Austin's Very Easy Guide to
Basic Principles and Concepts of Weather

2012 Revision 1

THINGS CHANGE OFTEN! CHECK MY WEB SITE PERIODICALLY TO ENSURE THAT YOU ARE USING THE MOST RECENT VERSION.

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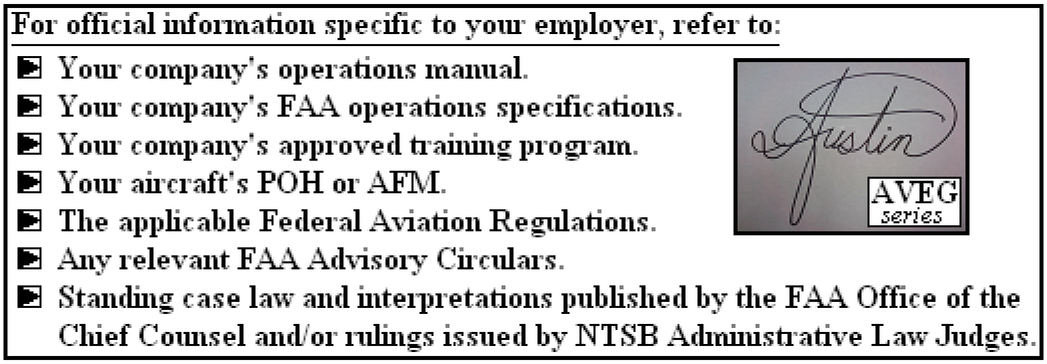

For official information specific to your employer, refer to:

- Your company's operations manual.
- Your company's FAA operations specifications.
- Your company's approved training program.
- Your aircraft's POH or AFM.
- The applicable Federal Aviation Regulations.
- Any relevant FAA Advisory Circulars.
- Standing case law and interpretations published by the FAA Office of the Chief Counsel and/or rulings issued by NTSB Administrative Law Judges.

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Although much of the information contained in this series is generic and could potentially apply to many areas of aviation, it is designed specifically as a study aid for those pilots engaged in on-demand Part 135 single-pilot IFR cross-country operations in small reciprocating aircraft. **THIS MATERIAL IS NEITHER ENDORSED BY NOR APPROVED FOR ANY SPECIFIC OPERATOR. IT IS GENERAL INSTRUCTIONAL AND GUIDANCE INFORMATION ONLY!**

PREFACE

Allow me to begin by explaining what this booklet *isn't*. It isn't a comprehensive course in meteorology. I am not an expert in meteorology. There are many excellent books available if you are seriously interested in the advanced study of this fascinating and complex set of interdisciplinary sciences.

Although I am by no means an authority on the subject, I do find weather extremely interesting. The sky, like the sea, is a source of endless awe and wonder. And as a pilot, I find that a solid working knowledge of the basic principles and concepts of weather is essential for making intelligent aeronautical decisions in real time.

I have been flying since 1988 and I have been a flight instructor since 1998 and a Part 135 Check Airman (examiner) since 2001. During that time, I have given thousands of hours of initial and recurrent ground and flight training and I estimate that I have given approximately 1,000 checkrides. One thing I have seen over and over again is that many pilots, although they have memorized a lot of technical jargon and terminology for the purpose of passing multiple-choice tests, don't really have a firm grasp on the topic of weather. The prevailing philosophy among such pilots is: look at the radar picture. Don't fly through the yellow, orange or red stuff. That strategy is adequate up to a point, but a deeper and broader understanding can help facilitate making the more complicated assessments and judgments.

This booklet is therefore designed to provide a brief summary overview of some of the most fundamental aspects of Earth's weather. It may be used as an introduction for student pilots or as a refresher and review for more experienced pilots. My primary intended audience, however, is pilots conducting Part 135 IFR-PIC operations in light piston aircraft.

THE TROPOSPHERE

The ***troposphere*** is the segment of the atmosphere that contains almost all of the weather that directly concerns human beings living on the surface of the planet. It goes from ground level up to an altitude of about 20,000 to 60,000 feet. (The top of the troposphere is lower at the poles and higher at the equator.) Since pilots operating under §135.89 cannot fly above 10,000 feet for more than 30 minutes without supplemental oxygen, everything I am going to talk about here will pertain to the troposphere. (The boundary where the troposphere ends and the ***stratosphere*** begins is called the ***tropopause***. It is the place where temperatures stop getting lower and start getting higher again. Turbojet pilots must learn about high-altitude weather, i.e., weather in the stratosphere.)

WIND

Here's a standard FAA test question for you: "What causes wind?" The standard FAA answer is: "Pressure differences." Most pilots, even student pilots, can quote that like a parrot. But what does it really *mean*?

Differences in ambient air pressure are caused largely by ***differential heating of the Earth's surface***.

Even though all areas within any given geographic region receive about the same amount of sunlight from above, some parts – such as a wet, grassy field – will not heat up as rapidly as other parts – such as a dry, black, paved parking lot. This is because all materials have a property known as ***specific heat***. Specific heat refers to the specific amount of heat that you have to add to a substance to cause it to change its temperature.

Water, for instance, has a very *high* specific heat. You can dump energy – in the form of sunlight – into it all day long but its temperature does not change much. I'm sure you've noticed that it takes a long time to boil water; that's why. Metal, on the other hand, has very *low* specific heat. Have you ever left a fork or a knife next to the burner on your stove? Even if you only left it there for a few seconds, it got very, very hot very fast, didn't it? It has low specific heat. If you put that knife or fork in the freezer, it will get very, very cold very fast. If you put a pot of hot water in the freezer, however, it will tend to *stay* hot for a while. Due to water's high specific heat, it resists changing temperature. It will eventually cool off and then freeze, but it will take it much, much longer than it took the knife or fork.

