Industrial Design

A Practical Guide

By

Harold Van Doren

1940
# Table of Contents

Clay Studies 3  
Clearance Models  3  
Industrial Design  4  
Modeling with Zinc Templates  5  
Fillets and Radii  8  
Painting the Clay  9  
Circular Forms  10  
Freehand Forms  11  
Presentation Models  14  
What Scale  14  
Five Steps  16  
Tools  16  
Supplies  17  
Modelmaker’s Grease  17  
1. Built Up Models  17  
Finishing  21  
2. Cast Models  23  
3. Combination Models  26  
4 Carved Models  27
Clay Studies

The inventor of the nondrying modeling days, variously called plastine, plastilene, or plasticene by their manufacturers and disrespectfully dubbed "putty" or "mud" by some people who use them, deserves a vote of thanks from every industrial artist. They are indispensable because they require little care, retain their shape indefinitely, and can be worked over and over again.

To describe the material itself is hardly necessary since everyone who has ever been to kindergarten has handled it. Many, however, do not know that it can be obtained in several colors and varying degrees of consistency, for the use of pattern makers a brick-colored wax is made in consistencies so stiff that it has to be worked with instruments. A grayish-green clay which works readily in the fingers, however, is usually preferred by sculptors and industrial designers.

Clay studies are simply visualizations in three dimensions instead of two. The industrial designer is really more sculptor than artist of pencil or brush. Many design problems, especially if freehand forms are involved, are carried through from start to finish without touching pencil to paper until mechanical drawings are made. You must have facility with the pencil, of course; but sketching and modeling often proceed side by side and, as you gain experience, you will find yourself depending more and more on clay and less and less on paper.

Some clay studies may be comparatively rough. If you are studying parts of a design which, because of a complicated juncture of different radii or because the amount of relief necessary to obtain a certain effect is in doubt, clay used right at the drawing board will clear things up in a fraction of the time required to make a shaded drawing. In rough work of this sort an ordinary kitchen knife and perhaps one or two small modeling tools will be all the equipment needed, except for the most versatile of all tools, your fingers.

On the other hand, clay models may be brought to a high degree of finish. This is necessary, of course, if you expect to make a plaster cast from your model. But in designing geometrical forms, that is, forms made up of straight lines and compass curves in various combinations, you may also wish to make rather accurate clay studies. The procedure involves a special technique.

Clearance Models

It is presumed that you have gone far enough to lay out your design roughly in elevation, plan, and side view. The next step is to build a clearance model of wood, use it as a core or "armature," and model the clay over it. By "clearance model" we mean one that will allow for all fixed dimensions as well as the extreme outward position, movement, or swing of moving parts.
For example, let us take the wringer gear housing of a washing machine. In Fig. 130 we have a simplified drawing of the mechanism. Taken in their proper order the parts are as follows: A represents the drive shaft connection with its bevel gear. BB are the bevel gears which change the direction of movement from vertical to horizontal, C is the eccentric which moves these gears into three positions: forward, neutral, and reverse. D is the spring latch which, when released by finger pressure on the lever outside the housing, permits the entire wringer to be swung in an are around the wringer post. It can be fixed in twelve different positions corresponding to twelve notches in an index ring.

Industrial Design

Now translate this drawing into a clearance-model drawing. The first step is to take the client's drawing literally and trace lines around the outermost points of all the stationary parts. Then, since the pair of bevel gears which actually drive the wringer roll have about an inch of maximum travel, you must provide clearance for both extremes of this movement. This is duly accounted for in your outline. When the first drawing is completed it looks like Fig. 131, although only the elevation is shown.
If you made your clearance model exactly to conform to this drawing, you would put the model maker to a good deal of unnecessary trouble. It is obvious that the finished housing, a die-casting, would look very odd if it followed all the ins and outs of the gears and would be difficult to cast, too. Further, it would be difficult to finish with enamel and hard to keep clean in the home. Therefore you fill in the gaps, making a smoother armature and one that is much easier to build, as in Fig. 132. If you wish you can make still further simplifications dictated by the ideas embodied in your rough sketches. Experience will teach you how intricate or how simple to make these wooden armatures.

Some like to make armatures with the "clearance" plus material thickness already added, that is, with an added thickness of wood of or ¼ inch -- like the peel of an orange. Others prefer to construct them so that their exterior represents the extreme limits of the moving parts, then add clay for the required clearance or air space. The first method saves a lot of time if you know exactly where your final surfaces are going to be, because when clay is added for the changed parts, the wood itself can be sprayed with color to match the clay. In the latter case you can slap on the clay and model freely, at any time poking some blunt instrument like a wire nail, or better still a small steel scale, into the clay until it touches the wood, then subtract the clearance specified.

With the armature completed, the clay is pressed on roughly and as rapidly as possible, building it up to the approximate bulk required. Figure 133 shows a phantom view of one possible design using this wringer gear housing as an example, and indicates how you can "feel" for the armature under the coating of clay.

The beginner has little difficulty in roughing out a clay model to the approximate form he desires. But as it draws nearer to completion and he wants to produce accurate surfaces and precise radii, he finds the clay increasingly difficult to manipulate in a clean-cut manner. Fortunately there are a number of short-cuts, simple if you know them, that will give your model a professional touch.

Modeling with Zinc Templates

Let us take some simple form such as a safety-switch housing for commercial or industrial installations. These metal boxes are usually mounted vertically against a wall or on a pillar, although for purposes of
illustration this one is shown lying flat on a horizontal surface. The cover is hinged at the left-hand side, the lever at the right serving to throw the switch tumblers into or out of contact with the prongs. Figure 134 shows the finished product we are planning to render in clay.

