# Measurements in the Inhomogeneous Convective Boundary Layer Using Three Powered Gliders

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Abstract

Three instrumented powered gliders have been built up and used for turbulence measurements in the atmospheric boundary layer. The present status of the system is summarized, and results from a recent field experiment are presented which demonstrate the horizontal variability of near-surface evaporation fluxes on scales of the order of several kilometers.

## 1. Introduction

Motorgliders represent a powerful research platform for atmospheric boundary layer (abl) studies. Their low flight speed enabling the resolution of very small scales and a high degree of flexibility makes them the ideal tool for complex terrain studies. Due to their relatively low cost multiple aircraft systems and thus, extended spacetime resolution can be achieved.

The main advantages can be summarized as follows:

- The use of multiple identical aircraft helps to overcome the sampling problem associated with airborne flux measurement (Lenschow and Stankov, 1986). Flying either side by side or repeated line averages reduces the required sampling length by at least a factor of three.
- The low flight speed (33 m/s) allows for increased spatial resolution, and thus - with fast sensors - for turbulence measurement at very small scales.
  On the other hand, it is easier to achieve good wind measurement accuracies with lower airspeed.
- The fleet of light aircraft provides a very valuable tool for flexible and low cost use in small projects, they can be flown at low altitudes even over very complex terrain.

At the Institute of Atmospheric Physics at DLR (German Aerospace Research Establishment) a system of three instrumented motorgliders ASK 16 has been built up since 1974, and used successfully in numerous field experiments. Jochum et al. (1984) give a detailed description of the aircraft and the basic measurement system along with an overview of past field projects and their results. This article compiles information about the most resent status of the instrumentation and gives an example of results on the horizontal variability of near-surface turbulent fluxes.

## 2. Aircraft and instrumentation

The ASK 16 is a low-wing powered glider manufactured of wood and metal. The aircraft has two seats, in general one for the pilot and one for the mission scientist or another pilot. The second seat may also serve to install additional equipment. Some aircraft parameters are given in Tab.1. All three aircraft are equipped with a tank below the right wing plus - under the left wing - an instrument pod constructed at the Institute of Atmospheric Physics. Fig.1 shows a schematic view of the aircraft with installation.

| | |
|---|---|
| maximum take-off weight (MTOW) | 765 kp |
| permanently installed equipment | 70 kp |
| allowance for crew and fuel | 200 kp |
| range | 700 km |
| service ceiling | 8500 ft msl |
| maximum rate of climb at 100 km/h | 2 m/s |
| speed range | 75 - 170 km/h |

