

Jour de Vol (Flying Day)

University students enrolled in a Technology and Society course explore gliding flight through the design and construction of non-rigid wing paraglider models.

BY MICHAEL WALACH

The ability for humans to take flight has not been a reality for very long. Flight is a challenge, even today with all of the technology and resources at our disposal. The first “Jour de Vol” (Flying Day) dates back to France in 1783 when François Pilâtre de Rozier and François Laurent took to the sky in the Montgolfier brothers’ hot air balloon (Millbrooke, 2006). The brothers, Joseph-Michel and Jacques-Étienne designed and built the first hot-air balloons. Powered flight (heavier-than-air machines) did not become a reality until about 120 years later, on December 17, 1903 when Wilbur and Orville Wright made their first flights in a heavier-than-air flying machine on the sand dunes near Kitty Hawk, North Carolina. Between the Montgolfier’s balloons, the airships that followed, to the Wright’s airplane, many people learned the fundamentals of flight through gliding.

The most famous of these aerial gliding explorers was a German, named Otto Lilienthal. Lilienthal made many flights in a variety of gliders that he designed and built himself. Otto published much of his research and many others looked to Lilienthal’s work as a reference for further development (Lilienthal, 1911). Otto, unfortunately died as the

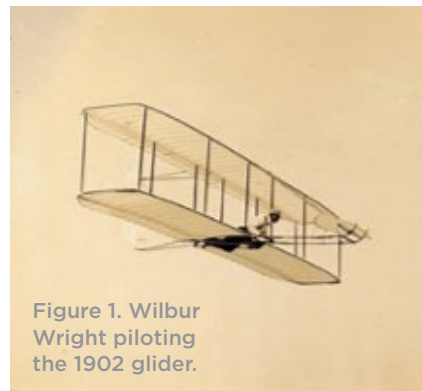


Figure 1. Wilbur Wright piloting the 1902 glider.

result of an accident flying one of his gliders. His death did not deter others, in fact, it was an inspiration for Wilbur and Orville Wright. They were determined to study the cause of others’ failures, especially Lilienthal, and engineer solutions to the problems they uncovered. What they found was clear; no one had yet developed a means for the lateral (roll) control of an aircraft. The ability to control roll was critical to the success of flight. Up until then, rather than a system to control roll, aircraft were designed to be inherently stable so that roll did not need to be controlled. This worked fine, that is, until you needed that roll control. It was this lack of lateral control that caused many early would-be aviators to crash and often die. Aviation had its own cruel natural selection process. Good ideas were passed on while bad ideas often died with

their inventors who most of time were their own test pilots. The key to flight was roll control.

Wilbur and Orville first dreamed up a roll control system of shafts and gears but thought the system was too heavy to be practical (Wright & Wright, 2000). Finally, the solution came to Wilbur while absentmindedly fiddling with a box while talking to a customer in the Wrights’ bicycle shop. It occurred to Wilbur that if they could warp the shape of the wings (like he could warp a cardboard box by twisting it), they might be able to achieve the roll control that they desired. They first built a kite that Wilbur tested in the presence of some curious neighborhood children. The control system worked, although as a kite, this model wasn’t easy to control as the young spectators learned when they had to dive to the ground to avoid being struck. The test flight taught Wilbur what he needed to know however, and armed with this test data, he set out to build a full-scale glider that would use wing warping. This wing warping system would be used by the Wrights on all of their gliders and their first “flyer” (the name they gave to their powered airplane). The Wrights would go on to build several gliders to learn how to fly and to refine



Figure 2. What would the Wright brothers say if they could be here today to witness what flight has become?

their airplane designs. In fact, the Wright brothers built and flew three gliders—one each in 1900, 1901, and 1902 before they finally attempted powered flight in 1903.

Most modern airplanes do not use wing warping, rather they employ a system of ailerons, movable control surfaces at the outer trailing edges of the wing that move opposite one another to control roll (one aileron goes up the other one goes down). There are some aircraft however that do still use a system of wing warping, although somewhat different than the Wright gliders, to control roll.

