Chapter 2
Technical Freehand Sketching

Abstract Freehand sketching is important for the initial transfer of an idea from the engineer's abstract world. Sketching techniques, in 2D and 3D, are presented, together with details of the motoric functions of the hand during the sketching. A special section covers the phases of making a sketch for a working drawing.

2.1 Sketching Basics

The language of graphics in the engineering environment consists of a number of images and symbols. It is used for the daily communication of ideas and concepts. Each idea is verified by an attempt to express it with different concepts and in details. This is followed by precise technical drawings of products, which are required for their manufacture.

The basic ideas and concepts are usually outlined by means of freehand sketching. Using the criteria of technical drawing, symbols and characters, such a sketch becomes clear to anyone familiar with the international technical language. To avoid problems with the presentation of a technical system or product, it is vital to take account of all the criteria that are necessary for a technical drawing, i.e., a plan. The only difference lies in the fact that on a plan, everything is precisely drawn (including writing), whereas the accuracy of a sketch depends on the accuracy of its author and his or her talent. In life, talent can be developed, but not without work. Knowledge, however, can be acquired through learning and studying. A routine is established through work, similar to getting fit in sport. It makes sense that professional designers and engineers are skilled in the art of sketching. Generally, however, their sketching abilities are near perfect. Sketching allows them to communicate abstractions from the metaphysical part of their brains as a document for themselves and others.

Sketching is also used so as to be able to quickly present, in a graphical form, an idea that is related to a particular problem. Sketching significantly improves the communications between the members of a team, the drafter and the customer. A sketch is usually freehand, without any assistance or the use of instruments or aids that

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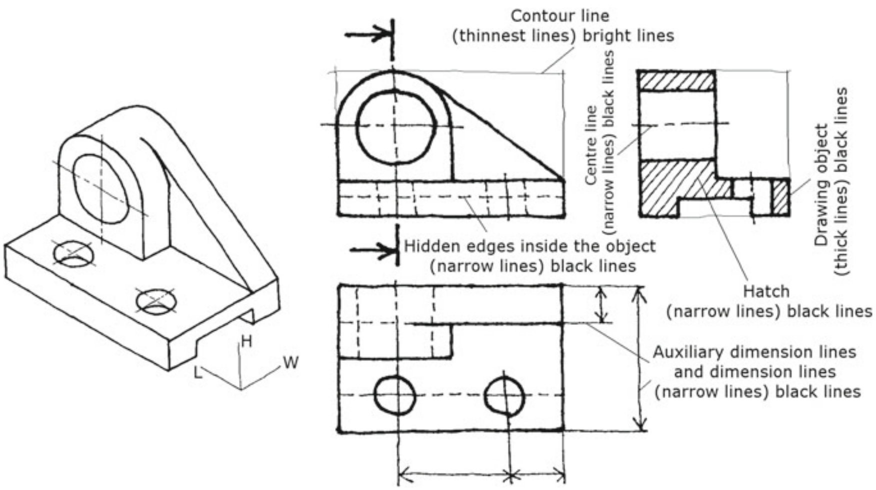


Fig. 2.1 A freehand drawn plane and a spatial sketch of an object, including the description of commonly used thicknesses, i.e., line intensities [10]

are otherwise used for technical drawing. Sketches can also be an integral part of analytical computations, where they are used to present and define the characteristic parameters of analysed physical objects.

Sketches are used to present the outside appearance of an object, with a little emphasis on concealed surfaces and features, which are included in the sketch in order to make the presentation as clear as possible. Sketches are direct graphical communications, often drawn in changeable conditions, such as at a building site, in a workshop or at a business meeting (Fig. 2.1).

In the field, a sketch can nowadays often provide a very good connection with photographs, showing nature or its details. By doing this, it is possible to include a sketch directly into the photograph of the environment in order to present an idea more clearly. By sketching, you can often present a technical system, force and power transmissions and other technical properties that are specific and focused on presenting certain information. In doing this, the information is 'cleared' of any redundant data that prevent a clearer insight into the subject of the analysis. For this very reason, engineers with inferior sketching abilities will face serious problems with communications in their development and research environment. As a result, it will take them longer to present an idea and it will be difficult for others to understand the details.

In this chapter we will explain and give guidelines for effective sketching. We will present the technique, process and templates showing how to make realistic sketches for engineering applications. Later, the technique of sketching will be presented together with short explanations that are related to the theory of technical drawing.

It should be pointed out that the greatest advantage of sketching is that it can be used anywhere and at anytime. You only need writing instruments (a pencil), drawing paper and a rubber (often not necessary), to make a sketch. With a finger, you can sketch in nature: on snow, sand or clay. It is possible to sketch with a piece of charcoal or a clay brick on concrete or asphalt. You can use any soft mineral in a colour that is different from the sketching surface, but it should be harder in this case.

With computer modelling, sketching is used in order to be able to present a rough idea or a modelling requirement. A sketch in this case is not precise, but specific details are exposed, as it is the image of the model that serves as a basis for an accurate digitised technical drawing model on the screen or plots, made on a plotter. Today, sketching is used—together with computer modelling as a way of providing high-quality space digitising—as an important part of the process of presenting the shape of a product or space in general.

2.2 CAD and Technical Freehand Drawing

Computer modelling (using CAD software) is possible if all the dimensions and features of a structure are defined at the input. Incomplete data do not allow a presentation, the object is recorded neither in RAM (on the screen) nor in the archives (file in data storage). This means that before modelling on the computer it is vital to acquire all the data as a free record, a sketch. Due to the volume of data, their structure is generally presented on a handy piece of paper. Generating a random model is conceptualized with a specific generic model, which the modelling software uses in its own way. For simple or less complex models or features, different types of software usually have similar shape generators. For the reasons of continuous data input, or at least to prevent lengthy breaks, you can take advantage of a rough presentation on a sketch that was done previously on paper. Later on, when the model is becoming increasingly complex, you should make a temporary copy of the model or detail on paper, which is then complemented with sketches that have improved details, which are necessary for the high-quality processing of a problem. Such a process is shown in Fig. 2.2.

Understanding data processing in freehand drawing can define the trends in the future development of computer modelling. Generally used modelling software (CAD programmes) still has difficulties with special shapes in terms of a computer description of specific technical products. For such products and for specific shapes, such as car tyres, steel structures (bars, framework structures, etc.), unfolded sheet metal, molecular structures etc., special modelling software is often developed. To present details, cross-sections, connecting systems, etc., specific routines are applied for each of those examples. In terms of future modelling software development we can expect the increasing use of natural communications, typical of human beings, such as: sketching, hands and fingers in space; eyesight, eye-pupil movement and image sharpening; hearing, communication for the simulation of sound phenomena; speech, voice commands for the computer; smell, recognizing the results of simulated processes.

In all these cases a representation in solid space is, of course, taken into account.

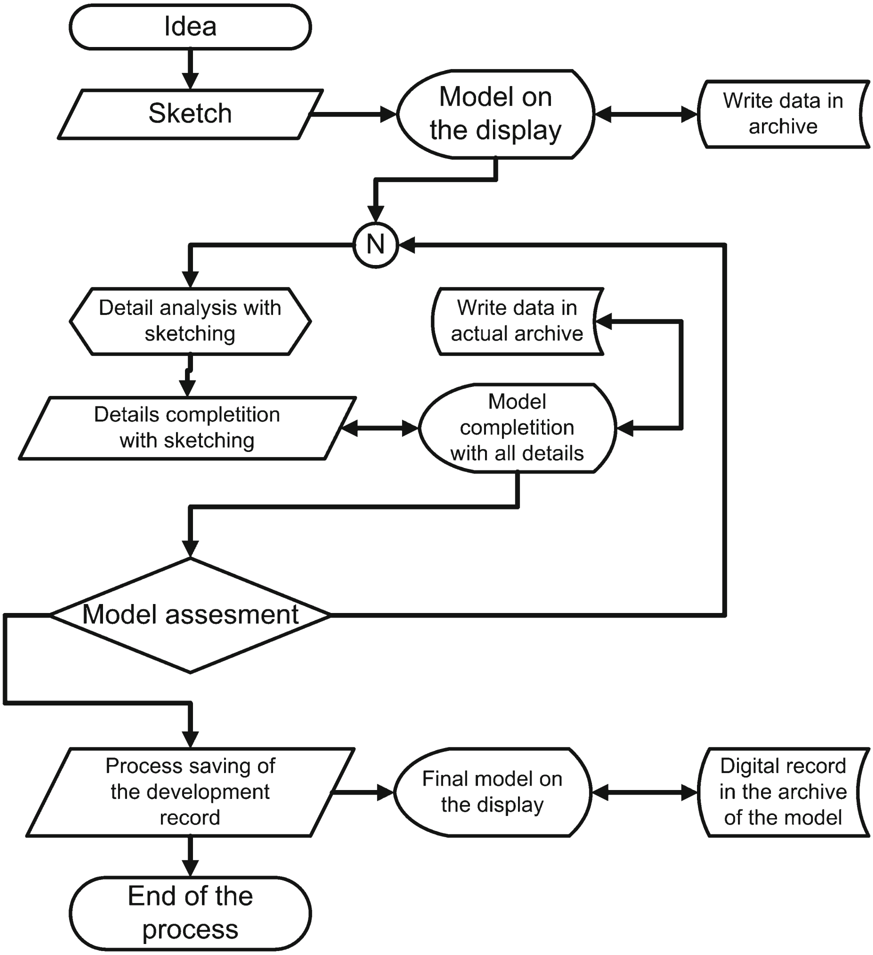


Fig. 2.2 Modelling with modelling software and computer equipment

2.3 Basic Rules of Freehand Drawing

2.3.1 Material, Sketching Tools

The sketching material consists of drawing and sketching tools. Drawing tools are required to make a sketch, and sketching tools offer the possibility to make a drawing.

Besides the basic material tools it is important to bear in mind the drawing technique. First, you need to learn how to make lines of different thickness.

Drawing tools Drawing tools consist of the various materials where sketches can be made. Technical sketches are usually made on opaque paper in sizes A4 or A3 (A2,

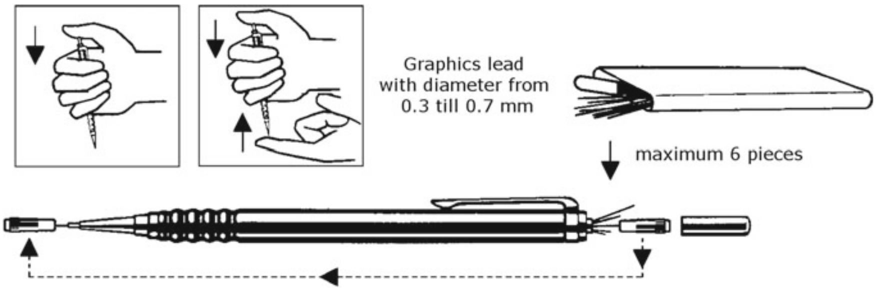


Fig. 2.3 A thinline propelling pencil for leads from 0.3 to 0.7 mm

A1 or A0 are also possible). Opaque paper is usually white, with weights of 0.80, 0.85, 1.00, 1.20, 1.40 and 1.60 N/dm^2 or more. Sketches on such paper are originals and can be copied on regular copiers. Continuous stationary paper is an extended version of the basic sizes. Besides opaque paper, tracing paper (the so-called paus paper) or drawing foils can be used in some cases.