Tab.1: Selected aircraft specification

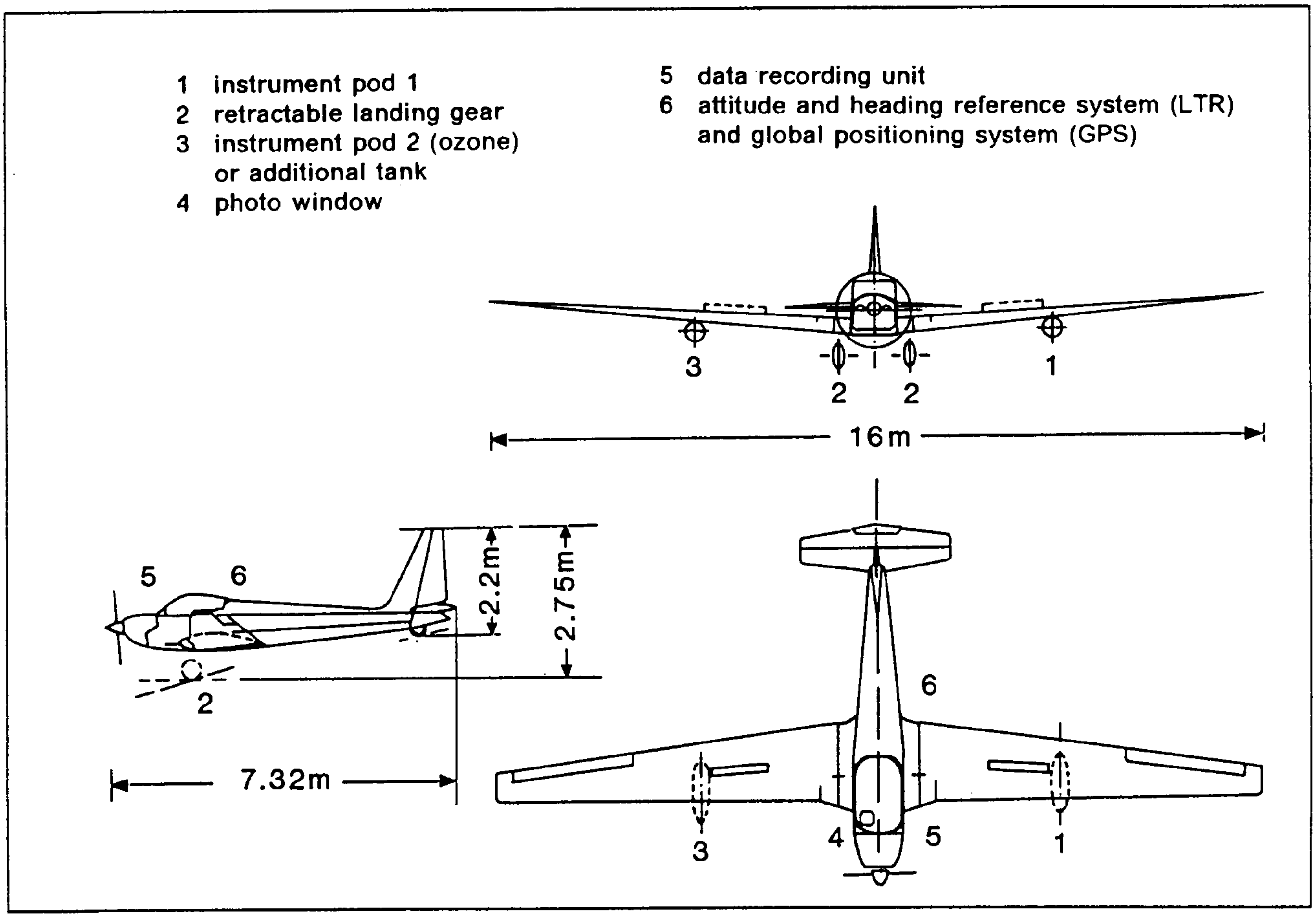



Fig.1: Ask 16 schematic view with installations

The main characteristics of the measurement system are presented by Jochum et al. (1987), where more detailed references are given. During the past years the system has been thoroughly modified and extended to include a full air motion sensing system (Jochum, 1988). The instrumentation of the three motorgliders used to be identical, and will be so again after the modification will be completed. At present time two aircraft have undergone complete modification. Tab.2 provides a list of equipment availlable in the old configuration and of major modifications that have been implemented.

The sensors for temperature, humidity and pressure are installed in and on the wing instrument pod. A pitot static tube protruding forward from the point of the pod has been replaced with a differential pressure probe mounted in the same place. The distance between the pressure apertures and the wing leading edge is sufficient to allow undisturbed pressure measurements. The humidity sensors are located in a channel in the pod. This channel is also fitted with a Pt100 for monitoring internal temperature. The sensor for external temperature is mounted in a case underneath the pod.

Temperatures

- ⊙ reverse flow temperature probe (Pt 100 manufactured in-house)
  Pt 100 in humidity channel manufactured in-house)
- ⊙ Barnes PRT-5 radiation thermometer (one aircraft)
- o fast response probe (manufactured in-house)
- • Heimann KT 17 radiation thermometer

Humidity

- ⊙ ERC Lyman-alpha hygrometer
- ⊙ Vaisälä humicap relative humidity sensor
- • dew point mirror (Swiss Meteolab)

Pressure and air motion

- o Rosemount static and dynamic transducers for pitot static tube
- • differential pressure probe (manufactured in-house) with Rosemount static, dynamic and differential transducers

Aircraft motion

- o 2 Sundstrand accelerometers
- o SFENA vertical gyro (pitch and roll angle)
- • AIM directional gyro (heading) attitude and heading reference system
  LITEF LTR-81 and magnetic flux valve

Aircraft position

- • Japan Aviation radar altimeter
- • GPS (Global Positioning System) receiver with additional ground
  based receiver for differential operating mode

Video camera(s) looking forward and/or downward (optional)

Tab.2: Instrumentation - old and new configuration:
o being replaced, ⊙ being retained, • new.

The attitude and heading reference system (AHRS) - a strapdown system manufactured by LITEF (Litton Europe) - is mounted in close vicinity of the center of gravity. A miniaturized airborne GPS receiver has recently been installed and tested successperformed one hour later than flight 1 (right hand side). It turns out that the horizontal flux pattern has not basically changed during that period of time, which is much longer than the persistence time of individual plumes or thermals. Possible correlations with unterlying soil composition or vegetation patterns are presently being investigated.

