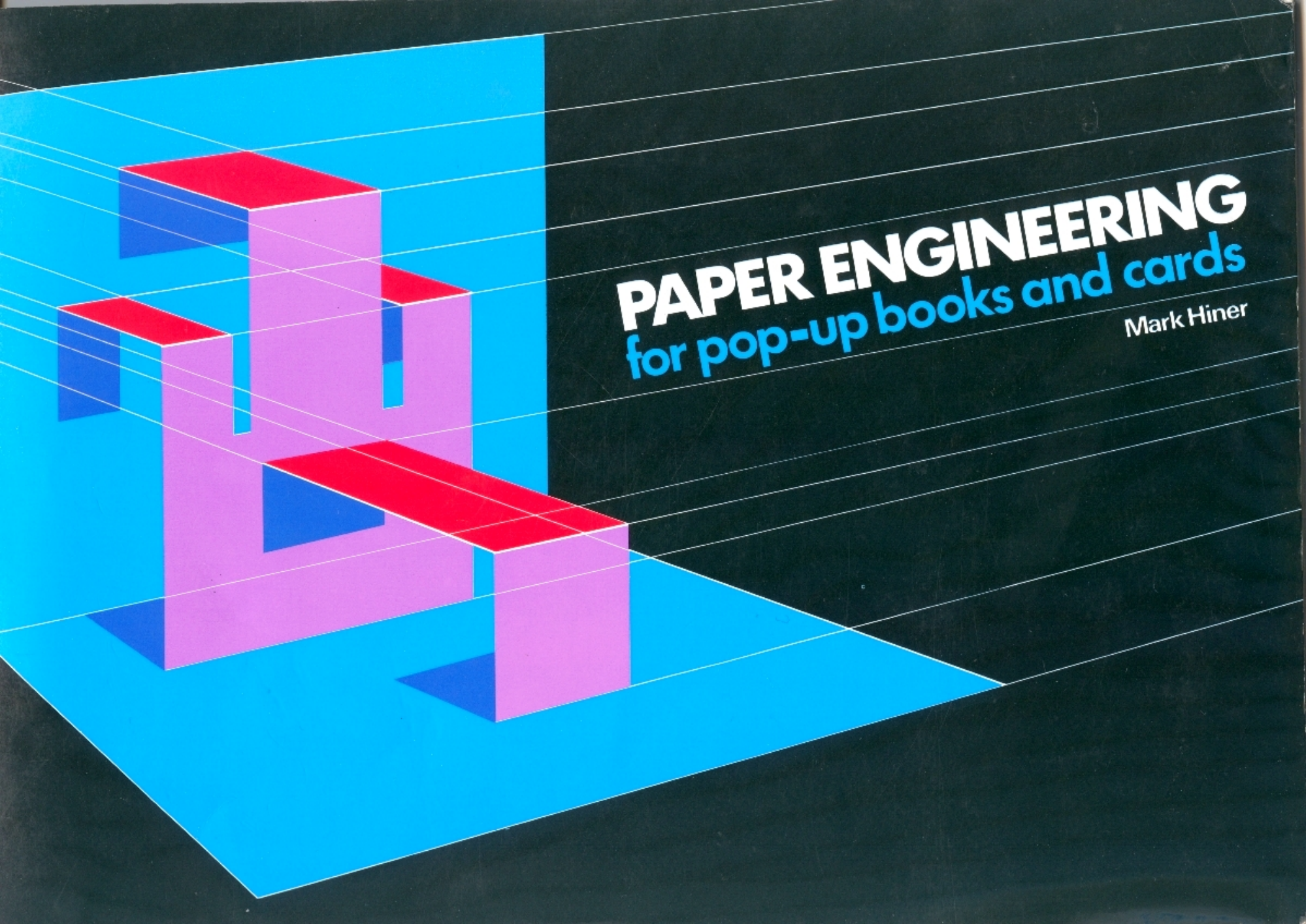


PAPER ENGINEERING
for pop-up books and cards

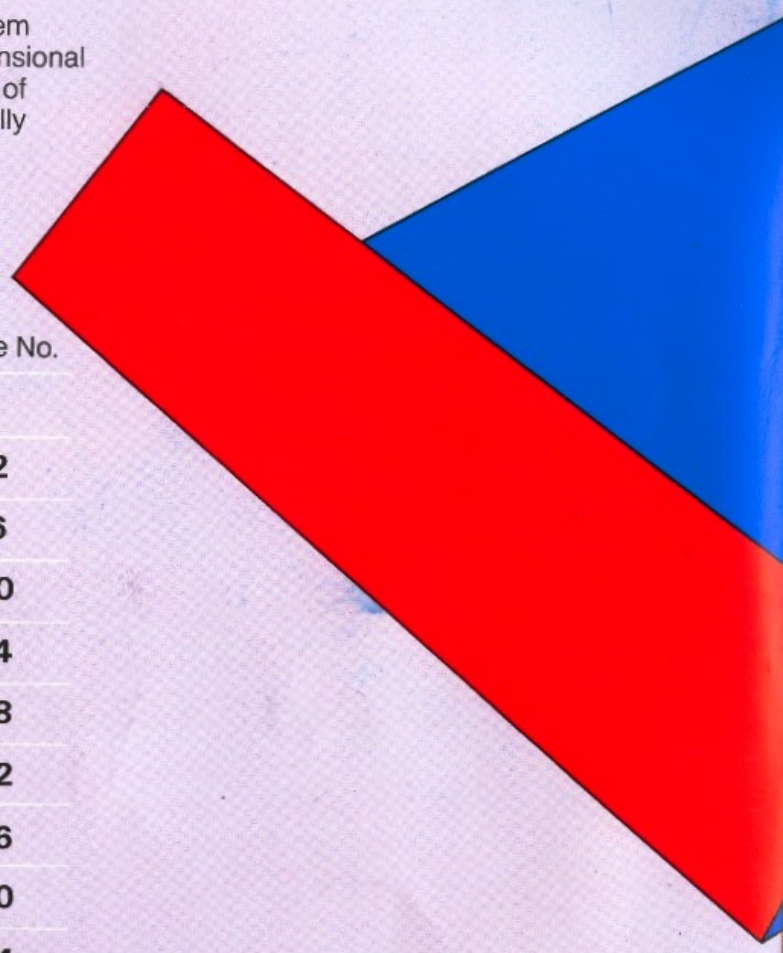
Mark Hiner

It moves....

The purpose of this book is to stimulate interest in the imaginative possibilities of the kind of paper engineering which is used for pop-up books. It can be regarded as a basic dictionary or encyclopedia of mechanisms which do work and which can be used as starting points for further inventiveness.

The effects of the mechanisms are dynamic and three-dimensional and so it did not seem either sensible or vivid enough to try to describe them only in words and static two-dimensional pictures. Hence, it is a feature of this book that you can make a working model of each of the mechanisms. Only by making and playing with each mechanism in turn, can you really appreciate the possibilities which it offers.

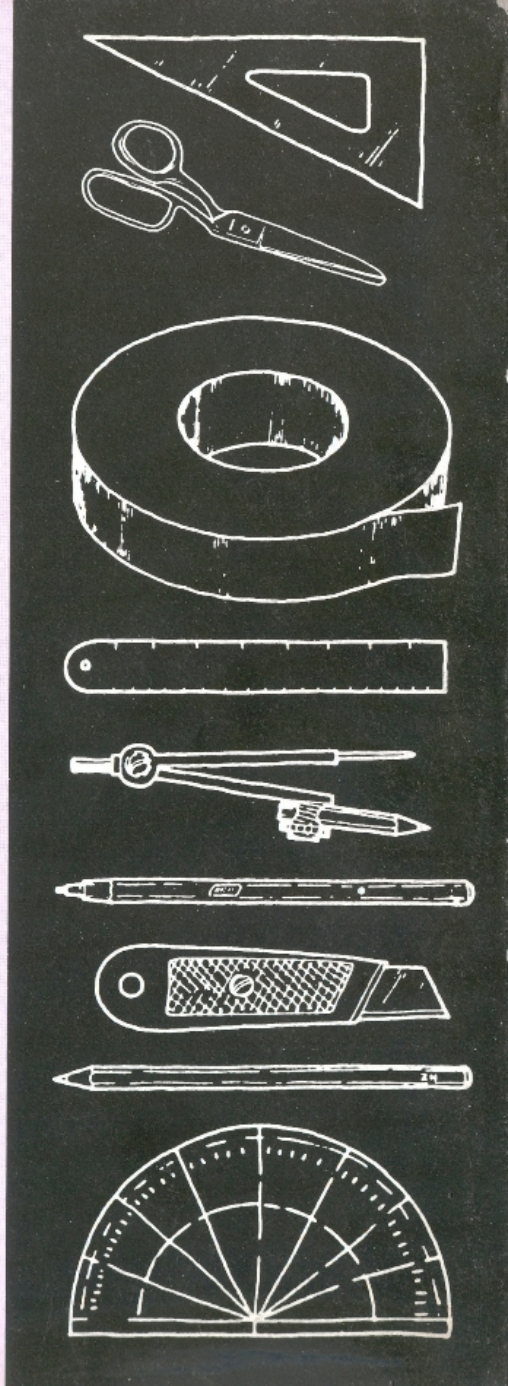
The working models



PAPER ENGINEERING

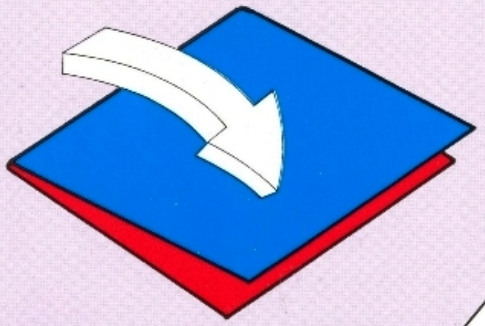
for pop-up books and cards

Mark Hiner



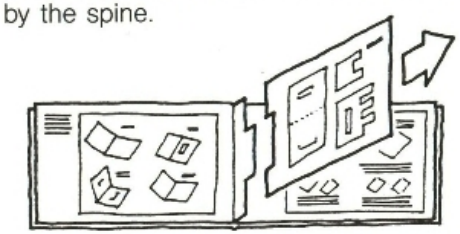
Making the models...

This book has been designed so that you can make a working model of each of the ten mechanisms and then conveniently keep them for easy future reference. Just follow the instructions on this page.



1.

Cut each working model sheet in turn out of the book, making sure that you do not cut off the tab by the spine.



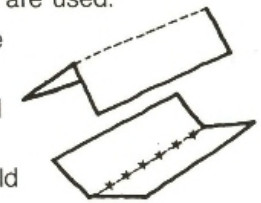
2.

Make up each of the mechanisms taking note of the following symbols which are used.

cut line

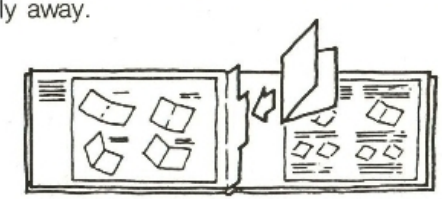
hill fold

valley fold



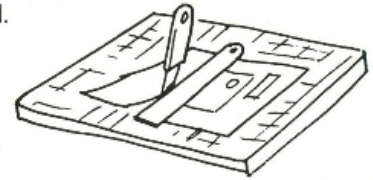
3.

When the model is complete, glue it back into the book on the tab provided. The mechanism is then available for easy reference and it will fold neatly away.



Cutting

Use either a pair of scissors or, better still a sharp craft knife. A metal ruler must be used to guide the knife. Protect the surface you are cutting on with a piece of thick card or a board of some kind.

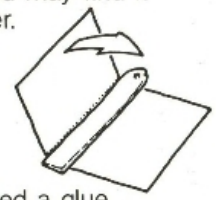


Scoring

Successful paper engineering needs creases and folds which are crisp and accurate. This means that the paper must be scored so that it folds precisely along the desired edges. The best method is to rule along the lines with a ball-point pen which is out of ink. Some people will feel happier with a scoring stylus or a blunt craft knife. The aim is to compress the fibres of the paper so that it will fold and flex easily, but not to cut right through.

Folding

Mostly it will be sufficient to fold and crease along the scored line. However you may find it helpful to fold against a metal ruler.



Glueing

To get the best results you will need a glue which sets quickly but not instantly and which does not make dirty marks. We particularly recommend a petroleum based glue like UHU or Bostic Clear. Good results may also be obtained with white adhesive like Copydex or PVA. Apply the glue sparingly, just a little too much in the wrong place can ruin a mechanism!

Your own designs...

The approach of Christmas or a birthday is a fine excuse to do some paper engineering. What about a special pop-up card or book for a special occasion?

With each of the ten mechanisms there is a page called 'technical considerations'. On it you will find useful advice for using that particular mechanism. You will also find two or three possible applications which may be helpful.

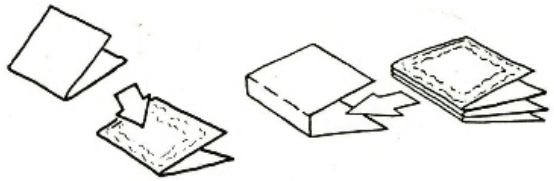
Pop-up cards

Try to exploit the surprise factor which is intrinsic to the mechanism which you choose. It is most satisfying where the message and the mechanism are seen to be in harmony.

However, the most important feature is that the mechanism works and continues to work. When you produce a successful and appropriate card it will be admired, handled and passed around. How much nicer if it does not collapse under the pressure! As a general rule, keep it simple!

Pop-up books

Most pop-up books have five or six spreads but it is best to treat them separately, just as if you were making a series of cards. Then carefully glue them together to make the book. There is no need to spread glue over the whole page area, a strip near the edges will be sufficient. Be careful to keep it clear of any mechanism.



Glue the collection of pages into a cover made of stiff card, scored so that it will open cleanly. Carefully measure the thickness required for the spine of the book.

Paper

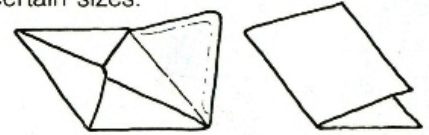
It is not necessary to use very thick paper for pop-ups. This book is printed on 170 gsm paper and for many purposes thinner paper would have sufficed. Try to find a paper which is stiff and springy and which will make a good crease when it is scored and folded.

The fibres in paper have a grain and the direction of the grain is usually referred to as the 'run' of the paper. The springiness can be different along and across the run of the paper. This is not usually a problem, but it is worth checking.

Check also that the paint or crayons do not have an unexpected effect on the paper you are going to use. Wax crayons may repell the glue you intend to use.

Envelopes

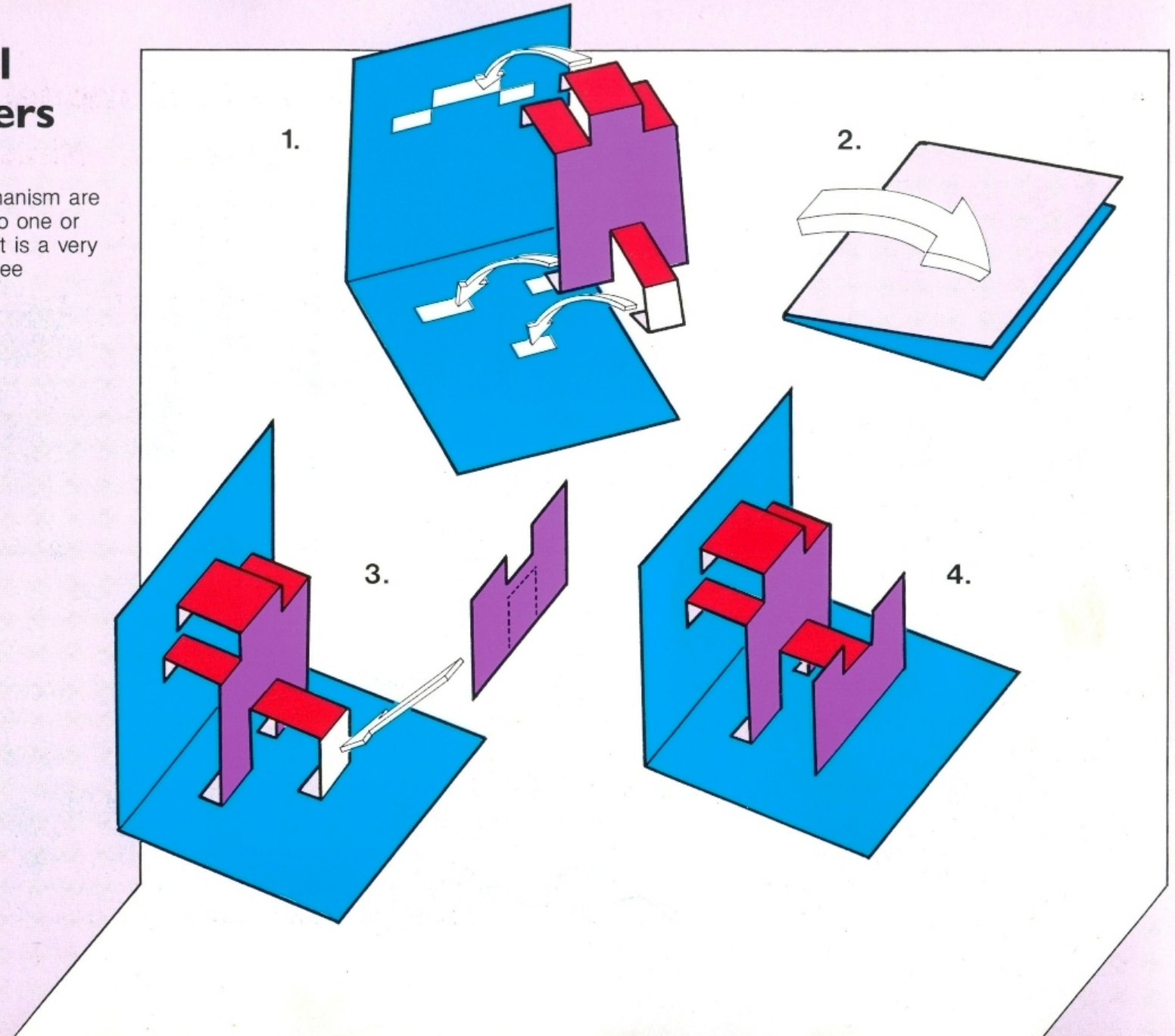
If you are going to make a pop-up card and intend to send it by post, it is a good idea to think of the envelope first. It is difficult to make a professional looking envelope and they only come in certain sizes.