Therefore, the presence of large bodies of water tends to exert a powerful moderating influence on the local climate. Have you ever noticed that the state of Florida is at roughly the same latitude as many of the great deserts of the world (the Chihuahuan desert of Mexico, the Sahara desert of Africa, the Persian desert of the Middle East and the Thar desert of India)? The fact that the peninsula is surrounded by the Atlantic Ocean, the Caribbean Sea and the Gulf of Mexico means that the highs do not regularly soar above 110º F during the afternoon nor do they plunge below freezing every night. Water moderates weather. Think of it as a shock absorber dampening out temperature dips and spikes.

Now back to the idea of differential heating of the Earth's surface. Sand or dirt, especially when it's dark and dry, has a relatively low specific heat. It doesn't take much energy (sunlight) to make it get extremely hot, as anyone who has ever walked across a beach barefoot on a summer afternoon can tell you. It also cools off very rapidly. This is why an arid plain can be searing at noon but frigid at midnight. A moist or shady section of the landscape – such as a marsh or swamp – receives the same amount of sunlight, but, unlike the parking lot or the dry, dusty field, it does not get very hot very fast.

Question: Is the atmosphere heated from above or below? Although it may seem counterintuitive, the atmosphere is actually heated from *below*. Air is invisible to sunlight. Sunlight warms the ground. The ground then warms the air. So the atmosphere is heated from the bottom up. The air directly above a hot surface, such as a parking lot or a dry, dusty field, will get hotter faster than the air directly above a cool surface such as a marsh or swamp. On a larger scale, the air above some large regions such as states or even continents will get hotter faster than the air above other large regions. This differential heating, on a micro, meso and macro scale, causes pressure differences which then cause air currents.

Here is a simple, classic example:

During the day, the sunlight heats the land. The ocean, which has high specific heat, receives the same amount of sunlight but remains relatively cool. So the air over the land is heated. It becomes less dense. It exerts less pressure. It rises. The air over the water remains relatively cool and dense. It exerts more pressure. It sinks. The sinking, high-pressure air over the ocean flows ashore. This is called a ***sea breeze***. You feel it whenever you go to the beach.

At night, the entire process reverses. The land, which has low specific heat, loses its heat very quickly by radiating it away into space. The ocean, which has high specific heat, retains its heat and stays at a relatively constant temperature. Now the air over the water is warmer and less dense; the air over the land is cooler and denser. The sinking, high-pressure air over the land flows out to sea. This is called a ***land breeze***.

Air always wants to flow from high pressure areas into low pressure areas. On a weather chart, ***isobars*** are lines of constant pressure. They form concentric rings around high and low pressure areas. The closer together the lines, the stronger the ***pressure gradient force***. The farther apart the lines, the weaker the pressure gradient. The strength of the wind is generally proportional to the pressure gradient force – the stronger the pressure gradient, the stronger the wind; the weaker the pressure gradient, the weaker the wind. [See Fig. A.]

