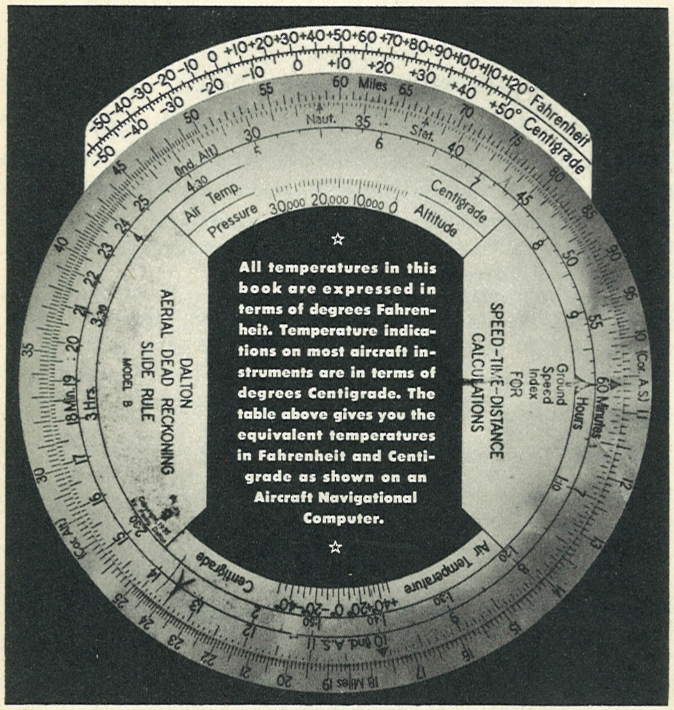
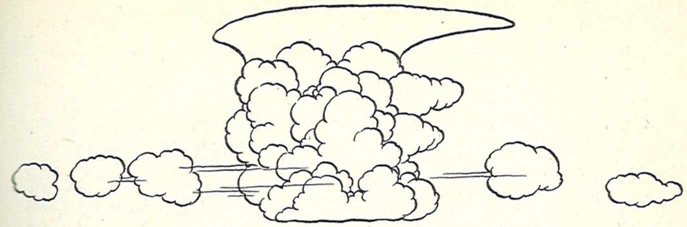




THUNDERSTORMS

AEROLOGY SERIES

NO. 2

PREPARED BY TRAINING DIVISION
BUREAU OF AERONAUTICS, U. S. NAVY

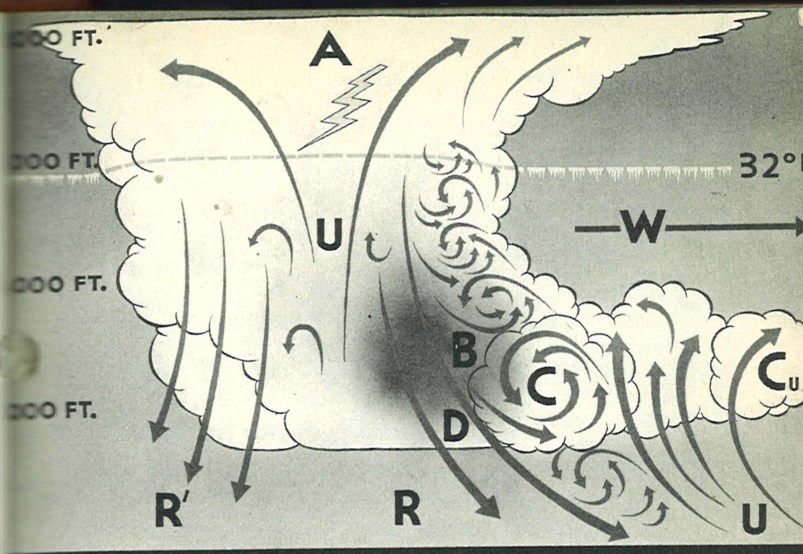
INTRODUCTION

This is a booklet prepared to help you to understand thunderstorms. It will not tell you how to fly any individual storm you encounter. There is no combination of ink and paper that can do that. If it could be done, this book would tell you to avoid thunderstorms, for in reality that is the only safe way of flying them. But you are to be a naval aviator, and in the course of your duty there will be times when your mission will require you to fly through thunderstorms, either on your way to your objective or in returning to your station.

Thunderstorms are your enemies, ruthless as gunfire and often harder to out-maneuver than an enemy pilot. It behooves you to study them carefully, not only as they are presented to you in this booklet, in motion pictures, and in the classroom, but most significantly, as you will encounter them—in actual flight.

This booklet is designed to introduce thunderstorms to you—to give you some idea of the danger signals that precede them, to tell you how they form and what causes them. There are included also some general rules for flying thunderstorms and some advice from experienced meteorologists and from naval and airline pilots whose familiarity with your problem comes from years of flying dirty weather.

Remember these rules and heed this advice, but bear in mind that in actual flight conditions there will be no salvation for you except the exercise of your own good judgment. There has never been a thunderstorm that a good plane piloted by a good man couldn't lick. Your equipment is the best there is. It won't let you down. So, even if the wind knocks you around, if lightning blinds you and the hail threatens to break your windshield, remember that if you keep your head, use your best judgment and fly your course, you'll get there and back.



Key to Diagram of Cumulonimbus Cloud

A —Anvil Top
B —Dark Area
C —Roll Cloud
C_U —Advance Cumulus Clouds
D —Down Drafts
U —Up Drafts
R —Primary Rain Area
R′ —Secondary Area
W —Wind Direction

HOW THUNDERSTORMS LOOK

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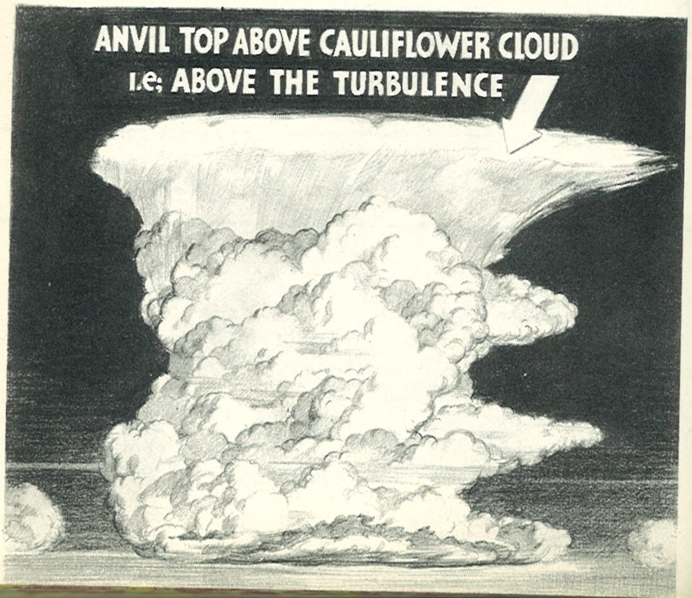
A thunderstorm is associated with a big cumulus type cloud that has grown to unusual heights. A cumulus cloud is the visible top of an invisible rising column of air. If it reaches beyond the freezing level, it may develop into a cumulonimbus cloud and a thunderstorm is likely.

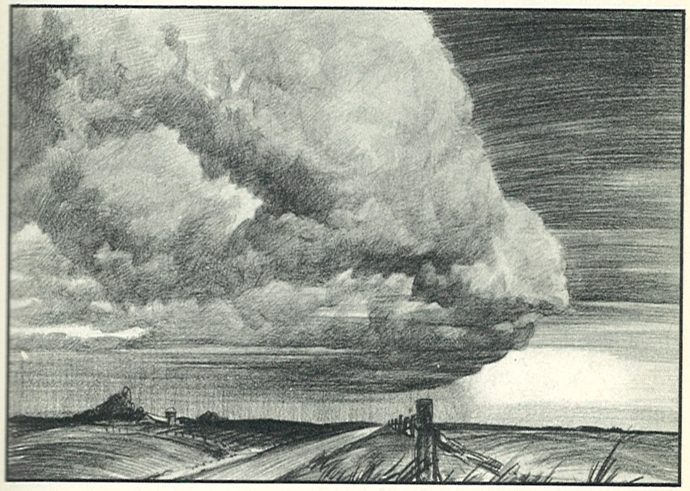
Although thunderstorms are more varied in appearance, size and shape than human beings, they have four characteristics that will help you to identify them by sight and at a distance.

