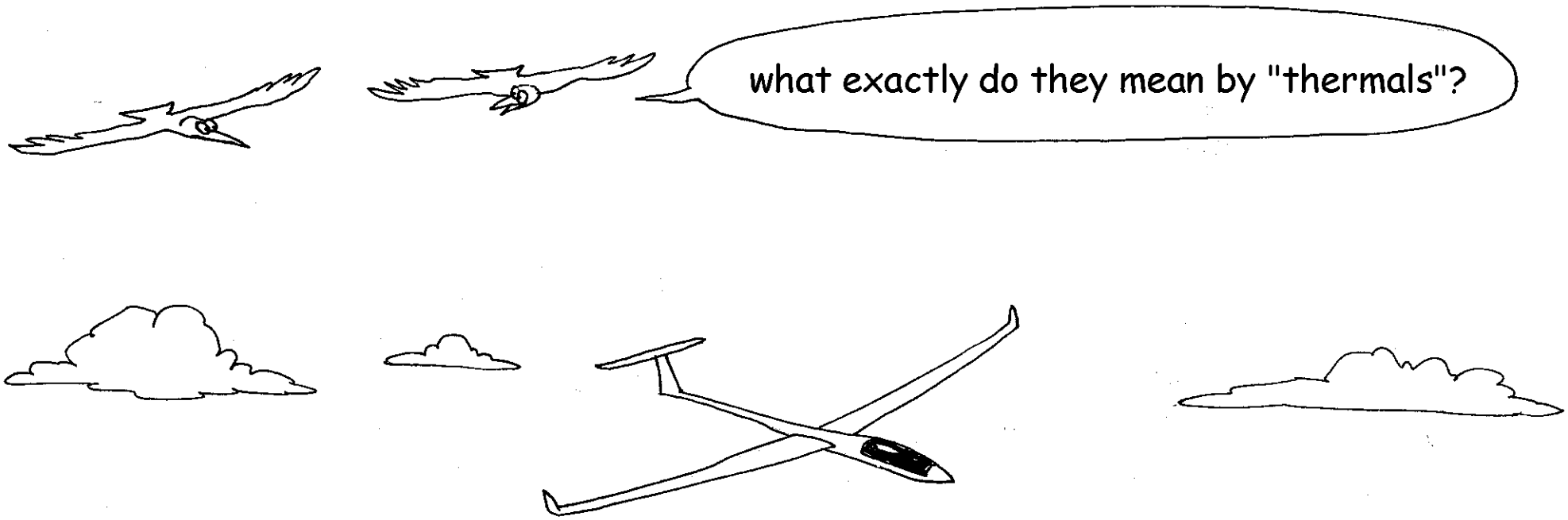
http://savoir-sans-frontieres.com

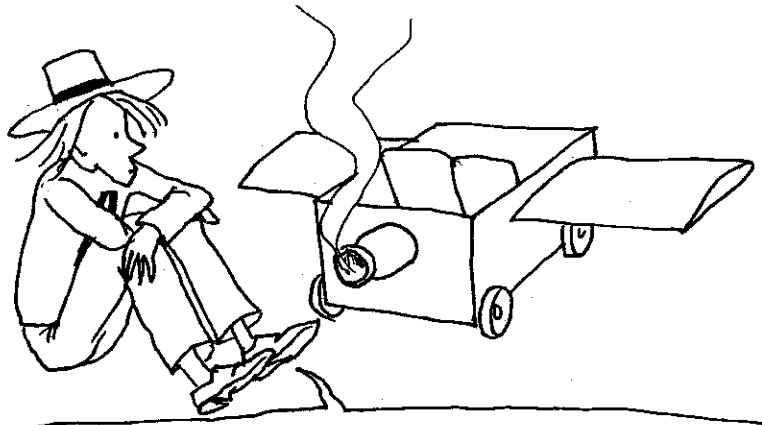


Jean-Pierre Petit, 2008

FLIGHTY MECHANICS

Translation: Pau Amma, 2011

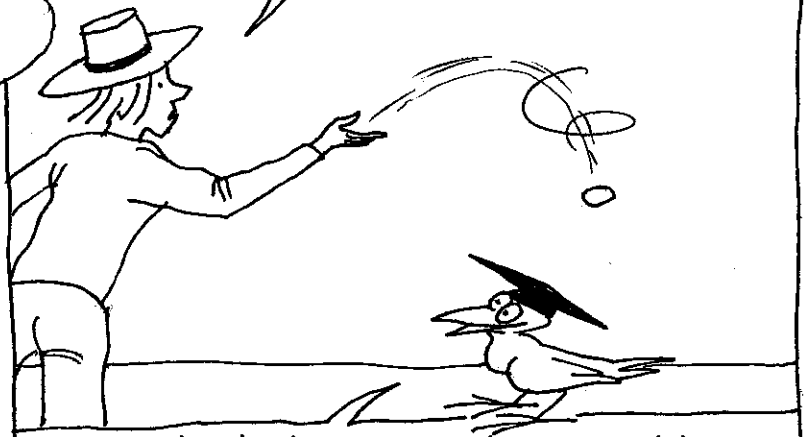
GLIDING



rocket propulsion is still hard, polluting and all. Until I have another engine design, how could I stay in the air?

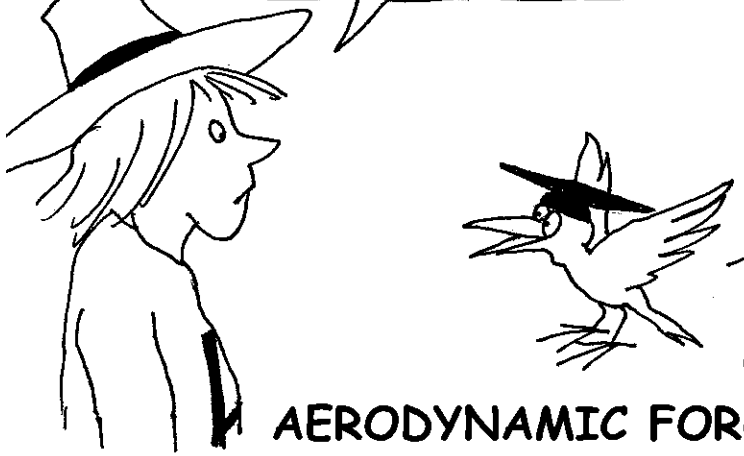
why not try using gravity?

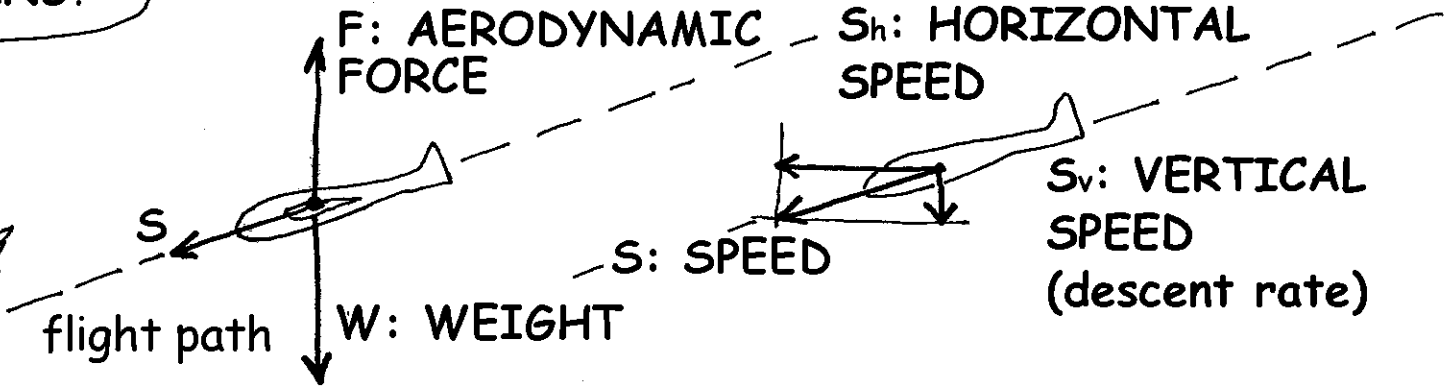
gravity? But that's not an **ENGINE**. When I throw a pebble, it falls down, nothing else. You can't call that flying.



you don't have to plummet like a stone. By **GLIDING** you can take your time going down.

what do you mean by **GLIDING**?

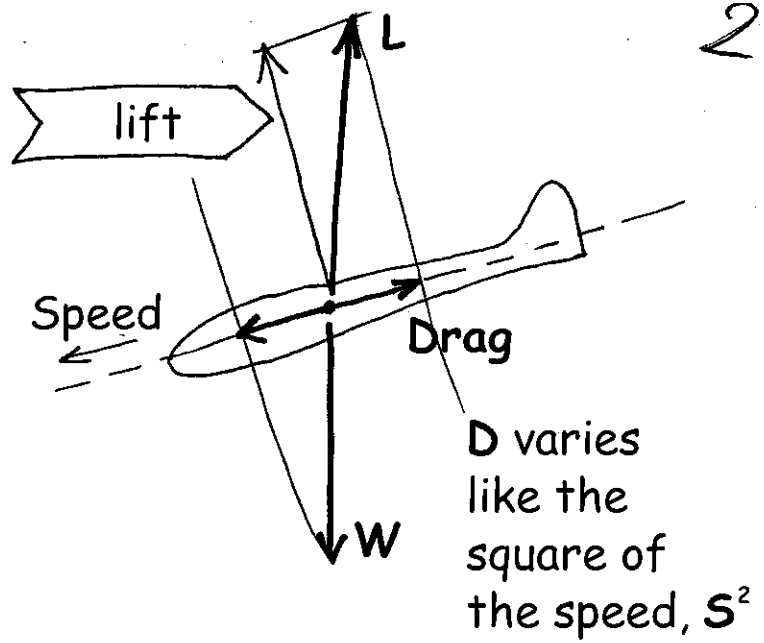




with **WINGS**, you can, if moving with speed **S**, create an **AERODYNAMIC FORCE F** proportional to the square of that speed, S^2

if I read your drawing right, weight **W** is the exact opposite of force **F**. But how come it has to be that way?

think: the drawing shows **STEADY FLIGHT**, at a constant speed **S**, with corresponding **ANGLE OF DESCENT** **α**. Your **SAILPLANE**'s(*) motion is associated with a **DRAG** force that balances out the propelling component of the **WEIGHT**



so the bottom line is, your weight moves you forward. That's truly a miracle

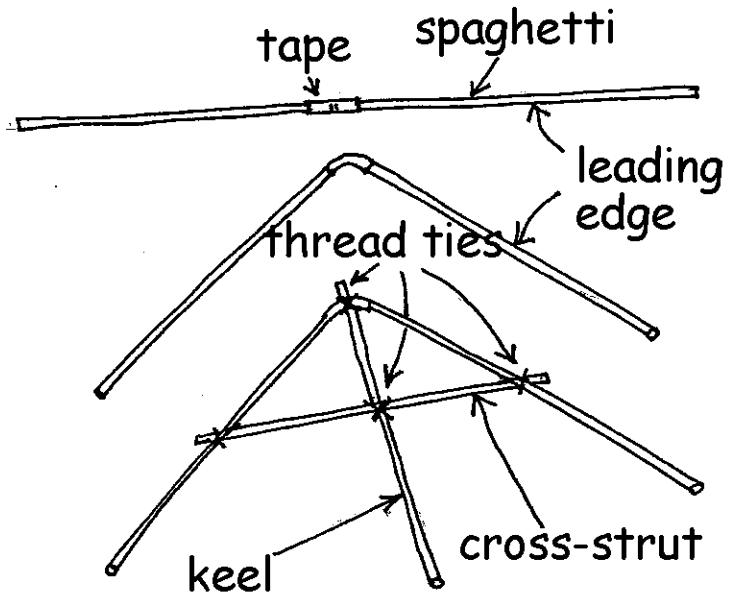
Tiresias, I know you never strapped on skis, but it's exactly the same. It's the skier's weight vector, projected on the **SLOPE**, that moves them forward. When going downslope steadily, at a constant speed, this motive force is balanced out by the **FRICTION** of the skis against snow, that goes up with speed **S**

(*) Also called "glider", although that term is more commmonly applied to hang gliders or paragliders. (See below pages 5 and 36.)

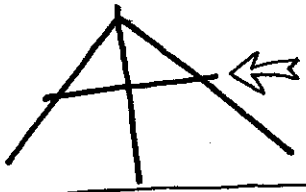
hey, Lenny, you never strapped on skis either!?

look, Archie, we're going to build a very simple flying machine using paper, tape, spaghetti, and a clothespin

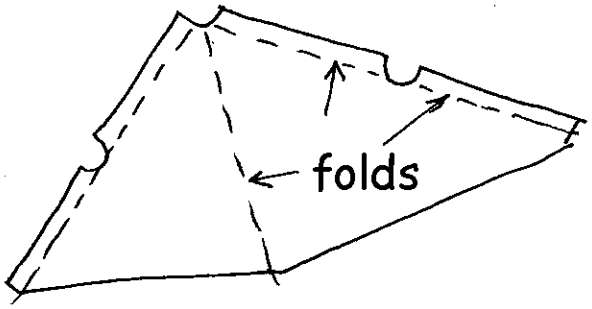
and a spool of thread

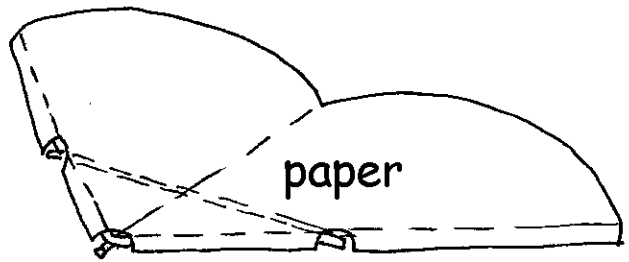


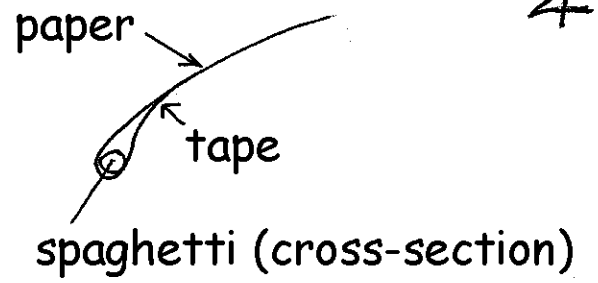
woman's stuff...



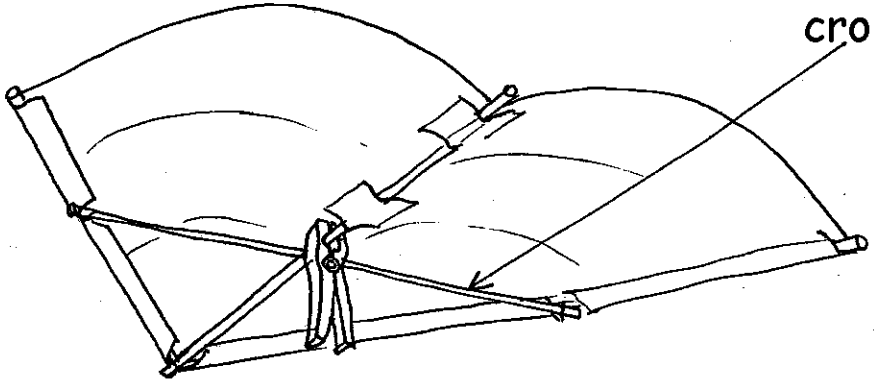
We'll build that frame out of spaghetti jointed with tape and tied together with thread

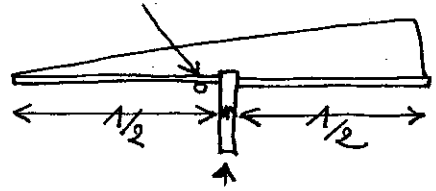


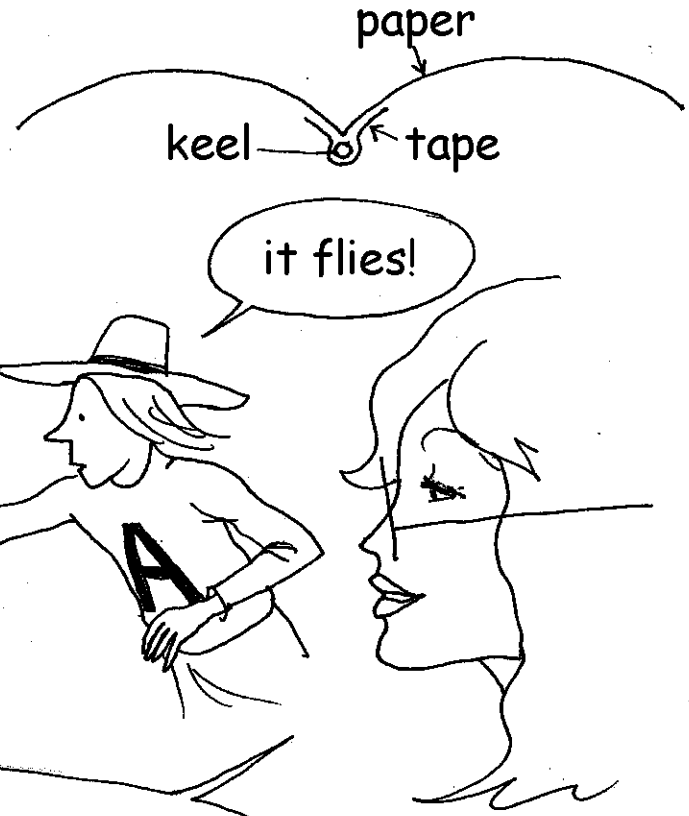




attaching the wing to the tube frame

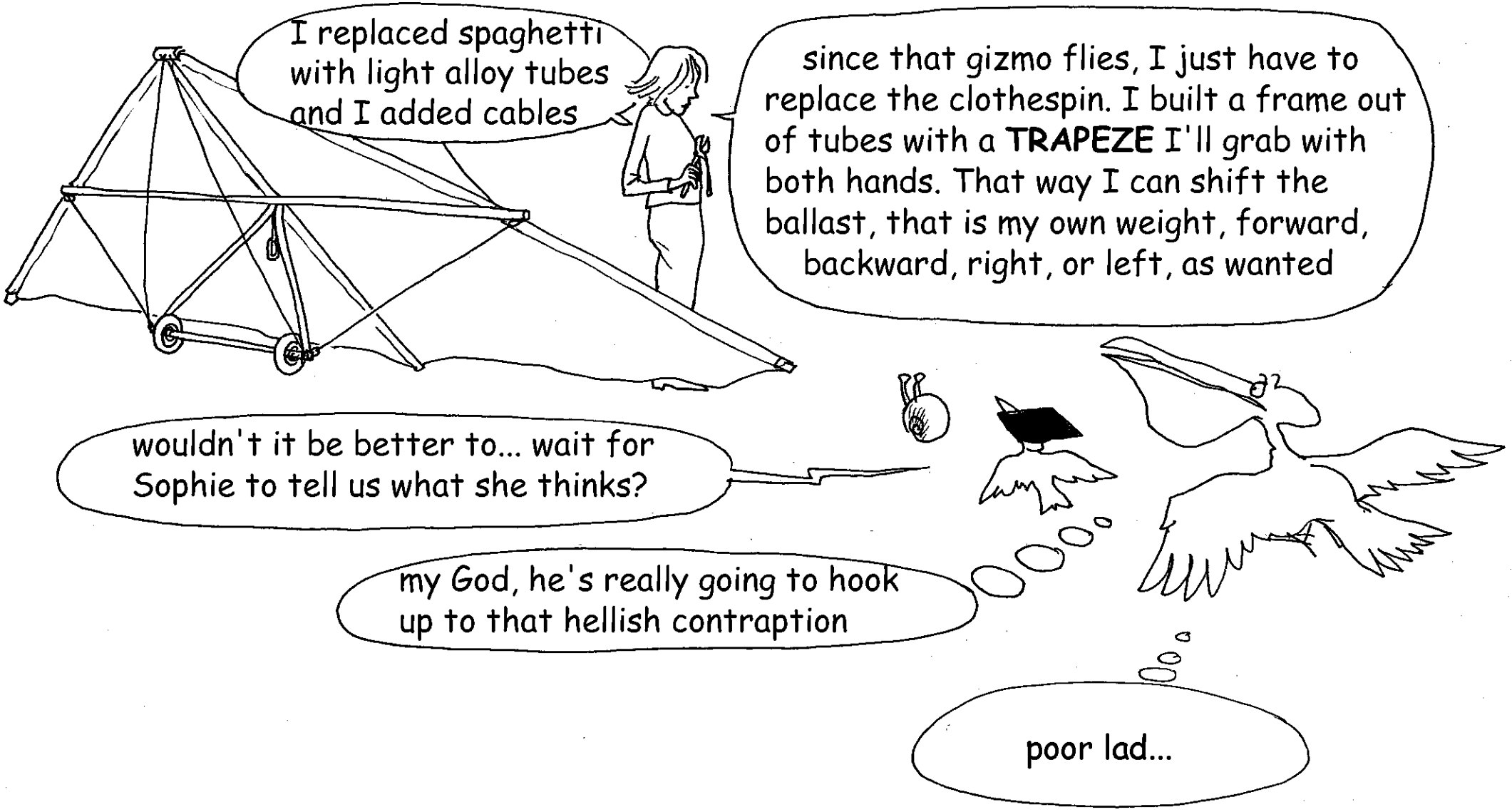


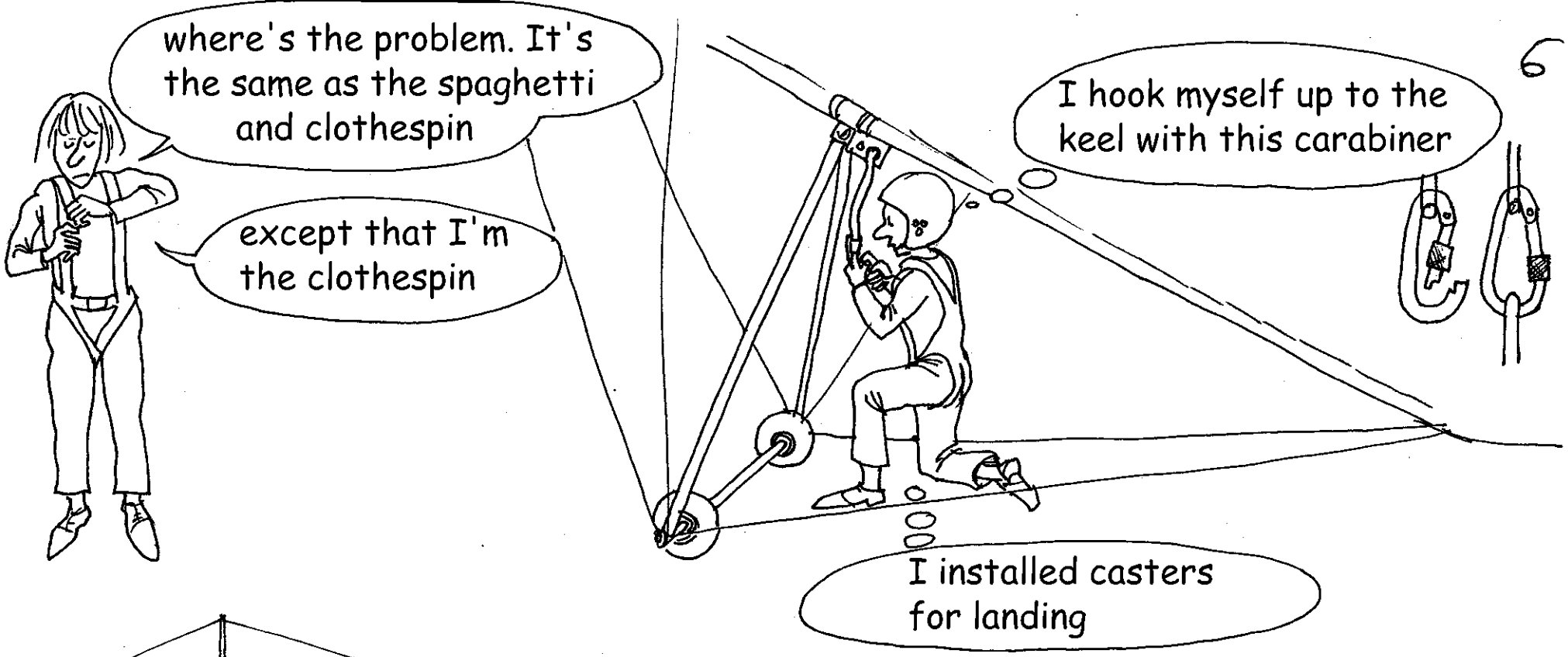


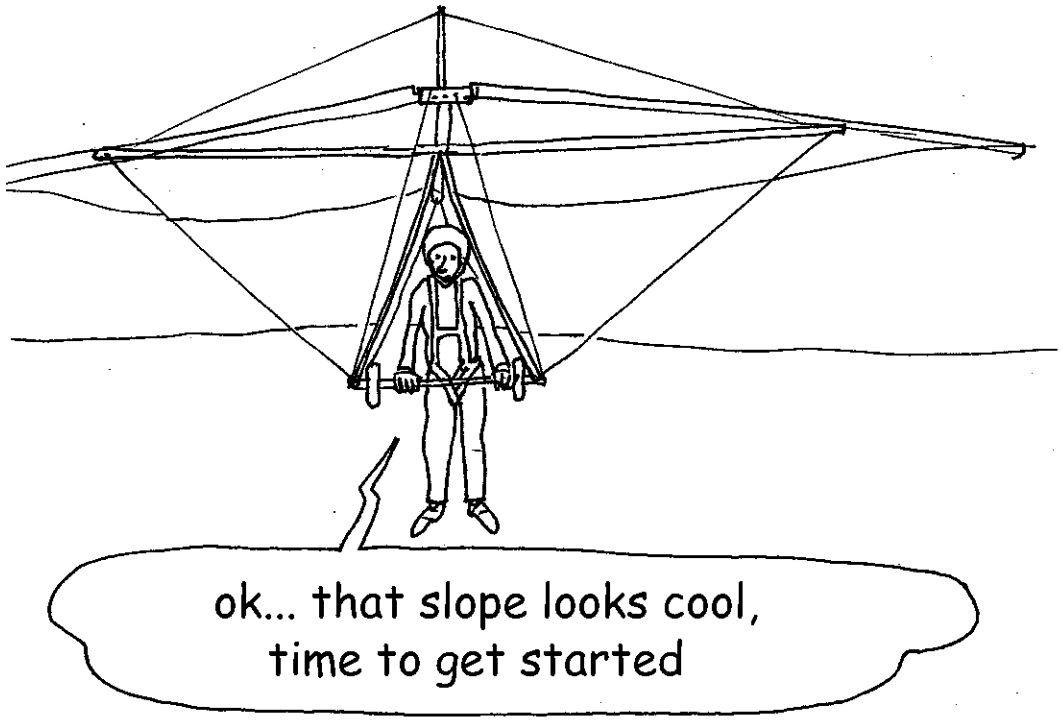


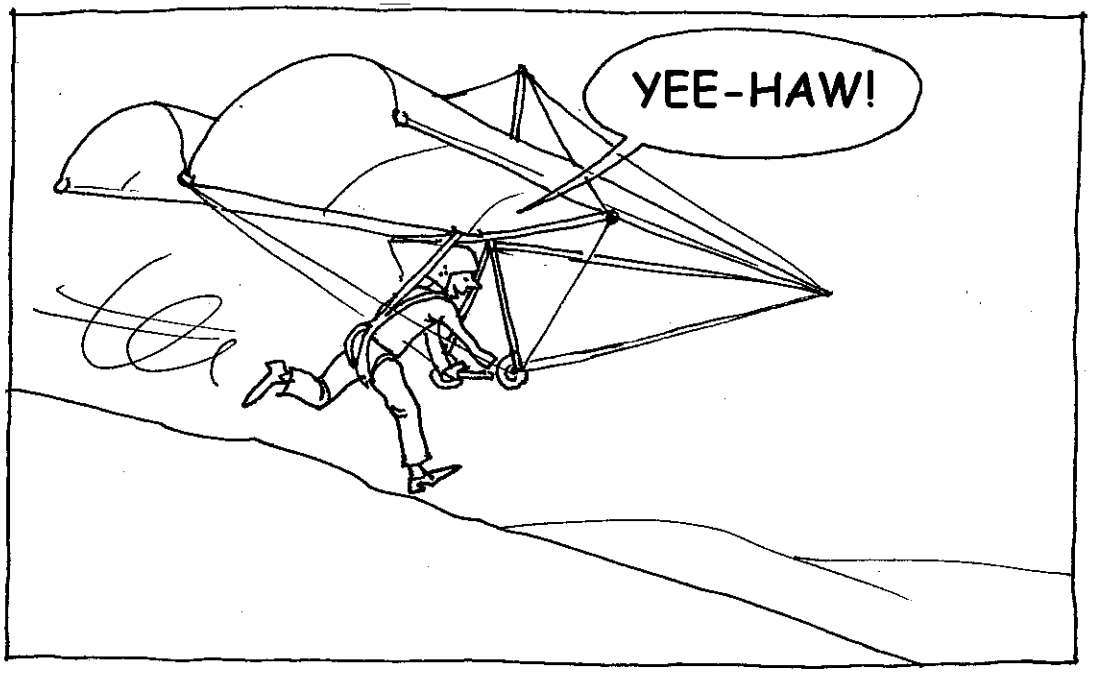
you adjust **CENTERING** by moving
the clothespin forward or backward

