Acoustics • Shock • Vibration • Signal Processing **October 2002 Newsletter**

Annyong ha shimnikka

Vibration waves are one of the mechanisms by which nature displays its awesome power. Mountain waves are an example. These waves form in wind flows over mountain ranges under certain conditions. A series of mountain waves may extend hundreds of miles downwind of a mountain range.

Lenticular clouds may form in mountain waves, as shown in the figure on the right side of this page.

Unfortunately, these same waves are a source of air turbulence, which is a hazard for aircraft and passengers. In extreme cases, mountain waves may even cause a catastrophic failure of the aircraft.

The month's newsletter discusses the characteristics of several types of mountain waves. It also gives a brief introduction to Kelvin-Helmholtz clouds, which resemble waves breaking near an ocean shore.

Sincerely,

Tom Irvine
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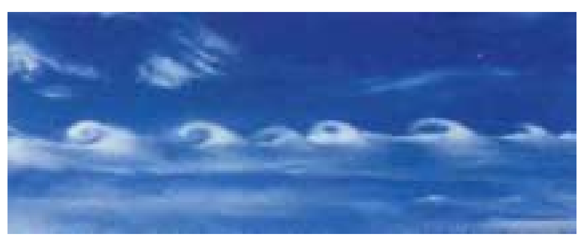
Feature Articles

(Lenticular Cloud in a Mountain Wave, Courtesy of K. Scott Hunziker, Ph.D.)

Mountain Waves, page 3



(Courtesy of Columbia University)

Kelvin-Helmholtz Clouds, page 8

Welcome to Vibrationdata Consulting Services

Vibrationdata specializes in acoustics, shock, vibration, signal processing, and modal testing. The following services are offered within these specialties:

1. Dynamic data acquisition
2. Data analysis and report writing
3. Custom software development and training
4. Test planning and support

Vibrationdata also performs finite element analysis.

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Dynamic Labs

ECS Composites

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Motorola Flat Panel Display

Motorola Government Electronics Group

Orbital Sciences Corporation

Prolink

SpeedFam

Sumitomo Sitix

Three-Five Systems

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MOUNTAIN WAVES

By Tom Irvine

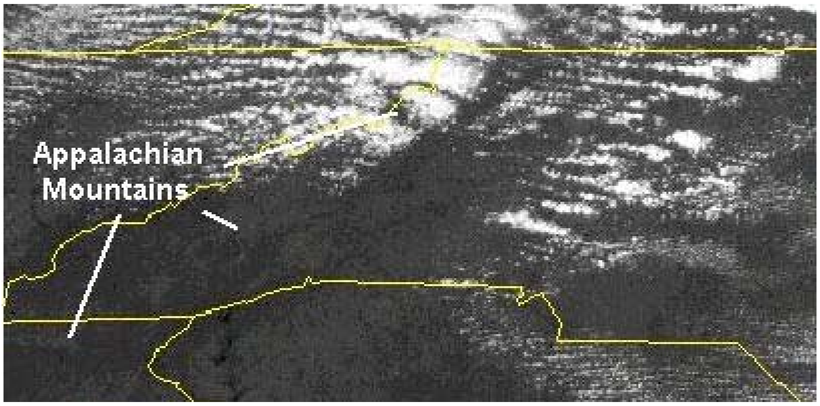

Figure 1a. Satellite Photo of Mountain Waves above the Appalachian Mountains, along the border of Tennessee and North Carolina

