Let's talk yaw stability

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For decades we all have calculated our model thanks to some formulae. I still remember this time where computers were not so familiar and where we were using those famous "Texas Instruments" or "Hewlett Packard" calculators... that's 30 years ago! I was under 20...

At this time, I was very surprised not to find any good and complete formula to define the vertical fin. The only thing I found was a general statement on a percentage of the wing surface. Nothing like the tail volume calculation formula. Very frustrating.

Everyone applied some experienced rules (more or less efficient) and got inspiration from aircraft produced by the full size aviation world.

And the fuselage length was quite different from one type of aircraft to another: sometimes short, sometime as long as half of the wing span, sometimes as long as the wing span, and sometimes even more.

Where is the truth?

This was so until Mark Drela published his AVL and Andre Deperrois provided us with his wonderful XFLR5 V6 software.

So let's have a look at yaw stability comparing calculation and experience.

Do gliders fly straight?

The answer to this question is NO ! NEVER !

This is quite surprising but measures made on radio-controlled gliders with a yawing flag provide us the answer (see http://www.xerivision.com). The flight is not a straight flight. It is a combination of oscillations on all axes. Such oscillations in yaw are up to +/- 3 degrees and +/-1 m/s in pitching.

The oscillations are due to any turbulence or action made to drive the model. Look how often you use the sticks! Every two to three seconds you act on them.

And when you do not act on them and you think that the flight is straight, you are cheated. A yawing oscillation of +/- 3 degrees is nearly impossible to be detected from the ground. Even with a camera, such oscillations are difficult to see. Put a flag on the plane and a camera behind it or register the signal with the "xerivision" probe and you will see them.

The consequence of such slow and tricky movement on the gliding ratio is a loss of one to two points. This is more or less the gain you can obtain if you do adapt the wing's profile to each wing section Reynolds number. This means that all the famous calculations made with any sophisticated computer are a waste of time. You think you have the best plane, but the plane may become a standard one if not well studied in terms of stabilities.

You then have a first interest to be sure that your model gets the right stability.

The benefit we can also obtain from good yaw stability is on circling ability. The more the model is circling with a high angle of attack, the lower is the margin from stalling. And stalling is easily obtained by adverse yaw that is generated by any aileron movement during a flight at high angle of attack. When the flight is at low speed - high angle of attack on the pitch axis - the adverse yaw is more important. The plane yaws, so the speed reduces, and then the stall occurs.

One easy way to reduce such stalling ability during circling is to increase the yaw stability.

Dynamic stability

Why do we have to study stability "dynamically."

Nature hates changes. Every time you try to change the way it goes, there is opposition. We call it "inertia." The more abrupt the change is the higher the opposition is. Think at your life. You are also conducted by such rule!

The movement change you want to impose on the model is then slowed and it does not follow the exact movement you wanted. Furthermore, movement may occur with some oscillations more or less amortized.

All our previous calculations were performed in a "static" mode. This means that everything is stable and not subject to any turbulence. Of course this is rarely true. As we said, we are acting on sticks every one to two seconds. We then have to think "dynamic." This means we have to predict the way the model is passing from one stable trajectory to another stable trajectory after a command or turbulence.

All such things are not new at all. It has been taught for decades, nearly a century in fact, in our university.

But formulas are quite complex and calculation is then not easy with our "10 fingers computer."

Thanks to well studied software, things are now different and all the math behind the formulae can be a bit forgotten. We can now explore the dynamic aspect without having a high degree of knowledge. This allows us to predict model reactions to any turbulence. We can then predict whether or not models are efficient on the yaw axis. You can be sure that any competitor is going to look at it. Mark Drela has already done it for years for his Supra, Supergee and so on. Thanks, Mark, for giving us some so useful tools.

Where do we have to think "dynamic" for our models.

Pitch axis

Pitch is to be studied with "dynamic tools" in order to predict the "neutral point." This is the point where the horizontal rotation axis is passing. This is quite important to predict the place of the CG (Center of Gravity) of the model. In order to have a "neutral" movement, the CG will be placed just a bit forward of that point.

Since the main mass are the wing and the radio, quite close to the pitch rotation axis, inertia is quite reduced. That's why we can use, and we have been using for decades, the standard static formula, also called the tail volume formula.

Roll axis

The roll axis is passing through the fuselage from the front to the rear. The wings and their mass, generally 50% of the weight plane, are quite far away from this axis.

Dynamics are then important to predict the roll rate of the model.

Everybody knows that the lighter the wings are, the easier is the roll rate.

Yaw axis

The yaw axis is located vertically and is passing somewhere near the CG.

All plane masses are then quite far away from this axis.

Yawing is then THE topic where "dynamic" is important.

How to characterize dynamic yaw movement

The "yawing" movement is quite a complex one. It is not a pure movement around the vertical yaw axis. It is a combination of movement around the three axes (pitch, roll and yaw). It is also called the "Dutch roll." (See Illustrations 1 and 2.)

Two parameters are important:

• The frequency also called "Dutch roll" frequency. Frequency is mainly depending upon efforts from the fin. Of course the size of a model is quite important. The oscillation frequency of a small plane is bigger than the one of a big plane. The oscillation also depends upon speed. As an example, the frequency is about 0.4 to 0.6 Hz at low speed for an F3J model. This is then not a speedy movement, one oscillation every 2 seconds. That's why it is not easy to see it from the ground.

