Take-off speed measured with CBL

2° ADT NATIONAL CONFERENCE

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ABSTRACT

An example of use of the accelerometer with CBL: the measurement of the take-off speed of an airplan.

1. The Vernier accelerometer for CBL

The Vernier accelerometer, that may be used with CBL or other interfaces (Coach, ULI…) is an analogic sensor that gives an output voltage proportional to the force applied onto a small mass, suspended inside the sensor.

The mass is tethered to the holding box by thin cantilevers which are deflected, due to the inertial mass, proportionally to the applied acceleration.

This sensor is vectorial: when it is kept blocked with the arrow (marked on the box) directed downward, the mass feels the gravitational force that provides an output between 0 and 5V: in this case the accelerometer measure the gravity acceleration.

If we flip it upside/down, the force changes sign, and a different voltage appears at the output.

If the arrow is kept horizontal the output corresponds to zero force, i.e. zero acceleration.

These considerations show how we may easily perform a calibration using the everywhere available gravity acceleration: we first keep the sensor with the arrow pointed down and we type-in the value +9.8m/s^2, then we flip it and we type-in the value –9.8m/s^2. Third we verify that, once calibrated, it measures zero acceleration when the arrow is horizontal.

There are three models of accelerometers for CBL: two monoaxial, which differ in the full scale value (5 g and 50g, respectively), and one tri-axial made of 3 sensors that measure the acceleration along three orthogonal axes. All them are obtained from integrated circuits from Analog Devices (ADXL05 and ADXL50 for the first two).

2 Measurement of the take-off speed of an airplane

The idea for this experiment was made public by Lars Jakobsson, teaching Mathematics at the Malmo University (Sweden), who showed it during the Meeting of T3-Europe co-ordinators last august in Chantilly (France). It seemed to me an easy and interesting experiment, so I decided to try it out during a fly from Venice to Barcelona, where I was going for the GIREP-2000 international conference on physics teaching.

The experiment essentials are the following: we measure the horizontal acceleration of the plane from the time of start up to few seconds after the take-off; because at take-off the plane tilts up suddenly (increasing the wings' lift), the accelerometer (which is kept with the arrow horizontal) measures, beside the plane acceleration, also a component of the gravity acceleration. Therefore the take-off time is marked by a sudden increase of the measured acceleration.

The plane speed may be calculated by integrating the acceleration (the area enclosed by the curve in the plot acceleration /time). In fact in a rectilinear motion with generic acceleration we have:

$$v(t1) = v(0) + \int_0^{t1} a(t)\,dt$$

In our case, because the plane start from rest $v(0)=0$, thespeed at the time t_1 of take-off is simply theintegral.

Alternatively, being the acceleration values a_i measured at discrete times t_i separated by the sampling time Δt, we may get the speed values as $v_j = \Sigma_{i=1,j}\,(a_i\,\Delta t)$. In the plot $v(t)$ the take-off speed is that where the slope changes (after t_1 the speed values are affected by the sistematic error introduced by the gravity effect mentioned above).

One more information that may be derived from these data is the length of the plane run still rolling on the ground: it is measured by the area beneath the curve $v\,(t\,)$, being the distance covered at time t_j defined as $s_j = \Sigma_{i=1,j}\,(v_i\,\Delta t)$.

3 Data taken during the take-off of a Fokker 100.

Strarting from the Marco Polo Venice Airport, I did not know whether I would have find a “smart captain” who could fastly understand that the “electronics devices” I wanted to use were absolutely free from electromagnetic interference with on board instrumentation.

Therefore I attached to one calf the accelerometer, using rubber bands, and passed the cable inside the trouser: in this way my measurement would have been possible with the small TI89 linked to CBL2 without rising unwanted curiosity, and this setting would provide stable positioning of the sensor.

Before I made a SETUP with the sensor[1] connected to channel 1, I calibrated it as explained above and when seated on board I checked the right tilt of my calf in order to get zero value by using MONITOR INPUT in PHYSICS[2]: this was the only way to assure that the sensor arrow were horizontal, because the airplane floor is not always horizontal. I chose a sampling time of 0.5 s and 100 points. The result of the measurement is shown in figure 1.

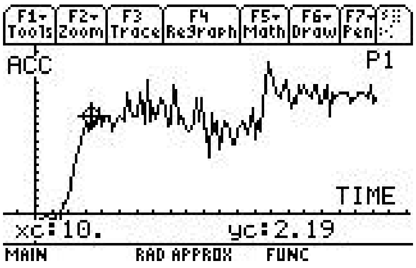

Fig.1 – Acceleration versus time

4 Data handling.

This measurement may be easily performed using PHYSICS or DataMate: both allow to calibrate the sensor, to choose the sampling time and number of points, to draw the plot of acceleration as a function of time and to calculate the integral of the curve between two point

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[1] Model LG-CBL.

[2] PHYSICS is my preferred software for data acquisition with TI89: it was implemented with respect to the original Vernier version, by adding some useful features fully described in the ADT web-site http://www.ADT.it .

arbitrarily chosen. However PHYSICS, in its version developed in Italy, offers the advantage of using, without CBL also data taken with DataMate, and the reverse is not true.

