Figure 6-4. A wave cloud oriented parallel to the upper-level flow looking west from Dillon, Colorado (photograph ©, R. Reinking).

Figure 6-5a. Circular lenticular clouds produced by a pair of eddies in the lee of an isolated mountain peak near Nederland, Colorado (photograph ©, 1990, P. Neiman).

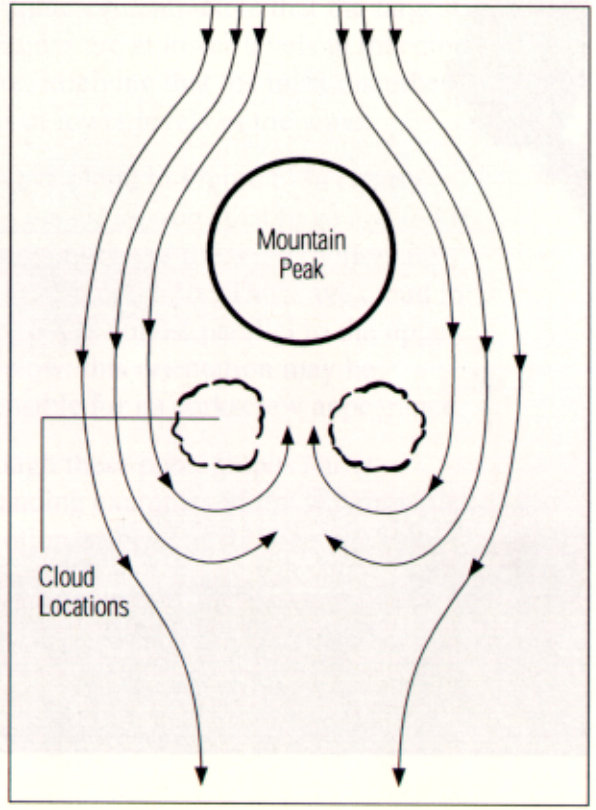

Figure 6-5b.

6.2 *SMALLER-SCALE FLOWS*

In the previous section, we reviewed the wave clouds and the flow patterns associated with waves that result from the large-scale movement of an air mass over a mountain range. Now we present photographs of clouds resulting from air motion over and around individual (or isolated) mountain peaks.

Figure 6-5a shows the results of flow over and around a set of higher peaks (to the left in the photograph). Various interpretations of these spectacular cloud forms are possible. One of these is shown in Figure 6-5b in which the pair of circular lenticular clouds represent a pair of eddies initiated by flow around these peaks. Another interpretation is that these lenticulars result from greater amplitude of the larger-scale mountain wave directly downwind of the peaks. Note that there are indications of disturbances in the lower portions of this cloud field, whereas the cloud appears smooth at higher levels. Significantly, the clear air below the central region of these clouds may contain intense small-scale vortices that could be hazardous for aircraft penetrating the area.

Figure 6-6 is a stunning photograph of a lenticular cloud that resulted from the strong flow around Mt. McKinley, Alaska.

Figure 6-6. A three-dimensional lenticular cloud that has developed in the strong flow around Mt. McKinley, Alaska (photograph ©, 1981, B. Martner).

In this case, the wind flowing around the mountain developed a stationary eddy in the lee of the peak. Although this cloud appears quite smooth and laminar, the shear zones created by such flow perturbations have the potential to produce destructive turbulence.

Figure 6-7. A field of circular lenticular clouds that have developed in the complex flow around a number of mountain peaks in Mt. McKinley National Park, Alaska (photograph ©, 1979, B. Martner).

If such turbulence were occurring at the time of this photograph, it likely occurred in clear air away from the cloud.

An instance of flow around a number of isolated mountain peaks (also occurring at Mt. McKinley National Park) is shown in Figure 6-7. This field of circular, three-dimensional lenticulars probably has associated with it centers of strong turbulence, interspersed with areas of relative calm. Of concern to flightcrews who might attempt flight through this type of disturbed airflow is the fact that regions of strongly circulating wind flow can produce localized areas of very strong and complex air motion patterns.

Figures 6-8 and 6-9 are photographs of lenticular clouds taken from an aircraft showing the effects of flow around complicated, heterogeneous topography. Figure 6-10 concludes this section with a photograph of a lenticular cloud at sunset.

