Why Won't It Fly?

The stability of single line kites.

Nicolas Wadsworth

When a kite won't fly it is often not obvious what is wrong with it. When I started flying I was often puzzled and frustrated by misbehaving kites. I would fiddle with the bridle, which sometimes worked, but when it didn't I did not know what to do. The few books which discussed the problem at all were mainly so superficial as to be useless, or seemed muddled.

Here I want to discuss the general principles I think are important for understanding kite behaviour. The idea is to get beyond "It won't fly" and to recognise in what way the kite is misbehaving. Once one has recognised this, and knows what causes that particular misbehaviour, there is a better chance of being able to do something about it.

Equilibrium and Stability. The first thing to be clear about is the difference between equilibrium and stability. If the kite is to fly properly there must be a position in the sky where it can sit with no force pushing it away. This is the kites' equilibrium position where the wind force, the force of gravity and the kite line tension all balance.

If the kite is symmetrical, downwind of the flier and facing properly into the wind there will be no side force on it, so one just needs a balance of forces in the "Vertical Plane" (See fig. 1).

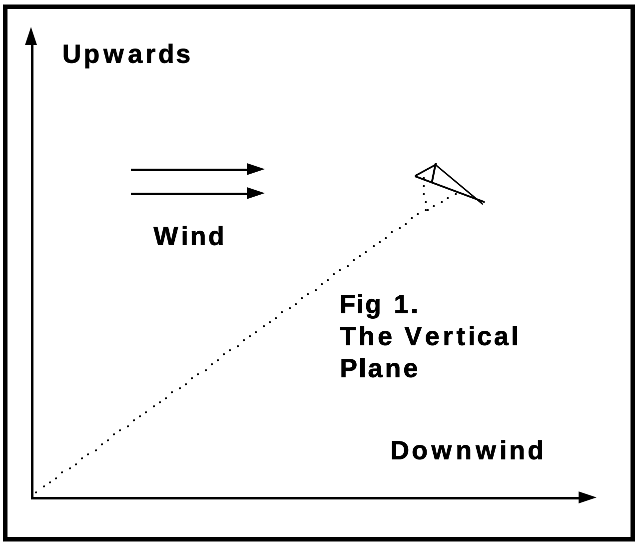

Fig 1.
The Vertical Plane

This balance is easy to arrange. If the bridle is adjusted so the kite rises when it is launched then there is a net upward force in that position. As the kite rises the kite lne will pull it downward and the change in angle to the wind will probably reduce the aerodynamic lift, so there will be less force making it climb. If it gets overhead the wind will blow it back, so somewhere in between there will be a position where the kite is not pushed either way. This is its equilibrium position. The actual equilibrium position will change with changes in wind speed and bridle adjustment, but so long as there is enough wind to lift the kite a suitable bridle position will produce equilibrium.

Is that all there is to it? Unfortunately not. A pin standing vertically on its point has no sideways force acting on it and the vertical forces from gravity and the table balance; so it is in equilibrium. But we all know it won't stay up. It is unstable:- if it is not precisely at the equilibrium position it will move away from it. We need our kite to be stable. It must move towards the equilibrium position if it is away from it, so it will get there in the first place and return there after a disturbance.

In the vertical plane there is not a problem. The kite rises on launch when it is below the equilibrium position and blows back if it is above it. So it will return. A very few kites, with short or non-existent bridles, can flip over if they get a wind under their raised nose. If your kite is one of these then a longer fore-and-aft bridle will cure it.

In summary, adjusting the bridle position on the kite will find an equilibrium position: hold the kite over your head and check it tries to rise. Move your hand along the spine to find the best place for the bridle point. If you have a fore-and-aft bridle, and probably even if you don't, the kite will be stable in the vertical plane. The real problem arises when the kite moves out of the plane. We consider this later in "lateral stability".

Over flying and free flight. Before we leave the vertical plane there is one other thing we need to consider. That is how the kite behaves when the kite line goes slack. This can happen when there is a lull in the wind or when one pays out the line rapidly. The line can also go slack when the kite "overflies". What happens is that on a hot day with a light wind a passing "thermal" produces an updraught. The upward wind moves

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the equilibrium position more nearly overhead and the kite follows. When the updraught passes the equilibrium position returns to its previous position and the kite moves downwind after it. The downwind movement reduces the wind speed over the kite and the reduced wind speed may be too little to support it.

