CHAPTER 17. TURBULENCE

17.1 Introduction. Aircraft turbulence is irregular motion of an aircraft in flight, especially when characterized by rapid up-and-down motion caused by a rapid variation of atmospheric wind velocities. Turbulence varies from annoying bumpiness to severe jolts which cause structural damage to aircraft and/or injury to its passengers. Turbulence intensities and their associated aircraft reactions are described in the Aeronautical Information Manual (AIM).

17.2 Causes of Turbulence. Turbulence is caused by convective currents (called convective turbulence), obstructions in the wind flow (called mechanical turbulence), and wind shear.

17.2.1 Convective Turbulence. Convective turbulence is turbulent vertical motions that result from convective currents and the subsequent rising and sinking of air. For every rising current, there is a compensating downward current. The downward currents frequently occur over broader areas than do the upward currents; therefore, they have a slower vertical speed than do the rising currents.

Convective currents are most active on warm summer afternoons when winds are light. Heated air at the surface creates a shallow, absolutely unstable layer within which bubbles of warm air rise upward. Convection increases in strength and to greater heights as surface heating increases. Barren surfaces such as sandy or rocky wastelands and plowed fields become hotter than open water or ground covered by vegetation. Thus, air at and near the surface heats unevenly. Because of uneven heating, the strength of convective currents can vary considerably within short distances.

As air moves upward, it cools by expansion. A convective current continues upward until it reaches a level where its temperature cools to the same as that of the surrounding air. If it cools to saturation, a cumuliform cloud forms.

Billowy cumuliform clouds, usually seen over land during sunny afternoons, are signposts in the sky indicating convective turbulence. The cloud top usually marks the approximate upper limit of the convective current. A pilot can expect to encounter turbulence beneath or in the clouds, while above the clouds, air generally is smooth (see Figure 17-1). When convection extends to great heights, it develops larger towering cumulus clouds and cumulonimbus with anvil-like tops. The cumulonimbus gives visual warning of violent convective turbulence.

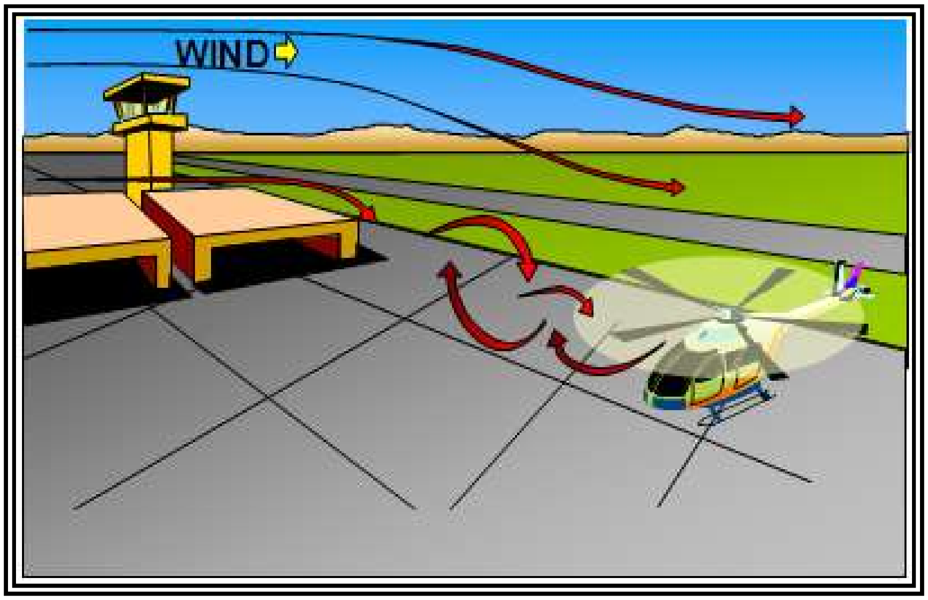
Figure 17-1. Convective Turbulence

When the air is too dry for cumuliform clouds to form, convective currents can still be active. This is called dry convection, or thermals (see Figure 17-2). A pilot has little or no indication of their presence until encountering the turbulence.

Figure 17-2. Thermals

17.2.2 Mechanical Turbulence. Mechanical turbulence is turbulence caused by obstructions to the wind flow, such as trees, buildings, mountains, and so on. Obstructions to the wind flow disrupt smooth wind flow into a complex snarl of eddies (see Figure 17-3). An aircraft flying through these eddies experiences mechanical turbulence.

