Skew T's – How to Read Them

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Compiled, Condensed, edited from many sources

Rising Air is our Engine!

Thermals & Instability: Sunlight, passes through the air without heating it, until it strikes something that absorbs it, and converts it to heat - such as a dark, plowed field, pavement, or exposed sunward facing rock face. Chlorophyll in grass and trees absorbs the sunlight perfectly without converting it to heat. Differential heating of the ground produces thermals. Yet, unless the air above it is cooler, it will not rise. How much cooler – determines how fast it can rise. This is called "Instability" or "Unstable" Air. It doesn't want to stay still! The air above is not holding it down (Stable).

Soundings: In the past, Radiosonde Balloons were sent aloft every morning at 0600 AM from Buffalo and other locations to record the temperature, dewpoint, wind direction and speed – at each altitude as it rose through the airmass. Now, satellites and can be used to measure, and computer models used to predict the characteristics of the Airmass over any location. The plots of these readings are called Soundings, and the graph is called a Skew-T diagram – due to the fact the same temperature line is plotted "Skewed" to the right". These plots present a tremendous amount of useful information to us as Soaring Pilots.

Motivation: Once you learn how to read these plots, you will be able to determine;

- Whether there is an Inversion that needs to be broken/mixed up to begin soaring
- Trigger Temperature – what surface temperature thermals will start
- What the max temperature can be expected for the day
- When that temperature is reached – how high the thermals will go
- Whether clouds will form, what altitudes, and how thick the layers may be
- Wind directions and speed at various altitudes-where to look for lift close to the ground/near clouds
- If there will overdevelopment, thunderstorms, or rain
- Overall – how good or bad the day will be, and what needs to happen to change it from what is forecast

Skew-T diagrams look pretty forbidding until they are explained to you, but, hopefully, I will provide enough guidance to enable you to take a quick look at them and draw conclusions about the kind of a soaring day is expected.

Where to get the Sounding Data: One of the best Websites is Bill Moninger's FSL website (http://www-frd.fsl.noaa.gov/mab/soundings/java/) Interactive Skew-T diagram. You will have to download and enable JAVA to view. If you are unable to use JAVA, use the HML5 button. If you enter the airport identifier, and the time you are interested in, it gives you a plot for that location. By dwelling the mouse pointer over the expected max temperature for the day at the surface altitude, and then click, it generates an additional plot that depicts the excess energy and condensation level, and convective levels expected.

Soaring Chart Forecast Websites: My Favorite website is XCSkies (http://www.xcskies.com/) which presents data from these plots and presents soaring forecasts. This website is updated throughout the day and is produced closer to the actual time we might be soaring.

Another useful Soaring website which also uses Skew-T information, yet produces multiple forecast maps: Dr. Jack's BLIPMAPS (http://www.drjack.info/BLIP/INFO/index.html). Both present charts, without your needing to interpret the Soundings info, yet, remember, you need to understand – and be advised- that pretty though they be, if the underlying numerical model is wrong, and it sometimes is, the forecast will be wrong. When you understand what the skew-T is showing, you are in a position to critically assess these forecast charts.

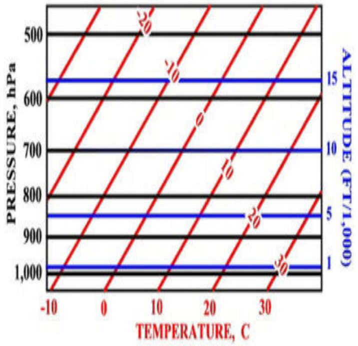
Parenthetically I note that although these diagrams are ideal as thermal soaring forecasts, they were developed as an aid by the government in forecasting convective storms. The enormous effort which goes into gathering the data, then accurately modeling it- is driven by the destructive potential of cyclones, hurricanes, and thunderstorms- not by our desire to have good soaring forecasts.

Design of the Skew-T Diagram

Skew-T's are graphs which display temperature and dewpoint data vertically in the earth's atmosphere. The constant temperature lines are "skewed" to the right as it goes up in altitude/pressure level. Additional lines are superimposed on the graphs, which are based on calculations which determine other valuable information we need to determine. These additional lines (dry adiabats, saturated adiabats, constant mixing ratio) were calculated by thermodynamic equations. Thankfully, we don't need to worry about the equations, and don't need to do any math. We do however need to understand what they represent.

