MET.O.14

METEOROLOGICAL OFFICE
BOUNDARY LAYER RESEARCH BRANCH
TURBULENCE & DIFFUSION NOTE

T.D.N. No. 50

The movement of a tethered kite balloon and its cable.

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March 1974

Introduction

For some years the Cardington Meteorological Research Unit and the Meteorology Division at Porton Down have used the tethering cables of kite balloons to support meteorological instruments above ground level. However these cables and the attached sensors do move about in response to the motions of the balloon, thus affecting the measurement of such quantities as wind speed and direction. Both groups have therefore studied these motions and attempted to assess their effects on the data obtained by the sensors. This note summarises the information that has been obtained on the movements of the balloon and its tethering cable. It does not attempt to assess the effects of these motions on the measurement of particular parameters such as temperature or wind speed. However, it must be stressed that the primary aim of these investigations was to quantify the effects of these motions on meteorological measurements. The early experiments relied on theodolite-tracking to monitor the sensor motions but it soon became clear that this technique did not provide enough information to satisfactorily quantify these spurious contributions. Thus in the more recent work, recourse was made to direct comparisons between balloon - and tower - based measurements. This of course led to rather limited data on the actual sensor motions.

Unless otherwise stated a 1300 cu metre/balloon (Mark II or Mark HZA), tethered by a 9/32" diameter steel cable, was used in all the experiments discussed in this note.

Cardington Studies

The inclination of the tethering cable of a kite balloon depends on many factors such as the lift of the balloon and the wind profile. Thus it is not surprising to find that this angle varies continuously. This is clearly illustrated by figure 1 which is taken from Jones and Butler (1958). Thus any sensor requiring constant orientation for proper operation cannot obtain this by being rigidly clamped to the cable but must rely on some external references such as gravity or the earth's magnetic field. A good example of this is the support for the inclinameter on the Cardington turbulence probe (see Readings and Butler (1972)). This consists of a pendulum sub-critically damped by an oil-dashpot.

In the late sixties Thompson (1969) carried out a series of observations of balloon and cable movement using data-logging theodolites. During the first part of this investigation he monitored the movements of the balloon with a single theodolite close to the tethering point and making the assumption that the cable catenary did not change, deduced that the balloon's vertical and horizontal velocities could often be as large as 0.2 m/sec or 1m/sec respectively.

He later extended this work by using a double-theodolite system to follow the motions of a package attached to the tethering cable. From these observations he was able to construct horizontal projections of the successive positions of the packages and to demonstrate that they formed a pattern which was usually elongated across wind. This reflects the observed tendency of these balloons to drift back and forth across the mean wind direction.

A few years later some more experiments were carried out at Cardington but this time the emphasis was placed on a direct comparison between tower - and balloon - based measurements (see Introduction). However some single theodolite observations were made of changes in the elevation of a package attached to the balloon cable at a height of about 40 metres. The altitude of the balloon was varied from run to run and it was found that the amplitude of the probe's vertical motion decreased as the balloon's altitude increased (see Figure 2). This clearly illustrates the way the motions of a package may be minimised by flying the balloon as high as possible. Figure 2 also shows that the period of these motions is of the order of a minute (or minutes) - in agreement with the earlier observations of Jones and Butler (1958).

The Florida Experiment

A further series of experiments were carried out in 1971 at Fort Eglin AFB (Florida), and here also the emphasis was on a direct comparison between balloon - and tower - based measurements. However in this instance two sets of double-theodolites were set up and these were used to monitor the movements of two packages which were attached to the tethering cable at 150 and 300 metres. The balloon was flown at four different altitudes (370,610,910 and 1220 metres) and the theodolite readings were recorded on magnetic tape, by the AFCRL mobile recording system (Kaimal et al.(1966)).

Though the data were of insufficiently high quality for very accurate velocities to be derived, the amplitudes of the motions of the packages were calculated. These confirmed that the predominant mode of motion of a captive balloon is a lateral one. Vertical and streamwise motions were also present but these were much smaller than the lateral ones.

