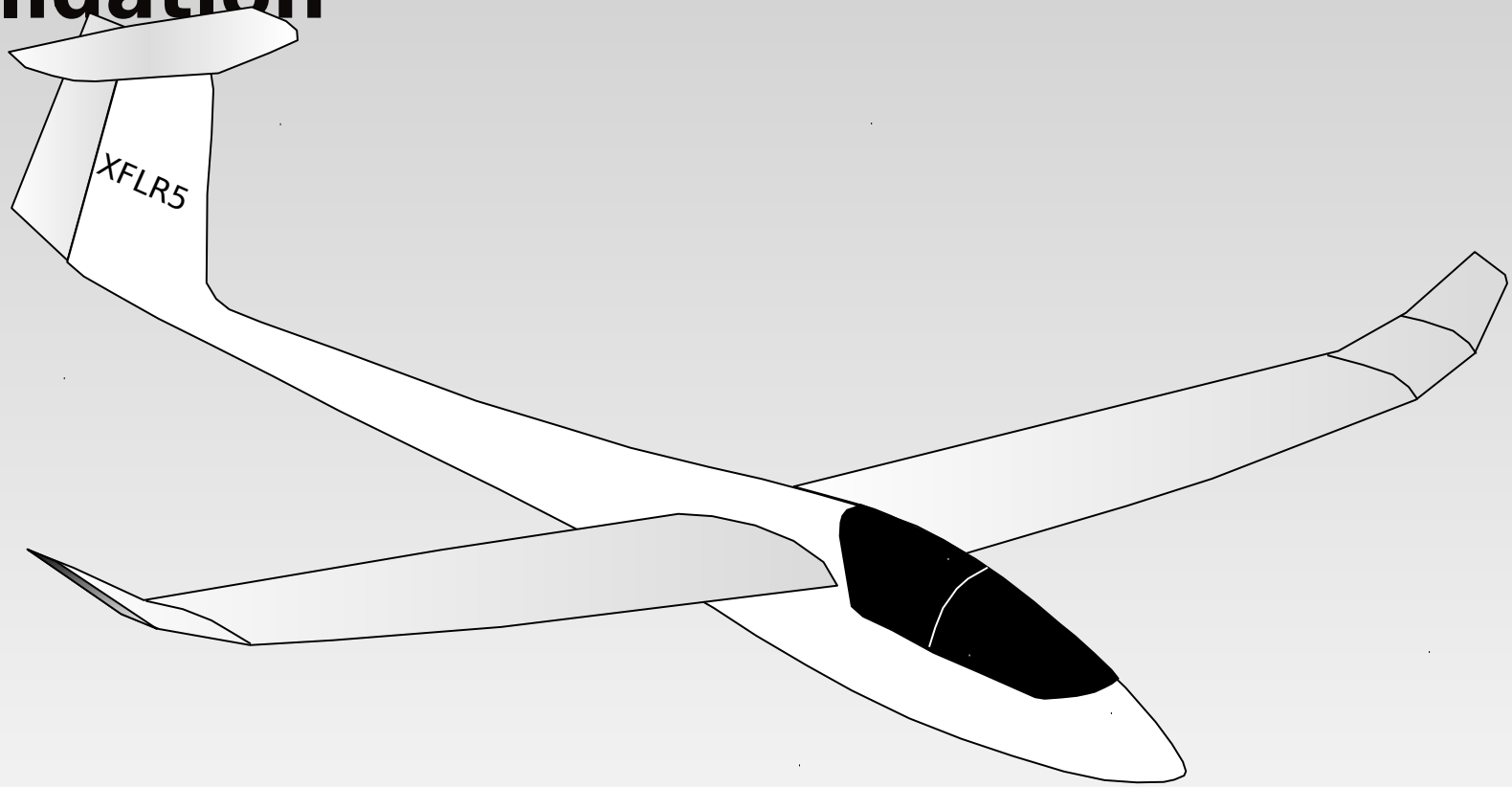
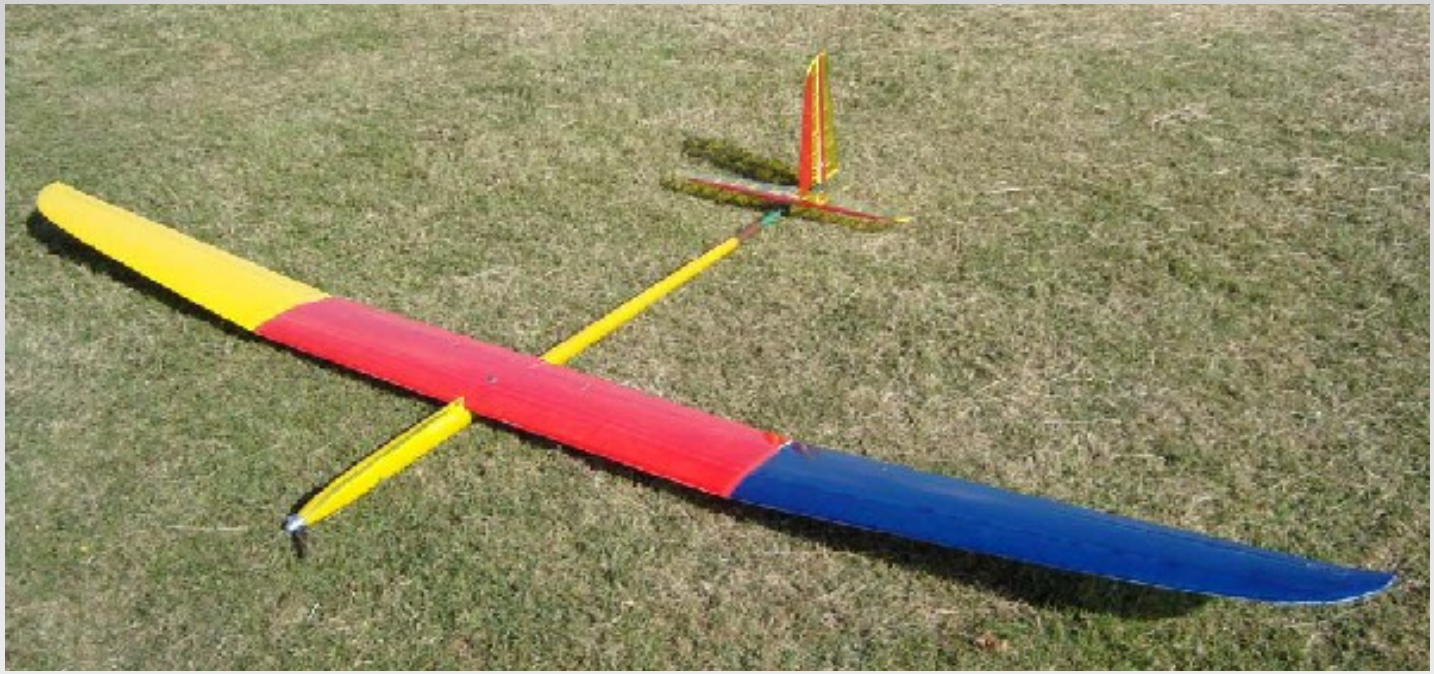
Modal analysis and experimental validation