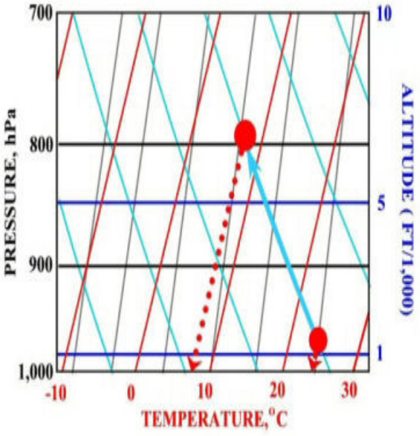
Temperature and Pressure Lines

The constant temperature lines are angled ("skewed") vertically to the right, and the decreasing pressure scale (altitude) is displayed horizontally / logarithmically. Therefore the official name is "Skew-T logP Diagram. These choices make the variables we will examine – easier to display by other lines. That is convenient when making extrapolations on a graph. For clarity, pressure altitude lines are added to the right. These altitudes maybe in feet above sea-level or Kilometers, depending on which agency produces the diagram.



Rate of Cooling (Lapse Rate): Air, as it ascends, expands, and because of this - it cools. Air, at the surface, holds a certain amount of suspended water vapor. As a parcel of air ascends, it cools at a given rate-called the Dry Adiabatic Lapse Rate (DALR) - until the air is so cold it can no longer keep the water vapor suspended. A cloud forms. It then ascends at the Wet, Saturated, or Moist Adiabatic Lapse Rate (SALR) . “Adiabatic” is a thermodynamic term meaning “rate at which temperature changes”.

Dry Adiabatic Lines



The dry adiabatic lines depict what happens to the temperature of a parcel of air as it rises before it becomes saturated (100% humidity). Because the density, and hence the buoyancy of air, depends upon its temperature and how much water vapor is suspended in it.

This is the first example of "calculating lines". They are depicted in cyan in this simplified skew-T to which are added only the dry adiabats. It depicts a red spherical bubble of air at the surface (in this case at 1,200 ft MSL and at a temperature of 23ºC) and tells us what happens when the bubble of air rises to about 6,000 ft MSL. This red spherical bubble is a simple model for of a thermal. As it rises, it cools, and the precise amount of cooling is determined by following the dry adiabatic lines. Note- because the temperature axis is skewed, care must be taken in choosing the correct temperature. The red dotted arrow shows how the temperature is derived by projecting down from that altitude to the surface temperature. Note - often there is no dry adiabat coinciding with the surface temperature (fog) - when this happens it is easy enough to construct it for prediction purposes.

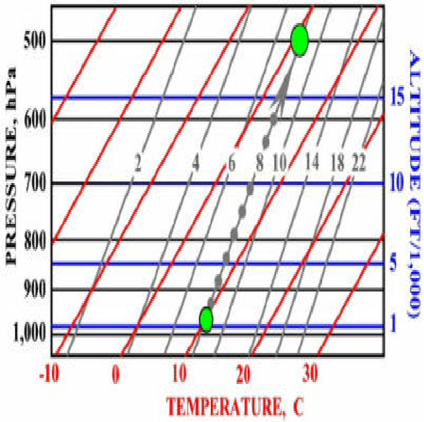
By the time the bubble is at 6,000 ft it has cooled to 8ºC and has expanded by about 20%. The cooling is driven by the expansion of the bubble. As it rises the pressure of the surrounding air decreases and the bubble expands and does work pushing away the enveloping air. It is this work, achieved by tapping the internal energy of the bubble, which is responsible for the cooling.

An adiabatic process is one which takes place without exchange of heat with the surroundings - so, in assuming an adiabatic process, we are assuming that the parcel of air maintains its identity and does not mix with the air through which it is moving. This is an acceptable assumption, at least in the sense that it yields useful and consistent results.

