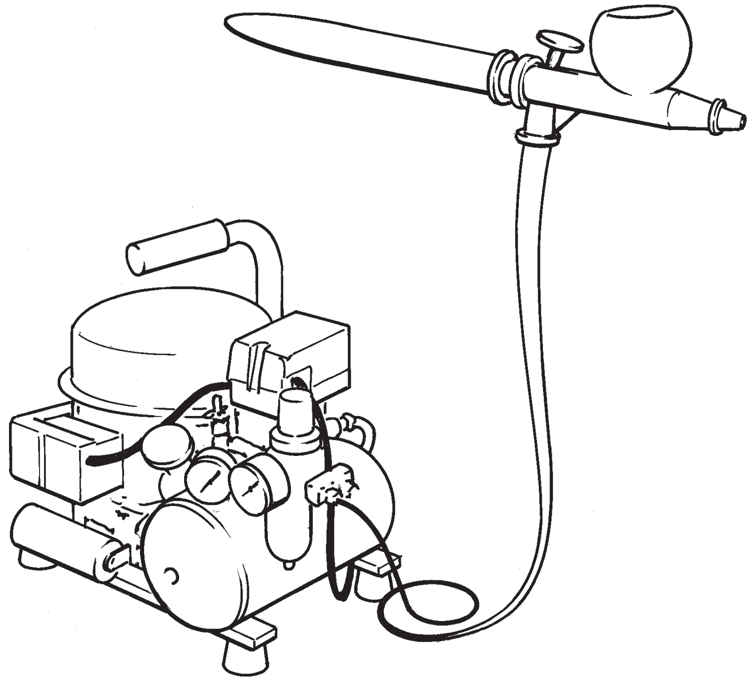
DESIGNING AND MAKING A LOW PRESSURE AIRBRUSHING SYSTEM

Graphic artists and designers often use airbrushes in the production of presentation graphics. The airbrush system is used to produce a very controllable *aerosol* of ink or paint. (Aerosol is the general term used to describe very small droplets of liquid dispersed in a gas). This allows the spray-gun to be used like a brush to produce many professional graphic affects.

Good professional airbrushing systems are readily available. They consist of a an electrically driven compressor unit and an airbrush. Both units are complex and are made using precision parts. Because of the specialist nature of this type of equipment they are quite expensive (several hundred pounds in most instances).

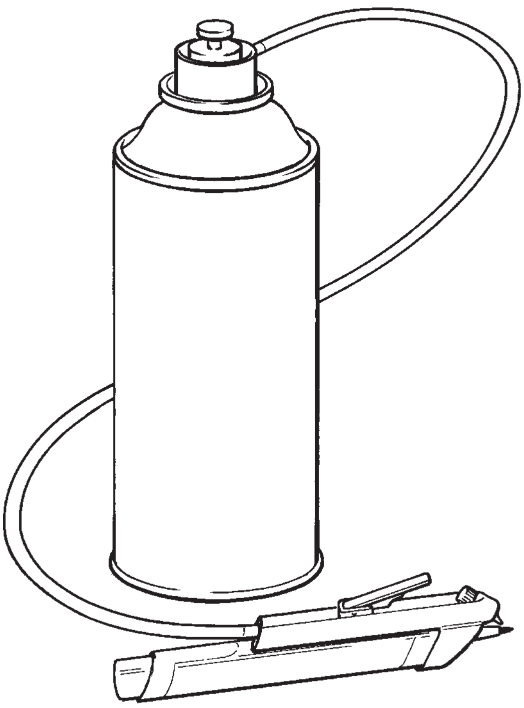


Designers have developed alternative airbrushing systems that produce reasonable results for less financial outlay.

Another type of system uses principles similar to the one described above but makes use of alternative technology to reduce the cost.

The electrically driven compressor is replaced by a canister of compressed air. This comes in a similar form to common aerosol cans. Instead of a spray nozzle, a fitting is provided at the top of the can to allow a plastic tube to be connected.

