MATERIALS USED IN MILLS

Timber

Oak (England)

A strong, heavy and expensive timber. It is resistant to rotting and is used for the main framework and drive shafts.

Elm (England)

Strong, medium weight and cheaper than oak but it will rot. It is used for the main framework inside and some machinery.

European Pine (Eastern Europe)

Fairly strong, light and cheap. It is available in long lengths and is fairly resistant to rotting. Used for beams, shafts and flooring inside, weatherboarding outside.

Pitch Pine (North & Central America)

Strong, heavy and expensive but it is resistant to rotting and available in long lengths. Used for windmill sails and external framing.

Apple, Pear and Hornbeam (England)

Hard and dense with fine grain but rots easily in wet conditions. Used for cogs on internal gears.

There is a display at the entrance to the Museum showing how timber was converted from trees using a pit saw and cross-cut saw and shaped using a side axe, twybill and adze. All the tools are original.

Metal

Wrought Iron

The earliest form of iron; strong in compression and tension and can be welded by hammering when red hot. Expensive. Used for shafts, brackets, nails and bolts.

Cast Iron

Strong in compression but can be brittle and cannot be welded or worked with tools. However, it can be made into complex shapes by melting and pouring into moulds. Used for gear and pulley wheels and structural parts.

Brass, Bronze arid Gun Metal

These metals are based upon copper, zinc and tin. They are softer than iron and can be cast and finished with hand tools. They were used as bearings to hold iron shafts and allow them to turn smoothly. Being softer than iron they tend to wear out first but it is easier to replace a small brass bearing than a large iron shaft.

Millstones

English Stones (Millstone Grit)

Made from a hard sandstone which grinds well but leaves some grit in the flour.

French Stones (French Burrs)

Made from blocks of quartz cemented together and bound with iron hoops around the edge. Hard and not gritty but much more expensive.

Leather

Leather was used for pulley belts and flexible joints, such as hinges for trap doors.

Fabric

Canvas was used for grain sacks but not for flour because the weave was too coarse. Calico was used for sailcloth, as a covering for sail shutters and for chutes carrying flour. Cotton or silk was used for the fine sifting of flour.

Brick

A cheap material for building the base of a mill because it was fire and rot resistant.

Stone

A building material that is strong in compression but heavy to transport so only used close to where it was found.

DESIGN AND TECHNOLOGY

Designing and Making Things

It is appreciated that not many schools have the facilities for making iron or bronze castings! This means that it is difficult to demonstrate the manufacture and use of such materials. Gearwheels made of cardboard are likely to demonstrate only one thing – that cardboard is about the worst material for making gears. For demonstrating the transmission of power through gears or pulleys it is recommended that a proprietary construction kit, such as Lego, should be used.

Notes on the properties and uses of materials are given on page 8 and constructing models to demonstrate the use of wind power on pages 18 and 19.

Knowledge and Understanding

In considering metals it is important to take into account not only their properties in use but also their suitability for different methods of manufacture. Metals such as wrought iron can be cut, shaped and welded. Cast iron cannot be worked in these ways but it can be cast into complicated shapes by using moulds. A wooden pattern is made to the exact shape required. It is then placed into a box (or a pair of boxes) filled with sand to which some bonding resin has been added. When the pattern is removed, a hole is left in the sand the shape of the pattern (a comparison with sand castle building is the best way to put over this concept). When the resin has hardened, molten iron is poured into the mould and left to cool. A considerable amount of skill and time is required to make the wooden pattern but this is justified by the fact that the mould can be used many times.

There is a display illustrating this and large and small examples of the wooden patterns used.

Another concept that is worth considering is the use of bearings for moving parts. Not only should the bearing be designed to minimize friction but it should also be designed to be replaceable. Even though bronze is a more expensive material it is easier to replace a small bronze bearing than a large iron shaft.

Certain principles can be demonstrated in model form and the suggestions on the following pages may be of use.

THE EVOLUTION OF WINDMILL DESIGN

Windmills offer one of the best opportunities to study early design solutions to technical problems. They represent a time warp; a chance to travel back to a time when sources of power were few, when the design of machinery was in its infancy and when the choice of materials was very restricted.

Sources of Power

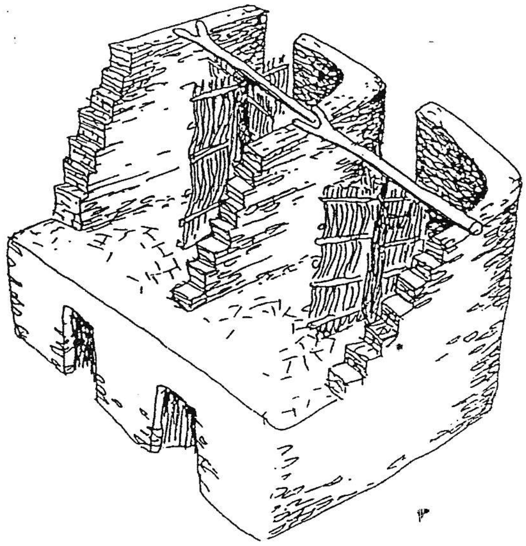
The Romans were the first to make extensive use of waterpower and water remained the main source of industrial power until the introduction of the steam engine. It was not until the 7th century in Persia and the 12th century in Europe that wind powered machinery came into general use. Even after windmills had been invented, water mills remained the first choice for industrial uses. This is because water is a more reliable and readily harnessed source of energy. Water tends to follow an established course and always flows in the same direction. You can control the speed and volume of water by using dams and sluices and water can be stored until it is needed. The wind, on the other hand, constantly changes speed and direction and sometimes it does not blow at all. It certainly cannot be stored for use the next day.

Most industrial processes were therefore sited where there were suitable streams to power a water mill. Flour milling was the exception. Flour was needed everywhere but before the development of railways in the mid 19th century transport was poor. Windmills, therefore, had to be built in places where the land was flat and where there were no suitable streams available e.g. mostly in the south and east of the country.

