THUNDERSTORM!

The first of two parts on the most violent, potentially destructive phenomenon pilots must deal with

By DENNIS W. NEWTON

ILLUSTRATIONS BY LEO GWINN

July 23, 1973, was not your normal day, at least not in St. Louis. I was the pilot of one of several weather research aircraft working a large urban weather project, and one of our jobs was to penetrate building storm systems as they moved toward the city. Although there were some storms reported in Missouri, and although every indication had been favorable, we had waited all day for something to happen in the St. Louis area with nothing to show for it but a bunch of empty Pepsi cans.

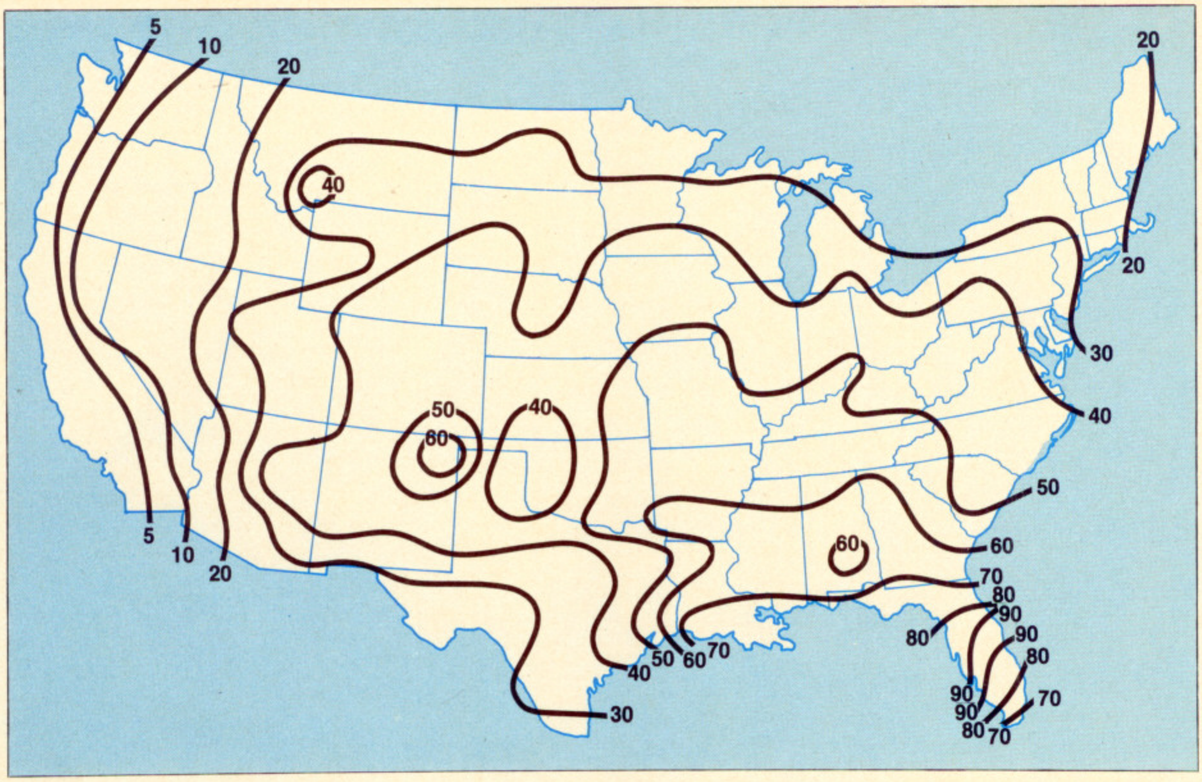
Finally, in the late afternoon, we made one last radar check of the area. There was nothing on the scope but one small buildup to the northwest of the city, which had been sitting there doing nothing for some time. Tired of watching the proverbial pot, we scrubbed the cloud flight and elected to launch a low-level air sampling flight crisscrossing the city VFR at about 1,500 feet agl. We fueled for a little over two hours of flying and bored off into one of the biggest weather surprises that I, for one, ever hope to have.

We were no sooner airborne from the Alton airport when, looking toward the northwest, we saw an ugly, dark-looking mass of cloud with a greenish cast and lightning all over the place. We flew up to the initial point for our air-sampling runs, which was about 10 miles north of the Alton airport, and we could see a tremendous, low roll cloud coming toward us with torrential rain behind it. We turned southwest and hit the gust front ahead of the storm. We began taking hard knocks, with everything not securely attached flying around in the cabin and downdrafts in excess of 1,000 feet per minute.

St. Louis approach control declared itself unable to handle VFR traffic at about that point, and there was no doubt as to why. The entire city was solid thunderstorm, Lambert Field had gone IFR, scud was already visible at the river, and as I watched this display in amazement I was treated to the sight of a magnificent lightning stroke from cloud to ground to the east of Parks airport, about 25

A menacing-looking roll cloud, above, is precursor to a full-blown thunderstorm

PHOTO BY THE AUTHOR



The highest number of thunderstorms a year are in areas that experience warm moisture and something to lift it. "Wet" air from the Gulf of Mexico spreads into the southwest to the southeast and the lifting is done by the mountains in the west and hot land and sea breeze fronts in Florida.

miles south of my position and already well east of the Mississippi.

I ran. Alton was still open to the west, and since I knew where the leading edge of the gust front was I elected to try it. Anyplace else would have meant driving off VFR with no plans and a totally blown weather picture and possibly letting the airplane sit outside in torrential rain, hail or worse. We put it on the ground in a four-knot wind, which had become 29 knots by the time we cleared the runway. We were back in the hangar just 30 minutes after we left it, happily thinking how much nicer it is to be on the ground wishing you were flying than vice versa.