Sketching tools Sketches are usually drawn with pencils in a black colour. However, in special cases, pencils with different colours can be used. Graphite pencils with different hardnesses, i.e., 9H—hardest, HB—medium hardness, 9B—softest). A graphite pencil of 2H hardness is normally used as it allows the drawing of both light (narrow) and dark (wide) lines by simply pressing the pencil against the drawing paper.

The term "propelling pencil" is often used. It refers to a pencil with a replaceable lead. For light thin lines, 2H grade leads are used. They are used to sketch construction lines, dimension lines, different signs, borders, and to write letters of up to 5 mm in size. 2B or B grade lead is used to draw contours, visible edges, shades and writing letters of 7 mm and more. Modern graphite pencils, used for technical graphics, are referred to as thinline propelling pencils. A thinline pencil of 0.3 mm generally used for the construction lines. Thicknesses between 0.5 and 0.7 mm are normally used to draw contours, i.e., dark heavy lines. Thinline pencils do not require any sharpening as the lines are of the same width as the width of the graphite lead (Fig. 2.3).

So, the following tools are recommended for sketching:

- two propelling pencils (with soft 2B or B and medium-hard 2H leads). Exceptionally, a third propelling pencil of HB grade (lead diameter 0.5 mm) for large sizes or drawings. For small drawings, a 4H lead is used with a diameter of 0.3 mm,
- a rubber,
- two set-squares (30°–60°–90° and 45°–45°–90°);
- a compass,
- white opaque paper (A4 or A3 size).

Line thickness It is possible to controllably draw all lines of thicknesses between 0.1 and 1 mm with a single thin lead of 0.7-mm thickness.

Straight lines should be drawn in one go, without breaks.

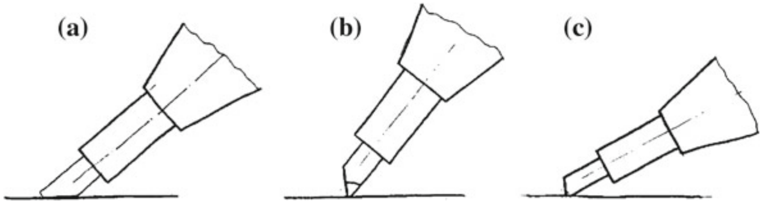


Fig. 2.4 Achieving lines of different thickness [4]. Different line thickness: thickness around 1 mm (**a**), thickness around 0.1 mm (**b**), thickness between 0.3 till 0.6 mm (**c**)

A thickness of 1 mm can be obtained by leaning the pencil and flat-guiding the lead. The lead should be leaned and guided along the surface without rotating it. Flatness can be obtained by a gentle slide against sandpaper (Fig. 2.4a).

A thickness of 0.1 mm can be obtained by guiding the lead on its tip, gently rotating the tip or the whole pencil. Due to wear, the line, i.e., the trace behind the lead, will of course be increasing in size. This can be solved by sliding the pencil against another paper in order to get the same sharp edges on the lead again. Pencils of 2H grade or more will maintain a thin line for longer (Fig. 2.4b).

The tip of the pencil can also be preserved for short fine (thin) lines. Without pressing too hard, the trace will be a lighter grey colour.

For the best copying and faxing results it is important for the lines to be black, which is achieved by pressing the tip hard enough against the paper. The drawing surface should be firm enough to prevent tears and impressions from the lead (Fig. 2.4c).

2.3.2 Sketching Straight Lines

For a clearer introduction to sketching systematics, the whole procedure will be shown for the example of making an arc and a straight line. Such exercises should be continuously revised to prevent a break in motoric function control and any loss of memory with respect to how to establish suitable conditions for drawing ratios.

Wrong: When the forearm rotates it functions as a compass (Fig. 2.5a).

Correct: Only the upper arm should rotate (Fig. 2.5b). The forearm and the hand stay still. The drawing hand should always be drawn in the direction of the body. Remember: pulling is mechanically always more stable than pushing. The easiest way to check the straightness of a line is to draw a line, pointing from the middle of our head towards our nose. Thus, the line is positioned at the centre of our line of sight.

Holding the pencil while sketching. The sketching trace shows the accuracy and skills in accurate rendering by the author of the sketch. For this reason, it is important to know how to achieve drawing accuracy more easily. The little finger and the

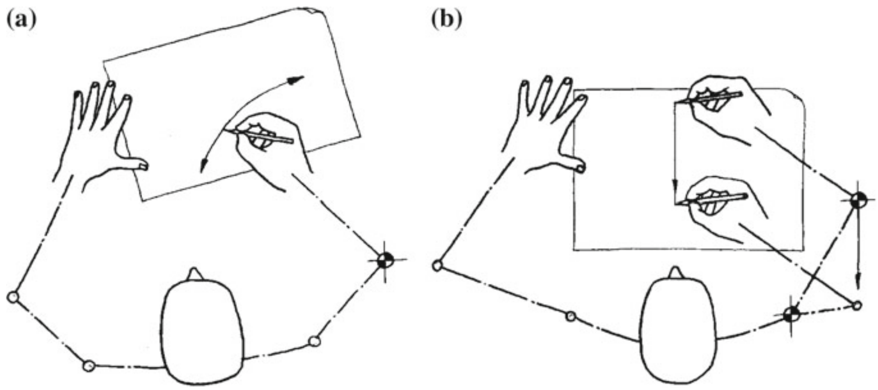


Fig. 2.5 Incorrect and correct movements of the arm when drawing *long straight lines* [4]. Forearm (**a**), upper arm (**b**)

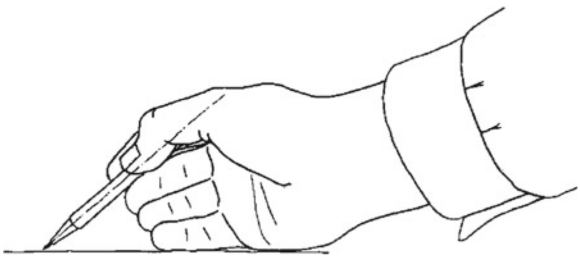


Fig. 2.6 A dry and clean fist should rest on the paper with a large area [4]

continuing edge of the hand should rest on the paper. All the other fingers, except the thumb, which partly holds the pencil, rest on the little finger (Fig. 2.6).

The pencil should point away from the finger tips (thumb and index finger) by around 40–60 mm in order to reach the paper surface in its entirety. In this case, the pencil should be held with the thumb, middle finger and index finger. The end of the pencil should be supported in such a way that the thumb and index finger are slightly bent. In this case, the pencil should have a straight end.

A long distance between the pencil tip and the fingers creates a gentle and steady pressure on the lead, which should be provided whenever fine or grey lines are being drawn. This position of the hand provides an obscured view of the area around the drawn lines (Fig. 2.7). It is important to prevent or minimize—with a sufficient spacing between the lead and the hand—any overlapping of the existing lines.

Some people do not use this grip due to the specific anatomy of the whole arm, especially the hand. However, there are cases when an improper introduction to the technique of sketching results in a cramped clutching of the pen or pencil. One should be aware that the hand muscles cannot remain tense or flexed for a long time. In both cases, it is a matter of partial breaks or a reduction in blood circulation. The first consequence is trembling in the back of the body, followed by a sudden

Fig. 2.7 This grip provides an obscured view of the area around the drawn lines [4]

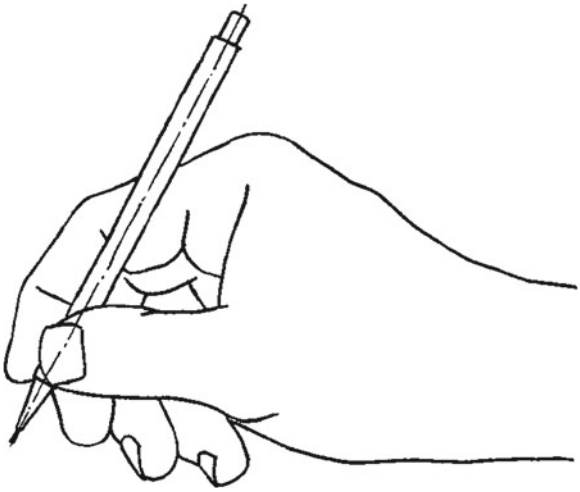


Fig. 2.8 This grip allows a very dark line. The black colour comes from a high pressure being applied to the surface [4]

muscle release in the entire hand musculature. This causes sudden uncontrollable hand movements, which leads to the drawing of undesired lines on the paper.

Line drawing Sketching should begin with fine grey lines, defining a coordinate system, a centreline, the edge of a drawing, etc. This is followed by defining the shape of the product (work, object) that is to be presented. Fine grey lines are still used here. When defining an object it can be presented with rough, thick lines, and the procedure begins with drawing heavy black lines. With each part of the sketch, the object comes to the forefront from the drawing plane. The thick lines are very black; however, they are heavier and of different types. The pencil should be held at its tip, straight and firmly pressed to the paper (Fig. 2.8). The distance between the finger tips and the pencil tip decreases, and is between 20 and 35 mm.

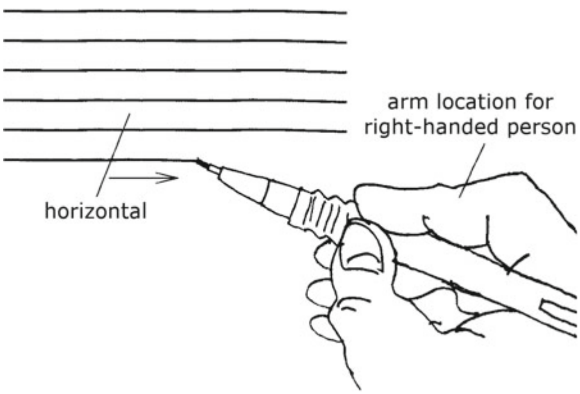


Fig. 2.9 Freehand sketching of *horizontal parallel lines* [10]

The hand should rest comfortably but firmly on the drawing plane. In this case, only the fingers are used to move the pencil, as moving the hand over the existing lines (grey, thin) could smudge it. For this reason, it is necessary to occasionally stop the process of drawing heavy, thick lines. Once the basis has been well presented and designed with thin grey lines, the presentation of the final shape can only become more accurate, compared to what was presented with the grey thin lines.

All this applies to people who use their right hand for sketching. Left-handed sketchers should mirror the kinematics and motoric functions of the hand over the centreline of the body. There is a mirroring problem due to a lack of testing and verifying the understanding of basic sketching elements. Creating freehand sketching rules should follow the same process as learning to write with the left hand.

Sketching straight lines Straight and curved lines are normally used for sketching. Straight lines can be divided into horizontal, vertical and oblique (sloping) lines. A standard approach to the freehand drawing of horizontal lines is from left to right (Fig. 2.9) for the right-handed, and from right to left for the left-handed. The freehand drawing of evenly spaced horizontal lines requires a fair deal of skill.

Attempting to draw straight lines often results in arcs or curved lines. This happens when the forearm remains in a fixed position, which is referred to as a stiff arm. So, when drawing horizontal lines, it is vital to move your whole arm. This is particularly important when sketching long horizontal lines. Your hand rests with its edge on the paper (Fig. 2.11) and the pencil sticks approximately 40 mm from the hand. Each straight line is drawn with the thumb and the index finger towards the body. Your movement must be controlled, and by changing the position of your arm, you can also draw oblique (sloping) lines.