Whatever the reason, the kite is up there without a pull on the line. What happens next? The important thing is that the kite does not come down too fast. It must stay up there long enough for you to pull the line tight again or for the wind to blow it downwind far enough to take up the slack. The best thing is for the kite to glide tail first in a stable manner, as that gets it downwind fastest to take up the slack. Few kites do this, although it can be arranged in special cases. The more normal behaviour is for the kite to flutter down like a leaf, remaining basically horizontal. This is normally quite acceptable as the kite will fall slowly while the wind carries it downwind where we want it. A <u>slow</u> glide upwind would probably do, as long as the glide was slower than the wind so the overall motion was downwind. The one behaviour which is unacceptable is a rapid (usually nose first) dive. This is likely to result in a serious crash before you can do anything about it.

How do we prevent a steep dive? Most kites recover from them without deliberate assistance, so the problem may not arise. But if your kite does not recover the important thing is to ensure that even if the kite is diving vertically the air gets under the nose of the kite to push the nose up. In other words there should be a slight bow along the spine. Indian fighter kites operate deliberately with very low line tension when spinning and are obviously at risk from a completely slack line. They always have a slightly bowed bamboo spine, I believe for this reason.

Out of the vertical plane. So much for the vertical plane. In practice when kites misbehave they almost always turn to one side or the other, so we need to look at what happens when the kite no longer faces directly into the wind in the vertical plane.

I find it easier if I think of the kite as a box kite flown "square on" with the side panels vertical. The movements are simpler and easier to understand if we also assume the bridle has long legs to at least two points across the kite so the cross spars are held at right angles to the kite line. Many kites are flown on bridles like this (Edo, Rokkaku, Sauls, Cody, Parafoil, Sled etc) and the general results derived this way apply equally to other kites.

Sideslip. So what happens when the kite is not facing directly into the wind? If the wind is not blowing directly along the length of the kite the kite is "sideslipping". The wind is blowing against the side panels at an angle called the "sideslip angle" and produces a <u>side force</u>. If the wind blows directly from the side then it will produce the same force on each of the (equal) front and rear boxes of our kite. The resultant side force will then act at the mid point of the kite. But at lower sideslip angles the wind blows mainly from the front and will pass over or near the front box first, so the rear box will be partly shielded by the front one. The rear box will produce less side force and the effective position of the side force will be well forward.

The position of the side force due to sideslip turns out to be important, and the shielding effect is quite large, especially at low sideslip angles. For our square box kite the position of the side force is usually well within the front box.

Lateral Stability. We are now ready to see what is important for lateral stability, that is for the kite to recover after a disturbance out of the vertical plane. We will consider two cases which between them bring out the main points.

The first case to consider is what happens when the kite is flying "a bit to one side", that is to say it is flying facing into the wind as usual but somewhat to one side of the vertical plane, as in Fig. 2.

Since we have transverse bridles the kite will be tilted like the kite line and the lift force on it will still be in the plane of the kite line, as will the line tension. The only difference from normal flight is that gravity still acts straight down

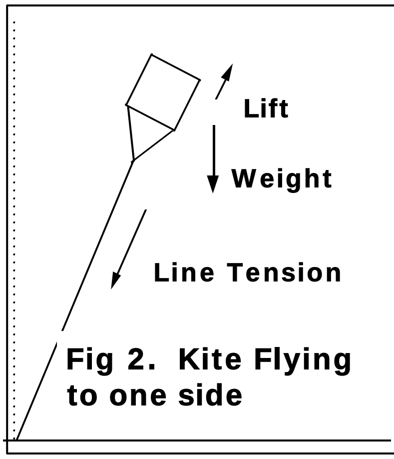

Fig 2. Kite Flying to one side

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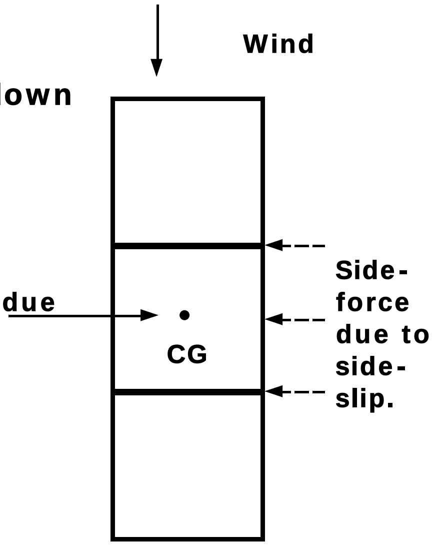
so there is now a force tending to move the kite out of the plane of the lift and the line tension – a small "side force due to gravity". Fig. 3 shows a view looking down on the kite.

