Thermals in the Sub-Cloud Layer of the Atmosphere

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We shall regard thermals as certain volumes of air at a temperature higher than that of the surrounding air which are rising from the Earth's surface and, during their vertical motion, are partially mixed with the ambient air having a lower temperature. Thermals in the sub-cloud layer are known to be the principal energy source for glider flights. In this connection the Central Committee of the USSR Voluntary Society for Auxiliary Army, Air Force and Navy initiated in 1965–1968 experimental studies of thermals at different stations in the USSR to meet the requirements of glider activities. Some results of the studies were published [1, 2, 3], and data on thermal structure were presented in the author's report to the XIIth OSTIV Congress (USA, 1970) [2].
The results of the studies on the thermal characteristics in the sub-cloud layer of the atmosphere (100–1500 m) which may be of interest to glider pilots and meteorologists are presented in this paper.

Method

The studies were carried out with the aid of a light aircraft Yak-12 and «Blanik» gliders equipped with scientific instrumentation. The instrumentation included an electric meteorograph for recording air temperature, temperature pulsations, atmospheric pressure and moisture, as well as a set of instruments to measure the air velocity vertical component (vertical speed recorder, acceleration detectors and air-speed indicators).
The air vertical velocity was determined according to A. S. Dubov's well-known formula [4] for a longitudinal flight regime of an aircraft with elevator fixed:

$$U_y = V_y + b \, \Delta n_y$$

where U_y is air vertical velocity, m/sec.
V_y is vertical speed of the aircraft, m/sec.
b is a coefficient characterising the transfer function of the aircraft in m/sec;
Δn_y is the increment in vertical acceleration in fractions of "g".
For the recording of the vertical speed of the aircraft a vertical speed recorder was used (a vertical speed indicator modified for optical recording) with a time constant of 2 sec, which enabled long-period disturbances to be detected.
The short-period disturbances were determined by means of an acceleration detector having a time constant of about 0.15 sec. The error of measurement amounted to about 20% of the vertical air velocity in the range ±10 m/sec and to about 10% of the diameter of the thermal. The measurement technique enabled convective formations with diameters of 35 m or more to be detected.
The research flights were usually made at about noon when the convection was well developed. Vertical sounding of the atmosphere was carried out up to altitudes of 1.5–2.0 km or up to cloud base; horizontal probings were then made at fixed levels, of 100, 300, 500, 750, 1000 and 1500 m, each for a duration of 15 minutes. Simultaneously with the probings from an aircraft, pilot balloons were released at shorter intervals to observe the horizontal component of the wind velocity. Moreover, barograms of many glider flights made during major contests were used in order to estimate the thermal velocities.

Results

Let us consider the vertical distribution of the velocities and the diameters of the thermals. On the basis of experimental data obtained at different sites in the middle zone of the USSR the following conclusions can be drawn.
1. Two velocity maxima are usually observed: a surface maximum at altitudes of 300–500 m and a sub-cloud maximum about 100–300 m below the base of the cumulus clouds. On cloudless days only the surface maximum is observed.
2. The average diameters of thermals increase with altitude, the greatest values – of the order of hundreds of meters – being observed at altitudes of about 200–400 m above the surface velocity maximum.

The following examples will illustrate the above facts. Table 1 presents the vertical distribution of the velocities and of the diameters of thermals (Orel, July 1968) for cases in which the base of the cumulus clouds was higher than 1500 m or when there were no such clouds.
It can be seen from Table 1 that there is one surface velocity maximum in the layer 300–500 m and that the average