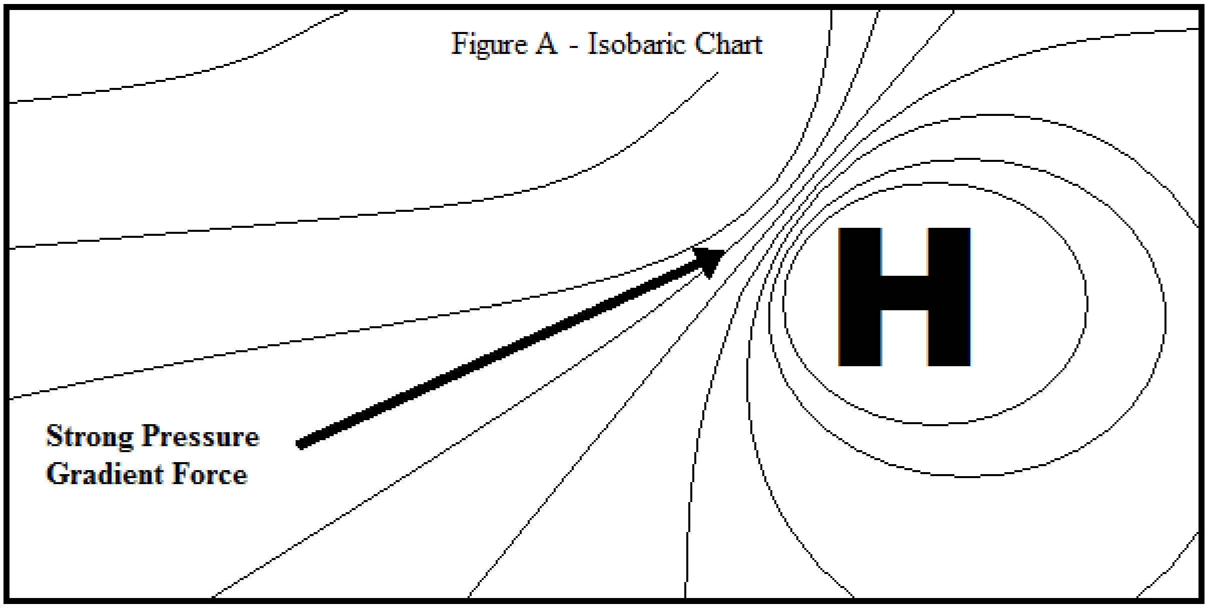


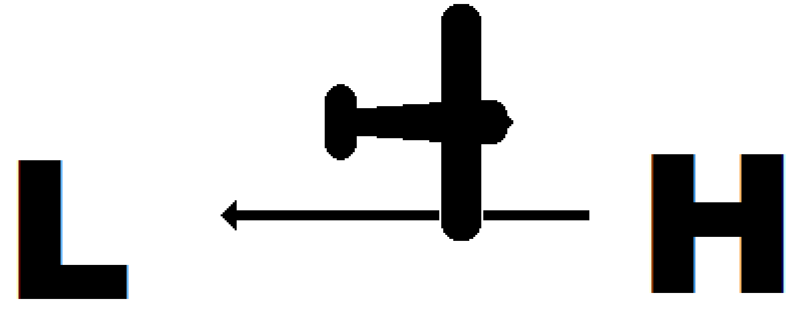
Figure A - Isobaric Chart

Wind tends to flow across the isobars from high to low. But! The Earth rotates. The rotation of the Earth *bends* the wind, deflecting its course like a ball rolling in a curved trajectory across the flat surface of a spinning playground merry-go-round. This is called ***Coriolis force***. A popular and pointless argument is whether Coriolis force is really a “force” at all. Well, it’s really more of an effect – or, to be even more accurate and precise – an *apparent* effect. The wind is just trying to travel in a straight line away from high pressure and towards low pressure; it seems to travel along a curved path because the planet is revolving on its axis and we are revolving with it. But “Coriolis apparent effect” is quite a mouthful, so for the sake of keeping things easy I’m just going to stick with Coriolis force. Can everybody live with that? Good. Moving on . . .

In the Northern Hemisphere Coriolis force deflects wind to the *right*. As a result, air tends to flow more *parallel* to the isobars rather than across them. Near the ground, surface friction slows the wind. It is therefore *less* affected by Coriolis Force and tends to flow more *across* the isobars. Up at higher altitudes, the wind generally blows harder. It is therefore *more* affected by Coriolis Force and tends to flow more *parallel* to the isobars.

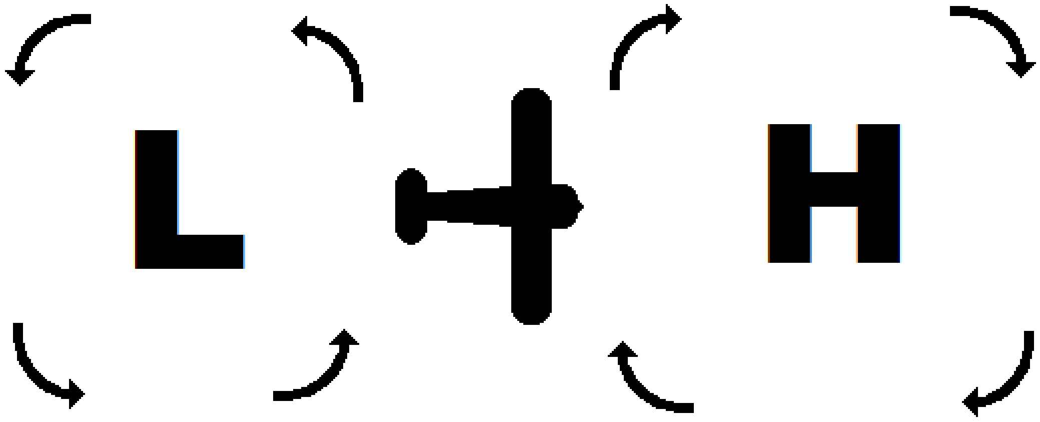
Imagine a low-pressure area over Westburg. Now imagine a high-pressure system over Easton. You want to fly directly from Westburg to Easton on a magnetic heading of 90º. Down low, the air is slowed by surface friction. So it wants to flow across the isobars directly from the high-pressure center over Easton towards the low-pressure system over Westburg; you will have a headwind on your nose. [See Fig. B.] At a higher altitude, however, the air is rotating counter-clockwise around the low-pressure center over Westburg and clockwise around the high-pressure system over Easton. You will have a crosswind from the south. [See Fig. C.]

Figure B - Low Altitude



(He has a headwind.)

Figure C - High Altitude



(He has a crosswind.)

Winds aloft are extremely complex and influenced by factors far too numerous to list here, but as a very rough, very general rule of thumb *as you climb higher, the wind will often shift to the right* due to Coriolis force.

Looking at national weather maps, you will often see the weatherperson pointing to large Hs and Ls surrounded by concentric isobars. These are centers of high pressure and centers of low pressure. These large-scale pressure systems, in conjunction with the jet stream (which I'll get to on page 13), drive most of the weather that we have to deal with on a practical daily basis.

You may visualize a ***high-pressure system*** as a huge *dome* of air which is *sinking*, *spreading out* and rotating *clockwise* (in the Northern Hemisphere). High-pressure systems generally bring fair weather.