HARNESSING THE POWER OF THE WIND

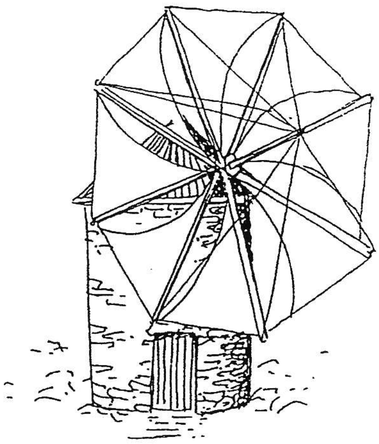
The fact that the wind can change direction means that windmills can only work with a prevailing wind or the building has to be designed so that the sails can face in any direction.

Persian Mills



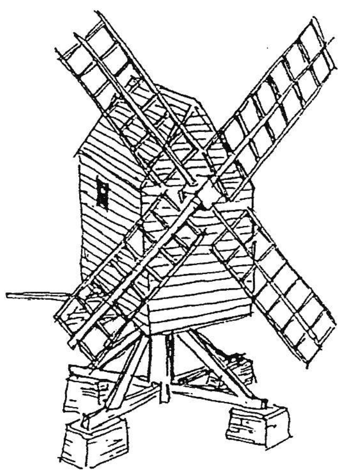
The earliest known form of windmill was the Persian mill or horizontal mill, so called because the sails moved in a horizontal plane. They relied upon a prevailing wind and could only work when the wind was in the right direction. The sails were made from matting or strips of wood fixed to spokes radiating from a vertical post, like the branches on a pine tree. These sails were surrounded by high brick walls with a narrow slot through which the wind could blow. The working machinery was housed in a building underneath. The narrow slot through which the wind blew onto the sails produced an increase in the wind speed because of the venturi effect (i.e. a moving fluid, such as air, increases its speed when passing through a restriction).

Greek Mills



Another type of early windmill was the Greek mill. Its sails were a direct development of the triangular or jib sails used on ships. Sheets of canvas were suspended from poles set radially around the end of a horizontal shaft, known as a windshaft. They were designed to produce rotation from wind pressure acting against the inclined surfaces of the sails.

Post Mills



The mill most commonly built in this country was the Post Mill, so called because it consisted of a building balanced on a central post. The post acted as a pivot so that the building (and its sails) could be turned to face the wind from whichever direction it blew. The sails were timber framed and covered with sailcloth. At first the frames were set at a constant angle throughout their length and two strips of cloth were needed to cover each sail. This was not a very efficient form of sail but it lasted from the 12th century until the 18th century when John Smeaton invented the common sail. The earliest mills of this type were very small, like a shed, but over the years larger versions were built, some with two pairs of millstones in the body. The timber trestle supporting the post was often enclosed by a brick built 'round house'. In early mills the body of the mill was moved by the miller pushing against a long tail pole, which projected at the rear. Later, in 1745, Edmund Lee invented the fantail. This comprised a circle of wooden blades mounted at the rear of the mill. When the wind blew from the side, the fantail would spin round and work gears to move the mill, or cap, back towards the wind.

The development of mills

Until the 18th century corn milling was a service rather than an industry and was controlled by the Lord of the Manor. It was the growth of population and the concentration of people in towns that led to corn milling becoming an industry. The commercialization of the process led to larger mills being built with more millstones than could be accommodated in a post mill.

A variation on the post mill design was the hollow post mill. This was used where additional millstones were placed in the round house. Any vertical driving shaft had to be in the centre of the building to avoid it being twisted when the body turned to face the wind. However, the central post supporting the body of the mill presented a difficulty because it was in the way. The solution found was to hollow out the supporting post so that the driving shaft could be housed inside it. Very few mills were built like this but Wimbledon Windmill was an example. The post and shaft have gone but the illustration of the mill in its working day (page 14) shows these features.

Other types of mill frequently built in this country were tower mills and smock mills which had sails mounted on a cap which turned at the top of a brick or timber tower. More details of these are given later.

Windmill Sails

There were many innovations in the design of sails in the 18th century, the most important being the result of a study carried out by the engineer John Smeaton. In a paper to the Royal Society in 1759 he reported on a design of sail in which the angle of the sail varied from a steep pitch near the wind shaft to an almost flat pitch at the end, like a propeller blade. This reflected the fact that although the wind speed was constant throughout the length of the sail the sideways movement of the sail was much greater at the tip than at the inner end. The new design was very popular and became known as the common sail. The single sheet of cloth that now covered the sail could be pulled back like drawing a curtain rather than having to climb the sail. Another invention introduced during this period was the shuttered sails in which a series of small moveable shutters replaced the cloth.

These sails were invented by the Scottish engineer, Andrew Meikle, to overcome the problem of having to cover and uncover the sails quickly to suit the changing strength of the wind. In the case of shuttered sails the shutters were held in position by springs and could be set fully closed for a light breeze or partly open for a stronger wind. Sudden gusts or gale force winds would push them open and let the wind spill through. This prevented damage to the machinery and the springs would close the shutters again when the wind died down.

In 1807, William Cubitt introduced his patent sail, which was similar but had the shutters controlled by a weighted chain rather than springs. It had the advantage that the shutters could be adjusted while the sails were moving.

The wind shaft of a windmill, which carried the sails, was usually tilted towards the back of the mill. The reason for this was that when the wind stopped blowing the sails would continue to turn for a time and they would then act like a propeller, pulling them forward and drawing the wind shaft out of its bearings.

A completely different design was the annular sail, which instead of having rectangular sails on radiating arms had a ring of shutters mounted at the end of those arms. This gave the greatest leverage or moment of force to turn the wind shaft. Not many of these were built because by the time they were invented steam power was beginning to take over. However, the design was developed on a smaller scale for wind pumps, many millions of which were built throughout the world in the 19th century for raising water from wells or bore holes.