If the balloon cable were straight and rigid, the motions of the package at 300 metres would always be twice those of the one at 150 metres. However the theodolite results revealed that the ratio was 1.7 for the lateral motions and 1.4 for the longitudinal ones - an instrument fault precluded any reliable evaluation of the ratio for vertical motions. These results serve to emphasize the complex nature of the motions arising from the shape of the cable and its flexibility.

The only component that showed any clear dependance on the atmospheric velocity field was the lateral one. This was a clear function of σ_v (the standard deviation of the wind's lateral components) and a slightly weaker one of $\bar{u}$ (the mean wind speed). Figures 3 and 4 summarise the results. In these figures σ_v and $\bar{u}$ at 300 metres on the tower have been used for the values at the level of the balloon. The standard deviation of the balloon's lateral motion σ_y(balloon) was estimated from the probe motion at 150 metres or 300 metres using the result discussed in the previous paragraph:

$$\sigma_y \text{ (balloon)} = \sigma_y\text{(probe at height } z) \times \frac{\text{Height of balloon)}}{z} \times \frac{1.7}{2} \quad \ldots\ldots(1)$$

Thus in practice figure 3 (or figure 4) may be used to estimate upper limits for the values of σ_y (balloon) from σ_v (or $\bar{u}$). The approximate value of σ_y at any position on the cable may then be derived from the inverse of equation (1). Figure 3 also shows that the tendency for σ_y(balloon) to increase with σ_v is detectable even when the balloon's altitude is held constant. The data in these two figures show no obvious relation between σ_y and the height of the balloon above the ground. However the possibility of a second-order effect cannot be ruled out.

Concluding comments

So far this note has concentrated on the motions of a large kite balloon. However many experiments are conducted with smaller balloons such as the 80 cu metre one used by Thompson (1972). These will also tend to drift back and forth across the mean wind direction but their relative smallness will probably mean that they will respond more readily to higher-frequency gusts than the larger balloons. They will also have less lift so vertical motions may be more of a problem. Thompson (1972) has described the use of these balloons tethered to the deck of a ship and has high-lighted the extra complications introduced by the motions of the ship.

In addition to the low frequency motions, the cables also undergo high frequency oscillations. These are of the order of cycles per second and with metal cables do not usually create any problems as they are of a fairly low amplitude. With nylon cables these oscillations are very much larger in amplitude and several workers have experienced severe difficulties such as the break-up of equipment due to the accelerations or the destruction of the cable by friction at the points where the instruments were attached.

A more general discussion on the use of balloons may be found in Readings (1971).

List of figure captions

Figure 1 - The variation in the inclination of a balloon's tethering cable as a function of time.

Figure 2 - An example of the variation with time in the height of a package attached to a tethering cable at a height of 40 metres. Successive points are 15 seconds apart and the separation between the balloon and the package is 60, 150, 300 or 600 metres.

Figure 3 - The relation between 6v and 6y (balloon) - see text for explanation of symbols.

Figure 4 - The relation between $\bar{u}$ and 6y (balloon) - see text for explanation of symbols.

List of references

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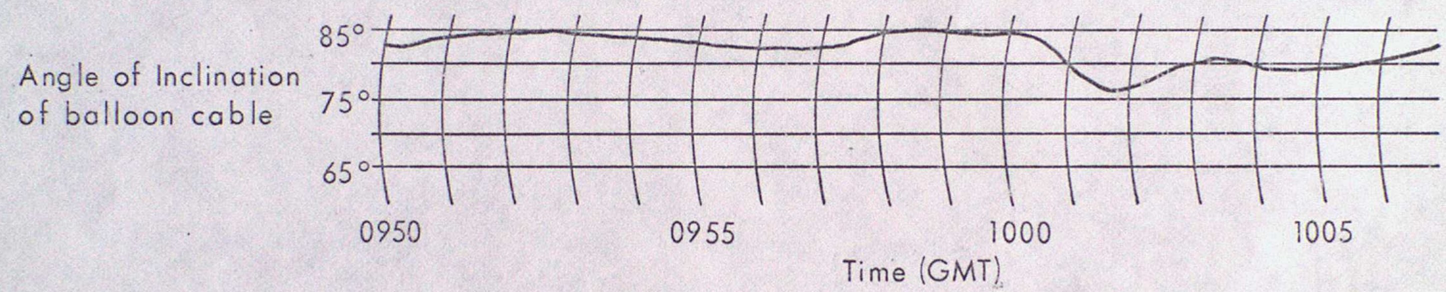

