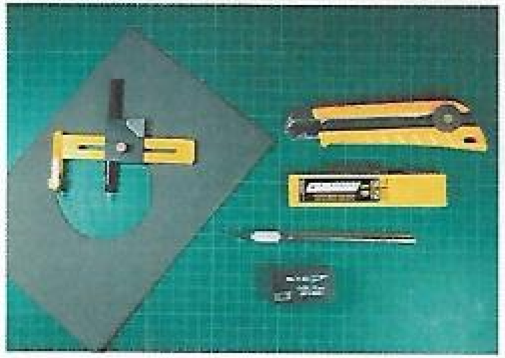
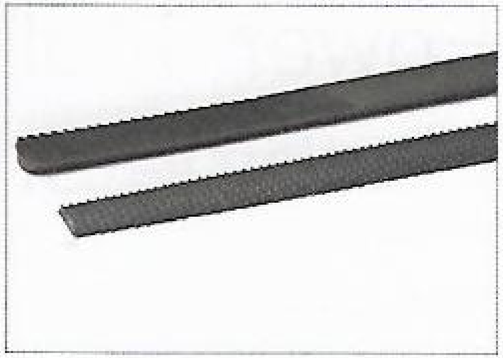
PRO 204 – Modeling Prototyping

POWER TOOLS AND MACHINE SHOP TOOLS

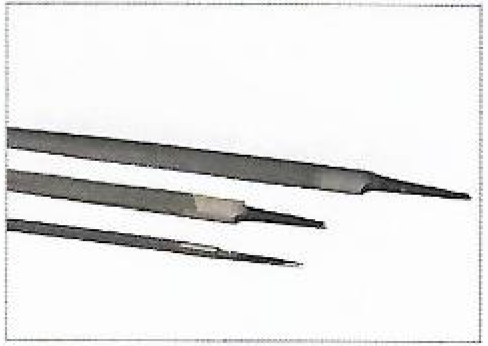


A Stanley knife and scalpel should be stocked with extra blades and used on a cutting mat.



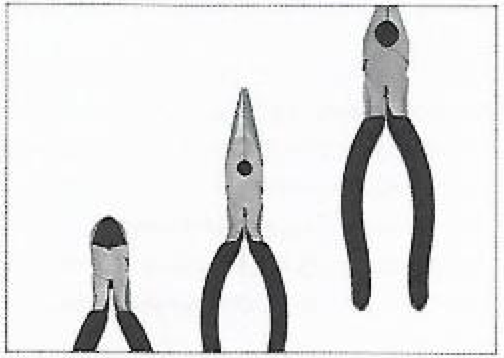
Rasps have large teeth and are essential for rough shaping of wood and other soft materials.

Different grit sandpapers are required for modelmaking. A basic toolset includes a range of coarse to fine sandpaper.



It is useful to have both flat and round files available.

Needle files are sold in kits and are for fine work and detail.



Pliers come in many shapes and sizes, including diagonal, long nose and combination types.

Cutting Tools

Precision-cutting tools include the scalpel and the Stanley knife. These should be stocked with an ample supply of sharp replacement blades. Make sure not to leave knife blades exposed and to keep all knives and blades safely away from children. Also wear eye protection, since a snapped blade creates a potential hazard. A cutting mat is essential for safety and will extend the life of the cutting blades, protect furniture and create a better and cleaner cut. Specialty cutters such as the circle cutter or a mitre cutter are not essential, but can save time.

Files and Rasps

Hand-shaping various materials requires a good set of rasps and files. Rasps will work effectively at removing large amounts of material from wood or foam. Files also work on a variety of materials and are useful for removing burrs and sharp edges on metal and plastic sheet. A workflow using rasps is shown in Chapter 15 (page 135). These tools are always used in conjunction with a vice to secure the workpiece.

