The Powered Sailplane as an Instrument Platform for Meteorological Research of the Planetary Boundary Layer and first Measurement Results

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1. Aim of Research and Choice of Instruments and Instrument Platform

The planetary boundary layer of the atmosphere is the link connecting the surface and the so-called free atmosphere. In this layer large amounts of heat and momentum are transported upwards. Under unstable or slightly stable conditions, thermal convection is the means by which this transport is accomplished. The development of thermal convection is governed by the synoptic situation to a degree which is not sufficiently known today. As soaring pilots know, thermals developing under similar synoptic situations can be well described above a certain height. Below this height they behave erratically due to turbulence.

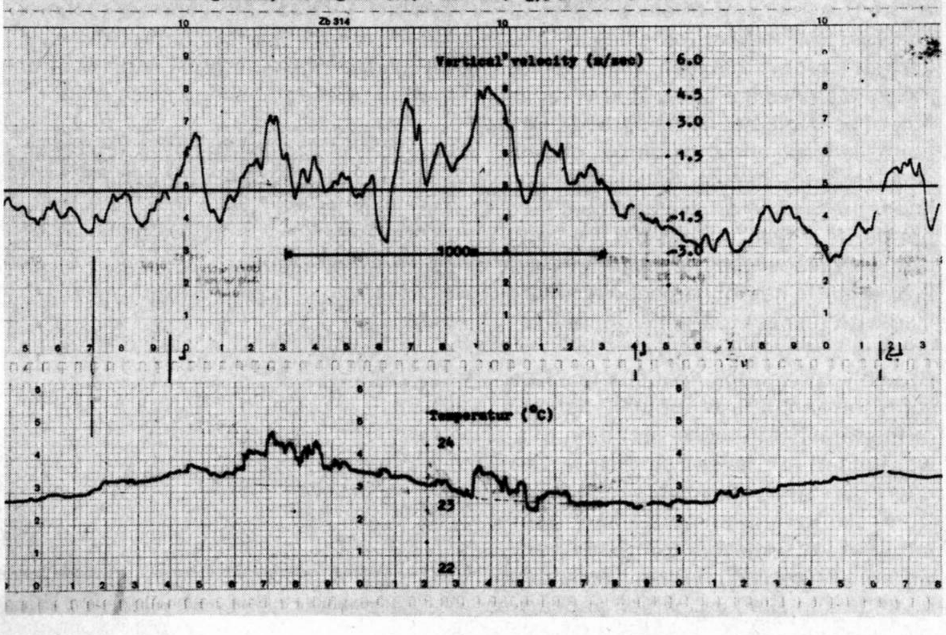
Meteorological investigations of the dynamics and energetics of the lower troposphere have been made for some decades, using balloons or heavy multi-engined aircraft (Lenschow, 1970 [1], Koprov and Tsvang, 1965 [2], Miyake, 1970 [3], Telford and Warner, 1962 [4], and others). From these measurements the turbulent vertical fluxes of latent and sensible heat, which are the most important parameters in the energy balance of the planetary boundary layer, can be computed. The accuracy of measurement of these modern research aircraft is extremely high, but for detailed investigation of single thermals they have the disadvantage of low maneuverability. Here small aircraft such as powered sailplanes are superior, and the running costs are only about one percent of those of the larger research aircraft. Furthermore, temperature and humidity measurements do not differ from those of larger aircraft, as the same rapid-response sensors (open platin wire thermometers and Lyman alpha hygrometers) can be used. The determination of accurate vertical velocity of the air is more complicated, as the vertical velocity of air relative to the aircraft and the vertical velocity of the aircraft itself should be separately measured. However, by using a powered sailplane with very low wing loading one can reduce the measurement of vertical velocity of air to the vertical velocity measurement of the aircraft itself. MacCready (5), who made meteorological measurements with a sailplane, found that it had nearly total response to vertical gusts of wavelengths longer than 40 m. Mansfield and Milford [6] made practical and theoretical studies with a powered sailplane and came to the conclusion that the vertical velocity of the air can be approximated by the vertical velocity of the motor sailplane for practically all thermal convection measurements. Kukharets and Tsvang, 1969 [7], found the power spectrum peak for turbulent heat flux at about 600 m wavelength. The response of a powered sailplane is well below this maximum so that even heat flux measurements should be possible. Based on these considerations we decided to use a powered sailplane of the type ASK-16 as an instrument platform for planetary boundary layer research. This aircraft is equipped with temperature and humidity sensors of high sensitivity and a response time of less than $^1/_{10}$ second, such as the Lyman alpha hygrometer and open wire platin thermometer, electric variometer (Rosemount) and a number of additional instruments for airspeed, pitch and roll, and vertical acceleration, which are recorded on magnetic tape (digitally) and on four analogue strip chart recorders. The best space resolution is less than 3 m.

