WEATHER TO FLY

BY DAN GUDGEL

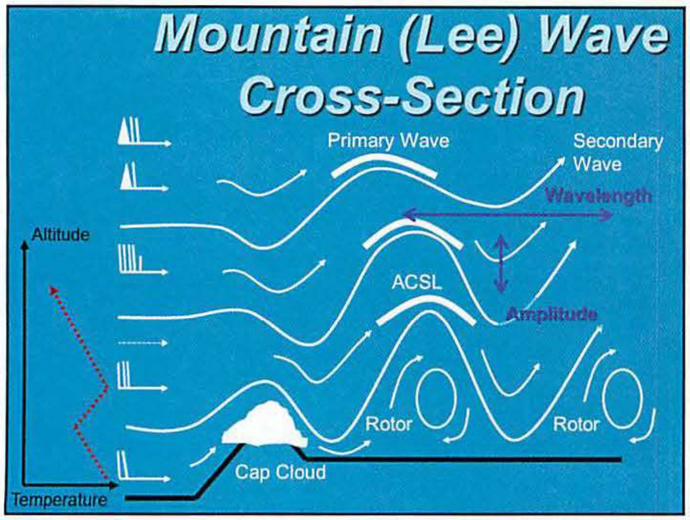
Lenticular Clouds

The late winter/early spring season brings transitory trough passages in the Northern Hemisphere's mid-latitude westerly wind flow that develops lee side or mountain waves with some frequency. When the right conditions are met, one of the more interesting cloud features within the mountain wave is that of lens-shaped clouds. While the mountain wave phenomenon was discussed a couple of years ago in this column, *Weather-To-Fly*, I thought I would write to just refresh a few points about the lens-shaped cloud feature known as the alto-cumulus standing lenticularis (ACSL).

Looking at the conceptual model of a mountain wave (See *Diagram: "Mountain (Lee) Wave Cross-Section"*), note the position of the ACSL cloud that soaring pilots often refer to as a "lennie." Like all clouds, ACSL forms when the air temperature lowers to its dew point temperature, the air becomes saturated (100% relative humidity), and a change in state of the water molecules occur, i.e., water transitions from its gaseous state to that of its liquid and/or solid state depending upon the air temperature. Of course, we know these latter states as either suspended water droplets or ice crystals, respectively, when discussing the visible moisture of a cloud.

The rapid lifting process on the front side of the lee wave(s) provides the cooling mechanism in response to an air layer's gain in altitude and subsequent lowering of atmospheric pressure. With the lifting process provided by the mountain wave, the only requirement for getting water to change its state to that of visible moisture in the form of water droplets or ice crystals is simply enough water vapor depicted by a sufficiently high dew point.

But why is there a smooth, lens shape to the ACSL cloud? When cloud development does occur because atmospheric water content is sufficient, there are *three* distinct cloud types that may be seen with the mountain wave phenomenon; cap clouds, rotor clouds, and ACSL or "lennies" (See *"Photo #1: Mountain Wave Cloud Features"*).



Without going into a lot of detail, the cap cloud resides on the mountain wave-initiating terrain feature, whether it is a single mountain peak or a mountain range (ridge lift). The cloud forms as the result of the lifting of an air layer over that terrain. The dissipation of the cap cloud on the back or lee side of the lifting terrain feature is due to compressional warming of the air layer as its pressure increases in its descent and subsequently leads to the evaporation of the cap cloud (change of state from visible moisture back to water vapor).

Rotor clouds develop as the result of uplift in the turbulent flow below the wave crests. (Note: A common error on check rides from applicants is an erroneous attempt depicting "rotor" clouds immediately against the lee side of the mountain range, as if turbulent flow in its general downward motion in that location would support cloud development. This is an area that is known as the "Foehn Gap," due to the break in the cap clouds or a <u>*clear area*</u> in cloud cover due to the aforementioned compressional warming and subsequent evaporation process.)

The smooth shape of the ACSL "lennie" cloud is the result of laminar air flow within the mountain wave. A relatively stable atmospheric layer – typically around the altitude of a mountain peak or ridge – to some degree provides a buffer layer from the lower atmospheric air characterized by terrain-induced mechanical mixing and/or surface heating mixing. Characteristic of the mountain wave, wind velocity shear upstream from the lifting terrain is minimal, as wind direction does not change appreciably with an increase in altitude. Speed increases only slowly with an increase in altitude. In other words, wind as a vector with components of both direction and speed does not change quickly in the troposphere where the lee wave is resident. Because of minimal wind shear, the temperature lapse