You can also sketch long straight lines by drawing a number of short straight lines and then connecting their ends (Fig. 2.10). The third and very efficient method is the technique of freehand drawing of straight lines. This is executed by using the little finger as a support, sliding along a guide, represented by the edge of the drawing board. You should put the pencil on the starting point and then draw the line while

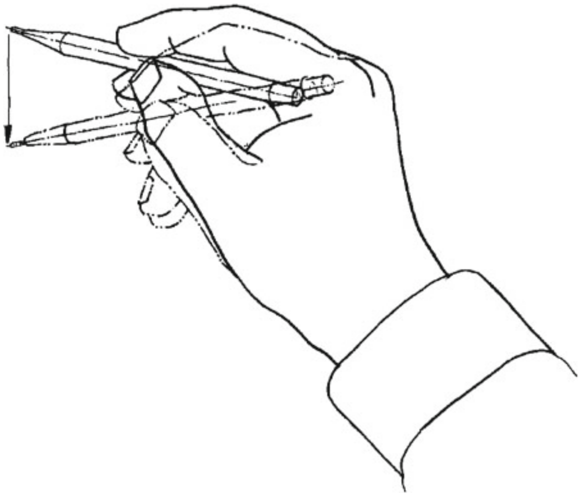


Fig. 2.10 Freehand sketching of *vertical parallel lines*, using the little finger as a guide to maintain the vertical direction (this is also possible for horizontal lines) [10]

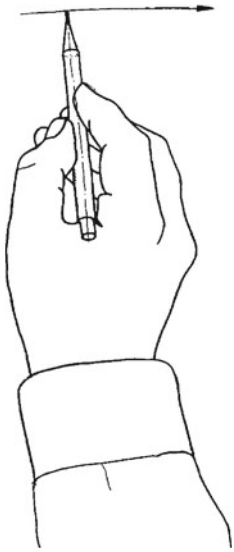


Fig. 2.11 Holding the pencil when drawing *horizontal straight lines* [4]

focusing your eyes on the end point. Figure 2.12 shows the procedure for the freehand sketching of vertical parallel lines, using the little finger as a guide to maintaining the vertical direction. When drawing horizontal lines, the little finger slides along the horizontal edge of the drawing board. You can also simply rotate the paper by 90°.

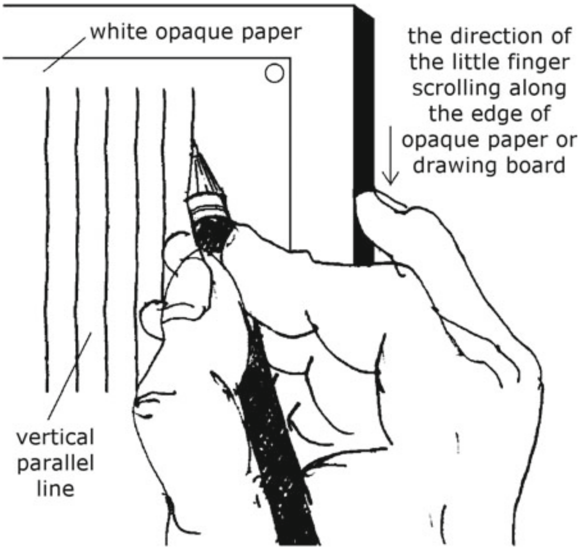


Fig. 2.12 Holding the pencil when drawing *vertical straight lines* [4]

Sketching vertical lines Vertical lines are usually drawn from the top to the bottom of the paper. The freehand drawing of evenly spaced vertical lines (Fig. 2.13) requires a lot of experience. However, the edge of the drawing board and the little finger can be of some assistance (Fig. 2.12).

Sketching horizontal lines When sketching horizontal lines, the hand and the forearm should pivot at the elbow. The thumb and the index finger can compensate for the forearm pivoting, while the edge of the hand should slide along the paper or travel above it (Fig. 2.12). You can first try drawing a line 'in the air', followed by an actual attempt, applying light pressure on the lead against the paper.

When drawing a medium-sized rectangle, the paper can be positioned in an orthogonal position (Fig. 2.15). With the paper rotated, vertical straight lines and horizontal straight lines are then drawn as oblique lines. The order of drawing the vertical and horizontal lines of a medium-sized rectangle is shown in Fig. 2.17.

Sketching oblique lines The right-handed person usually draw sloping or oblique lines towards the edges or from the bottom left to the top right of the page. It is rather unusual, even slighty difficult, to sketch an oblique line stretching from the top left towards the bottom right edge. The sketching is made much easier by rotating the drawing paper into a position that suits you better. Each motoric function of the hand corresponds to its own most suitable position of the paper (Figs. 2.14 and 2.16).

You can also draw straight lines by sketching them in the direction of the nose. To do this, rotate the paper according to the required angle for the oblique lines. In fact, you will be drawing a vertical line, relative to the drafter (Fig. 2.11). Beginners are advised to do a number of exercises for drawing long parallel lines on A4 or A3

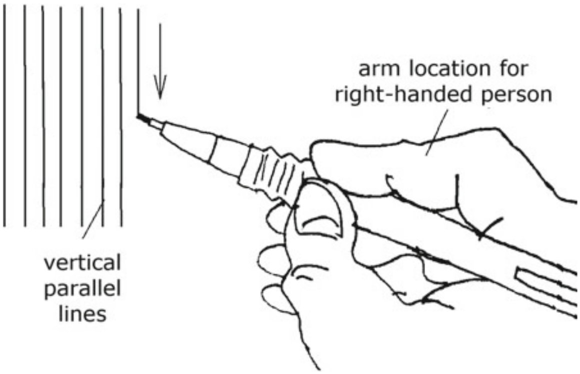


Fig. 2.13 Freehand sketching of *vertical parallel lines* [10]

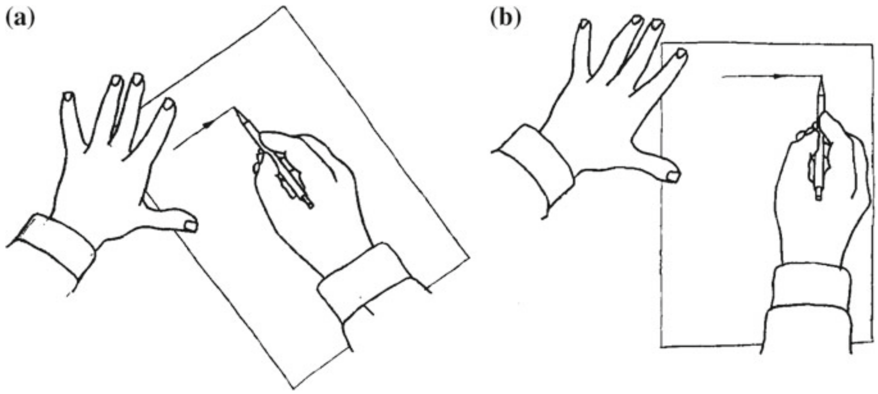


Fig. 2.14 Freehand sketching of *oblique parallel lines* [10]. Using forearm: long line (**a**), short line (**b**)

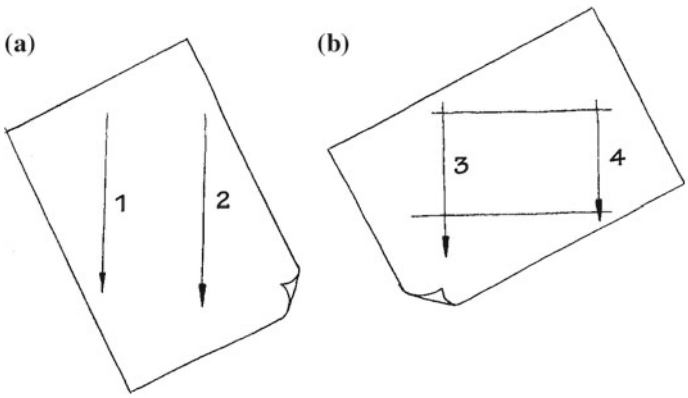


Fig. 2.15 Paper position for drawing [4]. Drawing larger rectangles or square: parallel line no. 1 and 2 (**a**), perpendicular line no. 3 and 4 (**b**)

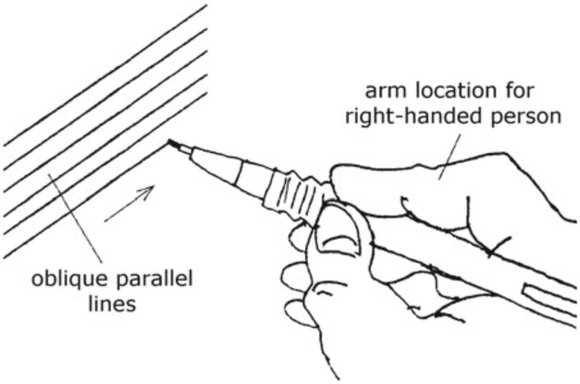


Fig. 2.16 Freehand sketching of oblique parallel lines as vertical by drawing vertical lines along paper rotated in the direction of the nose (**a**), and exercises on A4 and A3 paper sizes (**b**) [4]

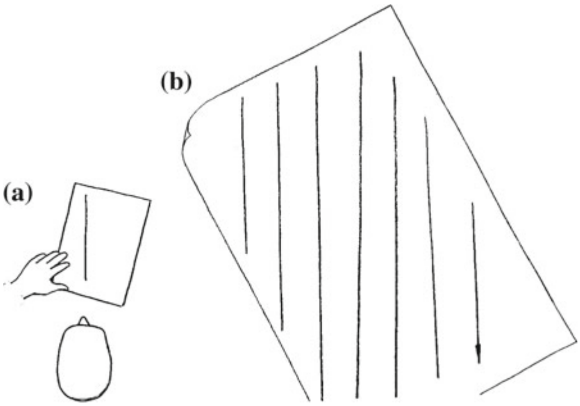


Fig. 2.17 Order of drawing *rectangle* edges—without hand position [4]. Long line should be controlled with two eyes in the middle (**a**), many lines we sketching compared straightness between them (**b**)

paper sizes (Figs. 2.13 and 2.14). In all cases, the paper is rotated so that the actually drawn vertical line is in fact oblique.

Drawing rectangles A rectangle (or a square) is a common shape in technical drawing. For sketching purposes, different techniques and rectangle sizes are used. They can be: large (exceeding 50 mm), medium (20–50 mm) or small (up to 20 mm).

With large rectangles, a technique similar to drawing long straight lines is used, combined with paper rotation (Fig. 2.15). You should become well acquainted with the procedure on A4 or A3 paper sizes. Drawing large rectangles is demanding (body control, paper rotation).