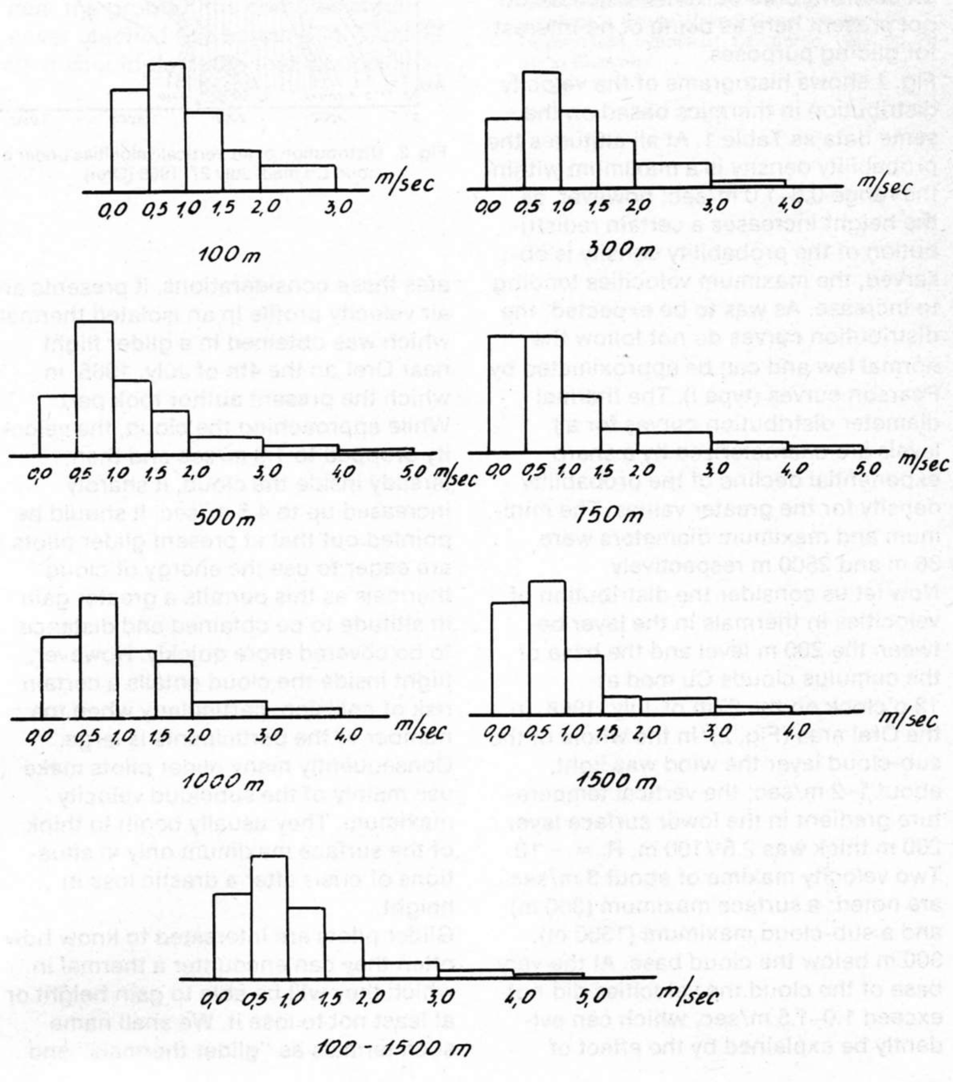

Fig. 1. Histograms of vertical velocity distribution in thermals.

Table 1

Altitude m	V_y m/sec	Dispersion m^2/sec^2	Skew Coefficient	Average Diameter m	Number of Observations
100	0.98	0.36	0.92	102	201
300	1.20	0.62	1.04	182	209
500	1.26	0.81	1.64	172	200
750	1.11	0.88	1.73	282	147
1000	1.18	0.65	1.64	232	132
1500	1.04	0.62	1.51	138	077
All	1.16	0.72	1.57	187	966

diameters of thermals increase with altitude, attaining their maxima somewhat higher, in the layer 750–1000 m. Taking into account the fact that crossings of thermals by aircraft were fortuitous, one concludes that coefficient k represents only quite roughly that part of the space which is occupied by the thermals as compared with the downward air currents (the corresponding part having downward air currents is found as the complement to the V_y equation. Then the relative part of the downward air currents in the whole layer under study is 0.60 and thus the thermal velocities must on the average be half as much as the velocities of the compensating downward air currents; this is actually substantiated by the data on downward air currents which we do not present here as being of no interest for gliding purposes.

Fig. 1 shows histograms of the velocity distribution in thermics based on the same data as Table 1. At all altitudes the probability density is a maximum within the range 0.5–1.0 m/sec; however, as the height increases a certain redistribution of the probability density is observed, the maximum velocities tending to increase. As was to be expected, the distribution curves do not follow the normal law and can be approximated by Pearson curves (type I). The thermal diameter distribution curves for all levels are characterized by a sharp exponential decline of the probability density for the greater values. The minimum and maximum diameters were 35 m and 2500 m respectively.