Figure 17-3. Mechanical Turbulence

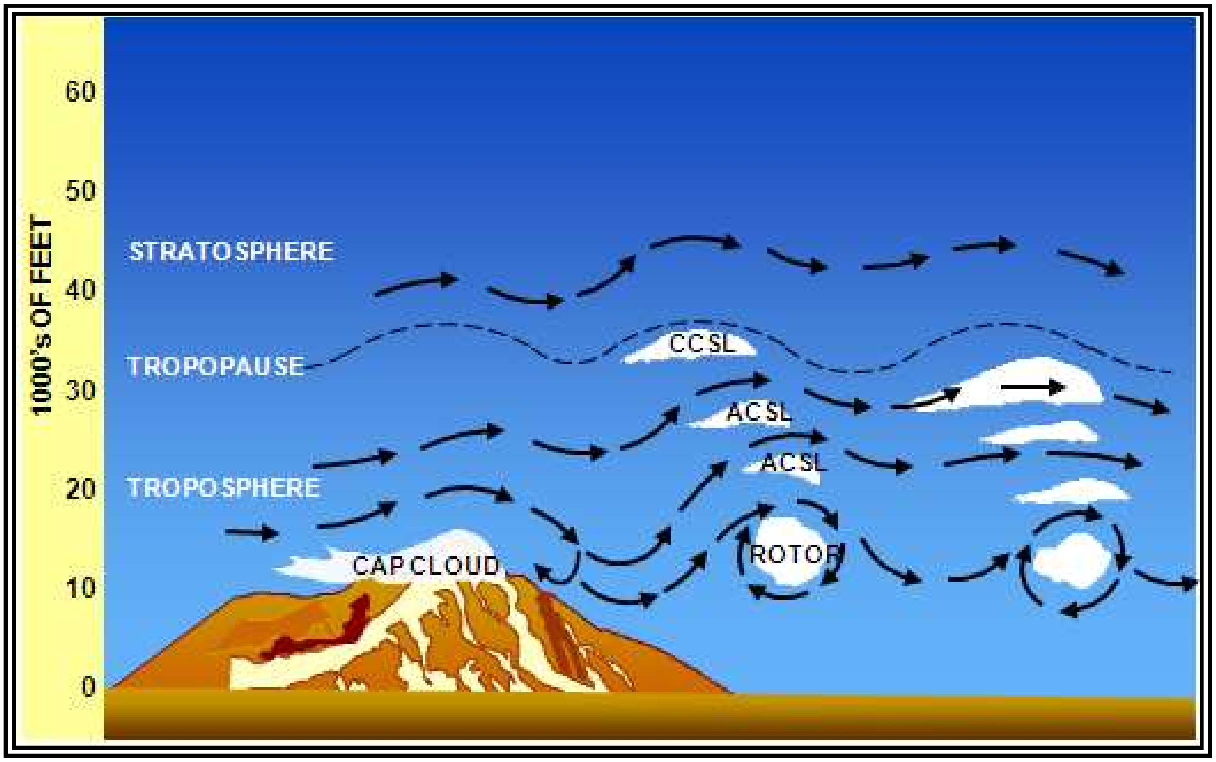


The intensity of mechanical turbulence depends on wind speed and roughness of the obstructions. The higher the speed and/or the rougher the surface, the greater the turbulence.

The wind carries the turbulent eddies downstream. How far depends on wind speed and stability of the air. Unstable air allows larger eddies to form than those that form in stable air; but the instability breaks up the eddies quickly, while in stable air they dissipate slowly.

17.2.2.1 **Mountain Waves.** A mountain wave (see Figure 17-4) is an atmospheric wave disturbance formed when stable air flow passes over a mountain or mountain ridge. Mountain waves are a form of mechanical turbulence which develop above and downwind of mountains. The waves remain nearly stationary while the wind blows rapidly through them. The waves may extend 600 miles (1,000 kilometers) or more downwind from the mountain range. Mountain waves frequently produce severe to extreme turbulence. Location and intensity varies with wave characteristics. Incredibly, vertically propagating mountain waves have been documented up to 200,000 feet (60,000 meters) and higher.

Figure 17-4. Mountain Waves



Mountain waves often produce violent downdrafts on the immediate leeward side of the mountain barrier. Sometimes the downward speed exceeds the maximum climb rate of an aircraft and may drive the aircraft into the mountainside.

