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IFR

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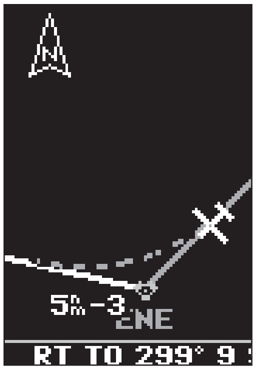

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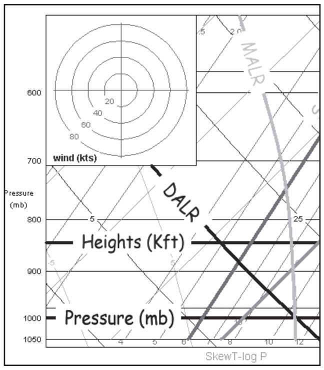

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READING A SKEW-T LOG (P)

To get Joe Cool points for magically finding the ice- and bump-free altitude, you have to understand the meteorologist's crystal ball.

by Scott C. Dennstaedt

Our ability to forecast the weather depends on our ability to observe the weather. Until commercial aircraft started carrying atmospheric sensors, balloon-borne instruments called radiosondes (now referred to as rawinsondes) were the most practical way to get vertical profiles of temperature and moisture aloft. Data from these instruments are best viewed using a thermodynamic diagram called a Skew-T log (p).

This diagram has been used by glider pilots and meteorologists for many decades, but other pilots are just beginning to see its value in identifying cloud bases and tops, convective turbulence and icing potential. The Skew-T has generated a wave of curiosity in the pilot community, especially when drawn with forecast data rather than actual soundings. Daunting as they appear at first, you can read them with practice.

Setting Off a Sonde

Forecasters at the National Weather Service (NWS) launch rawinsondes in 72 locations in the lower 48 twice a day at about 1100 UTC and 2300 UTC. The balloon and instrument package ascends at 1000 fpm recording air pressure, temperature and dew-point. Wind speed and wind direction aloft can be inferred by the balloon's drift from the station. The data are sent via telemetry back to the ground. At 90,000 feet the five-foot-diameter balloon has stretched to the size of a two-car garage and finally bursts. The instrument package parachutes back to earth.

The collected data is called a RAOB, which is short for rawinsonde observation. The rawinsonde data is shipped to the National Centers for Environmental Prediction (NCEP), where it is used as input for numerical weather prediction models. When forecasters depict this data graphically, it is called a temperature sounding.

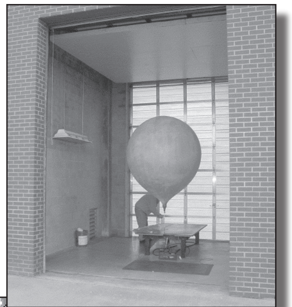
A temperature sounding is plotted on a thermodynamic diagram. There are four basic thermodynamic diagrams used by forecasters, but we'll exclusively focus on the Skew-T log (p) diagram. A thermodynamic diagram is considered a nomogram because it contains lines showing the "solutions" to a set of equations. Our journey through the magic of Skew-T log (p) diagrams begins with an analysis of this diagram. Think about the base diagram as just a sophisticated form of graph paper.

On the base Skew-T diagram, forecasters plot environmental temperature, dew-point and wind speed and direction all as a function of pressure (or altitude). The temperature, dew-point and wind can be actual data from a rawinsonde or forecast data generated by a computer model.

