The Aerodynamics and Piloting of High Performance Ram-Air Parachutes

$\boxed{\text{Draft 0.2}}$

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READ ME!

While it is the authors expressed hope that this document serve as a learning tool to teach the piloting techniques of high performance ram-air canopies, it must be understood that this document is not in itself enough. The techniques described in this document have proven to be very useful in developing good advanced canopy control techniques. However, jumpers wishing to develop the skills required to pilot high performance canopies should seek the advice and assistance of responsible experienced pilots who have the appropriate knowledge themselves of the aerodynamics involved.

This document does not constitute all the knowledge in the field. The techniques or principles discussed may not be applicable to a particular wing, or appropriate for a given individual. And due to the rapid evolution of the technology, may become obsolete or even dangerous as new products and technolgies become available.

It is the canopy pilot's responsibility to assume all risk.

Forward

A Generation of Improvement

Since Domina Jalbert introduced the first ram-air parachute in the late sixties, the designs and performance characteristics of these canopies have gone through a tremendous evolution to arrive at their present day configuration. There has always been a great deal of aerodynmic engineering and research involved in the design of these canopies, and that trend seems to be increasing.

The results are astounding. The "cutting edge" of high performance canopy technology has turned what was originally a simple deccelaration device into a semirigid wing capable of airspeeds as high as 60 mph, with high lift characteristics, and surprising versitality. These "square" canopies have proven their worth to such an extent that the classic round canopy has all but disappeared from sport parachuting.

However, while the manufacturers have pursued these technological advances in classic competitive form, and the sport parachuting community has enthusiasticly embraced these new canopies, there has been an unsettling trend in recent years of increased injury rates, in both quantity and severity, for parachutists piloting these canopies - or more acurately, these aircraft. And these injuries are not limited to the pilots themselves, but are also involving pilots of other more conventional canopies and ground personnel who are simply in the vicinity of the landing area.

The incremental advances in canopy technology are less dramatic to the "old timers" who have followed the technology through the years, building newer skills on the foundation of previously mastered skills as the technology evolved. However, today's students advance *extremely* quickly from large docile square canopies to much smaller, faster, and ultimately less forgiving canopies, sometimes in a matter of weeks or months and typically with a quantity of jumps that can be counted in the dozens. The sensitve nature of high performance canopies is enough to give even very experienced jumpers more than they can safely handle. Combining the minimal experience of the low-time jumper with the unforgiving nature of a high speed canopy is inviting disaster.

There–in lies the premise of this paper. The sport skydiving community, i.e. the individuals, the manufacturers, the training centers and drop zones, and the national association (the USPA) have all overlooked the impact (pardon the pun) that recent advances in canopy technology have made on the traditional skills of "parachuting", i.e. canopy control. From spotting skills to landing techniques, there is no formal training doctrine or curricula designed to increase the jumper's skill under canopy once they have achieved an A license. And only minimal training up to that point. The defacto method for learning how to manuever mid-range and high performance canopies is via the school of hard knocks.

The objective of this document is to provide an initial training program to develop *advanced* canopy control skills in jumpers at all experience levels. The two most critical points are the transition periods from student squares to smaller "conventional" square canopies (generally a novice's first gear purchase) and then, from these conventional, lightly loaded F111 squares to zero-porosity, high aspect ratio canopies designed for much higher wing loadings and considerably higher airspeeds. Of major concern is the increasingly common practice of making both transitions at once.

Many good pilots have succesfully negotiated these transitions without mishap. However, for these pilots that have already developed an instinctive sense of their canopy's performance envelope, a detailed technical study of the flight dynamics of their canopy can ward off the most frequent problems among experienced pilots — complacency and over confidence. Fear tactics, i.e. "just say NO to hook turns," do not work.

If this document is to be successful, the student must come away with a greater understanding of the technology behind ram-air parachutes. Without that understanding, there can be no respect.

It is the authors opinion that any such program directed towards high performance canopy pilots must meet two basic objectives:

1. It must provide the student with an intuitive understanding of the basic aerodynamic principles of flight and how they are applied to high performance ram-air canopies; and

2. It must define techniques and learning methods which allow the student to develop new canopy control skills with a minimum exposure to serious injury.

The original goal was to write a "how to" paper on high speed landings. The effort obviously morphed somewhere along the line, resulting in a broader and more detailed tome on high performance canopy skills in general.

The material presented in this primer is organized into four sections:

1. The atmosphere; It's make-up and how it affects flight characteristics.
2. The airfoil; Terminology and basic aerodynamic flight theory.
3. The ram-air canopy; Design aspects which define and constrain the canopy's performance;
4. The pilot; The skills set and learning techniques required to safely operate high performance canopies.

The first two sections necessarily require some rudamentary science and math. I have attempted to minimize the amount and complexity of the principles put forth, but a minimal working knowledge of high school algebra and physics is necessary. That being said, the formulas and examples are meant as proof of the concept being presented, not as skills every pilot need master. If the reader accepts the premise, and has an intuitive feel for the concept, the mathmatical proof is unnecessary. The student need not dwell on the math, and they will not be required to compute these things in the air (thank goodness!). The intent is to expose the student to the design principles, operating constraints, and inherent limitations of high performance canopies — not to create an aerospace techno-wizard.

By far the most important section is the last. And by far the most important concept presented there is that of "mindset." There are many concepts presented in this document, but they all pale next to the importance of the pilot's perceived responsibilities. This section should perhaps have been the first for this reason.

This document is intended to reflect current technology and instructional methods in training canopy pilots. And as such, it is only as good as the knowledge and skills of the individuals who contribute to it's content. The document will be updated and improved on a regular basis. So comments, suggestions, objections, corrections, and offers of assistance are encouraged and will be eagerly accepted by the author.

Be careful. Have fun.

The Atmosphere

When we think of an open ram-air parachute, we rarely take the time to ponder the physical principles that are working on that canopy to make it perform as it does. Obviously, how the ram air parachute works is directly related to its shape and construction materials. But there is more to studying these canopies than simply looking at their construction methods or design specifications. We must understand the *environment* in which they are meant to operate.

This environment is the earth's atmosphere. The atmosphere (or any gas for that matter) can be treated much like a fluid when we study the characteristics of its motion. This field of study is called "Fluid Dynamics", and it is responsible for many of the scientific principles behind airfoils, airplanes, jet engines, propellers, sails, kites, pipes, paint sprayers, and countless other items of day to day living.

More specific to our interests, however, is the study of how *air* acts on various objects. This is field of study is called "Aerodynamics".

In studying the atmosphere, there are two aspects we are concerned with:

First, is the climate, or the weather. These climactic aspects are typically large scale effects which create the conditions we fly in on a daily or seasonal basis. Examples are the wind conditions, frontal activity, precipitation, and temperature. Geographicfeatures such as proximity to water or mountains also contribute to these large scale atmospheric conditions. Understanding these characteristics are critical to developing smart piloting skills.

The other atmospheric characteristics that concern us are the actual make up of the air at any given point in the atmosphere. These are generally simple measurements such as air pressure, air density, temperature, and the like. While these local ambient measurements vary with the larger climatic weather changes, they are sufficient to describe the aerodynamic effects of the airflow across an airfoil and therefore are adequate for our purposes of studing [at least in theory] how a ram-air parachute works.

All of these aspects are related. And they all affect the performance characteristcs of you and your canopy.

The Fluid Medium

When we deal with normal air, i.e. the atmosphere, and its motion around some object, there are four basic quantities which come into play:

- Pressure.
- Temperature.
- Density.
- Velocity.

These quantities vary from point to point within the atmosphere. For the moment, we can ignore the role these values play in creating the weather. We want to look at them to see how they affect the flight characteristics of our parachute. To do this, we not only need to look at each individually, but more importantly, we need to have some idea of how they interact with each other. So, it is appropriate to introduce a simple but important equation called the **equation of state** for a perfect gas:

$$p = \rho R T \tag{1}$$

where p is pressure, ρ is density, and T is temperature. R is a constant related to the chemical makeup of the gas.

The equation of state provides us with a method of relating each of our quantities to one another. If the pressure changes, there must be some accomodating change in either the temperature, density, or general make up of the air in order for the equation of state to be satisfied. While it is quite unlikely you would use Eq. 1 while under canopy, you may wish to use it to predict the flight conditions at a new drop zone, or in unusual weather conditions, or some other similar situation. Being able to *predict* how your canopy will behave is the first step in being a competant pilot.

We will see in the following sections how this equation and the Velocity value can be used in a practical sense. But first, lets examine each of these values more carefully.

Pressure

Pressure is a point value, i.e. measured at a given point. However, it is measured in terms of some amount of force per unit area. For example: pounds per square inch (lbs/in^2) or newtons per square meter (N/m^2).

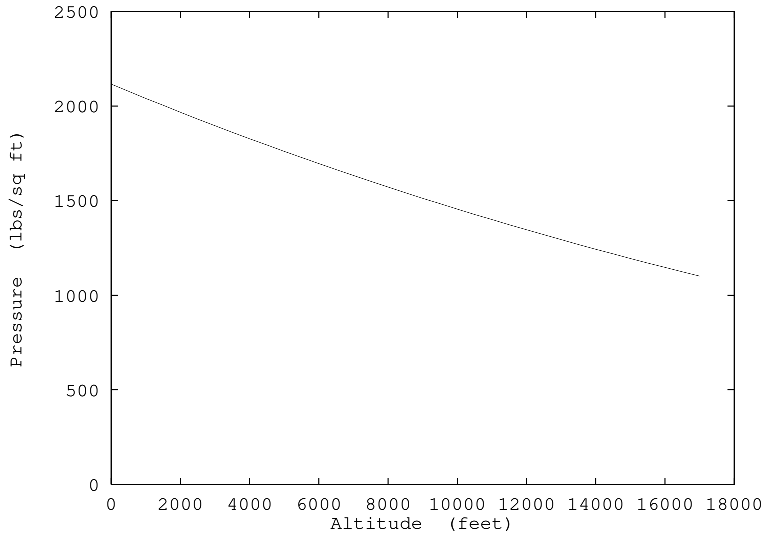

Figure 1: Atmospheric pressure vs. altitude.

In order to get an acurate picture of pressure, we must view a gas as a collection of molecules, all zipping around, bumping off one another and any objects that they may happen to come into contact with. Pressure, then, is the aggregate force exerted by these molecules upon any surface or object they encounter. Since the molecules are zipping around in essentially random directions, it makes no difference how we orient our surface, it still feels the same force.

Atmospheric pressure does vary, though, most notably with altitude and weather conditions. So, in order to create a constant reference value, we must define a pressure value that is equivalent to one "standard atmosphere". This standard atmospheric pressure is the average barometric pressure at sea level. This pressure is $14.7\,\mathrm{lbs/in^2}$ (or $1.01325 \times 10^5\,\mathrm{N/m^2}$).

It is important to note, and you can see from Fig. 1, that the atmospheric pressure decreases rather quickly as one gains altitude. At 2000 feet, the air pressure has dropped 7% to $13.67\,\mathrm{lbs/in^2}$. At 13500 feet, the atmospheric pressure has decreased by 40% to $8.8\,\mathrm{lbs/in^2}$. And by 17000 feet, the ambient atmospheric pressure has dropped by fully one half to only $7.65\,\mathrm{lbs/in^2}$. As we will see momentarily, this has a noticable effect on the aerodynamics of an airfoil. Even more importantly, though, is that at 17000 feet the pilot is getting only half the oxygen they would get at sea level. This can influence decision making in a very significant way.

Why is pressure important to us? Because the sum of all the point pressures (forces per unit area) incident on our canopy are what define the total forces acting upon the wing and consequently define the flight characteristics of the entire contraption. We must know the role pressure plays in flight dynamics so that we can predict how changes in the atmosphere or our canopy configuration will affect the pressure and thereby the flight characteristics of our canopy.

Temperature

Temperature is a measure of the kinetic energy contained in the molecules of a gas (or fluid). Refering back to our molecular model of the atmosphere, temperature is simply a measure of the average speed of the air molecules; Warmer air molecules are moving faster than cooler molecules, and generally, warmer molecules move further before they colide with another molecule.

If we were to confine a fixed volume of gas, say one cubic meter, at a given pressure, say 1 atmosphere, and were then to raise the temperature, we would notice that the pressure also increases. As the molecules warm up and start to move faster, they hit the inner surfaces of our cube with more force, creating a higher pressure. Conversely, if we take the same cubic meter of air, and cool it down, we would see the pressure decrease.

If we look at the equation of state

$$p = \rho R T$$

It is easy to see from this equation that raising the temperature must necessarily increase the pressure, assuming the density and R remain constant.

Like pressure, the air temperatures we encounter in our sport vary considerably. And so we must also define a standard reference atmospheric temperature. This standard temperature is $T_s = 288.16°\text{K}$ (or about 58°F).

Density

Density is a measure of mass per unit volume. In our case, atmospheric density is a measure of the total mass of air molecules found within a cubic foot or cubic meter of air. More formally,

$$\rho = \frac{m}{v} \tag{2}$$

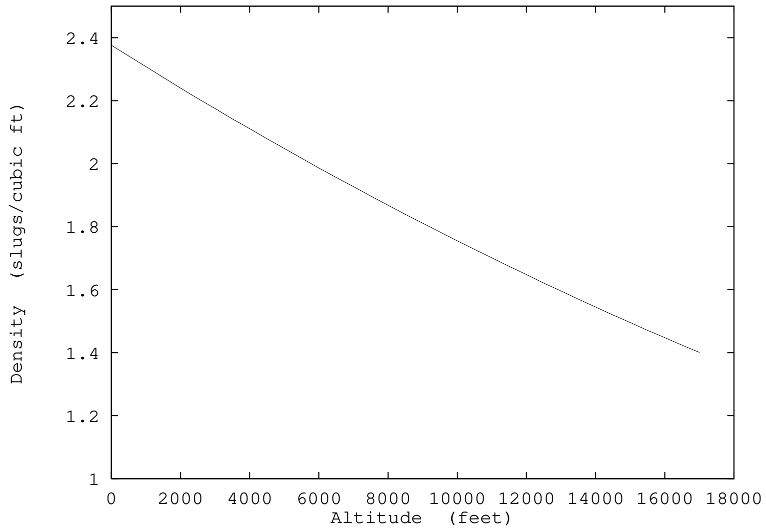

Figure 2: Atmospheric density vs. altitude.

where m is the total enclosed air mass, and v is the enclosed volume.

The "standard atmosphere" has a sea level density of 1.225kg/m^3 (or 2.377×10^{-3}slugs/foot^3). (A "slug" is the english unit for mass and is equivalent to 32.2 lbs.)

Like pressure, atmospheric density varies with altitude (see Fig. 2). To parallel our earlier examples, at 2000 feet MSL (mean sea level) atmospheric density is 94% of its sea level value. At 13500 feet MSL, it has dropped to 66% of sea level, and at 17000 feet, to 58%.

Air density also varies with temperature. To go back to our cubic meter of air, when we raise the temperature, we raised the pressure. However, if we wish to keep the pressure constant, the density must necessarily decrease.

By substituting Eq. 2 into Eq. 1,

$$p = \rho RT = mRT/v$$

$$pv = mRT$$

we see that in order to balance the equation, we must allow the enclosed volume to expand. Since there are now fewer molecules per cubic meter, the density of the contained air has decreased. Since warmer air is lighter than cooler air, it will tend to rise. This effect has been utilized by hot air balloons for several hundred years. It also explains why upstairs rooms always seem to be warmer than downstairs rooms.

Since normal atmospheric air is not confined, when it is heated (say by the sun), it rises causing thermals, and ground winds. Since it is less dense, it also has a pronounced affect on the flight characterisitcs of our canopy.

Humidity can also change the density of the fluid medium in which we are flying. Given a cubic meter of air (or any other gas), *at a standard temperature and pressure*, there will always be the same number of molecules present, no matter what type of gas it is! This fact is important. As the amount of water vapor (humidity) in the air increases, air molecules are replaced, one at a time, by water molecules. The average air molecule has a mass of $N_2 \times 80\% + O_2 \times 20\% = 28.8$ atomic units. However, a water molecule, H_2O, has a mass of only 18 atomic units! So, as we replace air with water, we are reducing the total mass in our cubic meter and thereby lowering the overall density. (Note: While we can still use the equation of state to relate the temperature and pressure to density for humid air, the gas constant R changes as the relative humidity increases.)

