DESIGN PARAMETERS

Individual canopies can be described in terms of wing shape, trim and loading. The designer determines the first two, the jumper the latter. Choices on these items determine the way a particular parachute flies, so without even jumping a canopy you can deduce to a great extent how it will fly if you understand these features. Wing shape is defined by aspect ratio and airfoil section. Aspect ratio is the ratio between span (side to side width) and chord (front to back.) Airfoil section can be thought of as the ratio of the wing's height to it's chord. Trim is adjusting the particular wing shape to the apparent wind to gain the best compromise in performance characteristics. And wing loading is the choice of how much power the pilot decides to give to the system.

Aspect Ratio

In theory, high aspect ratio canopies fly faster because the higher the aspect ratio, the lower the form drag for the amount of lift produced. In other words, a 200 square foot nine cell produces more lift than a 200 square foot seven cell for the same amount of form drag. Why not build a 200 square foot eleven cell at a very high aspect ratio?

The practical limits of aspect ratio are reached at about 3 to 1. At this point, a designer runs into several problems. Unlike an airplane wing, a parachute has no solid structure but maintains its shape through air pressure. To fly well the canopy must maintain good internal pressure in every cell. The higher the aspect ratio, the more difficult it is to pressurize the end cells. The wing needs to maintain a clean shape, too, which means more lines and ribs. But these mean more drag.

High aspect ratio canopies have a shorter control (toggle) stroke and therefore react more sharply. They tend to stall more sharply and inflate more unevenly than low aspect ratio canopies. Although it takes longer to initiate a turn on a high aspect ratio canopy, once the turn is under way it will be at a higher rate than a low aspect ratio canopy of the same surface area. Finally, more parts (cells, ribs, and lines) found in a high aspect ratio canopy means more pack volume for the wing area.

Between pressurization, diminishing returns on drag, and managing deployment of the canopy, the highest aspect ratio canopies on the market have never passed about three to one. Most nine cell canopies approach three to one; most seven cell canopies fall in the 2.2 to 1 range. Which is better? Everything has its price. A nine cell should fly faster than a seven cell because of less form drag - but it has 20% more lines, ribs, and cell openings than a seven cell - all contributing parasite drag. Throughout the 1990s prevailing wisdom has been that nine cell canopies also have better glide than seven cells. But the definite speed and glide advantages shown by nine cell canopies in the past decade may be largely a function of different foil sections and trim angles combined with more efficient construction. Time will tell; as designs improve seven cells seem to be catching up to nine cells in many aspects of performance but we can still expect high aspect ratio canopies to have more efficient gliding characteristics.

Because they tend to have more predictable inflation and stall characteristics, virtually all reserves are seven cells. So are canopies specialized for accuracy landings, canopy relative work, or fixed object jumping - applications where opening and slow speed flight characteristics are more important than speed and glide.

Foil Section

The foil section of a canopy is defined by the shape of the ribs - a "side view" of the canopy. Generally speaking a slow flying wing must have a thick foil in order to produce lift. (The reason for this is in chapter one but you will have to think about it!) The penalty is that a thick foil has more drag than a thin one. An accuracy or CRW canopy might have a foil section of 15 to 18% of the chord, while a high performance RW canopy might only have a 10% section. Although the thinner section flies faster, it has less lifting ability at slow speeds and will have more abrupt stalls and turns. The actual curve of the foil is also important. If the centre of lift of the foil is far forward, the canopy will have a high descent rate and very solid pressurization. Putting the centre of lift further towards the centre of the chord creates a flatter glide but makes it harder to pressurize the canopy. Combining this type of foil with a high aspect ratio will cause the leading edge corners to collapse in turns. Elliptical canopies are designed to address this problem: sweeping the leading edge back and reducing the size of the outer cells seems to increase the pressure in the end cells. As an added benefit, ellipticals feel the effects of a steering input more (proportionally more of the outside section of the wing affected by toggle input) giving very snappy response.

Summary

Here are some general guidelines about airfoil design, given a seven cell and a nine cell canopy of the same surface area.