2. First Measurement Results

The first measurements were taken near Oerlinghausen, Germany, in mid August 1973 during a period of anticyclonal weather. Typical values of temperature excess in thermals were found to be of the order of 0.5°C at 150 m above ground, decreasing upwards to 0.3°C at 600 m and less than 0.1°C below a temperature inversion which in most of these cases was at about 1200–1400 m. In view of a nearly constant vertical velocity between 100 m above ground and 200 m below the top (inversion), the decreasing temperature excess means a decreasing positive vertical heat flux.

Figure 1 shows the profile of vertical velocity and temperature in crossing a thermal. The vertical velocity seldom shows the parabolic profile of Konovalov, 1970 [8]. Typically the thermals have steep edges with strong horizontal shear. Temperature and vertical velocities are well correlated, resulting in a vertical heat flux of about 100 cal/cm^2.

FIGURE 1: horizontal sounding of vertical velocity and temperature under convective conditions, Oerlinghausen, 16. August 1973, 11.30 GMT, 270 m above ground



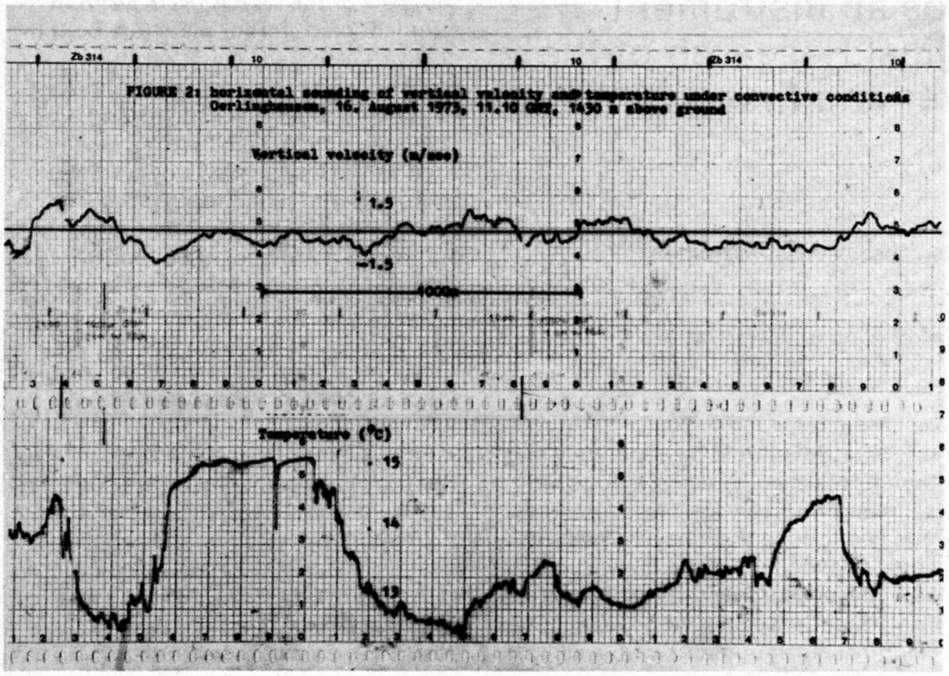


FIGURE 2: horizontal sounding of vertical velocity and temperature under convective conditions
Oerlinghausen, 16. August 1973, 11.10 GMT, 1430 m above ground

Figure 2 shows a temperature and vertical velocity profile at the height of an inversion layer. The vertical velocity has decreased to very small values compared to Figure 1, but the temperature differences are more than 2.5°C (in some other cases more than 4°C). Even if the vertical velocity has very small maxima, its positive values correspond more to lower temperatures than vice versa, resulting in a *negative* vertical heat flux. The explanation for the lower temperatures is that air from low levels has been cooled adiabatically while transported upwards by the thermals, but the kinetic energy of the thermals is large enough that colder air representing negative buoyancy can still penetrate into the warmer inversion layer where this energy is totally dissipated. The very low vertical velocities of the updraft support this idea.