The complex and precision airbrush is dispensed with altogether. The compressed air is instead fed to a nozzle that is clamped to a marker pen. The airflow is directed to the tip of the pen which causes ink from the tip to ‘fly off’. The ink will form an aerosol which can be directed onto the paper.

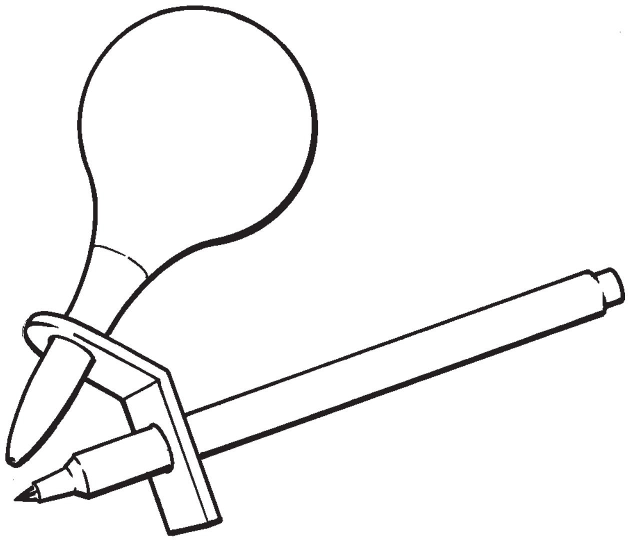


This type of system has many advantages if a slight reduction in quality is allowable. It is extremely portable, needs no electricity supply to run it and colours can be changed very quickly without the need to wash out the airbrush.

The principal disadvantage, however, is the disposable nature of the compressed air canister. If a lot of work is to be done with this system then the cost of replacing the canisters could be quite considerable.

Another very basic system uses the same nozzle and marker pen arrangement to produce the aerosol but dispenses with the compressed air supply. Instead a hand operated pump in the form of a bulb is used.

This system is more of a ‘toy’ than a graphics tool but it is an interesting rationalisation of airbrush technology and it can be used to produce some original graphic effects.



Analysing this information would suggest that there is a gap in the airbrush market. A low cost system that uses the nozzle and marker pen aerosol idea, but which also has an air supply that is easily replenishable would be a viable and useful product.

DESIGN OPPORTUNITIES

Design and make a low cost, low pressure airbrushing system. The system should be easily transportable, need no electrical power supply and produce results that are as near professional as possible.

In thinking about a design brief and specification, a useful starting point in this design project would be to look at how professional systems functions.

They consist of four major parts.

1. The compressor - This is basically an electric motor driving a pump. The pump takes in air from the atmosphere and pushes it out at a higher pressure.

2. The air receiver - The high pressure air stream from the compressor is fed into the air receiver. This acts as a reservoir for the compressed air. It is necessary because the compressor does not produce a continuous stream of air. The pump in the compressor works in a reciprocal fashion by taking in a small quantity of air, compressing it and then feeding it to the output. This cycle is repeated many times per second. The compressed air produced by the pump will, therefore, not be continuous, but pulsed. This pulsing effect may not be a problem in some applications but an airbrush needs a continuous supply of air otherwise the paint coverage will not be uniform.

3. The regulator unit - This has two main functions. Firstly, it controls the maximum air pressure in the air receiver. It does this by monitoring the pressure and turning the compressor on when the pressure falls below the minimum level and off when the pressure reaches the maximum level. The maximum and minimum pressure levels will vary for different airbrush systems but they are typically between **3** and **4 bar**.

Secondly, it allows the airflow out of the air receiver to be controlled. The pressure fed to the airbrush needs to be varied in the professional system to enable different painting effects to be achieved. This is done most simply using a form of valve.

4. The airbrush - This is a complex and precision engineered piece of equipment. It works,however on a fairly simple principle known as the *venturi* effect.

High pressure air from the air receiver is blown across the apertures at the top of the ink container and out of the nozzle. When the moving air reaches the *throat* the velocity of the airflow, and hence its kinetic energy, increases (the same effect as putting your thumb at the end of a hose pipe to produce a jet of water).

