Theory of Soaring Flight

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Part 7—METEOROLOGY OF GUSTS

IN order to form an idea of the chances of dynamic soaring by birds or manned sailplanes, it would be necessary to learn something about the magnitudes of gusts actually occurring in the atmosphere. S. P. Langley was perhaps the first to explore the "internal structure of the wind," as he called it, as early as 1893. Since then much experimental material has been collected. Some investigators have noted a marked increase of turbulence when the average wind speed exceeded a certain threshold such as about 15 ft./sec., though the threshold value differs for topographically different locations. There is reason to believe that there exists some typical Reynolds' number at which a transition from laminar to turbulent wind texture takes place, but the length element characteristic of the ground roughness entering into this Reynolds' number depends on the nature of the environment. Temperature gradients may also have an influence on the air mass exchange and hence on friction and turbulence.

The search for pronounced periodicity and definite frequencies in the free wind records has been rather futile, or at least inconclusive. Robitzsch has pointed out, however, that the random wealth of wind speed records does exhibit a certain repetition of wave traits; for instance, the common occurrence of a forerunner and an aftermath of a main gust surge. The intervals between major peaks are usually of the order of several seconds, but the coarser fluctuations of the "average" wind usually extend over many seconds or even minutes. These characteristics vary a great deal with climate and topography. For conditions at the levels above the ground where anemometric records are usually taken and under the meteorological conditions prevailing in central Europe, the following rough rules have been ferreted out from many records:

The fluctuation of the wind speeds in gusts is essentially proportional to the average wind speed; the extreme peaks reach almost twice the average values; the extreme lulls rarely drop below 20% of it. The average gust amplitudes are about ¾ of the extreme ones. The most frequent amplitudes are still less.

The fluctuations of the wind direction are more difficult to evaluate in view of the imperfection of most weather vane instruments and of the influence of surrounding wind obstacles. Most common weather vanes are insufficiently damped. Their own inertia causes them to show directions which may greatly differ from the actual wind directions at a given instant during a veering gust. This was the subject of an investigation carried out by the Netherland's Rijks-Studie-Dienst voor de Luchtvaart and described in their report of 1921. The best wind vane would be one having a high aspect ratio, a symmetrical wing profile of smooth properties. Let such a vane of wing surface area S and radius r from pivot to center of pressure, and moment of inertia J about its pivot be deflected by an error angle ψ against the impinging wind of velocity v and density ρ. The instantaneous transverse velocity of the swinging vane would be indicated by $r\frac{d\psi}{dt}$ and the effective angle of attack is $\psi + r\frac{d\psi}{dt}v$. Now let the lift (side force) coefficient be proportional to the angle of attack, viz. $\frac{1}{2}\rho v^2 m\left(\psi + \frac{r\,d\psi}{v\,dt}\right)$ where $m = \frac{dCr}{d\alpha}$ is the slope of the lift coefficient curve, (neglecting possible acceleration derivatives). With these assumptions, the dynamic equation of the rotation of the vane reads

$$J\frac{d^2\psi}{dt^2} = -\frac{1}{2}\rho v^2\left(\psi + \frac{r\frac{d\psi}{dt}}{v}\right)Sr$$

hence

$$\frac{d^2\psi}{dt^2} + Avr^2\frac{d\psi}{dt} + Av^2r\psi = 0$$

where $A = \frac{1}{2}\rho mS/J$.

The condition for the error angle ψ to subside, (critically) damped, is $Ar^3 = 4$ or $J/\rho Sr^3 (\leq) \frac{m}{8}$. Considering that, for a fair aspect ratio, m is of the order of 4, then $\frac{J}{\rho Sr^3} (<) \frac{1}{2}$

To obtain an idea of how light the vane structure