The rough sketches have settled many points in the design, such as necessary over-all dimensions, clearances for the throw of the switch, location of the hand lever, approximate decorative treatment of the hinged cover, and handling of the name plate and instruction data. But we have never seen it in three dimensions.

There are several points we wish to study further, such as the exact dimensions of radii along the edges and the number and width of ribs, before we make our presentation to the client.

Inasmuch as the product is only 7 by 12 by 5 inches, the problem of scale is easily disposed of—there is no point in making it anything but full size. First we knock together a rough wooden armature, little more than a box, in order not to waste time building up the entire form bit by bit, as in Fig. 135. This is not a clearance model, merely a timesaver. The nature of the product is such that the general dimensions of this particular size of switch box have been pretty well established in advance.

After clay has been generously slapped on, we begin to scrape down the top (really the front) of the cover with a piece of sheet steel with a true edge
until the clay is smooth, and, when checked with the spirit level, is parallel
with the workbench. The sides are scraped in like manner and maintained at a
90° angle from the bench by checking with triangle or square. When the main

![Fig. 136.](image)

form is accurately established, we cut two templates from sheet zinc to
conform to the corners A and the edges B, as in Fig. 136. To make these
templates, mark the desired radii out on the surface of the zinc with a pencil
compass or scribe the necessary lines with the sharp point of the dividers.
The rough cutting can be done with tin snips (there are snips made especially
for cutting curves) and the balance filed away until the edge of the zinc is
smooth and follows the contours exactly. If the cutting distorts the zinc out of
flat, it can quickly be smoothed out by clamping it between the jaws of a
bench vise.

Leave enough straight edge at both ends so that the templates will be
supported by the main mass of clay on the sides of the box, and file away
sharp corners which have a tendency to dig in and spoil the smooth day
surfaces. Now use template A as scraper for the corners, pulling upward until
all the excess clay is removed and the required radii are established as in Fig.
137. We are then ready for the second template B to finish the edges around
the front cover. This is made in the same manner and the edges scraped down
until we have completed the main form of the box, minus the arched section
in the cover.

The reason for omitting this bulge in the first stages of the of the work is
because it is much easier to establish smooth plane surfaces and then add to
them than it is to model the entire form at the beginning.

![Fig. 137.](image)
Now mark out the dimensions of the arch on the flat plane of the cover and begin adding clay until it exceeds the amount actually needed in the finished piece. You will realize by now that the basic principle is to make the rough model oversize and then scrape it down to the size required, rather than attempt to build it up to exact dimensions bit by bit.

![Fig. 138.](image)

Now heap the clay up on the surface and cut another scraping template to conform to the area of the surface bulge. Since this is rather large and sheet zinc bends out of shape easily, reinforce it with a piece of wood cut to a slightly larger radius, fastening the zinc to the wood with steel tacks (Fig. 138). Observe that this template also is made with ample flat at both ends so that its edges will not gouge the smooth surface of the top, and that the zinc protrudes about 1 inch beyond the wood wherever it is to scrape, but is flush with the wood where it rides on the surface of the top, for here you need as much bearing as possible; For even more accurate results, the wooden reinforcement may be made to extend beyond the ends and can be guided on wooden rails nailed to the workbench.

![Fig. 139.](image)

**Fillets and Radii**

Two more scrapers remain to be filed out as shown in Fig. 139, one for the small radius that follows the area of the raised part on parallel edges, X, and a small one for the fillet which will occur where the bulging part meets the plane surface, Y. Neither need be reinforced with wood since they can be held firmly in the fingers without bending. A little handwork with modeling tools will be needed at the four points where radius and fillet meet to join the flat surface of the cover, X and Y in Fig. 134.
The model is now complete except for the decorative ribs. Since this cover will be made on stamping presses, the ribs are to be pressed into the metal so that the peaks are level with the plane surface and the valleys $\frac{1}{16}$ inch below. Mark these out on a piece of zinc and cut and file the ribs to the reverse of the contours wanted in the clay. This template should be guided against a smooth piece of wood cut out on the jigsaw with an are slightly larger than the bulge, and held firmly with the left hand while the scraping is done with the right (Fig. 140).

**Painting the Clay**

It is perfectly possible to paint this model in order to study the final effect. The clay is first given several coats of casein paint, each sanded smooth, then the finish coat or coats sprayed on with a gun. If these preliminary precautions are not taken, the oils in the clay will bleed through the paint or lacquer in a few hours, leaving a greasy film and discoloring the finish coat. Examples of painted clay models, in varying stages of completion, are to be found in Plates 9, 14, and 15.

If great care is exercised and enough coats of casein are applied, each sanded in turn, a clay model can be brought to almost as fine a finish as one made of plaster. The effort is seldom worth while, however, unless time does not permit of making a finished plaster model. These clay studies are made expressly so that we can change the size of radii or fillets, modify the character of the ribbing, or otherwise perfect the proportions. With soft clay it is a simple matter to add more clay, cut new templates, and scrape out the new shapes.

Although the description sounds tedious, this method of modeling mechanical forms in clay is actually far more rapid than building them up by hand and results are more satisfactory.

The example chosen for this demonstration is a simple one, but it contains, in little, nearly all the points of technique involved in making clay models of products without freehand contours. Experience will teach the student many time-saving variations. Even freehand curves, provided they
curve only in one plane, can be rendered with these scraping templates. The example we have just used might have been designed differently, with a freehand curve sweeping down the face instead of a segment of a true circle. In this case the scraping template would be laid out on the zinc, cut and filed to the desired contour, reinforced with wood, and the contour scraped out by pulling the template across the face of the model as previously described (Fig 141).