Since pressure, density, temperature, and altitude are so closely related, it is frequently useful to relate changes in one of these quantities to equivalent changes in another. For instance: A humid day at sea level may be equivalent to a dry day at 1000 feet as far as air density is concerned.

We can use Eq. 1 to relate variances in temperature or density to a change in pressure, or vice versa. And by refering to our table of atmospheric pressure vs. altitude, we can equate real atmospheric variances to our standard atmosphere reference model. When jumping at a new drop zone, or under unusual conditions, this provides an astute jumper with a good predictor of local flight conditions relative to those with which the jumper may be more acustomed.

While it is pressure differences that enable the airfoil to produce lift, the amount of lift that is generated can vary dramaticly with changes in density and temperature of the ambient air.

Example 1.1

A drop zone on the Texas Gulf coast has summer temperatures reaching 95°F or more. Warm southerly breezes off the Gulf of Mexico pick up a great deal of moisture and frequently drive the relative humidity to 100% resulting in short but pronounced thundershowers.

On the other hand, during the winter, high pressure regions coming out of the North bring cool dry air down from Canada. Temperatures will drop to around 35°F with the relative humidity around 25%.

Using the standard atmospheric pressure altitudes, compare the landing conditions for this drop zone between a typical January day and a typical July afternoon.

Solution:

To solve this problem, we want to convert the conditions at each time of year to an equivalent standard atmospheric altitude. For this problem, we'll use the density altitude. We convert all our values to metric and solve for ρ in the equation of state.

The 95°F July ground temperature reduces the sea level density to 87% of the standard atmosphere. Then, replace 5% of the air molecules with water vapor and the density is further reduced by another 2%. The July density is approximately 1.04 kg/m^3.

The January density is about 4% greater than the standard atmosphere due to the lower temperature and minimal humidity. It is 1.28 kg/m^3.

This July density value equates to an equivalent standard atmospheric altitude of almost 1600 meters! And the heavier winter air equates to slightly below sea level conditions. This is the difference between landing at sea level and landing in Denver, Colorado! Or put another way, this is the difference bewteen landing a 135 square foot canopy and a 120 square foot canopy.

It should be noted that this example postulates two extremes in atmospheric conditions. But high performance canopy pilots must be aware that these otherwise wonderful skydiving conditions may still be enough to push the canopy beyond its safe operating envelope. You *must* understand all the issues.

Airfoils and Basic Flight Theory

To refine and limit our discussion of canopy aerodynamics, we must first define some terms. We should begin with the term **airfoil**.

What is an "airfoil"? And why do skydivers care?

An airfoil is, in its broadest sense, any object in a fluid stream designed to produce lift. Indeed, many texts use flat plates, spheres, cylinders, wedges, etc. as airfoils in order to demonstrate various aerodynamic principles. However, the specifics of this paper will deal with the more traditional shapes used in designing aerodynamic lifting surfaces, i.e. aircraft wings.

Fig. 3 shows crossections of several common airfoils. Airfoil (a) is a symetrical airfoil in that the top and bottom surfaces have identical curvature. Airfoil (b) is the airfoil typical of many light aircraft; essentially a flat bottom surface and a smooth curved upper surface tapering to a fine point. Airfoil (c) shows a cambered airfoil; i.e. the whole crossection appears to have been curved down towards the tail.

There are many variations on these airfoils: thicker, thinner, more curvature, different curvatures, etc. And they each have strengths and flaws. We will be studying airfoils most like Fig. 3(b).

Airfoils and Related Terminology

The **chord** of an airfoil is the distance from the leading edge to the trailing edge (Fig. 3). The chord is taken to be the distance from the trailing edge to the point furthest away on the airfoil cross section. The chord line so measured need not be centered in the wing crossection (Fig. 3b), and in fact, may actually extend outside the crossection for highly cambered airfoils (Fig. 3c).

The function of the chord line is to provide a basis for stating the angle at which the air strikes the wing, or the angle of the wing relative to the aircraft body, or even the angle of the wing relative to the direction of thrust. We will discuss these aspects more in a moment. The chord is also used in various ways to characterize the airfoil shape itself. For instance, a NACA [1] 2412

[1] NACA stands for the National Advisory Committee on Aeronautics and was the precursor to NASA. The NACA body did a great deal of airfoil research during the early days of flight.

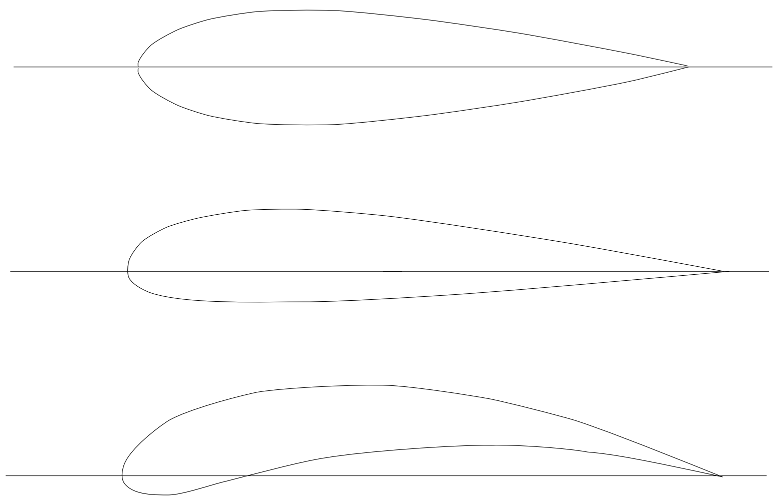

Figure 3: Three common airfoil crossections. a) symetric, b) asymetric, c) cambered

airfoil has its thickest point 24% of the chord length back from the leading edge, and that point is 12% of the chord length in thickness. The chord is also required for other functions such as computing stall points and scaling issues.

Fig. 4 shows an overhead view of three different wings. The design of the wing as viewed from above is called the wing's **planform**. Fig. 4a depicts a standard rectangular planform. Fig. 4b shows a swept back and tapered planform as might be seen on jet aircraft. And Fig. 4c shows an eliptical planform. Like the crossections, there are significant differences in flight characteristics exhibited by each of these designs.

As indicated in Fig. 4, the **span** of a wing is the length from one wingtip to the other as measured perpendicular to the air flow.

A term frequently used to characterize the shape of a wing is the **Aspect Ratio**. The aspect ratio is defined as follows:

$$\mathrm{AR} = \frac{\mathrm{span}^2}{\mathrm{area}}$$

which, for rectangular wings, reduces to the more commonly recognized value

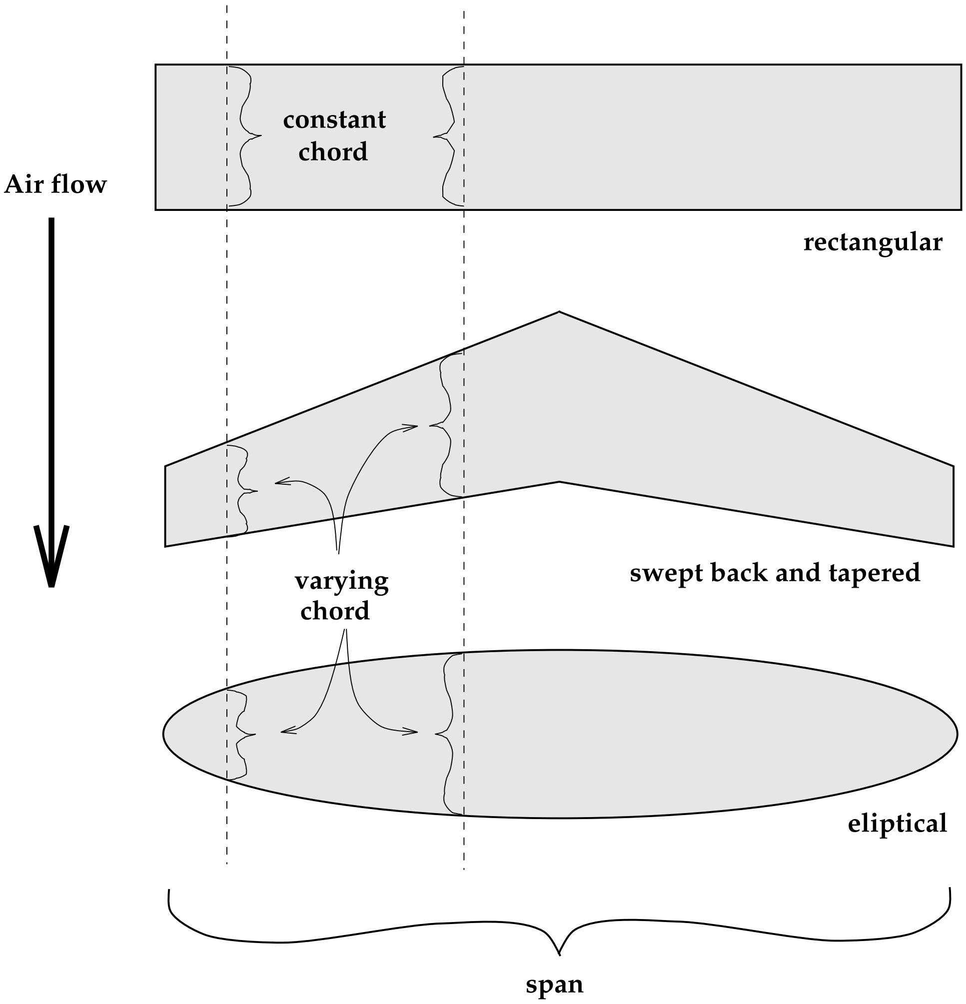

Figure 4: Three airfoil planforms.

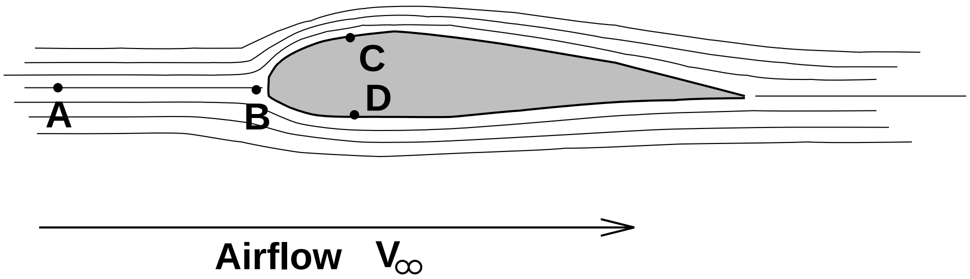

Figure 5: As the air is displaced by the airfoil, it must accelerate to get past the curved surfaces. The greater curvature of the upper surface induces a greater velocity than the less curved lower surface.

$$\mathrm{AR} = \frac{\mathrm{span}}{\mathrm{chord}}$$

Due to various complex principles beyond the scope of this document, the lift generated by the wing is directly related to the Aspect Ratio. In other words, given two wings of equal surface area with similar airfoil crossections, the wing with the higher AR will, in general, produce the most lift. This is why gliders and small aircraft with relatively low airspeeds will normally have very high aspect ratio wings. Conversely, aircraft designed for higher airspeeds can generate adequate lift with shorter wings (which are structurally superior).

Now we must define some terms relating to motion of the airfoil (be it a ram-air parachute or airplane wing) as it moves through the air.

While airplanes and parachutes move through an essentially stationary air mass, it is generally easier to study airfoil flight dynamics as if the airfoil was stationary and the air was moving past it. This is the situation found in wind tunnels. Also, since the direction and speed of the airflow changes as it passes around the airfoil, we would like to define the airflow velocity to be the direction and speed of the air far away from the wing i.e. where the presence of the wing has had no affect on it. We could say: the wind velocity at a distance infinitely far away. This value is refered to as the **freestream velocity** and is denoted as V_∞. Jumpers will recognize V_∞ as the speed and direction of the "relative wind".

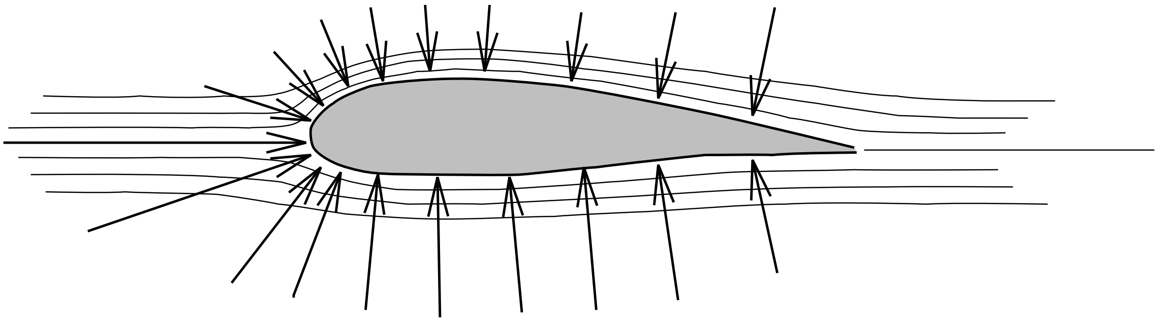

Figure 6: As the air passesover the wing, changes in flow velocity cause changes the pressure acting upon the surface.

There are analogs to V_∞ for pressure, density, and temperature as well — p_∞, ρ_∞, and T_∞ respectively. In low speed subsonic airfoils, changes in the air's temperature and density as it passes along the wing are so minute as to be negligible. But keep in mind that while the effects of the wing on these quantities is small, the effect of these quantities on the wing is quite a bit more substantial. So, we are concerned with temperature and density as atmospheric conditions, but we won't worry too much with them as we discuss the forces acting on our airfoils.

Bernoulli's Equation

So, what makes an airfoil fly?

In a nutshell, its pressure. As the air passes along the wing's surface, the pressure exerted onto the surfaces changes. The pressure on the lower surface increases and the pressure on the upper surface decreases. This difference in pressure creates a net force perpendicular to the airstream that is known as **lift**. (See Fig. 6)

But there's more to it than that. Why do wings "stall"? Why do some airfoils generate more lift than others? Why are faster ram-air parachutes more "rigid" than slower ones? To answer these questions, we need a couple of other facts:

First, we need to keep in mind that low speed subsonic aerodynamics deals with *incompressible flow*. That means that the air passing over or around a wing does not change density. (This is true up to about 250 knots when other effects begin to matter.) As the air mass encounters the leading edge of the wing, it diverges into two seperate airstreams, one stream passing over the wing, and one stream passing beneath it. The point on the leading edge where the airstream divides is called the **stagnation point**. The two airstreams will meet and combine again at the trailing edge of the wing. In Fig. 5 we have a fairly conventional airfoil with "streamlines" depicting the airflow around the surfaces. The air flows parallel to the streamlines and has a higher velocity where the streamlines are closer together.

Since the air displaced by the leading edge of the wing does not compress and get denser, what happens to it? It must move out of the way. To do so it must move very quickly over the top of the wing. The air stream passing under the wing is not displaced as much, and therefore, need not move as fast to get past the wing. This is formalized in the **continuity equation** for incompressible flow:

$$A_1 V_1 = A_2 V_2 \tag{3}$$

where A is some cross sectional rea through which the fluid is moving and V is the velocity. This effect can be observed in a common garden hose with a nozzle attached. The water exiting the nozzle is moving much faster than water inside the hose.

Given that we accept this admitidly cursory explanation as to why the air velocity on the upper surface is higher than that of the lower surface, we can move on to introduce the second principle of concern to us — **Bernoulli's equation**:

$$p_1 + \frac{1}{2}\rho V_1^2 = p_2 + \frac{1}{2}\rho V_2^2 \tag{4}$$

or sometimes written as

$$p + \frac{1}{2}\rho V^2 = p_0 \tag{5}$$

where p_0 is a constant and refered to as the **total pressure**.