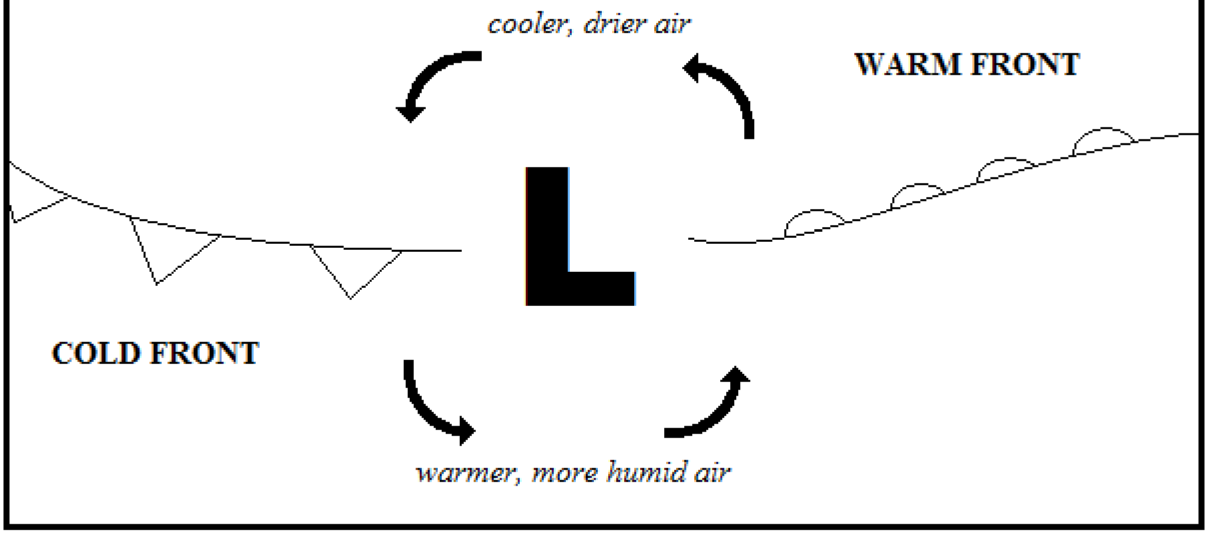
You may visualize a ***low-pressure system*** as a huge *vortex* of air which is *rising*, *converging* and rotating *counterclockwise* (in the Northern Hemisphere). Low-pressure systems generally bring poor weather. The ultimate example of a low-pressure system is a hurricane. On a much smaller scale, a tornado is an extremely small but also extremely strong low-pressure system.

Forgive the ludicrous simplification, but high- and low-pressure systems act as giant cog wheels in the troposphere, setting air masses in motion and causing them to collide with each other like bumper cars at an amusement park. Remember that air rotates clockwise around a high and counterclockwise around a low. This would result in nothing but wind if all the air were of more or less the same temperature and had more or less the same moisture content. But in reality, the situation is much more complex than that. Which brings us to . . .

AIR MASSES

An ***air mass*** is a giant section of the troposphere which has relatively uniform properties of temperature and moisture (looking at a horizontal "slice"). For example, to the north of that low-pressure system over Westburg you might have a cooler, drier air mass. To the south of that same low-pressure system you might have a warmer, more humid air mass. Because a low-pressure system rotates counterclockwise, this would cause the cooler, drier air mass to advance on the warmer, more humid air mass on the west side while causing the warmer, more humid air mass to advance on the cooler, drier air mass on the east side. [See Fig. D.] (This is, of course, a highly simplified and idealized example. The reality is almost always far more complex.)

Figure D - How a Pressure System Creates Fronts



The boundary between two air masses is called a ***front***. When warm air overtakes cool air it's called a ***warm front***. When cool air overtakes warm air it's called a ***cold front***. The *direction of movement* of the boundary, then, is what makes this determination. When the boundary does not move it is called a static, stationary or quasi-stationary front. When one front overrides another one it is called an ***occluded front***. If you have ever seen one ocean wave overtake another ocean wave and break on top of it, causing a confused swirl of circulation and counter-circulation, you have seen an excellent small-scale analogy for an occluded front.

Let's say you are inside an air-conditioned building on a hot summer day. When you open the door, warm, humid air will immediately begin to flow in and cool, dry air will immediately begin to flow out. If it were possible to see this, you would witness a glob of cool, dry (denser) air spilling outward through the bottom half of the doorway, spreading along the ground and a glob of warm, humid (less dense) air spilling inward through the top half of the doorway, spreading along the ceiling. You have just created two fronts. There is a warm front inside your house; there is a cold front outside your house. Now close the door. You're wasting energy.

A lot of bad weather (but certainly not all) is often associated with frontal activity. In fact, many pilots (as well as people in general) seem to think that the term "front" refers not to the boundary between two air masses (which it is) but to an area of bad weather (which it isn't, necessarily). It is quite common to have a front with no bad weather associated with it at all.

Some of the worst weather in the world can be found in ***squall lines***. A squall line is a narrow and often mostly unbroken band of steady-state thunderstorms usually found *ahead of* a fast-moving cold front. The term "steady-state" refers to the fact that a squall line thunderstorm does not follow the usual three-stage life cycle of a thunderstorm (cumulus, mature and dissipating). It just churns and churns, remaining at the most dangerous phase (mature) continuously. Squall lines often contain violent wind shear (including microbursts), hail, tornadoes, torrential rain and frequent lightning. Squall lines happen because a fast-moving cold front can generate a sort of "shock-wave" effect out in front of it; if the air is (A) moist and (B) unstable then this "shock-wave" effect will create a squall line. It's not really a shock wave, of course – it's just vertical displacement. But that's a useful metaphor.

