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The 1973 Minnesota Boundary-Layer Study.

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Introduction

During August and September 1973, the Meteorological Research Unit Cardington (Bedford, England) and the Boundary-Layer Research Branch of the Air Force Cambridge Research Laboratories (Bedford, Massachusetts) collaborated in a study of the turbulent structure of the earth's boundary layer. The experiments were carried out in the north-west corner of Minnesota - the actual site being about 50 miles from the Canadian border.

Although this note is mainly concerned with a description of the measurements made and the cases studied, a short outline of the background to these experiments is also given.

History

As a result of a series of meetings in 1968/69, it was decided to combine the resources of the two research teams in an investigation of the earth's boundary-layer. The observations were to be conducted on a flat and featureless landscape to avoid the complications introduced by an undulating or irregular terrain, or by any urban effects on the wind and temperature fields (ie the site should approximate as closely as possible to the idealised 'infinite flat plane').

The AFCRL team use a three axis sonic anemometer (plus a platinum resistance thermometer) and operate from fixed supports[1.]; the Cardington probe has a cup anemometer, a hot wire head and a platinum resistance thermometer, designed specifically for use on the tethering cable of a kite balloon[2.]. In view of this basic difference between the two systems it was necessary to carry out some preliminary studies to check their compatibility. This was planned in two stages - during the first part the two probes would be exposed side by side on fixed supports, while during the second, measurements from a tower would be compared with those from a balloon cable.

The initial comparison was conducted in October 1969 at Bedford (Massachusetts) using a 15.5 metre tower. A series of ten-minute runs was carried out with the two probes mounted 2 metres apart at about 16 metres. The results were very encouraging with the two sets of results agreeing quite closely (see figure 1).

The second stage was carried out during August and September 1971 at Eglin Air Force Base (Florida) on a 370 metre tower. Three-axis sonic anemometers were mounted on booms at 150 metres and 305 metres and Cardington turbulence probes were flown at the same heights on the tethering cable of a 1300 cu metre kite balloon. During the runs, the balloon-induced motions of the turbulence probes were monitored with theodolites. The results of this work were also very encouraging - the two systems again proving to be very compatible. Full details of this comparison have yet to be reported but the nature of the agreement is indicated by figure 2.

The full boundary-layer experiment was then scheduled for Autumn 1973.

The Site and the Measuring System

After an exhaustive consideration of the sites available in the United States, North-West Minnesota was chosen for the main experiment. This is a very flat and sparsely populated area and hence eminently suitable for this sort of study. The actual site lay in the middle of the Southern edge of one of the 1 mile x 1 mile fields. Winds in the range West-North-East were unaffected by the buildings and other equipment (see figure 3). During the experimental period the whole area was surveyed from the air using both infra-red and ordinary photography.

A 32 metre tower was erected on the site and both profile and turbulence equipment were mounted on it. This included both two and three-axis sonic anemometers, quartz thermometers and a net radiometer (see Table 1). About 30 metres to the North-West of this tower was another net-radiometer (1 metre above the ground) and a soil heat flux plate. There were also two drag plates - one 40 metres to the North-North-West of the tower and the other 40 metres to the

North-North-East (see Figure 3). 40 metres to the North-East of the tower was a 4 metre mast with a three-axis sonic and a quartz thermometer on it. These instruments were used in the main series of observations and also in comparison runs to check the compatability of the Cardington and AFCRL types of turbulence probes.

Five Cardington probes were used during these studies - four of them relaying information to the ground by radio and one by cable. Although these instruments were basically the same as these used in the earlier work, they had been modified so that the horizontal wind direction could be measured; hence enabling the three-dimensional wind fluctuations to be fully specified. This was achieved by using a magnetic device to locate the orientation of the probe in the Earth's magnetic field and a second hot-wire head in the horizontal plane to measure the instantaneous angle between the probe and the wind. These instruments were operated from the tethering cable of a 1300 cu metre kite balloon. The heights of the packages above the ground were measured by theodolite and their motions monitored by tracking a radio-sonde attached to the cable just above the top probe. "On site" radio-sonde ascents were made every $1\frac{1}{2}$ hours during the day and at intervals of about 3 hours during the night.

All the data from the turbulence probes and the profile/energy balance equipment was sampled by the data-logging equipment installed in one of the trailers. This information was stored on magnetic tape and will initially be processed at Bedford (Massachusetts).

