Luxpak HALE mission: discussion of the results

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Abstract:

This is an ongoing report discussing and evaluating the results of the Luxpak package flown by the HALE mission (http://www.unr.edu/nevadasat/hale/). The different points discussed will possibly be updated and edited in further versions, labeled luxpak_results0x.doc with x = sequential number.

Each chapter will be closed by a "What can be learned?" paragraph.

A couple of graphs and pictures are taken from the web site of the HALE project (ref [1]) or from those of participants to HALE.

Index:

1. Comments on the trajectory

The luxpak package was a payload of the second launched balloon, corresponding to the green curve of the plot (ref [1]):

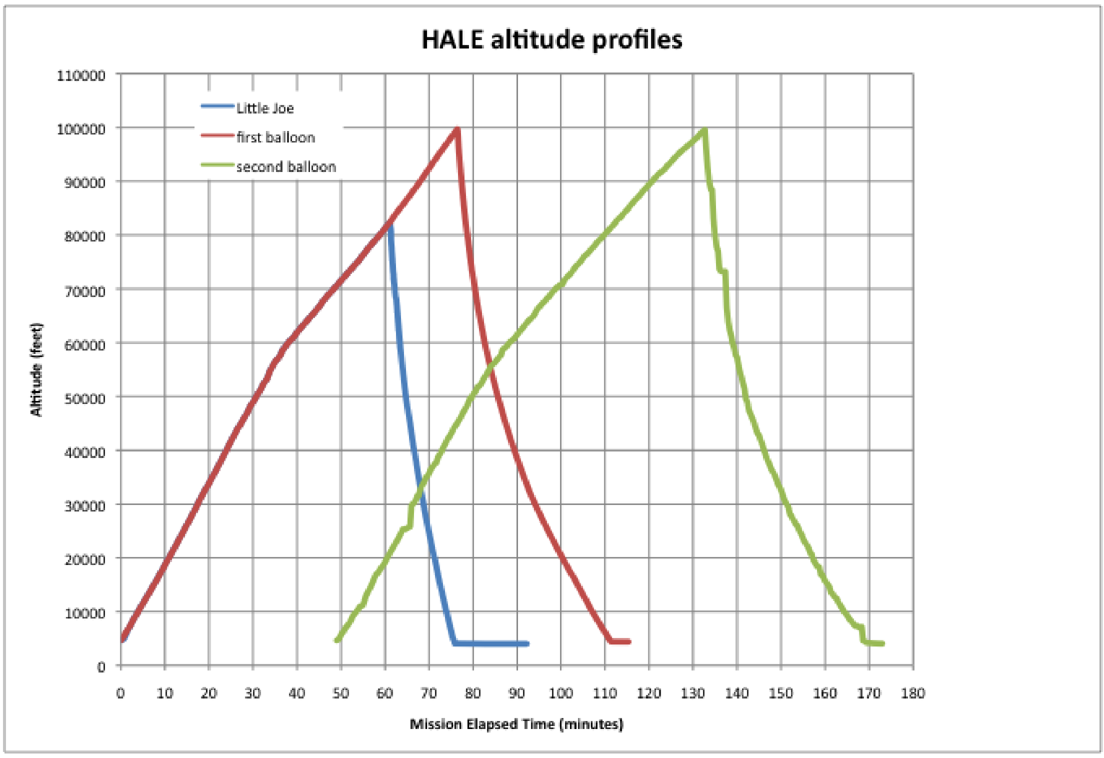

fig. 1: Altitude profiles. Luxpak corresponds to green trajectory.

A more precise analysis using the time and altitude data shows that the vertical projection of the flight path can be divided into 5 segments, of which four correspond (somewhat surprisingly) to practically constant vertical velocity movements (see fig. 2).

Segment	**Flight time from...to . .. in seconds**	**Approx. altitude in meters from...to....**	**Velocity computed by linear regression in ms^{-1}**	**Comment**
AB	11 - 2198	1400 - 17000	7.37	Local troposhere ends at 15000m (see fig.3 ref [2]). Lower air density is compensated by increasing volume of the balloon, and so increasing buoyancy
BC	2206 -	17000 -	4.59	Velocity lowered by

	5117	30000		diminishing buoyancy Due to smaller air densities, in spite of greater inflation of the balloon
CD	5125 - 5515	30000 - 19000	-26.44	Free fall, air friction quickly equals weight
DE	5531 - 6832	19000 - 5000	velocity has parabolic profile	Braking by parachute transition to lower velocity (deceleration due to parachute_drag + air_friction > weight)
EF	6840 - 7312	5000 - 1400	-6.08	Uniform parachute descend