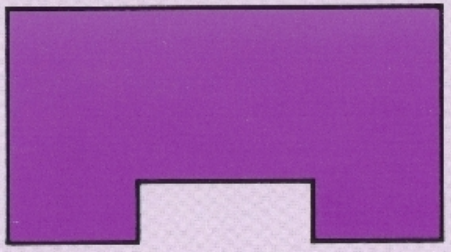
Cut the base to fit the envelope before starting your card.

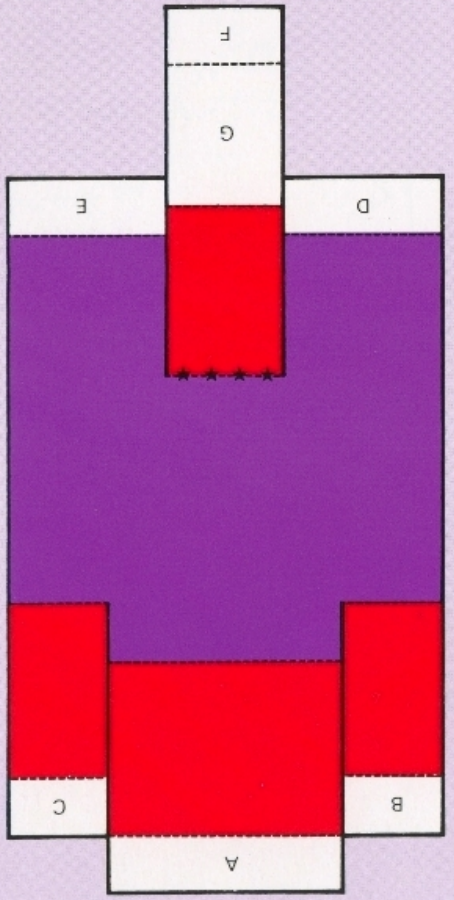
Mechanism 1
Multiple layers

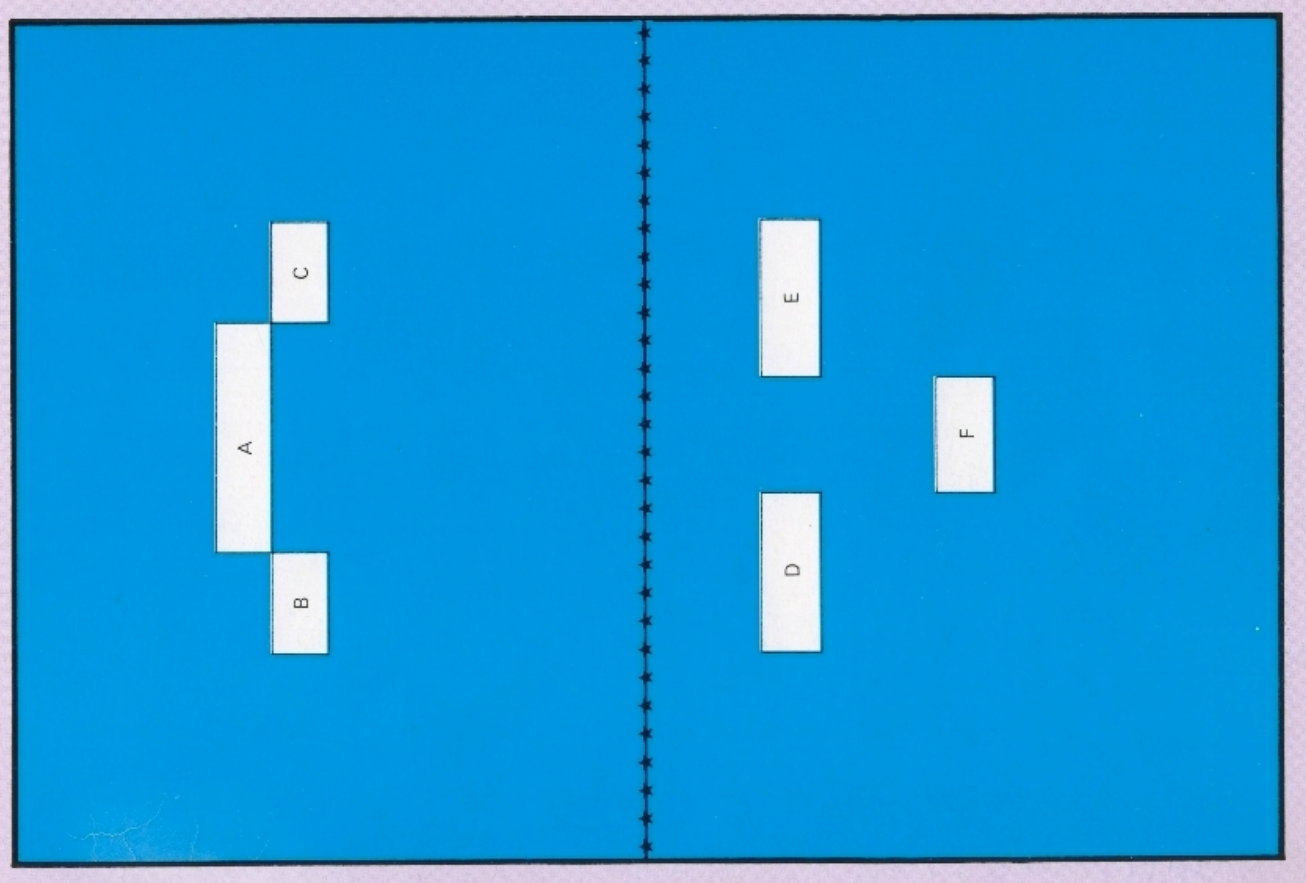
All the layers for this mechanism are planes which are parallel to one or other of the base planes. It is a very simple way of getting a three dimensional effect.



A working model to make
Mechanism I Multiple layers







1 GLUE COMPLETED MECHANISM NO. 1. HERE

1

MECHANISM 1. GLUE TO TAB WHEN COMPLETED

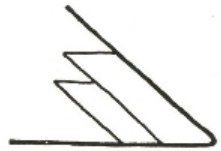
Mechanism I Multiple Layers

Mechanism 1
Multiple layers

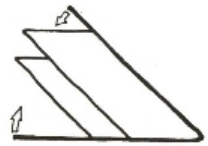
Technical considerations

This mechanism was one of the first to be used for pop-up books and is undoubtedly one of the simplest. Each individual image or picture is flat, but by means of multiple layers, an impression of depth is created. This impression can be enhanced where necessary by the detail and definition of the drawings used on the foreground and background layers.

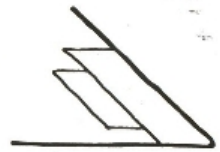
In theory any number of layers is possible as long as each space is a parallelogram. In practice it is best not to have too many or the bulk of paper prevents the card from closing properly. If you are doubtful about a design, look at it from the side so that you can see all the edges. Each edge must be parallel to one of the two base planes.



As long as the edges are parallel to one side of the base the card will fold flat.

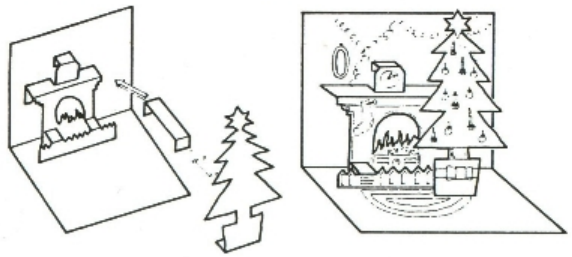


but be sure the the base is big enough.

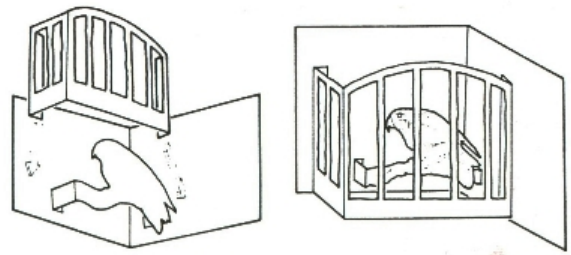


There are two parallels here, but it still will not work!

This mechanism is usually intended to be seen when the angle between the base planes is 90°, giving either a square corner or else a horizontal and vertical. If you are having trouble with a design, try rotating it by 90° and then think again. The following two examples illustrate this possibility.



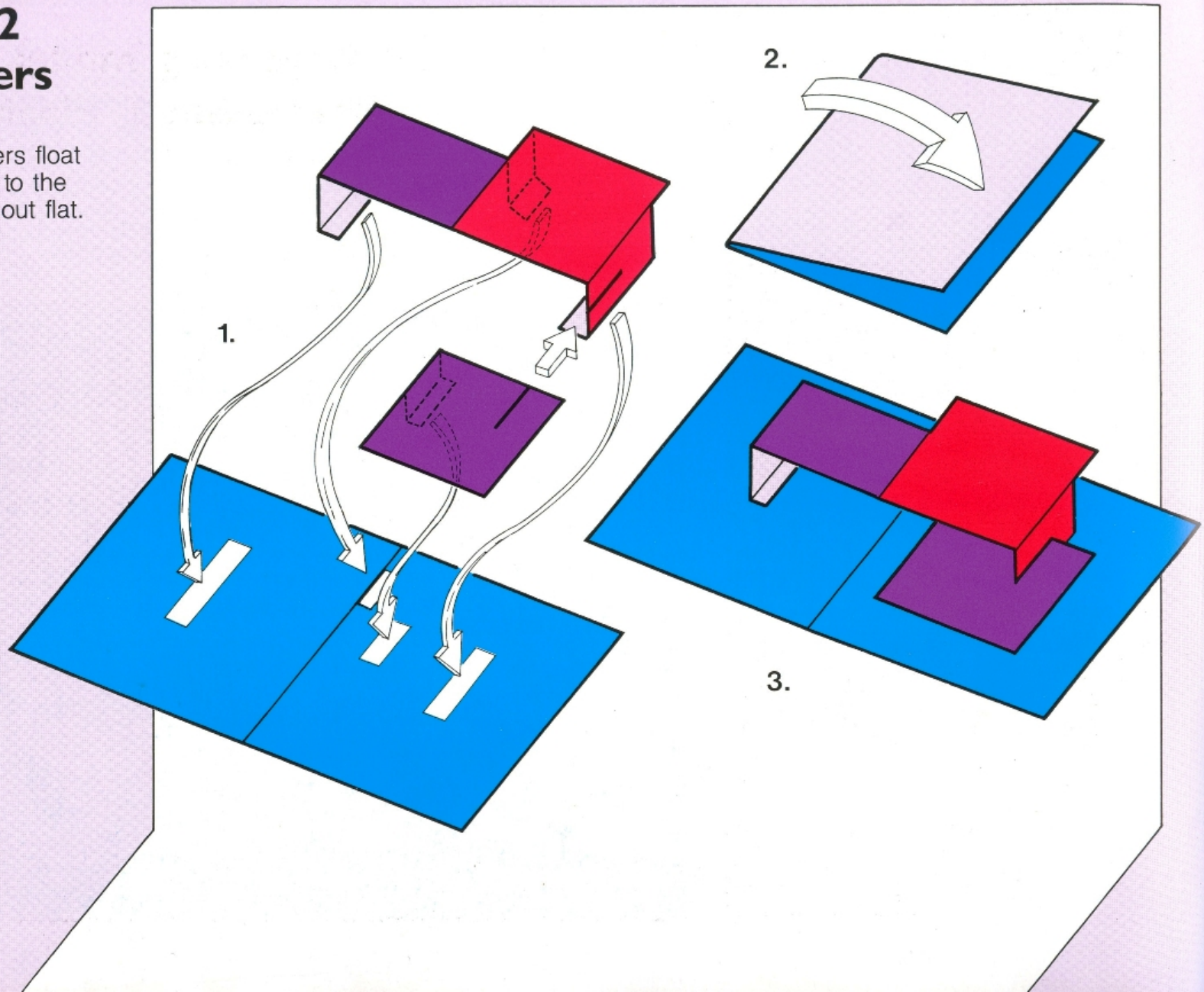
Here the two base planes are perceived to be horizontal and vertical making a floor and a back wall.



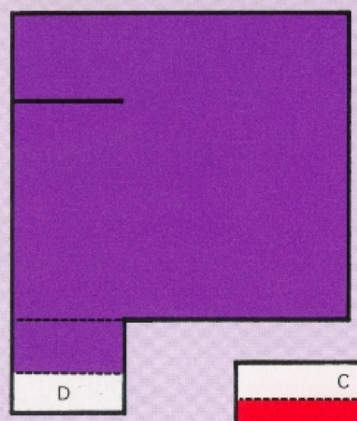
Here the two base planes are perceived as vertical making a square corner.

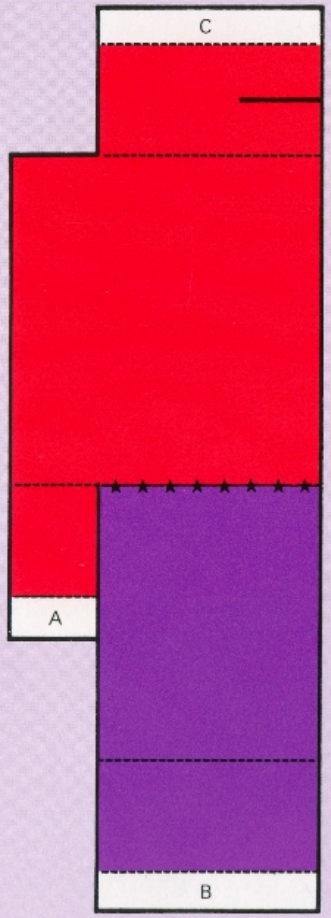
Mechanism 2
Floating layers

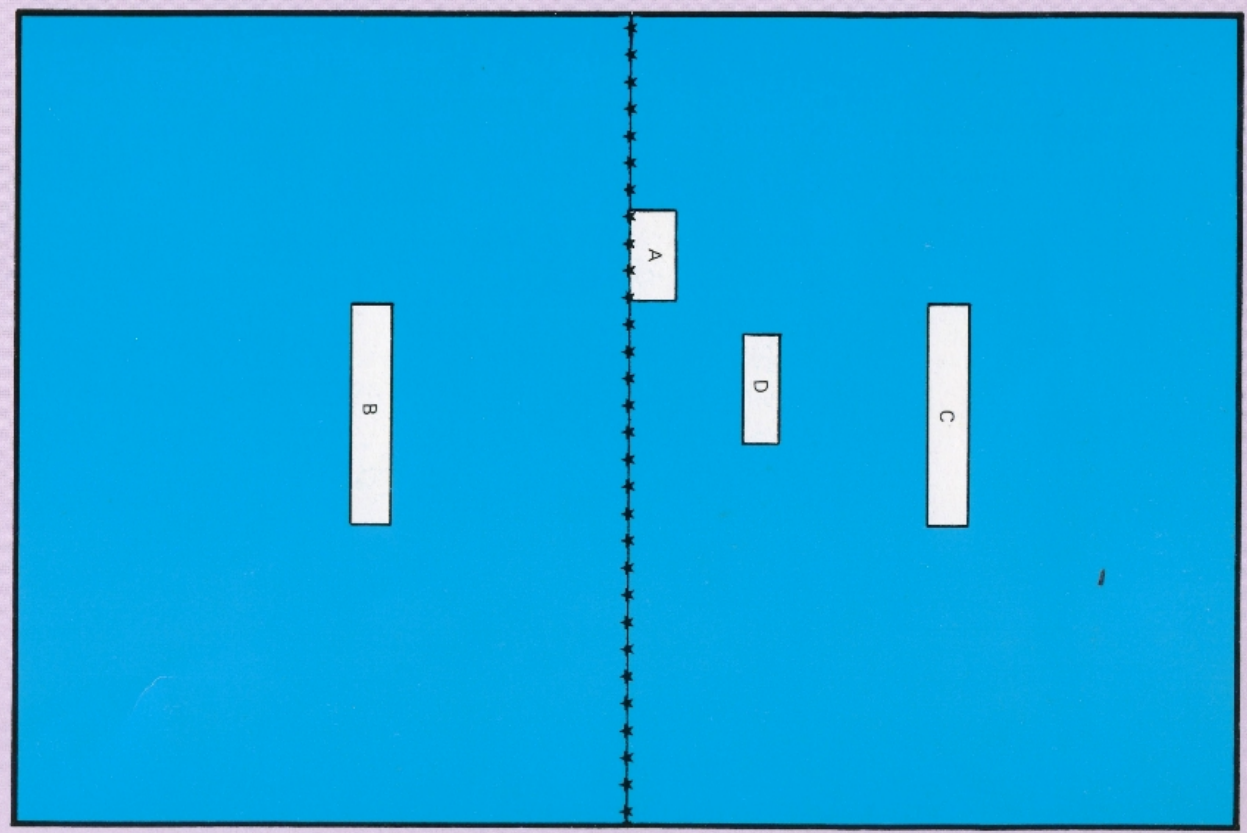
In this mechanism layers float above and are parallel to the base which is opened out flat.



A working model to make
Mechanism 2 Floating layers







▲ 2

GLUE COMPLETED MECHANISM NO. 2. HERE

2

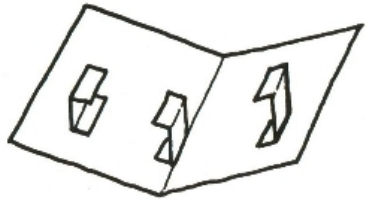
MECHANISM 2. GLUE TO TAB WHEN COMPLETED

Mechanism 2 Floating Layers

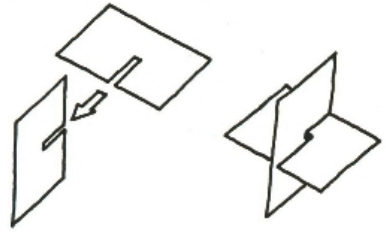
Mechanism 2
Floating layers

Technical considerations

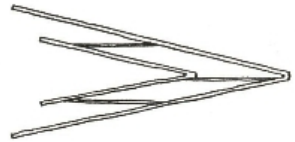
This mechanism is similar to mechanism 1 in that there can be multiple layers which are parallel to the base planes. However it is different in that it is intended to be opened until the base is flat. The working model shows how the main floating layer is used to support a secondary layer which can be attached to increase the apparent 'depth'.