The seven cell is more likely to open on heading, will pack slightly smaller for the same wing area, and is less vulnerable to malfunctions of a line-over type. In a partial malfunction situation, the seven cell will be less radical (have a slower descent rate and less violent behaviour.)

A nine cell will have a flatter glide, giving it slightly more range. It will have a longer flare, which may make the flare easier to time but requires a longer runway.

The seven cell will be more stable at slow speeds, give more warning before stalling, and recover from a stall more predictably than a nine cell.

The nine cell may have more forward speed, an advantage in winds.

Wing Loading

This term refers to the amount of weight a parachute is carrying and this is probably the single most important factor in how a modern parachute flies. In the U.S. wing loading is expressed as a ratio of pounds per square foot. For pounds, use your exit weight: combine the weight of your body and all of your equipment. For square footage, use the manufacturer's figure. Then divide the weight by the square footage for the wing loading. For example, I weigh 190 pounds and my equipment weighs another 25, including main, reserve, container, jumpsuit, and paraphernalia. That makes my exit weight 215 pounds. If I am jumping a 205 square foot canopy, my wing loading is 1.05. A student my size under a Manta (288 sq. ft.) would have a wing loading of .75. Someone my size under a Sabre 150 would have a wing loading of 1.43. Most manufacturers will have a suggested maximum wing loading for various designs; many also suggest a minimum. As a rule, the higher the wing loading, the higher the performance. At very low wing loadings, canopies are sluggish and unresponsive. Increasing wing loading increases forward speed and descent speed. This increased speed gives you a higher turn rate, and the controls will feel more sensitive. Keeping in mind that lift increases with speed, a high wing loading can mean that you get a longer flare than you would with a low wing loading. But since everything happens faster, your room for error is reduced. Partial malfunctions will be more severe with an increase in wing loading.

There is a point of diminishing returns with wing loading. Using an airspeed indicator and variometer (a device to measure descent rate) to test a variety of modern canopies, I found that at wing loadings above 1.5 the only performance increase is in turn rate and responsiveness. As more weight is added, the canopy loses glide (comes down faster) with no gain in forward speed. For general canopy flying, loadings above about 1.4 seem to confer zero benefit to speed and glide while increasing descent rate. Stall speed (the point at which flow separation occurs) also goes up as the wing loading increases.

Here are some general guidelines about wing loading given canopies currently on the market in 1997:

> For slow, soft landings, or for jumping at higher elevations, choose a low wing loading: .7 to .9.
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> For a good compromise of performance and safety, jump a 1 to 1 wing loading; one square foot of canopy for each pound of exit weight.
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> For a fast canopy, jump at a wing loading of 1.1 to 1.3. Any wing loading over 1.3 puts you in the experimental category, where the canopy is at the edge of its performance envelope. Experts routinely jump at wing loadings of 1.4 to 1.6 - but they are jumping in the same conditions, every day. Changing landing areas, altitude, or other factors make these wing loadings questionable.
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> As a rule, zero porosity canopies and 9 cells can be safely flown at higher wing loadings than F-111 seven cells. A skydiver who might jump an older seven cell at a .8 wing loading could, with a little training, safely jump a modern zero porosity 9 cell at 1.1.

Trim

How a parachute is trimmed and tuned has a great effect on its performance. Trim refers to the angle at which the parachute is set to descend - the angle of incidence. Nose down trim results in a higher descent rate and increases stability. Nose up provides more glide but makes the canopy less resistant to turbulence or deformation and such a canopy will also take longer to re-inflate once collapsed. Typically, Accuracy and CRW canopies are trimmed nose down (steep angle of incidence) while RW canopies have a flatter trim. Trim affects the flare in the same way it affects glide. A canopy with a steep angle of incidence will not flare very long, but the canopy will be more stable in brakes and recover from stalls faster.