Bernoulli's equation describes the pressure conditions at any point in the vicinity of the wing, and so, it is frequently used to predict the lift characteristics of low speed airfoils. We will use it in this manner as well. However, as we will see momentarily, there are some important points that this equation does not address.

It should be obvious that Bernoulli's equation is easily satisfied when the airfoil is at rest, i.e. when $V_\infty = 0$. The total pressure at every point on the wing is constant and equal to the ambient barometric pressure. Since the second term in Eq. 5 is zero in this instance, the first term is the only one that remains. This is refered to as the **static pressure**.

The second term in Eq. 5, $\frac{1}{2}\rho V^2$, is called the **dynamic pressure**. It is important to note that as the air velocity increases, the dynamic pressure increases with the square of the velocity, i.e. if we double the air velocity, we *quadruple* the dynamic pressure!

The air velocity at any point on the airfoil surface will always be tangent to the surface. Therefore, the pressure exerted directly onto the surface is only the static pressure. Bernoulli maintains that the total pressure at any two points surrounding the wing should always be equal. Therefore, if at some point along the wing surface the air is moving faster than the air "some place else", then the static pressure must necessarily be less. So all we need to do is make sure the air flowing *over* the airfoil is moving faster than the air flowing *under* the airfoil, and we have lift.

At the stagnation point, the air directly in front of the leading edge does not, in theory, experience any net force causing it to move to one side of the wing or the other, so it just stops. The dynamic pressure is therefore zero at the stagnation point and the static pressure exerted on the foil surface is in fact equal to the total pressure. We could compute the pressure at the stagnation point by choosing an arbitrary point infinitely far away from the wing, substituting p_∞, ρ_∞, and V_∞ into Eq. 5.

In fact, if we knew the relative velocity of the air at all points on the airfoil, we could sum them all up and compute the net forces on the wing using Bernoulli's equation. It is adequate to say that Eq. 4 must be satisfied for any two points in the airstream around the airfoil.

But there is always a catch. If we look at a symmetric airfoil for a moment, the air flow over and under the foil will be the same. By integrating the static pressure along both the upper and lower surfaces, we would find that *all* of the static pressure forces cancel out — i.e. that there is no net force on the airfoil. Obviously, there is in reality a net force that pushes the airfoil back in the direction of the air flow. This force is called **drag**. But Bernoulli's equation doesn't account for this force. So where does drag come from?

So far, we have only discussed airflow around an airfoil where the airstream flows very smoothly across the surfaces and recombines at the tail, a so-called *frictionless flow*. In reality, this doesn't happen. We have neglected the *viscosity* of the air.

All fluids have a quality called **viscosity**. In simple terms, viscosity is a measure of how "gooey" a fluid is. In more technical terms, it is a measure of the fluid's resistance to sheer forces.

In so far as we are concerned, even air has a certain amount of "gooey". As it passes along the surface of a wing or canopy, a thin layer sticks to the surface and the impedes the flow of adjacent air. This is called **skin friction** or surface friction. Surface friction causes the air directly along the surface to slow down — the closer to the surface, the slower it goes. This region of *viscous flow* surrounding the airfoil is called the **boundary layer**. The boundary layer is very thin near the leading edge and gets thicker as the air moves towards the trailing edge. The thickness of the boundary layer is a function of the air temperature, air density, distance from the leading edge, the shape of the airfoil, and other conditions within the layer itself.

Inside the boundary layer, the air sticks to the surface of the foil. As the air outside the boundary layer continues to move past, it "stretches" the boundary layer until it slips, causing swirls and other small vortices within the layer. The orderly flow before these vortices form is called a **laminar flow**, and the somewhat disorganized flow after the vortices form is called **turbulent flow**. While a laminar boundary layer generates less skin friction, it is not stable, and minor imperfections in the foil surface will cause it to change to a turbulent flow quite easily.

As long as the boundary layer continues to flow along the airfoil surface, we have an **attached flow**. If for some reason the boundary layer detaches from the surface and tries to follow some other path, it is called a **seperated flow**. In order to maintain the lift of an airfoil, we must insure that the airflow, i.e. the boundary layer, remains attached. A turbulent boundary layer, while a greater source of drag due to skin friction (but still relatively small), is far less likely to detach from the wing. Some high speed aircraft actually attach small metal vanes called *turbulators* to the upper surface of the wing to induce a turbulent boundary layer, and thereby delay seperation.

In low speed wings, the boundary layer almost always seperates from the wing before reaching the trailing edge. The object is to cause the point of seperation to remain as close to the tail as possible. Behind this point of seperation, the pressure increases, reducing the lift significantly and creating **drag due to seperation**. In low speed wings, creating a turbulent flow isn't normally a problem, but seperation is.

In a real airfoil, the pressure reaches a minimum near the point of maximum thickness, normally toward the front of the wing. As we move towards the trailing edge, the pressure increases until it equals that of the flow emerging from under the wing as the two streams recombine. This rising pressure over the trailing portion of the airfoil is called an *adverse pressure gradient.* The upper airflow is retarded by this adverse gradient and slows down. If this gradient is too steep, the air stream cannot overcome it and will seperate from the wing, effectively trying to get around it.

This drag due to seperation is commonly called **profile drag** or sometimes, *form drag.* All airfoils, even the most streamlined, have some amount of profile drag. However, the more streamlined the airflow around an object, generally the smaller the profile drag.

So far, we have only discussed the lift and drag characteristics of a level airfoil in a horzontal flow field. However, V_∞ need not always be parallel to the chord line of the airfoil.

If we were to incline the leading edge of the airfoil by some angle α, we would find that the lift generated increases quite dramatically as α increases — to a point. The angle α at which the airfoil is inclined is called the **angle of attack**. It is interesting to note that even when $\alpha = \deg 0$, many airfoils generate lift. If we decrease the angle of attack, the lift will decrease until at some angle $\alpha_{L=0} < 0$, the pressure on the upper surface will equal the pressure on the lower surface and the airfoil will no longer create lift. This is called the **zero lift angle of attack** and a line, drawn from the tail parallel to V_∞, is called the **zero lift line**.

In designing an aircraft, one must be cognizant of issues such as performance, lift, drag, available power, etc. Given a certain airfoil, an aircraft designer may want that aircraft to fly level at some arbitrary airspeed. By placing the airfoil on the aircraft at a high angle of attack relative to the thrust line of the aircraft, the wing will generate a great deal of lift, but at a relatively high cost in terms of drag. This would be nice for aircraft that fly slow or carry large payloads. On the other hand, if the desire is to fly fast, a lower angle of attack would be desirable. The angle at which the airfoil *as part of an aircraft* is designed to encounter V_∞ is called the **angle of incidence**. More on this later.

One of the ways to increase the lift of a given airfoil is to increase its angle of attack. However, this also increases the drag. If the lift generated by the wing is greater than the gross weight of the aircraft, the aircraft will

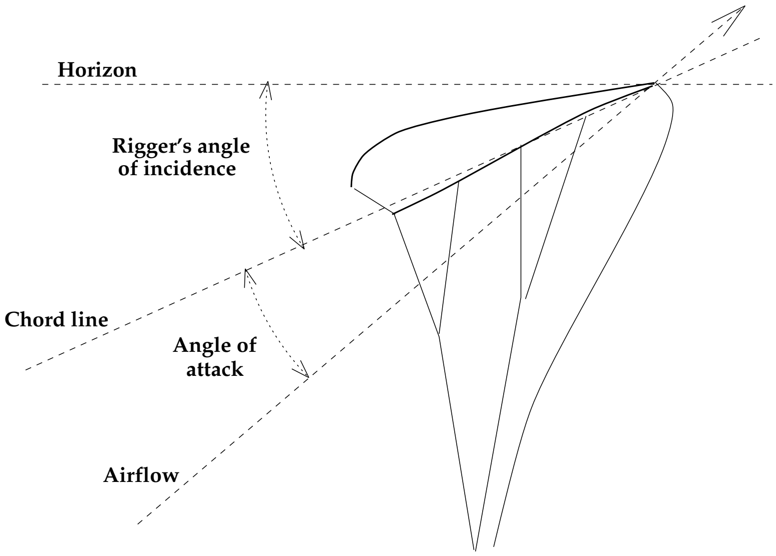

Figure 7: The angle of incidence relative to horizon, and the angle of attack rellative to V_∞.

accelerate upward. But beware — as the angle of attack is increased, the point on the wing where the boundary layer seperates will move forward. As the point of seperation moves forward, the wing generates less lift. If the point moves too far forward, the airstream will no longer be able flow smoothly over the wing and wing will **stall**. Note: stalls result from too high an angle of attack, not from a reduction in airspeed. In the skydiving world, stalls are normally associated with poor landing procedures where, in an attempt to maintain lift the jumper flares deeper. This results in momentary lift, but slows the canopy due to the increased drag — which decreases the lift and a vicious cycle results.

Finally, there are two other forces that we are concerned with:

Thrust is the force propelling the airfoil through the air. It is normally fixed relative to the aircraft and acts for the most part to counter the force due to drag.

Weight is the force generally opposite lift. In conventional aircraft design, the lift generated by the wings must overcome the total weight of the aircraft in order for it to ascend. In parachutes and other non-powered aircraft, the weight vector functions slightly differently. By rigging the airfoil at an appropriate angle of incidence, we can use a portion of the weight vector to supply the thrust for our canopy. We will examine this in more detail in the next section.

Due to the curvature of typical airfoils, the pressure is not distributed evenly along the surfaces. The bulbous leading portion of an airfoil will have a greater upper and lower surface pressure differential than the relatively straight aft section of the foil. This variance in pressure means that the thick portion of the wing generates most of the lift. There is a point along the chord where all the lift of the wing could be thought of as concentrated. This is called the **center of lift** and tends towards the thicker part of the foil. The center of lift can vary depending on the airspeed, angle of attack, airfoil shape, etc.

Opposing the center of lift, is the **center of mass**. The center of mass is commonly refered to as the center of gravity - or CG. In our present context, the CG is the point within the aircraft where all the weight could be said to be concentrated. In conventional aircraft, the CG is normally designed to be very near the wing.

The juxtaposition of the center of lift and the center of gravity vectors is what defines the **pitching moment** of a wing. In simple terms, if the center of lift and center of mass forces do not act directly opposite one another, the wing will try to rotate. If the CG is aft of the CL the wing will try to "pitch up".

This pitching effect is very useful for aircraft without elevators to control their pitch angle. By shifting the center of gravity or changing the shape of the wing, the aircraft can increase or reduce its angle of attack and consequently either climb or dive.

The Ram-Air Parachute

So how does a ram-air parachute differ from a conventional airfoil? And more, what are the differences between a jumper suspended under canopy and a conventional airplane?

First, parachutes are not structurally rigid, i.e. they do not have rigid metal ribs, spars, and skins such as conventional aircraft wings. Ram air canopies depend upon proper inflation in order to shape them into an airfoil.

Second, in conventional aircraft, the center of mass is situated very close to the center of lift of the wing. In a ram-air parachute, the center of mass is suspended beneath the airfoil, 10 to 12 feet away from the center of lift.

And third, the control of the ram-air parachute is effected by "wing warping", i.e. changing the shape of the airfoil, unlike conventional aircraft that have fixed geometry airfoils, control surfaces, and multiple wings.

These basic differences have a significant bearing on the handling characteristics and operating limits of the ram-air parachute.

Structure and Shape

Fig. 8 depicts a crossection of a generic ram air parachute. Lets look at what is happening to the canopy after it is inflated and flying. During deployment, air flows into and around the cells of the inflating canopy. In Fig. 8, point A represents the flow field conditions V_∞, p_∞, and ρ_∞. As the airstream reaches the canopy, it divides at the forward stagnation point B, into upper and lower streams. As air enters the cells, it "piles up" from the tail forward, losing its velocity until the total pressure inside the cells is equal to the total pressure at the forward stagnation point.

From Bernoulli's equation (Eq 5)

$$p_0 = p_\infty + \frac{1}{2}\rho_\infty V_\infty = p_{\mathrm{A}} + \frac{1}{2}\rho V_{\mathrm{A}}^2$$

and from Eq. 4

$$p_{\mathrm{B}} + \frac{1}{2}\rho V_{\mathrm{B}}^2 = p_{\mathrm{A}} + \frac{1}{2}\rho V_{\mathrm{A}}^2$$

Since the air velocity at the stagnation point B is zero,

$$p_{\mathrm{B}} + \frac{1}{2}\rho (0)^2 = p_{\mathrm{A}} + \frac{1}{2}\rho V_{\mathrm{A}}^2$$

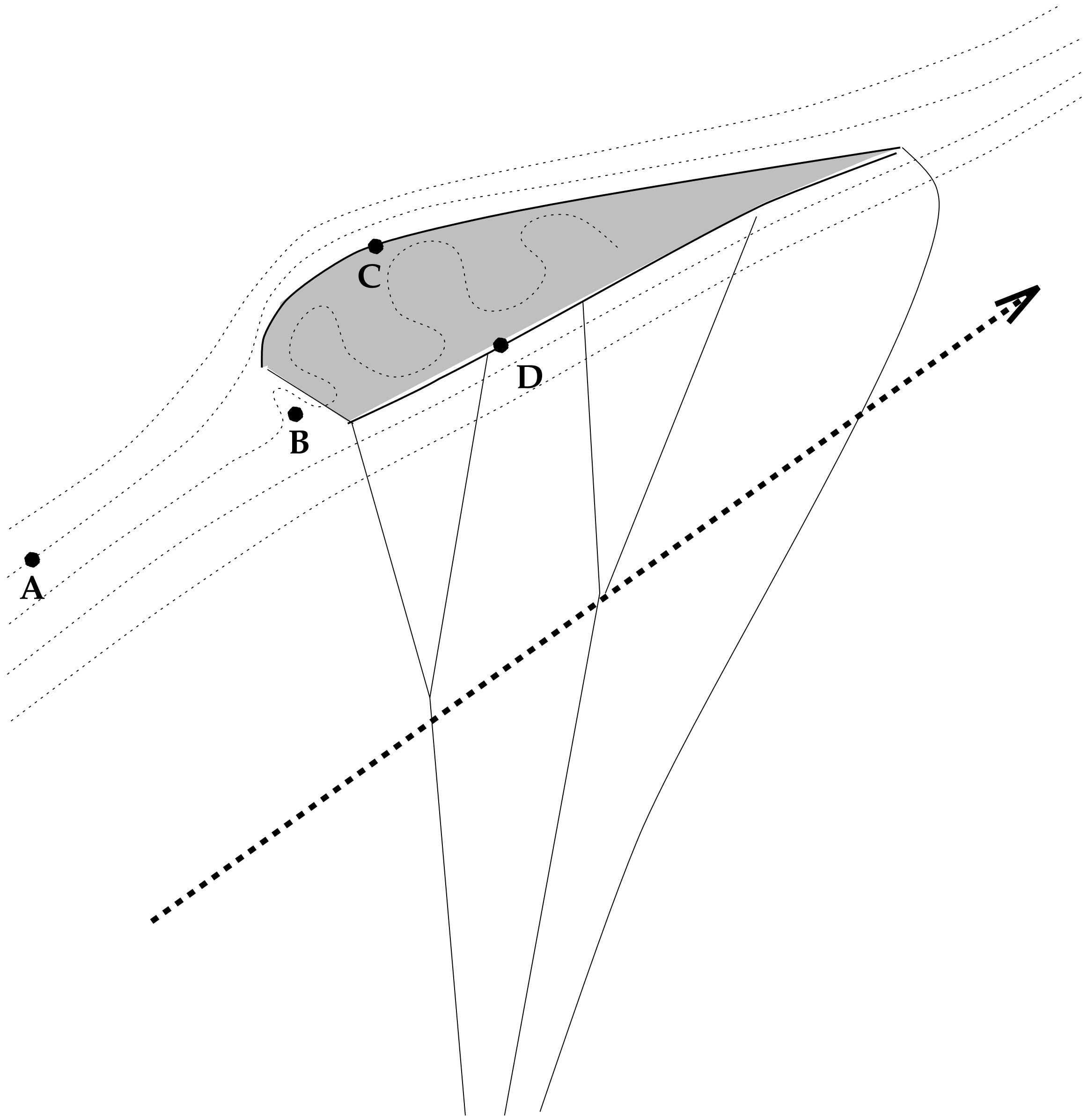

Figure 8: Airflow around the ram air canopy creates high pressure at the forward stagnation point (B). Internal cell pressure at C and D are equal, but external pressure at D exceeds that at C.

$$p_{\mathrm{B}} = p_{\mathrm{A}} + \frac{1}{2}\rho V_{\mathrm{A}}^2$$
$$p_{\mathrm{B}} = p_0$$

As noted earlier, the force exerted on a surface exposed to a fluid flowing tangentally across it is the static pressure component of the total pressure. The fact that the velocity at the stagnation point is zero, implies that the static component at point B, and at points C and D *inside* the cell, must all be equivalent and equal to the total pressure at point A.