Once again, the concern with this type of smaller-scale wave activity lies in its potential for producing localized areas of severe-to-extreme turbulence in small-scale eddies. These extremely strong vortices may have no associated cloud features to make them visible as the aircraft approaches, perhaps with catastrophic results.

Figure 6-8. A view of three-dimensional lenticular clouds taken from an aircraft (photograph ©, NCAR).

Figure 6-9. A view of three-dimensional lenticular clouds north of Boulder, Colorado, taken from an aircraft (photograph ©, 1988, S. Holle).

Figure 6-7. A field of circular lenticular clouds that have developed in the complex flow around a number of mountain peaks in Mt. McKinley National Park, Alaska (photograph ©, 1979, B. Martner).

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Figure 6-8. A view of three-dimensional lenticular clouds taken from an aircraft (photograph ©, NCAR).

Figure 6-9. A view of three-dimensional lenticular clouds north of Boulder, Colorado, taken from an aircraft (photograph ©, 1988, S. Holle).

Figure 6-10. A lenticular cloud over Boulder, Colorado, at sunset (photograph ©, B. Martner).

6.3 Rotors and Other Turbulent Zones

We have previously discussed the formation of rotor zones in association with lee waves, along with their potential for subjecting aircraft to strong turbulence and rolling moments. This section provides a sample of well-developed rotor clouds associated with lee-wave events.

Figure 6-11a depicts an example of clouds associated with vertically suppressed, trapped lee waves. These waves are occurring downstream (east, in this case) of the Continental Divide. In Figure 6-11b, the air motion is superimposed on the cloud fields. Because these clouds are flat and not very ragged, it is unlikely that turbulence within them is more than light-to-moderate.

In contrast to the vertically suppressed clouds of Figure 6-11 are the vertically enhanced clouds, viewed from the same location and also associated with trapped lee waves, shown in Figure 6-12a. The air motion in these rotors is depicted in Figure 6-12b.

Figure 6-11a. Clouds associated with vertically suppressed, trapped lee waves at Boulder, Colorado (photograph ©, 1987, P. Neiman).

Figure 6-11b.

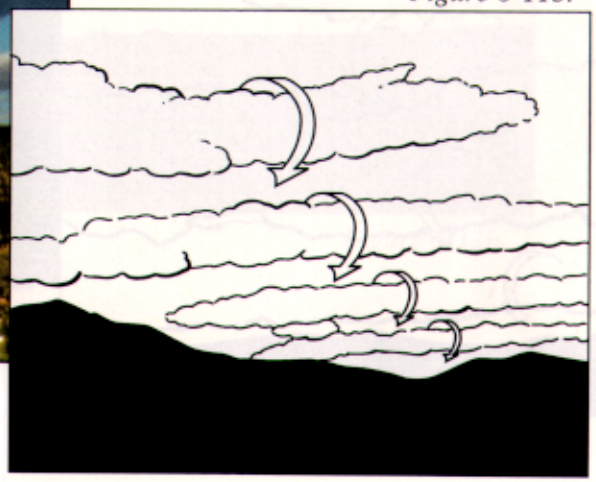

Figure 6-12a. Vertically enhanced clouds associated with a trapped lee wave at Boulder, Colorado, (photograph ©, 1992, P. Neiman).

Figure 6-12b.

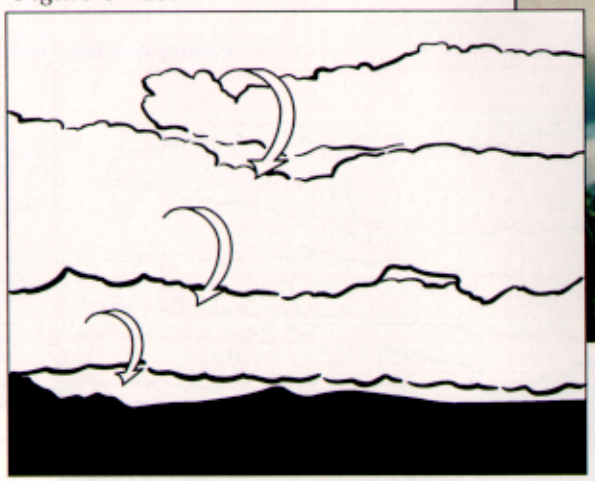

Figure 6-13a. Rotor cloud near State College, Pennsylvania (photograph ©, 1985, P. Neiman).