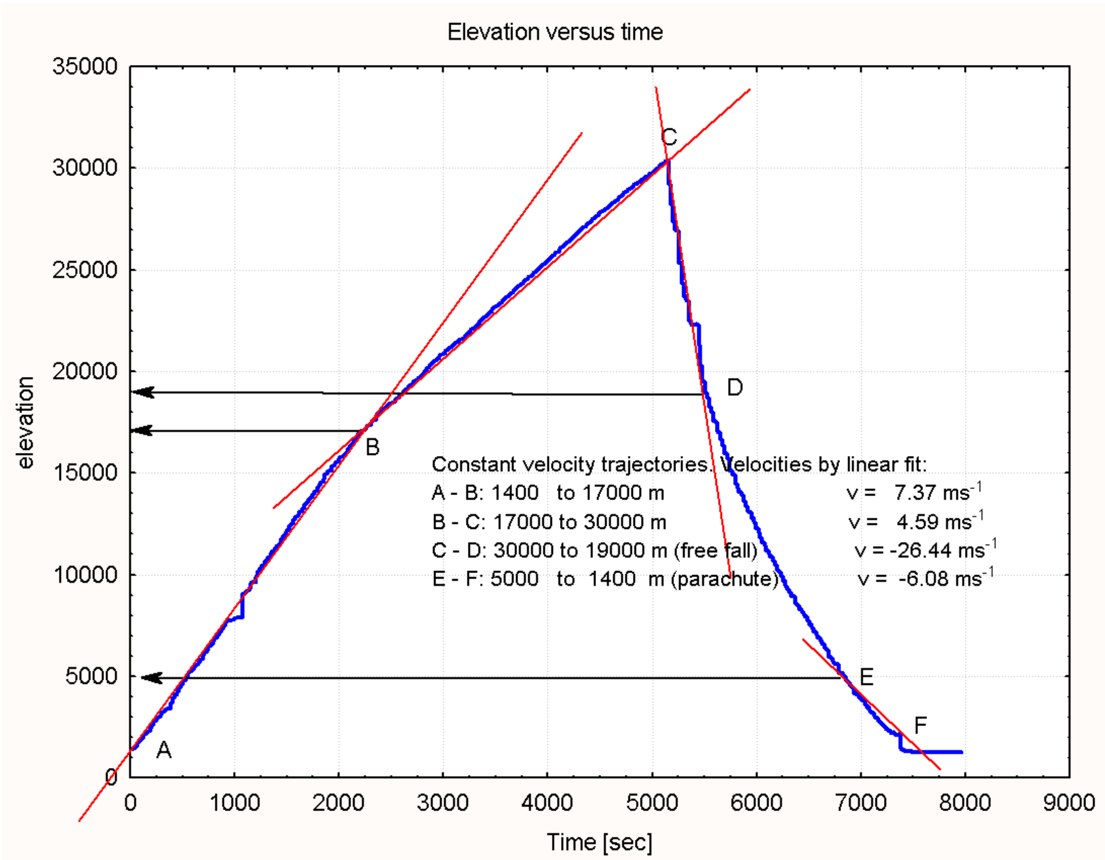

fig.2. The trajectory can be divided into 5 segments, of which 4 have a practically constant vertical velocity

Please note that B is located slightly above of the end of the local troposphere (see fig.3 which gives a temperature profile deduced by Brian Davis from the pressure measurements of his Gypsy payload flown on balloon #1.