Assortment of Other Small Modelmaking Tools

Other small hand-held tools include a hobby saw as well as pliers to hold small pieces while gluing and also to bend or cut small pieces of metal or wire.

Sandpaper

Sandpaper varies in coarseness, or grit. The lower the grit number, the coarser the paper. Sandpaper with grit below 100 is very coarse and will remove material quickly and can therefore be used to shape a surface. The medium-grit sandpaper of 240–320 will create a fairly smooth finish, whereas grit of 400–600 will start to polish the part. Different grits are therefore used in succession.

Rotary tools, such as this one made by Dremel, include a wide array of small bits suited to modelmaking work.

Hand-held drill, circular saw and jigsaw.

Table-mounted and floor-standing drill presses.

Drill press speed can be adjusted through a pulley arrangement between the motor and spindle. This should only be done when the machine is stopped and unplugged. The chart on the bottom of the guard cover on this machine shows speed options.

Workshop tools can loosely be categorized into three categories. Hand-held power tools are quite common and are sold for professional as well as home use. Stationary power tools include hobbyist varieties. The last category consists of larger industrial machine tools. Never operate any power or machine tool without obtaining professional training and supervision. The following description of various power tools is simply an overview of what they are used for and should in no way be interpreted as a substitute for proper training and education in the use of these tools. As a general safety preparation:

— Always wear safety glasses when using power tools
— Tie back long hair and remove loose clothing and jewellery that could become caught in the machine
— Wear proper footwear

Hand-Held Power Tools

A rotary hobby tool is a versatile modelmaking tool. It is supplied with a number of tool bits for cutting and grinding, as well as sanding. They are a useful addition to most basic toolkits, given their small size and versatility. Dremel is a popular brand of these tools.

Larger hand-held power tools include a cordless drill, a circular saw for cutting sheet materials and a jigsaw for cutting more complex outlines in sheet materials. Cordless versions now exist of many of these types of tools, adding even more mobility and flexibility.

Stationary Power Tools

Drill Press

The drill press (or pillar drill) is more accurate than a hand-held power drill and will provide more guidance and control during the drilling operation. Drill presses can also be used with circular saws, drum sanders and countersinks. The drill press is either floor or bench mounted and has an adjustable table that can be lowered or raised depending on the size of the workpiece. The drill bits are mounted in a chuck that turns via a motor. The speed can be changed through a pulley arrangement on top of the machine, which should only be adjusted when the machine has stopped and is unplugged.

Different materials require different cutting speeds. Steel, for example, needs to be cut at a slower speed than aluminium and also requires that cutting oil be used. A smaller diameter tool also requires a higher speed than a large diameter tool, since the velocity at the tool perimeter is lower. Refer to a drill speed chart for recommended speeds.

In addition to the general safety preparations listed above:

- Do not operate a drill press without adequate training and supervision
- Never hold a workpiece by hand, instead secure it by clamping it solidly to the work table
- Tie back long hair and remove loose clothing and jewellery that could become caught in the machine
- When drilling large pieces, secure them on the left side of the work bed as an extra safety precaution. A dislodged piece will then hit the back column
- Do not wear gloves that can become caught in the rotating spindle
- Never try to stop the drill by hand
- Unplug the machine before changing speeds
- Remove chuck key before starting the machine

Bandsaw

This is one of the most versatile power tools for modelmaking purposes. It can be used to cut a variety of materials, including plastics, polystyrene foam, polyurethane modelling board, wood and metals. A 36cm (14in) bandsaw is a standard feature in many small workshops. The bandsaw blade is tensioned between two wheels that rotate it in a circular path. A saw-blade guide has to be adjusted to be almost flush with the top of the workpiece, before cutting.

The bandsaw can be used to make straight or angled cuts, as well as curved cuts. This power saw can do the jobs of most other saws put together. A thin blade will allow the bandsaw to work like a jigsaw and cut the most intricate detail, whereas a thick blade will allow for a straight-line cut much like a table saw.