• The amortization factor. Amortization mainly involves Inertia. The higher is the inertia, the higher is the time for the plane to recover a straight flight after a deviation. At low speed, the less stabilized planes, let's take a 3m span glider, get eight to ten seconds to amortize the movement. This represents 3.5 oscillations. This means that planes require 80 m to get stabilized! In the opposite, a well studied plane like the original Supra requires only three seconds in the same condition to be stabilized (25m). One third the time!

Planes that are not well amortized in yaw will appear "heavy" in such axis. This is due to the fact that any action to the yaw stick will require time to be executed and also more time to be stabilized. As pilots generally adjust their commands every two seconds, the position of the plane in yaw is "somewhere," but never where the

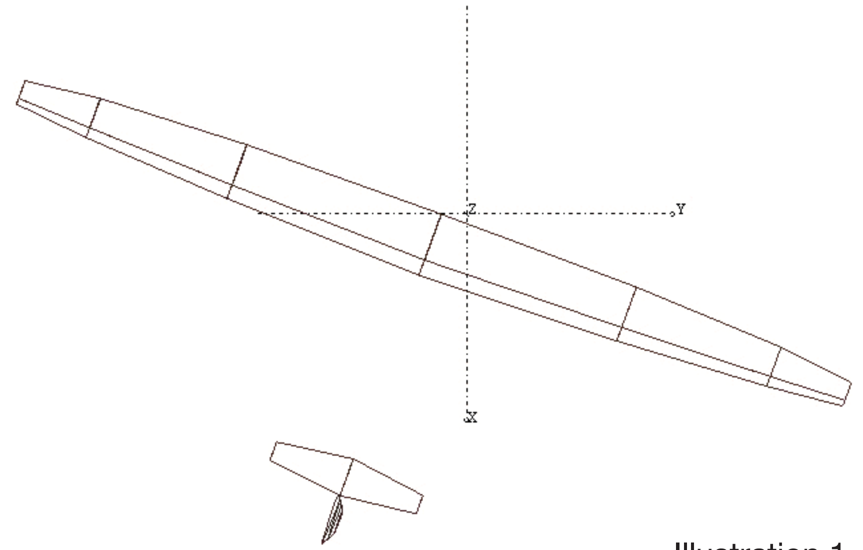


Illustration 1

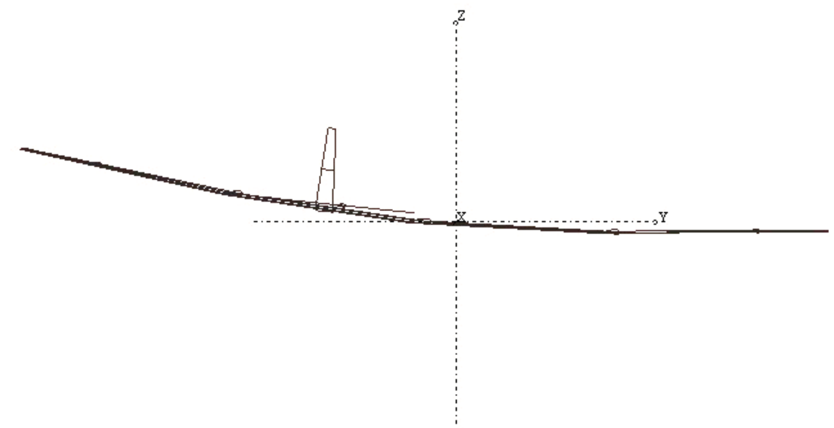
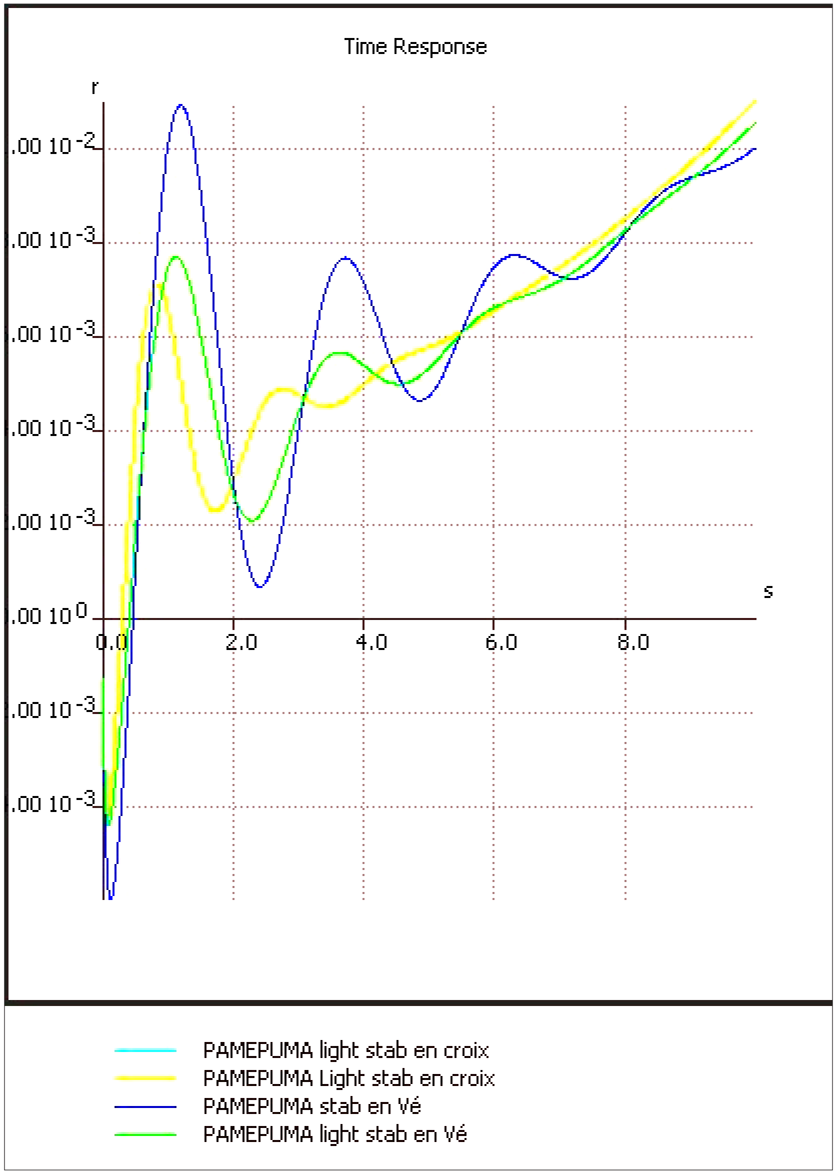