1. They are **Cumulus Type Clouds,** with a distinctive cauliflower appearance along their sides.

2. A thunderstorm usually has a spreading, flat top—**The Anvil**—which looks from underneath like a horizontal, solid deck of clouds jutting out in front of the main body of the



cumulonimbus cloud. This anvil leans in the direction of the upper wind, which usually will be the direction in which the storm is moving.



3. Along the leading edge at the bottom of the violent thunderstorm cloud there usually appears what is called the **Roll Cloud,** which resembles a rolling cylinder of dirty cotton. It is "rolled" by the rising air currents in advance of the storm and the downdrafts in the storm. Its presence indicates that the thunderstorm will be accompanied at the surface by strong gusts of wind.

Often, however, thunderstorms don't have roll clouds. That happens when the vertical velocity of air currents in the storm is not violent enough to form a roll cloud. It also happens when the storm is in the dissipating stage and its violence has subsided.

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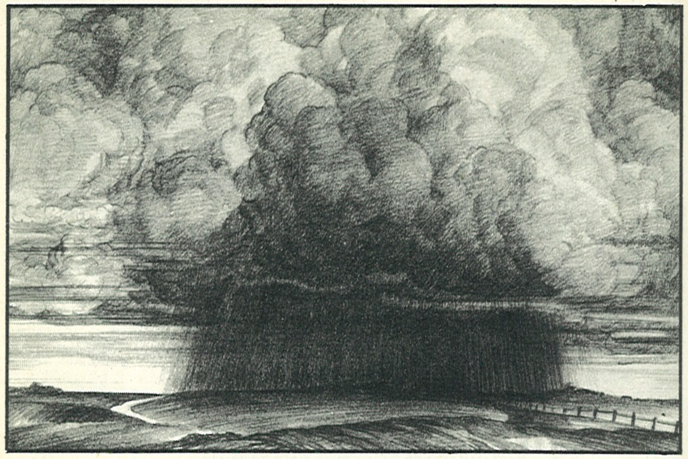
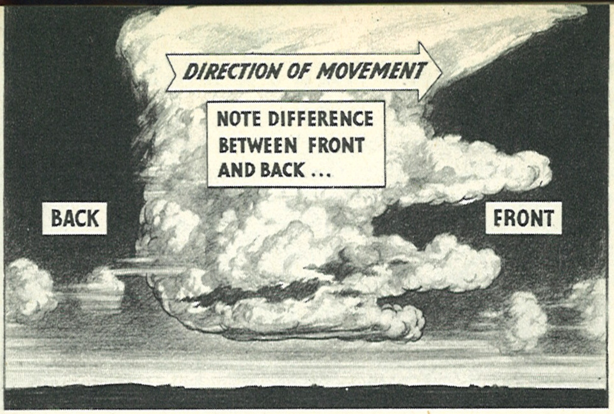
HOW THUNDERSTORMS LOOK



4. Within the storm and toward the base is the **Dark Area,** in many cases almost black, where the heaviest amount of rain is falling. This is the core of the storm.

It is not always easy to see all these identifying features, for they may be masked by other clouds. Low clouds may hide the roll cloud, the dark rain area, and the base of the real storm. Shelves of non-violent cumulus clouds sometimes extend for many miles in front of a thunderstorm, and these may hide its anvil top from a low-flying plane or its base from a high-flying plane. On the leading edge of the storm, these cloud shelves are irregular, while on the rear of the thunderstorm cloud they are of a smoother pattern. Thus the appearance of the shelves indicates the direction in which the storm is moving.

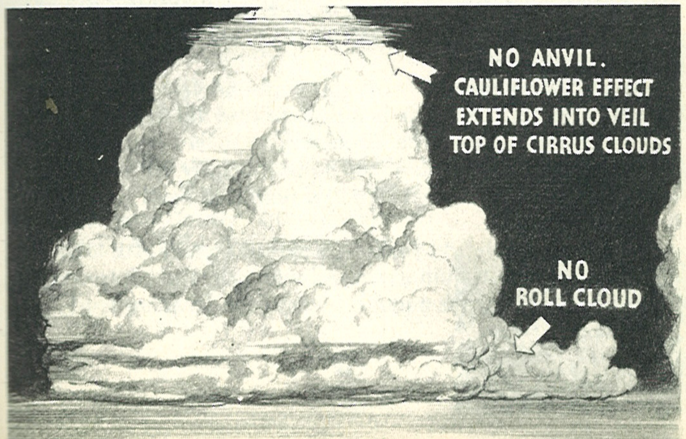
In the spring and fall of the year, when the icing level is relatively close to the earth's surface, tops of thunderstorm clouds are low (15,000 to 18,000 feet). In reality, such storms are not thunderstorms but showers, and the formation generally lacks an anvil top and a roll cloud. The cauliflower effect will extend to the top of the cloud with a veil of cirrus clouds around the dome.



Note Direction and Difference between Front and Back—Except in the Tropics

These thunderstorm clouds may contain violent turbulence while they are still building, but updrafts and downdrafts are not of long duration and lightning is uncommon in these storms. Rain is light, and hailstones, when evident at all, are generally soft and small. Examples of these storms, which are more common than thunderstorms, are the passing squalls along coast regions and over the open sea.

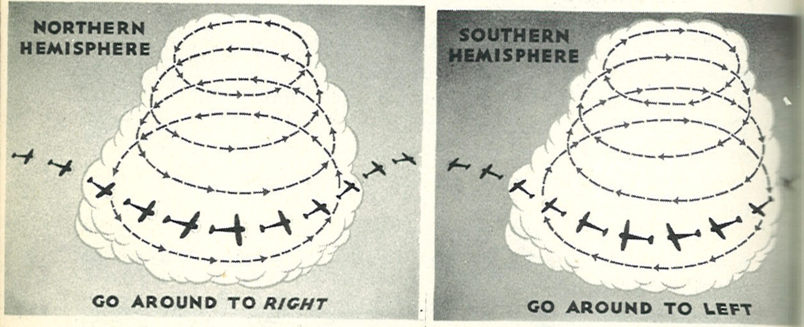
Storms of this type with low tops and no anvils, can be flown through without too much difficulty if there is absolute necessity to do so.



HOW THUNDERSTORMS ACT

The thunderstorms that build up from 30,000 to 60,000 feet are a different matter. The height to which they build is governed by the distance from the earth's surface to the ice level. The greater this distance, the higher the clouds and the more violent the thunderstorm activity. These storms are common in the tropics during all seasons and in the middle and high latitudes during the summer seasons.

Severe thunderstorms have cores which rotate counterclockwise in the northern hemisphere and clockwise in the southern hemisphere. This is good to remember, for it is a sound policy to take advantage of whatever tail wind



CORES OF THUNDERSTORMS

the circular rotation gives by going around the storm toward the right in the northern hemisphere and to the left in the southern hemisphere. The circular motion is very slight and what you gain from it may not be particularly noticeable, but it is good practice never to fly in a region of head wind when it can be avoided.

A thunderstorm is virtually a weather factory. Its towering masses of clouds contain ice mixed with rain and, if its vertical air currents extend far enough beyond the freezing level, you find hail.

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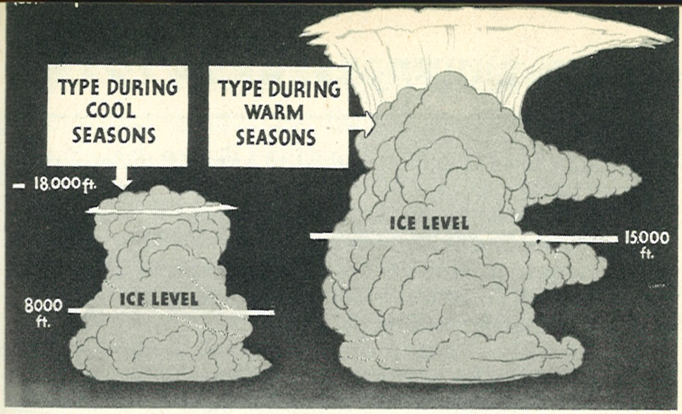
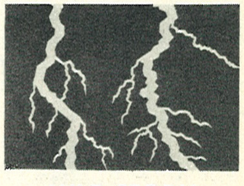


At night, lightning is usually the first warning of thunderstorms ahead. The region of the most frequent lightning flashes is ordinarily the most violent part of the storm. If you see more vertical than horizontal flashes, it indicates that you are approaching the storm from the front where there is greater violence, and conversely, if you see more horizontal than vertical flashes, you are approaching from the rear.

