Post-viewing comments

The chief thermoplastic of interest to Flymo is ABS (acrylonitrile-butadiene-styrene) which is mainly used for hoods on the air-cushion mowers. Flymo processes about 3000 tonnes per annum of the toughest grades available, and its molecular structure is important for determining its use in a very demanding application. An appreciation of its flow properties helped to overcome the family moulding problems mentioned in the video. Being a large-scale manufacturing unit has encouraged the company to apply robots in a variety of ways, keeping unit costs down to a low level.

Materials selection and design

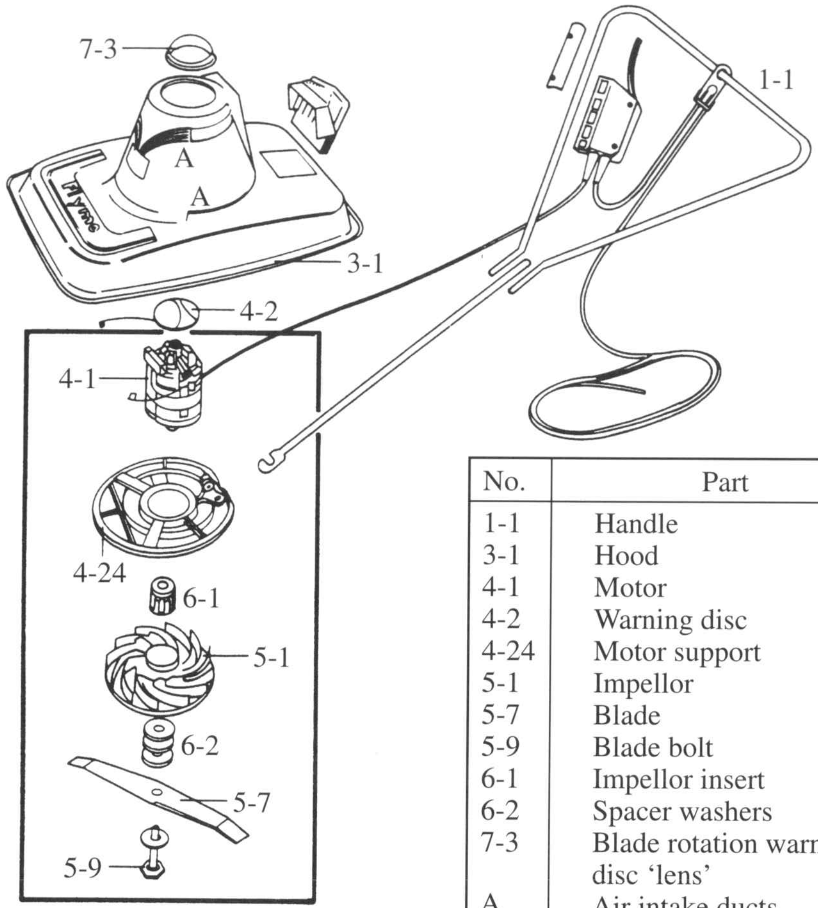
ABS has a microcomposite structure with spherical polybutadiene particles in a matrix of styrene-acrylonitrile copolymer. When a stress is applied to the material, a 'craze' forms at the surface of each rubber particle – each craze absorbing energy since the polymer is torn apart to create voids. The rubber particles are about 1 μm in diameter and the content is 20–30 wt%; so clearly a great deal of energy is absorbed in impact (1). This is what gives ABS its toughness over and above polystyrene homopolymer or styrene-acrylonitrile copolymer (**Block 5.2 and Data Book**):

Izod impact strength:	PS	1
(relative to PS)	SAN	1.2
	HIPS	3.5
	ABS	8

High impact polystyrene (HIPS) is a low rubber content styrene polymer grafted to polybutadiene and may be regarded as an intermediate polymer between PS and ABS. When ABS is processed in the melt, the morphology disappears, but on cooling it reforms, so preserving its strength. A key reason for this reversibility is the fact that the rubber chains are *chemically* bonded to the styrene-acrylonitrile chains. The principle of 'rubber toughening' is now very commonly employed for a range of homopolymers – nylon being a good example, where rubber-toughened grades are commercially available (e.g. du Pont's ***Zytel*** nylon). Other tough engineering polymers include polycarbonate and polypropylene-co-polyethylene, but the former is considerably more expensive (by about a fact of four) and, although polypropylene is much cheaper, it is only about half as stiff in tension (**Data Book**).

