WEATHER TO FLY

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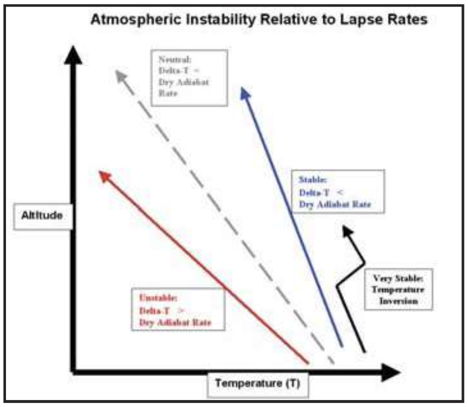
THERMAL DEVELOPMENT

The atmosphere provides vertical air motion or atmospheric lift in various forms and thereby provides the "engine" for soaring pilots to accomplish cross-country flight. In the "Weather To Fly" introduction in the April issue of *"Soaring"* I listed four mechanisms of atmospheric lift commonly used for soaring flight; thermal, ridge, mountain wave, and convergence. Last month we opened discussion on thermal lift (small-scale, upward moving, convective air current) in regard to *"Elevated Heat Sources"* or why terrain can enhance or speed thermal development. In providing aviation instruction, questions about why or what is needed for thermals to develop that I pose to students results in responses that vary from overly simplistic to quite complicated. Essentially a little conceptual model knowledge of thermals provides a good base that enables an aviation student to grasp several meteorological principles. There are myriads of fine, informational sources on thermal soaring so my purpose in this article is to discuss some very fundamental aspects of thermals as a review and thereby set the groundwork for other discussions related to thermal lift in subsequent articles.

Contradictory to the perception of the general public that soaring flight is impossible without wind (horizontally moving air), thermal lift is generally the most flexible means of atmospheric lift to accomplish soaring cross-country flight over a given area. (This statement is made based on the fact that flights utilizing ridge lift or mountain wave result in flight along or near mountain ranges rather than a general geographic area or region.) The ingredients necessary for thermal development are; some form of differential surface heating, an atmosphere that is or can be made unstable, and some form of triggering or convection initiation.

The ground must first warm up in order to subsequently warm the air immediately adjacent to it. In reviewing last month's discussion on the energy required to change the state of water, the high specific heat of water ***(See Text Box #1: Energy to Evaporate Water versus Raising Water/Air Temperatures)*** makes large sensible temperature rises highly unlikely on moist ground. Therefore, dry, dark ground that is open to receiving unimpeded, strong, incoming solar energy has the largest potential to increase its sensible temperature. A conduction process warms the air immediately in contact with the warmed ground and then a convection process mixes the air above this warmed surface. A volume or "bubble" of warmed air develops over this "source" surface area. The air density (mass of air per volume) of this warmed air will now be lower than adjacent air residing over cooler ground at the same level ***(See Text Box #2: Relationship of Pressure, Temperature, and Density).***

The second ingredient necessary for thermal development is the instability (a stability class) of the atmosphere. The International Civil Aviation Organization (ICAO) Standard Atmosphere specifies a standard sea level temperature of 59 deg F. or 15 deg C. with an average temperature drop of 3.5 deg F. or 2.0 deg C. per thousand feet of altitude gained. However, an atmosphere is deemed unconditionally unstable where the temperature lowers faster than the dry adiabatic lapse rate (DALR) or, as defined, one where it cools faster than 5.4 deg F. or 3.0 deg C. per thousand feet of altitude gained. ***(See Diagram #1: Atmospheric Instability Relative to Lapse Rates).*** Dry air rising in the atmosphere will cool at the DALR due to a decrease of pressure as altitude is increased in the atmosphere density ***(See Text Box #2).*** Heated air adjacent to a warmed surface will behave like a cork held underwater. Being less dense than the water in which it is immersed, the cork will bob upward being of lower density. Air that is warmer than the surrounding air is less dense and it will rise as it seeks air of equal density. This is a basic concept. As long as the rising air's temperature is higher than the surrounding atmosphere, i.e. the air is warmer, then the rising air



Equation of State for Dry Air

Defining Variables:

P = Pressure (in millibars or grams/centimeter^2 or mass/area)
□ = Density (in grams/ centimeter^3 or mass/volume)
R = Specific Gas Constant
T = Absolute Temperature (in degrees Kelvin)

EQUATION OF STATE FOR DRY AIR:

P = □ R T

In referencing the equation, note the relationships of the variables:

Pressure, **P**, is proportional to Density, □, and/or Absolute Temperature, **T**.
Or,
Density, □, is directly proportional to the Pressure, **P**;
Or,
Density, □, is inversely proportional to the Temperature, **T**.