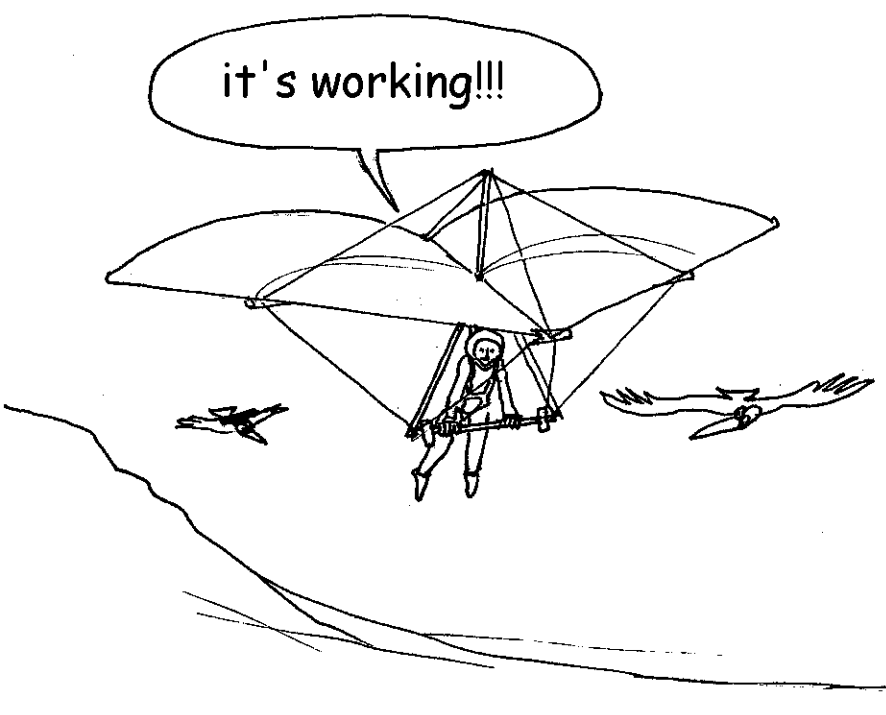
HANG GLIDER

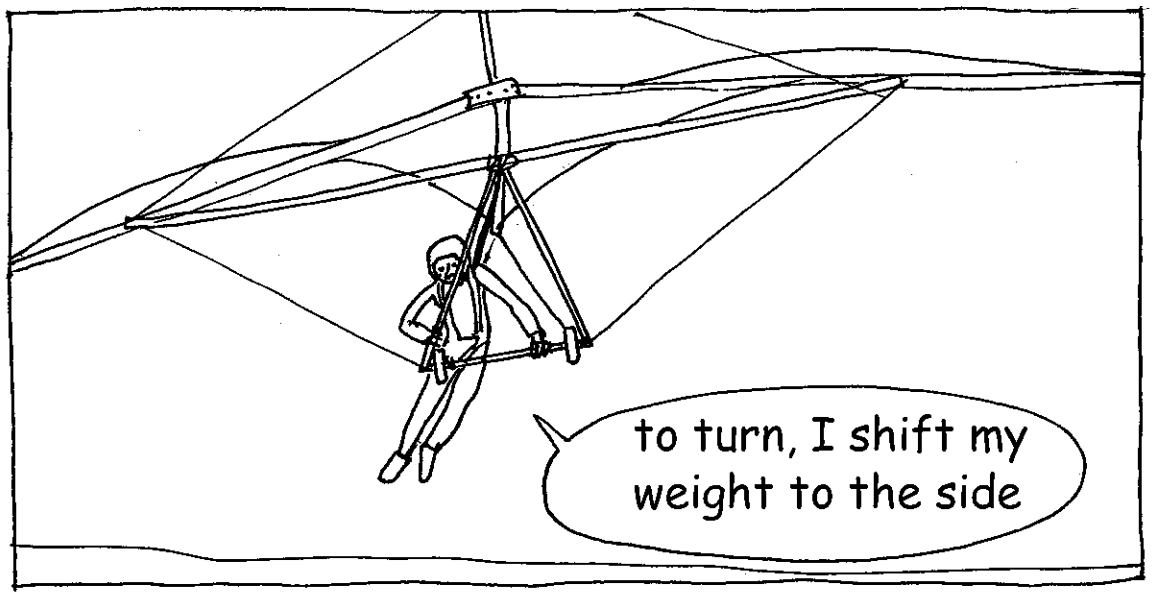

I replaced spaghetti with light alloy tubes and I added cables
since that gizmo flies, I just have to replace the clothespin. I built a frame out of tubes with a **TRAPEZE** I'll grab with both hands. That way I can shift the ballast, that is my own weight, forward, backward, right, or left, as wanted
wouldn't it be better to... wait for Sophie to tell us what she thinks?
my God, he's really going to hook up to that hellish contraption
poor lad...


where's the problem. It's the same as the spaghetti and clothespin
except that I'm the clothespin
I hook myself up to the keel with this carabiner
I installed casters for landing


ok... that slope looks cool, time to get started

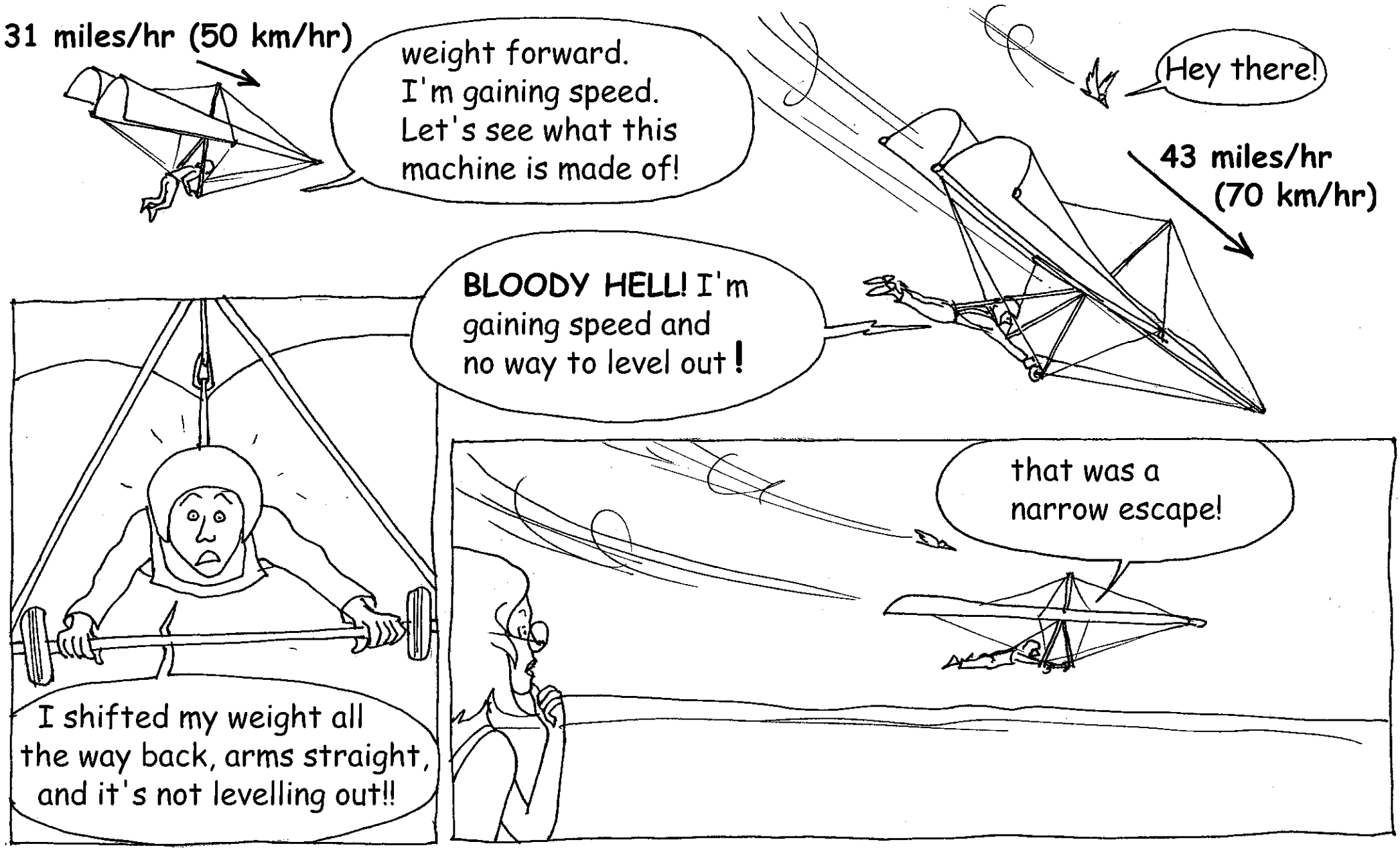

YEE-HAW!


it's working!!!


to turn, I shift my weight to the side

in a straight line: descent rate 8.2 feet/s (2.5 meters/s). When turning, strong slip inward and descent rate is 11.5 feet/s (3.5 meters/s)
glide ratio 3. Barely better than an anvil

SELF-STABILIZING



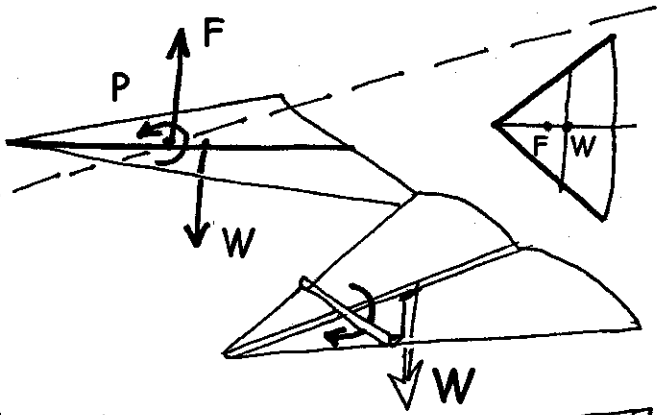
flare up to shed some speed

Sophie, why did the machine no longer want to level out?

Archie, remember the first volume of this comic. You can only get **LIFT** at the expense of a **PITCHING MOMENT P**. It's the same with your **HANG GLIDER**. It's your weight **W** that balances the diving torque in flight. You're hanging from halfway down the keel, behind the **AERODYNAMIC CENTER** of your wing, which in a hang glider is located 40% back of the **LEADING EDGE** (*)

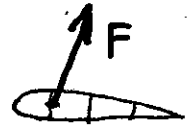
I was sure I wouldn't make it

pitching moment P



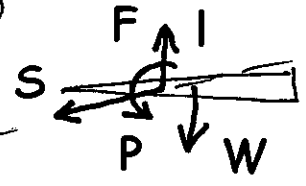
shifting the weight **W** backward creates a counter-moment that balances out the aerodynamic pitching moment

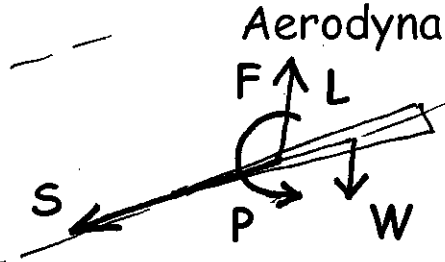
(*) In STRAIGHT wings the aerodynamic force **F** is applied at 25% back ot the leading edge

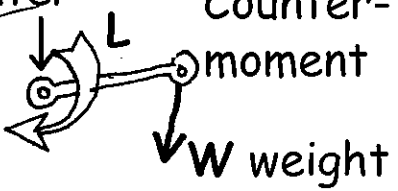


AERODYNAMIC CENTER

but why did my machine refuse to level out?







think about it: the counter-moment you get from shifting your weight is **W x L**. It balances out the pitching moment **P**, which varies like the square of the speed, S^2, like all aerodynamic effects (**LIFT**, **DRAG**) that together add up to the **AERODYNAMIC FORCE F** (*) applied to the wing's **AERODYNAMIC CENTER**. With your hang glider, if you dive and gain speed, you'll get the pitching moment **P** (which varies like S^2 as well) to a value so high that your counter-moment **W x L** will be unable to overcome it (**)

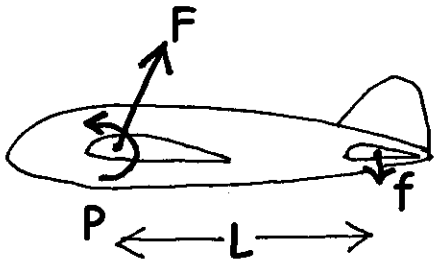
Archibald was that close to leaving his **FLIGHT ENVELOPE** and getting an **UNCONTROLLABLE** machine!

But that's horrible! What's the solution to that?

(*) Some textbooks call this **RESULTANT AERODYNAMIC FORCE**, abbreviated to **R**

(**) Lack of awareness of this hazard caused many accidental deaths through the 1970s

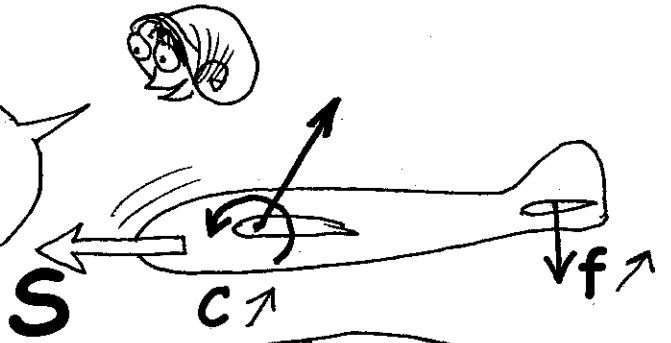
an aerodynamic problem requires a solution of an aerodynamic kind. That's what Sophie suggested to Archie in the first book of this series with the **TAILPLANE**



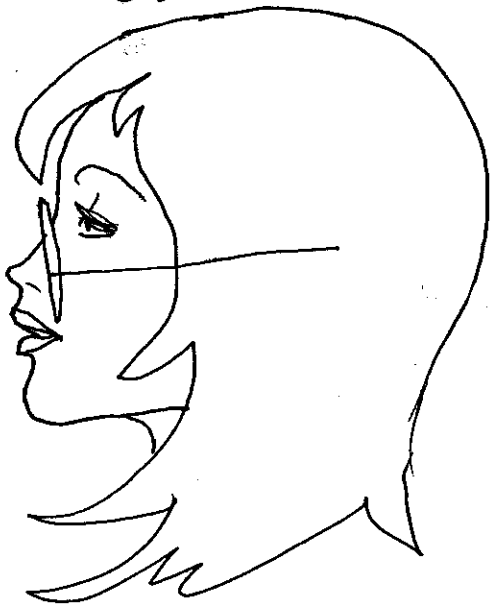
$P = f \times L$

A horizontal tailplane with a slightly negative lift easily balances the wing's torque due to the wide lever arm of the fuselage.

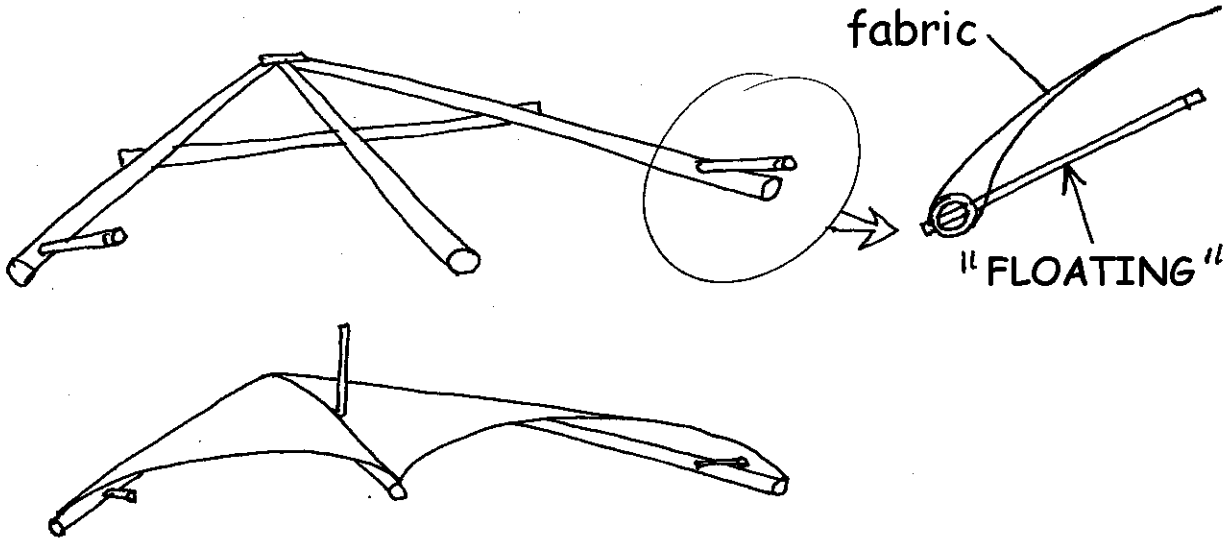
this system is also **SELF-STABILIZING**. If speed increases, the aircraft tends to pitch forward and down as the pitching moment **P** (which grows like S^2) goes up. But this is instantly balanced by the increased **DOWNFORCE f**

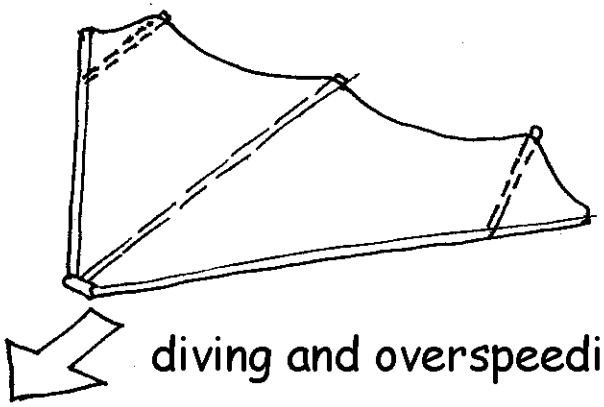


so I just have to add a tailplane to my hang glider?



you could indeed do it that way. But there's a simpler way to ensure your safety

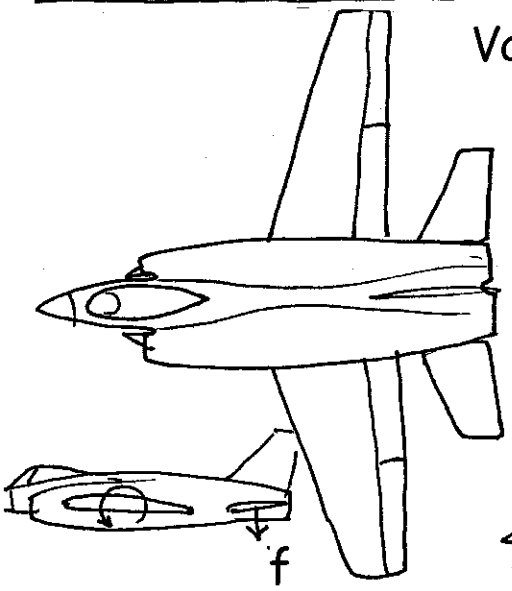


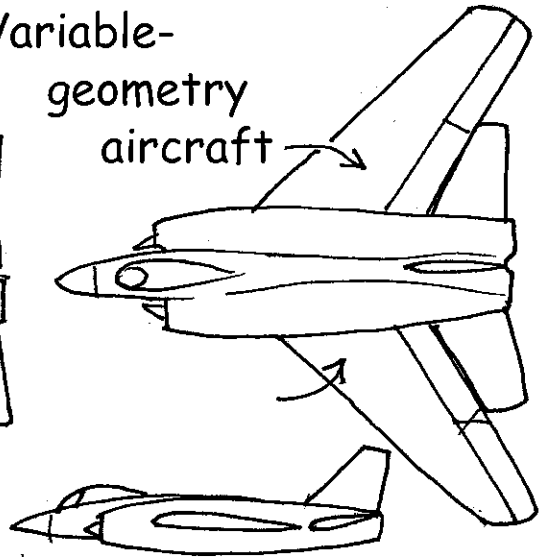


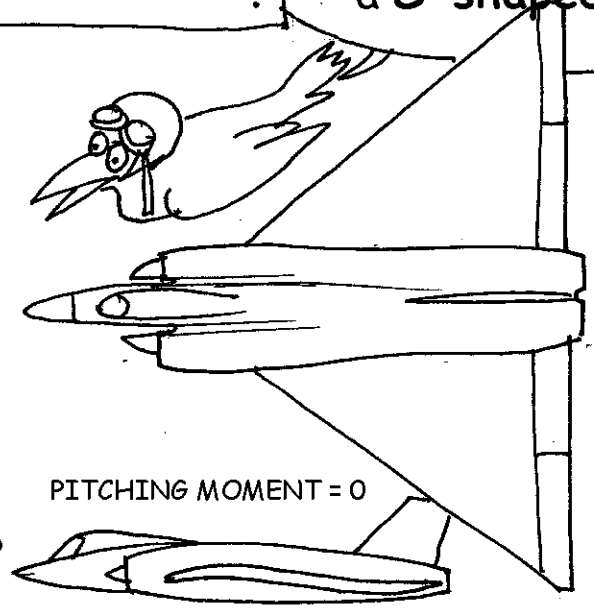
diving and overspeeding wing

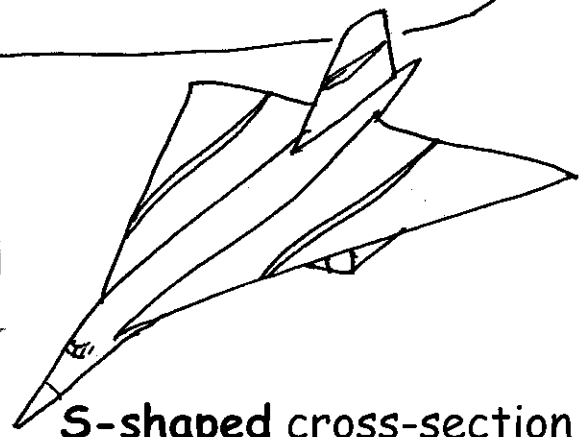
these devices, called "**FLOATINGS**", do not touch the sail in normal flight, but if overspeeding or nosediving become dangerous, they keep the back of the sail raised, forcing automatic leveling out (*)

Aircraft with rigid delta wings are made self-stabilizing (flying with pitching moment = 0) by merging the tailplane into the main wings and giving the airfoil a **S-shaped** cross-section





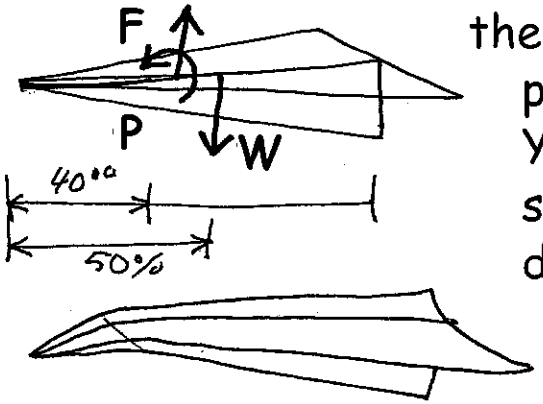




S-shaped cross-section of Concorde wing airfoil

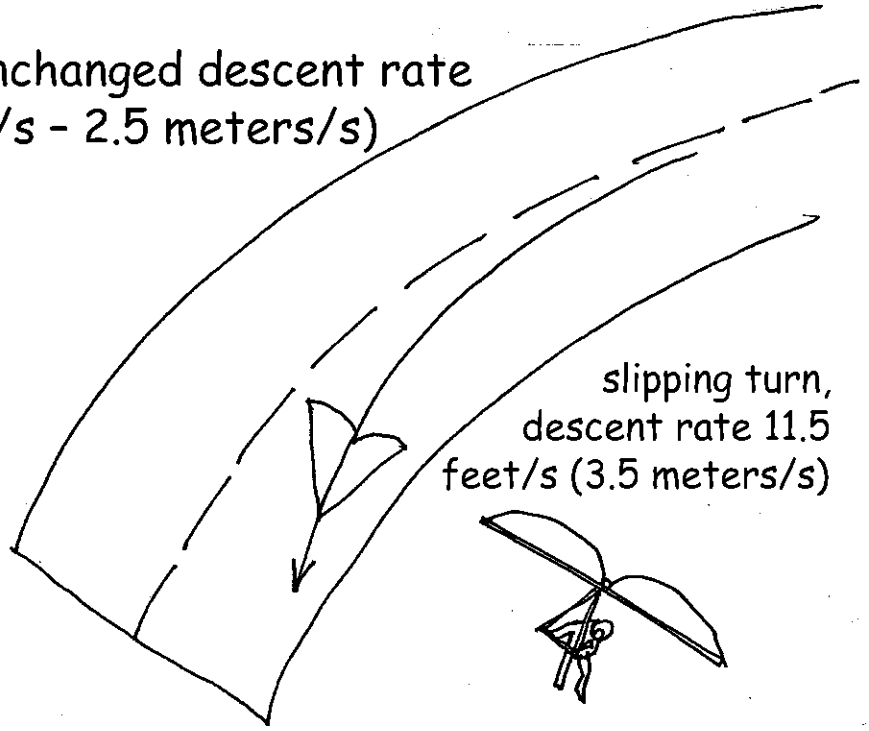
a traditional paper dart flies like a hang glider. The center of gravity is obviously in the middle, whereas the **AERODYNAMIC CENTER** is 40% along the **CHORD** of the airfoil. The counter-moment from the weight balances out the pitching moment from the lift. In a deep dive, it won't level out. You can make the airfoil self-stabilizing by folding down the nose slightly and by raising the tail equally slightly, This makes the dart S-shaped and lets it (among other things) fly more slowly.