Paragliders (Non-Rigid Wings)

A paraglider is a non-rigid wing (no internal structure) that holds its shape using ram air from forward motion and tension on a series of lines that a single pilot is suspended from. The paraglider is controlled by either weight-shift or by pulling on brakes lines that connect to the rear of the wing. Both weight shift and brake inputs warp the shape of the wing to control direction of travel.

The pilot holds a brake toggle in each hand and simply pulls on the side they wish to turn. The brakes deform the trailing edge of one side or the other of the wing and the

glider turns in the direction of the deformed wing. Weight shift can also control the glider. As the pilot leans right, the wing is deformed and a right turn results from the change in airfoil shape. Leaning left does the same but for a left turn. Just prior to landing the pilot pulls both brakes which slows the wing and allows for a gentle landing.

Paraglider wings are usually made from nylon fabric or some other similar strong, but lightweight synthetic material. The wings have lines that are attached to a seat and harness that the pilot is strapped into. At first glance, a paraglider might look like a parachute. In fact, the first paragliders were made from skydiving parachutes and rock-climbing harnesses. Paragliders were inspired in part by rock climbers who were looking for a quick way to descend a rock that they had just climbed (i.e., parachuting instead of climbing down). NASA's development of the Rogallo wing, a type of steerable parachute,



Figure 3. Aircraft with non-rigid wings (note the ram air opening on the leading edge). A group of paraglider pilots “kite” their wings in a steady breeze.

also helped to influence paraglider development. Paragliders have since evolved into what they are today, a lightweight flying machine with non-rigid wings controlled by wing warping. A paraglider wing is not a parachute, but a wing, just like an airplane wing. A paraglider wing needs airflow to remain a wing, otherwise, it just becomes a pile of fabric. Looking at a paraglider wing, the leading (front) edge of the wing is open to allow ram air (air from forward motion of the wing) to enter the wing. Most modern paraglider wings have small strips of plastic cord that help to keep the leading edge open (The only rigid structure in the wing). As the wing is inflated, it takes shape and will hold its shape until airflow stops. A pilot therefore must maintain forward motion, either by running, standing in a steady breeze or, once in the air, by descending. In the image above a smooth laminar breeze off a lake keeps the wings inflated, allowing the pilots to stand still and balance their wings, a practice called “kiting.” All gliders, when unpowered or not being towed, generate “thrust” by descending. Potential energy is exchanged for kinetic energy. A glider can stay aloft if the air is rising faster than the glider is descending in it. Therefore, a glider is always descending, even if it appears to be going up; meaning the glider may be in a column of rising warm air that is going up faster than the paraglider is descending through the rising air mass.

The lines that come off a paraglider wing are identified by letters. The lines from the front of the wing (the leading edge) are the “As,” then the “Bs” are in the middle and the “Cs” are in the back, or the trailing edge of the wing. Some wings have 4 sets of lines which will include “Ds.” High-end competition wings may only have two sets of lines, referred to simply as “two liners.” A set of lines

attached to the rear of the wing are the break lines, and these brakes are used for control of the wing.

The Basics of Flight

A paraglider in the United States falls under the Federal Aviation Administration (FAA) category of an ultralight as defined in Title 14 of the Code of Federal Regulations, Part 103 (<https://www.ecfr.gov/current/title-14/chapter-I/subchapter-F/part-103>). Paragliders are used for sport-flying. While there is no license requirement for ultralight aircraft in the United States, training is highly recommended as accidents can result in death or serious injury. An ultralight as defined by the FAA states that the ultralight must weigh less than 155 lbs. (unpowered) or 254 lbs. empty (powered), have only one seat, and no more than 5 gallons of fuel capacity (if powered). Max speed must not exceed 55 knots at full power in level flight and a stall speed not to exceed 24 knots. Stall speed is the speed at which the wing will no longer produce effective lift, and at which point the aircraft would start to fall (and often spin) out of the sky. Stalls on a paraglider are quite different than a normal fixed wing aircraft and will be discussed in a later section.