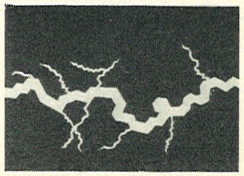
If horizontal lightning is the only kind you see, generally the storm is mild and its base is well above the ground surface. This type of lightning is common with warm front thunderstorms and with the type of storm so common in the middlewest which begins to develop out of a clear sky after midnight.

Thunderstorms at night present greater hazards than in the daytime, due to reduced visibility, but lightning will actually help you to fly them. The flashes reveal the height of the storm base above the surface; they illuminate the tops of the storm clouds; and many times they will disclose the type of surface beneath the storm, which is especially helpful over rugged country.

VIOLENT STORM



MILD STORM



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HOW THUNDERSTORMS FORM

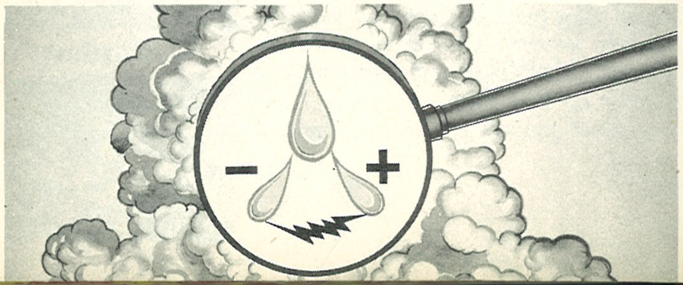
The fundamental thing required to form a thunderstorm is a strong upward current of air.

When air rises, it expands and thus it cools. If it cools sufficiently, the moisture in it becomes visible in the form of clouds. If the vertical air currents are strong enough to carry these clouds up to an altitude where the temperatures are well below freezing, a thunderstorm is possible.

Small cumulus clouds, or wool-pack clouds as they are sometimes called, are the forerunners of thunderstorms. They are composed of moisture. When the clouds build up to the freezing level, some of this moisture turns into ice particles, and these become the nuclei for raindrops. If the building continues beyond this point, more energy is developed in the storm, and more raindrops form until finally they begin to fall toward the ground.

These raindrops cannot fall through air of normal density when it is traveling upward at a speed of around twenty-six feet per second. When large raindrops are falling faster than twenty-six feet per second against the airflow in a strong upward current, they are blown to bits and the spray that results is carried aloft, because it is lighter than the drops and therefore is more easily airborne.

But in breaking up, the raindrops produce positive and negative ions of electricity, and thus, in addition to moisture, the cloud now has a static electric charge. When this charge builds up enough, it discharges from cloud to cloud or from the cloud to the ground, in the form of lightning. Thunder, as you know, is merely the sound that accompanies the discharge of the lightning.



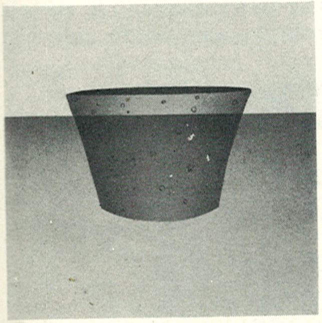
HOW THUNDERSTORMS FORM

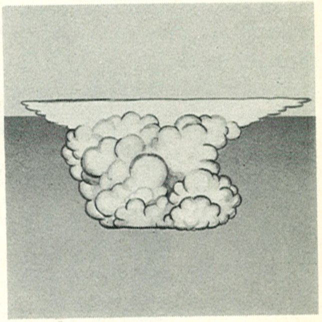
Now let's look into the means by which clouds get up to an altitude high enough for them to be subjected to the freezing temperatures that cause thunderstorms.

If you hold a cork beneath the water in a bathtub and then let go, it will rise to the surface because the cork weighs LESS than a corresponding volume of water.

When it reaches the surface, it stops rising, because it weighs more than a corresponding volume of the air above the surface of the water.

So it is with the air currents within a cumulus cloud. They rise, like the cork, until they reach a layer of air that weighs less than they do. There their upward progress can no longer be sustained, and having no other direction to move in, they spread out horizontally. This creates the **Anvil Top.**





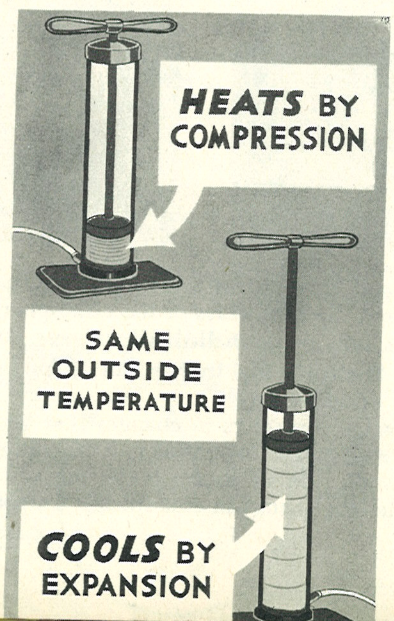
To understand how all this takes place, you need to know something about the mechanics of the atmosphere that cause thunderstorms, notably the **Adiabatic** process, and the difference between **Stability** and **Instability.** *(Don't give up. The diagrams will explain these.)*

The word adiabatic refers to changes that take place in a substance without heat being added to it or withdrawn from it. In this discussion, the substance is the atmosphere. For instance, an adiabatic change in atmospheric temperature would be one that is brought about by compression or expansion alone, and not from heating from the sun's rays or cooling from contact with a cold surface.

All widespread weather activity results from the adiabatic process, for it is the only process capable of changing the temperature state of large air masses, and it is these temperature changes that cause cloud formations.

To illustrate how the adiabatic process works, let's assume that we have a cylinder with a plunger, like a tire pump, with walls so perfectly insulated that no heat can get in or out. This cylinder is full of air. Now, if we push the plunger down, the air in the cylinder will heat up as it compresses, and the amount of heat gained will be exactly equal to the amount of mechanical energy necessary to push the plunger down.

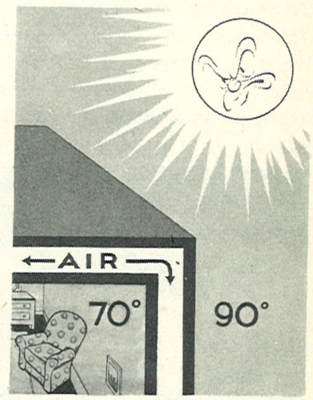
If we pull the plunger back and release the pressure, the air in the cylinder will cool, the drop in its temperature representing an amount equal to the energy necessary to pull the plunger back.



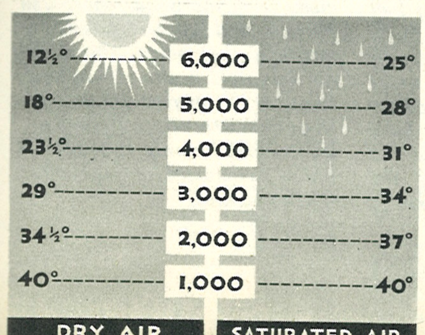
Thus the air in the cylinder was heated by compression and cooled by expansion, and outside temperature had nothing to do with the process. The temperature change was brought about by molecular action within the air itself.

Whenever a gas expands, it yields mechanical energy. The atmosphere is gas, and it expands when it is lifted. Like the air in the cylinder, it cools when it expands, and hence, when air masses in the atmosphere are lifted, they cool.

There is another characteristic of air: It is one of the best heat insulators we know and is used in the design of such insulating materials as asbestos wool and the air-spaces in walls of buildings. Therefore, if a great mass of air expands or contracts, it is just about as well insulated from outside heat influences as the air in the cylinder we talked about, and the process is always very nearly adiabatic.



Because of this "insulation," we can make some fairly definite statements about temperature changes that result when air particles rise or sink. When a particle of unsaturated or "dry" air is lifted, it will cool 5½° F. for every 1000 foot increase in altitude. When this particle of air has been lifted and cooled enough to become saturated and therefore visible, the rate of cooling drops down to approximately 3° F. per 1000 feet of altitude, which is the approximate change of temperature with increased altitude within a cloud.

