version of October 15, 2022. Sylvain FAUTRAT

PREAMBLE

This document is the technical presentation of a device for a different piloting of a paragliding wing. The text is expected to evolve according to the progress of the project.
It is a question of exposing the principles of design and not the method of manufacture of the material nor the technique of piloting.
Free flight is a risky activity. The precise choices of materials and dimensioning are not discussed. If readers are inspired by these pages for personal achievements, it is their responsibility to deal with all questions of resistance of the different structural parts, as well as questions of piloting adapted to their configuration.

At the current stage, the device plays the role of an experimentation platform, without worrying about supplying or selling equipment.

HISTORICAL

In the version of the paraglider which has imposed itself almost universally, the connection between the lines of the wing and the pilot is made by a set of risers attached to two fixed points of the harness. Piloting is ensured mainly by varying the inclination of the two trailing edge flaps (the brakes) and by tilting the harness into roll, and temporarily by modifying the relative lengths of the risers.

Since the beginnings of paragliding, several devices aimed at improving this or that aspect of wing piloting have been explored. The approach generally consists of installing the risers, or the lines themselves, on elements that can be operated by the pilot.

Among the systems that have had a certain visibility, we can mention:

- risers fixed on the seat plate, tilting, of the harness *(piloting harness,* X. Rémond / André Rose)

  Ref. : Treatise on piloting and flight mechanics, chap11, H. Aupetit
  https://www.pilotage-parapente.com/manuel-de-pilotage/sommaire/pilote-et-pilotage/le-poste-de-pilotage/7 - accelerator-and-trims/

- risers fixed on two 40 cm bars located to the left and right of the pilot, each of which can be rotated around a horizontal axis by the pilot to change the attitude of the corresponding half-wing *(pilot bars)*

  Ref. : Treatise on piloting and flight mechanics, chap11, H. Aupetit

- risers fixed on two 12 cm pivoting plates not operable by the pilot, each forming a self-stabilizing swing within certain limits *(pilot pads,* L. de Kalbermatten)

  Ref. : Treatise on piloting and flight mechanics, chap11, H. Aupetit

- lines fixed and distributed on a rigid rectangular frame located above the pilot *(pilot cage,* Jean-Louis Darlet) http://aspicage.fr/.

- lines fixed to two 40 cm bars located to the left and right of the pilot, each of which can be pivoted around a horizontal axis, but also around a vertical axis in order to modify the trim of the corresponding half-wing *(BDBC Bidirectional differential balanced control ,* experiments by Nikolay Yotov)

  Ref. : http://skynomad.com/articles/bidirectional-differential-balanced-control
  https://www.paraglidingforum.com/viewtopic.php?t=97424

STEERING CAGE

The cage is undoubtedly the only device to have been developed over time, and to still be used in 2020 by a certain number of pilots. The gestures are completely different since the main piloting is carried out by the inclinations of the rectangular frame in roll and pitch, and not by action on the flaps. Via the lines, the inclination is transferred directly to the entire wing; we can speak of controlling the incidence.

The lines were first installed uniformly on the rigid structure. In a second version, the lines located further forward of the wing have been brought closer to the middle of the structure. This results in a dynamic twisting effect of the wing: for the duration of a rolling of the structure, on the side of the wing which is lowered, the rear lines are pulled over a greater length than are their front counterparts of same numbers; on the other side of the wing, the same differences are found but in terms of line release. It is then observed that the roll of the wing is accompanied by a direct yaw, more or less significant depending on the degree of approach of the front lines to the structure. It is a dynamic phenomenon, the twisting of the wing and its effect on its movement are all the more pronounced as the rolling of the cage is faster.

Once the wing is installed in a turn, all the lines are tensioned in a constant way, the cause of the twist no longer exists. The structure being rigid, twisting is only transitory. (The existence of a residual twist in a sustained turn can be discussed by invoking a deformation of the wing, all the less as the turn is better balanced.)

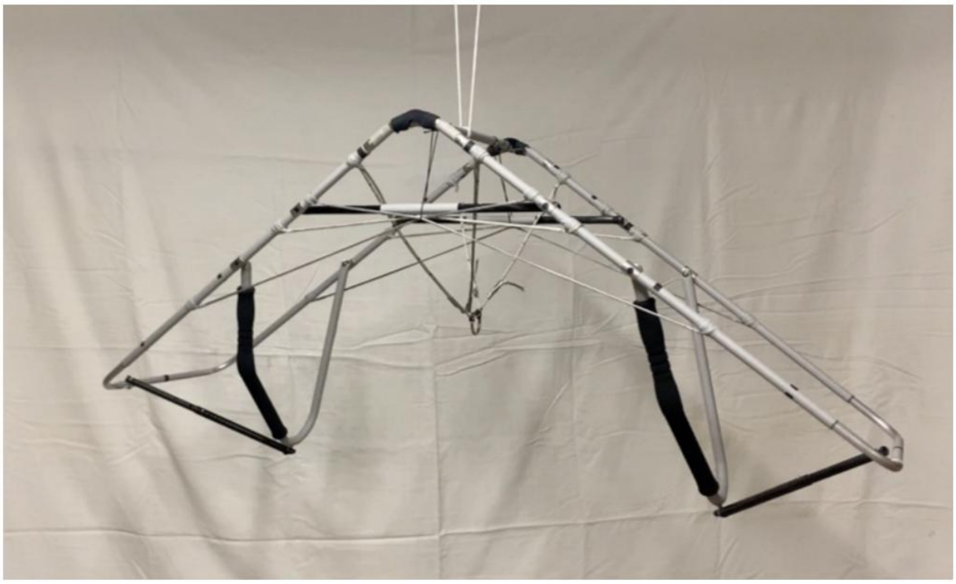
DPI

The word is an acronym for "Interface Aile Pilote", which can be pronounced *iape.*
The development of the iap has as its starting point the steering cage, from which it takes up the principle of the installation of the lines on an extended, rigid or quasi-rigid structure, as well as the principle of the main steering by inclination of the structure according to the roll and pitch axes. The iap is a technical extension of the cage in a certain direction, in the sense that different extensions are probably possible. The iap differs from the cage by choices for the shape of the structure, for the materials, and by the addition of a degree of freedom.

DESCRIPTION

• Shape of the structure

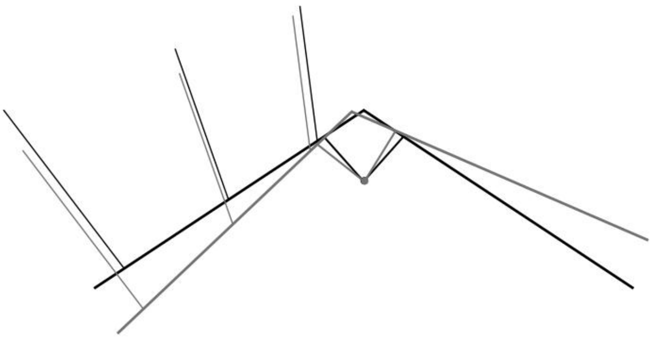
The lines are fixed on two rectangular surfaces forming a dihedral of 110°.
The angle is limited in opening by ropes, and limited in closing by tubular spacers, retracting to fold the iap.




• Angles between lines and iap

The line anchorages are distributed along four spars, all the further from the middle of the iap as they are more external on the wing. In addition, due to the dihedral shape, the angle between a hanger and the spar increases continuously from the middle outwards, to approach 90 degrees for column 3.

[Here, *the lines are identified according to a line-column diagram: • line 1 = row A: lines near the leading edge; then lines 2 and 3; • column 1: lines near the middle of the wing; then columns 2 and 3.]*

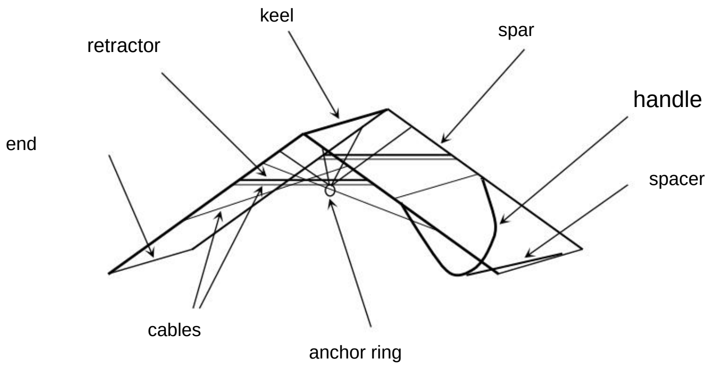


When a roll rotation is imposed on the IAP, each line is pulled a certain length on one side and released a certain length on the other side; and for the same line, these lengths increase continuously from column 1 to column 3 (and column 4 of the stabilizer lines, if there is one).