Figure 1 The variation in the inclination of a balloon's tethering cable as a function of time

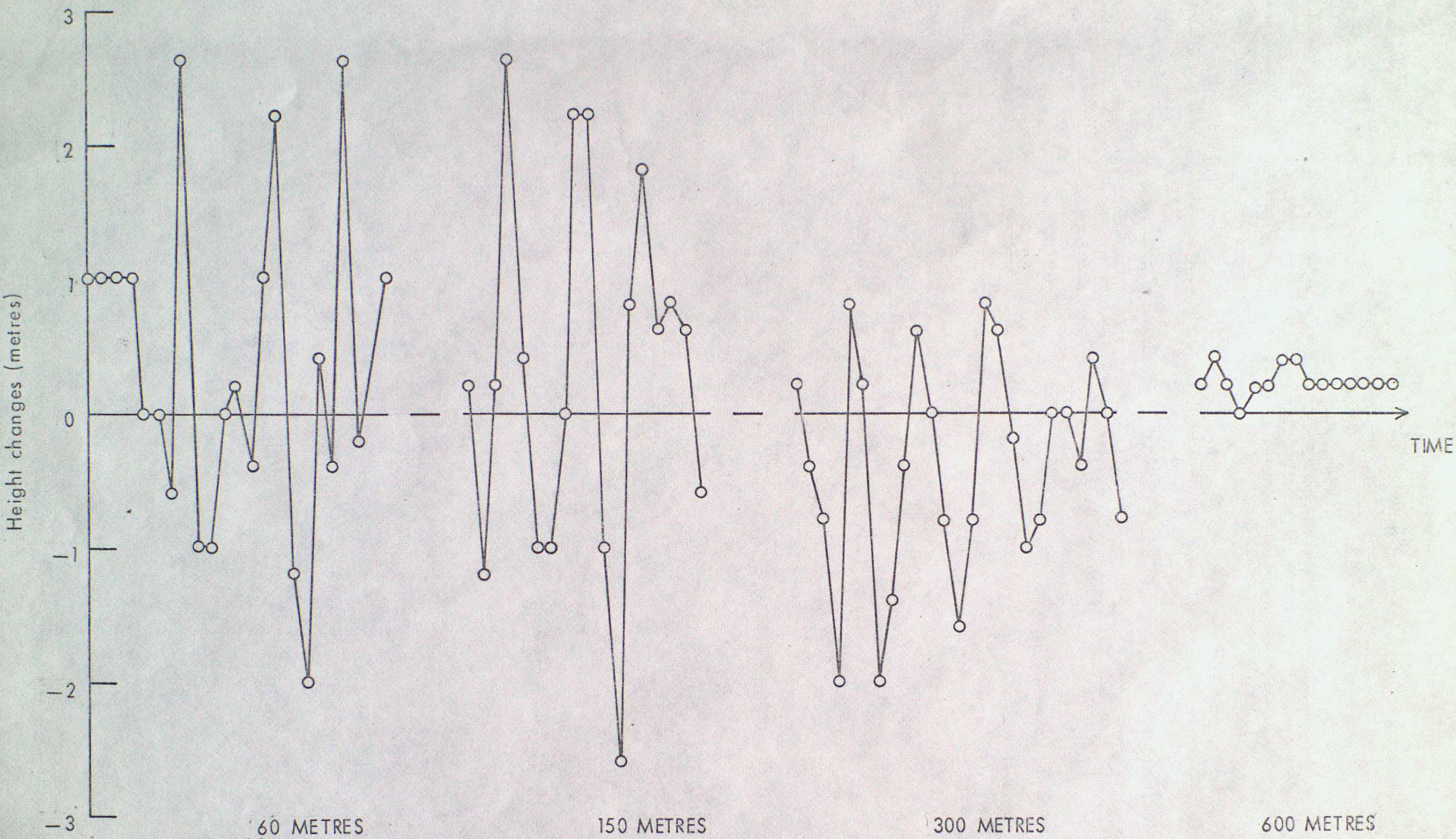

Figure 2 An example of the variation with time in the height of a package attached to a tethering cable at a height of 40 metres. Successive points are 15 seconds apart and the separation between the balloon and the package is 60,150,300 or 600 metres.