If we compare the internal and external static pressures at points C and/or D, we arrive at the following:

$$p_{\mathrm{int}} = p_0 \tag{6}$$

and

$$p_{\mathrm{ext}} + \frac{1}{2}\rho V_{\mathrm{ext}}^2 = p_0$$
$$p_{\mathrm{ext}} = p_0 - \frac{1}{2}\rho V_{\mathrm{ext}}^2 \tag{7}$$

Therefore, by substituting Eq 6 into Eq 7 we get

$$p_{\mathrm{ext}} = p_{\mathrm{int}} - \frac{1}{2}\rho V_{\mathrm{ext}}^2$$

To summarize, this means that as long as the external airstream continues to flow over the canopy surface, the interior cell pressure will remain larger than the exterior surface pressure, and the cells will remain inflated. Since the internal cell pressure is a function of the dynamic pressure due to V_∞, the faster a canopy moves through the air, the greater the internal cell pressure and the more rigid it becomes. <u>Rigidity is our friend</u>. A rigid wing is far less susceptible to turbulence or spurious collapse.

Do not lose sight of the fact that for cell pressurization to occur properly, the forward stagnation point *must* remain directly over the cell mouth. If the angle of attack changes, and the stagnation point migrates to either the upper or lower surface, the airstream will flow *across* the cell mouth, reducing the pressure there, effectively sucking air out of the cell. Result: cell collapse. (This is sometimes refered to as the "Venturi effect.")

Most (all) modern sport ram-air canopies have crossports cut into the ribs in order to reduce the risk of cell collapse and to improve reinflation characteristics. Crossports simply allow the pressurized air from more central cells to bleed over into adjacent cells.

Another interesting implication here is that cell pressurization is not dependent upon the size of the cell mouth. During inflation, a large mouth will allow the cells to inflate faster. But once inflated, a smaller mouth will [at least theoretically] provide all the pressure necessary for the canopy to retain it's shape - without a reduction in cell presurization. In fact, many high performance parachutes have a tendency to inflate too quickly. To address this problem, some new canopy designs employ cell "baffles" which impede the airflow into the cells during inflation but which do not affect pressurization during normal flight. But there is no such thing as a free lunch. Reducing the size of the cell mouth may restrict the useful angle of attack range for the canopy, resulting in a fast but not necessarily versatile canopy.

Another important implication of the dynamic pressure is that it is is a function of V^2. This is good. It means a small increase in airspeed will result in a significant increase in cell pressure. This implies that even a small reduction in drag - which results in a higher airspeed - will increase the rigidity of the canopy.

The ram-air canopy creates lift in the same manner as any other low speed airfoil. But the lift is transfereed to the payload slightly differently. The air rushing over the foil is moving faster than the air passing underneath the foil. If we look at Eq. 7, we will see by inspection that the difference in airstream velocities will cause a larger external pressure to develop on the lower surface than on the upper surface. (But both pressures will be less than the internal pressure.) These pressures are all transfered to the load bearing ribs via canopy skin tension. The net force thus generated is transmitted from the ribs, through the suspension lines to the harness where it supports the jumper.

Now we know why the ram-air parachute works. We now need to look more closely at the shape of the "wing", i.e. the actual application of the theory. Figure 9 shows a frontal view of an inflated canopy.

Cell pressurization not only shapes the top and bottom surface of the airfoil, it is also responsible for "spanwise" forces that keep the canopy spread out side to side. The cell pressure from the center cells pushes the end cells outward until spanwise tension in the upper and lower surfaces counters the

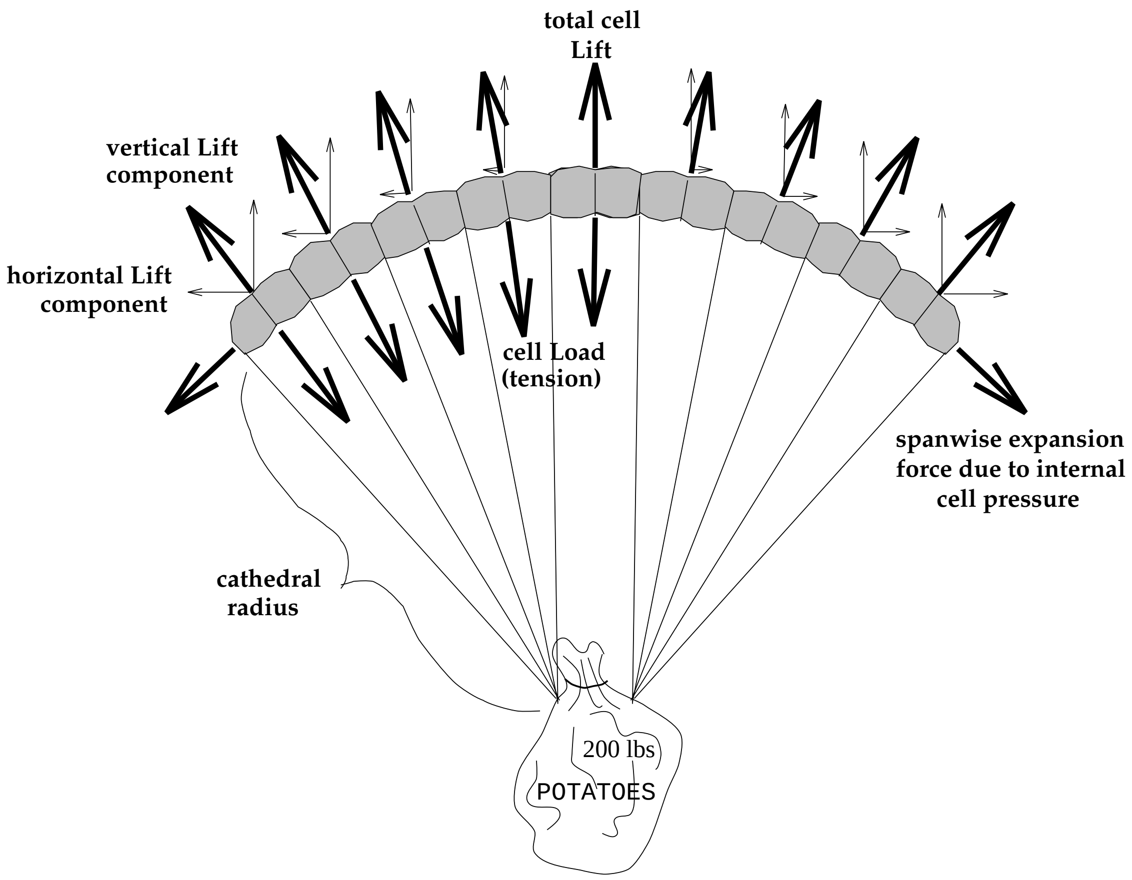

Figure 9: The forces acting upon the canopy as viewed from in front.

internal cell pressure.

Notice also that the canopy does not expand spanwise into a nice flat wing. It expands along an arc, creating a wing which is concave downward. This curvature is refered to as the **cathedral** of the wing. (Some conventional aircraft have wings which are lower at the tips than at the center where they meet the fusilage. These are called "cathedral" wings, or sometimes "anhedral" wings. Wings which are higher at the tips than at the center are called "dihedral" wings.)

Conventional aircraft with cathedral wings are *very* tricky to fly due to the center of lift/drag being below the center of mass. These aircraft are not normally "staticly stable" and require great skill by the pilot (or onboard computer) to control. However, in the ram-air parachute, the center of lift/drag is situated *above* the center of mass. This makes a properly inflated ram-air parachute very stable.

But the fact that the inflated wing is curved brings some penalties with it. Most importantly, we must look at what happens to cells as they are located further outboard on the wing. The curvature of the wing causes the airfoil segment defined by each cell to be rotated slightly relative to vertical. This means that the lift produced by outboard cells is broken into a vertical component and a horizontal component. (See fig. 9 The horizontal component does not increase the lifting capacity of the wing as a whole. The greater the curvature of the wing, the less lift the end cells can contribute to the total system. But here again is a design trade-off in that this horizontal component of endcell lift contributes to the spanwise rigiidity of the wing making it more stable.

Also, as the spanwise curvature of the wing increases, the effective angle of attack of each cell varies as well. On the center cell, the air moves from in front and below the cell directly backwards towards the tail. However, as we move outboard, the cell rotation due to curvature causes V_∞ to encounter the cell from slightly higher, i.e. at a decreased angle of attack.

On very high aspect/glide ratio canopies this can make the end cells particularly sensitive to "over input", e.g. radical front riser input, or even simple turbulence. A front riser manuever may reduce the angle of attack far enough that the stagnation point migrates to the upper surface resulting in end cell collapse or nose roll.

The decreased lift of the outboard cells can be countered by reducing the cathedraling. One common method of doing this is by use of a pulldown slider. These sliders can be pulled down past the connector links and stowed behind the jumpers head. This allows the risers to spread apart, effectively lengthening the outboard suspension lines and flattening the canopy. Some newer canopies are using wider sliders which do not constrict the riser spread as much. And modifying the slider or changing it may fall into the catagory of "alteration" and may require a master rigger. Check with the manufacturer of your canopy to find out which sliders have been tested and approved.

The change in angle of attack on outboard cells can be dealt with in other ways: by changing the line lengths, changing cell shapes, changing the airfoil, changing the entire planform, etc. It is not the purpose of this document to delve too deeply into all the design possibilities. The high performance pilot must, however, know how these conditions arise, and be prepared to deal with them.

Weight, Balance, and Stability

We need to create a weight and balance configuration which does two things: 1) the aircraft should be staticly stable, and 2) the weight of the aircraft must be the source of propulsion required for the canopy to inflate and generate lift.

Let us examine the first point. An aircraft is said to be **staticly stable** if, in the absence of any control input from the pilot, it "naturally" assumes some desired steady state flight configuration. In the case of ram-air parachutes, this steady state configuration is defined to be: a) the canopy will fly straight, b) it will fly level, and c) it will fly at some prespecified glide slope.

A staticly stable canopy will always return to this configuration as long as is operated within its design constraints. Obviously, our ram air canopies will continue to fly without input from the pilot, so they are stable aircraft. The stability arises from the juxtaposition of the center of mass and center of Lift/Drag. And as long as there canopy is properly inflated, it will fly straight and with the designed glide slope.

Now let us look at the second point. When the canopy is flying in a stable configuration, i.e. at a constant velocity, there is no acceleration in any direction and so all the forces acting on the aircraft are at equilibrium. In this situation, the Weight vector must balance the combined forces of the Lift and Drag vectors.

As noted before, there is no conventional "Thrust" force per-se for unpowered aircraft. The force propelling these aircraft through the atmosphere is the same force that pulls a sled down a snow covered hill — gravity. However, gravity is also responsible for holding that sled against the hill. So the Weight vector of the sled due to the downward force of gravity is decomposed into a component force acting horizontal to the hillside, and a component force acting perpendicular, or "normal," to the hillside.

The analogy of the sled can be applied to the ram-air canopy as well. The Weight vector of the jumper (and the canopy) can be decomposed into two components — one that acts oposite V_∞, and one that acts perpendicular to V_∞. For simplicity sake, we will refer to the former as Thrust, and the latter as the Load. The friction encountered by the sled is analogous to

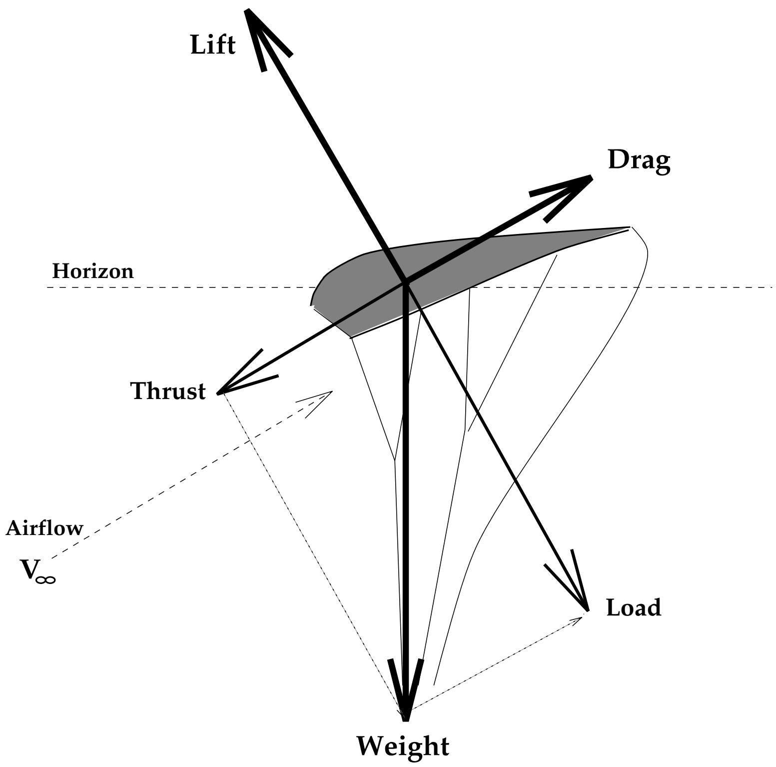

Figure 10: The total weight of the pilot and gear is decomposed into a Thrust force acting opposite Drag, and a Weight force acting opposite Lift.

the aerodynamic drag of the canopy, and the upward force of the ground is analogous to the lift generated by the canopy. The diagram in Fig. 10 shows these forces and the related angles they make with the vertical suspended weight. The slope of the canopy's "hill" is called the **glide ratio** or the **glide slope** and is simply a ratio of horizontal velocity to vertical velocity.

Example 3.1

A jumper and all his gear weigh 80 kgs (175 lbs). This jumper is decscending under a canopy with 25 mph airspeed at a 3:1 glide ratio.

1. How long will it take the jumper to reach the ground from 2000 feet?
2. If the airspeed is 35 mph with the same 3:1 glide ratio, how long would the descent from 2000 feet take?
3. Given that the lift to drag ratio, L/D, is equal to the reciprical of the glide ratio, could you compute the Lift and Drag forces acting on this canopy during a steady state glide?

Solution:

The glide ratio tells us the relationship between the airspeed V_∞, and it's horizontal and vertical components, v_x and v_y respectively. The ancient Greek aerodynamicist Pythagoris established this relationship as

$$V_\infty^2 = v_x^2 + v_y^2$$

Since $v_x = 3v_y$ (from the glide ratio),

$$V_\infty{}^2 = (3v_y)^2 + v_y{}^2 = 10v_y{}^2$$

$$v_y = \sqrt{\frac{V_\infty{}^2}{10}}$$

Since $V_\infty = 25$ mph $= 37$ ft/s,

$$v_y = \sqrt{\frac{37 \text{ ft/s}^2}{10}} = 11.7 \text{ ft/s}$$

The time to descend from 2000 feet is

$$\frac{2000 \text{ ft}}{11.7 \text{ ft/s}} = 171 \text{ seconds}$$

If we set $V_\infty = 35$ mph $= 51$ ft/s,

$$v_y = \sqrt{\frac{51 \text{ ft/s}^2}{10}} = 16.1 \text{ ft/s}$$

The time to descend from 2000 feet is now

$$\frac{2000 \text{ ft}}{16.1 \text{ ft/s}} = 124 \text{ seconds}$$

Note the difference in descent: Same jumper, same glide slope, but a faster canopy — 1/3 less hang time.
Computation of the L/D ratio is left as an exercise for the reader.