Twenty minutes later, an Ozark Airlines FH-227 went down in the storm, on an instrument approach to one of the runways at Lambert.

What is this thing that sends an airplane full of unsuspecting meteorologists running for cover and then brings down an airliner? What causes it? Airplanes have flown through thunderstorms for years, practically since the development of gyro instruments, but once in awhile one doesn't make it. Are these things flyable? If some are and some aren't, how do we tell which ones aren't? Airplanes have broken up in flight several miles from a storm, some of them apparently in clear air. Crashes have occurred on takeoff or landing as a result of thunderstorm wind effects several miles from the storm itself. Can this be anticipated and avoided? What about lightning? Is it dangerous to an airplane or not?

There are answers, of sorts, to all these questions. Some of them are good, some not so good, but all of them are a lot better than no answer at all. Some of them are obvious to anyone who gives the matter any real thought. Some of them, on the other hand, are subtle, and not at all what you would expect. Which are which? Is the obvious answer really the correct one?

When I was a young charter pilot and flight instructor, I asked a pilot who was an Old Pro and as weatherwise as most pilots I knew how he decided whether or not to fly a thunderstorm. He said, "Well, it more or less depends on how bad I want to get where I'm going." I didn't find that much of an answer, and sort of felt put off at the time—you know, "go 'way kid, ya bother me." I later realized, though, that he was just leveling and not trying to snow me. He really didn't have an answer. We can do better than that now, so let's take a walk in the rain, look at some clouds, and see what we can see.

For openers, thunderstorms are made of the same basic four ingredients that all weather is made of. They are as follows:

1. Water. All weather (except some of the winds that serve to move the water around) is made of water. Thunderstorms are made of lots of water.

2. Temperature. Various types of weather require temperatures in various ranges. Icing, for example, requires temperatures that are somewhat, but not too much, below freezing. Fog requires temperatures near the dewpoint. Thunderstorms require relatively warm temperatures in the lower layers of air in which they form, for the simple reason that warm air can hold more water.

3. Stability. This is one of the most important factors in weather, and one of the least understood. If you want to understand thunderstorms, or any other kind of weather for that matter, you have to understand stability. Fear not. Stability is very simple and even sort of fun; it is only the explanations that are weird and mysterious. A section on the subject of stability and thunderstorms, guaranteed to amuse and amaze all who partake thereof, will be found a little further on.

4. Lifting. Thunderstorms generally need a push to get them started. In the heat of the afternoon, a thermal

started by a hot parking lot could do it. A hill can do it. It is a very small oversimplification indeed to say that all a front does is lift air. There are such things as sea-breeze fronts and dewpoint fronts, in addition to the commonly known cold, warm and occluded fronts, which are in the business of lifting air. The jet stream, and other smaller-scale upper-air wind flows, create "holes" in the upper air that result in lifting of low level air to fill them.

Very well, wouldn't we expect to find that more thunderstorms occur in areas where there is lots of warm water and something to lift it than in other places? *Voilá!* Regard the southeastern United States on a chart depicting average numbers of thunderstorm days a year. The Gulf of Mexico is one of the best warm-water sources in the world. We have hot land and sea-breeze fronts to create lifting in Florida, which is surrounded by warm water, and we apparently have the most thunderstorm days (days on which one or more thunderstorms are observed by National Weather Service stations) in the country. I say "apparently" because there are also lots of stations in Florida to report thunderstorms, and that may have a little to do with it.

Look at the mountainous area in Colorado and New Mexico. Warm, moist air from the Gulf gets in there, too. Not as much as Florida or the rest of the Southeast, probably, but there is lots of lifting due to the terrain, which will continue to try to squeeze the water out. The area to the west, into Utah, might be a little more active than indicated due to a low density of reporting stations in the area. Two things that are apparent from the chart are the deep penetration of Gulf air into the United States and the effect of lifting by terrain.

What we've said so far will hopefully serve to illustrate the "big picture" of thunderstorms, the basic causes and the climate that favors them. All that is not much help, though, when you want to go from Okmulgee to Key West to visit Grandma on Memorial Day, or when your business requires you to be in the St. Louis area on July 23.

Let's start with a typical air mass thunderstorm day and go flying.

