I. Methods of Depicting and Dimensioning Shape on a Drawing

FROM THE TIME that the first man made crude drawings on the walls of his cave to the present day, his technique has gradually improved. He has, however, always been limited to the flat plane of his paper or other medium of expression of his ideas in line. In modern drafting in this country, three methods of depicting the shape of an object are in vogue: Perspective, Isometric, and Three-Angle (or Orthographic) Projection. In viewing any ordinary cubicle object, from whichever angle we look at it, we can see no more than three of its sides. We can, however, on a single piece of paper, show more than one view, and are thus enabled to depict the object from all sides.

Perspective drawing shows an object just as the human eye would see it. Parallel lines on the object appear to eventually come together, just as we would visualize a straight railroad track running across a level prairie. Perspective drawings are the kind we see in an etching or painting, and have the disadvantage of not being measurable to obtain accurate dimensions. They do, however, show more than one side of an object, if the drawing is made from the proper angle of vision.

Isometric drawings are similar to perspective in that more than one side of an object can be shown on the same drawing. They are produced with one side being drawn to a 30° angle from the horizontal to the right of a vertical corner, and the other side to a 30° angle to the left. All measurements of width for an end are laid off on one of the 30° lines, and measurements for length on the other. All measurements for height are made vertical. Thus at any place on the drawing (provided that the measurement is taken in any one of the three angles) true dimensions can be measured.

In Three-Angle Projection, a separate drawing is made for any view desired. The most common construction of the three-angle projection, is to draw the plan view just as we would see the object as viewed when we look directly down on it. The drawing is made with all horizontal dimensions shown as true measurements, and no effects of [illegible]spective are taken into account. PLATE 1, Fig. 1—A vi[illegible] of the right-hand end of the object is drawn to the right of the plan view; and if a view of the object's left-hand end is necessary to show some special feature, this is [illegible] the left-hand side of the plan. The front view is pro[illegible] below the plan view, and if another view of the opposite side is necessary, it is drawn inverted above the plan view. In some European countries, the reverse of this practice is common, and in this country these reversed views are spoken of as "Dutch projections." Views other than the plan are called "elevations." The front view is sometimes called the Profile.

In the depiction of curved surfaces of varying contour, it becomes evident that outline shape only can be shown in projected views. Some means must be devised to show the shape that cannot be shown by outline alone. If we were to cut a slice from a perfect sphere in any direction, we would get a flat surface bounded by a perfect circle. If we were to do the same with a cube, we would get a square or parallelogram depending on the direction of the slice. We thus see that a plane cut through any object will depict the shape of the object at that point. A series of these slices or planes cut through an object will give the shape at any point, much in the same manner as slices through a hard-boiled egg will give varying shapes, all of which when assembled will produce the shape of the egg.

Early in the art of shipbuilding, models were made of layers of wood running parallel to the water line. When taken apart, the boundaries of these layers gave an excellent idea of the shape of the ship at those particular levels of water lines, thus, when the art of drawing ship's lines developed to the present perfection, these levels were spoken of as waterlines. In the aeronautic industry the term is still sometimes used, as the method of employment is the same. At other times they are spoken of as level lines or horizontal sections. As this book has been written for both the ship and airplane loftsman, and there must be some standard of reference, the boundaries of all horizontal sections will be spoken of always as waterlines.

Similar to the waterlines are the vertical longitudinal sections. In early shipbuilding they were referred to as bow lines and buttock lines. The bow lines show the shape forward—the buttocks, the shape aft. Today the word "bow line" has disappeared from the shipyard drafting room and loft. The word "buttock" is used to describe all vertical sections, and will be so used all through this book.

Often a waterline or buttock will not adequately show the shape of a particular desired point, and here a diagonal plane is cut through the object. This plane is referred to as a diagonal.

So far, we have dealt with longitudinal sections. These, while giving us a very complete picture of longitudinal shape and contours, do not give us shape in the transverse direction. This is obtained by the process of cutting transverse sections through the object which are called "frame" or "station" lines. The entire collection of waterlines is referred to as the "Plan" or "Waterline Plan," the collection of buttocks as the "Profile," and the end views showing the frame lines or transverse sections are called the "Body Plan" (Plate 11).

Plate 2 shows the lines of a small motor boat with one waterline, one buttock and one station taken off from the main body lines to show how these planes are cut through the hull. At the left-hand side of the plate the top of the hull has been removed to show the shape of a waterline. Above this the rear portion of the hull has been removed to show the shape of a station; at the right-hand side of the plate a portion of the hull has been cut away on a buttock plane to show the shape of this feature. All of these planes have been assembled in the center of the drawing so that each plane can be seen in its relative position through the solid hull.

All drawings of shape are originally made on a reduced size or scale. This scale is a direct proportion of the full size object, and different fractional parts of an inch are used in this country to draw the representation of the actual size of the object, for instance, we could use one inch on our drawing to represent a foot on the full size object. Thus our drawing would be one-twelfth actual size. The conventional scales in use in engineering work in this country are: one-eighth inch, one-quarter inch, one-half inch, one inch and the series of three thirty-seconds, three sixteenths and upward to three inches equalling one foot. Some aircraft plans are made to half size, or six inches to the foot, and where small detail is involved they are laid off full size, and even twice or four times full size.

Where the scale is small, it is evident that a small error on the drawing is greatly magnified when the full-size object is laid off from a measurement taken from the plan. Thus, if

-THREE ANGLE & ISOMETRIC PROJECTION ~ PLATE 1~

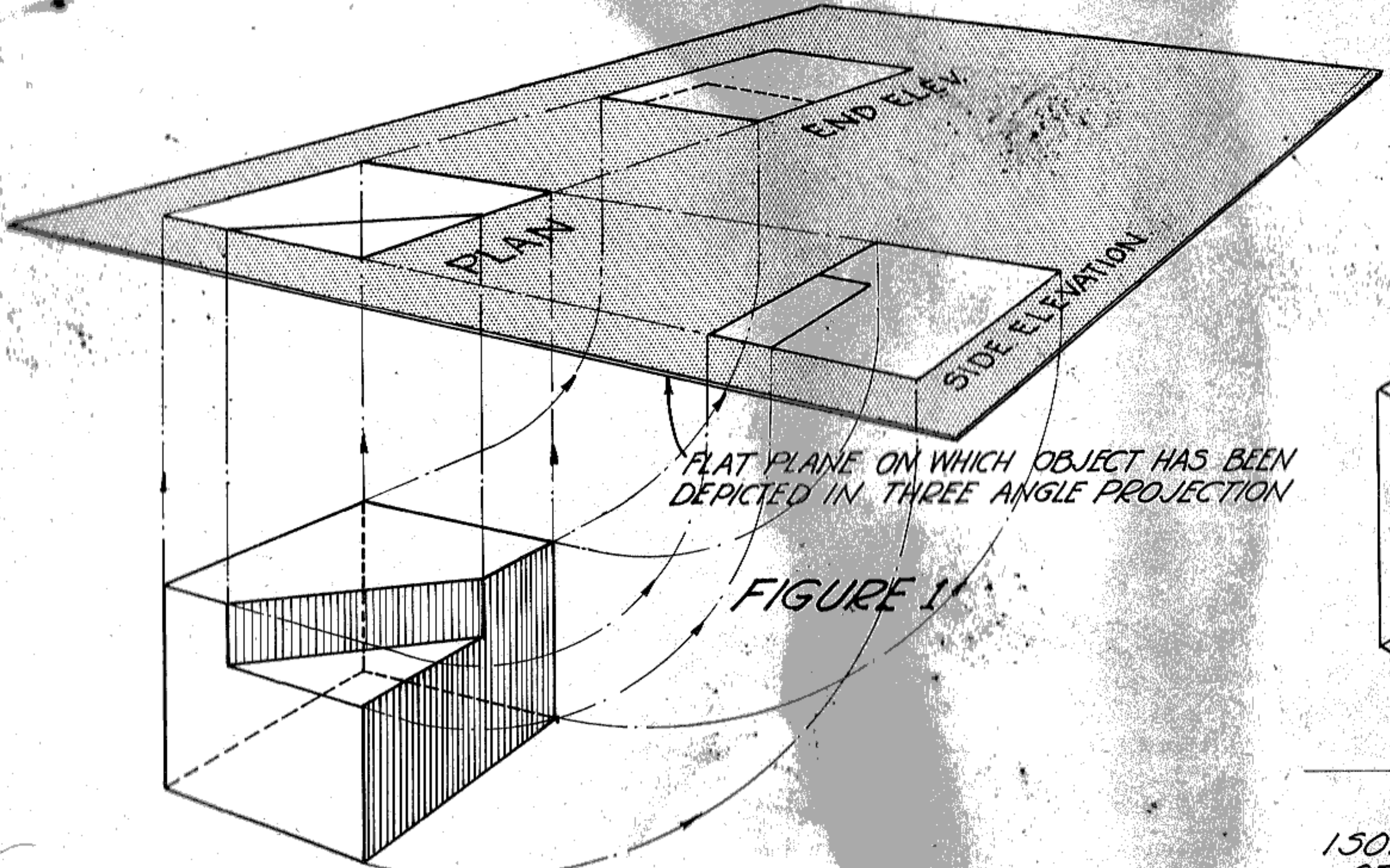
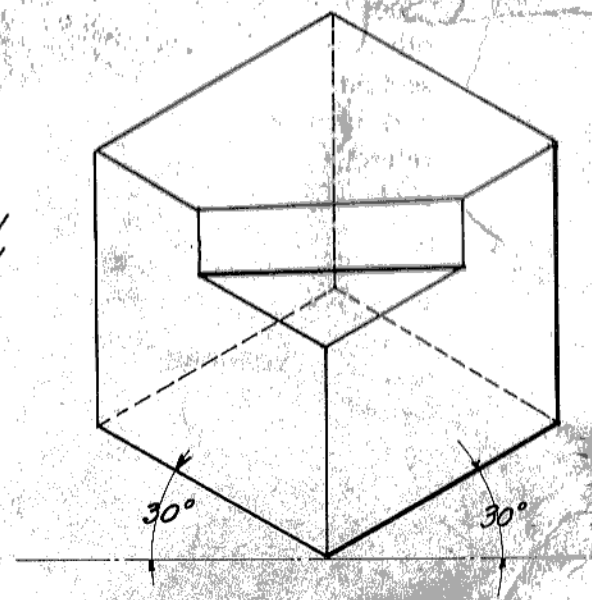