Notice how the main floating layer needs three verticals, one at each outer edge and then a vertical at the centre fold. All three must be the same height.

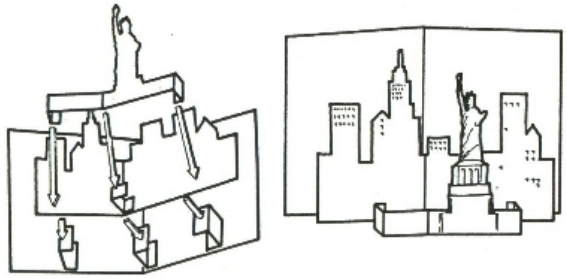


Observe the way in which two pieces may be joined by opposing cuts. This gives an interesting variation to joining by flaps and glue and in certain circumstances places less stress on the mechanism.

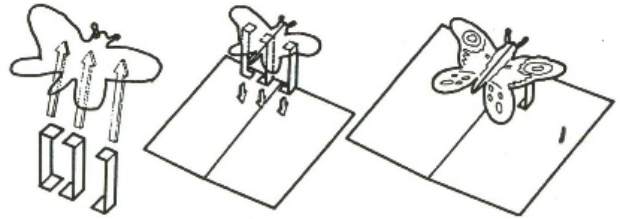


This view from the side shows how the mechanism moves out only by the vertical height as the card closes. This makes it possible to include quite large floating layers.

If the base plane is perceived to be vertical, then the layers float in front of it. If the base plane is perceived to be horizontal, then they float above it. These two examples indicate how this may be used to create appropriate scenes.



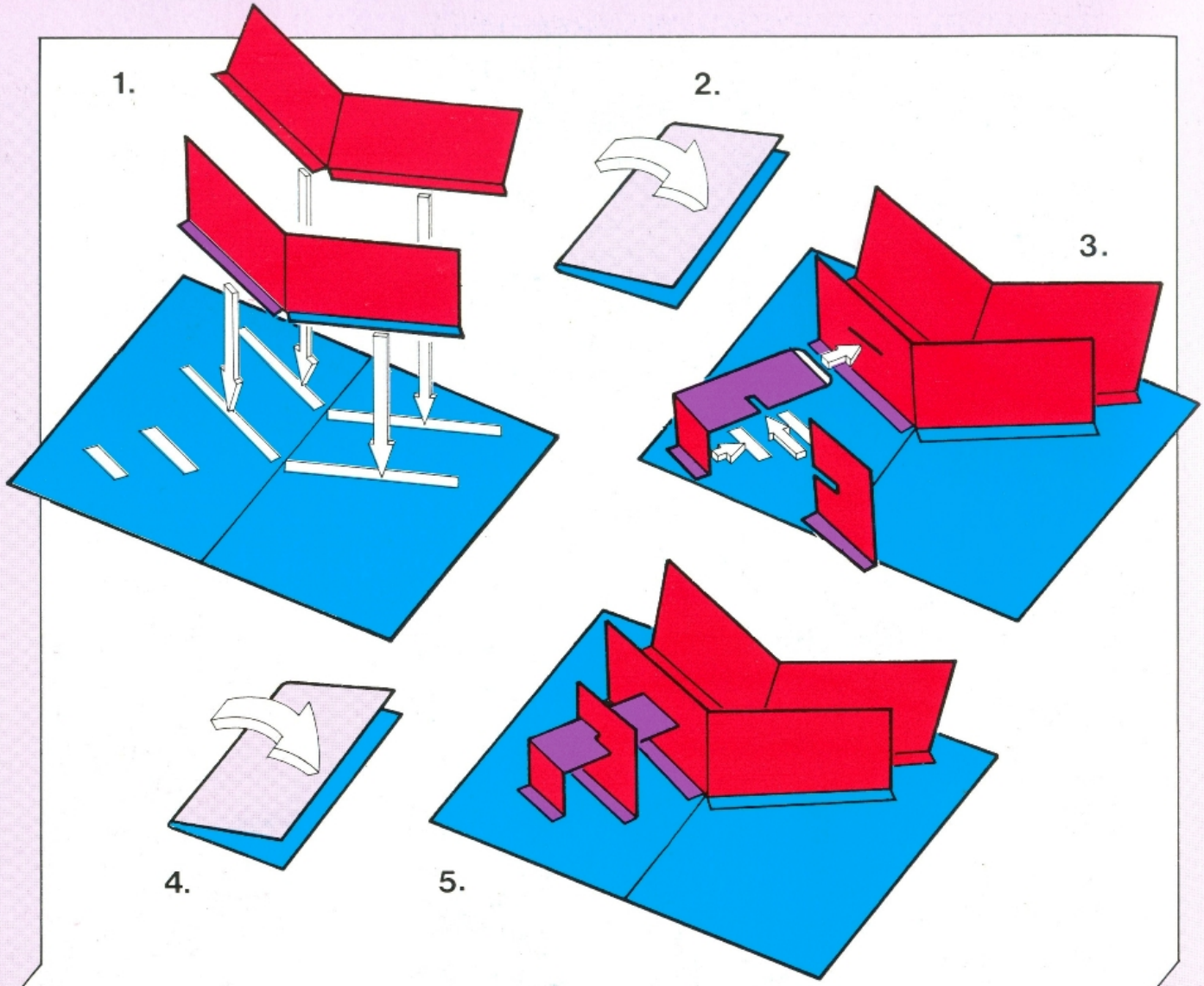
Here the vertical nature of New York demands a vertical treatment.



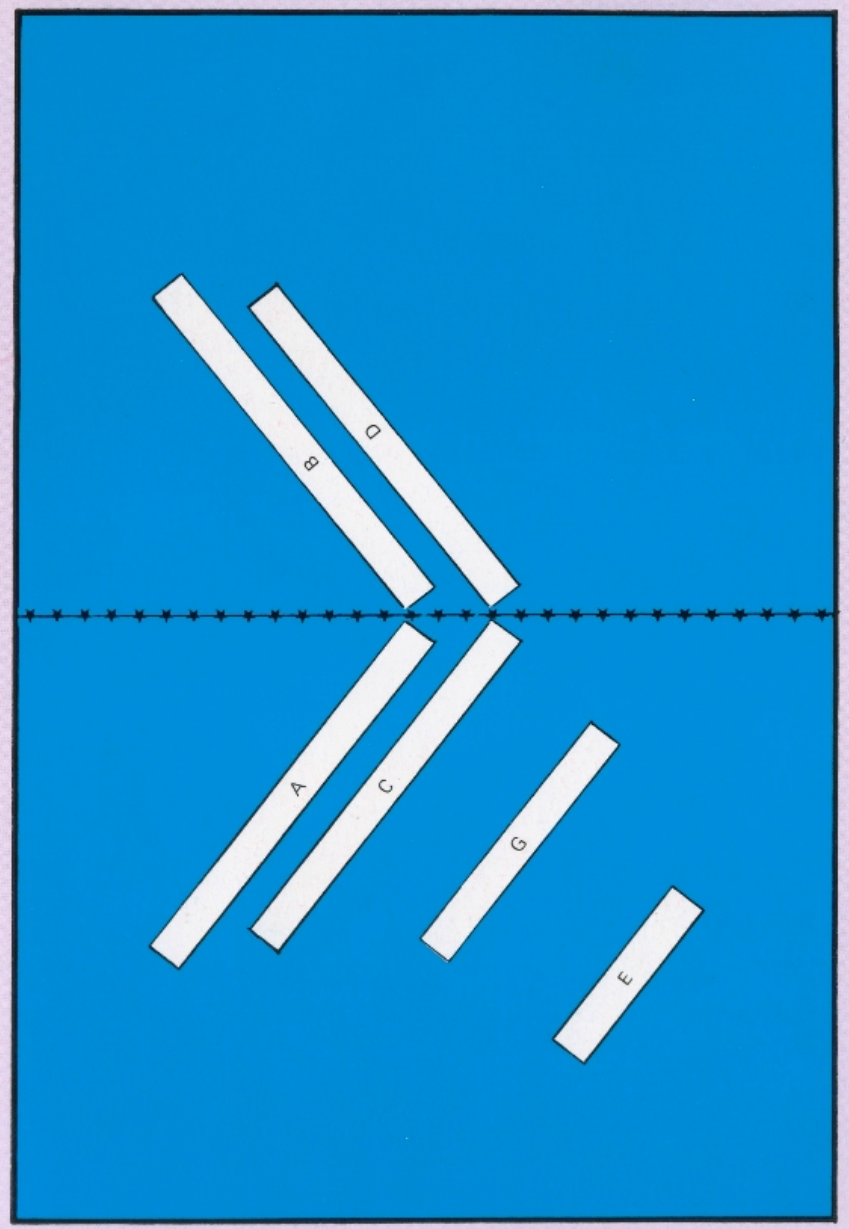
Here the horizontal base serves to emphasise the resting butterfly.

Mechanism 3
V–fold.

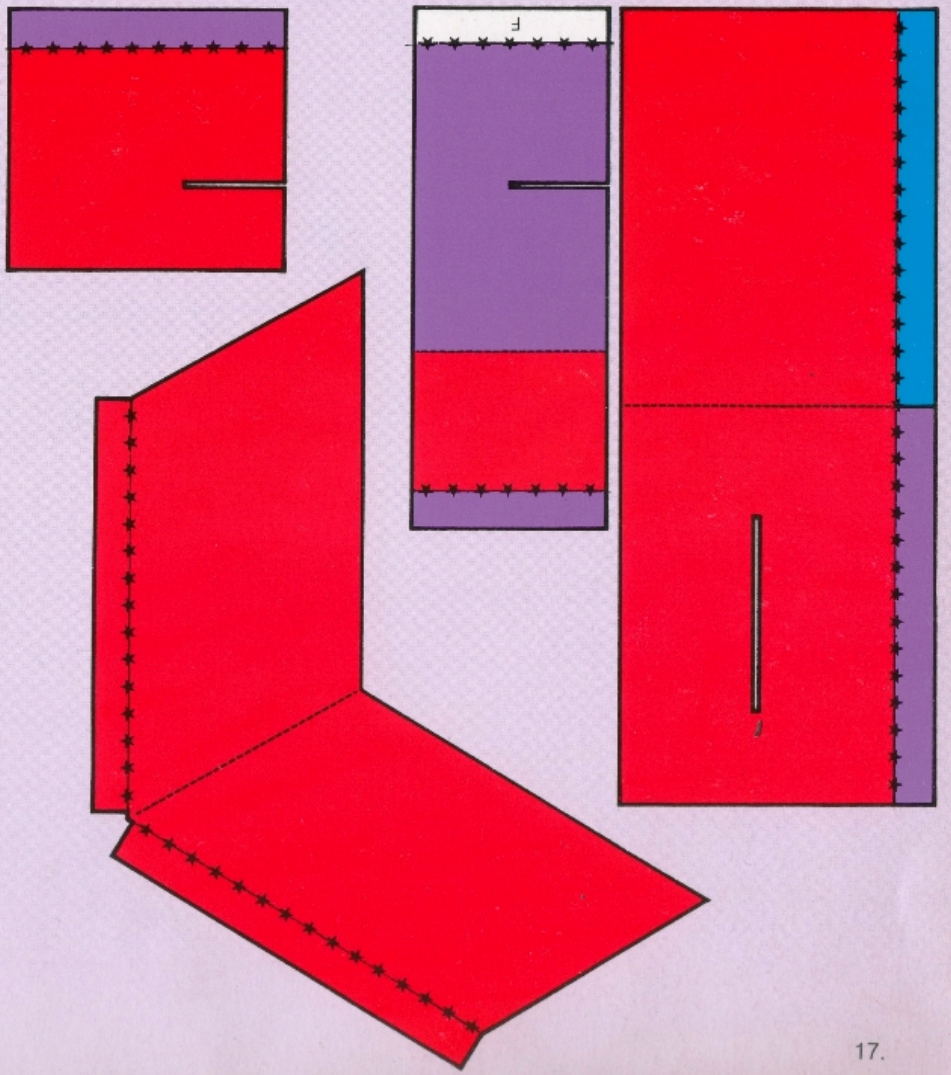
This mechanism is one of the commonest and most useful. The model shows two variations on the V-fold principle and how to strengthen a join by passing a flap through a slot. The model also shows how the strength of the V-fold mechanism can be used to pull up further horizontal and vertical layers.



A working model to make Mechanism 3 V–fold



GLUE COMPLETED MECHANISM NO. 3. HERE ▲ 3



G

D

MECHANISM 3. GLUE TO TAB WHEN COMPLETED 3

Mechanism 3. V–Fold

E

A

C

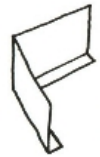
F

B

Mechanism 3
V–fold.

Technical considerations

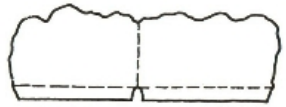
The name V–fold comes from the shape that the flaps make on the base. The size of the angles on either side of the central line is not important, but they must be equal.
If there were a letter Λ, then this mechanism could just as well be called a Λ–fold, because the V can be inverted. The V and Λ have different properties which can make one more suitable than the other for a certain application.



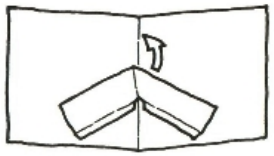
Flaps can be tucked away behind out of sight

or flaunted and made a feature of the design.

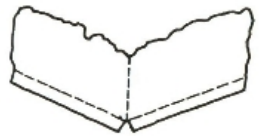
Where the flaps on the base make a V, the stand-up piece folds forward and its back can be seen when the card is nearly closed.
The V should be near the top of the card.



When the angles at the fold line are right angles, the piece stands up vertically.



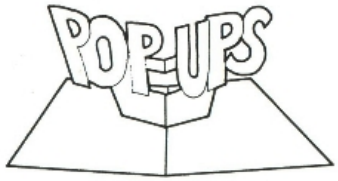
When the flaps on the base make an inverted V. the stand-up piece folds backwards and its base is never seen.
The Λ should be near the bottom of the card.



When the angles are less than a right angle the piece slopes forward or backwards depending on the orientation of the V.

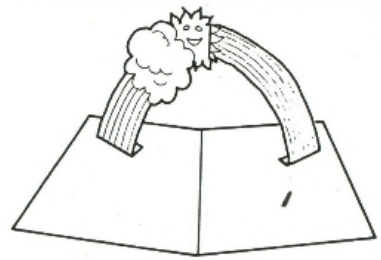
When the angles are greater than a right angle the piece slopes in the other direction. Experiment!

The mechanism is adaptable in many different ways.



You can use it to create surprise. It is an advantage for it to fold away forward on closing to enhance the surprise effect when it is opened again.

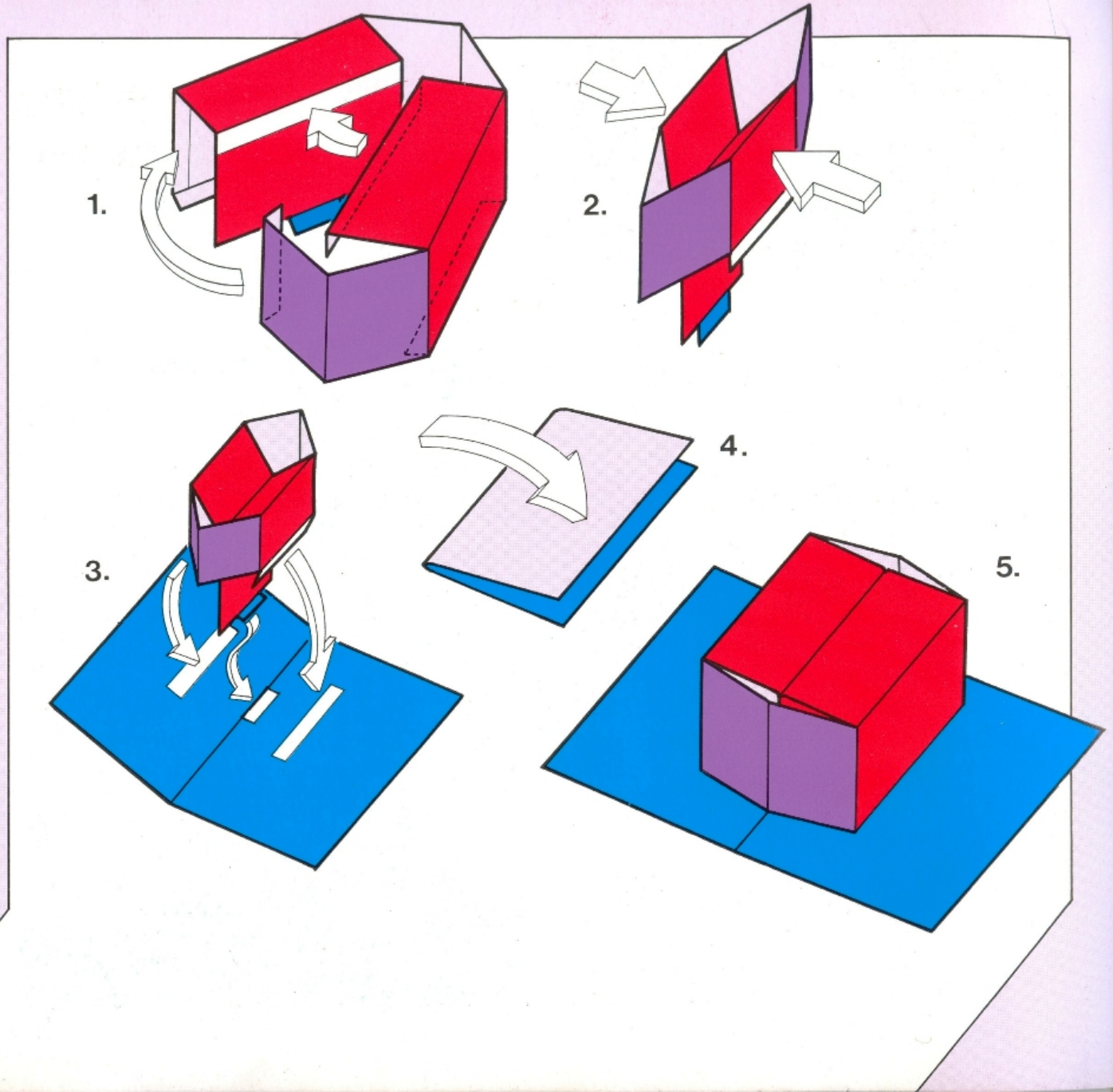
You can create realistic three dimensional scenes made up from several layers. In this case it seems better for the scene to be near the front and to fold away backwards.