Of the dozen or so grades of ABS available from one of the principal suppliers, Flymo chose the highest impact grade. It has a relatively low softening temperature (93 °C) and a low melt flow index or MFI. The flow ratio or index is a simple measure of how far molten polymer will flow along a standard tube or – for ease of moulding – a spiral. The higher the flow ratio or index, the further the polymer will flow (see **Block 3**). The softening point is usually determined by the point at which a test bar will deflect more than a prescribed amount under a given load – in this case, a 5 kg load. The stiffness is also a key parameter in design. If the material is not stiff enough in its moulded form, it will not hold the motor in place and will deform too easily when loaded in service or will allow the product to vibrate extensively when subjected to out of balance forces. For high impact grades of ABS, the higher rubber content necessarily implies a less stiff material. However, an acceptable compromise is to thicken up the hood to give a greater part stiffness.

Of the other polymers used in the Minimo (**Figure 1.1**), Peter Ginger pointed out the use of styrene-acrylonitrile copolymer for the warning disc cover (Part No 7-3) – the material is stronger than polystyrene, yet retains transparency for viewing the rotating warning disc. It also has a higher glass transition temperature than polystyrene alone. The extruded corrugated hose is composed of a random copolymer of ethylene with vinyl acetate (EVA) – the material is rubbery, so the hose is flexible in service. Extra strength and stiffness are provided by the corrugations, which also help inhibit crimping of the hose when bent at extreme angles. The second step in the process involves bonding with a low molecular mass EVA used as a hot melt adhesive – this adhesive forms an extremely strong joint simply because it softens the surface profile to be joined and as the adhesive cools, the joint formed is virtually continuous material.



No.	Part
1-1	Handle
3-1	Hood
4-1	Motor
4-2	Warning disc
4-24	Motor support
5-1	Impellor
5-7	Blade
5-9	Blade bolt
6-1	Impellor insert
6-2	Spacer washers
7-3	Blade rotation warning disc 'lens'
A	Air intake ducts

Figure 1.1 Component parts of the Flymo Minimo 'E' air cushion mower showing hood and handle at the top and the motor, impeller, blade assembly. The impellor fan draws air in through the ducts moulded into the side of the hood (AA) and throws a stream of air onto the underside of the flat top where it is redirected onto the ground surface at the end of the hood. Those components enclosed by the box are assembled by a Unimate robot

Processing

A trade moulder is primarily concerned with producing components to outside contracts, often to the extent that the customer owns the tool which shapes the moulding. The main objective is to maximize plant utilization by ensuring that moulding size (projected area at right angles to the flow direction, and locking force) is matched to machine size. A small amount of assembly and some finishing operations like silk-screening may be done on components, but the output of a trade moulder is usually a set of incongruous objects for different customers. By contrast, a manufacturer who moulds in-house is concerned primarily with the finished object, and the injection moulding machines are just one step in a much bigger operation. Several machines may be dedicated to components which are common to several models in the range – clearly the most efficient way of operating any machine since downtime for tool changes is minimal. Standardizing on one grade of material also helps towards running plants efficiently. No extra tests are needed to ensure that incoming material is up to specification under the SQA (Supplier Quality Assurance) scheme. A trade moulder on the other hand will typically be using several grades of several different polymers for a diversity of mouldings.

In-house moulding of the much larger range of components needed for the range of products from both Flymo and Electrolux gave much greater security against market fluctuations. The Flymo part of the joint venture produced over 23 models (both electric and petrol driven) in its range of garden equipment, ranging from the original air cushion mowers to wheeled rotary mowers, cultivators and a nylon line trimmer in 1983/4. It is an intensely competitive market in the UK, with several major domestic competitors (Qualcast, Black and Decker, etc.) and Japanese companies like Honda. Flymo was regarded as the market leader with some 40 % of total sales in 1983/4, and the company also exported to Europe, USA and 60 other countries.

The video went on to examine the quality testing procedures used by Flymo in its separate testing house. Customer safety when using an air cushion mower is of paramount importance and hoods must withstand objects thrown up by the spinning blade. Hoods extracted from production runs are subjected to an internal impact test and if brittle behaviour is observed, the whole of that particular batch must be rejected.