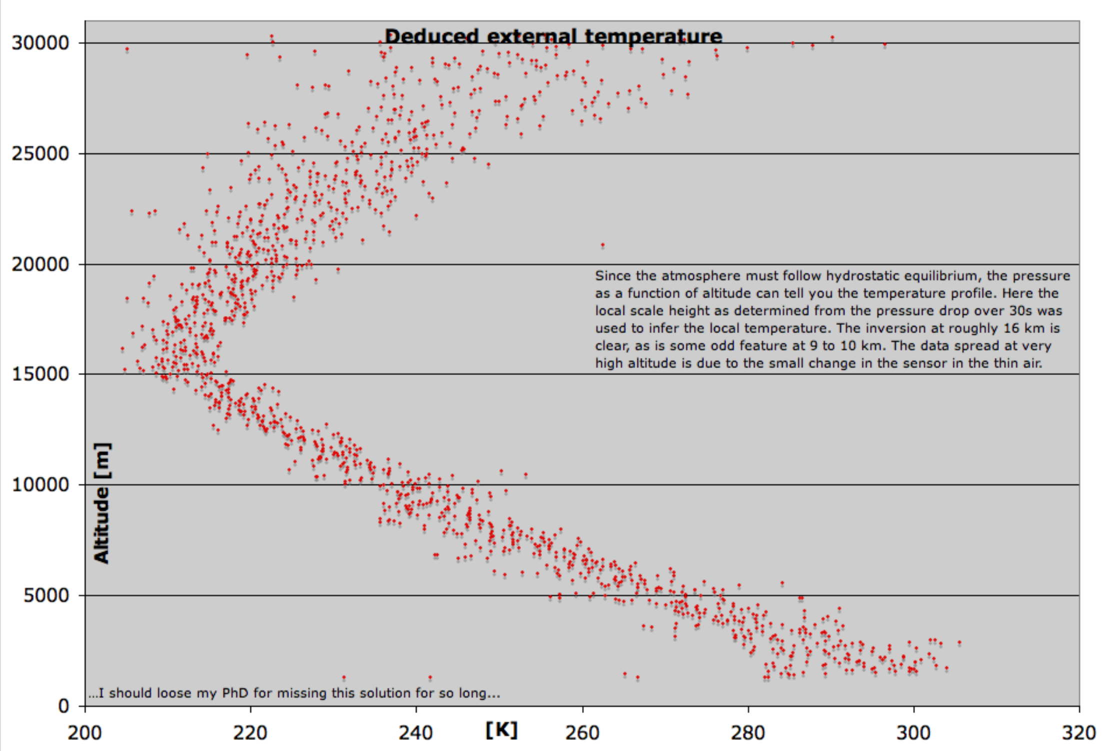

fig. 3. Deduced temperature from pressure measurements of the Gypsy payload (Brian Davis). Troposheric cooling rate ~6.6 K/km.

What can be learned?

Intuition would suggest that uniform vertical velocities would be rather exceptional during a potential very complex high altitude balloon flight, except perhaps for the last part of the parachute descend.
During the flight, many parameters do vary: air density diminishes with altitude, Archimedian buoyancy could vary as the balloon becomes more and more inflated, and the drag due to the friction of the air is also dependant on a changing viscosity.

In fact these complications often cancel out.: The major part of the the flight holds movements at constant **vertical** velocity, and the sole portion showing an acceleration (or better a deceleration) is the transition from free fall to fully deployed parachute descend.
This means that during 4 of the 5 parts, the sum of all **vertical** forces acting on the system was zero, and so according to Newton's law **F = m*a** the vertical acceleration **a = 0**, and the vertical velocity (of which **a** is the time derivative) is constant.

2. Luxpak air pressure measurements

Fig. 4 shows the readings of the SCX pressure sensor located inside the payload. For comparison the pressure profile corresponding to a constant temperature atmosphere, but with variable air density is plotted in read. The model for this (not realistic!) atmosphere used is:

$$p = p_0 * e^{-\frac{elevation}{7300}} \qquad \text{[eq. 1]}$$

with the elevation given in meters. The factor 7300 is called the "scale height"; it represents the elevation where the remaining air pressure is only p_0/ e. From this equation p_0 = pressure at elevation 0 meters can be computed as 1045.6 hPa, so that the equation becomes:

$$p = 1045.6 * e^{-\frac{elevation}{7300}} \qquad \text{[eq. 2]}$$

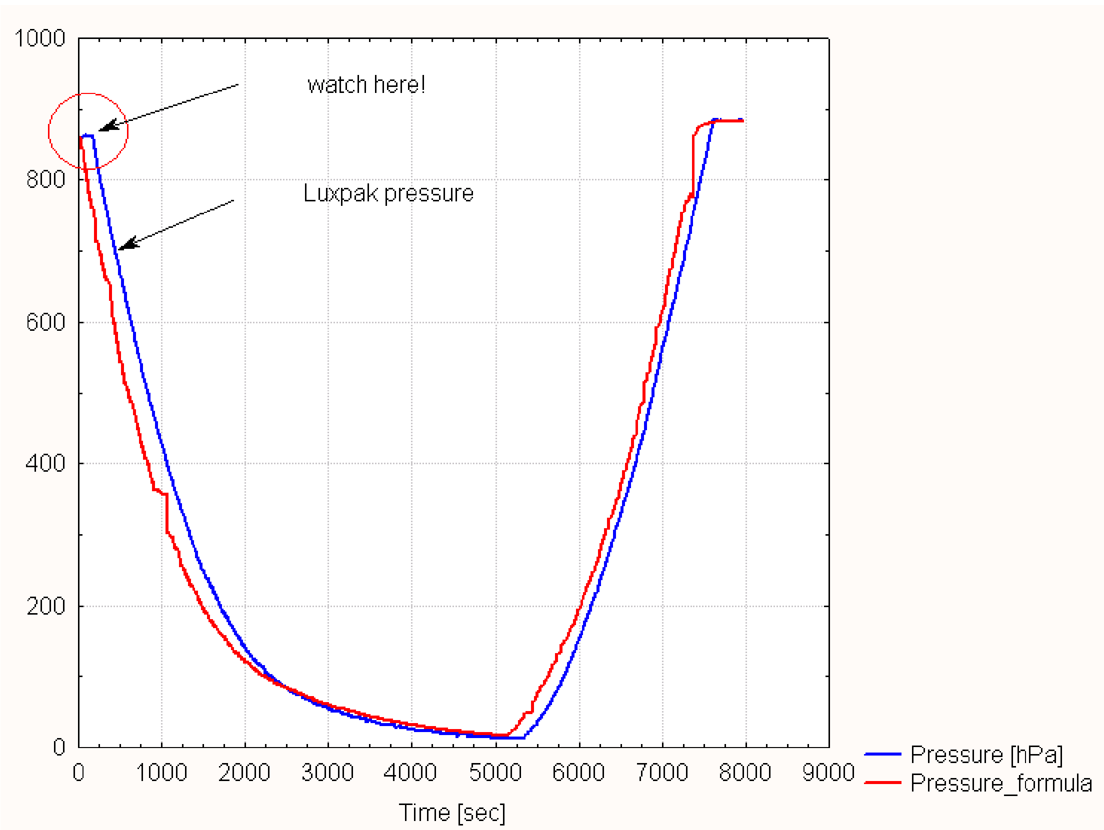

fig. 4: Luxpak measured pressure and pressure given by eq. 1. Note flat Luxpak pressures at the start!

At a first glance, the measured pressure is reasonably close to the simple constant temperature model. If we plot both pressures versus elevation, we get the following result:

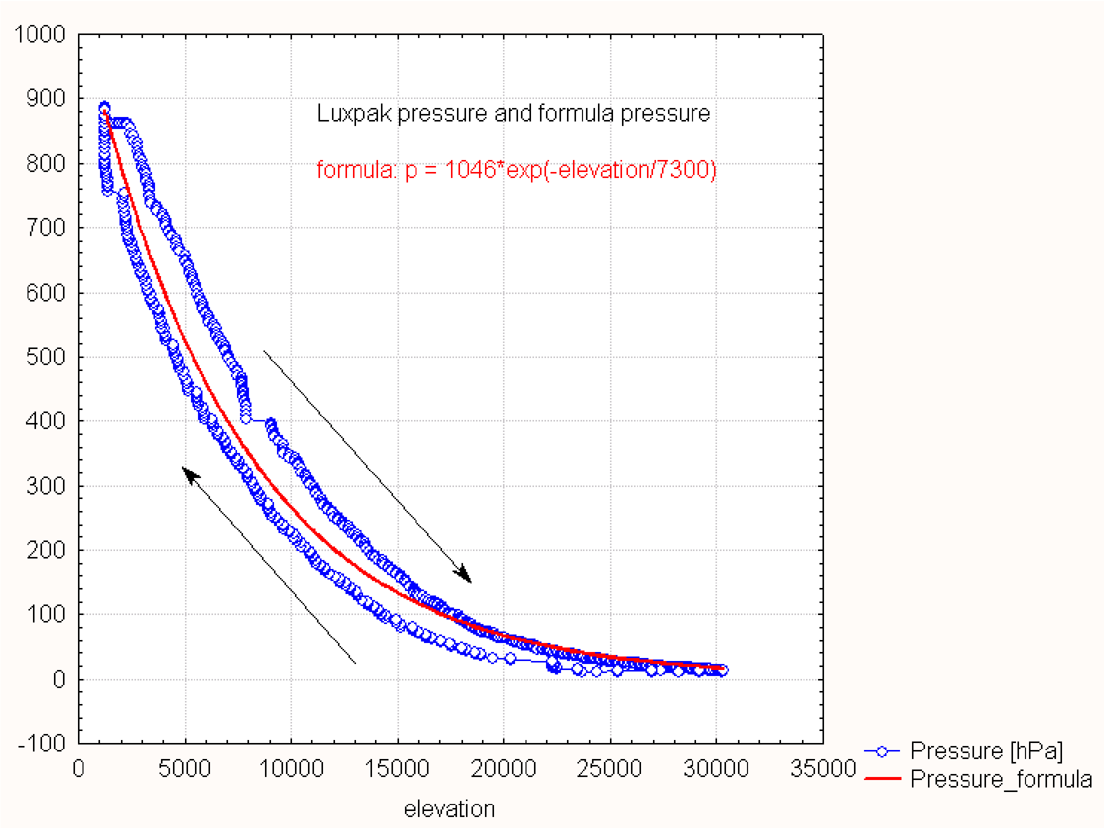

fig.5. At the same elevation, measured pressures during ascend are higher than those at the descend. Is this caused by different Bernoulli depressions ?

Obviously the pressures during the descend are lower at all elevations than those of the ascend. One possible explanation could be the following: The air flowing around the Luxpak box creates a Bernoulli-type depression dp which lowers the static pressure p measured if the balloon was not moving. As the descend has higher velocities (except last part EF) than the ascend, the measured ($p - dp_{descend}$) < ($p - dp_{ascend}$) because $dp_{descend} > dp_{ascend}$

This is a nice explanation, but alas, one should not rush into complications and always use Occam's razor: "the best explanation of a phenomen should be the simplest".

Fig. 4 shows that the Luxpak pressure readings were constant for quite a time before falling: actually during the first 157 seconds (up to an altitude of 2214m) the sensor did not register falling pressures. The reason for this obvious faulty behaviour is unknown. To get a correct (pressure, time) series, let us shift up the whole pressure series by removing the first 19 constant readings. The result is given by fig. 6 and fig. 7.

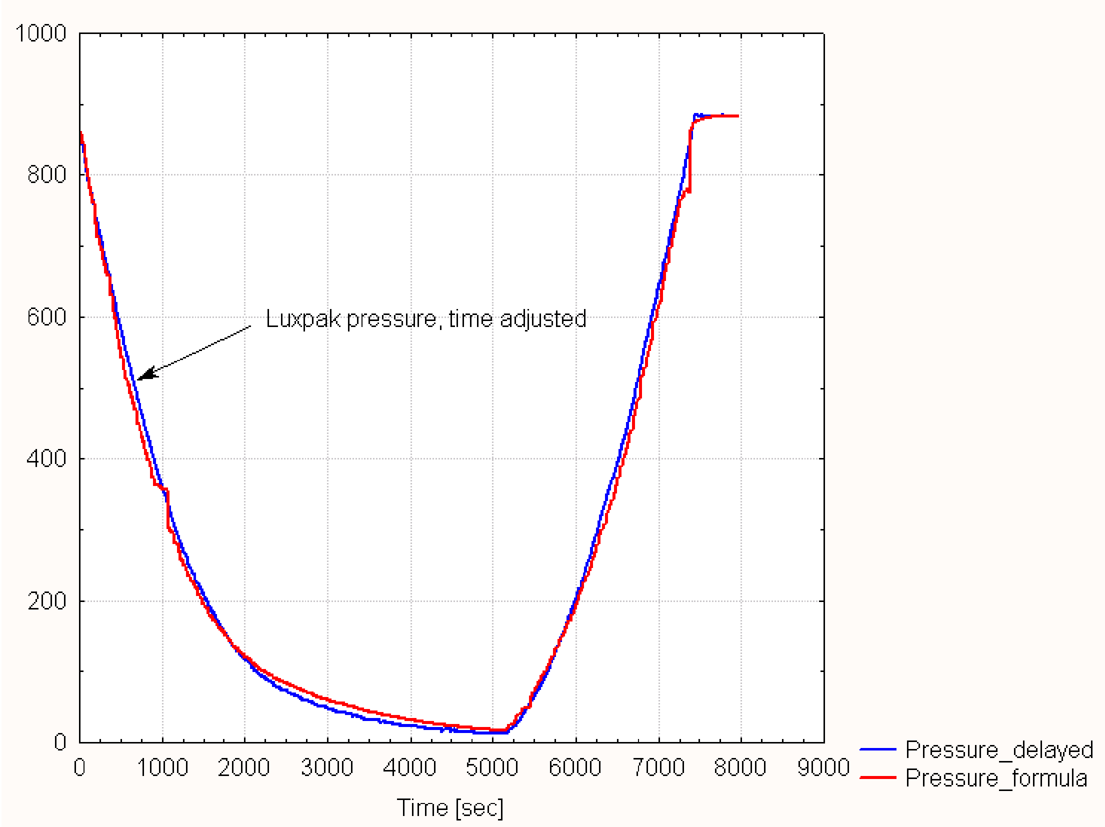

fig. 6: Time series of Luxpak pressures, adjusted for flat response. Very good correspondance to the simple model.