Context and objective

- **The purpose of the following experiments is to compare the measured frequency of the slow periodic modes to those calculated with AVL or XFLR5:**
  - **phugoid**
  - **Dutch roll**

First experiment : F3J type sailplane, January 2011



- **The fuselage has been specifically designed for a large tail volume**

Sailplane data

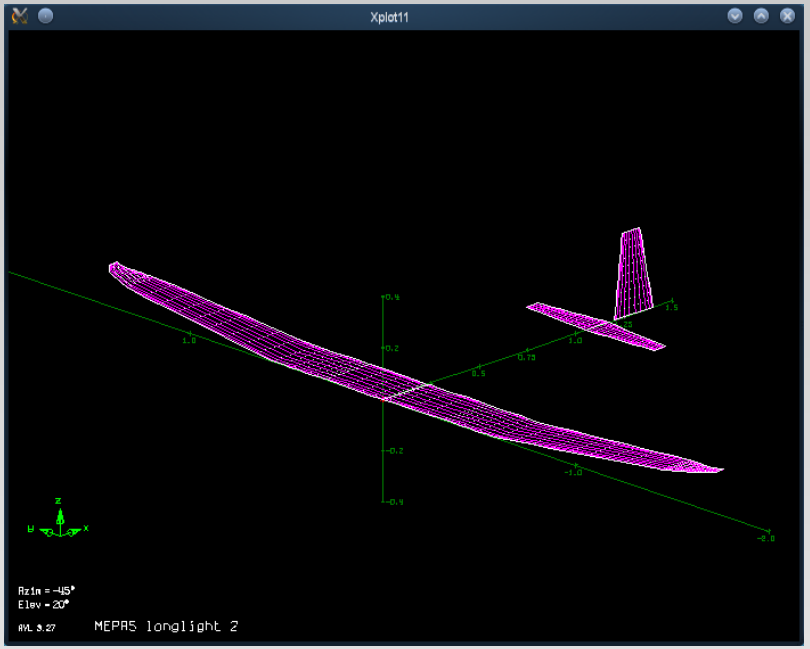
- **Name :** PAMEPUMA, design and make Marc Pujol
- **Span :** 3.150 m
- **Wing area :** 0.605 m²
- **Mean Aerodynamic Chord :** 202 mm
- **Airfoils**
  - Wing : HN 1036
  - Elevator: HT 14 at root, HT12 at tip
  - Fin: HT 14 at root, HT12 at tip
- **Mass :** 2.1 kg
- **CG position :** 90 mm from wing leading edge
- **Inertia tensor, estimated using XFLR5 calculation form**
  - **Ixx = 0,565 kg.m²**
  - **Iyy = 0,161 kg.m²**
  - **Izz = 0,723 kg.m²**
  - **Ixy = Ixz = Iyz = 0,0 kg.m²**

Calculations

- **All the calculations have been performed prior to the experiment**
- **Results with AVL and XFLR5 are close**

