On the Structure of Thermals

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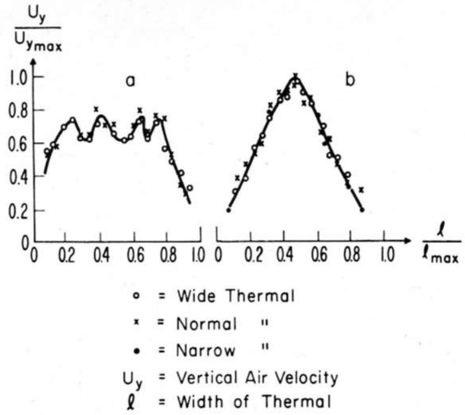

Fig. 1. Vertical velocity profiles of thermal types «a» and «b», based on 377 traverses. Type «a» has multiple, type «b» single core. Cross-sections are averaged and normalized.

The article discusses the structure of thermals as revealed by experiments in the atmosphere. Two basic types of thermals were discovered, one with a single core of maximum vertical velocity and one with several cores. Averaged, dimensionless cross-sections are plotted. Turbulent characteristics of the two types are discussed and the frequency of maximal velocities and dimensions derived. It is shown that the frequency of thermal types is related to the vertical gradient of air temperature in the lowest 300 m.

Thermals are rather poorly studied formations in the boundary layer of the atmosphere originating from the action of many meteorological and other factors. There is substantial literature on laboratory simulation of thermals aimed at revealing the mechanism of their formation, structure, and evolution. The «convention bubbles» described by Scorer [5] are widely known. Similar results were obtained by Woodward [6] and many other authors. The laboratory studies are, however, conducted under idealized conditions and cannot account for the shapes, sizes, and velocities of the actual thermals. Atmospheric studies are exceedingly rare; nevertheless, the research conducted by Woodward [7] and Chernov [3] with gliders needs mention. Due to the scarcity of data Woodward could not classify the thermals or determine the frequency of their sizes and velocities. Only Chernov [3] attempted to classify and characterize the thermals. The convection bubbles of a smaller size were studied by recording the pulsations of temperature and vertical accelerations from a powered aircraft [1] or a glider [4]. The data of the experimental studies of thermals in the boundary layer conducted by the Main Geophysical Observatory in Leningrad may prove to be an interesting contribution to this field.

The studies were conducted around the town of Rapla, Estonian USSR, and the city of Oryol in the summer of 1967 and 1968 by the Blanik L-13 glider and the Yak-12 light, single-engined aircraft, carrying scientific equipment such as an electro-meteorograph that recorded air temperature, temperature pulsations, humidity variations, and special equipment for measuring the vertical velocity of the air, consisting of a variograph, accelerometer, and air speed indicator.

The vertical component was calculated by the Dubov formula (2), which in its dimensional form is as follows:

$$U_y = V_y + K a_y, \text{ where} \qquad (1)$$

U_y = vertical air velocity, in m/sec
V_y = vertical velocity of the vehicle, in m/sec
a_y = vertical acceleration of the vehicle, in m/sec²
K = factor depending on the vehicle, in sec.

$$\text{Here } K = \frac{2m}{(\partial C_L/\partial \alpha)\rho V S}, \text{ and}$$

m = mass of aircraft
C_L = lift coefficient
α = angle of attack
ρ = air density
V = flight velocity
S = a representative area.

The aircraft vertical velocity was recorded by a recording variometer (variograph) in which the manometric box was rigidly connected to a mirror which was illuminated by an electric bulb; the beam reflected by the mirror traced a line on moving photographic paper tape. Its time constant was 2 sec; the calibration characteristics were linear within ±10 m/sec. The total reduced error was about 20%.

For the analysis of thermals, those cases were selected where the cross-sections were made through or close to the center.

These thermals were first marked by a glider or a group of gliders. The marking was used in crossing the thermals along a straight line close to a diameter of the thermal. Small convective formations with horizontal dimensions below 150 m were rejected. The sections were made by a Yak-12 at altitudes of 300 to 1,500 m.