Balance

Now lets look at how the weight is distributed about the aircraft.

First, unlike conventional aircraft, the center of mass for ram air parachutes (and their pilots) is nowhere near the airfoil itself. The jumper constitutes most of the mass, and not surprisingly, the center of mass (or center of gravity - **CG**) is a point somewhere near the jumper's chest. In order for the wing to be of any practical use to the jumper, the Lift and Drag forces generated by the wing must offset the Weight of the jumper. Therefore, the weight must be transfered to the wing somehow. This is the somewhat obvious purpose of the suspension lines.

But the suspension lines are also responsible for weight distribution and trim. As mentioned earlier, the Lift, Weight and Drag forces must counter one another for the canopy to assume a stable flight path. The suspension line configuration (lengths, cascades, attachment points, etc) defines the weight distribution and the angle of incidence for the wing.

Flight Characteristics

The fact that internal cell presurization is a function of the dynamic pressure implies that the angle of attack of the canopy must be such that the forward stagnation point stays in front of the cell openings. If the angle of attack is increased sufficiently, the stagnation point will move down and onto the lower surface of the canopy. This places the highest pressure on the outside of the canopy, and means that the pressure at the cell mouth, and consequently throughout the interior of the cell, has been reduced (since the air is now flowing across it). This sucks the air from the cells deflating them. This type of manuever on a ram-air canopy is frequently [and incorrectly] called "stalling" the canopy and results from applying too much brakes. Applying and holding brakes after deflating the canopy in this manner will normally result in the canopy flying backwards with little if any inflation and very little control. This type of manuever can foul the lines so as to make recovery impossible. Needless to say, there are times when this is not desirable.

For the sake of completeeness, we should describe “low speed stalls” and high speed, or “dynamic” stalls.

By increasing the angle of attack, we increase both Lift and Drag. In a glider such as a ram air parachute, when we increase the Lift, we increase the glide ratio — and at the same time reduce the Thrust. In other words when we “plane out” the canopy, gravity no longer is pulling us “down hill”. We are coasting along a flat glide path on momemtum alone. Unfortunately, Drag continues to be a factor and eventually slows us down. As our airspeed decreases, we flare a bit deeper to increase our angle of attack and so, produce greater Lift. While this works for a moment, the higher angle of attack also increases our Drag, which slows us down still more. And so we go until one of two things happens: We either reduce the load on the canopy by placing our feet on the ground, or the canopy quits flying altogether. The latter event is called a low speed stall.

A dynamic stall occurs in a similar fashion, but at much higher airspeeds. Even at high speed, if the angle of attack is suddenly increased, the boundary layer separates and and a precipitous reduction in Lift occurs. Where as a low speed stall occurs by a gradual increase in angle of attack, a high speed stall is brought on by a very abrupt increase in angle of attack. (A gradual increase in angle of attack with a high airspeed will result in an increased glide ratio. So the control input must be quick enough to stall the wing before the increasing glide slope can counter the increased angle of attack. Got that?)

There is an unspoken implication here: Too much control input applied too abruptly can have really disasterous effects. The classic example is the hot dog pilot attempting a swoop landing. After realizing they are way too low, they slam on the brakes attempting to pull up. Rather than having the desired effect of increasing the Lift, the pilot realizes – too late — that they have executed a dynamic stall. The wing stops flying and may actually collape. The necessary Lift does not appear. So, there are limits to how much control input is actually useable, or even desireable. Remember this!

There are also limits to how much the angle of attack can be reduced. Front riser manuvers reduce the angle of attack along some portion of the canopy by effectively shortening the A and B line groups.

By pulling both front risers an equal distance, the entire front half of the canopy is brought down relative the the rear half. For small deflection distances (1-2 inches) the “soft” nature of the airfoil will allow it to reform itself to fit the new angle of incidence, with a lower angle of attack. This has the overall effect of trading hang time for airspeed. The glide slope becomes steeper and the canopy gains speed.

However, since conventional front risers connect to both the A and B lines, pulling the front risers further than a couple inches will cause the canopy to assume a stairstep shape. This is not good. First, the overall angle of attack does not appreciably change after the first couple inches, and so pulling more front riser does not provide more airspeed. Secondly, and more importantly, the “stairstep” created between the B and C line attachments interupts the smooth flow of air across the canopy surfaces. The seperation of the airflow causes vortices to be formed and shed off the leading edge. At best, this is unstable behaviour and will cause the canopy to alternately surge and relax, surge and relax. Obviously not a desirable landing configuration.

Pulling a single front riser is an increasingly popular way to pick up speed. But single front riser manuevers are even more dangerous than dual riser manuevers. By pulling a single front riser, you not only reduce the angle of attack along a portion of the canopy, you cause a change in the direction of the airflow across the surfaces. As the front quadrant (left or right) is pulled down, the overall Lift vector of the canopy shifts to the side being pulled. The canopy shifts left (or right) and now is trying to fly in a circle. The jumper meanwhile continues forward. Due to the difference in Lift generated by the inside wing and the outside wing, the canopy essentially dives to the inside, pulling the jumper around into a corkscrew manuever. This is similar to what occurs with a toggle turn, but with far less Drag and a much higher rate of descent. And as always, the higher rate of descent is the source of the impressive airspeed.

Single front riser turns cause the canopy to dive to the side being pulled. This significantly changes the airflow over the surface. The air stream encounters the canopy from the inside leading corner, rather than square on the leading edge. Since the end cells are already at at a lower angle of attack (due to the spanwise curvature), further reducing it by diving the canopy could cause the forward stagnation point to move to the upper surface. This has the same effect as described earlier — cell collapse. End cell problems are further complicated by the presence of the stabilizer which acts like a sail. And unlike center cells which can be assisted by neighboring cells, the end cells only have one neighbor. Also, when end cells collapse, the top skin and end rib can cover the cell mouth preventing reinflation even after the stagnation point returns to a normal location. Thanks goodness for crossports.

If front risers are pulled too far, more than just one end cell may collapse. At this point a plethora of nasty events could occur to further destabilize the situation. Once one or more end cells collapse, there is a significant loss of canopy control. The collapsed portion of the canopy can entangle with other lines preventing recovery at all. Or an uncontrolled spin may result, which may also be unrecoverable. For all these reasons, front riser manuvers should be well understood before they are attempted.

Another less obvious implication of cell pressurization is the constraints it places on the wing loading. The greater the suspended weight, the greater the airspeed and consequently the greater the internal cell pressure. Many jumpers, however, want a zero porosity canopy because of its novelty or because of the wonderful landings they see performed by other jumpers. Many jumpers, novices and experienced jumpers alike, fall prey to the false belief that the performance of a canopy is simply a function of size, i.e. larger the canopy, the more forgiving it is — regardless of it's basic design. This can be a fatal misconception.

High performance canopies are designed to different specifications than more docile canopies. In order for these parachutes to exhibit the desired flight characteristics, they *must* have adequate airspeed. And since airspeed is directly related to the suspended weight, there must exist some minimum wing loading, under which they can not perform properly, and in fact, may become quite dangerous.

Lets do a "thought experiment" to bring this point home. What would happen if you took a 200 square foot canopy and suspended a two pound shot bag beneath it? Refering back to our diagram of the forces acting on the canopy, the Lift and Drag vectors would be very small. In fact, the air flow past the canopy would likely be inadequate to even pressurize the cells. The canopy would collapse under its own weight into a tangled mess, providing no lift and only as much drag as a streamer.

If we repeat our experiment, this time with a larger weight, say a 30 lb cinder block, we would provide minimally enough airspeed to inflate the cells, and theoretically, our canopy would fly. However, what happens in turbulence? Since the airspeed of the canopy is small, the internal cell pressure is also small. Turbulence such as wind shears, rotors, or wakes from other canopies could easily disrupt the airflow enough to deflate end cells and/or collapse the entire wing. And since these common sources of turbulence are usually found very near the ground, a poorly weighted canopy becomes especially dangerous during landings.

So, it is imperative for the high aspect ratio ZP canopy to be adequately weighted. By varying the wing loading on a high performance canopy one can *to a point* vary the performance. But it does not change basic flight characteristics such as glide slope, control range, or flare characteristics. And it cannot make up for lack of experience in the pilot. Some manufactures are now quoting *minimum* wing loads to ensure proper canopy cell presurization.

"High Performance" Ram-Air Canopies

We have used the term "high performance" quite liberally in this document. But what is a high performance canopy? What is the difference between a "high performance" canopy and a "low performance" canopy?

It would seem that since ram air canopies are actually airfoils, rating them by their lift characteristics would be appropriate. But then, the lift produced is a function of airspeed, lift coefficient of the particular airfoil used, aspect ratio, construction materials, rigging and trim, total suspended weight, etc. Obviously, the "performance" characteristics of a canopy are dependent upon all of these aspects. Also, most people rate a canopy's performance based upon it's airspeed under their normal flight configuration. This is a truly subjective method which varies greatly from individual to individual, particularly when comparing canopies which are similar in overall design but sport minor design or construction differences which the manufacturers invariably claim to be the "secret" edge their canopy has over the competition.

However, if we look at all the various measures and attributes, we would note that their are several general characterisitics that vary as we go from very tame student canopies to the very fast hi-tech canopies.

Most obvious, of course is size. High performance canopies are smaller than more docile canopies. The question is: Does size make a canopy high performance, or is it just a resulting characteristic? Well, here again we find that two different canopies, say a 170 square foot Wildfire and a 170 square foot Sabre, have drasticly different flight characteristics. And in general, the Sabre would be considered the higher performance canopy. So what are the differences?

One important difference is construction materials. The Sabre is constructed of zero porosity nylon. The Wildfire uses F111. This provides the Sabre with much better aerodynamic characteristics — the air flows *over* the surfaces, not through them.

The Sabre also has a different airfoil design, much smaller suspension lines, probably a colapsible pilot chute, etc. By merit of these newer materials, construction techniques, and designs, the Sabre flies more "efficiently" than does the Wildfire, an older (yet venerable) product.

We could also compare the Sabre to even higher performance canopies and come up with similar differences, this time with the Sabre looking like the more docile canopy.

Historicly, as ram-air canopy designs evolve, they are able to carry larger payloads, i.e. the amount of weight per square foot of canopy can be increased. This increase in wing loading provides still greater thrust and consequently greater airspeed, which in turn contributes to the manueverability and lift characteristics of these canopies.

So, in general, the ratio of total suspended weight to wing area, that a given canopy design can handle and still deposit the payload safely on the ground is directly related to its *perception* of being a "high performance" canopy.

It may be useful at this point to look at some wing loadings in common use today, and classify the loading figures as to their "performance" class. It seems to the author that ram-air canopies in common use today can be divided into 5 general performances classes that correspond to the necessary skill set in the pilot:

Class 1

> These are essentially student canopies. They typically support wing loadings of .5 to .75lbs/ft^2. Speed and manuverability is not the primary objective of these canopies. Safety and a forgiving nature are essential. Good for the first 25 jumps.

Class 2

> These canopies support somewhere from .75 to about 1.0lbs/ft^2. These canopies are still forgiving in nature, but due to their higher wing

loading, will give the novice something to keep them busy for their first couple hundred jumps.

Class 3

This class of canopy should handle from 1.0 to around 1.25lbs/ft^2. While not particularly sensitive canopies, it is now the pilot's responibility to be forgiving. Typically suited for intermediate jumpers with several hundred jumps or up jumpers who prefer a comfortable margin of error.

Class 4

These canopy configurations are the "high performance" systems. These canopies extend up from 1.25lbs/ft^2 to about 1.75lbs/ft^2. These canopies don't care about forgiveness. The pilot is expected to be extremely well qualified. 500 jumps minimum and at least 100 Class 3 jumps in preceding 12 months to even think about trying one.

Class 5

This class of canopy is essentially for real experts and test pilots. If you think you are an expert, you aren't. Extreme canopies run from 1.75lbs/ft^2 and up.

Since the recommended loading range for many conopies are reasonably large, the "class" a canopy fits into is frequently only decided by the actual wing loading applied. A Sabre 150 may be a Class 3 canopy for 130 lb jumper and a Class 4 canopy for a 170 lb jumper.

Remember: These classifications are general. And the skills required to safely fly a given class of canopy do not magicly appear when you have acquired some recommended minimum number of jumps. Like anything else, you learn thru patient practice, gradually increasing the performance characteristics as you master the skills.

As designs and manufacturing techniques evolve, we will no doubt see even higher wing loadings. And as training methods improve, and overall experience grows, the suggested class ratings and experience levels may change as well.

Piloting Techniques

Now that we have a better grasp of low speed aerodynamics, and understand the basic operating principles of ram air parachutes, we can move on to study techiques that the pilot can use to control these aircraft.

Lets reiterate some of the basic concepts:

1. The primary function of a ram-air parachute is to land the pilot safely.
2. Ram-air canopies are *flexible* wings, i.e. they are designed to change shape.
3. Ram-air canopies are wings only as long as they remain inflated.
4. Given the proper conditions, *any* ram-air canopy can, and will, collapse.
5. The glide ratio and airspeed of high performance ram-air canopies require a great deal of manuevering room, both at altitude and on landing.

The objective of the previous chapters has been to provide a scientific basis for the material presented in this chapter. The canopy control techniques offered here are not basic skills meant for the novice. These are advanced topics, and the reader is cautioned that many of these techniques and manuevers are extremely dangerous if done incorrectly. It is hoped that the aerodynamics covered in previous sections enables the reader to develop an inutitive understanding of how their ram-air canopy works. And whats more, apprecitate the fact that high performance ram-air canopies are not "toys" to be trifled with.

It should be well understood by now, that all ram air canopies are subject to limiting constraints. Some of these constraints are intrinsic to the design. Some are related to configuration (i.e suspended weight, trim, type of pilot chute and slider, etc.). And still others to the atmospheric conditions in which the canopy is flying.

The constraints we have not yet addressed are those of the pilot.

Over the last decade, the versatility of square canopies has proven to be such an improvement over round canopies that, after successfully instituting student programs using squares, we declared the "canopy control" problem solved. As long as we could teach students to release the brakes and flare, the tough part was done and they would learn the finer points as they progressed.

This process worked relatively well for the venerable elder jumpers, since their skills set evolved along with the technology. But this approach isn't working for today's up and coming jumpers. While student squares have not significantly changed over the last decade, the cutting edge technology of high end canopies has progressed quite dramaticly. This has resulted in a significantly greater performance range available to novice and intermediate jumpers. They must not only choose a canopy that suits their budget and taste in colors, they must choose a canopy that fits their skills and one which they can very quickly become competent at flying. These folks need to learn in 200 jumps what the up jumpers learned over 2000.

The argument could be made that "Canopies don't kill people, people kill people", i.e. that it is ultimately the actions of the pilot that makes a canopy safe or unsafe. It is the author's opinion that is in fact the case; That "pilot error" is the overwhelming cause of injury and death related to all ram air canopy accidents. It is rare for current generation canopies to exhibit basic design flaws or poor quality manufacturing. While some may argue that ultra high performance canopies get their performance at the expense of some subjective minimum safety margin, this is not necessarily a bad thing. Pushing canopy technology to its limit often means much tighter tolerances, not only in design and construction, but in the operation and maintenance of these parachutes as well. These latter two aspects are the responsibility of the pilot. What may be a safe operating configuration for one pilot may not be safe for another.

It is ultimately the responsibility of the pilot to assess their own skills acurately and to identify their limitations This is a big responsibility and one that is best made very conservatively. To misjudge your skills is to risk personal injury and creates a threat to the safety of your friends.

There exists a need to establish a new school of training for high performance canopy pilots that addresses the fact that ram air canopies are no longer just "aerodynamic decelleration devices"; Ram air canopies are aircraft. We need to impress this point on novice and experienced jumpers alike. What are the minimium pilot qualifications? What are the most effective methods for teaching high performance canopy control techniques (both at altitude and on final)? How do we certify individuals as "safeD""?