The horizontal mills produced by Captain Hooper and Mr. Fowler in the late 18th century were similar to Persian mills. They consisted of a brick building, to house the machinery, with an octagonal timber tower above. This was built as an open lattice through which the wind could blow. Inside was a cylinder of vertical timber blades that would catch the wind from whichever direction it blew. The speed of the mill was controlled by vertical shutters, which surrounded the rotating blades and directed the wind onto them. The shutters could be opened or closed according to the strength of the wind.

The Construction of a Post Mill

The construction of a Post Mill (fig.1) offers opportunities to study the use of materials and the design of structures that have to resist internal and imposed forces. Basically, the post mill is an example of medieval timber-framed building with a covering of boards. Most of these mills were built at a time when iron was an expensive material and nails and bolts had to be made by hand, so very little iron was used in their construction. Joints were often secured by driving wooden pegs, known as treenails, into pre-drilled holes but it must be understood that their purpose was only to keep the joint tightly together. The pegs could resist only a limited amount of shear force so the joints had to be designed with mortises and tenons combined with shoulders or dovetails to transmit the forces from one structural member to another.

The book 'English Historic Carpentry' by Cecil A. Hewett, published by Phillimore 1980, is the definitive work on this subject.

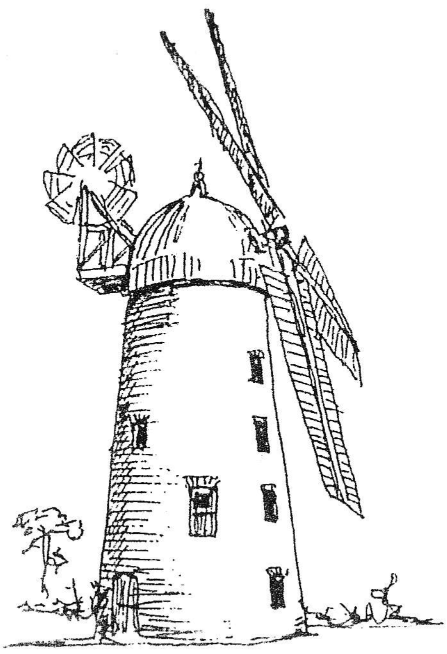
The construction of a post mill presented challenges to the skills of the medieval carpenter. The supporting post had to be very securely fixed to resist the movement of the building and the horizontal wind force acting against it. The solution developed by these carpenters was the trestle (see p.13). Two large beams, known as cross trees, were placed at right angles. These timbers were recessed slightly into each other in order to locate them. The post was set up where the timbers crossed and, being larger than the cross trees, its lower end was cut away to fit round them. The post was then braced by diagonal timbers on four sides. These timbers, known as the quarter bars, were joined to the post at the top, using mortise and tenon joints with shoulders to take the compressive load. At the bottom they were joined to the cross trees using mortise joints with a double birdsmouth, as shown. The weight of the building was transmitted down the quarter bars and the crosstrees acted as ties between them, hence the importance of the birdsmouth joints.

The post was continued up inside the building to its centre of gravity and a large timber, the crown tree, was balanced across it to form a T. The building was constructed around this.

Timbers known as side girts were housed and dovetailed onto the ends of the crown tree and these supported corner posts. The lower floor was hung from these corner posts. Unlike most buildings where the loads are transmitted through the structure to the ground as simple compression forces, the mill body was suspended at its centre and the joints in the lower part of the building were therefore in tension. The building was stabilized by means of a collar around the post below the lower floor.

Tower and Smock Mills

The other types of windmill most commonly found are the Tower Mill and the Smock Mill. Both are in fact constructed as towers and the only difference between them is that tower mills are usually circular in plan and are built of brick or stone. It is not difficult to build a large circular shape in stone or brick and this gives the maximum internal space for the material used. Smock mills have a tower built mainly of timber and are usually octagonal in plan. The plan shape is a reflection of the material used. Timber comes in straight pieces so it is easier to build a polygonal tower than a cylindrical one. Most were octagonal but some were hexagonal.