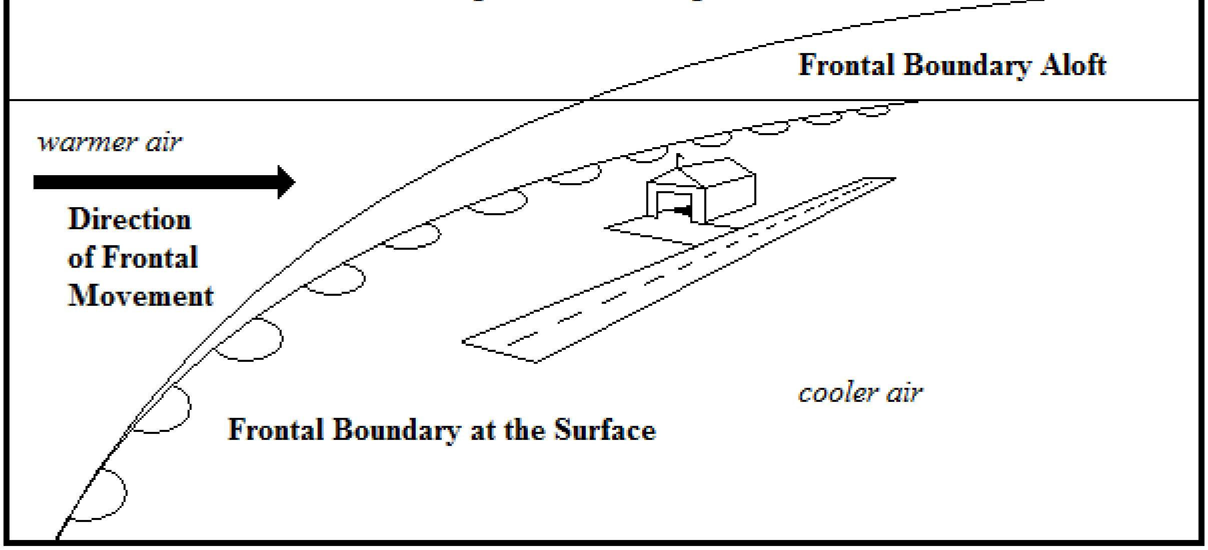
Squall lines are extremely hazardous and should be avoided at all costs. One good thing about a squall line is that it almost always passes over very quickly. One smart tactic for dealing with a squall line is to land, tie the airplane down securely, go inside the FBO, have a cup of coffee and wait for the line of severe weather to pass over. Once it has, then go back outside, sump the rainwater out of the fuel tanks and take off again on the back side of the system. Never attempt to penetrate a squall line.

Looking at a profile view of a front you can see that it has a *slope*. The slope of a cold front is usually much steeper than the slope of a warm front. The one thing that will always occur with frontal passage is a wind change. The wind may increase, decrease or switch direction but it will always change. Other things, such as relative humidity, barometric pressure and temperature may change as well, but not always. This wind shear may occur with frontal passage at the surface or it may occur when you fly through the frontal boundary. In either case, expect it.

When conducting flight planning, it is helpful to think in 4-D: visualize the atmosphere in 3-D and then add the dimension of time. The troposphere is dynamic, not static. Consider not just the current frontal position, for example, but the anticipated movement of the front along your proposed route during the proposed time en route.

Suppose there is a warm front approaching an airport. You are concerned about the potential for wind shear *above* the airport. When will the greatest hazard for wind shear exist *above* the airport – before frontal passage, after frontal passage or during frontal passage? The answer is *before* frontal passage. Visualize the slope of a warm front, beginning at the surface and then curving in an arc over the top of the airport. [See Fig. E.] If it were a cold front (i.e., if it were moving in the opposite direction), the greatest hazard for wind shear above the airport would be *after* frontal passage. And in either case, the greatest hazard for wind shear *at the airport surface* would be at the moment of frontal passage.

Figure E - Visualizing a Front



THUNDERSTORMS

Thunderstorms may be related to frontal activity or they may exist independent of frontal activity. Thunderstorms can even create their own small-scale fronts (called ***gust fronts***).

All thunderstorms, by definition, contain lightning. Lighting is caused when static electrical charges build up in the atmosphere due to agitated water droplets rubbing together. (It can also result from the friction between other atmospheric particulates, such as snow or volcanic dust.) The sudden discharge (release) of these massive static charges is lightning. Lighting can travel from cloud to cloud or from cloud to ground. Although it very often originates within thunderclouds, lighting can (and does) sometimes come from clear air.

I hate thunderstorms! I'm sure you do too. They are terrifying and dangerous. As pilots, we should seek to understand them, predict them and most of all *avoid* them! Unless you have the luxury of simply not flying when there are thunderstorms out there somewhere, avoidance often requires careful strategizing.

Generally speaking, the more frequent the lightning the more intense the storm. This is one of the clues you can use in flight to determine how dangerous a particular storm cell is and by how much of a margin you need to avoid it. Constant, heavy lighting suggests that it may be a severe cell. No lightning suggests that it may be no more than a harmless rain shower. Another excellent indicator is cloud tops. The higher the tops, the stronger the storm. A storm with a 10,000-foot top is going to be less dangerous than a storm with a 40,000-foot top. The presence of an anvil structure at the top of a cumulonimbus cloud often indicates a powerful and hazardous storm. The intensity of precipitation is a useful gauge as well. The heavier the precipitation, the stronger the storm. Finally, the speed of cell movement can be a very reliable gauge of its intensity. A fast-moving cell is almost always a strong one.

It is worth mentioning here that the ONLY thing radar shows you is precipitation! This, by itself, does not always tell you everything you need to know. It is absolutely possible to have severe turbulence in clear air. It is also possible to have a relatively smooth ride through fairly heavy, steady rain (or snow). So radar, while very helpful, does not tell the whole story! Do not rely too heavily on radar alone.