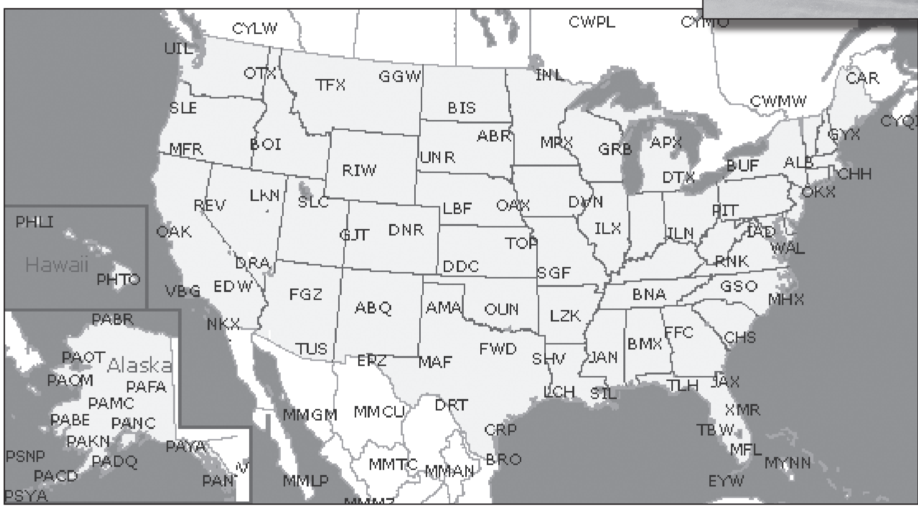
Each line on the base diagram is typically color-coded. Sometimes line type (dashed or solid) is used to distinguish the lines. For the Skew-T log (p) diagram, temperature is depicted in degrees Celsius on the x-axis using lines that are slanted up to the right at a 45-degree angle (hence the "Skew" in "Skew-T"). Warmer temperatures are on the right and colder temperatures are on the left.

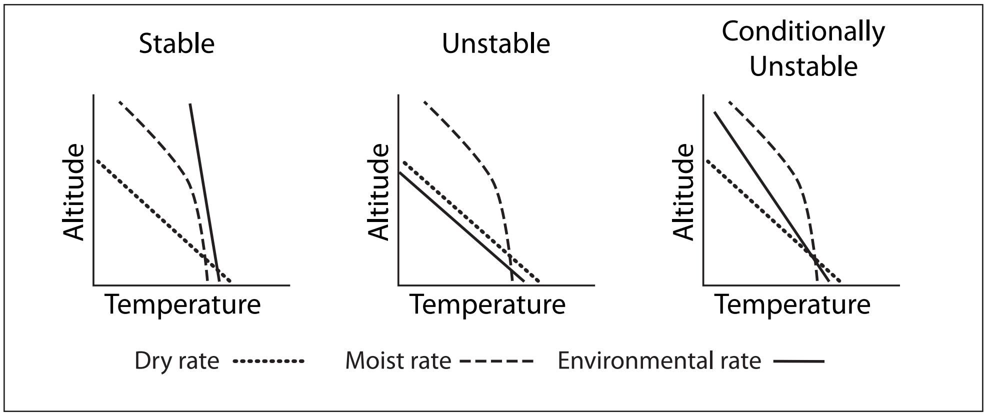
Pressure is depicted in millibars by horizontal lines on the y-axis, with higher pressures at the bottom and lower pressures at the top. Pressure altitude in thousands of feet or meters may also be depicted for the millibar-challenged.

Pressure surfaces are at a greater distance from each other as pressure decreases. In other words, each 100-millibar pressure slice is spread over a greater vertical span with increasing altitude. This is because the atmosphere is compressed under its own weight;



***Right and below**: Twice a day at 2300 UTC and 1100 UTC the NWS launches weather balloons (rawinsondes) at 72 locations in the contiguous U.S. That's far fewer datapoints than METARs or TAFs. The balloon is filled with hydrogen because it's cheaper than helium.*





Above: *Normally the atmospheric temperature decreases with increasing altitude. The diagram on the left shows a stable lapse rate. Here the temperature (solid line) decreases the least with altitude. On the other extreme, the diagram in the middle is the unstable lapse rate or one that has the greatest change of temperature with altitude. Finally, the lapse rate can be closer to the average lapse rate, is considered conditionally unstable, and is shown on the right. By comparing the environmental lapse rate to the dry and moist adiabatic lapse rates, you can get a quick sense of the stability of the atmosphere.*

lower layers are compressed more than the upper layers. Pressure decreases exponentially with height, which is where we get the logarithmic, or log (p), part of the chart.

Two of the remaining lines on the diagram are lapse rates. A lapse rate is a change of temperature over a given change in altitude. If the lapse rate is positive, then the temperature decreases with increasing altitude. If the lapse rate is negative, then the temperature increases with increasing altitude. The latter is called a temperature inversion.