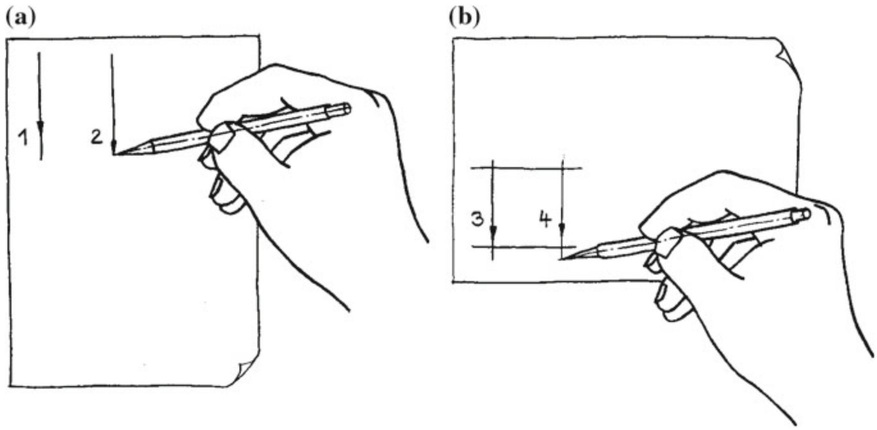


Fig. 2.18 Order of drawing a medium-sized rectangle—with hand position [4]. Drawing medium size rectangles or square: parallel line no. 1 and 2 (**a**), perpendicular line no. 3 and 4 (**b**)

Medium-sized rectangles (between 20 and 50 mm) are a very common feature of technical drawing (Fig. 2.18). They are not as difficult to sketch (body control, paper rotation) as large rectangles. The rotation of the paper can be limited. In the case of changing the sketching procedures or the drawing direction, the drawing technique should also be changed occasionally.

Small rectangles (under 20 mm) are drawn without rotating the paper and the hand. Only the thumb and index finger move (Fig. 2.18). During the drawing, the hand should rest still on the paper. The described thumb and index finger motion allows the drawing of lines of up to 20 mm in length (exceptionally up to 35 mm).

Everything said so far about drawing rectangles also applies to squares, as their angles are the same and the procedure is identical (Fig. 2.19).

The technique of drawing small squares also applies to the shapes that emerge when, for example, oblique lines tangentially meet the radii of fillets (Fig. 2.20). Fillets are first dotted (the distance between the dots is up to 2 mm), and when the straight lines are drawn, the fillets can be thickened.

Geometric shapes without right angles, such as a triangle, a pentagon, a hexagon or any other multi-angle shape, are freehand sketched, following the drawing technique that is used when sketching tools (a set-square, a ruler and a compass) are available. In principle, a shape is designed in the same way as when using the tools according to the rules of descriptive geometry, following the principle that all thin supporting lines are generally grey.

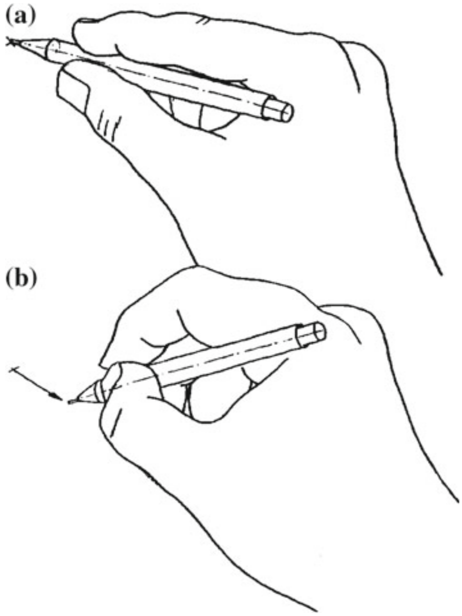


Fig. 2.19 Drawing small rectangles and other shapes with a fixed fist (only the thumb and index finger move) [4]. Drawing small rectangles or square: thumb and defined the line direction into the hand (**a**), direction into the hand (**b**)

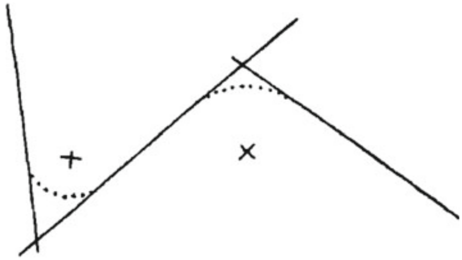


Fig. 2.20 A *dotted shape* before the final shape is drawn [4]

2.3.3 Sketching Curved Lines

Sketching curved lines Curved lines are either circles, arcs or irregular curves. To sketch a circle more precisely, draw the centreline first and mark it with radii. Shape the radii marks into a box, inside which you can sketch a circle.[1] Sketch the top left part of the circle first (draw the pencil in an anti-clockwise direction), followed by sketching the bottom-right part of the circle (move the pencil in a clockwise direction (Fig. 2.21b).

Larger circles require a second pair of centrelines, rotated by 45° relative to the first ones (Fig. 2.21c), due to an increase in the required number of radii marks from four to eight. For example, if you need four arcs (Fig. 2.21a), rotate the drawing paper for the last two quadrants, and sketching an arc is similar to sketching a circle.

[1] This procedure is known as the "boxing" of an illustration or a shape [4].

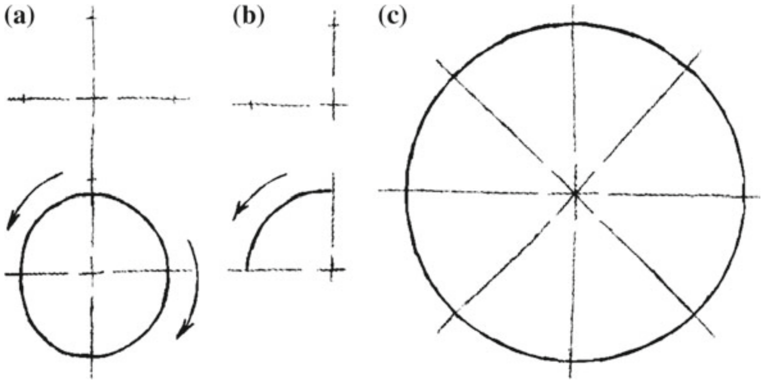


Fig. 2.21 Sketching a circle and an arc [19]. Principles: two arcs for small circle (**a**), sketching arc into clockwise direction (**b**), larger circle with eight arcs (45 degrees) (**c**)

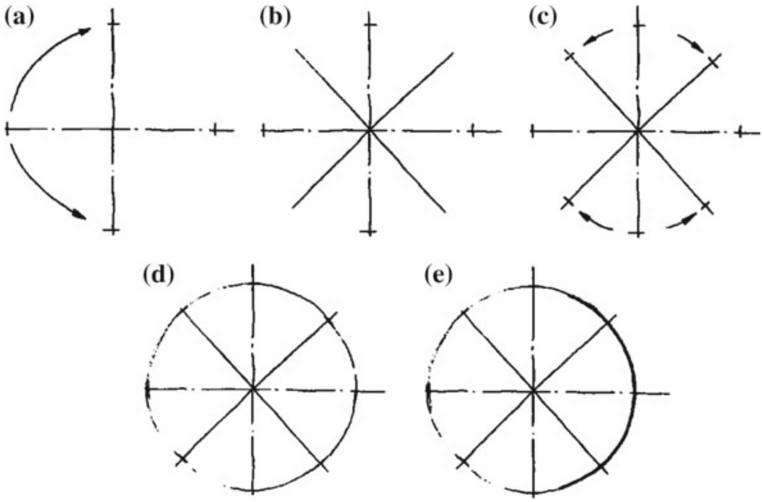


Fig. 2.22 The centre method's five steps for the freehand sketching of a circle. Steps: two perpendicular centre lines (**a**), rotation for 45 degrees perpendicular centre lines (**b**), radii dimensions transfer to all eight centre lines (**c**), first arc sketching (**d**), finalization with all arc the circle line (**e**)

The orientation and size of the arcs depend on the skills of the drafter. For medium and large arcs, it makes sense to draw centrelines and radii marks.

Sketching a circle is also referred to as the "centre method" (Fig. 2.22). It is similar to the above-described procedure in Fig. 2.21, with the difference being that the parts of the circle are sketched gradually, i.e., part by part. If the circle is of a short radius (under 50 mm), you can begin with the first phase and procedure from Fig. 2.23, while for larger circles (exceeding 50 mm) you should begin with the second phase.

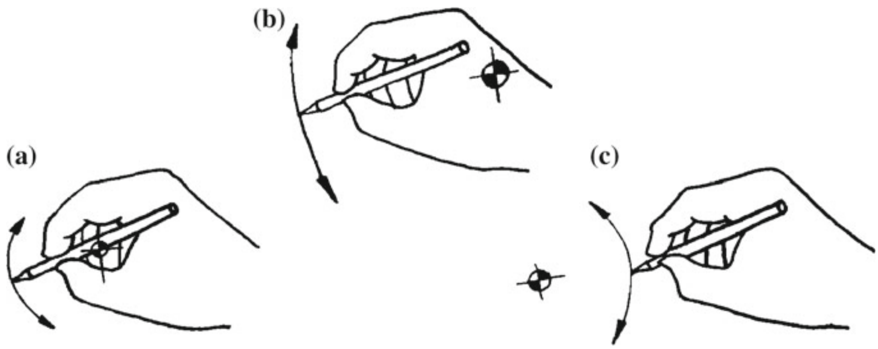


Fig. 2.23 Right (**a**, **b**) and wrong (**c**) positions of the fist, relative to the centre of the fillet when drawing a circle and an arc [4]

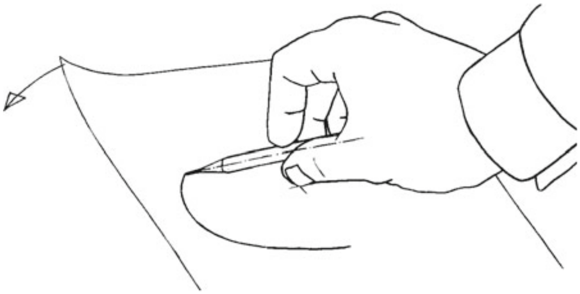


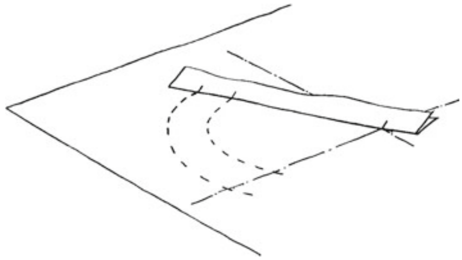
Fig. 2.24 Hand as a compass [4]

The hand can be used as a compass to draw lines of radii between 50 and 200 mm and their corresponding arcs (Fig. 2.24). Lean the part of the hand closest to the wrist against the paper, hold the pencil with the thumb and index finger and hold it in a position that corresponds to the required radius.

For all the movements on the paper, the hand should be clean and dry. Rotate the paper anticlockwise with your left hand, while the pencil and the hand remain motionless. This method allows the drawing of concentric circles. As a compass for marking dashed concentric circles or just circles, you can use a folded piece of paper with the appropriate marks, as shown in Fig. 2.25 or 2.27. Such thin circles can then be freehand thickened.

Sketching irregular curves Irregular curves are those without a specified radius of curvature. Sketch them with the strokes of a pencil that suit you best. Begin by drawing very narrow or light lines to sketch the background to produce the exact shape, followed by drawing wide and heavy lines for the final drawing of an irregular curve.

