AERODYNAMICS

There are 4 basic forces involved:

upward lift opposes downward weight
forward thrust opposes backward drag

When all forces are consistently equalized, the goal of stable straight and level flight is maintained.

For paramotor pilots, 3 of those forces hang below the wing, making paragliders inherently very stable. The pendular nature of our weight under the lifting surface helps makes the wing naturally return to stable flight whenever it's disrupted (that's why they 'practically fly themselves'). That's why also, if the wing rolls/pitches/yaws/oscillates unexpectedly, we teach HANDS UP and REDUCE THROTTLE slowly and progressively (in the beginning it's always better to let the wing fly and correct itself than to over-correct with improper inputs).

Wings produce lift in two ways:

1) Newton's Third Law of Motion (for every action, there is an equal and opposite reaction) is put to use by the downward deflection of airflow when a wing's angle of attack increases (like turning your hand outside of a car window, you can feel it being pushed up). With enough air flow, you could fly a picnic table.

2) The airfoil shape creates higher velocity over the top of a wing and lower velocity over the bottom of a wing, so Bernoulli's venturi effect creates upward pressure (venturi effect says that as the speed of a moving fluid (liquid or gas) increases, the pressure within the fluid decreases), so the wing shape creates higher pressure beneath the wing, pushing up.

Lift Equation: $l = cl ((r * v^2) / 2) a$

Explanation: lift is equal to the lift coefficient (Cl) times the density of the air (r) times half of the square of the velocity (V) times the wing area (A).

The lift coefficient is a complex factor in the equation, but altogether, lift basically depends on the density of the air, the Square of the velocity, the air's viscosity and compressibility, the surface area over which the air flows, the shape of the lifting body, and the body's inclination to the flow.

An important takeaway from the formula is that Doubling air speed Quadruples lift. That part of the equation (v squared) is why it's so important to have speed to fly. Wings need to maintain relative air flow (air speed over the wing) to maintain stable flight, and more speed dramatically increases lift.

Another takeaway from the lift equation is that Halving air density Halves the force. As altitude increases, the air density decreases. This explains why air vehicles have a flight ceiling (an altitude above which they cannot fly). This also explains why on low density altitude (hot) days, we don't get as much lift - the air is thinner, and that directly affects the formula.

Another takeaway is that larger wings produce more lift at slower speed (greater lifting surface area in the equation), and smaller, more heavily loaded wings need greater relative air flow speed to produce the same lift. Beginners should generally start on slightly bigger wings, so that they don't have to run or react as quickly (but not too lightly loaded that they can stall easily).

Probably the most important thing for new pilots to understand about lift is that adding thrust provides greater lift by increasing angle of attack (in the Newton's law way).

There are 2 types of drag:

parasitic drag - friction between of parts of the vehicle against moving air.
induced drag - a byproduct caused by lift (the angled wing 'scraping' forward through the air as it deflects downwards)

As with lift, doubling air speed quadruples parasitic drag. You would expect that lots of parasitic drag (we create lots of friction with air) would affect performance, but we fly so slowly, it's not as important as it is for faster aircraft.

Induced drag is the result of lift (a tilted wing is also causing drag), and that creates organized circular vortices off the wing tips that generally track down and out from each wingtip. The bigger and heavier the aircraft, the greater and more powerful the wingtip vortices will be. Stay away from them in flight - they generally last at least 2 minutes.

One of the most important things for new pilots to get about drag is that pulling one brake adds drag on that side of the wing, making the other side fly faster (then it's actually the centrifugal force of our banked swing that effects the turn - students need to learn to control that swing).

Another important concept is that flaring both brakes adds drag and changes angle of attack, to slow the wing and increase lift at the moment of landing. A large flair stalls the wing, so it must be timed correctly, at the right height. A light pull on both brakes also assists with added initial lift on launch, but then airspeed should be increased again immediately after launch.

Slowing the air speed too much with drag, or increasing the angle of attack too far upward (past the critical angle of attack) disrupts lift and stalls the wing (although paraglider wings typically deform before reaching CAOA). Stalling one side of the wing causes a spin.

On the subject of airspeed, there are only 3 ways to increase it on a pg: 1) change the angle of incidence (angle of chord to B line) 2) use a smaller wing surface, or 3) add more weight.

Changing trimmer settings and speed bar adjust angle of incidence, so that less lift is traded for greater speed.

Reflex profiles in a wing don't just change AOI, but change wing shape, raising the back portion of the wing, so that the center of gravity moves forward, increasing stability, but also reducing the surface area which provides lift, so reflex generally requires greater thrust. Also, turning is performed with tip steering in reflex mode, because pulling on rear brakes disrupts the bent up rear shape of the reflex profile.

Also, about AOI, minimum sink is typically achieved with slowest trim setting, with none or slight pressure on brakes (trim speed)

Some more about wing shape: the more rectangular a wing, generally the more stable, but the less efficient. Thinner aspect ratio wings are more efficient, but less stable. (aspect ratio = wing span / average chord line). The arc shape of a wing helps keep it spread out spanwise, since lines can only pull. One thing for pilots to watch for is that line stretch on older wings can deform wing shape.

One thing to understand about thrust is that it's directional. Thrust line and torque can affect pitch, roll, riser twist, etc., and teaching pilots to respond with reduced thrust when it adversely affects flight, is critically important.

One important thing for students to understand is that turbulence, wind sheer and other environmental factors can change relative air speed, angle of attack, and other pieces of the lift and thrust equations. Active piloting is the process of reacting to these external forces, to maintain straight and level flight. To check surge: more brake, add power. To check lift: less brake, reduce power.

Rain or a wet wing slows collapse recovery and increases chances of parachutal stall, because the wing gets heavy and moves more slowly than designed.

More terms:

glide ratio: lift to drag (the number of feet you move down compared to the number of feet you move forward). BTW, l/d is reduced 10-20% by a windmilling prop!

axes of rotation: pitch (tilt forward back, up down), roll (around longitudinal axis), yaw (around vertical axis)

center of gravity: where all the forces come to a point (on a PPG, somewhere between wing and nearer the pilot). It's important to understand intuitively if you're practicing high G maneuvers, or if you design harness connection points, thrust placement on frames, etc.

ground effect: generally happens when a wing is at half the height of its span or lower, so paragliders generally don't experience it.

Obviously, None if these aerodynamic properties come into play properly until the wing is pressurized. This happens during the inflation and launch process - then, during flight, greater pressure inside the parafoil than on the outside surfaces is automatically maintained by the ram-air design (don't stall it, because then all the aerodynamic rules go out the window).

downwind demon: imagine circling a boat in a moving river, the turn is just as circular, but the track on the beach is elongated. Turning into a tailwind feels like the brakes are not responding as much, but really ground speed is just increasing.

propellers: bigger diameters are better for efficiency and thrust, but less responsive.

Differences for 3 axis control pilots: pendulum swing behaviors such as throttle induced pitch changes, roll oscillations, different stall and spin behavior. We maintain stable flight without any control inputs. Lines can't push - we need to fly always in ways that maintain pressure on the lines. Rigid wings don't collapse, so there are some fundamental thoughts and patterns of flight which PG pilots need to ingrain, that GA pilots generally don't consider.