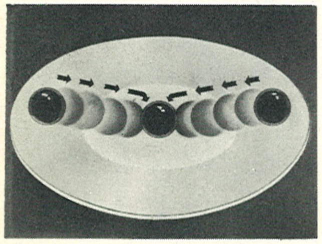


HOW THUNDERSTORMS FORM

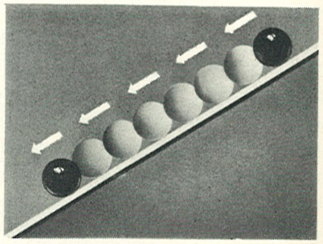
Now let's take a look at the reasons why air masses rise, and why they reach altitudes high enough so that the adiabatic process has significance to you, as an aviator. In examining the forces that cause them to rise, we must know something about **Stability** *and* **Instability.**

In the atmosphere, stability is a vertical distribution of temperature such that the particles of air resist vertical displacement from their level. Instability, on the other hand, is a vertical temperature distribution such that the air particles do not resist vertical displacement.

When unstable air is caused to rise in the form of a column, it continues its upward motion as long as it is in a state of instability. When it reaches a layer of stable air, its upward progress is resisted and it stops rising. Being compressed by the force of the stable air above and the lift which is being exerted on it from below, it flattens out beneath the layer of stable air. Thus the anvil top is formed.



You can get an idea of what stability is from the accompanying illustration. If you place a ball bearing in a saucer it has a tendency to remain at the bottom of the saucer and even if you move it away from this point, it comes back. Stable air particles have this same tendency to remain at the level they are occupying, and to return to this location if moved away from it.



Now, if you place a ball bearing on an inclined plane, it moves away from the point where you place it, and has no tendency to return to that point. This is instability, and in the atmosphere, unstable air particles have the same characteristic, although unlike the ball bearing, they are not pulled downward by gravity, but move upward.

TYPES OF THUNDERSTORMS

Due to the fact that thunderstorms result from clouds with vertical motion, the air in which they form must be unstable. An unstable lapse rate, or decrease in temperature with increase in altitude, may be assumed whenever the decrease of temperature with altitude lies between 5½° F. and 3° F. If the vertical temperature distribution is less than 3° F. per 1000 feet, the air can be assumed to be stable and thunderstorm activity is unlikely.

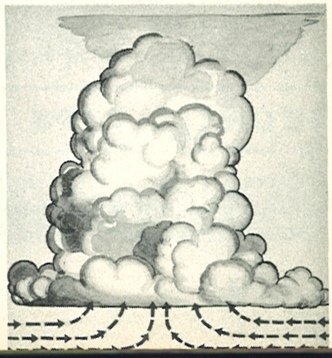
It takes a "push" to start the air column moving upward in order to form a thunderstorm, and the necessity for this push provides the way in which thunderstorms are classified as to type. In general, there are three kinds of thunderstorms: **Air Mass** thunderstorms, **Frontal** thunderstorms and **Orographic** thunderstorms.

AIR MASS THUNDERSTORMS

The sun's heating reaches its maximum during the middle part of the afternoon. Therefore this type of thunderstorm occurs in the late afternoon and evening. After the sun goes down and the heating ceases, the air next to the surface begins to cool, shutting off the motor in the thunderstorm manufacturing plant. This accounts for the dissipation of this type of storm after sunset. It is very common to have violent scattered thunderstorm activity in the late afternoon followed by a cloudless night.

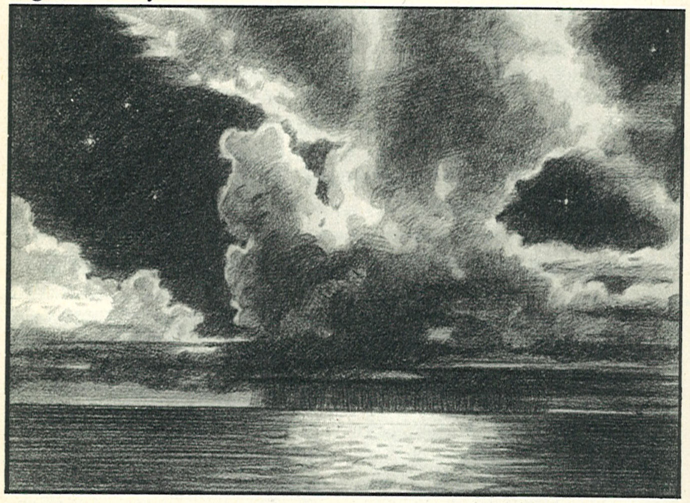
SUN HEATS AIR

RISING AIR FORMS CLOUDS



HOW THUNDERSTORMS FORM

Cold air moving over a warm body of water will produce the same processes of buoyancy, but these storms are not so violent and do not extend to such great heights as those formed over land. They are just as common at night as in the daytime, because the temperature of water remains relatively constant night and day.



Air mass thunderstorms result when the sun heats a land surface. This heating action gives the "push" that causes the air particles next to the surface to rise and cool. When they have cooled sufficiently to cause the temperature and dewpoint to be equal, they become visible in the form of clouds and continue to rise, forming a cumulus cloud.

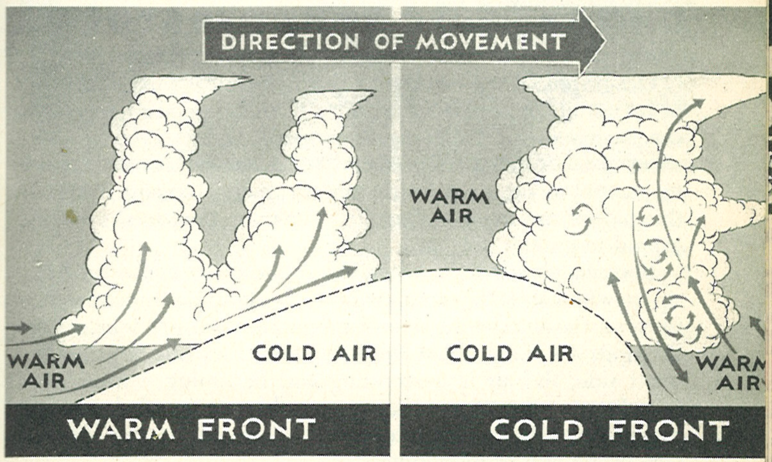
FRONTAL TYPE THUNDERSTORMS

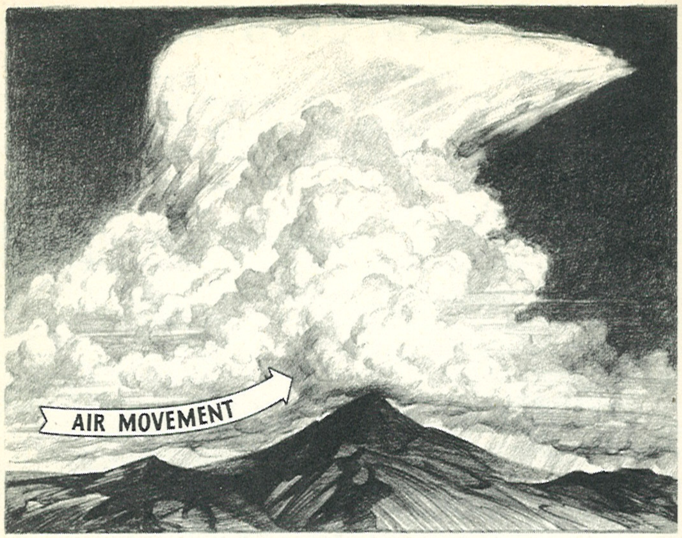
Frontal type thunderstorms are of two general varieties: When a wedge of cold air moves into a region of warmer air, the cold air acts as an inclined plane, with the result that the

warm air is forced upward and undergoes the process of cooling that produces thunderstorms, called the **Cold Front Type.** Because the cold front usually is steep, the warm air is lifted suddenly, and considerable violence results.

Thunderstorms formed in this way generally are concentrated in a zone about 15 to 50 miles wide, which may extend for hundreds of miles in length. Although the storm line may appear to be solid, it is really a series of individual thunderstorms closely compressed against other clouds, without visible space between.

