of the observer in relation to the object and the plane of projection is
      called the_____.

      A.   point of sight
      B.   parallel point
      C.   oblique point
      D.   orthographic point

4.   The observer views the features of the object through an imaginary_____.

      A.   station point
      B.   point of site
      C.   plane of projection
      D.   plane of perspective

5.   _____are the imaginary lines from the eye of the viewer to points on the
      object.

      A.   Images lines
      B.   Parallel lines
      C.   Planes of projection
      D.   Lines of sight

6.   _____projection consists of drawing the essential views of the same
      object from different angles and projecting the views on a single plane

      A.   Perspective
      B.   Oblique
      C.   Orthographic
      D.   Profile

7. Establishing an object's true height, width, and depth requires front, top, and side views, which are called the _____.

    A.   image planes
    B.   principal planes of projection
    C.   station points
    D.   lines of sight

8. **(True or False)** First-angle projection is commonly used in the United States.

    A.   True
    B.   False

9. A _____ projection of a cube will result with a front view on the vertical plane, a top view on the horizontal plane, and a right side view on the profile plane.

    A.   first-angle
    B.   second-angle
    C.   third-Angle
    D.   fourth-angle

10. Using a _____ offers a convenient method of laying out a third view while you are in the process of drawing two views.

    A.   projection line
    B.   mitre line
    C.   line of sight
    D.   projection plane

11. In the American standard arrangement of views, all views are rotated toward the view as though they are hinged; the _____ view always lies in the plane of the drafting surface and does not require any rotation.

    A.   back
    B.   front
    C.   left side
    D.   right side

12. When creating a balanced drawing, remember that the _____ of the object will determine the space between the views.

    A.   color
    B.   position
    C.   size
    D.   shape

13. In a third-angle projection, you always presume the plane of projection is _____the object and the observer, regardless of which view you are considering.

    A.   in front of
    B.   behind
    C.   between
    D.   in the same place as

14. When numbering a hidden corner point, the number is_____, and for a visible corner point,_____.

    A.   placed within the outline, outside the outline
    B.   placed outside the outline, inside the outline
    C.   circled, not circled
    D.   not circled, circled

15. A multi-view projection should contain_____.

    A.   four views
    B.   only front, side, and back views
    C.   all possible views
    D.   only as many views as required to describe the object fully

16. In a multi-view orthographic projection, a_____is parallel to two of the planes of projection and perpendicular to the third.

    A.   non-normal line
    B.   non-normal plane
    C.   normal line
    D.   normal plane

17. Views on planes other than the regular planes are called_____views.

    A.   auxiliary
    B.   regular
    C.   multi-
    D.   normal

18. A_____view is a view on one of the three regular planes of projection (horizontal, vertical, or profile).

    A.   auxiliary
    B.   regular
    C.   multi-
    D.   normal

19.   A_____on a surface that is parallel to the plane of projection will project as a_____.

   A.   circle, circle
   B.   ellipse, circle
   C.   circle, ellipse
   D.   circle, hidden line

20.   An imaginary plane that is parallel with the line or surface we want to project in its true shape that is NOT one of the regular planes is called a(n)_____.

   A.   non-normal plane
   B.   normal plane
   C.   auxiliary plane
   D.   regular plane

21.   **(True or False)** An auxiliary view is one that is projected on a plane other than one of the regular planes.

   A.   True
   B.   False

22.   In a_____, the object is projected on one or more of the regular planes of projection, but instead of being placed in normal position, the object is rotated on an axis perpendicular to one of the regular planes.

   A.   revolution
   B.   auxiliary
   C.   rotation
   D.   normal plane

23.   Use a_____view when it will better show the object's internal structure than using hidden lines.

   A.   regular
   B.   auxiliary
   C.   revolution
   D.   sectional

24.   When a cutting plane passes entirely through a symmetrical object and divides it into two equal parts, this view is called a_____section.

   A.   revolved
   B.   full
   C.   broken
   D.   partial

25. A section consisting of less than half a section is called a_____section.

    A.   revolved
    B.   full
    C.   normal
    D.   partial

26. In_____projection only one plane is used and the projection lines are perpendicular to the plane of projections, but the object is inclined to the plane of projection.