The Management



turn at unchanged descent rate
(8,2 feet/s - 2.5 meters/s)

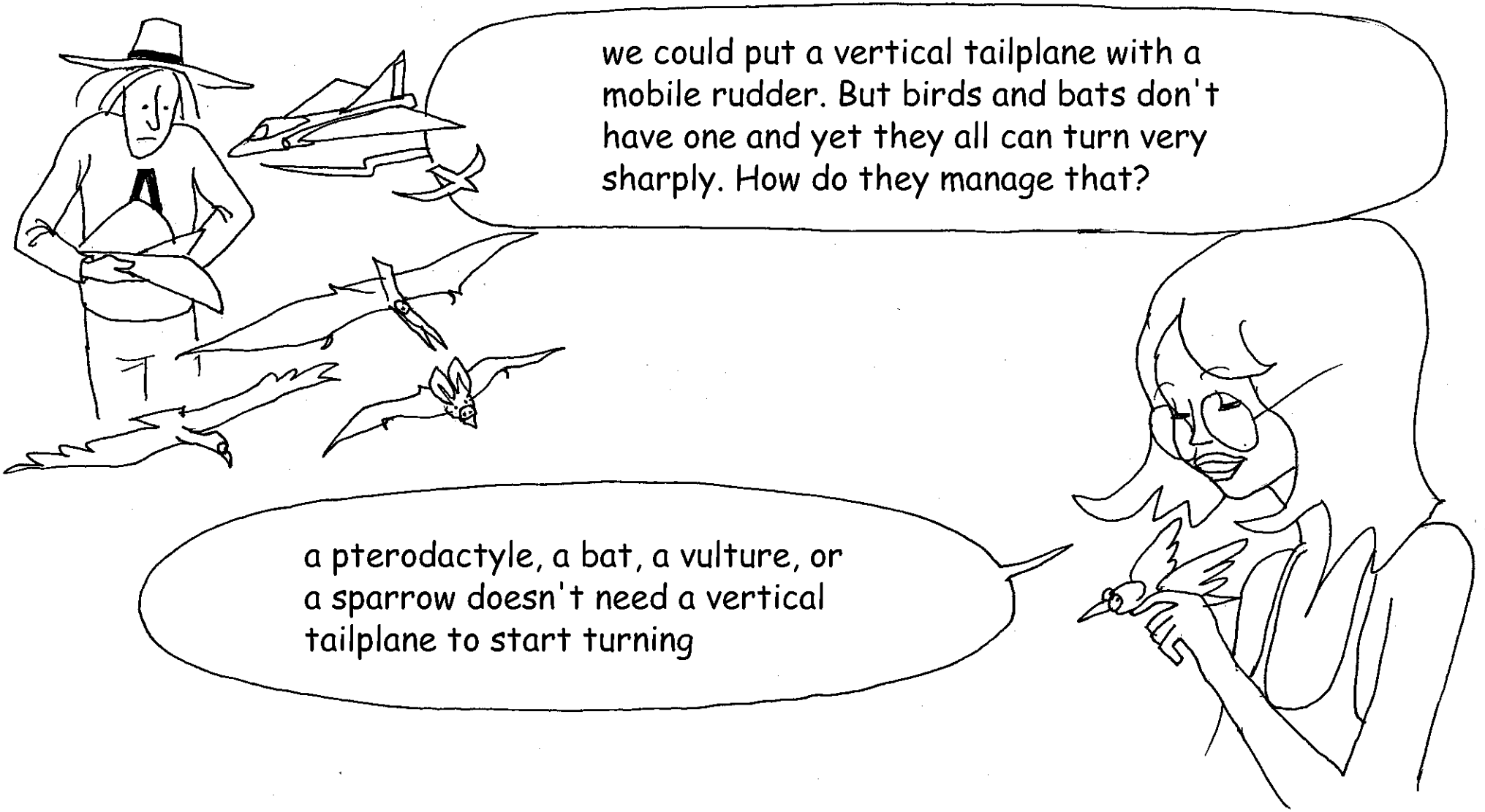
but your machine still has a major shortcoming. To turn, you must shift your weight in the turning direction, and this starts a strong **SLIP INWARD**. The **DESCENT RATE** becomes **11.5 feet/s (3.5 meters/s)**



slipping turn,
descent rate 11.5
feet/s (3.5 meters/s)

(*) these simple devices were shown at once to work perfectly.

HOW DO BIRDS MANAGE TO TURN?

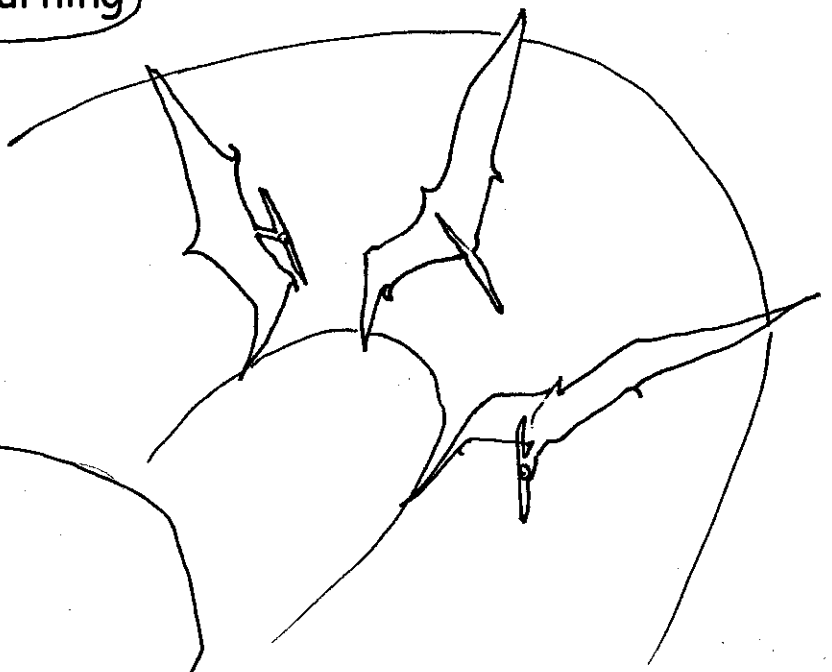


By extending a wing and folding the other, you get two results: the wing surfaces are changed. The extended wing has its trailing edge get lower, and conversely for the folded wing.

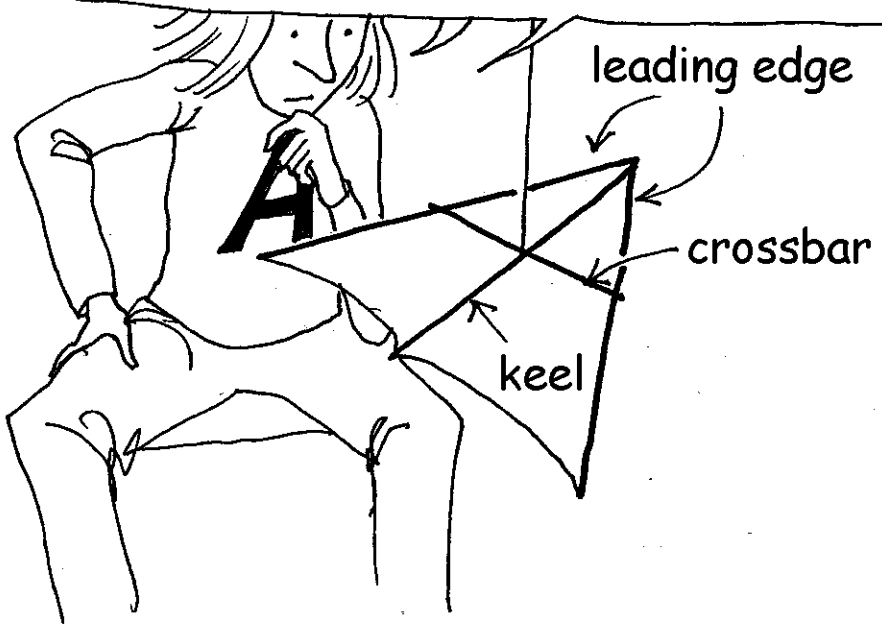
Pterodactyle seen from behind flying in a straight line

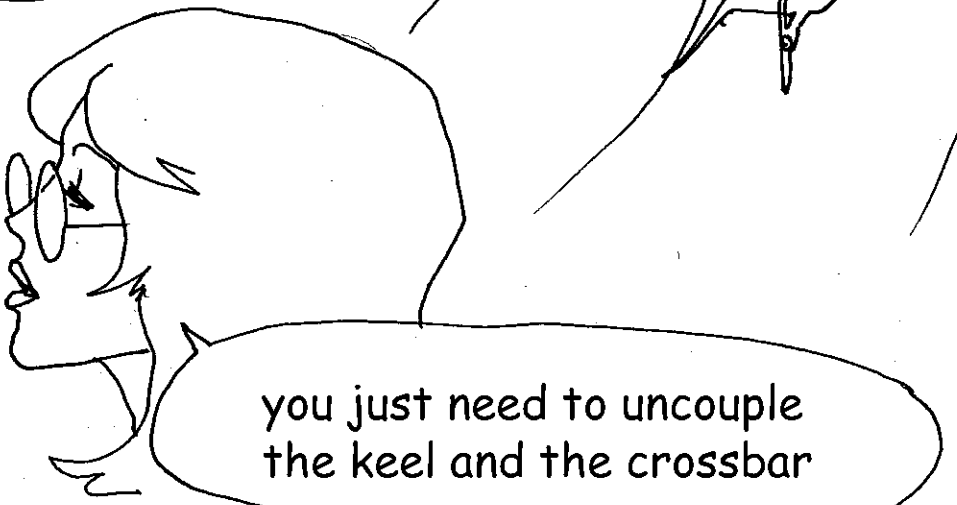
no one right, I'm turning

Safety check

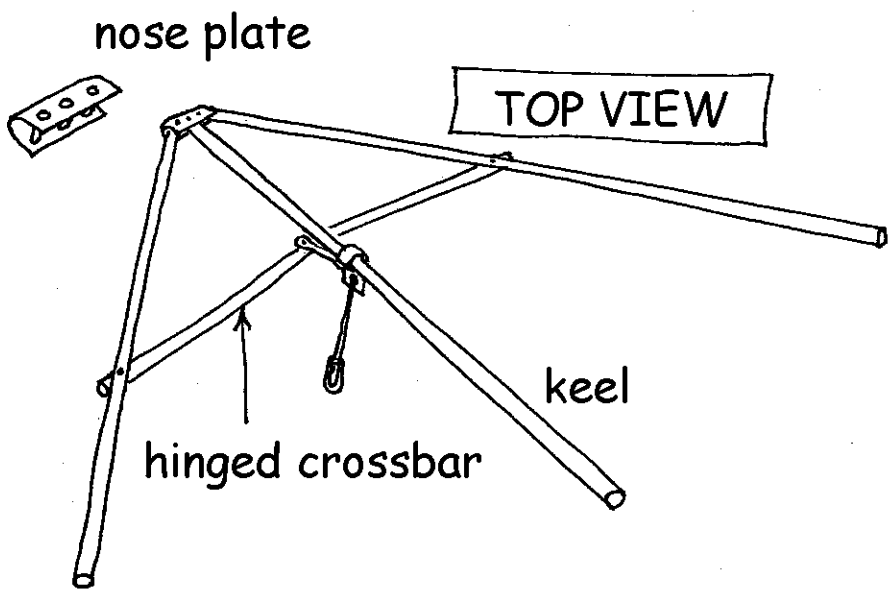


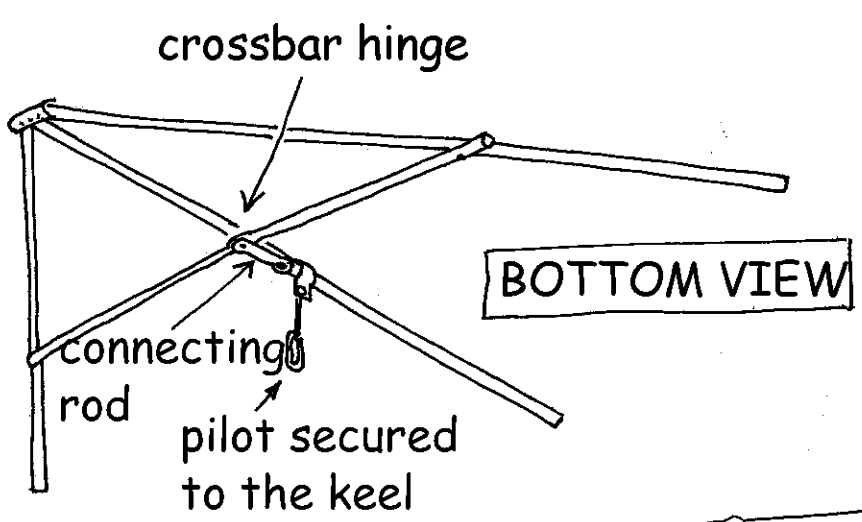
That's fine and dandy, but how can I extend a wing and fold the other, even slightly?

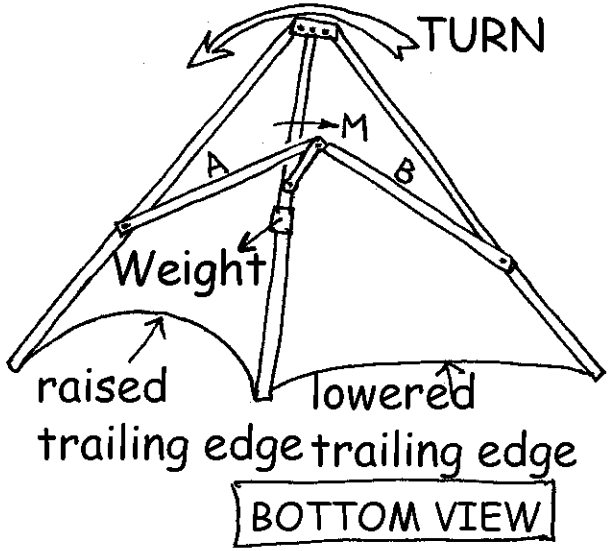


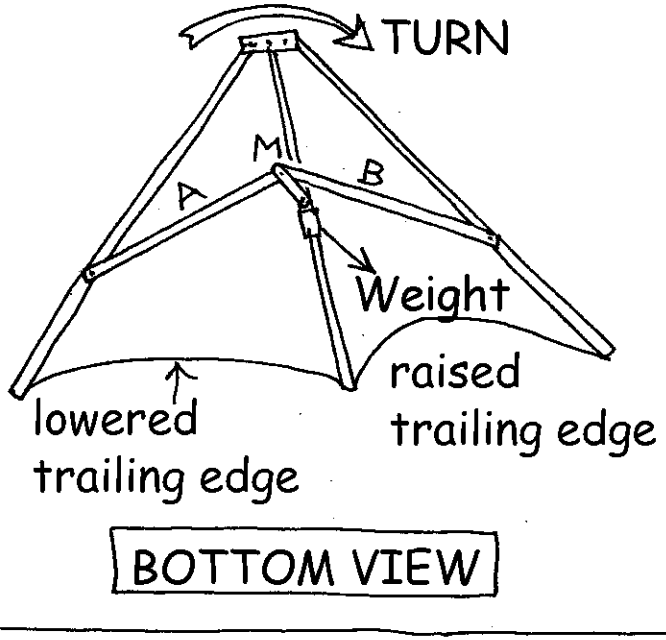


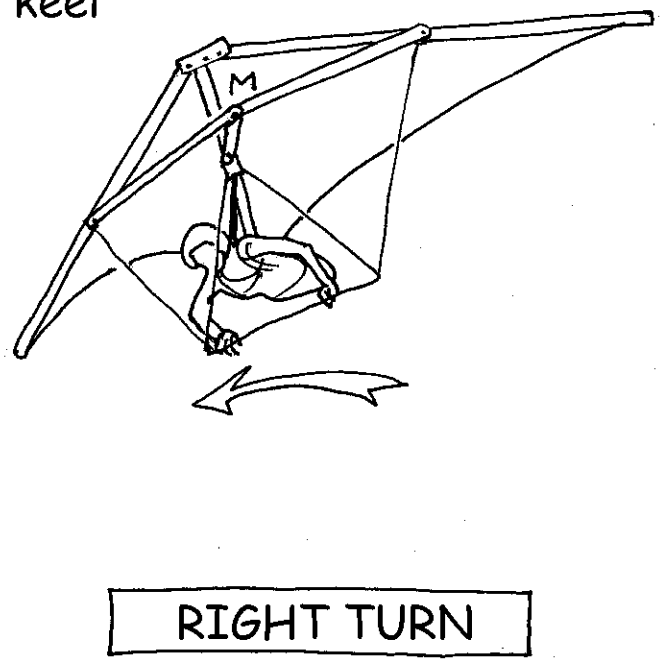
you just need to uncouple the keel and the crossbar





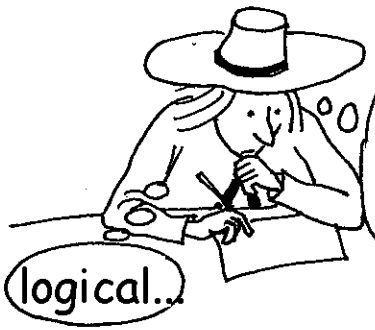






This very ingenious design called "floating crossbar" lets the pilot, by shifting weight, to move the keel from the hinge M of the half-crossbars A and B, which have the same length. Moving an inch or two (a few centimeters) lets you make tight turns.

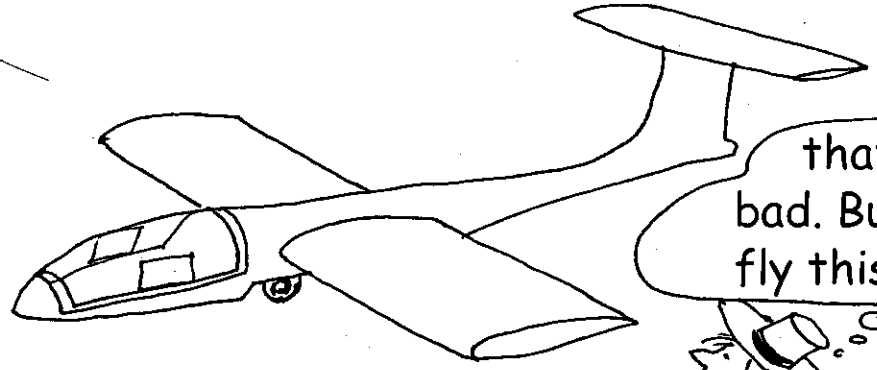
The Management



logical..

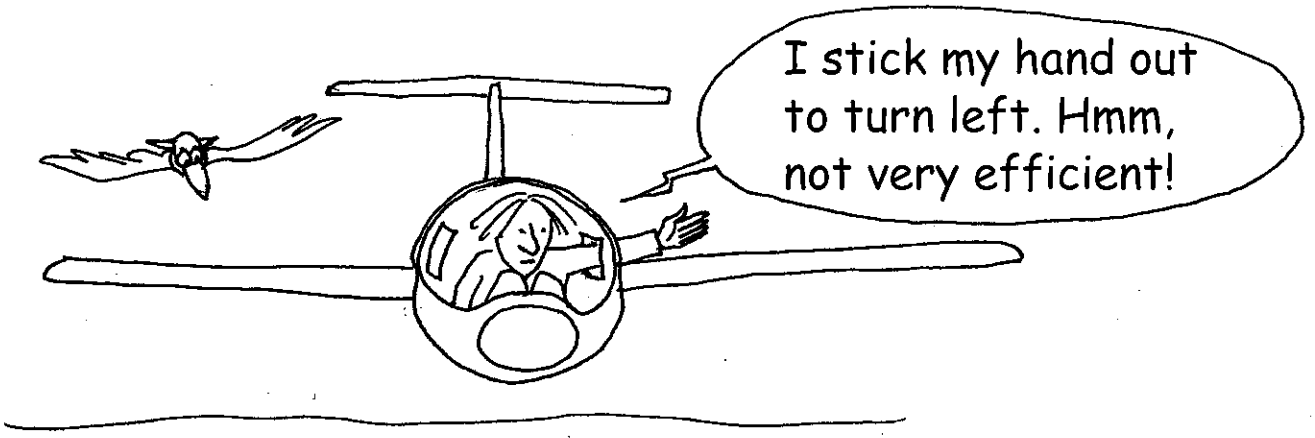
if I want to design an efficient **SAILPLANE**, I have to get rid of all sources of energy waste, **TURBULENCE** first and foremost. If my sailplane leaves behind a lot of air set in motion in its wake, that's wasted energy

all these cables are the source of significant **DRAG**: remove them. The pilot: inside the structure. Smooth walls, without protrusions. Everything needs redesigning

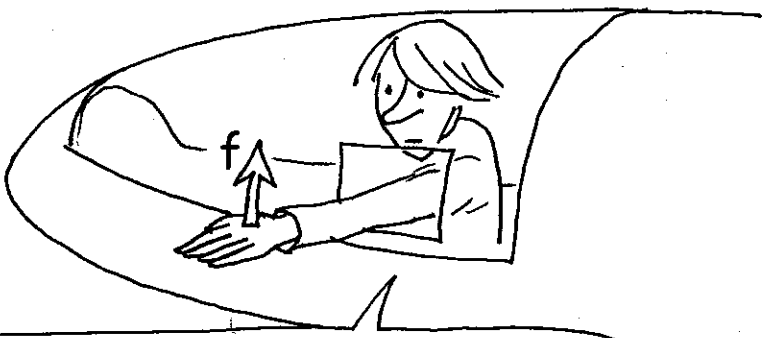


that's not bad. But how do I fly this machine?

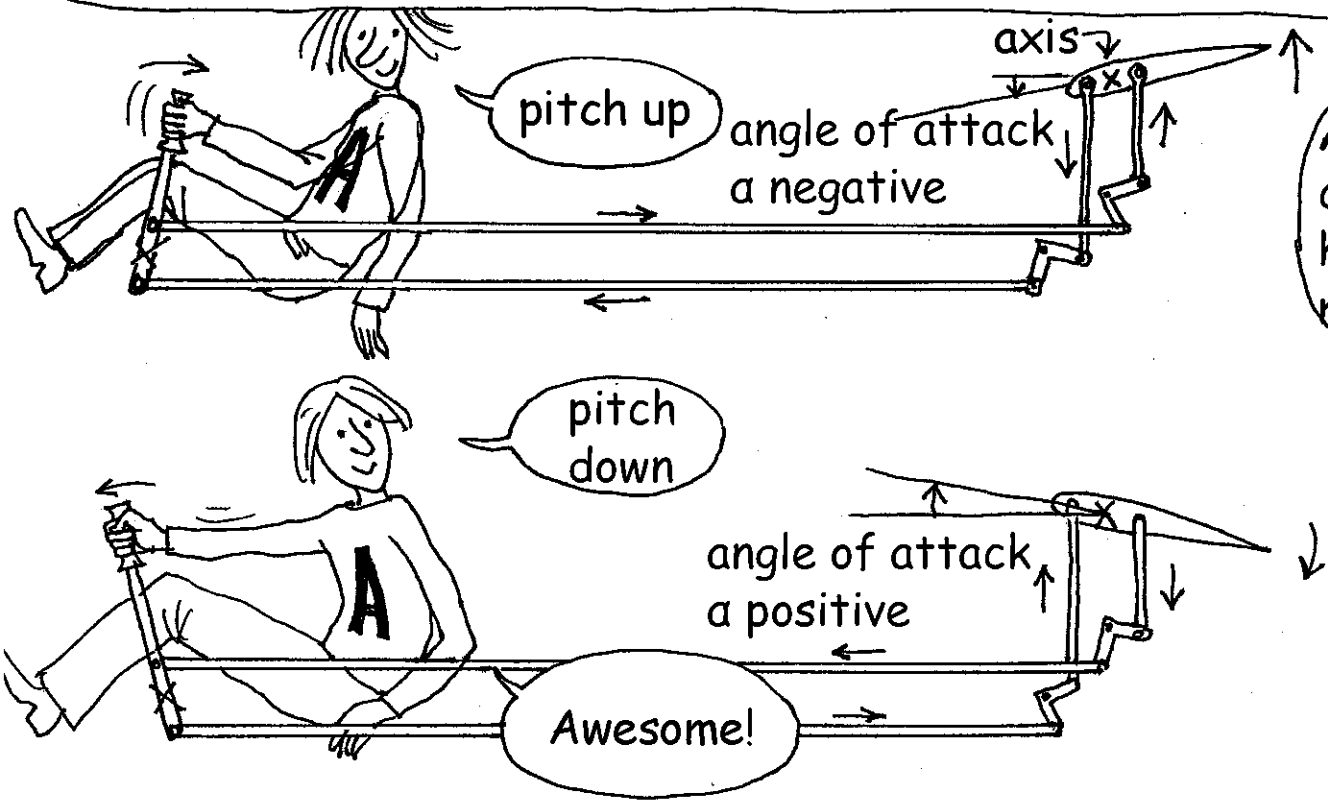
I can move back and forth in the cockpit to climb or dive. I installed windows on both sides, and by sticking out my hand I can turn. But it's not very efficient and it causes turbulence, which is exactly what I want to avoid at all cost



By the way...