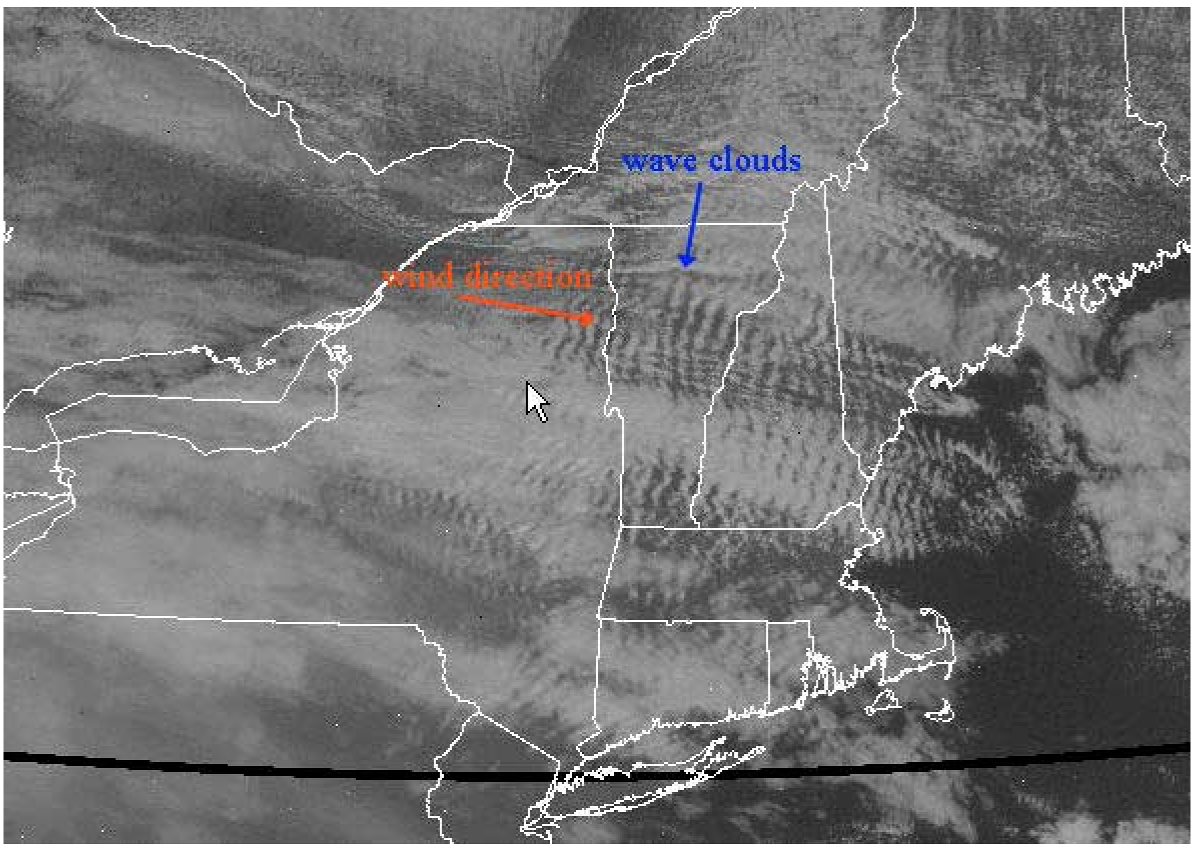

Figure 1b. Satellite Photo of Mountain Wave Clouds over New England

Introduction

Wind flowing over mountains may generate mountain waves. These waves are also known as orographic waves or lee waves.

The combined effects of gravity and the mountain terrain affect the formation of these waves.

Gravity acts on local variations in air density and creates a vertical undulation in the atmosphere. Stable air that is lifted over a mountain cools and becomes denser. The cooled air mass sinks again on the lee side due to the effects of gravity. The air mass warms as it descends downward. The cycle is then repeated as the warm air then rises downstream.

The oscillation creates a waveform. The waveform may be a standing wave that continues for several hundred kilometers. An example of this vast scale is shown in the satellite photos in Figures 1a and 1b. These figures show the effect of the mountain waveform on cloud formation.

Necessary Conditions

Three conditions are required for the formation of mountain waves.

1. The wind direction must be within 30° of perpendicular to the mountains.
2. The windward side wind velocity must increase with altitude, with mountain-top winds over 20 knots (37 km/hr).
3. There must be a stable air mass layer aloft or an isothermal inversion layer below 15,000 feet (4.5 km).

Wavelengths

The wavelength may vary considerably depending on the climate and terrain. Mountain waves in the Andes have preferential horizontal wavelengths at 110 km and 400 km, according to Reference 1.

The wavelength of mountain waves in the inter-mountain western United States averages 7 to 8 nautical miles (13 to 15 km), according to Reference 2.

Velocity

Research aircraft in the early 1950s estimated one mountain wave updraft speed about 80 mph (130 km/hr), according to Reference 3. This speed is comparable to the wind speed in a severe thunderstorm.