What are the Basic Safety Regulations for ultra high performance canopies? How should these standards be enforced? What are the responsibilities of the manufacturers, the dealerss, the drop zones, the USPA, and the general skydiving population?

It is the authors express desire that the discussion presented in the previous chapters impress the reader with the concept that any ram air will only "fly" as long as some basic but very critical conditions are satisfied. If for some reason those conditions do not exist, or are removed, the ram air carriage that we so depend upon will very quickly turn into a pumpkin — with similar flight characteristics.

But, while the design constraints are rigorous and the operating limits are tight, high performance canopies are the product of 25 years of advancements. When piloted properly, they are highly manuverable, in some respects more forgiving than their predecesors, and always exciting to fly.

This chapter will provide techniques for improving one's canopy piloting skills. Much of the information and many of the techniques were developed with cutting edge canopies in mind, however, they can generally be applied to other square canopies as well, albeit with somewhat diminished results.

The "Edge" is where exhilaration exists. It is also the gateway to much pain and heartache.

Mindset

The Type A nature of most jumpers, and the seemingly prerequisite self confidence, are a double edged sword. They are necessary to advance, yet they can lure the jumper into situations which they are not properly prepared to deal with.

By far the most important skill you must master when operating a high performance canopy is "mindset". Your mind is the source of all your decisions and actions. And your attitude influences these decisions.

The pilot's perspective on responsibility is critical. If your primary concern is to have fun without regard to the constantly changing conditions all around you, then you should be jumping by yourself or not at all. High performance canopies give a canopy pilot a great deal more manueverability than more docile systems, and this bears a responsibility to the other people in the air with you. It is not your sky alone.

This responsibility is just common courtesy. Right of Way is not related to the speed or wing loading of the canopy. As the pilot of a high performance canopy, you are [ostensibly] more knowledgable and skillfull at canopy control and therefore should be most capable of ensuring safety in the air. You should never intentionally cut off other jumpers or otherwise cause traffic problems simply because you want to land close-in or make a swoop approach. When there are other jumpers in the air, you owe them every bit as much safety and consideration as you would expect them to provide you. There are ways to be considerate and still have fun under canopy.

Be rested and alert. As is so typical of this sport, a well rested mind thinks clearer and faster. High performance canopies are very *very* fast — in every sense of the word. You descend faster, you fly faster, you turn faster. And you get into trouble faster. As the pilot of the quickest, most manuverable canopy in the air, you must be able to make decisions quicker, and with a much higher degree of certainty, than the pilots of slower, larger, and typically more forgiving canopies. Poor judgement, whether from inexperience or bravado, can be very dangerous. On a relatively docile canopy, a minor mistake might only embarrass the pilot. On a high performance canopy, even a minor misjudgment could seriously injure yourself, someone on the ground, or someone else in the air. On opening, and with your brakes still in the locking loops, your canopy will be flying as fast or faster than the midrange canopies at full drive. A single 360° spiral dive can easily consume 500 feet!

Fly defensively. Always be watching for other canopies. High performance canopies can overtake other canopies with blinding speed, even other high performance canopies. Remember, the thrills you get under a really manuverable canopy are the same for the pilots of other zippy canopies. Everyone wants to have fun, so you are not the only one up there stunt flying. If they don't see you, its up to you to stay clear. It takes two to cause a canopy collision. It only takes one heads-up pilot to avoid one.

Assume the other guy is going to do something unexpected. Be prepared to avoid or evade the situation. This frequently requires changes in your flight plan, setup, and/or landing approach, particularly the latter, as this is where canopies tend to converge. Even when you know the other pilots, and you know they are on top of the game, they may not know you are anywhere around. Anticipate and deal with situations *before* they turn dangerous. Spiral dives, swoop landings, and the like are luxuries you can indulge in only after the safety aspects have been properly dealt with.

It just can't be over emphesized how quickly things happen under a small, highly loaded, very fast canopy.

As canopy technology advances, newer, faster, smaller canopies will naturally eclipse the older cutting edge canopies. This is to be expected. However, if you are transitioning from an older, perhaps intermediate class canopy to a more advanced canopy, do not be lulled into a false sense of security by the fact that your new canopy isn't the smallest or fastest canopy on the DZ. It is just as fast now as it was when it first came out, and it is just as new to you as it was to the test pilots who first qualified it. Just because you are not riding the leading edge in technology, doesn't mean you aren't riding the leading edge in your skills. High performance canopies have very tight safety tolerences. Be careful.

So, you need to be in a responsible frame of mind, you must be alert, and you must be considerate. These are prerequisites for any canopy pilot, but they become critical for those pilots who are flying along the Edge.

Qualifications

Since this document is really only directed towards high end canopy pilots, the qualifications outlined below are offered as *suggested* minimum standards for jumpers wishing to fly Class 4 or Class 5 canopy configurations. Hopefully, following these guidlines will minimize the risk of serious injury to the pilot (and anyone else that happens to be nearby).

Experience

> It is strongly recommended that a pilot have significantly more canopy time than a D license provides. 500 jumps on canopies loaded at less than 1.25lbs/foot^2 is wise, with 100 of those jumps on Class 3 configurations (between 1.0 and 1.25 lbs/foot^2). This experience will generally require at least one year in sport and a reasonable amount of experience on at least two different canopies. The greater the experience of the pilot, the less likely they will do something stupid. And the more likely they will be to take the *proper* corrective action when they do.

Currency

> Transitioning to a high load canopy is not something to be done suddenly. Even very experienced jumpers, with years in the sport, can lose that edge if they lay off for some weeks or months. Jumping regularly

and often is the best way to retain this edge. It is recommended that a jumper have made at least 20 jumps in the preceding 30 days on gear with which they are very familiar. When you strap on a new, radically different canopy, you don't need the unfamiliarity of a strange rig, new DZ, or other factors complicating the learning process and making safety more difficult.

It is also recommended that the jumper have at least 100 jumps during the preceding 12 months. Suddenly coming out of retirment, getting current on ragged out old gear and then jumping a new piece of technology is stupid no matter how many jumps you have.

Training

The pilot should have "proper" training. It is the author's opinion that a seminar in advanced canopy control, incorporating the information provided in this document, should be formalized by the USPA and offered to intermediate jumpers through local dropzones as part of D license qualifications. However, in the vacumn that currently exists, prospective pilots should seek advice and coaching from proven knowledgable authorities who also exhibit the proper responsible mindset. One without the other is useless, and arguably dangerous.

The last point above: "training", points out that there are really two levels of qualifications at issue here. The first, obviously, are those of the propective high performance canopy pilot. However, in that no document alone (certainly not this one) is adequate to teach all the necessary skills, there must be some individual who functions as the Instructor, or mentor, for these pilots. So what are the prerequisites of a good advanced canopy control instructor? In that there are no existing standards, how can one recognize a suitable source of information and advice? The author recommends the following minimum standards for someone to be a qualified mentor to pilots transitioning to class 4 and 5 canopies:

1. They should have a minimum of 5 years in the sport.

2. They should have a minimum of 1000 jumps.

3. They should have made at least 100 jumps in the preceding 12 months.

4. They should hold a USPA Instructor rating or an FAA Flight Instructor rating.

5. They should have at least 200 jumps in each of the canopy classes for which they are rated.

6. They should have at least 50 jumps in the last year in the highest class for which they are rated.

7. They should have experience on the specifc canopy configuration the prospective pilot will be using.

These traits should guarrantee an Instructor as someone who a) has broad first hand knowledge of the subject, b) has some training in effective teaching methods, c) has demonstrated (to someone) some level of responsibility for students and their safety, and d) has up to date information and experience.

It is the author's opinion that for the Class 4 and Class 5 ratings, the Instructor should be intimately familiar with each model capable of flying in these classes. This may prudently require that the manufacturers "teach the teachers". The manufacturers should be providing field instructors with as much information and technique as possible through local seminars and instruction.

And ultimately, the expertise of the Instructor must be current; they should be re-qualified annually.

The transition process

When making a transition from one class of canopy to another, develop a transition plan. You don't transition in a single jump. Its a program of skills development. It may take an entire weekend for a small transition, or it may take a couple months and 50 or 100 jumps for a larger transition. Just jumping a new canopy and surviving the landing does not mean you are qualified to jump that canopy on a regular basis. You must develop and master the skills before you can say you are a qualified Class 4 (or Class 5) pilot. Patience and practice are the buzzwords.

Minimize the performance step. Do not transition from a 200 square foot intermediate canopy directly to a 110 square foot ZP rocket. Make the transition in several incremental steps. This allows the pilot to build the reaction time and judgement necessary to the handle the faster canopy, without overloading the pilot's skills with a sudden increase in performance and decrease in tolerance range.

If we refer back to our 120 lb. jumper from the earlier example, a good transition sequence might take her from a 170 square foot F111 canopy (.88lbs/ft^2) to a 150 square foot zero porosity canopy (1.0lbs/ft^2) for 25 or 30 jumps, then to a 135 square foot canopy (1.11lbs/ft^2) for another 50 or 75 jumps, and then finally to a 120 square foot canopy (1.25lbs/ft^2) if the desire is still there. The performance steps in this case, as measured by wing loading, never exceeded .14lbs/ft^2 increments, and yet was a very aggressive transition. The keywords: Patience and practice. Small incremental increases in performance over a number of jumps.

Individual pilot's skills base and progress must also be taken into account. A pilot with 3000 jumps would likely make this transition with far less risk than a pilot with 300 jumps. Indeed, a transition such as outlined above would not be appropriate for someone with 300 jumps. And likewise, a pilot with 400 jumps in the preceding 12 months is at far less risk than some one with 50 or 100 jumps in the same period.

Even so, some individuals are likely to develop the skills faster than others. One individual may safely make the entire transition in 50 jumps. Another may see God on the 135 and wisely elect to stay with the 150. How far one "needs" to downsize is the real question. Does an individual really need such a small canopy? Probably not. It is just a preference. You must consider all the conditions you will be jumping under: Hot, cold, humid, dry, sea level, high plains, 4 way, 40 way, demos, nite jumps, 3 jumps a day, 8 jumps a day, tight landing area, expansive landing area, etc. Don't be afraid to say "smaller is not practical for me."

Even if you are just "test driving" canopies to find a good fit, you should still have a plan. When making the transition, experienced jumpers and newbies alike should seek out a *truly qualified* individual who can help set up a tranistion plan and provide the necessary skills and coaching.

High performance canopies are not magic. But they are not toys either. Learning to fly them well is a hell of a lot more fun if you don't hurt yourself in the process. Remember your mindset — patience and practice are key.

Equipment

Always expect to have a rough landing. Jumping a docile canopy while barefoot may be ok, but landing a very fast canopy off the drop zone may require a PLF, or worse. Hard helmet, gloves, and shoes are always recommended, but are generally way too uncool for advanced pilots.

Along with having [and using] the right equipment comes maintaining that equipment. The last thing you need is to have a toggle come loose during a swoop landing, or a pilot chute reinflate due to worn out bungee chord, or blown cells or loose stiching due to hard openings, etc. On every jump, you should examine your equipment to make sure lines are not snagged, connector links are tight, velcro is not worn, knots are holding properly. Every few dozen jumps, a detailed inspection of the entire rig should be done. On new canopies, and particularly on new designs, check for line stretch or other stress related degradation which may affect the flight characteristics or entire air worthiness of the parachute. You may need a riggers's assistance and experience to do this.

Maintaining your equipment is always important, no matter which class canopy you may prefer, but it is even more important when proper flight characterisitcs depend upon things being "just so".

Many jumpers are increasingly relying upon professional packers to pack their gear. Many packers do not inspect their client's equipment as closely as the client might. A minor problem which goes undetected or left unchecked may become a major problem after as few as one or two jumps. It is crucial that *you* inspect your gear frequently whether you pack your own or hire someone.

As we progress down in canopy size and progress up in airspeed and performance, there are several other pieces of eqipment that should be part of the flight configuration.

First, you should have proper risers. One aspect of risers is their length from connector link down to the 3-ring. Most stock riser are about 24 inches long, which may be too long for an average jumper trying to reach the slider. Shorter risers can be ordered from almost any container manufacturer which will conform to the container system, yet allow the slider to come down within easy reach of the jumper. 20 inch risers, if they pack properly, are generally adequate for most jumpers. Consult your rigger and container manufacturer for their recommendations.

The other riser related option you should have are "dive loops." Dive loops are simply handles on the front risers which enable the pilot to manipulate the front risers easily. They do not reduce the forces required, they simply make it easier to grab and hold onto the front risers. Dive loops should be large enough to grab easily with gloved hands (like toggles). They should also be set as close to the connector link as possible so as to minimize brake line tension while in use. These really are required equipment for serious manuevering under a high performance canopy.

Second, is a collapsible or stowable slider. There are several good reasons for dealing with the slider. One, is to reduce drag. And we always want to reduce drag. Another, is to improve visibility. Another, is to reduce noise. And yet another is to improve the lift characteristics of the canopy.

Obviously, an inflated slider is producing drag. Perhaps not so obvious, is that a flapping slider produces just as much or more drag. We do not like drag. And we especially don't like drag that makes noise. There are several methods of collapsing the slider: Many sliders have a piece of velcro attached that allows the jumper to wrap up the slider to prevent it from catching air or flapping; There are "split sliders" which seperate in the middle; There are "draw-string" sliders which are constricted much like a hood on a coat. On small canopies, a flapping slider can causeintroduce considerable shudder in the suspension lines and canopy as it alternately pops open and closed (you are going 30 to 40 mph you know).

Generally, we would also like a slider that comes down as close to the harness as possible. This not only provides better visibility to the canopy, it allows the risers to spread apart a bit more. When the risers spead apart, the cathedraling of the canopy is reduced, making a flatter (less curved) wing. Obviously, this should result in slightly better lift characteristics. (Note: This changes the trim and can reduce the natural stability of some canopies.) Some sliders may be wide enough to allow the riser spread without pulling the slider down. This is something that you will need to check on your particular canopy and harness configuration. If you do wish to stow your slider, make sure the grommets are large enough to pass over the connector links and that once pulled down, it does not restrict your lateral vision or range of head motion.

A third piece of recommended equipment is a collapsible pilot chute. The drag produced by an inflated pilot chute is proportional to the dynamic pressure, i.e. it increases with the square of the velocity. Therefore, a pilot chute that remains inflated produces much more drag on a high speed canopy than a similar pilot chute would on a low speed canopy. Short bridles may also allow the pilot chute to catch the high speed air flowing over the upper canopy surface increasing the drag still more. And perhaps most importantly, an inflated pilot chute creates a shear stress at the attachment point on the upper skin. This can deform the canopy enough to significantly affect it's flight characteristics.

Equipment that affects flight characteristics can be less than obvious. Weight vests are good example. Many jumpers wear weights for free fall purposes. These directly affect the wing loading once under canopy (not to mention opening). For example: A 10 lb. vest on a 120 lb. jumper with 20 lbsof gear will increase the total suspended weight (TSW) by 7%. But this 7% increase in total load makes a far more significant increase in loading per square foot on a small canopy than a large one. If our hypothetical jumper is flying a 170 square foot canopy, the vest makes a .06 lbs difference per square foot (from .82 to .88). If he/she is jumping a 110 square foot canopy, the same vest makes a difference of .09 lbs per square foot (from 1.27 to 1.36). It may seem like were splitting hairs here, but this point should not be overlooked. As we decrease the area of our canopies, small variances in weight have a greater effect on the performance. So you winter couch potatoes should remember that come spring! A 7% variance in loading is *very* noticable. Weight considerations such as these seem to be a bigger issue with lighter jumpers who may find themselves jumping different weights for different dives. Typically, the lighter the individual, the more weight they wear, producing greater variances in wing loading.

Variances in TSW will also exagerate variances due to atmospheric conditions (with respect to flight characterisitics.) A 7% difference in TSW combined with say, a dropzone at a higher altitude, may push a canopy into the "red" in so far as landing characterisitcs are concerned.

Deployment and Opening

Now that you are ready to start flying your new wing, we need to check its "normal" flight characteristics. We want to see just how it reacts to classic control input. Find a day when you can fly your canopy at altitude (8000 feet or more) without other traffic in the area. Smooth weather is desirable; bumpy or windy weather makes it difficult to feel the normal control range.