In accordance with Bernoulli's Theorem, the pressure in the throat decreases as the velocity increases. The pressure at aperture A is therefore less than at aperture B, with the result that the ink is forced up the tube into the throat where it si mixed with the air and sprayed out of the nozzle.

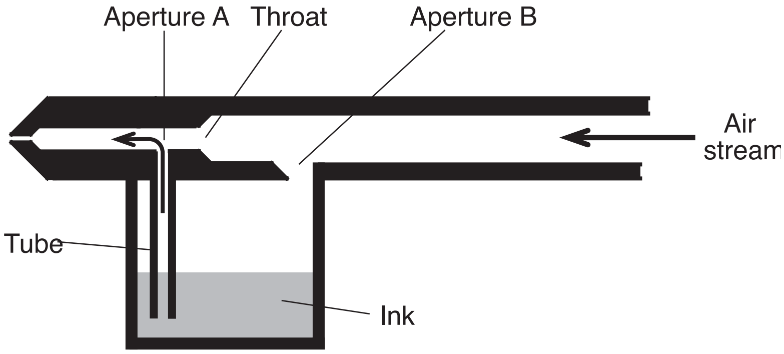
Bernoulli's Theorem

> *The total energy of a particle of fluid moving along a channel remains constant.*

Total energy = potential energy + kinetic energy + pressure energy

If the channel is horizontal, the potential energy of the fluid moving through it does not change.

So if the kinetic energy increases, the pressure energy must decrease. Therefore if the velocity increases, the pressure decreases.



NOTES ON PRESSURE

Pressure = force (Newtons) ÷ Area (m^2)

The unit of pressure is the Pascal (Pa) = 1.0 N/m^2

The pressure exerted by the atmosphere (atmospheric pressure) is approximately 100,000 Pa. Atmospheric pressure is also used as the basis for measuring pressure in units called bars.

1bar = atmospheric pressure (approx.) = 100000 Pa
2bar = twice atmospheric pressure = 200000 Pa
etc.

This design project will require you to use some of the technological principles from the professional system and some from the alternative disposable canister system.

You will need to use a mechanically operated pump that can compress the air in an air receiver. The output from the air receiver needs to be controlled by a valve. The aerosol will be produced by the nozzle and marker pen system.

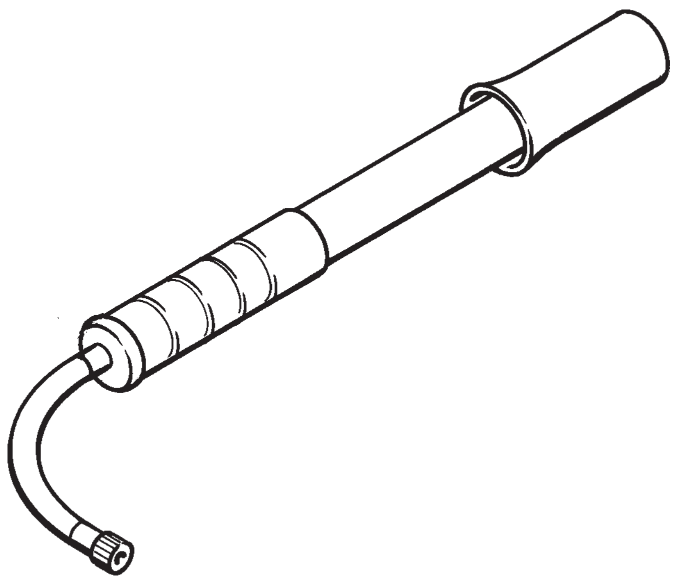
This means that your system will consist of four essential parts - The pump, the air receiver, the valve and the nozzle.

THE PUMP

The pump that you choose to use will depend on how much time you have available for the project and the design requirements that you will have for the overall package.

If the time and facilities are available then you might want to investigate making your own pump. A good way to find out about how simple mechanical pumps work would be to disassemble and analyse a car foot pump or a bicycle pump. Either of these designs would be suitable for adaptation for use in your system.