• Used materials

The straight sections are made of carbon fiber composite materials.
Curved sections are either aluminum alloy or stainless steel.
A number of connections are rope.

• Nomenclature



DEGREES OF FREEDOM AND MAIN MANAGEMENT ACTIONS

• Roll and pitch

The pilot acts on the handles to tilt the structure in roll or in pitch, the wing then also being stressed for the same inclination. The articulation allowing the inclination of the structure relative to the pilot is located at the level of the anchoring ring.

• Twist

For any turning aircraft, it is sought to obtain good coordination in terms of pitch-roll-yaw. It is a multi-factor problem that is more or less easily dealt with, the basic shape of the wing entering into the equation.
A wing only made of fabric offers the possibility of all kinds of deformation.
This possibility is exploited in paragliding during the lowering of the trailing edge flaps, and in the piloting cage during transient twisting for a turn. With the iap, we have the opportunity to explore the possibilities a little further by allowing the structure to twist to a certain degree. Through the lines, twisting of the iap results in twisting of the wing.

For a turn that is desired to be balanced in roll, one condition is the symmetry between the forces exerted by the air on the two half-wings. With a flexible wing, one can seek to deform this wing so as to adjust, all along the wingspan, the value of the angle of incidence, and consequently the value of the force exerted on each wing section . From the point of view of the usual parameters, it is rather the pitch angle that can be considered as more directly accessible to the command (in the reasoning, a distribution of the pitches over the wingspan being fixed, that of the incidences s follows, then that of the forces).
It is therefore necessary that a piloting action makes it possible to impose the attitude of the different wing sections as well as possible.

[Vocabulary : distinction between: •
warping: evolution of the camber of the profiles from the middle to the ends wing

• *twist (twist): evolution of the attitude of the profiles from the middle towards the ends of the wing.]*

The question arises of the degree of deformation of the iap in twisting that should be made possible for a typical bend. A theoretical approach sufficiently reductive to be treated by simple calculations, can provide orders of magnitude. The modeling used is described in the appended document. For a wing in a balanced turn according to the flight parameters chosen in the attached examples, it can be seen that the difference in inclination to be applied between the middle of the wing and one end does not exceed 2 degrees. Pros: a very steep typical turn, a pitch attitude in the middle of the wing quite far from its value in a balanced turn without twisting (concept introduced in the Appendix), and taking into account the reduced effective wingspan due to the vault, etc., one can for example retain 4 degrees as the greatest value necessary for twisting in order to obtain equilibrium.

Mechanically, the inclination of a wing panel is obtained by translation of the front lower line parallel to the rear lower line (considering them almost parallel). With regard to an end panel (lower lines of column 3), if the high points of the two lines are spaced apart, for example, by 1 meter, an inclination of 4 degrees corresponds to a translation of 7 cm. These 7 cm are found practically on the iap, at the level of the installation points of the two end lines. Here is an indication for the degree of deformation that the iap must allow.

In fact, in the installation under test, the front and rear lines of column 3 are not installed at the same distance from the keel; with, for example, respective distances of 34 cm and 66 cm from the keel, it is understood that a difference in translation between them of 7 cm corresponds at the level of the end of iap to a difference rather of the order of 18 cm (an angle of 25°).

At the time of writing, the efficiency of twisting is being evaluated.
Depending on the results, the next step will consist in defining more precisely one or more modes of use of this function.

• Felt inertia due to the structure

With a mass of less than 2 kg, the iap provides very little inertia during handling on the ground or gestures in flight.

• Secondary commands

- The central handle, present on the cage, which makes it possible to fold the two ends of the wing (make the ears) ends up on the iap.

- The two handles, present on the paragliders, which make it possible to lower the trailing edges of the two half-wings (the brakes) are found on the iap. The first targeted use is the creation of high lift when landing.

- A handle, at each end of the iap, allows you to pull the stabilo line in case of tie.

Various additional systems are to be considered:
- a system to reduce the effort deployed by the pilot to act in pitch (in the first place, to pitch the IAP) if necessary, a system to reduce the effort to act in roll
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- a system that would block or limit the movement of the iap in roll, and possibly in pitch, to temporarily free the hands. The principle of the cage and the iap is, to a certain degree, to separate the wing from the pilot on the three axes; in these conditions, without piloting, the wing is relatively free and the pilot is never supposed to let go of the controls for too long. The system in question would reintroduce on demand a more or less paragliding type connection.

COMPARISON BETWEEN “WING + RISERS” AND “WING + IAP”?

Using the same wing types, the two configurations obviously share most of their characteristics, and differ in a few others. The question of comparison arises naturally, but it is not a simple and unequivocal subject.

A certain characteristic may be an objective advantage in certain types of situation, and an objective disadvantage in such other situations.
Moreover, depending on the level of mastery of his aircraft by the pilot, or according to his type of practice, a characteristic will be perceived as either an appreciable advantage, or an anecdotal advantage, or even a disadvantage.
This is not the subject of this document, which essentially targets information of a physical nature.

VARIOUS EXPERIMENTS CARRIED OUT

• A greater or lesser depth of iap

The longitudinal distance between the anchors of the front lines and the rear lines, or iap chord, or iap depth, can be lengthened or shortened by changing the keel and the two end tubes. The depth is too great if there is difficulty in controlling the wing in pitch, the lines of which act on a large lever arm. The depth is too small if the pitch control is insufficient in amplitude, reaching its limit when the IAP is tilted to 90° when the nose-up or nose-down gesture should be prolonged. The depth is also too small when it is difficult or impossible to lift the wing from the ground, the rear lines being too little slack compared to the lines

Before.

The cage depth of 50 cm had already proven to be too big for some paragliding wings, i.e. not designed specifically for the cage. With 28 cm, on the contrary, we discover the problems associated with a depth that is too small. The current value is therefore intermediate. It can of course be modified if necessary depending on the wing you want to interface with an iap.

• Different values of the dihedral angle

In its first version, the iap had an angle of 120° between the two planes where the lines are fixed. The wing's ground handling was satisfactory.
The idea of reducing this angle serves two purposes. It is a means of increasing the structural resistance by making the triangulation by the different cables more efficient. It is also an opportunity to explore the possibility of eliminating the large handles, with manipulation carried out with the hands directly on the side members or on short sleeves fixed to the side members.
Tests with an angle of 90° showed two negative aspects. On the one hand, the ease of performing the various manipulations is not as good as with the dedicated handles.
In addition, instability was felt during pitch control with an irregular wind. When corrected by pitching up the pitch, from a certain angle the wing no longer resists, on the contrary it acts on the pitch by accentuating the pitch-up movement. The same phenomenon manifests itself in the nose-down correction. By analyzing the situation, we find that the disturbing moment of force is due to the lines hooked low on the iap, in this case the outer lines since the iap has a negative dihedral. When the iap progressively tilts in pitch, the outer suspension lines exert forces, which are always almost vertical, but whose lever arm with respect to the anchor ring lengthens progressively. The lever arm also depends on the distance at which the anchor ring is fixed under the iap. In summary, some lines exert nose-up moments on the iap, others nose-down moments; during the pitch-up movement, the different moments change, which leads, from a certain angle, to a resulting moment which is pitch-up, hence the instability. The situation is symmetrical for a dipping movement.

For a ring fixed at a certain distance, it is necessary to be able to recognize the dihedral angle values which are acceptable. One can proceed by multiple tests: one fixes a value for a distance, and one changes the angle of iap, with each time the same wing suitably interfaced on the iap.
We can also model the problem for a quantitative study. This is shown in the appendix. We note that an angle of 110° is acceptable for the anchoring distances used.

A dihedral effect can also occur with closed ears, depending on the type of veil and the size of the ears. In this configuration, the forces exerted by the lines of the two closed parts of the wing then have directions more inclined towards the rear than in normal flight; as the lines in question are precisely fixed quite low on the iap, it can result in a certain moment of force to sting.

It turns out that, from the point of view of piloting, such a moment has a positive effect since in flight with ears, it is advisable to nose down the wing to limit the growth of the angle of incidence on the open part of the wing.