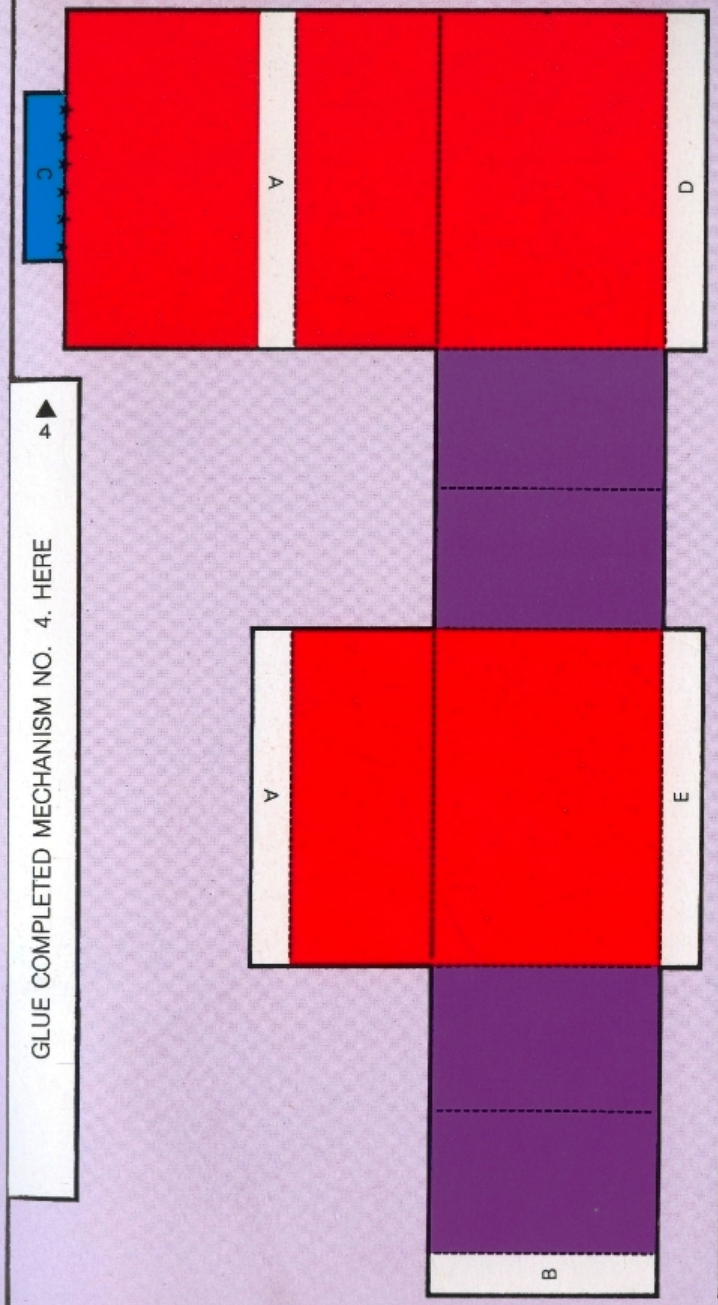
Paper near the centre line can be removed to create arches, doorways or peep holes or in this case an imaginative rainbow.

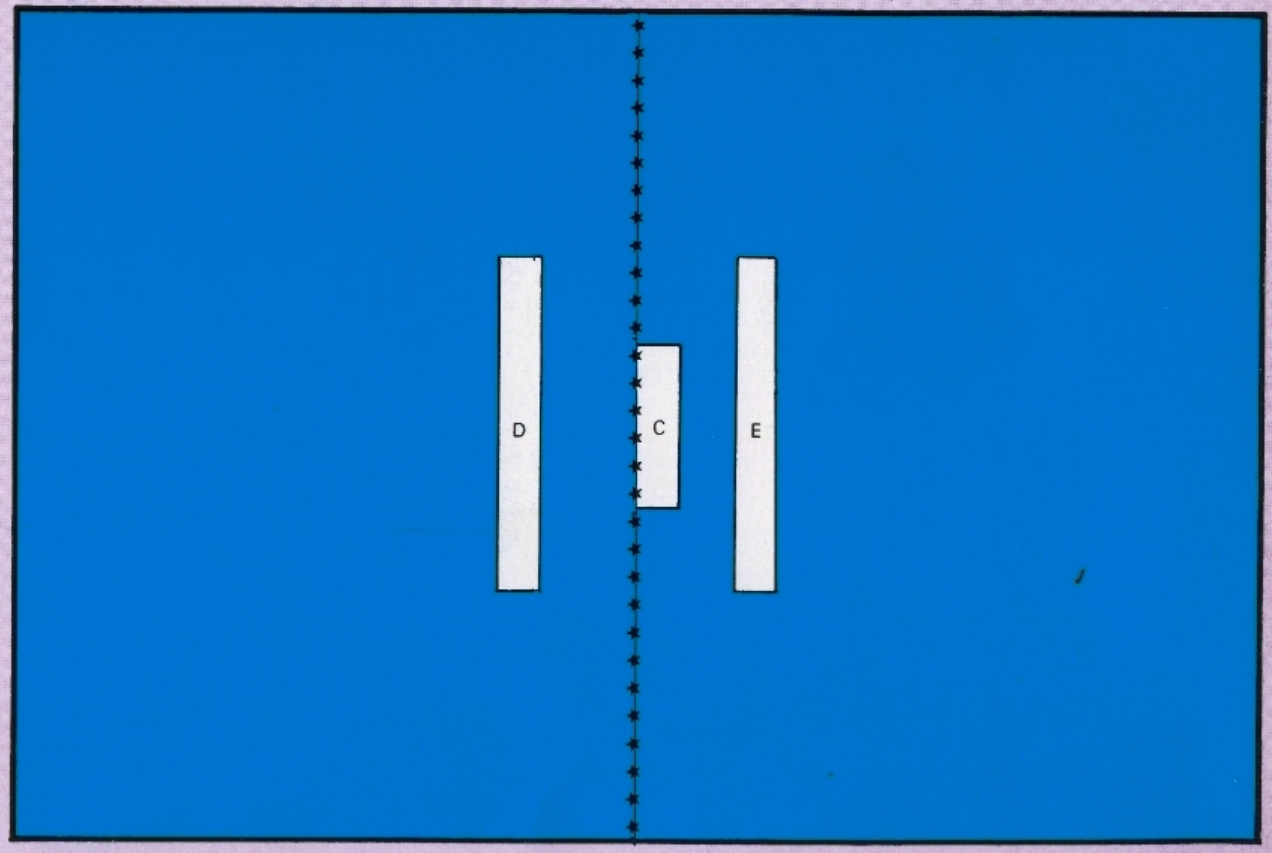
Mechanism 4
Magic box

The effect of this mechanism is to make a rectangular box of pleasing rigidity. It is set squarely on the base with two sides parallel to the centre line.
The box shape can be easily adapted to form basic designs that are truly three-dimensional.



A working model to make.
Mechanism 4 Magic box





B

C

MECHANISM 4. GLUE TO TAB WHEN COMPLETED

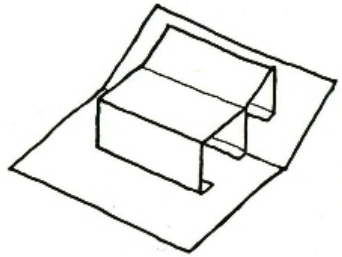
4

Mechanism 4 Magic Box

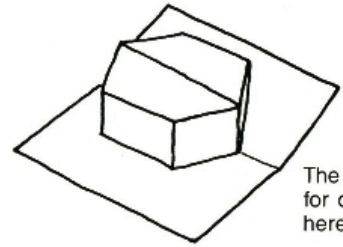
Mechanism 4
Magic box

Technical considerations

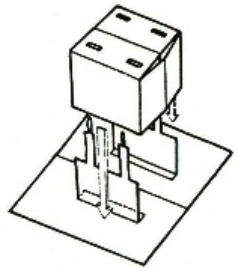
This mechanism is a good example of how a small change in the way of looking at a principle can produce something which appears very different. It is a simple adaptation of mechanism 2 and could well be described as ' floating layers with sides '.

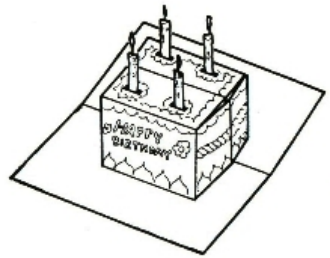


The effect of the central support is to push the 'roof' flat. Without it the mechanism will still work, but the 'roof' never becomes quite flat nor are the sides pulled in entirely.

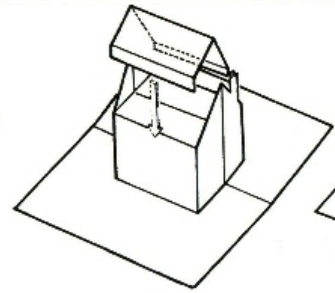


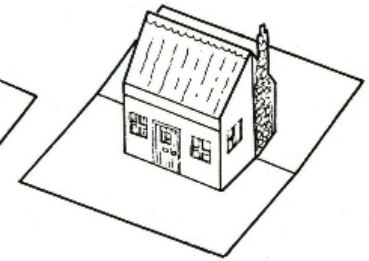
The same idea can be used for other symmetrical boxes, here a hexagon.



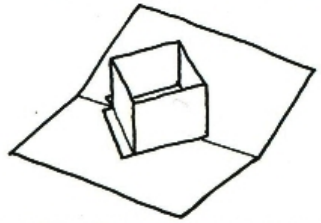


This idea makes a fine birthday card. Note how the candles pass through slots in the roof and thus remain upright. They cannot be glued to the cake itself! Unless you want all the candles round the edge!

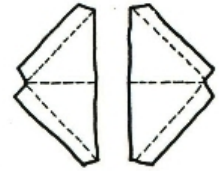




The basis of this cottage is the standard box mechanism with the sides extended and a roof added. But do not connect the roof to the central support.



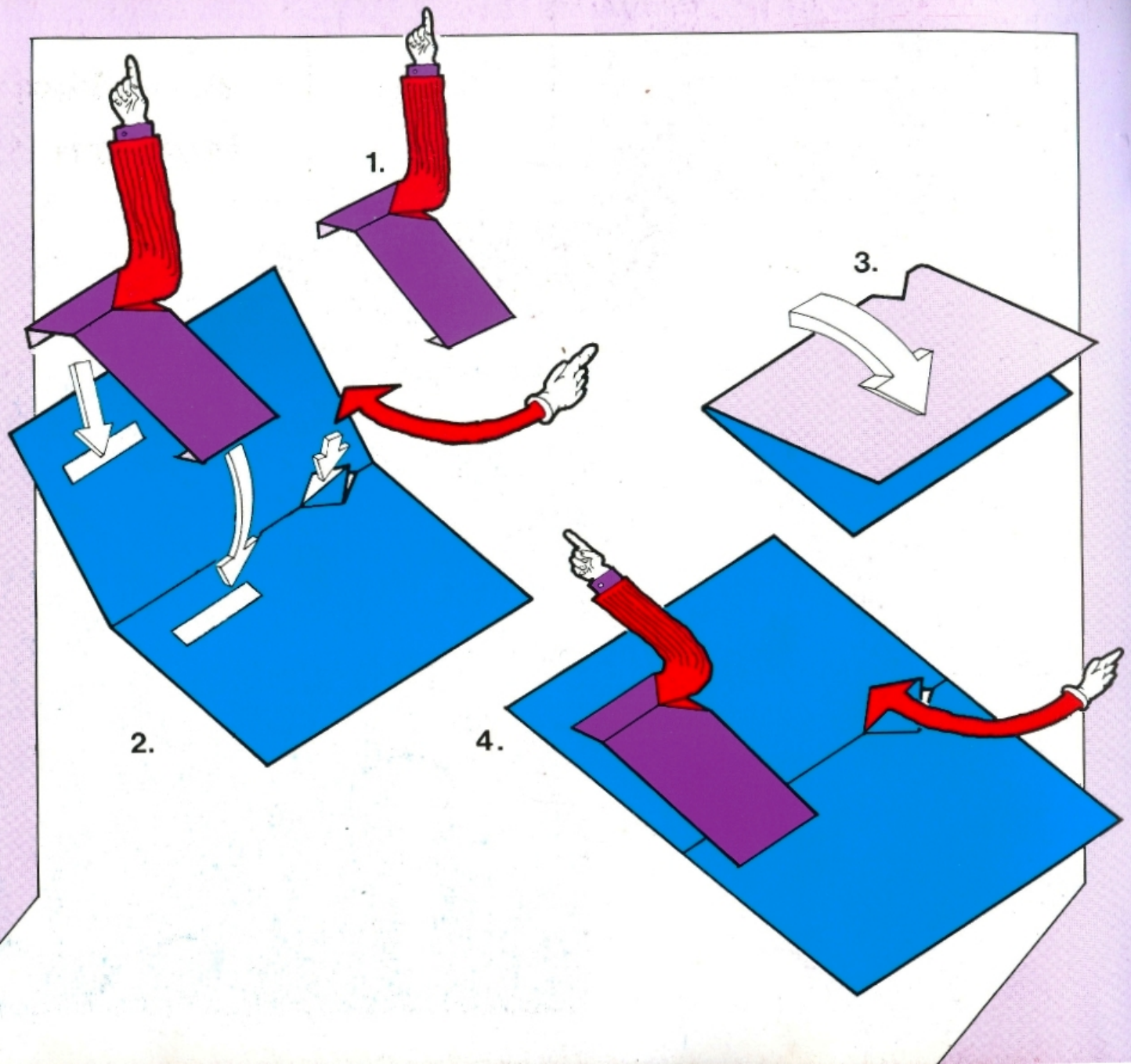
A magic box set skew on the base is also possible. It is then an adaptation of the V-fold mechanism. The two adjacent sides which are fixed to the base are each set at 45° to the central line.
The other two float freely.



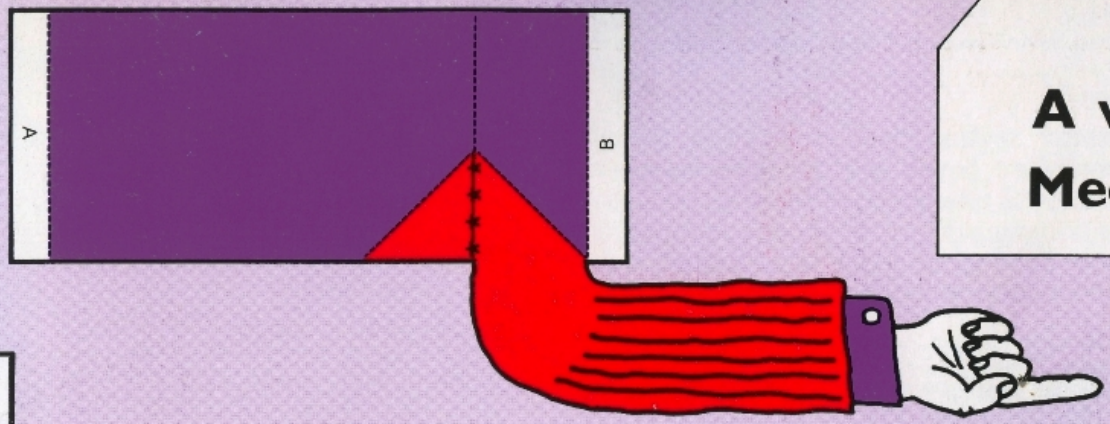
The 'roof' then has to be made out of two pieces. The folds bisect the right angled corners.