![Fig. 141.](image)

**Circular Forms**

Circular forms, such as a series of beads, flutes, or grooves, are easily scraped in the clay by firmly fixing a large nail in the center of the circle, bending the end of the zinc into a loop and soldering it fast, then swinging the template around the nail as a center post, as in Fig. 142.

![Fig. 142.](image)

The really well-equipped model shop will have a special piece of equipment, inexpensive to construct, for scraping circular forms in clay or running them in plaster. It consists of a flat wooden surface from the center of which rises vertically a steel or brass rod. A medium-sized bread board will serve for the wooden base. To the center of this a socket is screwed. The hole in the socket may be threaded to receive a similarly threaded rod about ¼ inch in diameter. When working with wet plaster (see Chap. XIX), a sheet of polished plate glass, cut to the size of the board or smaller, is added. A hole is cut out in the center of the glass to fit closely around the socket (see Fig. 143).

![Fig. 143.](image)

With this device various circular forms may be turned out. In fact it will simulate any form that can be made on a lathe (see Chap. XII). Clay can be heaped around the center post, a template cut and looped around it as
described above, and the template. swung circularly until the clay is scraped smoothly to the desired contours. The rod can then be removed and the hole puttied up.

![Fig. 143.](image)

Small round parts such as knobs, which would be difficult to model in clay, may be turned out of wood on a lathe and painted a grayish-green to match the clay.

**Freehand Forms**

Modeling freehand forms requires great skill and long experience. Since the clay is being manipulated by a sculptor, results are dependent largely on the talent and originality of the designer and his feeling for proportion and form--qualities gained only through long contact with varying problems. Even here, however, there are short cuts. Let us suppose that we are modeling the front end of a juvenile automobile, or perhaps a quarter-scale study of a full-sized car. The finished model, minus fenders, is shown in Fig. 144.

![Fig. 144.](image)

We have built the wood core or armature, this time of various pieces of lumber nailed together roughly to represent the chassis. A length of steel rod is affixed to the underside to represent the front axle. Down the center line we fasten with cleats two vertical pieces of plywood, the upper edges of which have been cut out on the Jig saw approximately to the contour of the center line, but about one inch shy of the eventual surface of the clay which will cover them. In the slot formed by these two boards we place, removably, a stiff sheet of steel or brass, about 18 or 20 gauge. This is allowed to extend
an inch or more above the surface of clay. The armature is shown in Fig. 145.

![Fig. 145.](image)

Compo board or some light material is now nailed in to save clay. When the clay is putted in and built up in generous masses, we begin the modeling process. We use scrapers and modeling tools of varying kinds, one of the most useful for purposes of freehand modeling being a metal loop fastened to the end of a wood handle, shown in Fig. 146. The two sides are modeled at first approximately alike to give a rough impression of the hulk we wish to obtain. As the work progresses, however, more attention will be given to one side and the other will be shown reflected in a mirror which has been temporarily substituted for the metal sheet in the slot. (A plated and polished steel mirror will be found good for this purpose.) When the desired contours of the hood and radiator grille have been obtained, the mirror can be removed and the sheet of steel replaced. This now forms a guide for locating templates which will be cut from stiff cardboard to

![Fig. 146.](image)

fit the hood or fenders at intervals of several inches on the finished side, as in Fig. 147. These cardboard templates are then flopped over to corresponding locations on the unfinished side and pressed home into the clay, making marks which guide the modeler in scraping off the excess. Thus in a short time the left-hand side can be made to match the right exactly, the sheet steel removed from its slot, and the crack puttied over.
We now have an accurate clay model of the finished hood and grille, which, if desired, can be treated with casein paint and sprayed with lacquer or enamel to simulate the final product. Fenders, although omitted from the drawings above, can be modeled and checked in like manner.

Modeling clay must not be thought of as material useful only in making small models. It can be used freely in making alterations on full-scale wooden dummies or metal models. We have built adjustable armatures 6 feet high and used hundreds of pounds of clay to study subtle refinements of large machines; in automotive work, full-size clay mock-ups are always made for study purposes.

At the close of the next chapter will be given a complete list of materials and tools for the model shop. In mechanical equipment the sky is the limit, but there is a minimum below which one cannot go without seriously lowering efficiency and slowing down speed of operation. We shall, therefore, give only those items that seem essential.

**Bench-type lathe:** There are many of these on the market. You should study various makes to determine which best suits your requirements. It should have a tilting table with setting for various angular positions and the necessary clearance to turn pieces up to six inches over the bed. Three or four speeds are desirable. A sanding disk attachment is important.

**Motor-operated jig saw:** It is possible to do without this, but it will eliminate a great deal of handwork in preparing armatures, building special cases for carrying and shipping models, etc.

**Compressor and pressure gauge:** This should give up to 40 pounds pressure. In place of the compressor a cylinder of carbon dioxide can be used. This can be obtained from any soft-drink bottling works or commercial chemical house and when empty may be replaced with a full cylinder.
**Spray gun:** For most small-scale model work, it is not necessary to invest in a regular commercial- or industrial-type gun. Some good inexpensive outfits are on the market with adequate glass or metal paint containers.

**Soldering outfit.**

**Small power drill:** Either electric or pneumatic.

**Presentation Models**

The Presentation model is the climax of your labors. If it "goes over," your work is by no means ended, but the remaining activities--the dimensioned drawings, the finished comprehensives of name plates and patent plates, the color specifications, and the supervision of the full-size models--constitute a definite slackening of pace.

The presentation model represents your final recommendation to the client. Here, then, is the place; where no effort should be spared to obtain the last word in perfection of finish and minuteness of detail. Therefore, since the preparation of it is expensive and takes great skill and patience, it should not be attempted prematurely, that is, before the project has been brought to the point where the general scheme has received the approval of executives and engineers and most of the problems of manufacture, assembly, and approximate cost have been reasonably worked out.