    A.   regular
    B.   sectional
    C.   axonometric
    D.   partial

27. **(True or False)** Isometric projection is the most frequently used type of axonomic projection.

    A.   True
    B.   False

28. **(True or False)** A foreshortened line in a projection is somewhat longer than the actual length of the edge on the object itself.

    A.   True
    B.   False

29. A_____line is a line that is not parallel to any one of the three legs of the isometric axis. It is not a normal line in a normal multi-view projection of the object.

    A.   regular
    B.   partial
    C.   isometric
    D.   non-isometric

30. **(True or False)** In a normal multi-view view of an object, an angle never appears in its true size,

    A.   True
    B.   False

31. **(True or False)** A circle in a normal multiview view will appear as an ellipse in an isometric drawing.

    A.   True
    B.   False

32.   **(True or False)** A line that appears as a noncircular curve in a normal multi-view view of an object appears as a non-isometric line in an isometric drawing.

A.   True
B.   False

33.   The isometric axis is commonly used with the lower leg vertical. The axis may, however, be used in any position, provided the angle between adjacent legs is always_____degrees.

A.   120
B.   90
C.   45
D.   60

34.   **(True or False)** Diagonal hatching on a sectional surface shown in isometric should have the appearance of making a 90-degree angle with the horizontal or vertical axis of the surface.

A.   True
B.   False

35.   There are two types of_____single-plane projections: cavalier and cabinet.

A.   abstract
B.   orthographic
C.   oblique
D.   isometric

36.   _____projection is a form of oblique projection in which the projection lines are presumed to make a 45-degree vertical and a 45-degree horizontal angle with the plane of projection.

A.   diametric
B.   cavalier
C.   cabinet
D.   trimetric

37.   In a_____projection, then, any line parallel to or perpendicular to the plane of projection is projected in its true length.

A.   diametric
B.   cavalier
C.   cabinet
D.   trimetric

38. When the receding axis is reduced by one half, the projection is called a
_____ projection.

   A. dimetric
   B. cavalier
   C. cabinet
   D. trimetric

39. **(True or False)** In an oblique projection drawing, the angle chosen for the
receding axis is either 30 degrees, 45 degrees, or 60 degrees because those
angles are easily constructed with triangles.

   A. True
   B. False

40. **(True or False)** A regular line in an oblique drawing is a line that would be an
oblique line in a normal multi-view projection.

   A. True
   B. False

41. **(True or False)** In an oblique projection, an angle on the surface that is parallel
to the plane of projection will appear in its true size; an angle on any other
surface will not.

   A. True
   B. False

42. In an oblique projection, a circle on the surface parallel to the plane of projection
will appear as a(n)_____. A circle on any other surface will appear as a(n)
_____.

   A. ellipse, ellipse
   B. circle, circle
   C. ellipse, circle
   D. circle, ellipse

43. _____ projection is obtained when the projection lines converge to a point
that is at a finite distance from the plane of projection.

   A. Cavalier
   B. Cabinet
   C. Perspective
   D. Oblique

44. **(True or False)** Of all the three-dimensional single-plane drawings, perspective
drawings are the ones that look the most natural.

   A. True
   B. False

45. **(True or False)** Sketching is not an important skill for an EA to have.

   A.   True
   B.   False

46. Sketching requires_____.

   A.   many specialized tools
   B.   only pencil and paper
   C.   drafting board and a T square
   D.   a ball point pen

47. Sketches drawn on transparent paper over existing drawings are known as _____sketches.

   A.   overlay
   B.   perspective
   C.   isometric
   D.   cabinet

48. **(True or False)** Your sketches do not have to conform to any kind of standard projection types.

   A.   True
   B.   False

49. **(True or False)** Draw each line with a series of short strokes instead of with one stroke.

   A.   True
   B.   False

50. **(True or False)** Vertical lines are usually sketched upward on the paper.

   A.   True
   B.   False

51. The simplest method of bisecting a line when freehand sketching is_____.

   A.   using a ruler
   B.   using a protractor
   C.   using a compass
   D.   using visual comparison

52. A 30-degree or 60-degree angle can be made by dividing the right angle into _____equal parts.

   A.   2
   B   3
   C.   4
   D.   5

53. One convenient way to sketch arcs and curves is by lightly drawing_____.

   A. dotted lines
   B. construction lines
   C. dots
   D. construction boxes

54. **(True or False)** When sketching an object, it is best to start at one corner and draw it detail by detail.