Steering line trim also affects canopy performance. Having the steering lines too long diminishes the effectiveness of control input and might mean the jumper is not getting the full potential out of the parachute at flare time. If the lines are too short, the canopy will always be in partial brakes and will be easy to flare past the stall point. Just moving the point where the toggle is tied to the steering line an inch up or down can make a big difference in your parachute's flare characteristics. If you have trouble slowing the parachute down on a calm day, chances are your toggles are too low. If your canopy rocks behind you on landing and is easy to stall, you may need to lengthen your steering lines.

Trim isn't always controlled by the manufacturer. Over time, lines stretch and wear. On higher performance canopies, an inch or two either way makes a big difference. Canopies need to have the lines replaced periodically as they come out of trim. Yet the same skydivers who would meticulously change oil or replace tires on their car may never think about how their canopy holds up over time.

Parachute Materials

The standard parachute nylon throughout the '80s and early '90s was F-111, after the designation given to it by the mill that produces it. Lately coated fabrics, commonly referred to as "zero-p" fabrics, are taking over the market. F-111 is less expensive and easier to work than zero porosity fabrics, which means parachutes of this material are cheaper. They are also easier to pack because air escapes from this fabric more easily than from zero-p. However, they wear out sooner. An F-111 canopy is at its prime for about 300 jumps, will work well for another 300, and will have lost a lot (20% or more) of its original performance by the time it reaches the last 300. Few F-111 canopies are any good after 1,000 jumps.
Zero porosity fabric is more expensive and harder to work with than F-111, so canopies made from it are more expensive. However, the expense is offset by several advantages. Zero-p canopies hold their shape better and less air passes through the fabric, giving them better flight characteristics than a similar canopy built of F-111. They also last much longer, and zero-p canopies may still fly well after 1,000 jumps. They have the disadvantage of being more difficult to pack - until you get used to them, which only takes a couple dozen pack jobs.
Some canopies combine the two fabric types for the best of both. These seem to work well.

Canopy Material Advantages Disadvantages
F-111:Cheap
Easy to Pack Less Aerodynamically Efficient
Good for only 600 - 700 jumps
Zero-P: More Aerodynamically Efficient
More Durable More Expensive
Harder to Pack

Parachute Lines
There are two basic types of parachute line, regular dacron line (the thick type) and microline or spectra (the thin type.) Microline is more expensive than dacron, adding to the cost of the parachute. However, since it is significantly smaller, it reduces drag, giving perhaps a 5% performance increase over a canopy equipped with regular line. Microline is very strong and does not stretch much when weight is applied, as dacron lines do. This means that it tends to cause harder opening shocks. It may

also shrink unevenly over time, causing a canopy to get out of trim. Some people find it slightly harder to handle and stow, and it is inappropriate for canopy relative work.

Line Material Advantages Disadvantages
Dacron: Easy to pack
Soft Openings Bulky
More drag
Microline::Low drag
Small pack volume More expensive
Harder openings

Other Modifications

Most skydiving equipment comes in a fairly stock configuration, but there are a number of small modifications you can make to the risers and canopy to improve flight characteristics. Not all of them are useful for everyone, but by customizing your gear you can get as much as a fifteen percent performance increase. Enhancements come in two forms; those that reduce drag and those that improve handling.

Reducing parasite drag has obvious benefits because by increasing speed you increase the lift your canopy produces without adding any weight to the system. The most common ways to do this are removable sliders, collapsible pilot chutes, and riser modifications. All of these are fairly simple modifications you can usually order from a dealer or have made for you by a capable rigger. But since they do require a little knowledge to use safely, be sure to get advice and instruction from someone familiar with the modification.

Slider Modifications

A slider is essential to deployment but serves no purpose once the canopy is open. From there on, it is just a burden to the canopy. If you think the drag is negligible, drive down the road at 25 mph holding your slider open. Getting rid of the slider provides another benefit by letting the canopy spread out more towards its original ideal design shape, reducing some of the anhedral of the parachute and giving a slightly flatter flight. Removing the slider not only increases a canopy’s performance, it confers aesthetic benefits too by eliminating a lot of noise and greatly improving the view.