As mentioned previously, high performance canopies tend to fly faster than other canopies, even when the brakes are applied. This makes break-off seperation and clearing your airspace at opening much more critical than with slower canopies. You should always be prepared to take evasive action immediately upon opening. This may mean rear riser turns or the occasional front riser turn. Also, high aspect ratio canopies are more likely to experience off-heading openings. This makes careful packing and clearing your air at opening all the more important.

Immediately after opening, while the brakes are still set and the air speed is relatively low, some canopies may be very close to stall conditions. It may take very little rear riser input to stall one side of the canopy or the other when performing evasive manuevers. As you gain more experience on a particular canopy, you may find front risers to be a viable means of escape.

The first thing we must discover on a new canopy is the control range. The typically high aspect ratio of high performance canopies means that the wing has a relatively narrow chord. The distance from the center of gravity (as projected on the wing) to the tail is much shorter than on a lower aspect canopy of similar size. Therefore, the distance the control lines must travel to deflect the tail a given amount will also be shorter. Since the higher aspect canopy generates more lift, the amount of deflection required by the tail to effect a flare or turn will likely be less as well. This, combined with the fact that the pilot is probably also flying a much smaller canopy, means the control range may be deceptively short.

Another issue of concern is that some fast, high aspect canopies may also have a higher glide ratio, i.e. the canopy is rigged to glide flatter (higher angle of incidence). This means a relatively small change in the control line input will result in significant changes in the canopy's angle of attack. This characteristic will also manifest itself as a "short" control range for the canopy.

Control range is a function of many design parameters though. Suffice it to say that it can vary quite a bit across models independent of simply canopy size or loadings.

Because almost all high performance canopies have a significantly shorter control range than midrange canopies, it is a good idea for the pilot of a new canopy (particularly when taking a step up in performance) to "play" with the canopy up high. You did this as a student on your first jump. You found the stall point, you practiced some turns and practiced flaring. Your first several jumps on a higher performance wing should be nice long solo canopy rides from 10,000 feet or more. There are just too many distractions and not enough time at 2000 or 3000 feet after an RW jump to learn all you need to know before trying to landing a new canopy.

Learning to Fly the Canopy

As soon as you release the brakes, you will notice the canopy surge forward accompanied by a dropping sensation. This is a result of the canopy accelerating both horizontally and vertically. Apply the brakes. How much toggle pressure does it require? Find the stall point. How far did you pull the control lines? Let it fly again. Do this several times until you have reprogrammed your own feel for full control range to that of the new canopy.

While the canopy is at full flight, look up at the control lines as they branch out to the tail. There should be enough play in them that they bow gracefully back and do not deflect the tail more than an inch or two. The control lines will always have some tension in them due to the drag they produce.

Now, try some toggle turns. Start with very easy turns at first. The new canopy may turn surprisingly fast - and by design, not just as a result of higher airspeed. How does the canopy recover when the toggle is let up? Do a 90° turn one way, then back the other. Does the canopy move smoothly from one turn back through neutral into the other turn? Do a 180° turn. Straighten out. How much altitude did you loose? Do a nice lazy 360° turn. Now how much altitude was lost? Now do a more aggresive 360. How much altitude was lost? How much airspeed was gained? Flare. What was the toggle pressure required? How far did you need to pull the toggles to flare? How did the G forces feel (i.e. how fast did the canopy pull up?).

Now we should try some very lowspeed manuevers. Gently bring the canopy to full brakes. How does it fly? Does it hold a heading or drift? How does the toggle pressure change close to the stall point? Slowly let up one toggle an inch or two. How does the canopy react? It should seem to slowly pirouette around the braked side of the canopy. Let the canopy fly, then gently bring it to full brakes again. This time, let one toggle up enough to make a smooth 90° turn. How much altitude was lost? How does this compare with the altitude lost performing normal toggle turns. Could you do this on final to avoid another canopy?

Practice these simple turns until you feel comfortable with the new control range and confident that the canopy is flying properly. These manuevers give you a feel for the mean flight characteristics of the canopy. The lowspeed drills familiarize you with the canopy's ability to perform very conservative manuevers - those that may be required on your very first landing approach under the new wing.

On a new canopy, only toggle manuevers should be used until the pilot is thoroughly familiar with the new flight characteristics. Nice easy turns at altitude, and level conservative approaches to landing. If you cannot land the canopy with a "by-the-book" straight in approach, your canopy is not a good fit for you. High performance manuevers with extra airspeed (particularly on landing) are not a substitute for either the parachute's basic functionality or the pilot's basic skills.

Once you have mastered a new canopy using conventional techniques, and you have developed an intuitive feel for its nominal flight characteristics, you can move on to more advanced techniques.

Riser Manuevers

In general, sport harnesses and canopies were not designed to be flown using riser manipulation. However, we know rear risers can be useful for steering the canopy in emergency situations, and front risers have been used for eons to increase a ram-air canopy's drive. And it is quite common to see front riser manuevers being used as a landing technique. So the use of risers does in fact work, and most manufacturers have tried to design canopies that recognize and allow for the use of risers as control input.

However, be warned: the degree to which riser manuevers can or should be used varies tremendously across manufacturers and models. Some canopies can become *very* unstable as the wing is deformed, and some manufacturers even state such provisions in their owner's manuals. If you intend to experiment with riser input on your canopy, it would be wise to discuss the implications of doing so with the manufacturer and then only try such manuevers at an altitude where a cutaway can be safely executed.

So let us begin our discussion with a bit about rear riser manuevers.

The most common application of rear risers is to cause the canopy to turn. This may be required immediately after opening before the brakes can be released, or it could be required in an emergency where one or both steering lines have been lost (broken?) Most high performance canopies handle rear riser manuevers pretty well.

However, if the brakes are still in the keepers, an over enthusiastic rear riser turn could stall the inboard section of the wing, resulting in a radical stall turn. Releasing the riser will normally allow the canopy to recover if no lines are tangles.

Practice flying rear risers up high. In both brakes-on and brakes-off modes.

Another aspect of rear risers is their use for landing. A common method for dealing with broken steering lines is to use the rear risers for flaring and turning. You may find a very small canopy that you can land by the book with toggles is too sensitive to land with risers. This isn't normally the case with larger more docile canopies, and so you may need to modify your emergency procedures. And you will need to decide if this canopy is really a good fit for you.

The problem with rear riser flares is that the flight characteristics of the canopy can be quite different than those of a toggle flare.

If you observe a normal toggle flare, the D lines on a canopy will go slack as the pilot applies deep brakes. In applying the brakes, the CG of the system is moved aft allowing the wing to pitch up and plane out. At the same time, the control lines deform the wing so as to increase the camber. This increased camber means that the D lines are now too long to support any of the load and so, go slack. This type of cambered wing produces a great deal of lift (and drag), and is therefore quite useful for landing purposes.

A rear riser flare acts a bit differently. By flaring with risers, you shift the CG rearward just as before, and the wing pitches up and planes out similar to before. But you do not change the camber. One might compare this to an airplane landing without the benefit of flaps. It can be done, but the flare point, touch down speed, attitude, and stall conditions are far different.

A prudent pilot will develop rear riser landing skills. It takes some practice to do well. And like every other technique we discuss, should be approached incrementally, practicing on larger very familliar canopies and gradually scaling down as proficiency is acquired. This is one of those skills that is rarely required, but could prevent an unecessary cutaway or injury if it is needed. And you may very well find that a very small highly loaded canopy cannot be riser flared with an adequate safety margin. So if you have downsized several sizes without having mastered a riser flare, you should go back to a larger canopy and practice your way back down.

On to front risers...

Front riser manuevers are generally used to build up speed. You essentially trade altitude for airspeed. When performing front riser manuevers, always keep the steering toggles in your hand. This is especially critical when near the ground or in the vicinity of other canopies — you never want to have to look for your toggles or take your eyes off of where you are going.

As always, plan a seperate canopy control dive to practice front riser techniques. We don't need to complicate the process by adding traffic or landing patterns into the equation..

So, once you are flying, with toggles still in hand, grab the front riser dive loops. Look up at the tail. Does reaching for the front risers cause a tail deflection? Ideally, you would like enough slack in the control lines so that grabbing and pulling front risers does not significantly deflect the tail. If you see significant deflection, or you start a turn by just reaching for one front riser or the other, you need to lower your toggles to provide more control line slack. You should not attempt further front riser manuevers until you have adjusted your toggles properly.

Now pull both front risers a couple inches. The air speed increases. Release them - gently. Try it again, this time pull them a bit further. Do this several more times. At some point, the front half of the canopy will be deflected so far that the canopy starts to lose it's nice airfoil shape and assumes a sort of "stair step" shape. You typically do not want to pull front risers as far as to distort the airfoil. If you do, the boundary layer can no longer flow smoothly across the canopy surfaces and will separate from the wing somehwere around the B and C line attachment points. As the boundary layer detaches and re-attaches, the canopy will surge or bounce. This eratic behavior makes control difficult and could result in more serious problems such as nose roll. So, the object is to find out how much front riser input the wing will accept without significant airfoil distortion. Normally, small canopies will not take more than a few inches.

Also note that the amount of effort it takes to pull front risers. Small, high aspect, high incidence canopies will require less "pull" than more conservative canopies of the same size. There are many design factors that dictate the amount of front riser tension in a canopy. Just because you can physically or even easily pull front risers doesn't mean the canopy can fly under those conditions. Know thy canopy. You *never* just yank a riser with all your might.

Now lets discuss front riser turns. Again, start with easy turns, pulling only one front riser at a time while retaining grips on the toggle. Keep an eye on your altitude. Front riser "dive" turns will lose far more altitude than normal toggle turns. Again, be cognizant of the fact that there are limits to how far a riser can be pulled before the wing no longer flies. When you pull a single front riser, you initiate the turn by lowering the angle of attack on the inside leading edge. Again, this has the overall effect of reorienting the Lift vector so that it points slightly inward towards the turn, causing the canopy to shift over the jumper's head. Holding this configuration will ultimately put the canopy into a corkscrew spiral losing as much as 500 feet per revolution.

How does the canopy react as your do a front riser turn? It should accelerate quickly and smoothly into the turn. If you notice anything unusual at this point, such as endcells folding up, or a "porpoising" effect, i.e. diving and surging as the turn progresses, you may have a trim problem. Frequently, when encountered during relatively mellow riser turns, trim problems are the result of control line toggle settings which are too high. As noted earlier, we do not want to deflect the tail as we pull front risers. If the toggles are set too high on the control lines, tail deflection will occur countering the riser input, essentially confusing the inside wing section. Longer risers may also contribute to this problem since the dive loops are further from the toggles. If this is a problem, you may want to try a riser turn without holding the toggles. If these turns are smoother, you can adjust the toggles before repacking.

Do not attempt further front riser manuevers until your canopy is trimmed properly. A surging canopy is not flying properly, and may be indicative of a structural failure. In any case, it should not be used for stunt flying — especially swoop landings — until it can perform these manuevers smoothly at altitude.

The manuevers discussed above may require several dozen jumps to master. Do not expect to perform them all adequately in one or two canopy rides from 2000 feet. There just isn't time. A more experienced pilot making a smaller performance step may feel comfortable after five or ten jumps. The problem arises when a jumper *thinks* they have a skill mastered before they really do.

As you get more comfortable with the control range, you will also gain an intuitive feel for how the canopy is behaving without actually having to look at it. You can now start flying more aggressively since you can keep your eyes on where you are going. You can pull hard front riser turns to see just how much speed you can gather. You can stall the canopy to see how it recovers. You can make rapid opposing toggle turns, or front riser turns to see how the canopy handles them.

You may find some surprises doing these manuevers. An endcell may close up, a line may get tangled, or worse. Very radical manuevers may result in unrecoverable canopy collapse or a complete loss of control. If this occurs, you will likely need to jetison the malfunctioned main and deploy your reserve. Even a partial collapse near the ground may result in your death. It is imperative, therefore, that you perform radical manuevers above 2000 feet where a cutaway is a viable option.

Landing

Now we can discuss the final phase of your canopy ride: landing.

One of the most critical factors in successfully piloting a very fast, very small canopy is learning the flare characteristics. Conventional straight-in approaches to landing are the safest way to do this. Building a feel for the canopy's landing flare is just as important as learning the flight characteristics up high. Your first dozen jumps should end with nice, conventional, straight-in landings. An intuitive knowledge of the flare characterisitics can only be had by starting simply and practicing. And it is prerequisite to attempting high speed landings.

"Know Thy Canopy"

Judging the proper flare point for a new canopy is tricky, even for experienced ram-air pilots. So your first dozen jumps should end with "by the book" landings. You should be able to feel the flare point, know how quickly to move into the flare, how much of a flare planes the canopy out, and how much runway is necessary to land yourself. A smaller canopy with a higher aspect ratio will have significantly different landing techniques than a larger, slower, lower aspect wing.

There is an old addage in skydiving that says, "99% of all skydiving injuries occur when the jumper comes into contact with the earth." The ultimate purpose of a parachute is to get the jumper *safely* to the ground. Obviously, landing technique is paramount to any discussion of canopy control.

Your landing procedures should begin at 1000 feet. You need to choose a safe landing location and decide what type of approach you will use. If you are in the air by yourself, or at least far away from other potential traffic hazards, you may decide to land close-in and with a flourish. This is a good situation in which to do so. However, if there are other canopies around you, or that are in the immediate vicinity of your primary landing area, you may prudently decide to let the other pilots do the fancy stuff, and choose an area further away with a more conservative landing technique.

Typically, small, highly loaded canopies will be decending much faster than larger canopies. This is not to say the smaller canopy has a steeper glide slope, just that it has a much higher airspeed resulting in a higher *vertical* component of the glide slope. This fact is important for several reasons.

First, the increased decent rate means you have less time to manuever into an appropriate location from which to setup your landing. You cannot wait until you are at 500 feet to pick your approach path.

Second, manuevers performed under small, high load systems will consume significantly more altitude. Not to mention the fact that much of our airspeed came at the expense of hang time, i.e. front riser manuevers convert potential energy (altitude) to kinetic energy (airspeed) at a much quicker rate than flat and level flight.

Flying in the face of popular opinion, high performance canopies really can make a classic approach and landing. The most obvious differences are the generally high glide ratio and/or greater airspeed. These characteristics will require you to set up further downwind than you may be accustomed to. Overdriving the target can be dealt with in the usual manner using S-turns. Remember, though, that even these gentle manuevers will cause you to descend considerably faster.

In so far as the safety/consideration factor goes, keep an eye open for other canopies which you may overtake on final. You may safely be able to handle close proximity flying, but the other pilot may be a novice and may do something stupid out of inexperience. Don't be responsible for panicing someone else, or even just getting in their way. Stay clear and be a responsible pilot.

Crash Landings

Most experienced jumpers have probably seen some poor soul who stalled their canopy one foot off the ground, fell backwards injuring their back, and ended up grounded because of it. And most jumpers have also seen some other yahoo come in hot on a no-wind day, and go sliding across the landing area at 25 mph... then they get up, dust themselves off, and manifest for the next load.

These instances illustrate the difference between vertical speed and horizontal speed. High performance canopies, by merit of there greater airspeed, have both a greater horizontal velocity and a greater vertical velocity than more docile canopies. It is the *vertical* component of the landing velocity which is responsible for most serious landing injuries. So, as we start our discussion on high speed landing techniques, we must always remember that our primary objective is to have a zero *vertical* descent rate when we touch the ground. Obviously, we shall endeavor to minimize the horzontal component as well, but if we cannot do so, at least it won't be as likely to ruin our day.

In point of fact, it is the decelleration that is injurious to the human body. A free falling body will impact at about 110 mph (160 ft/sec), decelerating from 110 to 0 in a split second. Like the old adage says, "Its not the fall that kills you, its the sudden stop at the end." The human body cannot survive that sort of decelleration. Even considerably lower speeds can cause serious injury or death if the decelleration is too great: 30 feet per second (a jump off a two story building) is enough to break a leg or two.