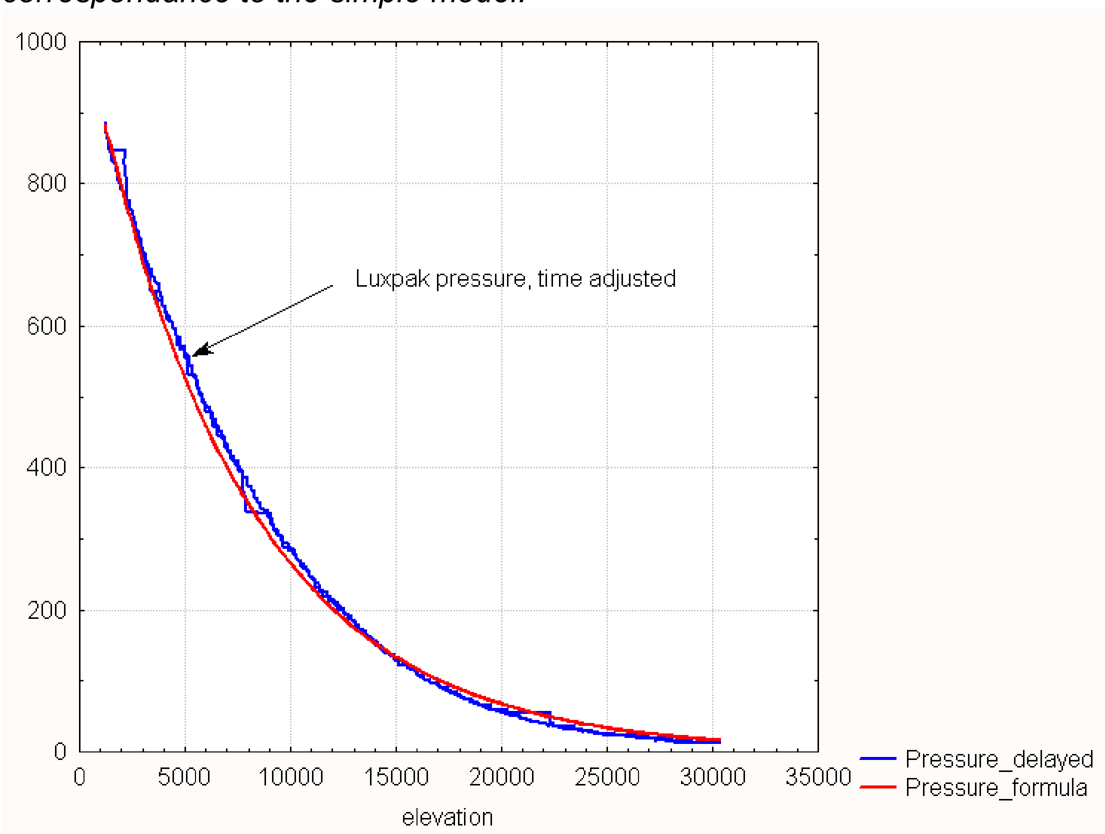

fig. 7: The banana-type hysteresis between ascending and descending pressures disappears with the time adjustment. Measured data are close to constant T model

We see that the (justified!) time-shift gives the same pressure for ascend and descend, as it should be for a good quality sensor that is reputed to be stable.

Let us now optimize the primitive model by finding an optimal scaling height; remember that the previous H = 7300m was suggested by mere eyeballing! We will use the Statistica software (version 7.1) to find the best H fitting the time-shifted pressure series as well as the best sea-level p_0 pressure. The computation gives a best estimate H = 7392.4 ~ 7392 m with a very small standard error of 18.1 m and p_0 =1065.1 hPa with a standard error of 1.8.