Outline of the Data obtained

The experiment received a major set-back very early in the period - the first balloon being completely destroyed by a thunderstorm which produced surface winds in excess of 70 mph. This meant that no measurements were made until 6 September. However some 76 hours of data had been gathered by the time the second balloon was lost on 21 September. This second loss appears to have been caused by a lightning strike.

Table 2 summarises the data that was gathered and gives an outline description of the predominant weather situations. All the times are in Central Daylight Time - this is six hours behind GMT. Each run consists of a series of $2\frac{1}{2}$ hour tapes. The interval between successive tapes was used to check the drag plates and re-orientate the sonic anemometers. It can be seen that although there are several periods which span the day to night transition only Runs 4 and 7 cover the reverse transition, and Run 7 is the only one to approach a full 24 hour coverage. Although a more comprehensive data set would obviously be preferable, the results should never the less provide very interesting case studies in both daytime and night time conditions and covering day to night transitions. The detailed analysis of the data should start early in 1974.

LIST OF FIGURES

LIST OF REFERENCES

1. Haugen D A, Kaimal J C and Bradley E F (1971)
"An experimental study of Reynold's stress and heat flux in the atmospheric surface layer". Quart Journal Royal Meteorological Society 97 168 - 180

2. Readings C J and Butler H E (1972)
"The measurement of atmospheric turbulence from a captive balloon."
Meteorological Magazine 101 286 - 298

TABLE I

Details of the Instrumentation on the 30 Metre Tower

Instrument	Heights (Metres)	Meteorological Parameters Measured
2-component sonic anemometer	1, 2, 4, 8 16, 24, and 32.	The horizontal wind components.
3-component sonic anemometer	4 and 32	All three wind components and temperatures.
Quartz Thermometer	0.5, 1, 2, 4 8, 16. 24 and 32	Mean Temperatures.
Net Radiometer	32	Net Radiation.
Pyrheliometer	32	Total Solar adiation.

TABLE II

Run Number	Start Time/Date	End Time/Date	Heights of the Balloon-borne Probes	Weather Situation
1	1514 CDT 6 Sept.	0501 CDT 7 Sept.	610m., 460m., 300m., 150m., and 60m	Anticyclonic - scattered cumulus
2	1217 CDT 10 Sept.	2242 CDT 10 Sept.	1220m., 910m., 610m., 300m., and 60m	Post-Cold Frontal-North-Westerlies. Clear Skies and High Winds
3	1510 CDT 11 Sept.	0146 CDT 12 Sept.	610m., 460m., 300m., 150m., and 60m	Anticyclonic - clear Skies
4	2315 CDT 13 Sept.	0939 CDT 14 Sept.	610m., 460m., 300m., 150m., and 60m	Cyclonic with low passing to the East of area - increasing cloud with rain at the end of the period
5	1622 CDT 15 Sept.	0014 CDT 16 Sept.	610m., 460m., 300m., 150m., and 60m	Anticyclonic with clear skies and light winds
6	1401 CDT 17 Sept.	2201 CDT 17 Sept.	1220m., 910m., 610m., 300m., and 150m	Pre-cold frontal passage - cirrus and light winds
7	0855 CDT 19 Sept.	0808 CDT 20 Sept.	610m., 460m., 300m., 150m., and 60m	Anticyclonic - the erosion of an inversion was observed.