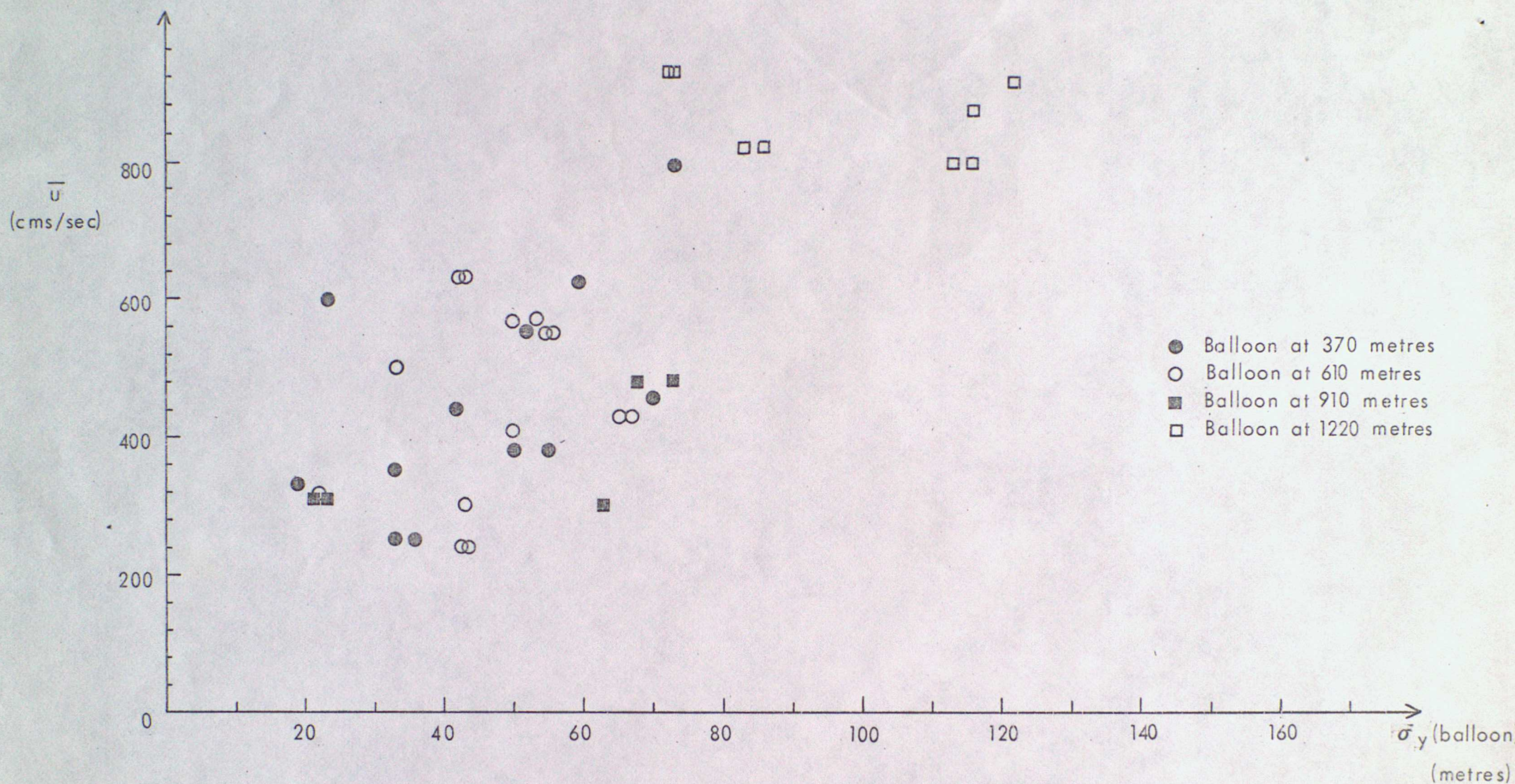

Figure 3 The relation between $\overline{u}$ and σ_y(balloon)—see text for explanation of symbols.