In order for a thunderstorm to develop, three "ingredients" must exist. They are: 1) ***atmospheric moisture***, 2) ***unstable air*** and 3) ***a source of lift***. The first factor, moisture, is mostly self-explanatory: water vapor must be present in the air. The second and third require some further discussion. Let's begin with the concept of atmospheric stability.

STABILITY AND INSTABILITY

The atmosphere, as I explained back on page 3, is heated from below. Thus, on a typical day, the air is warmer down near the surface than it is up high above the surface. Because cool air wants to sink and warm air wants to rise, this is an *unstable* condition; a disturbance to the atmosphere will quickly be multiplied into a swirling, roiling state.

When the upper air is very cold and the air down near the ground is very hot the atmosphere is extremely unstable. Even a small disturbance will result in strong – even violent – turbulence.

When the temperature only decreases slightly or remains more or less constant with increasing altitude, on the other hand, the atmosphere will be fairly *stable* and will resist any disturbance to its equilibrium.

And finally, when the temperature actually *increases* with altitude it's called an ***inversion***. This is an extremely stable condition. An inversion is the ultimate manifestation of atmospheric stability. The air will tend to be silky smooth above the inversion (although dangerous wind shear may exist below it or within it). An inversion is often visible as a distinct haze layer where particulate matter and pollutants are trapped. Smoke from a fire, for instance, will rise until it hits the inversion layer and then will spread out in a thin, flat, horizontal layer as if contained under a sheet of glass.

Stability is measured and determined based on the ***lapse rate***. The average lapse rate is about 2 degrees Celsius (or about 4.5 degrees Fahrenheit) per 1,000 feet, meaning that the air gets about 2º C cooler for every 1,000 feet you climb. So if the sea level air temperature is 30 degrees Celsius or 86 degrees Fahrenheit, for example, then the air temperature at 10,000 feet will be about 10 degrees Celsius or 50 degrees Fahrenheit. If the lapse rate is lower than average the air is stable. If the lapse rate is higher than average the air is unstable.

Many useful, practical things can easily be predicted by looking at the lapse rate.

On a stable day you can expect smooth air, poor visibility due to haze and smog, stratus-type clouds (if there is enough moisture in the atmosphere for clouds to form) and a steady, continuous kind of precipitation (if precipitation occurs).

Conversely, on an unstable day you can expect bumpy air, good visibility due to active mixing of atmospheric layers, cumulus-type clouds (again, if there is enough moisture in the atmosphere for clouds to form) and an intermittent, showery kind of precipitation (if precipitation occurs).

Wow! That's a *lot* you can forecast just by looking at the lapse rate! Specifically with regard to thunderstorms (assuming you have atmospheric moisture and a source of lift), a steep lapse rate means there will be frequent, powerful and widespread thunderstorms. A modest lapse rate means there will be limited thunderstorms – they will tend to be small, weak and widely scattered, easy to circumnavigate. A flat or negative lapse rate means there will be no convective activity at all. Thunderstorms cannot exist in very stable air.

LIFT

So much for the second factor – let's talk about the third, a source of lift. The most common sources of lift are ***thermals***, ***ridge lift***, ***convergence lift*** and ***wave lift***.

Thermals, technically known as ***convective currents***, are produced when the air directly above a warmer surface peels away and begins to rise as a bubble or column. If you could see air molecules on an unstable day the sky would resemble a giant Lava Lamp, with blobs and pillars of warmer, less dense air rising and blobs and pillars of cooler, denser air sinking. Contrary to the very common misconception, thermals do not actually require the air to be *hot* in order to form; they only require the air be *warmer* than the surrounding air. Thermals can (and do) occur in sub-freezing temperatures. If an airport surface temperature is 0 degrees Celsius, for instance, and the surface temperature of the surrounding countryside is –5 degrees Celsius then a thermal is likely to develop over the field.

If you are a glider pilot, you seek out thermals. Although a glider is always descending through the air, if the air is rising faster than the glider is descending through it, the glider can gain altitude. By circling in thermals, glider pilots (like soaring birds) can remain aloft for hours and gain thousands of feet of altitude.

Pilots of powered airplanes have another word for thermals – turbulence.

Thermals only go as high as the ***dew point altitude***. The dew point, as all pilots know, is the temperature at which water vapor condenses (i.e., changes from a gas to a liquid). When a thermal rises to the dew point altitude, all the water vapor it contains condenses. When this happens, all that water goes from the high-energy vapor state to a low-energy liquid droplet state – forming a cumulus cloud. (Cumulus clouds often form as a "cap" on top of a thermal.) This release of latent heat energy depowers the thermal. Cloudbase, obviously, is the dew point altitude. Therefore, thermals exist below cloudbase. They do not exist above cloudbase. If you are looking for smooth air on an unstable day, try flying above cloudbase.

Air that is at the dew point is said to be ***saturated***. In a humid place, such as Florida, the air is close to being saturated all the time. You don't have to drop many degrees to hit the dew point. Thus, cloudbase is low – often 3,000-6,000' on a typical summer afternoon. In a dry place, such as New Mexico, the air is far from saturated. You would have to drop many, many degrees to hit the dew point. Thus, cloudbase is often very high – sometimes 10,000-15,000' or higher.

Ridge lift, technically known as ***orographic*** lift, is developed when wind is deflected upward by a slope. When the prevailing horizontal air currents strike the side of a relatively wide, flat mountainside, for example, they become more vertical as they are forced to go up and over the mountain rather than around it.

Ridge lift can also be used by glider pilots. A man named Karl H. Striedieck II set a world record in 1977 by flying a Schleicher ASW 17 sailplane over 1,600 kilometers mostly by soaring along mountain ridges – often less than a wingspan above the trees!