The construction of a Post Mill

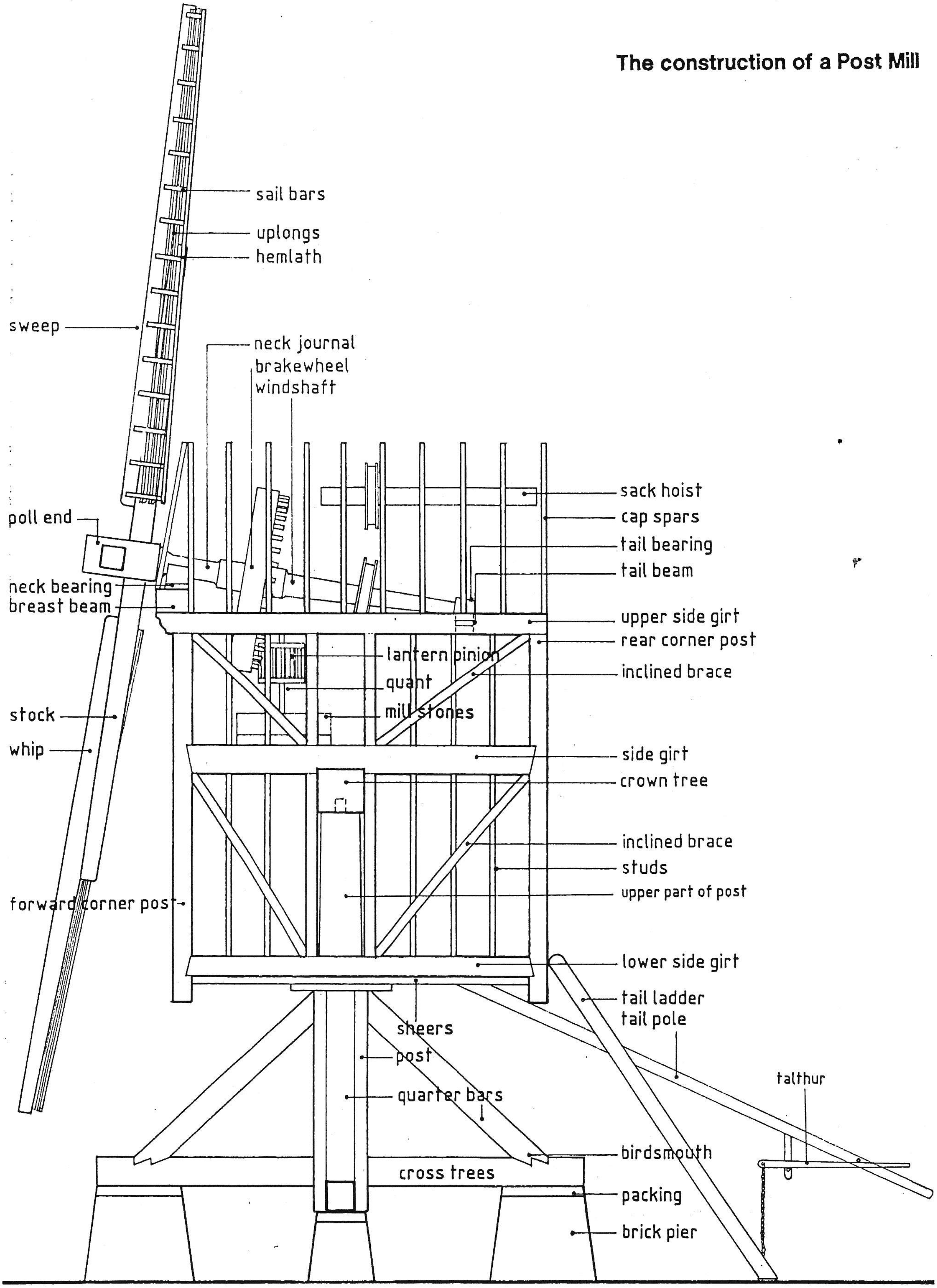
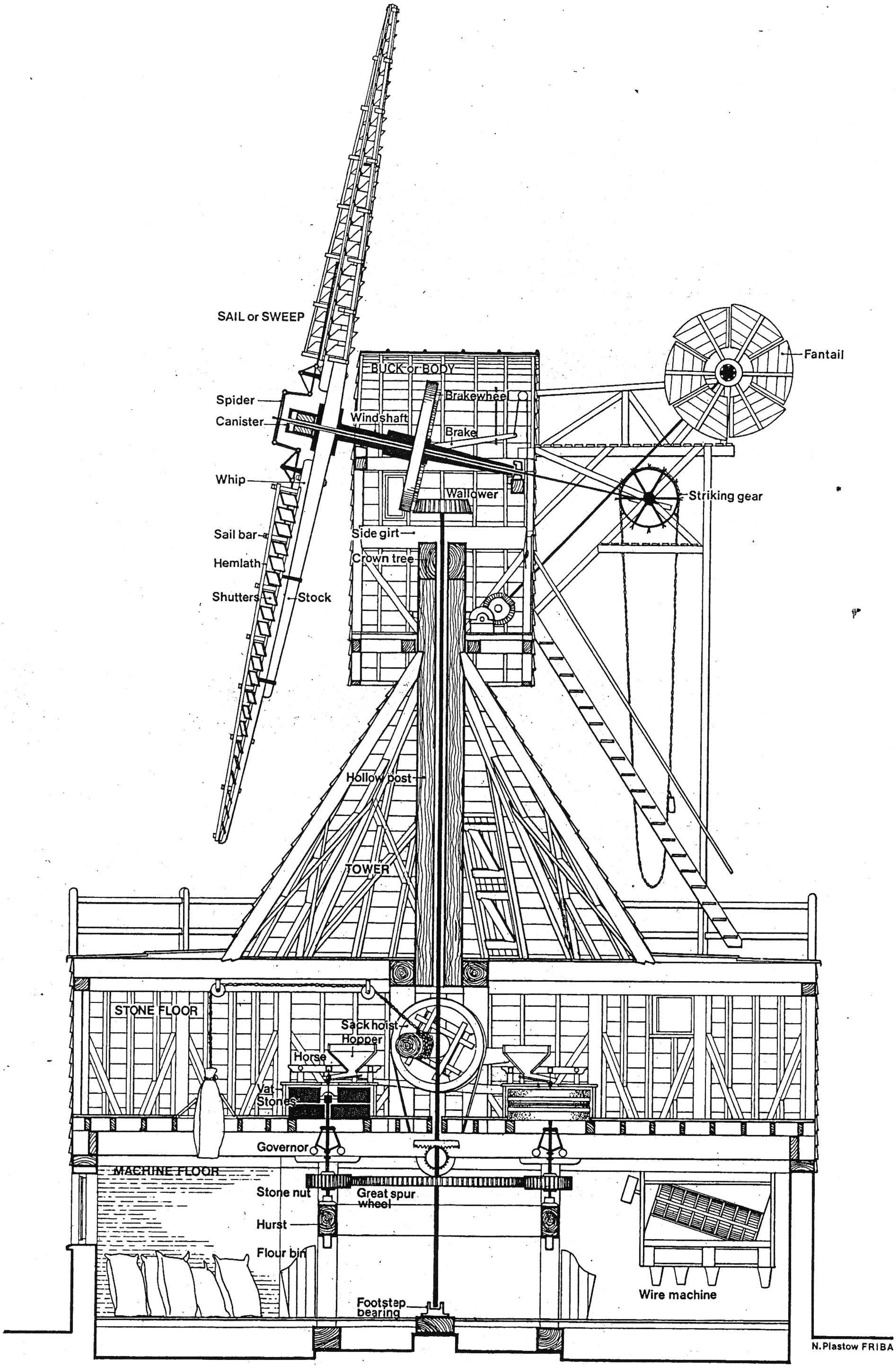


Fig. 1



WIMBLEDON WINDMILL AS IT WAS IN ITS WORKING DAYS (1817-1864)

4th EDITION 1991

Tower and Smock Mills

Smock mills were so called because their appearance was said to resemble a farmer's smock. Tower and smock mills had no central post. In these mills the tower was fixed and a cap, carrying the wind shaft, on which the sails were mounted, turned on a track around the top of the tower.