   A. True
   B. False

55. **(True or False)** You should draw the center lines of the object first.

   A. True
   B. False

56. **(True or False)** Pictorial sketches deal with planes and are drawn to scale.

   A. True
   B. False

57. In making an isometric sketch, remember that you start by sketching three isometric axes_____degrees apart, using two angles of 30 degrees and a vertical axis of 90 degrees.

   A. 90
   B. 120
   C. 60
   D. 30

58. The front face or view of an oblique sketch is drawn the same way as a(n) _____front view.

   A. oblique
   B. orthographic
   C. auxiliary
   D. non-normal

59. To make_____sketches, sketch freehand on transparent paper placed over existing drawings or other sketches.

   A. cavalier
   B. cabinet
   C. perspective
   D. overlay

Trade Terms Introduced in this Chapter

Broken Section
A part of a drawing showing less than half a section; also known as a partial section.

Cabinet Projection
A cavalier projection in which the receding axis is reduced by one half in order to reduce the visual distortion of an object.

Foreshortening
In isometric projection, the cube is inclined so that all of its surfaces make the same angle (35°16') with the plane of projection. As a result of this inclination, the length of each of the edges shown in the projection is somewhat shorter than the actual length of the edge on the object itself.

Full Section
When the cutting plane passes entirely through the object and divides it into two equal parts, a full section results.

Half Section
One half of a full section.

Image Plane
Also called plane of projection; a theoretical transparent plane between the point of sight and the object.

Line of Symmetry
Center line indicating the division between the section and unsections part of a sectional view.

Oblique Projection
A type of parallel projection in which the projection lines are parallel to each other but oblique to the plan of projection.

Oblique Sketch
A sketch which starts with a rectangle of the front view, and has an oblique base line at a 45-degree angle starting at the corner of the horizontal and vertical base lines.

Overlay Sketches
Sketches created on tracing paper; sketches can be modified or redeveloped simply by placing transparent paper over previous sketches or existing drawings

Parallel Projection
A projection type in which the projection lines are parallel to each other. May be oblique or orthographic.

Partial Auxiliary View
Only showing the points or lines needed to project the line or surface desired.

Perspective Drawings
Most natural-looking of all the three-dimensional single-plane drawings, but no single line or angle on the drawing has a length or size that has any known relationship to its true length or size when projected through perspective projections.

Pictorial Sketches	Provide q uick method of ex amining t entative construction det ails, d eals with volumes rather t han flat planes. Normally not drawn to scale
Plane of Projection	Also called image plane; theoretical transparent plane between the point of sight and the object.
Principal Planes of Projection	The t hree pr incipal (or pr imary) pl anes of pr ojection, known as the *vertical*, *horizontal*, and *profile planes*.
Revolution	The object is projected on one or more of the regular planes o f pr ojection an d r evolved on an axis perpendicular to one of the regular planes.
Secondary Auxiliary View	Used w hen t he sh ape o f the obj ect i s such t hat normal orthographic and auxiliary views will show the true size and shape of a surface. The reference plane for a se condary auxi liary view i s located i n t he orthographic view f rom w hich t he pr imary auxiliary view is projected. Usually, the primary auxiliary plane becomes the secondary reference plane.
Section Lining	Diagonal hatching or crosshatching
Station point	Position of t he o bserver i n r elation to t he object a nd plane of projection. Also called point of sight.

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

Blueprint Reading and Sketching, NAVEDTRA 14040, Naval Education and Training Program Management Support Activity*, Pensacola, FL, 2003.

Graphic Symbols for Electrical and Electronics Diagrams, American National Standard, ANSI 2.2-1975, The Institute of Electrical and Electronics Engineers, NY, 1986.

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Chapter 7

Wood and Light Frame Structures

Topics

To hear audio, click on the box.

Overview

Engineering Aids prepare drawings, and regardless of the type of drawing you need to prepare, you must apply your knowledge of materials and construction methods. Light frame structures using wood are some of the most common structures for both civilian and military application. This chapter covers wood; its uses, kinds, sizes, grades, and classifications. It also describes how builders use wood to frame and finish a structure with appropriate hardware and fasteners. A familiarity with this type of structure and its materials will help you prepare your drawings.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Describe the different types of wood EAs utilize.
2. Describe the different types of wood frame structures.
3. Describe the different types of building finishes.
4. Identify the different types of hardware.
5. Identify the different types of fasteners.