The files for the calculations can be downloaded from http://www.xflr5.com/docs/PM_Analysis.zip

AVL model



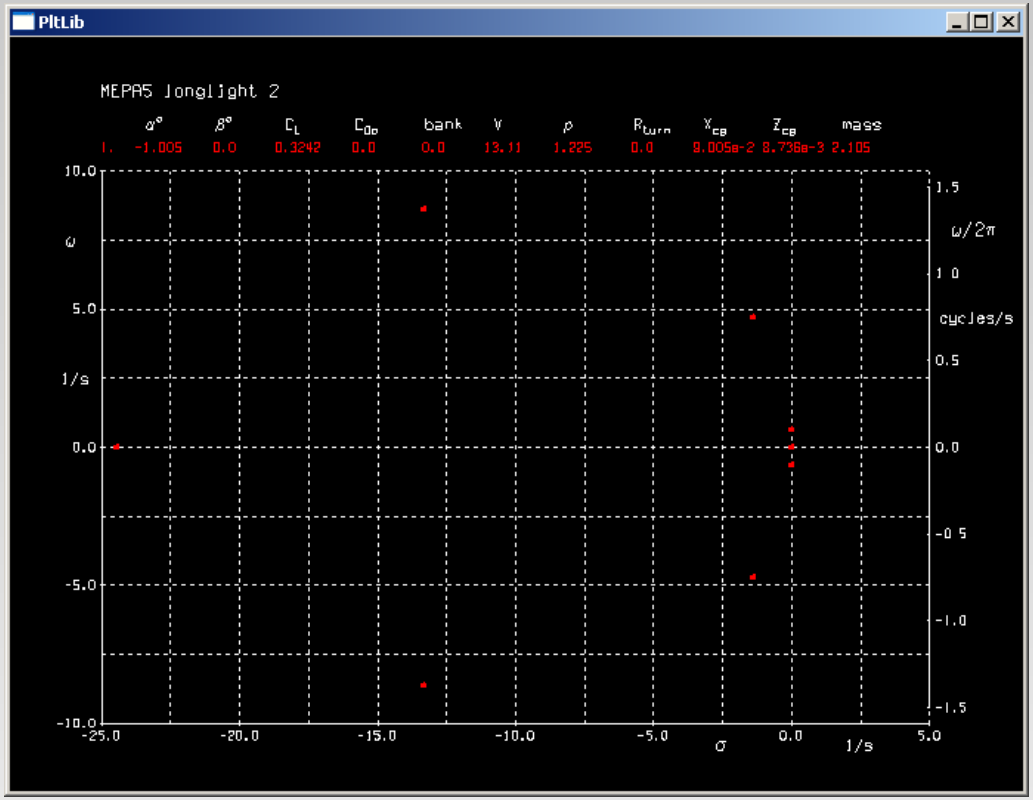

```
 ---------------------------------------------------------------
 Vortex Lattice Output -- Total Forces

  Sref = 0.60508       Cref = 0.20200       Bref =  3.1500
  Xref = 0.90048E-01   Yref = 0.19467E-07   Zref = 0.87358E-02

Run case: ZeroPitchingMoment

  Alpha =  -1.00454     pb/2V =   0.00000     p'b/2V =   0.00000
  Beta  =   0.00000     qc/2V =   0.00000
  Mach  =     0.000     rb/2V =   0.00000     r'b/2V =   0.00000

  CXtot =  -0.00770     Cltot =   0.00000     Cl'tot =   0.00000
  CYtot =   0.00000     Cmtot =   0.00000
  CZtot =  -0.32413     Cntot =   0.00000     Cn'tot =   0.00000

  CLtot =   0.32421
  CDtot =   0.00202
  CDvis =   0.00000     CDind =   0.00202
  CLff  =   0.32398     CDff  =   0.00147    | Trefftz
  CYff  =   0.00000         e =    1.3893    | Plane

  Stability-axis derivatives...

                              alpha                beta
                       ----------------    ----------------
  z' force CL |    CLa =   5.888990    CLb =   0.000001
  y  force CY |    CYa =   0.000001    CYb =  -0.243049
  x' mom.  Cl'|    Cla =   0.000000    Clb =  -0.093149
  y  mom.  Cm |    Cma =  -1.229251    Cmb =  -0.000003
  z' mom.  Cn'|    Cna =   0.000000    Cnb =   0.079325

                         roll rate  p'      pitch rate  q'         yaw rate  r'
                       ----------------    ----------------    ----------------
  z' force CL |    CLp =   0.000000    CLq =   9.351773    CLr =   0.000000
  y  force CY |    CYp =  -0.112617    CYq =   0.000001    CYr =   0.197400
  x' mom.  Cl'|    Clp =  -0.640904    Clq =  -0.000002    Clr =   0.095053
  y  mom.  Cm |    Cmp =   0.000001    Cmq = -23.403563    Cmr =   0.000002
  z' mom.  Cn'|    Cnp =  -0.033869    Cnq =   0.000000    Cnr =  -0.066497
```