Figure 3 shows the computed vertical flux of sensible heat. The spread of data points is large and the number of data small, but one can cautiously draw a line representing an average heat flux profile. The heat flux has been normalized with respect to the maximum heat flux, and the height has been normalized with respect to the height of the limiting stable layer or inversion.

Roughly spoken the heat flux line intersects the zero line at about 90 percent of the total height corresponding to a warming of this layer from below. The decreasing flux of sensible heat results from mixing (entrainment and detrainment) of the upwards-going thermals with the environmental air. The latter is heated by this mixing, which appears as a temperature increase from one vertical sounding to the next.

As mentioned already, the scatter of the heat flux data is large which, to our opinion, is caused by the short horizontal flight path. Besides the computation of heat fluxes and the measurement of the sizes of thermals and distances from each other, statistical methods can help to get further knowledge on the structure of thermal convection. Probability distributions, for example, of vertical velocity, specific humidity, and temperature, etc. give insight into the magnitude and frequency of thermals. More complicated is the computation of power spectra of vertical velocity, temperature, humidity, or even the heat fluxes. The power spectrum of vertical velocity, for example, represents the kinetic energy per frequency interval (m^2/sec) or wavelength, λ. It gives information on the prevailing sizes of thermals and the distance between them.

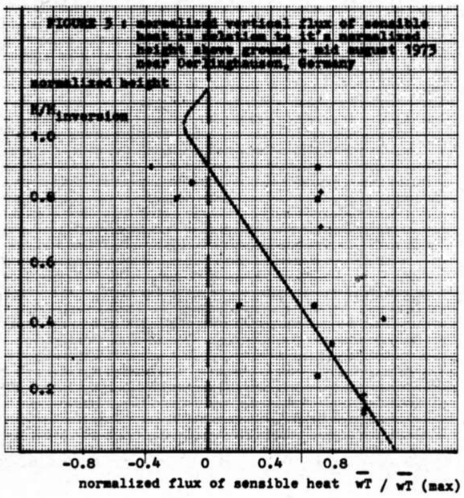


FIGURE 3 : normalized vertical flux of sensible heat in relation to it's normalized height above ground - mid august 1973 near Oerlinghausen, Germany

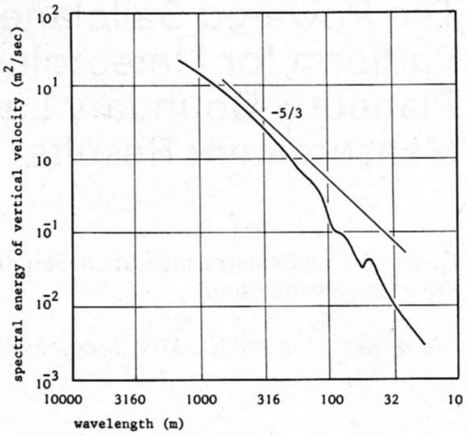


FIGURE 4 : SPECTRAL ENERGY OF VERTICAL VELOCITY AS A FUNCTION OF WAVELENGTH
MEPPEN, 22 of APRIL, 1974, 15.00
Height 500 m

Figure 4 shows a power spectrum of vertical velocity in relation to wavelength. No reliable maximum can be found here. This too is a hint that the flight paths were too short.

From such diagrams one can also estimate how the energy produced at longer wavelengths is transformed to smaller and smaller wavelengths, i.e. to smaller turbulent vortices, until it is dissipated and transformed into heat in the range of millimeters. There exists a $-5/3$ power law for isotropic turbulence based on theoretical considerations. In Figure 4 the logarithmic decrease is -1.96, i.e. steeper than the law dictates, but it cannot be expected that the turbulence has these theoretical characteristics of isotropy, since the thermals are in part organized. The behaviour of temperature and humidity power spectra is similar. Further measurements are planned.

There is little doubt that the powered sailplane with meteorological instrumentation is a valuable and inexpensive tool for exploring convection in the planetary boundary layer.

Literature

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