Pop-Up!
A Manual of Paper Mechanisms

Duncan Birmingham
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This manual offers a working guide to the intriguing mechanisms that leap up from pop-up books or cards. The only realistic way to understand the potential of pop-up technology and to learn how such mechanisms are designed and constructed is to make a wide range of them yourself. Appreciating how the standard mechanisms work and why they sometimes fail is an essential step towards creating original designs of your own.

**Pop-Up!**

True pop-ups are based on only three simple ideas. They are known as the 'V-Fold', the 'Parallelogram' and the '45° Fold'. It is the development of these three ideas which creates the wealth and richness which this field of artistic activity has to offer. A particular feature of this collection is how the mechanisms can be grouped into families and how one idea can grow out of another. The manual starts by introducing some simple and elementary designs and then shows how they can be extended, modified and combined to produce sophisticated fold-away paper sculptures, with the potential to illustrate a wide range of stories, topics and notions.

Although the title of this manual is 'Pop-up', it also deals with the slides, pull strips and rotating disks which commonly are found in the imaginative children's books, loosely referred to as 'Pop-up Books'. Since they are made of paper, the general name is 'paper engineering'. Use this manual as a compendium of paper engineering ideas and flick through the pages until you see a design to make. Alternatively, work systematically through it and so acquire a comprehensive understanding of the whole subject.

**Pop-Up!**

On pages 4 and 5 there is a list of the mechanisms which shows how they relate to each other. Each mechanism has a reference number and they are grouped under subheadings showing how a particular idea can be developed. Making the first mechanism in each family group will give a good basic understanding of what that particular pop-up technique can offer. The more distant relatives of some of the mechanisms are also listed. These will be useful to advanced paper engineers with a particular design problem to solve or to students seeking a fuller understanding of the possibilities of pop-up and other paper engineering designs.

Before you start to make up designs of your own, read pages 6 to 8. They cover the materials you need, the basic vocabulary and symbols used in the book and also the best order in which to work. Once you have started, it will not be long before something fails to work as you expected or hoped. Page 9 offers suggestions about problem solving and trouble shooting. After pointing out the most common causes of potential difficulties there is advice on how important it is to start by making quick roughs of a new idea.

**Pop-Up!**

The creative potential in paper engineering is very great and hopefully this manual will set you off on a rewarding trail which will give many hours of interest and pleasure.
LIST OF MECHANISMS

To explore a particular mechanism and see how it can be adapted, consider the other mechanisms in the same subgroup. Where other mechanisms are mentioned, further ideas and developments are to be found there.

SIMPLE V-FOLDS

1 & 2 THE SIMPLE V-FOLD; see also 39, 41, 58, 61, 91, 112, 118.
3 & 4 THE V-FOLD POINTING FORWARDS; see also 40, 56, 64, 79, 114.
5 ADDING CUTS AND CREASES; see also 46, 48.
6 V-FOLD WITH PROJECTIONS; see also 59.
7 & 8 BEAKS, NOSES AND MOUTHS; see also 73.

MODIFIED V-FOLDS

9 to 12 JAWS; see also 79.
13 to 17 SCULPTING THE V-FOLD; see also 60.
18 to 20 THE V-FOLD GLUED AWAY FROM THE SPINE; see also 57.

MULTIPLE V-FOLDS

21 to 27 V-FOLDS ON TOP OF V-FOLDS; see also 33, 56.
28 & 29 THE M-FOLD; see also 44.

ASYMMETRICAL V-FOLDS

30 ASYMMETRICAL MOUTHS AND BEAKS
31 ASYMMETRICAL SLOPING PLANES
32 SWIVELLING JAW
33 ASYMMETRICAL EXTENSIONS

THE PARALLELOGRAM

34 & 35 THE BASIC PARALLELOGRAM; see also 59, 62, 74, 75, 76.
36 MULTIPLE PARALLELOGRAMS
37 PARALLELOGRAMS CUT FROM THE BASE; see also 48.
38 PARALLELOGRAM STAND-UPS; see also 99.

COMBINING PARALLELOGRAMS AND V-FOLDS

39 & 40 THE PARALLELOGRAM LIFTING V-FOLDS
41 to 44 V-FOLDS LIFTING PARALLELOGRAMS
45 to 48 ZIG-ZAG FOLDS
49 POP-UP HOUSE; see also 83.
50 POP-UP PYRAMID
TWO PARALLEL STICKING STRIPS
50 to 53 SOLID SHAPES; see also 67.
54 to 58 QUADRILATERALS; see also 63, 66, 120.