Stability and the Skew

Before we can tackle the remaining lines on the diagram, we have to nail down the concept of parcel theory. Simply put, parcel theory is a "what if" game forecasters use to assess the current or future state of the stability of the atmosphere. Understanding the stability of the atmosphere helps forecasters predict convective outbreaks, precipitation, visibility, haze, clouds, fog, turbulence, mountain waves, and much more. All of these are of interest to pilots and the Skew-T log (p) can give you an extra edge in anticipating them.

An air parcel is an imaginary quantity of air that could move up or down in the atmosphere. While this air parcel may be saturated or unsaturated, picture the air parcel as a typical, white, puffy, fair-weather, cumulus cloud. Cumulus clouds are examples of saturated air parcels.

Pilots tend to dwell on the horizontal motion: wind. however, it's just as important to understand the vertical motion in the atmosphere. Most of the weather we experience is due to upward motion.

Air parcels can rise or descend in the atmosphere. Downward motion, or subsidence, is important, but we'll have to exclude this discussion for brevity. Fronts, terrain, upper-level divergence, shear and surface heating all contribute to upward vertical motion of the atmosphere. In an unstable atmosphere, vertical motion often leads to clouds, precipitation, icing, turbulence and, possibly, thunderstorms. Stable conditions can trap moisture and suppress lifting to produce a low overcast, reduced visibility or fog.

It's time for a bowl and marble analogy. The bowl represents the environment and the marble represents the air parcel. Place the marble in the center of the bowl. Push the marble away from the bowl's center and it will eventually settle back to its original position in the center of the bowl. This represents a stable environment. Now turn the bowl over and place the marble on the top. Bump the marble and it will immediately fall off, never to return to the top of the bowl. This represents an unstable environment.

Finally, there are cases where the environment is neutral or conditionally unstable. Place the marble directly on a level table. Given a push, the marble will move, but then stop in a new spot. Parcel theory lets us predict just how the parcel (marble) will react when lifted (placed in, on top of, or next to the bowl).

In order to determine if the bowl (environment) is right-side-up or upside-down, we must examine the environmental lapse rate, or the change of temperature with height. Don't confuse this with the "average" lapse rate. The lapse rate we're talking about is the change in temperature at a specific place, on a specific day, at a specific time. Small or negative lapse rates are indicative of a stable environment. In this case, the temperature changes slowly with in-

WHAT'S AN ADIABAT?

The term "adiabatic" rings familiar in the ears of many pilots, although few have ever been let in on the secret of what it actually means.

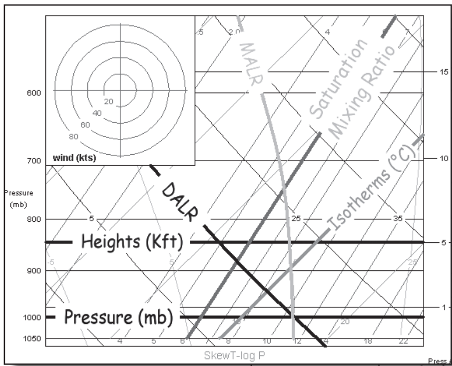
An adiabatic process for the purpose of parcel theory means that the parcel of unsaturated air that is being lifted is expanding and cooling at a constant rate and does not exchange heat or moisture (mass) with its surroundings. In other words, no heat is added and no heat is lost from the parcel during this lifting process even though the temperature is changing due to expansion and cooling. The parcel doesn't affect the environment and the environment doesn't affect the parcel—a parcel remains a parcel.