Illustration 2

"Dutch roll" flight representation provided by XFLR5. The top and rear view shows the complexity of the movement, a combination of oscillations around the three axes.



Oscillation graph provided by XFLR5. Whether the plane is well amortized or not, the result is quite different.

pilot wants. The only way to manage such a plane is to play with the plane, slowly, gently... And sorry for the air turbulences! They will destroy the gentle and smooth flight. You better see now why yaw is so important in circling. (See Illustration 3.)

Let's make few experiences on yaw stability

I have the chance to get one wing that is capable of being installed on two planes. The first one is an F3B plane with V-tail created in the 90s, the second one is using the same fuselage but with an X-tail and it is calculated to be far more stable in the Yaw axis. Both planes are of the same weight and same CG.

PAMEPUMA: An F3B plane of the 90s. The father of such plane is M. Patrick Médard. The "light" version is here presented. (See Illustration 4.)

PAMEPUMA with X-tail fuselage. Proportions are not unlike any F3K planes - even the fuselage length is representing 1.25 times the half span. Proportions are still not so strange for the eyes. (See Illustration 5.)

In terms of projected surfaces both fuselages are quite equivalent. (See chart on next page.)

The fuselages do differ. (See Illustration 6.)

Several pilots flew the two planes. Their conclusion was crystal clear. The V-tail version is difficult to circle, as any modern F3B plane, while the X-tail version can be managed as an easy glider.

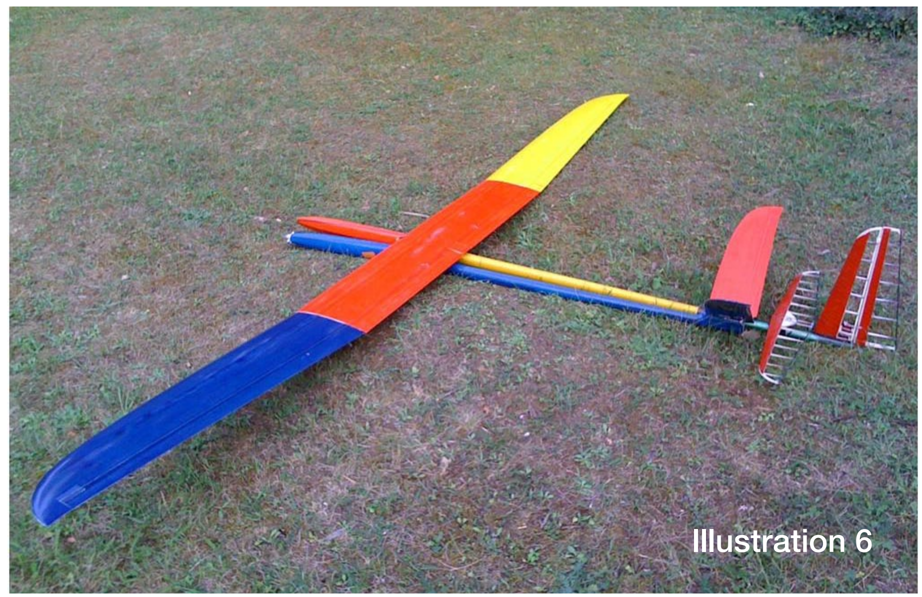
On the one hand:

- The V-tail version requires 50% aileron differential and the flight must be very well anticipated and managed.
- You are driving a truck.
- It is also difficult to circle at low speed. Only flat and large circles can then be performed. It is a "standard" F3B machine.
- The yawing management is performed with big orders on the stick.

PAMEPUMA V

PAMEPUMA X

Model	Developed surface	Projected vertical surfaces	Vertical efficient surface
PAMEPUMA V	8.5 dm² (V)	4.86 dm²	2.78 dm²
PAMEPUMA X	4.79 dm² (fin)	4.79 dm²	4.79 dm²



Comparison of the two fuselages. Yes, there is a difference.