JUTTING EXTENSIONS
59 to 63 SLOT JOINTS
64 to 66 V-FOLDS WITH JUTTING ARMS; see also 43.

MULTIPLE PARALLEL STICKING-STRIPS
67 to 69 THE BASIC BOX AND CYLINDER; see also 38.
70 to 72 AEROPLANE, BOAT, HORSE

THE 45° FOLD - MOVING ARMS
73 SIMPLE MOVING ARMS
74 45° FOLDS ON A PARALLELOGRAM
75 ARMS MOVING BEHIND A MASK
76 A TURNING DISC

PAIRS OF 45° FOLDS
77 TWISTING MECHANISM
78 JACK IN THE BOX
80 & 81 BRIDGE MECHANISM
82 & 83 BOX ENDS

SLIDES
84 to 86 PULL-STRIPS & SLIDES
87 & 88 EXTENDING THE IMAGE; see also 113.
89 to 91 A SLOT GUIDED SLIDE
92 & 93 DISSOLVING IMAGES

FLAPS
94 to 96 SINGLE FLAPS; see also 116.
97 & 98 DOUBLE FLAPS
99 & 100 FLAPS LIFTING POP-UPS; see also 38.
101 & 102 DELAYED DOUBLE ACTION FLAPS

PIVOTS AND HUBS
101 THE HUB
102 BRACKETED ARM
103 THE HUB
104 ROTATING WINDOW
105 to 106 SLIDING PIVOTS
108 THE FIXED PIVOT
109 MULTIPLE MOVING ARMS
110 ROCKING MOTION
111 & 112 ARTICULATED IMAGES
113 SWOOP MOVEMENT

MISCELLANEOUS MECHANISMS
114 & 115 SPIRAL
116 AUTOMATIC PULL-STRIPS
117 BOWING SHAPES
118 STAGE SET
119 SHUTTER SCENE
120 SAWING NOISE

MATERIALS

Paper or Card?
Cartridge paper can be used but it should not be lighter than 135 gsm. The ideal weight is 220 gsm. This is the type of card which is used for postcards.

Scissors or Craft-knife?
A pair of scissors is adequate for cutting out most of the pop-up mechanisms. However for the pull-strip designs a craft-knife is essential. A sharp edge is vital so the type of craft-knife with extending 'snap-off' blades is ideal.

Scoring
Scoring is very important. Using a ball-point pen which has run out of ink creates a strong fold, as the paper's fibres are compressed rather than cut.

Glue
A clear, solvent-based adhesive is best. The new 'Gel' types are probably the most effective as they can be more easily controlled. Water based glues dry quickly and are also effective.
most effective as they can be more easily controlled. Water-based glues dry too slowly and may wrinkle the card and the stick-glues, which are sold for paper craft, are not really strong or permanent enough for this type of work.

**Pencil & Ruler**
A propelling ‘clutch’ pencil or a hard ordinary pencil is advised. A ruler is essential for scoring long straight creases. A steel ruler is strongly recommened for cutting against when using a craft-knife.

**Cutting-board**
This is really necessary to save your surfaces. Thick cardboard, like the back of a drawing pad, will do, but a commercial mat is best of all.

**Paper-knife**
When sticking pieces into place, a paper knife is very useful for pressing down corners and edges that are hard to reach.

**Drawing Instruments**
Many lengths and angles have to be measured and drawn very accurately, so a set square, a protractor and a pair of compasses will be needed.
Throughout this manual the double-page to which the pop-up is glued is referred to as the **Base**.

There are three kinds of folded line:

1. **Valley folds**, marked A in the diagrams above.
   The crease goes back, away from the viewer.

2. **Mountain folds**, marked B in the diagrams above.
   The crease comes forward, towards the viewer.

3. **The Spine**, marked C in the diagrams above.
   The fold down the centre of the base.

There are also:

1. **Gluing-tabs**, marked D in the diagrams above.
   They are the little flaps that the glue is spread on when sticking a piece onto the base or another pop-up piece. These are usually about 1cm. wide. Any narrower and they tend to pull off.

2. **Sticking-strips**, marked E in the diagrams above.
   They are the areas on the base or other pieces that the gluing-tabs glue to.

**WORKING ORDER**

1. Measure and draw out the design.
   Accuracy when measuring lengths and angles is very important to create mechanisms which move and fold away cleanly.

2. Score all the fold lines.
Scoring makes for a much sharper and more accurate fold. It is easiest to do this before the individual pieces are cut out.