Prerequisites

None

This course map shows all of the chapters in Engineering Aid Basic. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Topographic Surveying and Mapping	E
Indirect Leveling/Level and Traverse Computations	N
Care and Adjustment of Survey Equipment	G
Materials Testing: Soil and Concrete	I
Direct Leveling and Basic Engineering Surveys	N
Horizontal Control	E
Direct Linear Measurements and Field Survey Safety	E
Surveying: Elements and Equipment	R
Construction Drawings	I
Electrical: Systems and Plans	N
Mechanical: Systems and Plans	G
Concrete and Masonry	
Wood and Light Frame Structures	AID
Drafting: Projections and Sketching	
Drafting: Geometric Construction	B
Drafting: Fundamentals and techniques	A
Drafting: Equipment	S
Mathematics and Units of Measurement	I
Engineering Aid Rating	C

Features of this Manual

This manual has several features which make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.

- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.

- Audio and video clips are included in the text, with an italicized instruction telling you where to click to activate it.

- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer

is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.0.0 WOOD

Wood is probably the most often used and perhaps the most important construction material. Seabees build very few construction projects, permanent or temporary, without using wood. In addition to wood for the structure itself, Seabees make temporary use of wood for scaffolding, shoring, bracing, and miscellaneous concrete forms.

There are several types, or species, of wood; the variety is practically unlimited. Each has its own characteristics and recommended uses. For most large projects, the specifications will indicate the required types and classifications.

For smaller projects that do not have written specifications, the drawings include the project's types and classifications of wood. *Figure 7-1* provides the types, sources, uses, and characteristics of some common woods. In addition, the *Architectural Graphic Standards* found in your unit's technical library lists the species, size classification, and design values of common structural woods.

Figure 7-1 — Common woods.

1.1.1 Lumber

In construction, the terms wood, lumber, and timber have distinct, separate meanings.

- Wood--the hard, fibrous substance that forms the major part of the trunk and branches of a tree

- Lumber--wood that has been cut and surfaced

- Timber--lumber whose smallest dimension is not less than 5 inches.

- Millwork--manufactured lumber products, such as doors, window frames, window casings, shutters, interior trim, cabinets, and moldings

1.1.1 Sizes

In the United States, to permit uniformity in planning and ordering materials, the construction industry uses standardized lumber sizes. You identify Lumber by ***nominal size***, which is larger than the actual ***dressed*** dimension.

Item	Thickness (inches)		Face Width (inches)	
	Nominal	Dressed	Nominal	Dressed
Boards	1 1 1/4 1 1/2	3/4 1 1 1/4	2 3 4 5 6 7 8 9 10 11 12 14 16	1 1/2 2 1/2 3 1/2 4 1/2 5 1/2 6 1/2 7 1/4 8 1/4 9 1/4 10 1/4 11 1/4 13 1/4 15 1/4
Dimension Lumber	2 2 1/2 3 3 1/2	1 1/2 2 2 1/2 3	2 3 4 5 6 8 10 12 14 16	1 1/2 2 1/2 3 1/2 4 1/2 5 1/2 7 1/4 9 1/4 11 1/4 13 1/4 15 1/4
Dimension Lumber	4 4 1/2	3 1/2 4	2 3 4 5 6 8 10 12	1 1/2 2 1/2 3 1/2 4 1/2 5 1/2 7 1/4 9 1/4 11 1/4
Timbers	5 & Thicker		5 & Wider	

Dressed lumber is surfaced (planed smooth) on two or more sides and designated according to the number of sides or edges surfaced. For example, S2S (surfaced 2 sides) identifies lumber surfaced on two sides; S4S (surfaced 4 sides) is lumber surfaced on all four sides and S2S2E is lumber surfaced on two sides and two edges. When you develop your drawings or order materials from suppliers, designate lumber by nominal size rather than dressed dimensions. *Figure 7-2* shows common dimensions for nominal and dressed lumber.

Figure 7-2 — Nominal and dressed sizes of lumber.