Caps could be turned by hand using a crank or a chain wheel operating a worm gear on fixed cogs around a curb at the top of the tower. On larger mills a fantail was used to turn the cap. The cap was prevented from slipping off the tower by means of 'truck wheels' mounted horizontally to run round the inside of the curb. All the milling machinery was housed within the tower.

Some small tower mills were built two or three storeys high but the advantage of tower mills over post mills was that they could be much larger. In a post mill all the machinery had to be housed in the moveable building. In a tower mill only the cap turned and the building housing the machinery could be as large as necessary. The largest mill recorded was 36m (120 ft) high with ten storeys.

Machinery

It should be borne in mind that most windmills were built at a time when iron was an expensive material and large iron castings were not practical. The large gear wheels needed in windmills and water mills were therefore made of wood until the latter part of the 18th century. The first set of gears needed in any windmill comprised the 'brake wheel' and the 'wallower'. The turning movement of the horizontal, or near horizontal, wind shaft was transferred to a vertical shaft. This change of direction was accomplished by gears that could also introduce a change of speed. The brake wheel, so called because it had a brake shoe fitted to it, was 1.8 - 3.6m (6ft - 12ft) in diameter with cogs projecting on one face. In early mills these cogs were simply pegs that engaged with the staves in a lantern pinion. The lantern pinion was mounted directly on the shaft, which drove the millstones and being much smaller than the brake wheel it turned the stones faster than the sails. In later mills the brake wheel and wallower became bevelled gears. Some large post mills had a second pair of stones driven by additional gears set further back on the wind shaft.

For tower or smock mills with a number of millstones a chain of gears was needed. The brake wheel remained but instead of driving the stones directly the drive was transmitted to a vertical shaft running for two or more storeys through the centre of the mill. At the top of this shaft was the 'wallower'. The vertical shaft turned faster than the wind shaft and at its lower end there was a large horizontal gear wheel, the 'great spur wheel'. This was usually larger than the brake wheel and around it were arranged the 'stone nuts'. These were small gear wheels each driving a pair of millstones. The gearing could be positioned above or below the stones. This was known as overdrift or underdrift gearing. The sails and wind shaft normally turned at about 15 r.p.m. and the stones at about 120 r.p.m. There were often other gears used to drive ancillary machinery.

The gear wheels themselves were built up from a number of timber sections. Although some bolts and wrought iron straps were used the strength of the wheel relied upon interlocking joints. The spokes of these wheels had to be substantial to resist torsion forces (unlike the spokes of a cart wheel which were much slimmer because they only had to take compression forces).

Early wheels were known as 'compass arm wheels' because they were built with four spokes resembling the points of the compass. This construction had the disadvantage that because the spokes passed through the shaft they weakened it so later gear wheels were made to the 'clasp arm' design. The spokes were fitted in pairs on each side of the shaft and locked together where they crossed with halved dovetail joints. This formed a collar around the shaft and was a good method of transmitting torsion forces without weakening the shaft.

Various timbers were used to make gear wheels, often pine or oak, but the cogs or teeth were usually made of apple wood because of its fine grain and freedom from knots. For larger cogs, beech, oak or hornbeam was sometimes used. However, there was always the danger of uneven wear occurring in wooden gears. To even out the wear an extra cog was sometimes introduced. The use of an odd ratio of cogs, say 37 to 18 rather than 36 to 18, would ensure that the same cogs only came into contact once in 18 revolutions.

The cogs fitted into sockets in the rim of the wheel and were held with wedges at the back. An example can be seen in the form of a crown wheel in the Museum. Even when large iron castings became possible and many gears were made of iron, wooden cogs were often retained as they were more easily replaced. An example of what can happen to a cast iron gear wheel if the gears jam can be seen in the Museum. At the top of Wimbledon Windmill there is a 1.8m (6ft) crown wheel, which has sockets for wooden cogs, and drove a wallower on a vertical shaft, 13.5m (45ft) long with a great spur wheel at ground floor level. Large iron gear wheels were usually made in two halves bolted together to make casting and fitting easier and to reduce the problems of shrinkage when cooling. Examples of wooden patterns for casting iron gears in sand boxes are shown.

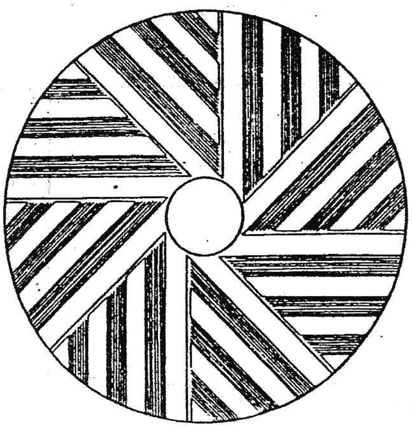
It was sometimes necessary to disengage one set of millstones while leaving other stones running and there were other pieces of machinery, such as sack hoists and flour dressing machines that had to be started and stopped frequently without having to stop the mill. Many methods of stopping and starting machinery were employed and a study of these methods could be the subject of a design technology project.

The Millstones

Millstones were used for grinding corn from about 100BC to the present day, although roller mills have now largely taken over. The design of millstones is based upon the hand quern in which one flat stone turns over another but without the stones touching. The lower or bed stone remains fixed and the upper or runner stone is supported above it. The runner stone has a hole in the centre large enough for the grain to be fed into it and across this hole is an iron bridge which rests on a pivot.