In addition to the general safety preparations listed above:

- Do not operate the bandsaw without adequate training and supervision
- Always keep your fingers and hands away from the path of the blade in case you slip
- Make sure that safety guards are in place and that the vertical guide/guard is adjusted to an appropriate height above the workpiece
- Use a push stick to push material through saw
- Never change blades without stopping and disconnecting power to machine

Scroll saw

The scroll saw is similar to the table saw and is one of the more versatile power tools for modelmaking. The scroll saw has the benefit of being able to create an internal opening. Since the saw blade is removable it can be inserted into a hole opening to create the cut from inside. If a scroll saw is not available, a hand-held jigsaw can usually be used. Scroll saws have an upward and downward stroke that tends to pull the workpiece vertically. It is therefore important to maintain a good grip on the workpiece. This involves both using the machine's hold-down foot and maintaining sufficient manual pressure on top of the workpiece.

In addition to the general safety preparations listed above:

- Do not operate the scroll saw without adequate training and supervision
- Always keep your fingers and hands away from the path of the blade in case you slip
- Use the hold-down device and sufficient pressure to keep workpiece secure
- Never change blades without disconnecting power to machine

Sanding Disc, Belt and Post Sanders

Stationary belt sanders are useful for flattening and creating curves or for

Different types of drill bits from left to right; countersink, twistdrill, spade drill and holesaw.

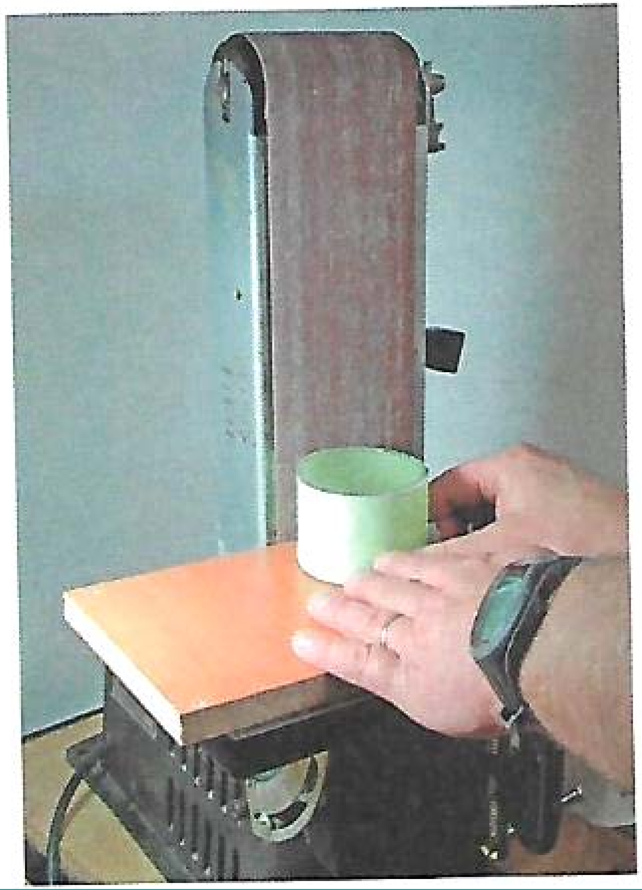
The bandsaw is a versatile shop tool for sawing straight as well as being useful for contoured cuts.

suitable for fine detail work and fitting. Smaller desktop machines are usually combined into one unit. Belt and disc sanders are usually used after the bandsaw to create the final edge finish. The outline is cut using a template, leaving approximately 1–2mm (1/16 in) extra for sanding.

The post sander is a useful tool for sanding cavities and concave shapes. It can also be used to shape circular openings after scroll sawing. For the small workshop, this tool can be substituted with a drum sander fitted on to a drill press.