On the other hand:

- The X-tail plane is fully different.
- Circling is easy and does not require anticipation.
- Small orders create "immediate" and "precise" response on the yaw axis.
- The inverse yaw effect during circling appears to be small and is easy to correct with very few commands required.
- Very small turn radius at low speed is now possible.
- Glider is now more agile. It is a plane for a beginner.
- It is not a transformation, it is "a revolution"!

Does XFLR5-V6 predict this? Of course!

XFLR5 modelisation

XFLR5 modelisation shows the following:

- The X-tail version is developing 2.4 more torque around the yaw axis compared to the V-tail version. This is the consequence of the V-tail efficiency effect, a V-tail fin is 0.57 as efficient as an X-tail fin for the same vertical projected surface, and the bigger level arm of the X-tail version. (See Illustration 7.)

Why increase the fuselage length?

In order to create efficiency in the yaw axis, it is required to generate torque and amortization.

This can be done by two ways:

- Increase the vertical fin surface
- Increase the lever arm.

It is demonstrated that the lever arm increase is far more efficient in terms of stability. An increase of 10% of the lever arm generates a 21% increase of the amortization factor (1.1*1.1=1.21). An increase of 10% of the surface is only creating a 10% improvement in stability.

An increase of 10% of the yaw torque capability will then have a different improvement consequence. There is then a certain interest in adopting a long fuselage.

Look at F3K, aerobatic planes, beginner's planes or even an F5D racer. They still know it.

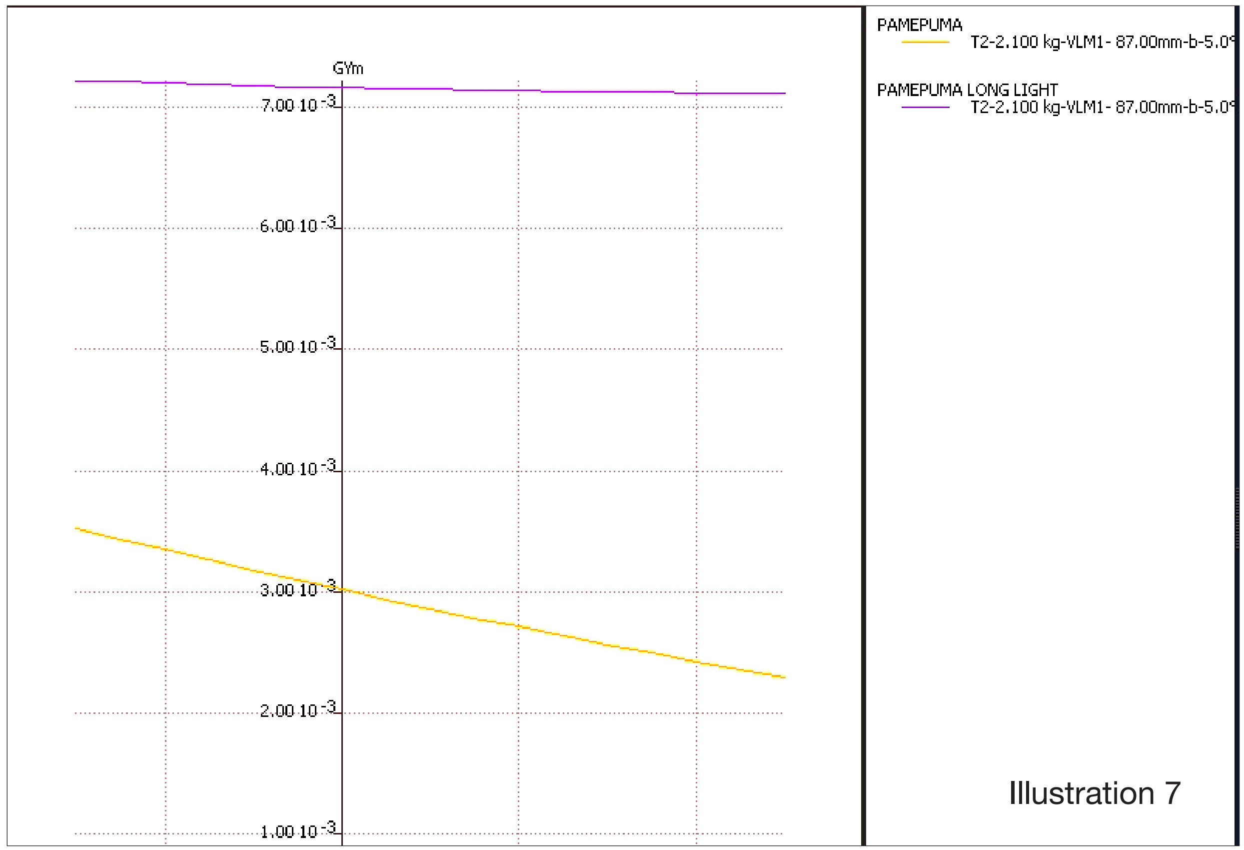
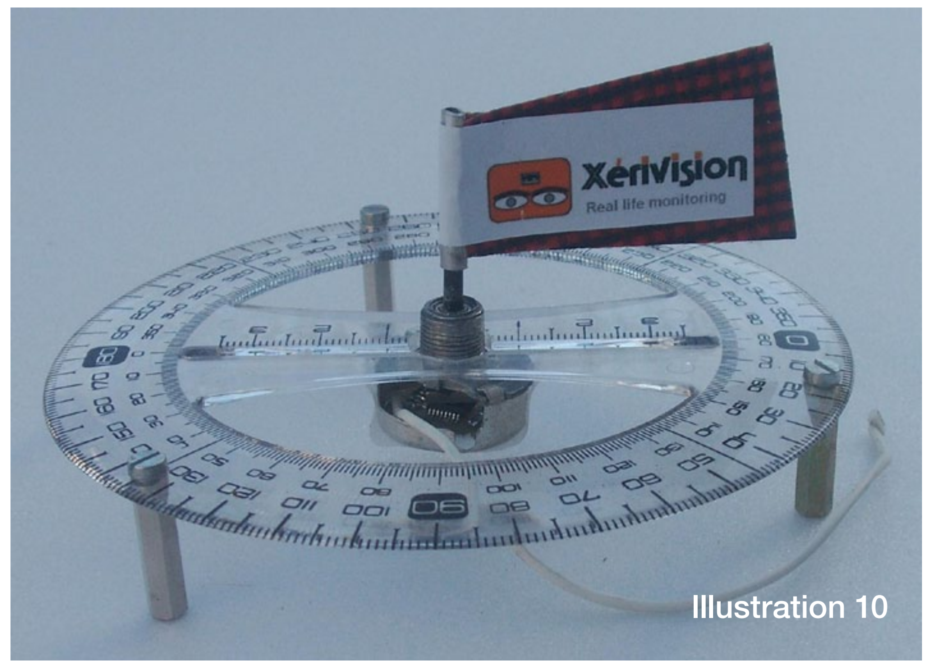