Selecting in PHYSICS the menu 3:ANALYZE, then 3:STATS/INTEGRAL, then 2:INTEGRAL, I got from my data the screen of figure 2.

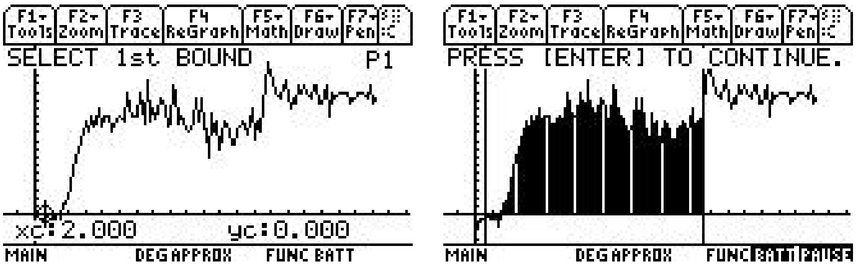
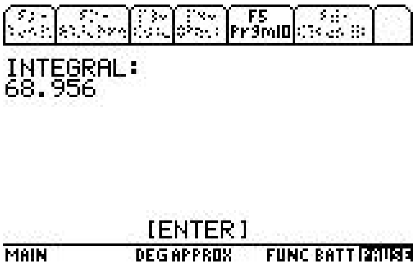


Fig.2 – Integral area from the curve a(t)

The result is shown in figure 3 which gives the speed value *v*= (68.9±0.5) m/s, or (248±2) km/h. The uncertainty is here evaluated assuming that t_1=(40±0.5)s. By adding an uncertainty of 1% on the sensor calibration we get *v*=(248±4) km/h.



INTEGRAL:
68.956

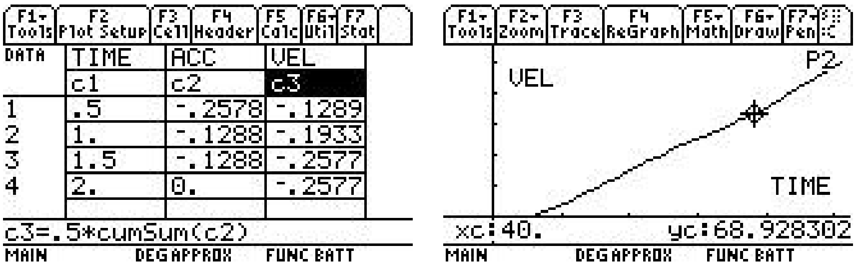
[ENTER]

Fig.3 – Take-off speed in m/s

This value, in spite of the large noise affecting the signal, is quite accurate: I checked the measured value asking to the captain, who appearing kindly interested, deduced from the known value of the airplane weight (we were few passengers and the weight was small) the value of (245±10) km/h .

The signal noise in fact does slightly affects the calculated speed value, more important is the value of the time t_1 of take-off. This is proved by an equivalent calculation that uses the velocity/time plot.

To get such a plot we may calculate the list of values $v_j = \Delta t \sum_{i=1,j} (a_i)$ inside DataMatrix Editor with the command `cumsum()`, as shown in figure 4, where Δ*t* =0.5s.



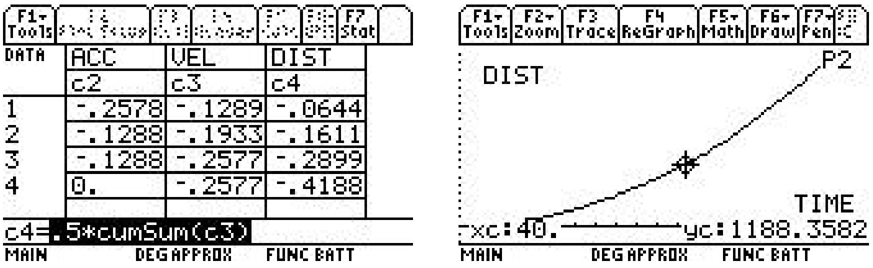
DATA	TIME	ACC	VEL
	c1	c2	c3
1	.5	-.2578	-.1289
2	1.	-.1288	-.1933
3	1.5	-.1288	-.2577
4	2.	0.	-.2577

c3=.5*cumSum(c2)

Fig.4 – Speed versus time and speed value at take-off

The plot $v(t)$ obtained from $a(t)$ results very smooth, making easy to detect the point where the slopes increases (due to the sudden change induced by the plane tilt). In our case the speed at t_1 =40s turns out again 68.9 m/s.

The length of the airplane run on the ground before take-off may be calculated as $L = \Delta t\ \Sigma\ (v_i)$, with the sum running from start to the time t_1, as shown in figure 5. Here the knowledge of the value t_1 is necessary, being not easy to detect in the curve $v(t)$ the curvature change of the parabola.