An in-house moulder will also position machines in such a way that component flows from machine to assembly area are optimized. The machines that produce the various polymer parts (Flymo possessed 57 injection moulding machines in 1883/4 with locking forces ranging from 63 to 1000 t) of the Minimo, for example, are very close to the robot-assisted cell seen in the last part of the video. Operating single machines in such a way that several components that are to be assembled together at a later stage are moulded together is clearly preferable to moulding the parts separately on different machines.

Although multiple cavity moulding of *4* parts usually presents no serious flow problems, family moulding of different shapes or sizes presented problems in terms of filling the cavities evenly and smoothly. In the past, using smaller gates for small cavities and larger ones for bigger cavities was the obvious solution but what is *not* obvious is exactly what gate sizes should be used. The problem can be tackled empirically by progressively machining larger and larger gates in a series of experimental mouldings, but this is time-consuming, expensive and increasingly complex as the number of cavities is increased. A much more systematic approach is to calculate the rate of flow for different gate and runner sizes for the geometries in question, using a computer visualization for rapid analysis. This is the computer aided design (CAD) method referred to in the text and it is examined in greater detail in **VIDEO 4, Block 4 Part 2** and **Band 3 of AV2**. Other methods referred to by Peter Ginger included hot runners and sprueless moulding. Runners connect the nozzle of the machine to the sprue and gate and heating them electrically means that material is kept molten after each cycle ends – they do not solidify and their use gives greater flexibility in mould design. Solid sprues are usually attached to the moulding at the end of the cycle and are normally trimmed by the operator. Using a mechanically operated pin, the sprue can be cut off automatically in the machine, so eliminating manual trimming.

Manufacturing

(a) Use of robots

Automatic production is not uncommon for low locking force injection machines – the mouldings are simply pushed out by ejector pins and fall into a waiting bin. But for large projected area components, it becomes much more difficult, and the parts can be damaged in their fall. Use of robots to extract large parts was becoming increasingly common in 1983/4 for the reasons stated by Peter Ginger in the interview. The ASEA/Electrolux MHU robots seen in action are, however, exceptional – so-called ‘pick-and-place’ units are more common in moulding shops by virtue of their lower cost. The payback time of a robot is as follows:

$$\text{payback time} = \frac{\text{initial cost of robot}}{\left(\begin{array}{c}\text{labour cost replaced}\\ \text{per annum}\end{array}\right) - \left(\begin{array}{c}\text{maintenance cost of}\\ \text{robot per annum}\end{array}\right)}$$

In effect, two operators working two individual machines are replaced by one operator servicing two machines. Payback time depends on the initial investment in the pick-and-place unit or robot, which varied from about £7000 to £14 000 in 1983/4. Assuming the operator was paid £5000 p.a. then, and ignoring maintenance, the payback would have varied from 1.4 years to 2.8 years. For Flymo, the company is helped by being part of the Electrolux group which manufactures its own in-house robots. Payback time for such robots was about 7 months assuming one operator is replaced.

There is an important distinction between the two types of devices: the pick-and-place unit is not programmable and is usually dedicated to a single machine, operating in gantry fashion. The true robot is programmable and can have a large number of programmes, so that it is much more versatile and can be used for other functions – such as loading handles for continuous powder coating, as shown in the video.

Apart from the financial implications, the use of robots also has important advantages from the safety view point. Despite safety catches and failsafe devices on injection moulding machines, operators do not like entering the working parts of presses. With hot mouldings, the job of manual extraction is tedious and exhausting: robot extraction is smooth, regular and enables even very hot mouldings to be taken out of the tool. In fact, it was one of the very first (1961) applications for robots: extracting hot metal objects from die-casting machines, which operate in a not dissimilar way to injection moulding machines (2).