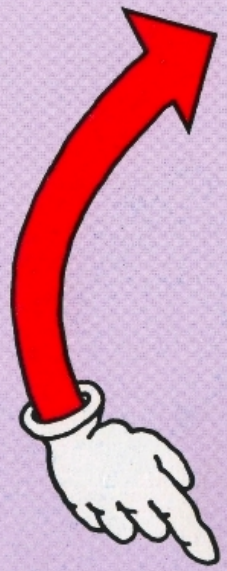
Mechanism 5
Moving arm

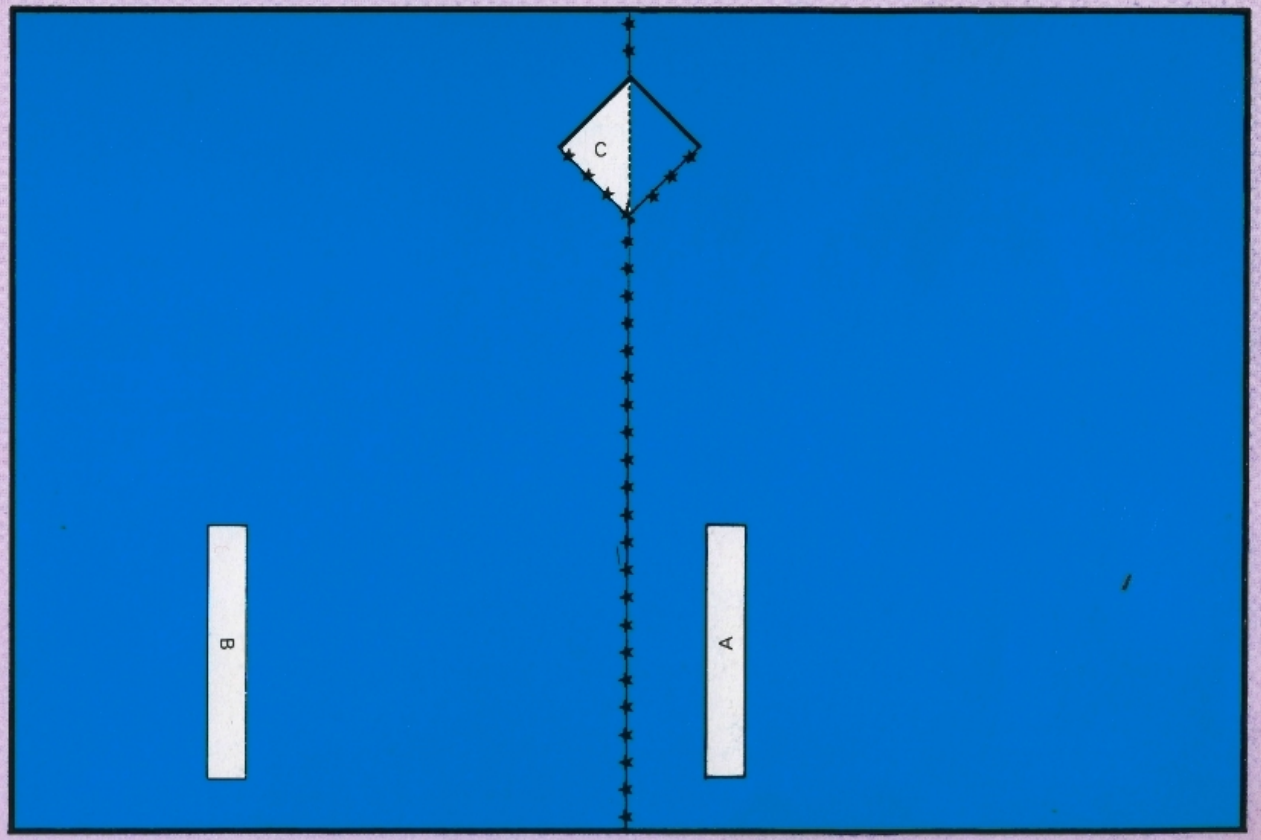
This is a favourite mechanism which can have a dramatic effect when a card or book is opened. It is one of the few mechanisms which has a large movement that is activated simply by opening and closing the card. The model shows two possible variations. The mechanism which provides the force and movement for the central arm is obtained from the base itself by a simple V-shaped cut. This cut in itself can be very useful for making 'mouths' which open and close.



A working model to make
Mechanism 5 Moving arm







▲ 5

GLUE COMPLETED MECHANISM NO. 5. HERE

▲
5

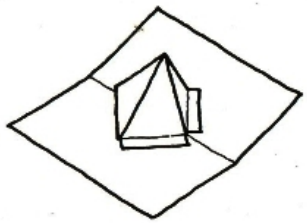
MECHANISM 5. GLUE TO TAB WHEN COMPLETED

Mechanism 5 Moving Arm

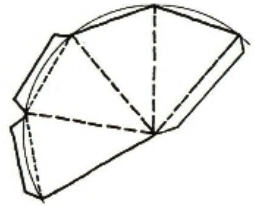
Mechanism 5
Moving arm

Technical considerations

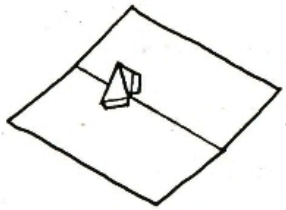
Different as they may seem on first impression the two mechanisms seen here are really both developments of the V–fold, transformed into parts of a pop-up pyramid. The square based pop-up pyramid is a useful idea in itself and the motive power for the arms comes from the fact that the faces of a pyramid fold away in different ways. Once you have made and understood how a pop-up pyramid moves, you will be able more easily to make moving arms to meet the requirements of your design.



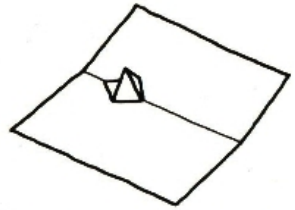
The square based pyramid has one of its diagonals along the centre line. It is glued along either the front two edges or the back two edges. The others float free. One way you can see inside the pyramid as it closes, the other way you cannot.



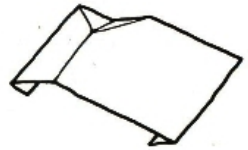
Draw the net of the pyramid inside a circle. Mark off equal lengths along the circumference. The actual lengths are not important as long as it looks pleasing and fits within the base when it is closed.



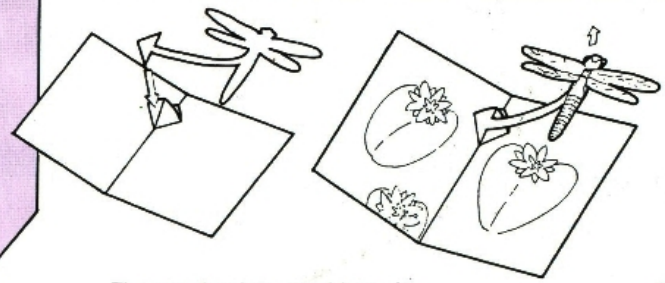
When using the pyramid concept as the motive power for moving arms, only the two faces which are glued to the base are needed. The others can be omitted.



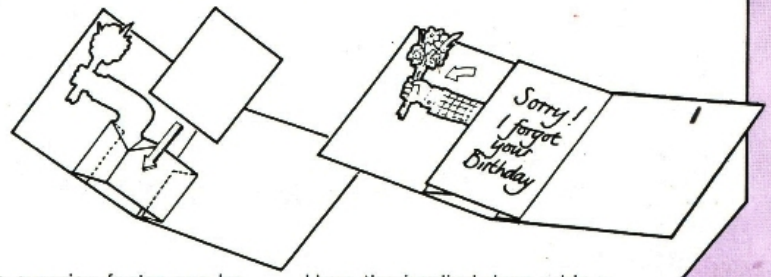
Instead of making a separate half pyramid it can be cut out of the base by a V-shaped cut. This gives motion to an arm near the centre of the base.



Here the half pyramid is indented into a floating layer to give motion to an arm near the edge of the base.



The mechanism used here is in harmony with the overall concept and design.

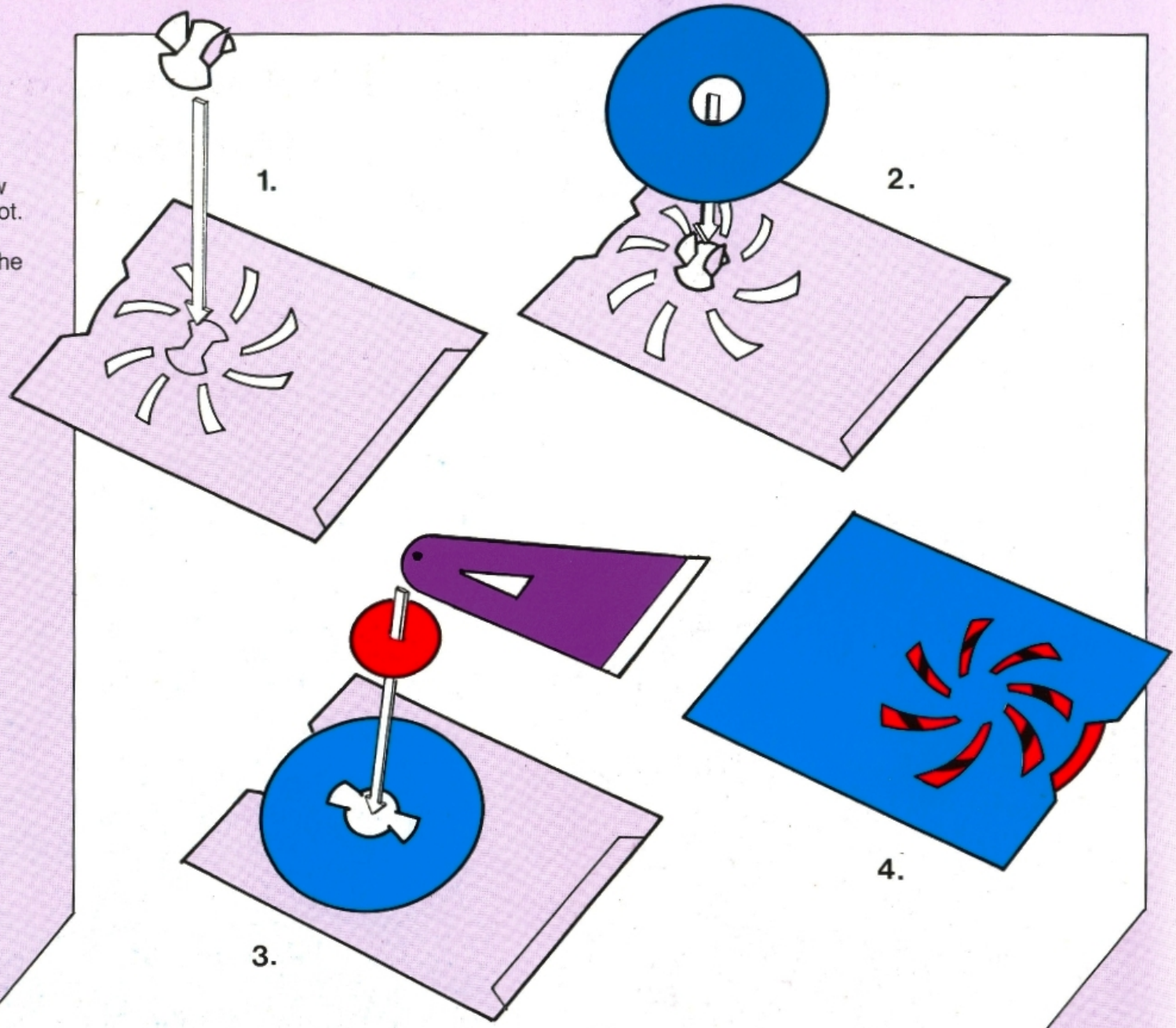


The surprise factor can be enhanced by hiding the mechanism behind an extra plane.

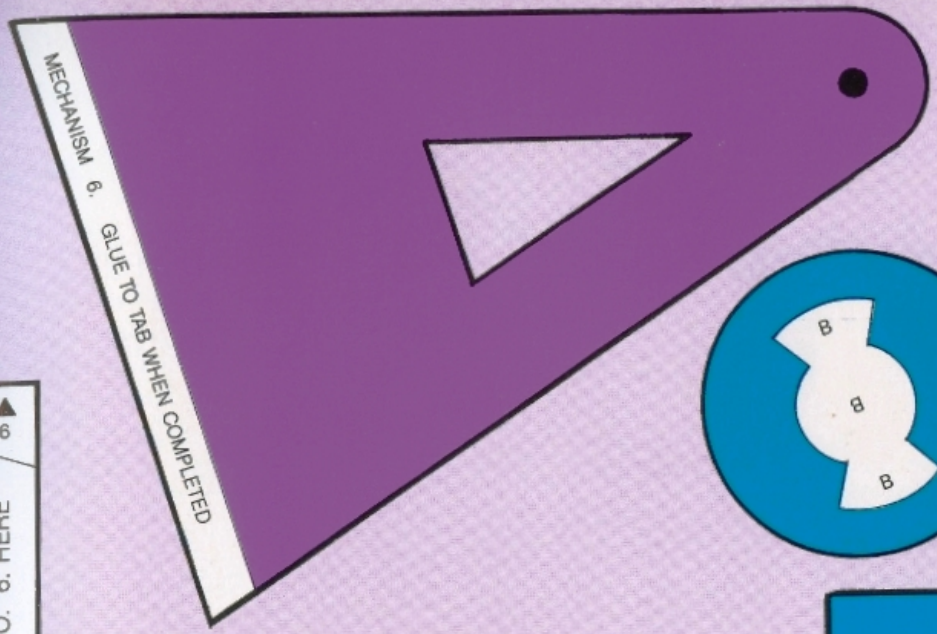
Here the implied door adds a certain impact to the message!

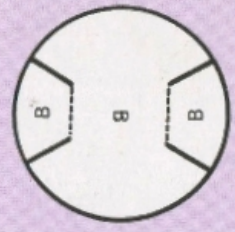
Mechanism 6
Rotating disc

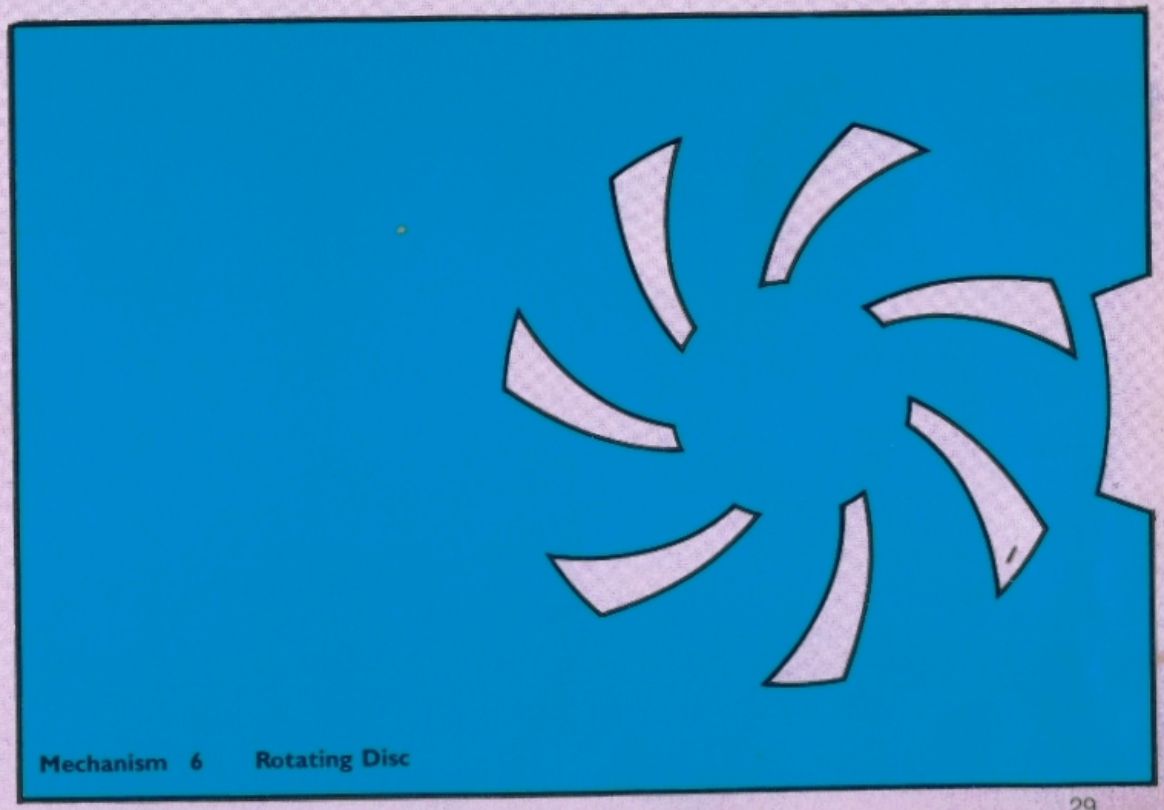
All this mechanism does is to allow a disc to rotate about a central pivot. The imaginative possibilities come from the choice of the design on the disc and the shape of the holes through which you see it.
The disc has two sides and both can be used to good effect.



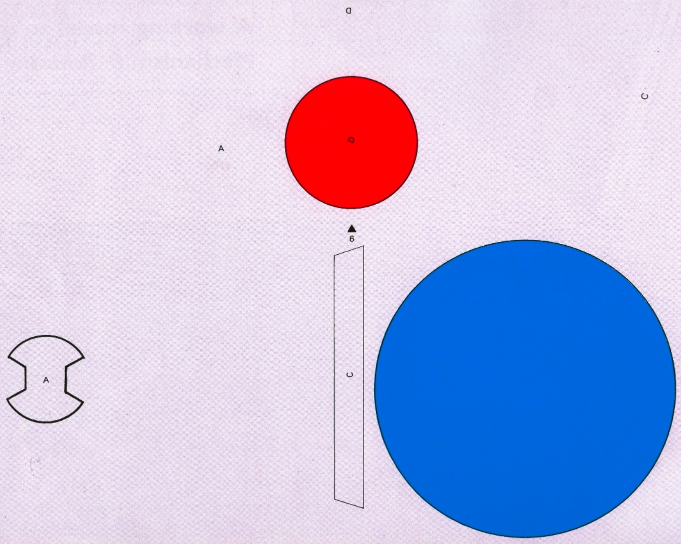
A working model to make
Mechanism 6 Rotating disc







GLUE COMPLETED MECHANISM NO. 6. HERE

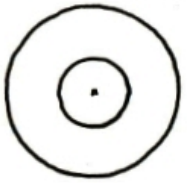

A
A
6
C

Mechanism 6
Rotating disc

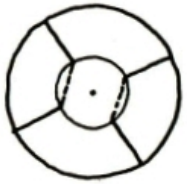
Technical considerations

The essential feature of this mechanism is the design of the central paper pivot, so that the disc turns smoothly.

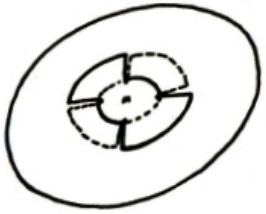
To make a pivot first draw two concentric circles. One should have its radius the same as that of the hole at the centre of the rotating disc. The other radius should be twice as much. Say 10mm and 20mm.



Mark out six lines like these. Then cut along the thicker lines and fold upwards to make the pivot.



This diagram shows how the rotating disc is sandwiched between the two kinds of leaves of the pivot. Be sure that no glue goes on to the rotating disc itself by accident.



In the working model the underside of the pivot was glued to the base and the upperside to the circular cover. No more is needed for the mechanism to rotate satisfactorily.
However, there are attractive design possibilities once it is realised that the mechanism can perfectly well be viewed from the back as well. It is a two sided mechanism.
The illustration on the right shows how a simple drawing and caption modify the working model to suggest a fairground invitation.

Useful as this mechanism is, the rotation is never precisely centred as it can be with discs made of plastic or metal. It is wise therefore to go for bold designs where the lack of precision is not important.