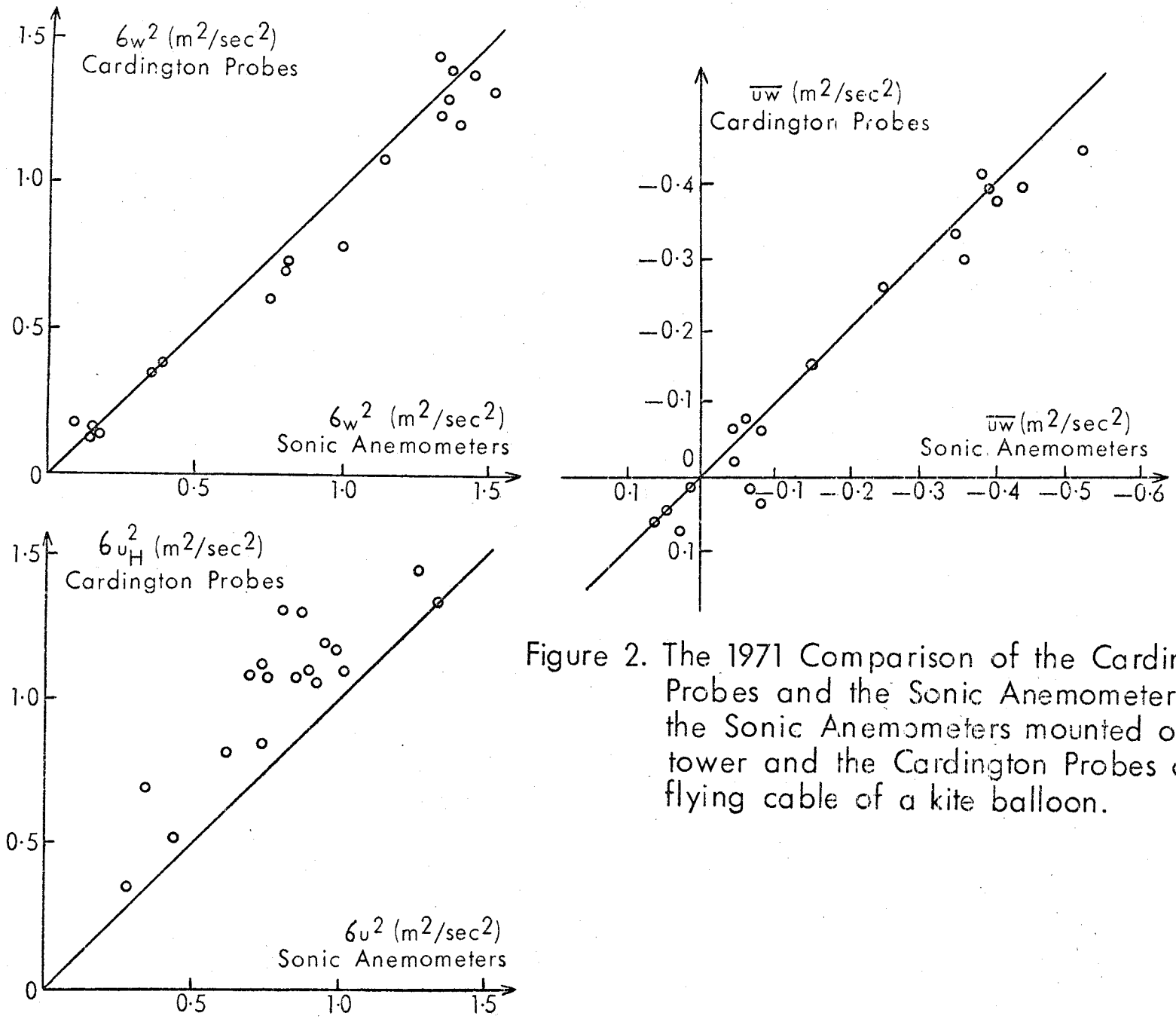


Figure 2. The 1971 Comparison of the Cardington Probes and the Sonic Anemometer with the Sonic Anemometers mounted on a tower and the Cardington Probes on the flying cable of a kite balloon.