The Air Mass Thunderstorm

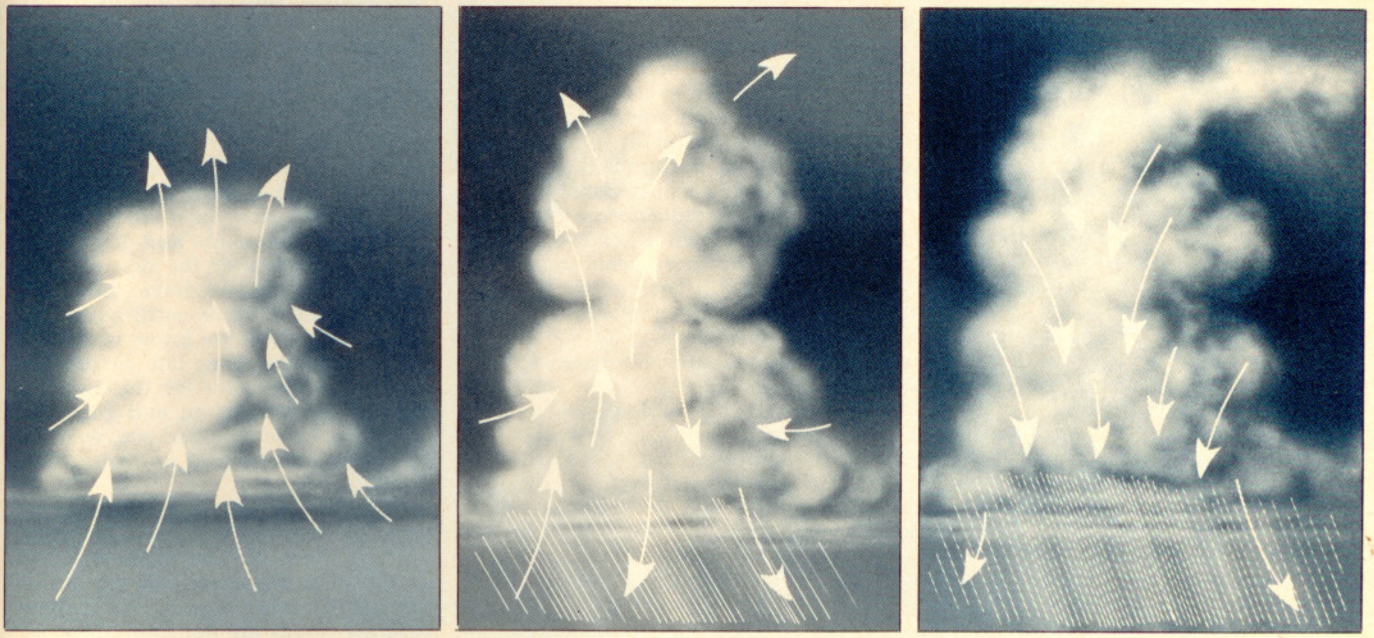
Let's pick a day during the thunderstorm season and go someplace. Take, for example, the Northeast or Southeast on a late spring or summer day under the influence of a stagnant, fairly humid high-pressure area. No fronts, not too much low-level wind, visibility at the surface reported as probably 10 miles or less. Perfect for air mass storms.

The first thing we will do, naturally, is check weather. If thunderstorms are forecast along the route, we will make note of where and when. We always take these forecasts with a grain of salt, however. If no thunderstorms are forecast, that does not necessarily mean that none will occur. If thunderstorms are expected, and if they do occur, they may not happen when or where expected.

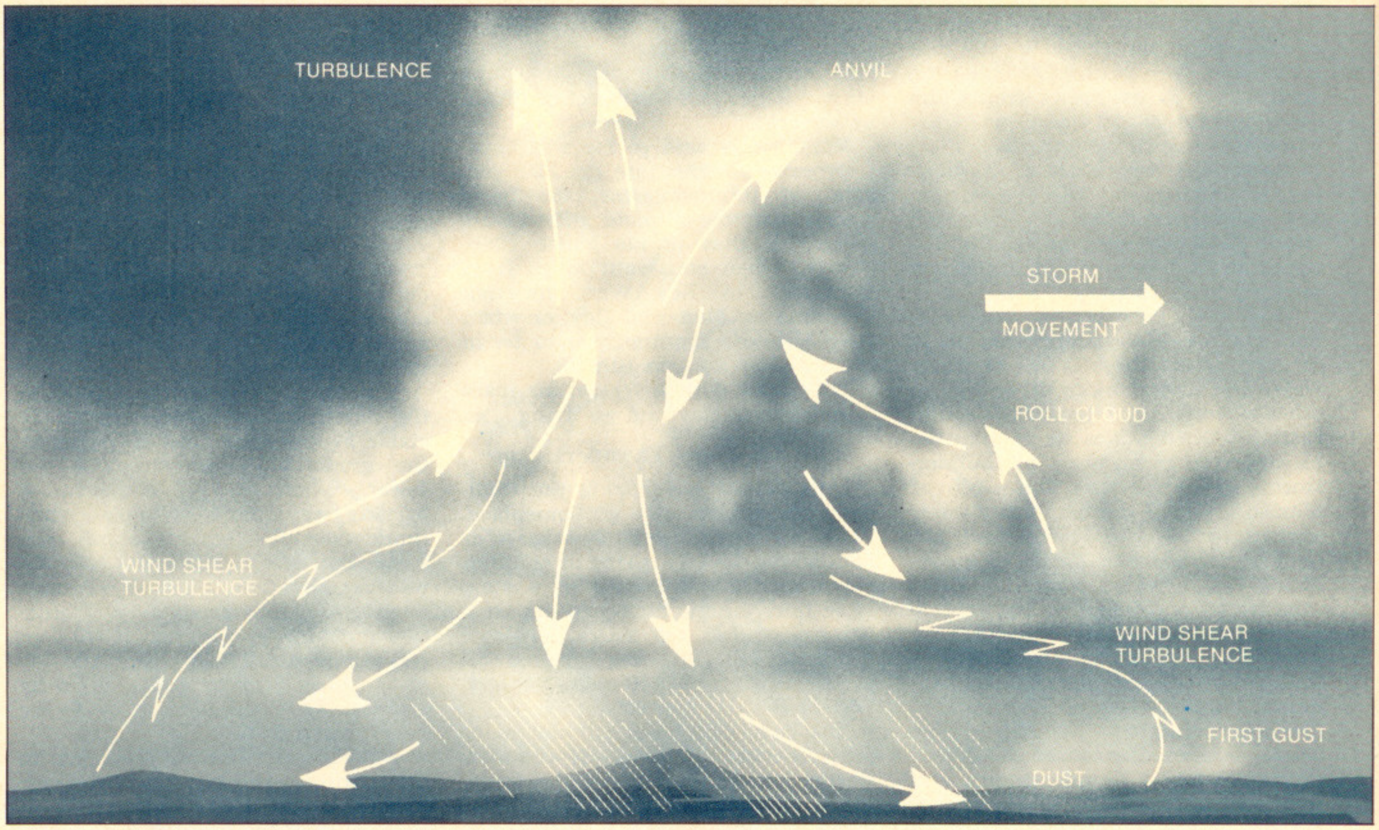
The distance between primary weather stations is about 100 miles, on the average, and the distance between upper-air stations is two hundred miles. Surface observations are made hourly, but usually only every 12 hours at the upper-air stations. This essentially limits forecasting to a statement that storms are probable in an area much larger than the storms themselves and, while such forecasts are far from useless, there is no way of knowing in advance that one will develop on Victor 16 or over the East Filchboro Airport on a particular afternoon. We must use our eyes, and what we know about moisture, stability and lifting, to fill in the gaps.