1.1.2 Classification

Use, size, and extent of manufacture determine lumber classification.

Lumber classified according to use falls into three categories:

- Yard Lumber-grades, sizes, and patterns generally intended for ordinary construction and general building purposes
- Structural Lumber-2 inches or more in thickness and width for use to meet any project requiring working stresses
- Factory and Shop Lumber- produced or selected mainly for manufacture of furniture, doors, cabinets, and other millwork

Lumber classified according to size has three general classifications:

- Boards-less than 2 inches thick and 1 inch or more wide. If less than 6 inches wide, they may be classified as strips
- Dimension-at least 2 inches thick, but less than 5 inches thick and 2 inches or more wide. It may be classified as framing, joists, planks, rafters, studs, and small timbers

- Timbers-smallest dimension is 5 inches and may be classified as beams, stringers, posts, caps, sills, girders, and purlins

Lumber classified by extent of manufacture consists of three types:

- Rough Lumber-not dressed (surfaced) but sawed, edged, and trimmed to the extent that saw marks show in the wood on the four longitudinal surfaces

- Dressed Lumber-surfaced by a planing machine to attain a smooth surface and uniform size

- Worked Lumber-dressed and matched, shiplapped, or patterned

1.1.3 Grading

The National Bureau of Standards, part of U.S. Department of Commerce, established the American Lumber Standards to grade lumber for quality.

Yard Lumber---There are two major grades. In descending quality, they are select lumber and common lumber. These grades have further subdivisions, also in descending order of quality.

- Select Lumber-good appearance and good qualities for finishing

  o Grade A-nearly free of defects and blemishes

  o Grade B---contains a few minor blemishes

  o Grade C---more numerous and significant blemishes than Grade B

  o Grade D---more blemishes than Grade C

A and B are suitable for natural finishes; C and D are satisfactory when painted.

- Common Lumber-suitable for general construction and utility purposes

  o No. 1---sound, tight-knotted stock, containing only a few minor defects, suitable for use as watertight lumber

  o No. 2---limited number of significant defects but no knotholes or other serious defects, must be suitable for use as grain-tight lumber

  o No. 3---contains a few defects, larger and coarser than those in No. 2; for example, occasional knotholes

  o No. 4---low-quality material, contains serious defects like knotholes, checks, shakes, and decay

  o No. 5---holds together only under ordinary handling

Structural Lumber---Allowable stresses determine the grade according to its safe load-carrying capacity. Various factors, such as species of the wood, density, moisture content, and other characteristics, affect the capacity of these allowable stresses and determine the grade.

Factory and Shop Lumber---generally determined by intended use, and the grades very greatly from use to use.

1.1.4 Board Measure

Board foot is the basic unit of quantity for lumber. The definition of a board foot is the volume of a board 1 foot long by 1 foot wide by 1 inch thick. You usually measure the length of lumber in feet, the width in inches, and the thickness in inches, so the formula for the quantity of lumber in board feet becomes the following:

$$\frac{Thickness\,(inches)\,x\,width\,(inches)\,x\,length\,(feet)}{12} \quad Board\,Measure\,(board\ ^{feet})$$

Example: Calculate the board measure of a 14-ft length of a 2 by 4. Applying the formula, you get

$$\frac{2\,x\,4\,x\,14}{12} \quad 9\frac{1}{3}bm$$

For board measure purposes, presume lumber less than 1 inch thick to be 1 inch thick. Calculate board measure using the nominal, not the dressed, dimensions of lumber. The symbol for board feet is bm, and the symbol for a unit of 1,000 is M. If you needed 10,000 board feet of lumber for example, you would indicate the quantity as 10Mbm.