In addition to the general safety preparations listed above:

— Do not operate power sanders without adequate training and supervision
— Make sure to have a dust-collection system running and wear a dust mask
— Always keep your fingers and hands away from the sanding surfaces
— The clearance between the sanding surface and work table should be adjusted to be minimal to prevent material from being pulled into the crack



Machine Tools

These machines are generally found in large machine shops as well as many schools, but require an exceptionally high level of training and supervision. When used in a safe, professionally supervised situation, then manual machine tools are still very useful as they produce very accurate parts. The cutting speeds and feeds have to be controlled and are a function of the material and cutting operation. Material is not removed in one pass, instead it is taken off in steps involving rough and final finishing cuts. A rough cut involves removing a larger amount of material than the final cut, but does not have the same fine finish.

Lathe

Woodworking lathes and metalworking lathes are two different types of machine that operate on the same principle. The workpiece is rotated, also known as turned, against a cutting tool that removes material to create radial symmetry, for example, bowls or cylindrical and conical shapes. The size of a part is limited to the maximum diameter that can be swung above the bed while turning. This is a function of the clearance between the bed and the revolving headstock spindle. The workpiece can be mounted directly onto a faceplate, held in a chuck or between the two mounting ends. Proper set-up and mounting is highly dependent on the shape of the part and the operation. It is therefore very important to get a technician to advise and guide you through the steps.

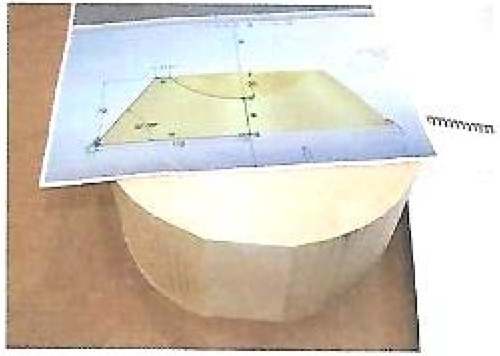
In the woodworking lathe, the cutting tools are held and guided by hand. This means that the accuracy is dependent on skill. Material is removed gradually and in steps. Templates are usually used to check the form, but only while the machine is turned off and the spindle has stopped turning. There are a wide variety of cutting tools that are suitable for different types of cut and detail. The basic tools include gouges for material removal, chisels for detailing and parting tools to cut deep grooves or to separate the part.

The metal-cutting lathe is a much more complicated piece of machinery. The cutting tools are guided and held in a carriage that can be accurately positioned using a hand wheel or a power leadscrew. This is a precision tool where all measurements are calculated and measured using the dials and settings on the machine. Metal-cutting lathes are also used to machine screw-threads. Specific tools are used for roughing cuts and for finishing cuts. The cutting tools are also specific to the material being turned.

Please see the safety reminder at the end of this section as well.

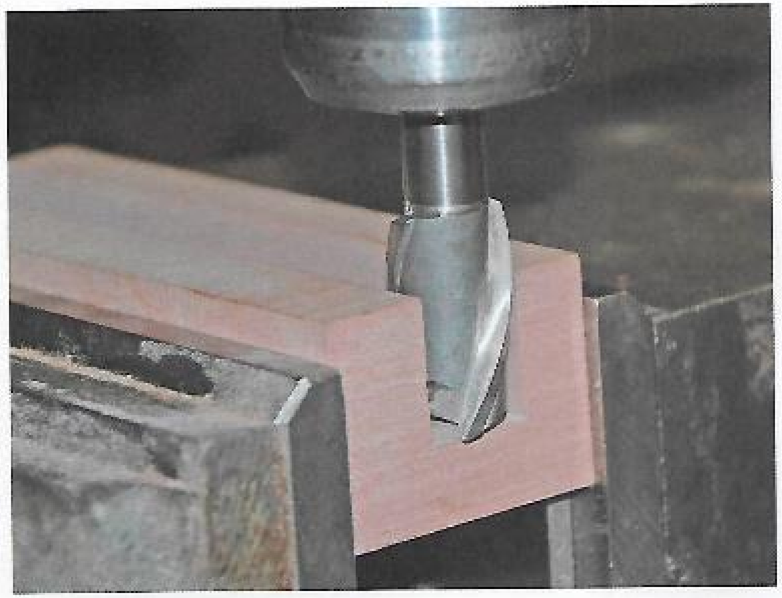
The metalworking lathe is a high-precision machine that moves the cutter along three axes to cut circular items. In this case the brass workpiece is held in a 3-jaw chuck. A clear polycarbonate guard is folded down during the machining.