When a warm air mass moves into a region occupied by a cold air mass, the warm air will overrun the cold air and a similar rising and cooling of the air results. Thunderstorms formed in this way are called the **Warm Front Type** and they form at higher altitudes; the cold front thunderstorm is closer to the ground and is more violent, as a rule. Below the warm front thunderstorm is a shielding layer of cold air, where little turbulence is to be expected. Warm front thunderstorms are scattered in the area ahead of the warm front.





OROGRAPHIC LIFT

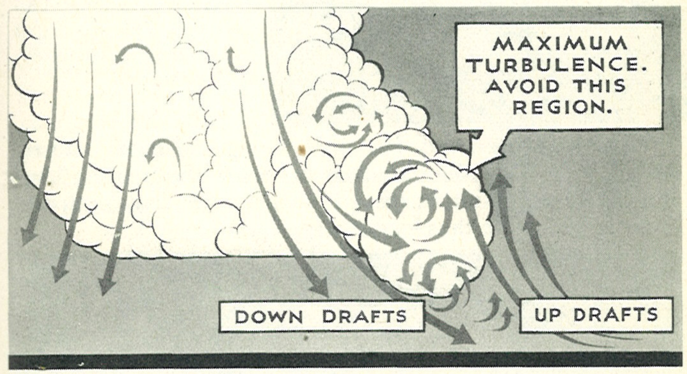
OROGRAPHIC THUNDERSTORMS

Orographic thunderstorms result when air is forced up a hill or mountain slope. Thunderstorms of this type are frequent in mountainous country and along coastal areas where on-shore winds prevail. They may be isolated over one mountain peak or general along an entire mountain range. Usually storms of this nature are more violent than air mass thunderstorms and extend to greater heights.

Because clouds form when air is becoming cooler and dissipate when air is becoming warmer, orographic thunderstorms form on the windward side of mountains and hillsides, where the updrafts bring about the formation of clouds. On the leeward side, the air is descending and becoming warmer, and therefore a pilot may expect to reach an area of decreasing turbulence after passing from the windward to the leeward side of the hills or mountains.

HOW THUNDERSTORMS ACT

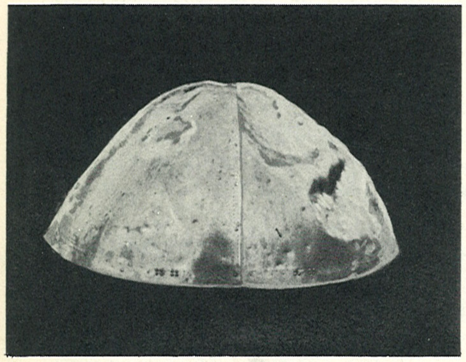
Whether thunderstorms are caused by air being heated from below or by air being forced up an inclined plane, they have the same general characteristics. The updrafts of air which are the fundamental causes of the storm are offset by downdrafts, both within and without the thunderstorm cloud; the result is great turbulence, with more violence ahead of the storm than at its rear. It is the eddies along the edge of these air currents that result in the cauliflower appearance of the outside of the cloud.



The updrafts of air ahead of the storm and the downdrafts within the storm cause the roll cloud to form at the base of the leading edge. Slightly ahead of this area, at the surface, variable and shifting surface winds prevail. In and around the roll cloud is the region of maximum turbulence. Avoid this region.

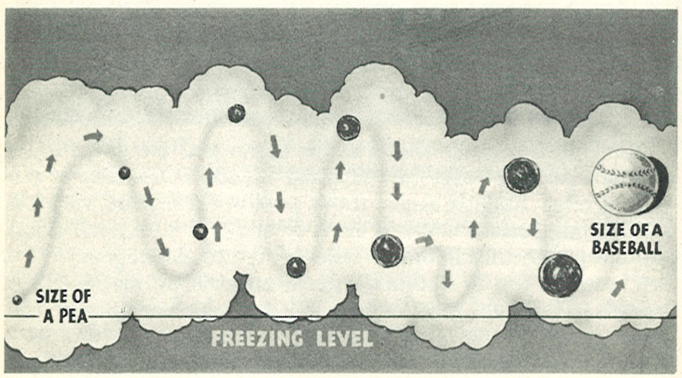
The anvil top of a thunderstorm consists primarily of ice crystals. The anvil top is above the turbulent activity of the storm.

Hailstones are balls or irregular lumps of ice, which may vary from the size of a pea to that of a baseball. Real damage from hail, however, is exceedingly rare, for it takes a vertical current of air exceeding 150 knots to suspend the larger hailstones, and ordinarily the updrafts don't exceed 60 or 80 knots. It is possible, of course, that they might break your windshield.



The accompanying photograph shows damage resulting to a Mexican transport plane from violent hail. The plane was in the area approximately 3 minutes.

There have been very few cases, though, of heavy hail reported in the case of a thunderstorm below the freezing level and it also appears that there is only a slight hail hazard at lower levels within the cloud itself.



HAILSTONES—HOW THEY CAN GROW

Hail forms in the chimney of the thunderstorm at an altitude above the freezing level. After the hail has once formed, reports indicate that it will overflow from the cloud at some point above the freezing level and fall down the sides in the clear air where there are no vertical currents to retard it. In many reports pilots have experienced heavy hail in the clear air outside a thunderstorm, which seems to support the theory that the worst hail generally is encountered around the main storm cloud underneath the over-hanging shelves, and not in the region of heaviest rain in the core of the storm.

At any given latitude, thunderstorms vary in size with the seasons. In summer they reach their maximum heights. In spring and fall, their tops are lower, because the freezing line draws nearer to the earth's surface. During these seasons, the anvil top is not so readily apparent. The ice level is closest to the earth during the cold season of the year, and therefore winter thunderstorms are less frequent.

The intensity of the storm depends upon the distance from the base of the thunderstorm cloud to the ice level. The greater this distance, the more violent the storm, provided the vertical motion extends above that point. Therefore in the high latitudes, storms are less violent and with lower tops, for the freezing levels are closer to the surface of the earth. As the equator is approached, the freezing level rises farther from the earth's surface, resulting in higher tops and more violent activity. The most violent activity occurs in the lower two-thirds of the storm clouds. If it is 30,000 feet from the base to the top of the cloud, you may expect the greatest turbulence in the lower 20,000 feet.

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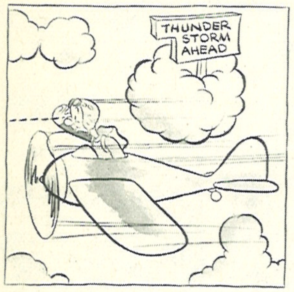
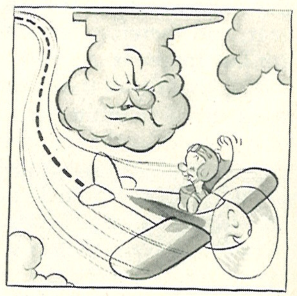
RULES ☆

1 When approaching a thunderstorm, analyze it before the surrounding clouds are encountered. They may obscure important characteristics of the storm after you get into them.

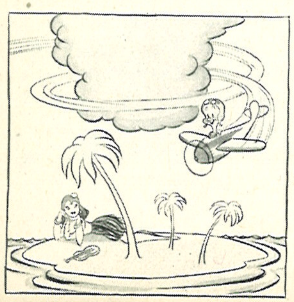


2 Before attempting to fly any thunderstorm, study the situation thoroughly.

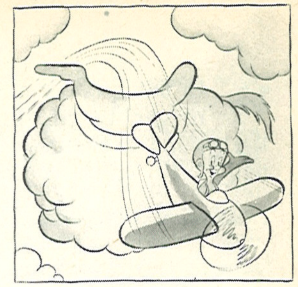


3 Whenever possible, circumnavigate a storm. Always fly around isolated air mass thunderstorms.

4 In coastal regions, where thunderstorms prevail along the mountains, fly a few miles to seaward and avoid them.

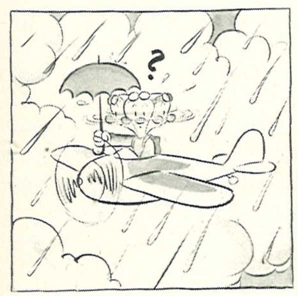


5 Thunderstorms over islands may be thousands of feet higher than those over the open sea. Fly around them.

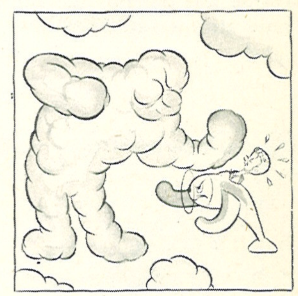


6 Cold front thunderstorms generally stretch too far to fly around. Remember that the storm front is a series of individual storms linked by intervening clouds. If you have to go through, fly between the storm centers or over the saddle-backs.