Convergence lift is developed when two air masses collide. In Florida, for instance, the Atlantic Ocean sea breeze front moves inland from the east coast while the Gulf of Mexico sea breeze front moves inland from the west coast. In the afternoon these fronts often crash into each other, producing a steady upwelling of air. In the summer, a band of randomly distributed thunderstorm activity with a very roughly defined north-south axis usually forms between 1 P.M. and 3 P.M. and doesn't usually dissipate completely until after sunset. (Central Florida, according to the National Weather Service, is the lightning capital of the United States! Brevard County receives an average of 6,676 strikes each August!)

And finally, wave lift, the least common of the four types, is developed when wind of about 40 knots or more blows nearly perpendicular to a broad, tall, well-defined ridgeline and the air near the top of the ridgeline is stable. This creates a series of standing waves downwind of the ridgeline. This is very similar to the way standing waves form downstream of a rock in a swift-flowing river. These atmospheric waves reach all the way up into the flight levels, impacting even airline traffic.

Using a mountain wave above the Andes, on August 30th, 2006 Steve Fossett and his co-pilot Einar K. Enevoldson flew a Glaser-Dirks DG-500 sailplane to a World Altitude Record of 50,699 feet!

Although the mountain waves themselves are invisible, standing lenticular clouds often mark their presence. A violent and dangerous horizontal vortex called the ***rotor*** exists close to the surface underneath mountain waves. Sometimes the rotor kicks up dust and debris, but it may also be invisible. Because the rotor may contain severe to extreme turbulence, low-level flights beneath a mountain wave should be avoided or conducted with great caution.

THE LIFE CYCLE OF AN AIR-MASS THUNDERSTORM

An air-mass thunderstorm (as opposed to a frontal or squall-line thunderstorm) has three phases in its life cycle: ***cumulus***, ***mature*** and ***dissipating***. During the cumulus phase, the developing storm contains primarily updrafts which are feeding its growth. The cumulus phase is like an accelerating chain reaction: condensing water vapor releases latent heat, which drives the cumulus cloud to billow higher, which causes more moisture to condense, which releases more latent heat and so on until the cloud has grown to a towering height.

The mature phase is reached when rain begins at the surface. The cumulus cloud has become a ***cumulonimbus*** cloud – a thunderstorm. During the mature phase, the storm contains a violent mix of updrafts and downdrafts. The mature phase is the most dangerous.

During the dissipating phase, the storm is "raining itself out" and contains mostly downdrafts. Although it remains dangerous until it is gone completely, the greatest hazard is over.

Thunderstorms should *always* be avoided if possible! Severe thunderstorms should be avoided by at least 20 miles. (Hail can be hurled many miles laterally from a cell, and outflow turbulence can extend far beyond the cloud itself.) If thunderstorms are ***embedded*** (concealed within widespread instrument meteorological conditions), then the entire area should be avoided unless you have excellent real-time airborne weather radar. When flying VFR, simply maintain visual separation from storm cells. *Never* try to out-climb a building cumulonimbus cloud! Go around it instead. They can grow at a rate that far exceeds your airplane's performance.

I have been a commercial pilot for many years. I always do everything I can to stay away from thunderstorms. Realistically, however, if you fly every single day, week after week, month after month, then despite all your caution and discretion sooner or later you are bound to get a little bit too close to a thunderstorm – especially in certain parts of the country. Thunderstorms can erupt very quickly and spread very rapidly. It is said that "good judgment comes from experience and experience comes from bad judgment." You might make every reasonable effort to avoid them, but eventually you are likely to find yourself boxed in and cut off by quickly developing thunderstorms all around you, even if it was perfectly clear and sunny when you took off. This is the real world, and it happens.

If you do end up accidentally penetrating a thunderstorm, *fly straight ahead* and do everything you can to *keep the wings level*. Accept large variations in airspeed and altitude but try to maintain a zero bank angle. Reduce the power to get below maneuvering speed but be prepared to deal with climbs and descents of thousands of feet and possible massive airspeed increases and decreases. Do not try to force the airplane to maintain a certain altitude or a certain airspeed – that would require extreme pitch and throttle changes likely to overstress the airframe. Use the manufacturer's recommended turbulence penetration configuration.

There are two important reasons you want to try to keep the wings level: first, your greatest danger is structural failure caused by severe or extreme turbulence. Any increase in bank angle increases the load factor, which may already be excessive. And second, your next greatest danger is entering an unrecoverable unusual attitude. Keeping the wings level will help to prevent this. Again, that is the only thing you should attempt to hold constant is your zero-bank attitude – allow all other things to fluctuate wildly, and they will.

You should also tighten down your seat belt as much as possible. Be sure to fully secure any items which could otherwise become projectiles. Turn up the interior lights to maximum intensity. Remember that lightning can leave you momentarily blinded. Some pilots have suggested wearing sunglasses to avoid this, or even to fly with one eye closed. I am skeptical of this advice, but if you're inside a storm definitely do keep your eyes on the instruments – not outside.

An ounce of prevention is worth a pound of cure goes the old saying, so do everything possible to avoid all thunderstorms. If ATC does not cooperate by giving you the headings you need, this may even include declaring an emergency. If a heading change is necessary to prevent you from entering a cell, that definitely constitutes an immediate threat to the safety of flight. If you are courteous, professional and clear in making your requests the controllers don't usually complain too much. Do try to think ahead and give them a reasonable opportunity to reconcile your needs with their IFR separation requirements. Sudden, last-minute demands are more difficult for controllers to oblige. This is particularly true when the frequency is congested with lots of pilots requesting heading and altitude changes.