Illustration 7

The yaw moment coefficient of the X-tail version is 2.4 times the V-tail. This is the main reason why the X-tail version is so easy to fly.



Above, Illustration 8: The Xerivision yaw sensor system *integrated into a streamlined pod.*

Above right, Illustration 9: At this time the Xerivision system was not integrated into a pod... But that's experimentation !

Right, Illustration 10: The Xerivsion yaw probe. This is the first probe tested. New probes are now half the size.

Is XFLR5 representative of reality?

Having the two planes (See Illustrations 8 and 9.), a Xerivision "data logging" system, and the famous yaw probe of the same company (See Illustration 10.), we decided to make a registration of all movements during a calm winter day.

The system allows measuring up to 10 times per second the following parameters:

- Altitude,
- Speed,

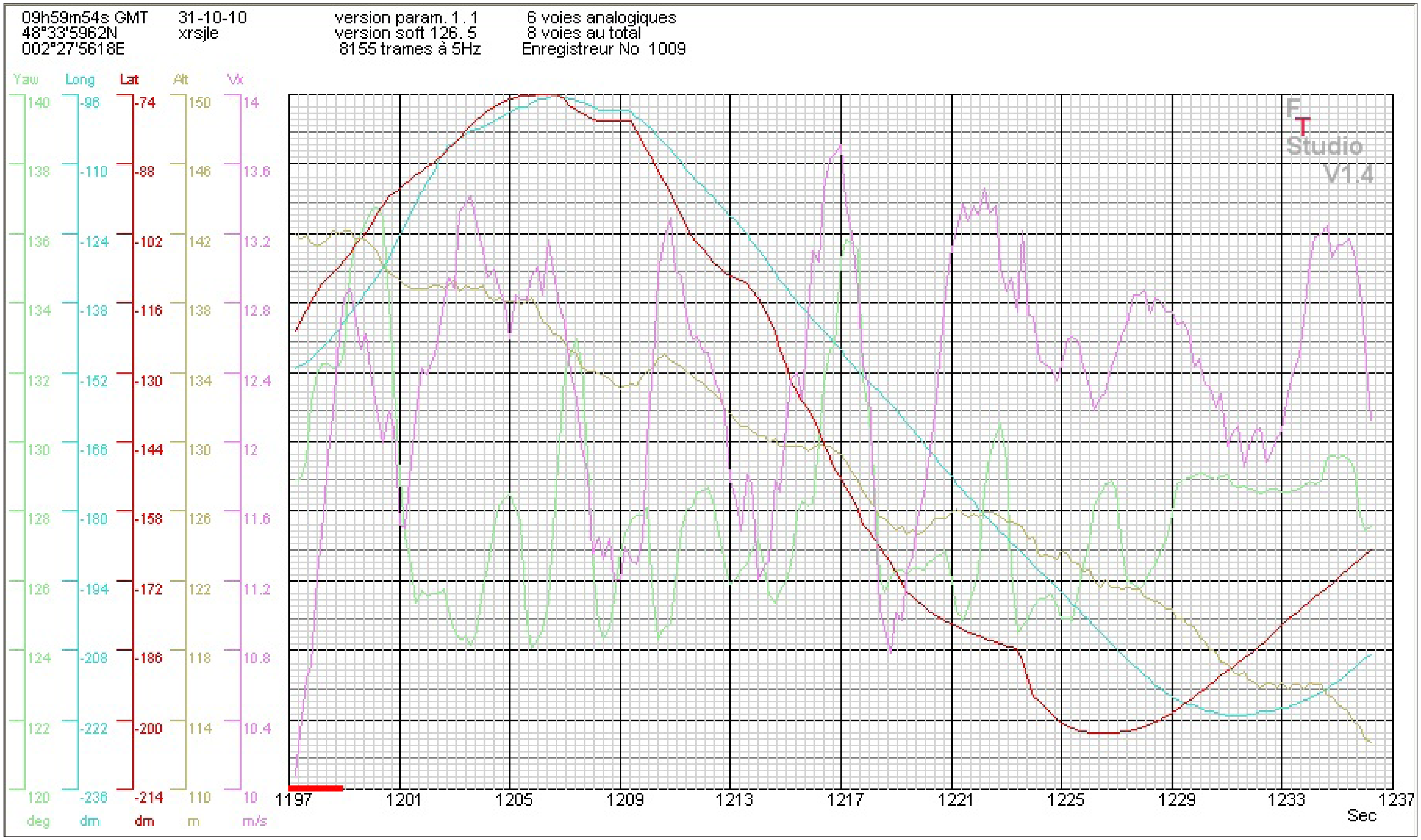