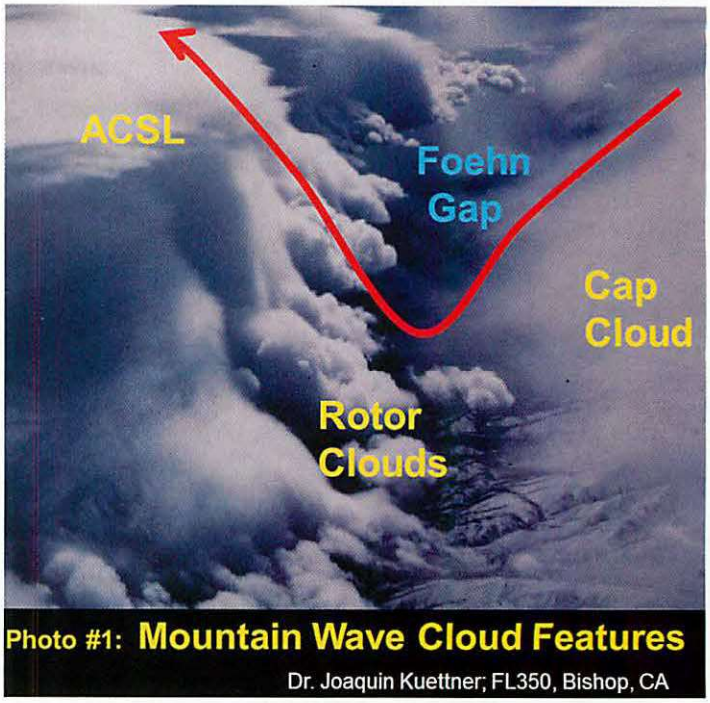


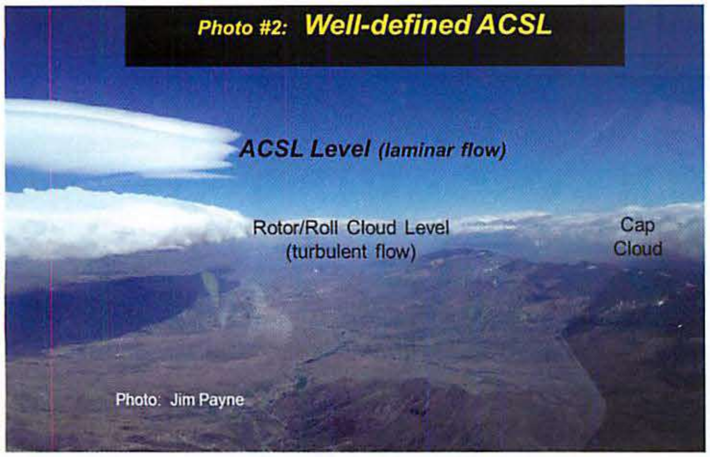
Photo #1: Mountain Wave Cloud Features

Dr. Joaquin Kuettner; FL350, Bishop, CA

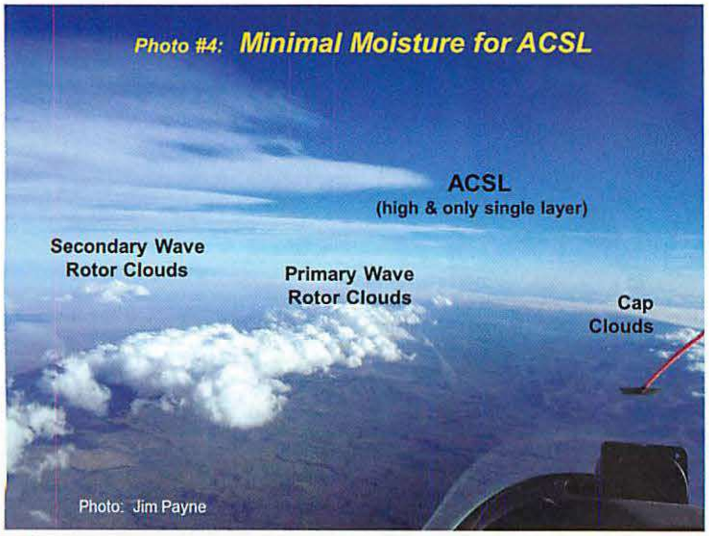
Looking southeast over the Owens Valley in documenting the Sierra Wave. Courtesy of the "Sierra Wave Project" and Dr. Joaquin Kuettner.

conditions (temperature decreasing with a gain in altitude) above the "stable" layer, and the buffer provided by the stable layer itself, the resulting wind flow at the higher altitudes is laminar or smooth. So the characteristic shape of the ACSL, i.e., a lens shape, is the visible moisture seen toward the top of the wave crest(s). The upstream edge of the ACSL is where the water changes state to that of visible moisture; and the back, or downstream, edge of the cloud is where the cloud evaporates as air begins to descend off the wave crest.

The "standing" part of the ACSL nomenclature is the relative lack of movement or static position of the lenticular cloud with respect to the ground. However, the admonishment is that the air through the lenticular cloud is by no means static. While the cloud is static or not moving with respect to the ground, the wind speed within the air layer of the cloud is very fast. Depending on the exact altitude and the strength of the overall weather system supporting mountain wave development, wind speeds at Flight Level 180 (about 18,000 feet mean sea level, or near the 500-millibar pressure level) typically can range from 50 knots to 100 knots! Especially in high mountain ranges with the mountain wave phenomena setting up in high altitudes through the Troposphere, wave soaring results in very high True Air Speeds, thereby causing serious concern in regard to potential control surface flutter issues.