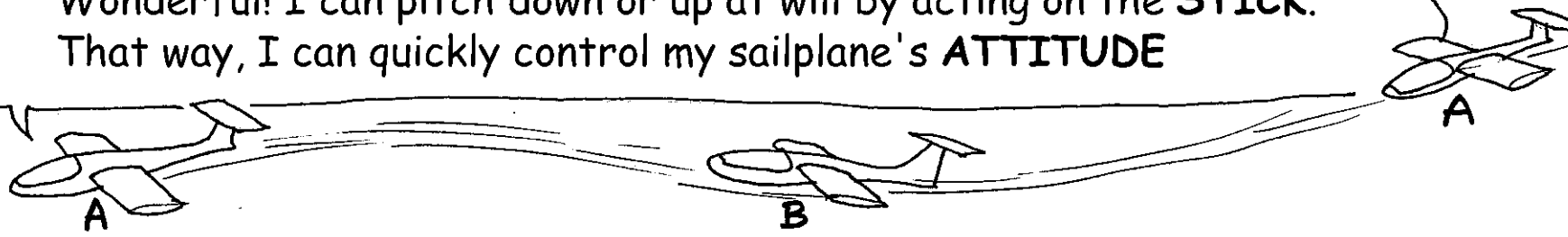


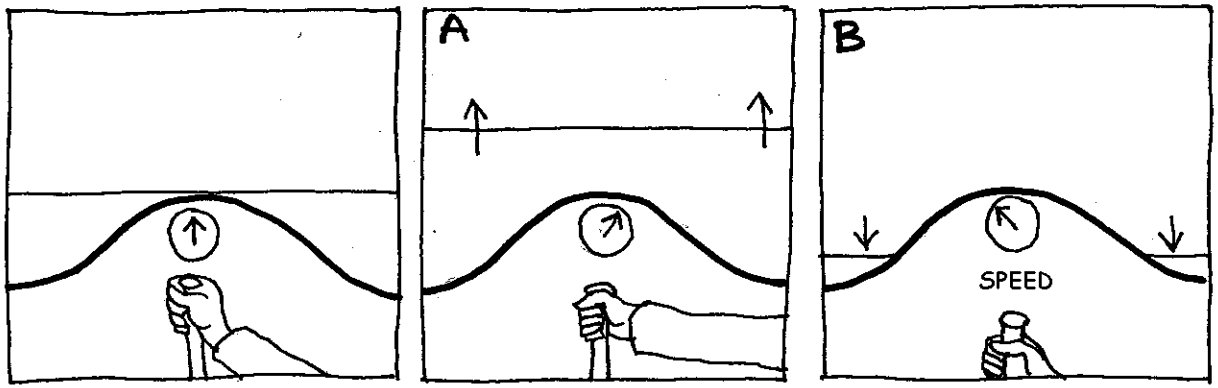
Now that's interesting. When I stick out my hand that way, kind of like a wing, and I change its **ANGLE OF ATTACK α**, the force changes by the same ratio as the angle. Let's rig a horizontal tailplane with an angle of attack a I can change at will



thanks to these **ACTUATING RODS**, Archie can remotely control the horizontal tailplane of his flying machine using a **JOYSTICK**

Wonderful! I can pitch down or up at will by acting on the **STICK**.
That way, I can quickly control my sailplane's **ATTITUDE**



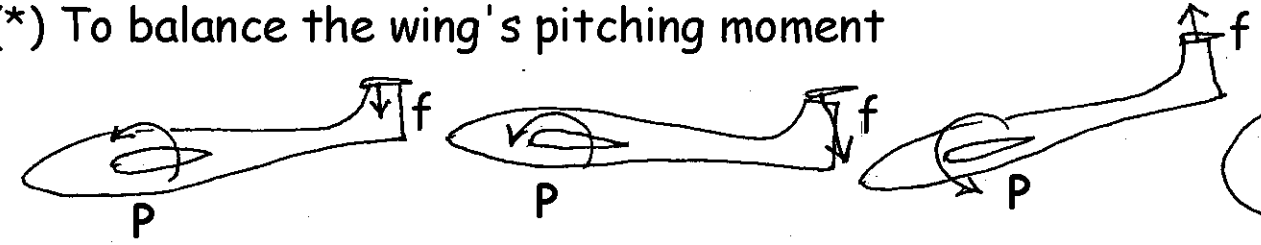


normal descent, stick in "neutral". The tailplane applies a slight downforce (*)

Archie pitches down by pushing on the stick: the horizon goes "up", speed increases

Archie pitches up by pulling on the stick: the horizon goes "down", speed decreases

(*) To balance the wing's pitching moment



I can just use my sailplane's cowling to check its **ATTITUDE**. If the horizon goes up, it means I'm pitching down. If the horizon goes down, it means I'm pitching up. The sailplane's speed changes accordingly.
Pitch-down attitude: it increases.
Pitch-up attitude: it decreases

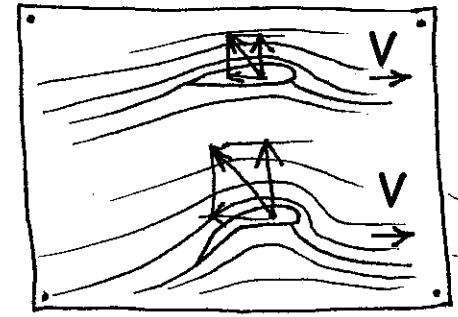
this **COWLING CHECK** is a most useful indicator

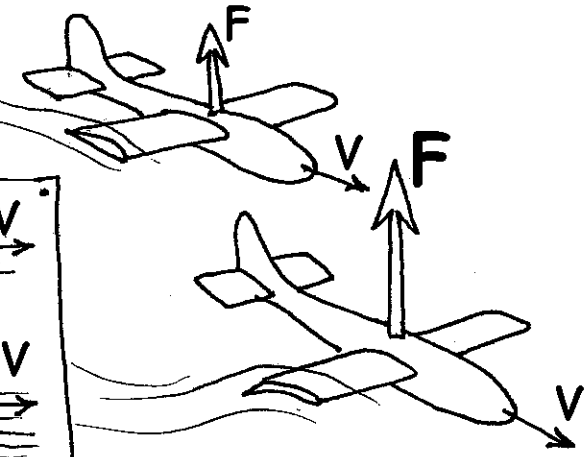
The faster a sailplane goes, the louder and more audible the noise from wing friction becomes. Before speed meters were invented, sailplane pilots could be recognized at their elongated ears, from adaptation

WING FLAPS

OK, **PITCH** control works well enough. But turning isn't anywhere near ready. Meanwhile, I'm going to watch birds, see how they fly

there!





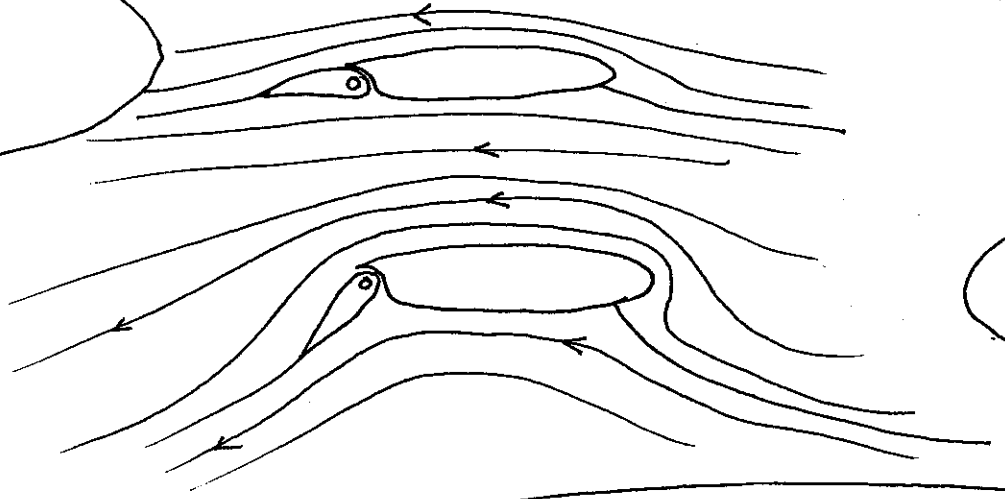
At the time they land they curve their wings by pulling on the feathers using muscles

By increasing the curvature of my **AIRFOIL**, the aerodynamic force the wing creates becomes higher for the same speed **S**. Conversely, by shaping their wings this way, birds can **APPROACH** at a lower speed

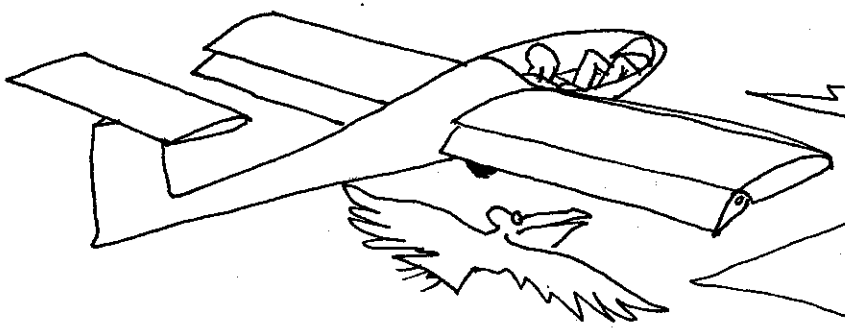
I cannot bend these wings. However, I can attach the back part using hinges

wings with... hinges!?!

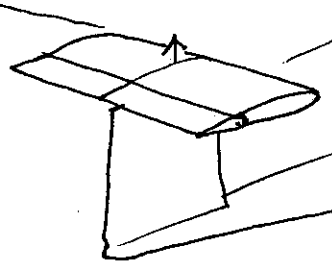
Look at this! Archie replaced wing feathers with a hinged assembly!

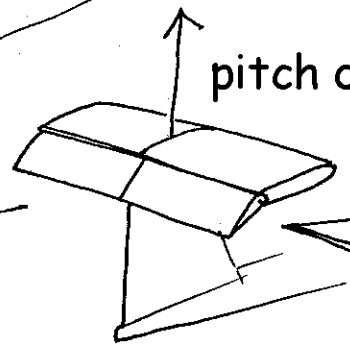


that's the airflow



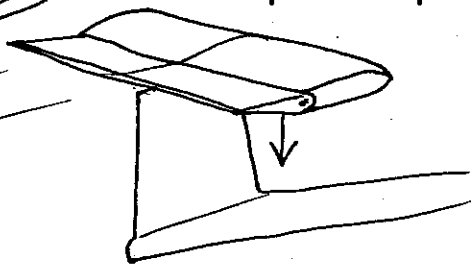
When landing, FINAL APPROACH is already much less of a bruiser





pitch down

pitch up

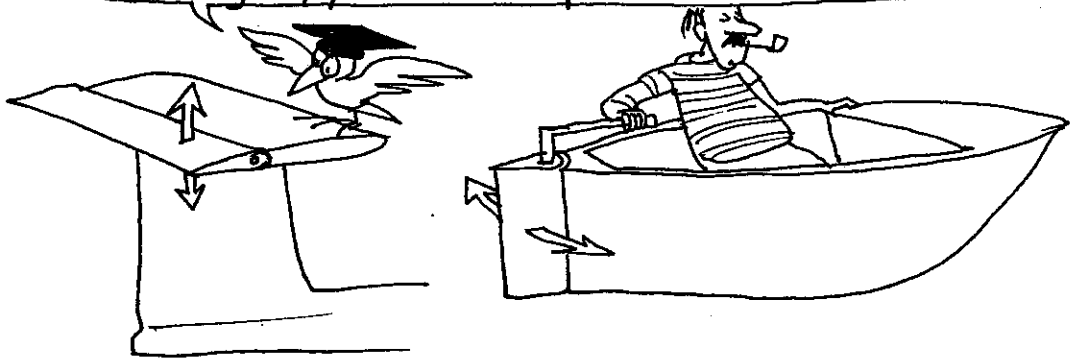


But why not use that hinged design everywhere, including on the horizontal tailplane?

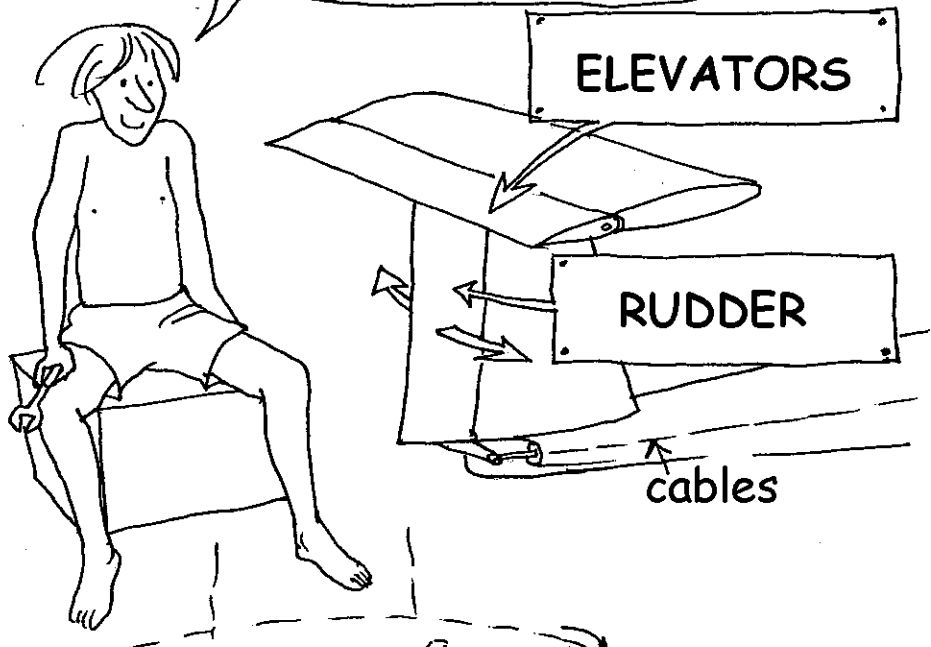
no sooner said than done

CONTROL SURFACES

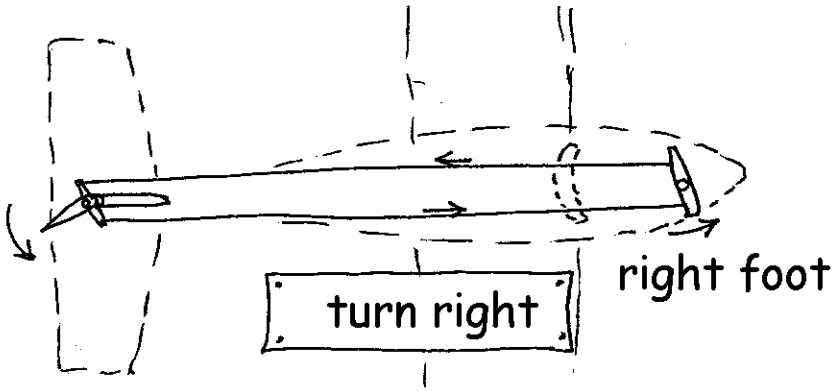
In the end, it works like a boat's **RUDDER**, except that instead of steering left or right, you steer up or down

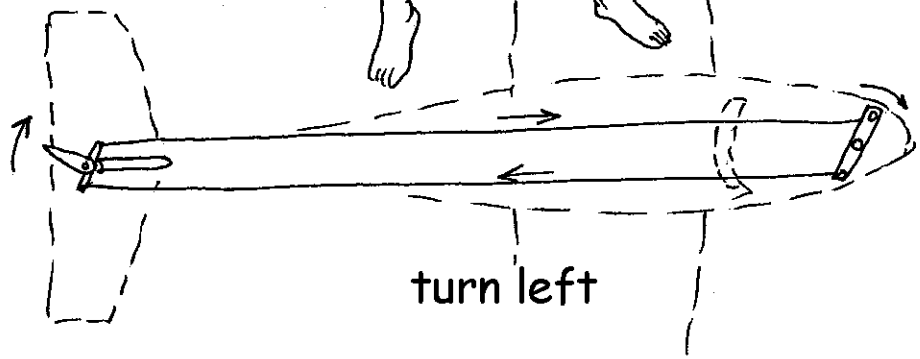


Hey, that's the solution! Why bother trying to turn by sticking out either my right hand or my left hand? I can just equip my sailplane with a **RUDDER**!



which I will control from my **COCKPIT**, using my feet, by attaching cables to the rudder and to a **RUDDER BAR**



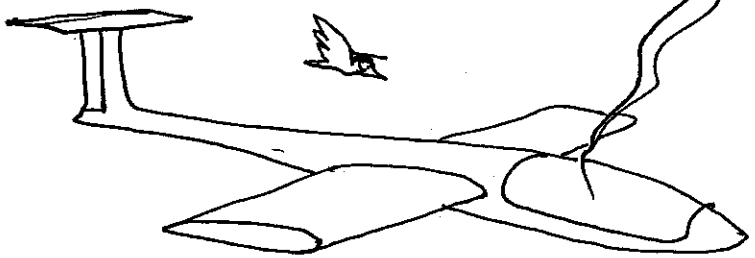


so, how is my favorite flyer man doing

wonderfully, Sophie. **FLIGHT MECHANICS** has nothing hidden from me. You just need to put control surfaces in the right places, and you can go up, down, right, or left

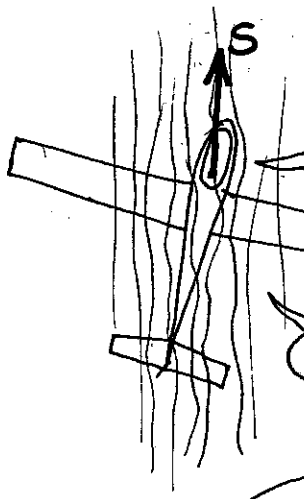
I even built a two-seater sailplane and if you'd like, I'll take you for a ride

Here. We're taking off downslope. With this joystick I can go up or down at will, and normally, by using the rudder bar



Gosh! I'm pushing my foot all the way and it's not turning! Sailplane's crabbing and nothing else!?!

what the...!



think: with your rudder, you just turned your fuselage askew. And since it doesn't catch the wind, we're **CRABBING** and nothing else

don't get it...

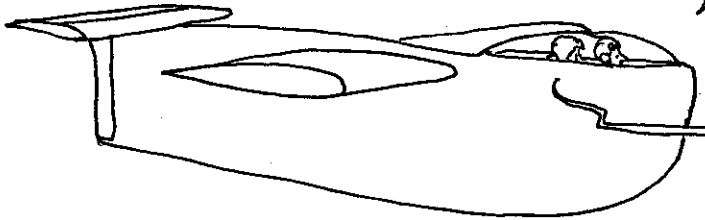
try steering a flat-bottom boat with just a rudder: it won't work

I'm pushing the tiller

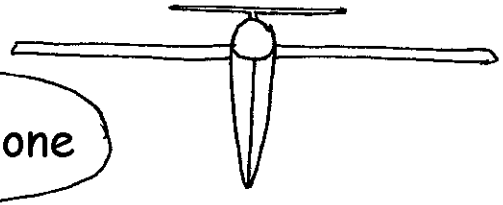
nothing!?

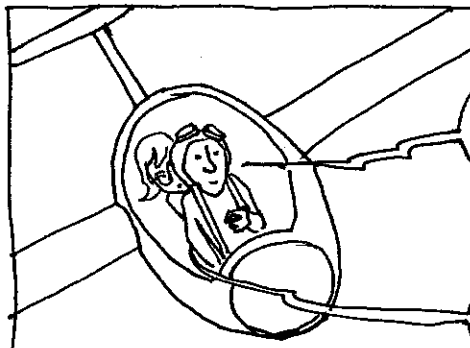
I'm just **SKIDDING** askew on water. I'd need **a CENTERBOARD** or a **KEEL**

Do I have to shape the sailplane's fuselage like a boat hull before it deigns turn?!?



yes, that's one way, but there's a simpler one





Whoa there! There's a strong **TURBULENCE**, a gust of rising air that lifts our left wing!

so what?

this makes us turn right. We're turning, when the rudder bar is on neutral?

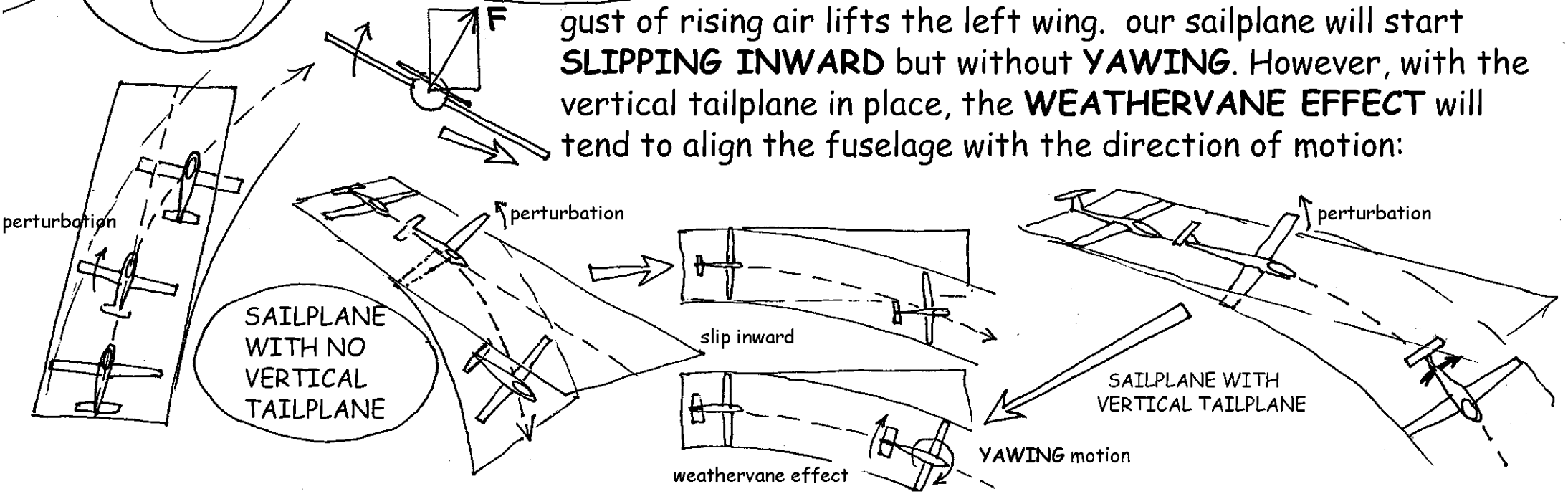
all this deserves an explanation. But first, pull lightly on the stick to prevent nosediving!

it's your vertical tailplane that makes you turn

I don't understand, since it's in the aircraft's symmetry plane

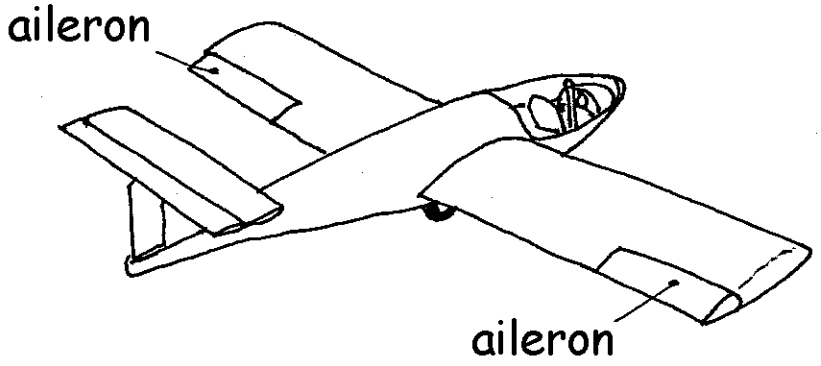
BANKING

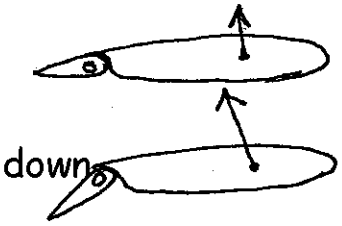
Picture your sailplane without a vertical tailplane. A gust of rising air lifts the left wing. our sailplane will start **SLIPPING INWARD** but without **YAWING**. However, with the vertical tailplane in place, the **WEATHERVANE EFFECT** will tend to align the fuselage with the direction of motion:

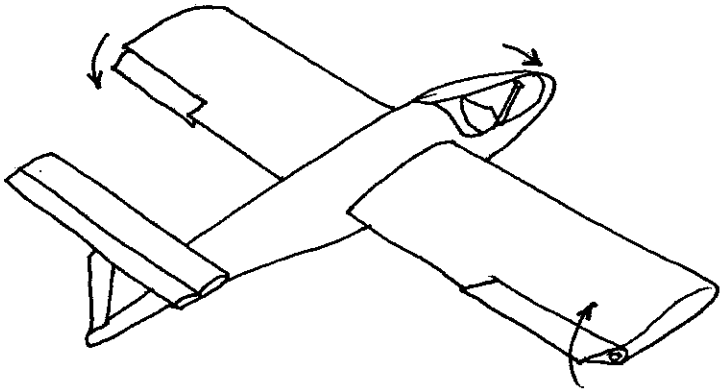


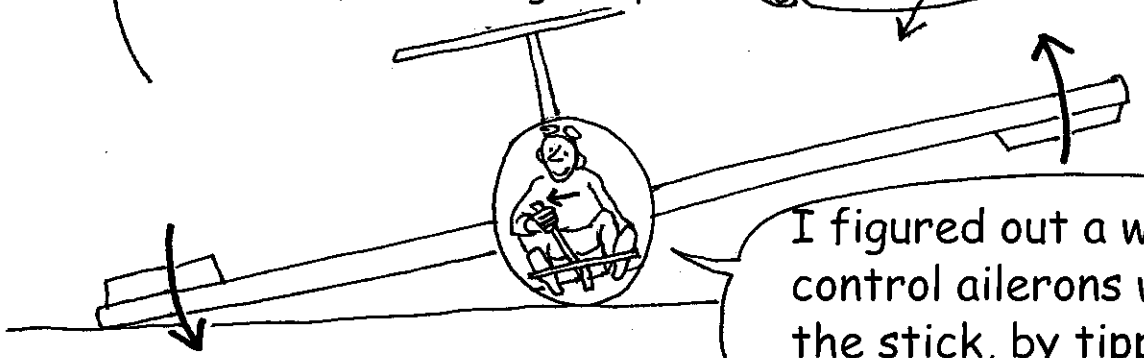
AILERONS

if **BANKING** is what makes the sailplane turn, then I can trigger it by changing the airfoil curvature using wingflaps: **AILERONS**, controlled separately



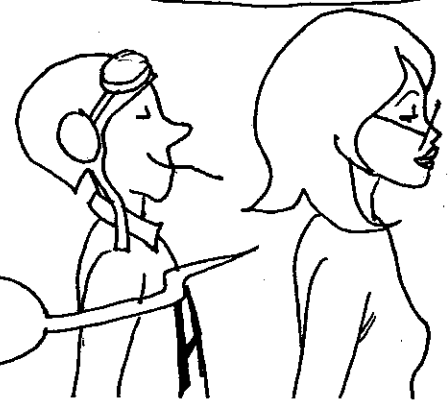






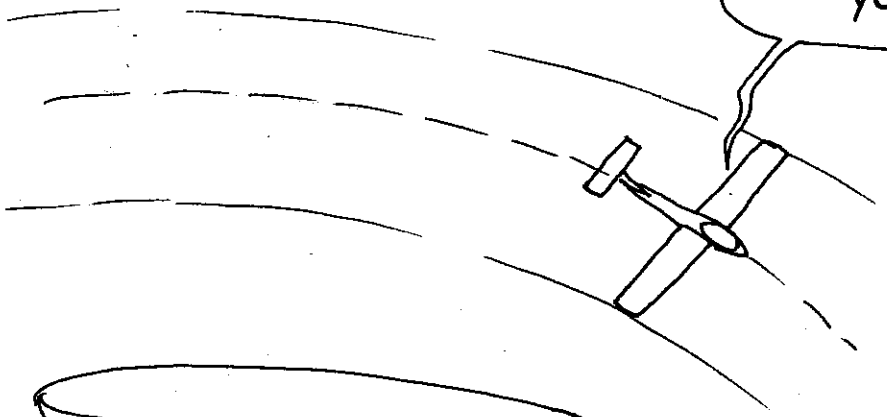
I figured out a way to control ailerons with the stick, by tipping it right or left

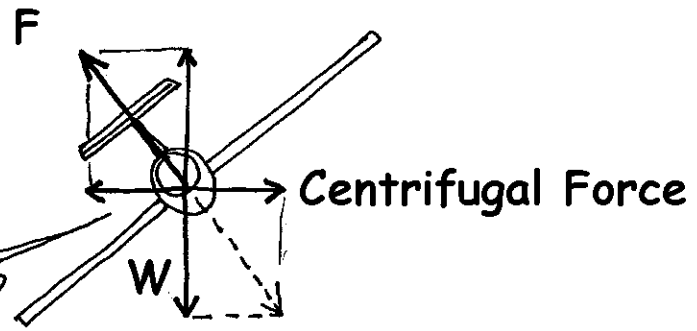
OK, I can bank my plane by actuating the ailerons with the stick. Then, due to the weathervane effect, my vertical tailplane will initiate turning, and I'll pull a bit on the stick to maintain my **ATTITUDE** to keep my sailplane from nosediving and going down



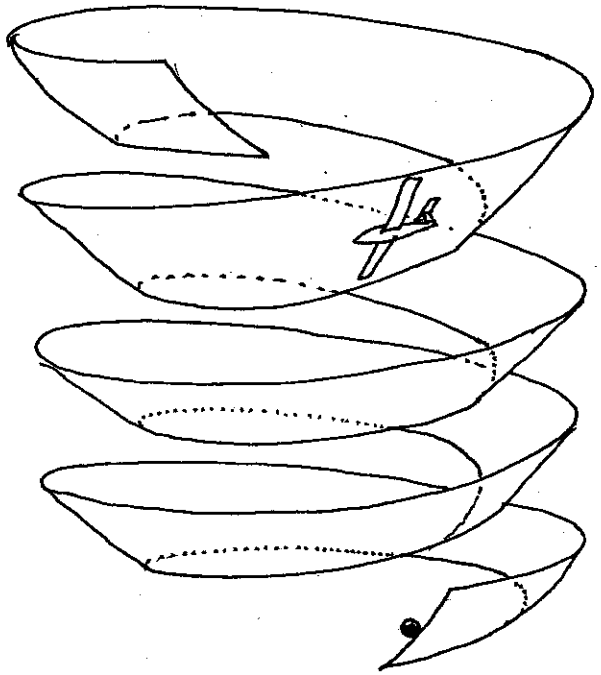
you should give it some foot as well, that will help

yay! It's working. Turn initiated





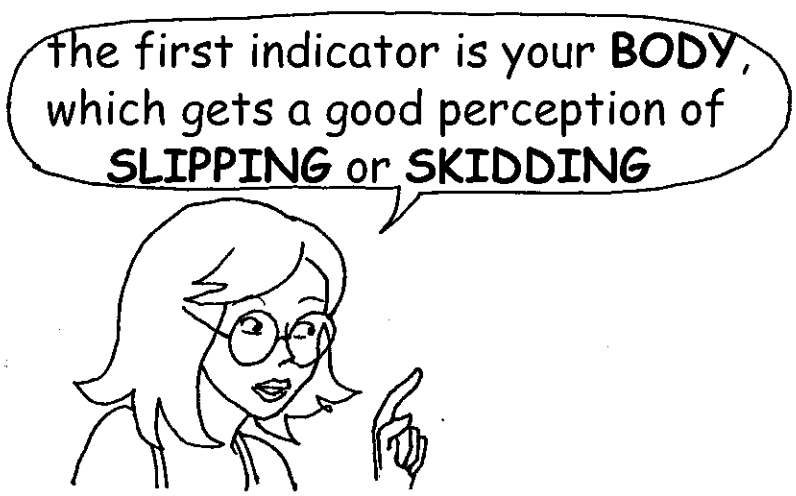
and see, once it's started, your sailplane turns almost by itself. You just use the controls to coordinate your turn



if the turn is well coordinated, the sailplane should slide like a ball rolling along a spiral-wound groove, or like a sleigh sliding over ice without skidding either left or right

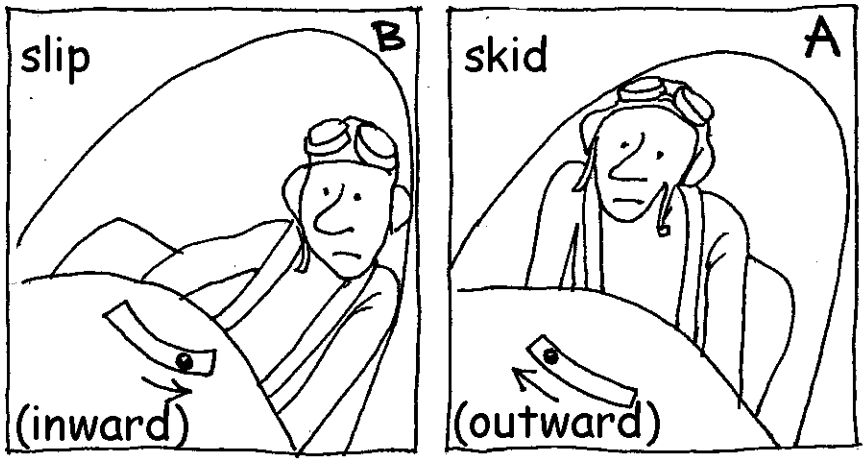
but how to tell whether you're slipping inward or skidding outward relative to something you can't see, like air

TURN CONTROL

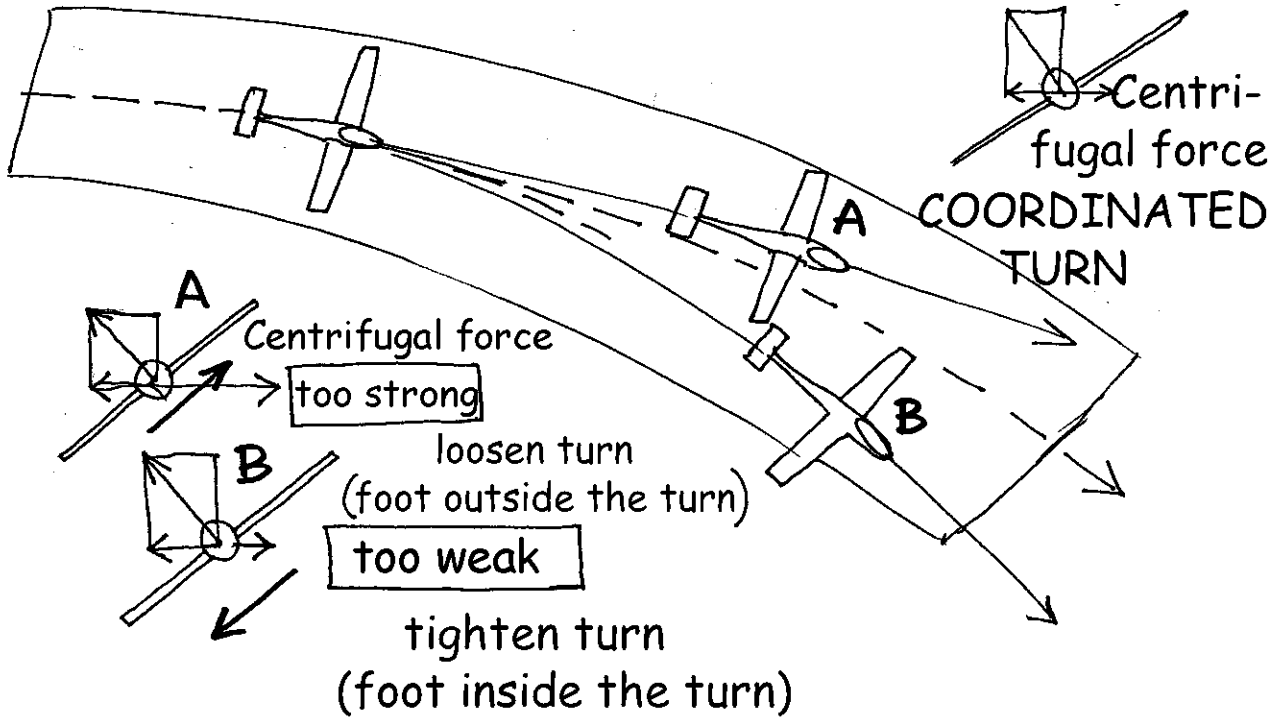


First instrument: **THE BALL**

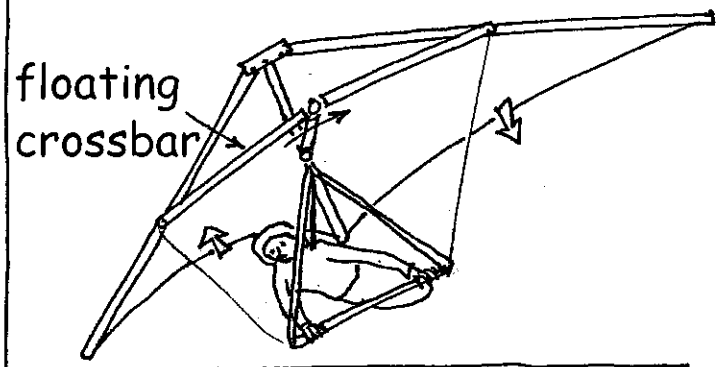
It's a curved glass tube filled with oil, inside which there is a ball



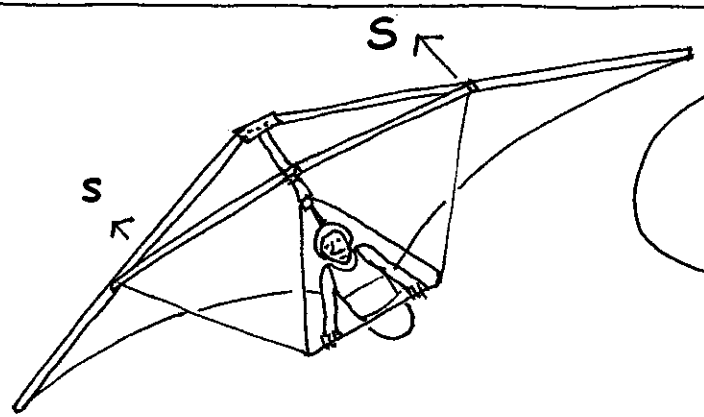
The ball slides in the direction of the **SLIP** or **SKID**



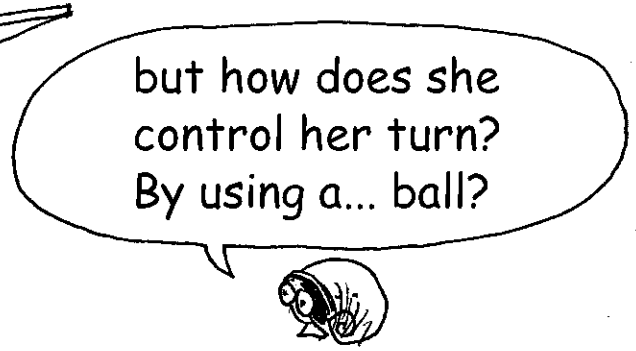
SHORT DIGRESSION ABOUT HANG GLIDERS (see page 16)



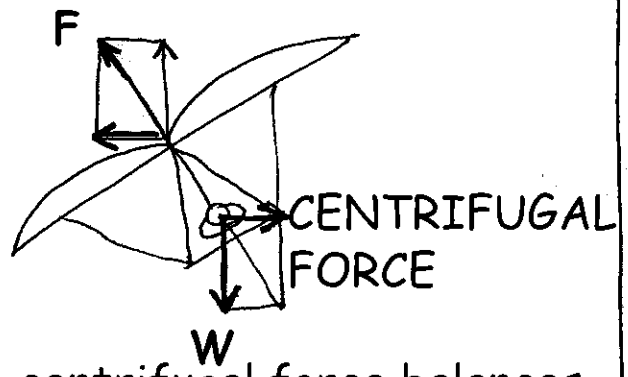
the hang glider pilot shifts her weight to start her turn



Once the turn starts, banking does its job. It persists because the outside wing moves a bit faster

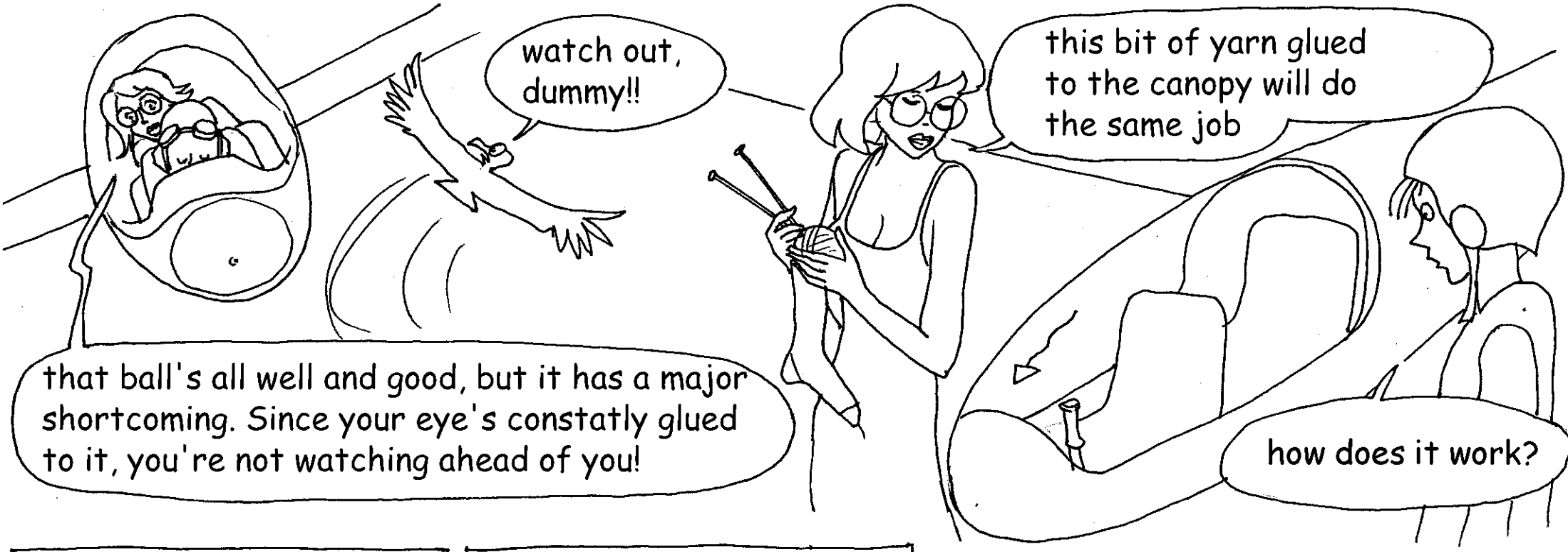


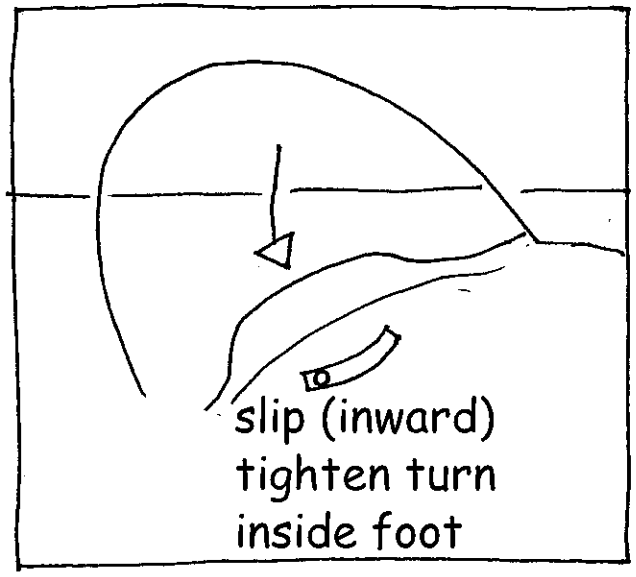
the hang glider pilot doesn't need a ball, **SINCE THE BALL IS THE PILOT!** The turn tightens until the centrifugal force aligns the pilot's body with the aircraft's plane of symmetry, where the floating crossbar system will keep it automatically

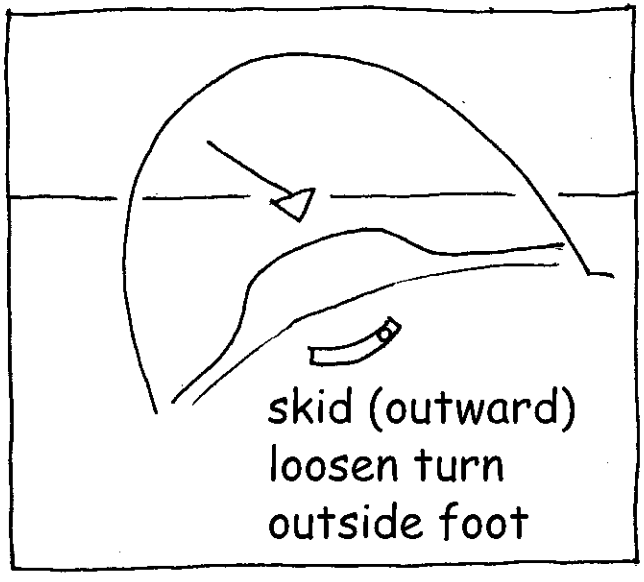


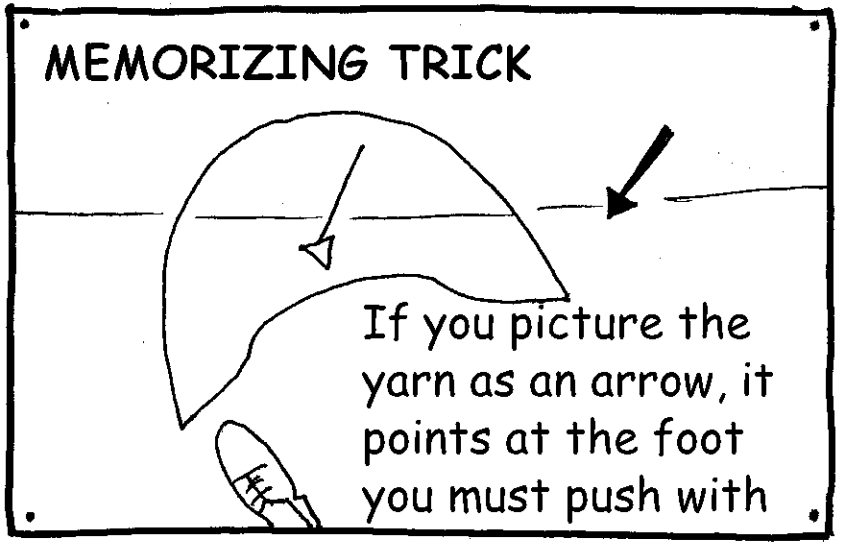
The centrifugal force balances out the radial component of the aerodynamic force

THE WOOL YARN







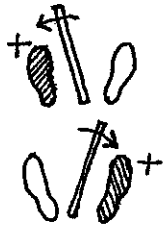


COORDINATING CONTROLS

when you start turning, when you straighten out, when you tighten or loosen your turn, you need to use your foot and the stick at the same time

this is called "coordinating controls"

* stick to the left, apply left foot
* stick to the right, apply righ foot



thanks to those controls the sailplane is now at my beck and call

I push the stick, I gain speed

STALLING

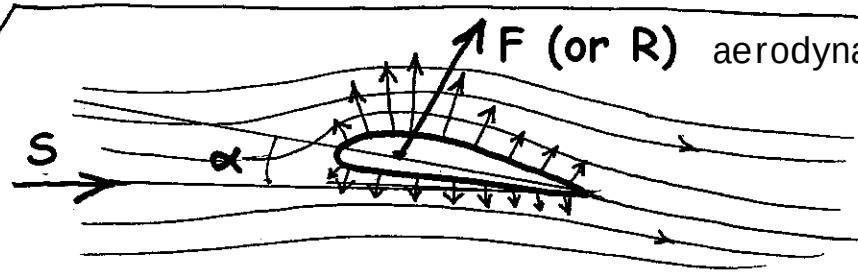
I pull on the stick to pitch the aircraft up

watch out, clouds, there I come

Sophie, we're falling down like a stone!!

and I didn't touch anything what's going on!

let me explain. This is a drawing of the airflow around your wing in normal conditions

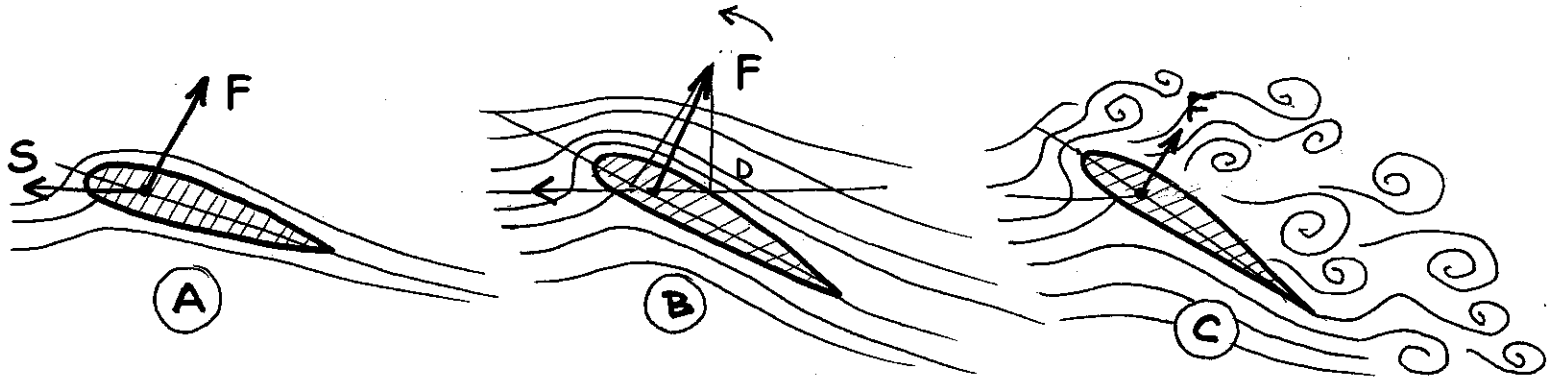


normal... how?