Fig. 2.25 "Paper compass" [4]



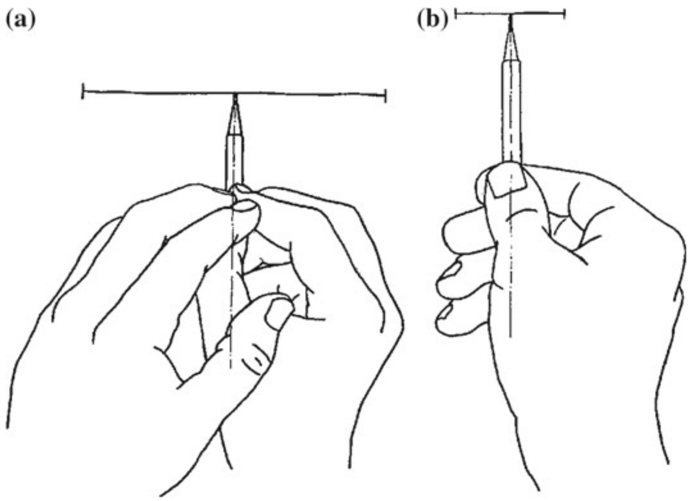


Fig. 2.26 Symmetry, judged with the fist and a pencil [4]. Long line with both hand (**a**), short line with one hand (**b**)

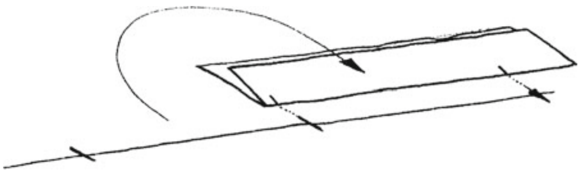


Fig. 2.27 Carrying an identical distance with paper [4]

Sketching grids Some drawing papers include printed sketching grids of narrow, usually light-blue, lines that can be of great assistance to drafters (Fig. 2.27). They usually come in the shape of a square or an isometric grid. A special case is a grid of thin, light-blue lines or dots, printed on transparent paper or a special drawing foil, which is very useful for drafters. Using the grid, it is easier to make clearer, freehand sketches.

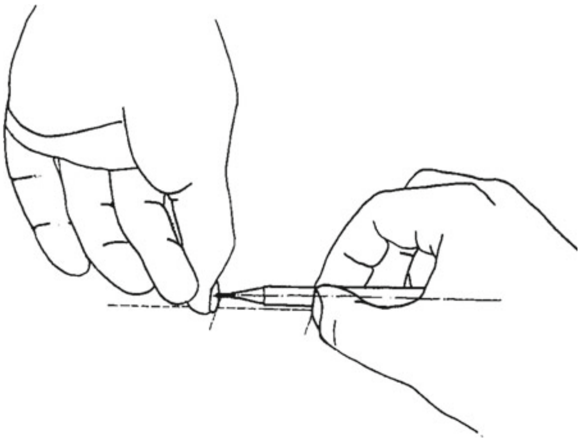


Fig. 2.28 Carrying an identical distance with a pencil and the *left* thumb [4]

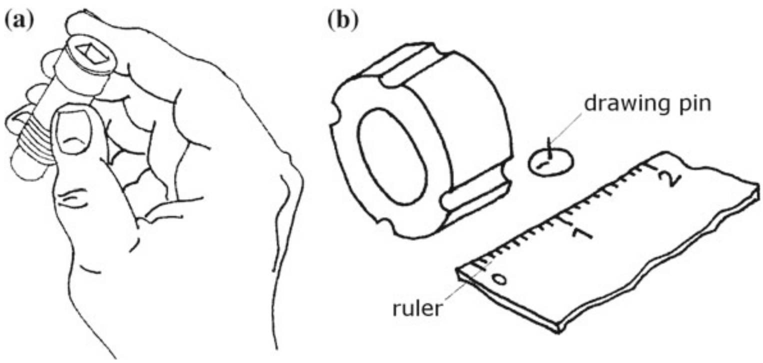


Fig. 2.29 Relative proportions of small objects can be shown by drawing them in the hand (**a**), or next to a familiar object, or a ruler (**b**) [10]

When you need to carry an identical distance and to maintain proportionality more easily, you can make use of a piece of paper with a mark on it (Fig. 2.27). Another option is shown in Fig. 2.28.

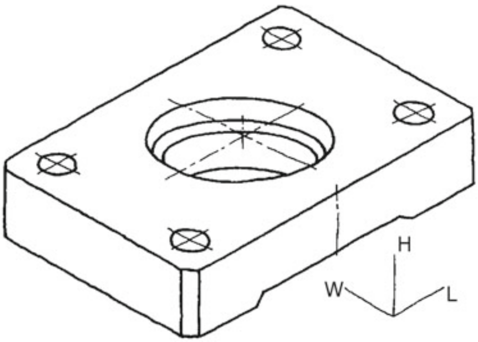
Sketching small objects with the hand and recognized proportions Small objects are sketched by taking them into your hands, and—by comparing their dimensions—carrying out proportional dimensions. Sketches often fail to provide an impression of the size of an object, especially when sketched without their dimensions. An impression of the size can be given by showing a hand, holding the object that is being observed (Fig. 2.29a). Instead of a hand, you can use other recognizable objects, such as a pencil or a ruler (Fig. 2.29b).

2.4 CAD and Technical Freehand Sketching

Having acquired the requisite sense of space, the designer can create the image of an object in his or her head, in abstraction. Based on a clear image in the mind, the idea is transferred onto the paper. When lacking the necessary feeling, a beginner should first sketch different models. The reader of the sketch should also acquire a sense of projection and recognize the rules of technical drawing and the sketching of realistic models. Those who use a sketch for modelling should acquire the wholeness of the model from the sketch. They should recognize the object in a 3D environment.

The sketching of models is, therefore, a skill shared by all engineers. Sketching is a process where individual phases follow one another in a particular order. But by not following individual sketching phases, gaps remain in the presentation space, i.e., there are indeterminacy of proportionality, inappropriate orientations of some shapes and the poor orientation of the lines of the product itself. Each phase of the process is therefore of great help in managing the sketching space. Below we will present a procedure for freehand sketching that is used for 2D product presentations. It is applied in the order shown in Figs. 2.30, 2.31, 2.32, 2.33, 2.34, 2.35, 2.36, 2.37, 2.38 and 2.39 [35].

Sketching procedures can be different. They are recognized by the different numbers of tasks or phases. For an easier understanding, they will be presented in one table, where the characteristics of individual phases are described (Table 2.1). The best known is procedural sketching with ten working phases (Figs. 2.30, 2.31, 2.32, 2.33, 2.34, 2.35, 2.36, 2.37, 2.38 and 2.39). The phases are precisely defined, which makes the procedure better suited to a beginner. A shortened procedure, known as stroke sketching, suggested by some other authors, has only five phases (the figures,



Name and main dimensions	Pos	View definition	Ortho. proj. by view and present.	Space present.	Simetric	Material
Basic plate 75 x 50 x 15	1		f.e. T	I	2x	S355J2G3

Fig. 2.30 First sketching phase. Figure shows a product and a handy working plan table

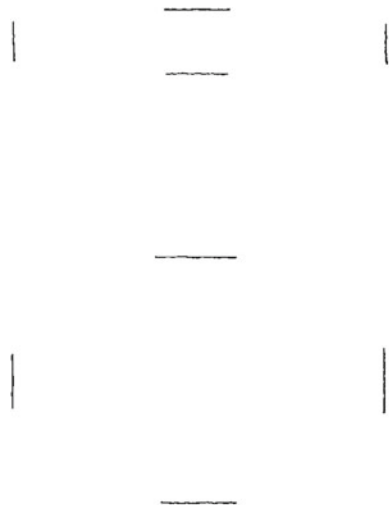


Fig. 2.31 Second sketching phase [10]

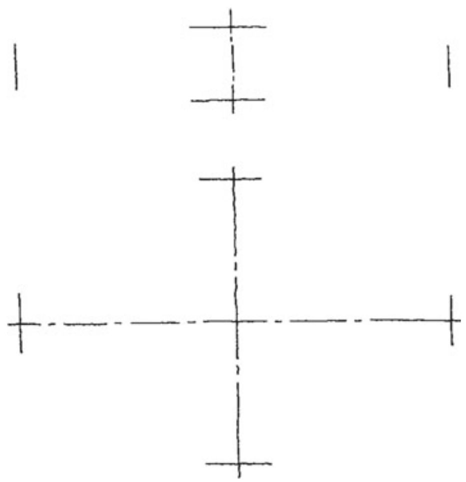


Fig. 2.32 Third sketching phase [10]

linked to the procedures from Table 2.1). For both procedures it is important never to erase the supporting or construction lines. Erasing or wiping is used in sketching only in the case of drawing mistakes. In no case should erasing be used for the lines that are procedurally required to determine the sketch.

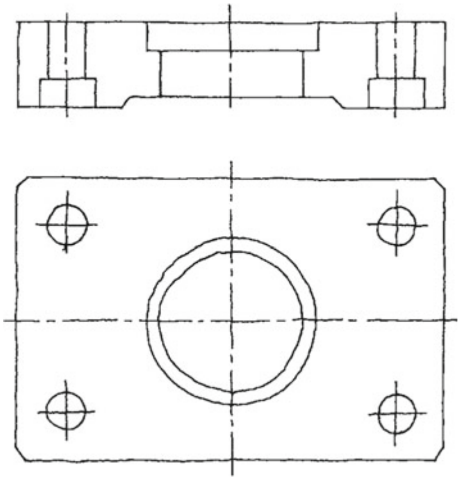


Fig. 2.33 Fourth sketching phase [10]

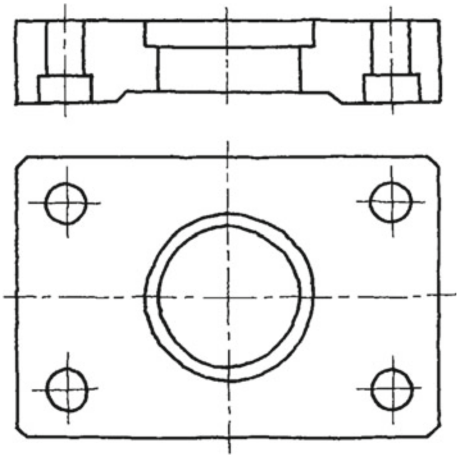


Fig. 2.34 Fifth sketching phase [10]

2.4.1 Procedural Sketching

Procedural sketching is used when dealing with an object that requires a detailed specification of all the details because of its size and complexity.

First sketching phase (Fig. 2.30) is intended to specify the positions of the objects to be drawn and the number of required projections to verify the possible symmetry of the object and to decide whether to draw a cross-section and how the dividing planes will run. All these data should be input into the working plan of the technical documentation (planning table, Fig. 2.30).