Above and below: Photos taken during his extensive mountain wave flying over the Argentinian Andes. Courtesy of Jim Payne.



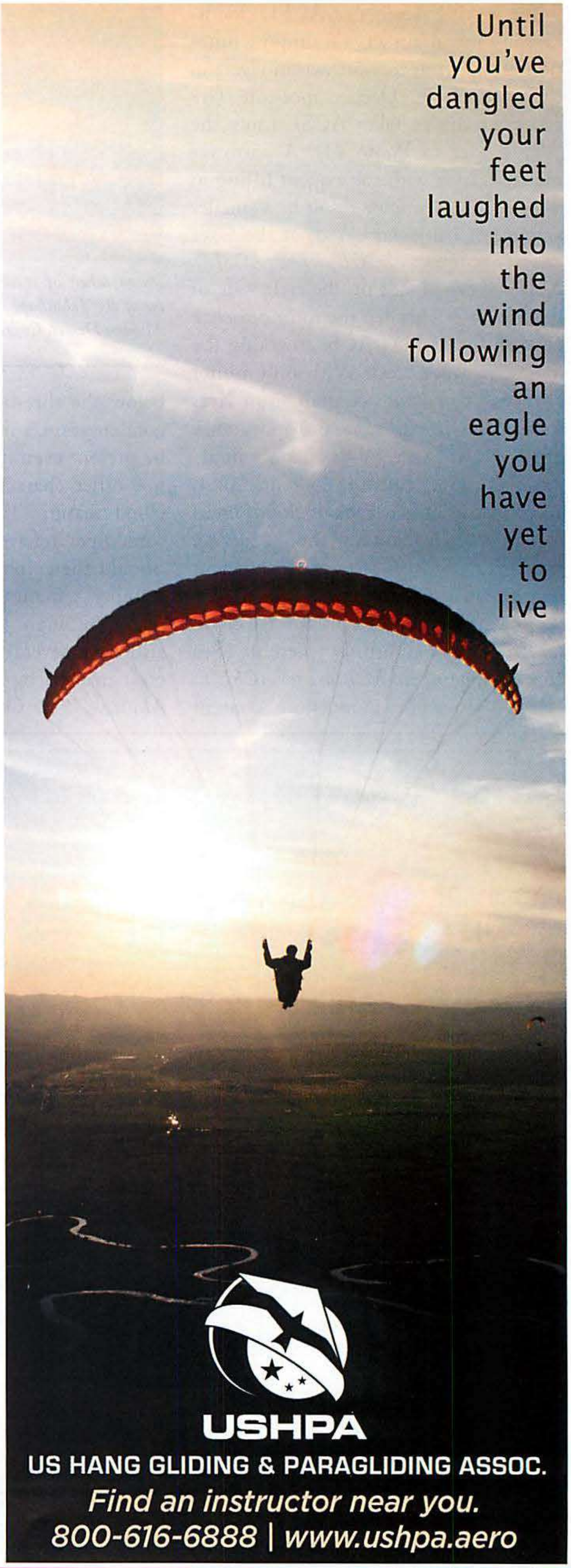


Photo taken of stacked ACSL generated in the lee of the Tehachapi Mountains over California's Mojave Desert. Courtesy of Jeff Kirby.

Several ACSL marking several mountain wave crests looking downstream from Mountain Valley Airport in the Tehachapi Mountains. Dan Gudgel

The varying degrees of ACSL cloudiness in a mountain wave is simply a function of moisture content within layers in the atmosphere. Deeper moisture layers will result in taller ACSL (note the ACSL layer in Photo #1). A narrower moisture layer with subsequent lifting in a mountain wave may result in a smaller amount of lenticular clouds at the wave crests (See "*Photo #2: Well-defined ACSL*"). Note the cap clouds on the right side of the *Photo #2*; and then the rotor presence beneath the arching ACSL marking the mountain wave crest. With only minor changes in moisture content from layer to layer, the development and appearance of ACSL will vary. With changes in atmospheric layer moisture content, ACSL will often result in a stack of clouds nicknamed "Pagoda Cloud(s)" (See "*Photo #3: 'Stacked' ACSL*"). Of course insufficient moisture may lead to minimal ACSL development even though other wave cloud features are definitively present (See "*Photo #4: Minimal Moisture for ACSL*").

With atmospheric moisture content below the threshold for lifted moisture condensation, a mountain wave may still be present even if not marked by ACSL nor other characteristic mountain wave cloud feature. This cloud-free wave is sometimes referred to as a "blue" wave. Should the combination of atmospheric stability parameters, moisture, and topography align, a mountain wave may also have several wave crests with each crest marked by ACSL (See *"Photo #5: Multiple Wave Crests"* and also *Photo #4* where rotor clouds mark a secondary wave crest existence).

In summary, the lifting action that results in ACSL in a mountain wave is one of the mechanisms that "powers" soaring flight. While there are hazards that must be understood before soaring in a mountain wave, the presence of ACSL and an understanding of the conceptual model of the mountain wave is a step toward safely utilizing a smooth form of lift for soaring flight.