If time and/or facilities are limited then you might choose to use an existing pump of this type and integrate it into your design. Both of these pumps are capable of supplying sufficient pressure to load your air receiver.



THE AIR RECEIVER

This is the major structural element of your system. The air receiver acts as a **shell structure**. It has to be strong enough to withstand a total internal pressure of up to 2 bar. This is approximately the pressure in a normal car tyre!

This presents a major design problem. The shell structure needs to be structurally very strong but also, if the system is to be portable, very light.

There are two major considerations with the design of the air receiver. The first is the form and the second is the material.

FORM

The form of the shell structure will affect its structural strength. The forms most resistant to internal pressures produced by compressed gasses are those with the least number of sharp edges or corners.

The form with no edges or corners is a sphere, which is the most resilient. (Most forms will tend to take on the characteristics of a sphere if you inflate them enough!) The resilience comes from the sphere's ability to share the internal forces equally around the whole surface area of the 'skin'. Corners and edges tend to concentrate the forces and the structure will fail at these points. Unfortunately the manufacture of a hollow sphere is quite difficult and the form is not convenient for storage, packaging etc.

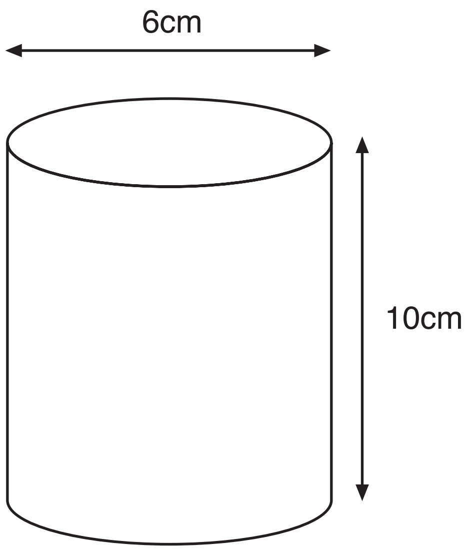
The form with the next least number of edges is the cylinder with just two edges. Cylinders are more easily manufactured and have a more convenient shape for most applications.

MATERIAL

The material chosen must be able to withstand a very high pressure loading. You can calculate the loading on the surfaces of a cylinder in a fairly simple way.

To calculate the loading on the ends of the cylinder you need to calculate the area of one of the end caps.

Using the cylinder shown:



area $= \pi r^2$
$= 3.14 \times 3 \times 3$
$= \underline{28.3\ cm^2}$

The maximum pressure in the cylinder is 2 bar but we should allow twice this to provide a margin of safety.

4 bar = 400 000 pa
= 400 000 N/m^2

or 40 N/cm^2

Therefore total loading on 1 end cap

$= 40 \times 28.3$
$= 1132$ N

Therefore total loading on both end caps

$= 1132 \times 2$
$= \underline{2264\ N}$

To calculate the total loading on the walls of the cylinder you need to calculate the area of the walls. This is done by multiplying the circumference of the end by the height.

Area = $\pi d \times 10$
= $3.14 \times 6 \times 10$
= $\underline{188.4\ cm^2}$

Therefore the total loading

= 188.4×40
= $\underline{7536\ N}$

So, the total loading on the surface area of a cylinder of this size would be:

$7536 + 2264 = \underline{9800\ N}$

Converting this to Kilograms shows that the total loading is 980 Kg which is almost a Ton!

It is obvious from this that the material that is used for the air receiver must be very strong, i.e. resistant to tensile forces. If it is not then the structure will deform and eventually fail by bursting. A material's ability to resist tensile forces is indicated by figures for its tensile strength.