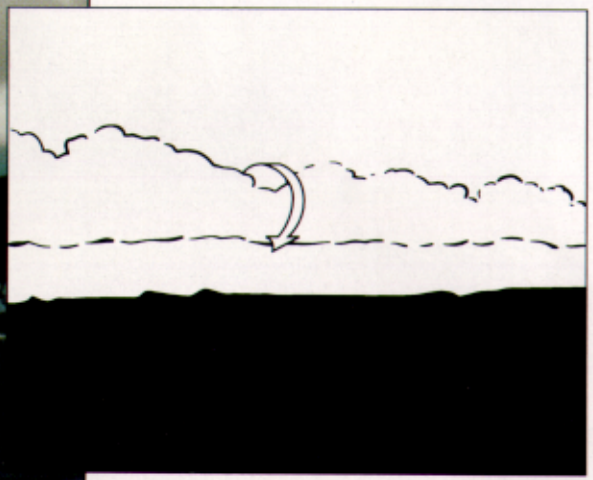

Figure 6-13b.

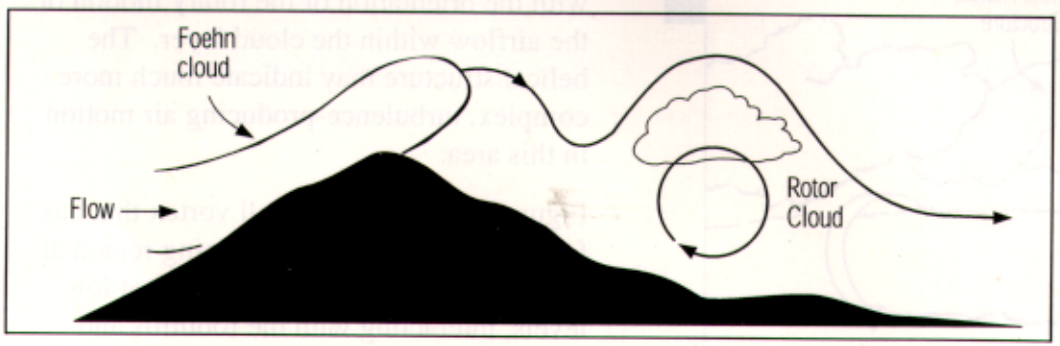

Figure 6-14. Schematic of the flow associated with a rotor zone in the lee of a mountain.