Now let us consider the distribution of velocities in thermals in the layer between the 200 m level and the base of the cumulus clouds Cu med at 12 o'clock on the 27th of July, 1968, in the Orel area (Fig. 2). In the whole of the sub-cloud layer the wind was light, about 1–2 m/sec; the vertical temperature gradient in the lower surface layer 200 m thick was 2.5°/100 m, $R_i = -10$. Two velocity maxima of about 3 m/sec are noted: a surface maximum (300 m) and a sub-cloud maximum (1300 m), 300 m below the cloud base. At the very base of the cloud the velocities did not exceed 1.0–1.5 m/sec, which can evidently be explained by the effect of compensating downward air currents and probably by the intracloud air circulation peculiarities. Fig. 3 substanti-

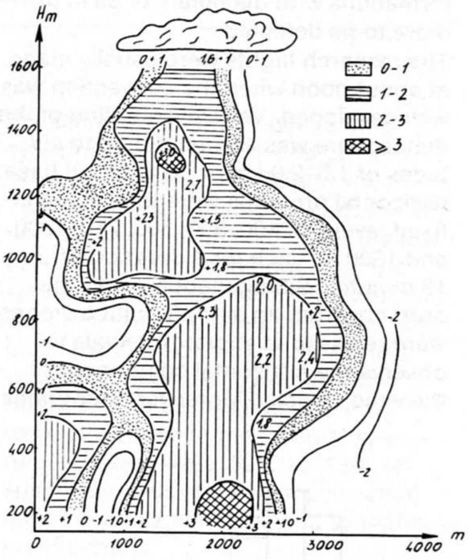

Fig. 2. Distribution of air vertical velocities under a cloud Cu med. July 27, 1968 (Orel).

ates these considerations. It presents an air velocity profile in an isolated thermal which was obtained in a glider flight near Orel on the 4th of July, 1965, in which the present author took part. While approaching the cloud, the velocity dropped to 1.3 m/sec and then, already inside the cloud, it sharply increased up to 4.5 m/sec. It should be pointed out that at present glider pilots are eager to use the energy of cloud thermals as this permits a greater gain in altitude to be obtained and distance to be covered more quickly. However, flight inside the cloud entails a certain risk of collision, particularly when the number of the participants is large. Consequently many glider pilots make use mainly of the subcloud velocity maximum. They usually begin to think of the surface maximum only in situations of crisis after a drastic loss in height.

Glider pilots are interested to know how often they can encounter a thermal in which they will be able to gain height or at least not to lose it. We shall name such termals as "glider thermals" and

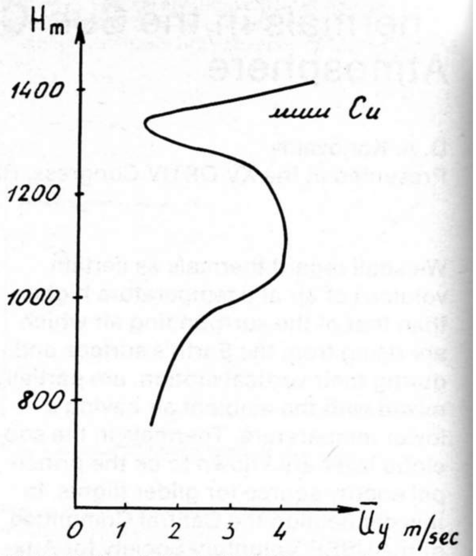

Fig. 3. Profile of air velocity inside an isolated thermal under a cumulus cloud, July 4, 1965 (Orel).