Pitched balanced conditions are achieved for $\alpha = -1.0°$

Calculated balanced $C_L = 0.324$

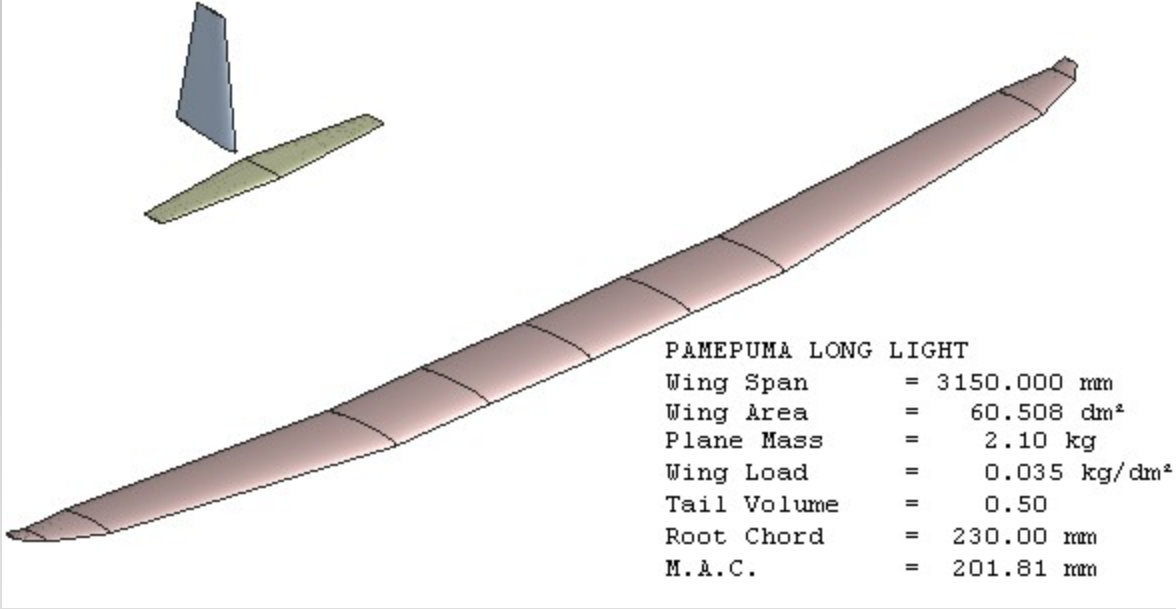
$$\Rightarrow \quad V_{Inf} = \sqrt{\frac{2\,mg}{\rho S C_L}} = 13.1\ m/s$$

AVL Modal results




```
# MEPA5 longlight 2

#
#   Run case     Eigenvalue                      Mode          Period (s)
        1    -24.460022          0.0000000   Roll Damping
        1    -1.4002885          4.7057629   Dutch Roll          1.34
        1    -1.4002885         -4.7057629   Dutch Roll          1.34
        1    -13.334693          8.6277199   Short period        0.73
        1    -13.334693         -8.6277199   Short period        0.73
        1     0.30454164E-01      0.0000000   Spiral
        1    -0.41586193E-02     0.62859261   Phugoid            10.00
        1    -0.41586193E-02    -0.62859261   Phugoid            10.00
```

XFLR5 model



Performance data

```
Pamepuma LongLight Xcg=90mm
T7-VLM2
QInf  =   13.917588 m/s
Alpha =   -0.988373
Beta  =    0.000°
Phi   =    0.000°
Ctrl  =    0.000
CL    =    0.287659
Cy    =    0.000011
Cd    =    0.013552     ICd   =    0.001513
PCd   =    0.012039
Cl    =  2.6127e-07
Cm    =  0.00117585
ICn   =   -0.000003     PCn   =   -0.000003
XCP   =    0.091743     YCP   =    0.000002
XNP   =    0.131675
Bend. =    7.147979
```

To save computations, XFLR5 determines the a.o.a. such that the induced pitching moment from pressure forces = ICm =0

Cm, which includes in addition the moment from the viscous drag is not quite zero. The difference is in the second order of magnitude