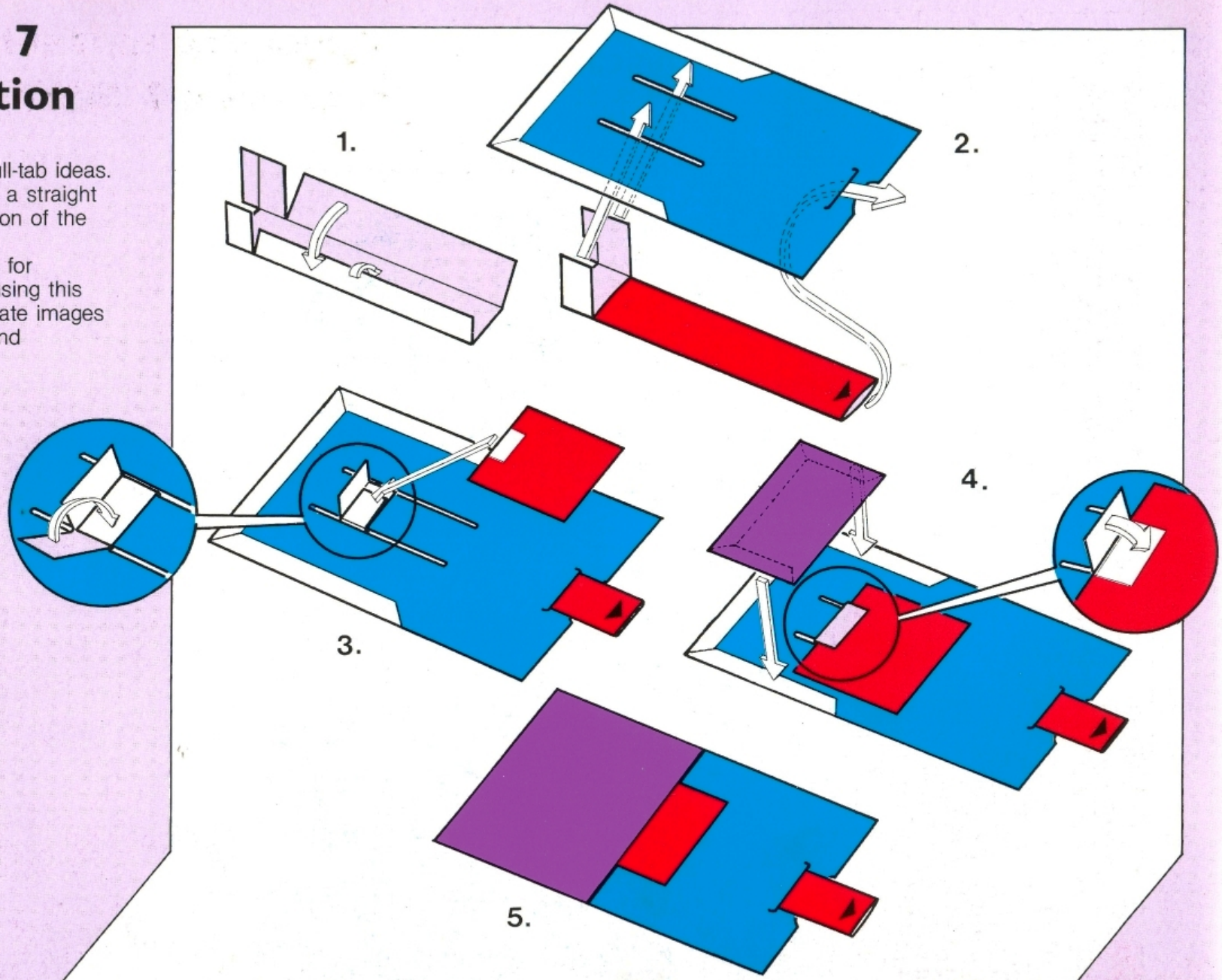
Snowstorm effect

Flickering flame effect

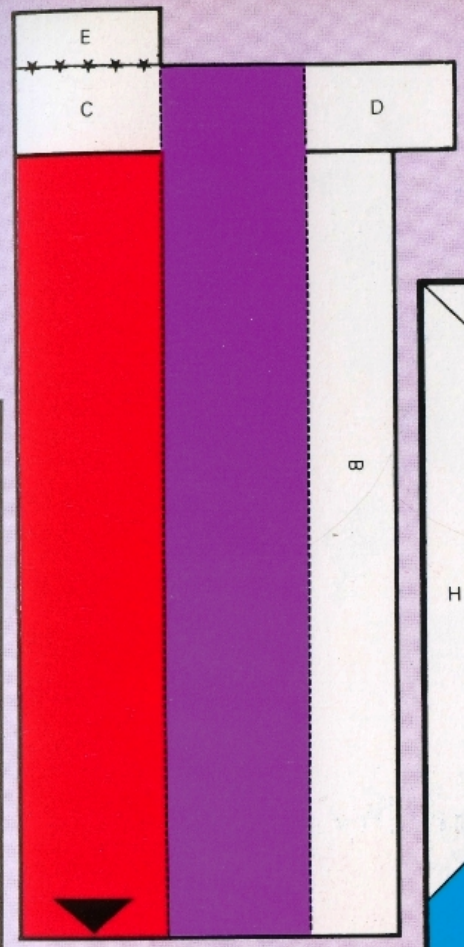
These two designs show simple applications of this mechanism.

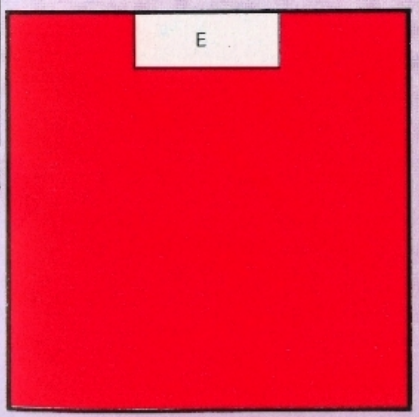
Mechanism 7
Sliding motion

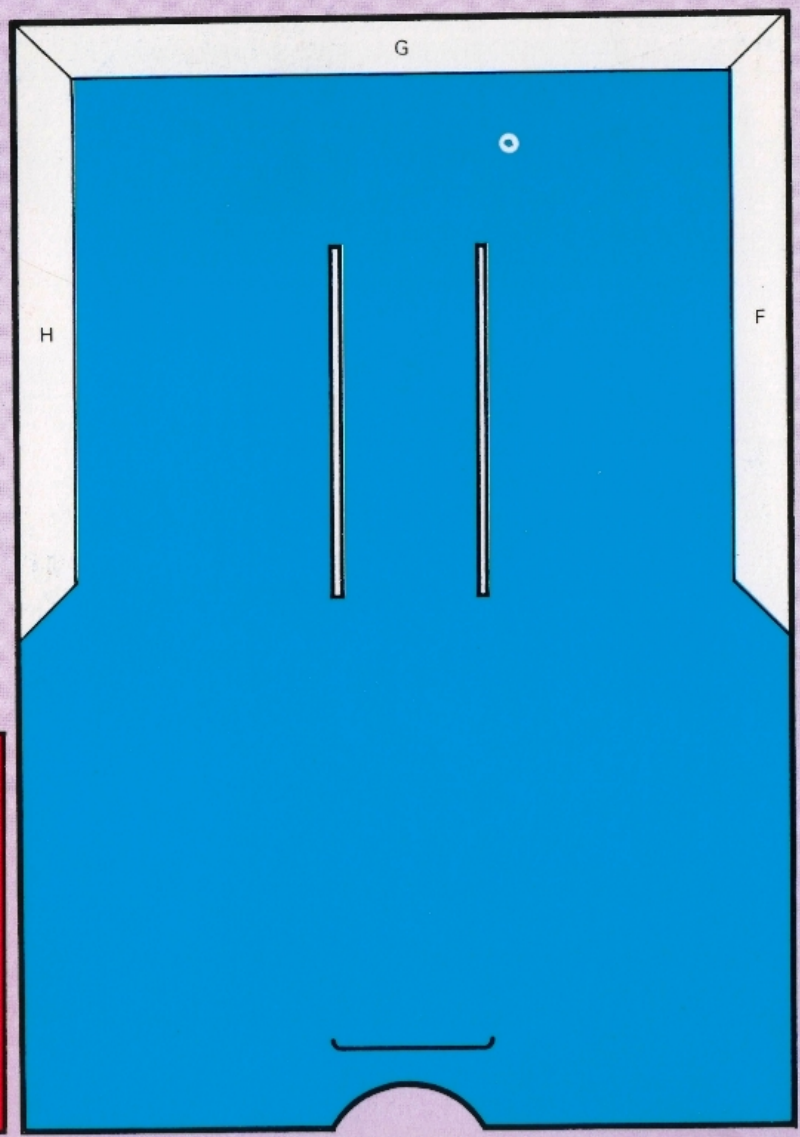
This is the first of the pull-tab ideas. The effect is to generate a straight line motion in the direction of the pull.
The creative possibilities for amusement arise from using this motion to make appropriate images and messages appear and disappear.

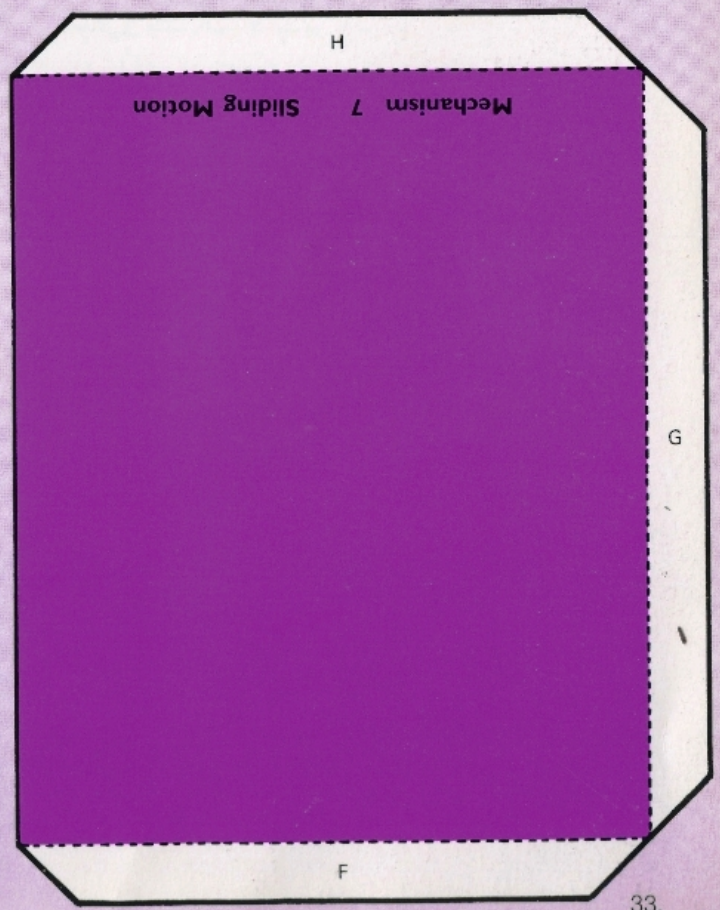


A working model to make Mechanism 7 Sliding motion









GLUE COMPLETED MECHANISM NO. 7. HERE

D

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MECHANISM 7. GLUE TO TAB WHEN COMPLETED 7

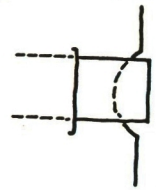
C

Mechanism 7
Sliding motion

Technical considerations

The principle of this mechanism is a simple one, but it still needs care if it is to move smoothly and to be robust enough to stand up to repeated use. The pull-tab needs to be strongly made and not pull out too far. If the length of travel is too great, the pull tab will bend as it is pushed back. Avoid the slightest trace of surplus glue on the sliding parts or it will tend to jam.

For easy movement, the parallel tracks should be slots about 1mm wide, not slits. Each slot should be cut with a knife, not scissors. It looks best if the slots are hidden under the cover.

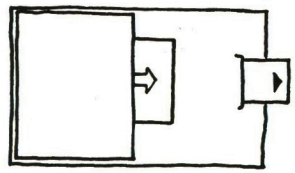


The pull-tab is best held by a simple slit. It prevents side to side motion and a single cut gives a tighter grip.

Cut out a semi-circular thumb hole in the base, so that the pull-tab may be gripped more easily

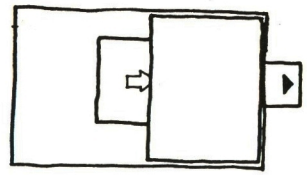
There are three basic design possibilities for this mechanism.

1



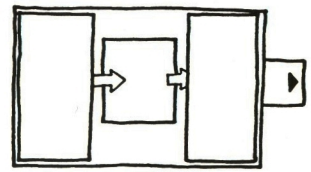
An object which was hidden comes into view.

2

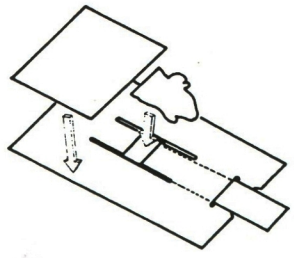


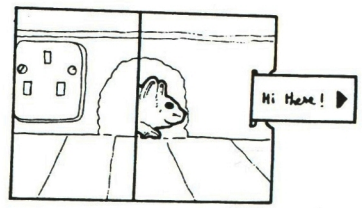
An object which was visible disappears behind a flap.

3

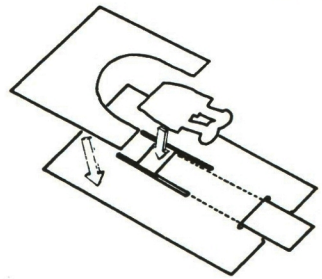


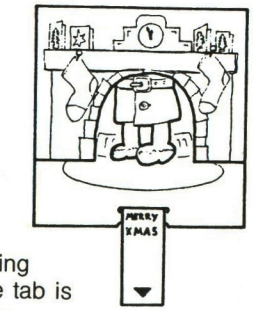
An object appears, passes across a 'window' and then disappears.





This cheerful greetings card has its subject, design and mechanism, all in harmony.

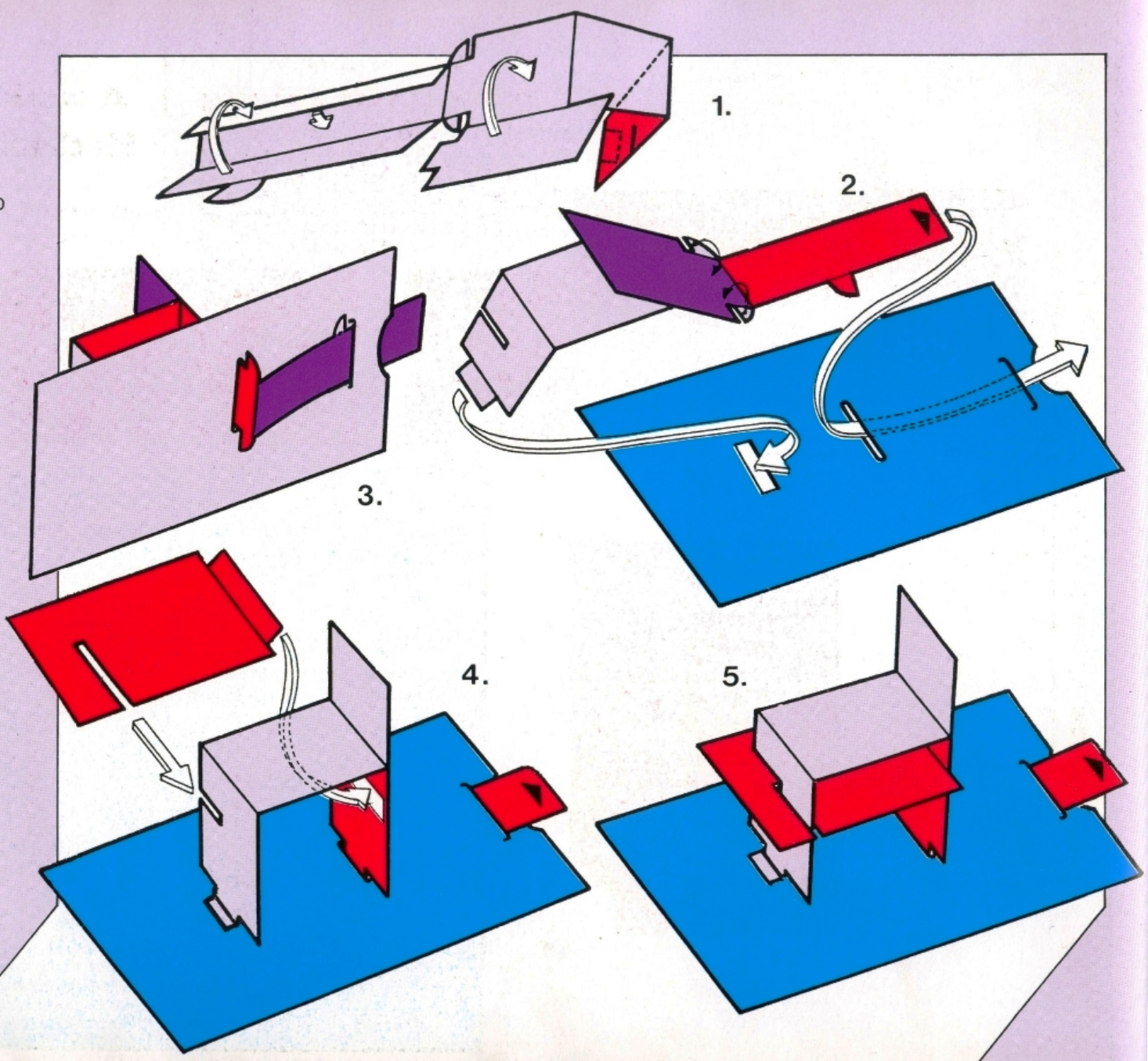




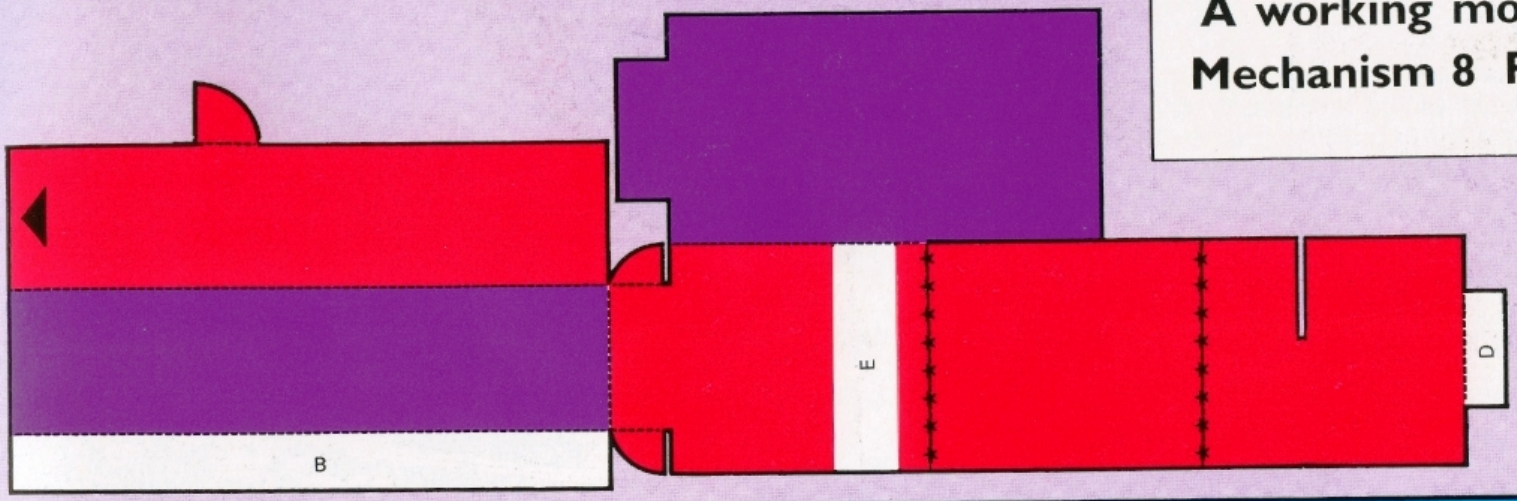
It is not essential that the moving part is totally hidden before the tab is pulled. Here the pair of boots is visible, but it is not obvious what they are. Such an ambiguity helps to enhance the visual joke.