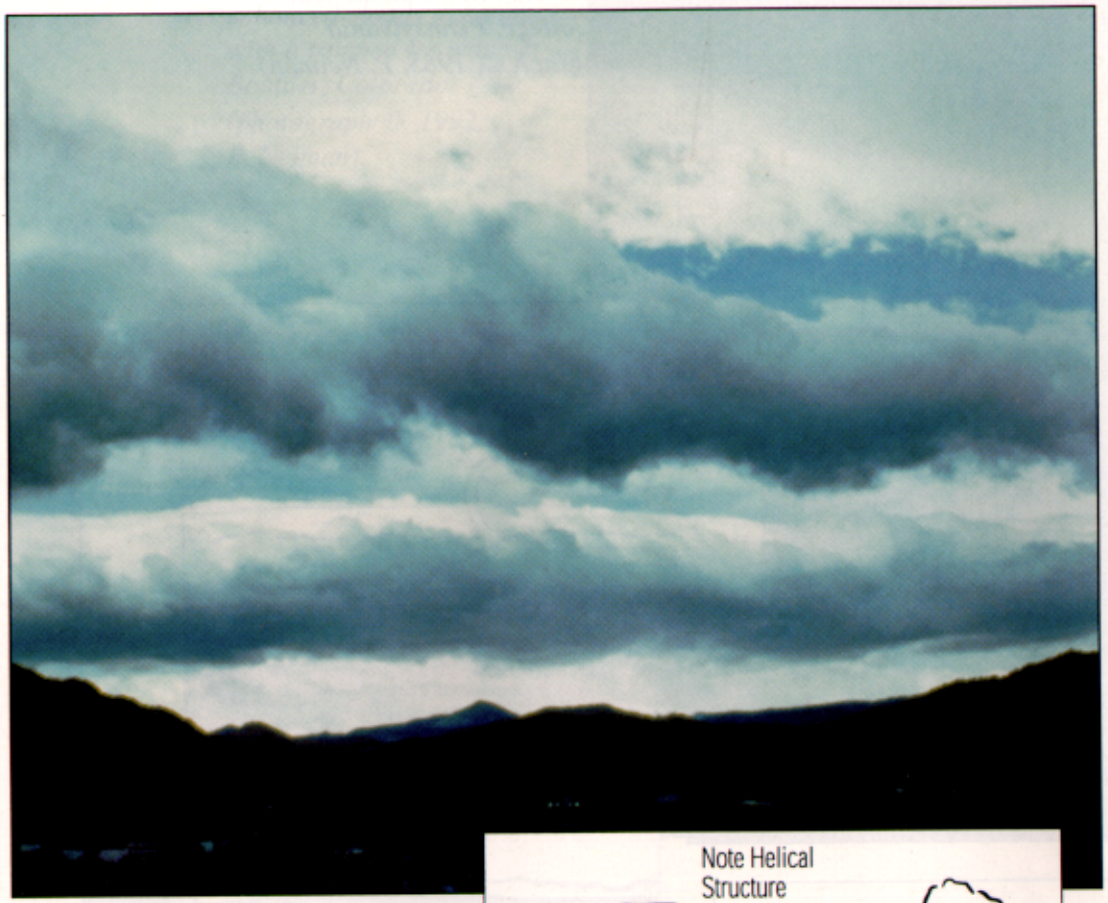

Figure 6-15a. A group of rotor clouds over Boulder, Colorado, one of which has developed a helical structure (photograph ©, 1992, F.M. Ralph).

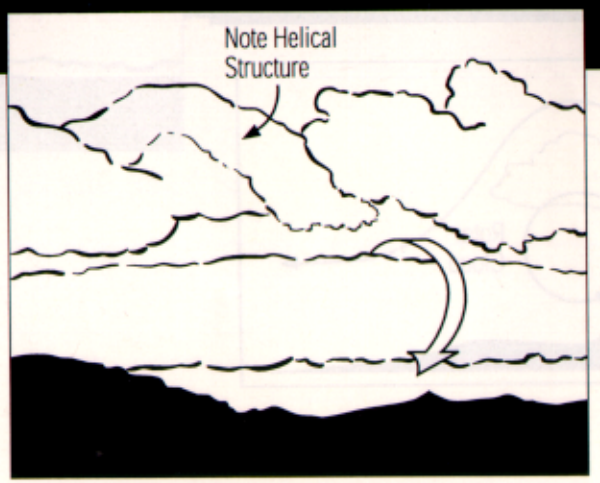

Figure 6-15b.

Figures 6-13a and 6-13b depict a rotor cloud over much lower terrain near State College, Pennsylvania. A Foehn cloud can be seen in the background of this picture. The flow associated with this feature is shown in the Figure 6-14 schematic. Note the well-defined wave that has resulted from the air motion over the ridge. The event shown in these photographs is graphic evidence that extremely high or rugged terrain is not a requirement for the development of significant wave activity. The turbulence in this situation is likely to be considerably greater than in the instance depicted in Figure 6-11a.

Rotor clouds can develop complex structures, as shown in Figure 6-15. Figure 6-15a shows a group of rotor clouds, one of which has apparently developed a helical orientation. This structure is shown in Figure 6-15b, along with the orientation of the rotary motion of the airflow within the cloud layer. The helical structure may indicate much more complex, turbulence-producing air motion in this area.

Figure 6-16 depicts a small vortex that has formed near the turbulent mixing region at the leading edge of cold, moist air at low levels, interacting with the foothills and westerly downslope flow just above.

Figure 6-16. A small vortex structure formed near a turbulent mixing zone (photograph ©, A.J. Bedard, Jr.).

Figure 6-17. Turbulent cloud structures near the tropopause over Boulder, Colorado (photograph ©, 1993, P. Neiman).