SEASONS

Why do we have seasons? It's a simple question, but the answer isn't so obvious. A common (but wrong!) answer is that the Earth is closer to the sun in summer and farther away from the sun in winter. This isn't true. If it were, then the seasons would be the same in the Northern and Southern Hemispheres. In fact, they are opposite. (When it's summer in the Northern Hemisphere, it's winter in the Southern Hemisphere.) Seasons are caused by the *obliquity*, or tilt, of the Earth's axis. When the Northern Hemisphere is tilted away from the sun, the air over the North Polar region gets extremely cold. Strong cold air masses then migrate south across Canada and the United States, bringing winter weather. (See the "AIR MASSES" section on page 6.) When the Northern Hemisphere is tilted towards the sun, we receive more direct sunlight and have a longer day. This brings summer weather. Remember that the atmosphere, as explained on page 3, is heated from below.

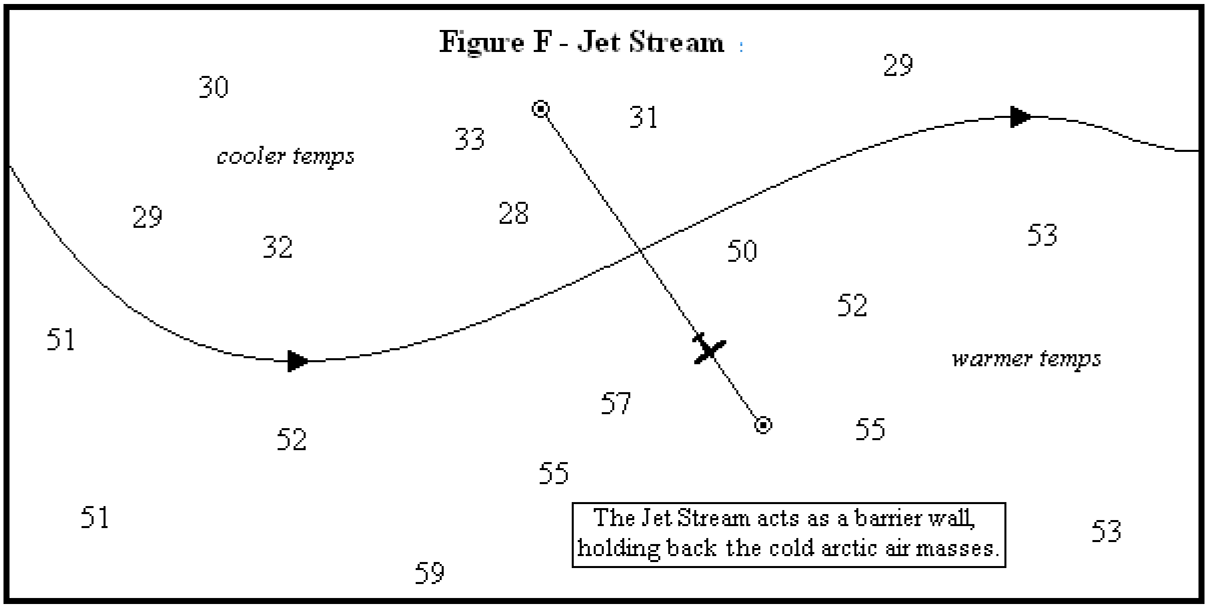
THE JET STREAM

Why do we need to know anything about the jet stream if we fly at low altitudes? Because even though it's way up close to the tropopause (the boundary between the troposphere and the stratosphere), the jet stream (along with pressure systems) drives – directly or indirectly – most of the weather in the troposphere.

What is a jet stream? The Earth revolves on its axis. Its atmosphere revolves with it – or tries to. The atmosphere spins fastest at the equator (far from the axis) and barely spins at all near the poles (on the axis). But air is slippery; it can't keep up with this whirling ball of rock upon which we live. Some air falls behind, creating a buildup of pressure. The result is a jet stream – a river in the sky, a band of wind 100 to 400 miles wide, 1 to 3 miles thick and thousands of miles long flowing west to east at speeds between 150 to 300 MPH, occasionally up to 450 MPH. It's the atmosphere's way of catching up.

The jet stream is dynamic and complex; it splits, merges and meanders. It is generally stronger and farther south in the winter. It weakens and retreats north in the summer. The jet stream acts as a barrier wall which blocks cold air masses, keeping them contained on the stream's north side. Thus, when the jet stream ***troughs***, or dips down, it allows those cold air masses to penetrate further south. And when a ***ridge*** in the jet stream carries it up towards Canada, it can help to keep those cold air masses mostly out of the continental U.S. The transition between temperatures on each side of the jet is often very abrupt, as you can easily see when you overlay a map of temperatures with the position of the jet stream.

Figure F - Jet Stream



The Jet Stream acts as a barrier wall, holding back the cold arctic air masses.

Another way the jet stream influences weather is by either reinforcing or disrupting the circulation around high and low pressure systems (discussed back on page 5). When the cyclonic rotation of a low pressure system moves *with* the jet stream, it can become very strong. When it moves *against* the jet stream, however, it tends to break down. That often makes the difference between a powerful storm system and a minor weather event. When the weather forecaster talks about "upper level support" (or the lack of it), he or she is referring to whether the jet stream is working *with* the rotation (to strengthen it) or *against* the rotation (to weaken it.)

SUGGESTED FURTHER READING

Pilot's Handbook of Aeronautical Knowledge
Aviation Weather
Aviation Weather Services