The advantages of a model over even the finest airbrush rendering have been mentioned in a previous chapter. It will do no harm to reiterate that a model can be viewed from every angle, can be lighted effectively, and will give a better idea of finish and the exact effect of high lights and shadows than the most carefully prepared drawing. Further, it can be photographed against a plain background in such manner that direct comparisons can be made with photographs of former machines (see Plates 10 and 11).

We had the curious experience of having an eighth-scale model of a large press, which we had designed, photographed by the client and the photograph used in advertising and publicity before the first machine was even assembled. Obviously the manufacturer had to be pretty sure of his engineering in order to take such a chance; it is hardly a procedure to be recommended in many cases, and never with consumer goods.

**What Scale**

The question of scale is important. Generally speaking, your model should be as large as practicable. A full-size model is always preferable and, even though the product under consideration is so large that the model must be made to a fractional scale, the wise manufacturer invariably builds at least one, sometimes many, full-size mock-ups first of wood, and finally in actual metal, during the course of a major design program. Full-size models of large
products, however, should not be expected from the designer, whose facilities are seldom adequate to construct them.

Among products suitable to preparation of full-scale models in the design studio—would be toasters and griddles, electric irons, percolators, desk lamps, typewriters, vacuum cleaners, cameras, check registers, adding machines, table radios, counter scales, coffee mills, and many other items of like size. Accessories and parts such as washing-machine and stove legs, escutcheons and dial groups, levers, knobs, and handles—in fact anything pertaining to a large product which can easily be handled in your own model shop—should always be made full size.

Larger equipment, such as refrigerators, ranges, home laundry machinery, air-conditioning apparatus, stokers, furnaces, machine tools, and tractors will have to be made one-half, one-quarter, or one-eighth scale—whatever is the most manageable and most transportable size without undue danger of breakage. Avoid odd scales, such as three-eighths or three-quarters, not only because they are more difficult to make, but because at a presentation meeting clients often want to scale off measurements from the model and may not have special scales or rulers available.

The small-scale model of a large product has a definite psychological advantage. Most people love a "miniature." This is borne out by the general interest in ship models, toy trains, and small-scale interiors. The very contrast in size with some familiar original shocks the mind to attention. Time and again we have galvanized a gathering of executives into immediate attention and curiosity by unveiling a beautifully finished small-scale model. Even clients who have been indifferent towards a design already seen in the form of a finished perspective drawing may warm up surprisingly when a model is put before their eyes in all the glory of its three dimensions.

There is one drawback, however, to the small-scale model. It is sometimes deceptive and must not be relied upon too implicitly for the refinements of proportion and balance—those subtle interrelations of form that make or break final appearance. Nothing will replace the full-size mock-up. A cabinet leg which looks sturdy enough in miniature may seem flimsy when enlarged proportionately to full size. A name plate may seem in perfect scale on the model yet look like a billboard on the final product. Once we were preparing a quarter-size refrigerator model. Due to an error in dimensions on the model layouts, the miniature door handle was made considerably longer than it should have been, but with model completed and handle affixed it looked quite satisfactory. No one in our office noticed the discrepancy in scale. But when the full-size handle model was begun, we immediately realized that, if attached to a full-size cabinet, it would seem as big as all outdoors.

Occasionally you can skip the small-scale model entirely. Your client may decide, after examining your renderings and clay studies, that he would
like to build a full-size model at once. You must then supply his pattern shop with completely dimensioned drawings, marked "for wood (or handmade) model only." But beware of this procedure if the product is at all complicated or involves many freehand forms. No matter how complete and accurate your drawings, slips are bound to occur, and you must follow every step carefully to see that the final result correctly interprets your scheme.

**Five Steps**

Let us recapitulate, outlining the successive steps involved in a well-integrated design program as far as model work is concerned:

1. Clay or wax studies; prepared by the designer.
2. Rough dimensioned layouts; taken from the above by the designer as a guide to his model maker.
3. Presentation model; prepared by the designer, full size if possible.
4. Full-size dummy ~model or mock-up; prepared by the client from drawings supplied by the designer, difficult parts to be cast from patterns copied from plaster casts supplied by the designer.
5. Full-size working model; prepared by the client and made in metal or other final materials to be used. Usually built from hand-machined parts, castings made from temporary wood patterns, freehand sheet-metal forms swaged on blocks.

We have already described the steps necessary to produce a fairly accurate study in modeling clay. The technique of making presentation models is much more exacting and demands a higher degree of professional skill. The latter may be divided into four groups:

1. Models built up from separate plaster pieces and assembled.
2. Models cast in plaster from a clay or wax original.
3. A combination of both.
4. Models carved from a single block of plaster or other materials.

The materials generally used in the construction of all types of presentation models are as follows:

<table>
<thead>
<tr>
<th>Tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vise</td>
</tr>
<tr>
<td>Hammer</td>
</tr>
<tr>
<td>Saws for wood and metal</td>
</tr>
<tr>
<td>Pliers</td>
</tr>
<tr>
<td>Screw driven</td>
</tr>
<tr>
<td>Wrenches</td>
</tr>
<tr>
<td>Brace and bits for wood and metal</td>
</tr>
<tr>
<td>Spirit level</td>
</tr>
<tr>
<td>Electric soldering iron</td>
</tr>
<tr>
<td>Assorted files</td>
</tr>
<tr>
<td>Scrapers made of sheet steel</td>
</tr>
<tr>
<td>Clay-modeling tools</td>
</tr>
<tr>
<td>Wood-turning tools</td>
</tr>
<tr>
<td>Wood carvers tools</td>
</tr>
<tr>
<td>Die makers files</td>
</tr>
<tr>
<td>Spray gun</td>
</tr>
<tr>
<td>Paint brushes of assorted sizes</td>
</tr>
<tr>
<td>Plaster brushes</td>
</tr>
</tbody>
</table>

