from aboard the moving aircraft along any particular direction defined with reference to the aircraft.

An aircraft free to maneuver in gusty air represents an excellent technical example of a system in which the conventional orientation with respect to the direction of gravity so familiar to earth bound creatures fails. Indeed here the equivalence of gravity and inertia becomes technically manifest; it becomes spectacularly impressive when the aircraft is deliberately so flown that the inertia forces experienced aboard deliver useful energy to it.

The description of the mechanism of certain dynamic manuevers, especially those in which the longitudinal equilibrium is not much disturbed, is simplified by reference to coordinate system flying with the aircraft and by consideration of the inertia forces as though they constituted an apparent modification of gravity. The energy gain (E, per unit mass) then appears as the time integral of the product of flight velocity (v) and of the apparent longitudinal component ($\dot{v}$) of the acceleration prevailing in the ambient atmosphere: $E = \int v \cdot dt$. Hence to wrest much energy from the gusts it is necessary to mind and parry them rather than to just let them pass. The net gain may be less than the gross gain, namely in all instances where the evocation of centrifugal forces require the creation of extra lift to balance them and this extra lift induces extra drag which requires extra thrust to make up for it. In mathematical terms the dynamic equilibrium in such maneuvers conforms to the expression:

$$g(\cos \gamma_x + E \cos \gamma_z) + \dot{w} (\cos \beta_x - \varepsilon \cos \beta_z) - \dot{v} + \varepsilon \omega_y v = 0$$

where $\gamma$ is the angle of gravity and $\beta$ the angle of the wind acceleration ($\dot{w}$) with respect to the longitudinal axis (x) and the vertical axis (z) respectively of the aircraft, while $\varepsilon$ is the glide ratio (D/L) and $\omega_y$ the angular velocity component along the flight path about the transverse axis. As far as the energy gain over an extended period is concerned the first and penultimate terms contribute nothing as they must average zero and of the remainder:

$$E \int (-g\varepsilon \cos \gamma_z + \dot{w} \cos \beta_z - E \dot{w} \cos \beta_z + \varepsilon \omega_y v)\, dt$$

of which the second term is the most fruitful and the last term the centrifugal penalty of the maneuver.

There is a significant difference between horizontal and vertical components of gust utilization. Flying on the average horizontally any horizontal inertia effect works as thrust with the D/L advantage over lift; any vertical intertia component works on lift directly. The former is therefore so much more economical. In other words: Of all wind currents it is the vertical velocity components and the horizontal acceleration component which are utilizable for soaring flight (the former statically, the latter dynamically) but not vice versa.

*The "Knoller-Betz" Effect*

The above statement would seem at first glance difficult to reconcile with a phenomenon which was independently pointed out by Professor Knoller in Vienna and Dr. Betz in Goettingen, and which deals with the gain of energy from vertical wind pulsations. Upon closer scrutiny, however, the mechanism of this phenomenon will be seen to be a sort of periodic static soaring flight pulsation which really utilizes the vertical velocity component and not the acceleration component. This is then a pseudo-dynamic effect; its discussion would therefore more aptly have been relegated to the previous chapter but because of its resemblance to other oscillation problems this discussion has been inserted here to precede the study of the real dynamic maneuvers.

In any region where the average wind may be horizontal the instantaneous wind at any one station may pulsate up and down. This is ample evidence of such vertical waves of long wave length and low frequency on days with cloud streets and other regularly spaced cloud formations, to be discussed in a later chapter. Smaller and faster vertical pulsations, however, may well escape our observation as they would merely manifest themselves in slight oscillations of the wind inclination.

Obviously all a flier would have to do to take advantage of such vertical wind pulsations is to make more lift while the going is good and less while it is not. Thus while soaring statically he would accumulate an energy reserve either in the form of excess speed or excess altitude, from which he would borrow while passing through the descending current phase, much like he would in any strategy of static soaring flight through locally limited thermals.

Betz distinguished two extreme techniques of utilizing these vertical pulsations: one he called the simplest, the other the best. The simplest case is that of an aircraft having neutral stability in pitch, flying through the pulsating air without appreciably changing its attitude and flight path so that the angle of attack is the only aerodynamically significant parameter that varies. Its oscillation amplitude is defined by the ratio of the vertical wind speed component amplitude to the flight speed. Such an oscillation is accompanied by a reduction of the average induced drag because during the up-draft phase the lift is inclined forward and large, whereas during the down draft phase the lift though leaning backwards is small. The gain increases at the rate of the square of the pulsation amplitude. It is of the order of $\Delta C_D =$

(*Continued on page* 10)