The speed of a paraglider is controlled by the size and shape of the wing. Therefore, speed is a (mostly) fixed value with a paraglider. Speed in this example refers to airspeed, not ground speed. All aircraft move through the air, independent of the ground. While flying at a constant airspeed, ground speed may be very different depending on direction of travel based on local wind speed and direction. This is because the aircraft is moving along with the air it is traveling through. Paragliders can have a speed system that changes the angle of attack of the wing, increasing airspeed at the cost of a higher descent rate. A

device called a speed-bar is pushed with the pilot’s feet and lines that run through a series of pulleys pull the leading edge down, increasing speed. Control and braking on a paraglider is achieved with the brake lines. A set of brake lines goes from each trailing edge of the wing to a toggle held in the pilot’s hands. To turn right, the pilot pulls on the right brake toggle and to turn left the pilot pulls on the left brake toggle. The brakes change the shape of the back of the wing, slowing the side of the wing (with brake input) slightly and causing the glider to turn. Pulling on both brakes slows down the entire wing and is typically only used on landing (and to a lesser degree at takeoff). Holding the brakes fully in flight will lead to a stall.

A paraglider can stall, but this can only be induced by the pilot. To stall a paraglider wing, both brake toggles are pulled to their limits and held. Once the wing stalls it will collapse and stop being a wing. Both pilot and wing will go into freefall. To come out of the stall the pilot smoothly raises both hands to release the brakes (while making minor adjustments to control the wing). The wing (should) reinflate. Once the wing reinflates it will typically surge forward as it builds energy. The pilot will dampen the surge by adding brake pressure, assuring that the wing does not overshoot the pilot and get below the pilot. In rare cases, a wing surge after a stall can result in the pilot falling into the wing (called getting “gift wrapped”) which is often fatal. Stalling a paraglider wing is best done in a maneuver course, more commonly called S.I.V. (Simulation d’Incident en Vol - French for “simulated incident in flight”). In an S.I.V. course, maneuvers are practiced at a high altitude (around 3,000 feet) above water with a safety crew and at least one, sometimes two reserve parachutes. Stalling a paraglider wing is a good



Figure 4. The author experiencing an asymmetric wing collapse in an SIV course.

way to fix in-flight cravats (wing tip folds) and other mishaps with the wing common in free-flight. Free-flight pilots must look for sources of lift such as thermals, which can produce strong turbulence and cause collapses and/or cravats in the wing.

Paragliding flights typically fall under one of the following categories: sled-rides, soaring, thermaling, or tows. A sled-ride is when a pilot hikes up to the top of a hill, launches and glides down to the bottom. Sled-rides can be as short as a few seconds or as long as 20+ minutes off a mountain top. Sled-rides are where most new pilots start their flying career. Soaring can happen at the same locations as sled rides, but the flight time is increased by air hitting and being pushed up and over a hill. Pilots on the windward side of a hill can zig-zag back and forth in the rising air and stay airborne for hours. Cliffs along the ocean, mountain-sides, and steep hills can often work for soaring in the right winds. Thermaling requires more skill. Pilots who thermal search for rising columns of warm air. On a warm summer day, the puffy white clouds you see are the tops of thermals. Pilots search for such conditions and will circle inside the thermal and ride it like an

elevator as high as they can, then glide to the next thermal. A 100-mile day is not unheard of, and the world record is around 600 KM (380 miles) with no motor! If you have ever seen large birds circling in the sky, they are thermaling. In fact, pilots often look for birds as they can lead them to the thermals. Finally, if a pilot does not have access to any hills, they can be towed up in the air by a car, boat, or even an aircraft. Tow systems consist of a special winch system designed specifically for towing paragliders. The operator(s) should also have professional training on how to operate the tow system safely. Tows up to 3,000 or 5,000 feet are not uncommon with

ground-based tow systems such as trucks or boats. Once a pilot is towed up, they release from the tow line then either glide back to the ground, or, search out sources of lift such as thermals to stay in the air for as long as they can. Non-rigid wings make a great platform for learning the basics of gliding while providing a challenge different from a typical rigid airframe. A brief examination of the mechanics of a non-rigid wing is a helpful place to start.