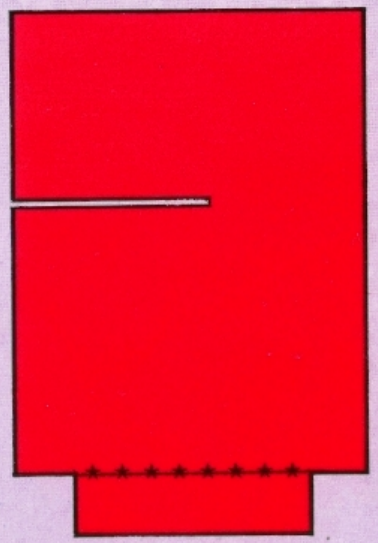
Mechanism 8
Pull-up Planes

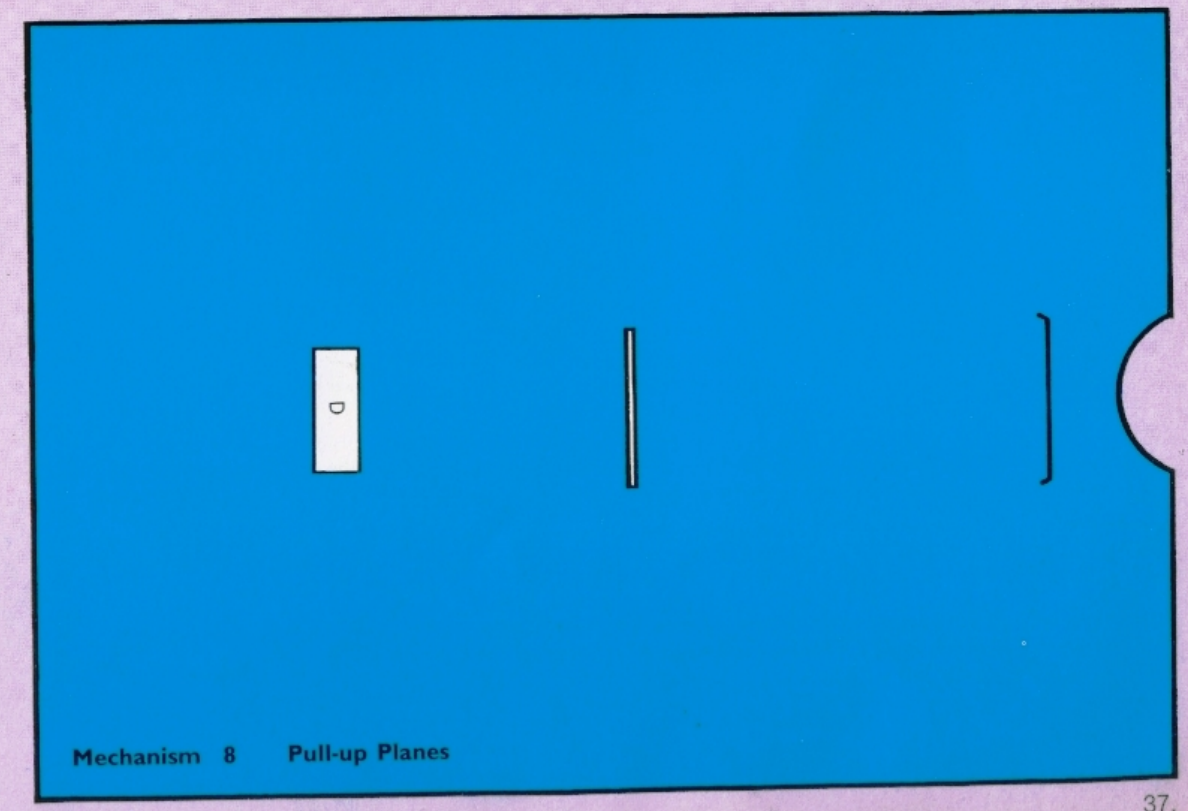
The effect of pulling the pull-tab is to cause some planes to rise up from the base in a rather surprising fashion. The working model demonstrates how to achieve this result and there are also suggestions how the mechanism can be further simplified.



A working model to make.
Mechanism 8 Pull-up Planes





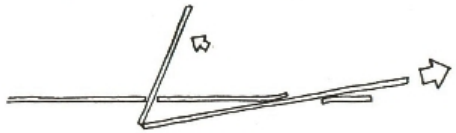


GLUE COMPLETED MECHANISM NO. 8. HERE ▲ 8

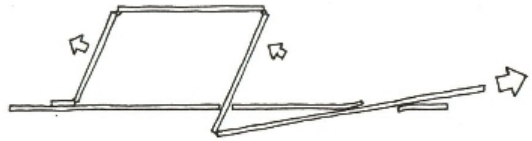
Mechanism 8
Pull-up Planes

Technical considerations

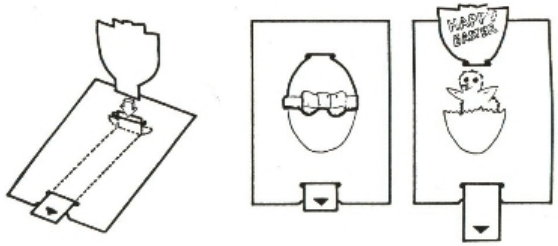
At first sight the pull on the pull-tab appears to be in the plane of the base as it was for the previous mechanism. However, a closer inspection shows that this is not the case. The mechanism uses leverage to convert a small movement of the pull-tab into a much larger movement in a different direction. A sketch of the side view shows how this happens and how it may be modified to produce different effects.



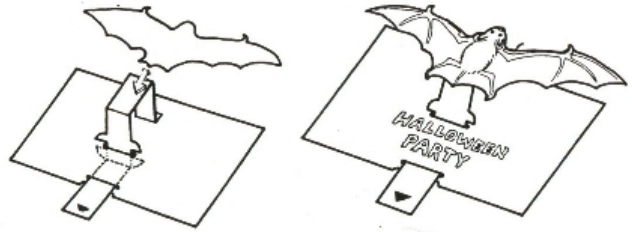
In its simplest form the pull causes a 'flip over' effect.



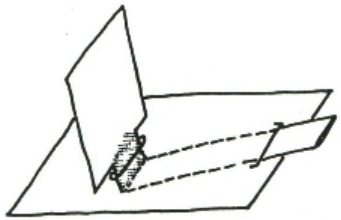
Completing the parallelogram produces a plane which pulls up from the base.
Other planes arranged in similar fashion give this mechanism its name.



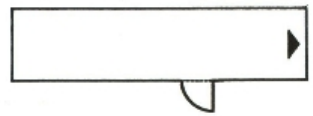
A small pull and the Easter egg springs open to reveal a cheerful chick and a 'Happy Easter' message.



Here a pull-up plane is used as the base for a cut-out bat to give a dramatic effect. It is just one possible idea for an amusing Halloween card.



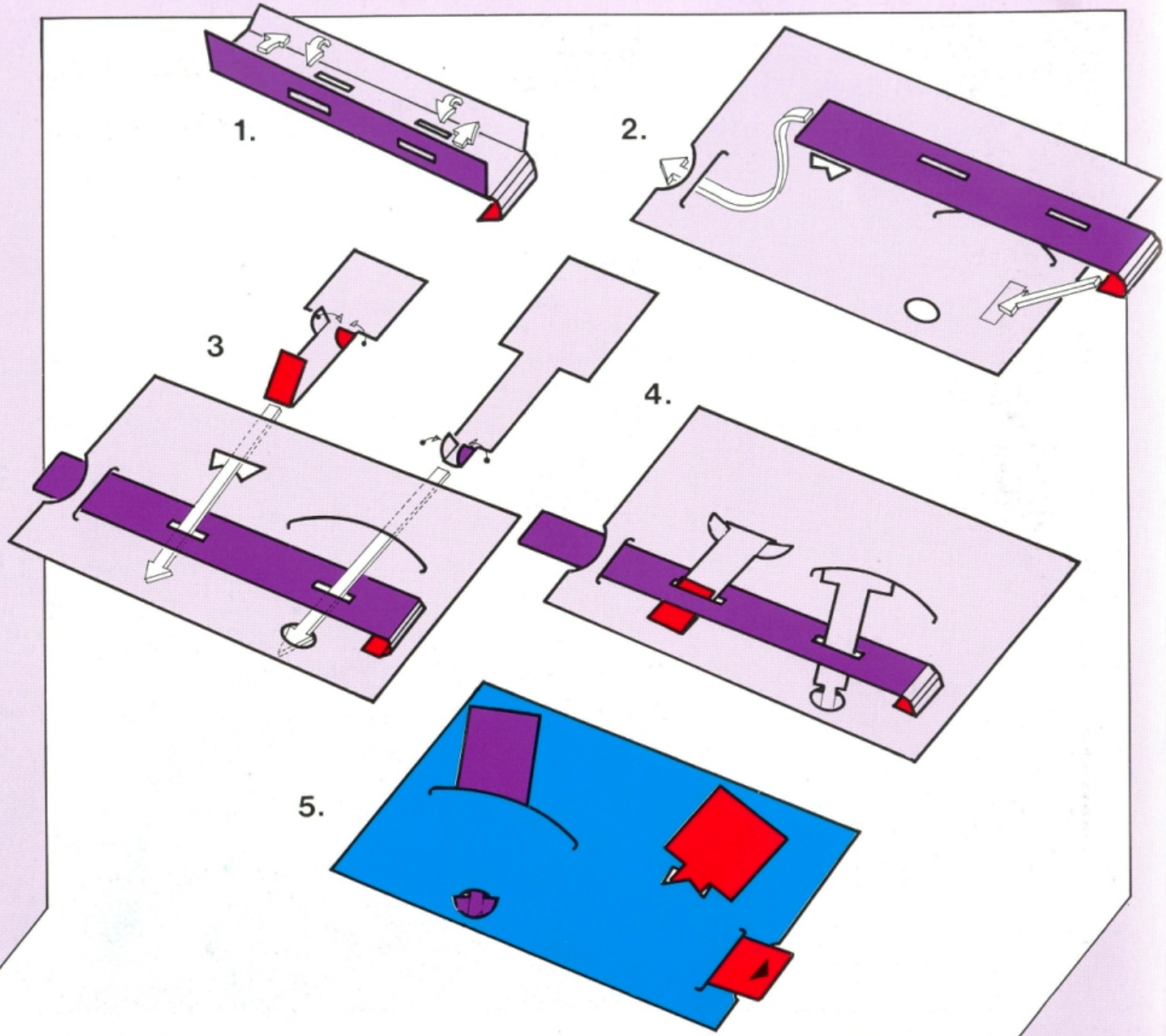
The position where the mechanism is under the greatest strain is where it passes through the base plane. It is wise to strengthen this piece by doubling the thickness.



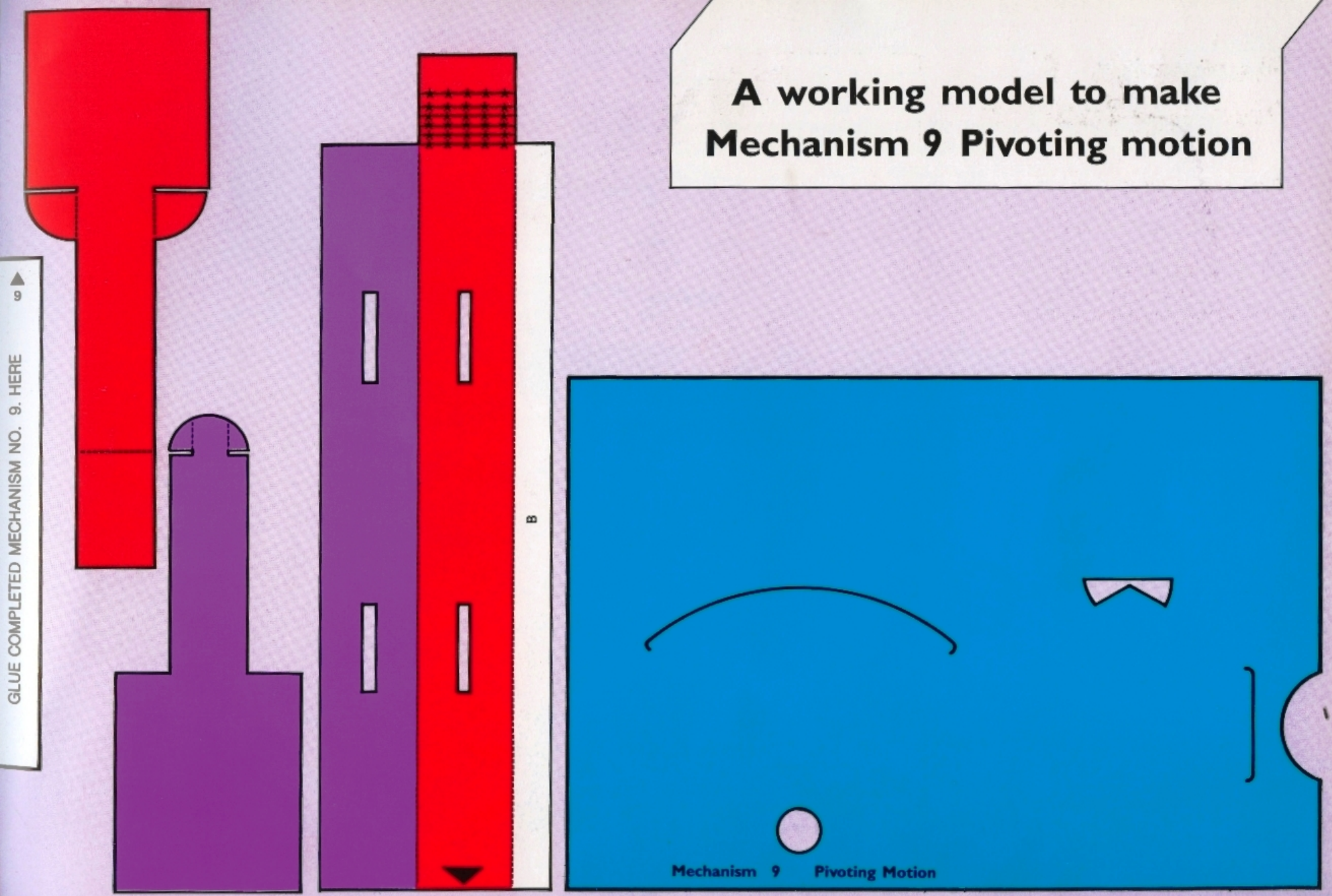
To allow the planes to rise up a certain distance and then stop it is best to fit a 'lug' to the pull-tab. Its position is determined by the effect you wish to obtain.
On the working model, the movement stops when the parallel planes are at their maximum elevation from the base. Without such a 'stop' the mechanism will flip right over. This may be satisfactory, but there is always the possibility that it will jam in the 'far down' position.

Mechanism 9
Pivoting motion

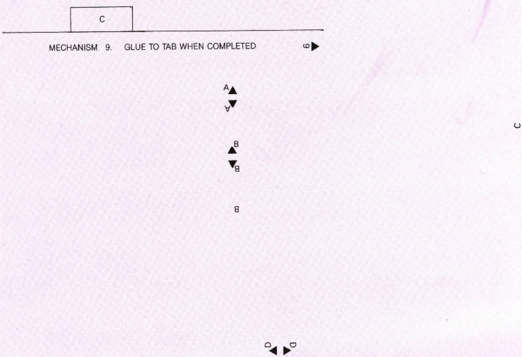
This mechanism converts the straight line motion of a pull-tab into a backwards and forwards swinging motion. It also demonstrates two simple kinds of pivot and a method of obtaining a straight line motion with a short distance of travel.