So the best constant temperature model fit to Luxpak time-adjusted pressure measurements can be written as:

$$p = 1065.1 * e^{-\frac{elevation}{7392}} \qquad \text{[eq. 3]}$$

Fig. 8 shows that ignoring obvious outliers the differences between measurements and model are the following:

- below ~2850 m: $p_{Luxpak} < p_{model}$
- from ~2800 to ~12900 m $p_{Luxpak} > p_{model}$
- from ~12900 to ~30000m $p_{Luxpak} < p_{model}$

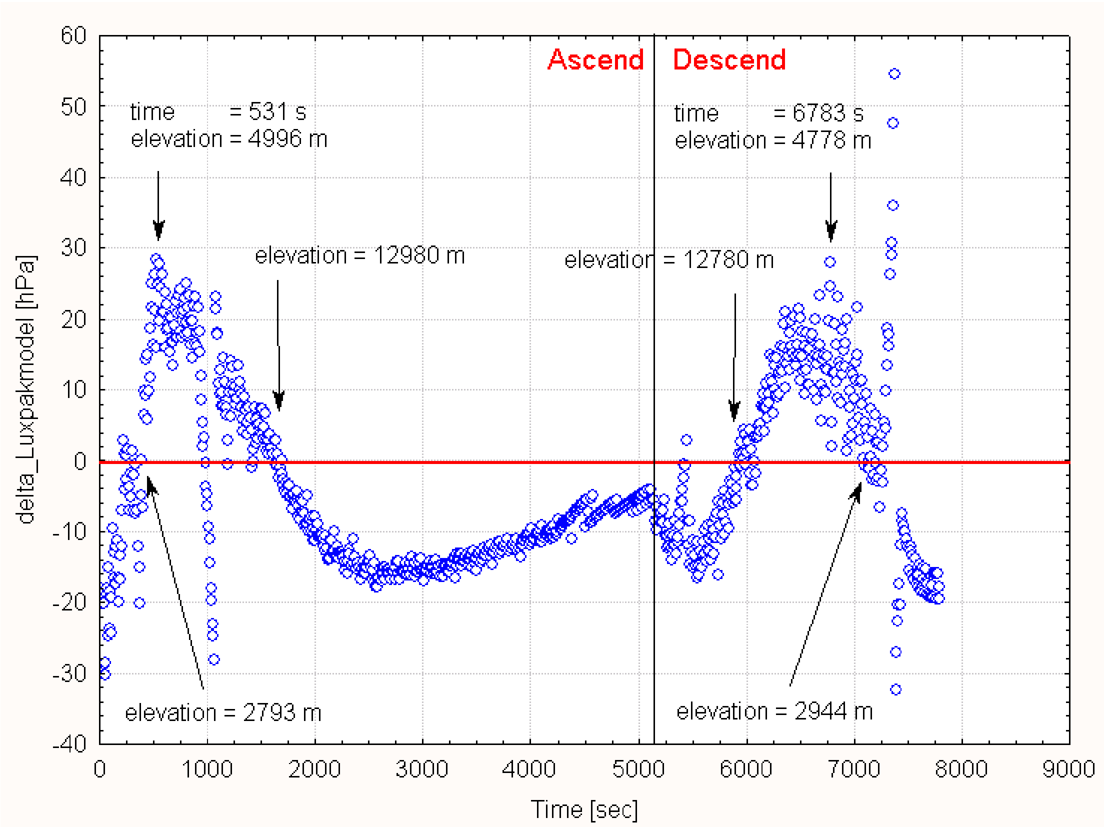

fig. 8: Differences between Luxpak pressure measurements and simple model

Thus the model predicts values that are too low for most of the troposphere, and slightly too high for the tropospause and stratosphere (up to ~30000m)

The optimum scaling height H = 7392 is equal to H = R*T/g with R being the gaz constant of the air (R = 287), T the temperature in Kelvin and g the gravitational intensity. Assuming g= 9.81m at sea-level and applying the simple Airy formula

$$g(z) = g_0 * (1 - \frac{2*z}{earth\_radius}) \qquad \text{[eq. 4]}$$

gives a mean value of 9.72 for g (g varies between 9.806 and 9.717). So we can compute the assumed constant temperature of the atmosphere as:

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$$H = \frac{287*T}{g}$$
$$T = \frac{H*g}{287} = \frac{7392*9.72}{287} = 250.4K = -22.8^\circ C \qquad \text{[eq. 5]}$$

To finish, we could try to deduce a temperature profile from the pressure series, as done by BrianDavis in fig.1.

From [eq.1] one can see, taking 2 points corresponding to indices 1 and 2 :

$$\ln(p_1) = \ln(p_0) - z_1 / H$$
$$\ln(p_2) = \ln(p_0) - z_2 / H$$
$$H = \frac{z_2 - z_1}{\ln(p_1) - \ln(p_2)} \qquad \text{[eq. 6]}$$

Let us choose for 1 et 2 one measurement point and the second one following (that is 2 points separated by 2*sampling_interval ~ 2*8 = 16 s)
For each H let us compute T. Ideally we should obtain a series of temperatures reflecting the near constant tropospheric cooling, an eventual constant temperature during the tropospause and the subsequent temperature rise in the stratosphere.