(b) Product assembly

Using robots for direct assembly of products makes greater use of their inherent flexibility in programming and a number of examples are discussed in detail in the relevant literature (3,4). Flymo began work on the development assembly cell for the Minimo model in 1981/2, and using the experience gained, constructed the assembly cell that is seen in the video. The Chief Engineer at Flymo, Mr. M. W. Leete, has described in detail the project as it was developed (5). The main objectives of the project were as follows:

- reduce direct labour content in assembly operation
- save overheads – 24 hour operation would give higher utilization of floorspace and other fixed overheads
- reduce materials handling – the elimination of storage between component manufacture and final assembly would reduce both indirect labour and forklift truck requirements
- Save inventory cost – previous to integration it was normal to hold at least one weeks stock of parts as a buffer between operations. The cost of holding this stock is calculated as 33 % of value per annum. This is made up from:
  – financing value of stock
  – space cost
  – cost of storage containers and racking.

The assembly cell as it existed in May 1983 and its mode of operation were shown in detail at the end of the video. In essence, the 5-axis Puma Unimate 500 assembled the motor, impeller and blade. The motor is fed in on a nylon base, which is recycled on roller belts. Other components are made ready in bowl feeders or magazines. At the end of the first step of assembly, an arm descends to check that the rotor has been assembled correctly and the sub-assembly is moved by the Cincinnati Milacron T3 to an operator behind the guard who adds the plastic hood fed by roller belt from the injection moulding machine. Completed mowers are fed back to the Cincinnati for transfer to an electrical testing station and are then placed in cartons. They are then moved to another operator who completes the packaging. In the final step the Cincinnati stacks the boxes on a pallet, which, when full, is pushed out to a waiting forklift truck. The robot pulls another pallet into the cell and the full cycle can be resumed. Also visible in the scene are the many PCs used to control each robot and the testing devices; a supervisory computer operating at a higher level is also used in the cell.

Progress to date (1997/8)