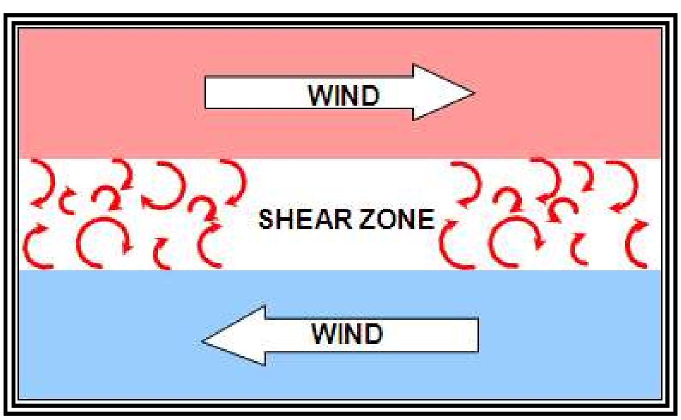
A mountain wave cloud is a cloud that forms in the rising branches of mountain waves and occupies the crests of the waves. The most distinctive are the sharp-edged, lens-, or almond-shaped lenticular clouds. When sufficient moisture is present in the upstream flow, mountain waves produce interesting cloud formations (see Figure 17-5) including: cap clouds, cirrocumulus standing lenticular (CCSL), Altocumulus Standing Lenticular (ACSL), and rotor clouds. These clouds provide visual proof that mountain waves exist. However, these clouds may be absent if the air is too dry.

For additional information on hazardous mountain waves, refer to the current edition of AC 00-57, Hazardous Mountain Winds and their Visual Indicators.

Figure 17-5. Mountain Wave Clouds

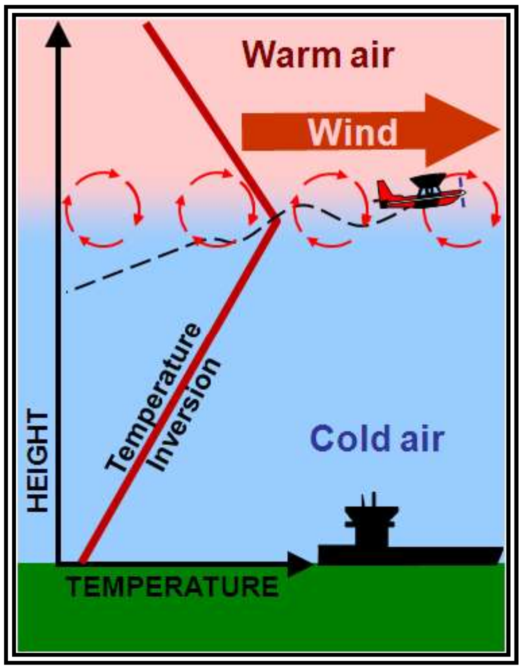
17.2.3 Wind Shear Turbulence. Wind shear is the rate of change in wind direction and/or speed per unit distance. Wind shear generates turbulence between two wind currents of different directions and/or speeds (see Figure 17-6). Wind shear may be associated with either a wind shift or a wind speed gradient at any level in the atmosphere.

Figure 17-6. Wind Shear Turbulence



17.2.3.1 Temperature Inversion. A temperature inversion is a layer of the atmosphere in which temperature increases with altitude. Inversions commonly occur within the lowest few thousand feet above ground due to nighttime radiational cooling, along frontal zones, and when cold air is trapped in a valley. Strong wind shears often occur across temperature inversion layers, which can generate turbulence (see Figure 17-7).

Figure 17-7. Wind Shear Turbulence Associated with a Temperature Inversion



17.2.3.2 Clear Air Turbulence (CAT). Clear Air Turbulence (CAT) is a higher altitude (~20,000 to 50,000 feet) turbulence phenomenon occurring in cloud-free regions associated with wind shear, particularly between the core of a jet stream and the surrounding air. It can often affect an aircraft without warning. CAT frequency and intensity are maximized during winter when jet streams are strongest.

For additional information on CAT, refer to the current edition of AC 00-30, Clear Air Turbulence Avoidance.

17.3 Turbulence Factors. How an aircraft will respond to turbulence varies with: intensity of the turbulence, aircraft size, wing loading, airspeed, and aircraft altitude. When an aircraft travels rapidly from one current to another, it undergoes abrupt changes in acceleration.