"Dry" in DALR does not mean quite what it says, since air is never dry. Specifically it means that no condensation has yet occured. Notice – this rate is slightly more than 3°C per 1000ft. When condensation does occur, the Saturated Adiabatic Lapse Rate (SALR) takes over. We will consider the SALR lines latter when considering what goes on above cloudbase.

Lines of Constant Mixing Ratio (Cloudbase)

We started with the empty skew-T logP graph to which we added dry adiabats. To describe what happens to the dewpoint of a rising parcel of air we need to add more lines - the lines of constant mixing ratio (depicted here by gray lines with the



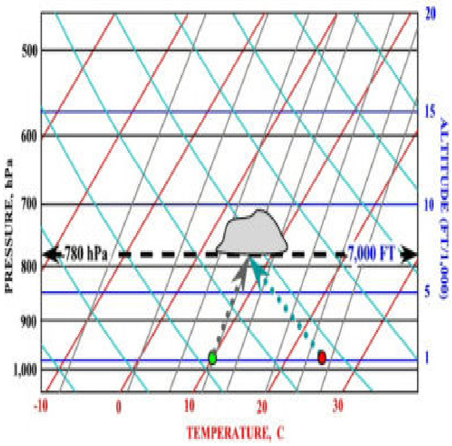
number of grams of water the parcel can hold when saturated). Where these lines intersect with the DALR determine where the water vapor will condense and form a cloud. We know from the dry adiabats how quickly the temperature cools with ascent of the bubble.

To predict whether or not clouds will form we need to know how the dewpoint of the bubble changes during its ascent. Lines of constant mixing ratio tell us. The "mixing ratio" is the concentration of water vapor in the air, expressed in grams of water per kilogram of air. Since this is a mass ratio (as opposed to a volume ratio), it does not change as the bubble expands. However, the dewpoint does change. A surface bubble with a dewpoint of about 10ºC has a dewpoint of about 2ºC at 18,000 feet.

To re-iterate: Lines of constant mixing ratio tell us how the dewpoint of a bubble changes with altitude. The mixing ratio line passing through the surface dewpoint tells us what the dewpoint of the lifted surface parcel is at any height. Since the temperature of rising air falls faster than does the dewpoint, unchecked ascent always results in cloud formation.

The origin of the decrease in dewpoint as a parcel ascends and cools is the associated expansion as the pressure drops. This expansion causes cooling, as we saw when considering the dry adiabats, but it also increases the average distance between water vapor molecules. Since condensation *ipso facto* involves an agglomeration of molecules, it is to be expected that having fewer molecules in a given volume will result in a lower dewpoint - i.e. the air will have to be colder to force condensation to occur.

Making Cumulus Clouds



We are now in a position to understand how the Skew-T handles clouds. Suppose we start with a surface parcel of air having a temperature of 25ºC and a dewpoint of 10ºC as depicted here . If the bubble is lifted from the surface to 7,000 ft its temperature drops to about 8ºC, and its dewpoint will drop to the same temperature: Since the dewpoint and temperature become equal at 7,000 feet condensation must occur, and a cloud forms.

The widely used formula for cloudbase is a consequence of the differing rates of change of the temperature and dewpoint of a lifted parcel of air.

DRY TEMPERATURE LAPSE RATE = 5.3 °F / 1,000 FT. (approximately) 2.5°C/1000ft

DEWPOINT LAPSE RATE = 0.9 °F / 1,000 FT (approximately) .5°C/1000ft

CLOUDBASE = ((T - DP) / 4.4) * 1,000 FT ((Temp°C - DP°C)/2*1000ft

It is comforting to see that our first use of the Skew-T diagram predicts a familiar result.

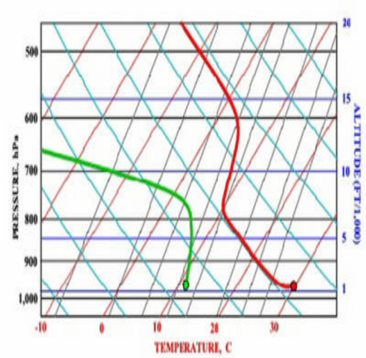
Our use of this feature of the chart occasionally fails since cumulus clouds never appear, especially if the air above the surface is significantly drier. The reason for this will soon become clear, as will the folly of relying too heavily on blind application.