Flymo

MODEL	Microlite E28
PRODUCT NO.	9632802

9632802-01	GB,EI	9632802-67	East Eu
9632802-22	CH	9632802-86	Eu

PARTS 5E

PARTS LIST

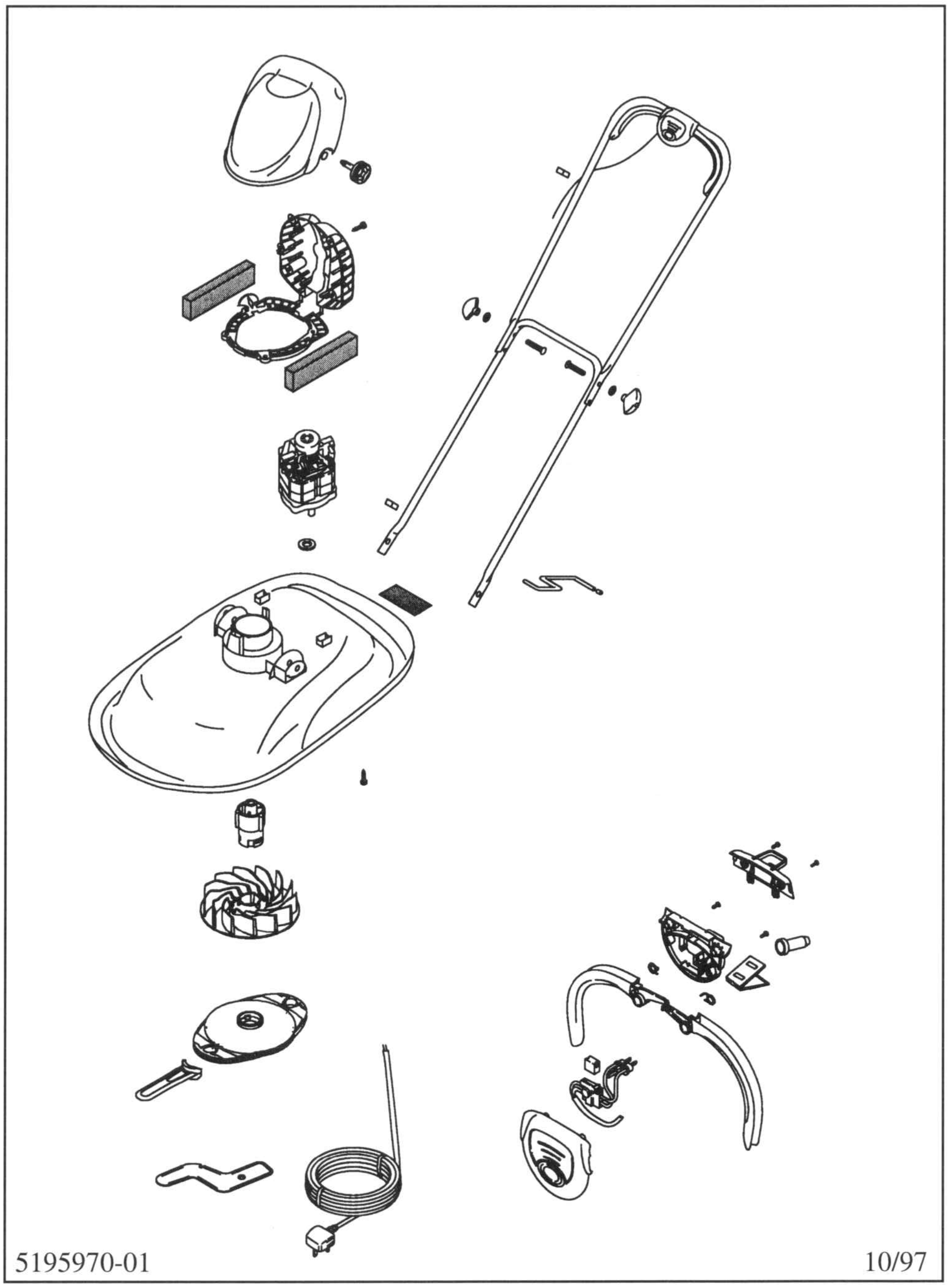


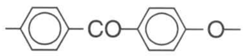
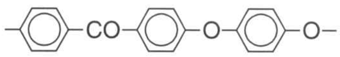
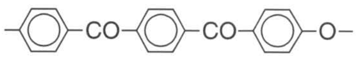
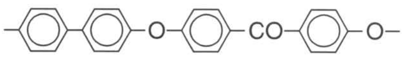
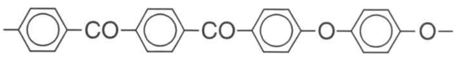
Figure 1.2 **Component parts of Flymo Microlite, which has replaced the Minimo**

Flymo Ltd has continued to expand its product range through product innovation and invention. The successor to the Minimo is the Microlite, shown in **Figure 1.2**. Every attempt has been made to achieve smooth curved surfaces (compared with earlier models), partly because they are easy to mould and also for their stiffening effect on the structure. Grass can now be collected over the top of the mower (see **SAQ 1** of **Block 1**) in Flymo's grass collecting range, blown into place by the same fan and motor which drives the blades. The system also compacts the grass into the collector, so improving the effectiveness of the mower. The cutting device is provided with extra safety in the form of plastic detachable blades (**Figure 1.3**), made from a new polymer, Shell's ***Carilon,*** a material known as a polyketone. Its repeat unit is

$$–CH_2–CH(R)–CO–$$

where R = H or a simple alkyl group such as methyl. The polymer has a high melting point of 220 °C, according to Shell literature (6). From DSC, it has a T_g of about 90 °C, so that it is rigid at ambient temperatures. Filled with carbon black, it is used for its wear resistance in this demanding application, despite its price of about £2000 t^{-1}. Flymo chose the material because it lasts on average ten times longer than the previous polymer used (modified acetal resin). It joins PEEK (see Table 1.1 below), an aromatic engineering polymer, which has been known for some years, although the new polymer is basically aliphatic in structure. The grade used in the blade also has high impact resistance (an important property in blades), a rather low tensile modulus of 1.4 MN m^{-2} and a tensile strength of about 55 MN m^{-2} at an elongation of 350% (6).

Table 1.1 Some polyaromatic ether ketones

	Polymer		T_g (°C)	T_m (°C)
A		(PEK)	154	367
B		(PEEK)	144	335
C		(PEKK)	—	384
D			—	416
E		(PEEKK)	160	—