Illustration 11

• Latitude,
• Longitude,
• Acceleration in:
    - X,
    - Y,
    - and Z,
• Yawing
• Plus additional data (temperature, rpm, etc.)

In order to have a long flight registration (more than half an hour), but quite a good sampling, it was decided to store five data batches per second. This is the minimum if you want to have good and easy data for interpretation.

(See Illustrations 11, 12 and 13.)

Yaw measure of a typical light F3B model with V-tail. Trajectory is straight and it takes more than six seconds to recover a straight flight (frequency of 0.43hz). Oscillation amplitudes are never less than +/- 2 degrees. Note that flight speed and altitude are in phase with the yaw. It is an amortized Dutch roll trajectory.

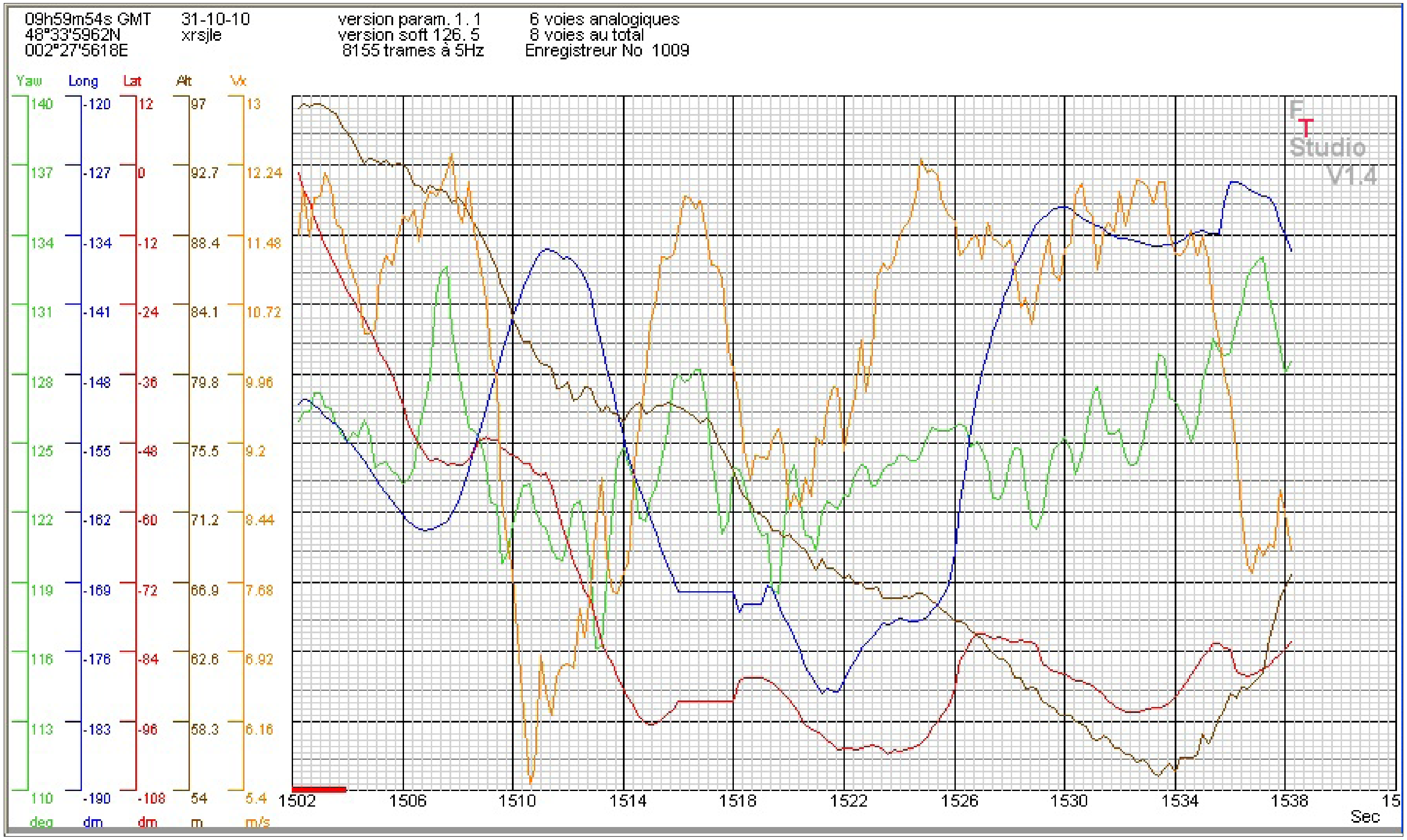


Illustration 12

Yaw trajectory of the light F3B plane using aileron and V-tail in conjunction. Oscillations are +/- 7° maximum.