7 If you can't see blue sky beyond the storm and must go through, determine the direction the storm is taking and head in at a right angle.



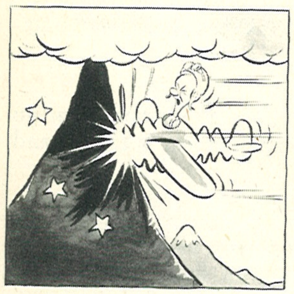
8 Once you have headed into a storm, don't turn around on account of turbulence, rain, or hail. If you do, you'll have to fly through the same condition twice, and you may get lost. Hold your original course.



9 In entering the front of a thunderstorm, you will encounter updrafts. Go in low, and if conditions permit, fly under the base of the storm.

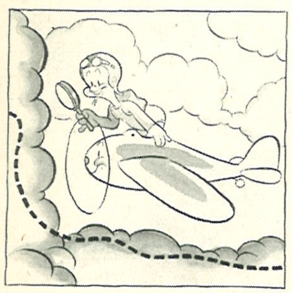
10 Entering a storm from the rear, you will experience downdrafts first. Go in high.

11 In flying under a storm, the higher the flight level, the rougher the trip. Fly about one-third of the distance from the ground to the base of the cloud if you can; but don't go underneath unless you can maintain contact flight.



12 Don't try to fly underneath a storm along mountain ranges unless there is a good ceiling and you can see peaks and ridges clearly. At sea you can usually count on being able to fly under any thunderstorm in daylight.

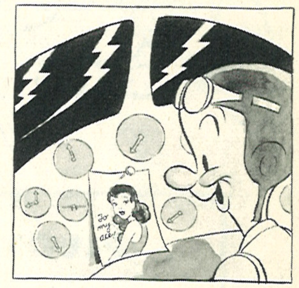
13 Never land at an airport when a thunderstorm is advancing toward the field. Shifting surface winds make it too hazardous. Wait until the storm center has passed, and the winds have stopped shifting, before you land.



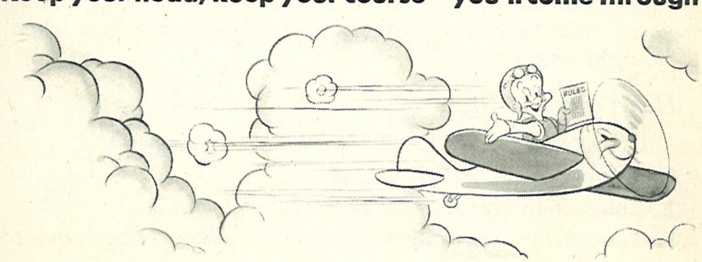
14 When you expect to try high level flight in flying a storm, get altitude before approaching it, so that you are on top of the cloud shelf around the storm and can inspect the storm line before selecting your course.

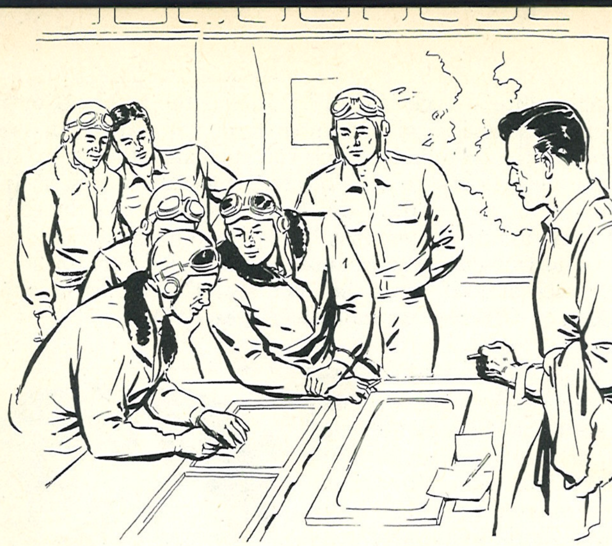
15 The altitude necessary to fly around the tops and over the saddlebacks of a thunderstorm will vary with the seasons and the latitude in which you encounter the storm. In high latitudes, 12,000 to 15,000 feet is generally sufficient. In the tropics, the tops of the saddlebacks may be above the ceiling of your aircraft and you may have to fly through the saddlebacks on instruments, a procedure recommended only for high performance aircraft. Over the open sea, 15,000 feet of altitude usually will clear the saddlebacks, except in the tropics.

16 Lightning is of little consequence when you are flying an all metal, closed-cockpit plane, which acts as a perfect conductor. Don't worry about it. Switch on the cockpit light and keep your eyes on the instrument panel, so that the bright flashes won't blind you. If you are flying an open cockpit plane, or a plane with a plywood or plastic fuselage, better keep away from the lightning.



Keep your head, keep your course—you'll come through





PILOT COUNSEL

These notes are compiled for you from the experiences of naval and airline aviators who have combatted thunderstorms successfully in virtually all latitudes.

They cannot tell you exactly what to do when you encounter any particular thunderstorm. No one in the world could do that, unless he were sitting alongside you in the cockpit. But these pilots are giving you general advice on ALL thunderstorms, and you can apply this advice to good advantage when the right time comes.

Here is what they tell you:

There are three basic ways to fly thunderstorms.

1. You can fly underneath them.
2. You can go over the tops of the saddlebacks.
3. You can fly around them at low, intermediate, or high levels.

If conditions won't permit you to go under, around, or over, you have only two alternatives:

1. You can turn back to the nearest clear airport and wait until the storm passes.
2. You can go through the thunderstorm, but you should only do this **as a last resort** if it is required by your mission.

The selection of the method you use to get past a thunderstorm depends upon several things, and therefore, as you approach a thunderstorm, it behooves you to take your time and size up the situation so that the method you attempt will be the proper one and you don't have to do any second guessing once you are on your way.

In estimating the situation, you will want to analyze these things:

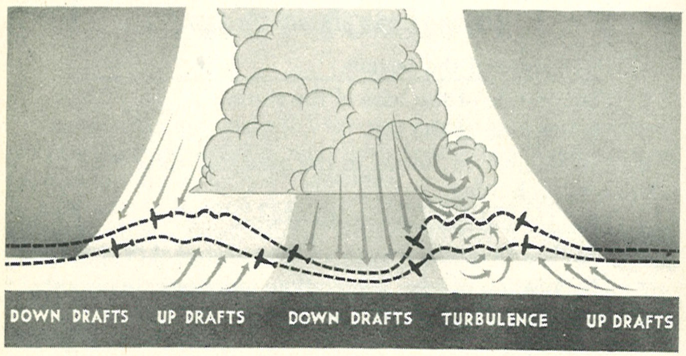
1. The nature of the terrain.
2. The altitude of the base of the storm.
3. The altitude of the top.
4. The number of storms in the area and their location in relation to each other.
5. The size and intensity of the storms.
6. The direction and velocity of the movement of the storm.
7. The location of your destination and alternate airport.
8. The type of aircraft you are flying.
   a. Service ceiling.
   b. Fuel range.
   c. Oxygen and pressure equipment.

Don't be in a hurry to take on a thunderstorm. Whenever you approach an area where thunderstorms are to be expected, fly either under the general cloud level, so that you may recognize the base of the thunderstorms, or above the general cloud layers so that you can recognize the main body or tops of the storms.

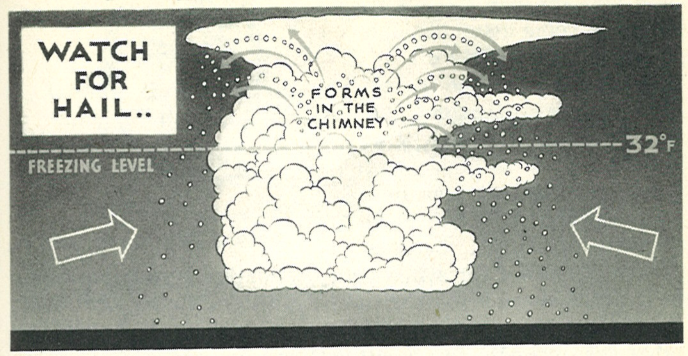
In dealing with cold-front types, it may be necessary for you to fly parallel to the front of the storm for some distance before you make your decision as to how you are going to fly it. Don't begrudge the time. When you finally make your decision it should be the right one and should not be changed thereafter.