Biomimicry

Technological innovation sometimes takes inspiration from nature. Biomimicry is when technological systems, such as paragliders, draw from natural phenomenon to solve real-world problems. Birds and flying insects all employ nonrigid wings, at least in some respect, to fly. Paraglider design is an attempt to mimic the flight of birds and insects. Generally, if hawks and eagles can climb in lift, a paraglider can as well. Birds are often studied by paraglider pilots to help locate sources of lift and to identify the edges and the cores of thermals. Wilbur and Orville Wright are reported to have spent hours studying how birds fly and watching the subtleties of bird wing movements as they soared in ridge lift or when they generate lift through the flapping of their wings. Students

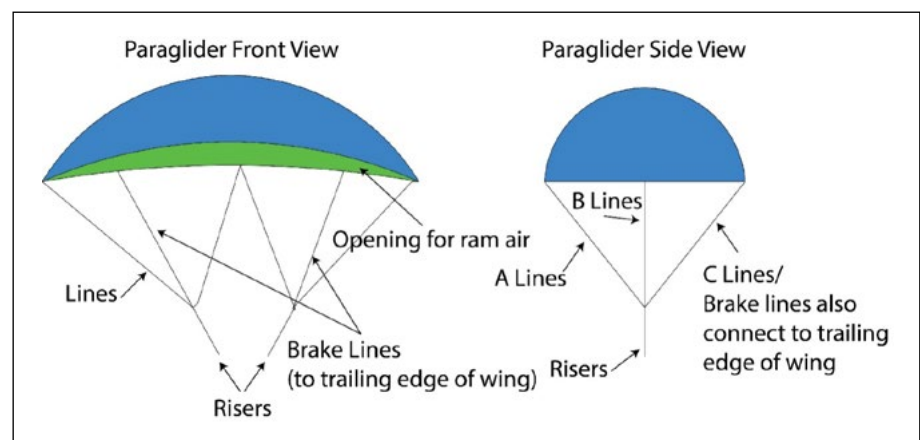


Figure 5. Basic structure of model paragliders.

are encouraged to look up pictures and videos of birds in flight as they design their non-rigid flying wings.

Aspect Ratio

The aspect ratio of a wing is the ratio of wingspan to mean chord. The chord is the distance from the leading edge to the trailing edge of a wing. On a rectangular wing this is an easy calculation. A tapered wing is a little more complicated to calculate. However, for simplicity, a long thin wing (high aspect ratio) is more efficient than a short fat (low aspect ratio) one. Short and fat wings tend to be more stable but less efficient. If you look at pictures of gliders, sailplanes, and paragliders, the more efficient wings are all long and skinny. Efficient wings are wings with a high aspect ratio. A fighter jet on the other hand has short stubby wings. While less efficient, they are more maneuverable. When designing a wing one must seek a compromise between stability (passive safety) and efficiency (less passive safety). Passive safety (low aspect ratio wing) in a non-rigid wing refers to a wing's ability to recover from a collapse without input from the pilot.

A paraglider wing should be constructed of two pieces of material (rip-stop nylon works well) that are either glued or sewn together around the edges. The leading edge should have openings to allow air flow to enter the wing but not escape from the sides or back. Some small amount of reinforcing material can be added to the leading edge to help it stay open but should be used sparingly. No other internal solid structure should be used. Kite string or mason's line works well for the models' lines and should connect to the front, middle, and rear of the wing. Three lines at each location work well but more or less can be experimented with. The wing needs to be under tension so a "pilot" must be included to help the wing

fly. Students can experiment with the amount of weight, or this could be a fixed value that everyone must conform to. Either way, pilot weight is required for this glider to work. Finally, the lines should be adjustable. Trimming a glider for flight takes patience and some trial and error. The trim system should be easy. Clothespins work well but this could be a great opportunity to 3D print a custom trim system.

This project was presented to a group of university students in a technology and society course. Most of the students were not technology education majors, rather they came from a variety of majors as they were in the general education elective. This activity spanned three class sessions that were each 75 minutes in duration. Their experience is documented below.