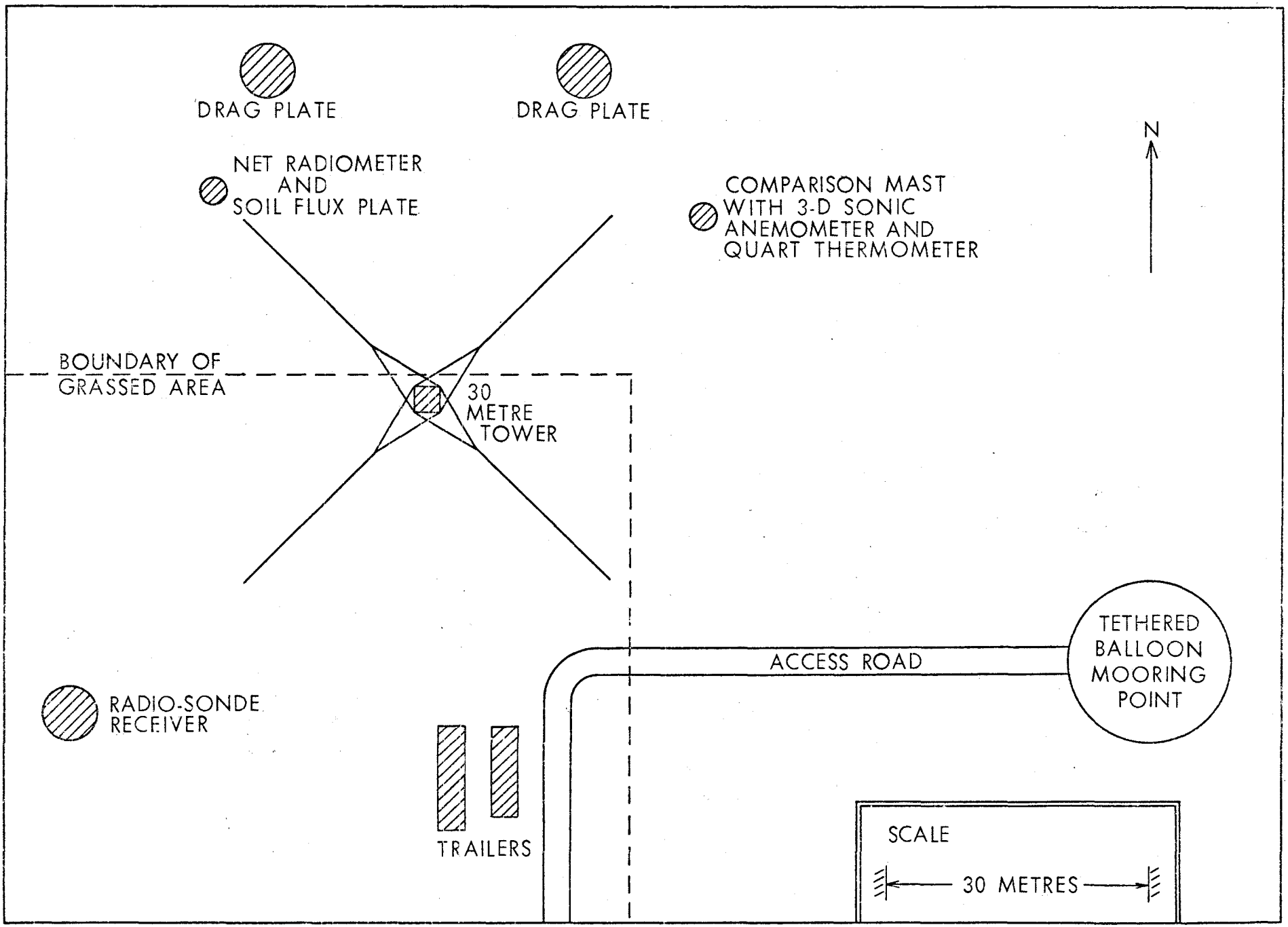
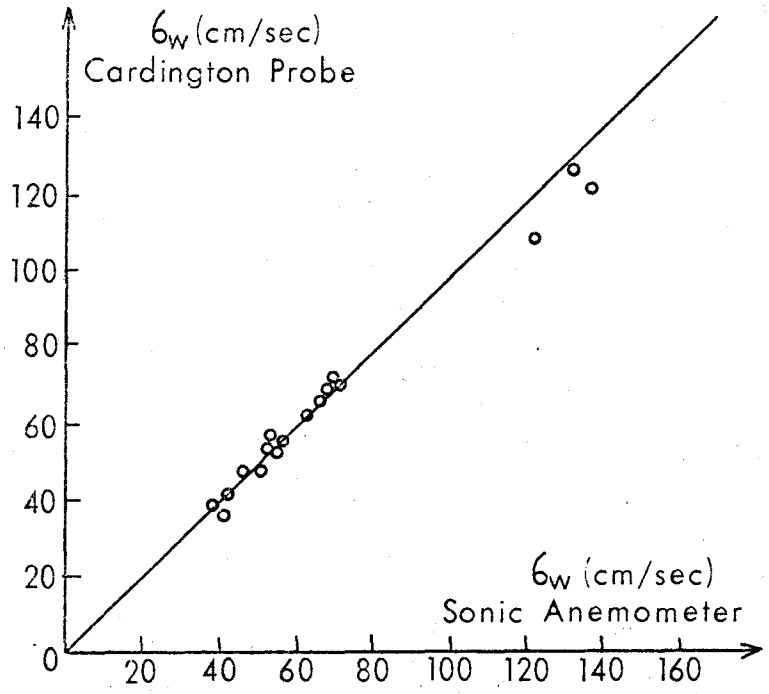
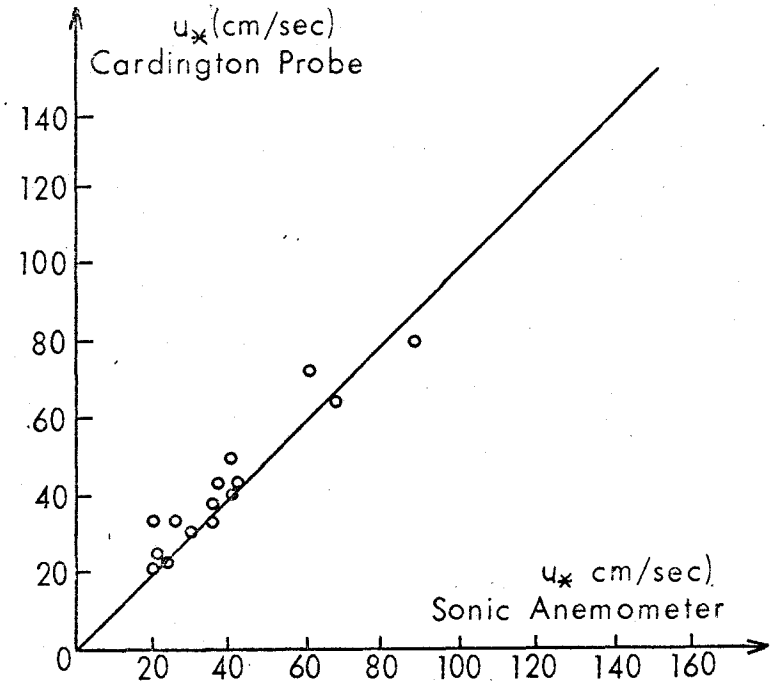