By the nature of the vertical velocity distribution along the sections, two basic types of thermals were found (see fig. 1): type «a» containing several maxima with depressions in between and type «b» with one pronounced maximum. Thermals with two pronounced maxima (two-headed thermals) were occasionally found, which seems to be the result of a fusion of two «b» thermals. Also, there are thermals without a pronounced maximum; but they, as a rule, have low velocity (below 1 m/sec) and can hardly be marked by a glider. Therefore, only those «a» and «b» type thermals will be discussed for which there are abundant statistical data available. They are especially attractive for weathermen, glider pilots, and glider designers.

In the classification proposed by Chernov [3] all thermals were divided into three classes, namely:

(1) «narrow thermals»

$$\left(\frac{l_{max}}{U_{y_{max}}} \leqslant 100 \text{ sec}\right),$$

(2) «normal thermals»

$$\left(100 \text{ sec} < \frac{l_{max}}{U_{y_{max}}} < 500 \text{ sec}\right), \text{ and}$$

(3) «wide thermals»

$$\left(\frac{l_{max}}{U_{y_{max}}} \geqslant 500 \text{ sec}\right).$$

Here l_{max} is the maximum thermal diameter (with positive vertical air velocity), and $U_{y_{max}}$ is the maximum vertical air velocity in the thermal. Then, for each of the three classes, dimensionless sections were made for the two types mentioned above, with the ratio

$$\frac{U_y}{U_{y_{max}}}$$

along the y-axis (vertical) and

$$\frac{l}{l_{max}}$$

along the x-axis (horizontal). After averaging in each of the three classes, the points were plotted (fig. 1). The good fit for the three classes demonstrates that the average sections are widely applicable.

Chernov studied a total of 114 thermals and found in 76% of all cases a so-called «nucleus» of the ascending air flow, i.e., an almost constant value of the vertical velocity along the x-axis near the center, except for small variations (no peaks). This seems to correspond to type «a». Because Chernov used rather simple equipment to find the vertical air velocity (a standard variometer recording through a wire potentiometer, time constant over 5 sec) he failed to detect the peaked thermals of type «b»; the peaks were «smoothed» out by the inertia of the instruments, and therefore he assumed the existence of the central «nucleus» with a flat vertical velocity maximum.

It might be useful to consider the statistical characteristics of these types of thermals, such as the frequency of maximal dimensions and velocities, the gradient of the velocity increase from the periphery to the center, and turbulent characteristics in various parts of thermal sections.

Figures 2 and 3 represent the frequency of occurrence of maximal velocities and dimensions in the two classes. The solid curves denote type «a» (286 cases), the dashed curves, type «b» (157 cases). The former are evidently more powerful in both vertical velocities and dimensions. As seen from figure 1, the maximum dimensionless, horizontal gradient of vertical velocity in type «a»

$$\left(\frac{\partial \bar{u}}{\partial \bar{l}} \approx 2.5\text{–}3.0\right)$$

is higher than in type «b»

$$\left(\frac{\partial \bar{u}}{\partial \bar{l}} \approx 2.0\right).$$

Here

$$u = \frac{u_y}{u_{y_{max}}}$$

is the vertical velocity in a thermal normed for its maximum value.

$$\bar{l} = \frac{l}{l_{max}}$$

is the distance from the thermal boundary normed for the dimension of the thermal.

This fact also explains the higher values of vertical accelerations (load factor $\overline{\Delta n_y}$) encountered at the periphery of type «a»

($\overline{\Delta n_y} \approx 0.15\text{–}0.20$ g, $\Delta n_{y_{max}} = 0.55$ g)

than in type «b»

($\overline{\Delta n_y} \approx 0.10\text{–}0.15$ g, $\Delta n_{y_{max}} \approx 0.40$ g).

In the center, the average values of the load factors are approximately equal,

$\overline{\Delta n_y} \approx 0.10\text{–}0.15$ g.

This in turn implies that the zones of high turbulence are observed at the outer rims of type «a», while type «b» is more uniform and generally less turbulent. These data can be used in the selection and calculation of glider parameters and by pilots in their flight technique.