If possible, we plan to go early in the day. The air is generally more stable at that time, and hot spots on the ground to start thermals are fewer. When we get our weather briefing, we will ask where and when thunderstorms formed along our route on the previous day. If the weather situation is about the same as yesterday, the thunderstorm situation probably will be, too. If we can, we will also find out where the top of the haze layer is and plan to fly above it. That will allow us to see the action when it starts.

We will peer from our window in the morning, and we will check current weather along our proposed route even if we are going to depart several hours later, looking for cumulus (Cu) and altocumulus clouds. When the low level Cu starts to bump, we know that instability is present. The earlier in the day, and the lower the cloud base, the more chance there is that some of that Cu will become Cb—the Cumulonimbus cloud that we don't want to tangle with. If we



The stages of an air mass thunderstorm are (l to r): cumulus, mature and dissipating. Airflow is depicted by arrows.



Vertical-standing air mass thunderstorm generates strong downdraft in mature stage that produces a gust front ahead of it and wind shear turbuluence elsewhere underneath the cloud bases.

see altocumulus, the cumulus cloud that forms at around 12,000 to 16,000 feet above the ground, we know that there is a moist and unstable layer aloft. This, by itself, does not indicate thunderstorm formation, but it tips us off that any low-level cumulus clouds that get that high will find a good environment to continue growing. A towering cumulus cloud that isn't doing much and looks like it's about to poop out can turn into a real tiger if it penetrates such a mid-level, unstable layer; if we realize the layer is there, we won't be taken by surprise.

If we have a moist wind in the lower 5,000 feet or so, we will look for a route that keeps us well upwind of rising terrain, or well away from it in some other direction if upwind is not possible, because we know that the upslope wind may provide the lift necessary to trigger orographic or upslope storms. If we have to cross a mountain range, the earlier in the day and the lower the terrain where the route crosses, the better are our chances of being where the storms ain't.

Then, having prepared ourselves as best we can with forecasts, a good route and what we can see for ourselves, we make one last call to flight service to check the latest weather for the existence of thunderstorms along the route, we mount our aeronautical steed, and we're off.

If the day permits it, we climb to the top of the haze layer, level off in the clear, and look around. We scan the horizon in the direction we're headed for indications of dense cirrus, which may indicate a thunderstorm top. Wisps don't bother us, but if the horizon appears overcast with cirrus or if we see high clouds that become thick in the upwind direction, we may be looking at a thunderstorm anvil.

This is our earliest visual warning that actual thunderstorms exist, and can often be seen when we are still 200 miles or more from the active storms. We will keep an eye on such areas as we move along, watching whether they develop or move. If a route change appears wise, we can probably make it early in the game so that it will only have to be a few degrees and won't affect our flying time much.

We look around for cumulus popping up through the top of the haze, and when we see some we spend a little time watching it. If the winds are right and there is not too much moisture, the tops of the clouds may shear off and dissipate in five minutes or so. Areas where that happens are fat city, for the time being at least, and we can rejoice.

Look up ahead, though, there at about 11 o'clock. See that one popping up? It's standing up straight, and the top looks hard, like cauliflower, not fuzzy around the edges. We watch, and 15 minutes later there's no doubt about it. The cloud towers into the sky and the cirrus is spreading from the top into the characteristic anvil. It's a thunderstorm, all right. Well, it's not in our way, but let's watch. Sure enough, there's another Cu popping up upwind. This is what we're looking for.

Thunderstorms tend to form in lines, more or less up- and downwind. Forty minutes after the first sighting of building Cu, we have three full blown thunderstorms getting lined up to do battle. Now we know where the activity is, and since our destination is on the other side of the forming line we get set for an end run. The line may close up, and we want to be on the other side if and when that happens.

The Cu is building at the point we pick for crossing when we get there, but the storms are not connected. We pick a spot where we can see lots of sky on the other side of the activity and the clouds are not solid above us. We examine the building cloud below us, and find an area where the tops are fuzzy and not active. The hole can close in a hurry if we try to penetrate over a sharply defined, cauliflowery, building Cu. In about five minutes we're home free, back on course to our destination with the activity behind us.

This is usually the best way to handle an air mass storm situation If there is a lower cloud deck that prohibits a VFR climb to an altitude in the clear, the pilot who is instrument rated is still generally better off to get on top of the lower deck and then visually avoid the storms. If he is not instrument rated, or if he is and can't get clear of cloud, the problem is more difficult. He will have less warning, and should make frequent weather checks and obtain whatever radar assistance may be available from the air route traffic control center or approach control facility serving the area.