1.2.0 Laminated Lumber

Laminated lumber is a solution when a design requires wood with increased load-carrying capacity and rigidity. It is usually made of several pieces of 1 1/2-inch -thick lumber, called laminations, that are nailed, bolted, or glued together with the grain of all pieces running parallel (*Figure 7-3 A*). When necessary, manufacturers can achieve extra length by splicing additional pieces so that no two adjacent laminations splice at the same point. Built-up beams and girders are examples of laminated lumber.
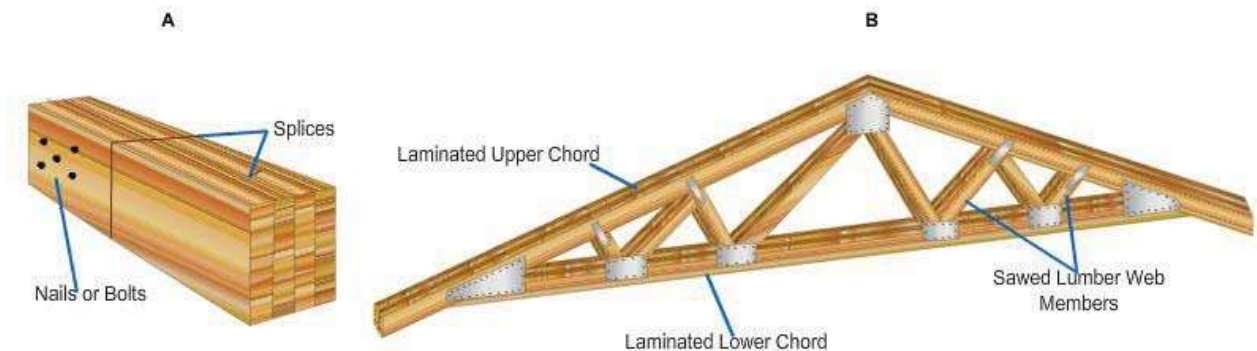

Figure 7-3 — Examples of laminated lumber and manufactured truss.

Designers can incorporate laminations independently or with other materials in the construction of a structural unit. They may design trusses made with laminations for the chords and sawed lumber for the web members (*Figure 7-3 B*). Special beams (Figure *7-4 A*) may have laminations for the flanges and sawed lumber for the webs.
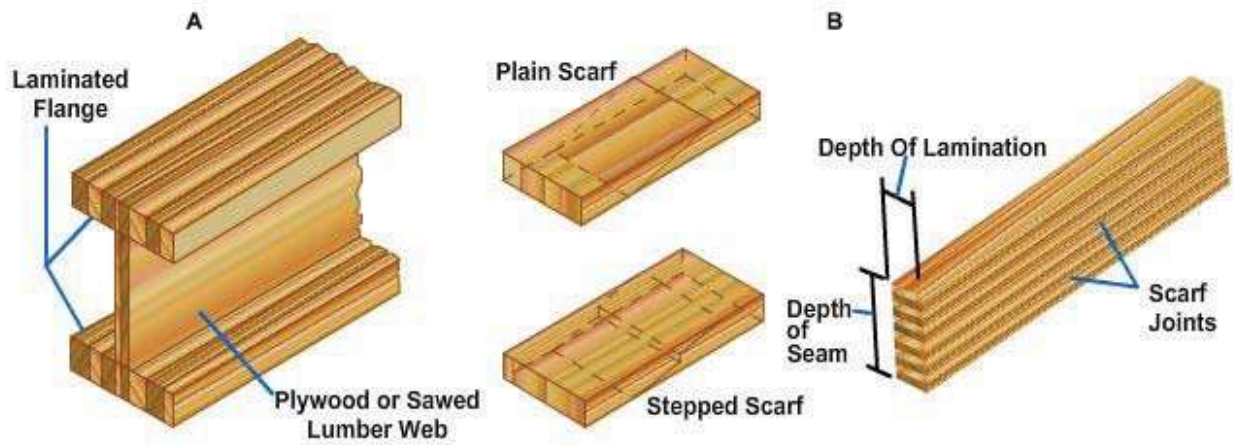
Figure 7-4 — Examples of laminated beam and scarf techniques.

Probably the most common use of laminations is in the fabrication of large beams and arches. Builders have erected beams with spans larger than 100 ft and depths of 8 1/2 ft with laminated beams manufactured with 2-inch boards. Laminations this large are factory-produced, glued together under pressure, and spliced using scarf joints (*Figure 7-4 B*). Then the entire piece is dressed to ensure uniform thickness and width.

1.3.0 Plywood

Plywood is a panel product made from thin sheets of wood called veneers. Manufacturers generally use an odd number of veneers, such as three, five, or seven, so the grains on the face and back of the panel run in the same direction. Cross-lamination distributes the grain strength in both directions, creating a panel that resists splitting and, pound for pound, is one of the strongest building materials.