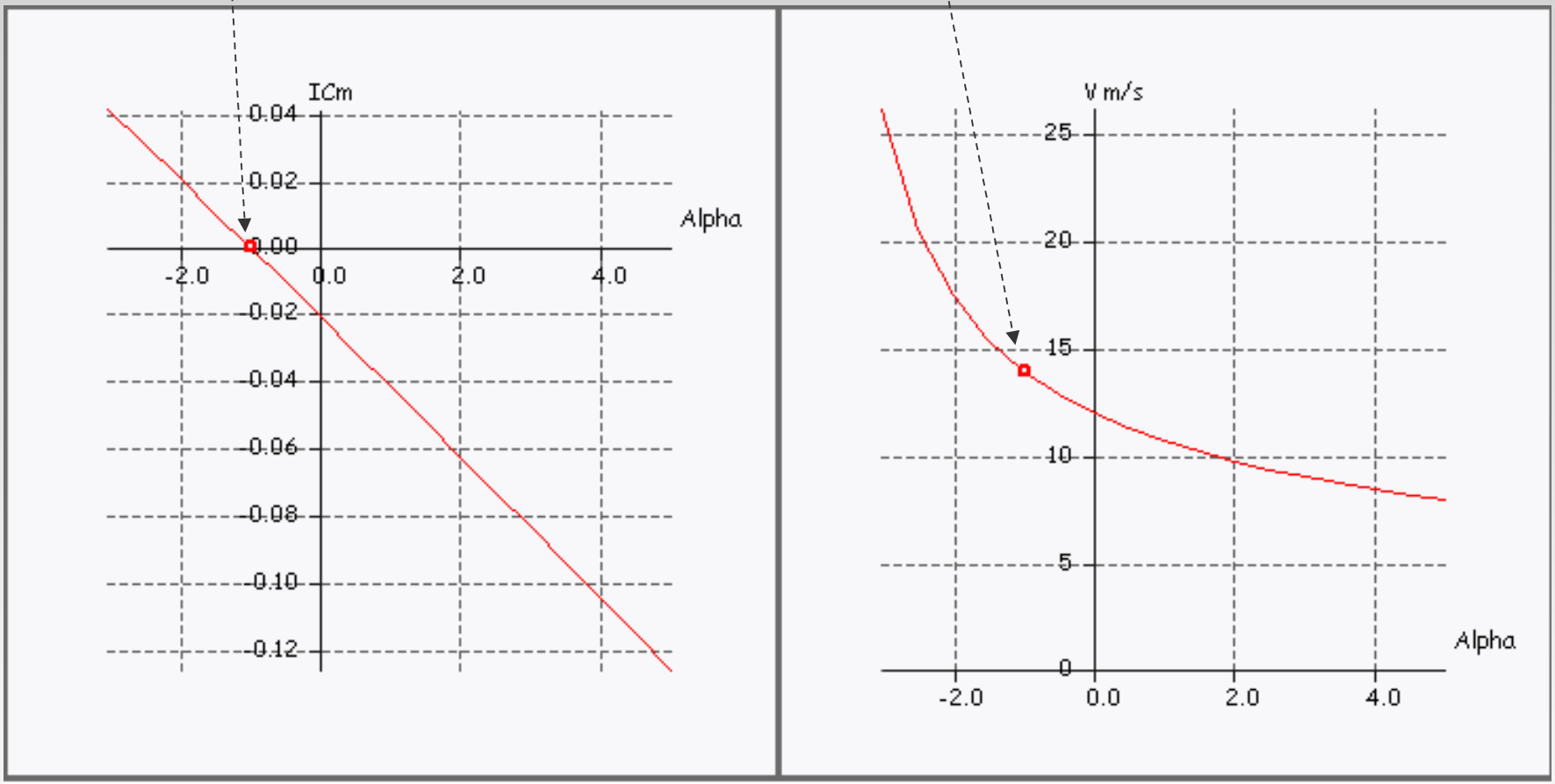
Stability derivatives

```
CLa =    5.879468
CLq =    8.653236
Cma =   -1.168585
Cmq =  -23.365110
CYb =   -0.244012
CYp =   -0.136409
CYr =    0.194332
Clb =   -0.087490
Clp =   -0.638573
Clr =    0.085139
Cnb =    0.078925
Cnp =   -0.042402
Cnr =   -0.063063
```

Trimmed conditions

The pitch-balanced conditions are achieved for α=-0.99°

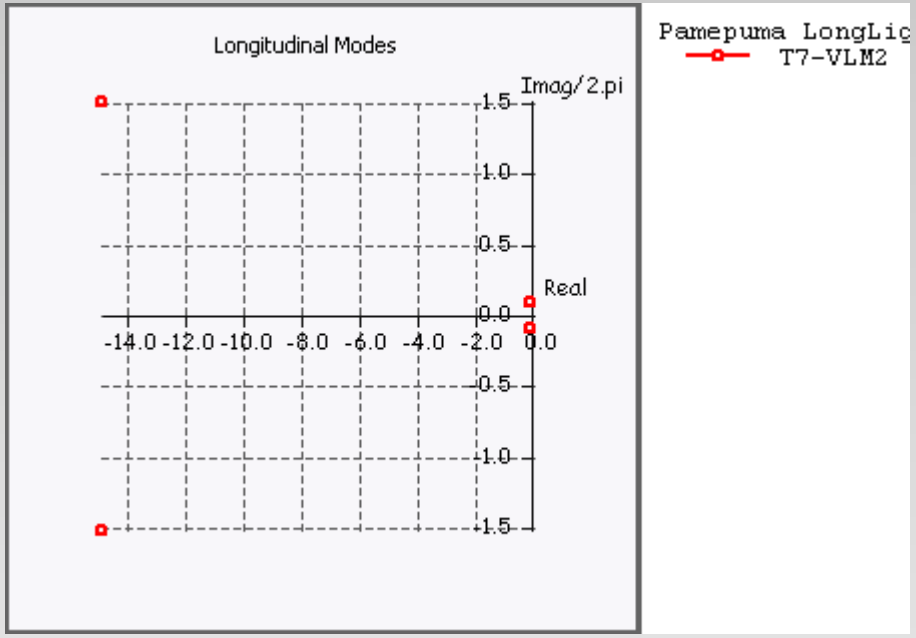
The speed in pitch-balanced conditions is V=13.9 m/s