If he doesn't have instrument en route charts with the frequencies, he can borrow them from someone and note the center frequencies along the route. Even if the radar is not painting the weather, just listening in to the conversations of other aircraft in the area, some of which will be flying in the clear, will help locate the activity. However, there will probably not be any early indication of which way the storms may be lining up. The VFR pilot, tooling along in the murk with five miles or so visibility and unable to climb above it, must be ready and willing to turn back and land if necessary. When the sky becomes dark ahead, or it looks as though one is flying into a wall (which will shortly prove to be water), or the pilot sees lightning or turns the squelch on the radio up and hears the crackling that sometimes indicates lightning, it's time to quit.

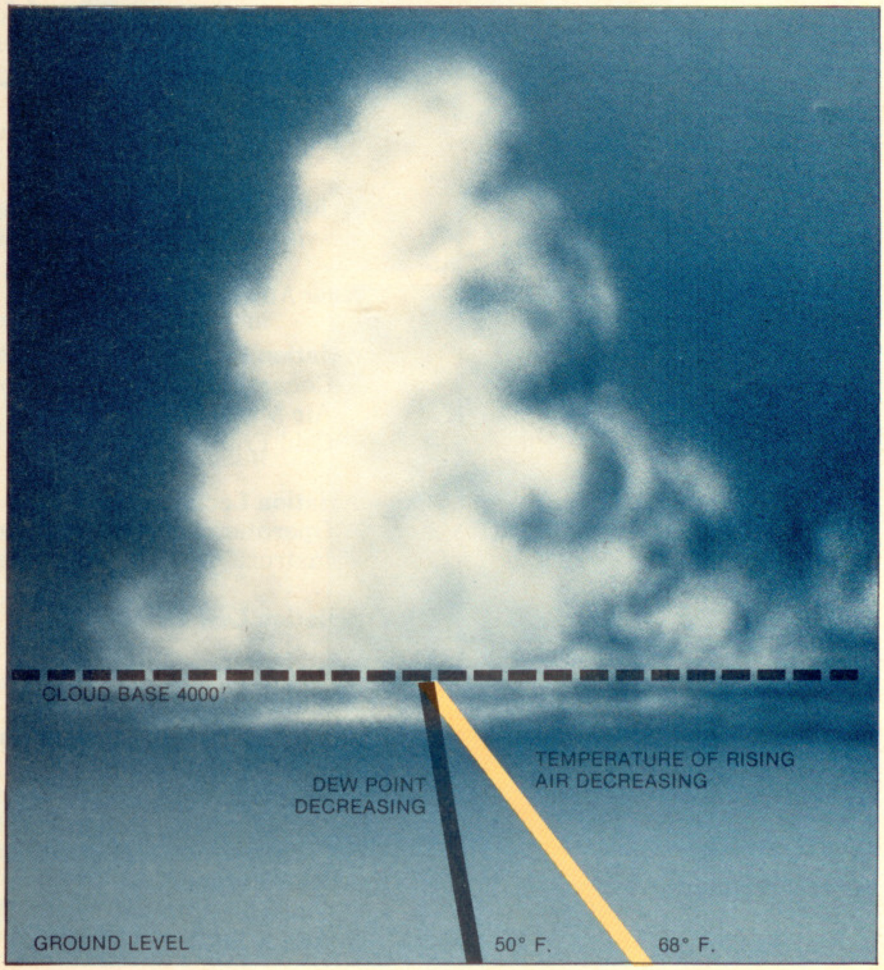
If a pilot is instrument rated, and is flying without radar, and if he flies long enough in IFR conditions favorable to air mass thunderstorms, sooner or later he is going to get caught. It happened to me on a trip home from the cloud project in St. Louis. We had sacrificed airborne radar for a gust-probe research installation in the nose. After about 95 hours of deliberately flying clouds with guidance from our own ground-based radar and never really getting into anything I didn't want to tangle with, there I was, on what was supposed to be a routine trip, on Victor 30 at 7,000 feet (more or less) in a thunderstorm.

Which brings us to the question, are these things flyable? You can have your choice of answers with respect to air mass storms. Yes, but. Or, no, but. A true air mass thunderstorm is the kind we have all known about for years. It begins with the cumulus (building) stage, characterized by building cloud and updraft. How much updraft? I have seen 3,000 feet per minute (fpm) any number of times. Ask yourself how fast a storm can get to 30,000 feet at that rate and you can see how we had three full-blown storms in sight in 40 minutes on the armchair flight we made a little while ago.

The air mass thunderstorm stands erect in a generally fairly light wind field, and is said to reach the mature stage when rain begins to fall. Since the storm is essentially vertical, the rain falls down through the updraft. This causes two things to happen. First, the drops have aerodynamic drag, just like any other object moving through air. This creates downdrafts. The water hits the ground and sticks, more or less, but the downward rushing air spreads out away from the storm, mostly ahead of it, creating a gust front to amuse the unwary aeronaut who tries to take off or land too

continued

In an unstable air mass, rising air cools at a rate of 5.5°F per thousand feet and the dewpoint at 1°, so the air approaches the dewpoint at the rate of 4.5°. To estimate the cloud base in thousands of feet, divide the difference between the surface temperature and dewpoint by 4.5.



close to the storm. How much downdraft? Since airplanes also tend to stick when they hit the ground, I don't fly under thunderstorms at low altitudes to find out. However, I'd believe 2,500 fpm easily. *Never take off or land in the face of an approaching thunderstorm.*

Is lightning hazardous to airplanes? You bet it is. There have been many, many lightning strikes on airplanes that have done no more damage to the airplane than a small hole somewhere in the skin and no damage to the crew that can't be repaired in a laundromat. Once in a while, though, serious structural damage occurs. The odds are strongly against a lightning strike bringing an airplane down, but what odds are you willing to accept with your neck?