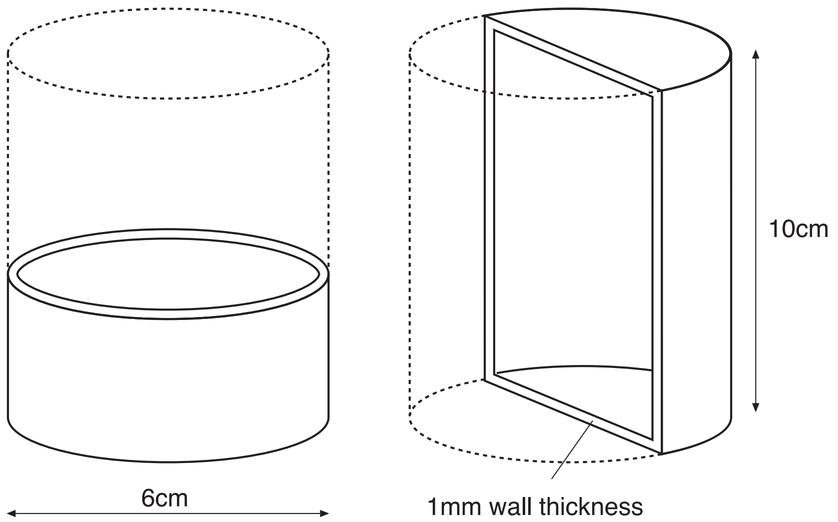
Material	**MN/m^2**
steel piano wire	3000
high tensile steel	1500
titanium alloys	700 - 1400
mild steel	400
aluminium alloys	140 - 550
traditional wrought iron	140 - 280
modern cast iron	140 - 280
copper	140
brasses	120 - 400
pure cast aluminium	70
flax	700
cotton	350
silk	350
spider's thread	240
bone	140
wood (along grain)	100
tendon (muscle)	100
hemp rope	80
leather	40
glass window or wine glass	30-170
ordinary brick	5
cement and concrete	4
wood (across grain)	3

To find out what tensile strength will be required, and hence what suitable materials are available you need to calculate the value of stress that is present in the walls of the cylinder.

Stress is the amount of compressive or tensile force acting upon the cross-sectional area of the material.

i.e. Stress = force ÷ cross-sectional area

The stress in the cylinder will be different in different parts of its structure. A simple, but reasonably accurate, stress analysis can be carried out by looking at the two major cross sections, i.e. vertically and horizontally through the cylinder's centre.



(Assume a wall thickness of 1mm)
To calculate the stress on the horizontal cross-section:

Calculate the cross-sectional area

CS area = πr^2(outside) - πr^2(inside)

= 28.8 - 26.4

= 2.4 cm^2

= <u>240 mm^2</u>

The force acting on this cross-section is the force acting on one end of the cylinder. We calculated this above as 1132 N.

Therefore, stress in horizontal cross-section

= 1132 ÷ 240

= <u>4.7 N/mm</u>^{2}

To calculate the stress in the vertical cross-section:

calculate the cross-sectional area

= area(outside) - area(inside)

= (6 × 10) - (5.8 × 9.8)

= 60 - 56.84

= 3.16 cm^2

= <u>316 mm</u>^{2}

The force acting on this cross-section is the force acting on the vertical cross section of the cylinder. We calculated this above as 7536 N.

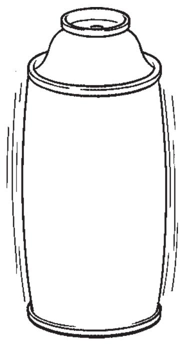
40 × 6 × 10 = 2400N

Therefore, stress in horizontal cross-section

= 2400 ÷ 316

= <u>7.6 N/mm</u>^{2}

This shows that the maximum stress is in the vertical cross-section. This agrees with common sense. If you were to over inflate a cylinder then it would be the vertical sides that would stretch first causing the cylinder to take on a more spherical shape.

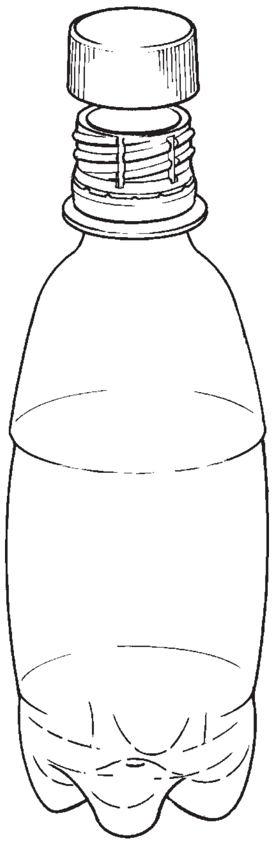


Over pressurised cylir

Looking at a table of material's tensile strength would show you that many constructional materials are capable of withstanding this kind of stress. The most suitable would perhaps be metals or some plastics.