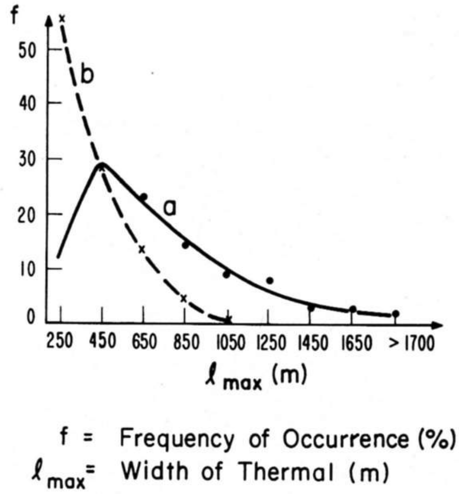

Fig. 2. Relative frequency (%) of maximum updrafts (m/sec) in thermals of type «a» (238 cases) and «b» (139 cases).

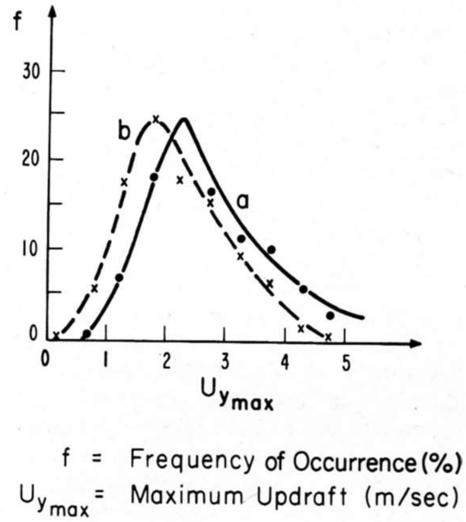

Fig. 3. Relative frequency (%) of maximum thermal diameters (m) as defined by vertical air velocity $U_\gamma = 0$.

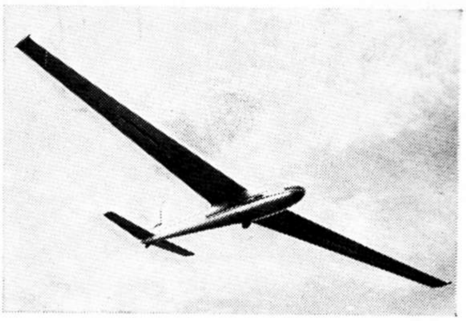

Fig. 4. Blanik L-13 two-seater sailplane used in this project.

An attempt was made to use the data for six days in July, 1968, over Oryol to relate the frequency of thermal types to the vertical gradient of air temperature, γ, measured by the Yak-12 aircraft in the lower 300 m layer of the atmosphere (see table I).

Table I

Date July, 1968	γ (°/100 m) 0–300 m	Type «a» Number of cases	Frequency %	Type «b» Number of cases	Frequency %
17	–0.65	33	45	40	55
27	–0.77	20	50	20	50
26	–1.17	77	62	48	38
18	–1.30	20	71	8	29
19	–1.47	55	78	15	22
24	–1.87	33	81	8	19
Total		238		139	

From table I it is seen that at $\gamma \approx -0.8$°/100 m both types occur with the same frequency. Starting at $|\gamma| > 0.8$°/100 m type «a» is prevalent and increases with γ, while at $|\gamma| < 0.8$°/100 m type «b» is prevalent. At this time we cannot state explicitly if it is precisely at $\gamma = -0.8$°/100 m that a balance between the two types is observed.

It is, however, evident that frequency of type «a» increases with $|\gamma|$, and that of type «b» decreases. The latter seems to represent the original element of convection. When the convective conditions improve, these thermals may merge to form type «a».

Table I may enable us to forecast in principle the types of thermals and their average characteristics by the vertical air temperature gradient in the lowest 300 m layer, which is important for cross-country flights of gliders. It should be noted that the data of figures 1, 2, 3, and table I were obtained at wind velocities as low as 2–5 m/sec. Strong winds are unfavourable for the formation and evolution of these thermals. Consequently, table I is only useful at wind velocities up to 5 m/sec.

References

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