Fig 3. Looking down on Kite



The side force due to gravity, acting at the centre of gravity of the kite, CG, will accelerate the kite sideways until it is sideslipping fast enough to produce an equal and opposite side force due to sideslip. If this side force also acts at CG that is all that happens and the kite continues to sideslip further and further to the side. If the side force due to sideslip acts behind CG it will support the rear of the kite more than the front and the nose will move sideways faster than the rear. The kite will turn its nose sideways (yaw) away from the vertical and the kite will turn ever further to one side. Clearly neither of these is acceptable.

If the side force due to sideslip is ahead of CG the nose of the kite will turn up until the kite points overhead and the kite will then climb towards the vertical plane. This is what we want.

So:- **The side force due to sideslip must be <u>ahead</u> of the centre of gravity** otherwise the kite will dive to one side and not recover.

The second case to consider starts with the kite stationary in its equilibrium position but facing at a small angle to the wind, see Fig. 4.

The wind will be blowing on one side so there will be a side force acting on the kite. This will have two effects. Firstly it will force the kite to move sideways. This will alter the direction of the wind seen by the kite and reduce the sideslip angle. The lighter the kite the more rapidly it will accelerate sideways and the faster the sideslip will reduce.

But we saw that the side force must be ahead of CG, so it will push the front of the kite round. This rotation will <u>increase</u> the angle of the kite to the wind and so increase the sideslip.

How fast the kite rotates depends on how difficult it is to turn. The main resistance to turning is that generated by the front and rear side areas which move in opposite directions as the kite turns. The larger the total side area and the further it is spread out the more difficult it is to turn the kite and the easier it is for the overall sideways acceleration to reduce the sideslip angle faster than the rotation increases it.

Once the sideslip has stopped the kite is left moving sideways across the sky, facing into the wind as it sees it but no longer pointing over the fliers head. The bridle holds the cross spar perpendicular to the sloping kite line so the kite is now tilted and the resulting "side force due to gravity" will make it sideslip to the other side and rotate back towards its equilibrium position.

If the side force due to sideslip is slightly too far forward then initially the rate of sideslip and rotation will increase. But the tilting produced by the rotation of the kite will increase the "side force due to gravity" in the opposite direction and this may be enough to stop the increase and return the kite to the vertical plane. However the kite will now overshoot and go even further to the

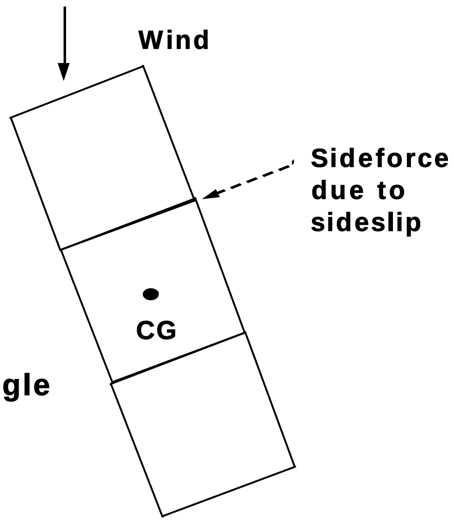


Fig 4. Kite at angle to wind.

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other side. The kite will then move in progressively larger swoops from side to side. If the side force due to sideslip is much too far forward the kite will probably spin on the spot, like an Indian fighter kite on a slackish line.

The conclusion of all this is:- **The side force due to sideslip must not be <u>too</u> far ahead of the centre of gravity.** If it is then the kite will swoop from side to side or spin.

In principle one can write all this down and solve the equations to get the exact behaviour. Unfortunately one has to make various simplifying assumptions – the main one being that it all happens slowly enough for the airflow to settle down before the angles and rate of rotation have changed much, which is not really true.

However the main result one gets is:-

$$0 < d/L < ALp/M$$

Where d = distance side force is ahead of CG
A = effective side area of the kite
L = spread of the side area
p = density of air
M = mass of kite

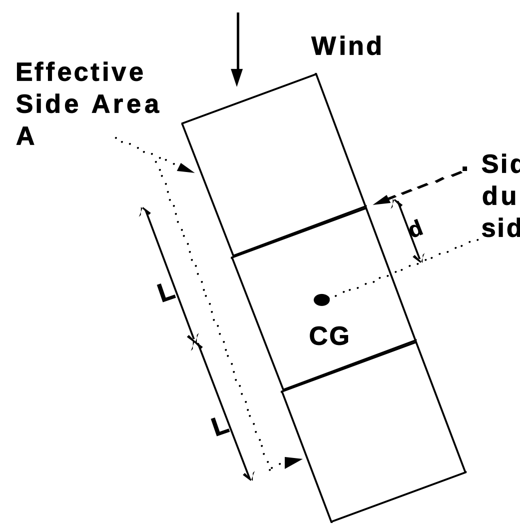

Fig 5.

