Theory of Soaring Flight

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Part 8

WIND LAYERS

When we spoke of gusts, we meant that aircraft flew through air masses which as a whole were under the influence of extraneous accelerative forces. This is not the only way the aircraft can encounter varying relative velocities. By virtue of its own flight movement, it experiences similar dynamic soaring effects when flying through regions of different winds which can be stationary with respect to the ground.

Soaring in stationary wind layers differs from soaring in gusts by the fact that the pilot has the choice of the depth and frequency of penetration into the different layers. The power any craft can wrest from such a constellation depends on the maneuver and how often the pilot cares to commute from one side of the boundary to the other. The basic idea is simply to fly from one layer slant into the other and vice-versa, but always in such a direction that the transition is felt as a head-on gust. The inertia force will then furnish a reserve which may be used up for the turn-around to complete the cycle in the opposite direction.

In reality, the boundary between two regions of different winds will seldom be sharp. Yet it is useful to consider two extreme cases, viz. that of a thin boundary region in which the transition is quickly made during a very short part of the cycle; and that of a relatively gentle gradient extending over a substantial depth which it takes the aircraft a considerable time to traverse. The layers can be superimposed above one another or adjacent lying alongside each other.

Consider for instance, two adjacent regions separated by a sharply defined border running East and West. In the region to the North of the border there is an East wind of speed w; in the region to the South of the border a West wind w. An airplane is headed West while flying at airspeed v just to the North of and parallel to the border, hence at ground speed $v + w$. Eventually this airplane, at a very acute angle, crosses the border and penetrates into the Southern region where, by virtue of its own inertia, it finds itself with an airspeed $v + 2w$ hence an excess of 2w over what it needs. It climbs to convert the gain into potential energy of altitude until the airspeed has dropped to v again and the ground speed to v-w. Now it turns 180°, keeping its airspeed constant. The ground speed is now -v-w. Next it recrosses over into the Northern region only to find its airspeed again increased by 2w. It climbs once more and makes another 180° turn ready to resume the cycle. The gain is of the same nature as that experienced when turning between gusts and lulls. Similarly, the condition which would suffice for sustained flight is $\frac{\Delta w}{T} = \frac{1}{2} g\varepsilon \operatorname{Cos} \delta$

if T is the time required to complete a cycle between layers differing by Δw in wind speed with an aircraft having an effective glide ratio $\varepsilon = \frac{D}{L}$, while δ is the (small) angle at which the border is crossed. A slight penalty is of course paid in that the centrifugal force evoked in the turns will deteriorate the effective glide ratio somewhat.

It is obvious that it is easier for a small bird to take advantage of wind boundaries near wind obstacles than it would for a large man-carrying craft. To change over every 6 seconds, for instance, between a free wind of say 12 mph and the lee side of buildings, trees or dunes must amply suffice to keep swallows and swifts aloft without batting a wing. Indeed, we frequently see these agile birds execute just this type of maneuver. They can be readily observed dashing down wind into the wind shade of the wind obstacle, turn and head out into the open, zooming up high without any apparent effort.

The flight through a stationary wind gradient $T = \frac{dw}{dx}$ at an angle $90° - \delta$ can be treated in the same manner by considering the velocity change $dw \operatorname{Sin}\delta$ encountered in a time differential dt. The apparent thrust gain is then $Tv\operatorname{Sin}\delta\operatorname{Cos}\delta$ per unit of weight. To suffice for sustained flight without any effort, the wind gradient must be sufficient to satisfy the equation

$$Tv \operatorname{Sin} \delta \operatorname{Cos} \delta = g\varepsilon$$

or

$$Tv \operatorname{Sin} 2\delta = 2g\varepsilon$$

The best course is at 45° to the gradient. For this the wind gradient required for sustained flight is

$$T = \frac{2g\varepsilon}{v}$$

Note that, for example, for $\varepsilon = \frac{1}{10}$ and $V = 32$ ft./sec. (22 mph), $T = .2$ seconds, or 1 mph in 7.3 ft. This