Designing and Building a Flying Non-rigid Wing

MATERIALS:

- String
- Tape (Packing)
- Scissors

- Fabric (rip-stop nylon or similar)
- Glue
- Weight (to represent a pilot)
Clothespins or binder clips work well

After a lesson on the difference between rigid and non-rigid wings, the students were challenged with designing, building, and testing a flying model of a non-rigid wing based on a modern paraglider. Students were grouped in pairs or groups no larger than three. Each group received 1 square of ripstop nylon fabric (roughly 24" x 18"), kite string, packing tape, scissors, glue (we used hot glue, but a thinner, lighter adhesive would have been better) and a variety of materials such as pipe cleaners, zip ties, etc. The payload (passenger) was a clothespin and/or a binder clip. Gliders were tested by first gliding them around the classroom, then down a flight of stairs (use caution around stairs and make sure to review student expectations before playing around a staircase!). It took some trial and error but eventually about half flew



Figure 6. The best performing wing in the class had 6 lines.

okay and about 20% flew very well. The gliders are made from 1 piece of fabric folded in half and glued (or sewn) along the open edges. The folded edge becomes the leading edge and holes are cut to allow air into the wing.

Lessons Learned (By the Students AND the Instructor!)

Keep the wing simple. Cut holes in the leading edge to allow air into the wing. The wing needs to inflate to be a wing and not a parachute. A strip of packing tape along the inside leading edge of the wing helped to hold the leading edge open and allow the wing to inflate. The number of lines matters. Students found that using only 6 lines was the “sweet spot.” Fewer lines made it hard to trim the wing to fly straight. Too many lines and they just got tangled and it made trimming the wing very difficult. Three lines across the back of the wing and three lines across the front (leading edge) of the wing worked well. Pull all the lines together and pinch with a clothespin or binder clip. You want to be able to slide the lines to trim the wing.

Students were judged on how far their glider flew as well as how straight they could trim it to fly. Tossing the gliders from the top of a staircase worked very well and was a good analog to launching a real paraglider from a hillside. The pitch of a standard staircase is steep enough to approximate a real glider launch site. The following are a few tips to help guide others toward success in their own model paraglider flights.

What to Look for Inflight and Correcting Problems

The lines at the rear of the wing control turns. If the glider keeps drifting right, solve by either making the left trailing edge line(s) tighter or loosen the right trailing edge line(s).



Figure 7. Students getting a close-up look at a paraglider.



Figure 8. A student-built glider in flight.



Figure 9. Students launching their non-rigid gliders



Figure 10. Students designing and building their non-rigid wings.

If the wing collapses along the entire leading edge (a symmetric frontal collapse), loosen the center front lines and/or the other two front lines. Adjustments should be small, about half an inch or less at a time. If one side of the wing is collapsing in flight (asymmetric collapse) loosen the lines on the side that is collapsing.

We found that these model gliders behaved very similarly to how a real paraglider performs. The collapses in flight were identical to collapses on a real paraglider wing, and the corrections for collapses were also the same. The project was a challenge but was more successful than it seemed like it might be. The students in this class were college freshmen and sophomores in a technology and society class. Most of the students were from non-technical majors and not accustomed to building things in a college classroom. The space that this class is held in is a very traditional college classroom set up for lectures with tablet desks. If this untraditional setup allowed for success, a more traditional technology and engineering lab would most likely allow for even better results. The cost of the project was minimal as it used simple supplies. The nylon fabric is readily available online and at local fabric stores for minimal cost.

Conclusion

The students and their instructor learned much about building working models of non-rigid wings. Both were surprised by how successful some gliders were, but also at how very fine changes made drastic differences in glider performance. Most importantly, however, students were engaged in a hands-on project that brought the history of the technology they were studying in class to life. The instructor noticed that everyone was engaged, excited, and motivated to learn more. This activity is very approachable for any age level. As shown here, the rigor can still excite



Figure 11. Designing and building!

and engage college students but would still be perfectly attainable by elementary, middle, and high school students with appropriate modifications for tools, safety around stairs, etc. Students reported that they enjoyed engaging in real-world problem solving and that feeling the struggle to build a working glider helped to provide insight into what the early pioneers of flying must have felt as they too tried to become masters of the air.

ITEEA Technological and Engineering Standards

- STEL-6F Relate how technological development has been evolutionary. Often the result of a series of refinements to basic inventions or technological knowledge.
- STEL-7AA Illustrate principles, elements, and factors of design
- STEL-7BB Implement the best possible solution to a design
- STEL-7CC Apply a broad range of design skills to their design process
- STEL-7DD Apply a broad range of making skills to their design process

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Want to learn more about flying non-rigid wings?

<https://www.youtube.com/@inboundwithwhiskyalpha>