A wood instructor supervises a student using a wood-turning lathe.



This bowl-shaped vacuum-forming mould was made on the wood-turning mill using a computer-generated template as a guide.

A knee mill can be used to create a variety of accurate cuts.



The Vertical Mill

The vertical mill resembles a drill press, except that it has three axes that allow the operator accurately to move a cutting tool relative to a fixed workpiece while cutting. Smaller desktop mills simply have a movable XY table, whereas larger knee mills allow the table to be raised and lowered as well, to accommodate larger workpieces. The accuracy of the movement is based on manual or electronic indicators. The head on the mill can be swivelled to perform angled cuts. A rotary axis can be added to machine circular shapes with a mill (similar to turning).

The end mill is the standard cutting tool for the milling machine and is available in two- or four-flute designs. End mills come in different diameters and lengths, suitable for a variety of cutting operations. The end mill can be used to mill holes, slots, pockets and surface cuts. For example, a pocket can be milled by lowering the end mill into the material and then tracing the contour of the pocket.

Machine tools are very complicated and involve a high level of understanding of materials, fixturing and set-up, as well as tool selection and machine setting. Machine shop technicians go to school and study this subject in detail, followed by significant industry training. It is paramount to understand that whereas this equipment is useful and a valuable teaching tool, these are dangerous and powerful tools that can easily cause very serious harm or death if treated casually or without proper training and supervision.

In addition to the general safety measures listed in this book:

— Do not operate any machine without adequate training and supervision
— Never attempt a set-up or operation that you have not been trained to do
— Know exactly where the emergency stop and off switches are located
— Make sure all safety guards are properly in place
— Always wear safety glasses
— Tie back long hair. Remove loose clothing and jewellery that could become caught in the machine. Do not wear gloves
— Never touch or try to remove shavings by hand while the machine is running
— Never reach around or behind the workpiece, nor attempt to do any measurements while the machine is running

Such parts as these can be printed in a matter of hours, allowing students to incorporate more detail into their projects.

Rapid Prototyping

Safety Check

- Read Chapter 5 on health and safety
- Obtain SDS for any uncured rapid prototyping materials that you handle or for any materials used for infiltration

Rapid prototyping (RP) is an additive computer-controlled process that builds parts inside a machine, layer by layer, using a variety of materials and processes. Also known as solid free-form fabrication, additive manufacturing, or 3D printing, this technology has revolutionized modelmaking by enabling physical prototypes to be output directly from the computer. From its beginnings in the late 1980s to the present, it has transformed our thinking about making prototypes, changing the process from one that takes place in the confines of the workshop to one that requires no more complexity than sending a file to the printer. This ability has greatly affected the speed of product development. The complexity and detail inherent in rapid-prototyped parts is especially useful when creating models of injection-moulded plastic parts. Thin walls, bosses and ribs are difficult to make by any other method. It also means that the risk associated with making expensive and complicated mass-production tooling is reduced, since the design can be evaluated and tested for form, fit and function prior to tooling.