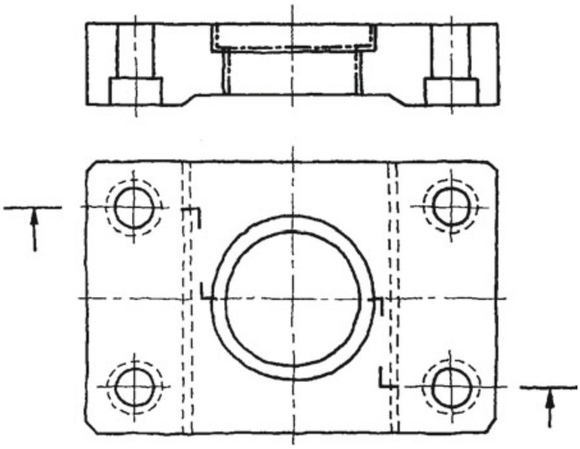


Fig. 2.35 Sixth sketching phase [10]

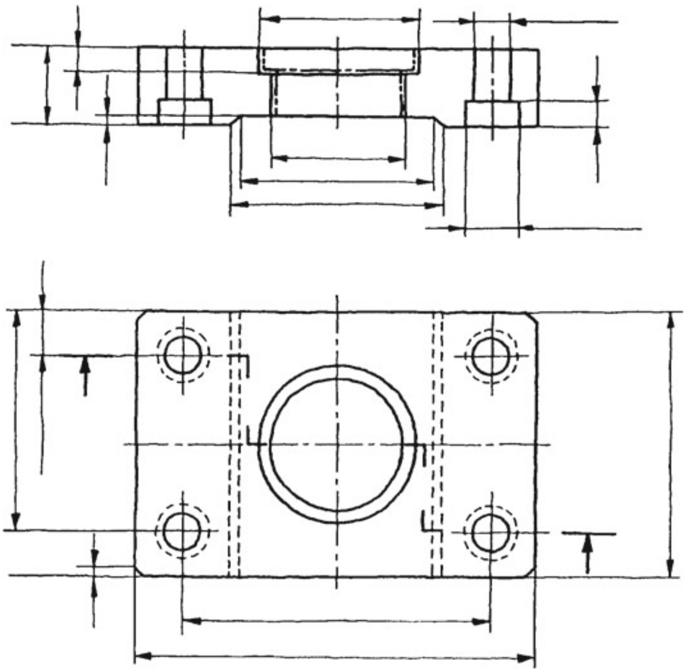


Fig. 2.36 Seventh sketching phase [10]

Second sketching phase (Fig. 2.31) is to verify the size of the space where the objects will be drawn, in order to be able to put all the projections, planned for the first phase on the same piece of paper or the selected format. It requires choosing a unit or deciding the size for 1 cm and specifying the dimensions of the object for

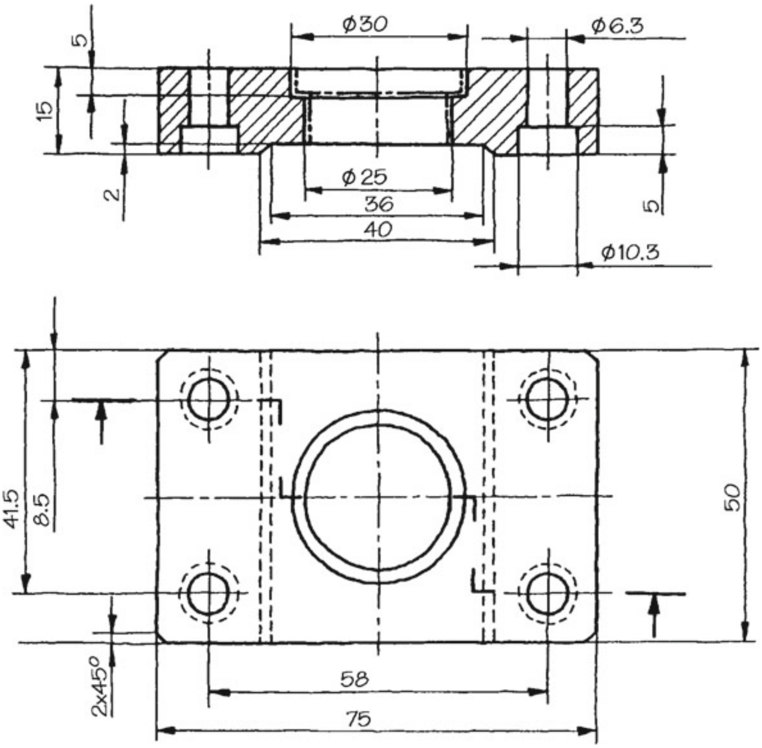


Fig. 2.37 Eighth sketching phase [10]

each projection, whereby you should take account of the dimensions that are visible in particular projections. You should save space for the dimensions and the drawing projections with a sufficient distance between them.

Third sketching phase (Fig. 2.32) is drawing the main bisectors with a hard pencil in all the projections where the object is symmetrical.

Fourth sketching phase (Fig. 2.33) begins with drawing the shapes of the object with thin lines. Start drawing the object with bisectors pointing outwards, dividing it in your mind into the basic geometrical shapes. Begin by drawing all the visible contours and edges in all the intended projections, drawing in each projection the most important part of the object, followed by the details.

Fifth sketching phase (Fig. 2.34) begins once the shape of the object has been drawn with thin lines in all the projection planes. In this phase, thicken the visible edges with a soft pencil of appropriate width. High precision is paramount.

First, draw the circles and fillets, followed by other lines. Begin with horizontal lines from the top to the bottom in all the projections and continue with all the vertical lines from left to right in all projections, finishing with all the oblique lines. During the process, correct all the minor errors in terms of matching and parallelism. There is no need to erase the thin lines in the corners.

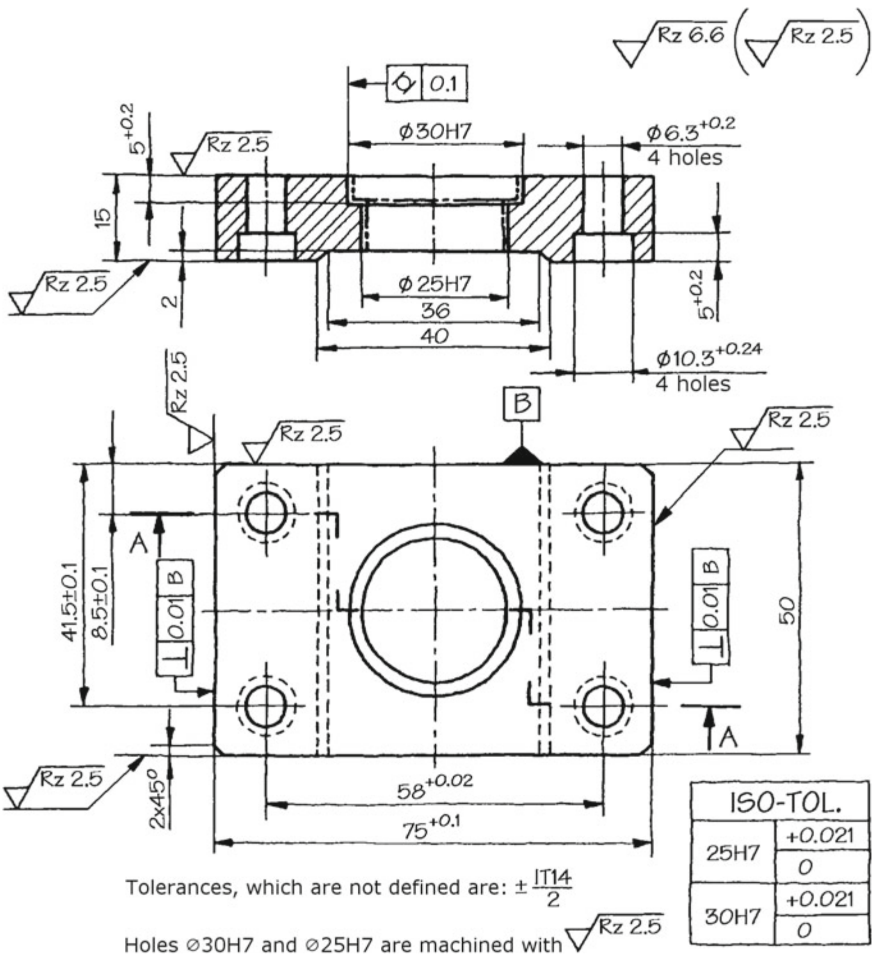


Fig. 2.38 Ninth sketching phase [10]

Sixth sketching phase (Fig. 2.35) follows once the visible edges have been thickened. In this phase, draw the invisible edges when they exist and continue by drawing the cross-section lines with a pencil of medium hardness and suitable thickness. This is followed by finishing all the other details of the object shape and marking, in order to achieve the required distinction between the importance of the individual lines, i.e., using lines of at least two thicknesses.

Seventh sketching phase (Fig. 2.36) is about adding blind measuring lines. Dimensioning rules prescribe the insertion of blind measuring lines, i.e., dimensions without numbers and symbols, in the order required by the manufacturing personnel for each working phase. Draw the supporting dimensioning and measuring lines

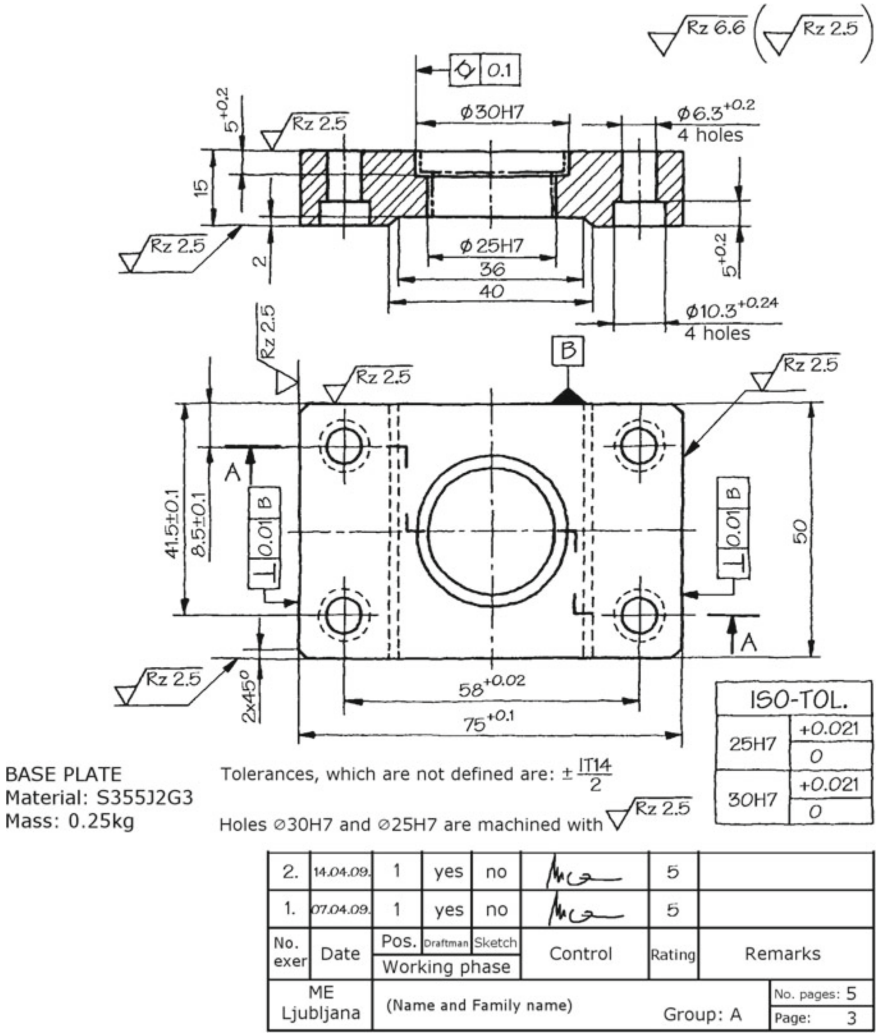


Fig. 2.39 Tenth sketching phase [10]

with a pencil of medium hardness and suitable thickness, and the arrows, with a soft pencil.