Grease brushes
Wire brush for cleaning files
Pans for mixing plaster (several sizes)
Spatula
Trowel (with straight sides)
Spoons
Plaster scoop
Sheets of plate glass
Wooden straightedge
At least one steel square
Several celluloid triangles
Calipers
Dividers
Small plane
6-foot rule
Drawing instruments
Beam compass
Supplies

<table>
<thead>
<tr>
<th>Modeling clay</th>
<th>Masking tape</th>
</tr>
</thead>
<tbody>
<tr>
<td>A good molding plaster</td>
<td>Sheet brass, .005 inch thick</td>
</tr>
<tr>
<td>Lumber; any Soft wood easily workable, for armatures, etc.</td>
<td>Glue, rubber cement</td>
</tr>
<tr>
<td>Pattern-maker's white pine or mahogany, for wood turnings</td>
<td>Casein paint</td>
</tr>
<tr>
<td>Wood doweling</td>
<td>Lacquers</td>
</tr>
<tr>
<td>⅛-inch plywood</td>
<td>Enamels</td>
</tr>
<tr>
<td>Cardboard</td>
<td>Shellac</td>
</tr>
<tr>
<td>Wire (several sizes)</td>
<td>Lacquer thinner</td>
</tr>
<tr>
<td>Solder</td>
<td>Turpentine</td>
</tr>
<tr>
<td>Sheet zinc</td>
<td>Alcohol</td>
</tr>
<tr>
<td>Benzene</td>
<td>Kerosene</td>
</tr>
<tr>
<td>Paraffin</td>
<td>Beeswax</td>
</tr>
<tr>
<td></td>
<td>Sheet celluloid</td>
</tr>
<tr>
<td></td>
<td>Nuts, bolts, screws, nails, tacks, etc.</td>
</tr>
</tbody>
</table>

Modelmaker’s Grease

Many different kinds of grease can be used for casting. Ordinary cup grease or Vaseline will give fair results, though it is usually too thick and must be diluted with a thin oil or kerosene. The grease commonly in use in casting shops is composed of commercial stearic acid and kerosene.

Good results can be obtained by using a grease composed of:

| ¼ pound of beeswax |
| 1 pound of paraffin |
| 3 pints of kerosene |

Heat these together in a double boiler until the wax melts; it will be ready for use when cool. The proportion of kerosene to wax should be varied according to the weather and type of work you are doing. This grease may be thinned, without reheating, by adding kerosene.

1. Built Up Models

In most of your work, this type of model will probably be indicated somewhat more often than the cast model, although that depends on the class of work you handle. Products or machines utilizing the usual processes of sheet-metal fabrication, ill lend themselves to construction by the built-up method.

These processes result in geometrical forms, regular radii, and compass curves. Machining of dies is expensive at best and geometrical forms are more economical than freehand forms. Sand casting, stamping, plastic molding, and spinning are much more flexible; therefore, models of such products may be either cast in plaster or built up.

To construct a successful built-up model, you are beyond the stage where you can experiment, changing as you go along. Guesswork won't do. Consequently you must nail down all dimensions to the last thirty-second of an inch. The drawings from which you work need not be so carefully prepared as the final mechanical drawings, but even though sketchy, every dimension
affecting the exterior must be accurately shown and they must all check out correctly.

Your first job is to study the drawings, analyzing them to determine the simplest and most direct way to construct your model. A previous clay study-model may be at hand to help visualize it. At this stage you are like the general of an army who sends out reconnoitering parties, consults maps of the enemy terrain, and plans his campaign accordingly.

Let us take as an example a comparatively simple form, a domestic refrigerator. Figure 148 represents the product as it will finally appear.

Analyze this to determine how many slabs of plaster you will have to use. Since the model is to be shown with the door closed, the entire body can be hollow, reducing weight and drying time. Figure 149 gives the result of your study, indicating that five pieces will be required. Four of them will have to be "run" in wet plaster with templates filed to conform to the sweep of the parts in question. (The process of "running" the plaster will be described later.) The fifth, the back piece, can be made from a flat slab of plaster, cut to fit. Leave the bottom open. Since the two sides are identical, run them in one slab twice as long as the height of the cabinet, then cut it in half.

Let us begin with this piece and describe the procedure step by step. The model is to be made quarter size. The total height of the cabinet according to manufacturer's specifications is to be 5 feet 6 inches. Therefore, the finished model will be 16 ½ inches.

The average thickness of plaster slabs on models of this size would be about inch, although the ¾inch set-back for toe space will necessitate making the front slab one inch thick or more. If you are working on a wooden table, fasten down a wooden straightedge with a couple of nails and shove a sheet of glass up against
Place a few small nails at the edges of the glass to keep it from sliding back and forth or away from the straightedge. If a slate or marble-topped table is available, you can place the straightedge upon it and clamp it firmly in position at both ends, the sheet of glass then being unnecessary. Next cut out a zinc template to the contour of the side of the refrigerator, making it the inch depth allowed for the side slabs. As zinc is soft and bends out of shape easily, it should be backed with wood, and braces will be found necessary to make it run smoothly and evenly against the straightedge (see Fig.150). Keep the wood backing about inch back from the cutting edge of the zinc so that the former will not come in contact with the plaster.

Mark off on the straightedge a distance a little more than twice the length of one of the side slabs to determine the length of the piece that must be run. After greasing the straightedge and the template, you are ready to mix the plaster.