A. *Flying Underneath*

If the terrain is flat, or if you are over the open sea, probably the easiest way to negotiate a thunderstorm is to fly beneath it. If your fuel range is short and your service ceiling low, this is the only method open to you, and unless you are sure that you can fly under the storm you had better leave it severely alone and land safely at the nearest available airport.



The underneath method should not be attempted in mountainous country unless you are sure of your familiarity with the terrain, and in no case unless you have visibility of from three to five miles and can see enough daylight beyond the storm to be sure that when you get past it you won't run into another one that will get you into trouble.



To avoid turbulence, it is good practice to fly at an altitude of approximately one-third the distance from the surface to the base of the storm. In addition to keeping you from getting too rough a ride, selection of this altitude will usually keep the updrafts from sucking the plane up into the storm and putting you in real danger.

You may encounter hail, falling out of the thundercloud around its edges at the front and on the sides, under the overhanging cloud layers. Stay away from it. You can suspect its presence by a greenish hue in the atmosphere that is unlike the dark blue or black that indicates rain.

Before selecting the underneath method of flying a thunderstorm, be absolutely sure that you can stay under all the way.

B. *Over the Top Method*

If your equipment permits, the method of flying thunderstorms by going over the top of the main body of the storm, or between the saddlebacks, is preferable to any other. But to elect this method you must be sure of your equipment, sure of your knowledge of the storm, and sure of yourself.

You must know that the service ceiling of your aircraft is sufficient to get you as high as you need to go. Your fuel supply must be enough to keep you up there as long as need be, for

once you are over the storm, you can't come down through it whenever you like.

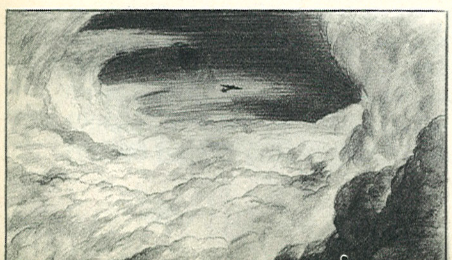
You must know the intensity of the storm, its extent, and the direction in which it is moving. If a succession of storms reaches over your destination, you will not elect over-the-top flight, because you can't come down when your destination is reached. Similarly, if the storm is moving toward your destination or toward an alternate airport that you have selected, some procedure other than over-the-top flying is clearly indicated.

If the height of the storm causes you to think that you may have to go on oxygen, be very sure that your equipment is adequate to cope with this condition.

Never be unduly optimistic about your fuel supply or the service ceiling of your aircraft. If there is any doubt whatsoever in your mind, don't attempt over-the-top flight.

The altitude necessary to fly around the tops and over the saddlebacks will vary with the seasons and the latitude in which you encounter the storm. In high latitudes, 12,000 to 15,000 feet is generally sufficient altitude. In the tropical regions, the top of the saddlebacks are often above the ceiling of the aircraft. Generally, lines of thunderstorms over the open sea are lower than those over land and in most cases, 15,000 feet will be sufficient altitude to fly over the saddlebacks, except in the tropics.

In flying over the saddlebacks or around the anvils it is well to remember that the higher you go the less turbulence you will encounter. It is also a good plan to avoid flying between the anvil top and the main body of clouds.



There are four principal disadvantages to over-the-top flying:

1. Ground contact is lost.
2. Moderate to severe turbulence may be encountered.
3. It may be necessary to descend through thunderstorm conditions to land, which is highly inadvisable.
4. If you have overestimated your aircraft and its equipment, it may cause you trouble.

C. The Circumnavigation Method

Isolated air mass thunderstorms and orographic thunderstorms usually are local and whenever possible you should fly around them. The added mileage and time usually are of little consequence.

PILOT COUNSEL

Circumnavigation is particularly advisable in mountainous regions and near coastal mountains, where a flight of a few miles to seaward will avoid storms. (This is also usually true of thunderstorms over islands, which may be thousands of feet higher than those over the open sea.)

Storms can be circumnavigated at low, high, or intermediate levels, depending upon the set of circumstances they present. In any case, it is vital to determine the direction in which a line of storms is moving and fly between the storm centers, heading in at a right angle.

At intermediate levels it is essential to keep either blue sky or light spots in the clouds in sight ahead of you and this may cause you to alter course from time to time to miss the storm centers. It is a poor policy to wander around too much, of course, if it can be avoided.

Once you have entered the storm area, if the hole closes up ahead of you and you have to go on instruments, **Do not change course.** Stick to your original right angle course and go through. Don't alter course on account of turbulence, rain or hail or you will find yourself flying through the same condition twice. There is also the possibility of getting lost.

If the turbulence becomes great, lowering your landing gear and reducing the air speed will prove helpful.

If lightning threatens to blind you temporarily, turn on your cockpit lights and keep your eyes on the instrument panel.

If St. Elmo's fire forms on the wings and the periphery of the propeller, cut down your air speed and the fire will usually go away. (St. Elmo's fire is not a hazard to flight, but may interfere with radio communication.)

In circumnavigating thunderstorms that are relatively close together, try to stay in the clear as much as you can so that you can see where the danger lies and avoid it.

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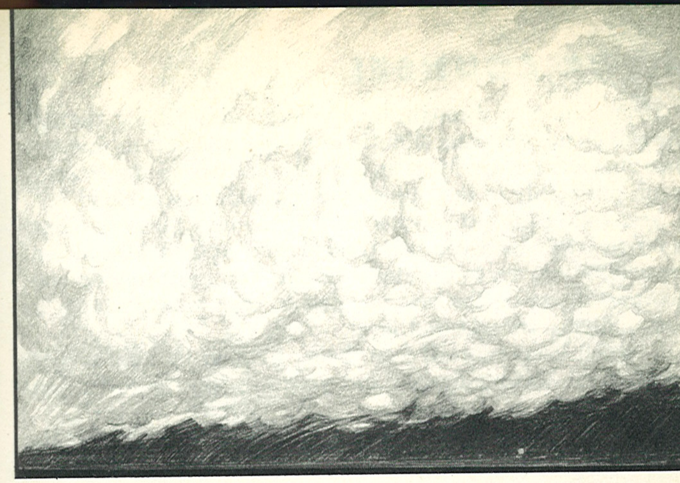


The mammatus sky pattern often precedes the activity, generally as a part of the underside of the layer of clouds that project out in front of the storm. If the mammatus formation precedes a thunderstorm, you may be sure that the disturbance is going to be violent.

If the roll cloud is not obscured by other clouds in advance of the storm, you can see the boiling in it from a distance. The weak spots in a line of storms are visible and you can identify them as areas where the clouds look decayed and spongy—placid-appearing compared to the boiling effect in the clouds where the greatest violence occurs.

In circumnavigating at intermediate levels it is a good plan to stay on top of intermediate clouds where you can keep the structure of the main cloud well in view.

Flying Through Thunderstorms

If luck is against you and you have no alternative but to fly through a thunderstorm, try to avoid the center of the storm or area where the most violent turbulence is apparent from the boiling in the clouds. Don't pick the middle of the storm to fly through if you can fly away from it. Select a course where the turbulence will be least and there will be the least possibility of hail.

PILOT COUNSEL

If you must go through, by all means avoid flying through the roll cloud. Set your altitude to fly just above it so that you miss its violence. Or fly at an altitude well above the freezing level, preferably in the upper of the thunderstorm cloud.

You will be on instruments most of the way through. There is no way in which you can foretell your approach to violent areas once you are in the storm clouds. You must rely on your instruments, so do the best you can to keep your plane on its course, flying straight and level.

You can keep yourself from being blinded by lightning by keeping the cockpit lighted and your eyes on the instrument panel.

You can relieve the stress on your plane by dropping the landing gear to reduce speed.

That is about all you can do.