Eighth sketching phase (Fig. 2.37) follows once all the blind dimensions have been set and properly distributed. This is followed by measuring the object and inserting the dimensions. Real numbers are rarely inserted as the numbers are usually rounded off to whole numbers, to 0 or 5 or just 0. The angles must be checked during this phase. Next to all the angular dimensions insert the necessary special characters, such as the circular shape sign Ø.

Table 2.1 Activities for individual sketching phases

Phase no.	Procedural sketching (PS)	Stroke sketching (SS)	Notes
1	Position of objects, projections, cross-sections, dividing planes	Defining the position of objects, drawing criteria, main and supporting bisectors of the object	Phases 1, 2, 3 of PS, combined in SS
2	Spatial definition of a drawing, scale unit, position of views	Drawing visible and invisible edges with thin lines	
3	Drawing the main and supporting bisector in views	Drawing special shapes in the order: small circles, large circles, small arcs, large arcs and irregular curves	
4	Drawing the vital contours of the object in all views	Thickening visible and invisible edges to make the object recognizable	
5	Thickening and intensifying all contours, beginning with circles, followed by lines. Thin lines are not erased. All visible edges are drawn	Dimensioning, writing tolerances, processing, special instructions, drawing the main image, inserting notes for technological procedures, final form of the drawing	
6	Drawing invisible edges to improve the imaginability of the object		
7	Drawing all the dimension lines without values (drawing the values follows the sequence of technological operations and procedures)		
8	Inserting dimensions for dimension lines, dimensioning the object		
9	Inserting tolerances, special instructions and processing, hatching		
10	Equipping the drawing with the header, other marks, edges, etc.		

Ninth sketching phase (Fig. 2.38) includes inserting the units of length and shape, the position tolerances, the surface roughness, the marking and denoting the cross-section planes, inserting the necessary instructions and all the other data. This is followed by hatching of the cross-section areas, paying attention to not drawing over the numbers and the text on the drawing.

Tenth sketching phase (Fig. 2.39) is the last phase, i.e., the phase where the freehand sketching is completely finished. This phase includes filling in the parts list, the drafter's name, and—in the case of an assembly—also the position number within the assembly drawing.

2.4.2 Stroke Sketching

Some authors [20] suggest that it is possible to merge these ten phases of sketching 2D drawings into just five phases. The individual phases are defined in Table 2.1 and combine the individual phases of the ten-phase procedure, especially the first part. Stroke sketching is recommended for experienced designers.

Practising is the most important part of sketching. Courses that include sketching exercises have different names. Their common names are sketching, technical drawing, modelling, space modelling, etc.

In the case of computer space modelling, the working method with a pre-printed table is particularly recommended. This is a reliable way of introducing a beginner to the development process, from product abstraction to a digitised product model.

2.5 Sketching Spatial Drawings

The easiest way to present the shape of an object is with a spatial drawing, as this makes it possible to also present complex details or knots. In Europe, this method is very rarely used, while in the USA, it is very common. In all cases of spatial views, generally originating in an orthogonal projection, it is first necessary to determine a coordinate system and the direction of the main width and height axes. For spatial sketching, an isometric projection is the one most frequently used. In isometry it is very easy to present cylindrical objects or the details of a cylindrical shape. With cylindrical shapes being the most common ones in mechanical engineering, isometry has emerged as the most suitable way. But before deciding for a spatial view, you have to first check all the surfaces, define their dimensions and then draw them according to the coordinate system.

A course of sketching free-form surfaces is prescribed and depends on the shape of the object. One course is suitable for rotational parts, while the other is more suitable for parts made according to the principle of free-form surfaces. These parts and products include intermediate products, castings or pressed parts.

Let us first take a look at the process of sketching cylindrical, rotational objects. With rotational objects (see the example in Fig. 2.41) and freehand sketching, follow the working phases below [35]:

First sketching phase Draw the object's main centreline, define the distances and draw the conjugate diameters, according to the coordinate system. Continue by specifying the size of the end surfaces' conjugate diameters, relative to the actual

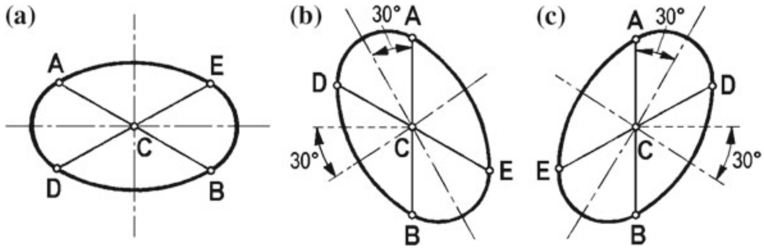


Fig. 2.40 Sketching the isometry of a rotational object. Two conjugate diameters defined centre lines for ellipse (**a**), isometric view of ellipse (**b**), opposite circle by isometric view (**c**)

dimensions, and the drawing scale. It should be pointed out that isometric sketching does not strictly follow the use of standard scales.

Second sketching phase Using thin lines, begin by designing the final ellipses. Usually, not all the lines that are required for a design are drawn. The simplified design approach is applied. In terms of designing, bear in mind that the centres of ellipse arcs are in the upper plane, on the horizontal and vertical axes. The side ellipses are designed by inclining their centrelines by 30° to the left and right, respectively, relative to the vertical line (Fig. 2.40b and c).

Third sketching phase Draw the remaining conjugate diameters at suitable distances according to the drawing scale. Using a thin line, draw concentric and other ellipses.

Fourth sketching phase Using thin lines, finish the presentation of the object. Connect the ellipses, draw slots, bores, fillets, ribs, nuts, threads and roughly specify the depths and all other details. In this sketching phase you often need to specify the visible and invisible parts of the object.

Fifth sketching phase Thicken the visible parts of the object. Using a dotted line, mark the invisible parts of the object (invisible edges) that significantly contribute to a clear view of the object in all its details. It should be noted that faithfully abiding by sketching rules will result in the thin lines not obscuring the clarity of the spatial view. By not following the sketching principles and drawing lines with the wrong thicknesses means you will have to erase the thin lines as they will not be easily distinguished from the heavy, dark ones. It is typical of freehand sketches that invisible edges are very rarely shown.

2.5.1 Presenting a Half Cross-Section

When for clarity reasons you want to show the inside of an object, cut out a quarter (1/4) of the object along its length x and width y (Fig. 2.42a), or half (1/2) of the object along the length x (Fig. 2.42b). When round surfaces are not in the direction of the object's dimensions, determine their centrelines and the approximate positions of

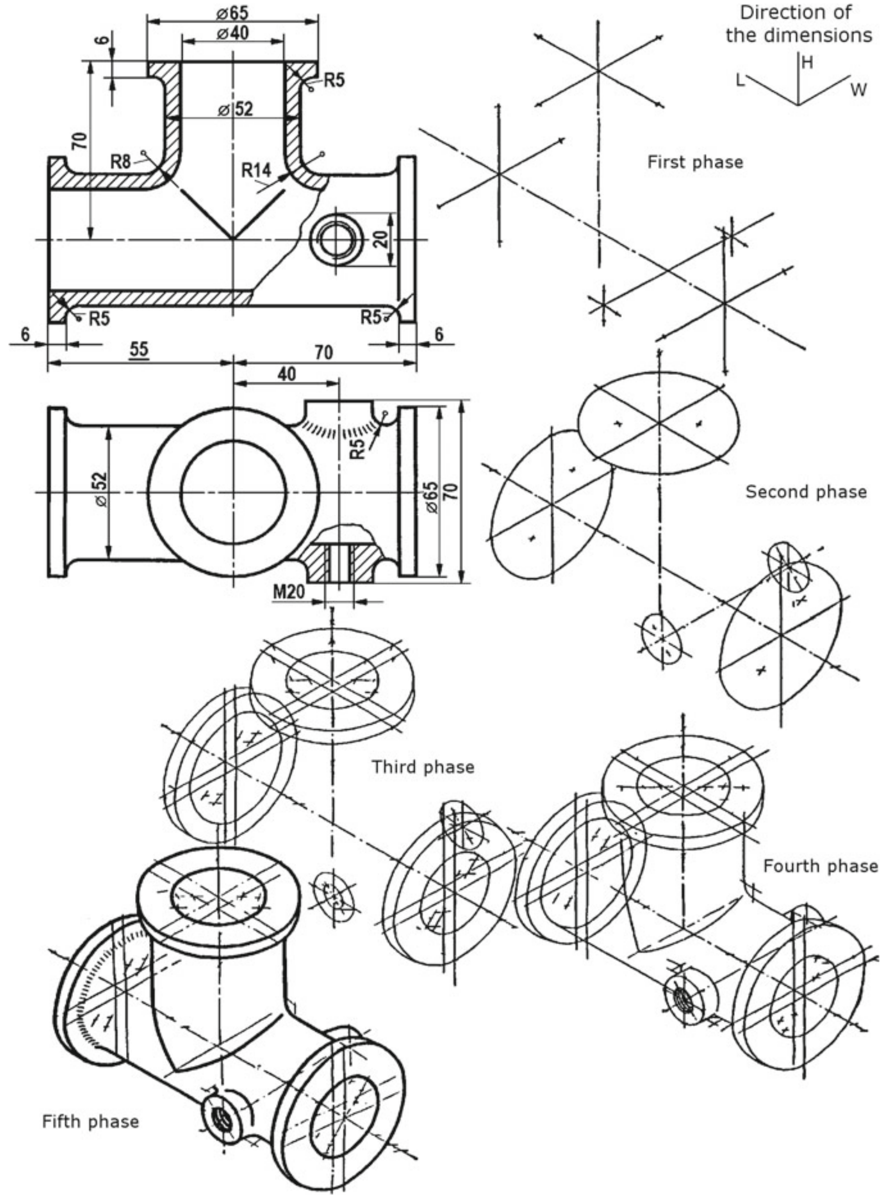


Fig. 2.41 Sketching the isometry of a rotational object [10]

the surfaces, relative to the part of the angle in reality, by dividing the corresponding angle in the isometry in the same direction.

Non-rotational objects (Fig. 2.43) are sketched in the following sequence:

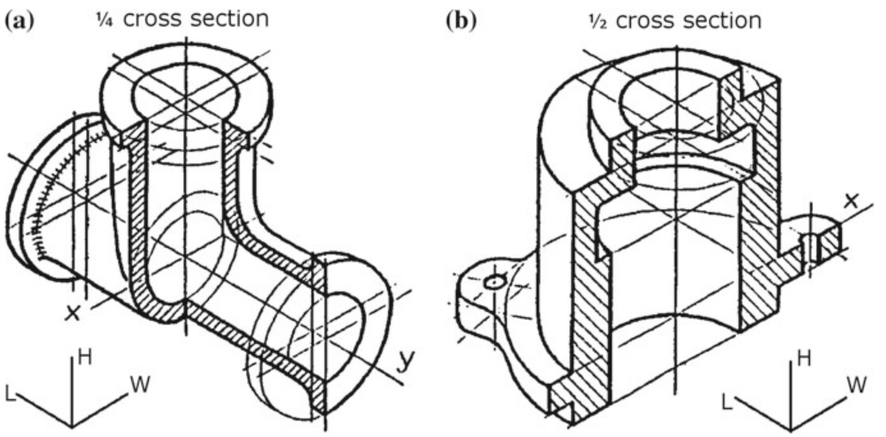


Fig. 2.42 Quarter (**a**) and half (**b**) cross-section in spatial view—isometry [10]

First sketching phase Using thin lines, draw the basic, unrounded shape of the object (rough shape of the object).