• Different possibilities of amplitude and stiffness of the twist

After several solutions considered, the recall of the twisting movement is ensured by the end tubes. The choice of the type of tube makes it possible to adjust the stiffness of the return. We feel good by hand if one end resists too much when trying to twist. Conversely, it is less obvious to decide on a lower limit. Zero-stiffness tests were carried out with four free joints between the ends and the stringers. It is then very difficult to lift the wing correctly from the ground and impossible to maintain it in an irregular wind. This is still the case if the amplitude of the twist is reduced, by using a half-trapezium iap whose ends are reduced by half.

Currently, the extremities are the same length as the keel, and the optimal degree of stiffness remains to be explored under different types of flight.

• Evaluation of the mechanical resistance of the structure under static forces

The various lines fixed to the structure each support a certain fraction of the forces exerted on the wing by the air. These fractions are roughly equal to the fractions of wing area to which the lines are attached. For a certain total force exerted on the wing, in balanced flight, we can then attribute to each lower line the fraction of force which concerns it.

To carry out a resistance test in a fairly simple way, one can proceed by turning the iap over and suspending it by the anchor ring at a fixed point. A total test force being chosen, the force corresponding to it is exerted at each point of installation of the hanger by attaching a heavy object having the correct mass by means of a rope. To obtain from the various cords that they have the same orientations with respect to the iap as the lines in a situation of balanced flight, light spacers are used placed between each pair of cords. (The cage had been tested like this, with the structure turned upside down, with equal forces applied at different points on the spars.)

The test was carried out by taking used wooden beams as heavy objects. The total load available was 220 kg (3G for a 70 kg pilot). The iap showed very little deformation. The triangulation cables did not slip. The most bent tubes being far from their ultimate curvature, to push the tests further, it will be necessary to provide for significantly heavier loads.

The good resistance to efforts is not a surprise since, on the one hand, the central lines, which are the tightest in flight, and the pilot's suspension cables, are fixed on the iap more or less facing each other with the others. On the other hand, the triangulation cords allow the tubes to be stressed partly in compression rather than in bending.

ADAPTED HARNESSES

The attachment under the iap is of the single-point type, instead of the two side links at the bottom of the two risers. The connection of a paragliding harness is therefore made by means of a spacer having a central anchoring, and the two ends of which are fixed to the harness at the level of the two links.

Such a spacer can be designed to have an elastic vertical movement. In the event of sudden support by the wing (violent reopening, fall of the pilot after a significant dive), the shock can then be smoothed out to a certain extent. A clearance of 10 mm per unit of G is for example achievable without problem.

A linking device between harness and iap weighs between 100 and 200 grams depending on the design options.
It is the semi-reclined posture which seems best suited to piloting with the hands on the handles of the iap. This position is possible with many paragliding harnesses.

APPENDICES

The following studies were initiated to answer questions that arose at different times, and to which, in order to move forward, it was necessary to find answers, even approximate ones. The constraints are conceptual simplicity and simplicity of calculation, not the search for the greatest accuracy.
At the current stage, there are two studies written, the third is pending.

Appendix A - STUDY OF A PITCH INSTABILITY LINKED TO THE DIHEDRAL OF THE IAP

An iap with a low angle could have the advantage of being controllable directly with the hands on the spars, thus eliminating the handles. However, handling tests on the ground with an iap angle of 90° revealed an unstable effect: from a certain pitch angle, nose-down or pitch-up actions were amplified by the wing itself; to stop this induced movement, it was necessary to quickly reverse the action of the hands...
The interpretation is not difficult: when a low angle iap is tilted (to the horizontal, to exaggerate), the lines hooked near the two ends act with a very large lever arm (measured in relation to the axis passing through the pilot's anchor point, here constituting the point of articulation).
Moreover, front and rear lines can tend to rotate the iap in the same direction, whereas the first idea would be rather that, if the front lines tend to rotate in one direction, the rear lines would tend to rotate in the same direction. opposite.

By comparison, with a flat structure (angle of 180°), the lines fixed along the same span of the structure all have the same lever arm. And the front and rear lines act according to opposite pitching moments.
The mechanism of the instability being understood, we still need a quantitative study to have more precise benchmarks when it is a question of choosing an angle of iap knowingly. The study is simplified to the maximum, while preserving the specific shape of the iap.

The following calculations are intended for people wishing to enter the subject themselves.

The conclusions can be read independently.

Model assumptions

The symbols used refer to the following drawings. • The lines exert on the frame forces whose projections in the vertical plane of symmetry are vertical (satisfactory approximation because the wing is high with the lines slightly inclined forwards or backwards). • We reason with only two lines of lines, a front line and a rear line.

All the forces exerted by the front lines are modeled by a single force, of vertical projection FA applied to point A of the drawing. The same applies to the rear lines with the force FB applied at point B. • The pitching moments are calculated with respect to point O which is the joint at the connector. • The pitch angle is not extreme, it remains less than approximately 80°.

(Otherwise, the direction of action of FA reverses, more precisely when QaPa < z.
For its part, QbPb always remains > z, so no inversion.) •
When we tilt the frame, the force on A remains the same, and the same for the force on B.
The study is aimed at the transient effects, after a rapid inclination of the iap, before the wing has advanced or retreated notably in relation to the iap. • To balance the moment of force in pitch created by the forces in A and B, the pilot's hands act at the two points B of the drawing seen from the front (the same points B are chosen here to simplify the diagram and the reasoning). This action is summarized by a force FPILOT ,
perpendicular to the direction OPb and defined as acting in the direction of the pitch considered (nose or nose up).

Study situations

Parameters specific to the iap

angle of iap = 90° chord of the

iap: QaQb = 360 mm anchorage O

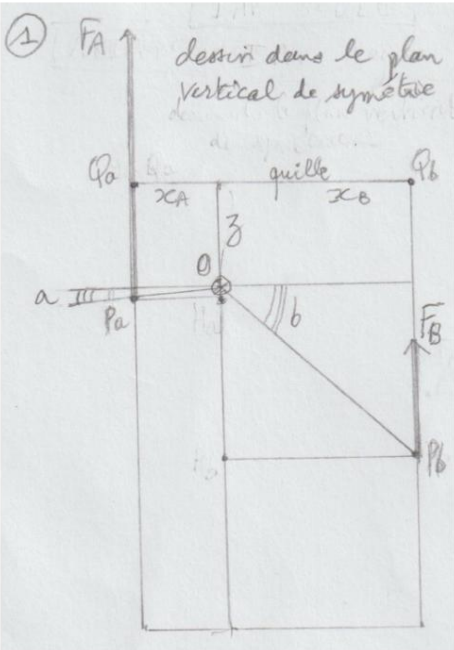
located at z = 130 mm under the keel at xA = 110 mm

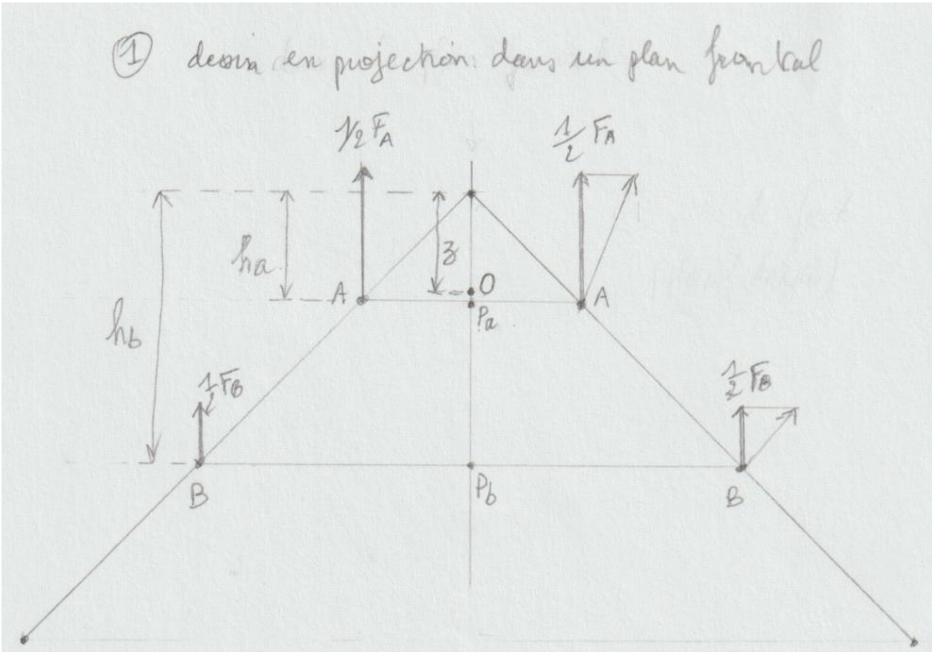
from the forward plane at xB = 250

mm from the aft plane

lines installed along the spars, at QaA = 200 mm from the keel, for the bows, at QbB = 500 mm from the keel,