Note: Radio controlled systems with on-ground return of flight information seem to be not so powerful as the Xerivision system. They provide one or two sets of data every second. Not enough for flight data analysis.

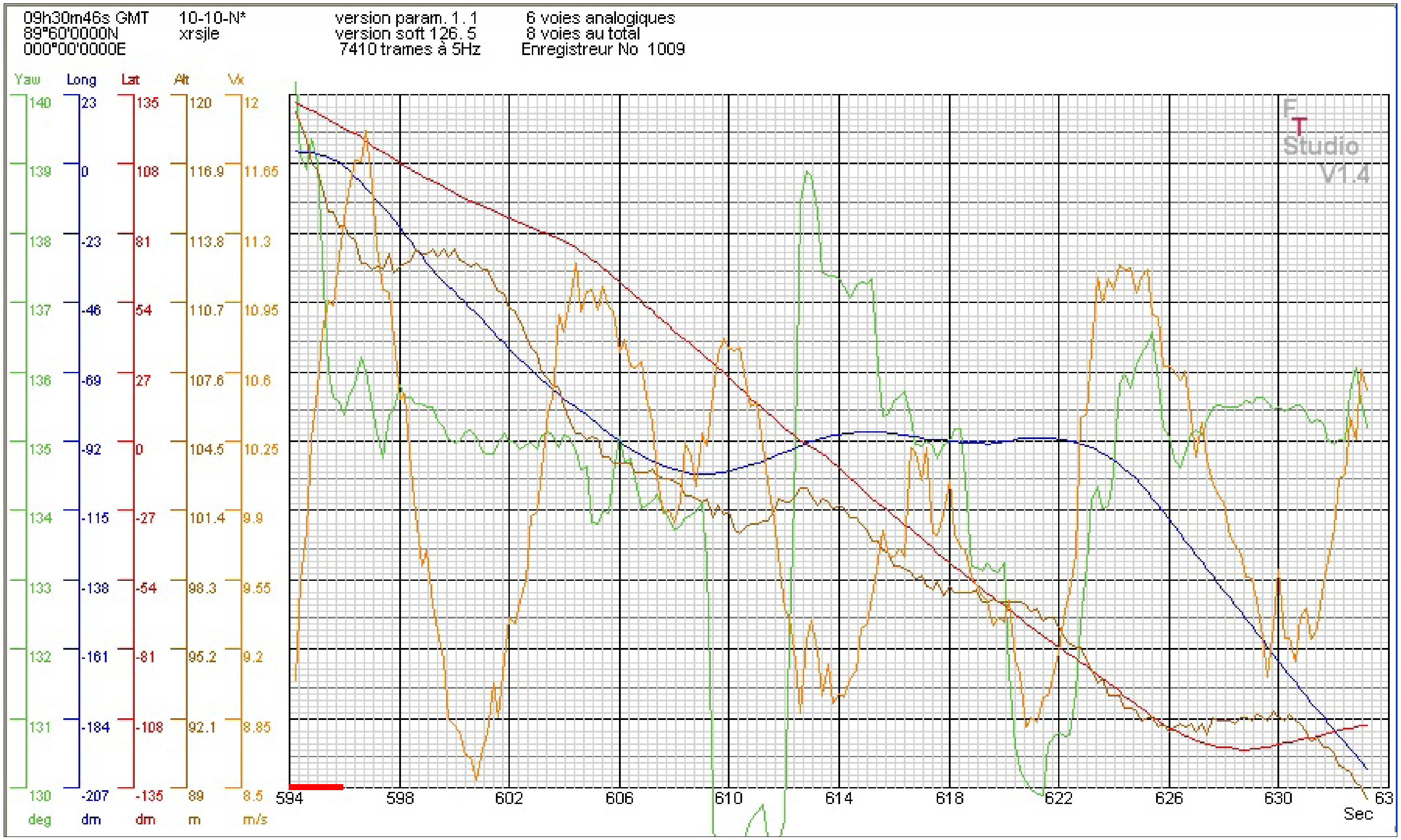


Illustration 13

Trajectories with a "well amortized" yawing plane. Every direction change (at 594s, 613s, 622s) has been performed with rudder only. At 610s, exercise have been made in putting rudder in one direction then opposite then neutral till recovery. Amortization is in two periods (less than four seconds). The flight is then straight (yaw oscillation less than 1°).

At the measured average speeds, the predicted trajectories are the following:

Plane	Speed (m/s)	Yaw frequency (Hz)	Number of periods to recover
V	10	0.42 (theory) 0.43 (measured)	3 (theory) 3 (measured)
X	10	0.6 (theory) 0.7 (measured)	2 (theory) 2 (measured)

Computation and measure are not so far away from each other. It has been estimated, thanks to the precision of all measures made (including plane weight, etc), that the precision that could be reached is better than 5%. That's all we want!