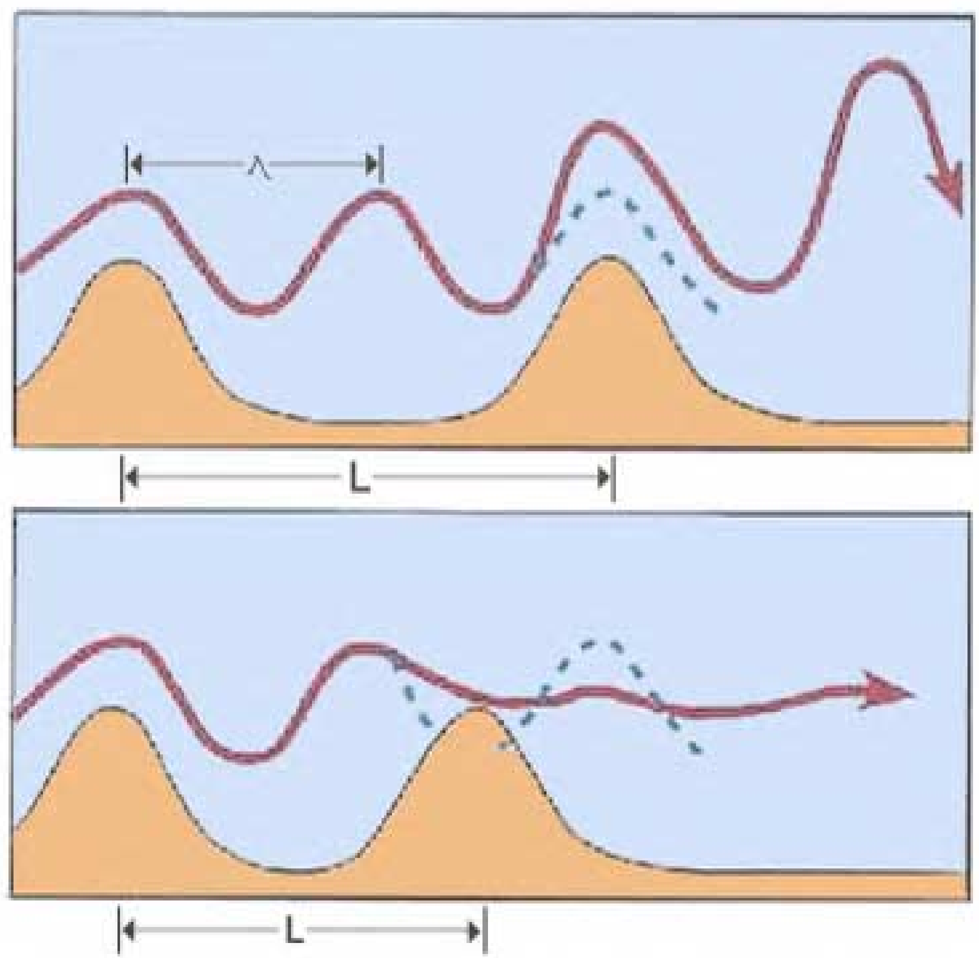

Figure 2. Mountain Wave Resonance
(Images Courtesy of Kim J. Runk, National Weather Service)

Resonance

A mountain wave may cross more than one ridge crest. The resulting waveform depends on the relationship between the wavelength and the distance between ridge peaks. Resonant amplification will occur if the wave crest and ridge crest are in phase, as shown in the top image of Figure 1, on the previous page.

On the other hand, attenuation will occur if the wave is 180 degrees out of phase with the ridge crest as shown in the bottom image of Figure 2.

Figure 3. Lenticular Clouds (Courtesy NASA/JPL)

Lenticular Clouds

Lenticular clouds may form in the mountain wave if there is sufficient moisture. These clouds remain stationary while the wind blows through them. They have the shape of lenses or saucers.

Lenticular clouds may occur at regular intervals for a considerable distance to the lee of a mountain range. The resulting cloud patterns are often visible on satellite photographs.

Furthermore, several of these clouds may appear stacked on top of one another, as shown in Figure 2.

The U.S. Navy gives the following description of lenticular clouds in a pilot's training manual:

> Lenticular clouds are much less obvious, but can be every bit as dangerous. A Lenticular, or lens-shaped cloud often marks the location of a mountain wave...some of the most turbulent conditions encountered. Lenticular clouds most commonly form as stable air is lifted over a mountain range, and then descends again. As the air is lifted, water vapor condenses, forming the cloud. As it descends, the cloud droplets return to their gaseous state. So, air is continually flowing through the cloud, but the water is changing state throughout the process. This type of cloud is also known as a "standing lenticular" cloud...because the air is moving but the cloud has the appearance of standing still.

Rotors

Turbulent eddies called "rotors" may accompany mountain waves, as shown in Figures 4 and 5. Rotors usually occur where wind speeds changes, or where friction slows the wind near to the ground. Pilots often experience rotors as gusts or wind shear.

Breaking Waves

Mountain waves ascend upward until gravity causes the air mass to move downward. This reversal of direction does not always occur in a smooth manner. Instead, the waves may break, causing a rotational motion as shown in Figure 4. This breaking motion is similar to that of an ocean wave.