Put a quantity of water into a pan and sift the plaster slowly into it (a large sugar scoop is useful for this purpose). As the plaster settles to the bottom of the pan, continue the sifting process until there is but little free water left above the saturated mixture. Do not stir until all of the plaster has been soaked with water. The amount of free water left on top determines the thickness of the mix. The first batch should be quite thick, which means that you should give the water about all the plaster it will soak up. Then stir it with a beating motion, keeping the spoon constantly below the surface of the mixture. Fast and thorough mixing will hasten the setting. In any case you must wait until the plaster is thick enough to use. Then ladle it out onto the glass where your template will be run. As it thickens, run the template over it, scraping off the high spots. Add more plaster in the low spots and run the template again. Repeat this process until the slab is perfectly formed to the contour of the template. As the plaster becomes too thick to work, make another and somewhat thinner mix. The number of mixes necessary will depend upon your skill and the shape of the section.

When the template has been run through for the last time, take the slab
up and set it aside to dry; placing it on a radiator will help to drive off the excess water. (Wherever you put it to dry, take care to see that it lies on a level surface or is supported at frequent intervals along its length, since plaster warps or bends easily when wet.) Thus in one run you have formed the two sides of the refrigerator.

The front is made in a similar manner, and the top likewise, with different templates of course. Since the top curves in more than one plane, only one of the curves can be run; the other must be carved in afterward.

The back slab, having no curves, is a simple matter. Place four well-greased sticks of the required thickness on the glass slab to fence in the required rectangle. (Gobs of modeling clay will serve to hold the sticks in place and stop up the cracks between them.) Fill this space with plaster and, when it has thickened, strike the top off level with a straightedge. Now, after sawing your double-length slab in two, you have the five pieces necessary to construct the model. This is merely raw material and from now on the work becomes more exacting and delicate.

First square off the side, front, and back slabs and reduce them to the exact length needed. If you have a sanding disk and table, this will take but a minute or two; it can be done with a plane and scraper, but requires more time. Since there is a set-back of 3 inches for toe space at the front of the refrigerator, cut this into the front slab. Scrape in the division line between the upper and lower doors with a small template and a straightedge. Then stand the four pieces upright on the sheet of glass in their correct relative positions. After testing with a square to see that all pieces are standing perfectly plumb, fasten them together.

Place a little water in a saucer or shallow pan and drop a spoonful of plaster into it. Don't stir the plaster, but let it gradually soak up water. Take a small blob of soaked plaster up on the bristles of a long-handled brush and place it in the angle at the intersection of two of the pieces. Repeat this until all the pieces are caught together in several places. Plaster may then be brushed more freely into these inside angles until the pieces are thoroughly stuck together the entire length of the joints. As the fresh plaster must be thoroughly set before you can handle the now partly assembled model, it should be allowed to stand while you turn your attention to the top.

Let us assume that the section that was run is through the center of the model from front to back. As the front and sides of this model are curved it is obvious that the top slab can be correct in section only on the center line, so that the remainder of the forming on this slab must be done by means of free-hand carving or scraping with additional templates. After cutting off the rough ends and reducing the slab in length to just a little more than its finished dimension, place it in correct position on the partly assembled model and trace on its under side the contours of the front and two sides of the model. Again the sanding disk comes in handy, for you can sand the sides

20
and front of the slab down to these lines very quickly, finishing up with a flat file. Now, from the plan view, our slab is correct in its contours. Referring to the front elevation of our drawings, however, we shall find that there is a radius at each side of the top and a gentle curve over the entire top connecting the two radii, as in Fig.151. With a wood carver's gouge rough out these radii, then scrape them with a zinc template made for the purpose, and finish with a file and sandpaper. The gentle curve between the radii can be roughed out with a chisel or a flat gouge, then filed and sanded.

The top now conforms with your drawing of the front elevation. Since the original section was run with a template made from the drawing of the side elevation, the top will be correct in that respect, at least on the center line. You find however, that in cutting the top to the curve of the front you have ruined the radius at every point except on the center line. You must therefore re-cut this radius between the center line and the front corners, using gouge, template, and file as before. You are then ready to affix the top to the assembled sides, front, and back, which by this time should be thoroughly set.

Now glace the top on the glass with the curved side down. (Use wedges to keep the slab from rocking and to hold it in a reasonably level position.) The rest of the model can then be assembled, upside down, and stuck with fresh plaster as described before.

When this has set you are ready to point up the cracks where the slabs come together. This may be done either by brushing plaster into the cracks or forcing it in with a penknife or spatula. Sometimes you can finish the joint by carefully smoothing it over while the plaster is still wet. As a rule, however, it is better to heap fresh plaster up a little above the finished surface, allow it to set, and then cut it down with a carving tool or file and a little sandpaper. At this time you must also fill all air holes, scratches, and other defects with moist plaster. Before being painted, the plaster must be thoroughly dry.

Finishing

In preparing models for finishing, casein paste paint is very useful. You can mix this paste to any desired consistency by merely adding water, or use it in its original form for filling scratches, small air holes, etc. It dries quite rapidly and can be sanded to a smooth, polished surface with fine sandpaper. Two or three coats of this, sanded after each coat, should prepare the model for its final finish.
Inasmuch as a high gloss finish is desired to simulate synthetic enamel and all parts of the model are easily accessible, apply the lacquer with a spray gun. The first coat should be light to avoid runs. After this is dry, apply a second and somewhat heavier coat. A third coat, still heavier, should ordinarily complete the painting operation. Since the contours of your refrigerator model are rounded, with no fine detail to be lost in the application of too heavy a coat of paint, a fourth or fifth coat could be used to advantage. In any event when the painting is completed the surface should have the appearance of a fine piece of porcelain.