We see once again that the stable range is greater if the kite has large widely spread side areas and is light. (The density of air does not change much unless you are trying for an altitude record, so you can normally ignore it).

We have derived the result by thinking of a specific kite and bridle system but the general result applies to all kites and bridle systems. Even aeroplanes, with no bridle at all, behave similarly. The rule of thumb for them is:- Too little dihedral at the front and too large a tail fin at the rear (side force due to sideslip too far back) results in "spiral instability" (an increasing turn to one side). Too much dihedral at the front and too small a tail fin at the rear (side force too far forward) results in "Dutch roll" (an increasing weaving from side to side).

So **What does all this mean in practice?** Side panels or keels fore and aft, dihedral or bowed cross spars which produce effective side area, and lightness make for a stable kite. But what do you do if the kite does not fly after you have, if necessary, adjusted the fore and aft bridle so it tries to lift?

If the (symmetrical) kite drifts or dives to the side one can conclude that the side force is too far back (or the centre of gravity is too far forward). If the kite swoops from side to side or spins one can conclude the side force is too far forward (or the centre of gravity too far back). You may be able to move the position of the side force somewhat by adjusting the fore-and-aft bridle slightly to alter the attitude of the kite and hence how much the rear of the kite is shielded by the front. Failing that, the easiest thing to do is to move the centre of gravity. Add weight to the nose or tail end and try again. Clothes pegs or spring paper clips are convenient and easily removable. Try about 10% of the weight of the kite in the first instance and increase or decrease as necessary. If the kite then flies alright you know what the trouble was and can decide whether to adjust the design to move the side area, or to lighten one end or to incorporate the extra weight in a more permanent fashion.

If when you add weight at the appropriate end the behaviour changes between swooping and diving without being satisfactorily stable in between, as for instance happens with a flat kite, the conclusion is that the side area is too small and the weight too large. If you cannot reduce the weight or increase the side area an alternative way to slow the rotation of the kite to make it more stable is to arrange tassels on either side of the kite, the further out the better. The drag of the tassels changes as the kite rotates and so op-

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poses the rotation. The technique is used by Chinese dragons and English archtops. If none of these changes are practical the only thing to do is to get the kite in the swooping/spinning range and then add a tail to damp the oscillations.

We saw that the aerodynamic side force moves back if the rear of the kite moves so that it is less shielded by the front. This produces some interesting effects. If the side force is slightly too far ahead of the CG the kite will start to weave from side to side. As the amplitude builds up the sideslip angle increases and the shielding of the rear gets less. The position of the side force then moves back and may move into the stable range. The amplitude will then stop increasing and the kite will settle down to a steady weaving from side to side.

On the other hand if the position of the side force is only just ahead of CG then the kite will slowly recover from a small excursion to one side. But if the kite moves further to the side its sideslip angle will increase, the side force will move further back, and the kite will become unstable and not even try to recover.

Both these things happen in practice.

The formula says that the range over which the kite will be stable is different for kites of different weights. I suspect this accounts for the conflicting advice one sometimes sees on making adjustments. A light kite will have a large range of allowed positions for the side force due to sideslip, and if the normal kite has its side force not far ahead of CG it will probably be advantageous to move it forward by, for instance, increasing the bow in the front spreader or reducing the angle of incidence to shield the rear more.

On the other hand if the kite is rather heavy but otherwise identical it will have a shorter stable range and it may be necessary to move the side force back to get it into the stable range at all. In this case one should increase the bow of the rear spreader or increase the angle of incidence to reduce the shielding of the rear. The changes which improve the stability of one kite will reduce the stability of another which appears identical unless you appreciate the effect of differing weights.

I had just this experience with a rather heavy Cody. It needed its rear pulled down to fly at all well. I then found that if I reversed it, so the large wings were at the rear (which moved the side force due to side slip back), it flew much better. (The reversed CODY is called a DYCO(!) in official reports). I thought this was a major discovery and tried it with a lighter Cody. I was very surprised and puzzled to find that in this case it made matters worse, not better!

If we want to compare **different size kites** we need to see how changes in size affect the allowable weight. If we halve the size of the kite, the side area, A, will become a quarter as large and L will be half as big, so for the same allowed range of d/L, M should be reduced to one eighth. In other words if you halve the dimensions of a kite you should reduce the weight to one eighth for the same performance. If you double the size then it can weigh eight times as much.