Lapse Rates

The Skew-T diagram does double duty: It depicts by displaying lines - the calculations of the change in the temperature and dewpoint of a rising bubble in the absence of condensation, and the change in the temperature of a rising bubble where condensation is occurring - and it presents observed data. Perhaps it is this dual role which gives rise to some of the confusion which Skew-T's occasion. Further confusion arises because the term "lapse rate" also does double duty.

There are four lapse rates with which we will be dealing: The dry adiabatic, the saturated adiabatic, the temperature, and the dewpoint. Since the term "lapse rate" tends to get used imprecisely, thisI will make the distinction clear: The first two, the dry and saturated adiabatic lapse rates are calculated (using the adiabatic approximation) and that is why both always appear unchanged on every Skew-T plot. The second two, the temperature and dewpoint lapse rate are measured (or in the case of numerical model soundings, predicted values at the valid time of the forecast).

In the next illustration I have superimposed data lines upon the calculating lines, and it will now become apparent why the Skew-T diagram is so useful. The solid red line is the temperature of the air at the designated altitude. It's important to appreciate that every point on this line represents the actual or forecast temperature of the air at a given height.



From this plot, there are three regions of interest, three different lapse rates, in the red line: Close to the surface, the temperature decreases rather rapidly with increasing height. Then, from about a few hundred feet above the ground to about 6,000 feet, the temperature decreases at the DALR. From 6,000 ft the temperature decreases much more slowly. We need to understand why each region is the way it is, and what this implies for thermal forecasting.

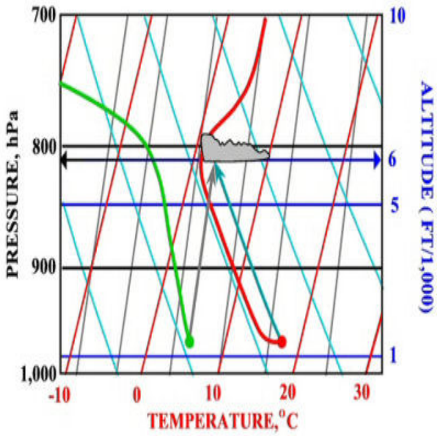
The lowest layer in this case, referred to as the "super adiabatic layer" exists courtesy of the sun. Its existence is of kinetic, not thermodynamic origin. As soon as the forcing insolation (heating) is cut off, it decays because any vertical displacement will result in the air finding itself in colder air. It is "unstable" in exactly the same sense that a rock on the edge of a cliff is unstable - a small push and it's gone. In the East super adiabatic layers are generally thin, akin to pushing off a small, shallow hill. In the West, this layer can grow to many hundreds of feet under sufficient sunshine, the equivalent of rolling the rock off the cliff. This is origin of dust devils which break loose with great energy, and rise to 15,000 feet or more.

From a few hundred feet above the surface to about 6,000 ft the temperature tracks the DALR - this is no accident: This depicts the area thermals will form. As the ground heats, and thermals mix up the air, so that its actual lapse rate inevitably becomes approximately dry adiabatic as long as the sun is shining.

Inversions: The next layer is generally referred to as an inversion. "Inversion" means the temperature remains the same, or increases with altitude. In this example, as is often the case, the temperature continues to drop with increasing height, so strictly speaking there is no inversion, however, the air above 6,000 feet is getting colder with increasing height a lot more slowly. On a blue day, it is the lowest lying inversion which caps the lift, and although this seems to place inversions in a poor light, their absence can cause problems, as I will show later on.

Dewpoint / Dewpoint Spread: The depicted solid green line is the dewpoint. If at any point the plotted dewpoint data touches, or is very close to the actual temperature plot – a cloud layer will form. If the dewpoint diverges away from the temperature plot, this indicates the air is drier. In this case, the shape is typical of a thermal soaring day, particularly in the tendency for the dewpoint and temperature to converge in the vicinity of the inversion and this too is no coincidence and has consequences discussed later.

Can We Soar?