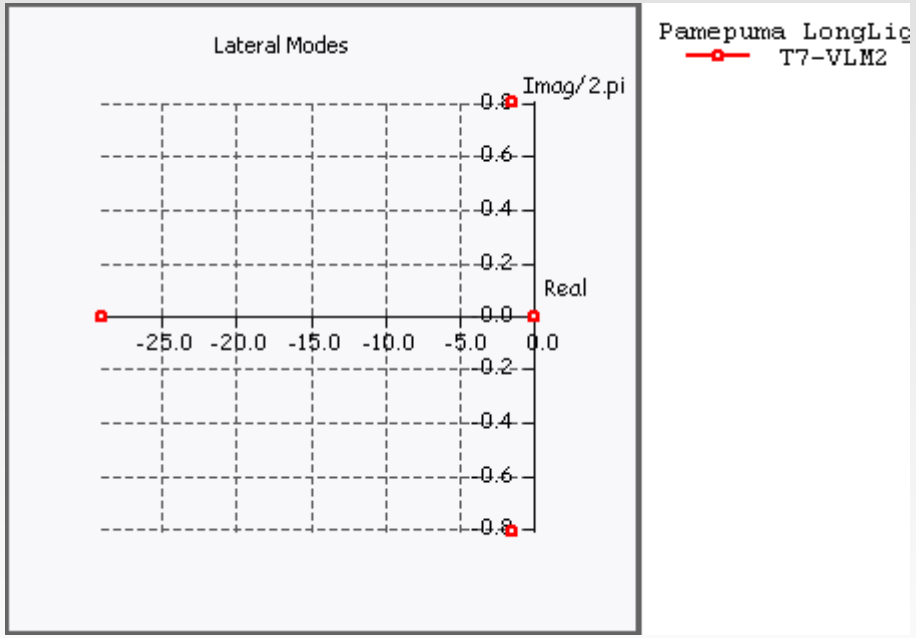
The balanced a.o.a., speed, and glide ratio are very sensitive to the slope of the curve ICm=f(α), and therefore to CoG position

XFLR5 Modal results

	λ	Period (s)
Short period	-14.82+/-9.444i	0.67
Phugoid	-0.0306+/-0.5765i	10.9



	λ	Period (s)
Spiral	0.01511 +0i	/
Roll damping	-28.88 +0i	/
Dutch roll	-1.455+/-5.039i	1.25



The experiment :
January 9th, 2011 @ Le Coudray-Montceaux

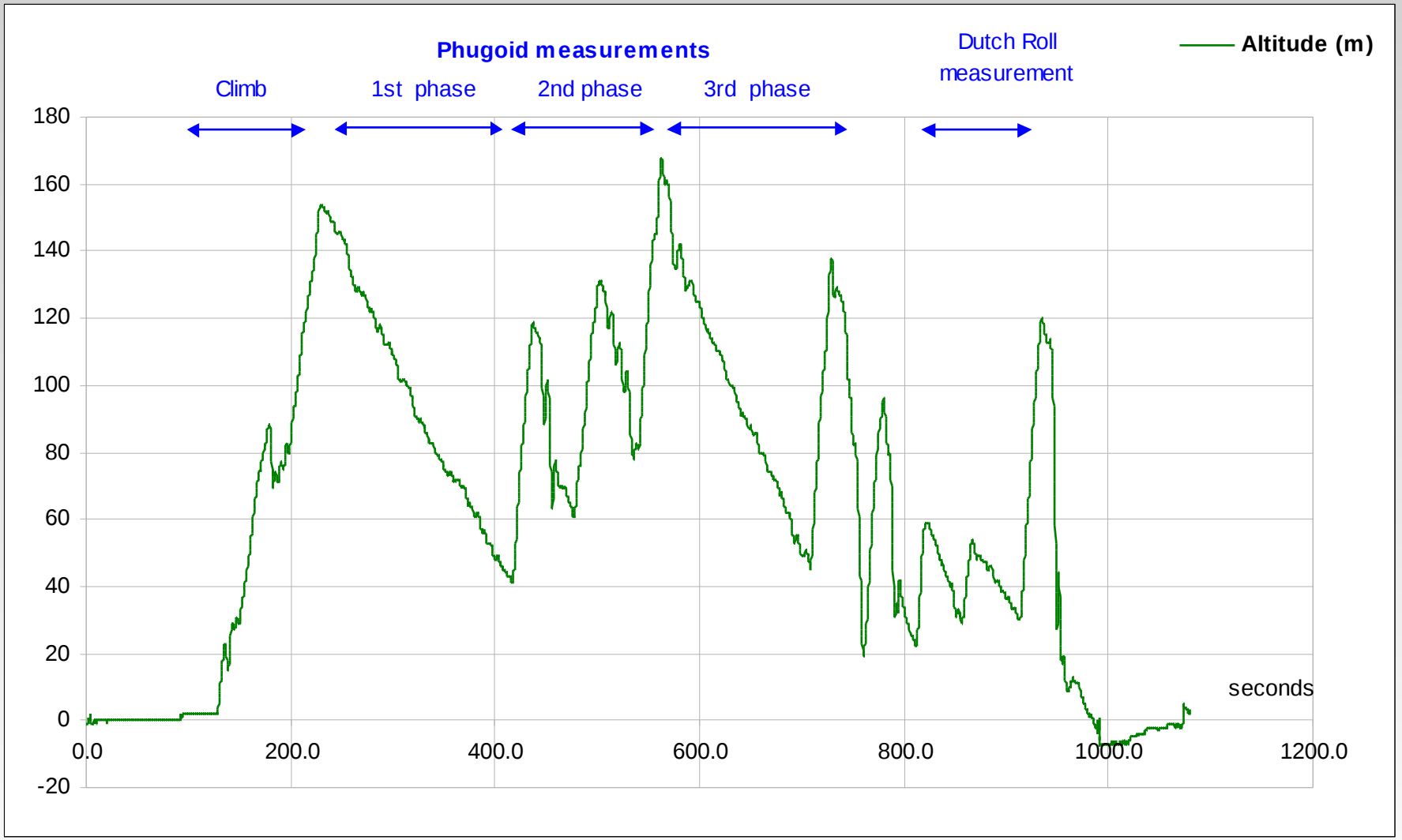
Marc (left) and André (right) checking the measurement system

