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1963

SovietRxiv

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Abstract

Full Text

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VERTICAL MOTIONS IN THUNDERSTORM CLOUDS

(Presented by Academician E. K. Fedorov, 13 XI 1963)

GEOPHYSICS

In 1959–1962, at the Central Aerological Observatory, investigations were carried out of turbulence in powerful cumulus and cumulonimbus clouds. For these purposes a TU-104 aircraft was used, equipped with scientific apparatus, including instruments that made it possible to record aircraft overloads, flight speed, changes in pitch angles, and also the integral of the aircraft overloads. The apparatus used is described in (^{5}). In addition, the aircraft was equipped with a radar installation, which made it possible, from the illumination on the screen of the cathode-ray tube, to see the position of the aircraft in space relative to the center of the echo formed by the precipitation zone inside cumulonimbus clouds. Flight experiments were carried out at different levels around and above powerful cumulus and cumulonimbus clouds, as well as inside these clouds.

Fig. 1. Distribution of root-mean-square values of the velocities of vertical air motions in a cumulonimbus cloud

The accumulated measurement materials made it possible to calculate the root-mean-square values of the velocity of vertical gusts of air in the aircraft-buffeting zones $\sigma(W)$, the scale of turbulent disturbances L, and the coefficient of turbulence K. The calculations of the velocity of vertical gusts of air and of the coefficient of turbulence were carried out according to computational schemes proposed by A. S. Dubov (^{1}). In particular,

$$W = A\Delta n(t) + B\int_0^t \Delta n(t)\,dt + C\varphi; \tag{1}$$

$$K = \frac{V\overline{\Delta\tau}\,|\overline{w}|}{2}; \tag{2}$$

Fig. 2. Distribution of the sizes of turbulent disturbances in a cumulonimbus cloud

Figure 2: Fig. 2. Distribution of the sizes of turbulent disturbances in a cumulonimbus cloud

$$L = V\Delta\tau, \tag{3}$$

where Δn is the aircraft overload in fractions of g (acceleration of gravity); φ is the–

of the pitch angle; t is time; V is the aircraft airspeed; $\Delta\tau$ is the time during which the sign (direction) of the velocity of the vertical gust of air is preserved; A, B, and C are numerical coefficients depending on the aerodynamic characteristics and flight regime of the aircraft. Some preliminary results of the investigations are set forth in (^{2}).

Fig. 2. Distribution of the sizes of turbulent disturbances in a cumulonimbus cloud

At the present time, experimental material has been accumulated and processed which already makes it possible to construct an averaged picture of the distribution of turbulence parameters in cumulonimbus clouds, a picture very useful in calculations for introducing various kinds of agents into powerful cumulus and cumulonimbus clouds with the aim of artificially regulating their development, and also in selecting flight levels for aircraft and ensuring flight safety.

First of all let us consider the distribution of the velocities of disordered vertical motions of the air. Figure 1 shows isotachs characterizing the distribution of root-mean-square values of the velocities of vertical gusts in the upper part of a cumulonimbus cloud with an anvil (Cb incus), for which the largest amount of data was obtained during penetrations into the cloud. A cloud in this stage usually reaches the limit of its vertical development and subsequently begins to dissipate (^{3,4}). In this stage it gives the most abundant precipitation, and thunderstorm phenomena occur. The horizontal dimensions of cumulonimbus clouds vary over wide limits–from several kilometers to 100 km and more–but in 70% of cases they were less than, or about, 40 km. The level of the upper boundary of the cumulonimbus cloud is taken as the zero height.

It is evident from Fig. 1 that the isolines of $\sigma(W)$ form a "core"in the axial part of the cloud, in which the root-mean-square velocity of the vertical motions of the air exceeds 7 m/sec. It should also be noted that the isotach of 5 m/sec borders the zone that gives the most intense precipitation echo inside the cloud on the radar screen. From the center of the "core" the velocities decrease, and near the outer boundary of the cloud they do not exceed 2 m/sec. Outside the cloud, $\sigma(W) \leq 1$ m/sec. During flights at altitudes of 300-400 m above the upper edge of the cloud, aircraft bumpiness is usually not observed ($\sigma(W) < 0.5$ m/sec).

Fig. 3. Distribution of mean values of the coefficient of turbulent mixing in a cumulonimbus cloud

Figure 3: Fig. 3. Distribution of mean values of the coefficient of turbulent mixing in a cumulonimbus cloud

In the stage of vigorous development of a cumulonimbus cloud (Cb calvus), the cloudless zone immediately adjoining the cloud is more turbulent than in the Cb incus zone (^{3}).

As observations have shown, the dimensions of the "core" with very large values of $\sigma(W)$ fluctuate in time, and the "core" itself shifts along the axis of the cumulonimbus cloud. As the cloud develops, this "core" rises toward its upper part and assumes its highest position when the cloud reaches

stage Cb incus. As the Cb cloud breaks up and settles, this core "slides" closer to its lower part.

As the scale of turbulent disturbances we have taken the distance (in meters) along the horizontal levels over which the direction of the velocity of vertical gusts of air is preserved. Fig. 2 shows the distribution of disturbance sizes in Cb incus. As can be seen, the sizes of the disturbances decrease in the direction toward the axial line of the cumulonimbus cloud. Here, too, in the developing dome of the upper part of the cumulonimbus cloud they are less than 200 m.

Fig. 3. Distribution of mean values of the coefficient of turbulent mixing in a cumulonimbus cloud

Let us now consider the distribution of the values of the coefficient of turbulent mixing. In Fig. 3, on which isolines K are drawn, it is seen that above the upper boundary of the cloud and when approaching directly the leading edge of the anvil the mean value of the coefficient of turbulent mixing is on average 70—80 m^2/sec; upon entering the cloud its value increases to 100 m^2/sec at the outer boundary, but inside the cloud, in the "core" zone with high velocities of disordered vertical motions of air, it reaches on average 300—400 m^2/sec.

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Received
10 XI 1962

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