We might as well start with a good day, so here's one I made up. It's typical of a good spring day in the East. The red line is what the model predicts the temperature lapse will be. The red dot is what the model predicts the average surface temperature will be. The cyan arrow follows the surface adiabat and because it is displaced from the temperature by about 2.5 C° to over 6,000 ft. this is a pretty unstable day. The greater the displacement, the greater the instability, the stronger the lift.

The green line and green dot are what the model predicts the dewpoint lapse rate will be. I have constructed the constant mixing ratio line passing through this value. That line intersects the surface adiabat below the inversion, telling me that on this day lift will be marked by cumulus cloud. Note - at cloudbase, the air is still forecast to be 2.5 C° warmer than its surroundings, so on this day I would not expect lift to decrease with increasing height, as sometimes happens.

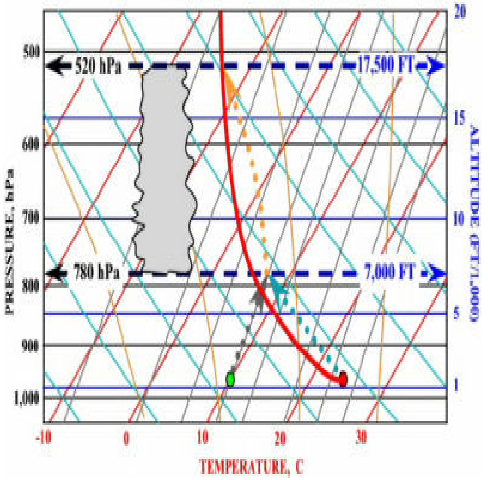
The dewpoint is well behaved, so I would not anticipate cumulus spreadout, and the inversion is more than enough to cap cloud growth, so overdevelopment is not predicted. I will discuss these two critical elements of the soaring forecast later.

I am going to repeat much of what I said about the good day with cu, since I want to be sure everyone gets the picture, so here is what a good day without cu looks like. The red line is what the model predicts the temperature lapse rate will be. The red dot is what the model predicts the average surface temperature will be.

The cyan arrow is the surface adiabat and is displaced from the temperature by about 2.5C to over 6,000 ft. so it's a pretty unstable day.

The green line and green dot are what the model predicts the dewpoint will be. I have constructed the constant mixing ratio line passing through this value. That line intersects the surface adiabat above the inversion, telling me that on this day lift will not be marked by cumulus cloud, and as a result, lift will be capped by the inversion.

What Goes on Above Cloudbase



When condensation occurs, the Saturated Adiabatic Lapse Rate (SALR) comes into play. Condensation releases heat - in the case of water vapor condensing to liquid water, large quantities of heat (7.5 Times than to evaporate at 440 cal./gram/C). Enough heat to drive convective storms and hurricanes.

We now add (orange) saturated adiabats. Observe that these lines and the dry adiabats (cyan) have a dramatically different slope at lower altitudes where the atmosphere is able to hold more water than it can at higher levels. Above about 500 hPa the saturated adiabats have the almost the same slope as the dry adiabats.

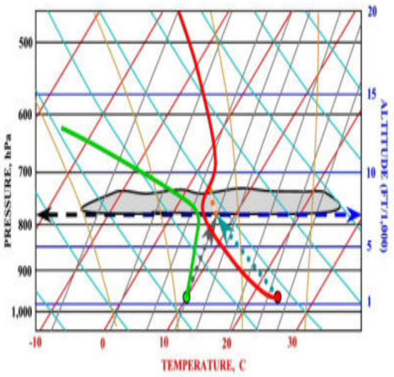
Air undergoing condensation as it ascends cools more slowly than does non-condensing air because of the release of latent heat from the vapor/liquid phase transformation.

From this example, the area of the figure below 780 hPa ought by now to look pretty familiar: Unstable surface air at about 24°C ascends until, at 7,000 ft its temperature and dewpoint are the same, at which point condensation occurs. So far so good, after all we want cu don't we?

The problem here is that there is no inversion in the vicinity of cloudbase. As soon as clouds form, the dotted orange adiabat SALR takes over and the cloud will grow to about 17,500 ft. If a cloud grows to above the freezing level (which this one easily does - the temperature lapse rate crosses the 0 degree dry adiabat at 700 hPa) rain can form.