Second sketching phase Insert conjugate bore diameters and draw fillets, matching real dimensions.

Third sketching phase Design ellipses or parts of ellipses, if necessary.

Fourth sketching phase Using thin lines, finish the shape of the object by drawing the side parts (cut-outs, cut-ins, ribs, concentric ellipses, visible due to wall thickness, etc.).

Fifth sketching phase Thicken all visible edges. Using a dotted line, also thicken the invisible edges that contribute significantly to the image of the product. It should be noted that spatial views only show invisible edges in exceptional cases, and this is the key difference between 2D and spatial views.

Drawing in isometry is difficult for beginners, who get lost in the sheer number of lines and do not follow closely the dimension plan. For this reason, it is recommended to do exercises in drawing those elements that appear more frequently as structural elements in sketching.

Repeat the exercises by sketching these elements in different positions and views. So, it is recommended to do exercises in drawing frequently occurring elements (except round surfaces) in different positions. Referring to Fig. 2.44, they include [24, 35]:

(a) When drawing a hex nut in different positions in isometry, the following is important: the diameter circumscribing the nut, the spanner opening and the parallelity of the nut surfaces with object dimensions. In the direction of one dimension are the tops of the edges on the ellipsis, representing the nut-circumscribing diameter. In the direction of the other dimension is the spanner opening. The nut edges are parallel to the first dimension, i.e., the joining line of the tops. Using the conjugate nut-circumscribing diameters, design an ellipsis, specify the tops of a

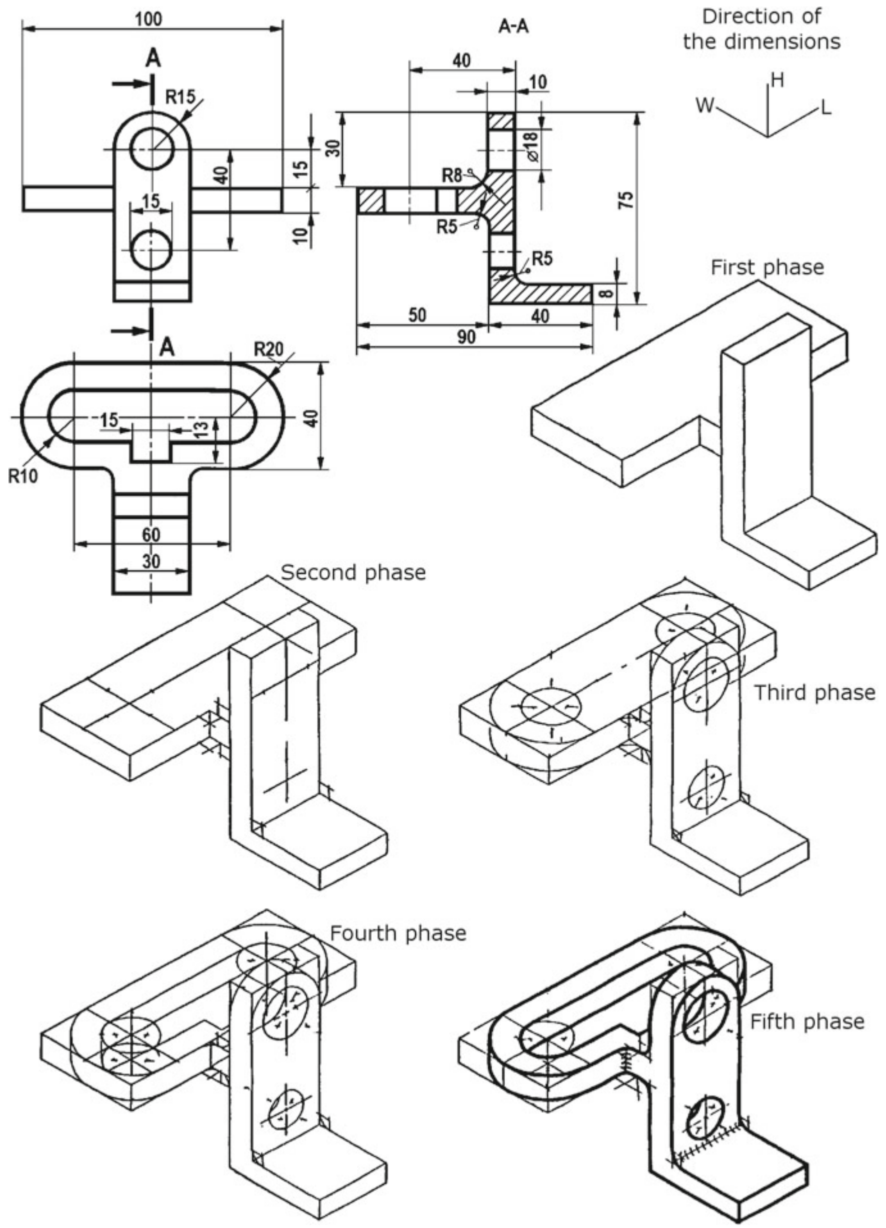


Fig. 2.43 Sketching the isometry of a non-rotational object [10]

hexagon, insert the spanner opening *s* onto the other dimension and specify the hexagon. Continue by specifying the thickness (height) of the nut in the direction of the third dimension and the parallel drawn surface. Drawing nut chamfering is approximate. Follow a similar procedure to draw an octagonal nut.

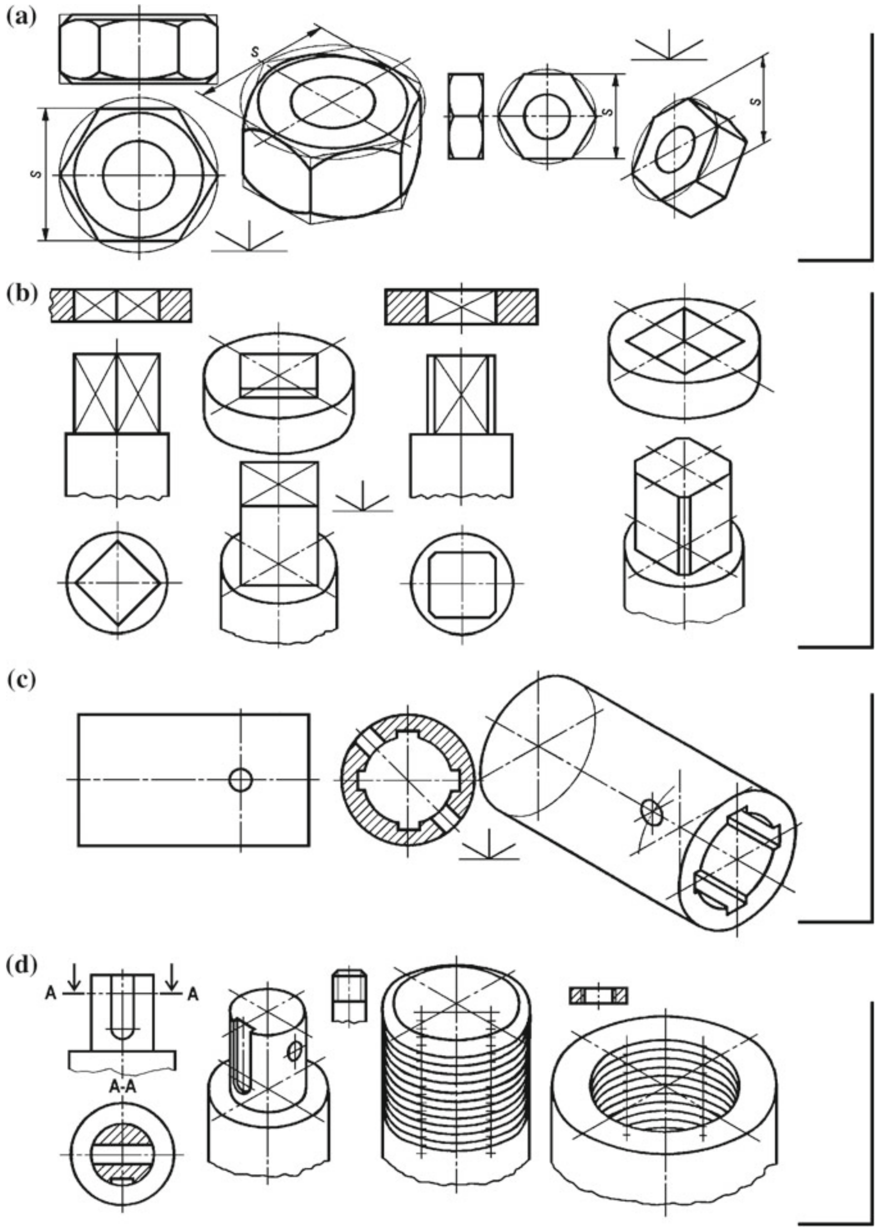


Fig. 2.44 Isometric view of the most frequently used elements (**a**—hex nut, **b**—four-sided extensions and holes, **c**— slots, bores and **d**—threads for nuts and bolts) [24]

(b) In isometry, four-sided extensions and deepenings are rotated from a rectangular projection. If there are two rectangular solid surfaces visible in a rectangular projection, there is only one visible in isometry and vice-versa. This originates in a proper observation of the dimensions and the proper use of the dimension plan, as shown in Fig. 2.43.
(c) In isometry, slots and bores are placed relative to the axis position; not in the same positions, however, but by sight, like in a rectangular projection. It is vital to have a good vision of which dimensions of such parts are visible and which dimensions they are parallel to. They are inserted in isometry with their actual distances and sizes, relative to the orientation of the main dimensions.
(d) Drawing thread for an explicit view in isometry follows the approximation procedure. Each groove is shown with an equidistant ellipse,[2] and the space between the ellipses matches the thread pitch (or approximately if the pitch is small). Because all these ellipses have identical radii of curvature, it is necessary to draw parallel lines into all three centres of the ellipse arcs, insert distances and draw the arcs one by one.

We have presented all the elements that are important for an engineering view of the environment.

It should be noted that sketching is not just a matter of engineering but also serves as a basis for other human expressions, such as art. The message of an artistic sketch is based on the metaphysics of the artist's cognition of the world, so an artistic sketch conveys a different message. In both cases, proficiency is represented by the creativity of a creator, so the expressing exclusiveness of the respective creations (engineering and artistic sketches) is unique to each creator. It also shows how important an engineer's sketch is.

It is possible to transfer models from the analogue into the digital world, managed by a computer. When it is about a complete relocation of a technical system in the real world, pure scanning, this transition is possible. Namely, dimensionally or proportionally the same space is used [7].

In practice, engineers' inferior skills are recognizable by many models of technical systems being developed without a sense of proportionality. During the last decade (up to 2009), a good example of this argument is often seen in an imperfect understanding of the space inside and under the bonnet, in the headlight area. Such a treatment of space and not understanding proportionality often results in difficult bulb replacements in some headlights.

[2] Equidistant ellipse.

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