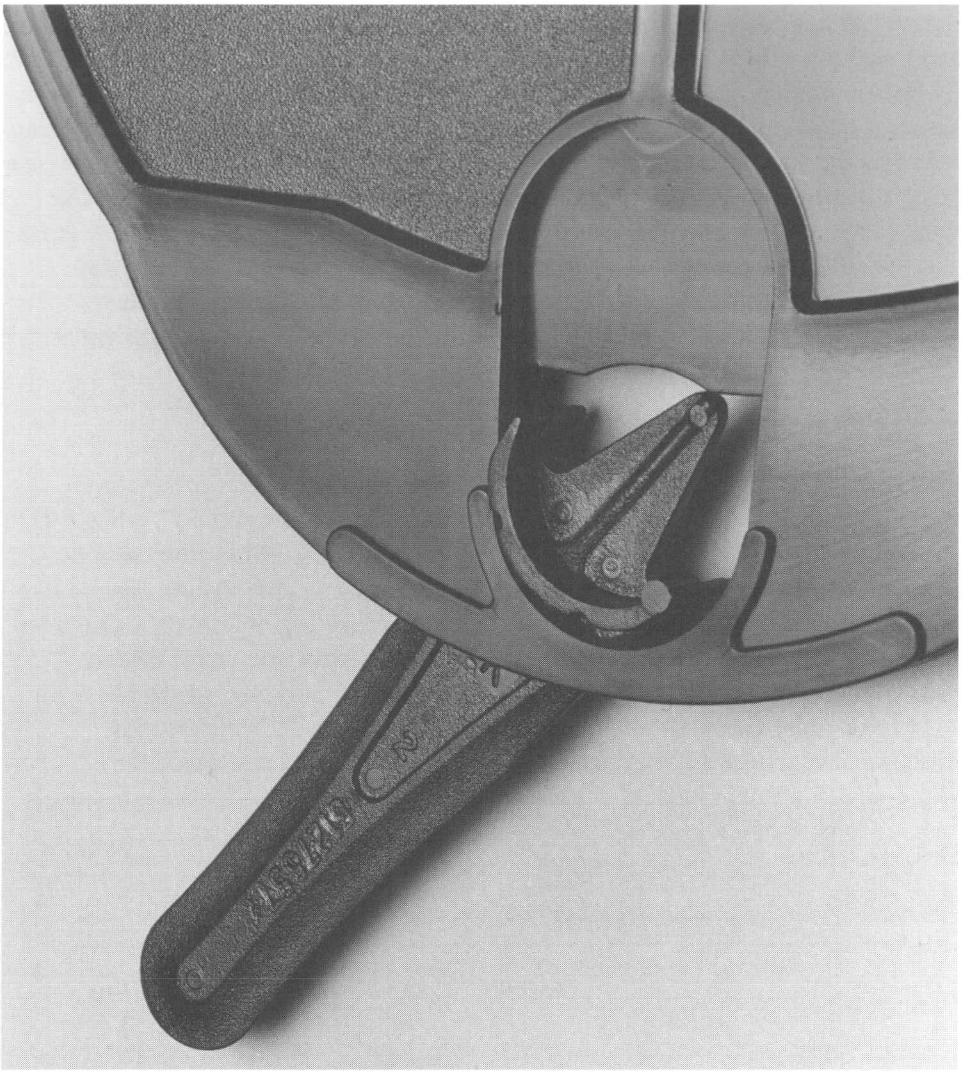


Figure 1.3 Cutter blade in polyketone (PK) for hover mowers (life-size)

Flymo has extended its market share of the garden products it makes, and has also recently combined with two other well-known names, ***Partner*** and ***Husqvarna***, to extend the range of models that it can offer the public. The company has an international profile, exporting about 50% of its products worldwide, except for the difficult US market. No doubt the company will exploit the economies of scale available in the very large moulding facility at Newton Aycliffe. It continues to innovate in its product range, with no less than five different innovative grass trimmers. Several of the trimmers are ergonomically designed with a curved shaft continuing into a curved handle, which allows the trimmer to be revolved for trimming lawn edges. In a new expansion, it will from 1998 be offering two hedge trimmers in the familiar orange colour, which is a distinctive part of the Flymo image. It is also useful to lazy gardeners, who are vividly reminded of unfinished jobs! With a polycarbonate safety guard and ABS motor enclosure, Flymo claims it to be one of the lightest products launched into the market. The company also continues the successful production of its garden vacs, effectively blowing, shredding and collecting waste leaves in the Autumn. Flymo have designed an entirely new concept, the Power Hoe, which it is claimed, will till the surface of the flower border with less labour and back strain than conventional methods. This is another way in which the company can overcome the seasonal variation in sales, by providing garden tools for every season, so that the manufacturing operation can work smoothly throughout the year.