The pivot keeps the runner stone central, allows it to turn freely and is adjusted to give just 0.25mm (1/100") clearance between the stones. The importance of this invention was that it provided the first continuous process for flour making and therefore lent itself to development as a machine. All previous methods of grinding, such as the pestle and mortar, were batch processes in which work had to be stopped while the finished product was removed and a new batch of grain was inserted. The hand quern used a continuous input of grain and produced a continuous output of meal. It is little wonder therefore that corn mills provide the first examples of industrial production.

The face of each millstone had a pattern of grooves or furrows cut into it as shown. As the stones turn these furrows help to reduce the grain to meal and at the same time feed it outwards to the edge of the stones. An interesting experiment is to draw out this pattern (10 - 15 cm diameter) on to card and onto a transparent sheet (making a copy on acetate sheet as used for overhead projectors is the best way). The clear sheet should be laid over the original drawing, so that the lines cross each other, and fixed with a drawing pin through the centre. The transparent sheet can then be rotated to show how the grinding process works. When turned in the correct direction the lines appear to produce a movement from the centre to the outer edge.

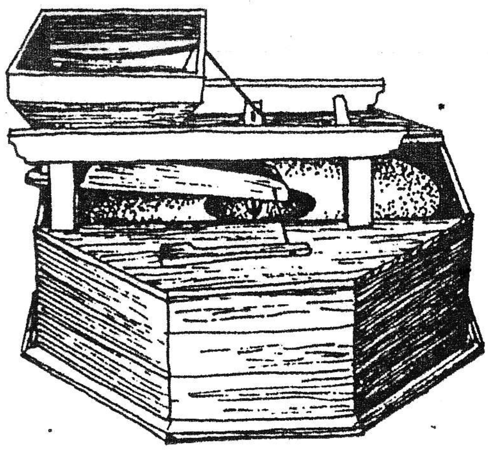


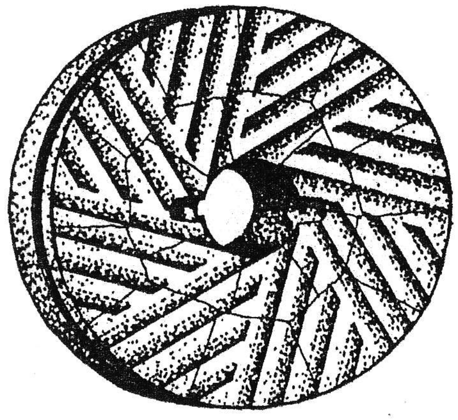
The average size for millstones was 1.2m diameter, each stone weighing about 1/2 to 3/4 tonne. Before the 18th century most millstones in this country were made from hard sandstone known as millstone grit. About the middle of the 18th century most millers changed to using French burr stones, made from quartz. This was a much harder stone but it was not available in large slabs so a French millstone had to be made from a number of quartz blocks, fitted and cemented together. The finished stone was bound with iron hoops, heated and shrunk on like fitting the rim to a cartwheel. In order to make the stone balance and run true it was necessary to fit lead weights in pockets around the edge. A pair of millstones needed about 6 bhp (4.5kw) to work them.

Grain was held in a hopper above the stones and ran onto a 'shoe' or chute, which directed the grain into the eye of the stones. The shoe was set at a shallow angle so that there was not a sudden rush of grain from the hopper into the stones. A spindle with projecting ribs, known as the damsel, shook the shoe and this shaking resulted in a slow and steady flow of grain into the stones.

Because the miller was normally working on the floor below the millstones he needed an alarm system to warn him when the hopper was nearly empty. The usual device was a strip of leather, which ran across the centre of the hopper and had one end fixed and the other end attached by a string to a bell that was suspended over a moving part of the machinery. When grain was poured into the hopper its weight would push down the leather strap, which would lift the bell clear of the machinery. When the grain was almost finished there would not be enough weight to hold down the leather strap and the bell would fall onto the machinery and start to ring.

In windmills the speed of the stones varied because of frequent variations in wind speed. About 120 r.p.m. was considered best and when the stones turned faster than this they tended to throw out the meal before it was finely enough ground. To counteract this, tentering gear was used. Tentering involved bringing the stones more tightly together by lowering the bearing of the shaft carrying the rhynd in the runner stone. Hand tentering used an adjusting screw but automatic tentering was common from the beginning of the 18th century. This was based on the use of centrifugal governors that worked a series of levers to move the bearing of the runner stone. Boulton and Watt developed their invention of governors for steam engines from this device.





NOTES ON WIND POWER

Wind and Water Power

Until the introduction of steam engines, wind and water were the main sources of power. However, there is an old saying, "No one ever built a windmill if he could build a watermill". The problem is that the wind is a very unreliable and unsteady source of power. A stream of water does not suddenly disappear but the wind can stop blowing at any time. A stream always flows in the same direction. The wind can blow from any direction and can suddenly change direction. A stream flows at a steady speed but the wind can change speed or blow in gusts. The speed of water can be controlled. The speed of the wind cannot. Water can be stored for use at another time. The wind cannot. The wind is, therefore, a very unreliable source of power.

Uses of Wind Power

Apart from milling, wind power was often used for pumping water. Wind pumps were simple and cheap to build and repair. At one time there were as many as six million of these in the U.S.A. It did not matter how or when the wind blew because the pumped water could easily be stored until it was needed.

Generating Electricity

Electricity can be generated by wind or water. Hydroelectric power stations are environmentally friendly but there are few suitable sites for them in the British Isles.