The second thing that happens due to the water falling through the updraft is that the storm "strangles." The air mass storm is, therefore, self-destructive, with a life cycle of usually 20 to 90 minutes. This kind of storm does not generally contain hail. Numerous penetrations of such storms were made during a thunderstorm study conducted in Florida and Ohio during the late forties. Ninety percent of the penetrations flown at 16,000 feet and 100% of penetrations flown at 6,000 feet found no hail in Florida, and in Ohio the numbers were 94% with no hail at 20,000 feet and 98% at 5,000 feet.

Icing in any thunderstorm can obviously be ferocious above the freezing level. The updraft regions are by far the worst areas, because that is where water vapor is condensing into liquid drops the fastest. About −10°C is usually considered to be the lower limit of temperature for serious icing, but that's not true in a thunderstorm updraft. Liquid water is condensing in these drafts at a rate much faster than it can freeze in the cloud, and literally no altitude above the freezing level can be considered safe from severe icing in a Cb updraft.

The air mass storm (by which we mean the type of thunderstorm just described, not necessarily any storm that forms without frontal or orographic lifting) is the gentlest kind of thunderstorm, and we have seen that it is more than sufficiently dangerous to warrant strict avoidance. Although the vast majority of such storms do not contain weather that is destructive of an airframe, there is just no way of knowing that any particular storm does not contain weather that can literally swat you out of the sky.

There are basically two other kinds of thunderstorms, both of which contain weather at least damaging if not catastrophic, and there is no way of guaranteeing that the storm you are looking at is not, or will not suddenly turn into, one of these other kinds. We will call the other two kinds the steady-state storm and the severe storm. That's more or less in accordance with the general usage of these terms, but have a little care in reading other things on the subject. The definitions may be a bit different. We will look at these storms a little further on. But first, let's talk about stability.

Stability

When we talk about something being stable or unstable, what we are discussing is how something reacts to being disturbed. This is true whether we are referring to an airplane, a personality, an air mass, or anything else that can be momentarily upset and then set free to do its thing. Something that is stable will return to its original course after the disturbance goes away. An unstable situation, on the other hand, results in the thing in question going out of control after it is disturbed and either never returning to its original situation or returning at such a rate that it rockets through and goes merrily off in the opposite direction.

We need to know two things to understand stability as it relates to the atmosphere.

1. Hot air rises. Also, to no one's surprise, cool air descends.

2. The sun does not heat the air to any great degree. The sun heats the surface of the earth, and the land and water heat and cool the air.

Now, knowing these two things, let's see what we can figure out. How about this? *Warm over cold is stable.* Hot air rises, right? Then warm over cold is the way things would druther be, if they had their druthers. When we say warm and cold, of course, we are talking in relative terms. If the temperature we see on our airplane thermometer rises as we climb, or even if it just remains the same and does not decrease, we have a case of warm air over cold air, and that's stable. On the other hand if the temperature drops as we climb, we have a case of cold over warm. This is against the nature of things. The warm air at the bottom wants to rise, and the cold air above wants to descend. Give it a push, and this layer of air will literally overturn. Make it hot enough at the bottom and it will overturn even without a push.

Suppose the air does overturn. A layer of air obviously can't roll over like a hibernating bear. What it does is start at the hot spots, or in areas where it is given a push. We then have an area in which the warm air is rising. The atmosphere doesn't like holes, so more low level air moves into these areas and then it, too, rises. The cooler air above descends to replace the air that is leaving the lower levels.

This process will shortly result in stable, warm over cold, situation, which is what the atmosphere likes. Unless, of course, the reason we had a cold over warm case in the first place was because the ground is hot. If that's the case, then the cool air that came down shortly becomes hot air, and we have a steady state, unstable situation.

Everything that's been said about stability up to now is true whether or not the air is moist. Now suppose the air that's going up contains water vapor. The warmer the air is, the more water vapor it can hold. However, if you begin to cool the air, sooner or later you reach the point, called the dewpoint, where the air holds all the water it can. At that point, if you cool the air any further, a cloud appears, composed of small droplets of liquid water.

We can make a pretty good guess at where this will happen. As a bubble of air rises in our unstable air mass, it cools at a rate of 5.5°F for each thousand feet that it rises. The surface dewpoint our bubble of air had decreases at the rate of about 1°F for each thousand feet of ascent. Consequently, the temperature of our bubble, which is decreasing as it rises, is approaching the dewpoint (which is also decreasing slowly) at the rate of 4.5°F for each thousand feet of ascent. To estimate the cloudbase in thousands of feet, we take the difference between the surface temperature and the surface dewpoint and divide by 4.5. For example, if the temperature at the surface is 68°F and the dewpoint is 50°F, and if the situation is unstable and air begins to rise, clouds will begin to form with bases at about 4,000 feet agl.