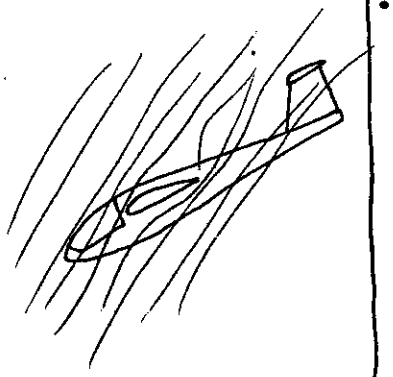
when **ANGLE OF ATTACK α** between the wing and the air flowing at speed **S** remains moderate, say 6 to 15°

sweetheart, you just performed a splendid stall

I did **WHAT?**

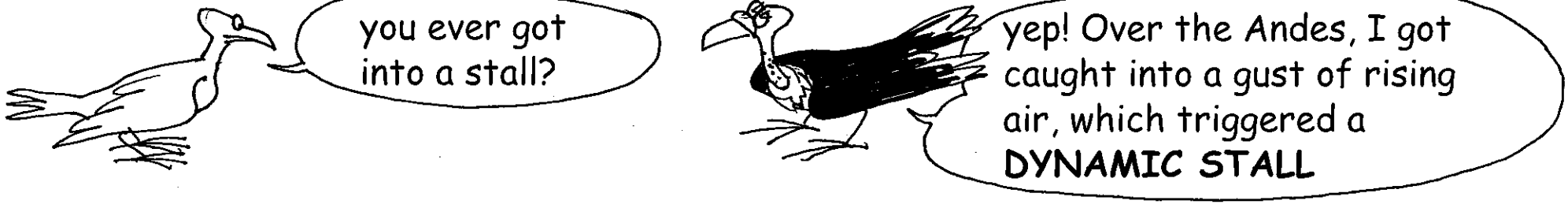


- On diagram **A**, a normal flight position
- On diagram **B**, flight at a high angle of attack. The aerodynamic force's projection onto the direction of speed **S** still provides drag **D**, but the forward tilt of force **F** makes it project <u>forward</u> on the wing's plane
- On diagram **C**, air can no longer go around the wing's leading edge. Due to centrifugal force, the airstream **SEPARATES**. Lift collapses. The sailplane "waves" and nosedives



After a **DIVE** the sailplane gathers speed again by itself. The airflow again becomes **ATTACHED** to the airfoil. Lift returns suddenly, because of the increase in speed **S**. When the pilot feels the sailplane is stalling or sinking, she can return to a normal configuration faster by pitching down slightly, by pushing the stick forward, by **LETTING GO**

The Management



SPINNING

I was spiraling quietly, looking for something nice to eat, a carcass or something, Then suddenly, oooooh boy!!

you stalled because the **RELATIVE WIND** shifted directions and increased the angle of attack?

yep. But since the wing inside the turn goes slower, that'sthe one that stalled. Then everything went topsy-turvy. I was spinning and spinning, oy veh!

RELATIVE WIND

inside wing is stalled

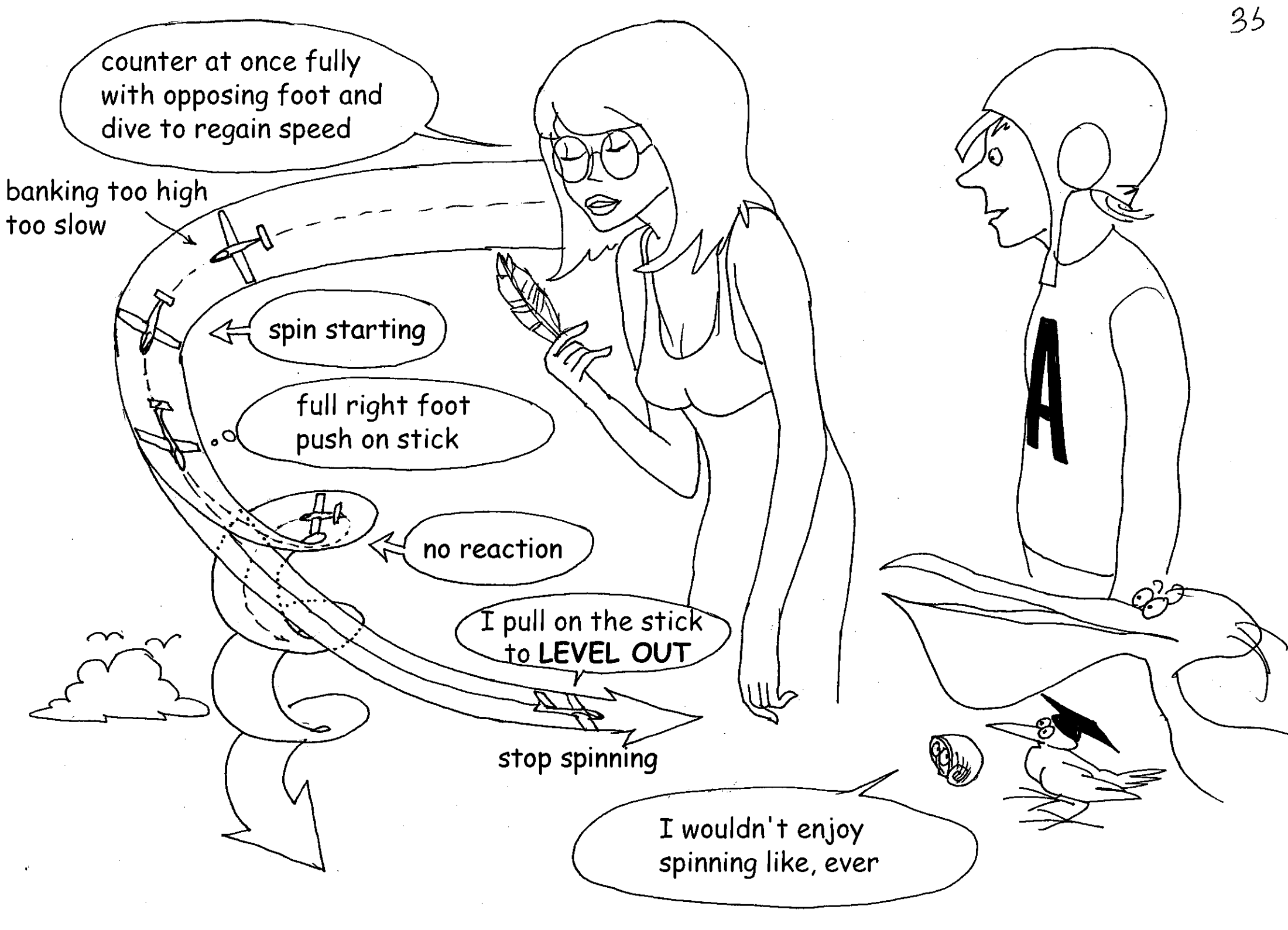
Pull on the stick? **Hell, no!**

F

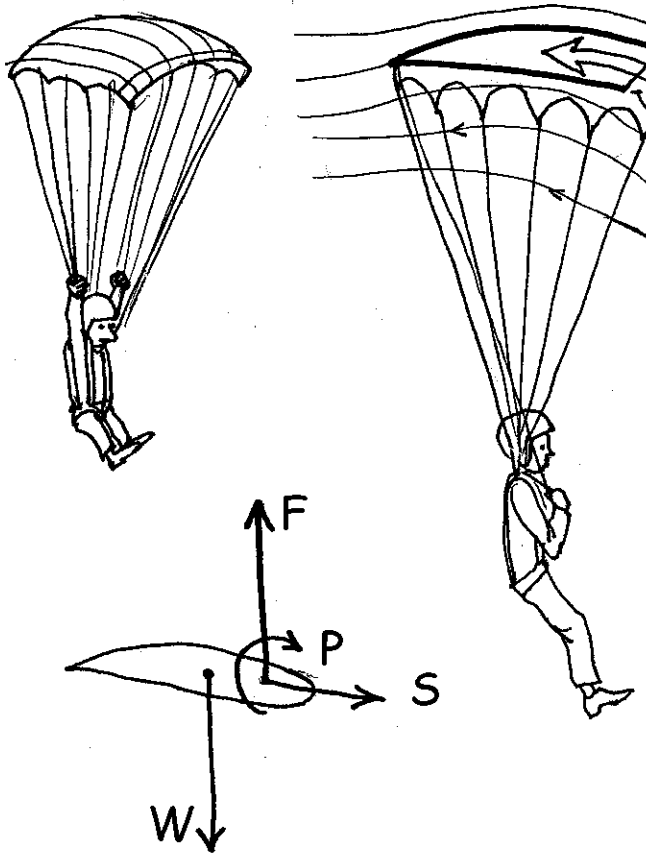
the outside wing works at high angles. Force **F** pulls on this wing and keeps the **SPIN** going

I have to do something but what?

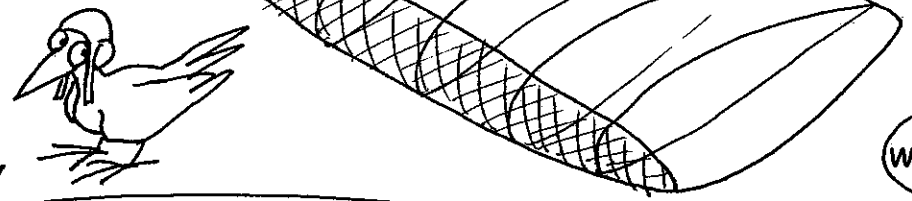
losing 330 ft (100 m) each turn!


counter at once fully with opposing foot and dive to regain speed
banking too high too slow
spin starting
full right foot push on stick
no reaction
I pull on the stick to LEVEL OUT
stop spinning
I wouldn't enjoy spinning like, ever
A

PARAGLIDER:
WHEN THE SAIL CAN BECOME A SHROUD



the paraglider evolved from the **CELL PARACHUTE** (or **RAM-AIR PARACHUTE**) that replaced the ancient round parachute(*), only used as a back-up parachute now

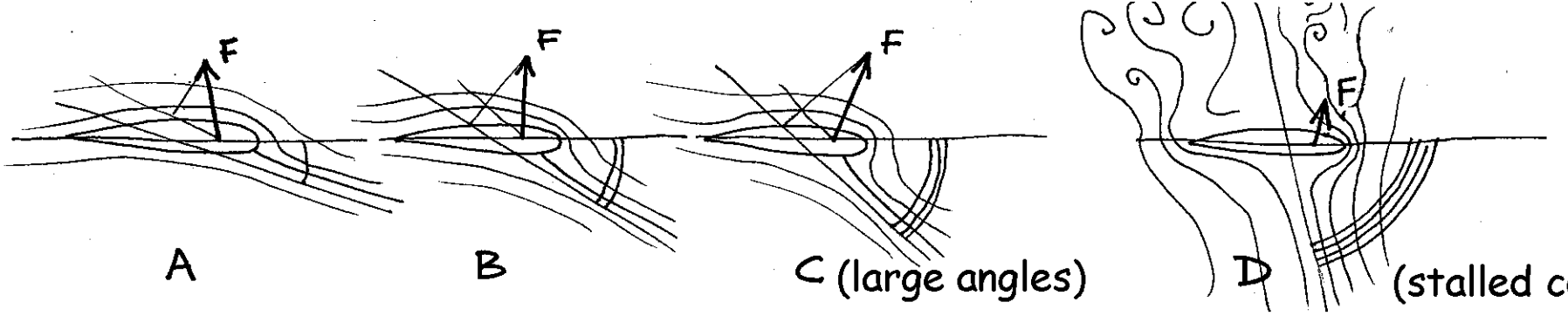


it's the median position of the pilot that balances out the wing's pitching moment. The airfoil is inflated by overpressure along the wing's leading edge, made of a loose-weave fabric

wearing a parachute is mandatory on sailplanes

sailplanes colliding

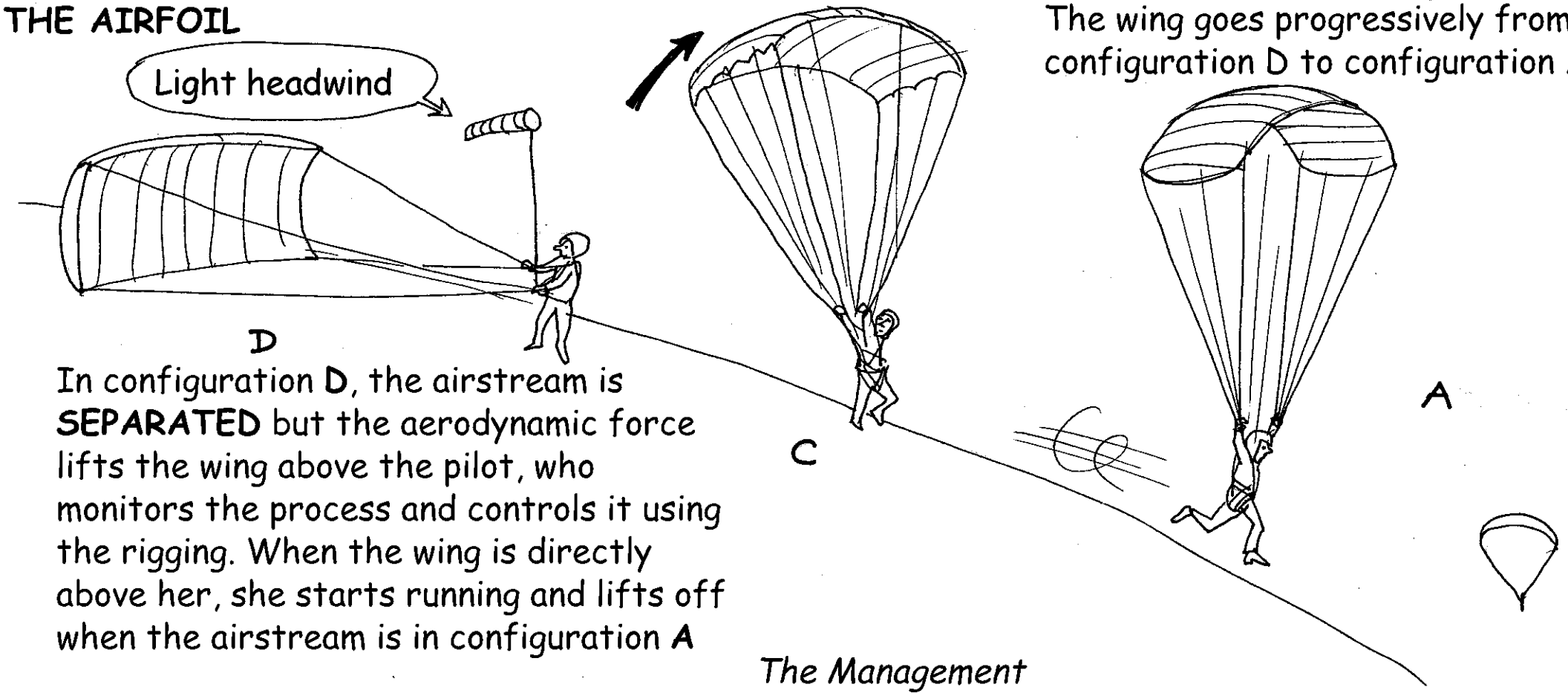
(*) Vertical descent rate is 19.5 ft/s (6 m/s). Descent rate of a cell parachute: 8 ft/s (2.5 m/s)



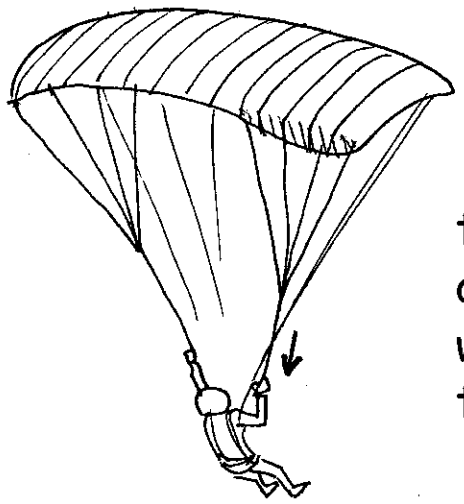
It's well-known that as the angle of attack (the direction of **RELATIVE WIND**) increases, the aerodynamic force applied to the wing's **AERODYNAMIC CENTER**, 25% along the **CHORD**, tilts forward progressively. The airstream eventually **SEPARATES**. The force decreases, but remains directed **FORWARD RELATIVE TO THE AIRFOIL**

TAKING OFF IN A PARAGLIDER

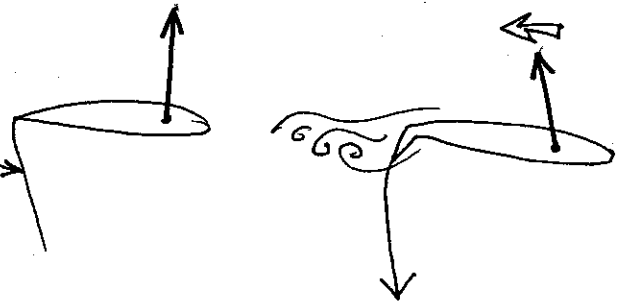
The wing goes progressively from configuration D to configuration A

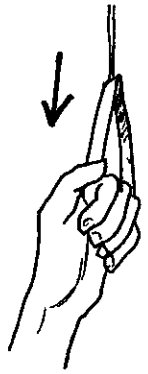


In configuration **D**, the airstream is **SEPARATED** but the aerodynamic force lifts the wing above the pilot, who monitors the process and controls it using the rigging. When the wing is directly above her, she starts running and lifts off when the airstream is in configuration **A**



brake control

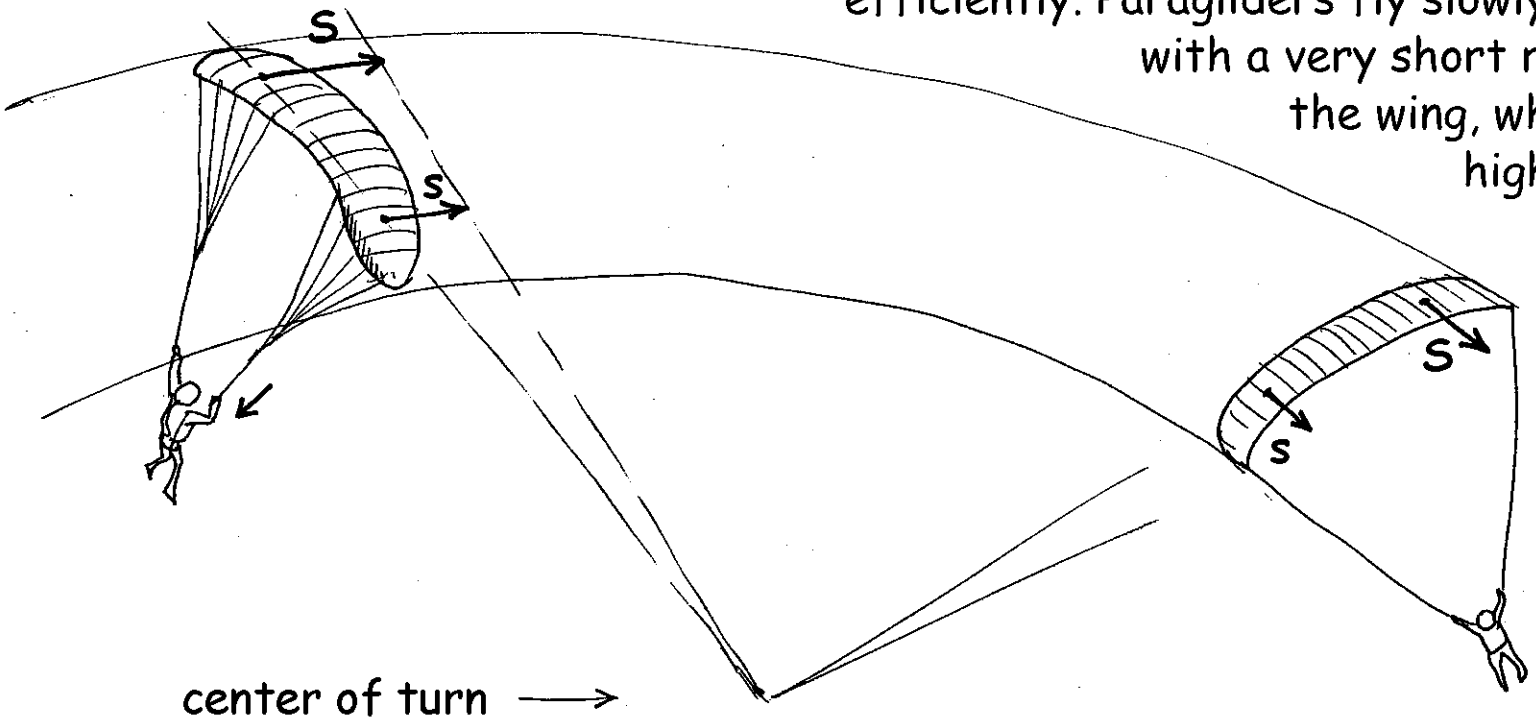




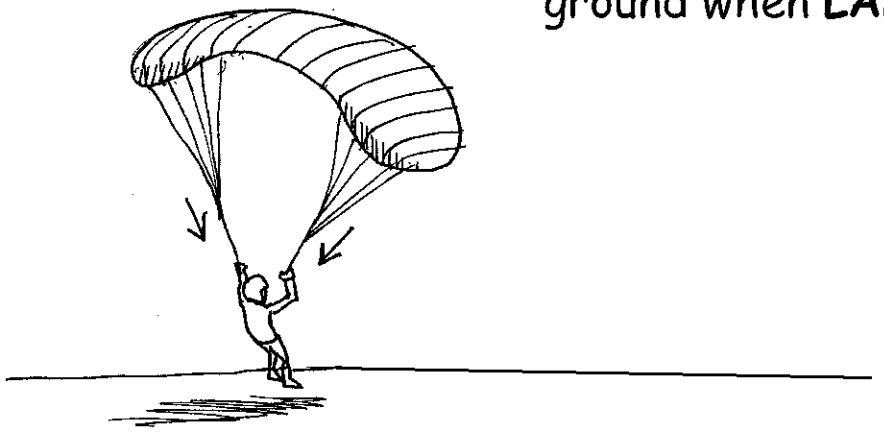
a brake control

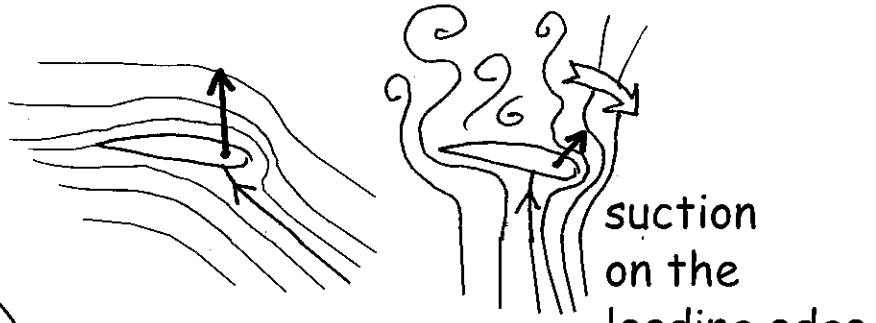
the paraglider pilot acts on the drag of the right and left halves of her wing, whose trailing edges are attached to control strings called **BRAKES**

Here, the pilot is pulling on her right brake. She increases the **DRAG** of the right half of her sail. This starts her turning very efficiently. Paragliders fly slowly and can easily turn with a very short radius. The outside of the wing, which goes faster, rises higher (**INDUCED ROLL**)



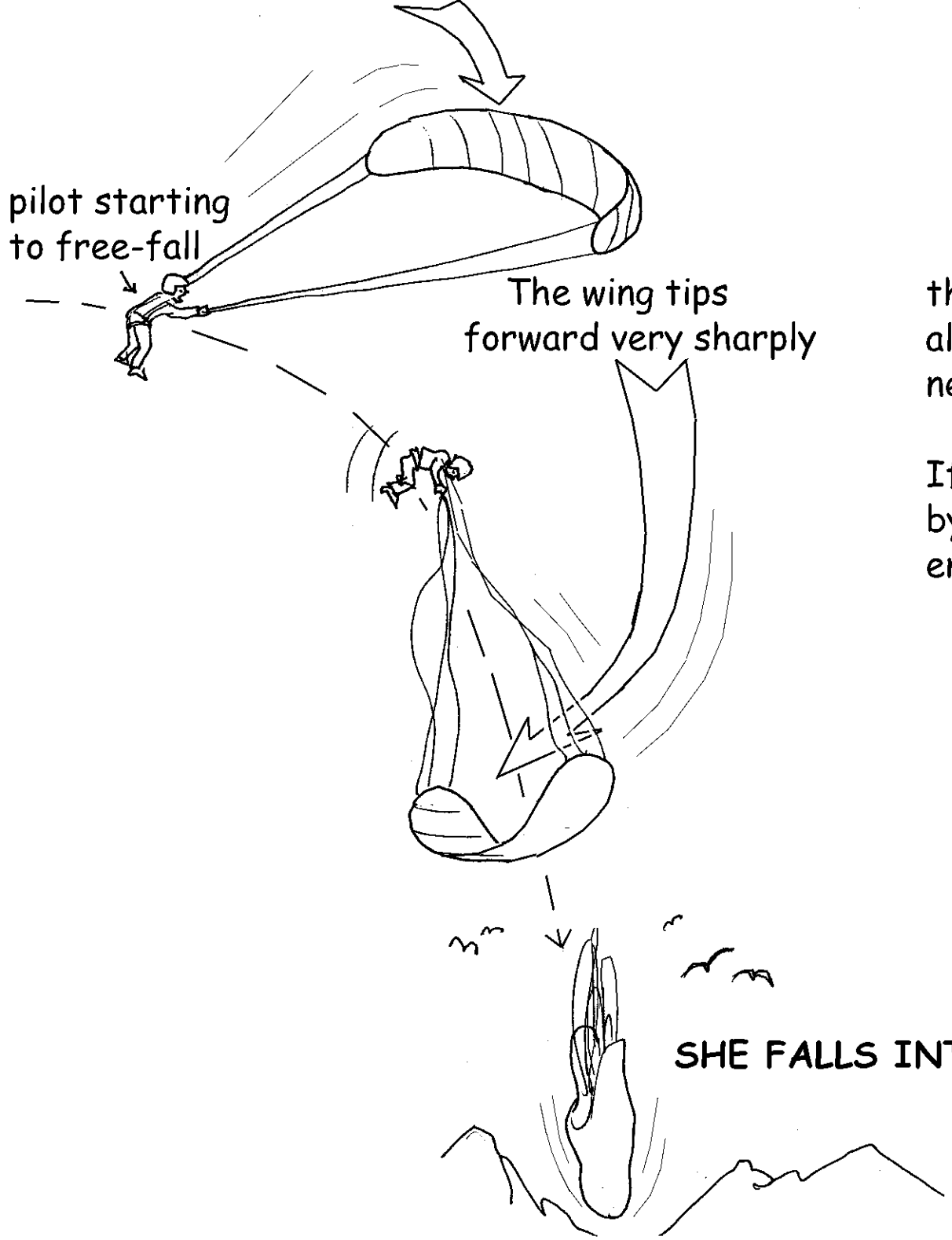
By pulling on both brakes at the same time, she can slow down her wing to the **STALL SPEED**. She'll perform that maneuver right before touching the ground when **LANDING**, to cancel her speed