for the afts

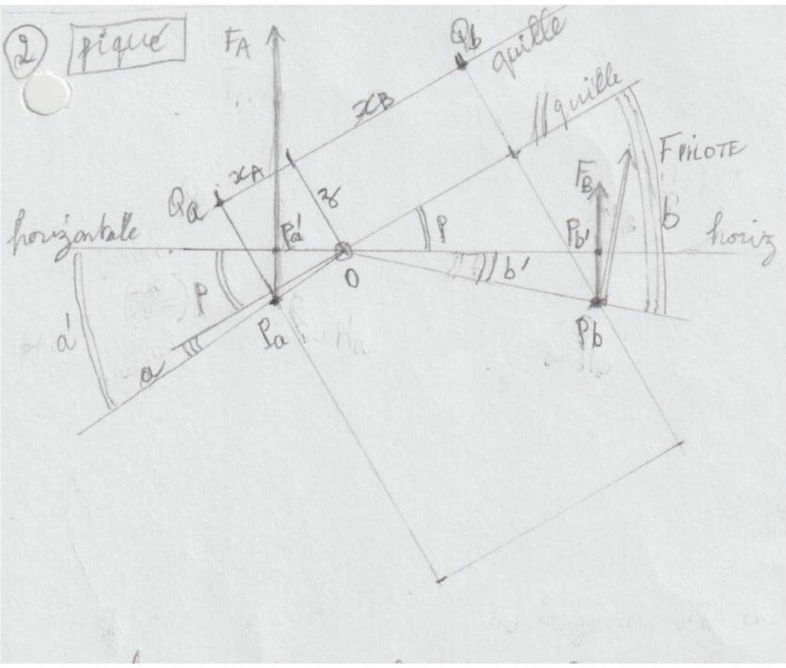


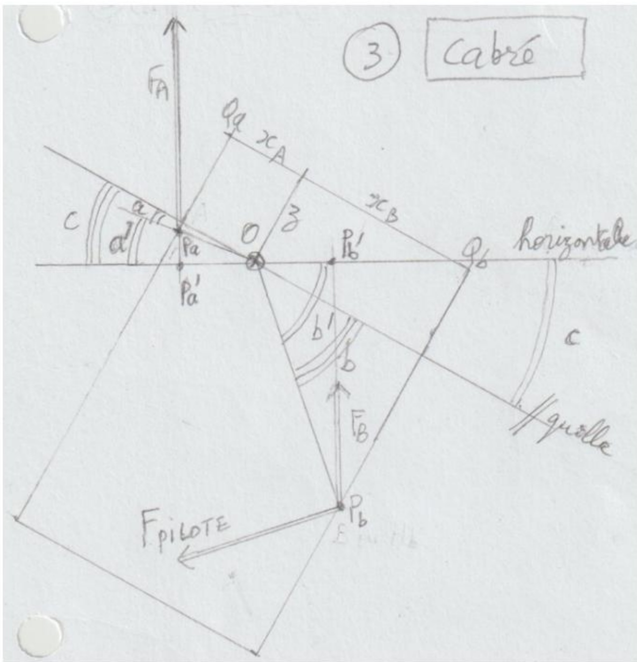


Parameters for situations with pitch pitch angles to

pitch down: p = 30° (for comparison accelerated to the other pitch up: c = 30°

maximum recommended, the drop between the front and rear links is around 150 mm, this is the case here if p = 25°)





Calculation formulas

The different angles a, b, p, c, a', b' are considered algebraically, i.e. including negative values.

1- right iap

The wing exerts a vertical force F which is distributed between FA and FB. The correct centering of the iap in balanced flight is achieved with values xA and xB such that: FA = F [xB / (xA + xB)]

FB = F [xA / (xA + xB)].

The heights ha and hb are given by: ha = QaA .

cos(½ . angle of iap) hb = QbB . cos(½ . angle of iap).

The lengths OPa and OPb are given by: + (ha – z)2]

OPa = [xA^2 ½ OPb = [xB^2 + (hb – z)2] ½.

The angles a and b are given by: a =

arctan [(ha – z) / xA] b = arctan [(hb – z) / xB].

Note: the formula for a is valid even if z > ha.

2- pricked

3-

The angles are connected by:

a' = a + p b' = b – p.

SO : OPa' = OPa . cos(a') OPb' = OPb . cos(b').

The balance of the moments of force in the presence of the force F can be written:

FPILOT . OPb + FB . OPb' = FA . OPa' .

Hence the strength:

FPILOT = (FA.OPa' - FB.OPb ') / OPb .

4- wheelie

5-

The angles are connected by:

a' = c - a b' = b + c.

SO : OPa' = OPa . cos(a') OPb' = OPb . cos(b').

The balance of the moments of force in the presence of the force F can be written:

FPILOT . OPb + FA . OPa' = FB . OPb' .

Hence the strength:

FPILOT = (FB.OPb' - FA.OPa ') / OPb .

Noticed. If, in the pitch-up formulas, we take for c the value - p, we recognize for a' and c' the same expressions as for the dive angle p, therefore also the same values for OPa' and OPb ' , and finally the same absolute value for FPILOT, with nevertheless a change of sign, which is to be rectified to take into account the opposite direction of definition of FPILOT in the case of the pitch-up. Thus, for a pitch angle value, whether nose down or pitch up, the value of FPILOTE is the same and it suffices to do the calculation only once.

(Note that this can be anticipated, for example in the following way. Since the two forces FA and FB are always postulated vertical, by turning the diagram 180°, we find the classic case of a compound solid rotating around a fixed axis, with mass concentrated at two points (A and B), subject to gravity and an external moment (that of the FPILOTE). The symmetry in this context is obvious.)

Calculation results

Values chosen for the parameters

Total vertical force, exerted by the wing on the iap, the value: F = 50 kg.

Parameters to vary and values chosen

angle of iap 90° 110° 130° 180° (iap flat) 15° 30° 60°
pitch angle p or c: distance from the 80°
anchor under the keel z: 130mm 170mm 210mm

Parameter of interest It

is the FPILOT force which is the parameter to be monitored. When its value is positive, it means that, in order to maintain itself, the system actually requires an action from the pilot in the direction of the current pitch. A negative value means on the contrary that the system is unstable, and all the more unstable as the absolute value is greater. What is desired is stability, that is to say positive values for FPILOTE.

Results

IAP angle (°)	90	90	90	90	110	110	110	110	130	130	130	130	180	180	180	180
pitch angle of the iap (°)	15	30	60	80	15	30	60	80	15	30	60	80	15	30	60	80
Results for a dive or a nose-up																
For z = 130 mm: different values of the iap angle and different values of the pitch angle																
Fpilot force required to balance the moment of the wing (kg)	*-2.9*	*-5.7*	*-9.8*	*-11.2*	*-1.6*	*-3.2*	*-5.5*	*-6.2*	*0.3*	*0.6*	*1.1*	*1.3*	*6.0*	*11.5*	*20.0*	*22.7*
For z = 170 mm: different values of the iap angle and different values of the pitch angle																
Fpilot force required to balance the moment of the wing (kg)	*-1.5*	*-2.9*	*-5.1*	*-5.8*	*0.1*	*0.2*	*0.4*	*0.5*	*2.4*	*4.6*	*8.0*	*9.1*	*7.3*	*14.1*	*24.3*	*27.7*
For z = 210 mm: different values of the iap angle and different values of the pitch angle																
Fpilot force required to balance the moment of the wing (kg)	*0.2*	*0.3*	*0.56*	*0.64*	*2.1*	*4.1*	*5.8*	*8.0*	*4.5*	*8.7*	*12.3*	*17.1*	*8.3*	*16.1*	*22.7*	*27.9*

Findings

• For a given angle iap and given z, the stable or unstable effect increases progressively when the pitch angle increases. • For the 90° iap, with z = 130 or 170 mm, the results (negative values) are consistent with the instability observed in the field. • Increasing z changes an unstable iap to stable. • Increasing the angle of iap changes an unstable iap to stable (at 180°, the stability would be strong in any case).