There are a number of ways people have dealt with the slider. Each has pros and cons. On every system, the biggest con is that you have to deal with your slider after opening. Remember that stowing your slider is not nearly as important as managing your flight - other traffic and the spot - so never mess around with your slider until you have a safe path back to the dz picked out!

The most common way to eliminate the slider is to pull it down and stow it under your chin or under a velcro strap on the neck of your jumpsuit. The good part of this method is that it is a very simple system in that it does not add significant time to packing and can't be screwed up at packing time. However, it doesn't work if you have thick risers instead of mini risers. If you pull it under your chin, it can blow loose and block your vision. If you wrap somebody or induce a malfunction after stowing it behind your neck, when you cut away your canopy might stay with you! Both the latter cons have occurred with disastrous results. Finally, do not put bigger grommets on your slider to ease the pull down unless you put correspondingly big stops on your canopy's stabilizers or you will get an exciting malfunction!

Fairly common is to leave the slider in place but collapse it with a drawstring. Actually, all this does is silence it a little and reduce some drag, so although this is the simplest possible solution to the slider, it is also the least effective.

Splitting the slider is common with accuracy canopies because it allows the canopy to spread out, it works with big risers and is fairly simple to use. This method is fine for slow canopies because the slight drag from the split slider isn't as much of a factor on an accuracy canopy - they have drag all over them anyway. Aesthetically, split sliders are rather ugly.

Removing the slider altogether is the final option. Removable sliders use a loop and pin system, kind of like a tiny toggle stow, that holds the grommets onto the fabric. To remove the slider you grab a loop in the middle of the slider where lanyards from the four corners come together. A quick tug and the fabric is loose in your hand. You then have to stow the slider in your jumpsuit or some other place where you won’t loose it. The grommets of the slider remain at the top of the risers. Before packing you re-attach the slider, which adds a minute or two to the packing process. Because you definitely do not want to hook it up wrong, it is important to pay attention to the re-attachment.

Collapsible Pilot Chutes

Collapsible pilot chutes are another easy after market feature to add to your parachute. There are two types. Bungee collapsed pilot chutes are simple in that they do not need to be "cocked" to work, as kill line collapsibles do. Their disadvantage is that if the bungee is worn out or when deploying at slow air speeds, they can fail to inflate and cause a pilot chute in tow. Kill line types are the opposite - they work well in most deployment conditions, but if they aren’t cocked before packing, you get a pilot chute in tow. As long as you understand and properly maintain the type you have, there should be no problems.

Both types have a somewhat bulkier, stiffer bridle than non-collapsible types. This may increase the probability of tying a knot in the pilot chute as it is inserted in the pocket. I have seen this problem several times and there seems to be a high correlation with collapsible pilot chutes, so be very careful about the packing technique you use.

Riser Modifications

Being able to steer with your front risers adds considerably to your piloting options, yet a stock riser can be hard to grip. Furthermore, as you turn the tension on the riser increases with the weight increase induced by centrifugal force. Therefore, most advanced canopy pilots have some kind of hand hold added to their risers. These usually come in the form of loops or blocks.

Front riser loops are loops of webbing sewn to the riser. Blocks are a stiffener of some kind, usually folded webbing or a metal ring, that is placed just below where your hand grabs the riser. The block keeps the riser from sliding through your hand when you pull on the riser. The advantage to loops is that they have little bulk and won’t catch on anything during deployment. However, you have to actually get your hand in and out of them. Blocks are simpler: you just grab the riser and close your hand around it. Open your hand, and you are free of the riser. For this reason canopy relative workers have a preference for blocks, as do many advanced canopy pilots.

Some pilots of small, high aspect ratio canopies have three risers instead of two. The third riser is for the steering line. This modification, like a removable slider, allows the canopy to flatten out, improving the shape and therefore the performance. The fact that third risers are uncommon may indicate that the increased performance may not be worth the increased complexity.

A final modification seen on a few canopies is trim tabs. These allow the pilot to mechanically lock in a certain amount of front riser trim. Trim tabs were fairly common on CRW canopies in the early and mid 80’s but are now rarely seen. They add some bulk to the riser but are only occasionally of any use.