Dry from the mill, plywood is never "green." From oven-dry to complete moisture saturation, a plywood panel swells across or along the grain only about 0.2 % and considerably less with normal exposures.

No other building material is as versatile as plywood. Builders use it for concrete forms, wall and roof sheathing, flooring, box beams, soffits, stressed-skin panels, paneling, partitions, doors, furniture, shelving, cabinets, crates, signs, and many other purposes.

Figure 7-5 — Typical plywood grain direction.

1.3.1 Sizes

Plywood is generally available in panel widths of 36, 48, and 60 inches and in panel lengths ranging from 60 to 144 inches in 12-inch increments. Other sizes are also available on special order. Panels 48 inches wide by 96 inches long (4 by 8 feet), and 48 inches wide by 120 inches long (4 by 10 feet), are the most commonly available sizes. The 4 by 8 feet and larger sizes simplify construction, saving time and labor.

Sanded panels range from 1/4 to 1 1/4 inch or greater nominal thickness, generally in 1/8-inch increments. Unsanded panels range from 5/16 inch to 1 1/4 inch or greater in nominal thickness, in increments of 1/8 inch for thicknesses over 3/8 inch, and increments of 1/16-inch for thicknesses under 3/8 inch.

1.3.2 Types

Exterior and interior are the two plywood classifications.

- Exterior plywood has high-quality veneers and more durable adhesives enabling it to better withstand exposure to the elements.

- Interior plywood can withstand an occasional wetting but not permanent exposure to the elements.
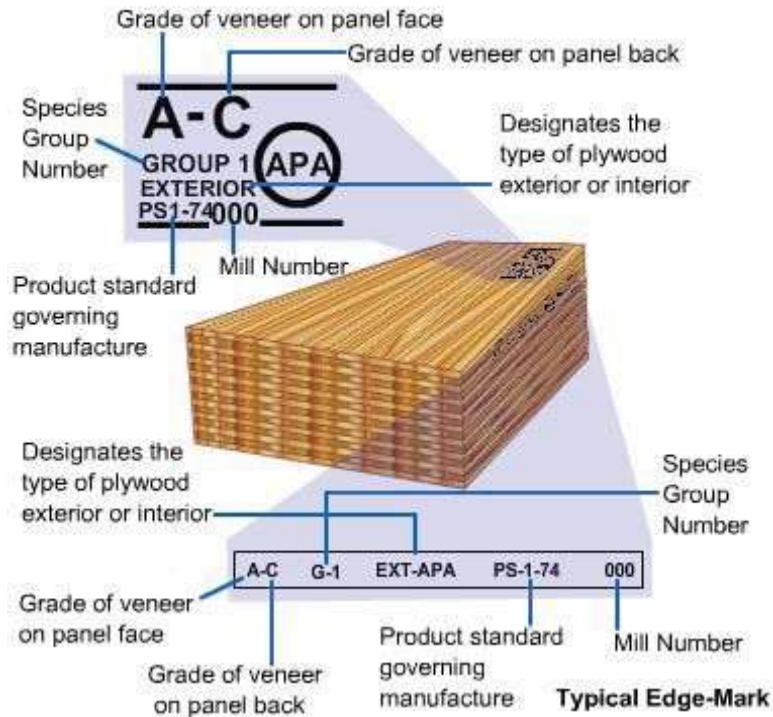
1.3.3 Grades

There are several grades within each type of plywood. Knotholes, pitch pockets, splits, discolorations, and patches, all affect the grade of the facing veneer, and the grade of veneer, along with the kind of glue used, will determine the grade of the panel (N, A, B, C, or D).

- N---Special order natural finish veneer. Select all heartwood or all sapwood. Free of open defects. Allows some repairs.

- A---Smooth and paintable. Neatly made repairs permissible. Also used for natural finish in less demanding applications.

- B---Solid surface veneer. Circular repair plugs and tight knots permitted.

- C---Knotholes to 1 inch. Occasional knotholes to � inch. Larger knotholes permitted providing total width of all knots and knotholes within a specified section does not exceed certain limits. Limited splits permitted. Minimum veneer permitted in exterior-type.

- C---Improved C (plugged) veneer with splits limited to 1/8 inch in width and knotholes and borer holes limited to % inch by � inch.