FIGURE 1

PERSPECTIVE DRAWING OF OBJECT.



ISOMETRIC DRAWING
OF OBJECT IN FIG. 1

the scale is one-quarter inch to the foot, an error is multiplied forty-eight times. From this it becomes evident that in curved surfaces the errors thus made in measurements for contour will be sufficient to produce unfair lines. These errors must be corrected in some manner, and this process is called "fairing," which will be taken up later in this book. From the foregoing it is also evident that all small-scale drawings must be made with extreme accuracy to avoid large errors in the full-size layout.

In the three-angle projection method of depicting shape, there are often contours which do not show on the surface of [illegible] [illegible]ect. For instance, a hole through the object might only ap[illegible] [illegible] in one view. Man has devised an ingenious method of showing these parts of an object which do not appear to his eye. On his drawings he visualizes these hidden parts by the use of dotted lines lighter than the outline of the object, thus allowing him to show on the drawing in phantom that which is nonexistent to his sight. If we were to view a cylindrical bar, we know that it has a center running its full length. Actually we cannot see this center, but on a drawing we can show a dot-and-dash line to represent it. Again, on looking at the bar we cannot see its length, but on a drawing of this same bar we can install dimension lines which will tell us that the bar is so many inches long. This dimension line is placed parallel to the length of the bar between projection lines run off the actual drawing of the bar. Arrow heads at the ends of this line tell us that it is a dimension line, and the figure between these arrows denote the dimension. We can also, on the same drawing, denote the diameter of the bar with dimensions in the view where the diameter is shown.

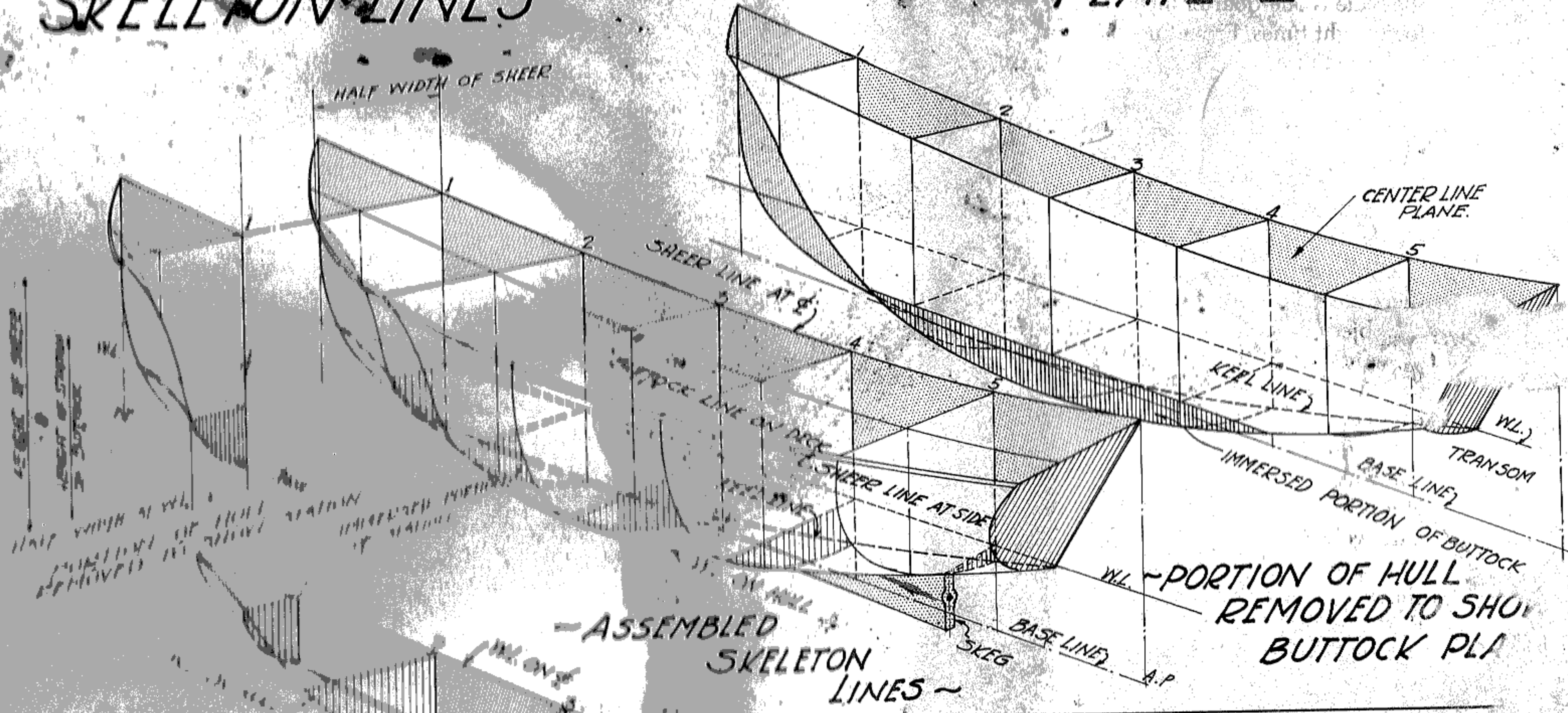
A curved line, having no regular shape that can be conveniently dimensioned in the regular way, must be dimensioned at regular intervals on the ever-changing curve. Thus, for instance, the dimensions of a ship's waterline must be given at every frame or station line. The aircraft curves are also given similarly on frame or rib lines. The dimensions for ship lines are termed offsets—PLATE 2—and are given in feet, inches and eighths. Thus, if the half breadth at a certain waterline where it crosses a certain frame were twelve feet, seven and three-quarters inches, the offset would be written 12-7-6; the six-eighths, of course, being three-quarters of an inch. These offsets are given in a tabulation for the whole of the ship's shape in the offset table. Separate offsets are given for half-widths and heights. Half-widths are given on all the waterlines at all the stations or frames, and denote the distance between the skin of the ship and its centerline. The dimensions for height are given on the buttocks above the base line.

As most aircraft dimensions are given in inches and fractions, the offsets are similarly given in inches. Thus the 12-7-6 offset for a ship would be written 151-3/4" on an aircraft drawing. Where the station shapes on aircraft or flying boats are often comprised of arcs and straight lines, radii and other similar figures, the offset table does not give waterline and buttock dimensions; but a diagram is drawn on the plan, and each similar dimension given a letter. Thus the half width would be *A*, the extreme height above the base would be *B*, the intersection of the bottom with the half beam *C* and the height of the keel *K*. (*See* PLATE 16.) In the offsets these dimensions would be listed under their designating letter for each individual station or frame.

Dimensions for decks, sheer, knuckles and stringers of a ship are given both as widths and heights, as they usually do not follow the regular lines of the waterlines or buttocks. Often on boats having straight sections with "vee" bottoms, no dimensions are taken on waterlines or buttocks. The keel, chine and sheer lines are dimensioned in the offset table or directly on the drawing by duplicate dimensions of height and

SKELETON LINES

~PLATE-2~



HALF WIDTHS					
STA.	1'-W.L.	2'-W.L.	3'-W.L.	4'-W.L.	5'-W.L.
1	0-3-4	0-9-7	-1-3-1	2-1-2	
2	1-4-6	-2-3-7	3-1-2		
3	2-3-5	3-3-1			
4	3-4-2				
5					

TYPICAL OFFSET TABLE

half width. On speed boats and flying boats having straight sectioned bottoms with curved flare in the bow, the offsets at this flare are given along a diagonal line which takes in the greatest portion of the flare. Thus the line is laid between three dimensioned points. The keel, the diagonal and the chine.