There are both advantages and limitations inherent in rapid prototyping:

Advantages

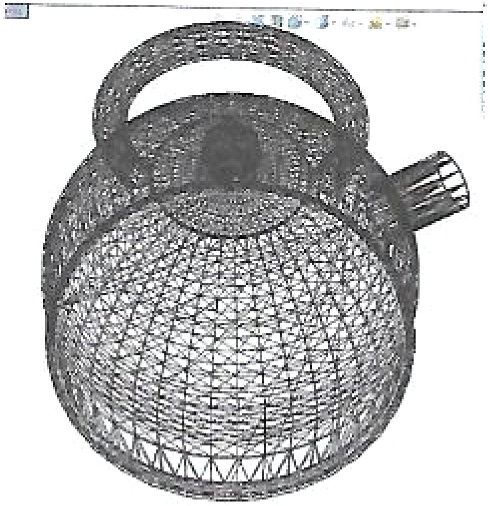
- Parts can have complex geometry (for example, all the typical internal features seen in an injection-moulded part) making them very useful for part verification prior to tooling
- Cleaner and safer compared to traditional machine shop practice
- Encourages more iteration
- Easier to make hollow parts that can be fitted with electronic or mechanical components

Limitations

- Material choices
- Requires access to a 3D CAD system
- Size of build volume
- Cost is directly related to volume
- Simulates predominantly plastics, rather than other materials such as textiles

Process

The development of rapid prototyping is tied directly to the development of 3D solid computer modelling, which made it possible to fully describe a solid object on the computer. It is necessary to have access to a 3D CAD program, and the required skill therefore moves from being able to build the parts physically to being able to manipulate 3D geometry on the computer. This fact is often overlooked, and the efficacy of the process can be severely affected if the designer does not have a good grasp of 3D CAD. The type of software used also affects the process. Parametric solid modelling software programs, such as Creo™ Elements/Pro™, SolidWorks® or Autodesk Inventor®, are inherently solid-based, whereas some software is primarily surface-based and requires that the operator knows how to stitch all the different surfaces together to describe a watertight solid that in turn can be printed. Once the 3D CAD geometry has been created as a solid, it is possible to create a rapid prototyping part.



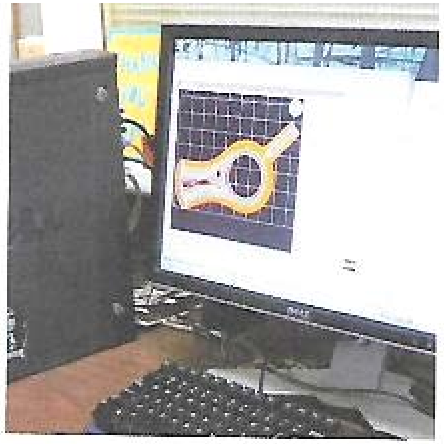
The resolution of an STL file is a function of a number of triangles that approximate the shape. The file on the bottom is three times larger than the one on top, but would create a smoother surface.

Data Translation

The 3D CAD file must first be translated into a format that the rapid prototyping system can read. This is known as an STL (stereolithography) file format and comes pre-packaged with most of the typical software programs used for CAD. The STL file is simply an approximation of the original solid using a triangulated surface mesh that is easy to import and manipulate in the rapid prototyping system. It is important to set the tessellation quality to be appropriate to the surface being generated. A sphere, for example, will require more triangles than a flat plane.

Rapid prototyping software then creates a series of sections, or slices, taken vertically through the model. These sections will be used to produce the 3D model. Each slice must be described as an enclosed area, which is printed sequentially one layer on top of the next until the entire volume has been created.

The software also has to determine if there are areas where a section is unsupported during the printing cycle. This happens when the geometry is overhanging or otherwise unsupported from below. The rapid prototyping systems therefore need some way in which to add support structure during the printing process in order to prevent the model collapsing while being built. Part orientation during the build is a major consideration since it affects how much support structure is required.



CatalystEX software is used to prepare a part for printing on a Dimension 3D printer. The software creates support structure automatically.