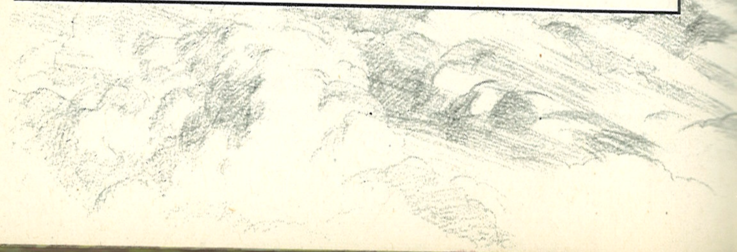
But remember this:

If you keep your head, your plane will outfly the storm.

Don't change your course.

Don't change your mind.

If you must go through a thunderstorm, the only way to do it is to go through.



GLOSSARY

Adiabatic—Reference to the corresponding changes that take place in the density and pressure of a substance without the addition or withdrawal of heat.

Air Mass—An extensive body of air which has approximately the same properties level for level throughout the whole mass.

Anvil Top—The flat-topped cloud formation at the top of a thunderstorm, formed when cumulus clouds, carried upward by air currents, are stopped by encountering a layer of stable air.

Cirrus—Detached clouds composed of ice crystals, delicate and fibrous, generally white, and often of a silky appearance formed at high levels (above 20,000 feet.)

Cold Front—The leading edge of an advancing cold air mass which is displacing warmer air in its path.

Cumulus—Thick clouds with vertical development and a flat, horizontal base, with domed and turreted tops, often referred to as the "wool-pack" clouds.

Cumulonimbus—A heavy mass of cloud with great vertical development, and with vertical summits rising in the shape of mountains or towers.

The upper part has a fibrous texture, and often spreads out in the shape of an anvil. The base has a watery appearance and one generally notices streamers extending down from the

lower portions of the cloud. The base often has a layer of very ragged clouds below it.

Cumulonimbus clouds generally produce showers of rain, or snow, and sometimes of hail, or soft hail, (and thunderstorms often are the result), with accompanying lightning and thunder.

If the whole of the cloud cannot be seen, the fall of a real shower is enough to characterize the cloud as a cumulonimbus. Even if a cumulonimbus were not distinguished by its shape from a strongly developed cumulus, its essential character is evidenced in the difference of structure of its upper part, when this is visible.

Cumulus clouds, regardless of how heavy they appear to be, should never be classed as cumulonimbus, unless the whole or parts of their tops are transformed, or are in the process of transformation, into a cirrus mass. This means that the cumulus cloud does not become dangerous or hazardous until this transformation takes place. The front portion of a cumulonimbus of great extent is sometimes accompanied by a roll cloud, of a dark color in the shape of an arc of a frayed-out appearance.

Fairly often a mammatus cloud structure appears in advance of the main cloud, either at the base of the cloud or on the lower surfaces of the protruding shelves.

When a layer of menacing clouds covers the sky and wisps of lower clouds and mammatus structure are both seen, it is a sure sign that the cloud is the base of a cumulonimbus, even in the absence of all other signs.

The cumulonimbus is a real factory of clouds. It is responsible in a great measure for the clouds to the rear of frontal disturbances. By the spreading out of the high parts, and the melting away of the underlying parts, the cumulonimbus can produce thin sheets of clouds lying at different levels in the atmosphere.

Hail—Balls or irregular lumps of ice, sometimes of considerable size which fall almost exclusively in connection with thunderstorm activity.

GLOSSARY

Ice Level—Altitude at which freezing temperatures exist.

Instability—A vertical temperature distribution such that the air particles do not resist vertical displacement.

Lapse Rate—The rate of decrease of temperature in the atmosphere with altitude.

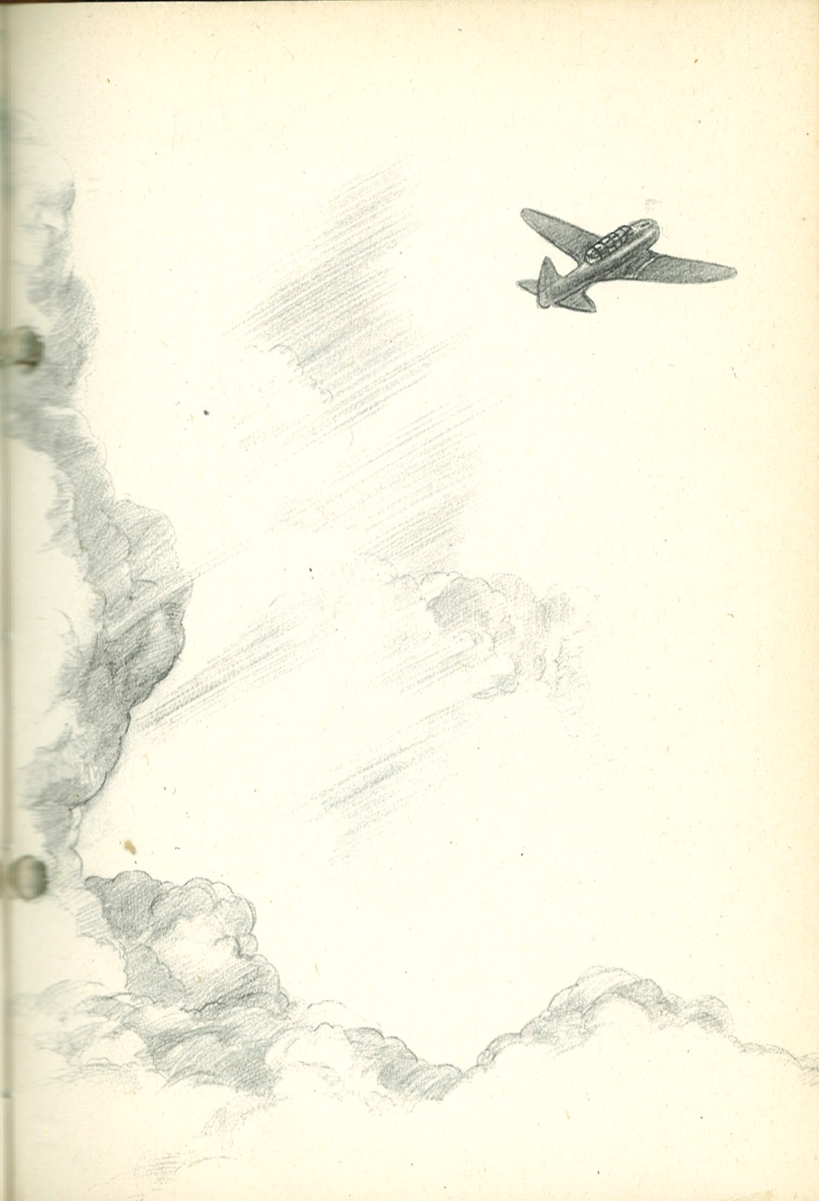
Mammatus—Clouds of a more or less regular, rotund appearance, generally found on the protruding underside of the leading shelves of clouds in advance of thunderstorm activity.

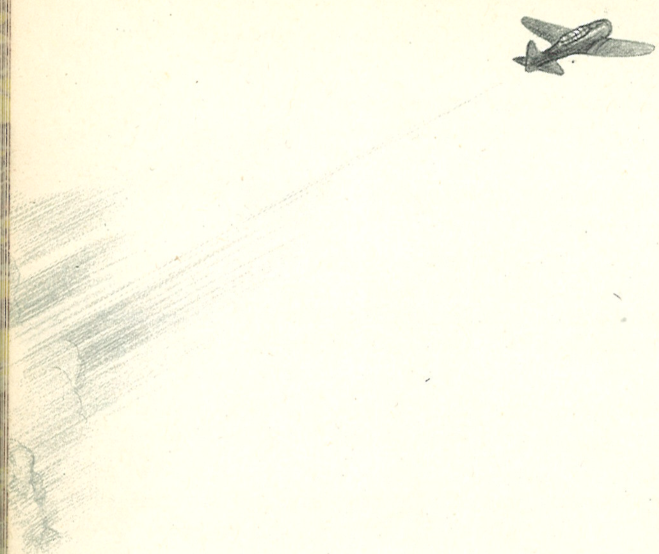
Stability—A vertical distribution of temperature such that the particles of air resist displacement from their level.

Stratus—A low uniform layer of cloud, resembling fog, but not resting on the ground.

Turbulence—Irregular motion of the atmosphere produced when air flows over an uneven surface, or when two air currents encounter each other from different directions or at different speeds.

Warm Front—The forward edge of a warm air mass replacing a receding mass of cold air.





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