This measure, weight/size^3 is very useful for comparing kites of the same type. The smaller it is the larger the stable range and the more stable the kite is within that range. If you have a satisfactory kite of one size you can predict from its weight whether a similar kite of a different size will behave similarly.

We need some data to see how far this is true in practice.

Published kite designs hardly ever mention the weight of the kite – and occasionally one suspects that the design has been "tidied up" and does not necessarily work quite as described – so there is very little information to go on. Because of this almost all the examples I can give here refer to my own kites.

I hope this will encourage you to weigh your kites and see if they match what I quote for mine. Unfortunately the most informative cases are the ones which one does not hear about: the kites which don't work or the kites which the proud builder claims fly well but are really a bit of a handful and crash in gusty weather more often than they really should. I have some of these which I can claim "work": it is quite possible to get them in the air and they fly at a good angle once they are up, but somehow I rarely fly them! It is these kites which show where the border lies between satisfactory and unsatisfactory behaviour.

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Of course kites can misbehave if they are not as symmetrical as they should be or if they distort in the wind. But if the kite is reasonably stable then small asymmetries should just result in it flying a little to one side of where you expect. It will then generate a force pushing it back to where it should be to counter the force produced by the asymmetry. It is the kites that are hardly stable in the first place, and so produce little restoring force which are very sensitive to inaccuracies.

So here are **examples** of some common kite shapes where I have some idea of the range of values of weight/size^3 where trouble starts. Of course the number one gets for this depends on which dimension of the kite one takes as the "size". In what follows I take the length of the kite, from nose to tail end, as the "size" of the kite. Naturally one would expect different shapes of kites to have different limits.

Box Kites. The shape I have investigated in most detail is the standard Hargrave box kite consisting of two boxes, each made of 4 squares, separated by the same distance. The length ("size") of the kite is three times the edge of the squares.

I first made various cut and folded paper versions of different sizes from 30mm to 300mm in various thicknesses of paper. From the area of the paper used I could calculate the weight, which varied from 0.009g to 6.4g. They were all flown from a single bridle point, "edge on". Kites of all sizes with weight/size^3 around 200g/m^3 flew reasonably well. Those around 325g/m^3 wove from side to side, and got worse at higher speeds when the rear rose more. Those about 500g/m^3 just spun wildly.

These small kites appeared reasonably consistent, but what about more reasonable sized real kites? I have a plastic bag and thin dowel kite 0.75m long which is 85g/m^3 and is very stable. A ripstop box (of slightly different dimensions) 0.9m long flies well at 175g/m^3.

A larger one 1.65m long at only 125/m^3 is even more stable. I also have a 0.75m ripstop kite at 300/m^3 . This flies at a good angle but is not very stable: it tends to weave from side to side and crashes more easily than I would like. This is about the weight at which the paper kites suggest there would be trouble, so the scaling seems to work.

What about other sorts of kites? I have some data for Cody kites (normal – not extended wing, no topsail) of various sizes from a length of 60mm to 1.65m (wingspan 100mm to 2.75m), The stability of these seems OK up to around 450g/m^3. One I made at 1000g/m^3 was hopelessly unstable.

There is an official report of tests on a large Cody in the 24ft wind tunnel at the Royal Aircraft Establishment, Farnborough. It was a "3-foot" kite, that is to say it was made from 3ft squares and so was 9ft long with 15ft wingspan. They report that at low angles of incidence it "may become unstable and swoop out of the jet". They blame this on distortion. It sounds like normal instability to me, especially as a similar kite flown backwards as a Dyco, with the side force due to sideslip further back, was stable at lower angles of incidence. The kite weighed 23lb (10.5kg), giving 510g/m^3. If we accept this then the stability limit is the same from a 60mm long Cody to one 2.7m long: one is just stable at 0.1g and the other at 10,500g.

I have seen a commercial Cody, possibly intended as a souvenir, with thick glass fibre spars which weighed over 1000g/m^3. It spun wildly when one attempted to fly it. Replacing the spars with much lighter ones got it down to perhaps 550g/m^3 and the proud owners could at least get it in the air.

For Delta kites with a 90 degree nose angle I again take the spine length (half the wing span) as the "size". Using this a 1.1m delta at 200g/m^3 was not really satisfactorily stable while a slightly larger, slightly lighter one at 130g/m^3 flies well, as do other lighter ones. Another one, of a different size, at 225g/m^3 had very limited stability and three others at 250 – 500 g/m^3 will not flay at all without tails.

I hope this article has shown the way I find it helpful to look at kite behaviour, and in particular at the role of weight in affecting stability. I would be interested to hear any comments or of other examples.

Nicolas Wadsworth