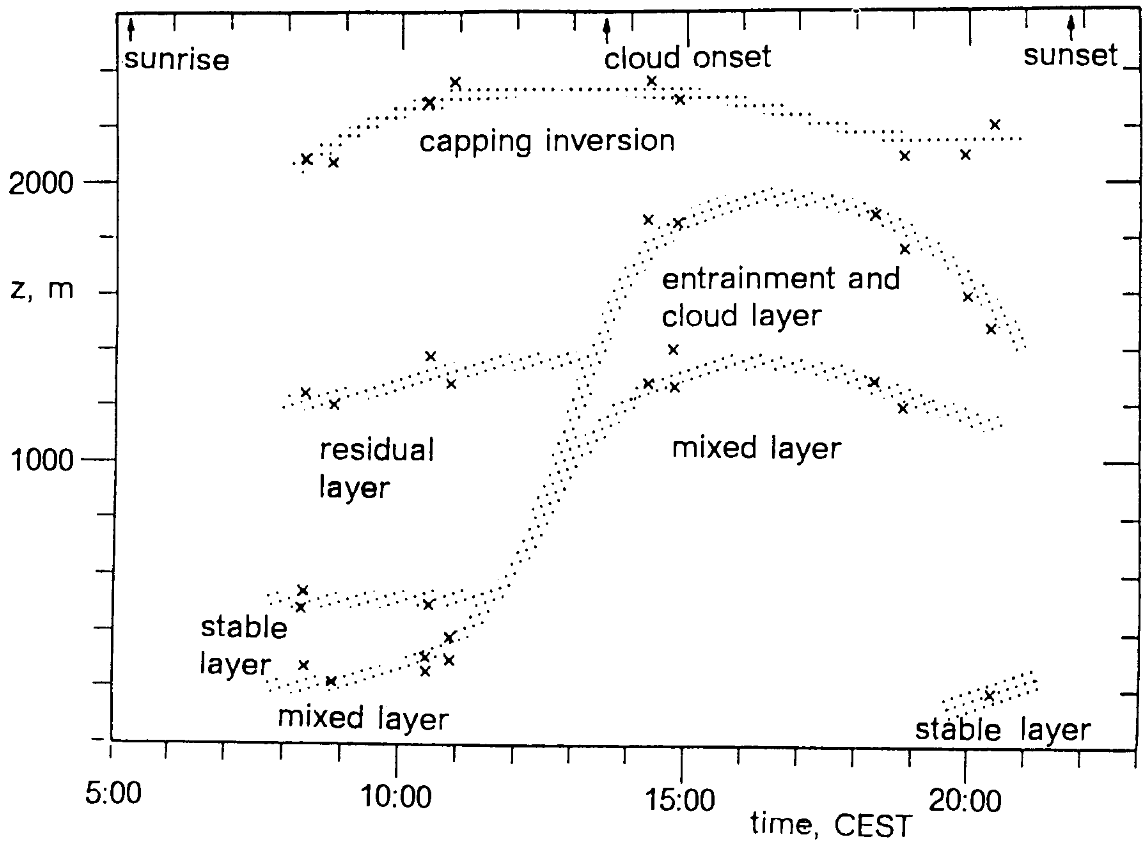
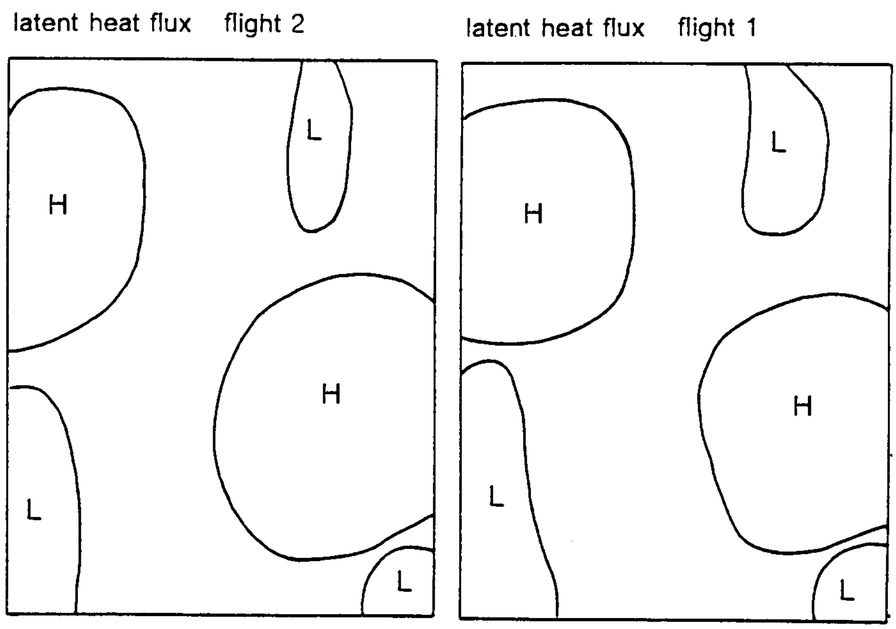