The measurement system

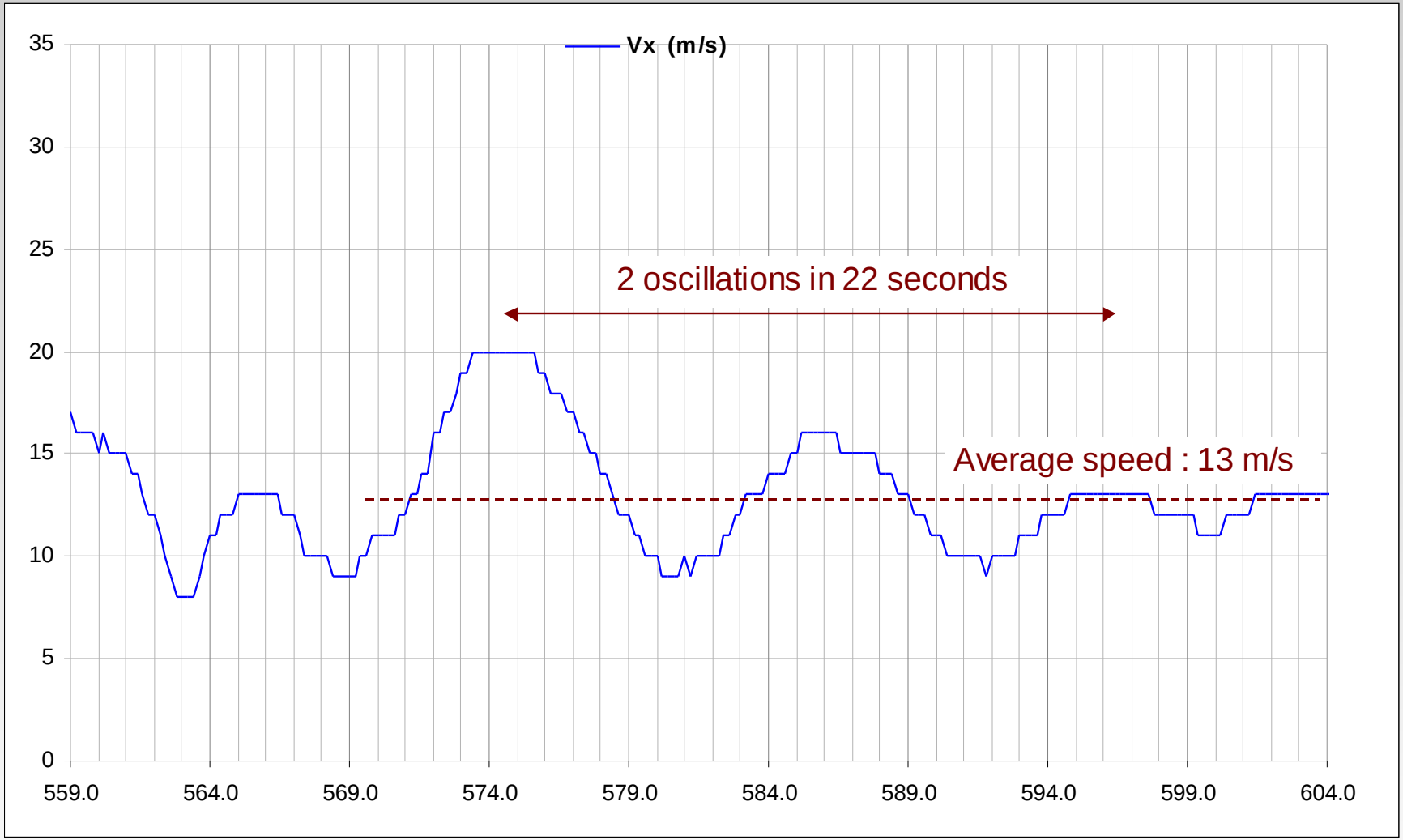
- **Xerivision system from http://www.xerivision.com/ "Measurement, recording, telemetry, HUD for RC modelers"**