In manufacturing management, Flymo has developed its own Product Integration and Development system to steer new products through concept, design. implementation and manufacture (**Figure 1.4**). For example, new products can be visualized using rapid 3-D prototyping, the 'fast track' development of **Figure 1.4**). The method involves converting the CAD direct to model by stereolithography, where urethane monomer is polymerized to the solid PU shape by a computer-controlled laser beam (**Figure 1.5**). The style, shape and function of the prototype can be evaluated before tooling-up (often now using Far Eastern toolmakers for their speed, low cost and reliability). Flymo uses on other external sources, such as independent inventors (e.g. the individual who patented the garden vac concept), universities for their special research equipment, as well as the large polymer suppliers for their development of grades specific to Flymo's needs.

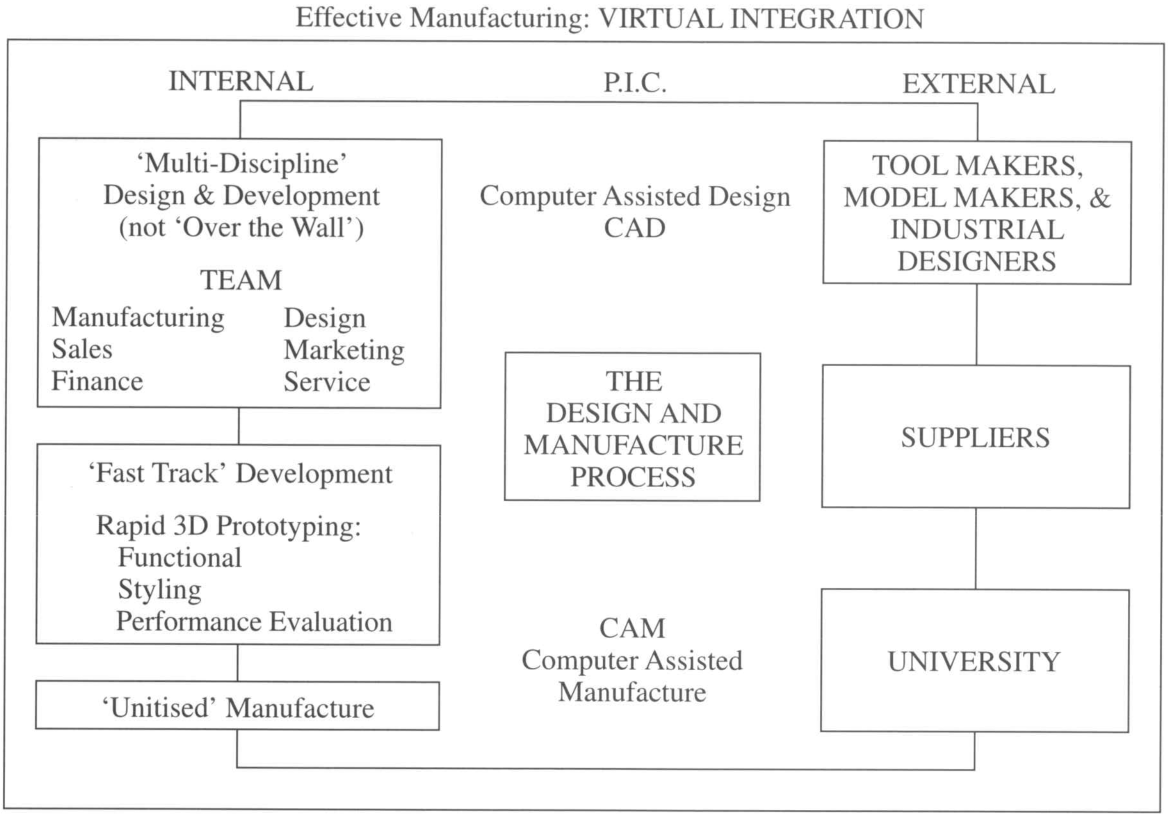


Figure 1.4 Innovation management at Flymo

Figure 1.5 Stereolithography in prototype development of hover mower handle. Pattern in PU at rear, prototype (middle) and finished product (front)

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