When water vapor condenses into liquid droplets, it releases heat into the air that contains it. Consequently, if our bubble of air (which now contains a cloud and is receiving heat from the water) continues to rise, it will cool off more slowly. The rate varies, but it will be something in the neighborhood of 2°F per thousand feet of ascent. Now, if we are interested in the possibility of thunderstorm formation, we must ask ourselves this question: *Will the air in our rising bubble become warmer than the air that surrounds it?*

First of all, suppose we have a case of warm over cold in the layer of air in which our bubble starts to rise. Then the answer to our key question is always *no.* We have already said that warm over cold is stable. Since our rising bubble is cooling, quickly if there is no cloud forming or more slowly otherwise, but cooling nonetheless, it will always be colder than the air around it. Cool air descends, so our bubble will head back whence it came, and that, after all, is what we said we meant by stability.

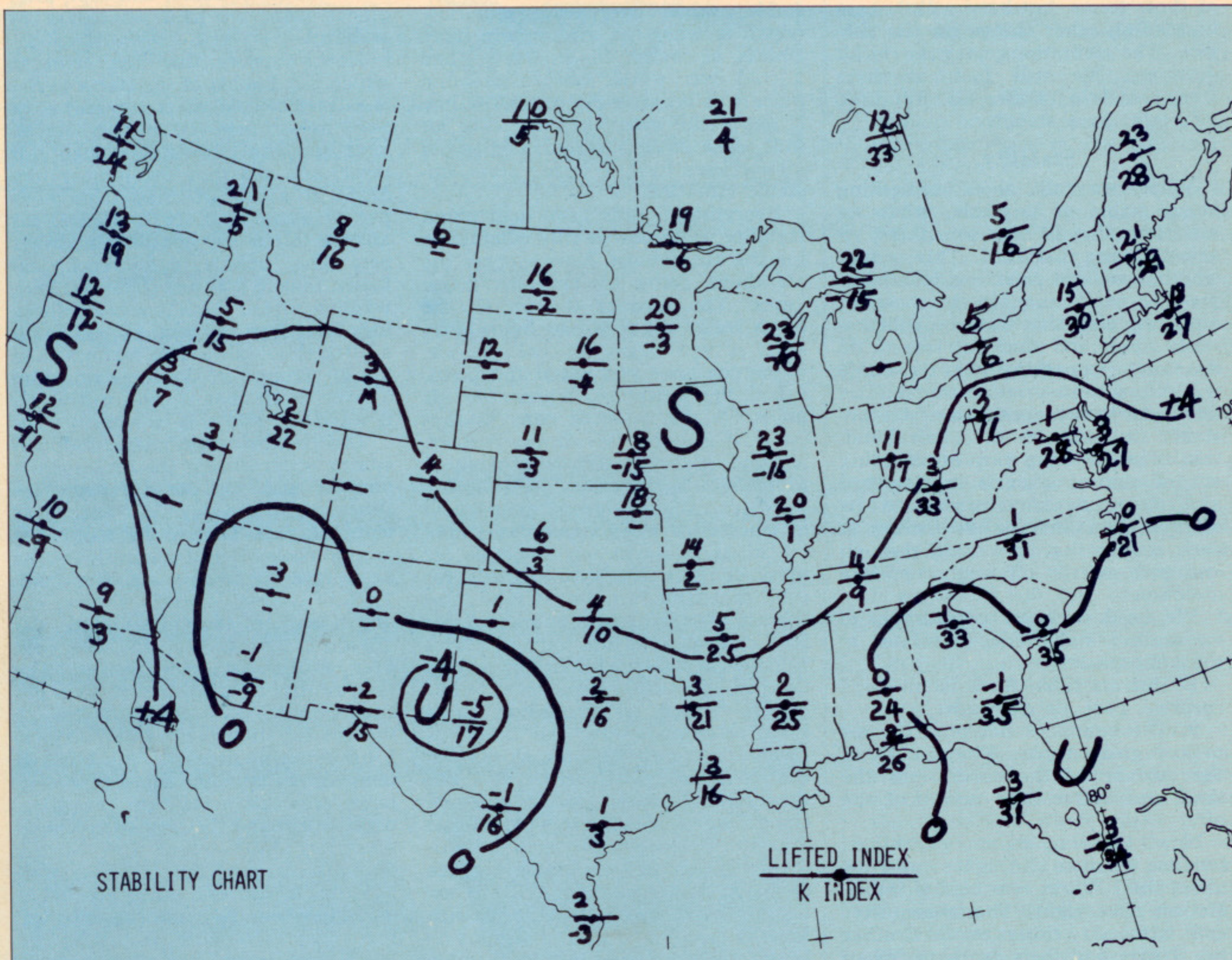
Now, suppose that the layer in which our bubble of air starts to rise is a layer of cold air over warm. Suppose, as you read the thermometer in your airplane climbing through this layer, you see that the temperature drops at a rate of more than 5.5°F per thousand feet. In this case, the answer to our key question is always *yes.* The bubble can't cool any faster than 5.5°F per thousand feet, whether or not there is a cloud forming. Therefore, as soon as you lift it a little, it will always be warmer than the air around it. We have said that a layer of air that is cold over warm is unstable, and this is why.

The reason why most thunderstorms occur during the afternoon is now as plain as the difference between night and day. Just exactly as plain, in fact. During the night, the ground cools off and generally results in a layer of warm air over cold. This, of course, is stable. During the afternoon, on the other hand, the ground is hot, and an unstable, cold over warm, situation results. The temperature in a layer of air over hot sand can be 50° colder 10 feet off the ground than it is at the surface. I have flown aircraft with infrared temperature sensing equipment over large areas of asphalt in the afternoon and found the asphalt temperature near 150°—about 70° warmer than its surroundings.

There is still one other possibility to think about. Suppose the temperature decreases with height as we climb and watch our thermometer, at some intermediate rate, say 3°F per thousand feet or so. Let's ask our key question again. Will the air in our rising bubble become warmer than the air that surrounds it?