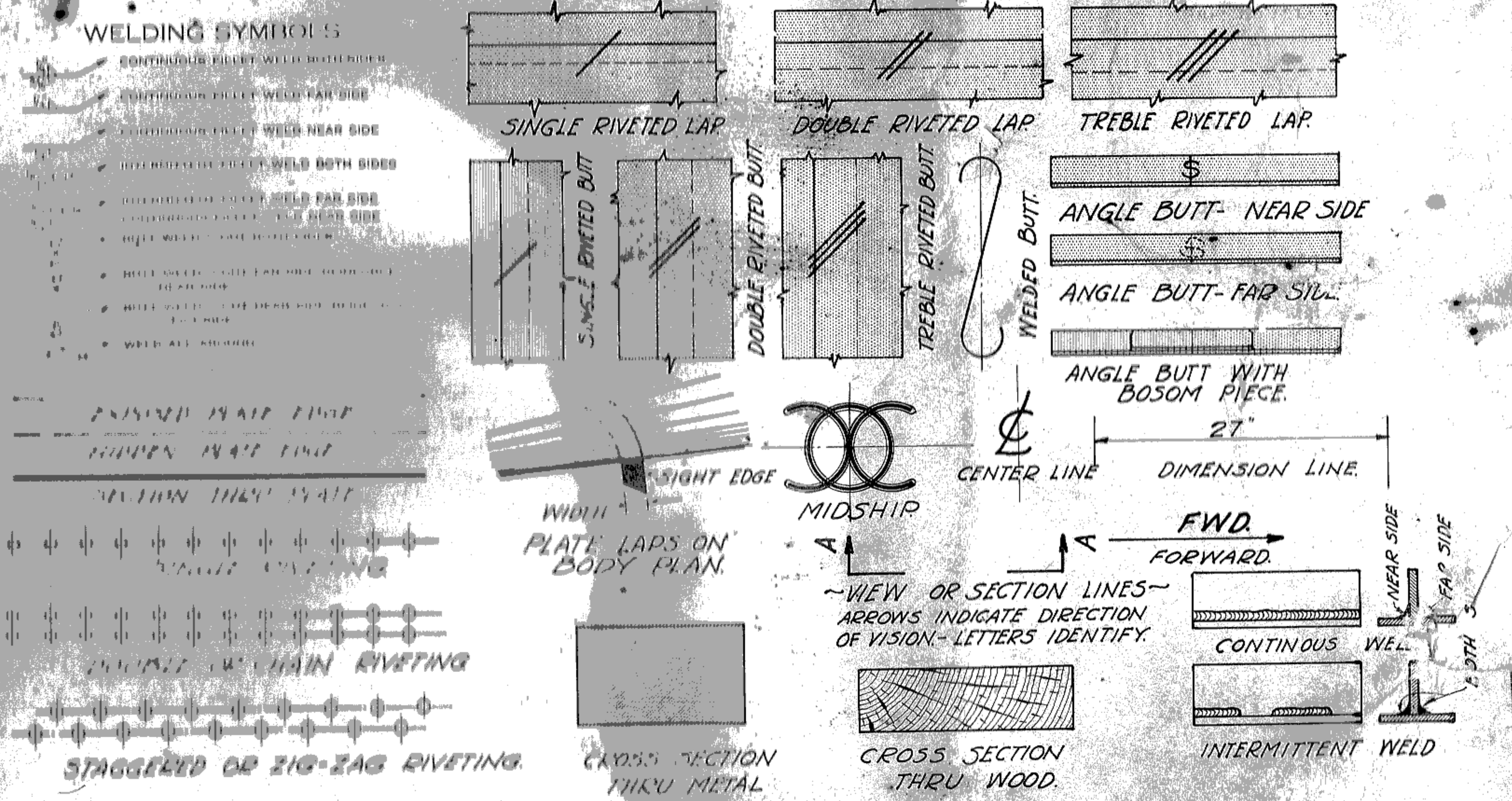
Where shape of a hull or other object follows true geometrical lines, such as an arc of a circle or a parabola, the center of the arc or the confines of the parabola are the only offsets or dimensions noted on the drawing or in the table of offsets. This is noted on the drawing as the trace, or locus, of the center of the arc, as "control lines," or limiting dimensions, for parabolas. Often the lines are not true parabolas, but some similarly arrived at section or curve that we will become more familiar with when the process of fairing is dealt with.

In the vee bottoms of flying boats, there is often a curve or "flam" introduced near the chine to deflect the spray downward. The rise of the bottom is nearly always a straight line. The curve or flam is usually an arc of a circle. It becomes evident that some line must be determined to fair the extremities of the bottom's rise. This is often done by laying out a line on the ship's half beam and fairing it along the intersection of the line of the bottom at the keel and the half beam. The dimension for the flam curve is then given at 90° to the ship's bottom at its beginning, or the point where it becomes tangent. The trace of this line along the bottom is generally termed the "tangency line." Similar tangency lines are used where the fillets of a wing or strut meet the fuselage on aircraft.

To eliminate the writing of numerous notes on a drawing, there have been signs and designations invented which through constant use have become conventional on ship drawings. Welding and riveting notes would become rather long if written out, yet these notes can be very easily designated on a drawing with conventional marks. Some of these are given on PLATE 3, and as an instance of the labor and confusion of drawing by various notes, we can take a treble-riveted butt strap or butt lap. Instead of writing all this information on the drawing, the draftsman simply makes three dashes across the width of the butt, and everybody concerned knows from experience with other plans that these three dashes mean treble riveting. In similar cases the dashes also indicate the riveting in seams and other laps.

Long ago in wooden shipbuilding, the shipwright marked his plan with an "S" wherever a scarph or joint in the timbers occurred. This sign became a mark for any kind of a joint, and today in steel shipbuilding it indicates a butt between two plates or two angle bars. When welded ships were designed the mark was still retained to indicate a welded butt. Welding notations also would take up a lot of the draftsman's time and a lot of space on the drawing, so the various welding societies have gotten together in conference and the symbols shown on PLATE 3 have been adopted for all welding notes. Other signs have been adopted by naval architects through the years of the art and the most common of these are also shown on this plate. The conventional signs for plate laps, scarphs of plating and midship, as well as the divisions of length of the vessel are also shown. Quite a number of these conventional signs can be seen in actual use on the shell expansion, PLATE 26.

CONVENTIONAL NOTATIONS ON SHIP PLANS — PLATE 3 —



II. The Mold Loft Floor

JUST WHERE the practice of laying a ship's lines down full size on a wooden floor originally took place, is lost in the antiquity of shipbuilding. We do know, for a fact, that some of the Roman galleys were outlined on the smooth marble floors of the temples. We also know that the Viking long boats and the canoes of the American Indians were outlined in stakes driven directly into the ground on which they were built; the stakes forming the outlines of the vessel's beam at various stations.

The term *loft* is easy to trace back to its origin. In the old days of wooden shipbuilding and in the early days of iron, some sort of shop buildings were present in the yard. To build a special covered floor on which to lay down the lines of the ship or to lay out the fabric for her sails, was both a waste of good ground space and a duplication of a roof. It was only natural, therefore, that a loft be constructed under the roofs of the shop buildings, and hence the terms mold loft and sail loft, even though today some of these floors may be on the ground.

Good practice today demands that a floor for a mold loft be laid of good grade white pine lumber over a sub floor of heavier material, both of which are tongued and grooved. Building paper or tar paper between the two floors help to preserve the upper floor from moisture effects. The sub floor of the loft is laid either longitudinally or transversely across the length of the loft. The upper floor or working surface is laid at an angle of 45° to the sub floor. This is done so that most of the lines which are laid down parallel to the edge of the floor or square to it, will not fall on a floor joint.

In the airplane factories, early in the development of their technique, it was realized that some process of fairing and development similar to that of a shipyard, would have to be adopted. The relative sizes of a ship and plane, of course, made the airplane loft of smaller size than that of a shipyard. Various forms of floor have been tried, and the ideal floor for an airplane plant is still a matter of development. Early in the construction of large flying boats, the lines were faired on egg-shell paper with a linen back. This drawing was made to a scale of three inches to a foot, or one-quarter actual full size. The drawings of the larger members were made to this same scale and of the smaller pieces to half or full size. The waste of laying out the member twice, once on the drawing board and again in the shop became evident, and a procedure of lofting similar to that of a shipyard was instituted.