The design brief asks for a system that is low-cost and highly portable. This would point towards using plastics as they are light and very easy to form using different moulding techniques. The main problem with this solution is that you are unlikely to have sufficient equipment to mould the cylinder in one piece. Remember the calculations assumed a perfect structure with no joins. If you fabricate the cylinder then it will be much weaker at the joints.

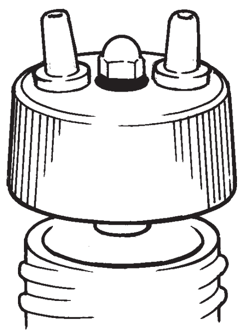
There is, however, a very cheap and readily available source of plastic cylinders that are light, formed in one piece and capable of withstanding the necessary pressures. These are plastic fizzy drinks bottles. It is estimated that over 1.5 billion of these bottles are sold and thrown away each year in the UK alone. They may appear to be a very mundane and commonplace item but they are in fact a very high technology product that resulted from many hours of design effort.



To find out more technical information about these bottles refer to page 118 to 120 of the Young Technologist's Handbook

So you have a perfect ready-made solution for the air receiver. This solution does, however, require some further thought.

Firstly, how will you connect the pipes to the receiver. This problem can be overcome by using the special TEP bottle top available from the Middlesex University Teaching Resources Centre.



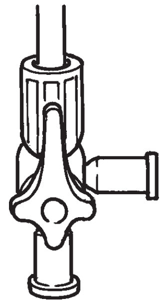
Bottle top

Secondly, the wall thickness of one of these bottles is approximately 0.2mm. If the side of the bottle were to get scratched or badly dented then the stress at the point of damage would increase considerably. This could cause the bottle to fail when it is pressurised.

To prevent this you will need to design and make another structure to protect the bottle. This could take a number of forms and be made from a wide range of materials. Its primary function is to protect the bottle from knocks and abrasions but will also act as a safety shield if the bottle were to fail under pressure. It could also provide other useful facilities. The system has to be portable so this structure could include a carrying handle. It could also be used to incorporate or store the other elements of the system (pump, tubes, valve, nozzle, markers etc.), leading to an aesthetically pleasing and highly functional product.

THE VALVE

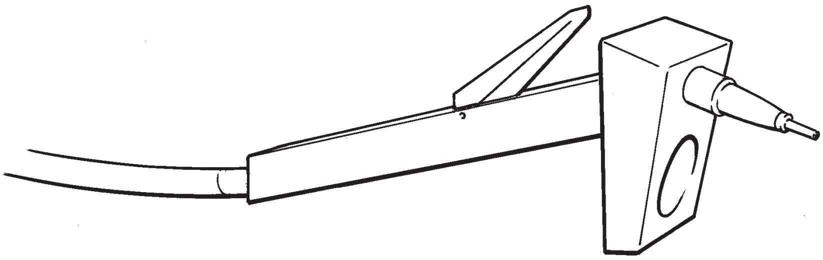
The design and construction of the valve could again take many forms. If you have the time available then you might wish to try incorporating it into the nozzle and clamp assembly that fits to the marker pen. This would give a good ergonomic solution. Alternatively you could use a ready-made plastic valve available through TEP.



3-port valve

THE NOZZLE

This part of the system is a small structure in its own right. You will need to design and make a method of clamping the nozzle onto the marker pen. The distance from the pen tip, the angle of the air stream and the air pressure will all affect the quality of the aerosol that you produce. You may need to do some experimenting with this. Perhaps you could produce a number of different nozzles to give you different effects or for use with different marker pens.



The success of your project will lie in the technical and aesthetic design of the system. Using the above information it should be possible to produce a very effective product that is highly portable and cheap to both manufacture and use.