- **Available data**
  - Accelerometers in X, Y, Z directions
  - Speed sensor with Pitot tube
  - Altimeter
  - GPS
  - Sideslip using a "flap" device
- **Sampling : 5 Hz**

The flight :
January 9th, 2011 @ Le Coudray-Montceaux



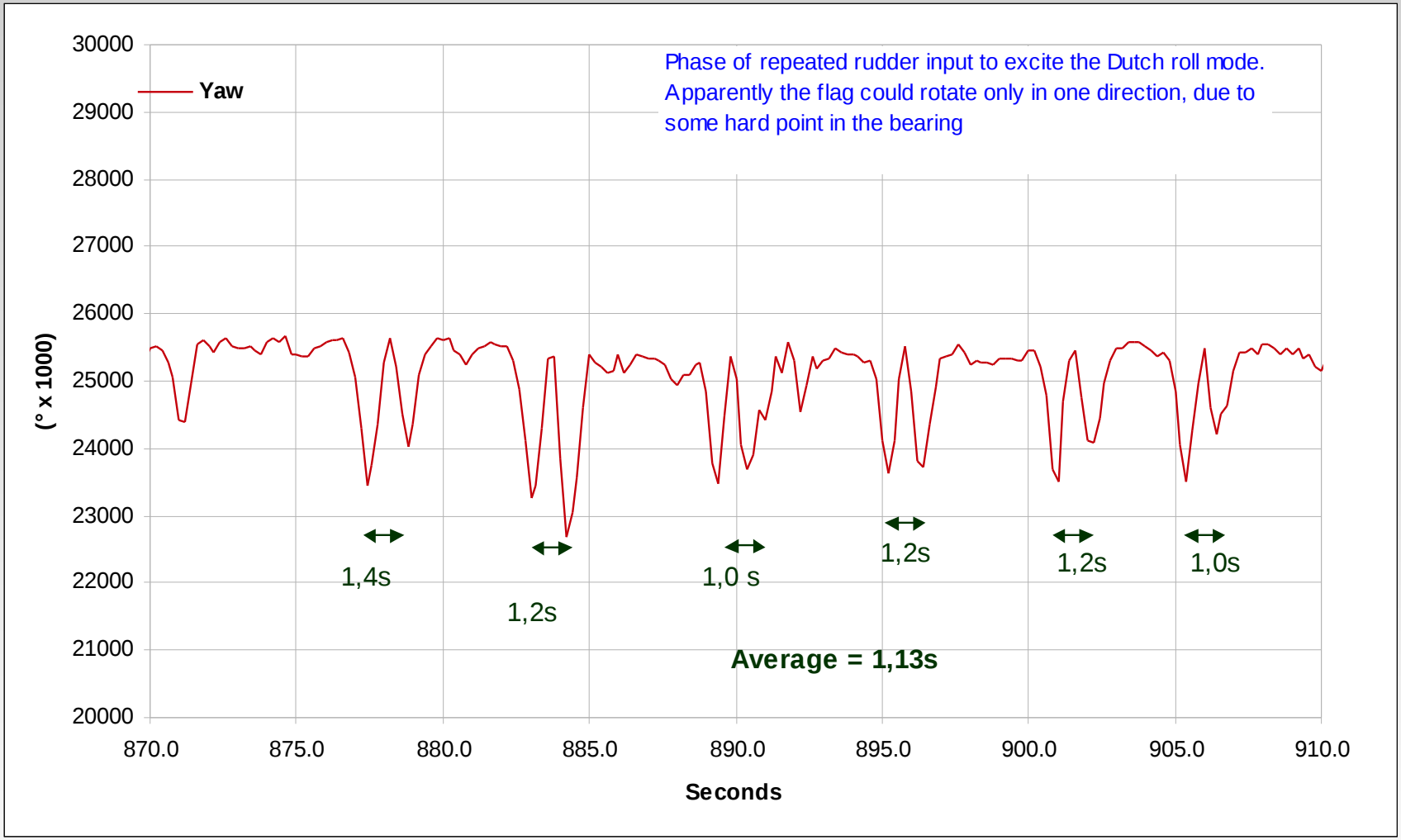
Average speed and phugoid frequency measurement



Average speed is ~13 m/s

Phugoid period is ~11 s

Dutch roll frequency measurement



Dutch roll period ~ 1.13 s

Comparison

	Measurement	AVL	XFLR5
Trimmed speed (m/s)	13	13.1	13.9
Phugoid period (s)	11	10	10.9
Dutch Roll period (s)	1.1	1.34	1.25

Conclusion

- All results are close and consistent
- The differences are well within the error margin of both the measurement and the calculation

So far, so good !

More measurements to come this year