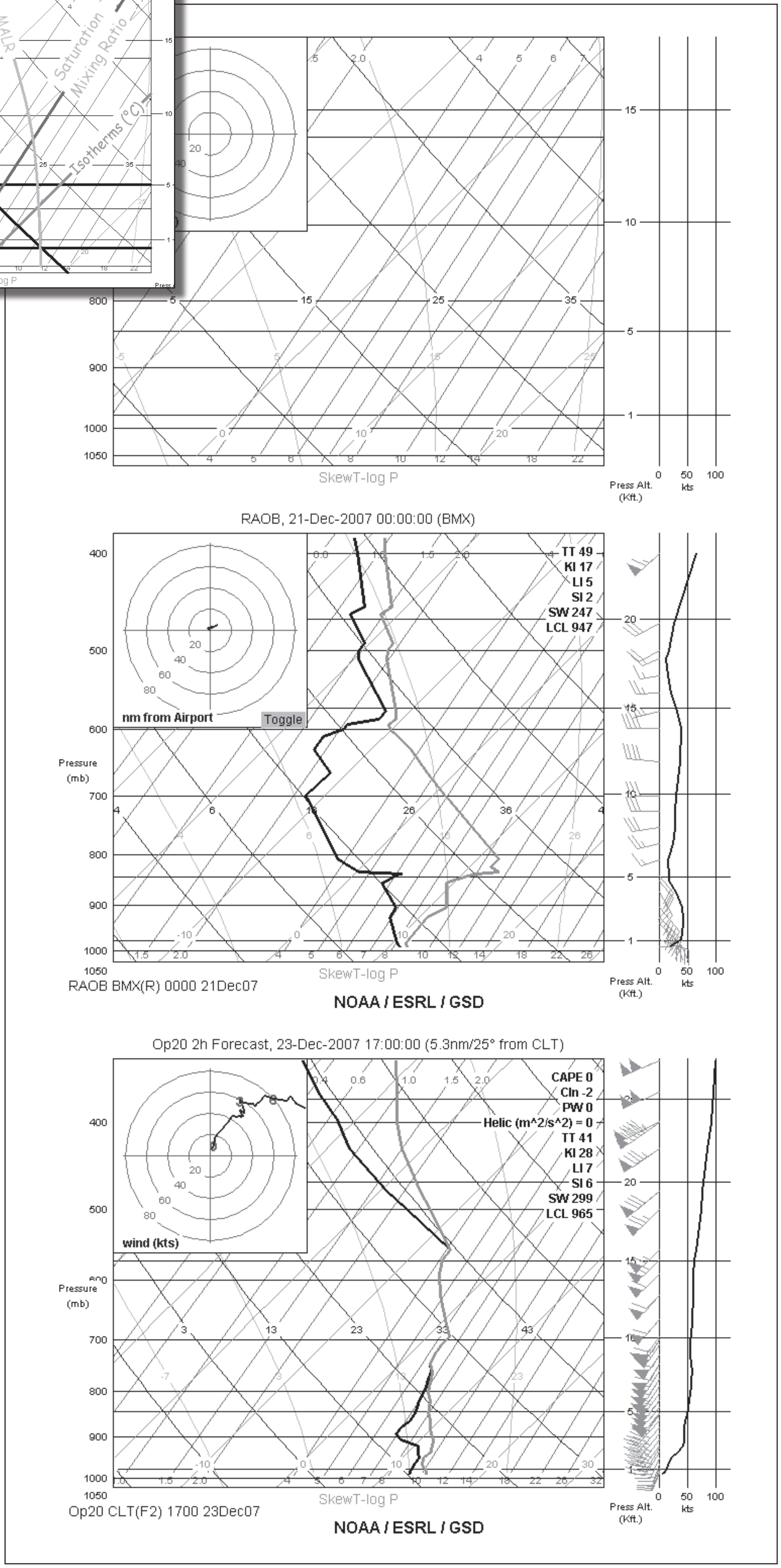
—S.D.

creasing altitude and the bowl is right-side up. Large (positive) environmental lapse rates are indicative of an unstable environment. Finally, when the environmental lapse rate is somewhere in-between, the environment is said to be conditionally unstable.

That's half the picture. Now we must separately look at the characteristics of a rising parcel of air. Let's examine dry air first. What happens to a parcel of unsaturated (dry) air as it rises? It will always expand and cool and it does this at a constant rate. It expands because it is rising into a region of lower pressure and cools due to the laws of thermodynamics. This rate is called the dry adiabatic lapse rate (DALR) and is about 3 degrees C per 1000 feet. This parcel is unsaturated, which means that it is not necessarily void of moisture but has a relative humidity that is less than 100 percent.

Assume the unsaturated parcel of air starts out at 20 degrees Celsius. When we lift this unsaturated parcel from 1000 feet to 2000 feet, it will expand and cool at a rate of 3 degrees Celsius per 1000 feet and be 17 degrees Celsius upon reaching





Right: *The blank Skew-T (top) serves as the grid on which observed data (RAOB) or forecasts are mapped. Shown here is the RAOB for Birmingham, Ala., valid at 0000 UTC on December 21, 2007 (middle) and a two-hour forecast from the Rapid Update Cycle (RUC) model for Charlotte, N.C., (KCLT) valid at 1700 UTC on December 23, 2007 (bottom). Note the small temperature inversion—the right-facing bump—in the middle image and the merged temperature and dewpoint—and probable cloud layer—in the lower one. Our key (top left) helps as you learn what each line means on the background grid.*

2000 feet. We can draw a line that is constant for any unsaturated air parcel and label it as the DALR. Notice that this says nothing about the environment around the ascending parcel—I'll address that in a minute.