In the Glenn L. Martin Company, builders of the famous trans-Pacific *China Clipper*, a large maple floor was constructed for the lay-down and fairing of the various members of the plane. With the war-time expansion and the rush of getting out a great number of different models, the maple floor became inadequate. An ingenious system of portable floors was adopted. These consist of plywood sheets joined together in an area large enough to lay down the plane full size. These are metal covered and painted, and ducks are used to hold down the battens. They are set up on trestles and can be readily removed and stored. When it becomes necessary to refer to the lines drawn on them, they are brought into the loft room and again placed on trestles, or even on top of another floor already there. When the contract for which they were laid down is finished, they may be painted and used for another.

The floor of the loft is generally painted a pearl or French gray, capable of taking pencil lines. In some lofts, brass plates with a mark in their center are set in flush with the surface of the floor. When the floor is originally laid down, these plates are laid out very accurately with a transit and serve to form a grid of accurate squares from which square lines may be established at any time wanted.

Many tools special to the trade are employed in the loft. Of prime importance is the long wooden splines or battens—PLATE 4, Fig. 1—used for drawing the curved lines on the floor. These are of spruce, white pine or fir. The best are made of vertical grain Douglas fir, which can be secured in very long lengths. They are secured to the floor with nails on each side of them—*never* through them. After the lines are drawn on the floor, it often becomes necessary to transfer them to a template. The loftsman has invented an ingenious gadget to accomplish this. This tool is termed a "take-off spider" because it resembles this insect (PLATE 4, Fig. 3). This tool is composed of a lot of strips of flat steel about an inch wide and an eighth thick. The ends are hooked to fit over a wooden batten about one inch wide by a quarter inch thick, and the opposite end is drilled to take an eight penny nail. The batten is set over the line to be taken off, and the hooked bars are slipped over it, and their far ends are then nailed to the floor. When it is desired to transfer the floor line to template wood, the batten is lifted, the wood slipped under it as shown in PLATE 4, Fig. 3, and the line marked off.

On the drafting board and in the aircraft lofts, it is impossible to nail battens to the floor and to draw the lines. Some other method of holding the battens down must be resorted to. Large lead weights called "ducks," which have a sharpened hook on one end, are provided for this operation. These are distributed along the batten in sufficient numbers to keep it in position. The sharpened hook prevents movement of the batten or spline, and the weight of the duck is large enough to produce the friction on the floor or board to keep it from sliding out of position. These ducks are shown in PLATE 4, Fig. 2. Often on a small drawing board when ducks are not available, ordinary dress pins can be used on the batten in the same manner as nails are used on the loft floor. Of course, this can only be done on a paper layout, as the pin holes will ruin a piece of tracing cloth.

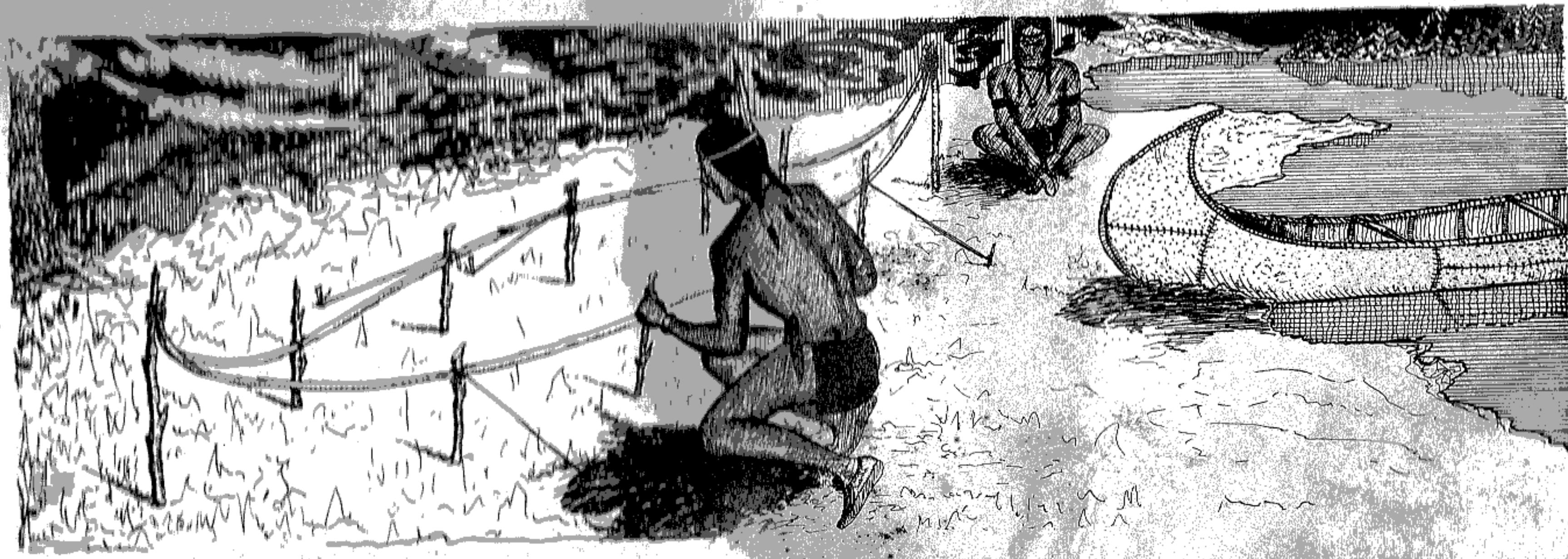
In the development of surfaces it is often necessary to draw a line "normal" or square to the tangent of a curve. In loft parlance this is termed squaring off, and the loftsman has a tool to accomplish this. This tool is termed the tangent or square-off square. These tools are made in the loft out of white pine or some hard wood and resemble a drafting tee square. Two small-radius arcs are drawn, and equidistant between their centers *a* and *a*, a perpendicular is erected (PLATE 4, Fig. 4). These tools are made in varying sizes for different uses. In the aircraft lofts and on a drafting board they can be well made from transparent pyralin.

In the determination of bevels on the loft floor, several sorts of tools are employed. The familiar carpenter's bevel gauge is often employed in addition to tools special to the floor. To determine the bevel from the body plan the bevel stick or "degree stick," as it is sometimes called, is used. The construction of this tool is described in PLATE 8, Fig. 3. A similar tool is used in the aircraft lofts. This is the degree board on which the angles are laid out on the board, and all the various frame spacings of the plane are squared to the zero degree base line. The bevel is determined by picking off the projected frame spacing from a body plan with dividers, and measuring the bevel on the board perpendicular to the base at the particular spacing that the bevel is to be measured at. In some lofts where the bevel is still given to the yard workmen on a bevel board, the bevel lifter (Plate 4, Fig. 5) is employed.

This tool is constructed similar to an overgrown carpenter's bevel gauge, with the exception that it is set vertically and has feet that keep it perpendicular to the floor. A sliding arm allows the base of the triangle, one side of which represents a frame space, to be increased or decreased. A lock nut at the upper end is fixed in the stationary part, and the arm can be fixed to prevent its moving if desired. A mark lining up with the pivot point on the top is placed on one frame line and the pointer placed on another. Due to the fact that the pivot point is exactly one frame space above the floor, the arm takes the angle that would exist between the particular frames on the actual ship. By placing the bevel board alongside the "lifter," the bevel can be marked on the board and sent to the yard.

Often it is necessary to draw large arcs or to transfer a measurement from one place on the floor to another. Trammels are used for these operations. These consist of two divider points which can be adjusted to any dimension desired along a wooden bar. The size of the dimension is only limited by the length of the bar obtainable (Plate 4, Fig. 6). Trammels are often fitted with an attachment to allow a pencil to be used in one end, thus allowing them to be used as large compasses for drawing arcs of large radius.

As a good number of the templates used in shipyards are made of eighth-inch bass wood, and are assembled right on the mold loft floor with tacks, the loftsman has in his kit of tools a steel plate which he slips under the two thicknesses of template wood when they are nailed together, to prevent the nails or tacks from entering the floor. This tool is called a clincher, and is shown in Plate 4, Fig. 7. The loftsman will also have in his kit a number of ordinary carpenter's tools such as a hammer, various sized steel squares, a stiff back saw for cutting the template wood, and a sharp knife. An awl or two, chalk and line, steel tape and rules, complete the kit generally found necessary in shipyard loft work.



An Early American Shipyard

III. Elementary Geometry Employed on a Loft Floor

BEFORE THE LINES of a hull or fuselage are laid down full size on a mold loft floor, there are certain operations of preparing the floor so that the offsets and various measurements may be laid down. A base line must be established and the stations erected square to it. Parallel lines for the waterlines and buttocks must be drawn, and other simple drafting must be done to provide the grids on which the offsets are spotted. Later in the work of fairing and the development, other drafting operations that involve simple geometric principles are involved. We will deal with each of these as a separate problem, listed as follows and illustrated on PLATES 5 and 6.