The series of computed H and deduced T's varies enormously, but a linear fit to the T's from start to about 15000m elevation gives a possible cooling rate of 6.1 K/km (see fig.9); the seal-vel deduced temperature is impossible high. Reasonable profiles can not be found neither for the tropopause nor the stratosphere.

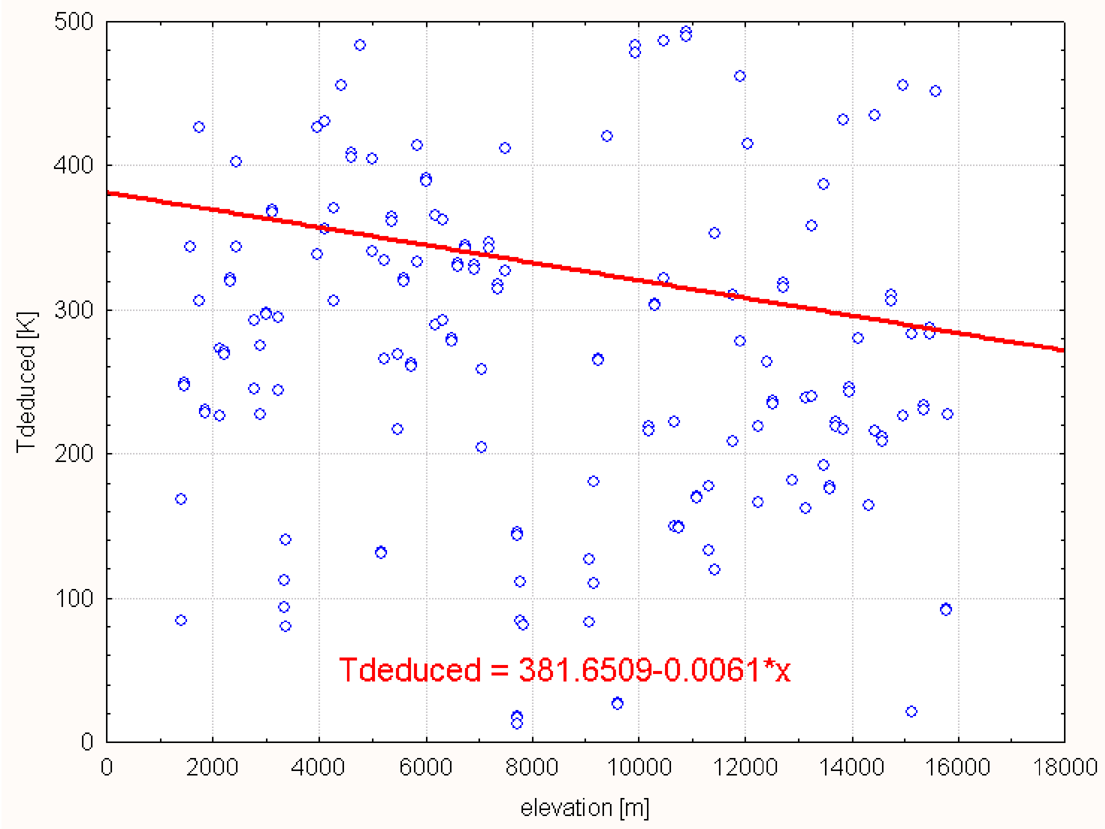

fig.9: Brian's method to deduce temperatures from pressures does not give a satisfying result, even if a linear fit shows a possible correct tropospheric cooling rate of 6.1 K/km, close to Brian's findings of 6.6 K/km.

What can be learned?

It comes as a surprise that the measured pressure profile is very close to that of an idealized atmosphere held at a constant temperature. Fitting this primitive model to the data suggests a scaling height of 7392m. Readings during ascend and descend are very close, after a mandatory adjustment of the series for an initial time lapse.
Using the pressure series to deduce a temperature profile does not give satisfying results, because the inherent pressure variability from point to point is excessive.

... to be continued

References

1	Prof. Eric Wang, web-site of the HALE mission: http://www.unr.edu/nevadasat/hale/
2	Temperature profile deducec from Brian's pressure measurements. Brian Davis, Gypsy paylod of the Hale project.