Technology Considerations

There are many differences between the various rapid prototyping technologies. The following overview of the fundamental technologies and systems is not meant to pinpoint specifications, since they continue to evolve and improve. It does, however, highlight some of the inherent advantages and limitations of various systems. It is worth considering many different issues when selecting a process for prototyping as in most cases it is a matter of trade-off between cost, speed and material properties.

What is the Difference between Industrial RP Systems and 3D Printers?

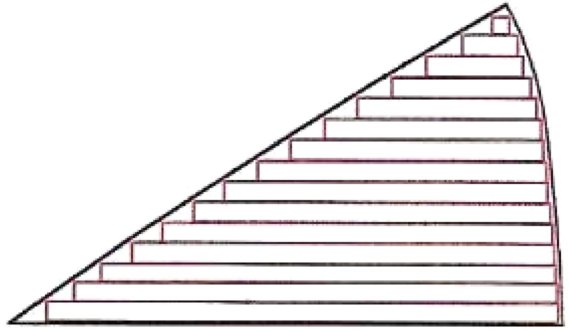
When rapid prototyping (RP) systems first emerged in the late 1980s, the high cost and complexity confined them to service bureaus or large corporations with dedicated prototyping facilities. At that time 3D solid modelling software was also expensive and less common than 2D drafting programs. The next ten years saw a drastic reduction in cost of solid modelling software and as it started to become the norm, the demand for rapid prototyping parts grew substantially. New RP technologies started to emerge to tap into this larger market. Consequently, the cost, size and complexity of rapid prototyping equipment dropped significantly, to the point that schools and design offices can now afford to own and operate their own machines. The smaller systems are generally referred to as 3D printers and are intended to be easy to use and networked in an office environment. Whereas the industrial systems have tended to have larger build volumes, more material selection and better resolution than their 3D printing counterparts, there is rapid convergence in terms of these qualities that keeps making 3D printing ever more accessible and desktop-friendly. There are some limits though – at the time of writing the 3D printer systems offer very limited elastomeric or clear plastic part capability, although this is possible with higher-end systems. 3D printers can, however, be used to print a 3D pattern in order to make silicone moulds (see Chapter 17, page 147) from which clear or flexible prototype parts can be produced, although this does require extra work.

Some industrial systems are now starting to compete with mass-production technologies such as injection moulding. The resulting benefit is greater manufacturing flexibility since no tooling is required. Tool-free production means you have the freedom to make changes more easily, get up and running faster and not have to worry about sink marks, draft angles and a host of other injection-moulding issues associated with steel tooling. The onus on the industrial systems is therefore to reduce post-operative procedures, while increasing accuracy and throughput in order to be competitive.

Build Material

The RP systems are classified according to the different material technologies they use: photo-curable liquids (photopolymers), solid powders or extruded plastic. The material selection is an important aspect of prototyping. The range of material properties needs to be considered carefully in the prototyping process, as there are associated trade-offs in cost, strength, surface quality and colour. If it is a works-like prototype that is to be handled and subjected to loads, it will need to have more strength than if it is a looks-like prototype made mostly for show and tell. The looks-like prototype on the other hand will need a high-level cosmetic finish if it is to be used for trade shows or other promotional material, such as pictures for packaging. This level of prototype may instead require a material and process that provides a better surface finish. Another trade-off is that many photopolymers are sensitive to heat and may deflect, or deform, even at modestly elevated temperatures. The heat deflection temperature (HDT) data therefore should be examined to see if it is applicable to the prototyping application.

For interactive electronic products, rapid prototypes are perfect because electronic components can easily be incorporated. For casings that are meant to be repeatedly assembled and disassembled, it is advisable to use threaded brass parts that are typically inserted into plastic bosses using a soldering iron. They can also be glued into oversized holes with cyanoacrylate glue (see page 79).



The staircase effect is more visible on a gradually curved surface and with systems that use thicker build layers.

Rapid prototype parts can be fitted with threaded brass inserts. These allow easier opening and closing of the housing using machine screws.

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