Appendix B - STUDY OF THE EFFECT OF WING TWIST ON ROLL BALANCE DURING OF A MAINTAINED TURN

Issues addressed

- in a steady steady bend, how does the angle of attack change along the the wingspan?
- how to define the notion of balanced turn in roll? - can the balance be improved by modifying the trim of the wing? thanks to a twist of the wing?
- for a typical turn with a paraglider wing, what is the order of magnitude of the degree of useful twist?

Procedure followed

- choice of a balanced flight criterion in roll - modeling of the wing, of the movement of the wing in turns, of the lift force - calculation of the kinematic parameters, then calculation of the forces from the data kinematics, via the most basic usual formulas
- examination of the values of the parameters obtained in some configurations of significant shifts, and lessons to be learned.

Balanced flight criterion

The aim is to identify trends and not to develop an exact study. In view of a simplified approach, we limit ourselves to the case of an elongated wing, in a slightly inclined turn. Under these conditions, for the study of balanced flight, the lift force is retained as preponderant on each profile, to the detriment of the drag components.

The following criterion is then given: a turn is well balanced when the distribution of lift along the span is symmetrical with respect to the middle M of the wing.

Modeling Model of the wing Initially,

the wing is described as flat (without arch, without twisting) and horizontal according to the wingspan (no roll). The distribution of chord values along the span is assumed to be symmetrical with respect to the middle M of the wing, but the values themselves of the different chords are not used in the intended calculation.

For the profile located at the coordinate r along the wingspan, its attitude is defined by the angle a(r) measuring its nose up above the horizontal. In the absence of twist, the attitude of the different profiles everywhere have the same value as that aM in the middle of the wing: a(r) = a(rM) = aM.

From the preceding description, it is possible to introduce a progressive twist from one end to the other of the wing, in the form of a certain distribution of an increase in attitude noted Aa(r). Consequently, the attitude of the profile at the coordinate r is no longer equal to a(rM) but: a(r) = aM + Aa(r).

The case of a linear twist, the only one that will be considered here, is of the form: Aa(r)=k(rM ÿr), with k the twist coefficient. The base supplement is nil in the middle, and the distribution is antisymmetrical between the two sides.

With such a twist, the attitude is written: a(r) = aM + k (rM - r).

We note that, if d is the half-span, the wing extends from (rM - d) to (rM + d).

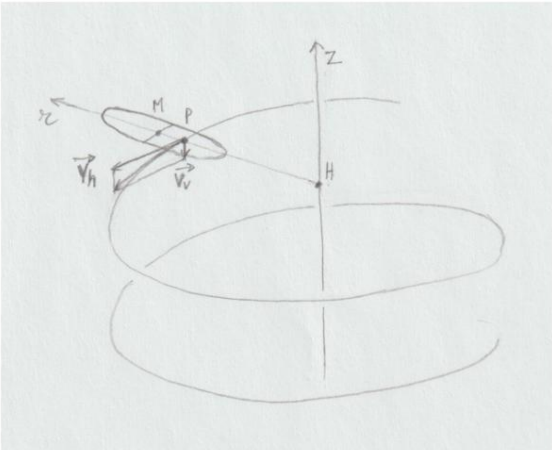
Model of the movement of the wing in the air mass

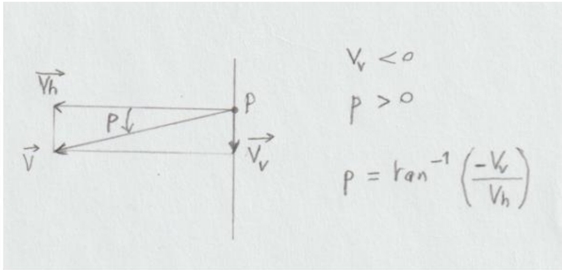
The ambient medium is homogeneous air fixed with respect to an inertial frame of reference.

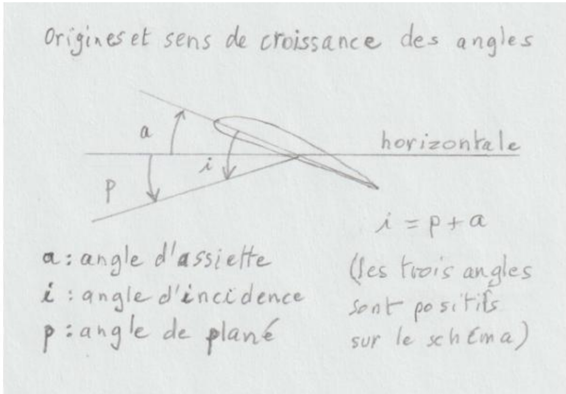
The wing is in helicoidal motion: it descends at a constant vertical speed -Vv, and is in revolution at a constant angular speed w around a certain fixed vertical axis Oz in the air.

We use the usual cylindrical coordinates (r, f, z), with the z axis upwards, and the radial coordinate r identifying with the variable introduced previously for a wing whose the wingspan is well aligned with the radial direction. The horizontal speed of each point of the wing is then of the form: Vh = wr.

The notion of “wing turn radius” corresponds to the value of rM.







Lift force model The lift (on a unit

area) is written in the form: FL = CL.(½)rV2 .

For the usual profiles, it is considered that the lift coefficient varies proportionally to the quantity (i – i0), called "absolute angle of attack", where i0 is the angle of attack at zero lift: CL = CLi. (i – i0).

In our case, for a profile with coordinate r, since V2 = (Vh obtains: FL(r) = 2+ Vv2) = (w2 r2 + Vv 2), we CLi (½)r.(w2 r2 + Vv 2).(i(r) - i0).

Parameter calculations

glide angles

The glide angle p(r) for a profile of coordinate r is expressed, from the components Vh Vv , by: p(r) = tan and 1(-Vv/Vh) = tan 1(-Vv/wr).

"Geometric" bearings

For each profile, the incidence is related to the glide angles p and trim a by :

i(r) = a(r) + p(r).

With a linear twist of coefficient k, this gives:

i(r) = aM + k (rM - r) + tan 1(-Vv/wr).

For the absolute incidence, this gives: (i(r) - i0) = (aM - i0) + k (rM - r) + tan (-Vv/wr). 1

By analogy, we can call (a(r) - i0) the "absolute attitude". In M, it is: (aM - i0).

Lift forces We now

have: FL(r) = CLi (½)r(w2 r We can write FL(r)2 + Vv2).[(aM - i0) + k (rM - r) + tan . 1(-Vv/wr)]. is written in the form KK = CLi (½)r fL(r) = (w2 r2 fL(r), by setting:

+ Vv 2).[(aM - i0) + k (rM - r) + tan 1(-Vv/ wr)].

In what follows, it is only the parameters aM and r that we will vary; it is therefore sufficient to consider the "lift factor" fL(r) for the study of the balance of the turn.

Parameter values used: half-span: d =

5 m vertical speed, two values:

Vv = - 1.5 m/s Vv = -2.0m/s

turn radius of the wing, two values: rM = 15 m rM = 20 m turn
period and angular velocity:

T = 14s - w = 2p/T = 0.45 rad/s T = 14 s - w = 2p/T = 0.45 rad/s

range of acceptable values for angles of incidence: 2° - 20°

[Ref. for paragliding profiles: (1) Treatise on piloting and flight mechanics, section 15, H. Aupetit: range 5° - 20°; (2) Sharknose patent: range 1° - 20° https://worldwide.espacenet.com/publicationDetails/biblio?FT=D&date=20120914&DB=worldwide.espacenet.com&locale=en_EP&CC=FR&NR=2972422A1&KC=

Numerical study

It is conventional to use flight mechanics formulas to show, for example, the relationship between flight speed and angle of attack, the latter depending on the attitude control, etc.

Here, the study is at fixed constant speed, and what is of interest is the relationship between the lift distribution along the span and the trim distribution (with and without twist).

First page: for information, some graphs of incidence as a function of radius r,

- first without twisting for two pitch values aM fixed at -5° and -8°, - then with three different twists for the pitch attitude of -5°.

Second page: plots of various graphs (in red) of the lift distribution along the span, in other words of the lift factor fL as a function of the radius r.

On the left of the page, there are three cases of absolute attitude (aM - i0) ; the second value was set by adjusting it to obtain an fL curve that has good symmetry with respect to the middle of the wing.

On the right, it can be seen that by adding a suitable twist, it is also possible to obtain a good lift symmetry with the first and second absolute attitudes on the left, this by adjusting the twist coefficient k each time.