Figure 3 A Schematic Diagram of the Minnesota Site.





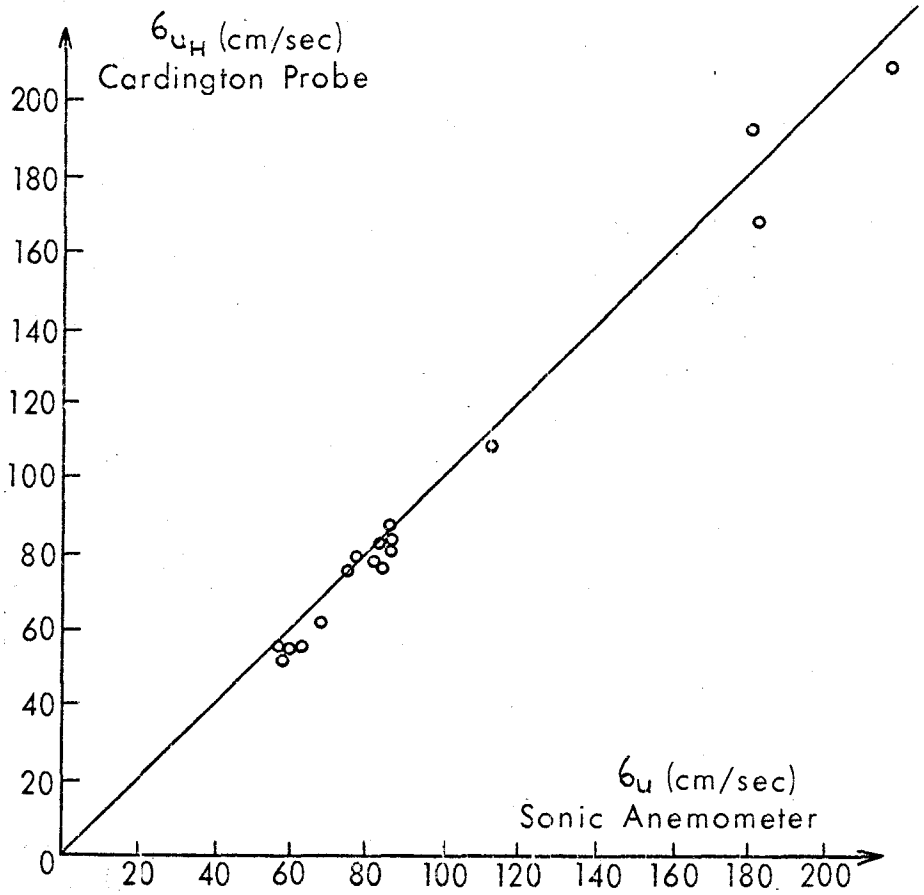


Figure 1-The 1969 Comparison of the Cardington Probe and a Sonic Anemometer with the instruments at 16 metres on fixed supports