Fig.2: Mean structure during LOTREX 5 July 1989. The crosses represent data from the Queen Air.

Fig.3: Latent heat flux pattern on 5 July 1989 in an area of 15 km$^2$. H: = latent heat flux higher than area average plus half standard deviation, L: = lower than average minus half sigma. See text for details.



fully. Signals from the AHRS and the GPS receiver are beeing processed by a small on-board computer in a complementary way in order to increase the accuracy primarily of wind measurements.

Recently, a new very fast response, light weight ozone sensor developed by the Institute of Physical Chemistry, University of Bonn, has been added to the instrumentation. Tests and first field observations have demonstrated the capability of the system to measure turbulent fluxes of ozone (Schmidt et al., 1991).

Data logging is accomplished by means of a small digitalization system (MINIDIG) developed in house. A combined sampling mode of 10 Hz for standard resolution channels and 40 Hz for high resolution channels (fast reponse temperature, humidity and pressure sensors) is offered. The combined sampling mode yields a spatial resolution along flight path of less than 1 m. Anti-aliasing analog filters are provided for 10 and 40 Hz sampling. A digital interface was developed to record data from the AHRS at 40 Hz. A serial digital interface is provided to record GPS data at 1 Hz. The new data collection system ist located in a small compartment below the panel together with the LCD control unit.

## 3. Observational Results

An example of field measurements during LOTREX / HIBE89 is presented. It was the objective to investigate the horizontal variability of near-surface fluxes and of possible effects of surface inhomogeneities on different scales. Reinhardt (1985) has used motorglider data taken near Munich to demonstrate the influence of vegetation inhomogeneities on the small scale local turbulence structure. Data from LOTREX have been collected and analyzed such as to make visible the turbulence structure and varibility on scales on the order of several kilometers. The area of investigation was a 15 by 15 $km^2$ agricultural area in North Germany. Fig.2 illustrates the basic abl conditions - as derived from all available data - on 5 July 1989: the shallow morning mixed layer develops around noon into a 1300 m deep mixed layer capped by an entrainment and cloud layer with 2/8 of small cumulus (for details see Jochum et al., 1991).

The horizontal variability of latent heat flux at 10:00 - 12:00 local time on this day is shown in Fig.3. The three motorgliders were flying along straight North-South low level legs separated by 1 km each in East-West direction, thus mapping the whole area. A special analysis method was developed (Klebelsberg, 1991) to derive horizontal flux patterns: first the straight turbulence legs were partitioned into overlapping segments of 4 km each and mean flux values computed over each segment (i.e. every 2 km). After carefully removing the temporal trend, segment mean values of three adjacent legs were averaged to yield a mean flux value representative for a grid area element of 4 x 4 $km^2$. Averaging over adjacent legs is possible through the use of multiple aircraft and assures that sampling statistics (see Lenschow and Stankov, 1986) are adequate inspite of short individual segments. Finally, isolines were drawn separating those areas with flux values lower than the whole area average (obtained from averaging all individual segment mean values) minus half the standard deviation (characterized by L in Fig.3) from those areas with flux values higher (H) than the whole area average plus half the standard deviation. Fig.3 represents an overview of the resulting latent heat flux pattern (horizontal = EW distance of 12 km, vertical = NS distance of 15 km) for two consecutive flights. Flight 2 (left hand side) was

Acknowledgements:

The motorglider measurement system has been built up in the mid seventies due to the initiative of Manfred E. Reinhardt. For many years he kept being involved with it as experiment coordinator, principal investigator, pilot and mission scientist at the same time. His enthusiasm, profound knowledge and continuous support have since encouraged many people within and outside DLR to work with the system and to extend it into one of the most promising research platforms of present days. We are all expressing our deep gratitude to him.

We also gratefully acknowledge the dedicated work of many colleagues at DLR for the motorglider system and during the field experiment.

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