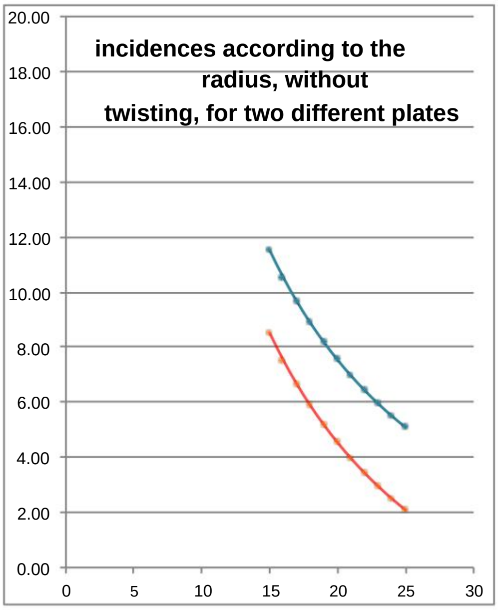
The angle of attack curves (in blue) are useful to ensure that the values chosen for the parameters are indeed compatible with angle of attack values located in the authorized range.

Third page. The same study as on the second page, for a tighter turn.

Incidence as a function of radius r, for some pitch values, without and with twist

rM (m)	Vv (m/s)	w
20	-2	0.45

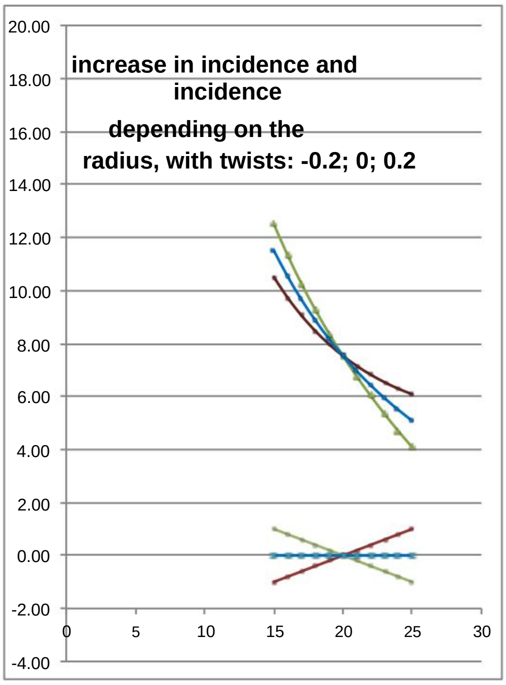
trim aM (°) =		-5	-8
	radius r(m)	incidence i (°)	incidence I (°)
	15	11.50	8.50
	16	10.52	7.52
	17	9.65	6.65
	18	8.87	5.87
	19	8.17	5.17
middle M	20	7.53	4.53
	21	6.95	3.95
	22	6.42	3.42
	23	5.94	2.94
	24	5.49	2.49
	25	5.08	2.08



Comment

Increasing pitch has the effect of increasing the various angles of attack along the wingspan by the same amount (shifting the curve upwards).

plate	aM (°) = -5					
coefficient. twist	k =	-0.2	k =	0	k =	0.2
	increase trim angle Aa (°)	i' (°)	increase trim angle Aa (°)	i' (°)	increase trim angle Aa (°)	i' (°)
	-1	10.50	0	11.50	1	12.50
	-0.8	9.72	0	10.52	0.8	11.32
	-0.6	9.05	0	9.65	0.6	10.25
	-0.4	8.47	0	8.87	0.4	9.27
	-0.2	7.97	0	8.17	0.2	8.37
middle M	0	7.53	0	7.53	0	7.53
	0.2	7.15	0	6.95	-0.2	6.75
	0.4	6.82	0	6.42	-0.4	6.02
	0.6	6.54	0	5.94	-0.6	5.34
	0.8	6.29	0	5.49	-0.8	4.69
	1	6.08	0	5.08	-1	4.08



Comment

The bottom graphs show the trim increases along the wingspan (we can also see the shape of the trailing edge, the leading edge being horizontal).

A negative twist coefficient corresponds to an angle of attack which decreases towards the inside of the bend, and increases towards the outside; it is the reverse with a positive coefficient.

lift as a function of radius r, for some pitch values, with and without twist (1/2)

rM (m)	Vv (m/s)	w(rad/s)
20	-1.5	0.4

VhM(m/s)	duration(s)
8	16

in yellow: value set arbitrarily (for test)

in orange: value adjusted to obtain a symmetrical lift distribution

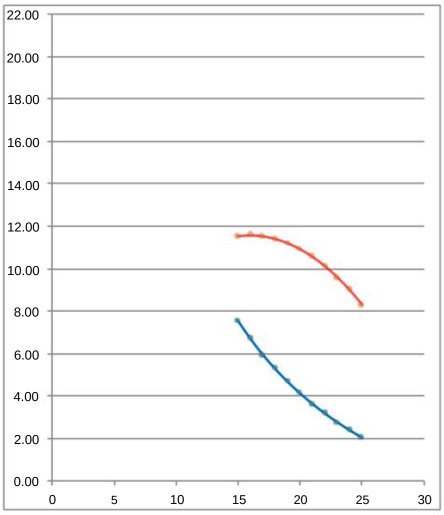
fL is divided by 25 to have displayable values on the same scale as the other quantities

left side: lift without twist (k = 0)

right side: lift with adjusted twist

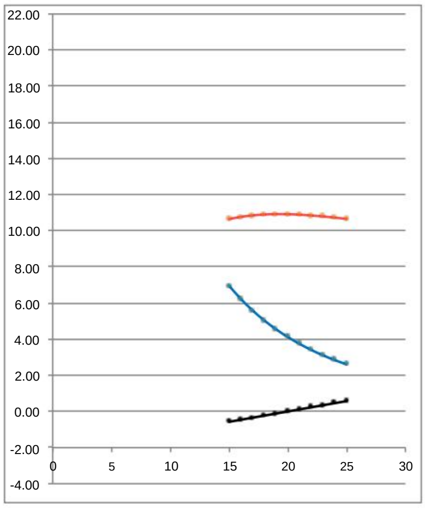
absolute plate (°) aM-i0 = -6.5

Ray r (m)	incident. absolute i-i0 (°)	fact. lift fL/25
15	7.54	11.5
16	6.69	11.6
17	5.94	11.5
18	5.27	11.4
19	4.66	11.2
M 20	4.12	10.9
21	3.62	10.6
22	3.17	10.1
23	2.76	9.6
24	2.38	9.0
25	2.03	8.3



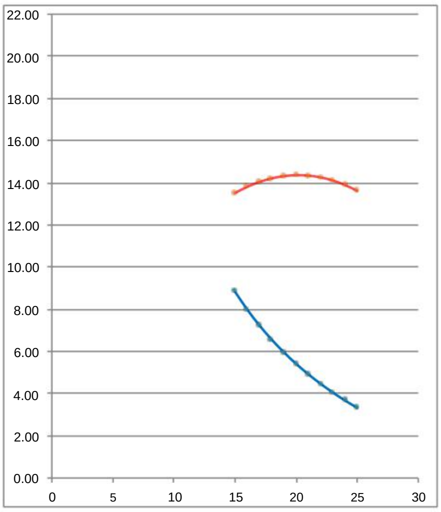
coefficient twist k= -0.115

aug. plate Aa (°)	incident. absolute i-i0 (°)	fact. lift fL/25
-0.575	6.96	10.7
-0.46	6.23	10.8
-0.345	5.59	10.9
-0.23	5.04	10.9
-0.115	4.55	10.9
0	4.12	10.9
0.115	3.74	10.9
0.23	3.40	10.8
0.345	3.11	10.8
0.46	2.84	10.7
0.575	2.61	10.7



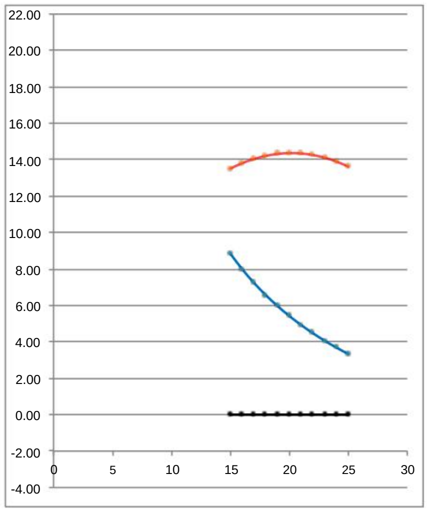
absolute altitude (°) aM-i0 = -5.2

Ray r (m)	incident. absolute i-i0 (°)	fact. lift fL/25
15	8.84	13.5
16	7.99	13.8
17	7.24	14.0
18	6.57	14.2
19	5.96	14.3
M 20	5.42	14.4
21	4.92	14.3
22	4.47	14.3
23	4.06	14.1
24	3.68	13.9
25	3.33	13.6