Wind farms can produce clean energy from the wind and they are far more efficient than traditional windmills. Although the sails are slimmer they are designed like aircraft wings and are pulled round by the wind passing over them, which makes then twenty times as efficient as traditional windmill sails. However, there are still many disadvantages to wind power. Although about 2,000 wind turbines have been built in this country this has not resulted in a single power station being closed down. This is because conventional power stations are still required to meet the demand for power when there is not sufficient wind, which even on exposed sites is about two thirds of the time. Another problem is that the power tends to come in surges because it does not vary in direct proportion to the wind speed but in proportion to the cube of the wind speed. For example, if a wind turbine is designed to be most efficient in a 40m.p.h. wind and the wind speed drops to 20m.p.h. the output is not halved, as might be expected, but is reduced by eight times to just 12.5% of the designed output. If the wind drops to 10m.p.h. the output is reduced to just 1.56%. This is when the conventional power stations have to increase their output to compensate for the loss of power.

Conventional power stations, using fossil fuels, are cleanest and most efficient when they can run at a steady speed. If they have to keep compensating for changes in the output of wind farms they become less efficient. It is estimated that if more than 10% of our power comes from wind farms the grid will be destabilised. This happened in 2005 when large areas of Europe were blacked out when a sudden surge from German wind farms caused many power stations to close down. Denmark has the world's largest concentration of wind farms but they stopped building them in 2002 because of this problem.

Another source of pollution comes from building the towers needed to support wind turbines. Some of these are now 100m high and require 500 tonnes of steel and 2,000 tonnes of concrete to construct. They contain complicated equipment that needs regular servicing and their life span is about 20 years. To make them viable they have to be heavily subsidised.

Unfortunately we have not found a way to store large quantities of electricity. Power produced on stormy nights cannot be stored for use the next day. Similarly, if there is a large demand for power when the wind is not blowing wind farms are unable to provide it.

Until these problems are solved wind power is likely to remain uneconomical

Making Models of Wind Machines

The following are suggestions for the construction of a suitable tower for making a model windmill. A large and strong cardboard tube can be used but it needs to be fixed to a flat base to provide stability. A plastic washing up liquid bottle can be used partly filled with sand or other heavy material to keep it upright. Holes need to be made on each side to take the shaft on which sails can be fitted or, to illustrate the need to cope with wind coming from any direction, a rotating cap can be constructed (fig.3). For larger towers a thick dowel fitted into a wooden base may be suitable or a triangular tower can be built from card.

This arrangement can be used to test the efficiency of different types of sail. Sails can be mounted on a thin dowel with a cork at one end. If all the sails are mounted on a similar size dowel they will fit the holes or notches in the cap (rub the dowel with candle wax to reduce friction). If a cotton reel is mounted on the far end of the shaft it will help balance the weight of the sails and provide a lifting mechanism for weights by which the efficiency of the sails can be judged. Alternatively the shaft may be connected to a small electric motor fixed to the cap. This will act as a generator but the sails will have to turn at very high speed to produce a measurable amount of electricity. There are a number of kits available for making more complex models, e.g. from the Science Museum, some of which can generate sufficient electricity to enable more accurate tests to be carried out.

Cardboard cut outs for making models of post mills, smock mills and Wimbledon Windmill are available at the museum but these are for appearance only and are not suitable for experiments.

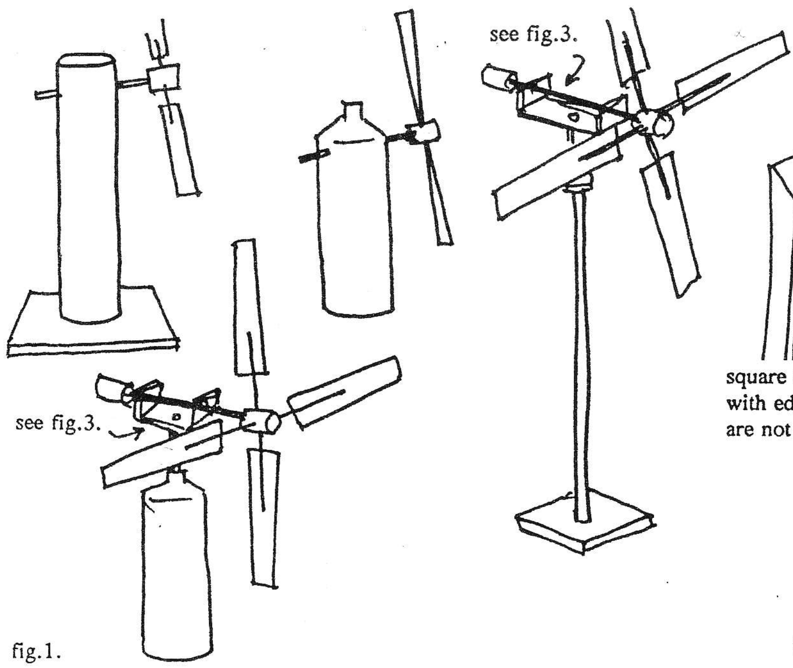


fig.1.

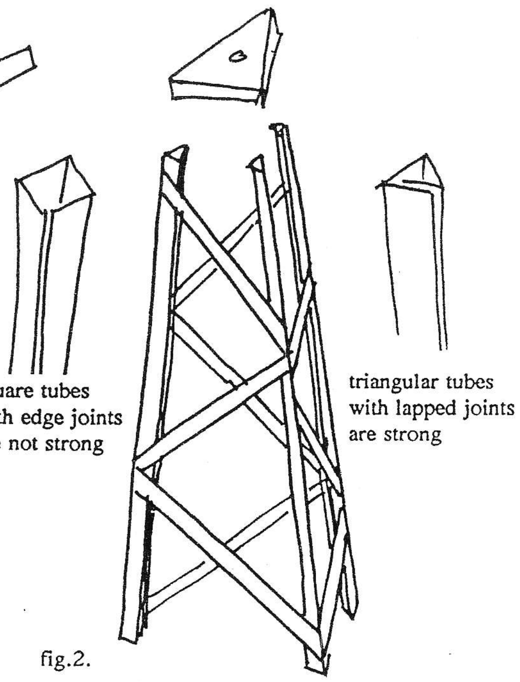


fig.2.