Now let's look at a saturated (or moist) parcel of air. Saturation means 100-percent relative humidity (in other words, the temperature equals the dew-point within the parcel). When this saturated parcel of air is lifted it also will expand and cool just like its dry counterpart, but at a rate that is less than dry air. This is called the moist adiabatic lapse rate (MALR). This rate is typically less than the DALR because as the saturated air cools, water vapor condenses and releases latent heat back into the parcel—it warms up the parcel—effectively slowing down the cooling process. In a saturated condition, the parcel cools off at a slower rate than if it were unsaturated.

The MALR is not constant like the DALR; it varies with temperature. For very cold air, the MALR and the DALR are just about equal. For warmer air, the DALR is larger than the MALR. This is because at colder temperatures there is less thermal energy to do the work of evaporation, producing less water vapor in the air. Less water vapor means less condensation, which means less release of latent heat. As a result, colder saturated parcels have a similar lapse rate to any dry parcel. Warmer saturated parcels, on the other hand, have a smaller lapse rate than dry parcels at the same temperature.

The remaining line on the Skew-T / log (p) chart is the saturation mixing ratio. The saturation mixing ratio describes how the dew-point changes within a rising parcel of unsaturated air. It is the ratio of the mass of water vapor per unit mass of dry air. Our study assumes that no moisture or mass can be exchanged between the parcel and the environment (i.e., adiabatic). Therefore, if no mass is added or subtracted from the unsaturated parcel, this mass ratio remains the same as the parcel moves up or down. What this means is that the temperature of the rising parcel will cool in such a way that the temperature will merge with the dew-point within the rising parcel and will eventually saturate. Don't get hung up on this detail right now; you'll see the application in a future issue of *IFR*.

Flying the Skew

Discovering the magic behind the Skew-T log (p) diagram requires some study and practice. The theory matters when it comes time to put this stuff into practice. Your next challenge will be practicing reading some of these to get a sense of how they work. Look for changes in the lapse rates and spacing between the dew-point and temperature lines that indicate altitudes where conditions are changing. Find them online at http://rucsoundings.noaa.gov. The page isn't exactly user-friendly, but some experimenting will show you how it works.

We'll reward that study with another article that builds on your new knowledge and explores how to use a forecast sounding to find those cloud tops or that glassy-smooth cruise altitude.

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THE QUIZ

Instrument flying is often about following the numbers down to the decimal. Here's a quick quiz about some of the tolerances you're allowed in your IFR world. Answers on page 23.

1. Flying along an airway 50 miles from the VOR station you're tracking to, you look up from your Dean Koontz novel and see a CDI needle deflection just shy of full. How far off the airway are you?

- **a. One mile**
- **b. Over two miles but still in protected airspace**
- **c. Four miles and flying on the edge**
- **d. More than four miles and trolling for mountains**

2. Flying that same airway, still 50 miles from the fix, same needle deflection, but you're using an older IFR-certified GPS to drive your CDI. How far off are you now?

- **a. One mile**
- **b. About two miles**
- **c. Almost five miles**
- **d. Depends on how close you are to the station**

3. Same place, same CDI, but with that WAAS upgrade that was supposed to cost $1500 and actually set you back five grand. Now how far off are you?

- **a. One mile**
- **b. About two miles**
- **c. Almost five miles**
- **d. Depends on how close you are to the station**

4. You've checked your VORs per the regulations and they look fine. What's the maximum amount they could be off?

- **a. Four degrees**
- **b. Six degrees**
- **c. a or b**
- **d. There's really no way to tell**

5. Suppose your VOR test showed the number-one CDI was two degrees off and now it's time to shoot an ILS. You should assume your CDI for the localizer is:

- **a. Two degrees off**
- **b. Between 0.5 and 1 degree off**
- **c. Spot on**
- **d. You can't tell using a VOR test**