Now we get an answer that may be the most important one we have. *It depends on the moisture.* If no clouds are forming, our bubble cools rapidly, becomes colder than the surroundings, and settles back down. However, suppose a cloud forms as the air bubble rises. We saw earlier that the closer the temperature and dewpoint at the surface, the lower the cloudbase will be. Once the cloud starts to form, the rising bubble cools off much more slowly. Now it stands a good chance of becoming warmer than its environment as it ascends. As soon as that happens, the brakes are off. The higher it gets, the warmer it becomes relative to the air around it, and the faster it moves.

A stability chart from the National Weather Service can help predict possible thunderstorm activity. A negative value of the lifted index (the number on top of the horizontal line at each reporting station) indicates instability; a high value for the K index, below the line, indicates a high moisture content—a combination that is apt to produce thunderstorms.



Lifted Index	K Index	*Area in figure*	*Probable weather*	*Operational impact*
Zero or Negative (unstable)	High (wet)	Georgia Florida	Instability showers or thunderstorms	Turbulence; may be hazardous; soaring plagued by clouds
Zero or Negative (unstable)	Low (dry)	Southwest TX Southern NM Eastern AZ	Limited cumulus activity; little if any precipitation	Bumpy but not hazardous; good for thermal soaring
Positive (stable)	High (wet)	New England	Stratified cloudiness; steady precipitation	Smooth for IFR flight; may restrict VFR; no thermals
Positive (stable)	Low (dry)	Northern Plains, Calif. coast	Predominantly fair	Smooth flight; generally good VFR; weak thermals if any

Perhaps it won't become a thunderstorm. It may hit a higher layer of stable air, which will stop it, or it may run out of moisture. However, once our bubble has a cloud forming in it and becomes warmer than the air around it as it climbs, it sure is on its way.

Let's summarize what we know about stability.

1. A layer of warm over cold is stable. If the temperature of the air through which we are climbing increases, or at least does not decrease, convection (the overturning of air) will not start in that layer.

2. A layer of cold over warm is unstable. The degree of instability depends on how fast the temperature decreases with height. A layer of air near the ground on a hot afternoon is likely to be very unstable, and will start overturning at the slightest push whether moisture is present or not.

3. Intermediate between these extremes, the stability depends on the moisture in the layer. The higher the humidity, the lower will be the base of any clouds that form, and the more likely that the situation will result in fireworks.

The National Weather Service publishes a much underrated weather chart depicting stability (see Stability Chart), which is a grand place to start a weather briefing on what may be a thunderstorm day. The lifted index, shown on the top of the horizontal line at each station on the chart, is just the temperature difference a bubble of air would have if lifted from the surface to the 500 millibar pressure level, which is a height of about 18,000 feet. The difference is in degrees Celsius, and a negative number means the bubble would be warmer than its surroundings if lifted. (The minus sign just comes from the way they do the subtraction. I don't know why.)

Therefore, negative lifted index values indicate instability. The so-called "K index," underneath the line at each station, is much more complex, but a high value of this number indicates a high moisture content. Therefore, this single, very useful little chart, provides at a glance the big picture of areas in which thunderstorms are probable. To relate this chart directly to aviation, a meteorologist named Modahl did a study of aircraft accidents associated with thunderstorm activity. A value of the lifted index of minus two (remember, this means that a bubble of air, *if lifted,* would be two degrees Celsius warmer than the air around it) is unstable enough to make tornadoes possible. Modahl studied 45 general aviation accidents and found the average lifted index existing at the time of the accidents was minus four. The average value in 18 air carrier accidents was a whopping minus seven.

And So, Back to Basics

The basics are four things: water, temperature, stability and lifting. Water provides the energy needed for thunderstorms, and the presence of sufficient moisture is generally indicated by the dewpoints found in the hourly sequence reports. A dewpoint of 53°F or greater is enough moisture for very severe thunderstorms, possibly with tornadoes. There is no such thing, however, as a light thunderstorm. An ordinary air mass storm has energy equivalent to about 13 WW-II atomic bombs.

Temperature and moisture are related, as are temperature and stability. The air has to be warm enough in the lower levels to hold enough water vapor to fuel the storm. The instability necessary to get thunderstorms going is the result of layers of air in which the temperature decreases with height, cold over warm. Moisture and stability are related. The more moisture in the lower levels of the atmosphere, the lower the cloud base will be, and the more likely that a rising bubble will become warmer than the air that surrounds it and head for the stratosphere.

Lifting is what sets it off, the match that lights the fuse of this atmospheric firecracker. If a moist parcel of air is driven up a hill so that its temperature reaches its dewpoint and it becomes warmer than the air around it, we have the beginning of a thunderstorm. A hot parking lot on a summer afternoon can provide the thermal lift necessary to get things going. Any kind of front can lift air along a line hundreds of miles in length.

Combine frontal lifting with lots of moisture and high instability, and we are talking about storms as destructive of property on the ground as an artillery barrage, and as destructive of aircraft as a Sidewinder missile. Storms with this destructive capacity can occur along with ordinary air mass storms, and we will ordinarily not be able to tell them apart by looking at them. One reason that it is worthwhile to know the lifted index from the stability chart is that it allows us to assess the potential for destructive storms. Remember, 55 general aviation aircraft that we know of have been swatted out of the sky by storms when that number was around minus four.

Armed with our knowledge of the basics, we are ready to take a look next month at the Mama Bear and Papa Bear of the thunderstorm family, the steady state storm and the severe storm. □