TO DRAW A LONG STRAIGHT LINE

Often in ship work it is necessary to lay down a straight line for two hundred or more feet. This is done by setting up blocks of wood at the two extremities of the line and stretching a piece of strong fish line or piano wire between them. The wire or line is set over the points in the extremities of the line, and care is taken so that at no point it touches the floor. At intervals a square is set up from the floor and placed against the wire. The point at the corner of the square is marked on the floor and later chalk lines snapped between these points. A variation of this in an aircraft loft is to set up smaller blocks and use a strong thread, in place of the fish line. A drafting triangle is used in place of the square, and a steel straight edge is used to connect the intermediate points. Where a steel wire is used, it is often stretched by a small turnbuckle at one end.

TO "SNAP" A CHALK LINE (PLATE 5, Fig. 1)

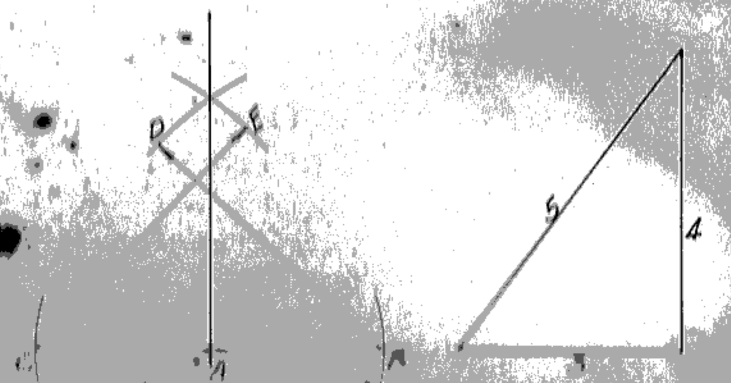
One of the oldest methods known to mechanics of drawing a straight line is that of snapping a chalk line. A nail is driven in the floor at one extremity of the line. A piece of stout cord is passed across a line of chalk until it becomes thoroughly dusted. A loop in one end of the cord is slipped over the nail and an assistant holds the cord on the other extremity of the line. When an assistant is not on hand, an awl or another nail may be used to secure the other end of the cord. The cord is tightly stretched and raised above the floor at its center. The cord is suddenly released and allowed to snap down to the floor; the sudden impact jars loose the chalk particles adhering to the cord and a straight line is imprinted where it strikes. It is important that the cord be raised square off the floor, otherwise a slightly curved line is the result of its striking the floor at an angle.

TO ERECT A SQUARE OR PERPENDICULAR LINE (PLATE 5, Fig. 2)

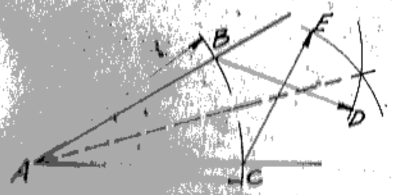
The right angle or square line is the most important of all of our layout lines after a straight base or centerline is established. All station lines are laid out at right angles to the base. All of the buttock lines are drawn "square" or perpendicular to the base; and we find this right angle being used throughout our development work. If a large steel square or drafting triangle is at hand it is a very simple matter to set one edge of this tool on our base line and draw a line along its other edge.

~LAYOUT PROBLEMS~

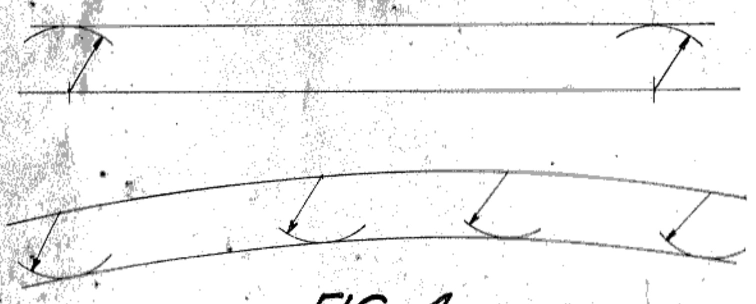
~PLATE-5~



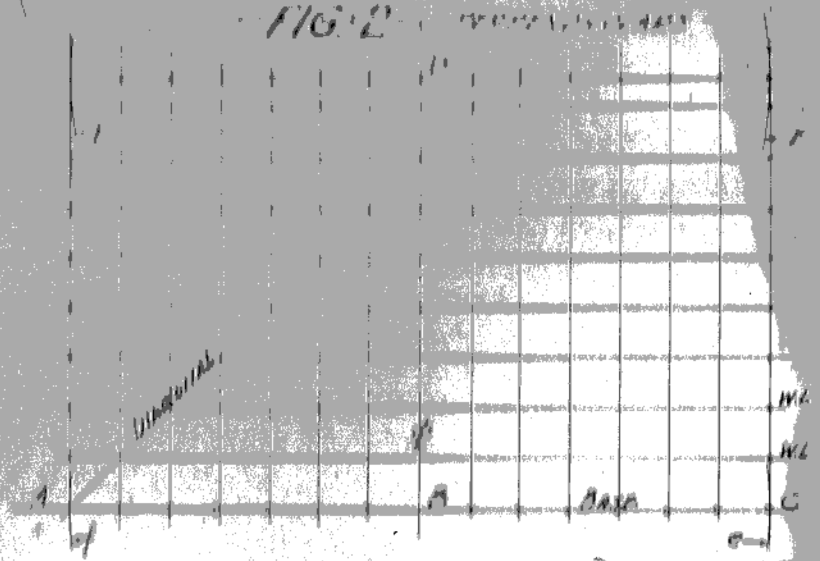
~FIG 2~



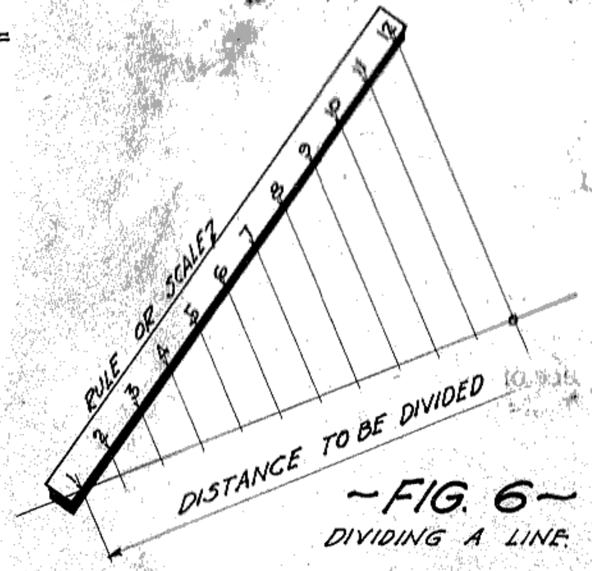
~FIG 3~
BISECTING AN ANGLE



~FIG. 4~
PARALLEL LINES



~FIG 5~
DRAWING A GRID



~FIG. 6~
DIVIDING A LINE

~SNAPPING A CHALK LINE~
~FIG-1~

If, however, our square line must run for a long distance, other means must be employed. At the point where we wish to erect our perpendicular, an arc is swept to the right and left. These arcs, *A-B* and *A-C*, must be of equal length. From the point of intersection of these arcs with the base, *B* and *C*, two more arcs are swept, *B-D* and *C-E*. At the point where these arcs cross or intersect, a line is drawn down to the base line where the perpendicular line is to start (A). We have thus bisected a 180° angle, and each angle alongside our perpendicular line must be 90° or a square angle. If it is desired to check the squareness of this line, a measurement of four feet is laid along the perpendicular, three feet is laid along the base; the measurement between these points in a straight line will be five feet. This is the old three, four, five rule of squareness, and works because five is the square root of three squared added to four squared, which is the method of calculating the hypotenuse of a right triangle. Multiples of three, four or five may be used such as nine, twelve and fifteen, to check long perpendicular lines. Similarly a perpendicular can be erected with two steel tapes. One is set at the point where the perpendicular is to be erected. The other is set at some multiple of three along the base line away from the point. Where the multiples of four and five meet when the tapes are crossed will be the point where the perpendicular will pass through.

TO BISECT AN ANGLE (Plate 5, Fig. 3)

It often becomes necessary in loft work to equally divide an angle. This is done by a method similar to erecting a perpendicular. From the apex of the angle *A* the arcs *A-B* and *A-C* are drawn with an equal radius. From the intersections of these arcs with the lines of the angle, other arcs are swept, *B-D* and *C-E*. A line drawn from the intersection of these two arcs to the apex of the angle will bisect the angle.

TO DRAW PARALLEL LINES (Plate 5, Fig. 4)

Waterlines are drawn parallel to a given base line at stated intervals, buttocks are drawn parallel to the vertical centerline. Parallel lines both straight and curved are used in many ways in ship and aircraft loft work. The process of drawing parallel lines is as follows: Arcs of equal radius are struck from the line to which the desired line must be parallel. The distance that these lines must be apart is that used as the radius of the arc. Where the lines are straight a chalk line may be snapped tangent to the arcs. Where the lines are curved, a spline or batten is used, and its edge is set on a series of arcs set off the curved line. The parallel line to a curve will find its greatest use in taking off the thickness of planking on a wooden boat. The radius of the arcs in this case is that of the thickness of the wooden planking.