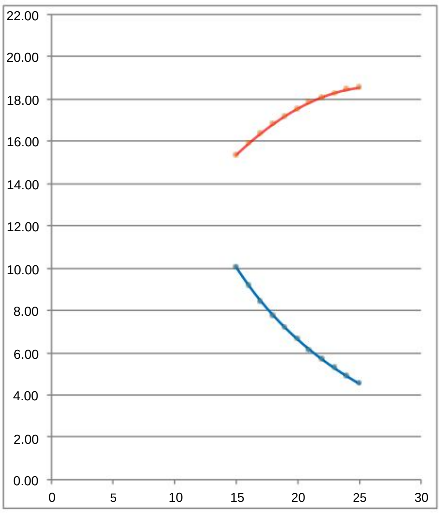
coefficient twist k= 0

aug. plate Aa (°)	incident. absolute i-i0 (°)	fact. lift fL/25
0	8.84	13.5
0	7.99	13.8
0	7.24	14.0
0	6.57	14.2
0	5.96	14.3
0	5.42	14.4
0	4.92	14.3
0	4.47	14.3
0	4.06	14.1
0	3.68	13.9
0	3.33	13.6



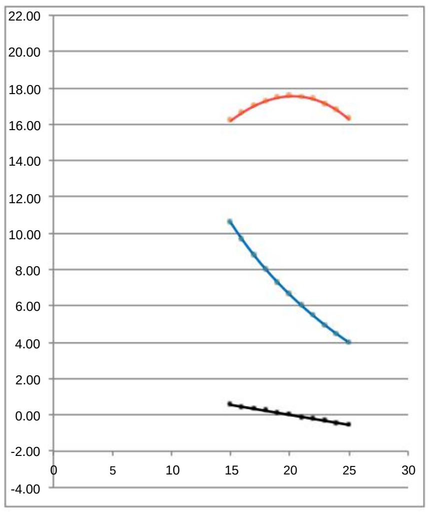
absolute plate (°) aM-i0 = -4

Ray r (m)	incident. absolute i-i0 (°)	fact. lift fL/25
15	10.04	15.4
16	9.19	15.9
17	8.44	16.4
18	7.77	16.8
19	7.16	17.2
M 20	6.62	17.5
21	6.12	17.8
22	5.67	18.1
23	5.26	18.3
24	4.88	18.4
25	4.53	18.5



coefficient twist k= 0.11

aug. plate Aa (°)	incident. absolute i-i0 (°)	fact. lift fL/25
0.55	10.59	16.2
0.44	9.63	16.6
0.33	8.77	17.0
0.22	7.99	17.3
0.11	7.27	17.5
0	6.62	17.5
-0.11	6.01	17.5
-0.22	5.45	17.4
-0.33	4.93	17.1
-0.44	4.44	16.8
-0.55	3.98	16.3



lift as a function of radius r, for some trim values, with and without twist (2/2)

rM (m)	Vv (m/s)	w(rad/s)
15	-2	0.45

VhM(m/s)	duration(s)
6.75	14

in yellow: value set arbitrarily (for test)

in orange: value adjusted to obtain a symmetrical lift distribution

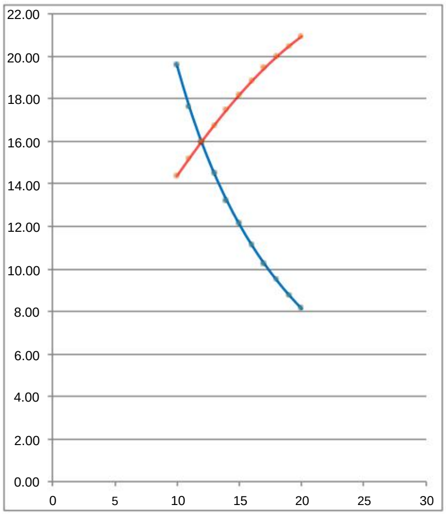
fL is divided by 33 to have displayable values on the same scale as the other quantities

left side: lift without twist (k = 0)

right side: lift with adjusted twist

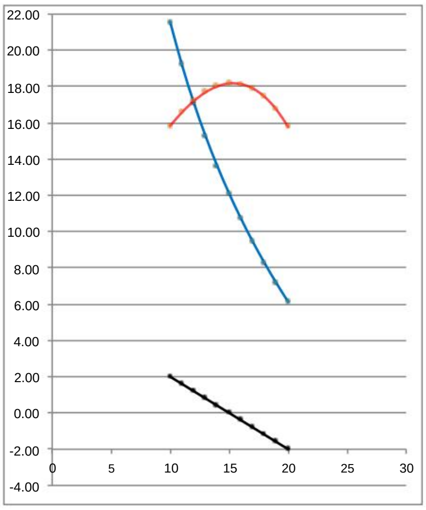
absolute plate (°) aM-i0 = -4.4

	Ray r (m)	incident. absolute i-i0 (°)	fact. lift fL/33
	10	19.56	14.4
	11	17.60	15.2
	12	15.92	16.0
	13	14.47	16.8
	14	13.21	17.5
M	15	12.10	18.2
	16	11.12	18.8
	17	10.25	19.4
	18	9.47	20.0
	19	8.77	20.5
	20	8.13	20.9



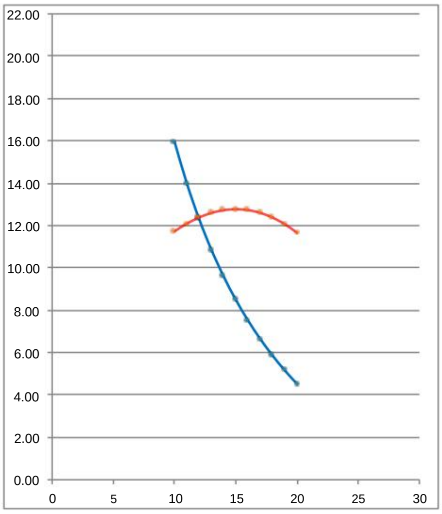
coefficient twist k = 0.4

aug. plate Aa (°)	incident. absolute i-i0 (°)	fact. lift fL/33
2	21.56	15.8
1.6	19.20	16.6
1.2	17.12	17.2
0.8	15.27	17.7
0.4	13.61	18.0
0	12.10	18.2
-0.4	10.72	18.1
-0.8	9.45	17.9
-1.2	8.27	17.4
-1.6	7.17	16.7
-2	6.13	15.8



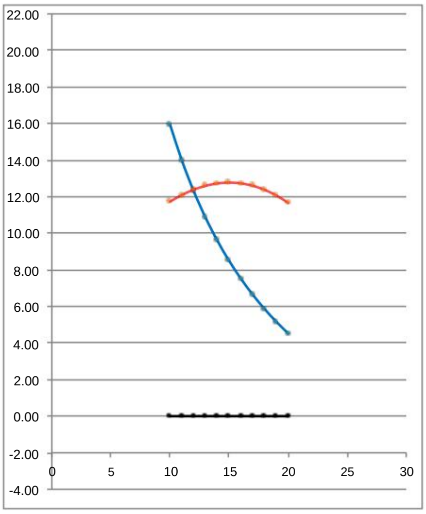
absolute plate (°) aM-i0 = -8

	Ray r (m)	incident. absolute i-i0 (°)	fact. lift fL/33
	10	15.96	11.7
	11	14.00	12.1
	12	12.32	12.4
	13	10.87	12.6
	14	9.61	12.7
M	15	8.50	12.8
	16	7.52	12.7
	17	6.65	12.6
	18	5.87	12.4
	19	5.17	12.1
	20	4.53	11.7