If any of the applications are too heavy and the lacquer runs, let it dry thoroughly and sand the defective areas to a smooth finish before applying the next coat. It is a common error to use paint too thick for spraying, which results in a textured or "orange-peel" finish. Most lacquers need the addition of an equal amount of thinner to bring them to a good spraying consistency. Air pressure of about 40 pounds usually gives good results. If the spray is properly adjusted and no runs occur, it won't be necessary to sand between coats of lacquer.

You are now ready to consider the hardware, name plate, and other details. Let us assume that your design calls for a piano hinge on the door. You may represent this by a piece of wire of the proper gauge, either chrome-plated or coated with aluminum paint. You may carve the door handle from a piece of wood or plaster, or actually cut and file it from a piece of brass and plate it. The manufacturer's name plate can usually be lettered on a piece of colored or metal paper with tempera paint and then sprayed with clear lacquer to protect it from dirt and moisture. Often the completion of such details as this takes as much time as the building of the main mass of the model, but upon them depends much of the final effect; their psychological value cannot be overestimated.

When the design has been accepted, and your client is building full-size models, you will make hardware, name plate, and hinges full size in your model shop, together with many interior details. For this model you will probably make the door handle in clay, then cast it in plaster or cut it directly from a block of plaster. Because of greater accuracy, the latter method is to be preferred in cases where the model is to be sent directly to the diemaker as a guide in making his dies, or used to make a master pattern for a sand casting.

Some full-size models for hardware, such as handles, dials, and escutcheons, are made directly in plaster from drawings, omitting the clay study. This is done either because the designer is sure of the result and wishes only to convey his idea to the client, or because the detail is too small in scale to be expressed in the softer medium,

The ideal way to present metal items of this kind is in the actual metal
from which they are to be made. They can then be mounted on the
manufacturer's mock-up and held in the hand, turned, or otherwise put
through their paces. This can be done by making the plaster model slightly
oversize, to allow for
shrinkage, and having it sand-cast. A good molder with the proper sand
can make a casting which, when filed, buffed, plated, and polished, will be
the equal of any die casting. This type of model leaves no doubt in the
client's mind as to the final appearance.

When this procedure cannot be followed, the next best thing is to finish
the plaster model to look as nearly like metal as possible. One way of
attaining such a result is to spray it with clear lacquer and, when partially dry
but still tacky, to brush it with aluminum powder. The powder will adhere to
the lacquer but, being free from any coating, will give a higher luster finish
than if it were mixed with the lacquer. You can get an even better polish by
giving it a light buff on a soft wheel. Spraying on a mixture of the powder
and clear lacquer (to which has been added a high percentage of thinner) will
give a finish almost as good.

Full-size name plates and trade-marks can usually be painted on metal-
coated paper with tempera paint, or on a thin sheet of metal, and sprayed
with clear lacquer, as in the scale model. Dial glasses, if not curved in more
than one direction, may be simulated by the use of sheet celluloid. Convex
forms call for the use of Lucite or other transparent plastics, turned on a
lathe.

2. Cast Models

The technique of casting a model from a clay or wax original differs in
no essential way from the process used in casting a piece of sculpture.
Various textbooks on the subject describe
it in much greater detail than can be given
here. However, the average problem met
with in industrial design is likely to be
much simpler than casting, let us say, a
bust or a full-length human figure. Let us
attempt, therefore, to describe the various
operations involved in making a plaster
cast from a full-size plastilene model of a
vacuum cleaner body, which involves soft
rounded forms and will eventually be cast
in some, alloy of aluminum by sand-casting, permanent mold, or die-casting.

In order to produce a good plaster casting, your clay original must be
finished with great care. The better the job of clay modeling, the better the
resulting plaster replica and the less hand finishing and patching you will
have to do.
When you have prepared a clay study model, it is sometimes debatable whether it will be best to cast the presentation model from the original study or to start from scratch and build an entirely new model in plaster. Much depends upon the nature of the design as well as the care with which you have made your clay model. Casting is usually indicated where freehand contours predominate, but it can often be employed to advantage on models consisting entirely of flat surfaces and mechanical curves if too many pieces are not required in the mold.

Figure 152 represents the finished machine. Your first job is to prepare a plaster mold, or negative, from which the final casting will be made. First analyze the clay original to determine how many pieces will be required for the mold. The forms should be divided up so that the smallest number of parts are needed. These must fit together perfectly to receive the poured plaster which will eventually harden and form an exact replica of the clay original.

Be sure to model the clay carefully so that it is symmetrical about the center line. In Chap. XIII the method of checking one side against the other was described in some detail. Smooth out bumps and hollows in the clay surface to as smooth a finish as possible. Your analysis now shows, in order to "draw" properly and permit the final casting to be removed from the mold without breaking, that you need four pieces, divided as shown in Fig. 153.

After fixing the boundaries of these divisions carefully in your mind, erect small metal fences upon them. This is done by cutting gut pieces of thin sheet brass to conform as nearly as possible to the various curves of the model, then pushing them part way into the clay so that they stand out about an inch from the surface. You now have the four parts of the mold clearly defined, and you are ready to begin the work of casting the pieces one at a time. Note that the pieces are numbered in the order in which they are to be cast.

The next step is to mix the amount of plaster necessary for the first piece in a pan or bowl and allow it to stand until it just begins to thicken. Then splash part of it onto the model so that it makes a thin coating about 1 inch thick over the entire area of the piece you are casting. (A spoon, spatula, or small wooden paddle may be used for this purpose.) After the clay is covered and the plaster in the bowl thickens, apply it with a trowel or spatula until a fairly even coating 1/4 inch to 1 inch in thickness is attained.