A working model to make Mechanism 9 Pivoting motion



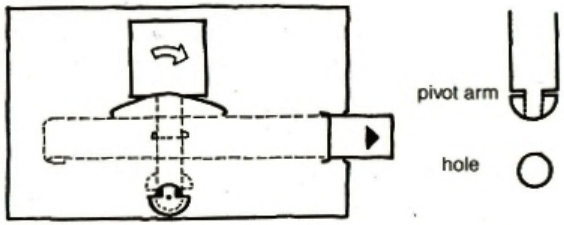
MECHANISM 9. GLUE TO TAB WHEN COMPLETED



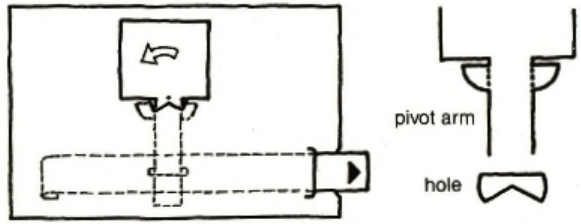
Mechanism 9
Pivoting motion

Technical considerations

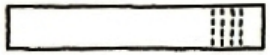
There are two different methods of obtaining this backwards and forwards rocking or swinging motion. Each requires a pivot and a suitable connection. It is the relative position of the pivot and the pull-tab which determines the precise characteristics of the motion.



If the pivot arm is attached to the pull-tab above the pivot, then it moves in the same direction as the pull-tab, and a greater distance.



If the pivot arm is attached to the pull-tab below the pivot, then it moves in the opposite direction to the pull-tab and a smaller distance.

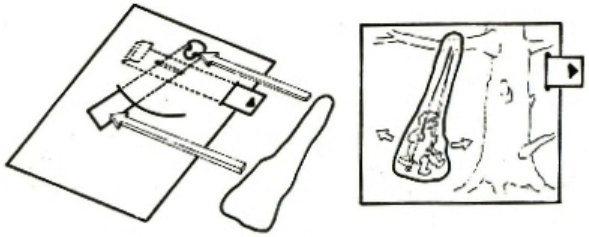


The multiple scoring gives the paper sufficient flexibility.

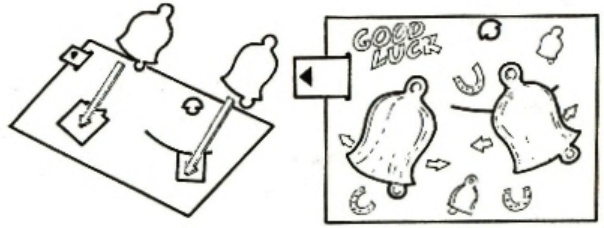
This mechanism will only operate smoothly over a relatively short length of travel. The working model demonstrates a very simple method to fix this length and it is far easier to make than the parallel slots of mechanism 7 and the 'stop' of mechanism 8.

The slots in the pull-tab which act as a connection to the pivot arms must not be too tight.

Make the mechanism first and then glue on the image afterwards.



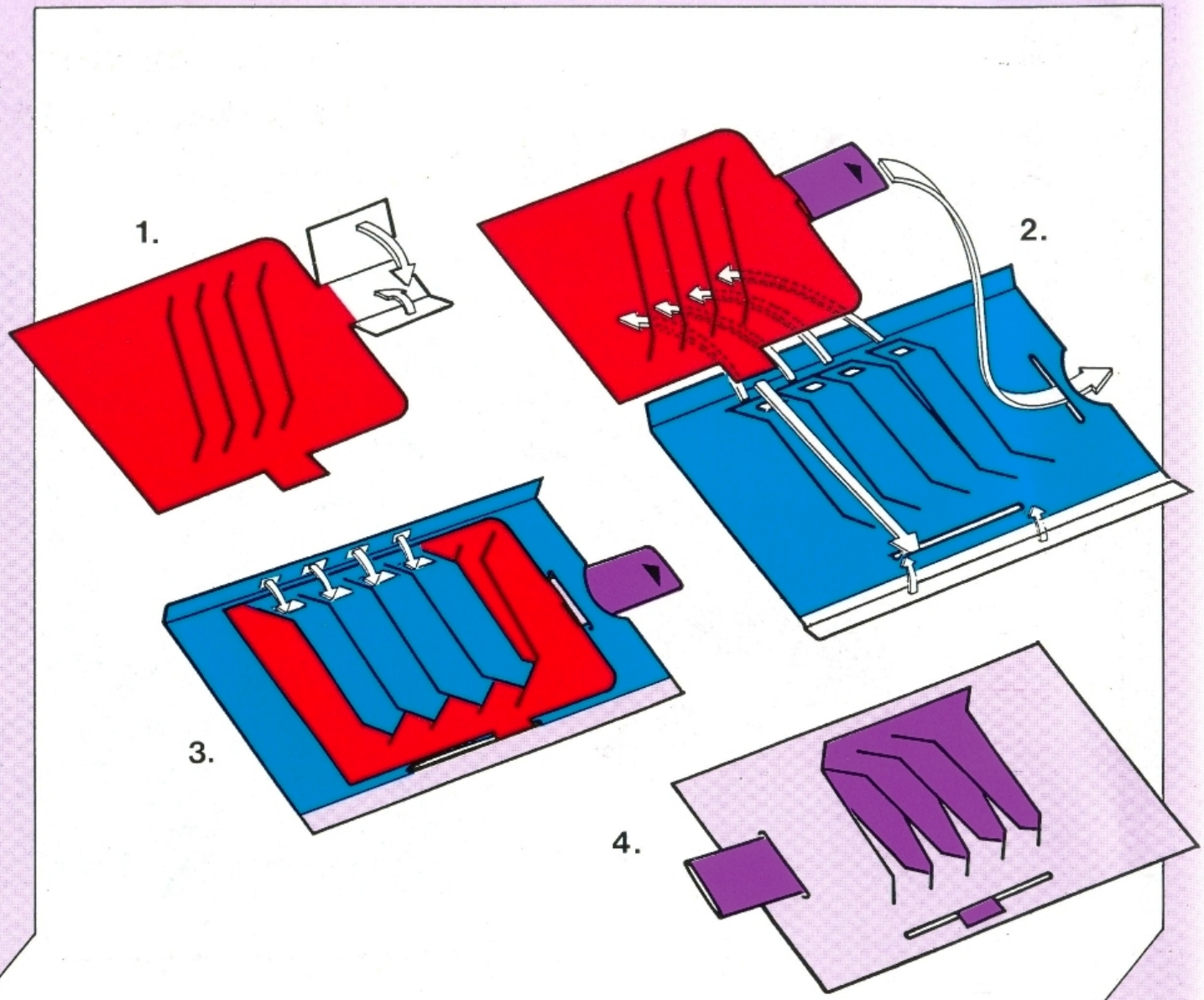
The mechanism suggests a child's swing. It is natural to use a long pivot arm, so that it swings through a sufficiently large arc.



A peal of bells for a 'good luck' card is a pleasing application for this mechanism in both its forms.

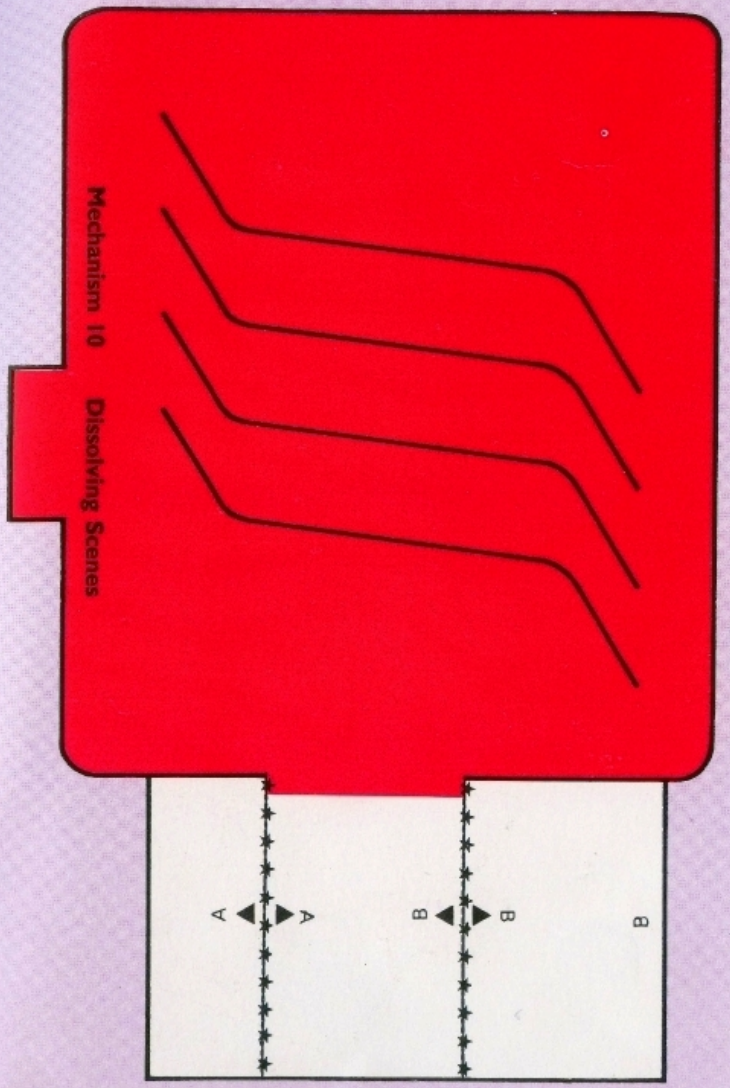
Mechanism 10
Dissolving Scenes

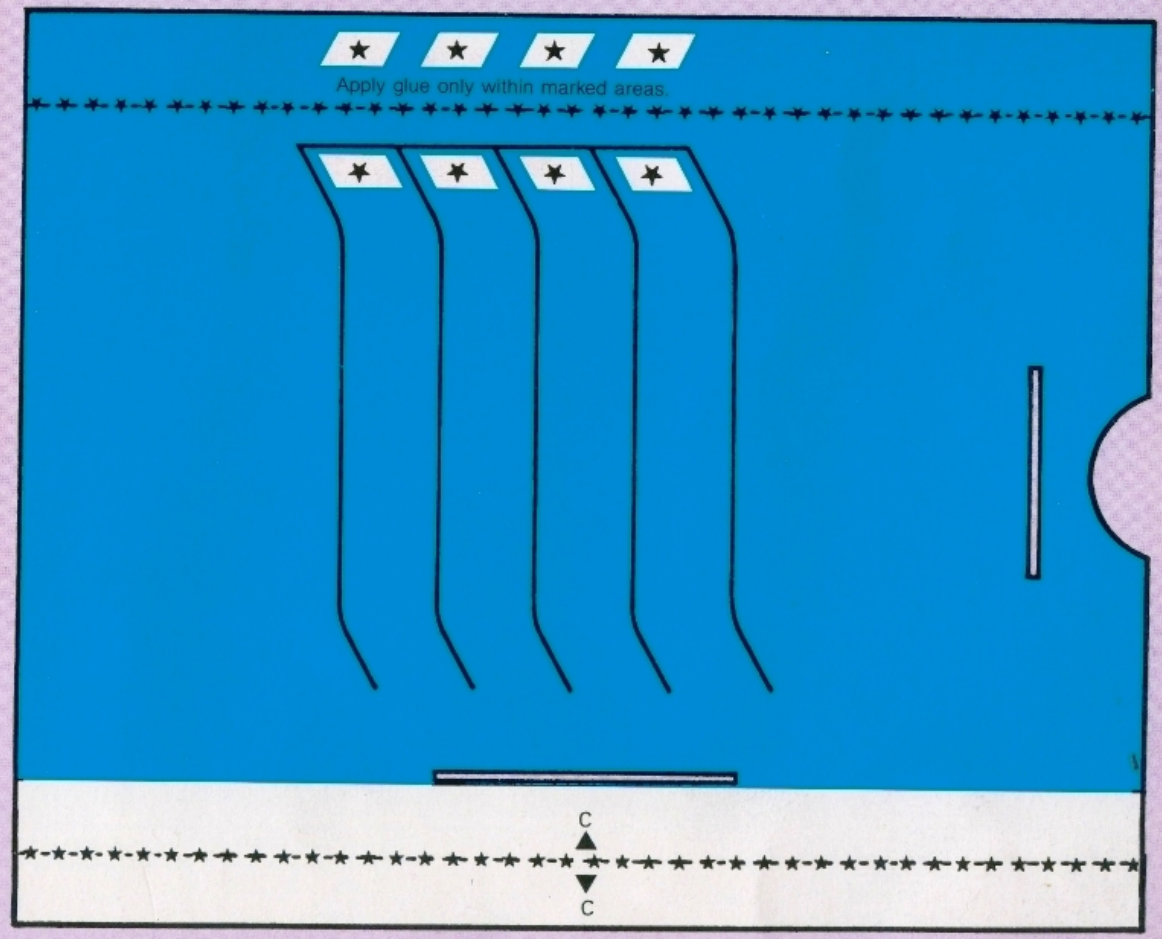
Movement of the pull-tab causes one picture to disappear and another to take its place. The design possibilities in this interchange of pairs of images are considerable and clearly explain why this mechanism has been widely used ever since its invention more than a century ago.



A working model to make.
Mechanism 10 Dissolving Scenes

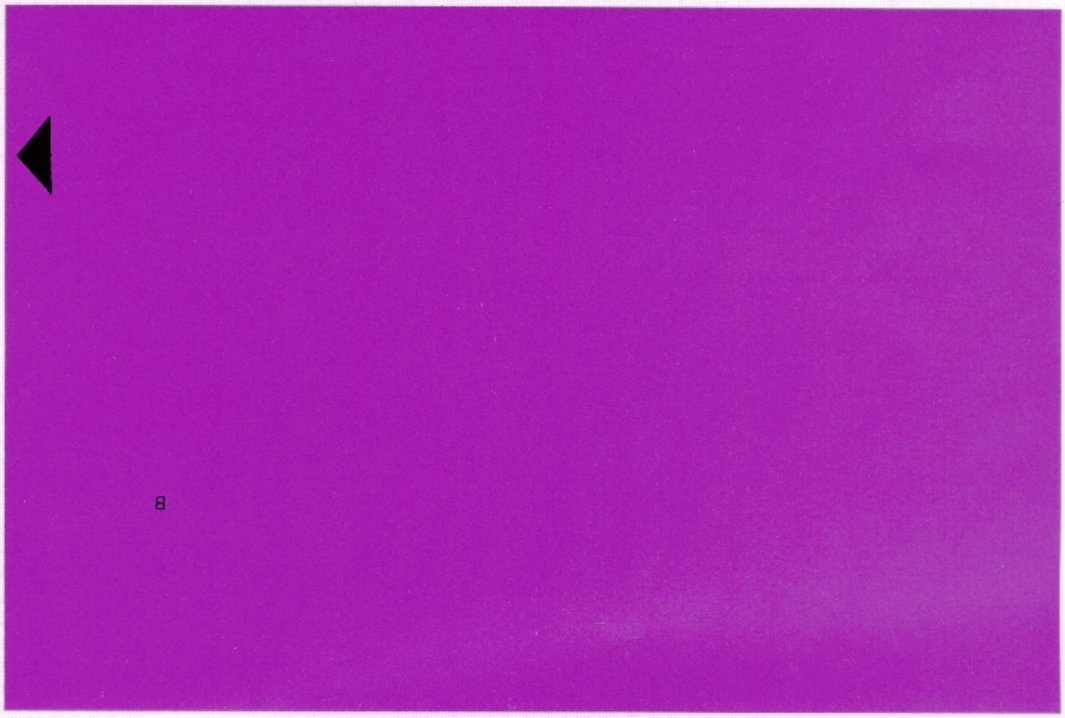
GLUE COMPLETED MECHANISM NO. 10. HERE ▲ 10





MECHANISM 10. GLUE TO TAB WHEN COMPLETED

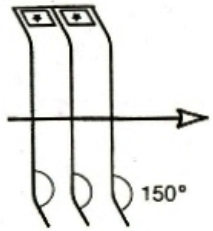
10 ▶



Mechanism 10
Dissolving Scenes

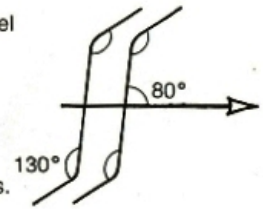
Technical considerations

The effect of this mechanism is very appealing, but it is probably the most difficult one in this book to make. To get a successful result it demands accurate drawing, cutting and glueing. For your initial designs it is wise to use the angles given below. They are not the only possible combinations, but it will produce a functioning mechanism. Start with only five parallel cuts on the base and four on the moving sections.

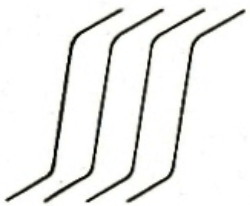


On the base section the parallel cuts should be at right angles to the direction of pull.
The tails should be set at 150°.

On the moving section the parallel cuts should be at 80° to the direction of pull.
The tails should be set at 130°.

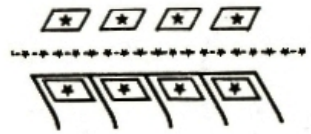


Notice that the tails sweep in the opposite direction on the two pieces.



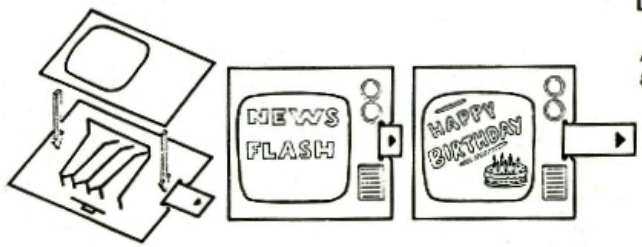
Be careful to cut exactly along the lines and to leave no ragged edges or unwanted extra cuts which could cause the other piece to catch.

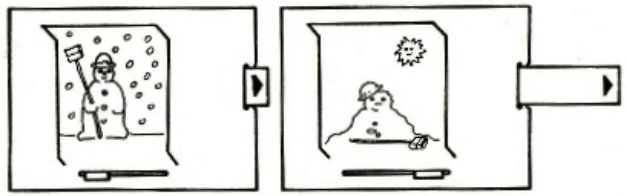
After the parallel slices are interleaved, they must be glued to the flap which folds over. The parallelograms serve as a reminder to make certain that no spare glue finds its way into the mechanism.



When making a design of your own, it is best to draw and finish colouring the picture before cutting the parallel strips.

An appropriate mask can hide the mechanism and increase the surprise effect when the tab is pulled.





A pair of images like these can be the basis for an amusing Christmas card.

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