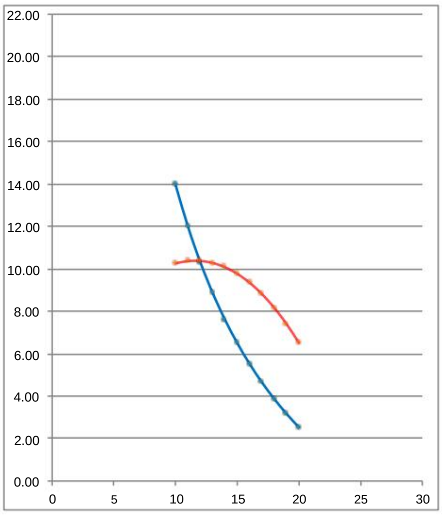
coefficient twist k = 0

aug. plate Aa (°)	incident. absolute i-i0 (°)	fact. lift fL/33
0	15.96	11.7
0	14.00	12.1
0	12.32	12.4
0	10.87	12.6
0	9.61	12.7
0	8.50	12.8
0	7.52	12.7
0	6.65	12.6
0	5.87	12.4
0	5.17	12.1
0	4.53	11.7



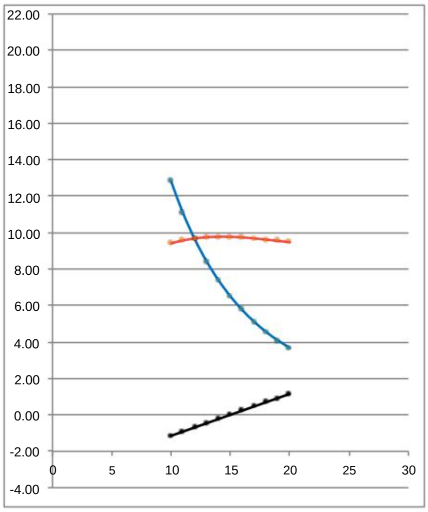
absolute plate (°) aM-i0 = -10

	Ray r (m)	incident. absolute i-i0 (°)	fact. lift fL/33
	10	13.96	10.3
	11	12.00	10.4
	12	10.32	10.4
	13	8.87	10.3
	14	7.61	10.1
M	15	6.50	9.8
	16	5.52	9.3
	17	4.65	8.8
	18	3.87	8.2
	19	3.17	7.4
	20	2.53	6.5



coefficient twist k = -0.23

aug. plate Aa (°)	incident. absolute i-i0 (°)	fact. lift fL/33
-1.15	12.81	9.4
-0.92	11.08	9.6
-0.69	9.63	9.7
-0.46	8.41	9.7
-0.23	7.38	9.8
0	6.50	9.8
0.23	5.75	9.7
0.46	5.11	9.7
0.69	4.56	9.6
0.92	4.09	9.5
1.15	3.68	9.5



Comments on the results • In summary, for a given turn kinematics: it is thus possible to balance

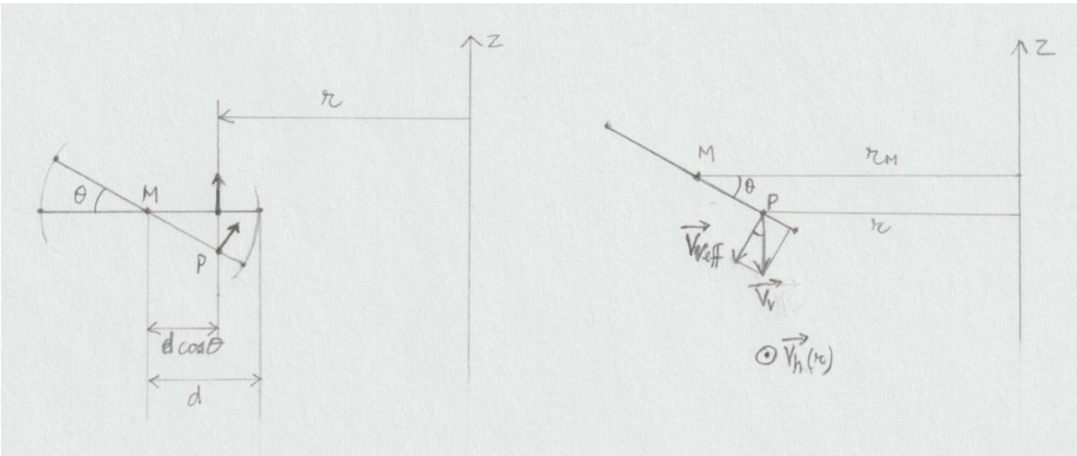
- the turn by adjusting only the attitude (within certain limits imposed by the permitted angle of attack values), if the attitude is not adjusted, it is possible to balance the turn by adjusting the twist. • Within the framework
- of this model, the mechanics of trim by adjustment of the trim are easily understood: when the trim is increased, the incidences on the whole wingspan are increased by the same amount, but the increase in the resulting lift is greater on the outside of the wing because the speed factor (squared) is greater there than on the inside of the turn. Symmetrically, the opposite is true for a decrease in attitude.

In conclusion, if the outside of the wing sinks, the wing must be pitched up. And prick if it's the inside that sinks. • The mechanics of balancing by adjusting the twist is more intuitive: if the outside sinks, you have to twist in the direction of an increase in trim on the outside, and on the inside if it is the sinking interior.

Value of results

In general, the modeling does not integrate all the characteristics of a real wing, of the detailed kinematics of a turn, nor of the air most often (see below).
The numerical values obtained are to be considered as indicative benchmarks to consider trends, and not as data to be found by precise measurements in real conditions.

Consideration of the inclination in the turn of the aircraft



On the diagrams representing the horizontal wing and the same wing inclined at an angle q, we see that the modifications which affect the quantities entering into the calculations are as follows:

rM ±d ----> rM ± d.cosq
vv ----> Vv-eff = Vv.cosq

Thus, the values of r to consider are along the projected span, which is smaller by a factor cosq, and similarly for the term replacing the vertical velocity.
(For the record, in the 20° example, the cosine differs from 1 by only 6%.)
Apart from these substitutions, the calculation formulas themselves are unchanged. It is still a matter of comparing the forces perpendicular to the wing. Finally, the study leads to the same types of graphs of the lift factor as a function of r, as when the wing was considered horizontal.

Imaginable complexity of modeling This is not the goal here, but we can list a few aspects that have not been taken into account. a) The velocity vectors are not the same, in norm and in direction, in (rM - x) and (rM + x). The difference in norm was taken into account in the calculation of the geometric incidence i(r), and consequently in the calculation of the lift norm. But the difference in direction implies a difference between the directions of the two lifts, which is not taken into account in the appreciation of the lift distribution along the span. This could be done at a reasonable complexity cost.

The difference in direction also results in a yaw moment: the inside lift is more inclined backwards than the outside lift. Qualitatively, this corresponds to a yaw moment in the direct direction (in the direction necessary for the turn).

b) If we consider that a profile has a certain length (its chord), it follows that its different points are not exactly at the same distance r from the axis of revolution, and therefore do not have exactly the same geometric incidence. c) A real wing is not flat but arched. d) In fact, the profiles chosen by the designers are not exactly the same from the middle of the wing to the ends (CLi and i0 depending on r) e) The air is most often not homogeneous; in particular, thinking about thermals, we can consider introducing a lift in the air, strong near the axis of revolution and decreasing when we move away from it.

f) Better than the lift, the RFA is more relevant to calculate to discuss the balance of the flight. Adding the parasitic drag at the level of the different profiles could be considered as the introduction into the calculations of approximate analytical formulas. For its part, the so-called induced component requires on the one hand to consider the wing globally in 3D flow, but also to distribute it here in a certain way on the different profiles. In the register of complex processing, modeling by digitization of fluid mechanics equations around a wing in turn, with and without twisting, may be preferred.

Appendix C - PROCEDURE FOLLOWED TO INTERFACE A PARAGLIDER WING

Here, "interfacing" represents the transfer to an iap of a paraglider wing initially connected to risers.

The operation is broken down into: -
obtaining the necessary information concerning the geometry of the bundle of lines
of the wing
- choose the pitch, i.e. here an attitude of the iap in a straight flight situation "at
neutral" (without effort to pitch up or pitch up)
- choose a distance between the wing and the iap (between the middle of the lower surface and the keel) -
choose the attachment point for each line on the iap - calculate the new length of each lower line - fix each
hanger on the iap.

Next, the position of the pilot's anchorage under the IAP must be determined: - in terms of
the abscissa along the keel (centering) - in terms of the vertical distance under the keel
(depending on the degree of pitch stability
research).

Finally, it may be necessary to make the connection between the anchor point and the iap more complex, by
seen :
- to adjust the degree of effort in roll - to modulate
the effort to pitch down or pitch up.

This section is unwritten.