Are our planes optimized in terms of yaw stability?

Let's talk yaw efficiency of our plane. three planes have been evaluated:

The original Supra (the one produced, homemade, in 2004), an F3J plane as you can purchase, and an actual F3B plane (they are nearly all equal in yawing).

Model	Time to recover a straight flight	Number of periods to recover
Supra Original	2 seconds	= 1
F3J plane	< 5 seconds	= 1.5
F3B plane	6 seconds	> 2

In terms of efficiency, the Supra Original is optimum. It has been studied with AVL and Mark Drela perfectly knows what he did.

Actual modern F3J planes are not so efficient in yawing. Of course they are not so difficult to circle with. But improvement can be easily made.

Actual F3B planes can be characterized as "the worst." Their circling ability at low speed is very low. They can very much be improved.

If you make the same comparison at high speed, things are the same. The distance to recover a straight flight is a constant for each model. It doesn't depend upon speed.

The GENOMA: A 3.65 F5J unlimited plane optimized in yawing. Look at <http://www.xerivision.com> or <http://www.f3k-fr.com/f5x/genoma/genoma_index.html> for more details. There is a complete pack of data to construct it (200 pages plus CNC files and profile charts). Sorry, only in French for the moment but lots of photos are provided.

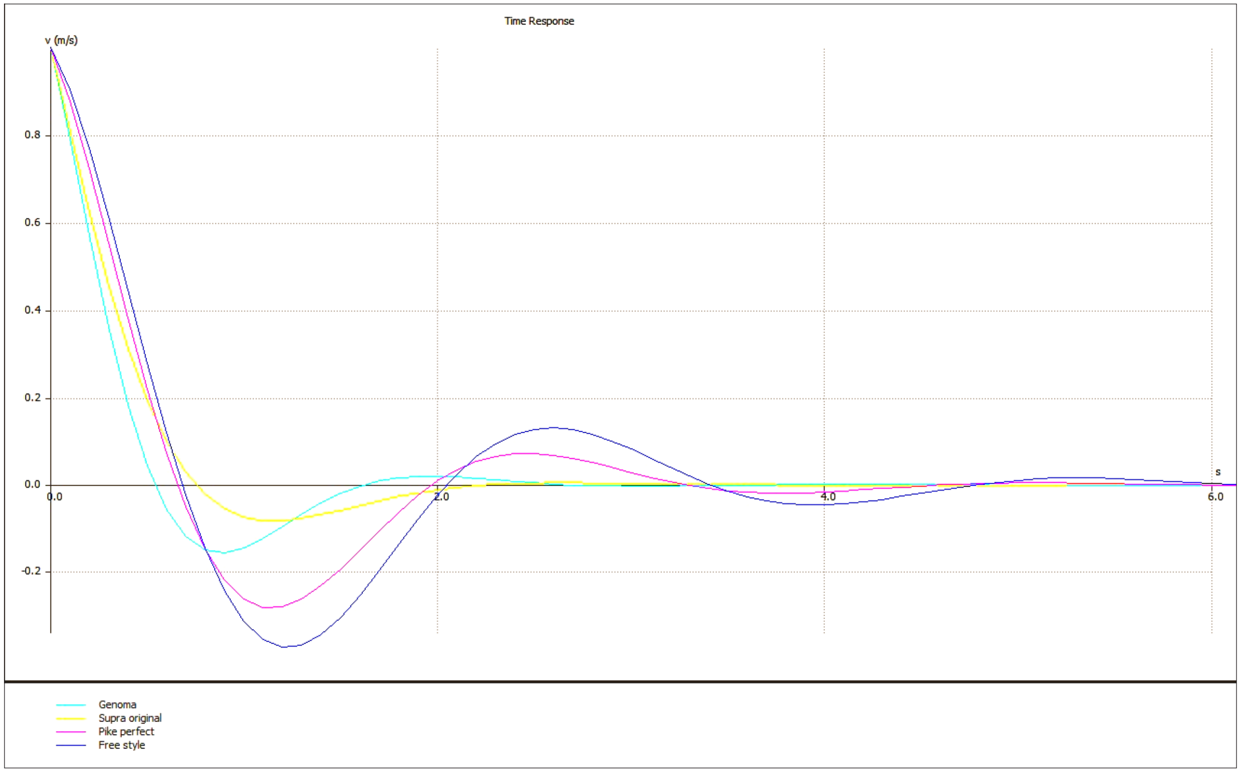


Illustration 14

If you compare several types of planes, the best yaw efficiency is obtained by the original Supra (in yellow), then the actual F3J planes (in magenta), then modern F3B planes (in dark blue). In light blue is the performance of an own design F5J, the Genoma.

What can we do to improve the yaw efficiency?

The first rule we can apply is to lengthen the fuselage. To be simple, the total fuselage length may be 1.25 the half span. It is like an "Easy glider."

The second rule we can apply is to size the fin in order that its surface represents 8 to 12% of the wing span.

The third rule is to limit the weight of any plane parts which are far away from the plane rotation center. We then need to lighten fin, tail, wings.

As you see, this is not very new at all. Lots of planes already apply it.

Of course, for optimization, AVL or XFLR5 are very useful and representative tooling. So let's use them. We still have some improvement to perform.