3. Cut out the pop-up pieces.

4. Having scored and cut out the pop-up piece, fold it along each crease and firmly run your finger nail along each fold. Then fold it back on itself and do the same thing again. The more thoroughly creased and easily folding the better. The fold is the hinge of the mechanism. Creasing it well is like oiling a hinge.

5. Think before you glue. Sometimes flaps become inaccessible as the construction builds up. Where this may be a difficulty the gluing order is explained.

6. When a mechanism uses several pieces, it is best to close the base and press it firmly after each new piece is glued on. If you leave it until the mechanism is complete, it may develop unwanted creases.

It is normal to glue all the gluing tabs on each pop-up piece to the base before the base is folded shut. However there is another method which is very effective.

1. Put glue on one flap and stick it to the base.

2. Fold the pop-up piece into its closed position, then put glue on the other flap.

3. Close the base. The second flap then finds its natural sticking position.
PROBLEM SOLVING

Occasionally a mechanism doesn't work properly and this is usually due to inaccuracy somewhere. If you do have any difficulties, the most common problems can be tracked down by checking this list.

If the mechanism 'lists' when the page is open, or crumples as the page is closed:
1. Check that the lengths and angles have the measurements which were intended.
2. Check that the lines that should be parallel are parallel.

If the mechanism moves stiffly, or tends to 'hang' in the closed position:
1. It may not have been scored and creased sufficiently.
2. The glue may have oozed and gummed up the works.
3. The card is too thin and is bending where it shouldn't.
4. The card is too thick and isn't bending where it should.

If the pull-strip moves stiffly when pulled:
1. The strip may be being gripped by the page. Check that the slots and sleeves are wide enough and that slits are long enough.
2. If the sleeves are too loose the pull-strip can wobble diagonally. This will cause it to stick.
3. Check for excess glue that's oozed.

DESIGN HINTS

1. When working out a new design always make a rough version first. This is advisable in order to check that pieces fit together and fold away as planned. Having a working model in front of you also makes it far easier to visualise extending and modifying the design.

2. Colouring and decorating the design is easiest while the pieces are still flat and before it is glued into place.

3. When making up new designs, consider the effect of cutting 'windows' in the pop-up planes. Experiment by cutting away parts and to see how little card is actually needed. In this way you can develop exciting pop-up shapes.

4. Remember that the actual mechanism may often only be the 'muscle' which lifts larger images which are stuck on later.

5. Gluing-tabs are normally positioned so that they fold back and are hidden from view.
1. THE SIMPLE V-FOLD

This is one of the most simple pop-up mechanisms, and one of the most useful. In this, its most basic form, it can be enhanced by cutting the pop-up planes into exciting shapes.

On the base:
Angles A must be the same.
They must be less than 90°.
Try making them about 70°.

On the pop-up piece:
The scored line B is straight.
The central crease C is vertical
Angles D are both 90°.
As the base closes the pop-up piece folds down backwards (away from the viewer). Before gluing check where the pop-up piece will fold away to. If it is tall it must be positioned near the front of the base to prevent it jutting out when the base is closed.

2. MULTIPLE SIMPLE POP-UP PIECES

With several pieces popping-up from the base, the danger is that as the base closes and the pieces fold down their central creases (A,B,C) will clash.

To avoid this the central creases of a piece should be positioned near the back of the base.
To avoid this the central crease of a piece should either fold back less than the one behind it (crease A folds back less than B); or they should fold down parallel to each other (crease B is parallel to C).

The smaller the angles between the sticking-strips and the spine, the less the piece will lean back as the base closes.

Because angles D are less than angles E, crease A leans back less than crease B. Because angles E and F are the same, sticking-strips G and H are parallel, this makes central creases B lie parallel to C when the base is closed.

3. THE V-FOLD POINTING FORWARDS

As the base closes the pop-up piece folds down towards the viewer. Therefore tall pop-up pieces need to be positioned near the back, or top, of the base. This is useful as it leaves more foreground clear for illustrations or text.
On the base: Angles A must match each other. Try: $A = 70^\circ$.
On the pop-up piece: Angles B must match each other. Try: $B = 80^\circ$.
Angles A must always be smaller than angles B or the base can't open out flat.

When the V-Fold points forward, if angles C are $90^\circ$ the pop-up piece will tend to sag forwards unless the base is opened out perfectly flat. Making angles C less than $90^\circ$ cures the sag effect. In Mechanism 1 the pop-up piece folds away backwards so the sag is away from the viewer and actually enhances the visual effect.
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