Since piece 2 has no common boundary with piece 1, you do not have to wait until the plaster of the first is set before beginning work on the second. In fact both of these' pieces could be made at one time by an expert caster,
but it would not be advisable for the beginner to try this. Instead, put the second piece on in the same manner as the first and when it has set you are ready to take out most of your metal strips. Remove all of the fence except the part forming the common boundary between pieces 3 and 4. Smooth the model over where the metal strips have been removed, grease the sides of the first two pieces, and cast the other two between them. After piece 3 has been cast, the last of the fencing can be done away with and the last piece cast with the other three forming its boundaries.

When the plaster in the last piece has set, remove the four pieces from the model and set them up on a sheet of plate glass in their correct relative positions. Then stick them together by means of fresh plaster applied to the joints on the outside in much the same manner as you assembled the pieces of the built-up refrigerator model. Do not bother to fill the joints on the inside of the mold, as these will make only small ridges on the casting which can easily be scraped or cut off. Next, apply a coat of shellac to the inside of the mold and, when this dries, grease it thoroughly. You are now ready to pour the casting.

You have your choice of making a hollow or a solid casting. If the casting were to be solid you would simply pour the mold full of plaster and strike it off level with a straight edge when it had become partly set. In this case, however, you have decided to make a hollow casting because it will be lighter and will dry more easily.

Pouring a small amount of plaster into the mold, pick it up and rotate it so that the plaster travels over the entire inner surface of the mold leaving a coating behind it as it moves. Continue this, pouring in more plaster and building up a heavier coat as the mixture becomes thicker. When it is too thick to handle in this manner apply it with a spoon or trowel, building the coating up to \( \frac{1}{2} \) inch or more in thickness. Striking off the top with a straightedge, let the cast become thoroughly set before removing the mold. After the cast has stood 15 or 20 minutes take a chisel and cut away the plaster binding the pieces of the mold together. Having removed all of this, drive a chisel into the crack between two of the pieces thus prying one of them loose. By this means you can remove all of the pieces but one. The last one can be driven off with a hammer and a block of wood.

Having removed the mold from the cast, inspect the latter carefully. An inexperienced person would probably be shocked to discover that surfaces he thought nearly perfect in the clay model now appear to be full of bumps and hollows. This is due not to lack of fidelity in the casting, but to the difference in color and character of the materials. These irregularities are not so noticeable in the soft gray green of the clay as in the merciless white of the plaster; and it must be borne in mind that if this model were finished at once in bright aluminum paint they would be even more noticeable. You will also discover a number of air holes in the casting as well as ridges where the pieces of the mold came together. These ridges can best be removed while
the cast is still wet and comparatively soft. Fill the holes also at this time. Then dry the cast out by placing it on a radiator or in an oven with a low fire. When the plaster is dry, go over the surface with files and sandpaper to remove all irregularities. The model can then be painted with casein paint and finished in the same manner as the built-up model previously described.

3. Combination Models

Frequently the two methods described above will be used in a single model, and the parts assembled. The procedures are the same. If the plaster is quite dry, you can fasten them together with china or airplane-model cement. A better way when conditions permit is to cut grooves across the joint, lay pins or pieces of stiff wire in the grooves, and fill with wet plaster. Doweling or even nailing may be resorted to under some circumstances. The latter is best done, however, before the plaster is dry. After parts are joined in proper location, you can make fillets by loading on plaster in the angles formed by the juncture of the parts and before it has completely set, scraping with a zinc template filed to the proper radius.

For the preparation of small and medium-size models, plaster is the most satisfactory material. It can be worked easily and it is hard and smooth. Plaster is much easier to patch and alter than wood. For spherical and cylindrical parts, however, such as knobs, tubes, etc., wood turned on the lathe may be quicker to make and stronger.

It is unwise to try to use wood and wet plaster together. Even if the wood is well shellacked before coming in contact with the moisture, it will be only a matter of time before expansion and contraction of the wood in varying humidities will cause the plaster to crack away.

For small objects to be manufactured in synthetic resins, your model shop may be called upon to make models full size in some plastic material. The thermosetting plastics, such as most of the phenolic and urea-formaldehyde compounds, are too brittle to be of value. But they may be simulated in various cast phenolics, cellulose-acetates, polystyrenes and the newly developed acrylic materials such as Lucite. The latter, almost as transparent as glass, can even be turned out on the lathe to represent wine glasses and tumblers that can hardly be told from actual crystal, except for the weight and flexibility. Nearly all of these materials can be obtained in rod or bar stock in various lengths, and some can be bought in solid blocks of almost any desired thickness as well as a large variety of colors and degrees of translucency.

In machining synthetic materials, take great care not to work the material at too high speeds, for the friction created may heat them to a point where their structure and character are destroyed.
4 Carved Models

Occasionally you may be called upon to provide models of lettering, floral designs, surface patterns in relief, etc., which would not come under any of the above headings, but rather would be analogous to wood or stone carving. If the relief is high and the forms rather bold, you can model the design in clay and make plaster casts in accordance with the procedures outlined above. If fine detail is involved, however, the modelmaker may be called upon to cut the design directly in plaster with chisels and gouges. In this case he works very much like a wood carver and uses much the same tools, although his material is a slab of plaster, cast with as smooth a surface as possible, and carefully prepared to avoid air holes or other imperfections. If the pattern involves a regular repeat you may save yourself a great deal of work by carving only one section in plaster, making a mold, casting a number of pieces from this, and then piecing them together.

Such models are sometimes required for articles to be made by die-casting, rubber-mold, or plastic-mold processes. Therefore, carve your model as it will appear in the finished piece, then provide the client with a plaster cast taken from this original, but showing the design in reverse. From this the diemaker prepares his dies or molds, reproducing the plaster piece faithfully in steel, beryllium copper, or other material. Plate 11 shows the original design for a rubber heel, carved and cast in plaster three later reproduced in steel on a pantographic machine times the size, and