TO DRAW A LAYOUT GRID (Plate 5, Fig. 5)

In ship and aircraft work where the offsets are given on waterlines and buttocks, it is necessary, before the curves of the profile and plan and the body plan are drawn, to prepare a grid of square lines for the offset dimensions. A perpendicular is first erected above the base line *A-B-C* at the point *B*, which should be the centerline of the hull. At the point of greatest depth of the hull *D* on the centerline, arcs *D-E* and *D-F* are swept equal to the half beam. The same radius (*B-e* and *B-f*) is used to lay out the half beam on the base line. The beam lines on the extreme right and left sides of the grid are now drawn. The heights of the various waterlines are now laid off on the beam lines and the centerline. These are now connected with straight lines. The spacing of the buttocks is now laid off on the base line and the uppermost waterline. These points connected by straight lines will give the buttock lines.

GEOMETRIC PROJECTION OF CURVES ~ PLATE-6.~

FIG-1

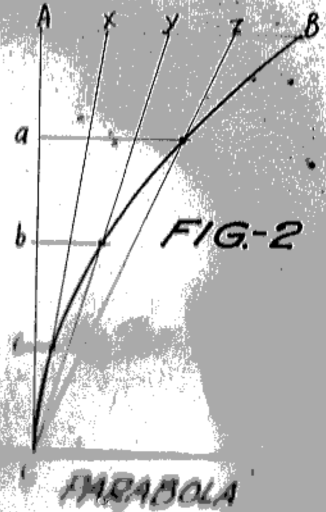


FIG-2

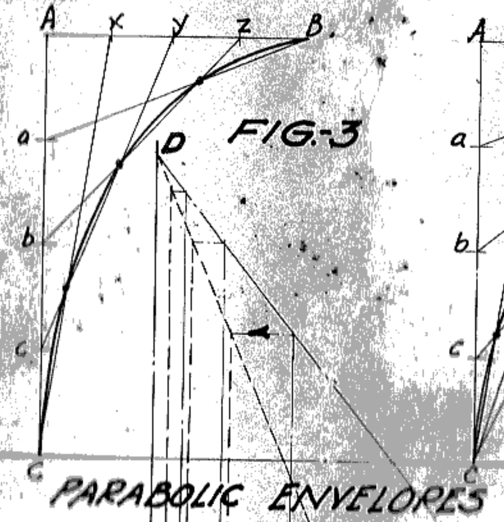


FIG-3

FIG-4

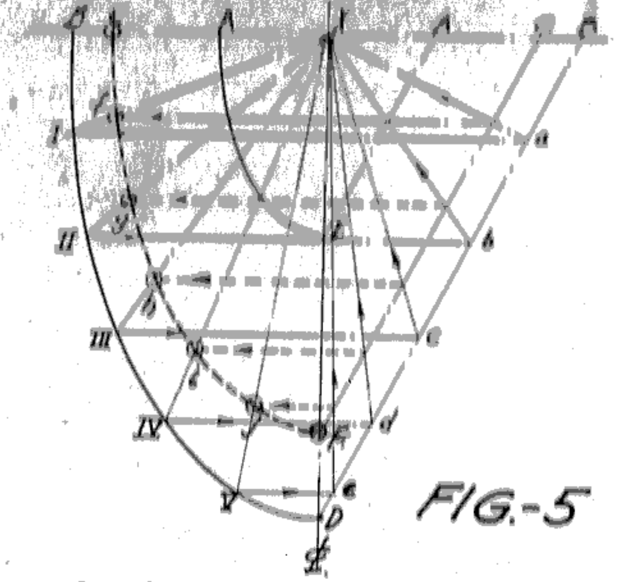


FIG.-5

INTERMEDIATE CURVES BY CONIC PROJECTION.

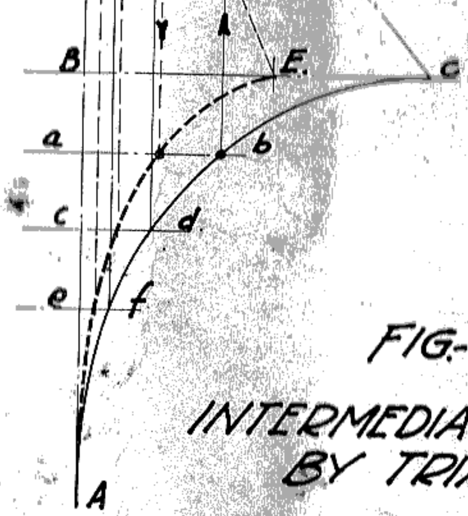


FIG-6.

INTERMEDIATE CURVES BY TRIANGULATION.

The grid can be checked by laying a diagonal line across the intersections of the waterlines and buttocks and, provided that they are of equal spacing (as they generally are in ship work), the diagonal line will exactly cross every intersection. When the waterlines and buttocks are not of the same spacing, but are equally spaced in each system, the diagonal will still cross every intersection. The grid for the longitudinal layout can be drawn in a similar manner, using the midship frame for the centerline and the fore and after perpendiculars in the same way that the half beams were used. The station or frame spacing is laid out according to the figures given on the lines plan for these ordinates.

TO LAY OFF EQUAL DIVISIONS ON A LINE (PLATE 5, Fig. 6)

Often on a layout floor or drafting board it becomes necessary to divide a line of a certain length into divisions that cannot be conveniently calculated so as to be measured in the accepted standard divisions of a foot. For instance, we wish to divide a line thirteen feet long in seven equal spaces. If we were to calculate the length of each division, we would find that each would be one and six-sevenths of a foot in length. Nowhere on our rule can we find inch divisions that will give us the desired six-sevenths. The nearest we can come to this figure is ten and twenty-nine sixty-fourths. Even though we were to set dividers to this figure we would find that in the end there was some slight error in the spacing. To divide this length with dividers is still a laborious method of cut and try. The easiest method is to erect a perpendicular at one end of the space to be divided. From this perpendicular to the other extremity of the given distance a line of seven known spaces is drawn so that it will meet the perpendicular. From each of the known divisions, lines are drawn perpendicular to the line to be divided. The line at the end of the divisions need not even be perpendicular as long as the lines from the known divisions to the line to be divided, are drawn parallel to the end line. Similarly, a line of unknown length may be divided proportionally as long as these proportions are laid down to scale on the line of known length, and all projections made parallel to the end division line.

TO DRAW AN ELLIPSE (PLATE 6, Fig. 1)

Often in the course of fairing and development it becomes necessary to produce an ellipse of certain known major and minor axes. This is done by squaring the two axes to each other. From the intersection of the axis lines arc *A* is swung, equal to one half the major axis. Arc *B* is swung equal to one half the minor axis. Arc *A* is divided into any number of equal spaces and these, *a*, *b* and *c*, are connected to the intersection of the axes crossing the arc *B* at points *x*, *y* and *z*. Horizontal lines are projected from *a-b-c*. Vertical lines are projected from *x-y-z*. Where the horizontals and verticals from points on the same radian cross, will be a point on the perimeter of the ellipse. By fairing a line through these points the ellipse is formed, as shown in Fig. 1. While only one quarter of the ellipse is shown, the process is the same for every quarter.

TO DRAW A PARABOLA (PLATE 6, Fig. 3)

The parabola is often used in the production of fillet shapes in fairing. It is produced by dividing the height *A-C* and the width *A-B* into a number of equal spaces, in this case four. *A-B* is divided into the ordinates *x-y-z*, and *A-C* into the ordinates *a-b-c*. Horizontal lines are projected from *a*, *b* and *c*. Points *x-y-z* are connected to point *C* by lines as shown. The intersections of *x* and *c*, *y* and *b*, *z* and *a*, lie on the curve of the parabola. A line faired through these intersections will produce the desired line.

TO DRAW AN ELLIPSE GRAPHICALLY
(Fig. 1, Page 19)

With the major and minor axis lengths known, prepare a strip of paper about a half inch wide, slightly longer than half the major axis length. On this strip lay off two points, *A* and *C*, whose distance apart is one half the major axis length. From point *C*, lay off the point *B*, whose distance from *C* is half the minor axis length. Keeping points *A* and *B* on the major and minor axes, mark off point *C* at intervals around the circumference of the ellipse, until enough intervals are secured through which a line may be drawn.