DATA	ACC	VEL	DIST
	c2	c3	c4
1	-.2578	-.1289	-.0644
2	-.1288	-.1933	-.1611
3	-.1288	-.2577	-.2899
4	0.	-.2577	-.4188

c4=.5*cumSum(c3)

Fig.5 – Covered distance versus time

Moving the cursor (in mode TRACE) along the curve $v(t)$ up to time t_1=40s gives the value L= (1.2±0.1) km, well compatible with the length of the runways of the Marco Polo airport (the longer is 3.3 km and the shorter 2.9 km) and with the small weight of Fokker 100 with few passengers.

5 Accelerometer working principle.

To the reader curious to know “how the sensor is inside” we may say that the probe is a variable capacity made of a moving central plate (inertial mass) placed between two fixed plates: theacceleration measurement reduces to a capacity-change measurement.

An oscillator drives, in phase opposition at 1MHz, the two capacities in series made of the three plates (figure 5). The two capacities are obtained by microlithography from a silicon chip by cutting the central plate in the shape of a double comb whose teeth are faced to the teeth of combs constituting the fixed plates. The direction along which the accelerometer is sensible is the simmetry axis of the central plate, which is held in place by 4 thin cantilevers.

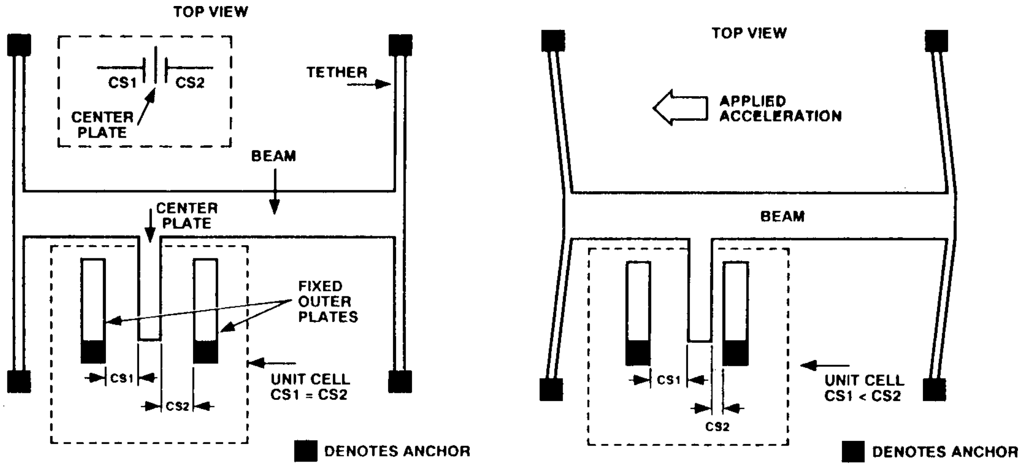


Fig.5 – Scheme of the sensible probe

The signal taken at the central plate is detected by a phase sensitive amplifier (synchronous demodulator) that removes spurious signals and drives an amplifier providing both the output signal and the electrostatic force to keep the central plate in balanced position (figure 6).

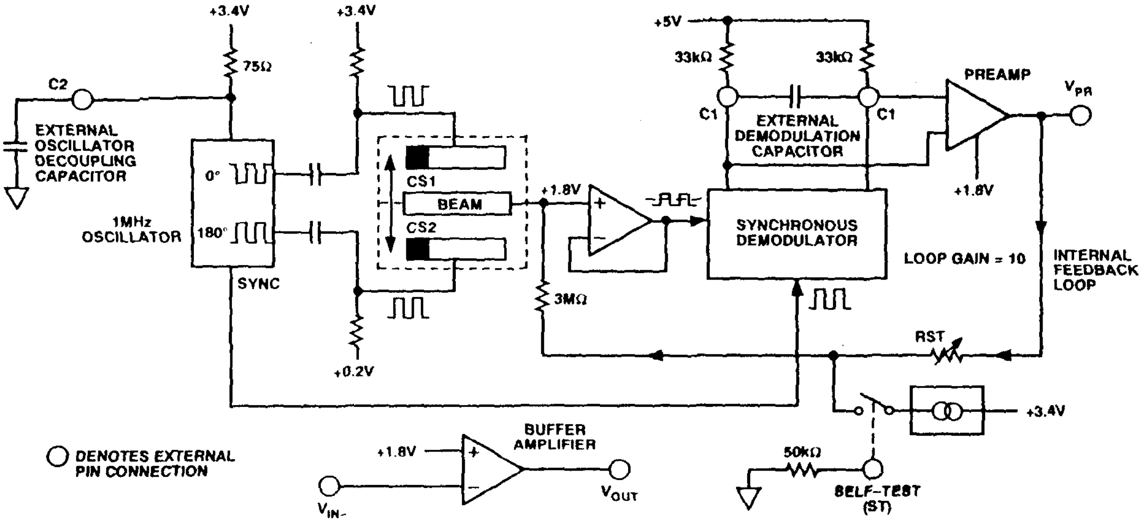


Fig.6 – Scheme of internal electronics