But other than that, this maneuver is **VERY DANGEROUS**. It may also be caused by a strong **GUST OF RISING AIR** triggering a **DYNAMIC STALL**

Dynamic stall flying in **TURBULENT AIR** during the middle of the day



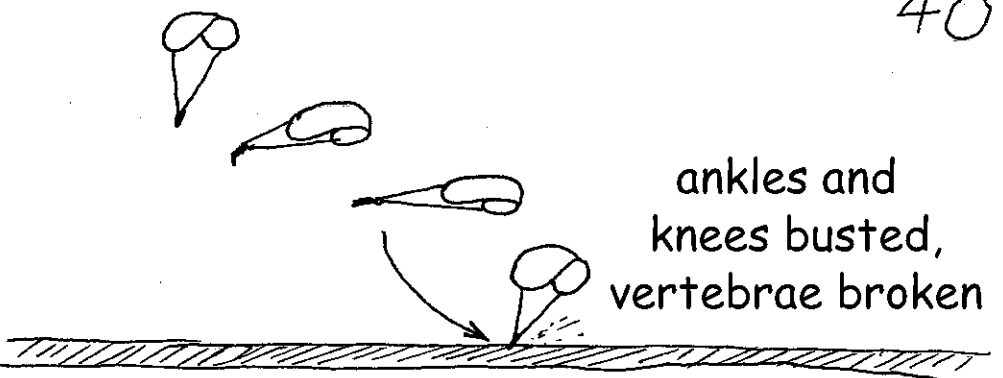
the tilt of the aerodynamic force forward along the airfoil pushes the wing (with its nearly-nil inertia) forward very fast

If the pilot doesn't counter that motion (*) by braking the wing immediately, the wing ends up under her

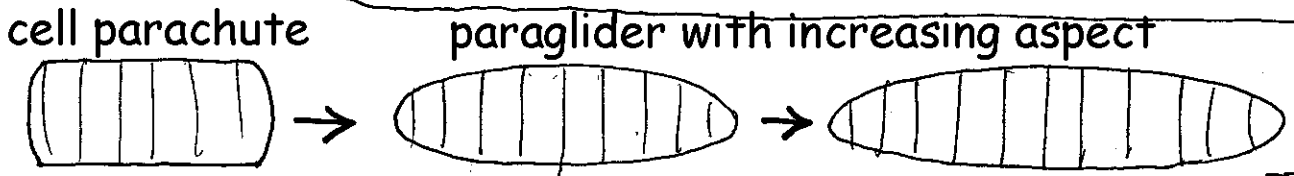
SHE FALLS INTO IT AND DIES

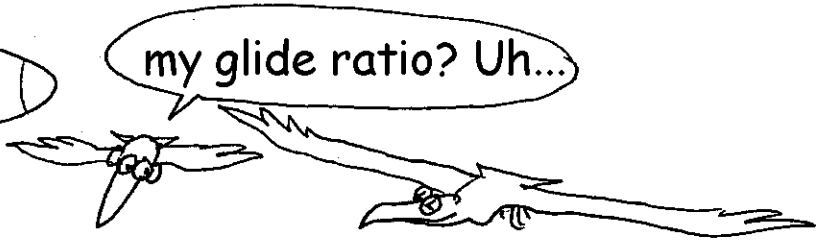
(*) An <u>inexperienced</u> beginner, however, will tend to... let go of everything!

If the incident occurs near ground level and the paraglider pilot is lucky enough not to end up inside her wing, a very sharp recovery may cause her to touch the ground very hard

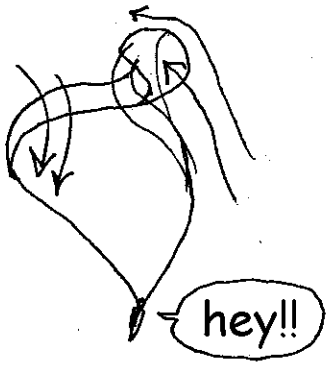


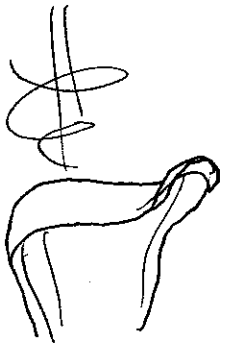
In aerial sports, there's a trade-off to be found between **PERFORMANCE** and **SAFETY**. A flat airfoil allows higher speed, which is desirable to fly from one thermal to the next. But the flatter the airfoil, the sharper the stall. Designers also attempt to increase the **GLIDE RATIO**(*) (more on which later) by increasing the paraglider's **ASPECT**, thus making it vulnerable to **WING COLLAPSE** in **TURBULENT AIR**, *which translate to altitude loss of at least* **164 ft (50 m)** before the wing **REOPENS**





midday
nice blue sky
no warning,,,



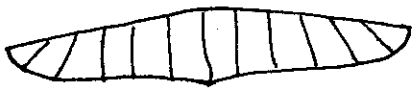


(*) From height **h** you can fly to distance **d** = **g** x **h**, **g** being the **GLIDE RATIO**

this performance race also affects the hang-gliding world

1975

1985



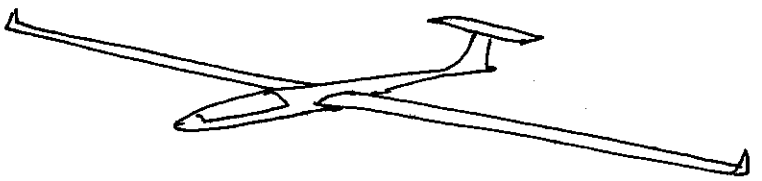
Currently

single surface

16 miles/hr
(25 km/hr)
glide ratio 3
8.2 ft/s (2.5 m/s)

19-47 miles/hr
(30-75 km/hr)
glide ratio 7
5.9 ft/s (1.8 m/s)

double surface
(with battens)
25-62 miles/hr
(40-100 km/hr)
glide ratio 10
3.3 ft/s (1 m/s)

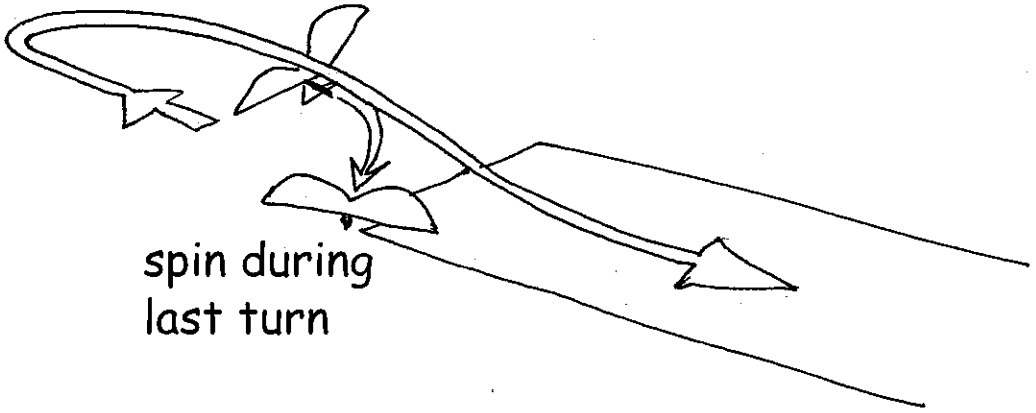


Modern gliders :
41-43.5-106 miles/hr
glide ratio 20 to 60
1.6 ft/s (0.5 m/s) extension 20 to 35

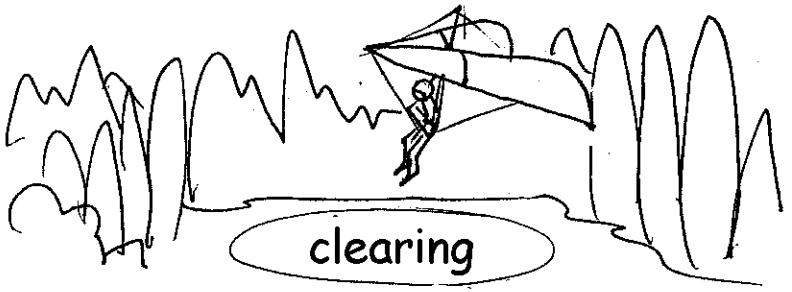
A good compromise is needed between performance and safety. The first hang gliders would never stall asymmetrically. Modern hang gliders, with their high aspect ratios and biconvex airfoils, behave as classical wings, and if stalling in a turn, can start **SPINNING**

20 ft/s (6 m/s)
parachute-like fall

turn into final approach



spin during
last turn



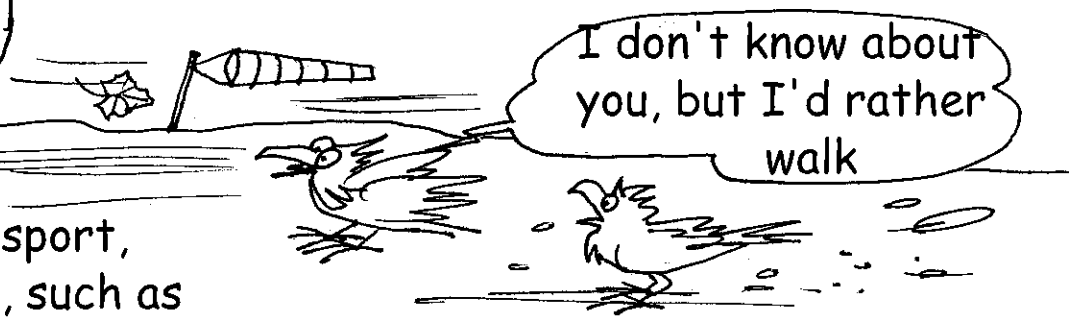
clearing

early hang gliders could serve as parachutes when falling straight down

FLIGHT ENVELOPE

there are three components
1 - atmospheric conditions
2 - the aircraft
3 - the pilot

There are atmospheric conditions that preclude flying for certain aircraft



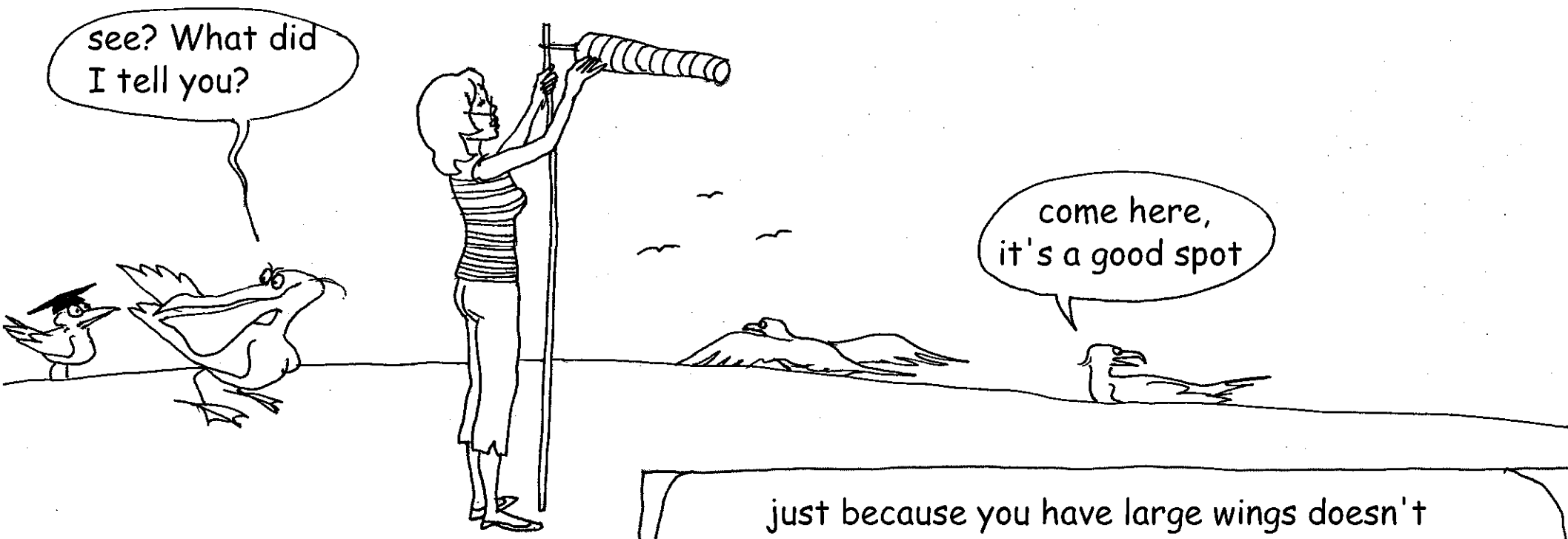
I don't know about you, but I'd rather walk

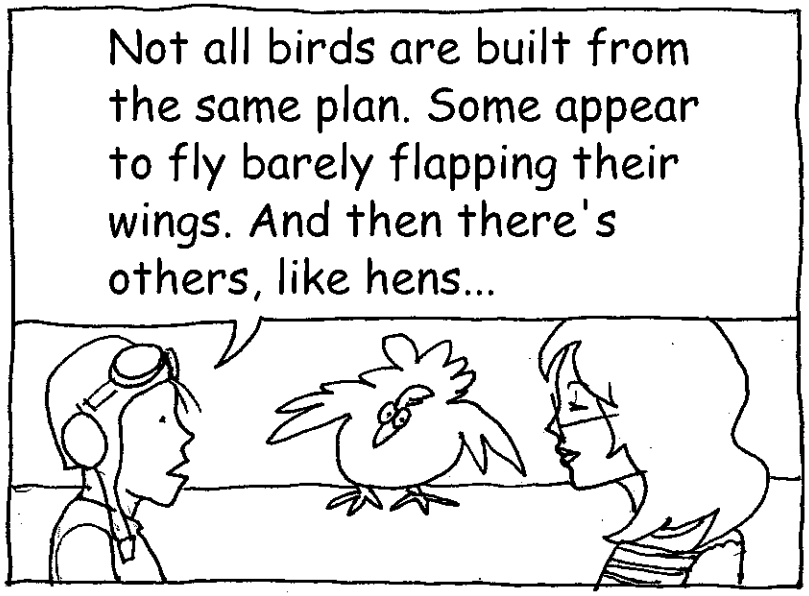
paragliding is a leisure sport, riskfree in calm weather, such as an early morning with no wind or turbulent air. In turbulent air, risk is always present. Aircraft that look alike can have very different flight envelopes. Some are forgiving, others not so. Performance race, that disease of today's world, favors risk-taking.

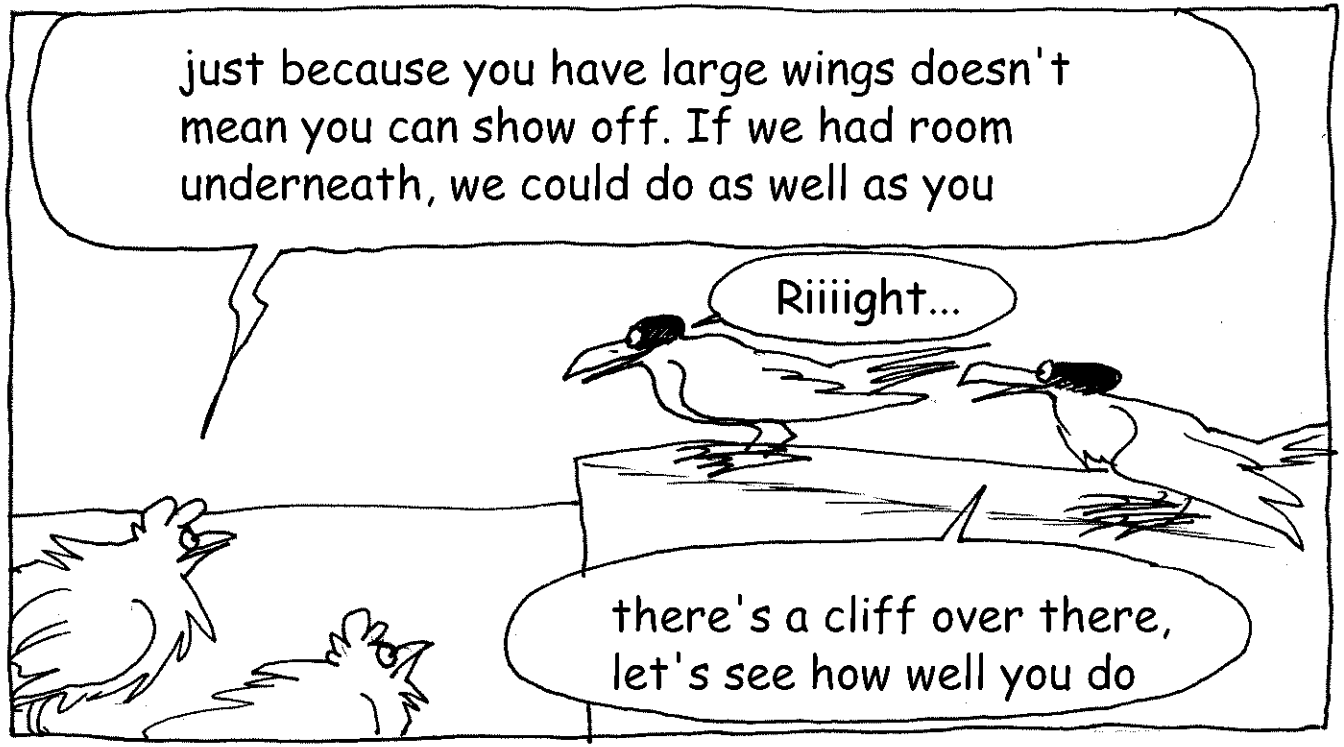
In the world of flying, a traditional saying goes:
THERE ARE OLD PILOTS AND BOLD PILOTS, BUT NO OLD, BOLD PILOTS

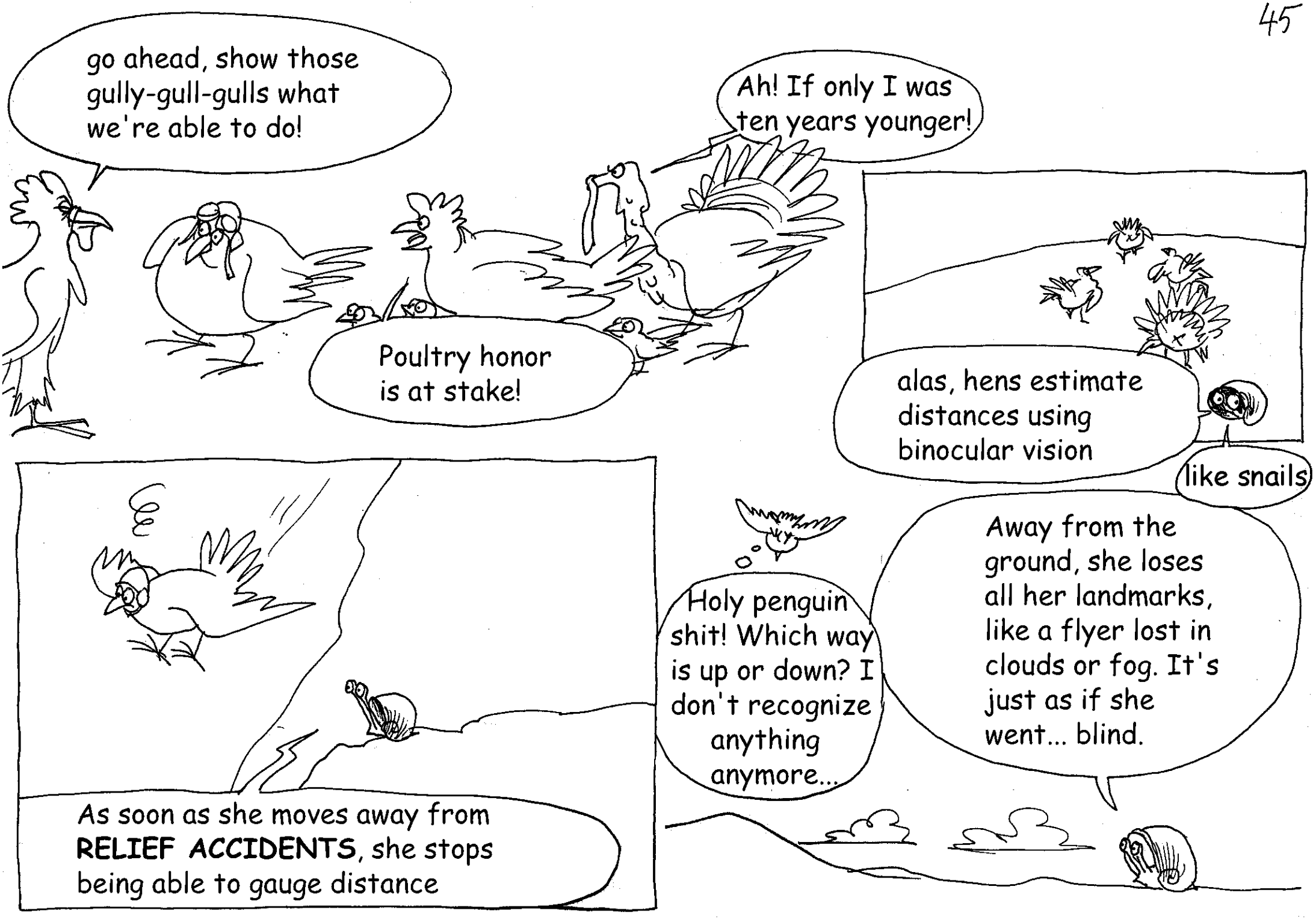
that's really nice. Using this road, we can take the sailplane up to 1600 feet (500 m) above the plain
stick, wool yarn, that's all woman's stuff
There, we're at the top. But which way should we take off?
into the wind. When getting up to speed, we get that for free
wind direction? There's the traditional wet-your-finger trick
wait, I have an idea. In this heat, I'll feel better wearing short sleeves. Go get me a stick
Lenny, don't you think you're going too far?

WINDSOCKS


see? What did I tell you?
come here, it's a good spot


Not all birds are built from the same plan. Some appear to fly barely flapping their wings. And then there's others, like hens...


just because you have large wings doesn't mean you can show off. If we had room underneath, we could do as well as you
Riiiight...
there's a cliff over there, let's see how well you do

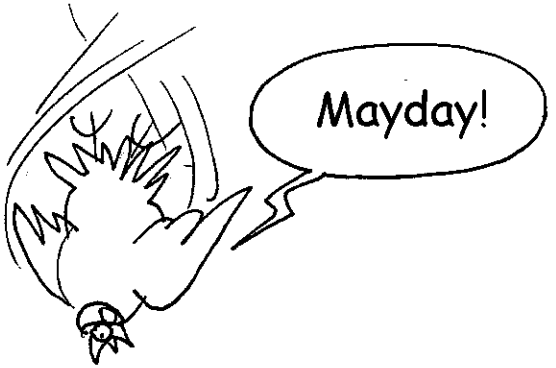

go ahead, show those gully-gull-gulls what we're able to do!
Ah! If only I was ten years younger!
Poultry honor is at stake!
alas, hens estimate distances using binocular vision
like snails
As soon as she moves away from **RELIEF ACCIDENTS**, she stops being able to gauge distance
Holy penguin shit! Which way is up or down? I don't recognize anything anymore...
Away from the ground, she loses all her landmarks, like a flyer lost in clouds or fog. It's just as if she went... blind.