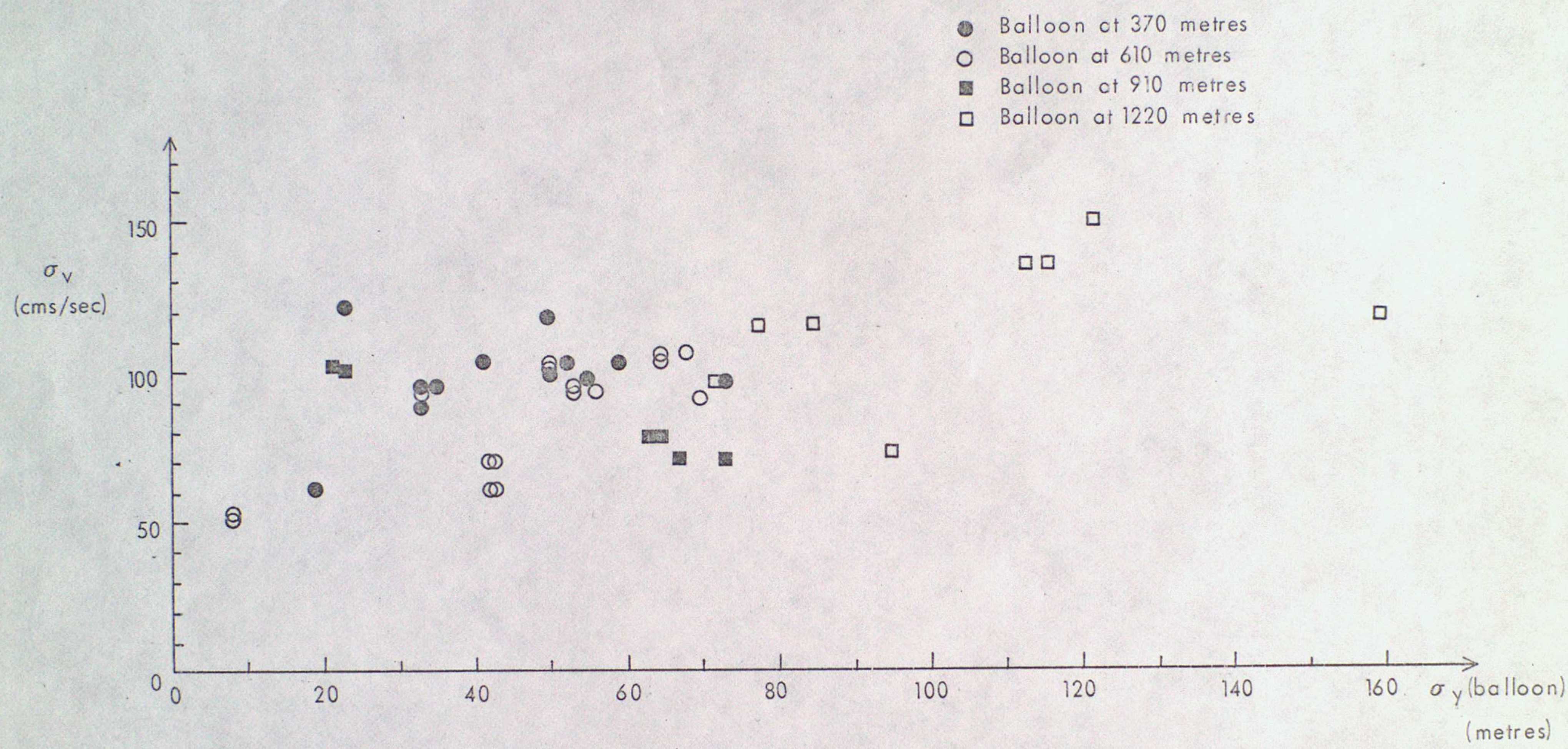

Figure 4 The relation between σ_v and σ_y (balloon)—see text for explanation of symbols.