Many injuries are due in part to the manner in which the individidual struck the ground. This is why Parachute Landing Falls (PLF) have proven so valuable: By using your legs to absorb some of the impact and then rolling, you experience a significantly smaller deceleration. PLFs can still be employed even under a high performance canopy when dangerous situations arise.

The relative safety of horizontal velocity can be seen in race car drivers who spin out at 200 mph, or down hill skiers who lose it while doing 70 mph. They may lose all control and go skittering along like a puck on an air-hockey table, but they won't be seriously injured unless they impact a wall or guard rail at a high speed. Even if they tumble their odds of serious injury are far less than the if they impact some solid object.

We will use this little secret to save ourselves. Knowing how to handle a botched landing is just as important as knowing how to not botch the landing in the first place.

As long as we are dispelling old myths, lets dispell one about landing into the wind. A ram air canopy doesn't *have to* land into the wind. There is no law of physics or aerodynamics that says you cannot or should not land crosswind or even downwind. (The S&TA may have a law, but they don't normally break your body when you goof.) Your canopy will in fact flare as it always does.

However, you will have a much higher ground speed. But ground speed is *horizontal* speed. And as we noted earlier, excessive horizontal velocity is far less likely to cause serious injury than an excessive vertical velocity. If you flare properly, your vertical descent rate will be zero, even though you may be shifting to red as you pass the clubhouse.

On a downwind (or crosswind) landing, a good flare is still important. It not only halts your vertical descent, it increases the drag of the canopy. Since the center of mass of the system is the jumper, the canopy tends to stay behind the jumper, allowing the jumper to slide feet first across the ground until they come to a halt. And so, if the jumper cannot "run out" a downwind landing, making sure your feet are in front of you and settling in on your butt will induce the slide.

To be sure, a downwind landing is not the "optimal" landing. Upwind is still the prefered direction. However, as we will see in a momemt, sometimes a misjudged approach can best be dealt with by looking stupid rather than looking dead. Downwind approaches should be avoided (nor should they even be necessary) when landing off drop zone into rough or unknown terrain (plowed fields, high grass, etc).

And remember, upwwind or downwind, obstacles in your path such as fences, cars, people, dumpsters, etc. are Bad Things.

Very High Performance Landings

Now we come to probably the most critical issue in this entire document — high performance landing techniques. We assume the pilot attempting these landing techniques is thoroughly familiar with the "theory" presented in the previous chapters. The surest way to injure yourself is to blindly attempt one these landings without the proper knowledge and skills. This section presents at least one method for learning these landing skills in an incremental fashion.

As always, the pilot intending to execute a high speed landing must plan in advance. Once under canopy and clear, check out the emerging traffic patterns. It is essential that the landing area be clear of other canopies and obstacles. Jumpers walking in after landing, spectators, students, etc. can suddenly do something unexpected that could cause a mishap. You don't need the added distractions.

What we would like to do is find a way to "practice" our high speed approaches without blindly executing a very dangerous (and stupid) hook turn. As always, we'll use an incremental process for doing so. So mastering the simple skills of judging airspeed and descent rate, tracking other canopies along your intended flight path, and the basic canopy control skills that get you into a good position for landing are crucial prerequisites.

A brief comment on hook turns: Even highly experienced jumpers should look at the statistics. Hook turn injuries and fatalities have occured to jumpers of all experience levels. And a careful analysis of the areodynamics involved in hook turns would force one to the conclusion that they are unnecessary for really impressive landings, and significantly reduce the pilot's ability to control the outcome. High performance landing techniques and hook turns are two different beasts - one is a calculated program of demonstrated skill, the other is a game of Russian Roulette. There are very few gamblers alive in this sport.

In fig. 11 we have projected a clock face over the intended target area. The windline extends from 12 o'clock to 6 o'clock. We will refer to this face as we study approaches.

A high speed approach gets its speed by diving the canopy towards the ground.

The secret to learning approaches is to start with long straight in approaches, progressing to gently curving approaches, and continuing to practice and hone your skills until your approaches get shorter and steeper.

In Fig. 11, point A is the setup point for our initial attempts. The approach will be a conventional straight in approach, starting at 500 feet AGL, but with some front riser input. These approaches will teach us several things.

First, we will learn to transition smoothly from pulling front risers to full flare.

Second, we'll learn the high speed flare characterisitics of the canopy (how far to flare, when, how quickly, etc).

And third, we learn to watch what's happening around us as we make increasingly more aggressive approaches.

As we setup for an approach, we always need to check the standard conditions:

1. **Is there traffic?** Are there other canopies on my desired flight path? How many? At what stage? Is there a secondary landing area, e.g. out of the way place to land? If not, we should scrap any plans to make a fancy landing and make a more conventional approach instead.

2. **Is the landing area visible and clear?** If you cannot see the *ground* clearly (not just the grass) do not attempt a high speed landing. If it is full of people, it would be unkind to put one or two in the hospital.

3. **Where are my "outs"?** Never try a high speed landing if you have no out! Can you handle a 30 mph crosswind slide where you are landing? If not, abort and make a conventional landing.

Most regular jumpers at a DZ know the other canopy pilots in the air with them. This makes it easier to decide if a high speed landing in close proximity to another canopy is safe, when in fact it is not. One of the most common causes of injuries today are canopy collision and/or entanglements below 300 feet. And almost always amoung very experienced jumpers. There are just too many variables to define a rule that can be accurately evaluated and applied in a matter of seconds. Landing in close proximity to other canopies risks significant turbulence very near the ground, when a swooping canopy is already close to its operating limits, and the pilot(s)' attention should be focused on the ground. An unexpected change in flight path by one or more nearby canopies would prove disastrous. Swooping through a crowd is excessively dangerous, not just to you but to others as well. Don't do it.

A good approach means a flat glide at 40 or 50 mph. Landing in a crowded packing area or among spectators (who are especially unpredictable) is insanity. Don't do it.

To begin the training process, we will start with straight in approaches. So we setup at about 500 feet downwind of the target area, and at about 300 to 500 feet altitude. Wind conditions and canopy characterisitcs will dictate the proper positions.

After verifying that we have a clear path and landing area, we can apply some front risers to gain some airspeed. Go easy at first, with just one or two inches of front risers. And remember to keep the steering toggles in your hands while manipulating the front risers.

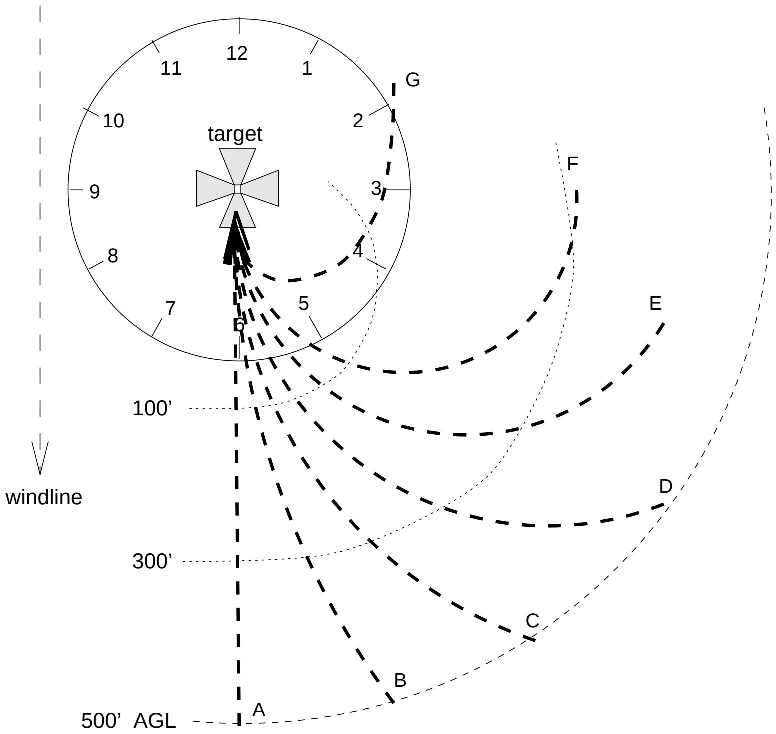

Figure 11: Setup locations and approach paths for high speed landings. Path "A" is a simple straight-in aapproach. Approaches increase in difficulty up to path "G", which requires a large arc, short radius turn to final. Approach path G is *extremely* dangerous if not done correctly.

As we approach our normal flare point, release the risers gently and move smoothly into the flare. Do not drop the risers suddenly. This takes the weight off the A and B lines momentarily and will cause the canopy to shudder as if it hit a bump. Learn to time the release so that you release the front risers and move smoothly into about 2/3 brakes. How does the canopy react as you drop the risers and flare?

Make a half dozen more jumps increasing the amount of front riser you pull on each jump. These are still straight in approaches. Get comfortable judging the ground approach. In fact, get really good at it. Do not pull the front risers so far as to create a "step" in the canopy. Pulling risers further will not produces any additional airspeed and may cause the canopy to act strangely.

Learn how much brakes it takes to plane the wing, i.e. to get a zero descent rate. Flaring too hard will result in the canopy ascending, stalling, and dropping you backwards from a dangerous height. Flaring too little or too late will result in a "hard" landing.

Do not progress until you are comfortable with the straight-in approach using front risers. You should be able to pull the front risers to their full aerodynamic range and still comfortably control the parachute.

Note: To avoid injury, <u>never</u> exceed the performance capability of the canopy, i.e. don't ask it to do something it can't. The only way to determine the actual capabilities of your canopy is through a series of carefully controlled, progressively more aggressive manuevers. When you perform these manuevers close to the ground, misjudging what the parachute can do will put you or someone else in the hospital — or in the morgue.

Once the straight in approach is mastered, which really isn't too difficult, we can move our setup point out to one side of the windline or the other. Refering back to Fig. 11, we can now begin our approach from a location closer to 5 o'clock (or 7 o'clock) such as point B.

Our objective now is to execute a very shallow front riser turn into landing. A front riser turn will lose altitude faster than did the straight-in approach on risers, so be prepared for it. Adjust your setup point by trial and error so that pulling a couple inches of front riser initiates a turn into the wind which completes right as we reach the flare point. Again, gently release the front riser and move quickly but smoothly into your flare.

This initial shallow riser turn to landing should be only marginally more difficult than the previous approaches. This is good. Practice these shallow riser turns to landing until you are consistantly starting them and completing them in good form.

Then, from the same 5 o'clock direction on the clock face but this time closer to the target, repeat the process. Notice that more front riser input is required and that the turn is steeper. This is called a **reduced radius turn**. The turn still only represents about a 15 deg to 30 deg change in direction, but the turn was much sharper.

As we improve our ability to judge the setup point and turn radius from a given clock direction, we will move our starting point out to around 4 o'clock, then 3 o'clock, etc. From the 5 o'clock position, we performed a 30 deg turn, from the 4 o'clock position, we execute a 60 deg turn, from 3 o'clock we do a 90 deg turn, and so on. This is called the turn's **arc length**.

Likewise, as we improve our skills at each clock position we will move the setup point closer to the target, reducing the turning radius and resulting in much steeper turns.

This entire document comes down to these two preceding paragraphs. If you rush this process, this whole program was for naught. You absolutely *must* be patient and practice these manuevers incrementally. And master them before increasing the degree of difficulty.

This is a good time to discuss what happens when you do not turn fast enough, or worse - turn too late to get into the wind. It should be obvious from the earlier discussion on crash landings, that we can abort our turn and land crosswind. Learning to judge the proper setup point, the altitude and distance from the target, takes some time. Particularly under the constantly changing atmospheric conditions we normally jump in (wind speed, direction, temperature, humidity, traffic, etc.) As you improve your skills and move on to more difficult approaches, you will at some point goof. You will likely get over ambitious and attempt a large arc, small radius turn from way too low.

How a pilot handles a botched approach is critical to their very survival. If you initiate a steep turn to final, and realize half way through it that you are too low to complete it, the only option is to abort immediately and hope you can pull out of the dive.

<u>DO NOT TRY TO TURN FASTER</u> to get the canopy into the wind. By

attempting to turn faster, you pull more front riser, simply increasing the rate of descent. This is the most common and disastrous mistake made by canopy pilots. You've already recognized that your turning speed was inadequate, why compound the situation? Abort the turn, release the risers, flare immediately if necessary. If you are going to pound in, get your feet in front of you and at least try to PLF. If your feet and knees are behind you, you will likely break your back and/or suffer other serious internal injuries.

If aborting the turn extricates you from this situation, a shallow toggle turn may still be able to get you into the wind. A toggle turn will lose far less altitude, and combined with the pitching effect of releasing the front risers, you may see a significant increase in glide ratio even while you are turning. At this point, count yourself among the lucky ones who learned something painlessly. You get to try again next time.

An interesting observation here is the lack of discussion about toggle turns in high speed landing technique. It is the author's opinion that toggle turns are a much riskier method to effect a high speed landing. A toggle turn slows down one side of the canopy. A high speed approach using toggles requires a very radical turn in order to get the canopy to dive and build airspeed. This momentarily unloads the canopy, reorients it and then reloads it headed towards the ground. Most of the airspeed so acquired comes from the jumper essentially swinging down beneath the canopy as it emerges from the turn. During this manuever, the pilot has very little control. He has committed to following the canopy. If the turn is executed too high, the canopy will pitch up as it levels out from the turn. This effectively bleeds off the excess air speed. If the turn is executed too low, there is very little the jumper can do to pull out until his weight is back under the canopy. This is a much more complex manuever requiring a great deal more timing and providing far less ability to abort.

A long carving toggle approach on a highly loaded canopy is not so dangerous. But neither does it generate as much speed.

One of the nice features of front riser turns is that, given a problem, you can significantly increase your angle of attack by releasing the risers, and therefore increase your lift. If further lift is required, a flare at the high speed can produce a great deal of lift. A toggle turn, on the other hand, brings the canopy closer to its low speed limits, giving the jumper less leeway to "backoff."

Finally, always plan your approach with your "out" in mind. If you do need to abort a swoop, you will most likely have to land wide of your intended flight path, i.e. to the outside of the turn. It would be poor form if your out was blocked by a building, port-o-let, dumpster, etc.

At this point, you should have the hang of the incremental process. However, as your aproach exceeds 90 degrees, you introduce some really significant traffic problems. A 120 or 180 degree turn to flare means that you will be flying downwind directly over the landing area - and headlong into congested air space full of jumpers making conventional upwind approaches. This a good way to hurt or kill someone, and is ample justification for disciplinary action by the S&TA.

Remember, just because you have a hot canopy, you do not own the skies or the have unrestricted access to the landing area. Proper piloting of your aircraft is not just avoiding other jumpers, but making it so they need not avoid you.

One method of doing this is to find your own air space. Typically, most everyone wants to land in the peas, and so there is a lot of congestion in that area. Your options are to move horizontally away from the crowd and land "out", or to move vertically away from the crowd and land first (or last).

Most drop zones have enough clear area that landing out may only mean having to walk a 100 meters or less. The larger the load, the more congested the landing area will be, and a cool swoop landing may be almost impossible to execute safely. The sooner you accustom yourself to the prospect of walking an extra 100 yards, the happier you'll be when you find yourself in the sky with a bunch of statistics waiting to happen.

Closing Remarks

It is the authors desire that this document add to the skills base of jumpers everywhere. It is not intended to encourage the purchase or use of very high performance canopies, or to establish the "One True Way" to pilot these wings. However, it is intended to foster the study, development, and dessimination of advanced canopy control skills for sport skydiving.

Using caution and good sense is everyone's responsibility. And in the final analysis, caution and good sense is what prevents accidents. So please, be careful.

If there is one thing the author would have you take from this document above all else, it is *mindset*. If everyone did everything they were taught to do, every time they had to, there would be no accidents. Accidents occur from being over-confident, or complacent about the risks and skills involved. As soon as you feel like you really impressed the gallery, you better start double checking your procedures. There will inevitably come the day you miss something — maybe another jumper in your peripheral vision, the slope of a hill you are landing on, some worn steering line... Hopefully, the other jumper notices you, or the slope is downhill, or the steering line doesn't come loose during your swoop.

Take no chances. Be smart. Be careful. Have fun.