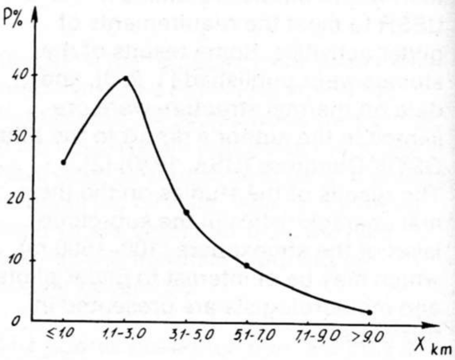

Fig. 4. Empirical probability (P, %) of encountering a "glider thermal" at distance X.

shall define them as having diameters not less than 150 m and velocities U_y not less than 1.0 m/sec. A relative rate of occurrence or empirical probability (P, %) of encountering a "glider thermal" at distance X classified according to a gradation scale is given in Fig. 4. The mean integral value of X is approximately 2.5 km, which means that in the sub-cloud layer under the conditions of well developed turbulence a glider thermal is on the average met every 2.5 km. Let us note that the ratio of the glider thermal extent to the total flight length is on the average only about 0.23 (see Table 1 where all the thermals wider than 35 m are taken account of). Diurnal variations of thermal velocities present a certain interest. In view of the fact that obtaining factual data for such a study with the aid of aircraft and glider, even if specially equipped, presents great difficulties, we used the data from processed barograms obtained in glider flight events on July 3–12, 1966, in Orel. Data for 7 days (220 barograms) were processed. Table 2 gives an idea of the diurnal variations of thermal velocities during the whole period of the event in the layer up to 2 km. The glider pilots evidently made use of the cloud thermals; therefore, these data should not be related to the sub-cloud layer alone.

Table 2

Hours	U_y m/sec			Number of Observations
	Mean	Maximum	Standard deviation	
11	2.2	4.9	0.4	202
12	2.6	5.7	0.2	1156
13	3.0	6.4	0.2	1417
14	2.9	6.0	0.2	1060
15	2.6	5.2	0.3	448
16	2.3	4.8	0.3	215
17	2.1	4.1	0.2	84
18	1.9	3.6	0.4	75

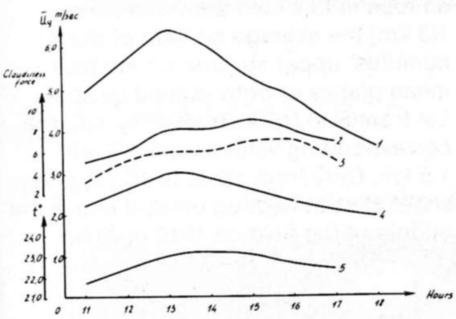

Fig. 5. Averaged for 7 days of July (Orel, 1966) diurnal variations of velocities in thermals, (1 – maximum velocities; 4 – mean velocities), of cloudiness (2 – overall; 3 – in the lower region), of air temperature at the Earth's surface in a meteorological cabin (5).

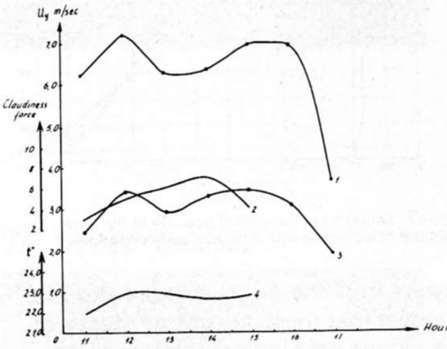

Fig. 6. Diurnal variations of the velocities in thermal (1 – maximum values, 3 – mean values), of cloudiness (2) and of air temperature at the Earth's surface in a meteorological cabin (4) on the 4th of July (Orel, 1966).

The maximum thermal velocity was observed at 13–14 h. These were also the hours of the maximum air heating near the ground; the cumulus cloud cover reached five tenths (Fig. 5, curve 3). It should be noted that a considerable increase in cloudiness diminishes warming up of the underlayer and, other things being equal, reduces the velocities in thermals. Diurnal velocity variations on the 4th of July may serve as an example (Fig. 6). Two velocity maxima, at 12 h and 15 h, are well pronounced (curves 1 and 3). An increase in cloudiness from three tenths at 11 h to seven tenths at 14 h (curve 2) may account for the decrease in velocities at 13–14 h.

The subsequent diminishing of cloudiness to four tenths at 15 h caused the occurrence of the second velocity maximum. The air temperature dependence at the Earth's surface substantiates the considerations set forth.

In conclusion the author wishes to thank all the persons and organizations who contributed to this study and to express a hope that the data presented in this paper will prove useful for practical gliding objectives.

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