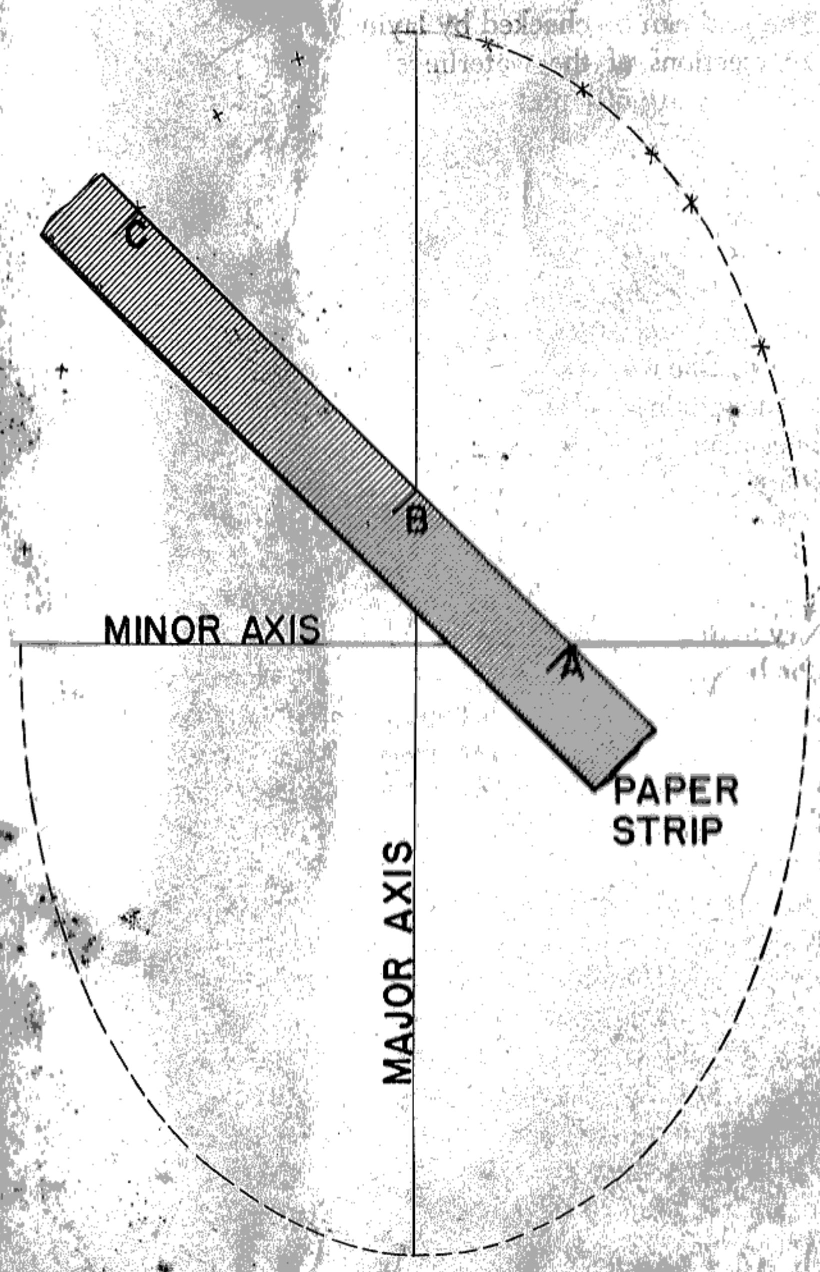


FIGURE I

IV. Principles of Plane and Solid Geometry—Projection of Lines and Surfaces

BEFORE THE ACTUAL development of surfaces is undertaken, the loftsman must know something of the laws governing the procedure. The basis of this art is the science of geometry. This science was originated by the Egyptians and brought to perfection by the Greeks under Euclid, before the Christian Era. Literally translated it means "earth measurement," as it was in this branch of engineering that it was first employed. The student loftsman will do well to secure for himself a book on plane and solid geometry and master the principles of this science.

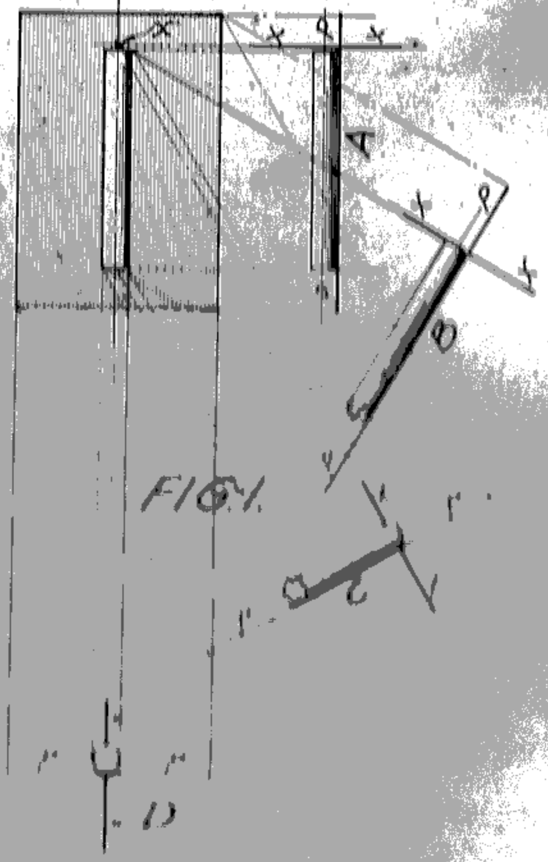
We have seen in Chapter I how views may be projected from one to another to show hidden sides or other features that are desirable to accentuate. In the art of development of surfaces of solids and intersections of planes with these solids, we must master the theories of projection. On PLATE 1, we have seen how two views were projected from a common plan view to show the elevations of the end and sides of an object. By the same method of projection, it is possible to show a view at any angle desired by projecting lines from a plan or elevation at the desired angle.

In doing this, we can consider that we have rotated the plan or elevation so that the desired view comes into our line of vision. It will be better to imagine the object rotated than to imagine ourselves going around the object to get out different views. In the analysis of the steps of development or projection, which we will deal with later, imagination will play no small part. In reality, dealing with the full size object, it would be a rather hard matter to turn a ship or plane through all the angles necessary for our various views. In our imagination it is a relatively simple matter to swing a ship through any angle which we may desire. Without imagination, we could have no engineering.

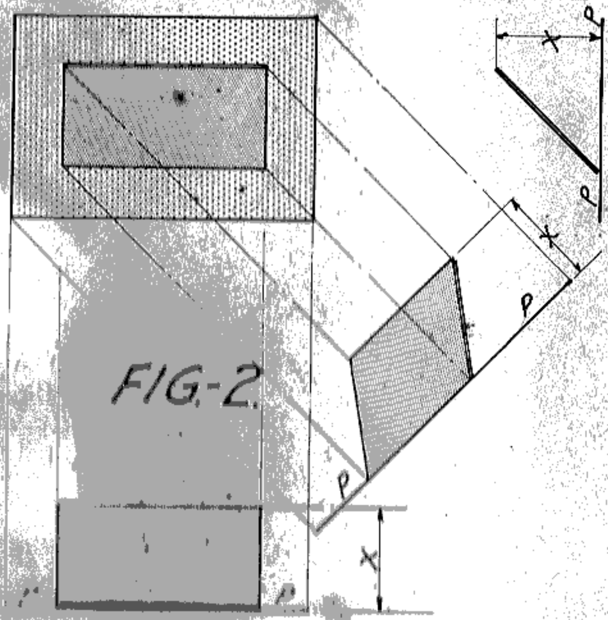
The designer must picture his project in his imagination before he puts a single line on his drawing board. We must imagine lines and planes in our fairing and development, and the greater our imagination, the easier this becomes. Picture your school-day studies in geography without that definition of the equator being an "imaginary" line on the earth's surface. In your mind's eye that line is as actual as if it really existed, and this illusion is so strong that more than one person has actually expected to see it when crossing it at sea. The more firmly we picture our projection lines in our mind the more readily we will grasp the theories of projection and development.