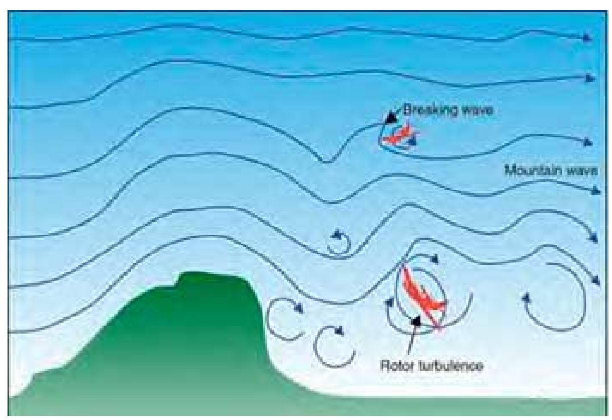

Figure 4. Breaking Waves and Rotor Turbulence (Courtesy Australian Aviation Transportation Safety Board)

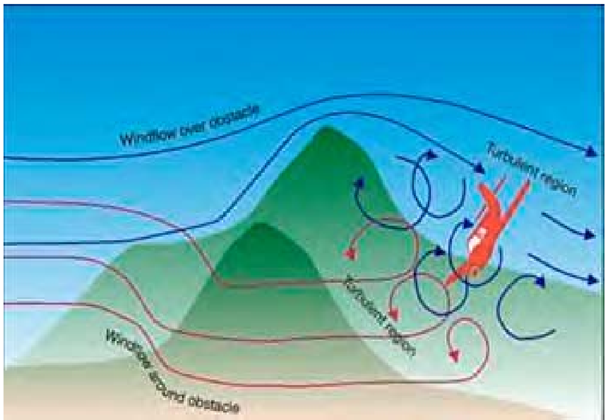

Figure 5. Turbulence due to Rotors and Ground Wind Effects

(Courtesy Australian Aviation Transportation Safety Board)

Hydraulic Jumps

Developing waves tend to propagate vertically if the wind has a strong component perpendicular to the mountain range. These waves ascend and expand through the depth of the troposphere.
Sometimes the energy associated with these vertically propagating gravity waves can be dispersed as turbulence. At other times, a large-scale instability can cause the entire mountain wave to suddenly collapse, similar to the way flow in a stream might collapse into rapids over a large boulder. Concentrated packets of wave energy are deflected and redirected toward the surface when this type of flow transition. This process of sudden transformation is often referred to as a "hydraulic jump".

Surface wind speeds at the base of the mountain may exceed those at any level in the overlying free atmosphere, where a hydraulic jump occurs.

Failures due to Mountain Waves

A B-52 had about three-fourths of its vertical stabilizer bitten off by 95-mph gusts at 14,300 feet over southern Colorado in 1964.

A mountain wave ripped apart a BOAC Boeing 707 while it flew near Mt. Fuji in Japan in 1966.

A Fairchild F-27B lost parts of its wings and empennage at Pedro Bay, Alaska, in 1968.

A Douglas DC-8 lost an engine and wingtip in mountain wave encounters southwest of Denver, in 1992.

References

1. Jonathan H. Jiang, Dong L. Wu, and Stephen D. Eckermann, UARS MLS Observation of Mountain Waves over the Andes.

2. http://www.keithmo.com/Html/Aviation/260SE/Andrew/MountainFlying.html

3. http://aviationweather.noaa.gov/awc/help/mwaveinfo.html

Kelvin-Helmholtz Clouds

By Tom Irvine

Figure 1. Kelvin-Helmholtz Clouds
(Courtesy of NOAA/NCAR)

Kelvin-Helmholtz clouds form between two layers of air traveling at different speeds. The top layer is a warm layer with low density. The bottom layer is a colder, dense layer. Eddies will develop along the boundary if the wind shear is sufficiently strong. A shearing instability is thus considered to exist at the boundary.

Kelvin-Helmholtz clouds are also called Billow Clouds. These clouds provide a visible signal to pilots of potentially dangerous turbulence.

Kelvin-Helmholtz clouds resemble ocean waves breaking on a shore. These clouds and ocean waves are in fact caused by the same shear instability mechanism, which is called the Kelvin-Helmholtz (KH) instability.

Professor James Graham of the University of California at Berkeley wrote, "The most common example of the Kelvin-Helmholtz instability is provided by the observation that a wind blowing over a water surface causes the water surface to undulate."