To test the efficiency of the sails it is best to use a direct source of moving air such as an electric fan. (All 240v. electrical equipment must be checked for safety). The natural wind fluctuates too much to make comparative studies. The air should be blown at the sails from various directions to see how this affects their speed and efficiency.

Some examples of sails are shown below (fig.4). Windmills designed for mechanical work usually have high solidity, i.e. The blades cover a large part of the area within the circumference of their span (examples 1 to 3). For the production of electricity, low solidity is needed, i.e. slim blades turning at high speed (example 6).

High solidity = slow speed and high torque or turning force.

Low solidity = high speed and low torque.

Unlike most of the sails illustrated the Savonius rotor (example 3) works in a horizontal plane and does not have to be turned to face the wind. Simple versions of these are used in some developing countries to pump water. They can be constructed out of an oil drum cut in half and mounted in a wooden framework. A cam on the vertical shaft is used to convert the energy produced to a vertical thrust operating a pump.

In considering the efficiency of generating power from the wind the construction and maintenance costs of the equipment need to be taken into account.

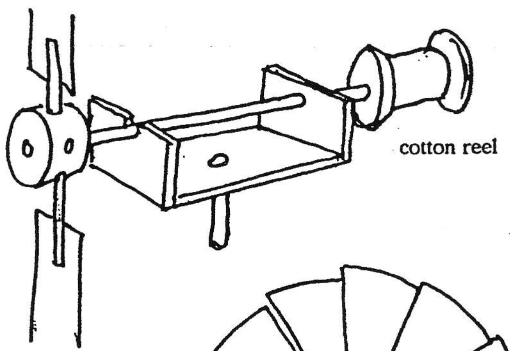
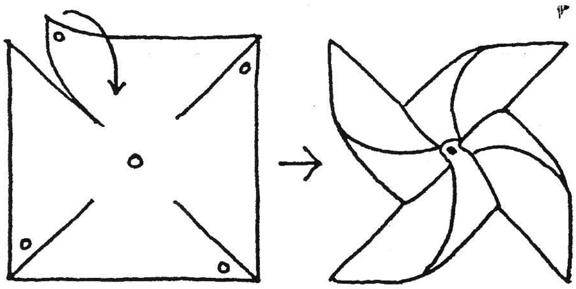
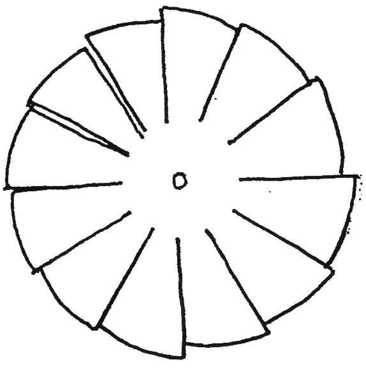


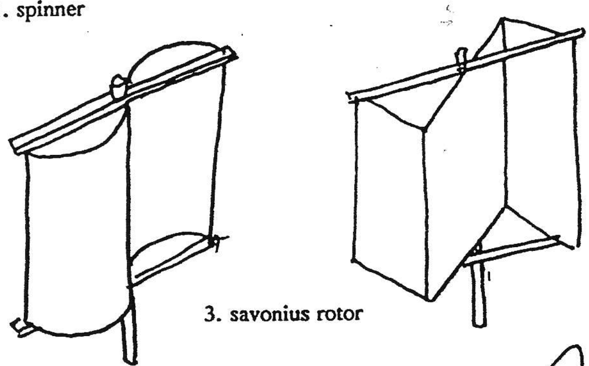
fig.3. test rig



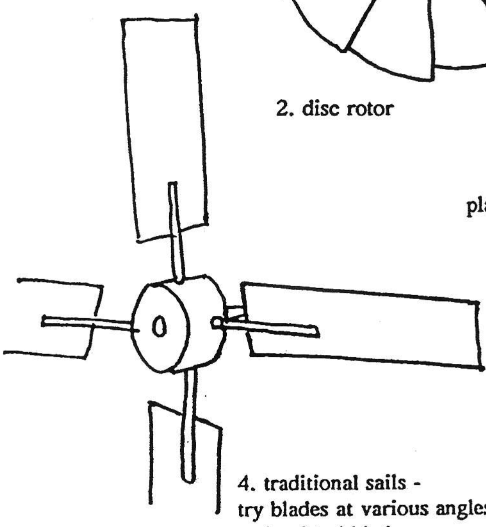
1. spinner



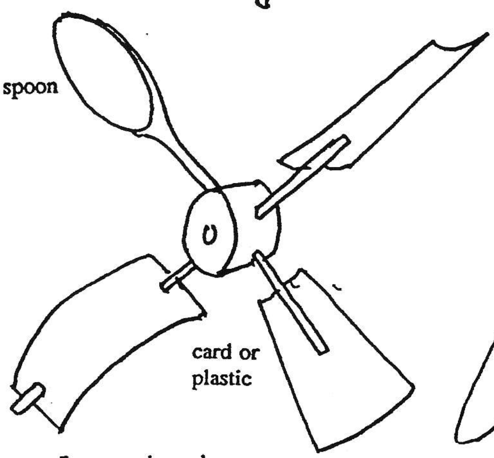
2. disc rotor



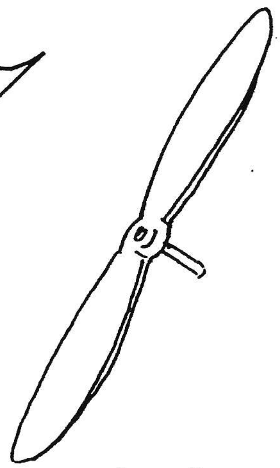
3. savonius rotor



4. traditional sails - try blades at various angles and twisted blades



5. try various shapes



6. propeller

fig.4.