- D---Permits knots and knotholes to 2 � inch width and � inch larger under certain specified limits. Limited splits permitted.

1.3.4 Identification Stamps

Typical Back-Stamp

Grade of veneer on panel face

Grade of veneer on panel back

Species Group Number

A-C
GROUP 1 (APA)
EXTERIOR
PS1-74 000

Designates the type of plywood exterior or interior

Product standard governing manufacture

Mill Number

Designates the type of plywood exterior or interior

Species Group Number

A-C G-1 EXT-APA PS-1-74 000

Grade of veneer on panel face

Grade of veneer on panel back

Product standard governing manufacture

Mill Number

Typical Edge-Mark

Each sheet of plywood has stamps on the edges and back for identification.

It shows all the information needed about the sheet, except its actual size.

Figure 7-6 — Typical plywood identification stamps.

Sheathing panels, structural and standard, have stamps that very somewhat from the standard stamps.

STRUCTURAL I
48/24 (APA)
INTERIOR
PS 1-74 000
EXTERIOR GLUE

STRUCTURAL II
32/16 (APA)
INTERIOR
PS 1-74 000
EXTERIOR GLUE

STANDARD
32/16 (APA)
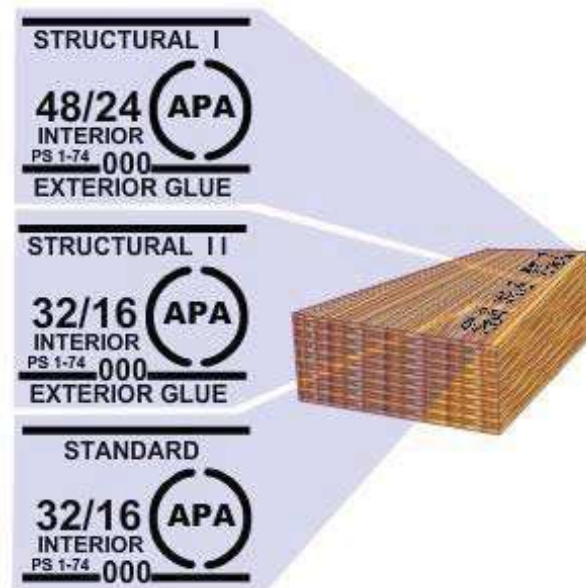INTERIOR
PS 1-74 000

Figure 7-7 — Typical sheathing identification stamps.

Sheathing identification stamps do not provide the grade or species group, but they provide index numbers, 48/24 and 32/16, for the maximum spacing (in inches) of supports.

- **48**/24, **32**/16---Left of the slash is the maximum O.C. (on-center) spacing of supports for roof decking.

- 48/**24**, 32/**16**---Right of the slash is the maximum O.C. spacing of supports for subfloors.

- 48/**0**, 32/**0**---A number **0** on the right of the slash indicates that the panel is not appropriate for subflooring.

For wall sheathing, you do not need to refer to the index number.

You can find detailed information on specific types, grades, and uses for plywood in the commercial standards for plywood manufacture established by the U.S. Department of Commerce.

You can find further information on general plywood characteristics and architectural usage in the *National Lumber Manufacturing Association*, or the *Architectural Graphic Standards*. The latter is a standard requirement in your unit's technical library.

1.4.1 Special-Purpose Plywood

There are other types of plywood available for specific purposes besides structural and sheathing. These include overlaid panels, decorative panels, and concrete form panels. *Table 7-1* lists some of the various types of plywood with their suggested uses.

- Structural plywood
    - for heavy-load application when strength properties are of great importance.
    - for box beams, gusset plates, and stressed-skin panels
    - typically unsanded grades of C-D plywood

- Standard plywood sheathing
    - for subfloors, roof decks, and wall sheathing
    - for use in spaces that may be exposed to moisture during construction, but will be covered when construction is complete

- Overlaid panels
    - for use in furniture, cabinets, millwork, and exterior trims
    - exterior or interior types with a resin-treated fiber-surfacing material, on one or both sides, to hold paint and finishes more readily

- Decorative panels
    - for exterior and interior wall sheathing
    - manufactured in a multitude of designs and patterns
    - can be painted, stained, or left to weather naturally

- Concrete form panel
    - for multiple use as a concrete form