As defined by the equation, a pressure increase results in a density increase, and conversely a pressure decrease leads to a density decrease. A temperature increase will result in an air density decrease, and conversely a decrease in temperature will increase the air density (more mass).

still has an upward force, buoyancy, or lift. Note the terms "warmer" and "cooler" are relative. Just because the air is hot or temperatures are high does not alone make for good thermals. There must be a large temperature *differential* between the lower atmospheric level and the air aloft for the best thermal lift conditions. Since air density differences at a given altitude (often expressed as a pressure level) are the result of temperature differences, water vapor can have a substantial impact on the temperature of the air if there is a change of state of that water presence. I will address the impact of water's change of state in future discussions.

Given an established differential heating of the ground – resulting in "pockets" of warmed air relative to adjacent surface area – and the air aloft is cooler to a large extent thus providing a high lapse rate (loss of temperature with altitude gained), then only some form of "trigger" is necessary to begin a thermal lift process. These "trigger" processes can be quite pronounced or subtle in nature. As discussed last month, terrain heating can result in the movement of air up a slope resulting in the release of rising air off or near ridges or mountains. Light winds can act as a "trigger" that encourages the release of warmed air from its surface source area. Human activity such as vehicular movement or farming operations can trigger convection. At a soaring contest some years back, a tow plane was dispatched to retrieve a sailplane that reported low in attitude over a remote airstrip. The tow pilot arrived while the sailplane was still struggling to stay aloft, and so he landed awaiting the sailplane's expected landing. To the tow pilot's amazement the sailplane climbed away to fly home as the tow plane landing triggered the last thermal of the day off the airstrip.

The small-scale upward vertical air current known as a thermal is generated by differential surface heating, propagates vertically as long as the rising column or bubble of air heated at the surface is warmer (less dense) than the surrounding air at a given altitude (or pressure level), and some initiation of that convection process occurred. The only other requirement for soaring flight to utilize such atmospheric lift is concerning the magnitude of the thermal lift. Obviously, a sailplane that sinks at 120 feet per minute (fpm) in flight will need the atmosphere to provide a lift rate generally greater than 120 fpm thus enabling the sailplane to climb and fly cross-country.

Next month I'll discuss the concepts of thermal strength, including the Thermal Index and other related thermal forecast tools.

Energy to Evaporate Water versus Raising Water/Air Temperatures

DEFINITIONS:

The ***"Heat of Vaporization"*** is the energy required to change the state of water molecules from liquid to gas (water vapor). For molecules of water to evaporate, sufficient kinetic energy must be available to overcome the liquid-phase intermolecular forces. Sensible temperature (or degrees of temperature) is a descriptor of this molecular kinetic energy.

A substance's ***"Latent Heat"*** is the heat absorbed per unit mass by a substance in a reversible, isobaric (equal pressure)-isothermal (equal temperature) change of phase.

The ***"Specific Heat"*** of a substance is the energy required to raise the temperature of one kilogram of a substance by one degree Kelvin (Celsius):

- The Specific Heat of Dry Air at 0 degrees Celsius = 1.006 joules/gram-degC
- The Specific Heat of Water at 0 degrees Celsius = 4.186 joules/gram-degC

One ***"Joule"*** is a unit measurement of energy equivalent to 0.2389 calories. (CRC Tables)

ENERGY REQUIREMENTS:

The energy required to change the phase of water varies with temperature but, nonetheless, it takes a tremendous amount of energy to change phase. At zero degrees Celsius it takes 597.3 calories/gram or 2500 joules/gram of energy to change the phase of water from liquid to its gaseous state at that same temperature. For simply changing the sensible temperature one degree Celsius and by comparing the Specific Heat of Dry Air to that of Water, it takes approximately four times as much energy to raise the temperature of a given mass of water to that of an equivalent mass of dry air, i.e., 4.186 vs. 1.006 joules/gram-degC., respectively.