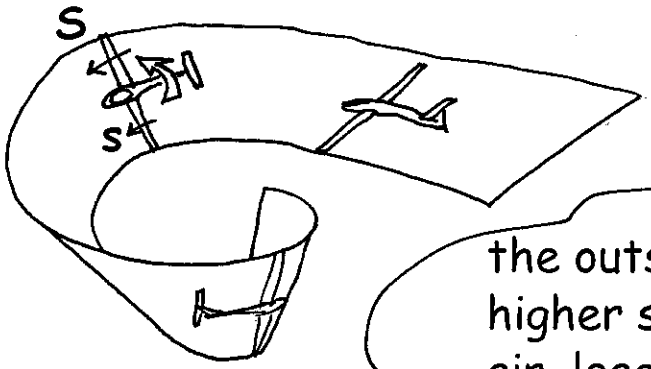
STEEP BANK TURN

I don't understand... My wool yarn's in the middle, my ball is centered, my controls on neutral (...) and yet my speed keeps increasing

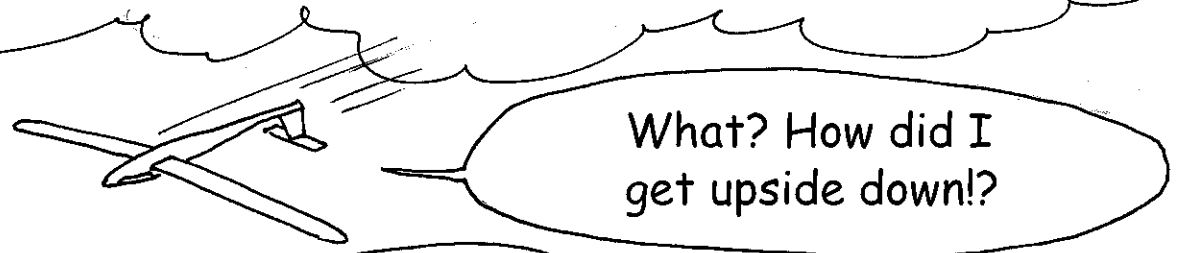
Stuck inside a cloud, Archie can't see he's no longer flying straight. In fact, without a gyroscopic **ARTIFICIAL HORIZON**, he has no way to gauge his angle of attack or his attitude. He can then enter a dangerous position: a steep bank turn

Dropped 650 feet (200 m) above ground, a hen finds herself unable to process her visual input into a 3-dimensional mental map of the world around her. She then gets into a steep bank turn and cannot escape it (*)





the outside wing, having a higher speed relative to the air, leads to **INDUCED ROLL**



(*) Verified

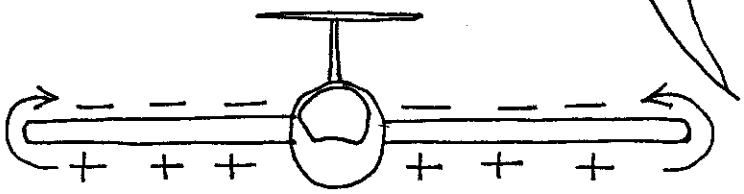
Birds that appear to fly and hardly get tired all have very long wings: raptors, albatross

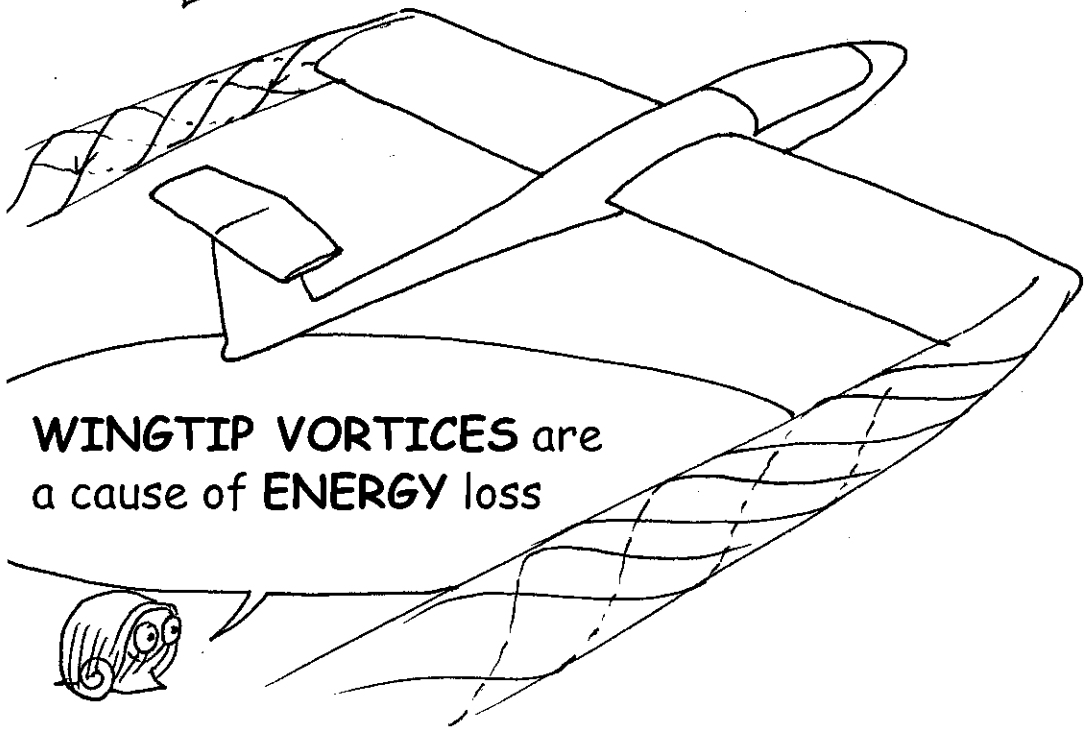
Why?

you switched from a hang glider to a sailplane with a cockpit, making all the surfaces as smooth as possible to lower energy waste from the turbulence your craft creates along the way. But you forgot one source

which one?

the way your wing works means you have higher pressure below, on the **LOWER CAMBER**, and lower pressure above, on the **UPPER CAMBER**. Then the following happens:

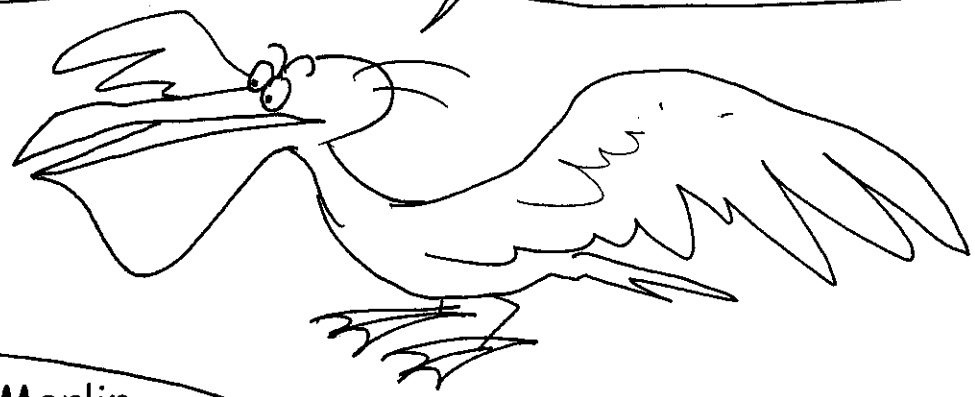




WINGTIP VORTICES are a cause of **ENERGY** loss

since the tips cause energy loss, you just need to remove them, to make an endless wing

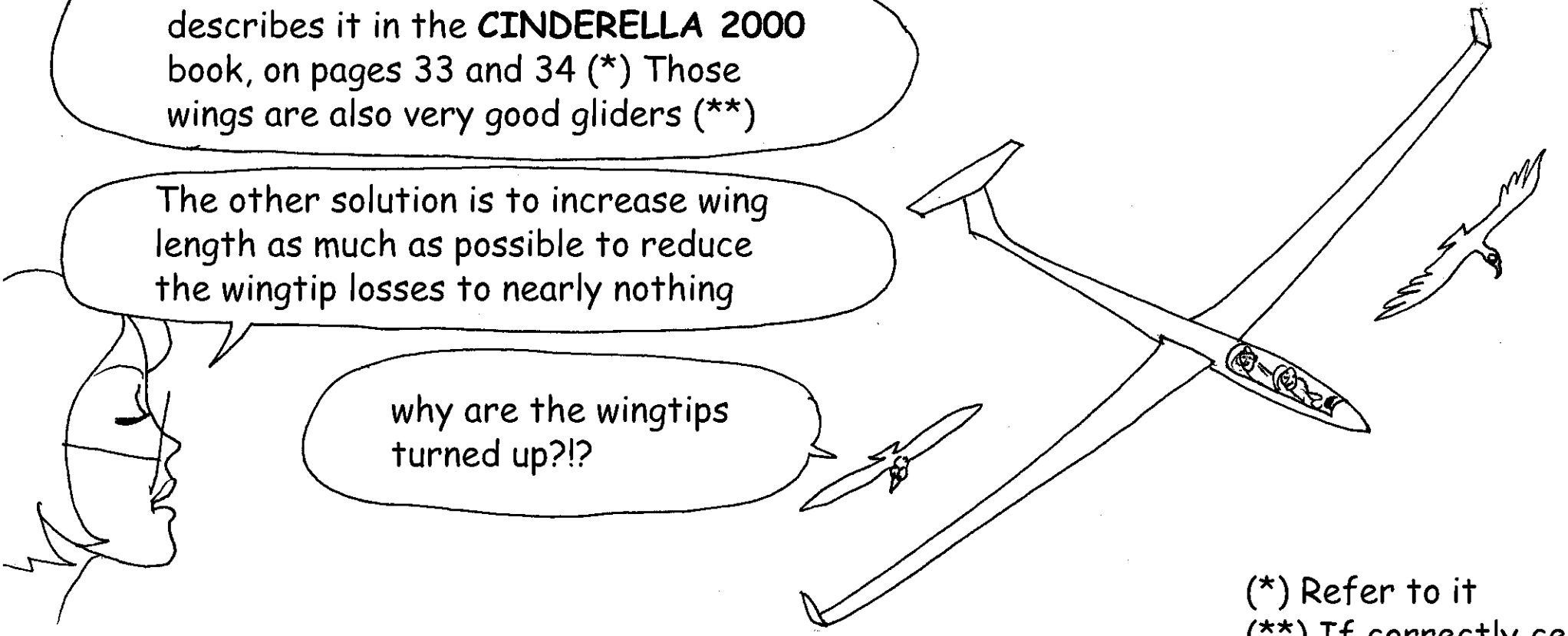
Tiresias, stop speaking nonsense. There's no such thing as an endless wing!!!



Yes, there is. And the wizard Merlin describes it in the **CINDERELLA 2000** book, on pages 33 and 34 (*) Those wings are also very good gliders (**)

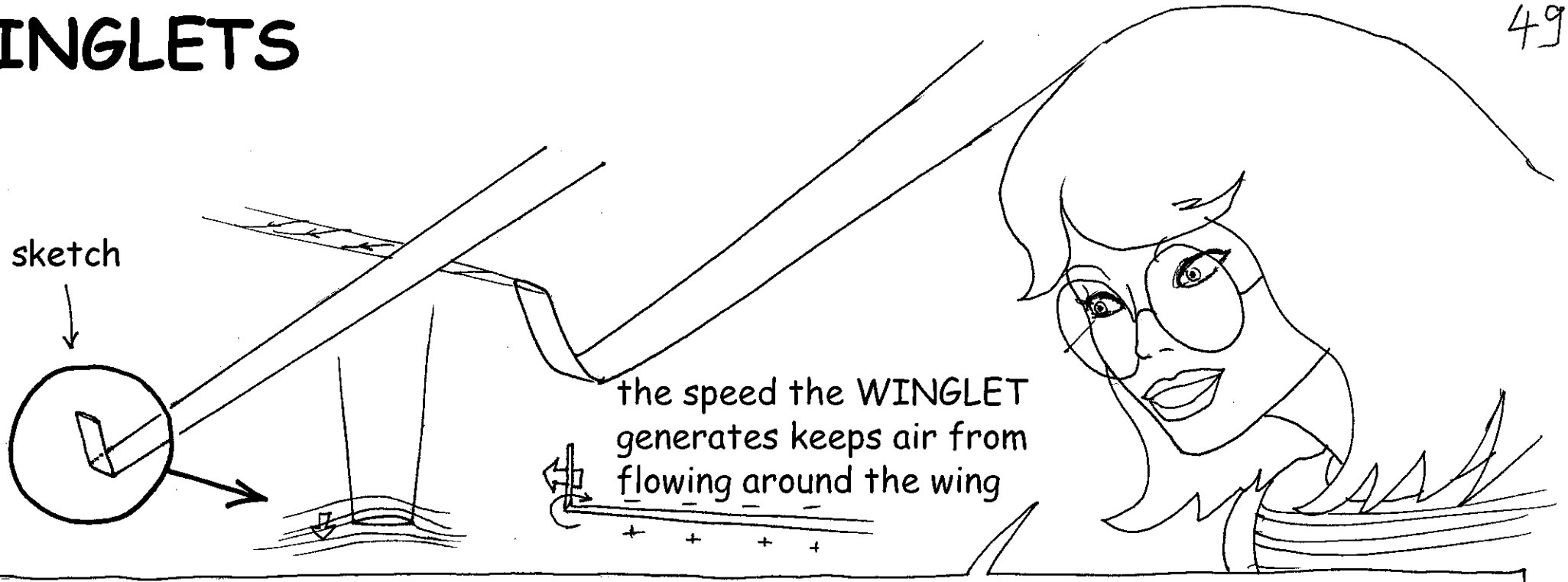
The other solution is to increase wing length as much as possible to reduce the wingtip losses to nearly nothing

why are the wingtips turned up?!?

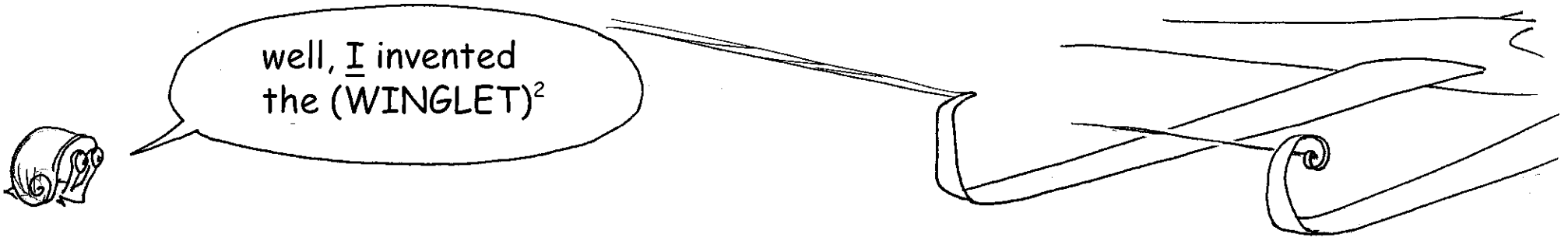


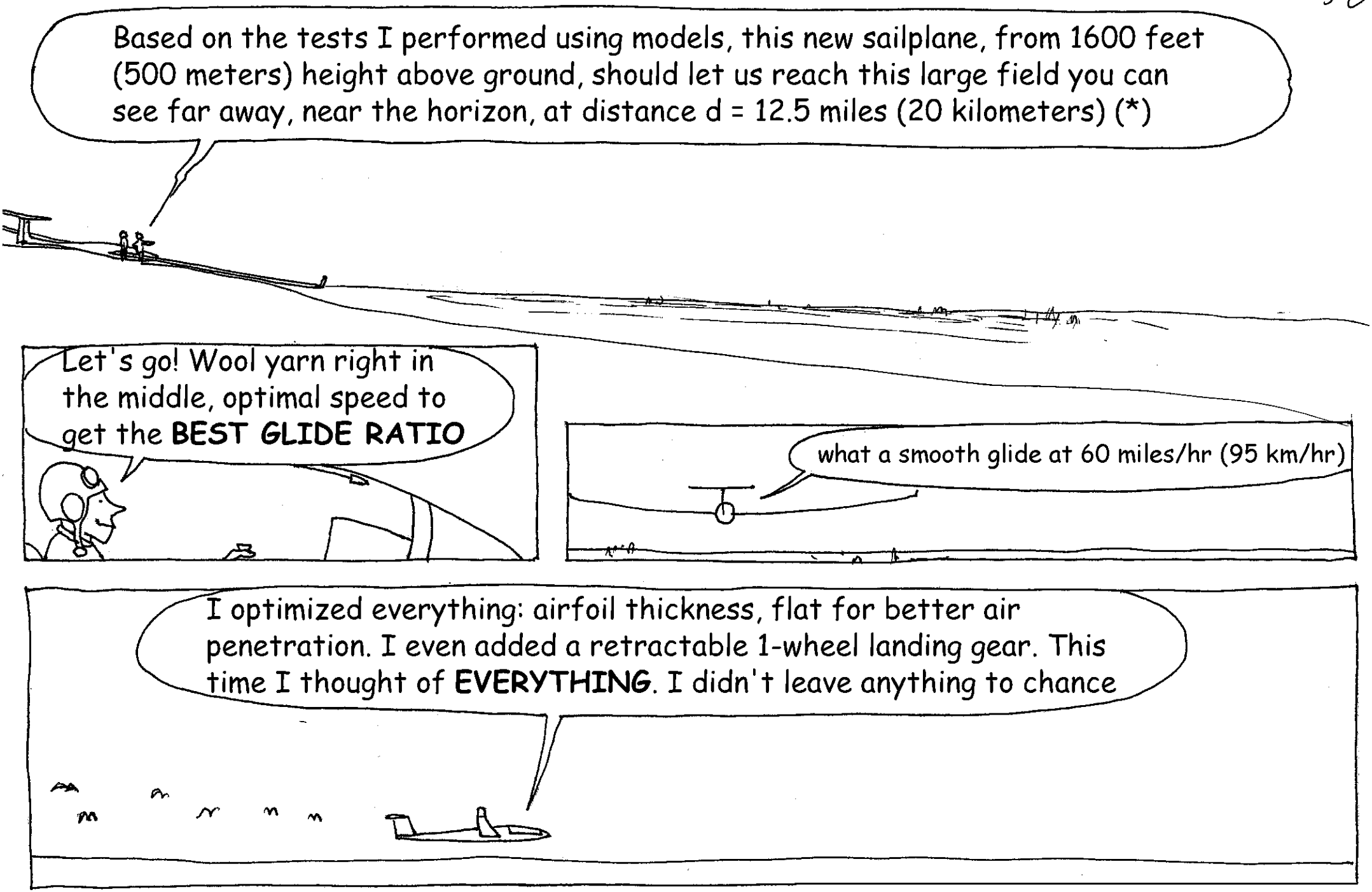
(*) Refer to it
(**) If correctly centered

WINGLETS



In a nutshell, **WINGLETS** are mini-wings perpendicular to the main wing, such that their airfoil generates a (low) **INDUCED SPEED** that prevents air from flowing around the wing, due to the pressure difference between lower camber and upper camber. Winglets create their own wingtip vortices, but the gain is so obvious that this idea, which might have emerged a century ago, is now progressively gaining ground throughout the aeronautics world.





(*) which translates to a GLIDE RATIO of d / h = 40. But some sailplanes do better than 60 (descent slope = 1 degree)

perfect approach, or nearly so. Extending landing gear. I skillfully winged over the trees at the start of the landing strip

we barely saw them, from afar

Sophie, what's going on? We'll eat through the whole landing strip!

your trees were 33 ft (10 m) tall. That adds 1300 ft (400 m) to your run

oh yes, you're right. We'll never touch down!

Ah, finally! Slamming the brakes

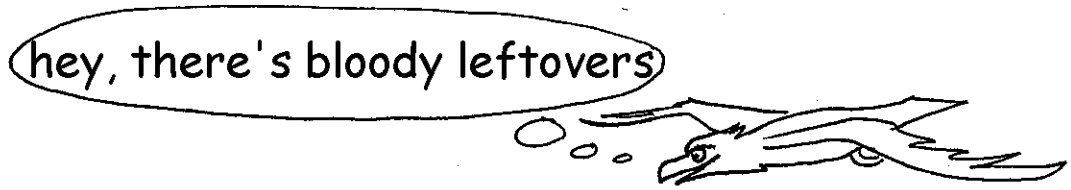
not too hard unless you want us to flip over

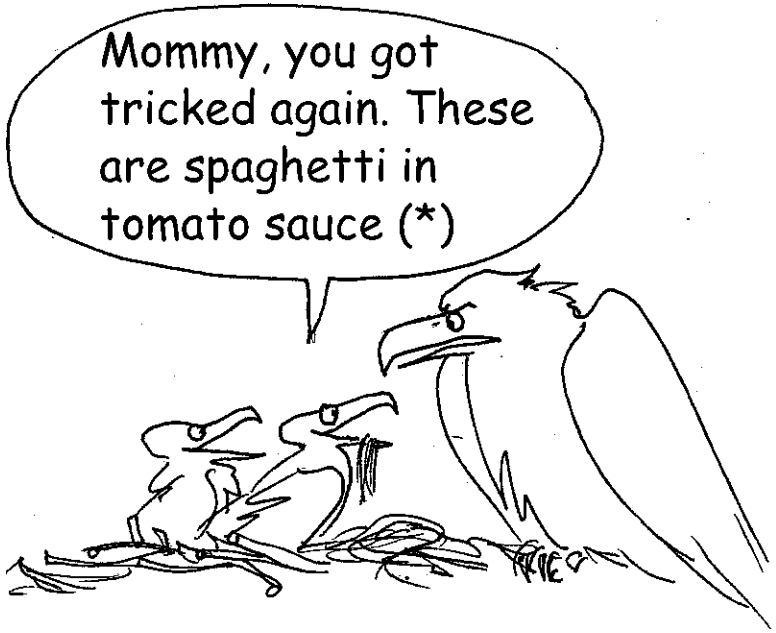
MOO!

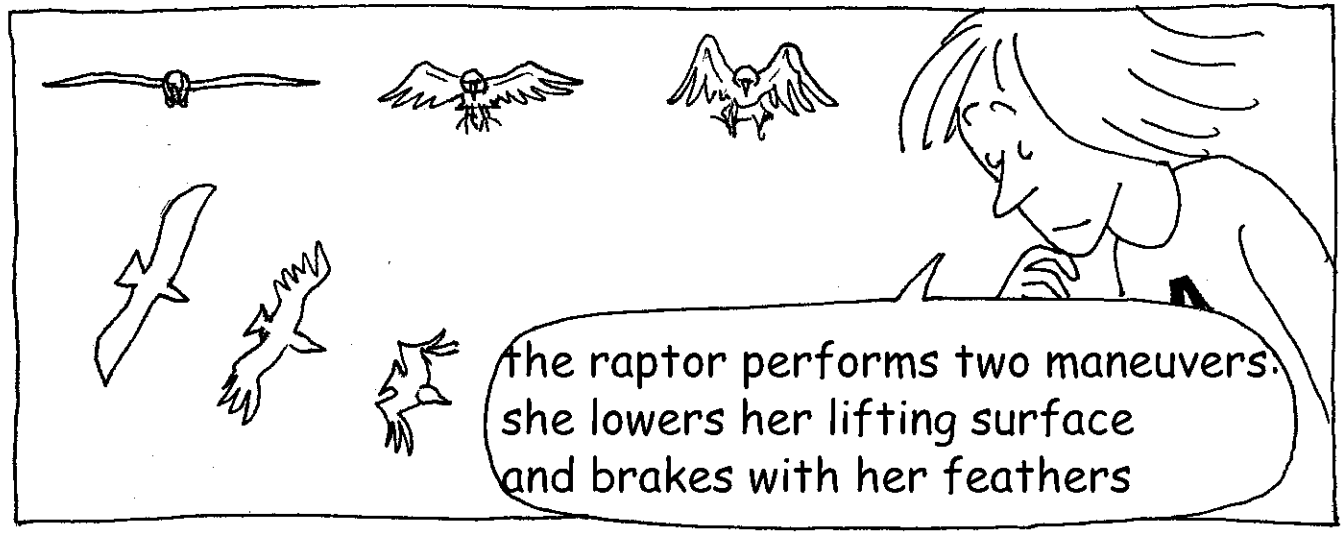
that was a narrow escape!

I really thought we were going to get the cow

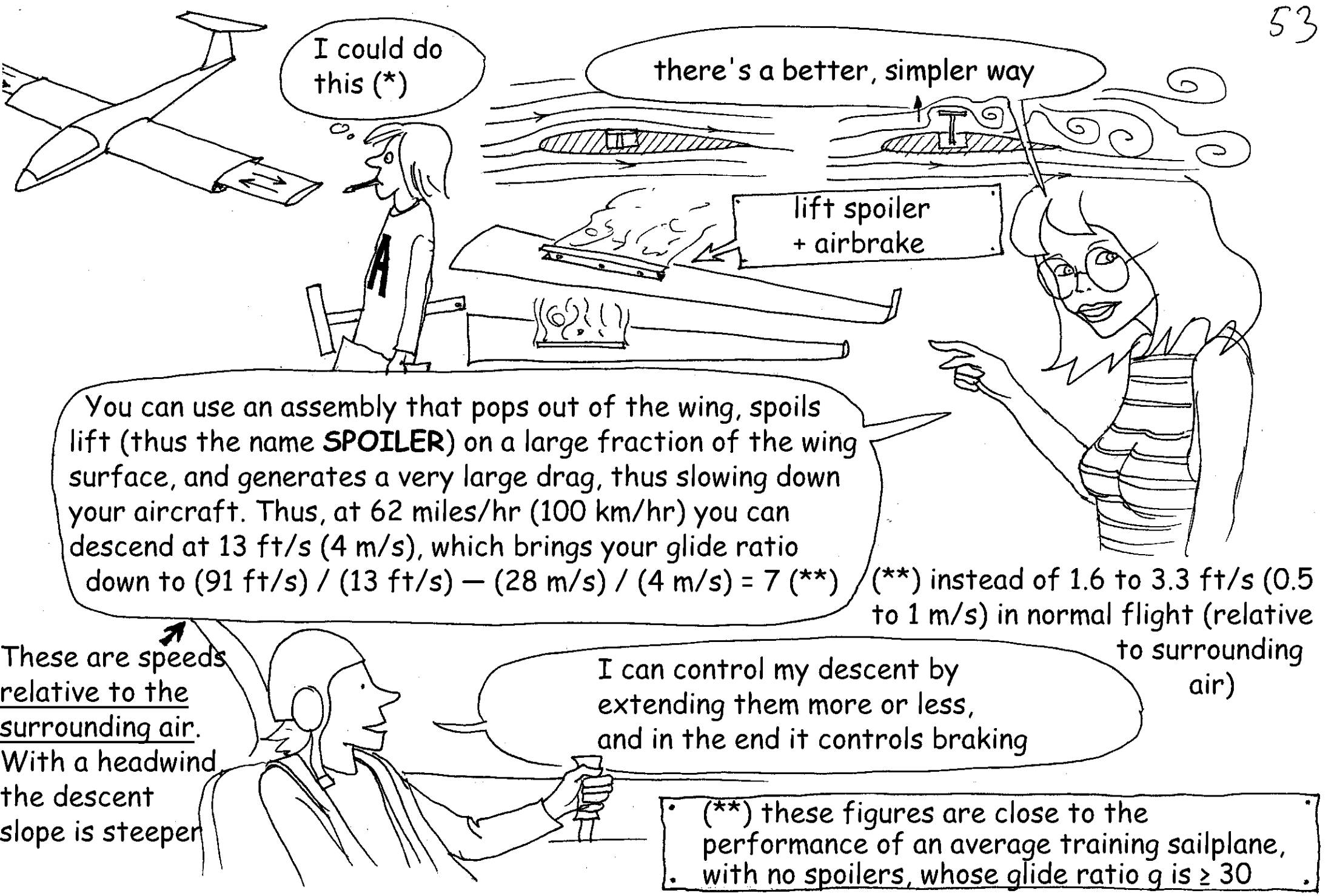
AIR BRAKES







(*) This happened to the author in Camp Simba at the Ngoro Ngoro crater in Tanzania back when he was a safari guide in Africa



(**) these figures are close to the performance of an average training sailplane, with no spoilers, whose glide ratio g is ≥ 30

(*) this was tried on airplanes in the 1930s, with limited success