One of the first things that we must firmly fix in our imagination is the location of the various planes of our drawing. The most important one and the starting point is the "plane of the paper." This is only an arbitrary title for this plane. It may be the plane of the loft floor or any other medium on which our drawing is made. It is the plane in our imagination which we see directly in front of us as we look at the drawing. It is the one at right angles to our line of vision. In the explanation of projection which we will now take up, we will consider that there is only one "plane of the paper," that one in plan view from which we have projected all the rest of our views. In actual practice later, when we start to deal with a multitude of

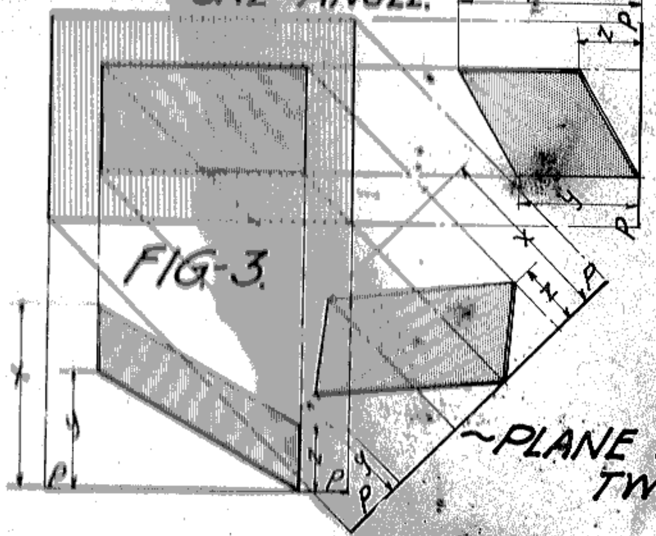
ANGULAR PROJECTIONS ~PLATE-7~



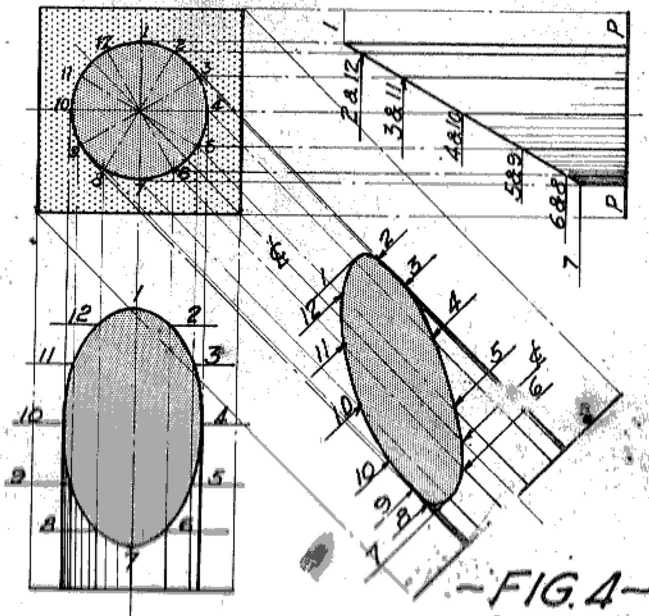
OBJECT FORESHORTENED BY PROJECTION



~PLANE INCLINED AT ONE ANGLE.~



~PLANE INCLINED AT TWO ANGLES.~



~FIG.4~

~INCLINED CUT ON CYLINDER.~

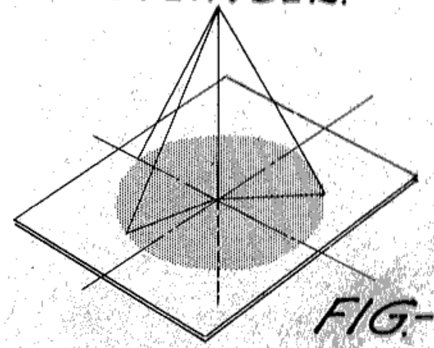


FIG-5.

planes, we must consider that the base of any and all of our independent views lies in the paper plane. We can see this readily in PLATE 1, where the two elevations, as well as the plan view, lie in the shaded area which we can now consider as our paper plane.

As we look at an object by revolving it about an axis at right angles to the paper plane, we see its various sides. If we look directly at its longest dimension we see this dimension in true length in our projected elevation. By looking at its longest dimension we were looking directly at it; or our line of vision was square or at 90° to the longitudinal dimension of the object.

Let us examine (PLATE 7, Fig. 1). Here we see a light shaded area with a round bar resting on it. The light shaded area on this and all other examples on this sheet may be considered as the paper plane, and the plan view. To the right of the plan is a projected view of the bar, and its true length is shown. The plane through the process of projection has become a line because we have turned our view 90° and are looking directly at its edge *P-P*. At the upper end of the bar in the plan view we can see a point marked *X*. We will now rotate the projected view around this point, which in the elevations becomes the axis of rotation, *X-X*.

As we swing the bar in our imagination around the axis *X-X*, from right to left, the length becomes foreshortened and the diameter, which shows as a width in the plan view, becomes more and more evident, until elevation *D* is reached. Then it becomes a circle, as we see it in its true view. We now note some important facts. The length of the axis of rotation has not changed. The plane of the paper has always appeared as a straight line, because we have viewed it on edge in all elevations. The length of the bar has become foreshortened more and more as the angularity of the projection increased. The circle of the diameter evolved from a straight line through varying degrees of ellipses until it became a circle in elevation *D*. Thus, elevations *A* and *D* projected at right angles to the sides of the object are the only true ones.

Let us now consider a plane inclined at a definite angle to the paper plane (the light shaded area in PLATE 7, Fig. 2). Here we have an example of a deliberate angular projection. We have a plan view which shows us the length of the plane (the dark shaded area), we have the end elevation whereby the angularity of the paper plane *P-P* and the plane in question is shown. In the side elevation, the other view of the plane appears as a dark shaded area, with one edge shown resting on the paper plane *P-P*. With this information on hand, the various points in the plane are projected to the angular view and set up, using height *X* to determine its upper edge from the paper plane, all other points being projections of the plan.

In PLATE 7, Fig. 3, we see a plane at two different angles to the paper plane *P-P*. There is nothing in the plan view that would indicate it to be any different than Fig. 2. The end view and the side view, however, do indicate that there is only one edge touching the paper plane. The angular projection is made in the same manner as in Fig. 2, setting up the heights of the corners of the plane, *X*, *Y* and *Z*, from dimensions secured from the elevations.

The angular planes, provided they have parallel edges will, regardless of how projected, form some sort of a parallelogram in any elevation. In PLATE 7, Fig. 4, we now have a cylinder cut at an incline and wish to make an angular projection from this. In one elevation we see the cut as a line of the true cut. In the elevation at right angles to this we see the cut projected as an ellipse. To produce the projections we must divide the circumference into a number of increments, numbered 1 to 12 in the plan view. The locations of these increments are projected to the elevation, where the cut appears as an edge of the intersecting plane. Note here how the intersection of a plane cut through a curved solid produces the effect spoken of in Chapter I. In this elevation, we can measure all the heights of the various sections of the cylinder's circumference, and when these are set up on the angular projections of the cylinder, the ellipses of the surface of the cut are produced.

We have seen how the axis of rotation X-Y in PLATE 7, Fig. 1, does not change with rotation. In Fig. 5 of the same plate we see a right triangle rotated about an axis on the paper plane, its apex remains stationary and the other corner in its rotation forms a circle on the paper plane. The hypotenuse, therefore, will remain of constant length, but its length will only appear true when the triangle is rotated to an axis which is at right angles to the line of vision. In this rotation of the triangle to get true length, the whole basis of triangulated development is formed, and we will deal with this interesting subject in another chapter.

Since we are to consider points and lines not all lying in the same plane, it is of prime importance to be able to distinguish one plane from another. This is all the more important since the three dimensional figures that we are to deal with have to be represented by lines on the drawing board or the mold loft floor. Briefly, the rules of geometry of interest to us are:

1) If two points of a straight line lie in a plane, the whole line lies in that plane. (This applies regardless of the length of line or plane.)

2) Through three points not in a straight line, one and only one plane can be passed.

3) If two planes have a point in common, they have at least another point in common.

4) Two intersecting planes have a straight line in common and no other points outside of this line in common.

5) A line is said to be perpendicular to a plane if it is perpendicular to every line of the plane passing through the point in which it meets the plane. In this case, the plane is also perpendicular to the line (PLATE 7, Fig. 5).

6) Any line or surface on, or parallel to the paper plane (the plane of the paper on which the drawing is made), can be revolved about any axis at right angles to the paper plane, without changing dimension or shape in the plan view, but not in the elevation.

7) Any line in elevation, not at right angles or parallel to the paper plane, changes its angularity but not its height as it is revolved about an axis at right angles to the paper plane. Any line at right angles to the paper plane can be revolved about any axis at right angles to the paper plane, without changing its angularity or height. The distance between the line and the axis does, however, become foreshortened or lengthened as the revolution progresses.

8) Any point, measured parallel to an axis of rotation away from a given plane, maintains that distance regardless of the amount of revolution.

9) The length of any line shown on a plan is true only when the line lies on or parallel to the plane of the paper, or when it lies in a plane of elevation at right angles to the plane of the paper and the line of vision.

10) On any body plan, a line between any two frame stations, regardless of the angle at which it is drawn, represents the base of a right triangle whose altitude is the spacing between those respective frames.

11) On ship's lines, in the profile, the centerline of a ship and centerline profile may be considered to be the paper plane; all buttock planes are, therefore, parallel to the plane of the paper. In the plan view, the base line may be considered as the plane of the paper and all water planes as being parallel to it. The spacing of the waterlines and buttocks may be considered as the distance between the planes. In the body plan, the midship station may be considered as the plane of the paper and all other stations as planes above or below this one. The spacing between them may be considered as the distance between the planes.