Not obvious from my illustration is that when convection extends to heights where winds are much stronger, those winds can mix down to the surface. My figure was adapted from the forecast sounding for a contest day at Mifflin County a few years ago. Although it was a generally good day, we saw isolated heavy rain showers and a 60 mph gusts at the field. This is why, at least on days with cu, we need an slight inversion to prevent overdevelopment, or Nimbus development, or at worst Thunderstorms.

CU Spreadout ("Over Development")



Many good soaring days are ruined by overdevelopment, or as I prefer to call it, spreadout. The cause of spreadout is predicted on inspection of this Skew-T example:

In the vicinity of cloudbase the dewpoint and temperature of the general airmass (i.e. all of the air NOT in thermals) are rather close to one another. Humidity is thus high, and dispersal of clouds through evaporation is slow.

If a temperature difference of less than 3°C at, or in the vicinity of cloudbase, there is a good possibility of spreadout. The smaller the difference, the greater the chance. It may seem historically, that the dewpoint so frequently approaches the temperature at the inversion, but this is no accident: The moisture is transported there by convection, and prevented from rising by the inversion.

Winds

Usually on the right hand side of the Skew-T is a vertical bar graph depicting wind barbs which depict direction (magnetic) and speed (knots) at the various altitudes. Whether the observed data, or predicted/forecast data, they are most helpful to determine where to look for thermals in relation to the surface, when low, or near cloudbase, when high.

Direction changes greater than or close to 90 degrees at any level will cause significant shearing of any thermals. Generally, a light wind of 5 knots will aid in the release of thermals from the surface tension, break bubbles into rising columns, and allow mixing and ground cooling that helps regular thermal generation, and often earlier than predicted triggering of thermals.

Significant speed increases can predict the same mixing effects. Wind speed in excess of 15-20K will begin to fragment and make thermals irregular and choppy. Occassionally, a wind shift of 90 degrees at cloudbase, will make it possible to climb up the side of cumulus, sometimes even above the thermal lift band.

The Effect of Moisture on Buoyancy

Because air is never completely dry, and since humid air is less dense than dry air, addition of water vapor decreases the density. Buoyancy depends on the density difference between the thermal that transports this parcel of air and the overlying airmass, we must account for the effect of water vapor. Another way of stating this is – Dry Air will have more momentum once it is motivated to move than more Humid Air. More Humid Air will cool at a slower rate when lifted, yet requires more energy to start the lifting process.

The effect is significant. It is accounted for by calculating the temperature the air would be at if it were dry, and of the same density. That temperature is known as the virtual temperature. On a typical East Coast soaring day the virtual temperature at the surface is about 2C degrees higher than the 2 meter surface temperature used for observations. The formula for calculating virtual temperature (Tv) is:

$T_v = T + W/6$ (approximately).

where T is the surface temperature in degrees C and W is the mixing ratio in grams of water/kg of air.

Incidently, what is displayed on every government Skew-T diagram that I am familiar with is the uncorrected temperature, not virtual temperature so I generally make the assumption (not completely true) that a correction in the surface temperature can be made. This mostly effects the predicted height of clouds, which will actually be higher.

Cirrus and other Clouds

General weather forecasts will usually include terms such as "partly" or "mostly" cloudy but they never say what kind of cloud. TAF and MOS (Model Output Statistics) forecasts are more helpful since they give the heights of cloud layers. Any Skew-T will make it clear the height and thickness of any cloud layer because the dewpoint and temperature lines will be close whenever cloud is likely.

Summary

The Skew-T diagram captures for a point on the surface the profile of the atmosphere above that point. It presents a complete picture of the temperature, the dewpoint and the wind speed and direction from the surface to about 80,000 ft. In addition to presenting a great deal of data in a highly compact form, the Skew-T also makes it simple to perform a variety of "what if?" calculations through the overlay of dry and wet adiabats, and lines of constant mixing ratio.

These diagrams are ideally suited to producing thermal soaring forecasts. With a little effort anyone interested in cross-country soaring (or even just staying up for that matter) can get a very good feel for the day with just a few minutes spent studying them. Even those pilots relying upon others for their forecasts would do well to take a look at the underlying data, and there is no better way to do that than the Skew-T.